NOAA / NESDIS

Office of System Architecture and Advanced Planning

NSOSA Study - SPRWG Report

22 March 2018

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NOAA Space Platform Requirements Working Group (SPRWG)

Final (Cycle 2b) Report
25 March 2018
Submitted by SPRWG Chair Richard Anthes

Preface

This is the final report[1] of the NOAA Space Platform Requirements Working Group (SPRWG) in support of the NOAA Satellite Observing System Architecture (NSOSA) study. It updates and revises the Cycle 2a Report dated 31 October 2016. It is a comprehensive report that summarizes the activities and results of SPRWG since its inception on 1 November 2015.

Major changes from the Cycle 2a Report include an extensively revised EVM (Environmental Data Record Value Model) and associated "two pagers" that describe each objective in greater detail. In addition to the Groups A (Weather and Ocean objectives) and B (Space Weather objectives), the EVM also includes a Group D (Strategic objectives). The NSOSA study also includes a Group C (Communications), but Group C was not considered by SPRWG.

The objectives and priorities within Groups A and B were developed by SPRWG; the objectives and priorities within Group D were developed by the Architecture Development Team (ADT) under the leadership of Mark Maier, with input and review from SPRWG. Integrated priorities of objectives in Groups A, B, and D were established by NOAA/NESDIS leadership, and are presented in this report.

1. Introduction

The NOAA mission is "to understand and predict changes in climate, weather, oceans, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources" (http://www.noaa.gov/about-our-agency). Global observations of the Earth system (atmosphere, oceans, land and ice surfaces, and the biosphere) are the foundation for meeting this mission, which serves society by protecting life and property and supporting a robust economy. Simmons et al. (2016) present an excellent up-to-date summary of the Earth system and the observations (emphasis on space observations) and modeling that are needed to understand and predict it. As the Simmons report makes very clear, observations from space are a key component of the Earth observing system and are the major observation types that

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[1] This final version, dated 25 March 2018, is an edited version of the document that was submitted to NOAA on 15 May 2017 and used in subsequent ADT analyses. The edits are minor and grammatical in nature; in particular, no changes in the EVM were made.

determine the accuracy of weather forecasts in the time range of up to two weeks. NOAA and NASA and their international partners play a major role in providing NOAA with the observations from space that are required to support its mission.

The current series of NOAA weather satellites is expected to provide operational satellite observations for terrestrial and space weather applications into the late 2020s and the early 2030s. As planning for satellite acquisition requires long lead times, it is necessary to begin planning for next generation systems that will be launched after the current series of satellites is no longer operational. The current space system carries high budgetary requirements, but leaves significant unmet needs behind, and budgets for future operational satellite programs are likely to be further constrained. Therefore it is prudent to undertake a process to examine the prioritization of measurements for NOAA's operational needs as well as different space architectures to make the highest priority observations in advance of any acquisition processes for future space-based platforms.

With those issues in mind, the National Environmental Satellite Data and Information Service (NESDIS) is conducting the NOAA Satellite Observing System Architecture (NSOSA) study in FY 2016-17 in order to determine the most cost effective space architectures for NOAA's weather, space weather, and environmental remote sensing missions. As a part of this study, NESDIS initiated the Space Platform Requirements Working Group (SPRWG) to evaluate the future needs and relative priorities for weather, space weather and environmental remote sensing (excluding land mapping) space-based observations for the 2030 time frame and beyond. This process was undertaken in support of the NSOSA Architecture Development Team (ADT), which is a component of the Office of Systems Architecture and Advanced Planning (OSAAP) within NESDIS. The SPRWG TOR is attached as Appendix A.

The SPRWG membership was chosen by the SPRWG Chair (Richard Anthes) with concurrence from the OSAAP Director (Tom Burns at the time, currently Karen St. Germain) and the NSOSA Architecture Team Lead (David Di Pietro at the time, currently Frank Gallagher), and consists of members from the user and research community associated with the NOAA Mission Service Areas (MSAs), including NESDIS, the National Weather Service (NWS), the National Marine Fisheries Service (NMFS), the National Ocean Service (NOS), and the Office of Oceanic and Atmospheric Research (OAR). SPRWG membership also includes representatives from other stakeholder organizations, such as NOAA Cooperative Institutes, academia, other research organizations, and private industry. Members were selected so that their collective expertise would span the spectrum of NOAA observational needs. The SPRWG used its members' expert knowledge of the types of measurement data needed to develop operational products (e.g. forecasts, watches, and warnings) from space-based observations of phenomena related to weather, climate, space weather, and the general Earth environment. A list of the SPRWG members and brief biographies are included in Appendix B.

SPRWG was formed in October and November 2015 and its first meeting was held 2-3 December at NESDIS in Silver Spring, MD and NCEP in College Park, MD. On 12 January 2016 SPRWG conducted a Town Hall at the AMS Annual Meeting in New Orleans and then met on the afternoon of January 13 in New Orleans. The second full meeting of SPRWG was held 4-5 February at NESDIS in Silver Spring. In addition to these meetings, SPRWG conducted its work through many conference calls and e-mail exchanges. The third and fourth meetings of SPRWG were held in Boulder, Colorado 12-14 July 2016 and 11-12 January 2017 respectively. The final meeting of SPRWG was held 20-21 June 2017 in Boulder.

SPRWG Tasks

A key element of the NSOSA study process is the Environmental Data Record (EDR) Value Model (EVM), which provides the most important *objectives* for meeting NOAA's observations from space, their performance attributes at different levels of capability, and their priorities for improving the performance of the objectives from the *Study Threshold Level* (a level below which the objective has little or no value) to the *Maximum Effective Level* (the level above which further improvements are not useful). The EVM plays a central role in assessing the value of different space architecture alternatives. The most important part of the SPRWG charge was to assist the ADT with the development of the EVM.

A second task of SPRWG was to develop, in conjunction with ADT, a number of scenarios (major use cases), which the ADT is considering as it develops alternative architectures. These scenarios may include critical operations that pertain to events that occur in various locations in a specific time sequence under a set of normal or contingency conditions. These scenarios will assist NOAA in determining how well NOAA can meet its mission under a variety of "normal" and "unusual," or extreme circumstances.

The EVM and set of Scenarios are presented below in Sections 3-5 and 6 respectively.

Iterative nature of NSOSA process

An important part of the NSOSA process is its iterative nature. The process was carried out in three cycles, with SPRWG providing a first-cycle EVM to the ADT on 25 May 2016 (Cycle 1). Throughout the process, the ADT developed a number of architecture alternatives that met the EVM objectives at different levels. The results were then reviewed and discussed with NOAA management, NOAA line offices, the SPRWG, and various NOAA stakeholders. Based on these results and discussions during the first cycle, SPRWG produced a modified EVM for the second cycle (Cycle 2a) on 6 September 2016, which was then used to develop a second round of architecture alternatives. The process was repeated a third time (Cycle 2b), with the result being a number of viable candidate architectures that meet NOAA's needs within different projected budget constratints. The responsibility for selecting and implementing the final architecture rests with NOAA senior leadership.

NSOSA and SPRWG priorities

For the NSOSA study, and thus for the SPRWG process, operational NOAA functions are considered the highest priority, and are defined as those which result in government actions that affect public safety or economic livelihood. Non-operational NOAA functions are to be considered as the next priority, and are defined as those which result in actions that are principally conducted to increase the state of knowledge. Other functions, such as those conducted by NASA or other agencies and international partners, are generally considered out of scope.

Because of the priority for NOAA operational functions as defined above, SPRWG paid less explicit attention to the important areas of climate and other long-term Earth observations and their continuity. However, many of the objectives and their performance attributes (such as atmospheric temperature and water vapor, sea surface temperature and height) considered by SPRWG are important climate variables and their accuracy, precision and stability were implicitly considered for their value for climate in addition to weather forecasting and other operational needs.

Although somewhat outside the scope of the SPRWG charge, SPRWG had considerable discussions about how NOAA could prepare for technological and scientific advances that will lead to potentially major or even revolutionary advances in making operational Earth observations from space. In particular, SPRWG felt that NOAA should pay special attention to measurements that are listed here as important, and where emerging technologies could revolutionize the impact. For example, SPRWG saw opportunities in specific areas such as continuous observations in the Day/Night band; improving technology to make wind measurements from time-separated Infrared (IR) soundings or LIDAR profiles, and constellations of cubesats to support emerging needs for data assimilation globally on a more continuous basis than done today. To the extent that these priorities may align with NASA's weather focus area, SPRWG felt that the agencies should work together to demonstrate these technologies as a way to limit the risk of these transformational technologies. SPRWG assumed that the NRC's second decadal survey for Earth observations from space, which is currently nearing completion, will include many other examples of exciting potential opportunities for NOAA's future space observing systems.

2. Background and Reference Materials

There have been many studies carried out by the U.S. National Research Council (NRC), U.S. agencies (including NASA and NOAA), the U.S. National Science and Technology Council (NSTC), the World Meteorological Organization (WMO), EUMETSAT, European Space Agency (ESA), and other organizations that have analyzed the importance and value of Earth observations from space and made specific recommendations for future observing systems. SPRWG used these studies, many of which SPRWG members participated in, as a foundation for establishing the requirements for the next generation NOAA satellite observing system. We summarize a few of the most relevant studies here; a more complete list is provided in Appendix F.

The WMO has published several documents creating a vision for the WMO Integrated Global Observing System (WIGOS), the most recent (and still under development) being the *Vision of the WIGOS Space-based Component Systems in 2040* (WMO, 2016). This document is intended to guide the efforts of WMO Member states in the evolution of satellite-based observing systems. It is based on an attempted anticipation of user requirements and technological capabilities, in 2040. The Vision, to be finalized by 2018 under CBS (Commission for Basic Systems) auspices, will be based on a broad consultation of user communities, WMO Technical Commissions, and space agencies.

Previous and ongoing studies by NOAA and the WMO have carried out extensive studies of user requirements of observations from different types of observing systems, including observations from space. NOAA's Technology, Planning and Integration for Observation (TPIO) has worked closely with NOAA program leaders and Subject Matter Experts (SMEs) to document observing requirements in an extensive database called the Consolidated Observing User Requirement List (COURL), sometimes referred to as the Consolidated Observing Requirement List, or CORL (NOAA, 2015). TPIO provided SPRWG with an updated COURL on 24 February 2017.

Specific attributes for each requirement are documented in the COURL. These include, for example, geographic coverage, horizontal resolution, vertical resolution, measurement accuracy, sampling interval, data latency and long-term stability.

SPRWG also made extensive use of the WMO Observation Systems Capability Analysis and Review (OSCAR) Tool (WMO, 2013c). This tool is an important building block of the WMO Integrated Global Observing System (WIGOS). OSCAR summarizes user requirements for observations in WMO application areas, as well as attributes and capabilities of space- and surface-based observing systems.

Another useful document was the ESA, 2014: The Earth Observation Handbook 2015 (ESA, 2014), which provided much useful information on current and planned missions. SPRWG used this reference extensively in developing its understanding of the current capability of objectives in the EVM.

In developing the objectives, performance attributes, rank order and swing weights, SPRWG used these documents, other studies that have appeared in the scientific peer-reviewed literature, and results from Observing System Simulation Experiments (OSSEs) and Observing System Experiments (OSEs) to inform its judgment. The result is a synthesis of many sources of information, adopted for NOAA's NSOSA planning process.

The most difficult, and sometimes contentious, part of studies such as this is the establishment of priorities, especially given the broad NOAA mission and the large number of disparate observations required to support it. SPRWG prioritized the objectives in Group A (weather and oceans) and Group B (space weather) according to its collective judgment, based on many factors, on how improvements in the performance of objectives would lead to improvements in meeting NOAA's mission. The ADT prioritized the Group D (Strategic) objectives.

Early in the process, SPRWG decided to provide Rank Orders for objectives in Groups A and B separately. The two user communities of the Group A (weather and oceans) and Group B (space weather) are so different that SPRWG members felt that they could not make decisions on the relative priorities for both Groups combined. Furthermore, the SPRWG felt that making the priority ranking across these disparate fields was more appropriate for NOAA executive leadership. The NSOSA leadership agreed with this approach. Thus, the NOAA/NESDIS leadership determined the integrated priorities among all three groups. The process went smoothly, and in the end, the NOAA/NESDIS leadership agreed with the integrated priorities SPRWG produced.

The most important principle governing the Nation's civil Earth observing systems is that the overall set of observations must yield a balanced portfolio of observations (OSTP, National Plan for Civil Earth Observations, 2014). Balances of different types are important in establishing priorities for a number of reasons, including providing support for diverse parts of the NOAA mission and supporting very different communities within a constrained budget. Thus, compromise is a key feature of any planning and prioritization process.

We realize that the objectives, their performance attributes, and priorities presented in this report are to some extent subjective, since they are ultimately based on the collective judgment of a relatively small number of subject matter experts. However, the process considered the peer-reviewed scientific literature and planning documents as summarized above, as well as the input and review of many scientists, engineers and policy makers. Every effort was being made to make the complex process as science-based and fair as possible. Because of the subjective component of the process, the final quantitative "results," such as performance attributes, rank orders, and swing weights, should be considered "soft" in that small differences (approximately 15%) in estimated values are considered acceptable. The priorities within Groups A and B should also be considered somewhat flexible in that the difference between close priorities (e.g. nine and ten) should not be considered significant.

3. The EDR Value Model (EVM)

The Environmental Data Record (EDR) Value Model (EVM) is a list of classes of EDRs (also called *functional objectives*) and their attributes that are required to support NOAA mission service areas, as well as certain *non-functional* or *strategic* objectives that are not associated with EDRs. For example, a functional objective is "provide real-time imagery over the continental U.S. (CONUS)." An example of a strategic objective is "develop and maintain international patnerships.” The EVM plays a central role in assessing the value of different satellite and observational architecture alternatives. It is described in detail in the document *EVM Terminology and Concepts* developed by Mark Maier (ADT Architecture Engineeer) working with the SPRWG Chairman (Apppendix C). This document, which is considered foundational for this report, discusses the terminology and concepts used in the EVM, gives a simple example, and provides a guide to how it was developed during the study.

International considerations in developing the EVM

The EVM developed by SPRWG provides the ADT with a list of objectives, or requirements, that are required to support NOAA’s mission service areas in 2030 and beyond. The performance levels of the attributes of these objectives is provided at several levels of capability, as discussed below. It is well recognized that international partners will play an important role in meeting these objectives. For example, Europe (EUMETSAT) provides global atmospheric soundings from infrared, microwave and radio occultation sensors. Japan, India, Korea and Europe provide images at different wavelengths from geostationary satellites. These data are shared freely with NOAA under the guidelines of free and open data exchange provided by WMO Resolution 40 http://www.wmo.int/pages/prog/www/ois/Operational_Information/Publications/Congress/Cg_XII/res40_en.html . In return, NOAA provides its satellite data freely to its partners, and indeed all users. It has been estimated that NOAA receives approximately three times more meteorological data from its international partners than NOAA provides the international community (https://www.nesdis.noaa.gov/content/why-does-noaa-collaborate-internationally).

Early in the NSOSA process, SPRWG and the ADT agreed that SPRWG would develop the objectives and their performance attributes that NOAA required to meet its mission, regardless of where the observations came from. The ADT would consider foreign sources that would provide some of these objectives as part of a baseline system, and would provide architecture alternatives that NOAA would provide to complement this international baseline in order to completely meet all of the objectives.

The ADT provided SPRWG with the NOAA Program of Record (POR) 2025. This POR gives the missions that NOAA expects and is relying on in 2025, and includes several foreign missions. The POR 2025 is given in Appendix D.

4. Development of the EVM

The development of the EVM began with an outline provided to SPRWG by NOAA that contained five groups of objectives. The first group (Group A) consisted of eleven functional objectives that support mainly weather nowcasting and short-range forecasting and warnings and medium-range weather forecasting (numerical weather prediction). The second group (Group B) consisted of six functional objectives that support space weather.

The third group (Group C) consisted of six functional objectives including ocean objectives and vertical profiles of atmospheric chemical species. The fourth and fifth groups consisted of non-functional objectives, Communications and Strategic objectives respectively. As the process of developing the EVM proceeded, SPRWG decided to combine Group C with Group A because of the overlap in missions served and similar types of satellite measurements supporting these objectives. SPRWG also decided, through discussions with NOAA, that the objectives in the Communications Group were not well posed for this process, so we recommended that this group of objectives be addressed in a different process. NOAA leadership then decided to not trade communication capabilities with other objectives. Instead, communication capabilities were fixed at current levels, with two alternatives to be explored: (1) Maintain legacy implementations and (2) commercial outsourcing. Communications (now Group C) remains for possible use in later trades.

For each of the functional objectives in Groups A and B, it was necessary to define the objectives, the performance attributes of each objective, and the performance values of the attributes at three levels - the Study Threshold (ST), Expected (EXP) and Maximum Effective (ME) levels (see below).

To create the EVM, the SPRWG created four subgroups of subject matter experts from its members: (1) Nowcasting (Chris Velden, Chair), (2) Numerical weather prediction (James Yoe and Robert Atlas, Co-Chairs), Space Weather (Tom Berger was the original Chair, Terry Onsager replaced him in June 2016) and Oceanography (Michael Ford and Pam Emch, Co-Chairs). These subgroups were responsible for developing the EVM objectives, attributes and performance levels and determining the Rank Orders of the objectives in their areas. The leaders of the four subgroups worked closely with the SPRWG Chairman and Mark Maier throughout the process and it evolved considerably over time during the three cycles of the study. The SPRWG found this iterative process to be extremely important, in fact essential, in developing a consensus document that could be used in the NSOSA process.

The final objectives for Groups A and B were determined through discussions among SPRWG members and users of NOAA observations, including forecasters and numerical weather prediction (NWP) experts. We used the scientific literature and previous studies as appropriate, as well as the COURL and SPRWG list of requirements. In the end, SPRWG settled on 19 objectives in Group A, and coincidentally, 19 objectives in Group B. We agreed upon these 38 objectives fairly early in the process (by March 2016). The Group A and B objectives are presented in the EVM and summarized in Tables 1 and 2 below.

While there are some similarities, the OSCAR and COURL set of observational requirements are quite different from the SPRWG set of objectives. The former generally present requirements for *products* developed from observations that are needed by a variety of users, while SPRWG presents objectives in terms of instrument *measurements* that are used to produce many different products that support a large number of disparate users. OSCAR has 588 “variables” such as temperature, cloud cover, and specific humidity that support application areas such as climate, agricultural meteorology, aeronautical meteorology, atmospheric chemistry, global and regional NWP, ocean applications and space weather. COURL provides more than 1500 “Environmental parameters” such as atmospheric temperature, water vapor, chemical constituents, sea surface temperature and height, solar imagery, and many more, often multiple entries for the same or similar parameter, but used for different purposes. Both sets of requirements were useful for determining and checking for reasonableness the values of the objectives we developed for this study. However, in some cases it was difficult to establish a direct link between a SPRWG objective and the variables in OSCAR and COURL.

As part of the EVM, SPRWG set *performance attributes* for each objective. A performance attribute of an objective is a characteristic of the objective that defines the properties of the objective. For example, attributes of a temperature sounding system include accuracy, vertical and horizontal resolution, and frequency of update rate, among others. SPRWG then established three levels of performance for each attribute:

- **Study Threshold (ST)**: The threshold or lowest level of performance on the specific attribute that would be acceptable. Objectives that fall below this level are considered of little or no use to NOAA and will not be part of any future architecture. The ST level of performance is often below the current capability for that objective.
- **Expected (EXP)**: Consensus on what the community expects for this attribute in the 2030 time frame. This level is often close to the current capability, but this is not a requirement. In some cases, the EXP level considerably exceeds the current level, as it should where there is an expectation of a substantial increase in quality or quantity of the attribute required to support operational functions.
- **Maximum Effective (ME)**: The highest level of performance on the specific attribute that can reasonably be considered to be worth pursuing. That is, there would be little or no additional value for outperforming the ME level.

In the temperature sounding example, the ST, EXP and ME levels for accuracy might be 2K, 1.5K and 1K. This means that a system that produced an accuracy of less than 2K would be nearly useless and would not be worth providing. An accuracy of 1.5 K would be what the user community expects for the 2030 time frame, and a value of 1K would mean that any system with an accuracy greater than 1K would have a marginal increased impact on users and would not be worth the increased cost.

The OSCAR and COURL also specify levels of performance that SPRWG interpreted as corresponding to the SPRWG levels of performance. OSCAR specified three levels of performance. The OSCAR Threshold is the minimum requirement to be met to ensure that observations are useful; it corresponds to the SPRWG “Study Threshold” (ST) level of performance. The OSCAR Breakthrough is an intermediate level which, if achieved, would result in a significant improvement for the targeted application optimum cost-benefit ratio; it corresponds roughly to the SPRWG “Expected” (EXP) level. Finally, the OSCAR Goal is an ideal requirement above which further improvements are not necessary; it corresponds to the SPRWG “Maximum Effective” (ME) level.

COURL specifies requirements at two levels of performance, “Threshold” and “Objective.” SPRWG interprets these to correspond to the Study Threshold (ST) and Maximum Effective (ME) levels of performance respectively.

In the EVM, the performance attributes given for each objective (e.g. accuracy, horizontal resolution, update rate, latency) are associated with the observation produced by the objective, not the products. Many of the products (for example, those listed in COURL and OSCAR) have their own set of performance attributes, and these ideally should be consistent with those of the objectives themselves.

For comparison with these possible future levels of performance, SPRWG also estimated the current capability of the objectives, based on satellite systems that NOAA uses or expects to use in the 2016-2018 time period. We included these in the Cycle 1 EVM, but changed this to the Program of Record 2025 (POR2025) for the Cycle 2a and final Cycle 2b EVM. Current capabilities are included in the detailed “two pagers” that describe each objective in Groups A and B (Appendix E).

One of the ground rules of the study was that an objective not in the POR2025 was assigned an ST level of zero capability.

The ST-ME range of performance establishes the “tradable range” in developing various future architecture alternatives. It is the performance level over which NOAA will trade alternatives. It is important that the lower end of the tradable range be affordable with considerable room to spare. The value of increasing the performance of the objective above the ST level determines its priority. If the ST level is quite mature and effective, then we expect little return from going much above that level. This is in contrast to areas where there is no capability or low maturity at the ST level and considerable room for enhancement. The concept of basing priorities on improvements of capability over the ST level rather than absolute priority of the objective was new to SPRWG members.

Finally, it was necessary to assign an *effectiveness scale* E to the Expected (EXP) Level of each objective. The effectiveness scale is a number between 0 and 100 that determines how far above the ST level the objective is achieved. The value E for every objective is by definition 0 for the ST level and 100 for the ME level. The value associated with meeting the Expected level varies between 0 and 100 and was assigned by SPRWG. A value of 50 means that meeting the Expected level is 50% of the total value of meeting the ME level. A value of 70 means that 70% of the value of attaining the ME level is met by attaining the EXP level and only 30% is attained by a further increase of performance to the ME level. The higher the value assigned to the EXP level, the less additional value there is to achieve the ME level.

Definition of the performance attributes

The various performance attributes used to describe the objectives in Groups A and B are listed and defined briefly in the EVM. Most are straightforward, but a few require explicit definitions.

Ground-projected instantaneous field of view (GIFOV): GIFOV, which is applied to images, is a measure of the horizontal scale of the smallest feature on the ground that can be measured by the sensor. It is related to the Instantaneous Field of View (IFOV), which is the angular field of view of the sensor independent of height, by the relationship

$$\text{GIFOV} = 2H\tan(\text{IFOV}/2) \qquad (1)$$

where H is the height of the sensor above the ground.

GIFOV is often called "horizontal resolution" (e.g. in COURL), and sometimes Ground Sampling Distance (GSD), horizontal footprint, or pixel size.

Horizontal Resolution: SPRWG uses a common definition of *horizontal resolution* for numerical models in which it is the spacing between model grid points, and observations such as vertical soundings in which it is the average spacing between the observations. Thus an observational system with an average spacing between observation points of 100 km is defined as having a horizontal resolution of 100 km.

Accuracy: Closeness of an observation to the true value as defined by the COURL: "The systematic error, as specified by the difference between a measured or derived parameter and its true value in the absence of random errors."

Sampling frequency (equivalently *sampling interval* or *update rate*): Average time interval between consecutive measurements at the same point or area of the environment.

Latency: Because SPRWG is representing user needs, we define latency as the time from the sensor making the observation to the time the observation or product is available to the primary NOAA users, e.g. NWS forecasters or the National Centers for Environmental Prediction (NCEP). Thus it includes the time from the sensor observation to the time received by the ground receptor site plus the time to process the data. The processing time depends on the observation or product and can be a substantial fraction of the total latency.

SPRWG realized that the ADT defines latency as the time of the sensor observation to the time received by the data processing center, not including data processing time. Thus neither SPRWG nor the ADT considered the latter explicitly , but it must be included in the overall architecture NOAA space environmental data and information system.

Priorities of Objectives and Swing Weights

The architecture planning process assumes that every architecture will provide all the objectives to at least the ST level within the fixed budget specified, which is $2.2B per year (in constant FY16 dollars). This figure is for all of NESDIS, so the amount for space observing systems is less. Depending on the objectives, and the ST level of performance for each objective, it may not be possible to find any architectures that meet this requirement. In that case, the objectives and their ST levels would have to be revised to meet the budget limitations, or the argument made to increase the budget limit to accommodate all the objectives at the ST level at least.

After the ST, EXP, and ME levels of performance for each objective were determined, SPRWG estimated the relative priority (Rank Order) of increasing objectives in Groups A and B from the ST to the ME level of performance. This process, which was relatively non-controversial, was carried out with numerous discussions and, as mentioned earlier, in a spirit of compromise. The SPRWG then developed the swing weights associated within the two groups of objectives, using a mathematical model as described below. SPRWG worked closely with the ADT (particularly Mark Maier and Monica Coakley) during the entire process. The swing weights quantify the priority of increasing the performance of one objective from the ST to ME level vs. the priority of increasing the performance of another objective from the ST to ME levels. The swing weights vary between 0 and 1 and the sum over all the objectives must equal 1.

For example, if Objectives X and Y have swing weights of 0.04 and 0.01 respectively, improving Objective X from the ST to ME level is judged to be four times more valuable than improving Objective Y from the ST to ME level.

<u>It is important to emphasize that the EVM approach demands that objectives be prioritized according to their potential value for improvement in capability over the ST level, not the objective itself.</u> For example, the most important objective in absolute terms might have such a high performance level at the ST level that it is ranked relatively low in terms of improvement to the ME level compared to a less important objective with little or no capability at the ST level. As illustrated in Fig. 1, the objectives with a high absolute priority (very important to NOAA’s operational mission) AND a low-level of capability (or no capability at all), rank highest in EVM priorities.

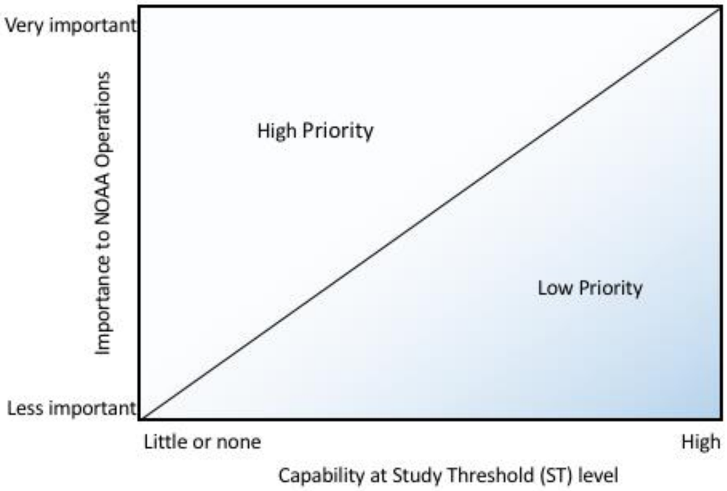

Fig. 1: Illustration of relative priorities of objectives. The highest priorities are objectives that are very important to NOAA's operational mission AND have little or no capability at the ST level.

During the discussions of priority setting and assignment of swing weights to the objectives, SPRWG agreed on the following set of principles or assumptions:

1. The difference between swing weights of adjacent priorities should be small because of significant uncertainty in priorities between neighboring priorities.
2. The decrease of weights with decreasing priorities should be smooth.
3. The lowest priority objectives are still important and their weights should not approach zero.
4. There is a group of highest priorities near the top and another group of lowest priorities near the bottom. The rate of decrease of swing weights should be relatively flat in these groups with steeper decrease in between, suggesting a tanh type of curve (see below).

Swing weights of prioritized objectives

For the first cycle, SPRWG specified the raw swing weights W within Groups A and B according to a simple power law:

$$W = x^y , \qquad (2)$$

where y=Rank number and x=0.95. The raw weights W were then normalized by the sum W_S of the raw swing weights W, which is given by

$$W_S = (x-x^{N+1})/(1-x). \qquad (3)$$

For Groups A and B with N=19 objectives, W_S =11.83028155.

In the “power law” model, the weights (priority) decreased exponentially from Objective #1 to Objective #19. The swing weights were assigned via this simple power law because the model was not considered fully stable, and so an effort to do a formal elicitation seemed unwarranted.

For Cycle 2a the SPRWG considered the “balance beam” model of scoring the objectives (see p. 15 of the *EVM Terminology and Concepts* paper in Appendix C), but found it cumbersome with 19 objectives. It was difficult to agree on the priorities of all of the possible comparisons between objectives and groupings of objectives; e.g. “is the swing in Objective X less than, more than, or equal in priority to the swing in Objectives Y plus Z?” Thus, as an alternative to this approach, we considered a revised (from the power law model used in Cycle 1) mathematical model to determine the weights. The new model (a hyperbolic tangent model) was chosen to reflect the principle that there should be relatively small differences in weights between closely ranked objectives near the top and bottom of the prioritized list, but a significant difference between the weights of the highest and lowest ranked objectives. In contrast, the power law model, which was used in Cycle 1, gives the most rapid change in priorities in objectives at the top of the list and least amount of change in objectives ranked lower in the list. In the hyperbolic tangent model, the priorities among objectives near the top (1-5) and bottom (16-19) of the rank order change more slowly than the priorities of objectives in the middle of the range (6-15).

The two models are admittedly simple and cannot account for large, abrupt shifts in swing priority (if they existed) between objectives ranked closely to each other. However, the models have the desirable property that the assumptions are clear, in contrast to the balance beam approach in which many arbitrary decisions would have to be justified individually (e.g. “justify why the priority of the swing in Objective X is less than the priority of the swing in Objectives Y plus Z”). They also have the advantage that changes in the rate of change of priorities and the overall shapes of the changes in priorities of the objectives can be easily and consistently varied.

During the priority discussions, a consensus developed among SPRWG members that a simple hyperbolic tangent model captured the desired general characteristics of the relative priorities and swing weights among objectives and would be satisfactory. After experimenting with several hyperbolic tangent models, we agreed on the following model for the raw (un-normalized) weights:

$$W(i)= eps + [1-\tanh((R/N)(i-mid))]^p \qquad (4)$$

where i is the index of the objective (ranging from 1 to N) and “mid” is the index of the objective for which the swing weight is roughly half (50%) of the swing weight of the top objective.

The range R may be varied depending on how much of the tanh function (which varies between -1.0 and +1.0) we want to use. For example, if we pick R=4.0 we will be using most of the tanh range and the weights will change fairly slowly for the top 5 and bottom 5 objectives and more rapidly in between. If we wanted greater variation at the top and bottom of the range of our objectives we could pick R=1.5 or 1.0.

Furthermore, SPRWG felt that the lowest-ranked objectives should approach some non-zero value instead of zero—they may be relatively indistinguishable, but they are not zero in priority. This model accomplishes this goal as for the lowest ranked objectives the weights approach eps.

In our model for both Groups A and B we chose R=4, p=1.2, eps=0.1, N=19 and mid=8. The swing weights calculated according to (4) are presented in Tables 1 and 2 and graphs of the swing weights are presented in Fig. 2.

For objectives near "mid," the swings of any two objectives from ST to ME is roughly equal in priority to the swing of the highest priority objective from ST to ME.

Even though we did not use the balance beam approach, we used it to test our assumptions and the "reasonableness" of the model we chose. We concluded that the model produced swing weights that produced reasonable priorities among the Group A and B objectives.

The priorities and swing weights for the objectives in Group D (Strategic objectives) were determined by the ADT.

5. Final EVM

The EVM spreadsheet for Cycle 2b (the final EVM) can be found at https://www.nesdis.noaa.gov/sites/default/files/EVT-EVM-Cycle-2b_Final_Report_20180325_Posted.pdf. The rank order and swing weights of the objectives in Groups A and B are summarized in Tables 1 and 2 respectively and the integrated rank order of the combined objectives are provided in Table 3.

The EVM presents objectives in three Groups:

- Group A: Weather and Ocean and related product objectives
- Group B: Space weather objectives
- Group C: Not addressed by SPRWG and so not in the EVM
- Group D: Strategic objectives

There are 19 objectives each in Groups A and B, and six objectives in Group D, for a total of 44 objectives. The objectives in Groups A and B are associated with certain instruments or types of instruments that measure properties of the atmosphere, oceans, land and cryosphere using passive or active remote sensing techniques. Some of the objectives (e.g. Non-RT Global Weather Imagery Visible and IR other than ocean color, Objective 3 in Group A) support many different products used by NOAA line offices (e.g. cloud top height, land surface temperature, ocean surface temperature, snow cover, and sea/lake ice concentration). The products listed in the EVM and the "two pagers" are examples only; we did not attempt to include an exhaustive list.

Table 1 summarizes the rank order of the objectives in Group A and Table 2 summarizes the rank order of those in Group B. These tables are consistent with the EVM, but present the priorities in the two groups in a way that is easier to see.

Table 1: Ranking of Group A Objectives

A ground rule of the NSOSA process is that all objectives will be included in any architecture to at least the ST level. Thus the rank order gives priorities for moving from ST to ME levels—the priorities in improving the capability above the ST levels, not absolute priorities. Highest priority is therefore given to objectives that are both very important to NOAA operationally **and** have a relatively low level of capability at the ST level (see Fig. 1). Highest priority for NOAA operations is assumed to be saving lives and property; therefore Nowcasting (severe weather) and NWP are the highest priorities in general for improvement.

Swing weights are given by the tanh model (Eq. 4 above) with the following parameters: p=1.2 eps=0.1 Range=4 N=19 mid=8

Rank Order (priority for improvement) and swing weight	Objective	ST level comments	Rationale for ranking
1 0.1268957	3-D winds	Some capability from atmospheric motion vectors from ABI. Large room for improvement	Holy Grail of NWP, and not well provided now. Very important to provide above ST level of NONE. Top priority for improvement.
2 0.1232025	RT regional wx imagery	ST level significantly below current capability	Other objectives provided in part by foreign partners; this one must be provided by the US. Important for severe wx warnings, incl. hurricanes, tornadoes. High priority for improvement.
3 0.117956	Global GNSS RO soundings	Relatively low level of capability (5,000 global soundings per day) far below optimum.	Major contributor to NWP, improves performance of IR. MW sounders, space weather and climate applications. High priority for improvement.
4 0.1107445	Global RT imagery	Important, significant capability at ST level with GOES-R series, EUMETSAT, and Japan satellites	Tropical cyclones, global cloud cover, extra-tropical storms. Important to US, but not as important as GOES. Significant capability at ST lowers its priority for improvement.
5 0.101262	Global RT MW soundings	Significant capability at ST level.	One of top contributors to NWP. Large capability at current and ST levels, which lowers its priority for improvement.
6 0.0895125	Global RT IR soundings	High level of ST, but not as high as current capability	One of top contributors to NWP. High capability at current and ST levels reduces its priority for improvement.
7 0.0759965	Global sfc vector winds	Significant with SCA scatterometer (EUMETSAT)	Important for NWP, ocean applications. Significant ST level -> medium priority for improvement.
8 0.0617462	Non-RT global wx imagery	6 bands is below current capability	Supports large number of applications and users. Significant ST level -> medium/high priority for improvement.

9 0.0480788	Global ocean color/phytoplankton composition	VIIRS is ST level	Supports variety of ocean applications. Significant ST level -> medium priority for improvement.
10 0.0361549	Microwave imagery	Fairly high ST level, but currently declining due to loss of SSMIS	Medium ranking due to existing/planned sensors (JPSS, GPM), but strong contribution to passive precip rates and tropical cyclone analysis.
11 0.0266211	Lightning	None (significantly below current capability of GLM on GOES-R)	Moderate importance for NOAA situational awareness operations, nothing at ST level -> medium level priority for improvement.
12 0.0195448	Radar-based global precipitation rates	None at ST level. Current capability includes DPR in GPM. Significant IR and MW assets also exist.	Low/medium priority for NOAA ops and significant ST level from other Objectives -> low priority for improvement.
13 0.0145955	Regional MW soundings	None, except significant contribution from global system.	Improvements in global system also improve regional, so priority for improvement relatively low.
14 0.0112857	Regional IR soundings	None, except some contribution from global system and ABI on GOES-16.	Improvements in global system also improve regional system, so priority for improvement relatively low.
15 0.0091432	Global sea sfc height	Significant capability (JASON-3) (Also JASON-2) – ST high	Important climate change indicator, global ocean models. Significant ST level implies low priority for improvement.
16 0.0077877	Global chemical conc	None	Fairly low priority for NOAA operations, but NONE at ST level -> increases priority for improvement.
17 0.0069435	Ozone	Significant-OMPS, IASI-current level	Low/medium priority for NOAA ops and significant ST level-> low priority for improvement.
18 0.0064232	Outgoing LW Radiation	Significant capability at ST level	Relatively low priority for NOAA ops, significant ST level --> low priority for improvement.
19 0.0061049	Incoming solar radiation	Significant capability at ST level	Relatively low priority for NOAA ops, significant ST level -> low priority for improvement.

Table 2: Ranking of Group B Objectives (Space Weather)

All objectives will be included in any architecture to at least the ST level. Thus the following table lists priorities in moving from ST to ME levels—the priorities in improving the capability over the ST levels, not absolute priorities. Highest priority is therefore given to objectives that are both very important to NOAA operationally and have a relatively low level of capability at the ST level (see Fig. 1). Note that the value of space weather observations and services could evolve considerably over time as changes occur in technologies affected by space weather. Consequently, the priorities for observations will also likely change in ways that may be difficult to anticipate.

Swing weights given by tanh model (Eq. 4 above) with following parameters:
p=1.2 Eps=0.1 Range=4 N=19 mid=8

Rank Order (priority for improvement) and swing weight	Objective	ST level comments	Rationale for ranking
1 0.1268957	Coronograph imagery: Off Sun-Earth line	No reliable current capability. STEREO research mission is often of no value due to constant drifting of spacecraft.	Needed to characterize coronal mass ejections that are responsible for geomagnetic storms. Used in conjunction with the Sun-Earth line coronagraph.
2 0.1232025	Coronograph imagery: Sun-Earth line	FOV is degraded from SOHO values. Current capability from SOHO research mission has poor and variable latency.	Essential measurement to characterize coronal mass ejections that are responsible for geomagnetic storms.
3 0.117956	Photospheric magnetogram imagery: Off Sun-Earth line	No current capability.	Needed for characterization of active regions rotating into a geoeffective position. Provides important input to solar wind models to forecast arrival of coronal mass ejections.
4 0.1107445	Heliospheric images	No reliable current capability. STEREO research mission is often of no value due to constant drifting of spacecraft.	Would enable the monitoring of the evolution of coronal mass ejections en-route from the Sun to Earth, allowing improved forecasts of arrival time.
5 0.101262	Auroral imaging	None available that meet operational data latency requirements.	Would provide accurate, real-time monitoring of the location and strength of geomagnetic disturbances and quantitative measures of energy input for magnetosphere/ionosphere models.
6 0.0895125	Thermospheric O/N2 ratio (height integrated)	No current capability	Thermospheric composition profiles are needed for ionosphere/thermosphere coupling in assimilative forecasting and specification models.
7 0.0759965	Upper thermospheric density	No current capability	Thermospheric composition profiles are needed for assimilation into global ionospheric/atmosphere forecasting and specification models.
8 0.0617462	Ionospheric electron density profiles	Slightly degraded from COSMIC-2 values.	Ionospheric electron density profiles are needed for assimilation into global ionospheric forecasting models of ionospheric disturbances that impact GNSS accuracy and HF communication.
9 0.0480788	Ionospheric Drift Velocity	No current capability	Ionospheric drift velocity measurements are needed to determine plasma transport as an assimilation input for forecast models.
10 0.0361549	Interplanetary Solar wind: Off Sun-Earth line	No reliable current capability. STEREO research mission is often of no value due to constant drifting of spacecraft.	Measurements of solar wind characteristics ahead of Earth (e.g. from L5) would allow several days advanced indication of incoming solar wind disturbances that can impact Earth.
11 0.0266211	Photospheric magnetogram imagery-Sun-Earth line	Degraded from SDO/HMI values.	Magnetograms on the Sun-Earth line allow for solar wind model initiation and active region characterization.
12 0.0195448	Solar X-ray irradiance	ST level is degraded from GOES-R and only includes one of the two current x-ray wavelengths.	Essential input to NOAA products. Allows characterization of solar eruption and is an essential input into HF radio impact models and radiation storm warning products.
13 0.0145955	Solar EUV imaging	ST level is degraded from GOES-R.	Essential input to NOAA products as the bases for event forecasting and identification.
14 0.0112857	Solar EUV irradiance	ST level is degraded from GOES-R.	Essential input for future satellite drag products.
15 0.0091432	Interplanetary Solar wind: Sun-Earth Line	ST level is degraded from DSCOVR. Limitation in velocity measurement range is significant.	Essential input for driving geomagnetic storm products and models.
16 0.0077877	Interplanetary Energetic particles	ST level is degraded from ACE and lacks highest energy proton measurements.	Data are used to improve forecasts of geomagnetic storm onset time based on energetic particle precursors at L1.

17 0.0069435	Geospace Energetic particles	ST level is degraded from GOES-R.	Main data input to radiation storm alert product and post-facto GEO satellite anomaly analysis.
18 0.0064232	Geomagnetic field	ST level is degraded from GOES-R.	Gives real-time assessment of geomagnetic disturbance, magnetopause crossings, and is used in energetic particle analysis.
19 0.0061049	Interplanetary Magnetic Field	ST level is degraded from DSCOVR.	Essential input for driving geomagnetic storm products and models.

The ratio of the swing weights of Objective (i) to the swing weight of the highest priority objective (Objective 1) for Groups A and B is depicted in Figure 2.

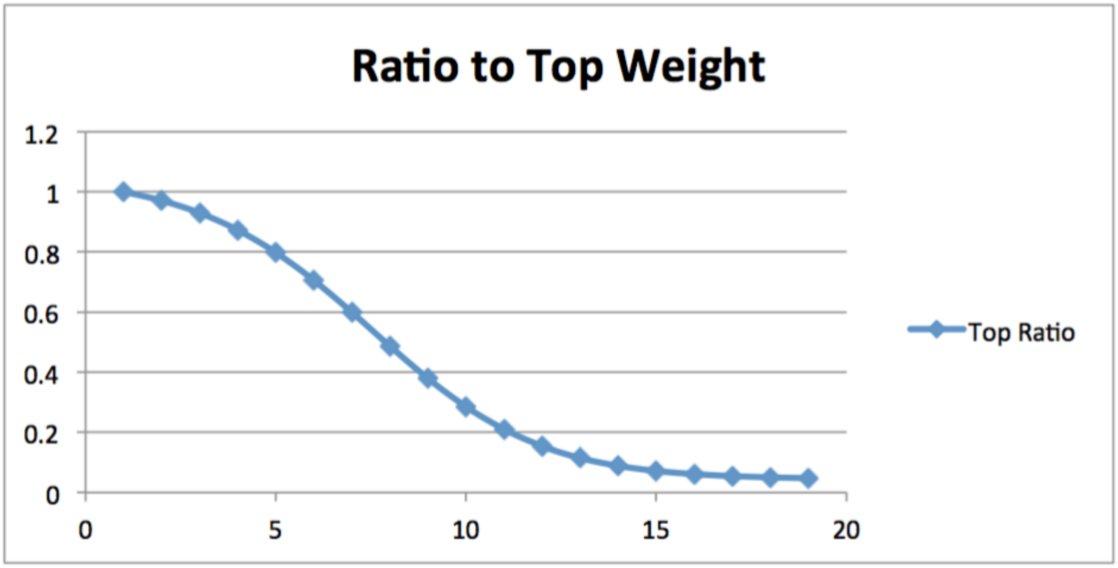

Fig. 2: Ratio of swing weight of ith Objective to swing weight of top ranked Objective (i=1) for Groups A and B.

Because many of the objectives listed in the EVM and their attributes have complexities that are difficult to include in a single spreadsheet, SPRWG developed a short, approximately two-page, summary of each objective. These “two pagers,” presented in Appendix E, describe the objective, how it is used, current satellite systems that meet the objective, the Program of Record 2025 and current capability, ST, EXP, and ME levels, and sources of information that went into making these estimates. Characteristics of the objectives that are important, but too subtle or complex to capture in a single spreadsheet are included. Finally, they summarize the rationale for the priorities of the objective.

The combined list of Objectives, their priorities for improvement, and their swing weights (as determined by NOAA leadership) are listed in Table 3. The swing weights for the 44 objectives was discussed at great length at the 11-12 January 2017 SPRWG meeting and the result was a SPRWG preference for the tanh model with the parameters

N=44, p=1.2, Eps=0.1 Range=4, and mid=13 (Fig. 3). Note that the priority for improvement from ST to ME level of the top 13 Objectives approximately equals the priority for improvement from ST to ME of Objectives 14-44.

Table 3: Overall priorities of objectives (established by NOAA)

Rank Order (priority for improvement)	Objective			
		Priority within Group	Swing weight within group	Integrated swing weight
1	D1-Assurance of core capabilities	D1	0.32	0.068538
2	A13-3D winds	A1	0.127	0.066988
3	A1-Regional real-time weather imagery	A2	0.123	0.065216
4	A9-Global GNSS-RO soundings	A3	0.118	0.063206
5	D2-Compatibility with fixed budgets	D2	0.23	0.060948
6	A2-Global real-time weather imagery	A4	0.111	0.058438
7	A7-Global RT vertical MW soundings	A5	0.101	0.055681
8	A5-Global RT vertical IR soundings	A6	0.090	0.05269
9	B2-Coronograph Imagery: Off Sun-Earth line	B1	0.127	0.049493
10	B1-Coronograph Imagery: Sun-Earth line	B2	0.123	0.046128
11	A12-Ocean surface vector wind	A7	0.076	0.042643
12	D3-Assurance of all capabilities	D3	0.16	0.039096
13	D4-Programmatic responsiveness and adaptability	D4	0.15	0.035549
14	A3-Non-Real-Time global weather imagery	A8	0.062	0.032066
15	A4-Global ocean color/phytoplankton composition	A9	0.048	0.028707
16	A15-Microwave Imagery	A10	0.036	0.025524
17	A10-Lightning	A11	0.027	0.02256
18	B5-Photospheric magnetogram imagery: Off Sun-Earth line	B3	0.118	0.019845
19	B10-Heliospheric Images	B4	0.111	0.017396
20	B16-Auroral Imaging	B5	0.101	0.015219
21	B17-Thermospheric O/N2 ratio (height integrated)	B6	0.090	0.013307
22	B18-Upper thermospheric density	B7	0.076	0.011649
23	B15-Ionospheric electron density profiles	B8	0.062	0.010226
24	B19-Ionospheric drift velocity	B9	0.048	0.009016
25	B9-Interplanetary Solar wind: Off Sun-Earth line	B10	0.036	0.007995
26	D5-Develop and maintain international partnerships	D5	0.08	0.00714
27	D6-Low risk at constellation level	D6	0.06	0.006429
28	A18-Radar-based global precipitation rate	A12	0.020	0.00584
29	B4-Photospheric magnetogram imagery: Sun-Earth line	B11	0.027	0.005355
30	A8-Regional (CONUS) RT vertical MW soundings	A13	0.015	0.004956
31	B6-Solar X-ray irradiance	B12	0.020	0.00463
32	A6-Regional (CONUS) RT vertical IR soundings	A14	0.011	0.004364
33	B3-Solar EUV imaging	B13	0.015	0.004148
34	A11-Sea surface height (global)	A15	0.009	0.003972
35	B7-Solar EUV irradiance	B14	0.011	0.00383
36	A19-Global soundings of chemical concentrations	A16	0.008	0.003714
37	B8-Interplanetary Solar wind: Sun-Earth line	B15	0.009	0.003621
38	A14-Ozone	A17	0.007	0.003545
39	B11-Interplanetary Energetic particles	B16	0.008	0.003484
40	A16-Outgoing LW radiation	A18	0.006	0.003435
41	B14-Geospace Energetic particles	B17	0.007	0.003396

42	A17-incoming solar radiation	A19	0.006	0.003364
43	B13-Geomagnetic field	B18	0.006	0.003338
44	B12-Interplanetary Magnetic Field	B19	0.006	0.003317

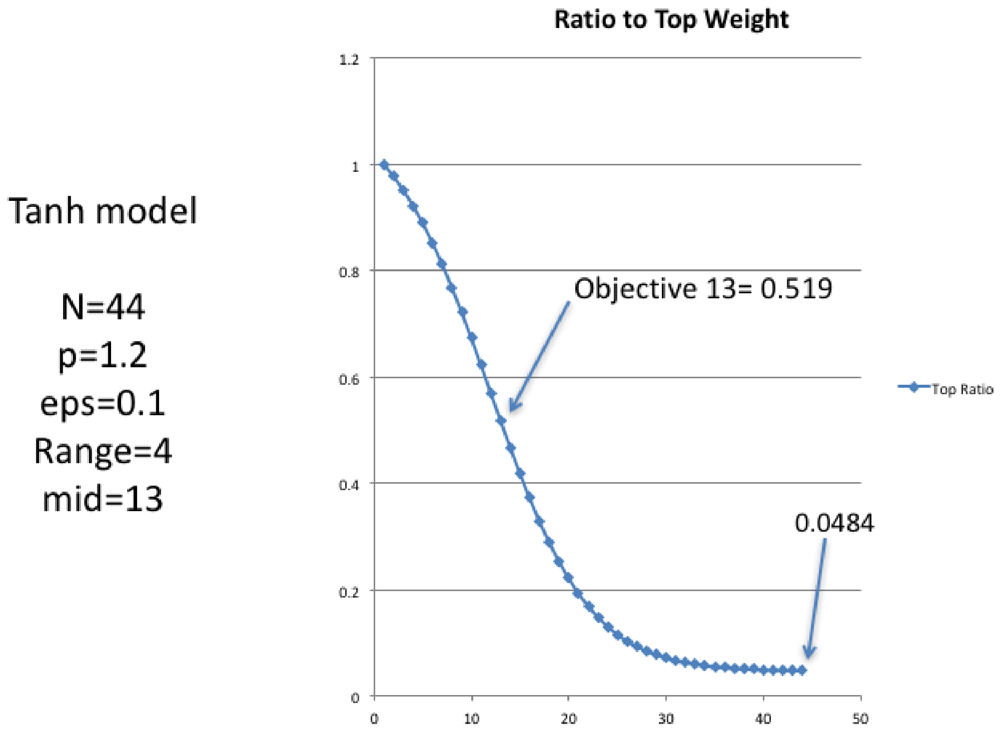

Fig. 3: Ratio of swing weight of ith Objective to swing weight of top ranked Objective (i=1) for combined 44 objectives.

6. Scenarios from SPRWG subgroups

This section describes scenarios developed by the SPRWG for evaluating architecture trades. There have been no significant changes in this section from the Cycle 1 report.

Introduction

To evaluate the strengths and weaknesses of observing system configurations, it is valuable to identify a set of stressing scenarios.

The specific guidance that has been provided to SPRWG for developing scenarios is:

- The SPRWG will develop the scenarios (i.e., major use cases) **for which the ADT will conduct architecture development**.
- Scenarios may include **critical operations** that pertain to events that occur in various locations in a specific time sequence under a set of **normal** or **contingency** conditions.

Scenario analysis should help answer questions about a particular architecture such as:

- Is the observing system able to provide accurate forecasts of the general conditions more than a week in advance? Five days in advance?
- Is it sufficient to support warnings 24 hours in advance?
- Is it sufficient to provide emergency managers of all kinds the information they need to cope with the weather?
- Are people given sufficient warning to respond to hazardous weather ranging from heavy snow, floods, freezing conditions in agriculturally sensitive regions, severe thunderstorms, hail, lightning and tornadoes?

Problem Definition and Context

Methodology. Scenario analysis is intended to determine whether undesired operational impacts arise under particular architecture choices when the system is stressed in complex ways. In particular, scenarios enable analysis of system interactions and resource contention that can be difficult when considering only simple situations. The approach used by SPRWG is consistent with the following assumptions:

1. Operational impacts will arise when the system is overly stressed by issues such as failure or operational demand overload.
2. Operational impacts arise largely from stress on particular aspects of the system (e.g., data volume). These system stressors should be identified and explicitly evaluated during architecture trades.
3. While system stressors can be assessed individually, complex operational situations can lead to issues that are not readily identified by individual analysis. It is helpful to identify scenarios representative of real-life situations that can be used to assess system stressors and operational impacts for comparing architectures.
4. NOAA operations depend on foreign satellites and other non-NOAA assets that are outside of NOAA's control, and are hence vulnerable to losses of these systems.

Objectives. The specific questions to be addressed through this scenario analysis include:

- What are the operational impacts of each architecture, as evaluated in the context of the provided Impacts table?
- How do the results differ when moving from the Study Threshold (ST) level of capability toward the Maximum Effective (ME) level of capability?
- Do conflicts between mission elements arise, and can these be resolved?
- Are there system bottlenecks or surprises that appear as the sequence of events in each scenario progresses?

Related Work. In preparing this scenario discussion, SPRWG reviewed a 2003 NASA report titled *Advanced Weather Prediction Technologies*[2] (AWPT) concerning development of more robust architectures for NOAA observing systems. This report presents scenarios in the context of evaluating their architecture recommendations. They identified 6 scenarios, all actual events that were known to have stressed the operational system. All 6 were related to major snowstorms in different parts of the country. For their analysis, they focused on only 2 of the 6, one that stressed NOAA's global forecast operations and one that stressed mesoscale capabilities.

AWPT assumed that stressing scenarios were those that exhibited operational and/or economic significance. The report identified six attributes of a scenario that could make it stressing to the NOAA observing system:

a. the scale of phenomena (*mesoscale, regional or synoptic*) being forecast;
b. the required forecast lead-time (e.g. *1 day vs. 5 day*);
c. dependency of forecast success on need and availability of upstream data;
d. reliance on space-based observing segments;
e. the nature of observation targeting (*model-based vs. observation-based*); and
f. the importance to forecast success of real-time feedback and supporting communications.

AWPT notes that "most forecast failures can be traced to deficiencies in one or more of five categories: communications, data availability, data accuracy or quality control, data analysis and synthesis, and decision support systems."

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[2] Glenn Higgins et al., *Advanced Weather Prediction Technologies: Two-way Interactive Sensor Web & Modeling System*, a report prepared for NASA's Earth Science Technology Office, Nov. 2003.

Approach

Scenario Classes. In its initial discussions, SPRWG identified a wide range of stressing scenarios for any NOAA architecture. We chose to categorize these into four scenario classes:

1. *Operational Demands* – Weather scenarios that stress the operational capabilities of the system. These potentially include:
    a. Operational overload from many high-impact weather events happening at the same time, such that other EDR choices could improve *workflow;*
    b. Unusual sequences and combinations of weather events that stress observing capability and resources; and
    c. Anomalous events that fall outside planned observing requirements.
2. *System Degradation* – System degradation over time leading to failure, such as a) satellite equipment failure in an instrument or bus, b) breakdown in the overall communications chain, and c) ground systems wearing out.
3. *Unplanned Events* – Unpredictable or statistically unusual events that can be anticipated in a general sense but not specifically predicted.
    a. *Human-caused accidents* that disrupt the system, such as: satellite collision, b) impact by space debris (man-made), and c) ground system failures.
    b. *Natural events* such as solar flares damaging equipment or communications, space debris (meteoroids, etc.).
    c. *Intentional Disruption* such as laser attack, jamming, taking over satellite commanding, cyber disruption, purposeful spectrum intrusion.
4. *Programmatic Pressures* – Changing programmatic constraints, such as future budget limitations or expanded performance expectations that introduce stresses on system performance.

Scenario Selection Issues. No one scenario is likely to stress all system elements so multiple scenarios are warranted. These should *test the system on the different time and space scales* associated with operational situations NOAA encounters, and include the many external failure drivers that could be present. Some of the included scenarios may serve a specific purpose. For example, certain situations stress NOAA's global forecast capability, while others stress mesoscale nowcasts and forecasts or even specific system capabilities such as space weather.

Ideally, selected scenarios are comprehensive in the sense of together being able to represent the range of stressing operational situations that could be faced. Collectively, the scenario set should stress: a) all elements of the candidate architectures individually, and b) the interactions among architecture elements.

SPRWG Scenario Choices. While each of the four scenario classes described above could contribute to an overall scenario set, <u>SPRWG chose to focus on only the first class of operational scenarios</u> for the purposes of this report. Future analysis could expand the scenario set.

SPRWG chose the following four scenarios for initial analysis:

1. A <u>demanding weather pattern</u> moving across the US that drives multiple weather events in different locations, each with forecast needs occurring simultaneously.
2. A major <u>space weather event</u> that includes demanding space weather observation/forecasting needs and place systems at risk.
3. An <u>operationally complex nowcast</u> situation, with demands from many simultaneous events.
4. <u>Geopolitical chaos</u> shuts down most foreign satellite capabilities or communications to NOAA.

SPRWG did not study in any detail the communication chain from satellites to ground to users in this cycle of the study; this must be considered in the total architecture study. In general, only Scenario 2 could potentially disrupt the transmission of observation data from satellite and non-satellite observing systems that could then further degrade NOAA's ability to respond to the scenario described. The WFO's and many other direct users of the observing systems might still be able to get some of the data where back up capabilities (IP modems, telephone lines, etc.) are in place. In Scenarios 1 and 3, the number of large geographic scope of phenomena would not disrupt communications, as data would continue to be transmitted and down linked as per the channel capabilities. Scenario 4 considers the disruption of foreign satellites so NOAA GOES communications don't apply.

System Stressors. The importance of scenarios is to test specific stressors to the system architecture. To assist with this process, SPRWG identified a set of anticipated system stressors that are impacted by architecture design and should be evaluated to assess relative architecture performance (Table 4). This is different from, but consistent with, the AWPT report.

Table 4: System stressors and examples of effects on system architecture.

SYSTEM STRESSOR	EXAMPLES IN ARCHITECTURE
System Functioning	• A space weather event takes out half of the satellites, reducing the number of sensors available • Normal lifetime degradation eliminates some sensors
Data Volume	• A mixed ground station architecture is employed using additional stations designed for downlinking some but not all data so as to reduce latency or key observations. An unusual event drives requests for downlinking more data with low latency, but comms links can't support all requests. • Instruments are designed with significant loss of onboard data compression. An unusual event drives requests for use of uncompressed data, but comms links can't support all requests.
Data Quality	• Data quality is degraded by reducing the number of sensors that contribute to a data product or by other means • Under operational stress, configurable instruments are operated in particular ways, such as reduced integration times, that degrade data quality.
Reconfigurable Instrument Demands	• Instruments are designed for shared operations, such as a combined imager/sounder. An unusual event drives competing requests for all instrument modes.
Tasked Collection Demands	• A regional imager is designed to image up to two regions per hour, but an unusual weather pattern drives the need to image more regions. • An instrument is designed with reconfigurable bands. An unusual event drives competing requests for all bands.
Operational Demands	• The architecture is designed with flexible operations that require choices (e.g., imaging region, instrument configuration) to be made hourly. A complex weather scenario with many competing needs pushes the limit of the operational team to make hourly decisions.

Operational Impacts. Table 5 lists potential operational impacts that should be considered in the analysis.

Table 5: Operational impacts and issues in Nowcast, Forecast and Warning capabilities

OPERATIONAL IMPACT	SPECIFIC ISSUES FOR CONSIDERATION
Nowcast Capability	• Reliable availability of observations needed to fulfill the range of nowcasting needs without conflict among them
Forecast Capability	• Timing and accuracy of storm designation escalations (e.g., tropical depression to tropical storm to hurricane) • Accuracy of global forecasts at multiple lead times (e.g., 1 day, 5 day, 10 day) • Accuracy of mesoscale forecasts at multiple lead times (e.g., hours to days)
Warning Capability	• Warning of imminent events • Long-term (1 day+) warning • Range of warning types available and reliable • Timing and accuracy of escalations (e.g., watch to warning) • Availability of additional information, as needed by emergency managers

Scenario 1: DEMANDING WEATHER PATTERN. An unusual mixture of high-impact weather affecting the United States

Purpose: Stress both global and mesoscale operational capabilities simultaneously over a duration of several days. This can be considered a normal scenario, with some contingency situations included as a result of the scenario's complexity.

Description

A large storm system moves across the US over the course of several days. As it reaches each part of the country, the impacts depend both on the local weather phenomenology and on the particular vulnerabilities of that area. Both advance forecast warnings and real time warnings are essential.

1. A deep, slow-moving trough approaches the Pacific Coast in April
    a. Heavy snows in California, Utah, and Colorado occur as the storm enters the U.S. and heads east.
    b. Travel is disrupted for three days, and power is out throughout much of the mountain areas.
    c. Heavy snowmelt and floods occur in Washington, Oregon, and California.
2. The storm moves into the Midwest

    a. An extreme outbreak of tornadoes occurs throughout Texas, Oklahoma, and Kansas.
3. The next day the severe weather moves into Alabama and Mississippi
    a. Torrential rains in the Mississippi Valley bring already swollen rivers well past their flood stage.
    b. Cold air behind the system brings freezing temperatures into the deep South, affecting spring agriculture.
    c. Blizzard conditions shut down Chicago O’Hare for two days. Fifty thousand flights are cancelled.
    d. Massive power outages occur over a 300 km wide band extending from northern Texas into Tennessee.
4. The storm finally reaches the East Coast
    a. The location of the snow-rain boundary falls over major cities and must be forecasted accurately to ensure appropriate warnings are provided.
    b. The amount of precipitation must be accurately forecast to indicate the severity of the impacts.

Particular Question to be addressed by Scenario (in addition to those in the Introduction)

- Are there conflicts between providing forecasts in one part of the country and another?

Issues Related to Moving from ST to ME

The following example illustrates the impact of moving from the ST level to the ME level on this scenario[3]:

> The global observations that support NWP from the U.S. and its partners at the ST level are adequate to give an indication of a possible major storm entering the western U.S. a week in advance, but there is large uncertainty in timing, location of landfall, and intensity of the storm. Ensemble forecasts show a large scatter and the forecasts vary significantly from one forecast time to the next. A few forecasts show no storm at all, while others indicate the potential for a 100-year event. The coverage of the Earth and the horizontal resolution of the sounding systems is too coarse to resolve medium- and small-scale atmospheric structures that grow and affect the large-scale forecasts over periods of days. The absence of high-quality wind observations contributes to the uncertainty in the initial fields of the models and the subsequent forecasts. Because of the large uncertainty, planners are

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[3] The impacts of moving from the ST to the ME level are based on qualitative judgments and a variety of quantitative studies (e.g. OSEs and OSSEs) that have been carried out over the past 20 years by NWP experts. These studies have demonstrated without doubt the increasing accuracy and decreasing uncertainty associated with medium-range forecasts as the number and quality of observations increases. Thus the illustrative impacts presented here are considered plausible estimates of the value of moving from the ST to ME level.

> reluctant to begin taking actions more than three days in advance. Public confidence in the medium-range forecasts is low.
>
> As the global observing system is improved from the ST to the ME levels, the uncertainty in the initial conditions is greatly reduced and the forecasts from different models and model configurations in the ensemble forecast system are much more consistent. Uncertainty is greatly reduced and planners are able to start preparations for a major storm event five days in advance. Public confidence is high and millions of people begin adjusting their plans and preparing for possible severe weather.

Scenario 2: SPACE WEATHER EVENT. An unusual severe space weather event (solar flare) stresses both hardware and operations.

Purpose: Stress Arctic search and rescue operations through a combination of space weather and winter weather events in the Beaufort Sea. This can be considered a contingency scenario.

Description

Search and rescue operations in the Arctic are often compromised by severe weather conditions. With increasing commercial use of longer ice-free periods in the Beaufort Sea north of Alaska, the ability to quickly communicate with, locate, and dispatch rescue operations to shipping or deep sea drilling platforms is critical. This scenario posits a commercial fishing vessel that is disabled during an early winter storm in December. The accident occurs during polar night so visibility is already compromised when the storm further decreases visibility to 50 meters in fog with 10-meter surf. During the initial attempts to communicate with the ship, an extreme space weather event occurs and temporarily eliminates all high-frequency radio communications (30—300 MHz). The ensuing radiation storm causes severe heating and convection of the ionosphere over the polar cap region (down to 70° N Latitude) leading to degradation of GPS signals at the ship's location. Positional accuracy of GPS degrades to 1000-m (when lock is occasionally achieved) and the ship is unable to relay an accurate location to the Coast Guard. A CG cutter is dispatched from near Barrow, but will take 10—12 hours to reach the ship. Due to the weather and lack of daylight, Coast Guard helicopters are unable to launch for 12 hours. Just as the CG SAR helicopters are launching, the coronal mass ejection from the eruption hits the Earth and causes a G5+ geomagnetic storm. The ensuing ionospheric currents again cause massive convection and complete loss of GPS signal lock over the entire Arctic region. CG SAR helicopters are subsequently unable to locate the ship in the low-visibility conditions and have to return to base without making contact. Compass headings are now useless as well as magnetic perturbations from the storm exceed ±15°/second. Shortly after the onset of the geomagnetic storm, the GOES West satellite experiences an on-board anomaly and is disabled. Aurora are visible down to 30° magnetic latitude, meaning that as night falls, they are visible overhead in Miami. The power grid in the Washington DC area is overwhelmed by geomagnetically induced currents, experiences voltage instability, and collapses as well as incurring major damage to a key EHV transformer. The subsequent blackout lasts for 3 days. The NOAA Satellite Operations Facility (NSOF) in Suitland, MD, switches to emergency generator power, but after 36 hours, the generators run out of fuel. The backup station in Fairbanks, Alaska is unable to receive satellite downlink data due to a reliance on GPS timing signals that are unreachable during the G5+ storm that lasts for 60 hours.

Timeline of the solar eruptive event and subsequent event timing at Earth:

T=0: Extreme solar magnetic eruption and flare occur
- Large (300 millionths) sunspot group at 10°E, 15° S
- X30 Long Duration Flare (3.5 hours) occurs on November 15th at 1600 Local Alaska Time.
- First indication is GOES X-ray photometer trace.
- Flare is followed within minutes by fast EUV wave and coronal dimming over half hemisphere indicating large/fast coronal mass ejection heading towards Earth.

T=5 minutes:
- SWPC issues R5 alert
- High Frequency (over the horizon) radio absorption in progress – air traffic control advising all transoceanic flights to move to higher frequencies. HAM radio operators unable to communicate at all.

T=15 min:
- Radiation levels at GOES satellite begin to rise rapidly. Pass S3 alert level.
- S4 radiation warning issued.
- NRO cancels launch of classified payload to LEO scheduled 2 hours from now.

T=17 min:
- S4 radiation alert issued. Astronauts in ISS take shelter between water tanks.
- S5 radiation warning issued.

T=20 min:
- S5 radiation alert issued (first time in 50-year SWPC history). FAA and airlines contacted by phone to ensure situational awareness.

T=30 min:

- Halo CME eruption first detected in coronagraph data – measurements by human forecasters indicate speed of about 3500 km/sec and Earthward direction (fastest CME ever measured by SWPC forecasters).
- High latitude and polar route commercial aviation flights are cancelled. Flights en route are diverted to more southerly courses and lower altitudes (if possible). The North Atlantic air routes to Europe are closed.

T=2 hours:

- CME model analysis indicates arrival time within 12 hours +/- 2 hours.
- S5 proton radiation levels continuing.
- Extreme G5 geomagnetic storm warning issued. Power grid operators begin planning for voltage stabilization requirements (bringing additional generators on line, adding line capacitance, coordinating via NERC).
- FEMA notified that extreme space weather event is likely within 10—12 hours.

T=3 hours:

- HF radio absorption decreases. HAM radio also now becoming usable again.

T=13.5 hours:

- DSCOVR satellite measures CME arrival at L1: speed = 3600 km/sec and magnetic field = -100 nT sustained – most extreme event ever measured by satellite instrumentation.
- Proton radiation level decreases to S4 magnitude.

T=14 hours:

- Geomagnetic storm onset at Earth. Dst measures -1900 nT, larger than the highest estimates for the Carrington event.
- Low energy electron flux at GOES exceeds alert threshold by 4 orders of magnitude.
- GOES West satellite experiences solar panel discharge event and fails.

T=16 hours:

- G5 storm in progress. Ionospheric disturbances so severe that all single-frequency GPS (e.g. in cell phones) is unusable over continental US.
- FAA's WAAS system for precision landing is unusable over CONUS and Alaska.
- Geomagnetically Induced Currents overwhelm step-down transformers at several locations in NE and NW CONUS causing sudden blackouts in New Jersey, Washington DC, and Seattle. Grid operators go into emergency mode to bypass damaged nodes.
- Texas interconnect experiences voltage instability leading to decision to break connectivity to neighboring grids. Destabilization in New Mexico, Louisiana, and Oklahoma cause rolling blackouts across those states.
- Intense aurora visible overhead in Miami and southern Texas.

- Proton radiation levels decrease to S3. Airlines still unable to fly polar or N. Atlantic routes.

T=20 hours:

- Radiation levels decrease to S2. Polar and N Atlantic air routes opened although GPS reliability still compromised and precision approach aids (WAAS) still not functioning.

T=24 hours:

- Geomagnetic storm decreases to G4 level.
- NSOF still unable to communicate with GOES West and intermittent communications with GOES East and Spare resulting in large gaps in weather data from Geosynch.
- Blackouts continue across the NE and have spread to several regions in the SE.
- WAAS system still unusable over CONUS and Alaska.
- FEMA and NORAD/NorthCOM deploying emergency generators, food and water to black out areas across the country. At least 5 major metropolitan regions are experiencing power instabilities or failures.

T=48 hours:

- Geomagnetic storm decreases to G2 level.

Key Questions to be addressed by Scenario

1. How is NWS warning accuracy, and the timely escalation of warnings, impacted at the different performance levels of the space observing system of 2030?
2. How are operations for other services, such as routine and severe weather, impacted by the emergency diversion of resources to space weather operations?
3. Are any important satellite systems impacted directly? Which ones? How are they addressed with alternate operations?

This scenario illustrates the broad range of impacts caused by a major space weather storm that can affect a diversity of industries and service areas. The required forecasts and alerts depend similarly on a diverse set of remote sensing and in-situ observations throughout the Sun-Earth environment, spanning from the surface of the Sun to the upper atmosphere.

Advancing NOAA's observing capabilities from the ST to the ME level will provide two primary advantages, one resulting from observations in interplanetary space taken off the Earth-Sun line and the other resulting from the enhanced density of measurements within the magnetosphere, ionosphere, and atmosphere. Observations made off the Earth-Sun line (primarily at the L5 Lagrange point), will enhance forecast accuracy by observing source regions of storms on the surface of the Sun before they are visible from Earth. In addition, these observations will more accurately characterize the initial properties and trajectories of Coronal Mass Ejections, enabling more accurate forecasts of their arrival at Earth and their consequences. Enhanced in-situ measurements around Earth will enable accurate specifications and improved forecasts of communication and navigation impacts, satellite and debris trajectories, and of the satellite-radiation environment.

It is important also to note that even the lowest priority observations for improvement from the ST to the ME level are essential for operational services. Significant benefit will be realized by improving all of the observations to the ME level.

Scenario 3: OPERATIONAL COMPLEXITY. Nowcasting challenges emerge in July 2030

Purpose: Stress rapid response weather information capabilities across the variety of impacted nowcast end-users (Figure 4). This can be considered a normal scenario, with some contingency situations included as a result of the scenario's complexity.

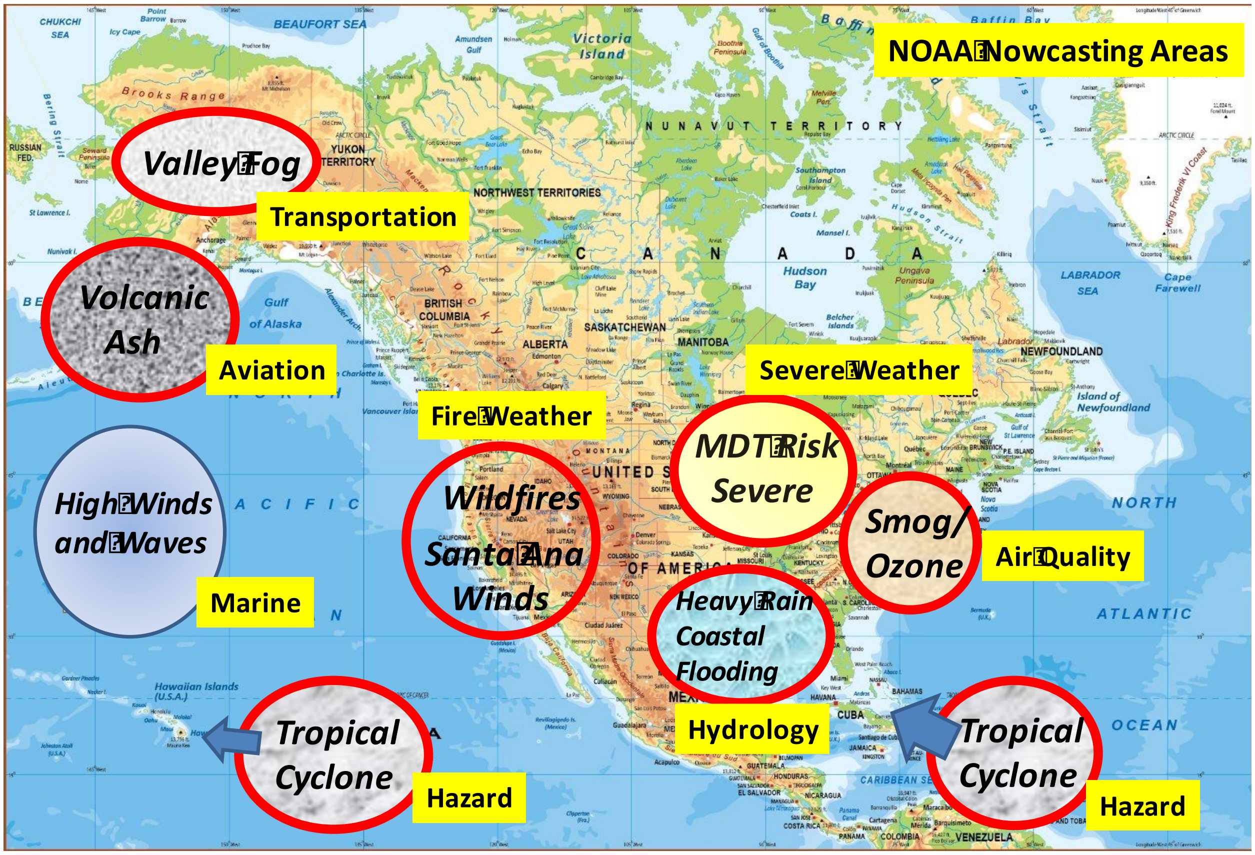

Fig. 4: Illustration of weather and hydrologic hazards and risks on a hypothetical July day in the future.

Description: An unusually active weather day in July drives widespread hazards and exacerbates other risks across a large portion of the NOAA Services Area of Responsibility (AOR). In this scenario, a weather pattern sets up that will greatly stress the nowcast and short-range weather forecast (SRWF) alert system. The impacts depend both on the local weather phenomenology and on the particular vulnerabilities of that area. Advance SRWF forecast alerts and real time (nowcast) warnings are essential at lead-times of hours and minutes. The NOAA operations areas involved in this scenario are highlighted in yellow in the figure above.

Service Impacts in moving from ST to ME level for Nowcasting and Short Range Weather Forecasts

The objectives that affect this scenario include, with priority in Group A given in **Appendix E**: **(1)** 3D Winds, **(2)** R/T Regional Imagery, **(4)** R/T Global Imagery, **(7)** Ocean Surface Vector Winds, **(8)** NonR/T Global Imagery, **(10)** Microwave Imagery, **(11)** Lightning, **(12)** Global Precip Rate, **(13)** Regional Microwave Soundings, **(14)** Regional IR Soundings, **(17)** Ozone

The most obvious gains to be made for the Nowcasting/SRWF service areas by moving from the ST to ME levels of performance will result from more rapid update/refresh rates of the indicated Objectives and their derived products. Secondary impacts will benefit from improved spatial and spectral resolution. Specifically:

<u>Alaskan valley fog</u>. Heavy low-lying/valley fog is a common phenomenon that can affect both ground and air travel safety, and disrupt transportation. Over most of Alaska, GEO imagery is not very useful due to view angle, and therefore LEO imagery is relied on but with 1-2 h latency in most cases. Attributes at the ME level would provide high-res (space/time/spectral) observations to better observe and forecast the onset, extent and lifting of the foggy areas.

<u>Pacific high winds/waves</u>. Maritime, fishing and shipping interests are greatly influenced by accurate marine forecasts of winds and waves. Ocean surface wind vectors from scatterometers are heavily relied on for nowcasts and forecasts of these events. Attributes at the ME level would greatly improve the availability of these observations to more frequently update and alert marine interests.

<u>Aleutian volcano ash</u>. Airline safety and flight diversions make this a primary concern of the aviation industry. Ash plumes are almost exclusively observed by satellites. Attributes at the ME level would provide faster and more accurate characterization of the plume location, concentration and dispersion to better alert aviation interests.

<u>Hawaiian/Bahamas Tropical Cyclones</u>. Hurricanes are a hazard on many fronts, particularly at and before landfall. Since these are primarily oceanic events, satellites are

relied on heavily to observe them. Several of our objectives are critical to the precision of the current analysis and SRWF by NHC and CPHC forecasters. The necessary observables include accurately determining the center location, extent of gale-force and hurricane surface winds, convective banding and eyewall structure, intensity (max winds and MSLP), and short-term storm motion. Attributes at the ME level would help fine-tune the SRWF of track and intensity.

California wildfires/high winds. The rapid onset and spread of wildfires make the quick detection and frequent observation of these events critical to the saving of life and property, and many of our objectives have a role to play. Attributes at the ME level would uniformly improve the detection, movement/spread, and short-term behavior of wildfires as they interact with the local temperature/moisture conditions and near-surface wind field. Lightning and precipitation detection from space would augment the land-based radars/sensors.

Midwest severe weather. From pre-convective environment, to convective initialization, to overshooting tops and supercell structures, satellites can be a key aid to radars for following the rapid evolution of severe weather events. Warning times are on the scale of minutes, so rapid-scanning strategies are paramount to forecaster decision-making. Attributes at the ME level for rapid-refresh wind, temperature and moisture profiles along with lightning would augment 1-minute imagery to improve the 'warn on forecast' of these rapidly evolving events.

Texas coastal flooding. Prolonged heavy rain events are often characterized by atmospheric moisture rivers that originate over the waters adjacent to CONUS. To this end, satellites can augment coastal radars to observe 'training events' and inform SRWF and warnings of potential flooding conditions. Attributes at the ME level would provide more frequent imaging of these events, particularly the microwave imagery that will reveal moisture/precipitation structures even through clouds, and would augment coastal radars for identifying potential training cells that lead to enhanced local flooding.

Northeast smog/ozone. Air quality affects millions of Americans with various respiratory ailments. Smog and ozone alerts have become common, and affect the daily lives of these individuals. Monitoring of these conditions is therefore essential, and will benefit from satellite-based visibility and ozone observations that are updated as frequently as possible. Attributes at the ME level would sharpen the ability to observe and monitor the heavier areas of smog and ozone, leading to improved public alerts.

Scenario 4: EXTERNAL DEPENDENCIES. Geopolitical chaos shuts down most foreign satellite capabilities or communications to NOAA in September 2035.

Purpose
Stress NOAA's dependence on foreign partners. This can be considered a contingency scenario.

Description

A sequence of global events severely degrades the availability of data from NOAA's satellite partners.

1. All foreign satellites that have been providing real time observations to NOAA are disrupted for an entire month during September 2035, at the height of hurricane season.
    a. Several hurricanes make landfall in the United States during the month.
    b. At the ST level of performance, the skill of medium-range NWP predictions is greatly reduced for this month, causing large uncertainties in the track and intensity of storms. At the EXP and ME level, the loss of the international sounders has much less impact and sufficient accuracy remains for useful forecasts and warnings several days in advance because of NOAA's global satellite temperature, water vapor, and wind soundings.
    c. The NOAA capability for RT images over the CONUS, Eastern Pacific, Western Atlantic and southward to 20° N is unaffected.
2. The system recovers, but is then disrupted again for a month during winter
    a. Major rainstorms in California threaten flooding and landslides.
    b. A major snowstorm moves across the Midwest.
    c. The East Coast is hit by a major snowstorm.

This scenario illustrates the necessity of NOAA having a "backbone" global observing system that provides sufficient data to support useful medium-range forecasts (up to 7 days). If we build to the ST level only and lose all observations from foreign partners, the impacts on U.S. forecasting would be catastrophic with the loss of global IR and MW soundings dropping us far below the Study Threshold level. (The loss to U.S. nowcasting and short-range forecasting would be minimal because we would still have real-time imaging over most of the U.S. and surrounding oceans). However, if we build to the ME level, the loss of all foreign observations would have a marginal impact on U.S. forecasts, as we would still have significant (greater than the Expected Level) global IR, MW and RO sounding capability as well as global wind observations. Building out to the ME level would thus also contribute strongly to the number one strategic priority-D1 Assurance of Core Capability, which is defined as (1) availability of CONUS RT imaging capability and (2) availability of 2 of 3 global MW, IR or RO soundings at the ST level.

7. Summary

We have summarized the activities of the Space Platform Requirements Working Group from 1 December 2015 through 30 April 2017. The main accomplishment was the production of the EDR Value Model (EVM) in support of the NOAA Satellite Observing System Architecture (NSOSA) study. SPRWG also produced four sceanrios designed to test the capability of the NOAA satellite observing system of 2030 and beyond to meet the challenges associated with unsual weather and geopolitical events.

Acknowledgments

The SPRWG acknowledges the significant contributions of Mark Maier throughout this process. Monica Coakley also provided significant input and assistance to the development of the EVM. Martin Yapur was very cooperative in providing current results from NOAA TPIO. We also thank NESDIS management including Steve Volz, Tom Burns, Karen St. Germain and Frank Gallagher for their support. This study was sponsored by NOAA/NESDIS through the Cooperative Institute for Research in the Enivronmental Sciences (CIRES) at the University of Colorado. We thank Waleed Abladati and Ted DeMaria for their support.

Appendix A: SPRWG TOR (19 February 2016)

Note: The lowest level of capability for the objectives and attributes was defined as Minimum Acceptable (MA) in the TOR. During the study, NOAA management changed the definition to Threshold Study (ST).

NOAA Space Platform Requirements Working Group (SPRWG)
Terms of Reference

1.0 BACKGOUND

The current US weather satellite program of record (POR) provides for continuous and evolving essential satellite services to weather and space weather missions to the 2020s and beyond. The services provided in the POR will fall below desired assurance levels at various dates (depending on the service) from approximately 2024 to 2032. Further, the current constellation carries high budget requirements and leaves significant unmet needs behind. The US Government intends to continue weather satellite services for the indefinite future and to continuously bring new capabilities into operation that promise to save lives in dangerous weather incidents, improve on warnings of environmental events, and contribute to economic growth. Given the long timelines required for satellite acquisition, it is necessary to make major near-term decisions about next generation systems to follow the POR.

The Office of Systems Architecture and Advanced Planning (OSAAP) within the National Environmental Satellite Data and Information Service (NESDIS) is conducting an architecture study in FY16 and FY17 to determine the most cost effective space segment architectures for performing NOAA weather, space weather, and environmental remote sensing (excluding land mapping) missions. The objectives, scope, and products of this NOAA Satellite Observing System Architecture (NSOSA) study are summarized in the NSOSA study Terms of Reference (TOR).

2.0 FUNCTIONS

The Space Platform Requirements Working Group (SPRWG) will determine needs and relative priorities for weather, space weather and environmental remote sensing (excluding land mapping) space-based observations in the epoch of 2030 in support of the NSOSA study Architecture Development Team (ADT). The priorities, as specified in the NSOSA TOR, will be NOAA operational functions first, followed by NOAA non-operational functions. The SPRWG has no decision authority beyond the deliverables defined within this TOR.

2.1 SPRWG Functions: The SPRWG will work in close coordination with the ADT lead, and ADT members identified by the ADT lead, in development of the following products.

a. Scenarios: The SPRWG will develop a reasonable number (e.g., 5-10) of scenarios (i.e., major use cases) for which the ADT will conduct architecture development. Scenarios may include critical operations that pertain to events that occur in various locations in a specific time sequence under a set of normal or contingency conditions.

b. Value Model: The SPRWG will participate in developing the user value model and will participate in developing and reviewing study products as discussed below.

Environmental Data Record (EDR) Value Model:

- Validate the classes of EDRs developed by the ADT to determine they're sufficiently comprehensive that they broadly represent NOAA's space-based observational needs
    - the SPRWG should consider needs not addressed currently but that may be operationally justifiable in the architecture epoch

- Set capability levels for classes of EDRs for the study epoch, to include:
    - **Minimum Acceptable:** The level at which decreases in capability no longer present a compelling investment (i.e., alternatives with capability below this level will be rejected)
    - **Expected**: The capability reflecting consensus expectations from the users
    - **Maximum Effective**: The level at which increases in capability no longer present a compelling investment (i.e., alternatives with capability above this level will receive no additional credit)
- Suggest attribute value levels for "strategic objectives" as defined in the NSOSA TOR
- Determine the relative priority of the swings in each class of EDRs and communications services that is within a group of EDR classes and communications services, respectively
- Suggest the relative priority of the swings within the group of strategic objectives.
- Provide input as deemed appropriate to assist NOAA in determining the relative priorities of the swings across groups of EDR classes, communications services, and strategic objectives

Mission Value Model:

- Provide input as deemed appropriate to assist NOAA in determining the relative priorities for Mission Service Areas (MSAs) based on NOSIA II products and metrics in the mission value model defined by the ADT
- Recommend metrics for key products identified by the ADT in the mission value model and identify any known simple, yet representative methods to assess these metrics

In the process of developing the findings in section 2.1, the SPRWG will engage with NOAA line offices (particularly with mission performing stakeholders), and community subject matter experts and stakeholders as needed to capture their opinions and concerns and to support the analyses and deliberations of the group. Such engagement may take the form of short duration “Tiger Teams”, community forums, or targeted studies. In conducting this engagement, the SPRWG will consider the stakeholder engagement and mission needs and requirements analysis performed by the Technology, Planning and Integration for Observations (TPIO) organization within NESDIS. It also will maintain cognizance of the “Vision of WIGOS [World Meteorological Organization Integrated Global Observing System] Space-based Component in 2040” activity to the extent that activity informs the SPRWG’s identification of user needs and priorities.

In developing products for the value model evaluation of section 2.1(b), the SPRWG should indicate important stakeholder preferences for how the associated needs could, or should, be achieved (e.g., via continuity of particular sensor records rather than via alternative sensor sets) where such implementation related issues are important to user satisfaction.

c. **Documentation:** The SPRWG will develop a report that contains a record for the results of sections 2.1(a) and 2.1(b) for each design “cycle”. Included in this report will be a record of sources used for judgments on validity and priority, references to background scientific studies used in these judgments, findings and results, rationale, decision analysis approach used, limitations on the use of the findings and results, and dissenting and minority opinions. The SPRWG also will summarize the report content in a briefing for each design cycle. The SPRWG additionally will develop a summary report for input into the final ADT report and will review the final ADT report.

2.2 User Expert Review: The SPRWG will provide user expert review of ADT products at the end of each NSOSA architecture design cycle and will advise on the appropriate values for parameters discussed in Section 2.1 to use for the following design cycle. The SPRWG will provide concurrence on the ADT’s list of prioritized investment recommendations at the end of the final design cycle. The SPRWG will provide input for, and will participate in, community day presentations as identified in the NSOSA study TOR.

3.0 MEMBERSHIP

The SPRWG core membership will be chosen by the SPRWG Chair with concurrence from OSAAP Director and the ADT lead. The SPRWG will consist of members from the user community associated with the NOAA MSAs, including membership from NESDIS, the National Weather Service (NWS), the National Marine Fisheries Service (NMFS), the National Ocean Service (NOS), and the Office of Oceanic and Atmospheric Research (OAR). Membership also should include representatives from other stakeholder organizations (e.g., cooperative institutes, academia, other research organizations, etc.). The SPRWG collective expertise should span the spectrum of NOAA observational needs. It should include expert knowledge of the types of measurement data needed to develop operational products (e.g., forecasts, watches, and warnings, etc.) from space-based observation of phenomena related to weather, space weather, and the general Earth environment (excluding land mapping). It also should include expert knowledge of the state of capability for processing these measurements into user products. The SPRWG Chair will be responsible to conduct a balanced and unbiased approach to evaluating user needs and to arbitrate decisions among SPRWG members.

4.0 INTERFACES

The SPRWG Chair will be accountable to the OSAAP Director and will work in close conjunction with the ADT lead. The ADT lead will identify additional ADT team members with whom SPRWG members will need to work to provide products for the functions shown in section 2.1.

5.0 DELIVERABLES

The SPRWG will deliver products as shown below. These products are described in section 2.

Deliverables	Date
Scenarios	Note 1
Validated classes of EDRs	Note 1
Capability levels for classes of EDRs	Note 1
Suggested attribute value levels for “strategic objectives” in NSOSA TOR	Note 1
Relative priority of the swings in each class of EDRs and communications services that is within a group of EDR classes and communications services, respectively	Note 1
Suggested relative priority of swings within the group of strategic objectives	Note 1
Input as deemed appropriate to assist NOAA in determining relative priorities of swings across groups of EDR classes, communications services, and strategic objectives	Note 1
Input as deemed appropriate to assist NOAA in determining relative priorities for MSAs	Note 1
Recommended metrics for key products identified by ADT in mission value model	Note 1
Known simple, yet representative methods to assess metrics for key products identified by ADT in mission value model	Start of Cycle 2a
Stakeholder preferences for how associated needs could or should be achieved	Note 1

User expert review of ADT products	Note 2
SPRWG report and brief	Note 2
SPRWG input to, and review of, final report	Note 3
Concurrence on ADT's list of prioritized investment recommendations	End of final design cycle
Input for, and participation in, community day presentations as identified in NSOSA study TOR	End of Cycle 2a and end of final design cycle

Note 1: Prior to start of each design cycle at time determined by ADT lead
Note 2: At the end of each design cycle at time determined by ADT lead
Note 3: At time determined by ADT lead for final report development and review

6.0 REVIEWS AND REPORTING

The SPRWG Chair will provide products to the ADT lead and participate in reviews at the times shown in Section 5.0. The Chair may be asked to present status or findings directly to NOAA leadership. Should this occur, the Chair will inform the ADT lead on the content to be presented and on the timing and venue.

7.0 MEETING LOGISTICS

Other than those meetings determined necessary by the ADT lead, the SPRWG Chair will define the schedule and location of SPRWG meetings and other key milestones. The SPRWG is encouraged to make use of tools for collaborative interaction to minimize travel expenses.

8.0 TERM OF PERFORMANCE

The SPRWG term of performance will be from the date of this TOR through 30 Sep 2017. Before expiration, this TOR will be reviewed for extension and/or modification.

9.0 RESOURCE REQUIREMENTS

Resource requirements for the overall SPRWG effort will be defined separately by NESDIS/OSAAP in coordination with the NESDIS Assistant Administrator.

Stephen Volz, Ph.D. Date
Assistant Administrator for Satellite and Information Services

Thomas Burns, Ph.D. (Acting) Date
Director for Systems Architecture and Advanced Planning

Appendix B: SPRWG Membership and Biographies

Richard Anthes, SPRWG Chair
President Emeritus, University Corporation for Atmospheric Research

Dr. Anthes, President Emeritus of the University Corporation for Atmospheric Research (UCAR) where is served as the fifth president from 1998 to January 2012, is an atmospheric scientist, author, educator, and administrator. He has won a number of awards from the American Meteorological Society (AMS), including the Clarence L. Meisinger and the Jule G. Charney Awards. In October 2003 he received the prestigious Friendship Award by the Chinese government. In 2007 Dr. Anthes served as president of the AMS. In 2015 he was presented the highest award of the AMS, Honorary Membership.

Dr. Anthes developed the first successful three-dimensional numerical model of the hurricane and was the father of one of the world's most widely used mesoscale models, the Penn State-NCAR mesoscale model, now in its fifth generation (MM5). In recent years he has become interested in the radio occultation technique for sounding Earth's atmosphere and was a key player in the highly successful proof-of-concept GPS/MET experiment and the Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC), a joint Taiwan and U.S. project which successfully launched six satellites on April 15, 2006. Dr. Anthes has published over 100 peer-reviewed articles and books.

Steve Ackerman
University of Wisconsin-Madison, CIMSS

Dr. Ackerman is a professor in Atmospheric and Oceanic Sciences and Associate Vice Chancellor for Research at the University of Wisconsin-Madison. He is director of the Cooperative Institute for Meteorological Satellite Studies (CIMSS). With over 140 scientists and graduate students, CIMSS works with the National Oceanic and Atmospheric Administration and the National Aeronautics and Space Administration to collect weather data from satellites to improve weather and climate forecasting. His research interests center on understanding how changes in the radiation balance affect and are affected by changes in other climate variables such as clouds, aerosols, water vapor and surface properties. These feedback mechanisms are studied using a compliment of theoretical models and observations. Ackerman encourages collaboration and the sharing of techniques, data, and expertise in order to foster advances in weather prediction. Ackerman received NASA’s Exceptional Public Service Medal in 2010, the American Meteorological Society’s Teaching Excellence Award in 2009 and is a fellow of the American Meteorological Society and the Wisconsin Academy of Science, Art and Letters. Dr. Ackerman received his Ph.D. and M.S. in Atmospheric Sciences from Colorado State University, and his B.S. in Atmospheric Science from the State University of New York, Oneonta.

Robert Atlas
Director, NOAA AOML, Miami FL

Dr. Atlas is the Director of NOAA's Atlantic Oceanographic and Meteorological Laboratory and also the Director of NOAA's Quantitative Observing System Assessment Program. He received his Ph.D. in Meteorology and Oceanography in 1976. Prior to receiving the doctorate, he was a weather forecaster in the U.S. Air Force where he maintained greater than 95 percent forecast accuracy. From 1976 to 1978, Dr. Atlas was a National Research Council Research Associate at NASA's Goddard Institute for Space Studies, New York, an Assistant Professor of Atmospheric and Oceanic Science for SUNY and Chief Consulting Meteorologist for the ABC television network. In 1978, Dr. Atlas joined NASA as a research scientist. He served as head of the NASA Data Assimilation Office from 1998-2003, and as Chief meteorologist at NASA GSFC from 2003-2005. Dr. Atlas has performed research to assess and improve the impact of satellite temperature sounding and surface wind data since 1973. He was a key member of the team that first demonstrated the significant impact of quantitative satellite data on numerical weather prediction and is a leading expert on Observing System Simulation Experiments, a technology that enables scientists to determine the quantitative value of new observing systems before funds are allocated for their development. He served as a member of the Satellite Surface Stress Working Group, the NASA Scatterometer Science Team, the ERS Science Team, the SeaWinds Satellite Team, the Working Group for Space-based Laser Winds, the Scientific Steering Group for GEWEX, and as Chairman of the U.S. World Ocean Circulation Experiment (WOCE) Advisory Group for model-based air-sea fluxes, and the Council of the American Meteorological Society.

Lisa Callahan
Associate Director for Mission Planning and Technology Development, Earth Sciences Division, NASA GSFC

Ms. Lisa Callahan received a Bachelor of Science degree in 1988 from the University of Michigan in Aerospace Engineering and started working at GSFC as a propulsion engineer that same year. Ms. Callahan went on to get a Master's degree in Science, Technology and Public Policy from George Washington University in 1992 and spent six years at NASA Headquarters before returning to GSFC. Over the course of her career, Ms. Callahan has designed, analyzed and tested propulsion systems, negotiated international agreements for the Space Station and managed Goddard's technology development program. Lisa currently serves as the Associate Director for Mission Planning and Technology Development in the Earth Sciences Division, a position that brings together scientists, instrument and systems engineers, and mission planners to develop new measurement concepts.

Gerald Dittberner
G. J. Dittberner Science and Technology, LLC

Dr. Dittberner, an AMS Fellow and Certified Consulting meteorologist, is founder and CEO of the consulting firm G. J. Dittberner Science and Technology, LLC in Springfield, VA providing services in Earth remote sensing, instrumentation engineering, orbit design, mission operations, ground systems development, data processing, climatology, and project management. He recently completed work with Harris Corporation on development and implementation of product science algorithms for the GOES-16 (R) ground system. Dr. Dittberner's 21-year Air Force career included duties as a meteorologist and climatologist processing satellite data for forecasters in the former Air Force Global Weather Central. He has served as a forecaster in the arctic, and was coordinator for real-time satellite data in the tropics during the Barbados Oceanographic and Meteorological Experiment (BOMEX). In his 12-years with National Oceanic and Atmospheric Administration he was instrumental in the development and successful launches of GOES 9 through 12 as NOAA's GOES Program Manager. He also led an observation technology research and development project to incorporate data from research satellites and products into NOAA operations. While in NOAA, he served as an interface between NOAA and the National Research Council's 2004 Decadal Survey project. In addition, he led a contract as an aerospace contractor supporting NASA for the prototype science data processing system for the TRMM project. Dr. Dittberner earned his Ph.D. in climatology and his M.S. degree in meteorology and space science and engineering from the University of Wisconsin. He has a bachelor's degree in Electrical Engineering from the University of Minnesota and has served as an Adjunct Professor for St. Louis University.

Richard Edwing
Director, Center for Operational Oceanographic Products and Services, National Ocean Service, NOAA

Richard Edwing has served as director of NOAA's Center for Operational Oceanographic Products and Services (CO-OPS), the nation's authoritative source for accurate, reliable and timely water-level and current measurements, since May 2010. In this role, Mr. Edwing oversees and continues to improve this 24-hour a day operation to provide mariners, coastal managers, and many other users with real-time data on ocean conditions along America's 95,000-mile coastline. Mr. Edwing's career with NOAA spans over three decades with much of that time spent advancing NOAA's navigation services mission. Mr. Edwing is an expert in designing, deploying, operating and employing oceanographic observing systems as well as in the data management processes used to quality control and generate products from those systems. He has traveled internationally to transfer and establish NOAA ocean observing technology in other countries. Graduating in 1976 from George Washington University, Mr. Edwing earned a Bachelor of Science degree in oceanography, and later completed graduate level work in civil engineering at the University of Maryland.

Pam Emch
Northrop Grumman

Dr. Emch is an Engineering Fellow with Northrop Grumman Aerospace Systems. She works on Northrop's weather, climate, and environmental remote sensing activities supporting NOAA, NASA, the Department of Defense, and additional customers. In over 30 years at Northrop Grumman (and formerly TRW), she has held a variety of science, engineering, management, and business development positions. Dr. Emch has experience managing end-to-end satellite-based remote sensing requirements and sensor design analysis, modeling and simulation, and geophysical product assessment. She has also led environmental data collection and application activities for airborne sensors. She was system engineering, integration, and test lead on Northrop’s Geostationary Operational Environmental Satellite (GOES)-R Phase 1 Program. Prior to that she worked on the NPOESS (National Polar-Orbiting Operational Environmental Satellite System) Program, including two years in Washington, D.C. where she served as Northrop’s system engineering and science interface to the government program office. Dr. Emch has a B.A. in Mathematics from UCLA and an M.S. in Aerospace Engineering from USC. Her Ph.D. in Civil and Environmental Engineering from UCLA was focused on Water Resources, with a minor in Atmospheric Science. She is the future chair of the American Meteorological Society’s Commission on the Weather, Water, and Climate Enterprise. She was a member of the U.S. National Research Council (NRC) Committee on the Assessment of the National Weather Service's Modernization Program and she currently serves on the NRC Board on Atmospheric Sciences and Climate.

Michael Ford
Oceanographer, NOAA National Marine Fisheries Service, Office of Science & Technology, Ecosystem Science Division and Research Associate, Smithsonian Environmental Research Center

Michael Ford believes in NOAA’s ability to bring together multiple scientific disciplines across many space scales. He currently serves as a biological oceanographer in the Ecosystem Science Division of the Office of Science and Technology where he directs the fisheries oceanography research program called Fisheries and the Environment (FATE). Prior to this assignment, he was the Ecosystem Science Manager for the NOAA Chesapeake Bay Office (NCBO) in Annapolis where he guided and supervised an innovative eleven-member division bringing earth-viewing satellites, fixed platform instrument arrays, ecosystem models, and science and mapping cruises to bear on Bay problems. Prior to Annapolis, Michael served as Oceanographer and Senior Science Advisor to the NMFS Chief Scientist where he built and managed the Comparative Analysis of Marine Ecosystem Organization (CAMEO) Program, an oceanographic and fisheries science research grant program following GLOBEC and supported by a NSF-NMFS partnership. He provided advice to the NMFS Chief Scientist and promoted NMFS Science across multiple disciplines. Michael maintains active research projects focused on swimming and feeding of jellyfish, the relationship between jellyfish and fish populations, and plankton ecology. His publications consider the biology and physics of individual organisms as well as population interactions at the shelf and basin scale. Michael finds new species of jellyfish and characterizes the most unexplored biome on Earth with DEEP DISCOVERER II, NOAA's 6000 m endurance deep ocean ROV. Michael advances the understanding of jellyfish and their ecological role from bay to continental shelf and from tributary to deep ocean trench.

William Gail
Global Weather Corporation, Boulder CO

Dr. Gail is co-founder and Chief Technology Officer of Global Weather Corporation, a provider of precision forecasts for weather-sensitive business sectors, and is a Past-President of the American Meteorological Society. He was previously a Director in the Startup Business Group at Microsoft, Vice President of mapping products at Vexcel Corporation, and Director of Earth science programs at Ball Aerospace. Dr. Gail received his undergraduate degree in Physics and his Ph.D. in Electrical Engineering from Stanford University, where his research focused on physics of the Earth's magnetosphere. During this period, he spent a year as cosmic ray field scientist at South Pole Station. Dr. Gail is a Fellow of the American Meteorological Society and a lifetime Associate of the U.S. National Academy of Science's research council. He serves on their Board on Atmospheric Sciences and Climate as well as on the steering committee for the 2017 Earth Sciences Decadal Survey, and has participated on many prior Academy committees including the 2012 review of the National Weather Service and the 2007 Earth Sciences Decadal Survey. He is a member of the US Commerce Data Advisory Council and serves or has served on a variety of other editorial, corporate, and organizational boards. His book "Climate Conundrums: What the Climate Debate Reveals About Us" was published in 2014.

Mitch Goldberg (*NOAA Liaison member*)
NOAA, JPSS Program Scientist

Dr. Goldberg is the NOAA JPSS Program Scientist and former Chief of the NESDIS Satellite Meteorology and Climatology Division. His scientific expertise is in developing scientific algorithms to derive atmospheric soundings of temperature and water vapor from microwave and infrared sounders. Dr. Goldberg serves as independent expert and representative of the science and user communities for the JPSS Program responsible for ensuring the scientific integrity at all stages of satellite development. He served as the chair of the World Meteorological Organization's Global Space-based InterCalibration System (GSICS), is the co-chair of the International TOVS Soundings working group, and is the NESDIS science representative to the Coordinated Group on Meteorological Satellites (CGMS). He is currently chair of the CREST Scientific Advisory Board. Dr. Goldberg has received three Gold Medals, one Silver Medal, and three Bronze Medals from the Department of Commerce and more recently the 2010 NOAA Administrator's Award for leadership in developing the international Global Space-based Inter-Calibration System (GSICS). He received the University of Maryland Most

Distinguished Alumnus Award from the Department of Atmospheric and Oceanic Science in 2004. Dr. Goldberg earned his B.S. from Rutgers University, and M.S. and Ph.D. degrees from the University of Maryland.

Steve Goodman (*NOAA Liaison member*)
NOAA, GOES-R Program Senior Scientist

Dr. Goodman is the Senior Scientist for the NOAA GOES-R series satellite program. His research interests include the global distribution and variability of thunderstorms, lightning and precipitation physics, and the application of space-based remote sensing to improve the short-range forecasts and warnings of severe storms. As the Senior Program Scientist for the GOES-R Program, he serves as the primary science authority for the United States next generation geostationary environmental satellite program, a joint agency development managed by NOAA and NASA. Dr. Goodman is the Lead Scientist for the GOES-R Geostationary Lightning Mapper (GLM) and an instrument team member for the NASA Tropical Rainfall Measuring Mission Lightning Imaging Sensor (TRMM/LIS) and the International Space Station LIS scheduled for launch in November 2016. Following a 20-year career with NASA as a senior scientist and as the Manager of the Earth Science Office at NASA Marshall Space Flight Center, and prior to joining the GOES-R Program Office in 2008, he served as the Deputy Director of the NESDIS Office for Satellite Research and Applications and as the Acting Deputy Director for the Joint Center for Satellite Data Assimilation. Dr. Goodman served two terms as the US representative to the WMO Working Group on Nowcasting Research. He is a past recipient of the NASA Medal for Exceptional Scientific Achievement and a Fellow of the American Meteorological Society.

Christian Kummerow
Colorado State University, CIRA

Dr. Kummerow is Professor of Atmospheric Science at Colorado State University where he also serves as Director of the Cooperative Institute for Research in the Atmosphere (CIRA). In addition to his University responsibilities, he is involved in the Joint NASA/JAXA Precipitation Science Team overseeing the operations and data products of the TRMM and GPM satellites, as well as the GEWEX Data and Assessments Panel. He was recently serving as a member of the NASA Earth Science Subcommittee. Professor Kummerow received his A.B., Physics from the University of California, Berkeley, 1982 (cum laude) and a Ph.D. in Atmospheric Physics from the University of Minnesota in 1987. He has received numerous awards including multiple Outstanding Performance Awards at NASA Goddard, the Goddard Exceptional Achievement Award in 1996; Maryland Distinguished Young Scientist Award in 1998; the NASA Outstanding Leadership Medal in 2000; and the Colorado State University George T. Abell Outstanding Early-Career Award in 2006; He became a Fellow of the American Meteorological Society in 2011. Professor Kummerow has spent much of his career studying the global water and energy cycles. He is particularly interested in observing the global water cycle and its uncertainties – how uncertainties relate to physical aspects of the atmosphere, and thus the fundamental processes underlying precipitation. From 1997 to 2000 he served as the TRMM Project Scientist and continues to serve on the science teams of both the TRMM as well as the recently launched Global Precipitation Mission where he leads the team responsible for the passive microwave rainfall products. He served as Associate Editor of the *Journal of Atmospheric and Ocean Technology* from 1992-97, the AMS Committee on Atmospheric Radiation from 1995-1998 and Editor of the *Journal of Applied Meteorology* from 2003-2005. He has authored over 100 Journal publications related to global clouds and the hydrologic cycle.

Terrance Onsager
NOAA Space Weather Prediction Center, Boulder CO

Dr. Onsager is a physicist at the National Oceanic Atmospheric Administration (NOAA) Space Weather Prediction Center (SWPC). Dr. Onsager is the liaison for international space weather activities at SWPC and a Working Group Co-coordinator of Goal 6 of the National Space Weather Operations, Research and Mitigation effort. He recently served as Co-lead of the Space Weather Societal Benefit Area team for the Second National Earth Observation Assessment under the Office of Science and Technology Policy. He currently serves as the Director of the International Space Environment Service, which consists of 18 centers around the globe providing a range of services including forecasts, warnings, and alerts of space weather activity. His research has focused on fundamental topics of solar-terrestrial physics and more recently on directing our scientific knowledge toward the growing need for space weather services.

Kevin Schrab
Portfolio Manager, NOAA/NWS Office of Observations, Silver Spring, MD

Dr. Schrab is currently the Portfolio Manager for the NWS Office of Observations. In this role, he ensures that the NWS' observation portfolio is continually evaluated for effectiveness and efficiency. This includes coordinating observation requirements, identifying observation gaps, assessing the impact of observations on NWS mission service areas, collaborating with observation partners whose data NWS leverages, and planning for the future of NWS observation systems. Prior to his position with the Office of Observations, Dr. Schrab was the Chief of the Observing Services Division of the NWS Office of Climate, Water, and Weather Services. In that role he coordinated and oversaw the policy and procedures for NWS observing services; including surface, upper-air, and satellite observations. Dr. Schrab joined NOAA in 1995 at the NWS Western Region Headquarters Scientific Services Division. His duties there included ensuring all Western Region field offices had access to and were trained to use the expanding suite of satellite data. Dr. Schrab has a Ph.D. degree in Atmospheric Sciences from the North Carolina State University, and an M.S. degree in Meteorology from the University of Wisconsin. He received his B.S. degree in geography and mathematics from Carroll College.

Chris Velden
University of Wisconsin, CIMSS

Dr. Velden received his B.S. from the Univ. of Wisconsin-Stevens Point in 1979 and M.S. from the Dept. of Meteorology, Univ. of Wisconsin-Madison in 1982. He is currently a Senior Scientist with the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison. During his 35-year career he has served on numerous National Academy of Sciences committees including the 2007 Decadal Study, and has chaired several AMS and WMO committees and working groups. Dr. Velden has participated in two dozen atmospheric science field programs, and was a visiting scientist for a year at the Australian Bureau of Meteorology (1987-88). He received the prestigious Univ. of Wisconsin Chancellors Research Excellence Award in 2012, and was elected an AMS Fellow in 2008. His areas of expertise include the development of remote sensing techniques and algorithms to monitor hurricanes and improve forecasts, and techniques to extract wind information from environmental satellites.

Thomas Vonder Haar
Colorado State University

Dr. Vonder Haar joined the CSU Department of Atmospheric Science faculty in 1970 after a post-doctoral appointment at the Space Science and Engineering Center at the University of Wisconsin. He has served as a Visiting Scientist and Lecturer at the Army Research Laboratory, the U.S. Naval Postgraduate School and the Woods Hole Oceanographic Institute. His consulting includes the World Meteorological Organization of the UN, European Space Agency, numerous U.S. Aerospace companies and Science and Technology Corporation (METSAT Division). At CSU he has served as Department Head (1974-84) and Founding Director of CIRA (1980-2008). He has enjoyed advising approximately 30 Ph.D. and 100 M.S. graduates from the Department. Dr. Vonder Haar is a researcher and advisor for USAF, NOAA and NASA satellite programs ranging from TIROS, pre-DMSP/NRO and Nimbus through GOES-R. CloudSat and Suomi-NPP. He was the lead PI for NASA ERBE Mission from 1978-1985, a member of several NASA Science Teams, awarded the AMS Charney award (1982) for international science leadership in satellite and radiation programs, and elected to the National Academy of Engineering (2003) for observation and analyses of Earth's radiation budget and its role in climate. He received his Ph.D. in Meteorology in 1968 (and M.S. in 1964) from the University of Wisconsin at Madison, and a B.S. in Aeronautics in 1963 from the Parks College of St. Louis University.

James Yoe
NOAA NWS, NCEP; JCSDA Chief Administrative Officer

Dr. Yoe is employed in the Office of the Director of the National Centers for Environmental Prediction (NCEP). He coordinates NCEP's activities for the Science and Technology and Observations Portfolios, and serves as the Chief Administrative Officer of the Joint Center for Satellite Data Assimilation (JCSDA). Prior to joining NCEP, he spent 14 years with the National Environmental Satellite Data and Information Service, working on the NPOESS Data Exploitation Project, serving as Deputy Director of the JCSDA, and developing applications for space-based remote sensors including Doppler Wind lidar and GPS Radio Occultation. He earned B.S. and Ph.D. degrees in physics from the University of the South and Clemson University, respectively, and conducted post-doctoral research investigating winds, waves, and turbulence using MST Doppler radar at the Max Planck Institute for Aeronomy.

Jeff Reaves
SPRWG Executive Assistant

Mr. Reaves was the associate vice president for Finance and Administration at the University Corporation for Atmospheric Research (UCAR) in Boulder, Colorado until his retirement in 2013. During his tenure at UCAR he was a key member of the team that developed the COSMIC program with the country of Taiwan and various U.S. government agencies, including NOAA, NASA and NSF, as well as in establishing the NCAR-Wyoming Supercomputing Center. He also served as the vice president of the UCAR Foundation and the vice president of Peak Weather Corporation, a UCAR Foundation company. Prior to joining UCAR he was the director of community services and in-country relations between the U.S. Army Corps of Engineers and the country of Saudi Arabia in Riyadh. Before that he was the managing editor and associate publisher at Technology Publishing Corporation in Los Angeles.

Appendix C: EVM Terminology and Concepts

Note: The lowest level of capability for the objectives and attributes was defined as Minimum Acceptable (MA) in this paper. During the study, NOAA management changed the definition to Threshold Study (ST).

EVM Terminology and Concepts

A key element of the NOAA Satellite Observing System Architecture (NSOSA) study process is the EDR Value Model (EVM), which plays a central role in assessing the value of different satellite and observational architecture alternatives, and which has evolved over time as the study has been developed. This paper discusses the terminology and concepts used in the EVM, and provides a guide to how it will be further developed during the study.

Administrative Information

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Reviewer(s): Richard Anthes (27-Jan-16 and 1-Feb-16); Johannes Loschnigg (31-Jan-16)
Version: 0.9.4
Date: 1-Feb-16

MAUT Introduction

The EVM approach is based on Multi-Attribute Utility Theory (MAUT) as used in decision analysis. Specifically, the goal is to develop a **utility function**, which takes as input all of the performance attributes of an architecture alternative (expressed over some suitable set) and returns a real number that is referred to as the “utility” of the alternative. The utility is intended to have the property such that if decision makers (in this case NOAA leadership) are presented with two alternatives, the preference for one over the other will map directly with the larger computed utility. The objective is to produce what is called an **efficient frontier plot** (Figure 1).

An efficient frontier plot can be used for a variety of decision-making and analysis purposes, as well as for assessing important aspects of a design effort. In the plot, an assumed budget corresponds to a vertical line, with alternatives both to the left and right of that budget line. If the budget is too low, then no alternatives are affordable and the process has broken down. Similarly, there may be alternatives with higher budgets representing the opportunity for increased value with greater funding. The slope of the “efficient frontier” at the point where it intercepts the budget line represents the cost-benefit tradeoff at the assumed budget. In general, the alternatives that populate an area around the budget line-efficient frontier intercept are of primary interest. Since both cost and value have many uncertainties, it would be inappropriate to exclude from consideration the alternatives other than the one closest to the intercept. In general, though, the alternatives close to the intercept represent the best value tradeoff given a fixed budget.

The process assumes that the decision maker is trying to maximize value with a given budget. If instead the decision maker is trying to maximize return-on-investment, then a budget line is irrelevant. In that case, attention should be focused on where the efficient frontier has a steep slope, and where there are structurally consistent choices as one moves up the slope.

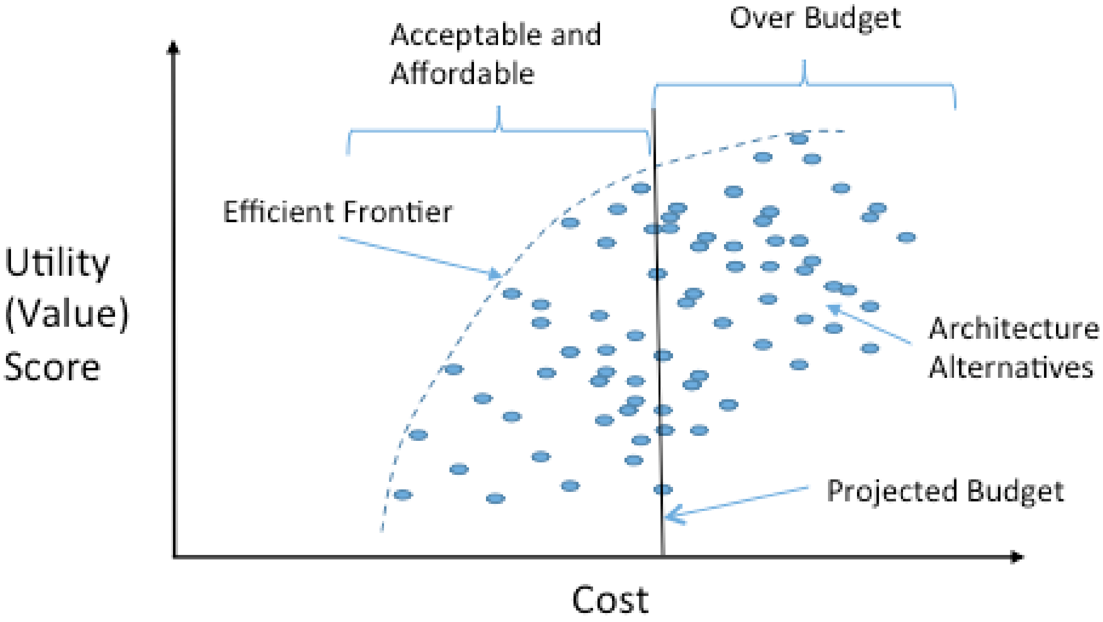

Figure 1: Notional efficient frontier plot.

An efficient frontier plot displays a point for the utility-cost pair for each of the architecture alternatives under study. In order to create an efficient frontier plot, we must be able to collapse cost to a single value. (Lifecycle costs and maximum yearly costs are typical choices for transforming the vector of multi-year costs into a scalar quantity.) We must also use a single number for utility (value). Note there will be a "hull" on the collection of points that represents the highest utility (value) possible at a given cost. (Or equivalently, the lowest cost that achieves a given utility.) Decision theory tells us that the optimal choice will lie along this frontier, and that interior points should be avoided. Logic dictates that any interior point could be replaced by a point with higher utility at the same cost by moving upward within the cloud of alternatives until the frontier is reached. In an architecture development process, it is important to examine the details of points close to the frontier in areas of interest (i.e. close to cost constraints) and observe any patterns. For example, do all alternatives close to the frontier share common features, such as particular orbital distributions? Or, do all alternatives close to the frontier neglect an important mission support area of NOAA, which would result in an unbalanced program if implemented? It would be a mistake in the architecture development phase to simply find the highest utility point at an acceptable cost and declare that point the preferred alternative without more closely investigating how it relates to nearby points, and whether or not the judgments can be considered robust.

I use three particular references to MAUT approaches:

Decisions with Multiple Objectives: Preferences and Value Tradeoffs, Keeny and Raiffa, Cambridge University Press, 1993. The standard textbook on the theoretical and mathematical foundation of our approach.

Value Focused Thinking: A Path to Creative Decisionmaking, Keeney, Harvard University Press, 1996. Addresses the mixed heuristic and quantitative problems related to the practicality of building good, useful models within the framework of Decision with Multiple Objectives. Keeney points out that no real analysis fails for lack of rigor; it fails for having a poorly conceived model. One must avoid creating a model so rigorous that it collapses of its own weight, but yet still quantitatively captures the most important elements of the problem.

Smart Choices: A Practical Guide to Making Better Decisions, Hammond, Keeney, and Raiffa, Crown Business, 2002. A business school level introduction to both of the above. It emphasizes finding quantitative, but less than rigorous, practical models for decision problems. I recommend it strongly for understanding our approach.

To define the terminology we need to define the concepts. What is sought is a **value model**, which is composed of N **objectives**, Obj_1 through Obj_N. Each objective has an **effectiveness scale (or level)** $E_k(A)$ on a scale 0 to 100. The **utility** is a weighted sum of the effectiveness level for each objective. If we then have an **architecture alternative** A, it has a score on each objective $E_k(A)$, and the overall utility is given by:

(1) $U(A) = \sum_{k=1}^{N} w_k E_k(A)$

where w_k is the "swing weight" of the kth objective and E_k is the effectiveness scale (or level) of the kth objective for alternative A. The effectiveness scale E_k and the swing weights w_k are defined formally below.

I include here a couple of technical asides, for those interested in the mechanics of decision theory. First, this particular method uses an **additive utility function,** and it should be noted that utility functions are not necessarily always additive. We assume that it is possible to build a model in the additive form such that will adequately represent a decision-maker's preferences. This is potentially a false hypothesis, and thus should be tested from time to time. Second, this is technically a value function, not a utility function. The difference has to do with how uncertainty and randomness are accounted for. A true utility function incorporates uncertainty of values directly into the individual judgments. Given the assumptions of this study, this aspect is something we can ignore, as we are separately evaluating the impact of uncertainties.

Broadly speaking, there are two kinds of objectives: **Functional** and non-functional (or **Strategic**). Again, there are technically other types, but we will not be concerned with those here**. Functional objectives** correspond to the desire that the system perform a valued function, and that it provide an end product to us. The collection of environmental satellite systems provides two goals: data and communication services. Obviously, the primary objective of our future satellite systems will be to provide various data records. So it is natural to construct the functional part of the objectives in the value model around the delivery of data records. But what specific data records? Today we recognize several data record types. The two most germane are Sensor Data Records (SDRs) and

Environmental Data Records (EDRs). SDRs are data records of particular sensors. EDRs are processed from SDRs and represent estimates of environmental values with operational or scientific interest.

Neither existing lists of SDRs nor EDRs are suitable in their current form to be functional objectives for the study. The existing SDRs are too strongly tied to the legacy architecture, and clearly do not allow the required degree of flexibility. The existing EDRs are largely independent of implementation, but are unsuitable for the following reasons: First, many current EDRs are significantly correlated. Many are produced from the same sensor data, so that performance on one effectively determines performance on others. Dependence of this sort is poor decision analysis practice. Second, existing EDRs are too far removed from cost-driving characteristics. In most cases, we cannot examine the EDR and rapidly understand its consequences on those sensors that drive architecture costs. Third, the performance of multiple EDRs is difficult to assess, making them difficult to use when comparing large numbers of architecture alternatives.

As a remedy, we introduce the concept of “EDR classes.” An **EDR class** is essentially an abstraction of multiple data types that we know we want our system to produce. The EDR class is then the object of the corresponding functional objective. Where the objective is “Provide Real-time Regional (CONUS) Weather Imagery,” the EDR class is “Real-time Regional (CONUS) Weather Imagery.” For all functional objectives, the objective-EDR class relationship is one-to-one, hence it is redundant. And thus for convenience we merely refer to the EDR class name, understanding that we are actually referring to the objective of providing data in that EDR class.

More formally we define:

Utility (or Value) function: A real valued function that is computed from the performance of an alternative (equation 1). The number produced by a utility function is intended to correspond to the decision maker’s preference for the alternative.

Thus if $U(A_1) > U(A_2)$, then A_1 is preferred to A_2 and vice versa.

In decision theory literature (such as those referenced above), there are technical differences between utility functions and value functions. These differences have to do with how we handle uncertainty in either stakeholder preference or the input performance values. Given how the NSOSA study is being conducted, these differences are unimportant, and we can use the term value function and utility function interchangeably. For consistency, in this document we use the term utility function.

Objective: A goal we want an alternative to achieve. An objective has an object (what is produced or of interest) and a direction of preference (the direction we want a preferred alternative to move).

A utility function with the specific structure given by equation (1) implies that we can score the value of an alternative by determining the effectiveness level on each of N objectives, and then take a weighted sum of those effectiveness levels. This structure also implies specific indifference tradeoffs, as the score on two objectives can each move by amounts equal to the ratio of their weights and leave the overall score unchanged.

Swing Weights: The weights w_k in equation (1) are the “swing weights” of objective k. They are referred to as swing weights because each provides a quantification of the relative value of objective k moving from 0 to 100 for the effectiveness level. The swing weights vary between 0 and 1, and the sum must equal 1.

Effectiveness Scale: A number between 0 and 100 associated with each objective, which determines how far above a minimally acceptable (MA) level the objective is achieved. E=0 implies the objective is met exactly at the lowest acceptable level. E=100 implies that the objective is fully satisfied; no additional value can be accrued once E=100. A value of E=50 indicates that 50% of the possible value above the MA level associated with the objective has been achieved.

Functional Objective: A function or capability that the alternatives should provide. In our case, "Provide Real-time Regional (CONUS) Imagery" and "Provide Earth-Sun Line Coronagraph Images of the Sun" are examples of functional objectives. Functional objectives provide an object - a data product or products or service, and we can measure how well they provide the object. A functional objective is defined by the goal that is being provided and is typically measured by performance measures (effectiveness levels) on that goal.

For functional objectives, the effectiveness level (from 0 to 100) is determined by performance measures on the goal we provide. If the goal is a data product, then the effectiveness level will be determined by performance measures (e.g.; accuracy, resolution, update rate, etc.) on the data product. If the goal is a data communication service, then the effectiveness level will be determined by performance measures (e.g. data rate, geographic availability, and latency) on the communications service.

For the EVM, the object of the functional objectives is an EDR class or a communication service. We use the name of the EDR class interchangeably with the objective, as they relate directly to one another.

Strategic Objectives: A non-functional property that we desire an alternative to have. In our case, "Support established international agreements" would be an example of a strategic objective.

EDR class: An abstraction of similar data products that may at present be provided by different sensors in different conditions. Data products in the class will be desired in the future architecture, but may be provided by different sensors divided over different orbits than today. An EDR class is the object of a Functional Objective in our model.

We recognize that there are four logical groups of functional objectives: those associated with providing terrestrial weather data products, those associated with providing space weather data products, those associated with providing non-weather data products (e.g. ocean products), and those associated with providing communication services. Within the first three groups, each objective is associated one-to-one with an EDR class.

- "Provide Real-Time Regional (CONUS) Weather Imagery" is an example of a terrestrial weather objective; and "Real-Time Regional (CONUS) Weather Imagery" is the associated EDR class.
- "Coronagraph Imagery, Earth-Sun Line" is a space weather EDR class, and providing this data is the associated space weather objective.
- "Support High Speed Weather Data Distribution" is an example of communications objective. There is not an associated EDR class because the object is not data; it is a service (specifically, a service that carries high speed weather data).
- "Compatibility with Level Budgets" is an example of a strategic objective. There is no EDR class, as this is not a functional objective.

Since “objective” includes both functional objectives (and associated EDR class) and strategic objectives (for which there are no EDR classes), we will generally refer to “objective” in the following sections for both types.

Performance Attributes and Scoring Objectives

Ultimately we want to score architecture alternatives by how well they meet the objectives. The utility function (equation 1) produces a singular real number that measures the overall performance of an alternative relative to how well it meets all the objectives. To do this we need to score an alternative on the effectiveness scale of 1 to 100. For objectives with an EDR Class, this involves determining how well the data defined by that objective are provided by the alternative. It involves introducing quality or performance measures on the data. The effectiveness score will then be some function of the underlying performance values. For strategic objectives, there are no data being provided; however a strategic objective still has to be assigned an effectiveness level. When there is no natural way of measuring performance in a single number, we have to construct a scale allowing us to determine a 0 to 100 score. To formalize this, we define scores as follows:

> **Effectiveness scale (level) = 0:** This represents the lowest allowable level of performance on that objective. If the objective is regarded as *essential*, then an alternative must provide that objective with at least the minimum acceptable (MA) level of performance, or it is disqualified. If the objective is regarded as *non-essential,* then an alternative is not required to include the objective at any level of performance, or at all.
>
> **Effectiveness scale (level) = 100:** This implies that the alternative fully satisfies the objective at the maximum effectiveness (ME) level. If the objective is functional, this implies that the data in the objective are as good as we have any application for. To improve the data any more would not be worth the cost.

Performance Attributes

To build scores we require **performance** (or **quality**) **attributes** and a combination rule. We start with the simplest cases where all of the performance attributes can be expressed in natural units. Imagery related EDR classes (objectives) usually have several familiar performance attributes:

- Horizontal Resolution: Measured in meters
- Accuracy: Measured in percent, degrees K, or other similar scales. Accuracy refers to the quantity (e.g. pixel) in the image (brightness, temperature, etc.).
- Update Rate: Measured in minutes or hours, and relative to a required geographic area.
- Latency: Measured in minutes or hours from when the image is taken to when it is available for use.

We establish three levels for each performance attribute:

- **Minimum Acceptable (MA):** The lowest level of performance on the specific attribute that we would accept. Anything below this level is a disqualification.

For a non-essential objective there is no MA level, or the MA level can be considered as "None," since there is no disqualifying level of performance.

- **Expected (EX):** Consensus on what the community expects for this attribute in 2030.
- **Maximum Effective (ME):** The highest level of performance on this attribute that we believe is worth spending money on. There is no additional value for outperforming the ME level.

As an example, consider the "Global Non-Real-Time Weather Imagery" case. If we applied only the four simple performance attributes above, a reasonable case might be:

Quality attribute	MA	EX	ME
Horizontal Resolution	1 km	500 meters	300 meters
Accuracy*	15%	10%	5%
Update Rate	Once per day	Twice per day	Four times per day
Latency	2 hours	1 hour	30 minutes

*percent accuracy in the luminance/radiance value of a pixel.

Where would the actual MA, EX, and ME values come from? There is no master source; the chosen values require making judgments which are based on experience or scientific studies (e.g. OSSEs). To some extent they can be drawn from official sources such as NOAA's Consolidated Observing User Requirements List (COURL) and from official studies of future needs. Because the chosen values necessarily reflect judgments, setting the values is not a solely scientific or technical matter and requires stakeholder engagement.

Now we get to the hard part. Most imagery and sounding products are multi-spectral or hyperspectral collections that are processed into many more EDRs. How do we factor that in? Certainly when an architecture collects data fitting into one of the EDR classes, the spectral content is as important to its value as is its horizontal resolution. One approach is to simply include spectral information, such as spectral range and resolution or lists of bands, as performance attributes. This has the advantage of familiarity. As a drawback, specifying the spectral content may inadvertently bias the model towards legacy collection. In some cases there may be approaches that yield the same overall EDR information from different combinations of spectral range and resolution.

An alternative approach is to construct attributes that correspond to the ability of the collected data to support derived products. In this case, the attribute will not have natural units like km or seconds. It will be in some constructed form, such as lists of data products whose derivation is supported, or comparable levels of performance to other sensors. The form of constructed attributes is limited only by the analyst's creativity, and by their mapping to convenient assessment approaches. The current EVM spreadsheet has examples of different approaches to performance attributes.

Finally we need a rule that maps a set of performance attribute effectiveness scales to an overall effectiveness scale for the associated objective. There are few constraints on this rule, with the exception of the following. If all performance attributes on an EDR Class are at the MA level, then the associated effectiveness scale is 0. If all attributes of an

EDR Class are at the ME level, then the associated effectiveness scale is 100. If some performance attributes are below the MA level, then the associated effectiveness scale is regarded at negative infinity and the alternative is disqualified. For values in between, one can use weighted combination, lowest-score-rules, highest-score-rules, or any other rule. An effective and simple approach is to have an expert panel judge where an alternative that hits the EX levels on all performance attributes would be on the 0 to 100 scale, then perform linear interpolation on both sides. This will not be exact, but it is likely sufficient to capture most issues, given the overall atmosphere of necessary approximation.

Strategic objectives also have effectiveness scales, but may not have a list of performance attributes. For Strategic objectives, it is customary to merely build a constructed scale for the objective without defining separate performance attributes. This is what has been done for each of the EVM Group E objectives.

We can formalize the following: The i^{th} objective, Obj_i, has M performance attributes a_{i1} through a_{iM}. For each attribute we define three performance levels: MA, EX, and ME. We also require a combination rule that maps the effectiveness scales of individual attributes to the overall effectiveness scale of the objective, ranging from 0 to 100. For example, assume that each attribute receives a score from 0 to 100, with the MA level being 0 and the ME level being 100. The overall effectiveness scale could then be reasonably defined as a weighted sum of the individual attribute scores, with the weights summing to 1.

Ranking and Swing Weighting

The last element involved in forming the full value model is to determine the appropriate **swing weights** for each objective. The term was defined as part of the utility model (equation 1). Undertaking this involves an interesting mixture of rigorous and heuristic procedures. Realistically, the utility function in all likelihood does not exactly mimic a decision maker's preferences. If the decision maker were capable of providing adequate abstract judgments to make formation of an arbitrary utility model possible, then building the model would likely be superfluous; one would merely ask the decision maker. Good use of decision analysis is not about grinding out the "optimal" answer; it is about using structured thinking to reveal qualities about your assumptions that you did not know. If one gets lost in the formalism, one should step back, look around, and be sure that the complexity of what is being performed is appropriate to the problem at hand, and is not being pursued for its own sake. It is common that a good, practical value model may accrete additional complexity over time as each new case is considered, and the entire model collapses of its own weight.

That said, we can more formally define the concept of swing weights. As a thought experiment, suppose one had 2^N alternative architectures with the following special property: Evaluated objective by objective, each of them has a score (effectiveness level) of either exactly 0 or exactly 100 on each objective. Put another (equivalent) way, each alternative either exactly meets the MA performance attribute level for an objective, or meets the ME attribute level for that objective. As there are N objectives, there are also 2^N possible such hypothetical alternatives. Suppose further that we can put these 2^N hypothetical alternatives into rank order, from the most desirable to the least desirable. Clearly the most desirable should be the one that scores 100 on every objective, and the least desirable the one that scores 0 on every objective. The others may be arranged however they are, subject to a few rules. For example, if one alternative has the same or higher score on every objective than another, it should rank higher in the overall order. If we had this hypothetical rank order, then we should be able to find a set of weights that when applied to the scores yields the desired order.

The 2^N approach is not practical when the number of objectives is large, as it will be in this case. The number of comparisons would be overwhelming. However, it does lead directly to a simple procedure that is quite practical. To do this simpler procedure we need N+1 hypothetical alternatives:

- A_0: This alternative exactly achieves that MA level on all performance attributes of all objectives for every element of the value model. In other words, it provides exactly the minimum levels specified in the model. This alternative may not actually exist, but it is useful to imagine it for the purposes of this model.
- Ai, i from 1 to N: This alternative has exactly the same performance as alternative A_0 except on the ith objective. On the ith objective it exactly provides the ME level on each attribute of the ith objective. For example, the hypothetical alternative A_1 has MA levels on all objective attributes except for Real-Time Regional (CONUS) Imagery, on which it has performance at the ME levels.

Now take these hypothetical alternatives and place them in rank order of desirability. A_0 will obviously be the last. Which one is the most desirable? In answering that question, one is saying: "Given that we start at A_0 and we have the opportunity to raise the performance attributes of one objective from the MA to ME level, which one would we do?"

Suppose that we have ranked alternative A_k as the top alternative on the rank list. Suppose that A_1 is second on the rank list. Then we should choose $w_k > w_l$. Further suppose that A_i is third on the rank list. Then $w_l > w_i$. Obviously this continues down the list to provide a set of inequalities. The second step is to compare the highest ranked alternative with a new alternative that moves two objectives from the MA to ME level. You search for points on this list where you judge that moving a combination of two lower ranked swings is equivalent to moving one higher ranked swing. As you examine these judgments, you generate an additional list of inequalities (and sometimes equalities) among the swing weight values. Generally after a modest number of judgments, the collection of relationships will converge to either a single or a narrowly confined solution for the swing weights. A mathematically intensive process would involve solving the set formally as a system of algebraic inequalities. Alternatively, there is a simple algorithm that fixes the lowest two swing weights and solves backwards up the chain. There are also heuristics for taking the ranked list and converting it to a best guess at weights without doing multiple comparisons.

Again, to summarize terminology discussed here more formally:

Rank Order: Of the hypothetical alternatives A_1 through A_N, which is the most preferred? Which is the second most preferred? The rank order is the order of preference in the hypothetical alternatives A_1 through A_N.

An equivalent way to of looking at this is by imagining you have an alternative that provides exactly and only the MA levels of performance. You have the choice of improving the performance of the attributes of exactly one objective from the MA level to the ME level. Which objective's performance is most preferred to increase from the MA to ME levels?

Note that this is not equivalent to asking which objective has the highest priority. The rank order comes from looking at the priority of increasing performance from the MA to ME level. For example, an objective viewed as very important might have the MA level defined high enough that further increase from the MA to ME level does not have a high priority. In MAUT, the concept of "Which objective has the highest priority" is irrelevant. What is relevant is "Which MA to ME swing has the highest priority?" One way to look at overall priority of an objective is how the MA levels are set. If the MA levels are set so low that we can ignore that objective (e.g. not produce an associated EDR Class at all; the objective is non-essential), then in some sense we can say that it has a low priority. Conversely, if the MA levels are high, then we are rejecting any alternative not meeting those MA levels, and thus the objective could be considered high priority.

Swing Weights: Swing weights capture the relative value preferences between improving the performance of objectives from the MA levels. The swing weights are a set of N positive real number summing to 1. A swing-weighted sum of the scores (effectiveness levels) for all of the objectives of an alternative produces a number whose ordering should reproduce a decision maker's preferences on the corresponding alternatives. Note the definition in terms of the utility function (equation 1).

If desired, one can compute swing weights on a subset of objectives. This is often done if one wants to produce different preference orderings corresponding to different stakeholders who are known to care about different objectives.

A further ranking and swing-weighting example.

If the rank of "Real-time Regional (CONUS) Imagery" is 1, it means that increasing the performance of "Real-time Regional (CONUS) Imagery" from its MA values to its ME values is the highest priority of improvements from MA to ME among all of the objectives.

If the swing weight for "Real-time Regional (CONUS) Imagery" was 0.25 and the swing weight for "Global Vertical MW Soundings" was 0.125, it would mean:

- Increasing the performance on "Real-time Regional (CONUS) Imagery" from its MA level to its ME level on all of its quality attributes accounts for 25% of the total value of increasing every quality attribute of every objective from its MA level to its ME level; and,
- Increasing the performance of "Global Vertical MW Soundings" from its MA level to its ME level accounts for 12.5% of the total value of increasing every objective from its MA level to its ME level; and,
- Increasing the performance of "Real-time Regional (CONUS) Imagery" from its MA level to its ME level is twice as valuable as increasing the performance of "Global Vertical MW Sounding" from its MA level to its ME level. (This

would be an alternative that would require that the sounding increase have an incremental cost equal to one half of the incremental cost of making the imagery increase in order for them to be indifferent choices); and,

- Given that we also have EX levels for both, we could use the scores of the EX level to further quantify the relative value of any intermediate alternative that fell between the MA and ME levels on both objectives.

An Integrated Example

As a further illustration of how this approach works, we utilize a toy 5-objective model to illustrate the concept and workings of an EVM. This model is not meant to be realistic, but it contains all of the relevant parts, and shows how the model is used to score and assess alternative architectures.

Initial EVM: Objectives and Performance Measures

The first step is to identify objectives against which we will assess architecture alternative effectiveness. Assume that we choose five objectives: two functional objectives relative to terrestrial weather, two functional objectives related to ocean observations, and one non-functional strategic objective. These five are assumed to be:

1. Provide estimates of Surface Pressure (the EDR class).
2. Provide estimates of Surface Temperature (the EDR Class).
3. Provide estimates of Sea Surface Height (the EDR Class).
4. Provide estimates of Ocean Surface Temperature (the EDR Class).
5. Develop and Maintain International Partnerships. (There is no EDR Class since this is a non-functional, strategic objective.)

Each objective has associated with it a set of performance attributes with measures of performance (quality). For each attribute, we need to set three performance levels (MA, EX, and ME). Each objective requires an effectiveness scale (level) from 0 to 100. By definition, if all of the attributes have performance at the MA level, the overall effectiveness scale is 0. If all of the attributes have performance at the ME level, the overall effectiveness scale is 100. SPRWG's task is to determine, through its judgment and research, what performance level the community expects for next generation systems and what effectiveness level (0 to 100) would be achieved by a system that achieved those performance levels.

All of these elements (the performance attributes and their definitions, the three levels, and the mapping to effectiveness scales) are shown in the table below. Note that in this example, "Surface Pressure" is a non-essential objective. The performance values in the MA cells are given as "None," since it is acceptable (if not desirable) to have an alternative that does not measure surface pressure.

		Definition		**Minimum Acceptable**		**Expected**		**Maximum Effective Level**
				0				100
Group A, Terrestrial Weather related Data Products								
1	Surface pressure			0		50		100
		Geographic Coverage		None		Western Hemisphere		Global
		Spatial Resolution		None		300 km		100 km
		Update Rate		None		6 hours		1 hour
		Accuracy		None		1 mb		0.25 mb
2	Surface temperature			0		75		100
		Geographic Coverage		Colorado		CONUS		Global
		Spatial Resolution		200 km		100 km		10 km
		Update rate		12 hours		3 hours		1 hour
		Accuracy		2 K		1 K		0.5 K
Group C, Ocean Products								
3	Sea surface height			0		30		100 (JASON equiv.)
		Spatial Resolution		1000 km		500 km		100 km
		Accuracy		10 cm		5 cm		1 cm
		Update rate		monthly		weekly		daily
		Geographic Coverage		N Atlantic N Pacific		N Hemisphere		Global
4	Ocean Surface temperature			0		50		100
		Geographic coverage		Coastal US		N Hemisphere		Global
		Horizontal resolution		100 km		50 km		10 km
		Accuracy		2 K		1 K		0.5 K
Group E, Strategic Objectives								
5	Dev/maintain intl partnerships			0		50		100

		Maintains or expands established international agreements and partnerships		No partnerships		Maintains current number of partnerships		Increases number of partnerships

Ranks and Swing Weights

With this mapping established, the next step is to determine rank order of the swings (i.e. improvements from MA to ME levels) and the swing weights. Note that this process is independent of rating or even enumerating architecture alternatives. We can, in theory, create all of the swing weights before setting out the architecture alternatives. The ranks and swing weights are independent of the architecture alternatives.

To perform this step, SPRWG would first rank order the desirability of the MA to ME swings from most desirable to least desirable. In other words, we imagine that we must select an architecture alternative that performs exactly at the MA level on all performance attributes, except for those associated with one objective. The attributes of that one selected objective will all perform at the ME level. Which of these completely hypothetical alternatives would be most preferred? Whichever one that gets a rank order of 1. We repeat with the remaining objectives until all are ranked. With that process completed, the result is given in the following table:

Obj Num.	**Objective**	**Rank**
1	Surface pressure	3
2	Surface temperature	1
3	Sea surface height	4
4	Ocean Surface temperature	2
5	Develop/maintain Int’l partnerships	5

To obtain the swing weights, we can use a variety of simple or complex procedures, depending on what level of detailed elicitation we are willing to do, and what sort of preferential fidelity we require. In an early cycle, it is unlikely to be worth using a complex procedure. In a late cycle, we probably want to take considerable care. A relatively complex, but precise, procedure is balance beam scoring. To do this we make a series of comparisons where we ask “Which is preferred: moving just objective X from the MA to ME level or moving both objectives Y and Z from their MA to ME levels?” To make sense, the comparisons have to be from a higher ranked single objective to pairs of lower ranked objectives. For this case, imagine that the dialog went as follows (where w_i is the swing weight on objective number i):

- The swing in Objective #2 is equal to swinging both objectives #4 and #1. This implies that $w_2 = w_1+w_4$
- The swing in objective #4 is equal to the swing in objective #1. This implies that $w_4 = w_1$
- The swing in objective #1 is equal to the swinging both objectives #3 and #5. This implies $w_1 = w_3 + w_5$
- The swing in objective #3 is much more desirable than the swing in objective #5. This implies that $w_3 > w_5$

This results in a space of solutions defining the uncertainty range on the swing weights. For our purposes, we do not usually need that much detail; we only need a valid solution. One such valid solution is captured in the table below:

Obj Num.	**Objective Name**	**Rank**	**Swing Weight**
1	Surface pressure	3	20
2	Surface temperature	1	40
3	Sea surface height	4	15
4	Ocean Surface temperature	2	20
5	Dev/maintain intl partnerships	5	5

Performance Scoring the Architecture Alternatives

At this point, the EVM is almost fully defined. The only element lacking is the combination rule to create a performance score of an architecture alternative based on the objective-by-objective effectiveness scales of that alternative. We leave that aside from the moment (since it can be done by Subject Matter Expert (SME) judgment instead of by algorithm if desired), and introduce the architecture alternatives and their scoring. Assume that we have seven architecture alternatives, labeled A through G. The exact contents of each alternative are irrelevant for this discussion, but each must be composed of some set of instrument, satellite platform, and launch policy. Given an architecture alternative, we can score it on the EVM performance attributes using standard engineering methods. The resulting table is given below:

		Architecture Alternative Label		**A**	**B**	**C**	**D**	**E**	**F**	**G**
Group A, Terrestrial Weather related Data Products										
1	Surface pressure									
		Geographic Coverage		None	None	W. Hem	W. Hem	W. Hem	W. Hem	W. Hem
		Spatial Resolution		None	None	300 km	100 km	300 km	300 km	300 km
		Update Rate		None	None	6 hours	2 hours	12 hours	6 hours	12 hours
		Accuracy		None	None	1 mb	1 mb	10 mb	10 mb	10 mb
2	Surface temperature									
		Geographic Coverage		Colorado	CONUS	CONUS	Global	CONUS	CONUS	CONUS
		Spatial Resolution		200 km	100 km	100 km	100 km	200 km	100 km	200 km
		Update rate		12 hours	3 hours	3 hours	3 hours	12 hours	3 hours	12 hours
		Accuracy		2 K	1 K	1 K	1 K	2 K	1 K	2 K
Group C, Ocean Products										
3	Sea surface height									
		Spatial Resolution		500 km	100 km	500 km	1000 km	500 km	100 km	500 km
		Accuracy		5 cm	1 cm	5 cm	5 cm	5 cm	1 cm	5 cm
		Update rate		weekly	daily	weekly	weekly	weekly	daily	weekly
		Geographic Coverage		N. Hem	Global	N. Hem	Global	N. Hem	Global	N. Hem
4	Ocean Surface temperature									
		Geographic coverage		Coastal US	Coastal US	N. Hem	Global	N. Hem	Coastal US	N. Hem
		Horizontal resolution		100 km	100 km	50 km	50 km	100 km	100 km	150 km
		Accuracy		2 K	2 K	1 K	1 K	2 K	2 K	2 K
Group E, Strategic Objectives										
5	Dev/maintain intl partnerships			50	50	50	0	0	50	0
		Maintains or expands established international agreements and partnerships		Maint.	Maint.	Maint.	No Part	No Part	Maint.	No Part

One important point to note immediately: Architecture Alternative G has Horizontal Resolution performance of 150 km on objective 4 (Ocean Surface Temperature). This is below the MA level, and implies that Alternative G is disqualified from further consideration. It is possible in realistic situations that when a situation such as this occurs, some may disagree, with the belief that one low performance score should not be disqualifying. If that were true, and if the team believes that the score is not low enough to disqualify it, then the MA level was set too high and would need to be adjusted.

Scoring the Utility (Value) of the Alternatives

Next we determine the overall utility number (equation 1) of each alternative. To do this, we begin by determining the effectiveness level (E) for each objective in the alternative. If the effectivness levels for each objective happen to exactly match the MA, EX, or ME levels, then this is simple: merely assign the same effectiveness level score to the objective that was given in the EVM definitions. For example, observe that with Architecture Alternative A, each of its scores match those given in the EVM for one of the assigned levels, and thus there is no computation required.

If the effectiveness levels do not exactly match the MA, EX or ME levels, then some interpolation must be done. For this simple example we using an “eyeball interpolation” rule; the score is what “looks right” to the subject matter expert. Interpolation by SME judgment is a legitimate approach, assuming it is consistent. SME interpolation is only feasible for small numbers of alternatives. Linear interpolation, curve fits, and alpha-beta rules are all legitimate approaches. The entire approach pre-supposes that the full MA to ME range is a legitimate tradable range with relatively linear preference across the range, so linear interpolation is typically quite adequate.

Once the objective effectiveness levels (E) are determined for all the objectives within each alternative, an overall utility or value score for each alternative is simply the weighted sum of the E scores, using the swing weights and normalizing to a range of 0 to 100. Note that the utility numbers (Value scores) are relative to an alternative that exactly meets the MA level of all objectives and not more. Thus a score of 0 does not mean the alternative has no value. It is an alternative in which all objectives are met at exactly the MA level and no more. Thus it has no value above the MA level. The table below provides the compiled results. (In this table, the “Costs” were chosen arbitrarily.)

			Cost		3	4	6	10	5	7	
			Value Score		7	47.5	57	65.75	20.5	52.5	DSQ
		Architecture Alternative			**A**	**B**	**C**	**D**	**E**	**F**	**G**
		Overall rank order	**Overall swing weight**								
Group A, Terrestrial Weather Products											
1	**Surface pressure**	3	20		0	0	50	80	15	25	15
2	**Surface temperature**	1	40		0	75	75	85	25	75	25
Group C, Ocean Products											
3	**Sea surface height**	4	15		30	100	30	25	30	100	30
4	**Ocean Surface temperature**	2	20		0	0	50	60	15	0	DSQ
Group E, Strategic Objectives											
5	**Dev/maintain intl partnerships**	5	5		50	50	50	0	0	50	0

Efficient Frontier Chart

If we have a cost number for each alternative, we can do an efficient frontier plot. The plot for the above data, and assuming that the available budget is “8”, is shown here:

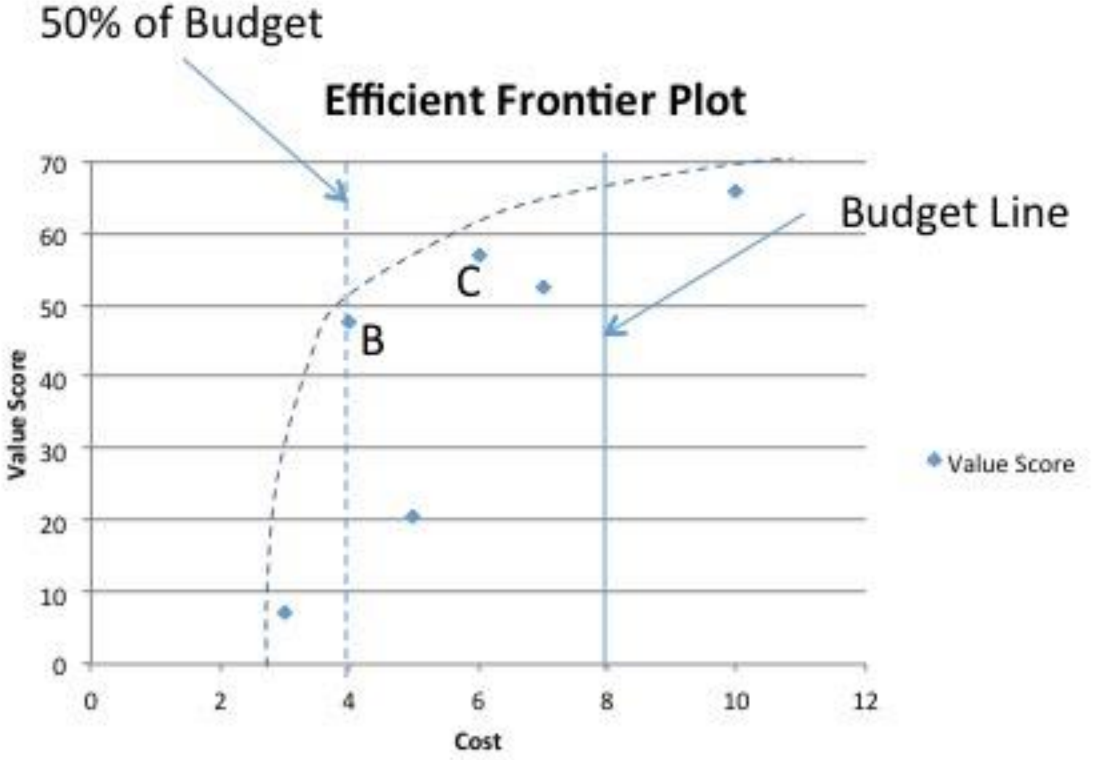

Figure 2: Efficient Frontier chart for the 5-objective model and seven notional alternatives.

If this were the actual situation for the NSOSA study, we could make several observations and conclusions:

- There are five assessed alternatives that are affordable and acceptable, and one that is unaffordable.
- If we were forced to select one alternative immediately, the highest value affordable alternative would be “C,” the alternative that costs “6” in Figure 2.
- There are two alternatives that cost ~50% of the available budget and one of those delivers value within ~20% of the highest value affordable alternative. This is a beneficial, as it would indicate that our process is robust, and that we have substantial alternatives within a trade-able range.
- Assuming we do not have to select an alternative immediately, alternatives “B” and “C” are especially deserving of further study. “C” is the highest value affordable alternative, thus we should attempt to generate some variations on it to determine if we can increase the value without exceeding the budget. Alternative “B,” the one that costs “4,” has exceptional benefit/cost ratio and

considerable budget headroom. Can we identify what makes it such a high benefit/cost ratio and generalize it? Is alternative “B” inherently scalable, that is, allowing performance to grow as budget increases with a favorable value floor at considerably reduced budget?

- Given that we make an optimal choice at a budget level of 8, what value are we leaving out? Specifically, what stakeholders are relatively less satisfied by solutions at this budget point? Are there ways to argue for the increased value we could achieve from increases above a budget of 8?

Assessing an EVM

How can we tell if an EVM is a “good” value model? In general, value models are not unique. In practice, there is no perfect value model; there are only good ones and poor ones. Building a good one is substantially a matter of judgment. That said, here are some factors to keep in mind:

- The model should be preferentially complete. There should not be other information other than scores on objectives (and cost) needed to make a decision on preference for a real alternative. If decision makers appeal to factors not in the model, then the model is not complete.
    - One way to test for this is to see if all of the EDRs in other models (such as the TPIO model) known to have high importance ratings map to the EDR Classes in the EVM. NESDIS/ADT is currently studying that mapping now.
    - Alternative orderings should be readily explainable. If the model says that alternative A is better than B, it should be easy, using the model, to explain why, and map it to mission impact. If the reasons for particular preference orderings are obscure, that is a problem with the model.
- The model should be economical and frugal. It should not include too many objectives or it will be completely unaffordable. It should only include the most important objectives. There should be stakeholders who are substantially concerned about everything in the model. The MA to ME swing in every objective should have potential to change preferences. If some are viewed as too low of importance to effect a decision, then they should be dropped.
    - It should be easy to find an individual or group to advocate strongly for increasing any objective from the MA to ME level. That constituency should be able to clearly articulate why increasing performance from the MA to ME level would be very beneficial for NOAA’s mission. If you cannot readily find enthusiastic advocates for an MA to ME increase, you can probably drop it.
- The objectives should be (mostly) independent. Scores (effectiveness scales or levels) on objectives should not be closely correlated. In the EVM, this means the EDR Classes that are the subject of most of the objectives should

be substantially different. They should not correspond to the same sensor modalities. As a practical matter, total independence is never achieved.

- Cost Correlation. Moving from the MA to ME levels on any objective should have significant cost impact. If you can always achieve the MA to ME swing with a very small cost delta, then you might as well build in the ME level as a stand-alone requirement.
- Feasibility with room to spare. There should be multiple real alternatives that score uniformly above the MA level and cost much less than available budgets (ideally 50% or less).
  - If no alternatives meet this condition, then the model is broken and must be changed.
  - If all real alternatives that meet the MA levels are very close to the maximum budget (i.e. >90% of available budget), then the trade exercise is probably pointless. It would probably be better to convert the effort into searching for the least expensive way to meet the MA levels, treating them as threshold requirements.
- Legacy Independent. The model should provide reasonable results when applied to alternatives that differ greatly from the legacy systems. In this case the EVM should be able to fairly evaluate All-MEO and All-LEO alternatives.
- Alternative Suggestive. If you examine the objective with the largest swing weight and ask how it would be possible to build an alternative that provides the corresponding ME level, the answer should be "interesting." Using the ME levels to drive alternative generation should be fruitful. If they are not then it is probably time to go back and reconsider the ME levels.

END

Appendix

Definition of Terms

Architecture Alternative: The definition of the key features of a system alternative that delivers some or all of the objectives at varying levels of effectiveness. For this project an architecture alternative will typically consist of a set of instrument capabilities, an assignment of instrument capabilities to orbits, and rules for when and how satellites occupy orbits. The goal is to determine a number of alternative systems with distinct values and costs that will aid decision makers in selecting the future NOAA space system for 2030 and beyond.

Constructed Scale: A way of measuring how the performance of a strategic objective where there are no corresponding characteristics measured in natural units (e.g.; kilometers, degrees, or percent). A constructed scale normally consists of descriptions of characteristics defining each point along the scale.

COURL: Consolidated Observing User Requirements List

CORL: Consolidated Observing Requirements List (same as COURL)

Environmental Data Record (EDR): A data product corresponding to a recognized environmental characteristic, such as temperature or water vapor. EDRs are derived from Raw Data Records (RDRs) and Sensor Data Records (SDRs).

EDR Class: An EDR class is an abstraction of multiple data types that we know we want our system to produce. The EDR class is the object of the corresponding **functional objective**. For example, where the functional objective is "Provide Real-time vertical temperature profiles," the EDR class is "Real-time temperature profiles." An EDR class may be provided by different sensors under different conditions. Data products in the class may be provided by different sensors in different orbits than today.

EDR Value Model (EVM): A model that assesses the overall value of different architecture alternatives in terms of their ability primarily to deliver EDR Classes. An alternative will be evaluated and assigned a score between 0 and 100 (see **Utility Function**).

Effectiveness scale, or level (E): A number between 0 and 100 associated with each objective that determines how far above the Minimum Acceptable (MA) level the objective is achieved, up to the Maximum Effective (ME) level. A value of E=0 implies the objective is met exactly at the MA level. A value of E=50 implies that half of the value relative to that objective of moving between the MA and ME levels has been realized, while E=100 implies that the objective is met at the ME level. For functional objectives the effectiveness scale is typically a composite of performance measures on the associated performance attributes. For a strategic objective in which there are no natural performance measures (e.g. "support international partnerships,") the effectiveness scale is a constructed scale called the **Abstract Effectiveness Scale**.

Efficient Frontier Plot: A diagram that shows different architecture alternatives plotted as points on a graph with cost of the alternative on the x-axis and the **Utility** function number (or **Value**) of the alternative on the y-axis.

Objective: Something we want an alternative to do. An objective has an object (the thing produced or of interest) and a direction of preference (the direction we want a preferred alternative to move it). How well objectives are met is measured by an **Effectiveness scale** (see above).

There are two types of objectives:

Functional objective: A functional objective is associated with something we want the system to do, e.g. an objective is to "provide vertical temperature profiles."

Strategic Objective: A non-functional property that we want an alternative to have. An example of a strategic objective is “Support international partnerships.”

Performance Attribute (also called **Quality Attribute**): For functional objectives the performance attributes are characteristics of the data being produced (e.g. horizontal resolution, accuracy, update rate, latency, etc.). We establish three levels for each performance attribute: **Minimum Acceptable**, **Expected**, and **Maximum Effective**.

Minimum Acceptable (MA): The lowest level of performance on that attribute that we will ever accept. An alternative that goes below this level is disqualified.

Maximum Effective (ME): The highest level of performance on this attribute that we believe is worth spending money on. There is no additional value for outperforming the ME level.

Expected (EX): Consensus on what the community expects for this attribute in 2030.

Rank: The order of preference of improving the performance of objectives. The objective of Rank 1 means that improving the performance level from MA to ME of that objective is higher priority than improving the performance level from MA to ME of any other objective. The rank order of objectives is directly related to the magnitude of the swing weights (higher ranks = higher swing weights).

Swing weights: Swing weights capture the relative value preferences between improving objectives from the MA to ME levels. The weights w_k in the **Utility function** (equation 1) are the “swing weights” of objective k. They are referred to as swing weights because each provides a quantification of the relative value of objective k moving from the 0 to the 100 effectiveness level. The swing weights vary between 0 to 1.0 and the sum must equal 1.0.

Utility function (also called **Value function**): A function that delivers a measure of the utility (or value) of how well an alternative architecture meets the objectives. A **utility function** takes as input all of the effectiveness levels of the performance attributes of the objects in an architecture alternative and returns a real number that is referred to as the “utility” or “value” of the alternative. An **additive utility function** is a weighted sum of the effectiveness scales on each objective. The utility number is also called a **Value** or **Value Model Score**. The equation for the utility function is:

$$U(A) = \sum_{k=1}^{N} w_k E_k(A) \qquad (1)$$

where w_k is the “swing weight” of the k^{th} objective and E_k is the “effectiveness level” of the k^{th} objective for alternative A.

Value Score (also called **Value Model Score**, **Utility Function** or **Utility Score**. The overall value of an alternative architecture. It is created by considering the effectiveness scales of the different objectives in an alternative. It is the y-axis on the Efficient Frontier Plot.

Appendix D: Program of Record for 2025 (POR2025)

The tables below are from the NSOSA final report (NSOSA Final Report_3_Study Overview_20170414)

Table 3-7. Summary of POR2025 U.S. and international geostationary weather satellites.

Geostationary Satellites	
Satellites	*Payloads*
U.S. GOES-R Series Two active and one spare satellite in three geostationary positions (GOES-W, GOES-E, and the spare position centrally located)	ABI multi-spectral imager (Vis/IR)
	GLM lightning detector and mapper
	EXIS EUV and X-Ray irradiance sensors
	SUVI solar UV Imager
	SEISS space environment sensors
	SEM/MAG Magnetometer
	Communication payloads for GOES rebroadcast, data collection, and HRIT/EMWIN lower rate services
EUMETSAT: Meteosat third generation geostationary series (payloads divided onto separate “imager” and “sounder” satellites) One imaging and one sounding satellite assumed active. With high probability there will be one additional imaging satellite in an eastern position (41.5° E) and residual backups for the primary.	IRS IR sounder
	Sentinel-4 UVN (UV,Vis,NIR) sounder
	FCI multiple spectral imager (Vis/IR)
	LI lightning detector and mapper
JMA: Himawari (single satellite in geostationary orbit)	AHI multi-spectral imager (Vis/IR)
KMA: GEO-KOMPSAT series (single satellite on orbit)	AMI multi-spectral imager (Vis/IR)
	Space environment sensor suite

Table 3-8. Summary of POR2025 U.S. and international polar weather satellites.

LEO Sun-Synchronous Satellites	
Satellites	*Payloads*
U.S.: 1 JPSS satellite in 1330 orbit. There is a high probability that there will be two JPSS satellites in the 1330 orbit, though that does not improve weather forecasting performance	CrIS infrared sounder
	ATMS microwave sounder
	OMPS ozone sensor
	VIIRS imager for global functions
EUMETSAT: 2 EPS-SG satellites (one of each type) in 0930 orbit	3MI multi-spectral imager (Vis/NIR/SWIR)
	IASI-NG IR sounder
	Sentinel-5 UVN (UV,Vis,NIR) sounder
	MetImage multi-spectral imager (Vis/IR)
	MWS microwave sounder

	RO receiver
	ICI ice cloud imager
	SCA OSVW scatterometer
	MWI microwave imager

Table 3-9. Summary of POR2025 U.S. and international weather satellites in other orbits.

<table>
<tr><th colspan="2">L1 Space Weather Satellite</th></tr>
<tr><td><i>Satellites</i></td><td><i>Payloads</i></td></tr>
<tr><td rowspan="4">U.S. : 1 Space-Weather Follow On satellite in an L1 halo orbit</td><td>Coronagraph</td></tr>
<tr><td>Proton and alpha-particle spectrometer</td></tr>
<tr><td>Electron spectrometer</td></tr>
<tr><td>Magnetometer</td></tr>
<tr><td colspan="2">Additional Capabilities</td></tr>
<tr><td colspan="2">GNSS-RO constellation with COSMIC-2 capabilities. 12 total satellites, 6 in low inclination LEO and 6 in high inclination LEO</td></tr>
<tr><td colspan="2">Ocean altimetry satellite equivalent to JASON-3 in capability and coverage</td></tr>
<tr><td colspan="2">CDARS: Satellite in TBD LEO (nominally 1330 polar sun synchronous) with A-DCS and SARSAT communications payload</td></tr>
</table>

Appendix E: Short Summaries of Objectives in Groups A and B

Group A

Objective A-1: Regional real-time weather imagery

Priority: #2 in Group A. Importance to severe weather warnings, including hurricanes and tornadoes. High priority for improvement.

Authors: Chris Velden, Kevin Schrab, Jerry Dittberner**,** Rick Anthes

Brief description: Multispectral imagery of North and South America (excluding more than half of Alaska), the western Atlantic, and the eastern/central Pacific to at least 65°N and westward just past the dateline to at least 65°N, with latency <10 min, and sampling of 30 minutes or less.

Use/Users: A wide range of qualitative and quantitative weather, oceanographic, climate, and environmental applications, including traditional NOAA operational users such as the National Weather Service and the DoD weather services. Data are used to generate terrestrial EDRs for use in a number of operational applications, ranging from real-time weather operations to forecast model input and environmental monitoring to broadcasting applications. Derived products include atmospheric motion vectors, hurricane intensities, land and sea temperatures, cloud-top heights/temperatures, identification of fires and hot spots, aerosol and smoke detection, insolation, precipitation, and fog among others.

Program of Record 2025 and current sources of data: Program of Record 2025 is GOES-R series. Those values listed under POR 2025 assume availability of data from the Advanced Baseline Imager (ABI) on GOES-16(R), -S, -T, and –U. GOES-13 through -16 are the operational geostationary satellites at the time of this report.

Impact of improving from ST to ME level: There are very significant impacts of moving from Study Threshold level to the Expected level and additional impact when moving from the Expected level to the Maximum Effective level. The ST level is less capable than current GOES. Moving from 30 minute sampling frequency to 5 minutes (with 15 second mesoscale sectors) as with GOES-16 will greatly improve the monitoring and nowcasting of impactful environmental events (severe thunderstorms, hurricanes, wild fires, flash flooding, convective initiation, volcanic eruptions). Additional channels will allow better identification of environmental hazards (fires/smoke, algal blooms, dust, volcanic ash, fog/stratus). Improved horizontal resolution will allow better definition of these environmental hazards (detect smaller wild fires, narrow fog bands, convective initiation, hurricane interrogation, and flood boundaries).
A prominent impact of moving to ME would be the addition of the Day-Night Band (DNB). The DNB has shown significant impacts from Suomi NPP and has been elevated to a Key Performance Parameter for JPSS. It allows for better identification of environmental hazards at night (fog, fires, severe thunderstorms, hurricanes, volcanic eruptions and ash).

A1 Regional RT weather imagery	*POR 2025 GOES-R series*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough H Resol*	*ME*	*OSCAR Goal H Resol*	*COURL Objective*
GIFOV Visible IR Near IR	0.5 km 2.0 km 1.0 km	2 km 4 km 3 km	20 km (H resol) λ not specified	0.5 km 1.0 km NA	0.5 km 2 km 1 km	5 km λ not specified	0.25 km 1 km 0.3 km	1 m λ not specified)	NA NA NA
Sampling frequency (update rate)	5 min	30 min	1 hour	15 min	5 min	3 min	2.5 min	30 s	NA
Latency (image time to delivery)	1 min	10 min	30 min	NA	5 min	1 min	2.5 min	1 min	NA
Mesoscale (movable 1000kmx1000km)				X					X
Nmbr reg in CONUS Update rate Latency	2 move 0.5 min 0.5 min	1 CONUS 7 min 7 min	X		2 move 30 s 30 s	X	5 move 15s 15s	X	
Wavelengths covered				X					X
Lower edge (microns) Upper edge (microns)	0.47 13.7	0.630 11	X		0.47 13.35	X	0.4 13.7	X	
Day-night bands	0	0 (None)	X	X	0.001 (None)	X	1 at 0.64 microns	X	X
Number of specific bands	16	4 (LWIR, SWIR, WV, Vis)	X	X	16	X	32	X	X
Radiometric accuracy	0.1 K NeDT	0.2 K	X	0.2K IR 0.1K MW	0.1 K	NA	0.05 K	NA	NA
Navigation accuracy at nadir	1.0 km	3.0 km	X	X	1.0 km	X	0.5 km	X	X

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

GIFOV (Ground-projected instantaneous field of view) is called "horizontal resolution" in OSCAR and COURL. Also sometimes called Ground Sampling Distance (GSD).

Sampling Frequency: These are shown for two different geographic coverage areas: Full area/ Mesoscale (movable).

Accuracy:
Radiometric accuracy: T_b

Program of Record: 0.1 K noise equivalent differential temperature (NeDT); mostly IR bands

Navigation accuracy: km
Program of Record: 1.0 km at nadir (ABI)

Sources/References supporting this objective and its attributes:

Sources

COURL Requirement ID #:
30078: Imagery: Infrared, Storm Area/Tropical Cyclones (used in Table)
30083: Imagery: Visible, Storm Area/Tropical Cyclones (used in table)
30454: Radiance IR (used for radiometric accuracy in Table)
30455: Radiance MW (used for radiometric accuracy in Table)
COURL has other related requirements (IDs).

OSCAR values for Requirement Row 103 ID # 430 "Cloud Cover, Nowcasting/VSRF" are used in the table; OSCAR version dated 20 Feb. 2017.

References

English, S., and Coauthors, 2013: Impact of satellite data. ECMWF Tech. Memo 711, 48 pp. [Available online at http://www.ecmwf.int/en/elibrary/9301-impact-satellite-data]

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Objective A2: Global real-time weather imagery

Priority: #4 in Group A. Objectives and services provided in part by foreign partners. Important for global tropical cyclone monitoring, aviation, and marine applications. High priority for improvement, especially over high-latitude northern hemisphere polar regions.

Authors: Chris Velden, Kevin Schrab, Jerry Dittberner, Rick Anthes

Brief description: Global multispectral imagery over regions in addition to those defined in regional real-time imagery, with sampling (update) rate of 60 minutes or less.

Use/Users: A wide range of qualitative and quantitative weather, oceanographic, climate, and environmental applications, including traditional NOAA operational users such as the National Weather Service and the DoD weather services. Data are used to generate terrestrial EDRs for use in a number of operational applications, ranging from real-time weather operations to forecast model input and environmental monitoring to broadcasting applications. Derived products include atmospheric motion vectors, hurricane intensities, land and sea temperatures, cloud-top heights/temperatures, identification of fires and hot spots, aerosol and smoke detection, insolation, precipitation, terrestrial surface properties, and fog among others.

Program of Record 2025 and current sources of data: Program of Record 2025 assumes availability of data from the geo imagers (ABI, FCI, and AHI) on the operational geostationary satellite ring: GOES-16 (R), -S, -T, and -U (US), Meteosat (Europe), and Himawari (Japan). GOES-13 through 16 are the U.S. operational geostationary satellites at the time of this report.

Impact of improving from ST to ME level: There are very significant impacts of moving from Study Threshold level to the Expected level and additional impact when moving from the Expected level to the Maximum Effective level. The ST level is less capable than current GOES. Moving from 60 minute sampling frequency outside NOAA AOR (30 min within NOAA AOR) to 5 minutes will greatly improve the monitoring and nowcasting of impactful environmental events occurring outside the RT Regional coverage area (severe thunderstorms, hurricanes, wild fires, flash flooding, convective initiation, volcanic eruptions) and allow determination of more impactful atmospheric motion vector winds. Additional channels will allow better identification of environmental hazards (fires/smoke, algal blooms, dust, volcanic ash, fog/stratus). Improved horizontal resolution will allow better definition of these environmental hazards (detect smaller wild fires, narrow fog bands, convective initiation, hurricane interrogation). This is especially important for those NOAA AORs and portions thereof that are poleward of 60 degrees N and outside GOES coverage. A prominent impact of moving to ME would be the addition of the Day-Night Band (DNB). The DNB has shown significant impacts from SNPP and has been elevated to a Key Performance Parameter for JPSS. Outside of the GOES high-quality coverage (i.e. poleward of 60N) it would allow for the better identification of environmental hazards at night such as fog, fires, volcanic eruptions and ash, and support of objective B16 (Aurora

Imaging lists its latency at 10 min at EXP and 1 min at ME). The biggest impact from getting ME-level imagery to 90°N is to allow for the provision of the same warning, advisory, and nowcast services that are available at lower latitudes within the GOES realm (i.e. RT Regional objectives met for areas north of 60°N that are in NOAA AOR). Improved services would benefit the electric power industry, users of satellite navigation (GPS), and users of HF radio communication.

A2-Global RT weather imagery. Global imagery (whole GEO ring) with update rate shorter than 1 hour and latency less than 1 hour	*POR 2025 AHI (JMA),FCI (EUMETSAT), GOES-R Series*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Obj*
Poleward extent with high quality	Up to 60°N/S (ST level)	Up to 60°N/S	Global	NOAA Areas of Responsibility (AOR)	ST plus 75°N	Global	ST plus 90°N	Global	NOAA AOR
GIFOV (nadir view) Visible IR Near IR	 0.5 km 2.0 km 1.0 km	 4 km 8 km Same as IR	H resol 5 km λ not specified	 0.5 km 1.0 km NA	 0.5 km 2 km Same as IR	H resol 1 km λ not specified	 0.25 km 1 km Same as IR	H resol 0.5 km λ not specified	 NA NA NA
Sampling frequency (update rate)	15 min	60 min	30 min	15 min	10 min	7 min	5 min	3 min	NA
Latency (image time to delivery)	10 min	60 min	60 min	NA	10 min	15 min	5 min	15 min	NA
Wavelengths covered Lower edge (microns) Upper edge (microns) Day-night bands	 0.470 13.7 0	 0.630 11 0 (None)	X	X	 0.470 13.35 0.001	X	 0.4 13.7 1	X	X
Number of specific bands	16	4 (LWIR, SWIR, WV, Vis)	X	X	16 (Similar to ABI)	X	32	X	X
Radiometric accuracy	0.2 K	0.2 K	X	0.2 K (IR) 0.1K (MW)	0.1 K	X	0.05 K	X	NA
Navigation accuracy at nadir	1.0 km	3.0 km (6.0 km outside NOAA AOR)	X	X	1.0 km	X	0.5 km	X	X

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

GIFOV (Ground-projected instantaneous field of view) is called “horizontal resolution” in OSCAR and COURL. Also sometimes called Ground Sampling Distance (GSD).

Poleward extent of high-quality images of POR2025 given as 60º N/S. Even though imagery of some use is provided by geostationary satellites up to 84º N/S, the lower viewing angle above 60º results in some degraded products. ST level is equal to POR2025. For EXP and ME levels, high-quality, rapid update imagery should be extended to 75º N and 90º N respectively. Increasing high-quality images with rapid update rates in north polar regions is a higher priority than in south polar regions because of operational needs of Alaska and strategic importance of Arctic Ocean. South polar regions have some imagery from polar satellites (JPSS-VIIRS and EPS-SG).

Accuracy:
Radiometric accuracy: T_b (in degrees K)
Program of Record 2025: 0.2 K noise equivalent differential temperature (NeDT); mostly IR bands

Navigation accuracy/geolocation: in km at nadir
Current capability: 1.0 km at nadir (ABI)

Sources/References supporting this objective and its attributes:

Sources

COURL Requirement ID #:
ID 30078 (Row 707): Imagery: Infrared, Storm Area/Tropical Cyclones (used in Table)
ID 30083 (Row 712): Imagery: Visible, Storm Area/Tropical Cyclones (used in Table)
ID 30454 (Row 1082) IR radiance used for radiometric accuracy in Table
ID 30455 (Row 1083) MW radiance used for radiometric accuracy in Table
COURL has other related Requirements (IDs).

Regional RT Imagery requirements are considered valid globally (especially in Western Pacific), as NWS has Areas of Responsibility (AOR) that require regional-type imagery in areas not covered by U.S. GOES satellites. The two COURL requirements used in the table are the same as in objective A1.

OSCAR Requirement ID #: 493 (Row 104) Cloud Cover, Ocean Applications (Global). OSCAR version 2-20-17

References

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Objective A3: Non-real-time global weather imagery (VIS and IR) other than ocean color

Priority: #8 in Group A. Supports large number of applications and users. Significant ST level implies medium priority for improvement.

Authors: Pam Emch, Chris Velden, Kevin Schrab, Rick Anthes

Brief description: Global IR/VIS imagery (including poles) with update rate greater than 30 min – typically 1-2 times updates per day. (Microwave imagery is a separate objective.)

Use/Users: This objective supports a large number of applications and users (e.g., aerosols, cloud properties, terrestrial and cryospheric products, fires/smoke detection) and includes sea surface temperature.

Program of Record 2025 and current sources of data: VIIRS on JPSS, MetImage on EUMETSAT 2EPS-SG in 9:30 orbit

Impact of improving from ST to ME level: The main impact in moving from ST to ME is to increase the sampling frequency from 12 hours to 1 hour, resolution to 0.2 km for all channels, and increasing to hyperspectral coverage. Much of the impact is gained in the ST to Expected levels due to increasing the sampling rate from 12 hours to 3 hours, improving latency from 3 hours to 1 hour, and adding more channels (including the Day-Night Band).

This will improve the monitoring of impactful environmental events (severe thunderstorms, wild fires, flash flooding, volcanic eruptions) and allow more impactful derived motion vector winds. Increasing the sampling rate is important for observations of those geophysical processes and parameters that are likely to change on a shorter timescale, for example, atmospheric/cloud processes.   Additional channels will allow better identification of environmental hazards (fires/smoke, algal blooms, dust, volcanic ash, fog/stratus).   Additional channels are also important for improved assessment of aerosol and cloud properties. In particular, the improved ability to apply "aerosol corrections' impacts a variety of EDRs.

The main impact of moving to ME would be the improvement in horizontal resolutions and going to hyperspectral. These improvements would allow better monitoring of a plethora of environmental processes and dangers. The introduction of many, many spectral channels will provide the ability to differentiate and analyze the geophysical and chemical make-up of substances much more clearly. Extending the top end of the spectral range to 15 microns from 12.5 microns will add an ability to observe volcanology phenomenology, chemical effluents, trace gases, and CO2.

A3 - Non-Real-Time global weather imagery (Vis and IR) other than ocean color	*POR 2025 VIIRS, EUMETSAT 2EPS-SG 9:30 orbit*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
GIFOV High Resolution Low Resolution	 0.375 km 1 km	 1.1 km 1.1 km	 20 km	Horiz resol: IR=100km, Vis=1 km	 0.375 km 0.75 km	 5 km	 0.2 km 0.2 km	 1 km	 NA
Wavelengths covered Lower edge (microns) Upper edge (microns) Day-night bands	 0.40 13.5 Yes	 0.58 12.5 0	X	X	 0.41 14.4 1 band	X	 0.40 15 2 bands	X	X
Update rate to 90% coverage	5.9 hours	12 h	6 h	6 hours (IR and Vis)	3 h	1 h	1 h	30 min	NA
Latency (image time to delivery)	45 min	3 h	2 h	3 h (Vis)	1 h	15 min	15 min	15 min	NA
Number of bands	22	6	X	X	28	X	1000	X	X
Radiometric accuracy	NeDT ~ 0.03 K	0.05 K	X	0.2 K IR 0.5 K Vis	0.03 K	X	0.02 K	X	NA
Navigation accuracy	0.2 km	0.5 km	X		0.2 km	X	0.1 km	X	X

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

ST, EXP, and ME imagery attribute values reflect the fact that attribute values for a suite of derived products are drivers on imagery.

COURL requirements are for radiances.
ID: 30454 (Row 1082): Radiance: Infrared (Global and high-resol NWP)

ID: 30456 (Row 1084): Radiance: Visible (Global and high-resol NWP)

OSCAR ID: 360 (Row 249): Cloud Cover (Hi Res Global NWP)
OSCAR does not give Visible or IR imagery attributes; instead it gives attributes of the many products the imagery supports. OSCAR Threshold, Breakthrough, and Goal values represented in this table are based on values for Cloud Cover for Hi-Res Global NWP. This is one of the important products derived from imagery and was chosen to be representative. However, there is a great deal of variability among the requirements values for GIFOV, update rate, and latency across the broad range of products derived from imagery, depending on the needs of the end user and the specific utility.

GIFOV (ground-projected instantaneous field of view) GIFOV is called "horizontal resolution" in COURL. Also sometimes called Ground Sampling Distance (GSD). See SPRWG report for details.

Elaboration of EXP level of GIFOV: 22 Moderate Resolution Bands ranging from Vis to LWIR: 0.75 km. 5 Imagery Bands ranging from Vis to LWIR: 0.375 km.
DNB: 0.75 km.

Radiometric accuracy in K: NeDT (Valor et al., 2002). Value for POR2025 given for Bands M15 (10.729 µm and M16 (11.845 µm). These are the LWIR window channels and the most commonly used frequencies for imagery as well as derived products such as SST.

Navigational accuracy in km

Program of record: VIIRS on JPSS and MetImage on EUMETSAT 2EPS-SG.
ST = Approximately AVHRR/3 level; (Note: ST level of 6 bands is well below current capability; significant room for improvement.)
EXP = VIIRS level; (Update Rate value is based on using data from three polar satellites plus leveraging data from additional satellites.)

The EXP level is based on using 22 bands from VIIRS and then adding six additional bands. The six bands added could be chosen to be similar to selected MODIS bands in the 6-14.4 micron range. Specifically, atmospheric absorption bands could be added, i.e. water vapor and CO2 bands.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA)

Hillger, D., T. Kopp, T. Lee, D. Lindsey, C. Seaman, S. Miller, J. Solbrig, S. Kidder, S. Bachmeier, T. Jasmin, and T. Rink, 2013: First-Light Imagery From Suomi NPP VIIRS. *Bull. Amer. Meteor. Soc*., **94**, 1019-1029.

Valor, Enric; Vicente Caselles, Cesar Coll, Eva Rubio and Francisco Sospedra, 2002: NEDT influence in the thermal band selection of satellite-born instruments. *Intl. Journal of Remote Sensing*, **23**, 17, 3493-3504.

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

There are many source of information on VIIRS, AVHRR and MODIS on the web; a few are given below:

http://npp.gsfc.nasa.gov/viirs.html
http://www.jpss.noaa.gov/instruments_interactive.html
http://rammb.cira.colostate.edu/projects/npp/Beginner_Guide_to_VIIRS_Imagery_Data.pdf
http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
http://modis.gsfc.nasa.gov/

Objective A4: Global ocean color/phytoplankton composition

Priority: #9 in Group A.

Authors: Michael Ford (Michael.ford@noaa.gov), Rick Anthes

Brief description: Ocean color (chlorophyll a concentration) and phytoplankton composition at the ocean's surface are parameters that can be estimated using satellite-based radiometers. Much of the theory behind the technique to collect ocean color and phytoplankton composition is based on the fact that phytoplankton (algae) are typically the most abundant particles in the ocean that reflect incoming light from the sun. Inclusion of ratios of certain wavelengths, corrections for atmospheric particles, and consideration of certain optical properties of seawater have advanced this oceanographic discipline.

The objectives being considered in this study are chlorophyll a concentration and phytoplankton species composition, both of which contribute to NOAA mission areas. Chlorophyll a concentration is estimated by using reflectances in the blue and green ranges. A time series, started with the Coastal Zone Color Scanner (CZCS; 1978) has provided the scientific community with the capability to understand anomalies to ocean color data fields. The maintenance of a consistent time series with good accuracy and precision is an important capability. Phytoplankton species composition is a newer capability than chlorophyll a concentration (Jefferey et al. 1997). Based on the initial studies with radiometers handling more and more wavelengths, and with the promise of hyperspectral radiometry, the community has been focused on identification of all phytoplankton pigments in order to identify various taxonomic groupings of phytoplankton. Since specific phytoplankton composition suggests relevant aspects of the food web, this objective provides a useful capability. Where chlorophyll a concentration allows determination of the abundance of phytoplankton in a particular spatial unit of ocean, phytoplankton species composition allows information on the type of phytoplankton allowing deeper ecological understanding.

Use/Users: NOAA NMFS, NOS

Program of Record 2025: VIIRS and Sentinel 3 (ESA). MODIS (AQUA) also being used at present (October 2016).

Impact of improving from ST to ME level: This improvement is to add bands of ocean color to the level of hyperspectral (tens to hundreds of bands). Additional bands will allow detection of nearly all pigments in phytoplankton cells to enable detection of specific groups of phytoplankton species. Detecting these details will provide a capability to understand shifts in ocean ecology at a very large scale.

A4: Global ocean color/phytoplankton composition	*POR 2025* VIIRS, Sentinel 3 (ESA)	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Accuracy (0.05 – 50 mg/m3)	20% (RMS) as compared to in-situ via Kahru et al 2014; 0.2 mg/m3	30%	0.2	10%	20%	0.1	15%	0.05	NA
Update Rate	< 24 hours	48 hours	6 days	Once per day	24 hours	2 days	6 hours	1 day	NA
GIFOV	0.75 km	5 km	500	1 km (Horiz resol)	3 km	200	1 km	100	NA
Bands for chlorophyll-a concentration	Sentinel 3	VIIRS ocean color bands (412, 445, 488, 555, 672, 746, 865 nm)	X	X	ST PLUS 400, 510, 674, 709, 779, 1020 nm		Hyperspectral/PACE (~200 bands)		X
Bands for Phytoplankton composition: Multi-pigment identification leading to species attribution	Multispectral	VIIRS ocean color bands (5)	X	X	OLCI bands (21)		Hyperspectral/PACE (200 bands)		X

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

OSCAR Row 296 ID 197: Ocean chlorophyll concentration – CLIVAR

COURL Row 365 ID 20011 “Chlorophyll Surface Coastal US” values are used in above table.

GIFOV(Ground-projected instantaneous field of view) GIFOV is called “horizontal resolution” in COURL. Also sometimes called Ground Sampling Distance (GSD). See SPRWG report for details.

Mike Ford verified the accuracy levels with the publication referenced for this record; radiometric accuracy should be 0.5% . This allows water-leaving radiance accuracy to be close to 5% and accuracy of the chlorophyll concentration product to be ~30% (in terms of RMS estimates from Kahru et al.) This is the accuracy level to be applied to all bands discussed for ocean color and vicarious calibration is required to achieve this level. The IOCCG Report 10 in 2010 supports this information.

The three levels (ST, EXP, ME) associated with these objectives represent a progression toward accurate and precise chlorophyll a concentration and very good capability in determination of phytoplankton species composition. The minimal acceptable level includes the bands associated with VIIRS. The several bands associated with VIIRS provide reasonable capability to determine ocean color and is the current configuration in orbit. While some studies have made progress, there is very little capability at this level to determine species composition due to the sensor lacking numerous wavelengths to detect certain pigments. The expected level for these objectives provides very good chlorophyll a concentration capability through the addition of a spectral band centered on 510 nm. This band, along with ones at 410 and 443 provide an ability to configure a ratio between wavelengths to very accurately determine chlorophyll a concentration. Good performance here allows excellent indices of phytoplankton bloom timing, spatial patterns in phytoplankton production, and detection of harmful algal blooms. The expected level does not contain additional specifications to improve the capability for phytoplankton species composition. The maximum effective level for these objectives moves toward hyperspectral. With hyperspectral, the scientific community in this discipline of oceanography will have many wavelengths to work with to achieve superior chlorophyll a concentration and excellent phytoplankton species composition. The specifications offered here match the design of the NASA PACE sensor, which is expected to be in orbit prior to 2030.

Accuracy
Program of record 2025 (current capability): 20% (RMS) as compared to in-situ 0.2 mg/m3. POR should be better of VIIRS and Sentinel 3.

Phytoplankton composition
(Multi-pigment identification leading to species attribution)
Current capability: None

Bands collected
ST: SeaWiFS/MODIS capability; Chlorophyll-related wavelengths (nm): 412, 443, 490, 510, 555, 665
EXP: VIIRS capability; Chlorophyll-related wavelengths (nm): 412, 443, 490, 555, 665
ME: Move to hyperspectral with NASA PACE specifications

Using IOCG (2010) Report 13 Table 3.4 and 3.5 as a starting point and modifying as needed based on consultations; added bands will allow increased performance for chl-a concentration using band-ration algorithms that include 510 nm; other wavelengths add capability for CDOM (colored dissolved organic matter) detection/subtraction and FLH (fluorescent line height), and/or atmospheric correction.

Sources/References supporting this objective and its attributes:

IOCCG (2010). Atmospheric Correction for Remotely-Sensed Ocean-Colour Products. Wang, M. (ed.), Reports of the International Ocean-Colour Coordinating Group, No. 10, IOCCG, Dartmouth, Canada.

Jeffrey SW, Mantoura RFC, Wright SW (1997) Phytoplankton pigments in oceanography: guidelines to modern methods. Monographs in oceanographic methodology. UNESCO. 661 pp.

Kahru M, et al. (2014) Evaluation of satellite retrievals of ocean chlorophyll-a in the California Current. Remote Sensing 6:8524-8540

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA)

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at https://www.wmo-sat.info/oscar/satellites OSCAR Version 2017-02-20.

Add additional refs on PACE

Objective A5: Global real-time vertical IR soundings

Priority: #6 in Group A. Very important objective – one of top five observing systems for NWP. But high capability at ST level reduces its priority for improvement.

Authors: Jim Yoe, Mitch Goldberg, Rick Anthes

Brief description: Global vertical IR soundings of temperature and water vapor provide a foundational basis for all medium- to long-range numerical weather prediction (NWP). Observation System Experiments (OSEs, or data denial experiments) and Forecast Sensitivity to Observational Impact assessments performed by national and international NWP centers consistently indicate that global vertical IR sounding data are among the most important contributions to providing NWP skill.

Use/Users: Users of global NWP typically assimilate the L1BIR radiance data into operational analyses and models. Users include: NWS/NCEP Central Operations; U.S. Navy's Fleet Numerical Meteorological Operational Center (FNMOC); the USAF 557th Weather Wing; and international NWP centers including UKMO, ECMWF, and numerous others.

Program of Record 2025 and current sources of data: IASI NG (EUMETSAT)), CrIS (JPSS). Current sources include IASI (METOP-A and B), CrIS (S-NPP), Aqua/AIRS.

Impact of improving from ST to ME level: Improving from ST to ME level is expected to provide substantial increase to the skill of operational global NWP modeling systems by providing more detailed (higher resolution) initial conditions with more frequent updating. Observation System Experiments (OSEs) such as Boukabara et al (2016) demonstrate that current NWP model skill is degraded at the ST level. Improving to the ME level will not only restore this capability, but will be commensurate with the demands for initializing higher resolution global NWP models of the future.

A5: Global RT vertical IR soundings	*POR 2025 IASI NG (EUMETSAT) CrIS (JPSS)*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*

Horizontal Resolution	14 km	15 km	500 km (T) 250 km (q)	100 km (T) 50 km (q)	10 km	100 km (T) 50 km (q)	1 km	15 km (T and q)	NA
Update Rate	6 hours	12 hours	24 h (T) 12 h (q)	6 hours	3 hours	6 hours	1 hour	1 hour	NA
Latency	50 min	180 min	6 hours	NA	60 min	6 min	15 min	6 min	NA
Vertical Resolution	1.5 km	2 km	3 km	1 km	1.5 km	1 km	1 km	300 m	NA
Accuracy Temperature Water Vapor (specific humidity)	1 K 0.2 g/kg	1 K 2 g/kg	3 K 10%	1 K 10%	0.75 K 0.2 g/kg	1 K 5 %	0.5 K 0.15 g/kg	0.5 K 2%	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

ST levels are relatively high, but are not as high as current capability.

It may be impossible to achieve 0.5K accuracy with current technology.

The Rows and IDs from COURL in table above (no values given for Objective level) are:

Rows 1047 ID 30419 and 1049 ID 30421: Air temp NWP upper and lower troposphere

ID: 30479 (Row 1107): Specific humidity profile - Lower troposphere; Water Vapor Profiles; Global NWP

Row 1082 ID 30454 gives Threshold values for "IR radiances for global and high-resol NWP." Same horizontal resolution, vertical resolution and update rate as in above table, but accuracy given as 0.2K

The following entry used is for OSCAR levels in table above:
ID: 257 (Row 185): Atmospheric temperature; Lower Troposphere; Global NWP
ID 303 Row 481 Specific humidity Global NWP lower troposphere

Recent NWP community recommended reducing field of view (FOV) size regarding the CrIS from 14 to 7 km to trade marginally higher noise for increased fraction of clear scenes (TOVS, 2016)

Sources/References supporting this objective and its attributes:

Boukabara, Sid-Ahmed; Garrett, Kevin; Kumar, V. Krishna , 2016: Potential Gaps in the Satellite Observing System Coverage: Assessment of Impact on NOAA's Numerical Weather Prediction Overall Skills. **Mon. Wea. Rev.**, **144**, 2547-2563 DOI: **10.1175/MWR-D-16-0013.1**

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA)

TOVS, 2016: A report of the twentieth International TOVS Study Conference, Lake Geneva, Wisconsin, 28 Oct.-3 Nov. 2015 page 41. http://cimss.ssec.wisc.edu/itwg/itsc/itsc20/itsc20_wg_report_final.pdf

WMO, 2012: Final Report of the Fifth WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction, Sedona, AZ. [Available online at: http://www.wmo.int/pages/prog/www/OSY/Meetings/NWP5_Sedona2012/Final_Report.pdf]

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective A6: Regional (CONUS) real-time vertical IR soundings

Priority: #14 in Group A. Improvements in global system also improve regional observations, so priority for improvement for regional observations alone is relatively low.

Authors: Jim Yoe, Steve Goodman, Mitch Goldberg, Rick Anthes

Brief description: Regional vertical IR soundings of temperature and water vapor used for numerical weather prediction (NWP), with a latency of less than 30 minutes. Regional NWP requires regular temperature and moisture sounding capability with adequate vertical resolution, refresh rate and data latency matched to the length of the data assimilation window. Although in-situ and surface-based sensors still play a dominant role in regional NWP, satellite-based IR sounders also contribute. This contribution is expected to increase in the future as higher refresh/resolution and lower latency observations become available (WMO, 2012).

Use/Users: NOAA NWS (regional NWP)

Program of Record 2025 and current sources of data: Program of Record 2025: None. Partial contribution from polar-orbiting systems, including NASA’s Aqua/AIRS, S-NPP and JPSS CrIS, METOP A/B IASI. GOES-16 L1B radiance assimilation adds robustness and offset the negative impact that might occur in the event of a data gap in the polar sounding capability. Anticipated regional (non-CONUS) sources include EUMETSAT Geo IR sounder to be launched in ~ 2022. ABI on GOES-16 provides low vertical resolution (3-5 km) soundings.

Impact of improving from ST to ME level: Improving IR sounding capability for the CONUS from the ST to the ME level will improve definition of the thermodynamic (temperature, water vapor and stability) structure of the pre-convective environment, as well as improve regional NWP. Meeting this Objective at the ME level will provide near-continuous and accurate updates with horizontal resolution commensurate with convection-allowing models for assimilation and verification, in conjunction with radar and in-situ data.

A6: Regional (CONUS) RT vertical IR soundings	*POR 2025 ABI on GOES-R provides low vertical resol (3-5 km) soundings*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Horizontal Resolution	10 km (ABI)	15 km (None)	10 km (T) 20 km (q)	20 km	3 km	2 km (T) 5 km (q)	1 km	0.5 km (T and q)	NA
Vertical Resolution	4 km	2 km (None)	1 km (T and q)	1 km (T)	1.5 km	250 m (T) 200 m (q)	1 km	100 m (T and q)	NA
Update Rate (all of CONUS)	30 min	1 hour (None)	6 hours	6 hours	30 min	1 hour	15 min	15 min	NA
Latency	5 min	30 min (None)	2 hours	NA	15 min	15 min	10 min	15 min	NA
Accuracy Temperature Water Vapor (relative humidity)	2 K 20%	1.0 K 20%	3 K 10%	0.909 K 7.9%	0.75 K 10%	1 K 5 %	0.5 K 5%	0.5 K 2%	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

ST level: None (except there is a significant contribution from global system). Some of this objective is provided by Global IR soundings (Objective A5)

OSCAR values given for High-resolution NWP (Row 70 ID 341 T lower trop) and Row 483 ID 379 (specific humidity lower troposphere). Many other OSCAR Rows contain temperature and water vapor for different users.

COURL values given for high-resolution NWP troposphere for T (Row 1050 ID 30422 higher troposphere and Row 1052 ID 30422 lower troposphere and q (Row 1109 ID 30481, lower troposphere).

Many other COURL IDs contain temperature and water vapor requirements for different users. Row 1082 ID 30454 gives Threshold values for "IR radiances for global and high-resol NWP."

Sources/References supporting this objective and its attributes:

Li, Jun and Hui Liu, 2009: Improved hurricane track and intensity forecast using single field-of-view advanced IR sounding measurements. *Geophys. Res. Letters*, **36**, L11813, doi:10.1029/2009GL038285.

Li, Zhenglong, J. Li, T. Schmit, F. Zou, P. Wang, A. Liu, Jinlong Li, R. Atlas and R. Hoffman, 2016: A quick regional OSSE impact study on Geostationary Hyperspectral Infrared Sounder for Hurricane Forecasts. Presentation at AMS 2016 annual Meeting, 10 – 14 January 2016, New Orleans, LA, 20th Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS), Observing System Simulation Experiments (OSSEs) II.

Lin, Haidao, 2010: Assimilation of hyperspectral satellite radiative observations within tropical cyclones. Ph.D. thesis from Florida State University, 137 pp.

Lin, J., C.-Y. Liu, P. Zhang and T.J. Schmidt, 2012. Applications of full spatial resolution space-based advanced infrared soundings in the pre-convection environment. *Weather and Forecasting*, **27**, 515-524.

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Schmit, T.J., Jun Li and S.A. Ackerman, and J. Gurka, 2009: High-Spectral- and High-Temporal Resolution Infrared Measurements from Geostationary Orbit. J. Atmos. And Oceanic Tech., 26,

WMO, 2012: Final Report of the Fifth WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction, Sedona, AZ. [Available online at: http://www.wmo.int/pages/prog/www/OSY/Meetings/NWP5_Sedona2012/Final_Report.pdf]

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective A7: Global real-time vertical microwave soundings

Priority: #5 in Group A. Number one contributor to NWP. Large capability at ST level lowers its priority for improvement.

Authors: Jim Yoe, Rick Anthes

Brief description: Numerical weather prediction (NWP) modeling requires regular global temperature and moisture sounding capability with adequate vertical resolution throughout the depth of the troposphere and lower stratosphere. Observation System Experiments (OSEs, or data denial experiments) and Forecast Sensitivity to Observational Impact assessments performed by national and international NWP Centers consistently indicate that global vertical MW sounding data is the most important contribution to providing NWP skill, particularly in situations for which infrared sounders are precluded from sensing at levels below cloud tops.

Use/Users: Users for global NWP typically assimilate the L1B MW radiance data (or brightness temperatures) into operational analyses and models. Users include: NWS/NCEP Central Operations; U.S. Navy's Fleet Numerical Meteorological Operational Center (FNMOC); the

USAF 557th Weather Wing; and international NWP centers including UKMO, ECMWF, and numerous others.

Program of Record 2025 and current sources of data: Program of Record 2025 is ATMS (JPSS) and MWS (EUMETSAT). Current (October 2016) contributions from AMSU-A, MHS on METOP-B, ATMS on Suomi NPP; NOAA 15, 18, and 19; SSMI/S (DMSP).

Impact of improving from ST to ME level: Improvement is expected to provide substantial increase to the skill of operational global NWP modeling systems by providing more detailed (higher resolution) initial conditions with more frequent updating. Observation System Experiments (OSEs) such as Boukabara et al. (2016) demonstrate that current NWP model skill is degraded at the ST level. Improving to the ME level will not only restore this capability, but will be commensurate with the demands for initializing higher resolution global NWP models of the future.

A7: Global RT vertical MW soundings	*POR 2025 ATMS (JPSS), MWS (EUMETSAT)*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Horizontal Resolution	32 km	50 km	500 km (T) 250 km (q)	100 km (T) 50 km (q)	25 km	100 km (T) 50 km (q)	5 km	15 km	NA
Update Rate for 90% coverage	5.8 hours	12 hours	24 h (T) 12 h (q)	6 hours	3 hours	6 hours	1 hour	60 min	NA
Latency	50 min	165 min	6 hours	NA	45 min	6 min	15 min	6 min	NA
Vertical Resolution	3 km	4 km	3 km	1 km	3 km	1 km	2 km	300 m	NA
Accuracy	1 K	2 K	3 K (T) 10% (q)	1 K (T) 10% (q) 0.1K (ID 30455)	1.5 K	1 K (T) 5 % (q)	1 K	0.5 K (T) 2% (q)	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

<u>Comments and notes:</u>

2 km is maximum possible vertical resolution for microwave sounders.

The horizontal resolution values for ST, EXP and ME are based on the assumption that a scanning technology in which observations are contiguous and so the horizontal footprint and resolution are the same. The ST level is easily met and is not a driver for determining architectures for this objective.

COURL IDs and Rows used in table above (no values given for Objective level)
ID: 30455 (Row 1083): Radiance (Microwave), Global and High Res NWP.
Also given are T and q from COURL:
Rows 1047-1049 (IDs 30419, 30420 and 30421) Air Temperature Profiles; Global, NWP
Row 1107 (ID 30479): Specific humidity profile - Lower troposphere; Global NWP

COURL also provides other related requirements (IDs).

The following entries are used for OSCAR values in table above:
Rows 64-67 (IDs 255-257): Atmospheric temperature; Global NWP, Troposphere and stratosphere (all same)
Row 481 (ID 303): Specific humidity, global NWP, lower troposphere

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA)

WMO, 2012: Final Report of the Fifth WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction, Sedona, AZ. [Available online at: http://www.wmo.int/pages/prog/www/OSY/Meetings/NWP5_Sedona2012/Final_Report.pdf]

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

> OSCAR provides many other rows for T and q for different users. For information on cross-track scanning MW sounding instruments (used for producing atmospheric soundings) see: http://www.wmo-sat.info/oscar/instrumenttypes/view/3

Boukabara, Sid-Ahmed; Garrett, Kevin; Kumar, V. Krishna, 2016: Potential Gaps in the Satellite Observing System Coverage: Assessment of Impact on NOAA's Numerical Weather Prediction Overall Skills Author(s): **Mon. Wea. Rev., 144**, 7, 2547-2563. DOI: 10.1175/MWR-D-16-0013.1

Objective A8: Regional (CONUS) real-time vertical microwave soundings

Priority: #13 in Group A. Improvements in global system also improve regional system, so priority for improvement relatively low.

Authors: Jim Yoe, Mitch Goldberg, Rick Anthes

Brief description: Regional vertical microwave (MW) soundings of temperature and water vapor used for numerical weather prediction (NWP), with a latency of less than 30 min. Regional NWP requires regular temperature and moisture sounding capability with adequate vertical resolution, refresh rate and data latency matched to the length of the data assimilation window. Although in-situ and surface-based sensors still play a dominant role in regional NWP, satellite-based microwave sounders also contribute, and this contribution is expected to increase in the future as higher refresh/resolution and lower latency observations become available, and as improved surface emissivity models facilitate assimilation of data over land (WMO, 2012).

Use/Users: Users include NWS/NCEP for NWP.

Program of record 2025 and current sources of data: None in Program of Record 2025. Some regional sounding capability provided by global MW sounding systems: ATMS (JPSS) and MWS (EUMETSAT) in POR. Current (2017) contributions from AMSU-A, MHS on METOP-B, ATMS on S-NPP; NOAA 15, 18, and 19; SSMI/S (DMSP). However, full CONUS update rate is too slow for all of these systems.

Impact of improving from ST to ME level: Improving MW sounding capability for the CONUS from the ST to the ME level are expected to convey moderate improvements to regional NWP by providing near-continuous and accurate updates even in the presence of clouds with resolution approaching that of convection-allowing models for assimilation and verification, in conjunction with radar, in-situ data, and IR satellite imagery and soundings.

A8: Regional (CONUS) RT vertical MW soundings	*POR 2025*	*ST None (values given for scoring only)*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Horizontal Resolution	None	50 km	10 km (T) 20 km (q)	20 km (T) 20 km (q) 100 km (ID 30455)	25 km	2 km (T) 5 km (q)	5 km	0.5 km	NA
Vertical Resolution	None	4 km	1 km	1 km	3 km	250 m (T) 200 m (q)	2 km	100 m	NA
Update Rate	None	1 hour	6 hours	6 hours	30 min	1 hour	15 min	15 min	NA
Latency	None	1 hour	2 hours	NA	30 min	15 min	10 min	15 min	NA
Accuracy	None	2 K	3 K (T) 10% (q)	0.909 K (T) 7.9% (q)	1.5 K	1 K (T) 5 % (q)	1 K	0.5 K (T) 2% (q)	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

<u>Comments and notes:</u>

Maximum possible vertical resolution for MW sounders is 2 km.
Spectral bands covered: for temperature and water vapor only.

COURL values in table: ID: 30455 (Row 1083): Radiance (Microwave), Global and High Res NWP. No values given for Objective Level

COURL values for Accuracy row are from Rows 1050 and 1053 (IDs 30422 and 30424) high-resolution NWP troposphere for T and Row 1109 (ID 30481) for and q, lower troposphere).

COURL also provides many other related IDs on T and q for other users.

OSCAR values given for High-resolution NWP (Row 70 ID 341 T lower trop) and Row 483 ID 379 (specific humidity lower troposphere). OSCAR also provides other rows on T and q for other users.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA)

WMO, 2012: Final Report of the Fifth WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction, Sedona, AZ. [Available online at: http://www.wmo.int/pages/prog/www/OSY/Meetings/NWP5_Sedona2012/Final_Report.pdf]

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective: A9-Global GNSS-RO soundings

Priority: 3 in Group A. High priority for improvement because of large impact in NWP and significant impact in space weather, but ST capabilities are far below optimal.

Authors: Rick Anthes (with help from Sergey Sokolovskiy, Bill Schreiner and Tom Meehan)

Brief description: RO soundings of the ionosphere, stratosphere and troposphere. Produces electron density in ionosphere and bending angles, refractivity, and with ancillary data temperature, pressure and water vapor profiles in stratosphere and troposphere.

Use/Users: Assimilation in numerical models, weather, climate and space weather applications. RO has been shown in some studies to rank in the top five of all observing systems in reducing the errors in NWP, and to complement IR and MW soundings by reducing the need for bias corrections in models.

Program of Record and current and future sources of data: Program of Record 2025 is COSMIC-2 and EUMETSAT (2 EPS-SG). Capability in May 2017 includes COSMIC-1 (which is well past its lifetime and decaying slowly), METOP-A and –B and a few others. COSMIC-2 Equatorial scheduled for launch in late 2017, but could be later due to SPACE-X launch issues. COSMIC-2 Polar planned for 2020 or later, but Congress has not approved funding. Current number of observations far below what is considered needed, and number is decreasing slowly as COSMIC satellites reach their end of life.

A9: Global GNSS-RO soundings	*POR 2025* COSMIC-2, EUMETSAT (2 EPS-SG)	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Number of soundings per day	8000 (COSMIC-2, conservative estimate)	5,000	2,000 (H resol 500 km)	51,000 (H resol 100 km)	20,000	51,000 (H resol 100 km)	50,000	2.2M (H resol 15 km)	NA
SNR (40-80 km altitude avg)	1600 V/V (COSMIC-2)	800 V/V (COSMIC -1)	3.0 K	1.0 K	1600 V/V (COSMIC -2)	1.0 K	2000 V/V	0.5 K	NA
Latency	30 min (COSMIC-2)	90 min (COSMIC -1 level)	6 hours	NA	30 min	6 min	10 min	6 min	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

Latency is as defined in COSMIC-2 as the median time from an occultation to delivery to the user (NOAA). Of the 30 min latency, 5 min is allotted to data processing.

The SNRs in the table above are necessary but not sufficient for observations of large bending angles (BA ~0.1 rad) as found in the lower troposphere (see comments below).

Neither OSCAR nor COURL give any values for RO, so instead we use temperature values for NWP in the high and low troposphere (values are the same for high and low troposphere).
OSCAR Row 65 ID 255 High troposphere
OSCAR Row 67 ID 257 Lower Troposphere

COURL Row 1047 ID 30419: High troposphere temperature profile
COURL Row 1049 ID 30421: Low troposphere temperature profile

Number of soundings per day for OSCAR and COURL corresponds to their horizontal resolution (distance between observation points) values (see note below). TriG is JPL Tri-GNSS receiver used in COSMIC-2.

The SPRWG estimates of number of soundings per day at EXP and ME are conservative compared to the COURL Threshold and OSCAR Breakthrough. The CGMS in its May 2015 meeting adopted the recommendation of the IROWG (International Radio Occultation Working Group) for “at least 20,000 occultations/day to be made available to the operational and research communities of Numerical Weather Prediction, Climate, and Space Weather.” (EUMETSAT, 2015)

The horizontal resolution (mean spacing between profiles) is closely related to the number of soundings per day, but also depends on orbits. For uniformly distributed RO profiles, the horizontal resolution is equal to SQRT(A/N) where A is surface area of Earth (510 x 10^6 sq km) and N is number of profiles per day. Relatively uniform global resolution requires a mix of LEO inclinations.

The quality of RO soundings is important, but difficult to quantify with a few simple metrics. The upper stratosphere and lower troposphere are the regions of maximum errors and uncertainties. In the lower troposphere the signal reduces below noise level in terms of the amplitude. The main error source is thermal noise and a high (2000 V/V) SNR is important to achieve. In the upper stratosphere the signal reduces below the noise level in terms of phase. The main error sources are ionospheric residuals, unmodeled GNSS clock errors, receiver (on LEO) clock errors, attitude instability, and thermal noise. The ionospheric residuals are fundamental and cannot be substantially reduced at GNSS frequencies (higher frequencies would be required). The GNSS clock error is different for different GNSS (e.g. for GPS and GLONASS). It can be reduced by enhanced ground processing. The other three error sources are instrumental, i.e. directly related to receiver and satellite quality and should be minimized.

The SNR attribute values are specified as an average between approximately 40 and 80 km. The SNR cannot be specified in the lower troposphere because the SNR gradually decreases to zero at the surface; the rate of reduction varies and depends on the distribution of water vapor in the troposphere. Bending angle (BA) accuracy is specified for altitude range 30-60 km. Achieving these SNR and BA attribute values at these altitude ranges, as well as an accurate model-aided open-loop tracking with single or multiple correlators that maintains the RO signal in the tracking bands under low-SNR conditions (and thus preserving the SNR), will provide sufficient levels of SNR and BA quality in the upper troposphere/lower stratosphere and the lower troposphere. Additionally, this will allow observations of large BA (~0.1 rad) that indicate super-refraction and are very important for assimilation of the BA in the boundary layer.

Additional requirements for obtaining high-quality RO soundings in the moist lower troposphere include:

- OL tracking depth in terms of HSL (Height of Straight Line). Objective: -350 km or deeper.
- SNR loss due to errors of the Open Loop models at -350 km HSL. Objective: not more than -6dB.

The two objectives above are aimed at detection of the tropospheric ducts, which is important in the assimilation of bending angles in NWP models.

Sources/References supporting this objective and its attributes:

Cardinali, C. and S. Healy, 2014: Impact of GPS radio occultation measurements in the ECMWF system using adjoint-based diagnostics. *Q. J. Roy. Meteor. Soc.*, **140**, 2315-2320. doi:10.1002/qj.2300

EUMETSAT, 2015: Plenary Report of the 43d Meeting of the Coordination Group for Meteorological Satellites, 18-22 May 2015, Boulder, Colorado. P. 23 Available at http://www.cgms-info.org/documents/CGMS-43_plenary_report.pdf

GCOS, 2015: Status of the Global Observing System for Climate, pp. 240-241 [Available online at www.wmo.int/pages/prog/gcos/ as GCOS-195]

Harnisch, F., S. B. Healy, P. Bauer, AND S. J. Englisch, 2013: Scaling of GNSS Radio Occultation Impact with Observation Number Using an Ensemble of Data Assimilations. *Mon. Wea. Rev.*, **141**, p. 4395-4431 DOI: 10.1175/MWR-D-13-00098.1 Found no saturation up to 128,000 soundings/day. 16,000-20,000 soundings/day gave half the impact of 128,000—a “sweet spot.”

Horányi, A., S. Healy. A. von Engeln and A. Yago, 2015: Impact of Different Radio Occultation Constellations on NWP and Climate Monitoring. EUMETSAT Study: EUM/C0/14/4600001312/AvE, 42 pp. Found significant increasing impact at least up to 18,000 soundings per day.

Kaye J., 2016: Vision of the WIGOS Space-Based Component System in 2040. *WMO Consultative Meeting on High-Level Policy on Satellite Matters, Geneva, Switzerland, January 28-29, 2016* (CM-13) Doc. 2, p. 8 [Available online at: http://www.wmo.int/pages/prog/sat/meetings/documents/CM-13_Doc_02_Vision-Space-2040-Draft20160119.pdf]

Meehan, T. and co-authors, 2012: Development status of NASA’s TriG GNSS Science Instrument. Presentation at IROWG-2 Workshop, Estes Park, CO, March 29, 2012. Gave “Threshold” and “Objective” levels of bending angle and refractivity accuracy.

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Sokolovskiy, S., W. Schreiner, Z. Zeng, D. Hunt, Y.-C. Lin, and Y.-H. Kuo (2014), Observation, analysis, and modeling of deep radio occultation signals: Effects of tropospheric ducts and interfering signals, *Radio Sci*., **49**, doi:10.1002/2014RS005436.

WMO, 2009: Vision for Global Observing System in 2025. *Commission on Basic Systems*, 6 pp. [Available online at http://www.wmo.int/pages/prog/sat/documents/SAT-GEN_ST-11-Vision-for-GOS-in-2025.pdf]. This document called for “at least 8 receivers,” but this has been called “not representative” (meaning too conservative) in the draft WMO Vision for 2040 (see WMO (2015) below.)

WMO, 2013: Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP). *WIGOS Tech. Report No. 2013-4*, pp. 71-72. [Available online at: https://www.wmo.int/pages/prog/www/OSY/Publications/EGOS-IP-2025/EGOS-IP-2025-en.pdf] “**Action S21**: Ensure and maintain a radio-occultation constellation of GNSS receivers onboard platforms on different orbits producing at least 10,000 occultations per day (order of magnitude to be refined by the next Action).”

WMO, 2015: ET-SAT input to the Vision of WIGOS Space-Based Components in 2040. (Draft 3, April 14, 2015), pp. 10 and 15. the Global Navigation Satellite Systems (GNSS) radio-occultation (RO) coverage should be increased to ensure a higher number of occultations per day, and their regular distribution around the globe through different orbit inclinations The “number of receivers” mentioned in the Vision-2025 is not a representative indicator (meaning too conservative).

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective A10: Lightning

Priority: #11 in Group A. Moderate importance for NOAA situational awareness operations and no ST capability, so medium level priority for improvement.

Authors: Steve Goodman, Rick Anthes

Brief description: Detection and location of total lightning, both in-cloud as well as cloud-to-ground. The total lightning data is complementary to, and used in combination with, other imagery and radar data that are used in Nowcasting and Very Short Range Forecasting of storm development and intensity. Demonstrated methods to assimilate lightning data into NWP models are similar in framework to the assimilation of precipitation. In data sparse areas not covered well or poorly by radar, such as oceans and complex terrain, lightning combined with imagery-derived cloud properties provides information to inform forecasters and provide enhanced situational awareness and confidence of the probability of high impact convective weather and severe storms.

Use/Users: NWS forecasters at the NCEP national service centers and WFOs in each state, as well as the other federal agency members of the OFCM and private sector. NWS desires to combine GLM with ABI, radar, and ground-based lightning networks--all of which provide complementary information on cloud properties, high impact and severe weather phenomena, fires, and interannual and decadal variations of extreme weather. The satellite-based total lightning is considered more uniform and stable spatially and temporally, yet ground-based lightning detection can better determine individual flash type (in-cloud or cloud-to-ground) and has higher spatial resolution of 1 km or better over most land areas. The forecaster intended use of these data is to combine the space-based and ground-based data into selectable space-time accumulated total lightning grids for blended products and comparisons with other meteorological observations and model output.

Also used as proxy of convective precipitation and information on severe storms and tropical cyclones, Earth’s electric field, and production of NOx.

Program of Record 2025 and current sources of data: Program of Record 2025: Geostationary Lightning Mapper (GLM) on GOES-. Current sources of data EUMETSAT.

Impact of improving from ST to ME level: The impact of improving from ST to ME is to provide a uniform product accuracy (POD>80%, FAR<1%) that is consistent and stable at any point in time and not an average value of the 24-hr day as specified now for the GLM. The stability of the Detection Efficiency for the TRMM LIS has been shown to be <0.7% over the 15-yr mission’s duration. Because ground-based networks have varying POD and FAR as a function of space-time due to the density and location of radio receivers over land areas, the ME level will provide a higher and more uniform lightning product throughout the day and also include regional gaps such as over Alaska. The ME level will also provide a much improved product for blending with radar, satellite and new generation of higher resolution forecast models.

A10: Lightning	*POR 2025 (GOES-R series)*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Latency	20 sec	1 min (None)	30 min	1 min	30 sec	30 sec	20 s to match ABI on GOES-R	30 sec	1 min
Horizontal Resolution (nadir view)	8 km	20 km (None)	15 km	4 km	8 km	3 km	4 km to match EUMETSAT MTG	1 km	4 km
Accuracy (Minimum instantaneous probability of correct detection of flashes over 24 hours)	70% (24 h avg ranging from 60-100% through diurnal cycle)	50% (None)	15%	30%	70%	5 %	80%	1%	1%
Sampling Frequency	2 msec	1 sec (None)	15 min	10 sec	2 msec	5 min	1 msec	30 sec	1 sec
Geographic Coverage	GLM coverage of W Hem from west coast of Africa to N Zealand, 54° N & S (2 full disks)	CONUS (None)	Global	Global	Same as POR 2025 (2 GLM Full Disks)	Global	Same as EXP plus Alaska	Global	Global

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

Accuracy is probability of correct detection of flashes.
Latency: Lockheed is allocated 10 seconds to produce L1B (calibrated and navigated instrument data). They can actually process faster. The L2 (Level 2, environmental parameters) algorithm takes at most 4 seconds. It takes another 4 seconds to move through the NESDIS plumbing. Lightning flash files containing L1B files are transmitted every 20 seconds as they are created. NWS we rounded up to 20 seconds. If user has GOES Rebroadcast (GRB), he/she could get the data as they are produced and transmitted.

OSCAR:
OSCAR units defined in https://www.wmo-sat.info/oscar/variables
ID 747 (Row 493): Total Lightning Density (used in table above). Units for accuracy are different from those in the EVM: "Total number of detected flashes in the corresponding time interval and

the space unit. The space unit (grid box) should be equal to the horizontal resolution and the accumulation time to the observing cycle.” (Although only dimensionless number 15, 5 and 1 are given for the accuracy values, we think the values represent % error.)
Other relevant OSCAR IDs/rows are:
ID 748 (Row 136): Cloud to Ground lightning density

COURL:
ID: 30031 (Row 660): Lightning (this entry used for COURL levels in table above)
Other related IDs/rows are also present.

<u>Sources/References supporting this objective and its attributes:</u>

Albrecht, R., S. Goodman, D. Buechler, R. Blakeslee and H. Christian, 2016: Where are the lightning hotspots on Earth? *Bull. Amer. Meteor. Soc.* (In press; published online February 17, 2016) doi:10.1175/BAMS-D-14-00193.1 [Available online at: http://journals.ametsoc.org/doi/10.1175/BAMS-D-14-00193.1]

Buechler, Dennis E., William J. Koshak, Hugh J. Christian, Steven J. Goodman, Assessing the performance of the Lightning Imaging Sensor (LIS) using Deep Convective Clouds, Atmospheric Research, Volumes 135–136, January 2014, Pages 397-403, ISSN 0169-8095, http://dx.doi.org/10.1016/j.atmosres.2012.09.008.

Gatlin, P. and S. Goodman, 2010: A total lightning trending algorithm to identify severe thunderstorms. *J. Atmos. Oceanic Tech.*, **27**, 3-22.

Goodman, S., R. Blakeslee, W. Koshak, D. Mach, J. Bailey, L. Carey, D. Buechler, C. Schultz, M. Bateman, E. McCaul, and G. Stano, 2013: The GOES-R Geostationary Lightning Mapper. *Atmos. Res.*, **v. 125–126**, May 2013, 34-49. http://dx.doi.org/10.1016/j.atmosres.2013.01.006.

Goodman, S., D. Buechler, K. Knupp, K. Driscoll, and E. McCaul, 2000: The 1997-98 El Nino event and related wintertime lightning variations in the southeastern United States. *Geophys. Res. Lett*., **27**, No. 4, 541-544, Feb. 15, 2000.

McCaul, E., S. Goodman, K. LaCasse, and D. Cecil, 2009: Forecasting Lightning Threat Using Cloud-Resolving Model Simulations. *Wea. Forecasting*, **24**, 709–729.

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Schultz, C., W. Petersen, and L. Carey, 2009: Preliminary development and evaluation of lightning jump algorithms for the real-time detection of severe weather. *J. Appl. Meteor. Climatol.*, **48**, 2543–2563.

Schultz, C. J., W. A. Petersen, and L. D. Carey, 2011: Lightning and severe weather: A comparison between total and cloud-to-ground lightning trends. *Wea. Forecasting*, **26**, 744–755.

Stano, G., C. Schultz, L. Carey, D. MacGorman, and K. Calhoun, 2014: Total lightning observations and tools for the 20 May 2013 Moore, Oklahoma tornadic supercell. *J.*

Operational Meteor., **2**, 7, 71-88, doi: 10.15191/nwajom/ [Available online at: http://www.nwas.org/jom/abstracts/2014/2014-JOM7/abstract.php]

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Zipser, E. J., and K. R. Lutz, 1994: The vertical profile of radar reflectivity of convective cells: A strong indicator of storm intensity and lightning probability? *Mon. Weather Rev.*, **122**, 1751–1759.

Zipser, E., C. Liu, D. Cecil, S. Nesbitt, and D. Yorty, 2006: Where Are the Most Intense Thunderstorms on Earth? *Bull. Am. Meteorol. Soc.*, **87**, 1057–1071, doi:10.1175/BAMS-87-8-1057. [Available online at: http://journals.ametsoc.org/doi/abs/10.1175/BAMS-87-8-1057]

Objective A11: Sea surface height (global)

Priority: #15 in Group A. Used in global ocean models to provide essential configuration and accuracy. Same global ocean models impact missions across the agency. Significant ST level capability in JASON-3 (also JASON-2) implies low priority for improvement.

Authors: Mike Ford, Rick Anthes

Brief description: The measurements made from satellite-based radar altimeters today boast an impressive statistic – covering all but 5% of the ice-free global ocean in 10 days. Looking at the level of the sea surface with great precision allows the identification and measurement of ocean currents and features like El Niño. The determination of sea surface height is important for precise tide estimates, and modeling of ocean circulation. Indices of positions and intensities of ocean currents are valuable information for commercial shipping. Also, they provide information on the heightened or limited exchange of water masses. Shifts in water mass are associated with shifts in temperature, salinity, and nutrient concentration. All of these products – El Nino, tides, ocean circulation, and identification of characteristics of ocean currents, are reasons to include this objective as high-value.

Use/Users: NWS, NOS, NMFS, OAR-NWP, weather and ocean models, hydrology, monthly and seasonal forecasting (e.g. El Niño and La Niña), and climate monitoring. These data support offshore industries, ship routing, and search and rescue. Monitoring of large lakes and rivers useful to hydrologists. On longer time scales, sea-surface height is required to improve understanding of climate and to verify climate models.

Program of Record 2025 and current capability: Program of Record 2025 is JASON-3 equivalent. Current capability includes Ocean Surface Topography Mission (OSTM)/JASON-2 and JASON-3.

Impact of improving from ST to ME level: Increased accuracy, sampling rate and horizontal resolution will allow significantly better monitoring of the short-term variations of sea level height and wave heights, which will be more useful in ocean and weather modeling through assimilation in these models. Faster global coverage will provide much more complete analyses of upper ocean conditions, ocean currents, and interactions between tropical cyclones and the ocean.

A11: Sea surface height (global)	*POR 2025 (Jason 3 Equivalent)*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Horizontal Resolution	18 km	30 km	50 km	10 km	20 km	25 km	10 km	10 km	NA
Accuracy	3.4 cm	3.4 cm	10 cm	2 cm	2 cm	7 cm	1 cm	5 cm	NA
Sampling Rate (global coverage)	Global coverage every 10 days	Every 10 days	3 days	1 day	Every 5 days	1 day	Every day	6 hours	NA

NA: COURL/OSCAR requirement exists but no value given
X: COURL/OSCAR requirement does not exist

Comments and notes:

OSCAR Row 363 ID 472 Sea surface height anomaly

COURL Row 1089 ID 30461 Sea surface height Global NWP (no values specified at Objective level)
COURL also provides other related requirements (IDs).

Current capability: JASON-3. Values in table above are from CEOS Instrument Table. JASON-3 also gives significant wave height (accuracy 0.4 m) and horizontal wind speed (accuracy 1.5 m/s).

The ST level specifies the Jason-3 and Jason-2 configuration in order to maintain the long time series of altimetry so important for detection of intensity of currents and changes in ocean circulation. The Expected level and the ME levels increase the accuracy and the spatial resolution and decrease the time required to complete global coverage. This ramping places some pressure on the architecture to provide global coverage in half the time and with twice the spatial resolution. However, since the timeframe is 2030 and beyond, this seems an acceptable goal for this first cycle of architectural simulation. The ME level in particular has a demand that is 10 times the speed to cover the globe, with four times more precision, and at the higher end of spatial resolution. The results of the architectural study will indicate whether the ME level is too ambitious.

Sources/References supporting this objective and its attributes:

COMET Module: Jason-2: Using Satellite Altimetry to Monitor the Ocean This module provides an excellent summary of Jason-2 and how ocean altimetry data are used for operational and research purposes.

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http://www.ospo.noaa.gov/Products/ocean/ssheight.html

http://sealevel.jpl.nasa.gov/
http://www.oceanobs09.net/work/oo99/docs/Mitchum.pdf

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective: A12: Ocean surface vector winds (OSVW)

Priority: #7 in Group A. Important in NWP, but significant ST level capability implies medium priority for improvement.

Authors: Bob Atlas, Chris Velden, James Yoe, Rick Anthes

Brief description: Accurate observations of ocean surface wind direction and speed are needed for tropical weather and marine forecasting, and to drive ocean and surface wave models, and provide initial conditions for NWP models (Atlas et al 1996, 2001, 2011; Chang et al., 2009; Brennan et al., 2009).

Use/Users: NWP, NHC, OPC, marine applications.

Program of Record 2025 and current sources of data: Program of Record 2025 is the SCA scatterometer (EUMETSAT 2 EPS SG). Current capability includes ASCAT (on MetOp, 0930 orbit), RAPIDSCAT (on ISS); JASON-3; OceanSat-3 (India) to be launched 2018.

Impact of improving from the ST to ME level: Improved horizontal resolution, update rate and reduced latency will provide important data for research on air sea interaction, high resolution weather and ocean model development, operational marine weather and wave forecasting and in providing improved initial conditions for operational numerical weather prediction (NWP). Based on earlier observing system experiments (OSE and OSSE), the impact on NWP is expected to be modest, while the impact on tropical analysis and marine forecasting should be substantial.

A12: Ocean surface vector wind (OSVW)	*POR 2025 (SCA scatterometer EUMETSAT 2 EPS SG)*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Latency	165 min	165 min	2 hours	NA	45 min	15 min	15 min	15 min	NA
Horizontal Resolution	25 km	50 km	20 km	10 km	25 km	5 km	1 km	0.5 km	1 km
Accuracy Direction Speed	 20 deg 2 m/s	 30 deg 2 m/s (or 10%)	 NA 3 m/s	 10 deg 0.5 m/s	 20 deg 1.5 m/s (or 10%)	 NA 1 m/s	 10 deg 0.5 m/s (or 10%)	 NA 0.5 m/s	 NA 0.5 m/s

Average update time (revisit rate) in ocean areas gaps acceptable	24 hours	24 hours	3 hours	1 hour	12 hours	60 min	1 hour	30 min	1 hour

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

ASCAT (MetOp): Global coverage, but banded gaps between swaths of coverage.
ASCAT accuracy 0.57 dB

There is a difference between average and maximum update rates—average given here.
Significant current and ST capability.

OSCAR values:
While multiple rows may be used, for table above the values from the following row are used:
ID: 389 (Row 564): Wind speed over the surface (horizontal) (High Res NWP)

COURL values:
Requirement ID #:
ID 10069 (Row 77): Wind Direction, Offshore
ID 10070 (Row 78): Wind Speed, Offshore
Related objectives appear in other rows.

Sources/References supporting this objective and its attributes:

Atlas, R., R.N. Hoffman, S.C. Bloom, J.C. Jusem, and J. Ardizzone, 1996: A multiyear global surface wind velocity dataset using SSM/I wind observations. *Bulletin of the American Meteorological Society*, 77 (5), 869-882.

Atlas, R., R.N. Hoffman, S.M. Leidner, J. Sienkiewicz, T.-W. Yu, S.C. Bloom, E. Brin, J. Ardizzone, J. Terry, D. Bungato, and J.C. Jusem, 2001: The effects of marine winds from scatterometer data on weather analysis and forecasting. *Bulletin of the American Meteorological Society*, 82 (9), 1965-1990.

Atlas, R., R.N. Hoffman, J. Ardizzone, S.M. Leidner, J.C. Jusem, D.K. Smith, and D. Gombos, 2011: A cross-calibrated, multi-platform ocean surface wind velocity product for meteorological and oceanographic applications. *Bulletin of the American Meteorological Society,* 92 (2),157-174.

Bi et al., 2010: Impact of METOP ASCAT Ocean Surface Winds in the NCEP GDAS/GFS and NRL NAVDAS COAMPS. Presentation at 10th International Winds Workshop, Tokyo, Japan 22-26 February 2010 (Presentation and paper available on SPRWG shared drive)

Brennan, M.J., C.C. Hennon, and R.D. Knabb, 2009: The operational use of QuikSCAT ocean surface vector winds at the National Hurricane Center. *Weather and Forecasting,* 24(3):621-645 (doi:10.1175/2008WAF2222188.1).

Chang, P.S., Z. Jelenak, J.M. Sienkiewicz, R. Knabb, M.J. Brennan, D.G Long, and M. Freeberg, 2009: Operational use and impact of satellite remotely sensed ocean surface vector winds in the marine warning and forecasting environment. *Oceanography*, 22(2):194-207 (doi:10.5670/oceanog.2009.49).

Isaksen, Lars and Peter A.E.M. Janssen, 2004: Impact of ERS scatterometer winds in ECMWF's assimilation system. Q. J. R. Meteorol. Soc., 130, pp. 1793–1814 doi: 10.1256/qj.03.110

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WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

http://www.nesdis.noaa.gov/jason-3/press.html Press release saying JASON-3 measures ocean surface winds.

http://www.opc.ncep.noaa.gov/articles/quikscat.shtml

http://science.nasa.gov/earth-science/oceanography/physical-ocean/winds/

Objective A13: 3-D winds (Horizontal wind in troposphere)

Priority: #1 in Group A. This objective is essentially the "Holy Grail" of NWP, and not well provided now, as shown by Baker et al. (1995, 2014); Atlas (1997); Atlas et al (2015 a,b); Ma et al. (2015); and Riishojgaard et al. (2012). Very important to provide above ST level of None, thus the top priority for improvement in Group A

Authors: Bob Atlas, Chris Velden, James Yoe, Rick Anthes

Brief description: Global wind profiles (horizontal components) from tropopause down to near-surface.

Use/Users: NWP, Nowcasting and Very Short-Range Forecasting, Aviation

Program of Record 2025 and current sources of data: Program of Record 2025 is Atmospheric Motion Vectors (AMV) from ABI. Geostationary satellite imagers (AMVs) provide some information on winds, but these are constrained to cloud tops and moisture gradients and are not wind profiles. Even so, they have a large positive impact on NWP, indicating true profiles would have a much greater impact (also supported by OSSEs).

Impact of improving from ST to ME level: Extensive Observing System Experiments (both OSE and OSSE) have demonstrated that improving from ST to ME level would lead to meaningful improvement in numerical weather prediction forecast accuracy in both northern and southern hemisphere mid-latitudes, and significant improvement in the tropics (See references below, especially Riishojgaard et al., 2012 and Atlas et al., 2015b.) This impact would be larger than for any other space-based observing system, and would allow for reductions in some of the observing systems currently being used. New OSSEs would be required to determine what reductions are possible.

A13: 3D Winds (Horizontal wind in troposphere) Global coverage, gaps acceptable (like OSVW)	*POR 2025 (None, some provided by AMV from ABI)*	*ST (none, values given for scoring)*	*Oscar Speed Threshold*	*COURL Threshold*	*EXP*	*OSCAR Speed Breakthrough*	*ME*	*OSCAR Speed Goal*	*COURL Objective*
Latency	60 min	165 min	6 hours	0.5 hours	60 min	6 min	30 min	6 min	30 min
Horizontal Resolution	40 km	400 km	500 km	100 km	250 km	100 km	15 km	15 km	15 km
Vertical Resolution		4 km	3 km	1 km	2 km	1 km	0.5 km	500 m	500 m
Accuracy Direction Speed		30 deg or 20% 10 m/s	NA 8 m/s	10 deg 3 m/s	20 deg or 10% 3 m/s or 10%	NA 3 m/s	10 deg or 10% 2 m/s or 10%	NA 1 m/s	10 deg 1 m/s
Update Rate (average)	24 hours	24 hours	12 hours	6 hours	12 hours	6 hours	3 hours	1 hour	1 hour
Number of Stripes (continuous, fore and aft looks)	0	0	X	X	4	X	12	X	X

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

Latency: The latency for doppler wind lidar (time from observation to the user) that is possible now from space is 30 minutes. This includes the processing time and is currently being proposed under NASA's EVI missions. Almost no time is required for data processing. The requirement is for the Level 2 line of sight data to arrive at the NWP centers in BUFR format within 30 min. The data would be ready for assimilation. This could happen after the instrument is fully calibrated."

OSCAR Row 534 ID 311 Wind (horizontal) high troposphere

COURL Row 682 ID 30053 Wind Dir profiles global
Row 688 ID 30059 wind speed profiles global
Other COURL ID/rows have related requirements (IDs).

Average update rate is much longer than maximum update rate.

Number of stripes (continuous, fore and aft looks), assumes lidar solution. MISTiC (https://www.wmo-sat.info/oscar/satellites/view/692) like solutions should also be considered, in which case this column can be ignored.
https://esto.nasa.gov/forum/estf2014/presentations/B6P3_Maschhoff.pdf

Sources/References supporting this objective and its attributes:

Atlas, R., 1997: Atmospheric observations and experiments to assess their usefulness in data assimilation. *J. Meteor. Soc. Japan*, 75 (1B), 111–130.

Atlas, R., L. Bucci, B. Annane, R. Hoffman, and S. Murillo, 2015a: Observing system simulation experiments to assess the potential impact of new observing systems on hurricane forecasting. *Marine Technology Society Journal*, 49 (6), 140–148, doi:10.4031/MTSJ.49.6.3. Special issue, Evolution of Marine Technologies: Commemorating the 50th Anniversary of the MTS Journal, guest edited by Donna Kocak.

Atlas, R., et al., 2015b: Observing system simulation experiments (OSSEs) to evaluate the potential impact of an optical autocovariance wind lidar (OAWL) on numerical weather prediction. *J. Atmos. Oceanic Technol.*, 32 (9), 1593–1613, doi:10.1175/JTECH-D-15-0038.1.

Baker, W. E., et al., 1995: Lidar-measured winds from space: A key component for weather and climate prediction. *Bull. Amer. Meteor. Soc.*, 76 (6), 869–888.

Baker, W. E., et al., 2014: Lidar-measured wind profiles: The missing link in the global observing system. *Bull. Amer. Meteor. Soc.*, 95 (4), 543–564, doi:10.1175/bams-d-12-00164.1.

Borde, R., Hautecoeur, O., Carranza, M., 2016. EUMETSAT Global AVHRR Wind Product. *J. Atmos. Ocean. Tech.*, In press. http://dx.doi.org/ 10.1175/JTECH-D-15-0155.1

Ma, Z., L. P. Riishojgaard, M. Masutani, J. S. Woollen, and G. D. Emmitt, 2015: Impact of different satellite wind lidar telescope configurations on NCEP GFS forecast skill in observing system simulation experiments. *J. Atmos. Oceanic Technol.*, 32 (3), 478–495, doi:10.1175/jtech-d-14-00057.1.

Riishojgaard, L. P., Z. Ma, M. Masutani, J. S. Woollen, G. D. Emmitt, S. A. Wood, and S. Greco, 2012: Observation system simulation experiments for a global wind observing sounder. *Geophys.*

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

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Objective A14: Ozone - global vertical profiles in troposphere and stratosphere and total column

Priority: #17 in Group A. Significant capability at the ST level, and medium priority for NOAA operations, thus a low priority for improvement.

Authors: Rick Anthes

Brief description: Global vertical profiles of ozone (low vertical resolution) and total vertical column ozone.

Use/Users: NWS (assimilated in NWP models, improves temperatures and winds). Also used in chemical weather forecasts and analyses. NOAA ESRL (Chemical Science Division, Global Monitoring Division), CPC, NCDC. NWS. NOAA measures ozone quantities in the atmosphere as part of the international agreement known as the "Montreal Protocol on Substances that Deplete the Ozone Layer."

Program of Record 2025 and current sources of data: Program of Record 2025 is JPSS (OMPS) and IASI (2 EUMETSAT EPS-SG). Current capability includes GOME-2, AURA (AIRS, TES) (Also: SBUV/2 on NOAA-14, NOAA-16).

Impact of improving from ST to ME level: Improved horizontal resolution and sampling frequency would produce a modest improvement in NWP forecasts and forecasts of chemical weather.

A14: Ozone – Global vertical profiles in troposphere and stratosphere and total column	*POR 2025 JPSS (OMPS) and IASI (2 EUMETSAT EPS-SG)*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Vertical Resolution 5 km	~3 km (OMPS limb profiler)	NA	10 km	10 km	NA	2.2 km	NA	1 km	NA
Horizontal Resolution	~250 km	250 km	250 km	250 km	100 km	100 km	50 km	15 km	NA
Accuracy	10% or 0.1 ppmv, whichever is greater	15%	20%	10%	10%	10%	5%	5%	NA
Sampling Frequency	Daily (24 h)	24 h	12 h	12 h	12 h	6 h	6 h	1 h	NA
Total Column									
Accuracy	10 DU	10 DU	20 DU	10 DU	8 DU	10 DU	5 DU	5 DU	NA

Horizontal Resolution	25 km	50 km	250 km	250 km	20 km	100 km	15 km	15 km	NA
Sampling Frequency	12 h	24 h	12 h	12 h	12 h	6 h	6 h	1 h	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

Vertical resolution for OMPS Limb is 2-3 km.
Typical values of total column ozone are 250-350 Dobson Units (DU).

COURL values given for troposphere/stratosphere for global NWP (Rows 1068-1070, IDs 30440-30442) and total column for global NWP (Row 1072 ID 3044) at Threshold level only (no values given for Objective level).

OSCAR gives values for high troposphere, lower stratosphere and lower troposphere (Rows 281-283, IDs 283-285) and these are all the same (values entered here) and total column for global NWP (Row 294 ID 286). OSCAR gives other related values as well.

Sources/References supporting this objective and its attributes:

Boynard, A. and Coauthors, 2009: Measurements of total and tropospheric ozone from IASI: comparison with correlative satellite, ground-based and ozonesonde observations Atmos. Chem. Phys., 9, 6255-6271. doi:10.5194/acp-9-6255-2009 [Available online at: http://www.atmos-chem-phys.net/9/6255/2009/]

Boynard, A. and Coauthors, 2016: Seven years of IASI ozone retrievals from FORLI: validation with independent total column and vertical profile measurements. Atmos. Meas, Tech., 9, 4327-4353. doi:10.5194/amt-9-4327-2016 Available online at: www.atmos-meas-tech.net/9/4327/2016/

Eskes, H., 2004: Stratospheric ozone: satellite observations, data assimilation and satellite observations, data assimilation and forecasts. ESA Summer School *2004*. Available online at https://earth.esa.int/documents/973910/987578/he2_eskes.pdf

Flynn and Co-authors, 2014: Performance of the Ozone Mapping and Profiler Suite (OMPS) products. *J. Geophys. Res. Atmos.*, 119, 6181-6195, doi:10.1002/2013JD020467.

Myhre, G. and Coauthors, 2013: Anthropogenic and natural radiative forcing. In: Stocker, T.F., Qin, D., Plattner, G.-K., et al. (Eds.), Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, xx pp.

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WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

There are many web sites on measuring ozone from satellites; here are a few:

http://disc.gsfc.nasa.gov/uui/datasets/SBUV2N16L2_V1/summary

http://rammb.cira.colostate.edu/dev/hillger/ozone-monitoring.htm

http://www.ospo.noaa.gov/Products/atmosphere/ozone.html

Objective A15: Microwave imagery

Priority: #10 in Group A. This objective has a relatively high ST level due to the existence of many different microwave sensors, thus the medium priority for improvement.

Authors: Jerry Dittberner, Chris Velden, Chris Kummerow, Rick Anthes

Brief description: Multispectral passive microwave imagery provides observations of tropospheric moisture and ice hydrometeors, even in areas that are persistently cloud-covered, allowing views of meteorological features that cannot be seen with VIS/IR satellite sensors (e.g., hurricane rain bands and eyewalls). In this objective (A15) we are distinguishing microwave imagers from microwave sounders (which are the focus of objective A7). We define MW imagers here as primarily viewing the surface and the atmospheric column, and generally with the historical distinction that imagers are conically scanning while sounders are cross-track scanning. Microwave imagery provides information on precipitation and clouds, the intensity and position of tropical cyclones, and to denote atmospheric rivers. Other applications include the observation of surface characteristics such as ocean surface winds, sea and lake ice concentration and motion, as well as soil moisture.

Use/Users: NOAA NWS, NHC, CPHC, NOS, JTWC

Program of Record 2025 and Current sources of data: Program of Record 2025: Microwave Imager (MWI) on EUMETSAT (one EPS-SG-B satellite). Current capability (2016) includes SSMIS on the DMSP morning orbit, AMSR2 in the afternoon, GMI on GPM, and ATMS on JPSS.

Impact of improving from ST to ME level:
There are very significant impacts of moving from the Study Threshold (ST) level to the Expected level and additional impact when moving from the Expected level to the Maximum Effective (ME) level. Increased ground resolution will improve feature detection which is important for deriving geophysical parameters such as precipitation or sea ice that can vary over small spatial scales. Lower data latency will lead to increasingly accurate NWP forecasts due to the earlier availability of data ahead of assimilation cycles and as computer systems capabilities

evolve in 2030 to 2050 and beyond. At the ST level, sensing channels are comparable with older SSMIS systems. At the Expected level, added channels are comparable to more recent AMSR2 systems. At ME, the added 157 and 183 GHz channels incorporate the successes of the more recently launched GPM Microwave Imager (GMI). This will factor in additional water vapor profile measurement capabilities that will greatly improve the monitoring and nowcasting of impactful environmental events (e.g., tropical cyclones, hurricane rain bands, hurricane intensity, flooding, landslides, sea/lake concentration and motion, soil moisture, atmospheric water vapor and winter weather).

A15: Microwave Imagery – Derived products sea/lake ice concentration and motion, rain rate, water vapor, cloud liquid water, SST	*POR 2025 MWI (microwave imager) EUMETSAT (1 EPS-SG-B satellite)*	*ST*	*Oscar Threshold (ID 430)*	*COURL Threshold*	*EXP*	*OSCAR Break-through (ID 430)*	*ME*	*OSCAR Goal (ID 430)*	*COURL Objective*
Ground-projected instantaneous field of view (GIFOV) for 90 GHz	10 km	14 km (SSMIS)	20 km (H resolution)	10 km (H resolution)	5 km (AMSR2)	5 km (H resolution)	4 km (GMI)	1 km (H resol)	NA
Latency	45 min	165 min	30 min	NA	45 min	1 min	15 min	1 min	NA
Frequency (low)	MWI=18.7 GHz (both polarizations)	19 GHz	X	X	7.0 GHz	X	6.9 GHz	X	X
Frequency (high)	MWI=183 GHz (one polarization); 89 (both polarizations)	88 GHz	X	X	180 GHz	X	183 GHz	X	X
Number of Bands	MWI has 18 freq grouped into 8 bands	4	X	X	6	X	8	X	X
Radiometric Sensitivity (NeDT)	0.8K (89 GHz frequency)	0.8K (89 GHz)	X	1K	0.4K	X	0.1K	X	NA
Sampling Frequency (average)	12 hours	12 hours	60 min	1 h	3 hours	3 min	30 min	30 s	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

GIFOV (Ground-projected instantaneous field of view) GIFOV is called "horizontal resolution" in COURL. Also sometimes called Ground Sampling Distance (GSD). See SPRWG report for details. GIFOV given for 90 GHz; GIFOV for other frequencies follows from GIFOV for 90 GHz.

MW imagery is provided by conical scanning MW radiometers. (In contrast, MW soundings (in A7) are provided by cross-track scanning MW radiometers.)

Detailed information on the MicroWave Imager (MWI) on EPS-SG-B, scheduled to be launched in 2022, is provided by https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg

MWI has 18 frequencies grouped into 8 bands.

NeDT ranges from 0.6K to 1.2 K depending on frequency

OSCAR also provides information on MWI: OSCAR info on MWI
https://www.wmo-sat.info/oscar/instruments/view/683

OSCAR does not provide performance attributes for MW imagery in general; it provides values for products derived from MW imagery such as surface temperature, soil moisture, cloud cover, sea ice cover, etc. Here we use values from OSCAR ID 430 (Row 103) Cloud cover for Nowcasting lower troposphere.

The COURL provides several observation requirements that contain MW imagery. Some give accuracy as navigational accuracy in km; others give accuracy in terms of radiances. Examples are:

Row 603 ID 20249: NOS, microwave imagery for oil spills
Row 709 ID 30080; Imagery: MW, NWS-WRN Marine/Surface Analysis
Row 710 ID 30081; Imagery: MW, Storm Area/Tropical Cyclones
Row 1024 ID 30396; Imagery: MW
Row 1083 ID 30455 MW radiances, Global and high res NWP

In table above we use values from ID 30081 Tropical Cyclones storm area.

Sources/References supporting this objective and its attributes:

Al-Yaari, A., Wigneron, J.-P., Ducharne, A., et al., 2014. Global-scale evaluation of two satellite-based passive microwave soil moisture datasets (SMOS and AMSR-E) with respect to land data assimilation system estimates. *Remote Sens. Environ*. **149**, 181–195. http://dx.doi.org/10.1016/j.rse.2014.04.006.

Ardanuy, P. E., and Coauthors, 2015: Optimizing Requirements for the Next Generation of Satellite Observing Systems. *Proc. 2015 EUMETSAT Met. Satellite Conf.*, Toulouse, France, September 21-25, 2015.

English, S., and Coauthors, 2013: Impact of satellite data. ECMWF Tech. Memo 711, 48 pp. [Available online at http://www.ecmwf.int/en/elibrary/9301-impact-satellite-data]

Hollmann, R., and Coauthors, 2013: The ESA Climate Change Initiative: Satellite Data Records for Essential Climate Variables. *Bull. Amer. Meteor. Soc.*, **94**, 1541- 1552, doi: 10.1175/BAMS- D- 11- 00254.1.

Munoz-Sabater, J., 2015. Incorporation of passive microwave brightness temperatures in the ECMWF soil moisture analysis. Remote Sens. 7, 5758–5784. http://dx.doi.org/10.3390/rs70505758.

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Randa, J. and Coauthors, 2008: Recommended Terminology for Microwave Radiometry. NIST Technical Note 1551, 32 pp.

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.
Information on MWI: https://www.wmo-sat.info/oscar/instruments/view/683

http://www.wmo-sat.info/oscar/instrumenttypes/view/4
information on microwave imaging radiometer, conical scanning, and its uses

http://www.wmo-sat.info/oscar/instrumenttypes/view/3
information on cross-track scanning MW sounding instruments (used for producing atmospheric soundings)

Objective A16: Outgoing Longwave Radiation (OLR)

Priority: #18 in Group A. Fairly low priority for NOAA operational purposes. Significant sources for ST level, so low priority for improvement.

Authors: Tom Vonderhaar, Steve Ackerman, Rick Anthes

Brief description: Outgoing Longwave Radiation (OLR) is the infrared radiation emitted at the top of Earth's atmosphere. It is a broadband energy with most of the energy in the 4 µm and 100 µm spectral range. OLR is determined from radiation budget instruments or derived from spectral measurements.

Use/Users: Used by CPC. Assessment of model simulations is done by comparing simulated global and regional means of OLR and anomaly time series of OLR with satellite measurements. OLR is also used to identify areas of deep tropical convection to correlate with various climate indices. OLR is primarily a benefit for seasonal and climate forecasting and monitoring, but it is also used in NWP.

Program of Record 2025 and Current sources of data: Program of Record is CrIS, IASI, CERES and RBI on JPSS. Other current capabilities include AIRS, CERES on NASA missions, and ABI on JPSS.

Impact of improving from ST to ME level: Higher accuracy and horizontal resolution and lower latency will enable improved determination of Earth's radiation budget and tighter constraint in NWP and climate models. The ME level improves understanding of the variability of Earth's energy imbalance for NOAA's climate and ocean energy studies.

A16:Outgoing Longwave Radiation (OLR)	*POR 2025 CrIS, IASI, CERES and RBI on JPSS*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Accuracy	5 W/m2	5 W/m2	20 W/m2	3.0 W/m2	1.0 W/m2	10 W/m2	0.5 W/m2	5 W/m2	1 W/m2
Sampling Frequency	6 hours	720 hours (monthly)	12 h	1 h	24 hours (daily)	3 h	6 hours	1 h	NA
Horizontal Resolution	14 km	500 km	100 km	100 km	250 km	30 km	25 km	10 km	NA
Latency	2 hours	720 hours (monthly)	30 days	6 h	24 hours (daily)	24 h	6 hours	24 h	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

OSCAR Row 498 ID 307 Upward long-wave irradiance at TOA (Global NWP) used in above table. Also
ID 116 Row 502 Upward long-wave irradiance at TOA (Climate-AOPC)
ID 382 Row 499 Upward long-wave irradiance at TOA (High resol NWP)
ID 409 Row 500 Upward long-wave irradiance at TOA (Hydrology)
ID 633 Row 501 Upward long-wave irradiance at TOA (SPARC)

COURL Row 1265 ID 40142 Outgoing longwave radiation at top of atmosphere

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA)

Kiehl, J. and K. Trenberth, 1997: “Earth's Annual Global Mean Energy Budget.” *Bull. Amer. Meteor. Soc.*, **78**, 197–208.

Susskind, J., G. Molnar, and L. Iredell, 2011: “Contributions to Climate Research Using the AIRS Science Team Version-5 Products.” *Proc. SPIE*, **8154**, Infrared Remote Sensing and Instrumentation XIX (17 September 2011) doi: 10.1117/12.893576 [Available online at: http://spie.org/Publications/Proceedings/Paper/10.1117/12.893576]

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Xie S.P., Y. Kosaka and Y. Okumura, 2016: Distinct energy budgets for anthropogenic and natural changes during global warming hiatus. *Nature Geoscience*, **9**, 29-33. doi:

10.1038/ngeo2581 Available online at:
http://www.nature.com/ngeo/journal/v9/n1/abs/ngeo2581.html

Objective A17: Incoming solar radiation (TOA). Full solar disk.

Priority: #19 in Group A. Fairly low priority for NOAA operational purposes. Significant sources of data at ST level means that this is a low priority for improvement.

Authors: Steve Ackerman, Tom Vonderhaar, Rick Anthes

Brief description: The total amount of incoming radiative energy from the sun received at the top of Earth's atmosphere, or TOA. It is the direct energy input into the Earth system, and is needed to understand climate and climate change. Accuracy of 0.1-0.3% is needed for studying long term trends of solar energy at Earth and variations of solar cycles.

Use/Users: Incoming solar radiation is used for computing the downwelling solar radiation at the surface, and is thus needed for weather forecasting and studies of climate, agriculture, boundary layer models and the solar energy industry. Knowledge is needed to compute energy fluxes in the atmosphere and at the surface.

Program of Record 2025 and Current sources of data: TSIS on SIDAR (to launch in 2017) continues NASA SORCE, CERES and RBI on JPSS. NASA assumed to be provider of this objective in POR 2025.

Impact of improving from ST to ME level: Higher accuracy and horizontal resolution and lower latency will enable improved determination of Earth's radiation budget and improved input into NWP and climate models, resulting in modestly improved long-range and seasonal forecasts.

A17:Incoming solar radiation (TOA) – Full solar disk	*POR 2025 TSIS capability assumed to be provided by NASA (in NASA POR)*	*ST None required; values for scoring only*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Accuracy	TSIS 100 ppm (0.01%)	2 W/m2	2 W/m2	1 W/m2	1.0 W/m2	1.3 W/m2	0.5 W/m2	1 W/m2	NA
Sampling Frequency	NA	Monthly	6 days	24 h	Weekly	4 days	Daily	3 days	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

<u>Comments and notes:</u>

Accuracy of 0.1 to 0.3% needed for annual trends.
Latency not important.

The following entry used is for OSCAR levels in table above:
OSCAR Row 184 (ID 94): Downward shortwave irradiance at TOA (Climate-AOPC) used in table above.
Other similar ID in OSCAR: Row 185 ID 230: Downward shortwave irradiance at TOA (Climate Modeling Research)

COURL Row 1261 (ID 40138): Radiation: Incoming Solar: Top of the Atmosphere (TOA) is used in above table. COURL is missing entries for "Objective" level.

Sources/References supporting this objective and its attributes:

Kopp, G. and J. Lean, 2011: A new, lower value of total solar irradiance: Evidence and climate significance. *Geophys. Res. Lett.*, **38**, L01706, doi:10.1029/2010GL045777 [Available online at: http://onlinelibrary.wiley.com/doi/10.1029/2010GL045777/abstract]

Lean, J., 1991: Variations in the Sun's radiative output, *Reviews of Geophysics*, **29**, 4, pp 505-535.

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WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective A18: Radar-based global precipitation rate

Priority: #12 in Group A. The medium-level priority for NOAA operational missions, as well as significant ST level capabilities from other objectives, makes this a low/medium priority for improvement.

Authors: Chris Kummerow, Rick Anthes

Brief description: Estimation of precipitation rates globally with active radar.

Use/Users: Radars in space, while providing some sampling, act primarily as accurate calibration references for less direct measurements of precipitation from passive microwave and infrared sensors. Users of composite rainfall products are operational forecasters, hydrologists, emergency managers, assimilation in numerical models, and climate monitoring.

Program of Record 2025 and current sources of data (including non-satellite): Program of Record 2025 is None. Current capability for precipitation rates in general includes rain gauges, radars, GPM (global), Passive Microwave Imagers, geostationary IR data from ABI (GOES-16, CONUS and adjacent regions), as well as partner agencies.

Impact of improving from ST to ME level: There is currently no requirement for an active radar system in space. Algorithms from passive microwave and geostationary IR can be calibrated against surface radar data over the US. The Expected level, which is consistent with GPM, and the ME level, which is consistent with GPM but with slightly better FOVs to reduce uncertainties due to rainfall inhomogeneities, as well greater sensitivity to address lighter rain rates common at high latitudes as well as frozen precipitation (e.g. snow) will allow the calibration to be performed on a global basis needed to achieve the accuracy listed in the table.

A18: Radar-based global precipitation rate	*POR 2025 (Not assuming continuity of GPM sensors)*	*ST (None required, values for scoring only)*	*Oscar Threshold (ID 30033)*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Minimum Detectable Rate	None	1 mm/hour	X	X	0.2 mm/h (GPM)	X	0.1 mm/h	X	X
Accuracy	None	20%	1 mm/h	1 mm/h	10%	0.5 mm/h	5%	0.1 mm/h	1 mm/h
Horizontal Resolution	None	10 km	50 km	15 km	5 km at nadir (DPR)	15 km	3 km at nadir	5 km	5 km
Latency	None	6 h	6 h	3 min	3 h for each orbit	6 min	1.5 h for each orbit	6 min	3 min
Update Rate	None	30 days	12 h	3 h	~9 days	3 h	1 day	1 h	1 h

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

Current capability (GPM Dual-frequency radars) given in CEOS (2014) p.27.
OSCAR Row 344 ID 289: Precipitation intensity at surface (liquid or solid) for global NWP.
COURL Row 662 ID 30033 Precipitation Rate Global.

An overview article on GPM is given by Hou et al. (2014)

There is no single source of precipitation data that meets all user requirements. Gauges are considered accurate and useful for climate monitoring, but are spatially inhomogeneous and therefore useful primarily for droughts and hydrology of large catchments. When radars are added, and data is properly merged, real-time data become useful for forecasters warnings of extreme events, NWP such as the HRRR hourly data assimilation cycle, and hydrology on small basins. Products are available over CONUS except mountainous terrain where gauges are sparse and radar beams are blocked.

Satellite observations try to mimic merged surface products in accuracy and resolution. GPM radars are very accurate with 5 km spatial resolution but poor temporal coverage (e.g. 72 hr revisit). GPM radiometers (SSMIS in addition to sounders from NOAA, EUMETSAT, and instruments of opportunity) are trained by the radars, but are less accurate. Their spatial resolution is 5-15 km (depending on sensor) but revisit time is roughly 2-3 hrs. Data is available with 1-3 hour delay. ABI and partner geostationary satellites (EUMETSAT and JMA) provide global 30 minute IR data. These are trained to the radiometer constellation in GPM as well as other state-of-the art programs (e.g. NOAA's CMORPH, JMA's GSMAP). Global products are usually released within 3 h but more timely information is also possible. Over the GOES coverage area, a separate Vis/IR based product is available. It is calibrated by ground based radars or microwave radiometers also.

Historically, this cascade of products, whether surface- or space-based, is ignored and requirements and capabilities are written without regard to the data source. Here, we use the GPM radars product and GPM composite products of geostationary IR plus trained microwave (when available) as the baselines to make explicit that radars play a role but are not the sole source of precipitation data being used operationally today.

The radars are maintained separately in order to highlight their role in applications such as the precise climate monitoring capabilities or their assimilation into global models when only the highest quality products are needed. (See: http://www.nasa.gov/mission_pages/GPM/spacecraft/index.html)

Sources/References

CEOS, 2015: The Earth Observation Handbook 2015 Key Tables (updated Dec. 2014) and associated on line references:
*http://database.eohandbook.com*http://database.eohandbook.com
http://database.eohandbook.com/database/missiontable.aspx

Hou, A.Y., R.K. Kakar, S. Neeck, A.A. Azarbarzin, C.D. Kummerow, M. Kojima, R. Oki, K. Nakamura and T. Iguchi, 2014: The Global Precipitation Mission. Bull. Amer. Meteor. Soc. May 2014, p. 701-722 DOI:10.1175/BAMS-D-13-00164.1

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WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective A19: Global soundings of chemical concentrations,

Priority: #16 in Group A. Low priority for NOAA operations, but ST level of "None" increases the priority for improvement.

Authors: Steve Ackerman, Rick Anthes

Brief description: Various gaseous trace species in the atmosphere are important parameters in air quality and atmospheric chemistry. These chemical species include nitric acid (HNO_3); a component in the photochemistry of stratospheric ozone destruction through its role in the formation of polar stratospheric clouds (PSCs). Column observations of HNO_3 in tropical troposphere have been measured with IASI (Infrared Atmospheric Sounding Interferometer). Peroxyacetyl nitrate (PAN, $CH_3CO\text{-}O_2NO_2$) concentrations have been derived from the Aura Tropospheric Emission Spectrometer (TES). PAN is a trace gas in the troposphere and lower stratosphere due primarily to pollution from fuel combustion and from biomass burning. Nitrogen Oxides (NOx) observations are essential for air pollution quantification and mitigation. Dominant anthropogenic sources of NOx include combustion processes in the transportation, industrial, and residential sector and emissions from power plants. Methane is a greenhouse gas emitted by a range of natural and anthropogenic sources.

Use/Users: NWS (working with EPA) air quality forecasts, OAR, climate monitoring and research.

Program of Record 2025 and current sources of data: Program of Record 2025 is CrIS (JPSS), IASI -NG (EUMETSAT), Sentinel 4 & 5. Current capability also includes GOME, GOME-2, OMI, OMPS, AIRS, GOSAT (Greenhouse gases Observing Satellite).

"Physical retrievals from AIRS data include: water vapor, temperature, relative humidity, carbon dioxide, carbon monoxide, cloud properties, methane, outgoing longwave radiation, ozone, surface properties, tropopause, geopotential height, planetary boundary layer, and flag values for dust and sulfur dioxide." http://airs.jpl.nasa.gov/

OMI measures key air quality atmospheric components such as NO2, SO2, BrO, OClO, and aerosol characteristics. http://www.nasa.gov/mission_pages/aura/spacecraft/index.html

TES measurements of NOy, CO, O3, and H2O for use in the determination of the global distribution of OH, an oxidant of central importance in tropospheric chemistry. http://www.nasa.gov/mission_pages/aura/spacecraft/index.html

GOSAT measures methane (CH4), a potent climate forcer and important for atmospheric chemistry (e.g., tropospheric formation of ozone).

Impact of improving from ST to ME level:
Improving from ST to ME will provide the observational coverage needed to understand the changing composition of the atmosphere as well as improving chemical weather forecasts and air quality models. Remote sensing of trace gases from satellite instruments supports the monitoring of the detection and changes in the global distribution of these gases and of anthropogenic sources. Global observations from satellite platforms provide constraints on the sources and transport of aerosols and trace gases that negatively impact air quality. Satellite observations, even as fundamental as total column, provide better constraints on identifying the natural and anthropogenic aerosol/trace gas source regions.

A19: Global soundings of chemical concentrations	*POR 2025 JPSS, IASI -NG (EUMETSAT), CrIS, Sentinel 4 & 5*	*ST (None required, use for lower*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*

		bounds of value)							
Horizontal Resolution	8 km	1000 km	500 km	100 m	500 km	100 km	50 km (IASI)	50 km	NA
Vertical Resolution	6 km (Vertically integrated total column)	12 km	Total column	10 m	6 km	Total column	3 km layer averages	Total column	NA
Sampling Rate	5.8 hours	96 h	24 h	1 s	12 h	10 h	6 h	6 h	0.2 s
Species	13 (aerosols, CO, CO2, CH4, H2O, HNO3, N2O, NO2, O3, SO2)	0	HNO3	HNO3	10	HNO3	15	HNO3	HNO3

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

Even though water vapor and ozone are listed as separate objectives, they are listed here as well. Accuracy depends on species, typically 10-20%, accuracies for many individual species given in OSCAR and COURL.

COURL values in table are shown as an example: Row 1433 (ID 40310) HNO3.
There are many other COURL requirements representing individual chemical species in different parts of the troposphere and stratosphere.

OSCAR values in table are shown as an example: Row 224 (ID 163) HNO3.
There are many other OSCAR objectives for atmospheric chemical concentrations in the troposphere and stratosphere.

Sources/References supporting this objective and its attributes:

Boersma, K. and Coauthors, 2007: Near-real time retrieval of tropospheric NO2 from OMI, *Atmos. Chem. Phys*., **7**, 2103-2118 [Available online at http://www.atmos-chem-phys.net/7/2103/2007/]

Cooper, M., R. Martin, C. Wespes, P.-F. Coheur, C. Clerbaux and L. Murray, 2014: Tropospheric nitric acid columns from the IASI satellite instrument interpreted with a chemical transport model: Implications for parameterizations of nitric oxide production by lightning. *J. Geophys. Res. Atmos*., **119**, doi:10.1002/ 2014JD021907.

Fisher, J and co-authors, 2008: Remote Sensing of Tropospheric Pollution from Space, *BAMS*, **89** pp 805-821; DOI:10.1175/2008BAMS2526.1

Jacob, D. J., A. J. Turner, J. D. Maasakkers, J. Sheng, K.Sun, X. Liu, K. Chance, I. Aben, J. McKeever, and C. Frankenberg, 2016:Satellite observations of atmospheric methane and their value for quantifying methane emissions, *Atmos. Chem. Phys. Discuss*., doi:10.5194/acp-2016-555.

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA)

NRC, 2016: The Future of Atmospheric Chemistry Research: Remembering Yesterday, Understanding Today, Anticipating Tomorrow. Committee on the Future of Atmospheric Chemistry Research, Board on Atmospheric Sciences and Climate. Pages, 207. www.nap.edu

Payne, V., M. Alvarado, K. Cady-Pereira, J. Worden, S. Kulawik and E. Fischer, 2014: Satellite observations of peroxyacetyl nitrate from the Aura Tropospheric Emission Spectrometer. *Atmos. Meas. Tech.*, **7**, 3737-3749, doi:10.5194/amt-7-3737-2014

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

http://www.nws.noaa.gov/ost/air_quality/

https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=65491

Group B Space Weather

Objective B1: Coronagraph Imagery-Sun-Earth line

Priority: 2 in Space Weather: Coronagraph imagery provides unique and critical information about the speed, extent, and direction of coronal mass ejections. These data are required to know if Earth will be impacted by a coronal mass ejection and to generate the inputs to numerical modeling to predict when they will arrive at Earth. Coronal mass ejections are responsible for the most severe geomagnetic storms and typically impact Earth 1-4 days after they erupt from the Sun. Geomagnetic storms are a concern for the electric power grid, satellite operators, GPS users, aviation customers, and many others. This is the second highest priority for improvement over the ST level of capability in space weather because of the impact these storms have and because there is no operational coronagraph imager.

Authors: Doug Biesecker and Terry Onsager

Brief description: Observes coronal mass ejections from L1 or some other location on the Earth-Sun line

Use/Users: Coronagraph images are used by the SWPC forecast office to observe and characterize coronal mass ejections in the solar corona. This characterization is used as the first and earliest input to issue the Geomagnetic Storm Watch product. It also provides a vital input to the WSA-Enlil model that became operational in October of 2011. WSA-Enlil has become an important tool for forecasting the arrival of coronal mass ejections at Earth, having improved over previous techniques by a factor of two. Geomagnetic storm watches allow the electric power grid to begin planning for any measures necessary to protect the grid infrastructure from damage. This advance warning also allows satellite operators and aviation customers to take protective actions that typically take long times to implement.

Program of Record 2025 and current sources of data: Program of Record 2025 is Space Weather Follow-on. Current capability includes the Large Angle and Spectrometric Coronagraph (LASCO) instrument, one of 11 instruments included on the joint NASA/ESA SOHO (Solar and Heliospheric Observatory) spacecraft. SOHO was launched on 2 December 1995 from Cape Canaveral, Florida. The LASCO instrument is a set of three coronagraphs that image the solar corona from 1.1 to 32 solar radii. The coronagraph covering the innermost field-of-view, covering the field of view between 1.1-2 solar radii, failed in 1998. Current estimates from NASA indicate SOHO could fail as early as 2020 due to degradation of the solar panels.

Impact of improving from ST to ME level: The ME level provides images with higher spatial resolution at a higher time cadence and lower latency. The improved spatial and temporal resolution will improve the identification of CME features and their evolution, which will improve the accuracy of the inputs to numerical prediction models and to the accuracy of arrival-time forecasts. The lower latency will improve the lead time forecasters receive of the CME forecasts, and it will allow early estimates of solar energetic particle acceleration based on the observed near-Sun CME velocity.

B1: Coronagraph Imagery: Sun-Earth Line	*POR 2025 Space Wx follow-on (SWFO) in L1 halo orbit*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Field of View			X			X		X	
Lower Limit	2 Rs	5 Rs		3 Rs	2 Rs		1 Rs		3 Rs
Upper Limit	32 Rs	15 Rs		17 Rs	32 Rs		35 Rs		17 Rs
Spatial Resolution	56 arcsec	100 arcsec	5 arcsec	50 arcsec (H resol)	30 arcsec	1 arcsec	25 arcsec	1 arcsec	50 arcsec (H resol)
Sampling Frequency	20 min	30 min	15 min	15 min	15 min	5 min	1 min	5 min	2 min
Data Latency	15 min	6 hours	60 min	15 min	15 min	5 min	5 min	5 min	1 min

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

COURL values are from COURL_2015vs2017v2-RA.xlsx - Solar Imagery Corona, L1- Rows 50/51

OSCAR is Row 459 ID 615: Solar Coronagraph Image-does not distinguish between on line and off line (L1 or L5)

Comments and notes: The OSCAR requirements differ mainly in asking for very high spatial resolution. However, there is no evidence this higher spatial resolution would have a positive impact on space weather forecasts. At the ST level, FOV is degraded from SOHO values. Current capability from SOHO research mission has poor and variable latency.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA)
(SpaceWeather Specific tab)

Brueckner *et al.* Solar Physics 162, 313-356, 1995

GOES-R Solar Imager Workshop Report (ed. F. Eparvier) 9 Sept 2002.

SIS-MidTerm Review - Solar Coronagraph TS5c (A trade study performed during GOES-R formulation phase)

http://lasco-www.nrl.navy.mil/index.php?p=content/about_lasco

http://sohowww.nascom.nasa.gov/

Objective B2: Coronagraph Imagery: Off Sun-Earth Line

Priority: Highest priority (1) for Space Weather: Coronagraph imagery off the Sun-Earth line provides unique constraints on the speed, extent, and direction of coronal mass ejections. These data are required to know if Earth will be impacted by a coronal mass ejection and to generate the inputs to numerical modeling to predict when they will arrive at Earth. Coronal mass ejections are responsible for the most severe geomagnetic storms and typically impact Earth 1-4 days after they erupt from the Sun. Geomagnetic storms are a concern for the electric power grid, satellite operators, GPS users, aviation customers, and many others. This is the highest priority for space weather because of the impact these storms have and because there is no operational coronagraph in a position off the Sun-Earth line (no capability at ST level).

Authors: Doug Biesecker and Terry Onsager

Brief description: Observes coronal mass ejections (CMEs) from a viewpoint off the Sun-Earth line to provide stereographic images of coronal mass ejections.

Use/Users: A coronagraph off the Sun-Earth line, when used in conjunction with a coronagraph on the Sun-Earth line, provides stereoscopic views of coronal mass ejections. This stereoscopic view removes ambiguities in the CME direction, speed and width that otherwise exist when only one view is available. These data are then used to estimate if the CME will impact Earth. They are also used as inputs to numerical models to forecast more accurately whether and when Earth will be impacted. It has been demonstrated the off Sun-Earth line view improves the arrival time prediction by an additional 25%. These data are used to issue Geomagnetic Storm Watch products. Also, they are used to generate the necessary inputs for the WSA-Enlil model, which is used to predict the arrival of CMEs at

Earth. Geomagnetic storm watches allow the electric power grid to begin planning for any measures necessary to protect the grid infrastructure from damage. This advance warning also allows satellite operators and aviation customers to take protective actions that typically take long times to implement.

Program of Record 2025 and current sources of data: Program of Record 2025 is None. Current capability includes the NASA Solar Terrestrial Relations Observatory (STEREO) Observatories, which are twin satellites that orbit the Sun, traveling in opposite directions around the Sun. The STEREO-A satellite, moving ahead of the Earth and the STEREO-B satellite falling behind, each at an angular rate of 22.5 degrees per year. STEREO was launched Oct 25, 2006. The Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) includes the C2 coronagraph, which is used in conjunction with SOHO LASCO to get a stereo view of CMEs. Communication was lost from STEREO-B in 2014, however efforts in August 2016 to recover STEREO have regained intermittent contact. The propellant on STEREO-B is frozen and the spacecraft is undergoing a complex rotation. Even under a fully successful scenario, it will likely take several months to recover, if that is even possible. Status updates can be found at http://stereo-ssc.nascom.nasa.gov/new.shtml.

Impact of improving from ST to ME level: There is no ST capability. An off-Sun-Earth-line coronagraph will remove ambiguities in the CME direction, speed, and width, which will improve estimates of CME impacts at Earth. It has been demonstrated the off-Sun-Earth-line view improves the arrival time prediction by an additional 25%. It also removes ambiguities when there are multiple near-simultaneous eruptions.

B2: Coronagraph Imagery: Off Sun-Earth Line	*POR 2025*	*ST* None-values given for scoring only	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Field of View Lower Limit Upper Limit	None	5 Rs 15 Rs	X	3 Rs 17 Rs	2 Rs 32 Rs	X	1 Rs 35 Rs	X	3 Rs 17 Rs
Spatial Resolution	None	100 arcsec	5 arcsec	50 arcsec	30 arcsec	1 arcsec	25 arcsec	1 arcsec	50 arcsec
Sampling Frequency	None	30 min	15 min	15 min	15 min	5 min	1 min	5 min	15 min
Data Latency	None	6 hours	60 min	15 min	15 min	5 min	5 min	5 min	1 min
Off Sun-Earth Angle	None	20-160 deg drifting	X	X	40-140 deg drifting	X	60 deg fixed	X	X

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR is Row 459 Solar Coronagraph Image. Does not distinguish between L1 (Sun-Earth line) and L5 (Off Sun-Earth line.)

COURL values are from Rows 52/53 Solar Imagery Corona, L5

Comments and notes: The OSCAR requirements differ mainly in asking for very high spatial resolution. However, there is no evidence this higher spatial resolution would have a positive impact on space weather forecasts. No reliable current capability, as STEREO research mission is often of no value due to constant drifting of spacecraft. Nothing in POR 2025.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

GOES-R Solar Imager Workshop Report (ed. F. Eparvier) 9 Sept 2002.

SIS-MidTerm Review - Solar Coronagraph TS5c (A trade study performed during GOES-R formulation phase)

Biesecker, D. et al., STEREO Space Weather and the Space Weather Beacon, Space Science Reviews, 136, 2008.

Kaiser, M. et al., The STEREO Mission: An Introduction, Space Science Reviews, 136, 2008.

Howard, R. et al., Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI), Space Science Reviews, 136, 2008.

Objective B3: Solar EUV Imagery

Priority: 13 for Space Weather: Solar EUV imagery provides comprehensive situational awareness of the inner solar corona like no other instrument. Significant capability at ST levels implies modest priority for improvement.

Authors: Steve Hill and Terry Onsager

Brief description: Provides images of the inner corona (atmosphere) of the Sun in multiple different EUV spectral bands. These bands were selected to be sensitive to different plasma temperatures for feature and phenomenological discrimination. These observations:

- Locate coronal hole boundaries for forecasts of recurrent geomagnetic activity
- Locate flares for forecasts of solar energetic particle events
- Assess active region complexity for flare forecasts
- Monitor active regions beyond the east limb for solar activity ($F_{10.7}$) forecasts, and
- Determine occurrence and qualitative significance of coronal mass ejections

Use/Users: These high-resolution images will reveal details about the distribution, structure and related activity of active regions, filaments, and solar prominences. Also of interest to space weather forecasters are the boundaries of coronal holes and how the entire surface of the Sun behaves during solar flares. Higher-level products made from these imagery products by the NOAA Space Weather Prediction Center along with other organizations will provide early warning of potential radiation hazards, such as SEP events, flares, geomagnetic storms and radio blackouts. [http://www.goes-r.gov/products/baseline-solar-xray-imagery.html]

Program of Record 2025 and current sources of data: Program of Record 2025 includes GOES-R SUVI data, which will be available in 2017. Currently on orbit are two instruments that produce imagery similar to SUVI imagery. SDO-AIA has a higher resolution, but the SOHO-EIT instrument has a plate scale nearly identical to SUVI. Between these two instruments, we can fairly reproduce the L1b products, which SUVI will provide. [http://www.goes-r.gov/products/baseline-solar-xray-imagery.html]

Impact of improving from ST to ME level: The primary differences between the ST and ME requirements levels are rather dramatic improvements in field of view, spatial and temporal resolution with a reduction in latency. While the ST levels are in some cases somewhat below current capability, the steps to the ME level are mostly anticipatory of capabilities existing only in the research domain at this time. For example, the improved spatial resolution could in principle be used along with magnetograms to model coronal magnetic fields and anticipate eruptive events. A similar comment could be made regarding the 1-second cadence revealing precursors of impactful events. However, the expanded field of view, from 1.3 Rs to 5.0 Rs could potentially have strong forecasting benefits via early detection of coronal mass ejections, below the altitudes at which coronagraphs are effective.

B3: Solar EUV imagery	*POR 2025 SUVI (GOES-R series)*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Field of View	1.5 Rs	1.3 Rs	X	1.3 Rs (vertical range high)	1.5 Rs	X	5 Rs	X	1.3 Rs (vertical range high)
Spectral Range starting at 30.4 nm Lower Limit	9.4 nm	17 nm	X	X	9.4 nm	X	1.0 nm	X	X
Spatial Resolution	5 arcsec	10 arcsec	5 arcsec	5 arcsec	5 arcsec	1 arcsec	1 arcsec	1 arcsec	3 arcsec
Sampling Frequency	10 sec	60 sec	5 min	<2 min	10 sec	1 min	1 sec	1 min	<2 min

Data Latency	1 min	10 min	15 min	<1 min	1 min	1 min	10 sec	1 min	<1 min

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR is Row 461 ID 601 Solar EUV image.

COURL values are from lines 64/65 - Solar Imagery: Multi-Spectral X-Ray/EUV Radiance, Earth-Sun Line

Note: COURL values for Field of View are indicated in “Vertical Range High” field for the COURL spreadsheet.

Comments and notes:

Solar EUV imagery is essential input to NOAA products as the bases for event forecasting and identification. OSCAR values differ most significantly in the ST Update Rate and Latency values. The OSCAR values of 5 min and 15 min make the observations useless for real-time flare detection and location.

Sources/References supporting this objective and its attributes:

Alexander Krimchansky ; Dino Machi ; Sandra A. Cauffman and Martin A. Davis "Next-generation Geostationary Operational Environmental Satellite (GOES-R series): a space segment overview", *Proc. SPIE* 5570, Sensors, Systems, and Next-Generation Satellites VIII, 155 (November 4, 2004); doi:10.1117/12.565281; http://dx.doi.org/10.1117/12.565281

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA)

Objective B4: Photospheric magnetogram imagery-Sun-Earth line

Priority: 11 for Space Weather. Continual high-resolution mapping of the solar photospheric magnetic field is required in order to accurately model the solar wind velocity, density, and magnetic polarity values that cause both minor to moderate geomagnetic storming and influence CME arrival time. No ST capability and moderate importance to space weather implies moderate priority for improvement.

Authors: Terry Onsager and Tom Berger

Brief description: A solar “magnetogram” is a map of the magnetic field at a given layer in the Sun’s atmosphere. It is produced by polarimetric measurements of a spectral line produced in the solar atmosphere, the profile of which is altered in accordance with the Zeeman effect. For a spectral line in visible wavelengths, the atmospheric layer corresponds to the “photosphere” or visible “surface” of the Sun where sunspots are most visible. Because sunspots and their associated “active regions” are caused by accumulations of magnetic field in the atmosphere and are the sources of all major solar eruptions and hence geomagnetic storms, the primary use of magnetograms is to judge the eruptive capacity of a given sunspot region. However a growing use for magnetogram data in space weather forecasting is as input to models of the solar wind. The magnetic field is a vector quantity, but for the purposes of contemporary solar wind models it is sufficient to measure only the “line-of-sight”, or sometimes the radial, component of the magnetic field vector.

Use/Users: Currently the most common magnetograms used in space weather forecasting are photospheric line-of-sight maps of the Earth-facing hemisphere of the Sun used to subjectively judge the magnetic complexity of sunspot active regions. These maps are required on a cadence that captures the evolution of sunspots (about 30--60 minutes during rapid evolution periods) and with sufficient spatial resolution to detect small opposite polarity intrusions as they emerge from below the photosphere (about 500--1000 km spatial resolution). Another use of photospheric magnetograms is as boundary condition maps for potential-field models of the magnetic field in the corona, a higher layer of the solar atmosphere where the solar wind is believed to be accelerated. Finally, from the spectral line derivation of photospheric magnetograms, white-light images of the Sun are an automatic by-product that are frequently used to track the evolution of sunspots on the visible disk. In the not-too-distant future, new analysis techniques or models may require full vector magnetic field maps that drive substantially higher data volumes and processing time compared to current line-of-sight magnetogram data.

Program of Record 2025 and current sources of data: Program of Record 2025: None. Current capability includes the Solar Dynamics Observatory (SDO) Helioseismic and Magnetic Imager (HMI) instrument, which observes the full solar disk at 6173 Å from a geostationary orbit with an angular resolution of about 1 arcsecond (corresponding to 720 km in the solar photosphere). HMI provides four main types of data: dopplergrams (maps of solar surface velocity), continuum filtergrams (broad-wavelength photographs of the solar photosphere), and both line-of-sight and vector magnetograms (maps of the photospheric magnetic field). The line-of-sight magnetic field precision is about 10 Gauss with a cadence of 45 seconds. Data from HMI are received continually by a dedicated ground-station at the White Sands Missile Range, processed at Stanford University, and disseminated by the Goddard Space Flight Center, resulting in a data latency to the NOAA Space Weather Prediction Center of less than one hour.

Impact of improving from ST to ME level: There is no ST capability. A Sun-Earth-line photospheric magnetogram will enable higher resolution measurements of solar active region evolution than available from ground-based instruments, and it will improve the inputs to models of the background solar wind and the propagation of CMEs. Although ground-based networks exist to continuously measure solar magnetic fields, these systems have a duty-cycle of only about 90% due to weather and atmospheric seeing conditions. Also, due to the higher spatial resolution and data continuity possible from a space-based magnetogram relative to ground-based instruments, space weather forecasters can better gauge the magnetic field complexity and eruptive capacity of solar sunspot regions and thus provide more accurate solar flare forecasts using space-based data.

B4: Photospheric Magnetogram Imagery: Sun-Earth Line	*POR 2025*	*ST* *None required, use for scoring only*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*

Spatial Resolution	None	50 arcsec	5 arcsec	5 arcsec	2 arcsec	1 arcsec	1 arcsec	1 arcsec	1 arcsec
Sensitivity	None	50 Gauss	5 Gauss	X	1 Gauss	1 Gauss	0.5 Gauss	1 Gauss	X
Sampling Frequency	None	3 hours	60 min	3 hours	10 min	10 min	1 min	1 min	3 hours
Data Latency	None	6 hours	60 min	1 hour	15 min	1 min	1 min	1 min	1 hour

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR values from Row 463 Solar Magnetic Field
COURL values are from Rows 58/59 - Solar Imagery: Magnetogram L1

Comments and notes:
COURL update rate is insufficient to capture rapid evolution of sunspots during flaring periods (see e.g., Kubo et al., 2007) and should be updated. Similarly, latency of 1 hour combined with update rate of 3 hours could result in 4 hour gaps in magnetogram data in the forecast center, again unacceptably slow during rapid evolution periods. EVM values are aligned with OSCAR values for the most part.

Sources/References supporting this objective and its attributes:

Kubo, M., Yokoyama, T., et al, "Hinode Observations of a Vector Magnetic Field Change Associated with a Flare on 2006 December 13", Pub. Astron. Soc. Japan, **59**, S779, 2007.

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B5: Photospheric magnetogram imagery: Off Sun-Earth line

Priority: 3 for Space Weather. Continual high-resolution mapping of the solar photospheric magnetic field is required in order to accurately model the solar wind velocity, density, and magnetic polarity values that cause both minor to moderate geomagnetic storming and influence CME arrival time. Currently, models of the solar wind are based on potential-field extrapolations of the photospheric line-of-sight magnetic field into the corona where the solar wind is accelerated. Since we currently only measure in the Earth-Sun line direction (i.e. from Earth orbit), we see only about 30% of the solar magnetic field around the sphere with sufficient accuracy for forecasting. Thus the model solar wind outputs (velocity, density, temperature) are often inaccurate by as much as 50--100%. In order to more accurately model the solar wind, more accurate global maps of the coronal magnetic field are required, which in turn require global maps of the photospheric magnetic field. This can only be accomplished by measuring the solar magnetic field from one or more vantage points off the Sun-Earth line. In addition, if the vantage point were to the East of the Earth in its orbit (e.g. at the L5 Lagrangian point), the observations could be used to detect sunspot active regions before they rotated onto the Earth-facing disk, potentially giving 5--7 days warning of solar eruptive activity.

Authors: Tom Berger, Terry Onsager and Doug Biesecker

Brief description: A solar "magnetogram" is a map of the magnetic field at a given layer in the Sun's atmosphere. It is produced by polarimetric measurements of a spectral line produced in the solar atmosphere, the profile of which is altered in accordance with the Zeeman effect. For a spectral line in visible wavelengths, the atmospheric layer corresponds to the "photosphere" or visible "surface" of the Sun where sunspots are most visible. Because sunspots and their associated "active regions" are caused by accumulations of magnetic field in the atmosphere and are the sources of all major solar eruptions and hence geomagnetic storms, the primary use of magnetograms is to judge the eruptive capacity of a given sunspot region. However a growing use for magnetogram data in space weather forecasting is as input to models of the solar wind. The magnetic field is a vector quantity, but for the purposes of contemporary solar wind models it is sufficient to measure only the "line-of-sight", or sometimes the radial, component of the magnetic field vector. Measurements from off the Sun-Earth line would complement existing measurements from the Sun-Earth line to give a much more complete view of the global solar magnetic field.

Use/Users: Solar photospheric magnetograms from a vantage point off the Sun-Earth line would be of use to both space weather forecasters and solar physics researchers. Currently only line-of-sight magnetograms would be of use in solar wind modeling, but in the near future full vector magnetic field measurements may be used in forecasting tools and solar wind models. Magnetogram maps are required on a cadence that captures the evolution of sunspots (about 30--60 minutes during rapid evolution periods) and with sufficient spatial resolution to detect small opposite polarity intrusions as they emerge from below the photosphere (about 500--1000 km spatial resolution).

Program of Record 2025 and current sources of data: Program of Record 2025: None. SDO/HMI is the research prototype of a magnetograph instrument. Note that HMI is a highly capable research-grade instrument that far exceeds the requirements for space weather forecasting. Smaller, lighter, much cheaper "compact magnetographs" are currently in development, e.g. the PHI instrument slated to fly on Solar Orbiter in 2018.

Impact of improving from ST to ME level: There is no ST capability. An off-Sun-Earth-line photospheric magnetogram will enable measurements of solar active regions on the portion of the Sun that is rotating towards the Earth, thereby providing advance warning of developing active regions. Combining these measurements with those of the Sun-Earth-line magnetograph will enlarge the coverage of solar photospheric measurements and improve the accuracy of numerical models of the background solar wind and the propagation of CMEs.

B5:Photospheric Magnetogram Imagery: Off Sun-Earth Line	*POR 2025* None	*ST* *None required, use for scoring only*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*

Spatial Resolution	None	50 arcsec	5 arcsec	5 arcsec	5 arcsec	1 arcsec	1 arcsec	1 arcsec	1 arcsec
Sensitivity	None	50 Gauss	5 Gauss	X	10 Gauss	1 Gauss	1 Gauss	1 Gauss	X
Sampling Frequency	None	3 hours	60 min	3 hours	60 min	10 min	1 min	1 min	3 hours
Data Latency	None	12 hours	60 min	1 hour	60 min	1 min	1 min	1 min	1 hour
Off Sun-Earth Line Angle	None	20-160 deg drifting		L5 ~60°	40-140 deg drifting		60 deg fixed		L5 ~60°

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR values from Row 463 Solar Magnetic Field (OSCAR does not give on line and off line values);
COURL values from Rows 60/61 - Solar Imagery: Magnetogram L5

Comments and notes:
COURL values of update rate and latency at ME level are insufficient to capture sunspot active regions during rapid evolution periods prior to eruptive events.

Sources/References supporting this objective and its attributes:

Gandorfer, A., Solanki, S. K., et al., "*The Solar Orbiter Mission and its Polarimetric and Helioseismic Imager (SO/PHI)"*, in GONG–SoHO 24: A new era of seismology of the sun and solar-like stars, Journal of Physics: Conference Series **271** (2011).

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B6: Solar X-ray irradiance

Priority: 12 for Space Weather. Solar X-Ray Irradiance is critical to quick and early assessment of space weather impacts on Earth. These observations have been made from the operational GOES spacecraft since the first geosynchronous weather satellites were launched in 1972. The current operational requirements and ST level of capability meet the minimal needs of operational space weather forecasting.

Authors: Rodney Viereck and Terry Onsager

Brief description: Measures the integrated (whole sun) x-ray irradiance in two x-ray bands, 0.05-0.4 nm and 0.1-0.8 nm with ≤3-second cadence.

Use/Users: There are two uses of these observations: 1) early measurement of the magnitude of solar flares which correlate with the magnitude of other space weather storms; 2) x-ray flux into the upper atmosphere which enhances the lower ionosphere and blocks radio communication. Continuity in these observations (bandpass, coverage, and cadence) is critical. These measurements have been made from all GOES satellites and the continuous record goes back to 1972.

These observations define the magnitude of solar flares and provide the first warning of impending space weather storms. Solar x-rays disrupt communications. X-ray flare magnitude is used to predict solar proton events which also disrupt communications. The Space Weather Prediction Center uses these observations to issue warnings based on increases in Solar X-ray flux, specifically increases by several orders of magnitude from solar flares. These observations drive one of the three NOAA Space Weather Scales (Radio Blackouts) and provide alerts of radio blackouts of terrestrial HF radio communications. These data are essential for driving critical space weather models and products. It is one of the longest records of space weather and provides context for recent events.

Program of Record 2025 and Current sources of data: Program of Record 2025 is X-Ray Sensor (XRS) on EXIS (Extreme Ultraviolet and X-ray Irradiance Sensors) on GOES-16. XRS was also on all previous GOES. NASA SDO EVE sensor provides a real-time proxy when GOES XRS data are not available.

Impact of improving from ST to ME level: The primary improvement of ME over ST is two x-ray channels (current capability) vs one. With one channel (0.1 – 0.8 nm) the primary uses will be achievable. The second XRS channel (0.05 – 0.4 nm) provides two additional capabilities: 1) a short term prediction to when the flare will reach its peak magnitude; and 2) the differential temperature and emission measure of the flare using the ratio of these two channels. Capability 1 is used in the space weather forecast office. The second capability is used in some test or prototype products. It is used in research and the development of new capabilities that may have future operational relevance.

B6: Solar X-ray Irradiance	*POR 2025 XRS on EXIS (GOES-16)*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Number of Bands	2	1	X	X	1.9	X	2	X	X
Sensitivity	1e-09 W/m2	1e-07 W/m2	X	5e-09 W/m2 Measurem	1e-09 W/m2	X	1e-10 W/m2	X	1e-9 W/m2 Measure

				ent Range Low					ment Range Low
Sampling Frequency	3 sec	60 sec	X	3 sec	3 sec	X	1 sec	3 sec	1 sec
Data Latency	10 sec	60 sec	5 min	3 sec	10 sec	1 min	3 sec	1 min	3 sec

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

OSCAR values from Row 469 Solar X-Ray Flux.

COURL values are from Rows 46/47 "Solar Flux: X-Ray Irradiance

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

L.M. Winter and K. Balasubramaniam, May 2015: Using the Maximum X-ray Flux Ratio and X-ray Background to Predict Solar Flare Class, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 13, DOI:10.1029/, p. 286-297

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B7: Solar EUV irradiance

Priority: 14 for Space Weather. This is an important observation for driving space weather models of the upper atmosphere and ionosphere. The requirements are currently satisfied from the operational GOES spacecraft and the ST level of capability, so priority for improvement is relatively low.

Authors: Rodney Viereck and Terry Onsager

Brief description: Solar Extreme Ultraviolet (EUV) is solar radiation that covers the wavelengths 1 – 120 nm of the electromagnetic spectrum.

Use/Users: Solar EUV irradiance is highly energetic and it is absorbed in the upper atmosphere, which not only heats the upper atmosphere, but also ionizes it, creating the ionosphere. Solar EUV irradiance varies by as much as an order of magnitude on time scales of minutes to hours (solar flares), days to months (solar rotation), and years to decades (solar cycle). The highly varying EUV radiation causes the thermosphere and ionosphere to vary by similar magnitudes and time scales.

Solar EUV irradiance is used to drive models of the thermosphere and ionosphere. Variations in the thermosphere are directly related to satellite drag and satellite orbit prediction. Satellite collision avoidance at LEO altitudes has become a critical concern as the number of space objects grows exponentially. Variations in the ionosphere impact radio communication and satellite navigation. The ionosphere and thermosphere are highly coupled requiring that both systems be specified and modeled together. Specifications and forecasts of these regions of the Earth's upper atmosphere require complex models and specification and forecasting of the drivers of these models. Solar EUV irradiance is one of the three main variable driving forces (along with geomagnetic storms and lower atmospheric tides/waves).

Until recently, modelers used ground-based observations of the solar F10.7 cm radio emissions as a proxy for solar EUV. These daily observations are inadequate to drive modern models and unable to meet the demands of customers.

Program of Record 2025 and Current sources of data: Program of Record 2025 is EXIS on GOES-R. NASA Solar Dynamics Observatory (SDO) also provides data.

Impact of improving from ST to ME level: The ST-to-ME changes are higher spectral resolution, expanded spectral range, and improved data latency. Improving the spectral resolution and range will improve the accuracy of the models driven by these data. It is anticipated that by 2025, these data may introduce some of the largest errors in the models, therefore improved accuracy will be important. Improving the latency will improve the timeliness of the products during high activity periods where changes occur on timescales of seconds.

B7: Solar EUV irradiance	*POR 2025 EXIS on GOES-R*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Wavelength Range			X	X		X		X	X
Lower Limit	5 nm	10 nm			5.01 nm		5 nm		
Upper Limit	127 nm	124 nm			127 nm		170 nm		
Coarsest Resolution across the wavelength range	5 nm	10 nm	X	X	5 nm	X	1 nm	X	X
Sampling Frequency	30 sec	60 sec	3 sec	30 sec	30 sec	X	10 sec	X	10 sec
Data Latency	30 sec	3 min	5 min	30 sec	10 sec	1 min	5 sec	1 min	10 sec

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR values from Row 460 Solar EUV Flux. Does not give wavelength range or resolution.

COURL values are from Rows 44/45 Solar Flux:EUV. Does not give wavelength range or resolution.

Comments and notes:

Current and planned solar EUV observations from GOES do not meet the observation requirements listed above. However, with solar EUV irradiance models, the requirements can be met. ST level is degraded from GOES-R.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

EUV Irradiance Observations from SDO/EVE as a Diagnostic of Solar Flares, Ryan O. Milligan (Submitted on 26 Apr 2016 to conference proceedings for the symposium on "Solar and Stellar Flares and their Effects on the Planets" at the IAU General Assembly in Honolulu, HI, August 2015; arXiv:1604.07793 [astro-ph.SR].

Objective B8: Interplanetary Solar Wind: Sun-Earth Line

Priority: 15 for Space Weather. The interplanetary solar wind observations provide crucial information required to provide accurate geomagnetic storm warnings. The solar wind is an important driver of the geospace environment and is a critical input to numerical geomagnetic storm prediction models as well as ionospheric storm models. NASA's Advanced Composition Explorer (ACE) and NOAA's Deep Space Climate Observatory (DSCOVR) both provide these data today, though neither meets current COURL requirements. Significant ST level of capability implies relatively low priority for improvement.

Authors: Doug Biesecker and Terry Onsager

Brief description: The solar wind consists of a stream of plasma and magnetic field flowing from the Sun. The plasma component consists of mostly electrons, protons and alpha particles.

Use/Users: Solar wind data are used to issue Sudden Impulse Warnings and Geomagnetic Storm Warnings. They are also used as input to predictive models, including the Geospace Model, Ovation Auroral Forecast, Wing-Kp, CTIPe, and the Relativistic Electron Forecast Model. It will be used in the future for the Whole Atmosphere Model. It is also used for real-time validation of the WSA-Enlil model. Geomagnetic storm warnings allow the electric power grid to take immediate actions necessary to protect the grid infrastructure from damage. In addition, the low-energy proton measurements detect the increases of particle flux that are the precursors of approaching interplanetary shocks. These interplanetary shocks and the coronal mass ejections that drive them are the causes of the largest geomagnetic storms.

Program of Record 2025 and Current sources of data: Program of Record is Space Weather follow-on in L1 halo orbit. The NASA Advanced Composition Explorer (ACE) satellite orbits the L1 Lagrange point 1,500,000 km upwind of Earth. This vantage point provides between 15-60 minutes warning of solar wind arrival at Earth, depending on the wind speed. The Solar Wind Electron, Proton, and Alpha Monitor (SWEPAM) is used to observe the speed, density, and temperature of the solar wind. In 2016, SWPC will begin to use the NOAA Deep Space Climate Observatory (DSCOVR) to monitor the solar wind from L1. The Alan Lazarus Faraday Cup (FC) instrument is used to observe the speed, density, and temperature of the solar wind.

Impact of improving from ST to ME level: Improving the capabilities from ST to ME would result in an increase in the percentage of storms for which valid data is returned from 77% to 100% of all of the storms reaching the severe (G4) or extreme (G5) levels in the last 40 years. Without this improvement, modern numerical models that can be used to accurately warn users of the intensity and location of the storms will fail at the times the power grid is most at risk. The ME level will also provide twice the warning time than can be provided to customers at the ST level. Finally, the higher cadence data will allow for robust averaging algorithms to evaluate the data quality to throw out bad data while still providing quality, actionable data with little to no substantive delay.

B8: Interplanetary Solar Wind: Sun-Earth Line	*POR 2025 Space Wx Follow-on in L1 halo orbit*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Density			X			X		X	
Lower Limit	0.22 cm-3	0.3 cm-3		0.1 cm-3	0.22 cm-3		0.1 cm-3		0.1 cm-3
Upper Limit	220 cm-3	75 cm-3		150 cm-3	150 cm-3		200 cm-3		150 cm-3
Speed			X			X		X	
Lower Limit	168 km/s	400 km/s		200 km/s	200 km/s		0 km/s		200 km/s
Upper Limit	1250 km/s	1250 km/s		2500 km/s	2000 km/s		3000 km/s		2500 km/s
Temperature			X			X		X	
Lower Limit	0.04 MK	0.04 MK		0.04 MK	0.03 MK		0.02 MK		0.04 MK
Upper Limit	70 MK	70 MK		2.0 MK	72 MK		74 MK		2.0 MK
Low Energy Protons			X			X		X	
Lower Limit	10 keV (SWPC expectation)	47 keV		10 keV	10 keV		5 keV		10 keV
Upper Limit	2000 keV	1000 keV		1000 keV	1500 keV		2000 keV		2000 keV

Sampling Frequency	60 s	60 s	60 s	1 min	5 s	20 s	1 s	10 s	1 s
Data Latency	5 min	5 min	15 min	5 min	3 min	60 s	1 min	60 s	1 min
Distance From Earth	1.5 e06 km (0.01 AU)	1.0e06 km (L1)	X	1.5e06 km	1.5e06 km (L1)	X	3.0e06 km (inside L1)	X	3.0e06 km

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR gives three rows for solar wind: 466 (ID 606) density, 467 (ID 607) temperature, and 468 (ID 608) velocity. Only values are given for update rate and latency, and they are the same for each row. These are the values we used in the above table for OSCAR. OSCAR version 2-20-17

COURL values in the above table are from:
Row 78/79: Solar Wind: Low Energy Particle Population, L1
Row 86/87: Solar Wind: Plasma Ion Density, L1
Row 90/91: Solar Wind: Plasma Ion Temperature, L1
Row 94/95: Solar Wind: Plasma Ion Velocity Vector, L1

Comments and notes: Essential input for driving geomagnetic storm products and models, though the Study Threshold (ST) requirements differ rather significantly from the COURL threshold requirements. The ST requirements would be sufficient to observe the solar wind that drives about 96% of the most severe storms. However, the remaining few percent that would be missed are the ones that carry the most risk for the electric power grid.

Sources/References supporting this objective and its attributes:

Zwickl et al., The NOAA Real-Time Solar-Wind (RTSW) System using ACE Data, Space Science Reviews, 86, 1998.

Stone et al., The Advanced Composition Explorer, 1998: *Space Science Reviews*, **86**.

McComas et al., Solar Wind Electron Proton Alpha Monitor (SWEPAM) for the Advanced Composition Explorer, 1998: *Space Science Reviews* **86**, 563. doi:10.1023/A:1005040232597

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B9: Interplanetary Solar Wind: Off Sun-Earth Line

Priority: 10 for Space Weather. Due to the average 27 day rotation of the Sun, slowly varying structures on the Sun that generate different solar wind conditions can be observed off the Sun-Earth line from 3-7 days prior to the same structures arriving at Earth. The slowly varying components of the solar wind are the slow and fast wind streams and are known as recurrent structures. The fast streams drive most of the lower intensity geomagnetic storms. Stronger storms are driven by coronal mass ejections. These data can be used to issue more accurate geomagnetic storm watches.

Authors: Doug Biesecker and Terry Onsager

Brief description: Off Sun-Earth Line solar wind observations provide 3-7 day lead time of solar wind speed, density and temperature for recurrent solar wind features.

Use/Users: The off Sun-Earth line solar wind data are used for increasing the lead time and confidence in the predicted solar wind that will arrive at Earth 3-7 days in the future. These data are used to improve the Geomagnetic Storm Watch product and to provide real-time validation of the WSA-Enlil model.

Program of Record 2025 and current sources of data: There is nothing in the Program of Record 2025. The NASA Solar Terrestrial Relations Observatory (STEREO) Observatories are twin satellites that orbit the Sun, traveling in opposite directions around the Sun. The STEREO-A satellite, moving ahead of the Earth and the STEREO-B satellite falling behind, each at an angular rate of 22.5 degrees per year. The Plasma and Suprathermal Ion Composition (PLASTIC) portion of the scientific payload samples the solar wind and is used to determine the speed, density and temperature. The In-situ Measurements of Particles And CME Transients (IMPACT) portion of the payload samples the interplanetary magnetic field. Communication was lost with STEREO-B in 2014.

Impact of improving from ST to ME level: Moving from ST to ME would provide an improvement in the ability to forecast the most common source of geomagnetic storms, co-rotating structures. Solar features that are the source of high-speed winds can persist for many 27-day solar rotations. However, they can vary significantly from rotation to rotation and forecasters today rely mostly on what happened 27 days ago to forecast the next storm. Having the improvements of ME will also enable improved forecasts of co-rotating structures that have only just formed in the last 27 days, as they won't have yet been observed on the Sun-Earth line.

B9: Interplanetary Solar Wind: Off Sun-Earth Line	*POR 2025* None	*ST* None-values given for scoring only	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Density			X			X		X	
Lower Limit	None	0.3 cm-3		0.1 cm-3	0.22 cm-3		0.1 cm-3		0.1 cm-3
Upper Limit	None	75 cm-3		150 cm-3	150 cm-3		200 cm-3		150 cm-3
Speed			X			X		X	
Lower Limit	None	400 km/s		200 km/s	200 km/s		0 km/s		200 km/s
Upper Limit	None	1250 km/s		2500 km/s	2000 km/s		3000 km/s		2500 km/s
Temperature			X			X		X	
Lower Limit	None	0.04 MK		0.04 MK	0.03 MK		0.02 MK		0.04 MK
Upper Limit	None	70 MK		2.0 MK	72 MK		74 MK		2.0 MK

Magnetic Field Lower Limit Upper Limit	None None	-100nT 100 nT	X	0.1 nT 200 nT	-200 nT 200 nT	X	-250 nT 250 nT	X	0.1 nT 200 nT
Low Energy Protons Lower Limit Upper Limit	None None	47 keV 1000 keV	X	X	10 keV 7000 keV	X	5 keV 12000 keV	X	X
Sampling Frequency	None	60 s	X	1 min	30 s	X	10 s	X	1 sec
Data Latency	None	2 hours	X	5 min	60 min	X	15 min	X	1 min
Off Sun-Earth Line Angle	None	20-160 deg drifting	X	60 deg (L5)	40-140 deg drifting	X	60 deg fixed	X	60 deg (L5)

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes: No reliable current capability. STEREO research mission is often of no value due to constant drifting of spacecraft.

There are no corresponding OSCAR requirements.

COURL values in the above table are from Rows:
84/85 Solar wind: Magnetic Field Vector, L5
88/89 Solar Wind: Plasma Ion Density, L5
92/93 Solar Wind: Plasma Ion Temperature, L5
96/97 Solar Wind: Plasma Ion Velocity Vector, L5

COURL gives Off S-E- line angle as “L5”, which we approximate as 60 degrees.

Sources/References supporting this objective and its attributes:

Akioka. et al., The L5 Mission for Space Weather Forecasting, Advances in Space Research, 35, 2005.

Biesecker, D. et al., STEREO Space Weather and the Space Weather Beacon, Advances in Space Research, 136, 2008.

Kaiser, M. et al., The STEREO Mission: An Introduction, Space Science Reviews, 136, 2008.

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

Zwickl et al., The NOAA Real-Time Solar-Wind (RTSW) System using ACE Data, Space Science Reviews, 86, 1998.

McComas et al., Solar Wind Electron Proton Alpha Monitor (SWEPAM) for the Advanced Composition Explorer, 86, 1998.

Objective B10: Heliospheric imagery

Priority: 4 for Space Weather. Heliospheric imagery provides the only way to observe the solar wind and coronal mass ejections all the way from the Sun to Earth. Coronal mass ejections drive the most severe geomagnetic storms and their propagation is significantly impacted by structures in the solar wind. Geomagnetic storms are a concern for the electric power grid, satellite operators, GPS users, aviation customers, and many others. This imagery is a relatively high priority for improvement due to the importance of geomagnetic storms, the lack of use of these data in current forecasting, and the ST level of none.

Authors: Doug Biesecker and Terry Onsager

Brief description: Heliospheric imagers image the space between Sun and Earth. The purpose is to study the 3-D evolution of CMEs through their full journey from the Sun through the interplanetary medium to their impact at Earth.

Use/Users: Heliospheric imagers can be used to predict the arrival time of coronal mass ejections at Earth, though to date all studies show no improvement over SWPC's forecasts with the WSA-Enlil model. It is likely the heliospheric imaging data when used in conjunction with WSA-Enlil will improve the results, either through direct comparison of the model to the data or by assimilating the data into the model. Geomagnetic storm watches allow the electric power grid to begin planning for any measures necessary to protect the grid infrastructure from permanent damage. This advance warning also allows satellite operators and aviation customers to take protective actions that typically take long times to implement.

Program of Record 2025 and current sources of data: There is nothing on this objective in the Program of Record 2025. The NASA Solar Terrestrial Relations Observatory (STEREO) Observatories are twin satellites that orbit the Sun, traveling in opposite directions around the Sun. The STEREO-A satellite, moving ahead of the Earth and the STEREO-B satellite falling behind, each at an angular rate of 22.5 degrees per year. On each satellite, there are two Heliospheric Imagers (HI-1 and HI-2) needed to cover the full volume of space between the Sun and Earth. Communication was lost with STEREO-B in 2014.

Impact of improving from ST to ME level:

Providing heliospheric imaging at the ME level will improve the forecasting of geomagnetic storms. While coronagraphs and numerical modeling provide significant improvements, they still leave us far from a perfect solution. By incorporating the heliospheric data into numerical models, via data assimilation or ensembles, it will enable the next significant leap in predicting the arrival of events at Earth. Improving the accuracy in the onset time of storms will enable customers to better plan their responses and ensure actions are only taken when needed.

B10: Heliospheric Images	*POR 2025*	*ST* None-values given for scoring	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Field of View Lower Limit (Inner Edge) Upper Limit (Outer Edge)	None None	15 Rs 50 Rs	X	15 Rs 220 Rs	12 Rs 100 Rs	X	10 Rs 320 Rs	X	15 Rs 220 Rs
Spatial Resolution	None	10 arcmin	5 arcsec	10 arcmin at inner FOV; 2 deg at outer FOV	1 arcmin	1 arcsec	30 arcsec	1 arcsec	10 arcmin at inner FOV; 2 deg at outer FOV
Sampling Frequency	None	2 h	60 min	1 hour	1 h	10 min	30 min	10 min	1 h
Data Latency	None	6 h	60 min	15 min	4 h	10 min	30 min	10 min	10 min
Off Sun-Earth Line Angle	None	20-160 deg drifting	X	60 deg (L5)	40-140 deg drifting	X	60 deg fixed	X	60 deg (L5)

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR values from Row 222 ID 588 Heliospheric Image
OSCAR version 2-20-17

COURL values are from:
Row 56/57 Solar Imagery: Heliospheric, L5.

The COURL gives Off S-E- line angle as “L5”, which we approximate as 60 degrees. Field of view is indicated in Vertical Range Low (15 Rs) and Vertical Range High (1 AU). Whereas the mean distance from the Sun to Earth is 1 AU ~ 215 Rs, the farthest distance from the Sun to Earth during the year is approximately 220 Rs, which is used as the outer range of the field of view.

Comments and notes: No reliable current capability. STEREO research mission is often of no value due to constant drifting of spacecraft.

The Study Threshold (ST) field of view begins far outside the coronagraph field of view. This limits the ability to continually follow a particular CME and biases the observations to be closer to the Earth, which limits the lead time on any resulting forecast. Also, the ST latency requirement is so large that an extreme event will hit Earth before any heliospheric imagery data containing the CME arrives at Earth. The combination of the OSCAR update rates as well as the spatial resolution requirements would require collecting an immense aperture to collect enough photons to have a measurable signal.

Sources/References supporting this objective and its attributes:

Biesecker, D. et al., 2008: STEREO Space Weather and the Space Weather Beacon, *Advances in Space Research*, **136**.

Eyles et al., 2008: The Heliospheric Imagers On-board the STEREO Mission. *Space Science Reviews*, **136**.

Kaiser, M. et al., 2008: The STEREO Mission: An Introduction, *Space Science Reviews*, **136.**

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B11: Interplanetary Energetic Particles at L1

Priority: 16 for Space Weather. The ST level for this observation is largely adequate.

Authors: Terry Onsager

Brief description: Energetic particle measurements in interplanetary space detect the solar energetic particle events that have widespread impacts on critical infrastructure, including satellite anomalies, high-frequency communication outages, and human radiation risks.

Use/Users: The energetic protons (>1 MeV) measured at L1 correspond closely to the energetic proton measurements on GOES that are the basis for operational alerts and warnings. Measurements at L1 can at times provide solar energetic particle event detection in advance of GOES. These measurements are important to protect astronauts in space and to inform commercial airlines of enhanced radiation levels. Enhanced proton fluxes also degrade high-frequency radio communication at high latitudes and are responsible for a class of satellite anomalies referred to as single event upsets.

Program of Record 2025 and current sources of data: Program of Record 2025 is None. Current interplanetary energetic particle data are obtained from the ACE Solar Isotope Spectrometer.

Impact of improving from ST to ME level:

Interplanetary energetic particle measurements at the ME level will allow detection of the higher energy protons (up to 1 GeV), which are responsible for satellite anomalies and human radiation risks at commercial aviation altitudes. These observations at L1 in some cases provide advance warning of solar energetic particle events over the current operational measurements at geostationary orbit (GOES).

B11: Interplanetary Energetic Particles at L1	*POR 2025* None	*ST (Values for Scoring Only)*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Energy Range Lower Limit Upper Limit	 None None	 1 MeV 10 MeV	X	 10 keV 1 MeV	 0.8 MeV 500 MeV	X	 0.7 MeV 1 GeV		 10 keV 2 MeV
Sampling Frequency	None	1 min	10 min	5 min	5 sec	5 min	4 sec	1 min	1 min
Data Latency	None	15 min	100 min	5 min	5 min	1 min	1 min	1 min	1 min

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR values from Row 357 Proton Differential Directional Flux at L1. OSCAR includes observing requirements for “proton differential directional flux” at L1, but the requirements do not refer to specific energy ranges.

COURL values in the above table are from:
Rows 78/79: Solar Wind: Low Energy Particle Population, L1.

Comments and notes:

The COURL only includes requirements for the lower-energy portion of the proton spectrum, 50 keV - 1 MeV. The ST level is degraded from ACE and lacks the highest energy proton measurements, which are currently made by GOES.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

Stone, E. C., et al. (1998b), The Solar Isotope Spectrometer for the Advanced Composition Explorer, Space Sci. Rev., 86, 357–408.

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B12: Interplanetary Magnetic Field at L1

Priority: 19 for Space Weather. The ST level is adequate for most routine observations; however, for extreme events these levels would not be adequate to support customers. Therefore, raising the priority of this EVM should be considered.

Authors: Howard Singer and Terry Onsager

Brief description: A magnetometer, such as the one on DSCOVR, located at the L1 Lagrange point 1.5 million km upstream of Earth towards the Sun, measures the three components of the interplanetary magnetic field (IMF). The orientation and strength of the magnetic field in interplanetary space that encounters Earth's magnetic field is key to whether or not electromagnetic energy from the solar wind is able to couple effectively into Earth's near space environment and to cause intense geomagnetic storms and ionospheric disturbances.

Use/Users: Observations of the solar wind and the IMF at L1 provide a 15 to 60 minute warning time, depending on the solar wind velocity, before a magnetic field and solar wind disturbance arrives at Earth. During the most severe events, the solar wind speed is high and the lead time is short. The IMF, as well as solar wind velocity, density and temperature, are critical input parameters to nearly all models of geomagnetic activity and the multitude of customers affected by intense solar wind conditions. These users include high-profile customers such as the electric power utilities, satellite operators, and users of HF propagation and navigation systems.

Program of Record 2025 and current sources of data: Program of Record 2025 is the Space Weather Follow-on. Current interplanetary magnetic field observations used in operations are from the DSCOVR satellite, which recently replaced ACE. The DSCOVR magnetometer is a triaxial-fluxgate that was developed at Goddard Space Flight Center. The satellite is in orbit around the L1 Lagrange point about 1.5 million km upstream of Earth toward the Sun where it remains along the Earth-Sun line in a tight Lissajous orbit, essentially perpendicular to the Earth-Sun line with 150,000 km along z and 300,000 km along y.

Impact of improving from ST to ME level: Improvements from ST to ME, in some cases such as for uncertainty (accuracy) and sampling frequency, will provide measurements comparable to those we already have in operations today. This will provide our customers with the quality of product they have come to expect. The reduced latency, in going from ST to ME is critical for driving models that rely on these data and improves their forecast lead time.

B:12 Interplanetary Magnetic Field at L1	*POR 2025 Space Wx Follow-on in L1 orbit*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Resolution	0.05 nT	1 nT	X	X	0.1 nT	X	0.05 nT	X	X

Range (per axis)	+/- 200 nT	+/- 100 nT	X	0.1-200 nT	+/- 200 nT	X	+/- 250 nT	X	0.1-200 nT
Uncertainty	1.0 nT	2 nT	1 nT	+/-1 nT up to 100 nT 1% for B>100 nT	1 nT	0.1 nT	0.5 nT	0.05 nT	+/-1 nT up to 100 nT 1% for B>100 nT
Sampling Frequency	50 Hz	0.1 Hz	60 s	60 s	0.5 Hz	10 s	50 Hz	1 s	1 s
Data Latency	2.5 min	5 min	15 min	5 min	2.5 min	1 min	1 min	1 min	1 min

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR values from Row 233 ID 590 Interplanetary magnetic field.
COURL values are taken from Rows 82/83 Solar wind: Magnetic Field Vector, L1.

Comments and notes:

To meet magnetic field measurement requirements, it is essential to have a good magnetics cleanliness program for the spacecraft and all instruments and systems. Regarding differences between NOAA attribute values and those in OSCAR and COURL, the NOAA values are those needed to support NOAA's operational needs and comparable to what is now available from DSCOVR. ST level is degraded from DSCOVR.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)
Smith et al., 1998: The Ace Magnetic Fields Experiment, *Space Science Reviews* **86**: 1–22.

Zwickl et al., The NOAA Real-time Solar-Wind (RTSW) System Using Ace Data, 1998: *Space Science Reviews* **86**: 633–648.

http://www.nesdis.noaa.gov/DSCOVR/

http://www.nasa.gov/feature/goddard/nation-s-first-operational-satellite-in-deep-space-reaches-final-orbit

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B13: Geomagnetic field at GEO

Priority: 18 for Space Weather. Over many years, these much-used measurements have only required minor improvements, such as increased data rates; therefore, the priority is not high to go from the Study Threshold (ST) to Maximum Effective (ME) because the ST values are, for the most part, adequate to serve space weather customers.

Authors: Howard Singer and Terry Onsager

Brief description: The geomagnetic field shields Earth from all but the most energetic particles emanating from the Sun. It also controls the transfer of energy from the background solar wind and from extreme conditions, during coronal mass ejections (CMEs), which can result in major space weather disturbances in Earth's magnetosphere and ionosphere. Furthermore, the geomagnetic field controls the motion, energization and loss of energetic particles in the vicinity of Earth.

Use/Users: The geomagnetic field measurements are important for informing many customers, including satellite operators and power utilities, about the level of geomagnetic disturbances. The GOES-R Magnetometer products will be an integral part of NOAA's space weather operations, providing information on the general level of geomagnetic activity and permitting detection of sudden magnetic storms. In addition, measurements will be used for real-time validation of large-scale space environment models that are used in operations.
http://www.goes-r.gov/spacesegment/mag.html

Program of Record 2025 and Current sources of data: POR 2025 is GOES-R magnetometer. GOES-13, -14 and -15 each have two magnetometers, mounted on an 8.5 m boom, returning data for space weather operations. These satellites will be followed by the GOES-R series with two magnetometers mounted on an 8.5 m boom. Each satellite provides measurements of the space environment magnetic field that controls charged particle dynamics in the outer region of the magnetosphere. These particles can be dangerous to spacecraft and human spaceflight. http://www.goes-r.gov/spacesegment/mag.html

Impact of improving from ST to ME level:

Improvements from ST to ME include better uncertainty (accuracy), sampling frequency and latency. The significant improvement in sampling frequency will enable the measurement of waves that are important for controlling the radiation belts. Improvement in accuracy enables better characterization of energetic particle pitch angles and geospace models, and improved latency provides for faster notification of rapid processes in Earth's magnetosphere that affect customers such as those who operate power grids.

B:13 Geomagnetic Field at GEO	*POR 2025 GEOS-R Magnetometer*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Range (nT/axis)	(+/-) 512	(+/-) 400	X	-400 to 400	(+/-) 512	X	+/- 550	X	-400 to 400
Uncertainty (nT/axis)	1.0	2.0	1.0	1.0	1.0	0.3	0.2	0.1	1.0

Sampling Frequency	10 Hz	2 Hz	0.1 Hz	2 Hz	10 Hz	0.1 Hz	20 Hz	1 Hz	20 Hz
Data Latency	5 s	60 s	10 min	5 s	10 s	1 min	5 s	1 min	5 s

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR values from Row 209 ID 613 Geomagnetic field, GEO.
COURL values are from Rows 24/25 Geomagnetic Field: GEO

Comments and notes:

Measurements of Earth's geomagnetic field are particularly useful from geosynchronous orbit because that is the location of many critical US spacecraft, but also because geosynchronous is a unique location for monitoring all of the major current systems in the magnetosphere that contribute to geomagnetic disturbances. However, since magnetic measurements in space are sparse, in addition to GEO, measurements in other orbits would aid in the interpretation of energetic particle observations and characterizing geomagnetic disturbances. Regarding differences between NOAA attribute values and those in OSCAR, the NOAA values are those needed to support our operational needs. ST level is degraded from GOES-R.

Sources/References supporting this objective and its attributes:

Handbook of Geophysics and the Space Environment, Air Force Geophysics Laboratory (AFGL), 1985.

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

Russell, C.T., 1978: The ISEE 1 and 2 Fluxgate Magnetometers, *Transactions on Geoscience Electronics*, **Vol. GE-16**, no. 3.

Singer, H.J., L. Matheson, R. Grubb, A. Newman and S.D. Bouwer, 1996: Monitoring Space Weather with the GOES Magnetometers. *SPIE Conference Proceedings*, Vol. 2812, p. 299-308, GOES-8 and Beyond, Edward R. Washwell, ed.

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B14: Geospace Energetic Particles

Priority: 17 for Space Weather. The Study Threshold (ST) capability corresponds to the particle measurements made on GOES 8-12. These measurements were restricted to energetic protons and alpha particles of direct solar origin and relativistic radiation belt electrons [Onsager et al., 1996].

The GOES 8-12 particles capabilities are at the ST level because they are sufficient to support SWPC's current real-time Solar Radiation Storm alerts and >2 MeV radiation belt electron alerts [http://www.swpc.noaa.gov/noaa-scales-explanation]. However, the ST capability falls far short of the current (GOES-16) capabilities.

Authors: Juan Rodriguez and Terry Onsager

Brief description:
Historically, the NOAA energetic particle detectors on GOES and POES/MetOp have measured charged particle populations that present hazards to robotic and human space flight and to aircraft flying high-latitude or trans-polar routes. These populations also have an effect on the chemistry of the upper atmosphere when they are lost to the atmosphere through collisions with neutral gas particles, resulting in additional ionization that hinders radio communication and navigation through absorption and scattering of radio waves. The NOAA energetic particle detectors have measured (1) hot plasma (electrons and ions); (2) radiation belt electrons and protons; and (3) energetic ions of direct solar origin. The Space Environment Monitor (SEM) instrument suites on GOES and POES/MetOp have had different instruments and different combined energy ranges.

Use/Users:
The GOES Space Environment Monitor (SEM) (on GOES-16, the Space Environment In-Situ Suite (SEISS)) measures the in-situ energetic particle environment at geosynchronous orbit, providing real-time data to the NOAA Space Weather Prediction Center (SWPC). This information is important for military and civilian radio communication; satellite communication and navigation systems; electric power networks; geophysical exploration; human space flight; high-altitude and high-latitude aviation; and scientific researchers. The capability enhancements represented by GOES-R over previous GOES came out of a NOAA workshop attended by representatives from NOAA, the U. S. military, other government agencies, academic institutions, and industry [Mazur, 2003]. See also: http://goes.gsfc.nasa.gov/text/GOES-N_Databook_RevC/Section05.pdf

Program of Record 2025 and current sources of data: Program of Record 2025 is the GOES-16 SEISS and GEO-KOMSAT (SESS). SEISS is comprised of five instruments: Magnetospheric Particle Sensor - Low Energy (MPS-LO), Magnetospheric Particle Sensor - High Energy (MPS-HI), Solar and Galactic Proton Sensor (SGPS, two per satellite), and Energetic Heavy Ion Sensor (EHIS). MPS-LO comprises four electrostatic analyzers (two for electrons, two for ions), while the other instruments are comprised of solid state telescopes that use silicon detectors to discriminate particles of different species and energies [Dichter et al., 2015]. Their energy range, and angular coverage are summarized in the following table:

SEISS Instrument	Species	Energy Range	Energy Channels	Angular Range
MPS-LO	Ions	0.03-30 keV	15	180° fan in body reference frame (BRF) yz-plane centered on –Z axis; 12 unique angular zones separated by 15°

MPS-LO	Electrons	0.03-30 keV	15	180° fan in BRF yz-plane centered on –Z axis; 12 unique angular zones separated by 15°
MPS-HI	Protons (H+)	80-10,000 keV	11	170° fan in BRF yz-plane centered on –Z axis; 5 telescopes separated by 35°; 15° half-angle conical FOVs
MPS-HI	Electrons	50-4000 keV and >2000 keV	11	170° fan in BRF yz-plane centered on –Z axis; 5 telescopes separated by 35°; 15° half-angle conical FOVs
SGPS	Protons (H+)	1-500 MeV and >500 MeV	11	Two SGPSs, +X (eastward) and –X (westward) look directions; <45° half-angle conical FOVs
EHIS	Ions (H through Ni, separately resolved)	10-200 MeV/nucleon	5 per species	One 28° half-angle conical FOV along –Z axis

Impact of improving from ST to ME level:

The ME level includes measurements that enable important space weather hazard assessment capabilities, including the assessment of surface charging by hot plasma and of single-event effects (SEEs) due to heavy ions. These measurements will be made throughout the volume of space occupied by Earth-orbiting spacecraft to improve the knowledge of radiation levels at all orbiting locations. Through improved resolution of radiation belt electron fluxes, the ME level also enables improved assessments of internal charging hazards over ST capabilities. Also, improved accuracy of measurements of >500 MeV protons will improve specification of the radiation levels at commercial aviation altitudes.

B14: Geospace Energetic Particles	*POR 2025 SEISS ON GOES-R; SESS on GEO-KOMSAT (Korea)*	*ST*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Orbital Coverage	GEO	GEO	GEO, MEO, LEO	GEO, MEO, LEO	GEO, LEO	GEO, MEO, LEO	Volume constellation (GEO,	GEO, MEO, LEO	GEO, MEO, LEO

							MEO, LEO at least)		
Energy Range-Electrons Lower Limit Upper Limit	30 eV 4 MeV	0.8 MeV 4 MeV	X	Low, Medium and High	30 eV 6 MeV	X	20 eV 10 MeV	X	Low, Medium and High
Energy Range-Protons Lower Limit Upper Limit	30 eV 500 MeV	1 MeV 500 MeV	X	Low, Medium and High at GEO and LEO; Low at MEO	30 eV 750 MeV	X	10 eV 1 GeV	X	Low, Medium and High at GEO and LEO; Low at MEO
Energy Range-Heavy Ions Lower Limit Upper Limit	10 MeV/n 200 MeV/n	15 MeV/n 150 MeV/n	X	Energetic heavy ions at GEO and LEO	10 MeV/n 200 MeV/n	X	5 MeV/n 250 MeV/n	X	Energetic heavy ions at GEO and LEO
Uncertainty	25%	40%	25%	25%	25%	10%	10%	5%	10%
Sampling Frequency	30 s	60 s	10 min	30 sec	30 s	5 min	10 s	1 min	10 sec
Data Latency	30 s	60 s	100 min	1 min	30 s	1 min	15 s	1 min	1 min

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

ST level is degraded from GOES-R.
Orbital coverage is biggest cost driver.
This objective is split among several EDRs in OSCAR and the COURL.

OSCAR includes Geospace Energetic Particles as “Electron Differential Directional Flux” (Row 191 ID 739) and “Proton Differential Directional Flux” (Row 356 ID 595) in the LEO, MEO, and GEO layers.

COURL values in the above table are from COURL_2015vs2017v2.xlsx-RA.

COURL includes these measurements as “Electrons and Protons: Low Energy, GEO” (Rows 12/13), “Electrons: Medium and High Energy, GEO” (Rows 14/15), “Magnetospheric Electrons: Medium and High Energy, MEO” (Rows 106/107), “Electrons: Medium and High Energy, LEO” (Rows 16/17), “Energetic Heavy Ions” (Rows 18/19), “Energetic Ions, LEO” (Rows 20/21), “Ions: Medium and High Energy, LEO” (Rows 34/35), Protons: Medium and High Energy, GEO” (Rows 36/37), “Solar and Galactic Protons, GEO” (Rows 42/43), “Electrons and Protons: Low Energy, MEO” (Rows 100/101). Note that COURL “Energetic Heavy Ions” refers to GEO, and COURL “Energetic Ions, LEO” refers to “Energetic Heavy Ions, LEO.”

The requirements vary among the different components of the geospace particle environment. The Uncertainty, Sampling Frequency, and Latency in the above table refer to “Electrons: Medium and High Energy, GEO” (Rows 14/15).

Sources/References supporting this objective and its attributes:

Dichter, Bronislaw K., Gary E. Galica, John O. McGarity, Sam Tsui, Michael Golightly, Clifford Lopate, and James J. Connell, 2015: "Specification, Design, and Calibration of the Space Weather Suite of Instruments on the NOAA GOES-R Program Spacecraft," *Nuclear Science, IEEE Transactions on*, **62**, no. 6, 2776-2783

Mazur, J. E., 2003: *Summary Report, Workshop on Energetic Particle Measurements for the GOES R+ Satellites*, held at the NOAA Space Environment Center, Boulder, CO, October 28-29, 2002.

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

Onsager, T. G., R. Grubb, J. Kunches, L. Matheson, D. Speich, R. Zwickl, and H. Sauer, 1996: “Operational uses of the GOES energetic particle detectors,” in *GOES-8 and Beyond, Proc. SPIE*, Vol. 2812, edited by E. R. Washwell, pp. 281-290, Bellingham, WA.

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B15: Ionospheric electron density profiles

Priority: 8 for Space Weather. These observations are critical for ionospheric specification and modeling. It is assumed that COSMIC-2 will provide reasonable coverage. However, COSMIC-2 will not provide good latency (33 min). The actual latency requirement is 5 minutes.

Authors: Rodney Viereck, Terry Onsager and Rick Anthes

Brief description: Vertical profiles of electron density (number per m^3) in ionosphere (from about 90 to 1500 km altitude).

Use/Users: Radio communication and satellite navigation rely on radio waves. Radio wave propagation depends on electron density profiles in the ionosphere. Layers in the ionosphere reflect HF radio waves (3-30 MHz) allowing people to communicate even if they do not have line-of-site connections. The height integrated Total Electron Content (TEC) impacts single frequency GPS accuracy. Small-scale plasma structures in the ionosphere create multi-path for radio waves, which induces scintillation of the radio waves. Severe scintillation conditions can prevent GPS receivers from locking on to the satellite signal and can make it impossible to calculate a position. Less severe scintillation conditions can reduce the accuracy and the confidence of positioning results.

There are other potential applications of these data in the detection of earthquakes and tsunamis.

Program of Record 2025 and Current sources of data: Program of Record 2025 is COSMIC-2 and EUMETSAT (2 EPS-SG). Other observations are currently provided by ground based ionosondes and dynasondes, Incoherent Scatter Radars, and COSMIC-1.

Impact of improving from ST to ME level: The most important improvement is the latency. The models will be run on a 5-10 minute cadence, and 5-minute latency is critical to providing customers with real-time products and services. Improving the accuracy, revisit time, and resolution will improve the overall accuracy of the models and products, but improved accuracy is not as important as improving the latency.

B15: Ionospheric electron density profiles	*POR 2025 COSMIC-2, EUMETSAT (2 EPS-SG)*	*ST*	*OSCAR Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Sensitivity (10**10 e-/m3)	3.0	10.0	X	0.1	3.0	X	0.5	X	0.01
Uncertainty (Accuracy)	Less than the greater of 3x10^10 or 10% (from COSMIC-2 Req. Doc)	Less than the greater of 10x10**10 or 20%	X	30%	Less than the greater of 3x10**10 or 10%	X	Less than the greater of 1x10**10 or 5%	X	30%
Profiles per day (global)	8000 (COSMIC-2) (Same as A9)	5000	X	100 km horiz resol	20,000	X	50,000	X	50 km horiz resol
SNR (40-80 km altitude avg)	1600 V/V (COSMIC-2) (Same as A9)	800 V/V (COSMIC-1)	X	X	1600 V/V (COSMIC-2)	X	2000 V/V	X	X
Vertical Resolution	2 km	10 km	X	10 km	2 km	X	1.5 km	X	10 km
Average Data Latency	30 min (COSMIC-2)	30 min (A9=90)	X	15 min	15 min (A9=30)	X	5 min (A9=10)	X	5 min

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR does not provide information on this objective.
COURL values are taken from Rows 32/33 Ionospheric electron density profiles

Comments and notes:

ST level slightly degraded from COSMIC-2 values. Other sources of ionospheric requirements (e.g. OSCAR) often list derived products such as the height of the F2 layer (hmF2) or the peak density of the F2 layer (nmF2). These and other parameters can be derived from height profiles of electron density.

Sources/References supporting this objective and its attributes:

http://www.swpc.noaa.gov/phenomena/ionospheric-scintillation

Jakowski, N. et al., 2010: Products and services provided by the Space Weather Application Center – Ionosphere (SWACI). Presentation at Space Weather Workshop, 27-30 April 2010, Boulder, CO. http://www.swpc.noaa.gov/phenomena/ionosphere http://www.swpc.noaa.gov/sites/default/files/images/u33/JAKOWSKI%20SWW%202010.pdf

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B16: Auroral imaging

Priority: 5 for Space Weather. These observations provide specification of the intensity and location of the aurora. White-light image data, such as from VIIRS, provide qualitative information. UV image data, such as from DMSP, provide information on the energy deposition into the thermosphere and ionosphere. The aurora changes on timescales of a few minutes. This observational requirement is currently not being met with the latency required and the ST level is zero, implying high priority for improvement.

Authors: Rodney Viereck and Terry Onsager

Brief description: Images of the entire Northern auroral oval in visible and UV wavelengths.

Use/Users: Spatial, temporal, and energy information are used in models of the thermosphere and ionosphere. Location and intensity of the aurora are used for situational awareness by power grids, airlines, and other users of impacted technologies located in the arctic region. The location of the aurora is a good indicator of where navigation and communication issues will occur. It is also a good proxy for the location of the most severe ground induced currents in electric power grids. The intensity of the aurora is a direct measure of the energy input into the upper atmosphere. Auroral heating of the upper atmosphere expands the neutral atmosphere and raises the ionosphere. This will impact satellite orbit prediction and radio communication.

Program of Record 2025 and current sources of data: Program of Record 2025: None. VIIRS gets visible light aurora images, but at uselessly long latency. Similarly, DMSP SSULI and SSUSI provide some information on energy and location of the aurora. Both have latencies of 30-120 minutes, which is unacceptable. Both DMSP and POES are LEO satellites and only capture a portion of the auroral oval on each pass.

Value of going from ST to ME: The most important of the improved parameters is the data latency. Going from 15 minutes to 5 minutes will greatly improve the forecaster's ability to capture the onset of a major auroral storm. Improving the spatial resolution and the sample interval will increase the value and accuracy of the derived products such as the determination of the auroral boundary, which is important for electric power industry.

B16: Auroral imagery	*POR 2025*	*ST (None, values for scoring purposes)*	*OSCAR Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Field of View	None	>65 latitude	X	Global	>60 latitude	X	Hemisphere	X	Global
Band Passes			X	X		X		X	X
Lower Limit	None	400 nm			110 nm		100 nm		
Upper Limit	None	650 nm			180 nm		190 nm		
Spatial Resolution	None	60 km	X	10 km	50 km	X	10 km	X	1 km
Refresh Rate	None	45 min	X	5 min	20 min	X	1 min	X	1 min
Data Latency	None	60 min	X	15 min	10 min	X	1 min	X	5 min

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

COURL values from Rows 98/99 – Multi-Spectral Auroral Imagery

There is no information on auroral imagery in OSCAR.

Comments and notes:

Older versions of the COURL had threshold latency of 90 minutes to justify using POES and DMSP. This level of latency is unacceptable. No auroral imagery are available that meet operational data latency requirements. The most recent COURL calls out "Banded Auroral Imagery" with the goal of measuring spectrally resolved aurora. The specific values (FUV 110-180 nm) are not called out in the COURL and these are left TBD. Spectrally resolved auroral imagery will allow for the quantitative use of these data in forecast models of the ionosphere-thermosphere.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

http://sd-www.jhuapl.edu/Aurora/

http://www.swpc.noaa.gov/phenomena/aurora

Objective B17: Thermospheric O/N2 ratio (height integrated)

Priority: 6 for Space Weather. These observations are available from DMSP and other research satellites but the latency (30-90 min or longer) make the data unusable in real-time. ST level of zero implies high priority for improvement.

Authors: Mihail Codrescu and Terry Onsager

Brief description: Height integrated Oxygen to molecular Nitrogen ratio (O/N2).

Use/Users: The composition of the thermosphere is primarily atomic oxygen, molecular nitrogen, and molecular oxygen. Solar EUV photons ionize the neutral atmosphere creating a region of plasma called the ionosphere. The thermosphere and ionosphere are highly coupled, and thermospheric composition variations manifest themselves as variations in the ionosphere electron density. O/N2 ratio is the most important parameter for specification and forecast using numerical ionospheric models.

These data will be assimilated into thermosphere/ionosphere models. The output of the models will provide specification and forecasts of neutral density for satellite orbit prediction and of ionospheric density for communication and navigation.

Program of Record 2025 and current sources of data:

Program of Record 2025: None
Current: DMSP SSULI and SSUSI
Future: NASA GOLD mission

Impact of improving from ST to ME level:

The spatial gradients in O/N2 ratio are sharp and cannot be properly specified with a horizontal resolution of 250 km. During a major geomagnetic storm the gradients move and a horizontal resolution of 100 km sampling frequency of 1.5 hours are necessary to characterize and possibly forecast their position.

B17: Thermospheric O/N2 ratio (height integrated)	*POR 2025 None*	*ST (None values for scoring purposes)*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Spatial Coverage	None	CONUS	X	Dayside	Western Hemisphere	X	Global	X	Dayside

Horizontal Resolution	None	300 km	X	250 km	200 km	X	100 km	X	250 km
Refresh Rate	None	5 h	X	NA	1.5 h	X	15 min	X	NA
Data Latency	None	3 h	X	NA	1 h	X	30 min	X	NA

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

OSCAR does not provide information on this Objective.
COURL values are taken from Row 150 Thermosphere Neutral Height-Integrated Atomic Oxygen/Molecular Nitrogen Ratio.

Comments and notes:

No current capability due to long data latency.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

Qian, L., S.C. Solomon, and T.J. Kane, 2009: Seasonal variation of thermospheric density and composition. *Journal of Geophysical Research-Space Physics*, **114**, 15 pp, DOI: 10.1029/2008JA013643.

WMO, 2013: Observing Systems Capability Analysis and Review (OSCAR) Tool. [Available online at http://www.wmo.int/oscar/] OSCAR Version 2017-02-20.

Objective B18: Upper thermospheric density

Priority: 7 Thermospheric density measurements near 400 km altitude are needed for assimilation into global ionospheric/atmosphere forecasting and specification models. There is no current capability, implying high priority for improvement.

Authors: Mihail Codrescu and Terry Onsager

Brief description: The thermosphere is the upper layer of the neutral atmosphere from 90 km upward. The thermosphere is highly variable and can change on tens-of-minute time scales with geomagnetic and solar conditions. Tides and gravity waves from the lower atmosphere propagate upward into the thermosphere inducing oscillations and waves. They also deposit energy affecting the thermosphere temperature structure and winds. Solar EUV photons ionize the neutral atmosphere creating a region of plasma called the ionosphere.

Use/Users: The thermosphere and ionosphere are highly coupled and thermospheric variations instantly manifest themselves as variations in the ionosphere. Monitoring the variability of the thermosphere is critical for satellite drag specification and forecast and radio wave propagation through the ionosphere.

These data will be assimilated into thermosphere and ionosphere models. The output of the models will provide specification and forecasts of neutral density for satellite orbit prediction and of ionospheric density for communication and navigation. The increase in LEO satellites and debris has grown exponentially and will continue to grow making these observations more and more critical.

Program of Record 2025 and current capability:

Program of Record 2025: None
Current capability: GRACE, CHAMP and GOCE accelerometers.

Impact of improving from ST to ME level: There is no civilian operational capability to measure total mass density at 400 km at this time. Measurements of the mass density would constrain physics based models of the thermosphere ionosphere system and improve the specification and forecast of satellite drag and radio wave propagation for communications, positioning, navigation, and timing applications.

B18: Upper Thermospheric Density	*POR 2025 None*	*ST (None, lower bounds for scoring purposes)*	*OSCAR Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Altitude Location - 400 km mean – Range is variable (approx. 50-60 km)	None	40 km	X	150-500 km	50 km	X	60 km	X	90-1000 km
Horizontal Resolution	None	90 deg longitude	500 km	250 km	60 deg longitude	200 km	30 deg longitude	100	250 km
Refresh Rate	None	3 h	30 min	NA	1.5 h	30 min	1 h	5 sec	NA
Data Latency	None	3 h	60 min	15 min	1 h	30 min	30 min	30 min	5 min

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

OSCAR values from Row 55 ID 711 Atmospheric density (High Thermosphere Layer).
COURL values are taken from Rows 110/111 – Neutral Density Profiles.

Sources/References supporting this objective and its attributes:

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

http://www.swpc.noaa.gov/sites/default/files/images/u33/ForbesMURIReviewSWW-April2013.pdf

Qian, L., S.C. Solomon, and T.J. Kane, 2009: Seasonal variation of thermospheric density and composition. *Journal of Geophysical Research-Space Physics*, **114**, 15 pp, DOI: 10.1029/2008JA013643.

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Objective: B19: Ionospheric Drift Velocity

Priority: 9 for Space Weather. Ionospheric drift velocity measurements are needed to determine plasma transport as an assimilation input for forecast models. There is no ST (or current) capability, implying relatively high priority for improvement.

Authors: Mihail Codrescu, Terry Onsager, and Nick Pedatella

Brief description: Ionospheric drift velocity measurements are needed for both operations and research in order to separate the influence of penetration and dynamo electric fields from neutral composition effects.

Use/Users: Estimating the effects of the ionosphere on the propagation of radio waves is critical for HF communications, GNSS positioning, navigation and timing applications. Ionospheric drifts are a required measurement for estimating the ionosphere effects. These data will be assimilated into coupled thermosphere-ionosphere models. The output of the models will provide specification and forecasts of neutral density for satellite orbit prediction and of ionospheric density for communication and navigation. Drift velocity measurements are also useful for observing, and possibly predicting, equatorial F-region irregularities.

Program of Record 2025 and current sources of data
Program of Record 2025: COSMIC-2 IVM
Current sources of data: C/NOFS

Impact of improving from ST to ME level: There is no civilian operational capability to measure the ionospheric drift velocity at this time. The measurements would constrain physics based models of the thermosphere ionosphere system and improve the specification and forecast of radio wave propagation for communications, positioning, navigation, and timing applications.

B19: Ionospheric drift velocity	*POR 2025 COSMIC-2 IVM*	*ST (None, lower bounds for scoring purposes)*	*Oscar Threshold*	*COURL Threshold*	*EXP*	*OSCAR Breakthrough*	*ME*	*OSCAR Goal*	*COURL Objective*
Refresh Rate	15 min	90 min	30 min	0.1 sec	30 min	5 min	10 min	1 min	0.05 sec
Latitudinal Coverage	72 deg	+/- 25 deg latitude	X	X	+/- 60 deg latitude	X	Global	X	X
Longitudinal Resolution	25 deg	90 degrees	X	X	30 degrees	X	15 degrees	X	X
Data Latency	15 min	30 min	60 min	15 min	15 min	1 min	5 min	1 min	5 min

NA: Attribute listed in COURL/OSCAR, but no values given
X: Attribute not listed in COURL/OSCAR

Comments and notes:

The longitudinal resolution refers to the desired longitudinal spacing assuming near-polar orbiting spacecraft. The longitudinal resolution given for the COSMIC-2 IVM refers to the longitudinal separation between subsequent 1-second cadence measurements along a 24-degree inclination orbit.

OSCAR values from Ionospheric Plasma Velocity, Row 234 ID 591.
COURL values from Rows 134/135 In-Situ Plasma Velocity: LEO.

Neither OSCAR nor COURL specify an altitude for these measurements, latitudinal coverage, or longitudinal resolution. They just specify measurements that would be made on a LEO satellite.

Measurements at low latitudes (<25 deg) should be made below 600 km. Measurements at mid latitudes (25 - 60 deg) should be made below 700 km. Measurements at higher latitudes should be made below 1000 km.

Sources/References supporting this objective and its attributes:

Heelis, R.A. and W. B. Hanson, 1998: Measurements of Thermal Ion Drift Velocity and Temperature Using Planar Sensors, Measurement Techniques in Space Plasmas: Particles, Geophys. Monogr. Ser., 102, AGU, 61, edited by R. F. Pfaff, J. E. Borovsky, and D. T. Young, pp. 61–71, AGU, Washington, D. C.

NOAA Consolidated Observing User Requirements List (COURL-2015vs2017v2-RA) (Space Weather Specific Tab)

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Excellent reference manual. Contains the following information:

Agencies	Agency **table** with links to agency summary pages.
Missions	**Table** Searchable mission table with links to mission and instrument summary pages. **Index** An alphebetical list with links to mission summary pages.
Instruments	**Table** Searchable instrument table with links to instrument and mission summary pages. **Index** An alphebetical list with links to instrument summary pages.
Measurements	**Overview** An overview of the measurement categories and detailed measurements indexed in the database.

	Timelines Customizable measurement timelines with links to mission summary pages.
Climate	**Overview** An overview of satellite contributions to climate monitoring in support of GCOS. **Index** An index of GCOS Essential Climate Variables linked to actions, status, and satellite measurements.

ESA, 2015a: ESA's Living Planet Programme: A New Era for Scientific Advances and Societal Benefits. *ESA SP-1329/1 (Vol. 1)*. European Space Agency, Noordwijk, the Netherlands. Available at: http://esamultimedia.esa.int/multimedia/publications/SP-1329_1/ A high-level strategy document for the European Space Agency that describes the importance of Earth observations from space. No specific recommendations on observing systems.

ESA, 2015b: ESA's Living Planet Programme: Scientific Achievements and Future Challenges. *The Scientific Context of the Earth Observation Science Strategy for ESA. ESA SP-1329/2 (Vol. 2)*. European Space Agency, Noordwijk, the Netherlands. Available at: http://esamultimedia.esa.int/multimedia/publications/SP-1329_2/

The Introduction of this document states: "This volume complements the *Earth Observation Science Strategy for ESA: A New Era for Scientific Advances and Societal Benefits* (ESA, 2015). It highlights specific scientific challenges to increase knowledge and capabilities in the Earth science disciplines. These discipline-based challenges are indicative of the scientific advances that will be needed to tackle the serious global environmental issues we now face. In the context of these new scientific challenges, this volume also summarises the achievements of ESA's Living Planet Programme with respect to the challenges set out in July 2006 in *The Changing Earth: New Scientific Challenges for ESA's Living Planet Programme* (ESA, 2006)."

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GCOS, 2015: Status of the Global Observing System for Climate. 358 pp. [Available online at http://www.wmo.int/pages/prog/gcos/Publications/GCOS-195_en.pdf

This comprehensive report provides an account of the current state of the global observing system for climate and an assessment of the progress that has been made in developing the system over recent years. It contains excellent background material of the importance and complexities of a global Earth observing system (including such topics as data management, international cooperation and data sharing, reanalysis), and although focusing on climate, is relevant for NOAA's entire operational observing system needs since there is a strong overlap between uses

of satellite observations for day-to-day operations and longer-term climate studies. It includes extensive discussion and references of how observations of key Earth parameters (e.g. temperature, water vapor, precipitation, clouds, ozone, sea ice, ocean color, wildfires) are obtained from space, as well as other in-situ and non-space-based observing systems. It does not recommend future observing systems except by implication as it describes the importance and use of existing observations. It does describe progress made since the 2010 GCOS report (GCOS, 2010a. Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update). GCOS (2010, Publication no. 138), which did provide specific recommendations on high-priority future observations.

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Web sites:

WMO Observing Systems Capability Analysis and Review (OSCAR) Tool:

- Main OSCAR page: http://www.wmo-sat.info/oscar/
- Overview of Space-based capabilities: http://www.wmo-sat.info/oscar/spacecapabilities
- Review of Satellite Observation Capabilities: http://www.wmo-sat.info/oscar/observingmissions (Lists the satellite observation capabilities as identified in the “Vision for the GOS in 2025” and the Implementation Plan for the Evolution of Global Observing Systems, or EGOS-IP.)
- Gap Analyses by Variable: http://www.wmo-sat.info/oscar/gapanalyses
- OSCAR Users Manual: http://www.wmo.int/pages/prog/sat/documents/OSCAR_User_Manual-22-08-13.pdf

- Space weather glossary: http://www.swpc.noaa.gov/content/space-weather-glossary

- Summary of observations used by NOAA Space Weather Prediction Center: http://www.swpc.noaa.gov/content/space-weather-glossary

- TPIO NOSIA Glossary: https://nosc.noaa.gov/tpio/main/nosia_glossary.html

Appendix G: Acronyms

ABI - Advanced Baseline Imager
ACARS - Aircraft Communication Addressing and Reporting System
ADT - NSOSA Architecture Development Team
AIRS - Atmospheric Infrared Sounder
AMDAR - Aircraft Meteorological Data Reporting
AOC - NOAA Aircraft Operations Center
ASOS - Automated Surface Observing System
AVN - Aviation model
AWIPS - Advance Weather Information Processing System
CBS - Commission for Basic Systems (WMO)
CERES - Clouds and the Earth's Radiant Energy System
CME - Coronal Mass Ejection
CONUS - Continental United States
COSMIC - Constellation Observing System for Meteorology, Ionosphere, and Climate
COTS - Commercial-Off-The-Shelf
COURL: Consolidated Observation Users Requirements List (previously CORL)
ECMWF - European Centre for Medium Range Weather Forecasts
ECS - External Control System
EDMC: NOAA Environmental Data Management Committee
EDR - Environmental Data Record
EUMETSAT - **Eu**ropean Organisation for the Exploitation of **Met**eorological **Sat**ellites
ESA - European Space Agency
EVM - Environmental Data Records (EDR) Value Model
FOV - Field of View
GAINS - Global Air-ocean IN-situ system
GEARS - Ground Enterprise Architecture System
GEMSEC - GSFC Mission Services Evolution Center
GIFOV – Ground-projected instantaneous field of view
GIFTS - Geosynchronous Imaging Fourier Spectrometer
GFS - Global Forecast System model
GOES - Geostationary Operational Environmental Satellite
GPM - Global Precipitation Measurement
GPS - Global Positioning System
GNSS-Global Navigation Satellite System
HES - High-Resolution Environmental Sounder
HPC - NCEP Hydrological Prediction Center
IASI - Infrared Atmospheric Sounding Interferometer instrument
IFPS - Interactive Forecast Preparation System
JCSDA - NASA/NOAA/Navy/Air Force Joint Center for Satellite Data Assimilation

LAPS - Local Area Prediction System
LEO - Low Earth Orbit
MAPS - Mesoscale Analysis and Prediction System
MESONET - Mesoscale Observing Network
MSAS - Mesoscale Surface Analysis System
METAR - Meteorological Aviation weather Report
METOP - (European Operational Polar Orbiting Weather Satellite)
MDAS - Modeling and Data Assimilation System
MODIS - Moderate-Resolution Imaging Spectrometer
MSA - NOAA Mission Service Area
MSAS - Mesoscale Surface Analysis System
NASA - National Aeronautics and Space Administration
NCAR - National Center for Atmospheric Research
NCEP - National Centers for Environmental Prediction
NCO - NCEP Central Operations
NDFD - National Digital Forecast Database
NEC - NOAA Executive Council
NEP - NOAA Executive Panel
NESDIS - National Environmental Satellite Data and Information Service
NMFS - National Marine Fisheries Service
NOAA - National Oceanographic and Atmospheric Administration NORPEX - North Pacific Experiment
NOS - National Ocean Service
NOSC - NOAA Observing Systems Council
NOSIA - NOAA Observing System Integrated Analysis (under TPIO)
NPOES - National Polar Orbiting Environmental Satellite System
NSOSA - NOAA Satellite Observing System Architecture
NRC - National Research Council
NSF - National Science Foundation
NSTC - National Science and Technology Council
NWP - Numerical Weather Prediction
NWS - National Weather Service
OAR - Office of Oceanic and Atmospheric Research
OPPA - NESDIS Office of Projects, Planning and Analysis
OSAAP - NESDIS Office of Systems Architecture and Advanced Planning
OSCAR - WMO Observing Systems Capability Analysis and Review
OSGS - NOAA Office of Satellite Ground Services
OSE - Observing System Experiment
OSSE - Observation System Simulation Experiment
OSTP - Office of Science and Technology Policy
PALMA - Portfolio Analysis Machine (model used by TPIO)
RASS - Radio Acoustic Sounder System
RRW - Rapid Refresh WRF model
RUC - Rapid Update Cycle
SAB - NOAA Science Advisory Board
SEE - Strategic Evaluation and Execution

SEM - Space Environment Monitor
SPRWG - Space Platform Requirements Working Group
SSCS - Storyboarding and Scenario Case Study
SREF - Short Range Ensemble Forecast
SRWF - Short Range Weather Forecast
SWORM - OSTP/NSTC Space Weather Operations, Research, and Mitigation Task Force
TCA - Transformational Communications Architecture
TDRSS - Tracking and Data Relay Satellite System
TES - Tropospheric Emissions Spectrometer
THORPEX - THe Observing-system Research and predictability experiment
TOR - Terms of Reference
TPIO - NESDIS Technology, Planning and Integration for Observations
TPC - Tropical Prediction Center
TRMM - Tropical Rainfall Measurement Mission
UAV - Unmanned Aerial Vehicles
UCAR - University Corporation for Atmospheric Research
VAD - Velocity Azimuth Doppler (Radar winds)
4DVAR - Four Dimensional Variational Assimilation
WFO - Weather Forecast Office
WIGOS - WMO Integrated Global Observing System
WMO - World Meteorological Organization
WRF - Weather Research Forecast Model
XRS - X-Ray Sensor (On GOES-8)