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The Integration of a Dual-Mission L1 Lagrangian Satellite into an Established Geostationary and Low-Earth Orbit Satellite Operational Framework

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The National Oceanic and Atmospheric Administration (NOAA) Office of Satellite and Product Operations (OSPO) has successfully operated and disseminated data for Geostationary (GEO) and Low-Earth Orbit (LEO) operational environmental satellite constellations for over fifty years. Satellites in both categories have typically provided Earth science data as their primary missions, with geostationary satellites yielding data for national, regional, short-range warning and immediate forecasting, and polar-orbiting satellites providing data for global, long-term forecasting and environmental monitoring. In 2015, after a hiatus of over a decade, and years of repurposing, the Deep Space Climate Observatory (DSCOVR), formally known as Triana, was launched and placed in a Lissajous orbit at the L1 Lagrangian point, and subsequently integrated into NOAA's Office of Satellite and Product Operations (OSPO) operational framework. With a primary mission of Space Weather Forecasting financed by NOAA, and a secondary mission of Earth Science Measurements financed by NASA, OSPO expanded its satellite operations footprint by inheriting its first deep space mission, setting the stage for the operation of future deep space constellations, and the subsequent expansion of OSPO operations beyond Earth weather forecasting. This paper outlines the challenges of developing and implementing a seamless integration of a L1 Lagrangian satellite, with a primary Space Weather Forecasting mission, into NOAA's Geostationary and Low-Earth Orbit Earth Weather Forecasting operational environment, and addresses various issues and aspects encountered when fulfilling the requirements for a satellite with both a primary and secondary mission, and two discrete end user organizations.

I. Introduction

> As the ancient myth makers knew we're children equally of the earth and the sky. In our tenure on this planet we've accumulated dangerous evolutionary baggage, propensities for aggression and ritual, submission to leaders, hostility to outsiders, all of which puts our survival in some doubt. But we've also acquired compassion for others, love for our children, a desire to learn from history and experience and a great soaring passionate intelligence, the clear tools for our continued survival and prosperity. Which aspects of our nature will prevail is uncertain, particularly when our visions and prospects are bound to one small part of the small planet Earth. But up there in the Cosmos an inescapable perspective awaits. – Carl Sagan, *Cosmos*

Perspective can mean several things:

1. The angle of direction in which an object is viewed
2. An accurate rating of what is important and what is not
3. A particular attitude toward or way of regarding something; a point of view
4. The faculty of seeing all the relevant data in a meaningful relationship

From space, perspective can be used to describe the manner in which we look back toward Earth, and on Earth it can be an integral part of how we engage with one another to better understand and accomplish a common goal. By

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employing the proper perspective, one can acquire insight, broaden his or her own perceptions, and view things in a different, often illuminating, light; yet, it is often difficult to remove oneself from his or her own viewpoint.

It is within human nature to become enveloped in a sense of self-importance, even taking the perspective that humanity is the center of the universe (at points even literally), especially given the considerable advancements mankind has made in many fields, including science and technology. For all of its accomplishments, it can be argued that humanity has the right to carry itself with a proud sense of self-righteousness, but it is easy to overlook the fact that there are forces in play outside of human control, and mankind can forget that its success is subject to the effects of the surrounding environment, sometimes with little or no notice. Knowing this, humanity learned that in order to have the best chance of success, it must break out of the delusion of isolation and, through collaborative efforts, account for all of the external impacts from its immediate and extended environmental surroundings. Immediate threats are often apparent and are more easily predictable or manageable; one can simply look up, ascertain that it is raining, and react appropriately, either by taking shelter, or planning alternate navigation. However, humanity soon learned that planning beyond immediacy would be required for successful endeavors, and thus the concept of weather predictability was created as a factor in preparedness.

For centuries, noble advancements were made in developing predictive capabilities with respect to weather events. Early civilizations used reoccurring astronomical and meteorological events to assist them with monitoring seasonal changes in the weather, including the Babylonians who utilized cloud patterns, and the Chinese astronomers who developed a calendar divided by different types of weather. As time passed, further attempts were made to produce forecasts based on weather lore and personal observations, but by the end of the Renaissance, it had become evident that the speculations of the natural philosophers were inadequate and that greater knowledge was necessary to further mankind's understanding of the Earth and its atmosphere. In modern times, the National Oceanic and Atmospheric Administration (NOAA), often in collaboration with the National Aeronautics and Space Administration (NASA), has pioneered the science of operating satellites used for Earth weather predictions, leading the nation, and often the world, in collecting and distributing important meteorological data. Over the years, NOAA has developed a comprehensive operational framework for measuring atmospheric Earth data through the use of a global suite of satellites. However, environmental threats extend far beyond that on Earth, and with this perspective NOAA realized that in order to develop a more complete picture of environmental prediction and protection, providing data for just weather on Earth was not enough; the Sun has its own climate, with the potential to impact daily life on Earth, and any climate can be predicted if measured correctly. So, with this perspective, NOAA set out to expand its realm of environmental predictions by turning its eyes away from the Earth and toward the Sun.

II. The Birth and Development of Climate Monitoring Satellites

In order to obtain the required advanced knowledge of Earth’s climate, mankind needed instruments to measure the properties of the atmosphere, such as moisture, temperature, and pressures, from a new perspective, and the means with which to use these instruments to gather the data. The first known proposition of using meteorological satellites fitted with these instruments was by Dr. Harry Wexler in 1954, when he stated “A satellite vehicle traveling about the Earth outside the atmosphere would not assist in portraying the pressure, temperature, humidity and wind fields by direct measurement. However, by a ‘bird’s-eye’ view of a good portion of the Earth’s surface and the cloud structure, it should be possible by interference to identify, locate, and track storm areas and other meteorological features.” [37] The first meteorological satellite experiment flew on the Explorer VII on October 13, 1959; the satellite was meant to measure solar data and cosmic rays, but had a secondary objective of studying the Earth-atmosphere heat balance, making it not only one of the first attempts to use satellites to measure meteorological data, but also the first satellite to have dual mission objectives of collecting both Earth and Solar data. The Explorer VII carried a flat-plate radiometer that took the first Earth radiation budget measurements from space and was one of the first experimental steps to determine if satellites could be useful in the study of Earth’s weather, as proposed by Dr. Wexler, officially starting the era of satellite studies of the climate. Scientists quickly developed capabilities to monitor weather on Earth to predict and account for meteorological phenomena, continually adapting to and taking advantage of technological advancements to further enhance these capabilities, and one organization soon emerged as a leader in meteorological data acquisition.

The United States Department of Commerce (DOC) Weather Bureau was established in 1870 with the purpose of taking meteorological observations at military stations across the continent and giving notice via telegraph and marine signals of the approach and force of storms. When the Weather Bureau moved under the Department of Agriculture in 1890, it expanded its operations to include issuing fire weather forecasts and flood warnings, and began outputting the first daily national surface weather maps. Additionally, it also established a network to provide warnings for tropical cyclones, laying the groundwork for modern-day hurricane predictions, and created an international data exchange service with European services, which is still utilized today.

In May of 1962, President Kennedy requested 53 million dollars for the Weather Bureau "to give us at the earliest possible time a satellite system for worldwide weather observation (since) (s)uch a system will be of inestimable commercial and scientific value, and the information it provides will be made freely available to all the nations of the world." [35] The Weather Bureau became part of the Environmental Science Services Administration (ESSA) when it was created in 1966. On October 1, 1970, the Weather Bureau became the National Weather Service (NWS), and ESSA was renamed the National Oceanic and Atmospheric Administration (NOAA), establishing the current framework of the NWS Line Office operating as part of NOAA operations. In August of 1980, the National Earth Satellite Service (NESS) was removed from the Office of Oceanic and Atmospheric Services and became a principal agency line organization in NOAA, reflecting the increasing importance of satellite observations in NOAA's environmental science and service responsibilities.

III. The Establishment, Qualification, and Evolution of the NASA and NOAA Partnership

After the *NASA Act of 1958* formally established NASA, the Chief of the Weather Bureau, Dr. Francis Reichelderfer, established the Meteorological Satellite Section (MSS), a branch of the Meteorological Satellite Research Unit established at the same time. Shortly after, the MSS relocated to Suitland, Maryland, and after operations began expanding, changed its name to the Meteorological Satellite Laboratory (MSL).

> The NASA Act of 1958, also known as the "Space Act," … created a new agency … to conduct the nation's civil space activities. The Space Act also provided NASA with the authority to enter into agreements with other U.S. government agencies, commercial entities, academic institutions, and other organizations. In particular, the Space Act authorize(d) and encourage(d) NASA to enter into partnerships that help fulfill its mission. [11]

In response to this new guidance, Dr. Wexler recognized the advantages of a working relationship with NASA and sent a memo to the Weather Bureau outlining a plan in which the Bureau would be formally designated as the meteorological agent for NASA, providing the meteorological instrumentation, data reduction and analysis of observations taken by satellites. This officially established a collaboration framework between the agencies under which NOAA would determine requirements, operate command and data acquisition stations, and process data for integration into weather analysis using satellites designed and launched by NASA. In the more than 50 years since the launch of the first weather satellite there have been many successful transfers of NASA research into NOAA operations, and through the years, the partnership between NASA and NOAA evolved through many phases, with collaboration efforts taking many forms, in varying degrees of success.

> Because NASA is a research and development agency, the long-term benefits of its contributions to operational decision support hinge on effective processes for transferring sensors to operational entities such as NOAA. NOAA has dual responsibilities in this regard: ensuring that it carries NASA sensor systems into full operation and that its requirements for NASA products are conveyed to and considered by NASA and its science community. The research-to-operations transition between NASA and NOAA has a long history, particularly with respect to weather monitoring and prediction. Despite some successes the overall NASA-NOAA relationship is mixed. [12]

Each agency maintains a significantly different perspective with respect to satellite goals and operations, complicating the growth of a successful working relationship. By definition, NASA is a mission-based agency with a perspective founded on the research, development, and launching of space-based instruments, and NOAA is a regulatory agency with a perspective on operations that draws on the results of research and serves external user communities and internal entities such as the National Weather Service. Operations are the basis for production and dissemination of official forecasts and warnings, while research, in addition to systems development, and technology development and implementation, is conducted to improve the skill of weather forecasts. An important aspect of NASA-NOAA collaboration is the transfer, or transition, of research to operations, and to make this transition work effectively, considerations need to be made in order to resolve and bridge these two, often conflicting, perspectives.

Research-to-Operations (RTO) transition collaborations between NASA and NOAA fall within five primary ***Categories of Implementation***; each category requires its own distinct transition pathway [19]:

A. **Meteorological System Upgrades**
B. **Algorithm and Data Product Improvements**
C. **NASA Systematic Measurements that Transition to NOAA Operational Measurements**
D. **NASA Exploratory Measurements that Transition to NOAA Operational Measurements**
E. **Technology Demonstrations that Transition to Operational Systems**

Through the years, NASA and NOAA have engaged in collaborative efforts in all of these categories, executing transition pathways to different levels of success. In this paper, the term "collaboration" is used to characterize the working relationship between NASA and NOAA; there are four main ***Types of Collaboration*** in increasing complexity (See Fig. 1):

1. **Use of Resources**
2. **Procurement of Services or Products**
3. **Coordination**
4. **Cooperation**

As shown later, the working relationship, i.e., collaboration, between NASA and NOAA has usually been classified under one of these four types, but as depicted in Fig. 1, there are previously undefined areas in between these types into which a collaborative effort can fall, complicating the selection and formation of the management and project integration approaches.

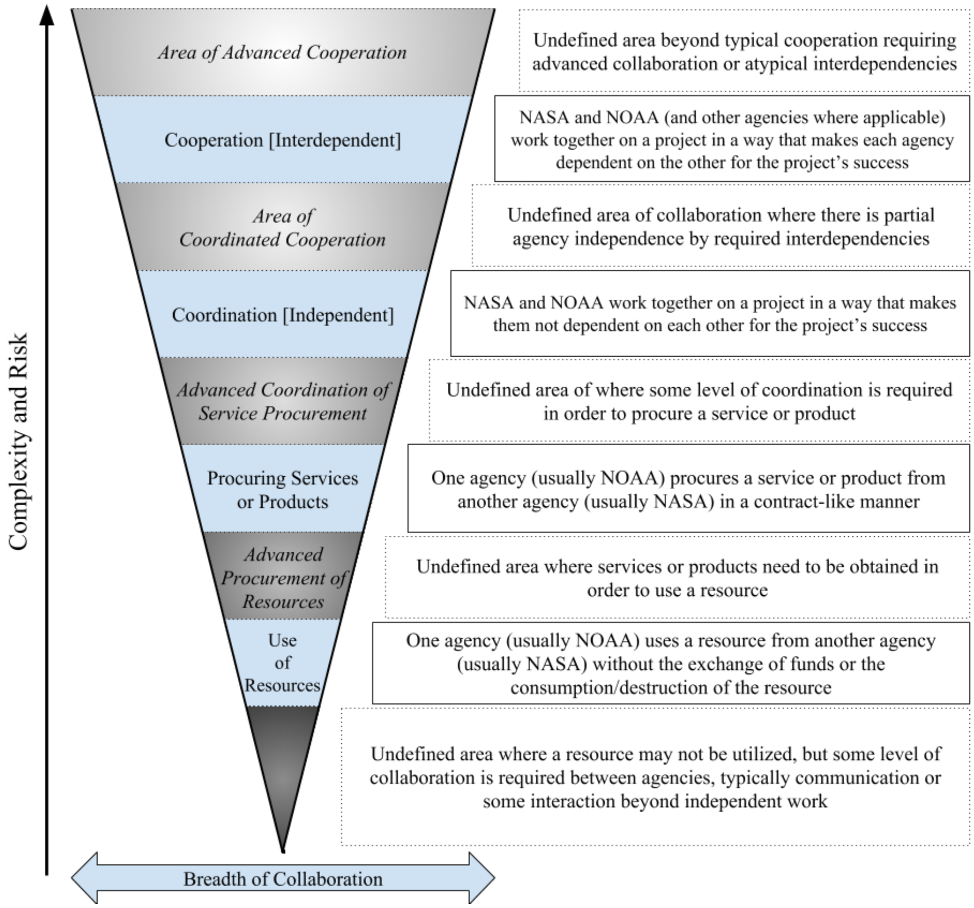


Fig. 1 Types and Complexities of Collaborative Relationships

Before implementing a working relationship, it is essential for one to resolve the required approach in order to avoid disruptions in the dynamic, delays in schedules, or destruction of the project. Mutual understanding between the two organizations is an important aspect of this partnership, as is addressing and resolving differences in approaches and perspectives. From the beginning of the NASA-NOAA partnership, there has been an ebb and flow of successful shared endeavors, but they all have stemmed from an underlying shared core perspective:

> NASA and NOAA share the motivation and need to transition research capabilities to operational status. Analyses of case studies indicate that effective transition pathways incorporate **strong management**, **well-defined transition objectives and plans**, **effective processes for performing the transition**, and **adequate human and fiscal resources** to accomplish the transition. [19]

With this in mind, a successful working relationship with respect to transition first needs to be defined by its

1. ***Type of Collaboration*** (to determine the management approach), and
2. ***Category of Implementation*** (to determine the scientific approach and transition pathway(s)).

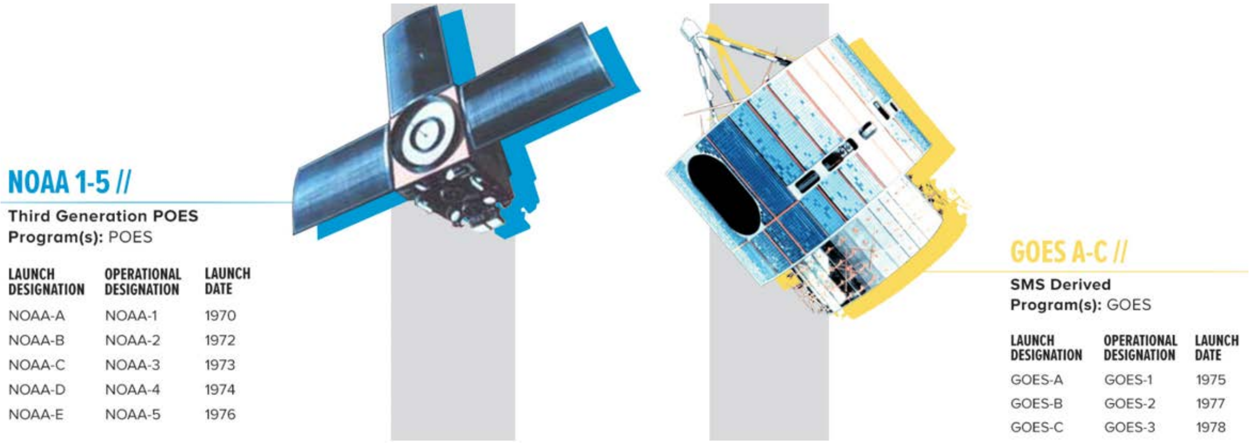
Once this is qualified, a successful transition of a new mission from research to operations can be designed and implemented. An analysis of how current and past NOAA operations have been transferred from NASA and then operated can lead to more effective transitions and implementations of additional satellite missions.

A. An Early Partnership and the Operational Satellite Improvement Program: 1962-1981

In one of the first concrete steps toward establish a lasting working relationship, the Weather Bureau entered into an agreement with NASA in January of 1962 via the Supplemental Appropriation Act, which stated that the Weather Bureau should make appropriated funds available to NASA for costs required to build and operate a satellite system. The Weather Bureau and NASA allocated and outlined the responsibilities for each agency in a 1964 Basic Agreement. "The agreement was worded similarly to a joint project, with the (Weather Bureau) funding the establishment and operation of what would eventually be titled the National Operational Meteorological Satellite System (NOMSS), and NASA providing acquisition services and research and development funding for new technologies that could be used to enhance environmental satellites" [10] Under this agreement, the Weather Bureau would determine requirements, operate command and data acquisition stations, and process data for integration into weather analysis, and NASA would design the spacecraft, operate launch sites, and coordinate launch operations. Through this arrangement, the Television Infrared Observation Satellite (TIROS) satellite was superseded in 1966 by the TIROS Operational Satellite (TOS) and in 1970 by the Improved TOS (ITOS); this agreement and subsequent successes established a pattern where NASA would fund the development, launch, and test of each new generation of satellite and NOAA would participate in the tests and then procure (via NASA) succeeding satellites in the series.

The success that followed led to a 1973 Basic Agreement between the DOC and NASA that contained many of the provisions of the 1964 Basic Agreement, but also included a section called "Memoranda of Understanding (MOU)" that stipulated that a separate MOU (or in some cases a Memorandum of Agreement [MOA]) be created for each major project. At the very least, these MOUs were to include "commitment of NASA and NOAA staff to be assigned directly to the project for planning, technical, and administrative monitoring, including resident representation at contractor facilities; definition of authority; reporting requirements; schedule; and commitment of resources (funds, facilities, etc.)." [10] However, despite this mandate, NOAA and NASA never established MOUs for their initial Low-Earth Orbit (LEO) and Geostationary (GEO) satellites under the 1973 Basic Agreement. Additionally, the 1973 Basic Agreement not only outlined the relative roles of each agency, but also led to the establishment of the line item for the Operational Satellite Improvement Program (OSIP) in the NASA budget. As a result, NOAA never made a provision in their budget to fund the research and development costs of new satellites, or any other capabilities beyond small incremental changes to space and ground systems, which proved problematic in the future.

Nevertheless, the 1970s saw a highly successful partnership between NASA and NOAA which laid the groundwork for the core components of the NOAA satellite operations framework. The experimental Synchronous Meteorological Satellite (SMS) was launched in 1974 and led to the Geostationary Operational Environmental Satellite (GOES) series, with the first GOES satellite launched on October 16, 1975 (see Fig. 2). Additionally, NASA funded the move to the TIROS-N class satellite, with the first of the series launching on October 13, 1978, as well as the enhancement of the satellite that became the Advanced TIROS-N (ATN) launched for the first time on March 28, 1983, paving the way for what became the Polar Operational Environmental Satellite (POES) series. These two series became the two early pillars of NOAA operations that stood for decades.



NOAA 1-5 //
Third Generation POES
Program(s): POES

LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
NOAA-A	NOAA-1	1970
NOAA-B	NOAA-2	1972
NOAA-C	NOAA-3	1973
NOAA-D	NOAA-4	1974
NOAA-E	NOAA-5	1976

GOES A-C //
SMS Derived
Program(s): GOES

LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
GOES-A	GOES-1	1975
GOES-B	GOES-2	1977
GOES-C	GOES-3	1978

Fig. 2 POES and GOES Initial Series of Satellites

Although the agencies continued to work well together into the early 1980s, there was always the underlying fact that operating entities generally worked on longer time constants than research organizations, and so in a parallel, almost divergent effort, that resulted from NASA's mandate to produce new technology rather than to await a user need, NASA initiated and continued to fly its own series of Nimbus research satellites. Since both the new approaches and the higher costs of the Nimbus series were more than could be digested by NOAA's Weather Bureau, NOAA continued to employ the TIROS series after the Nimbus series began. Soon after, the partnership between NASA and NOAA began to change:

> The two agencies were essentially partners in fashioning the operational weather satellite system, with NOAA (at least initially) playing the role of junior partner. As the capability of the NOAA satellite service increased, it was probably inevitable that NASA management would begin to think of the operational program as '"their" program, not "ours." And when budget pressures increased, perhaps it was inevitable that NASA management would view the funds spent in support of the operational program as a burden when compared to more "NASAlike" research. [14]

NASA was faced with expanding funding needs to support its own programs, but there was also building in the agency a distaste for the operational missions, since research missions and human exploration missions were not burdened with the time-consuming cost-benefit analyses that were required for applications, or operational, missions utilized by NOAA. Financial limitations and divergent approaches soon fostered a perspective of “Us” verses “Them” between the agencies. In other words, when all of the available time and money could be devoted and utilized on in-house missions, NASA began to question the benefit of allocating funds and resources to tasks that were essentially the responsibility of another agency. As noted by the National Research Council (NRC):

> NASA and NOAA cooperation became less effective over time. During the transition to the Reagan Administration in 1981, NASA faced cost overruns with ongoing programs and began to spend more of the available resources, including the line item that was used for NOAA development, on the Space Shuttle. As internal pressures mounted, NASA decided not to fund development of NOAA operational sensors and spacecraft. With the concurrence of the Office of Management and Budget, NASA eliminated the budget line used to fund development ... for NOAA systems. [14]

With that, the Operational Satellite Improvement Program (OSIP) was terminated, and with it, the ability of the operational weather satellite program to deploy innovative instruments used to observe the atmosphere from space by taking advantage of the excellent engineering capability of NASA without cost. However, as the NASA program in meteorology gradually became oriented more toward basic science, and turned away from operational goals, NOAA moved forward as the leader in weather prediction and forecasting at the end of the 20th century.

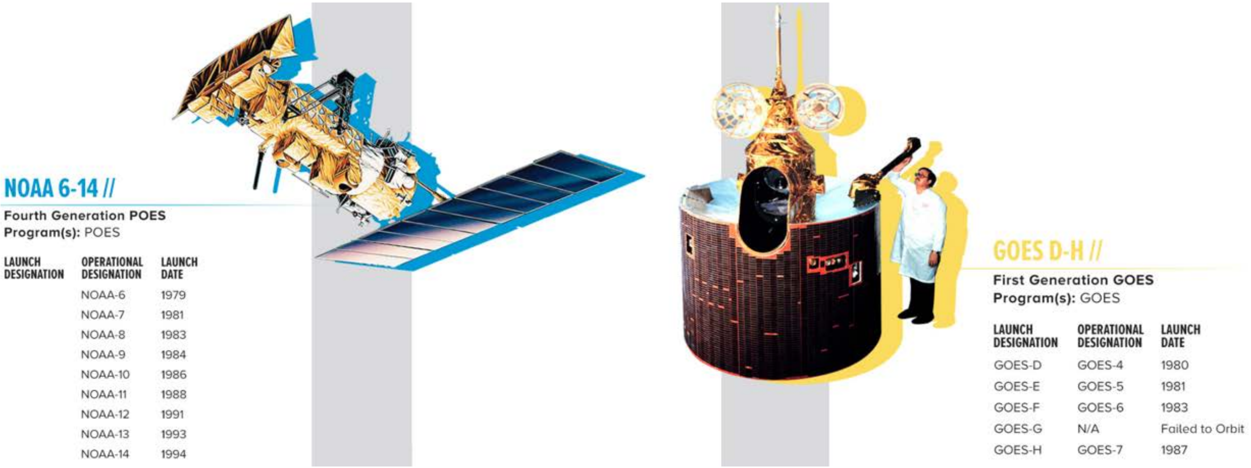
B. Navigating a Relationship beyond the OSIP: 1982-2000

Once the OSIP was dissolved, NOAA found itself at a disadvantage, having lost an arrangement that had been the backbone of their technological development in the field of satellite operations.

> The elimination of OSIP impacted NOAA’s ability to access the requisite engineering support and expertise to design, develop, and test new spacecraft and instrument technologies before incorporating them into the agency’s operational satellite systems. (M)any of the technical problems that plagued GOES-Next development could have been addressed and resolved more efficiently and less expensively within the context of a smaller, experimental precursor program, such as OSIP. [11]

NOAA had to develop a new approach for implementing and maintaining satellite operations, gaining a new perspective on their relationship with NASA, and recognizing that “two forces—the mission to meet operational requirements and the opportunities to improve and expand predictive capability and services—create a dynamic tension that is inherent in decisions about how and to what extent NASA research and technologies can be transitioned into NOAA’s operational service system.” [19]

Beginning in 1982, NOAA developed a formalized upgrade process for their sensor capability, primarily for the POES and GOES systems, which met immediate requirements, but had some drawbacks. “NOAA never developed a replacement for OSIP; instead it continued with a procurement practice of specifying the instrument performance and having the contractor delivery the instrument for flight on the operational satellites. This procedure did not allow for the iterative development process that was so successful in the OSIP program.” [17] The goal of this process was to implement either incremental or major upgrades to existing sensors, and/or develop and insert new sensors if/when they were needed. Under this arrangement, NOAA delegated the authority to NASA to initiate the procurement of the POES and GOES systems on the basis of NOAA requirements and budgets, choosing to maintain the working relationship with NASA as opposed to seeking alternative options. However, although established procedures between NASA and NOAA were in place for major parts of this process, they were “largely derived from historical precedent developed over the multi-decade POES and GOES collaboration rather than being carefully developed and documented procedures.” [19] As a result, shortcomings in the processes led to plans that were difficult to implement or were not established in a timely manner. The deterioration of the relationship between NASA and NOAA, and the resulting effects, did not go unnoticed, and in 1985 the NRC’s Space Application Board (SAB) wrote that “(t)he successful weather satellite system in NOAA has been severely affected by programmatic reductions, by stretch-outs in satellite procurement, and by reduced cooperation between NOAA and NASA.” [14]



NOAA 6-14 //

Fourth Generation POES
Program(s): POES

LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
	NOAA-6	1979
	NOAA-7	1981
	NOAA-8	1983
	NOAA-9	1984
	NOAA-10	1986
	NOAA-11	1988
	NOAA-12	1991
	NOAA-13	1993
	NOAA-14	1994

GOES D-H //

First Generation GOES
Program(s): GOES

LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
GOES-D	GOES-4	1980
GOES-E	GOES-5	1981
GOES-F	GOES-6	1983
GOES-G	N/A	Failed to Orbit
GOES-H	GOES-7	1987

Fig. 3 Fourth Generation POES and First Generation GOES Series

Despite this deterioration, the partnership continued, with NOAA-10 launching in the fall of 1986, and the POES K, L, and M (i.e., NOAA-15, -16 and -17) development contract signed on July 26, 1988, and then modified on December 16, 1994 to accommodate POES N and N-Prime (i.e., NOAA-18 and -19). In between the contract modifications, NOAA-12, NOAA-13 and NOAA-14 (see Fig. 3) were launched on May 14, 1991, August 9, 1993 and December 30, 1994, respectively. The early nineties also saw a string of rapid successes in the GOES series that promoted a steady pace of continuity in satellite operations, with GOES-8 launching on April 13, 1994 and GOES-9 launching on May 23, 1995.

Collaboration Type 2: *Procurement of Services or Products* - POES and GOES Series: NOAA's procurement from NASA of launch services and acquisition of instruments and spacecraft for the POES and GOES programs was an example of this type of collaboration (*Procurement of Services or Products*), which is the second lowest level of complexity and risk. The 1998 MOUs between NASA and NOAA for cooperation in the POES and GOES programs described the multi-agency process used to design and develop the operational POES and GOES systems, in which NOAA procured NASA spacecraft, instruments, and launch services to accomplish its operational objectives. Specifically, NOAA established requirements, provided all funding, and distributed the environmental satellite data for the United States, while NASA managed the procurement, design, development, and launch of the spacecraft and its instruments. There is a clear division between research and operations in this model, with typically no cross-involvement.

In May 1994, the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program was instituted between NASA, NOAA and the Department of Defense (DOD), via a MOA signed in May 1995, to merge POES with DOD's Defense Meteorological Satellite Program (DMSP). The agencies established the NASA NPOESS Preparatory Project (NPP), a new collaborative effort to transfer NASA Earth Observing System (EOS) instruments to NOAA's NPOESS, to provide collaborative management, and serve as a bridge to transition research capability into operational systems. They also established the NPOESS Integrated Program Office (IPO) as a tri-agency partnership, with NASA tasked to jointly develop and manage NPP for the benefit of all the involved organizations, and individual agencies responsible for funding, managing and developing specific portions of NPP on a "no exchange for funds" basis. This latter stipulation required each partner to be responsible for all costs incurred for the mission segments under its area of responsibility. At the time, many considered the IPO the leading example of how a collaborative effort should be managed; however, a later study determined deficiencies in this model that eliminated it as an example of optimal collaboration, stating that "the primary objective in forming the NPOESS IPO was to address the duplication problem caused by largely similar NPOESS and DOD operational polar environmental satellite programs--not to address the broad research-to-transition problem…(and) the IPO (did) not itself represent the needs and requirements of the user community, but rather (had to) seek them elsewhere within NOAA..." [19]. Regardless, the agencies pressed forward in the late nineties to continue the development of the mission, initially focusing on a launch in the 2006 timeframe.

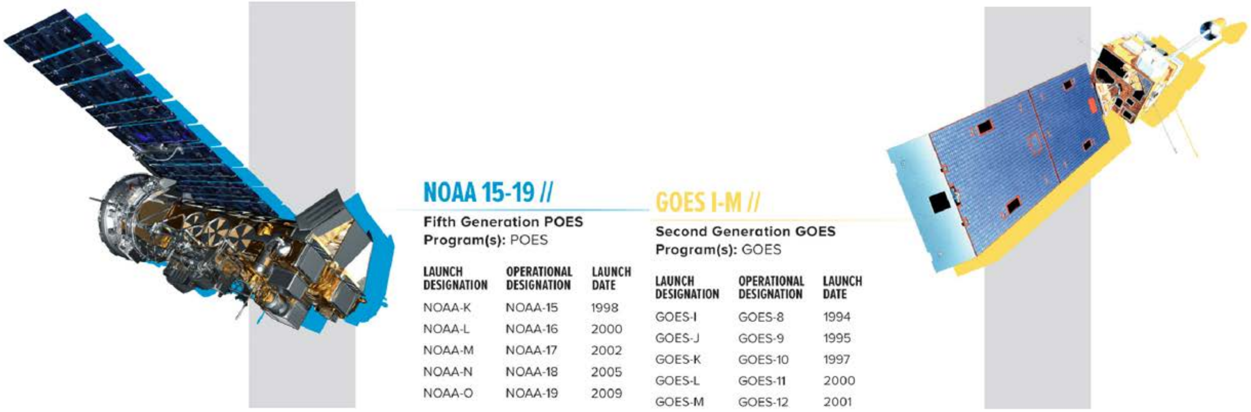
While the collaborative efforts between the agencies continued with enough success to launch additional POES and GOES spacecraft, a study by the NRC in 1995 assessed the state of the NASA-NOAA partnership, ten years after the SAB's initial review.

> In the environmental satellite programs of NOAA, no systematic program has been formed to replace the NASA Operational Satellite Improvement Program (OSIP) … upon which NOAA had relied. In its stead, the U.S. operational weather satellite program has only a limited internal research and development arm addressing needed improvements in the current generation of sensor systems and requirements for the next generation of sensors. [14]

However, research and operations pressed forward, with GOES-10 launched on April 25, 1997, and NOAA-15 (see Fig. 4) launched on May 13, 1998, as did the evolution of the partnership, with additional POES and GOES agreements signed in March 1998, and a Basic Agreement signed in June 1998 to expand both satellite constellations. The 1998 Agreement, which was updated to account for the elimination of the NASA Research and Development (R&D) funding in the 1980s, superseded the 1973 Basic Agreement.

> The (1998) Basic Agreement serve(d) as an umbrella agreement for establishing the NOAA and NASA desire to work together collaboratively. Two separate but virtually identical agreements discuss(ed) the specific POES and GOES projects. Under provisions of the 1998 POES and GOES agreements, NOAA (was) responsible for defining the requirements and operating the satellites after they (had) been successfully launched. NASA use(d) its technical expertise to manage the development effort and launch the satellites. NOAA receive(d) the appropriation for acquiring the satellites and in turn, provide(d) funding to NASA. Both agencies play(ed) a role in overseeing the aspects of the development; however, NASA (was) the single official interface with the spacecraft, instrument, and launch service contractors. [10]

While this new agreement outlined the importance of a collaborative partnership between NASA and NOAA, it removed the requirement that NASA fund research and development efforts. It also included a more specific legal authority, the Joint Project Authority, 15 U.S.C. 1525, which enabled NOAA and NASA to work together on a project of mutual interest in which the agencies divided the cost equally.



NOAA 15-19 //

Fifth Generation POES
Program(s): POES

LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
NOAA-K	NOAA-15	1998
NOAA-L	NOAA-16	2000
NOAA-M	NOAA-17	2002
NOAA-N	NOAA-18	2005
NOAA-O	NOAA-19	2009

GOES I-M //

Second Generation GOES
Program(s): GOES

LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
GOES-I	GOES-8	1994
GOES-J	GOES-9	1995
GOES-K	GOES-10	1997
GOES-L	GOES-11	2000
GOES-M	GOES-12	2001

Fig. 4 Fifth Generation POES and Second Generation GOES Series

Simultaneously, the NOAA Space Weather Prediction Center (SWPC) (formally the Space Environment Center [SEC] until 2007) began utilizing data from NASA's Advanced Composition Explorer (ACE), a satellite launched on August 25, 1997 and placed in orbit at L1 on December 12th, to provide solar weather forecasting. While NOAA did not operate ACE (as they did the POES and GOES series) they coordinated with NASA in a lower form of collaboration, and introduced NOAA to the utilization of spacecraft beyond geostationary and polar orbits. Since NASA was tasked with operating the spacecraft after commissioning, NOAA did not participate in pre-launch activities for ACE, acting in a more passive role as a basic customer receiving services. As such, this simplified the collaborative arrangement greatly, reducing the risk of delays or failures to transition from research to operations (since agencies on both sides were effectively the same, i.e., NASA). However, lessons learned from the relationship under the ACE mission, and from the use of its data, proved beneficial in laying the groundwork for collaborative efforts on deep space missions. At the time, the near-real-time reporting of space weather using a subset of data from four scientific instruments at L1 was both innovative and unique. ACE carried the first Real Time Solar Wind monitor for NOAA/SEC, and introduced NOAA to a major application of environmental measurements other than those obtained from Earth.

At the turn of the century, after the launch of GOES-11 on May 3, 2000, and around the time of the launch of NOAA-16 on September 21, 2000, the Office of Inspector General (OIG) released a report which showed that many of the agreements implemented between agencies had been "improperly or haphazardly completed making them difficult to implement." [10], with their report focusing specifically on the two MOAs between the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) and NASA. In their report they noted that NOAA had not followed existing guidance when creating the agreements in 1998 for the POES and GOES programs, nor did they provide the required justification for using NASA as the procurement source (as required by provisions for the Economy Act), stating that "(c)onducting the analysis and having the appropriate acquisition review would (have) help(ed) to ensure that NESDIS (was) acquiring the satellites in the most convenient and economical fashion as required by acquisition regulations." [10] Additionally, the report determined that existing (and future) agreements could be improved significantly by implementing standards that better outlined management structuring and quality assurance guidelines. They found that "additional steps could be taken to more precisely identify parties responsible for each activity (since) this type of information assigns accountability and ensures that appropriate management controls are in place to accomplish the work." With respect to quality assurance, they noted that a better definition of NOAA oversight of NASA work could help ensure that work was performed in a timely manner and produced results that met NOAA's standards or requirements. The report also remarked that when NESDIS officials were asked how they ensured that NASA and their contractor(s) were accomplishing the tasks, NESDIS provided a detailed listing of meetings and events that had been used to monitor project execution. The recommendation was to place these activities and responsibility allocations in the MOUs as they would be beneficial for strengthening the project management.

Collaboration Type 1: ***Use of Resources*** **- Space Weather Data from the Advanced Composition Explorer:** An example of the least complex and least risky arrangement is NOAA's use of space weather data acquired by the NASA Advanced Composition Explorer (ACE) spacecraft. Since the launch of ACE in 1997, the importance of space weather data collection has grown significantly, yet the development of resources to support this has failed to keep up, as outlined in a previous study:

> Difficulties in ensuring the availability of real-time solar wind data beyond the mission lifetime of ACE are illustrative of a problem more frequently associated with the Earth observation programs of NASA and NOAA: failure to manage a timely transition from research to operations. Although recognition of this issue is long-standing, budget pressures and disputes about agency roles and responsibilities have worked against the development of timely solutions. [11]

The ongoing arrangement for NOAA's use of NASA's ACE data (i.e., *Use of Resources*) is of the lowest level of complexity and risk since one agency uses a resource from another agency without the exchange of funds or the consumption/destruction of the resource.

In general, research has shown that major components of successful partnerships between NASA and NOAA included early and continuous inclusion of NOAA in development activities, sufficient oversight, and partnered management. An initial study in 2000 attempted to key in on and resolve deficiencies in the partnership that were hindering mission growth and success; although the study focused on one specific mission, it made recommendations that were applicable for transitioning from research to operations for any mission.

> Robust programs of technologic development, exploratory sensor development, and research missions at NASA are needed to enable a continuous push toward improved capability and innovative product development. In turn, a continuing process similar to the former OSIP can assess the state of research and operational technology and update (NOAA) as needed to accomplish its national mission. This requires a more coordinated plan for research and technologic innovation that includes coherent budget and timing links for a transition to operations. [17]

Although the study focused heavily on analyzing the dynamic of the NPP endeavor, it launched additional studies into the NOAA and NASA partnership. These studies also yielded recommendations to replace the OSIP with a mechanism that fostered growth, cooperation, and positive feedback between NASA and NOAA at a time when such a mechanism was needed to ensure NOAA could keep up with technological advancements and provide the best weather forecasting data leading into the 21st century.

C. Refocusing the NASA-NOAA Partnership in the 21st Century: 2001-2011

As NOAA entered a new millennium, the old NASA-NOAA collaborative framework of the 20th century persisted, producing the launch of GOES-12 on July 23, 2001, and NOAA-17 on June 24, 2002, and fostering progress for NPP development. However, the agencies recognized potential for improvements in multiple areas with respect to transitioning between NASA and NOAA. In order to prepare themselves for an accelerated pace of technical advancements that would test their abilities as pioneers in weather forecasting satellite operations, NASA and NOAA tasked the NRC's *Committee on NASA-NOAA Transition from Research to Operations* in 2003 to perform an evaluation by doing the following [19]:

> 1. Review the potential layers of new users for future operational measurements and assess the implications of the future set of user communities in terms of future needs and approaches for transitioning from research to operations
> 2. Examine examples of the heritage of current NOAA satellite sensors, capture the lessons that can be gleaned … and review possible approaches that would smooth and speed the path from … research … to … an operational satellite
> 3. Recommend principles for determining what levels of in-house capability will be required within NASA and NOAA … to ensure that there is a spannable distance between R&D experts and operational users
> 4. Recommend means to implement a more systematic transition process that might shorten the cycle time for major program changes and makes the system more responsive to user wishes (including) still closer collaborations between NASA and NOAA (and) increased resources within NOAA for the conduct of instrument and satellite development

The study, which examined past collaborative efforts, was the most extensive and complete review of the NOAA and NASA partnership to date. In considering expansion beyond the existing framework, with respect to upgrades, or major additions beyond the existing POES/GOES operational structure, the study noted:

> Transitions have been largely implemented on an ad hoc, case-by-case basis rather than as part of an overall plan. While an effective relationship between NOAA/NESDIS and NASA/GSFC (Goddard Space Flight Center) has been established for procurement and incremental upgrades of the POES and GOES satellites, the relationship has been less successful in planning and implementing major system upgrades. [19]

The study also provided an updated analysis of the ongoing NPP endeavor with respect to its applicability as a model for future collaboration, taking note of its successes, but also of its shortcomings as a universal template for transition collaboration.

> The NPP project offers a method for transitioning some of the recently developed sensors from NASA to NOAA. In some respects NPP fulfills some of the important characteristics of the former OSIP program; however, it is presently planned as a single mission … (and) additional effort is still required for an effective national program of transition. [19]

From this perspective, recommendations were provided, primarily that an Interagency Transition Office (ITO), in lieu of an expansion of an IPO model, should be established to manage the planning and coordination of activities in support of transitioning research to operations for missions in general.

The study noted that without strong influence by the IPO over NASA research activities, the ability of the IPO to plan transitions was no more effective than the current system, and created an imbalance in the transition dynamic with all of the authority on the operations side. In contrast, the ITO streamlined transitions by taking advantage of existing frameworks and infrastructures within each agency, rather than instituting redundancies, and facilitated progress for any mission, independent of function or purpose. Without expanding the IPO role as already established, the IPO could not serve as an entity with responsibility for the end-to-end transition process, particularly with regard to representing the end user.

> Transition pathways between NASA and NOAA will continue to require a wide-ranging set of approaches, as each research concept and operational need will be associated with its own matrix of both opportunities and obstacles. NASA and NOAA have worked for more than two decades to improve these modes of transferring research into operations, but have been faced with "too many degrees of freedom" in trying to match the NASA research and NOAA operational programs as a whole. In the past 10 years, NASA has focused on climate monitoring and, consequently, separated itself to some extent from its historical role of transitioning weather prediction research capabilities to NOAA operations. [19]

The ideal dynamic between the two agencies for any given collaborative endeavor as suggested via the ITO framework is depicted visually in Fig. 5.

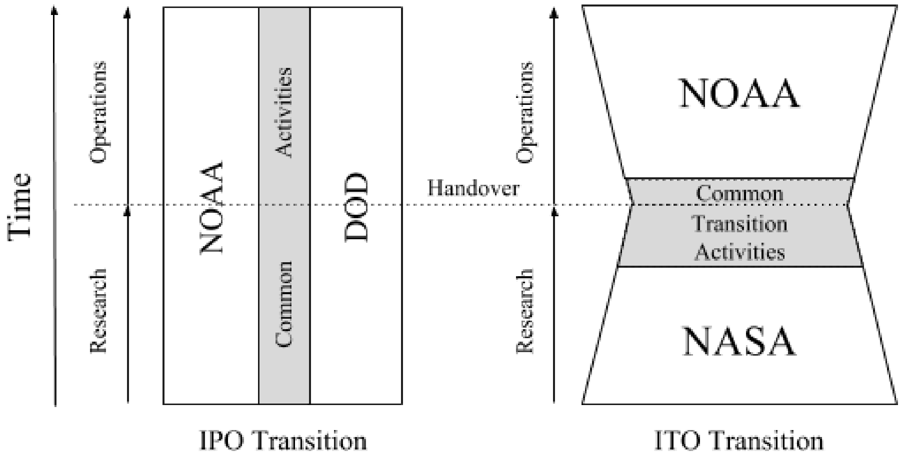


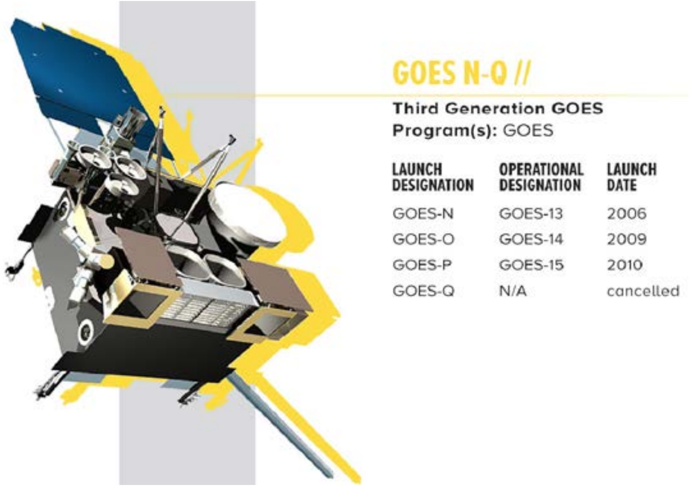
Fig. 5 IPO Model versus NASA-NOAA ITO Transition Dynamic

The horizontal “gray area” in the ITO dynamic encompasses a wide range of missions and capabilities, occurs at the handoff between research (NASA) and operations (NOAA), and is the primary focus of this paper. Past studies have provided minimal insight into the framework and content of the gray area, where the agencies work in tandem in the overlap between research under NASA and operations under NOAA, yet this is where the majority of issues are encountered. This gray area required major expansion and analysis in order to structure it in the most efficient manner to facilitate a successful transition.

Operationally, the remainder of the decade saw additional progress, including the launch of NOAA-18 on May 20, 2005, as well as additional guidance, including the stipulation in the NASA Authorization Act of 2005 which stated that “the (NASA) Administrator and the Administrator of (NOAA) shall appoint a Joint Working Group, which shall review and monitor missions of the two agencies to ensure maximum coordination in the design, operation, and transition of missions where appropriate” and that both Administrators should “evaluate relevant NASA science missions for their potential operational capabilities and … prepare transition plans for the existing and future Earth observing systems found to have potential operational capabilities.” [7] What resulted from this guidance was the successful launch of GOES-13 (see Fig. 6), the first in the Third Generation GOES Program, on May 24, 2006. However, as work continued on subsequent satellites in that program, the NRC conducted a follow-up study in 2007, and noted that the same residual impediments still existed:

> NASA … has (no) formal mechanism to plan missions that support NOAA’s operational activities, or to transfer sensor-level components directly to users in these areas. There is no doubt that some significant successes in research-to-operations transitions have occurred in spite of the lack of overarching formal arrangements, of requirement-generation processes, and of dedicated funding. Personal relationships and hard work of individuals on science teams and joint working groups have provided the foundation to overcome some of these issues and have led to the successes of this partnership. However, the informal background to the successes is problematic in that it causes peaks and valleys in the achievement curve and greatly affects the confidence of users and the rest of the community in the continuity and strength of individual programs. [12]

The study, like the others, argued that progress was hindered by lack of organization, but also conveyed that the perception portrayed to the community because of this was one of a lack of joint cooperation. There would be no better example of what can happen because of poor transition coordination than the eventual fate of NPOESS/NPP.



LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
GOES-N	GOES-13	2006
GOES-O	GOES-14	2009
GOES-P	GOES-15	2010
GOES-Q	N/A	cancelled

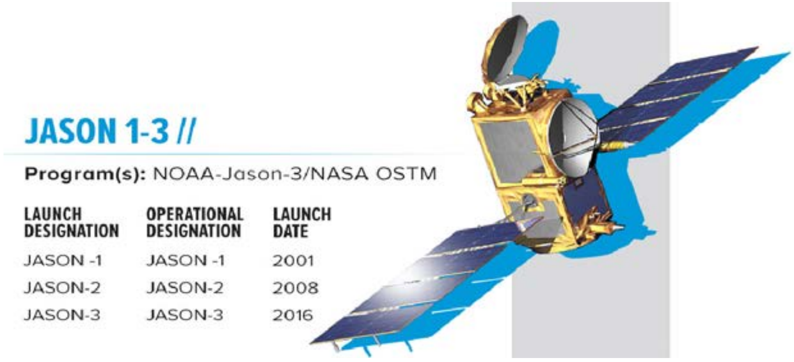
Fig. 6 Third Generation GOES Series

By November 2005, it became apparent that NPOESS would overrun its cost estimates by at least 25 percent, triggering a Nunn-McCurdy termination review by the DOD. In June 2006, a certified NPOESS program emerged from review. The certified program reduced the planned acquisition of six spacecraft to four, delayed the launch of the first spacecraft until 2013, and refocused the program on core requirements. As a result, several sensors were canceled or de-scoped in capability, and secondary sensors designed to provide crucial continuity to long-term climate records were not funded, which would not be the last time that secondary climate-monitoring Earth Science instruments would be subject to cancellation. The president’s fiscal year 2011 budget, announced on February 1, 2010, stipulated that the agencies dissolve the NPOESS satellite partnership, and pursue two separate lines of polar-orbiting satellites instead. The NOAA/NASA portion was called the Joint Polar Satellite System (JPSS). The Defense Department's portion was called the Defense Weather Satellite System (DWSS), but was eventually cancelled in January 2012.

Collaboration Type 4: ***Cooperation*** **- NPOESS:** The National Polar-orbiting Operational Environmental Satellite System (NPOESS) program, with its complex, multi-agency governance and acquisition arrangements was an example of *Cooperation*, whereby two or more agencies work together on a project in a way that makes each agency dependent on the other for the project's success. This type of partnership has the highest level of complexity and risk of failure. As specified in a MOA for the project, the NPOESS program was to be managed by an integrated program office (IPO) consisting of three agencies, NASA, NOAA and the DOD. NASA had the lead responsibility for improving the remote sensing capabilities of the operational system through the insertion of new technologies, NOAA had the lead responsibility for satellite and ground segment operations, and DOD had the responsibility for component acquisitions that were necessary to execute the acquisition program baseline. The MOA also specified that the DOC (NOAA) and the DOD (Air Force) were to share equally the funding for NPOESS at the program level, with part of the Air Force share residing in the launch vehicle. These program and funding arrangements were unique within the federal government, but there were significant differences in the risks and costs for each partner. This illustrates another level of complication that can become an impediment to collaboration, and ultimately determine the success or failure of a mission.

After the project was dissolved, NASA performed an assessment of NPP, focusing primarily on their management of the project itself. Firstly, they noted that although they met schedule and technical requirements for producing the spacecraft and instruments, other partners under the IPO were unable to deliver instruments before the outlined deadlines, which resulted in a 5-year launch delay and more than a 50 percent increase in costs. Secondly, they faulted the "no exchange for funds" arrangement because it did not impose financial liability on a partner that encountered challenges which directly increased costs for another partner. NASA noted that although the Final Implementation Agreement allowed the partners to amend the terms of the agreement at any point, to potentially change or remove this stipulation, there had been no effort to make such a revision; NASA management cited a mutual spirit of collaboration that was agreed upon at the onset of the agreement. In other words, including language to make partners liable for cost of delays would have been contrary to the collaborative intent of the agreements and dissuaded partners from participating, thus impacting NASA's ability to accomplish missions that required such a partnership. However, a review of other MOAs for other partnerships, including those for the GOES missions, had not included cost-sharing provisions, yet were moderately successful. These findings and the failure of the project contributed to the ultimate dismissal of the IPO model as a successful template for transition.

Although NPP was a prime example how a collaborative effort can fall apart when the complexity and risk of the collaboration type is not properly considered, NOAA had one of its most successfully managed projects with JASON-2 (see Fig. 7). Launched on June 20, 2008, JASON-2 was the result of a collaborative effort between NOAA, NASA, France's Centre National d'Etudes Spatiales (CNES) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). While the predecessors, JASON-1 and TOPEX/Poseidon, were operated by NASA, NOAA earned the right to operate JASON-2, a move indicative of the shift of meteorological satellite operations from NASA to NOAA, and one in line with a 1998 NRC report which "recommended that the continued monitoring of climate variables be a specific mission of the operational satellite programs of NOAA, in contrast to the research satellite programs of NASA." [17] The collaborative effort for the JASON-2 mission was of the "*Cooperation*" type, and was one of the first transition efforts where the end user of the satellite was heavily involved early in the mission, something that proved to be essential in its success.



LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
JASON -1	JASON -1	2001
JASON-2	JASON-2	2008
JASON-3	JASON-3	2016

Fig. 7 JASON Series

Just as NASA provided an analysis of why the NPP endeavor had not worked, NOAA performed a similar assessment to document where JASON-2 had succeeded, and where improvements could be made. Engineers on the Engineering and Mission Operations Support Services (EMOSS) contract, the primary contract that has executed satellite engineering and management support for NOAA missions since 2000, worked with NASA as contractors for NOAA to execute mission management and transition activities. The JASON-2 EMOSS team was involved from the planning stage, through the development process and into the deployment into operations, and noted many areas in which the project succeeded, citing strong collaborative efforts, frequent and open correspondence, and a firm dedication to maintaining schedule milestones. The team also noted lessons learned from the process, including early consideration of IT security, regular reviews of project schedules, a well-established operations concept, full dedicated staffing for transition activities from all relevant branches of NOAA, intermediate documentation deliveries to ensure compliance during development, and complete consideration of applying automation where possible. While some of the lessons learned were specific to the mission, many were general notes on coordination, planning and staffing, and outlined the fact that although the mission was highly successful, the rudimentary requirements for successful transitioning as outlined in multiple studies were still lacking in the NASA-NOAA relationship for this mission.

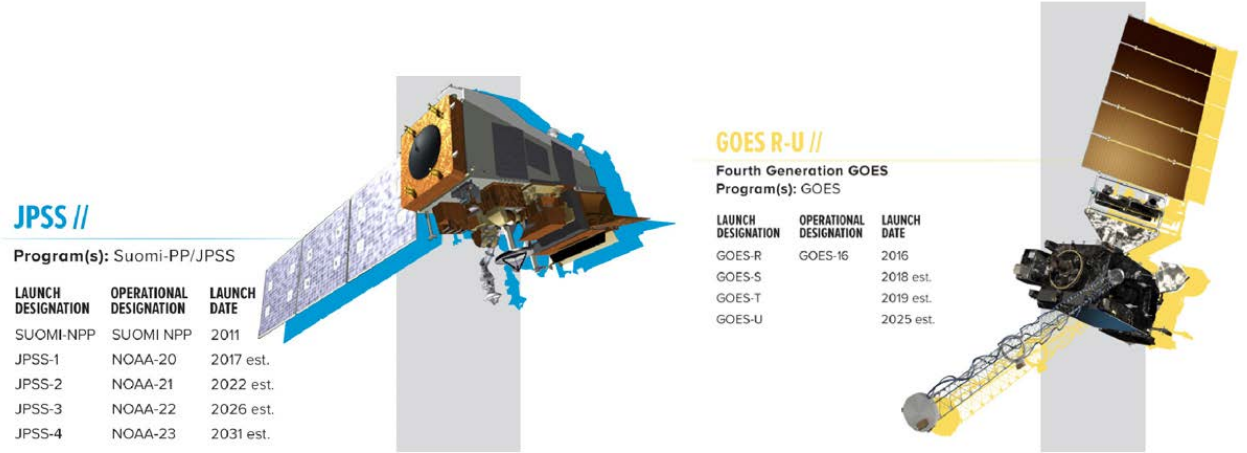
Collaboration Type 3: *Coordination* - JASON-2: *Coordination* is an elevated level of collaboration between agencies, but one whereby overall mission success can still be achieved by an individual partner agency. An example of this relationship between NASA and NOAA was for the JASON-2 mission, since NOAA's role was not one of a dependent relationship; in other words, NASA could have still achieved mission success if the partnership had dissolved at any point. After the completion of post-launch tests, and certification of the satellite and ground system, NASA and their European partners (CNES) handed over operational control to NOAA and their equivalent European operational partners (EUMETSAT). With respect to the working relationship throughout the phases of the mission, a study made the following observation:

> Although NOAA's primary contribution to the collaborative mission occur(ed) during the operational phase of the mission, the committee note(d) that the expectation that NOAA would assume post-launch operational responsibility for the mission was also beneficial to gaining support for the mission by NASA, the administration, and Congress during the early stages of mission development. [11]

This is an example of how unstated strategic objectives (e.g., increasing the number of stakeholders and supporters) can served to motivate collaboration. Involving the end-user in the process enabled substantial progress in mission development.

Following the relative success of JASON-2, in mission management, ground system integration into an existing operational framework, and the launch itself, the end of the decade saw an expansion of focus begin to develop for NOAA operations. The NASA Authorization Act of 2008 contained an outline of prospective progress in both mission collaboration and integration, directed the NASA Administrator "to assess impediments … to the successful conduct of interagency cooperation on space science missions, to provide lessons learned and best practices, and to recommend steps to help facilitate successful interagency collaborations on space science missions", and instructed the Director of the Office of Science and Technology to "develop a plan for sustaining space-based measurements of solar wind from the L1 Lagrangian point in space and for the dissemination of the data for operational purposes (in) consult with NASA (and) NOAA." [8] This recommendation was in line with a recommendation made in 2003, which stated that "NOAA should assume responsibility for the continuance of space-based measurements such as solar wind data from the L1 location as well as near Earth and for distribution of the data for operational use" [22], a suggestion that lay dormant for the early part of the decade, but began to resurface as ACE neared the end of its projected lifetime.

As the prospect of deep space satellite operations began to present itself, NOAA was closing the door on its Fifth Generation POES Program with the launch of NOAA-19 on February 6, 2009, as well as its Third Generation GOES Program with the launch of GOES-14 (i.e., GOES-O) and GOES-15 (i.e., GOES-P) on June 27, 2009 and March 4, 2010, respectively. (A fourth GOES satellite, GOES-Q, was only intended to be built by Boeing if GOES-O or GOES-P had failed to be delivered on-orbit in good working order.) With these satellites launched, NOAA officially ended an era of collaboration with NASA that started with the first POES and GOES satellites.



Program(s): Suomi-PP/JPSS

LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
SUOMI-NPP	SUOMI NPP	2011
JPSS-1	NOAA-20	2017 est.
JPSS-2	NOAA-21	2022 est.
JPSS-3	NOAA-22	2026 est.
JPSS-4	NOAA-23	2031 est.

Fourth Generation GOES
Program(s): GOES

LAUNCH DESIGNATION	OPERATIONAL DESIGNATION	LAUNCH DATE
GOES-R	GOES-16	2016
GOES-S		2018 est.
GOES-T		2019 est.
GOES-U		2025 est.

Fig. 8 JPSS and Fourth Generation GOES Series

NOAA realized that newer collaborative efforts with NASA lay ahead, including the launches of the next series of Polar (i.e., LEO) satellites (JPSS, beginning with the long-awaited Suomi NPP), as well as the launches of the Fourth Generation GOES Program satellites (see Fig. 8). This finally provided the opportunity for NASA and NOAA to reinvent their relationship in order to truly address the many studies that noted their inadequacies, most recently as 2011:

> NASA’s lack of funding and institutional interest to launch new instruments to continue existing measurement records and the lack of funding and expertise within NOAA to take on this responsibility are already affecting the continuity of climate data. NOAA, NASA, and other involved agencies have not yet come to agreement on how both operational and sustained climate data are to be provided. (A) more systematic and sustained approach is warranted to facilitate NASA-NOAA collaborations. [11]

A new approach was needed for not only the new generation of LEO and GEO satellite operations, but also for the new frontier of NOAA operations, the Lagrangian neighborhood. Of the four types of collaboration outlined above, there were areas where one collaboration type failed for one category of implementation, yet succeeded in other categories. The goal was to determine why one approach succeeded, yet another failed, and if necessary, approach the problem from a completely different perspective. “Traditional processes and expectations often form impediments to instituting changes of the magnitude required to improve NASA-NOAA transitions.” [19] A culmination of reports with various recommendations, opinions and perspectives were presented over several decades, but at their core was the fact that no matter what the type of collaboration was, or what category of implementation was being sought, any successful interaction between NASA and NOAA contained at the very least the ***Four Pillars of Successful Transition***, which are *Strong Management*, *Well-defined Transition Objectives and Plans*, *Effective Processes for Performing the Transition*, and *Adequate Human and Fiscal Resources*. Without these pillars sustaining a transition effort for a new satellite mission, there could be no successful integration of any new missions into the NOAA OSPO operational framework, which first must be understood before being amended.

IV. The NOAA OSPO Operational Framework in the pre-DSCOVR Era

To fulfill the need of using satellites to collect environmental data for weather prediction purposes by the NWS and other organizations across the globe, the NESDIS Line Office, represented in Fig. 9, was established in 1982 with the merger of the National Earth Satellite Service (NESS) and the Environmental Data Service. Within that organization, NOAA established the Satellite Products and Operations (OSPO) (initially two organizations, the Office of Satellite Operations [OSO] and the Office of Satellite Data Processing and Distribution [OSDPD]) and tasked OSPO with collecting, processing and distributing environmental satellite data and derived products about Earth's weather, atmosphere, oceans, land, and near-space conditions to domestic and foreign users. OSPO, which is physically located at the NOAA Satellite Operations Facility (NSOF) in Suitland, MD, was also tasked with managing and directing the operation of the central ground facilities which ingest, process, and distribute environmental satellite data and derived products.

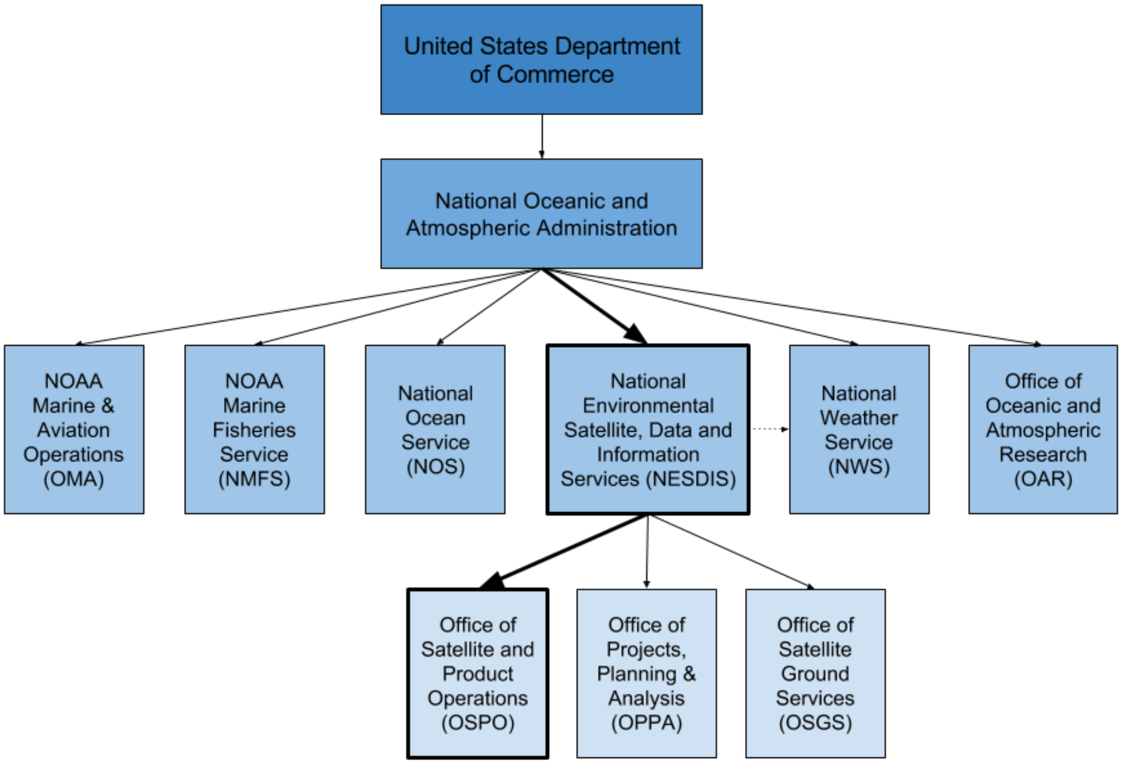


Fig. 9 National Oceanic and Atmospheric Administration (NOAA) Organization Structure

In parallel operations with OSPO is the Office of Projects, Planning & Analysis (OPPA) (formally the Office of Systems Development [OSD]), which “provides the primary contact with NASA and arranges for the development of major system elements (spacecraft, sensors, communications, ground receipt, and data/product processing and delivery); and the integration, installation and acceptance of the NOAA civil operational remote-sensing satellite systems.” [10] OPPA is also tasked with reviewing MOAs that are created to ensure compliance with any requirements and to ensure they are sufficient to enable successful collaboration between agencies.

Through a structured, and compartmentalized management approach (see Fig. 10), OSPO maintains a continuous and reliable stream of satellite data and products. Satellite operations are managed under the Mission Operations Division (MOD) which serves as the primary entity responsible for ensuring the success of all missions through the delegation and implementation of responsibilities (shown in Table 1) via five discrete branches: Information Technology (IT) Services, Systems, Support, Engineering, and Operations.

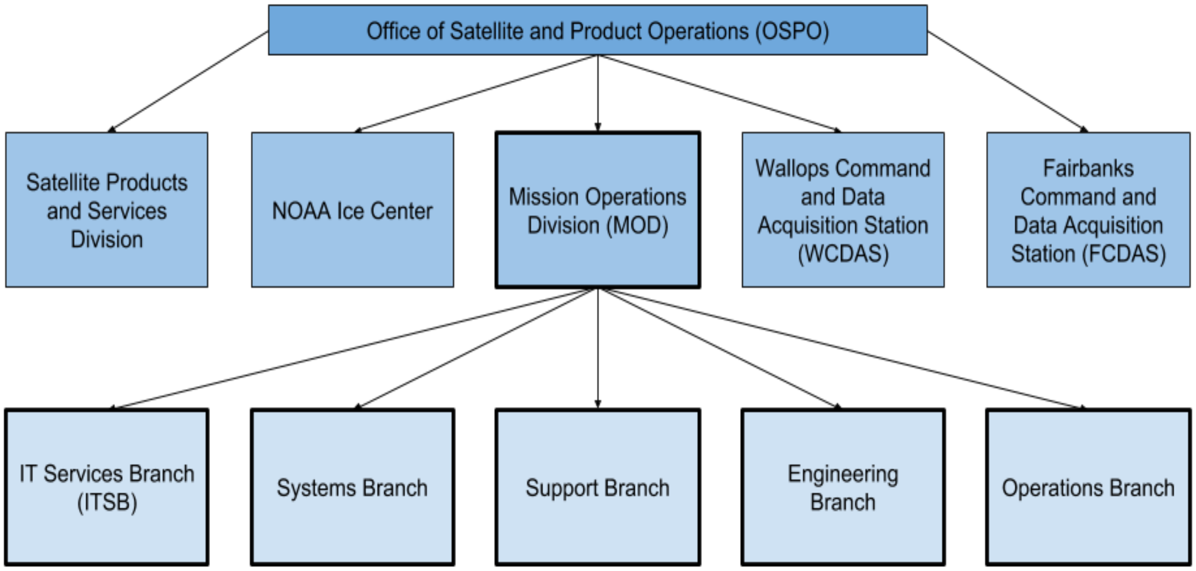


Fig. 10 Office of Satellite and Product Operations (OSPO) Organization Structure

The NOAA operations concept for OSPO is based on three principles expressed in order of importance, which are to: 1. operate the satellite safely, 2. acquire and disseminate spacecraft telemetry, instrument, and product data, and 3. operate as efficiently as possible, where efficiency is measured by the cost of achieving the first two objectives while meeting product data availability and latency requirements. These principles form the foundation of any operational system within its framework, and each facet of mission operations addresses these priorities. The following "*Areas of Focus and Measurable Objectives*" are utilized to facilitate mission success and assist in meeting or exceeding the purpose and goals of each OSPO mission:

1. **Telemetry and Command** - Control and interpret spacecraft and payload behavior and actions via software that provides insight into intended actions and corresponding results.
2. **Mission Planning** - Meet mission objectives by efficiently balancing workload demands with personnel abilities between various groups involving both the Ground Segment (GS) and the Space Segment (SS).
3. **Flight Dynamics** - Maintain required orbital components of the spacecraft
4. **Trending and Analysis** - Provide engineering insight into the behavior of the satellite and its payload, and predict behaviors and actions relative to technical limits and physical constraints with respect to scientific goals and objectives.
5. **Automation and Notification** - Utilize software and other methods that alleviate human-workload with respect to data-driven and time-driven automation requirements.
6. **Infrastructure** - Maintain ground system components with respect to IT Security Requirements
7. **Document Review, Validation and Management** - Sustain knowledge through solid training and documentation. Procedures are developed, validated and simulated in mission readiness simulations prior to operations and training simulations are performed during the operational phase when time permits. Operational components that ensure spacecraft health and safety are validated in "test as you fly" mission readiness simulations. Procedures and tools for special events are peer reviewed and validated in simulations before each event for the duration of the mission.
8. **Anomaly Response** – Recognize abnormal behavior or signatures and yield modifications that prevent future occurrences and lower error rates.

Up until 2015, NOAA's operational environmental-monitoring satellite suite consisted of only two types of satellites dedicated to collecting and distributing primarily Earth environmental data: low-earth orbit (LEO), or polar, constellations for global, long-term forecasting and environmental monitoring and geostationary earth-orbiting (GEO) constellations for national, regional, short-range warnings and more imminent weather predictions. Both types of satellites had become necessary for providing a complete global weather monitoring system, but there was more to be monitored than global weather, and some of the satellites had been fitted with instruments to monitor more than just Earth science. After decades of operations, scientists developed a thorough and well-established approach for predicting and accounting for changes in Earth weather, and OSPO had structured a solid framework in which to operate satellites that would gather data for global predictions. However, a new perspective developed that outlined humanity's susceptibility to forces even larger than those on Earth itself. The sun, while providing much of the energy to create and sustain life on Earth, also contained within it the capability to destroy our established technology, disrupt our lives, and render mankind literally powerless.

Table 1 OSPO Branch Members and Responsibilities

Branch	Staff Members	Responsibilities
IT Services	Network Engineers, Security Analysts	Operations (OPS) Local Area Network (LAN) Maintenance | NSOF Cable Plant Maintenance | IT Security and Vulnerability scans | Penetration Tests | System administration | Security | Patches Install and Verification | System backups | CM of Network Configuration Items | Preventative Maintenance | Provide 24/7 contingency support
Systems	Software Engineers	Maintain Missions OPS SW | Support new Missions OPS system development/testing | Assist with regression and parallel testing of Missions OPS Systems | Update maintenance documentation & SW release notes | Perform SW archiving | Perform Configuration Management (CM) of HW & SW configuration items | Licenses Maintenance | Preventative Maintenance | Provide 24/7 contingency support
Support	Schedulers, Communication Engineers, Facility Managers	Property Management (including Hardware Inventory) | Mission OPS Documentation Management | Wide Area Network Communications & HW Support | Voice & Data physical lines and Network Provider Contracts | Non-IT Security including encryptors, Training | Preventative Maintenance | 24/7 contingency support | Mission Planning and Scheduling
Engineering	Spacecraft (SC) System and Subsystem Engineers, GS Engineers, Mission Engineering Team (MET), Mission Assurance Team (MAT)	Verify nominal daily ground system operation and performance | Verify ground system anomaly response and management | Verify and maintain ground system mission operations products | Develop and execute ground system related procedures | Track and manage ground system changes | Verify IT security patch implementations | Verify acceptance testing to ensure requirement verification and validation | Conduct Operations Regression Tests and report results | Conduct Parallel Operations Tests and report results | Verify deployments to operational system | Conduct configuration management of MOCIs | Provide international mission coordination | Provide 24/7 contingency support | Verify Health and Safety | Coordinate spacecraft activities
Operations	Flight Operators, Shift Supervisors, Controllers, Aerospace Engineering Technicians	Monitor satellite telemetry for execution of commands (onboard command sequence or real time) | Monitor the end-to-end configuration and performance of the Ground System | Ensure operational continuity in the event of a ground system anomaly | Implement scheduling change requests through the instrument tasking process | Contact engineering, ground system, or supervisory personnel in the event of a significant anomaly | Report Data Capture | Pre-Authorized Anomaly Isolation and Recovery | 24/7 contingency support

One of the most influential collaborative efforts implemented between NASA and NOAA as it relates to this paper, not only with respect to recognizing the need to rework the collaborative process, but also in regards to expanding the type of data collection performed by NOAA, was that for the Solar X-ray Imager (SXI). The SXI was an instrument that had been designed to collect images of the Sun in the x-ray region of the spectrum. These images have proven valuable for predicting solar activity and its impact on the near-Earth environment as well as on space-based and ground-based systems. SXI has been flying as part of the GOES satellite payload sine GOES-12 in 200l, but the establishment of the instrument's operation within NOAA's framework did not come easily.

> Space weather instruments, such as particle detectors and magnetometers, had historically been small and relatively inexpensive. NOAA/NESDIS was willing to fly a solar x-ray imager on the GOES-NEXT satellites being designed at the time, but had no budget to do so. Limited personnel left NOAA scientists overburdened during the development of SXI, requiring them to both do science and support the SXI development. These same human resource limitations resulted in

> use of NOAA personnel with primary expertise in data analysis as the technical advisers responsible for understanding and establishing the SXI instrument design and operational requirements.

The implementation of the SXI instrument as part of NOAA operations was an example of a transition that was slowly, but eventually completed successfully, despite a number of difficulties encountered in the process. However, NOAA Space Environment Center (SEC) forecasters quickly recognized that an operational follow-on based on imaging the entire solar disc was a high priority, and although difficulties with establishing funding and coordinating the transition mechanism for SXI prolonged the process to nearly 30 years, the data being collected once operational was providing valuable insight into solar space weather behavior.

> Space weather hazards are becoming increasingly important to the performance and reliability of space-borne and ground-based communication and observation systems because of the increased sophistication of the deployed systems. The demand for space weather forecasts will grow as large constellations of satellites are launched in low earth orbit over the next several years. With the development of increasingly sophisticated technologies and the expansion of human activities into near-earth space, there will be an increasing need to forecast the changing fluxes of … upper atmosphere/near space conditions. [17]

For all of the preparedness gained through meteorological predictions, NOAA realized it had to make plans to ensure that they were providing not only geological data but heliophysics information as well in order to develop a complete framework within OSPO that could foster greater weather-related preparedness. Additional instruments utilizing more advanced technology would be required to provide a complete picture of solar behavior, and it would be the responsibility of NOAA to implement these instruments operationally in the coming years.

> The demand for new and diverse forecasting products will continue to grow and, with implementation, these expanded products will promote increased human safety ... The foundation for these products is NOAA's forecasting capability, which can improve by capitalizing on U.S. investments in weather and climate research and technology. However, until current research advances are incorporated effectively into operational forecasts, the nation will not realize the attendant benefits of its research investment. It is important to understand the transition process and to ensure its efficient operation. Otherwise, impediments that may exist now will become more problematic in the future as a consequence of anticipated expanded demands on the nation's weather and climate forecasting. [17]

Changing or amending the OSPO framework to foster the inclusion of additional capabilities first required an understanding of the existing framework in order to gauge potential areas of adjustment, utilize shared resources where applicable, and determine the most efficient approach for transitioning these capabilities to NOAA operations.

A. Operations and Management of Low-Earth Orbit and Geostationary Earth-Orbiting Constellations

By 2012, the operational framework within OSPO had been well-established as a dichotomy of GEO and LEO satellite operations, primarily consisting of POES and GOES. This orbital dichotomy led to the implementation of a very discreet manner in which mission operations had been divided (see Table 2), which had been beneficial for adding missions with similar orbital parameters, but created conflict when attempting to diverge from that established approach.

GOES spacecraft operate as a two-satellite constellation above the equator, each observing around 60 percent of the Earth’s surface and measuring atmospheric temperature and moisture, cloud cover, and the solar and geosynchronous space environment. The eastern and western satellites are positioned to provide a best view from near Africa to beyond the central part of North America and from the center of the United States to beyond Hawaii. In addition to the GOES series, NOAA monitors data from two of the original six COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate) satellites stationed in a geostationary orbit, with COSMIC-2A expected to launch in mid-2018 and be added to the existing COSMIC operational framework within the geostationary orbital operations framework. The COSMIC satellites (Fig. 11) have not been managed by Engineers on the EMOSS contract like POES and GOES, but are managed through separate OSPO Engineering management processes.

Fig. 11 COSMIC Satellite

The POES satellite system offers the advantage of daily global coverage, by making nearly polar orbits 14 times per day approximately 520 miles above the surface of the Earth. The Earth's rotation allows the satellite to see a different view with each orbit, and each satellite provides two complete views of weather around the world each day. Each DMSP satellite has a 101 minute orbit and provides global coverage twice per day. OSPO also monitors the polar-orbiting DMSP satellites for the Department of Defense, which are also not managed by Engineers on the EMOSS contract.

Table 2 OSPO Geostationary and Polar-orbiting 2012 Operational Footprint (w/ Future Missions)

Geostationary Orbit		Polar-orbiting Orbit	
GOES-13	GOES-14	NOAA-15	~~*NOAA-16 (Lost in 2014)*~~
GOES-15	GOES-16 (2016)	~~*NOAA-17 (Decom. in 2013)*~~	NOAA-18
COSMIC-1A	COSMIC-1B	NOAA-19	NOAA-20 (2017)
		MetOp-A	MetOp-B
		MetOp-C (2018)	S-NPP
		DMSP-F14	DMSP-F15
		DMSP-F16	DMSP-F17
		DMSP-F18	~~*DMSP-F19 (Lost in 2016)*~~
		JASON-2	JASON-3 (2016)

Additionally, NOAA entered into agreements with EUMETSAT to provide continuity of measurements from operational satellites in polar orbits, by implementing cost-sharing and improved forecast and monitoring capabilities through the establishment of the Initial Joint Polar-orbiting operational Satellite (IJPS) System, which included two series of independent but fully coordinated NOAA and EUMETSAT satellites. Under the agreement, NOAA provided two of their satellites (NOAA-18 and NOAA-19) for flight in the afternoon orbit, and EUMETSAT provided their MetOp series of satellites (see Fig. 12), with MetOp-A and MetOp-B operational by 2012, and MetOp-C expected to launch in 2018. All satellites carried a common core of instruments, with some owned by EUMETSAT and others owned by NOAA, setting up a collaborative dynamic of dual-user interest and ownership in payload and data generation on an operational mission; this dynamic yielded lessons applicable to future missions in which payload was shared between two agencies.

Fig. 12 MetOp Satellite

The EMOSS contract implemented a two-pronged management structure, as shown in Fig. 13, to coordinate for OSPO the integration of new missions (or extensions of satellite constellations) through *Mission Development and Transition* via Mission Operations Systems Engineers, and the maintenance of current missions through *Mission Operations and Sustainment* via Operations Phase Systems Engineers. Within the *Mission Operations and Sustainment* framework, expansions of existing Geostationary and Polar-orbiting missions (such as GOES and POES) have been managed via Technical Constellation Leads, while new mission frameworks (such as SNPP/JPSS) have been imported under the management of Mission Leads, who then coordinate mission operations with the Technical Constellation Leads when necessary, or integrate the mission underneath the Technical Constellation Lead altogether. Prior to integration, mission development and transition efforts are managed in a discrete framework that keeps that work separate from the operational framework; this framework is expanded and elaborated on in subsequent sections to address the integration of the Deep Space Climate Observatory (DSCOVR) mission into OSPO.

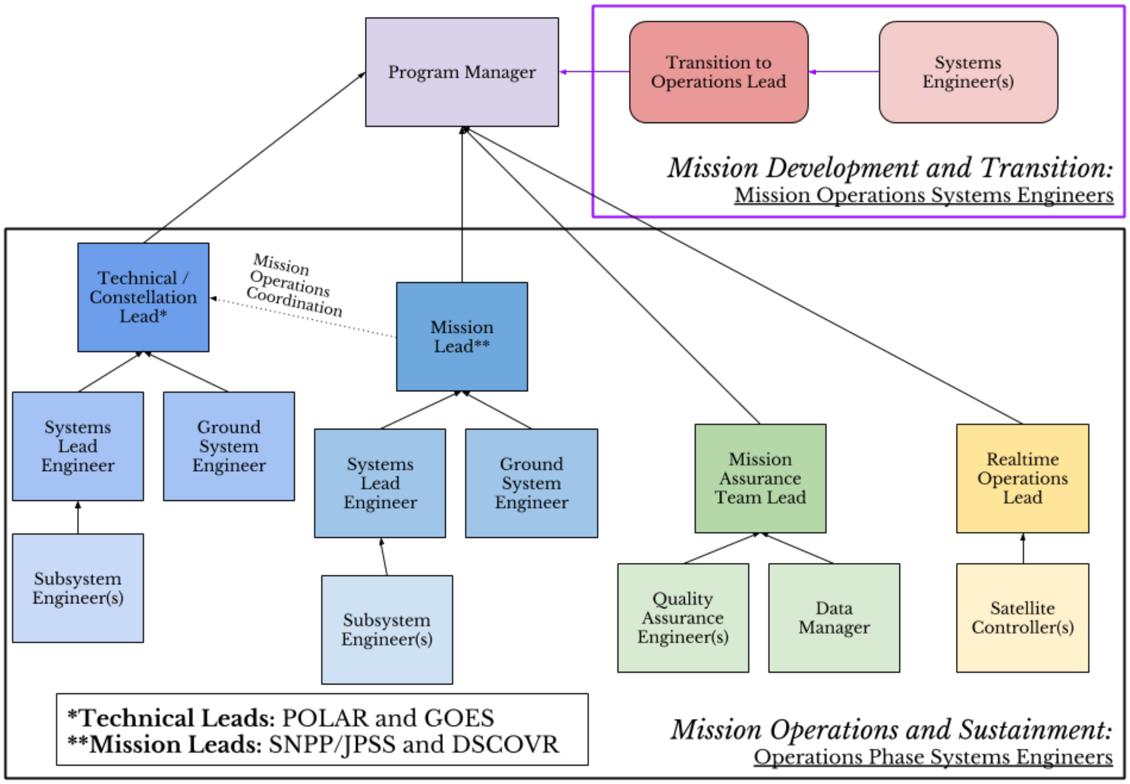


Fig. 13 EMOSS Mission Integration and Operations Management and Team Structure

The management structure of the EMOSS contract falls under OSPO's Engineering Branch, with Engineers reporting to OSPO Government Leads, who then report to the Engineering Branch Chief. This management structure had been primarily split to provide services for GEO and LEO (Polar) series since its inception, with overarching Configuration Management (CM) support by the Mission Assurance Team (MAT) provided for both. Engineers under the Polar-orbiting Technical Lead have provided support for all active POES/MetOp satellites and their subsystems, including spacecraft health and safety monitoring and mission planning. Similarly, engineers under the Geostationary Technical Lead provide the same support for all active GOES satellites, with differences relevant to the specific operations and orbits for each satellite. Engineers within the Engineering Branch provide services as outlined in Table 1.

The delegation of responsibilities for operational satellites among the five branches within OSPO has been a successful management approach for decades, but just as equally important has been the inter-branch cooperation and coordination within OSPO which is required to execute mission functions. Engineers work with Schedulers in the Support Branch to schedule ground station supports to collect real-time and stored spacecraft data for distribution, yet the dynamic of the relationship differs between missions. For example, schedulers for the GOES satellites do not have to schedule ground station contacts since the satellites are always within view of their respective ground stations, while Engineers for the POES satellites do not have to schedule supports for station keeping maneuvers since their orbits do not require adjustment. Engineers also work with personnel within other Branches, including network engineers within the IT Security Branch, software engineers within the Systems Branch, and coordinate commanding the spacecraft via Flight Operators under the Operations Branch, who are on console monitoring spacecraft health and safety 24/7. For all missions within OSPO, planned commanding to the spacecraft is authorized by management and coordinated with the Flight Operators. This collaborative dynamic has proven essential for successfully operating a satellite, but it is also imperative to maintain this dynamic during the transition period to ensure all branches of OSPO are prepared to receive and manage a new mission, either one within the same established framework, or as part of a new or modified framework.

B. Expanding NOAA Satellite Operations beyond the Local Neighborhood

By the beginning of the 21st Century, NOAA had mastered operating Earth-monitoring satellites in both the Low-Earth and Geostationary orbits, but with real-estate crowded in the local neighborhood, and an oversaturation of Earth climate data, NOAA began to look further into space, and at other orbit types, for more opportunities. “The growth in the number and types of data users is putting continued pressure on NOAA to meet new and evolving user needs and, at the same time, to satisfy the expanding requirements of existing data users.” [19] NOAA would have to expand its perspective into new territories, visually depicted in Fig. 14, without abandoning or degrading its support of existing missions,

A Lagrange point is a location in space where the combined gravitational forces of two large bodies, such as Earth and the sun, equal the centrifugal force felt by a much smaller third body, such as a satellite. The interaction of the forces creates a point of equilibrium where a spacecraft may be "parked" to make observations, and in the Earth-sun system, the first Lagrange point, L1, lies between Earth and the sun at about 1 million miles from Earth. By being positioned at L1, a satellite has an uninterrupted view of the sun, and by 2012, NASA had already taken advantage of this prime observational scenario, having placed the Global Geospace Science (GCS) Wind satellite, the Solar and Heliospheric Observatory (SOHO), and the Advanced Composition Explorer (ACE) in this neighborhood to gather data for solar research.

While the data from GCS and SOHO have been managed and distributed by NASA, primarily for use in NASA products, the data from ACE have been used by SWPC to generate forecasts and warnings of solar storms as outlined earlier. ACE has allowed for the investigation of elemental and isotopic composition of matter, the origin of the elements and subsequent evolutionary processing, the formation of the solar corona and acceleration of the solar wind, and the particle acceleration and transport in nature, but ACE cannot last indefinitely and will soon need to be replaced. “An example of a data acquisition activity that is of critical importance for both scientific and operational purposes and that raises questions of continued availability and of the transition from science to operations is the upstream monitoring of the solar wind and the interplanetary magnetic field.” [22] This data from ACE have allowed forecasters to issue predictions for incoming solar storms, in a manner similar to that of a weather forecaster on earth. In 2003, the National Space Weather Program proclaimed the transition of solar measurements from research to operations as a primary goal, stating that they wanted to achieve an active, synergistic, interagency system to provide timely, accurate, and reliable space environment observations, specifications, and forecasts within the next ten years.

Fig. 14 Expanding the Footprint of NOAA's Operational Satellites

As mentioned earlier, in 2008 the NASA Act stipulated that a plan be generated for sustaining space-based measurements at L-1. At the turn of the century, that deadline had been more than halfway exhausted, and with ACE significantly past its projected life, there was a sense of urgency to provide a replacement to maintain those "reliable space environment observations" as well as enhance the quality of the measurements using advances in technology. It became obvious that it was time to act on the recommendation of the NRC's 2003 study which stated that "NASA and NOAA should initiate the necessary planning to transition solar and geospace imaging instrumentation into operational programs for the public and private sectors." [22] Plans were set into motion to resurrect and operationally implement at L1 a satellite that once had a purpose, was then abandoned as a result of political upheaval and financial deficiencies, and deserved to be viewed and considered from a new perspective.

V. Formally Known-As Triana:
The Political History and Uncertainty of the Deep Space Climate Observatory

Satellites may begin as just a concept, sometimes as a result of a new proposal or a unique perspective on an existing idea, and only get so far as just a written proposal. Others get much farther in the design process, but are scrapped due to financial constraints or limitations, and are never built. Only one satellite has had the distinguished honor of being the result of the dream of a vice president, and the equally crushing fate of being placed, fully built and tested, deep inside of a warehouse instead of deep into outer space. Given enough power, the perspective of one man or governing power can override the scientific promise and potential of a piece of technology.

The mission concept that would eventually become Triana resulted from a proposal by Vice President Al Gore and was announced to the public on March 13, 1998. The concept that was proposed was to build and launch a small spacecraft that would provide the public with continuous views of the sunlit hemisphere of the Earth via the Internet by the end of the year 2000. Work began quickly, but by the end of the decade, the House voted to terminate the mission, and the fully built satellite was placed into storage on November 1, 2001. Triana remained in storage for six years, was renamed the Deep Space Climate Observatory (DSCOVR) in the interim, and then unearthed under the new perspective of the Obama administration to be given a new life. The journey from a politician's dream to the launch pad was one of transformation, perseverance, perspective, and collaborative compromise.

A. Triana: From a Dream to a Warehouse

In 1998, NASA began development on a satellite based on a recommendation and proposal from Vice President Al Gore for the purpose of Earth observation. A memo issued on March 13, 1998 first outlined the early plans which envisioned "a 330-pound satellite linked to Earth through three simple, low cost ground stations equally spaced around the globe to provide continuous downlink capability. One new image (of Earth) would be downlinked every few minutes. The satellite would be developed and launched within two years of a competitive selection process." [6] The expectation at the time of the announcement was that it would be a quick turnaround, and that the applications of the data could be used for weather predictions as well as education, as college students would "participate in the design and development of the spacecraft, and student teams would operate the ground stations." [6] The estimated cost in the announcement, including launch and operations, was quoted as under $50 million, but initial estimates by NASA hoped to keep the costs at around $20 million; NASA released the Request for Information (RFI) in April 1998 with these costs in mind.

NASA issued an Announcement of Opportunity (AO-98-OES-2) for Triana on July 10, 1998, and the baseline government spacecraft described in the July 1998 AO was 45% greater than the spacecraft described in the project's April 1998 RFI. The proposals in response to the AO were due to NASA 45 days later, on August 24. Forty-five days is the minimum response time allowed by Federal Acquisition Regulations for any NASA AO and was criticized as being too short of a response period, but was chosen to meet the deadline of the year 2000. Nine proposals were received, but NASA deemed only three compliant. All of the compliant proposals incorporated the use of a spacecraft provided by GSFC and a launch on the Space Shuttle. Two months later, on October 27, NASA selected a proposal from the Scripps Institution of Oceanography at the University of California, San Diego after executing a scientific and peer review process. NASA also selected portions of a proposal from GSFC, which included adding an ultraviolet capability for the Earth-imaging camera as well as a plasma magnetometer to monitor magnetic fields and the solar wind; to accommodate these enhancements, which were outside the scope of the original proposal in March, as well as not part of the initial directive of Al Gore, NASA increased the mission budget to $77 million.

As NASA accelerated the evolution of the mission, the size, cost, complexity, and purpose of Triana changed as well (see Table 3); a low-cost mission primarily aimed at inspiring and educating students and the public quickly became a larger, higher-cost science mission with minimal educational content. A review of previous assessments of the mission found four main points that potentially doomed the future of the mission:

1. **Government Spacecraft and Launch Vehicle** – The original concept of the mission specified neither use of a NASA spacecraft nor a launch on the Space Shuttle, but NASA wrote the AO such that it provided strong incentives to use a NASA-provided launch vehicle.
2. **Addition of Scientific Capability** – Once NASA selected the Scripps Institute, they directed them to modify the camera, and add space weather monitoring instruments, which increased its mass, mission complexity, and cost, pulling resources from other Earth Science missions at the time.
3. **Mission Goal Fluctuation** – The institution of a scientific (vs. educational) perspective on the mission deviated from the original concept. The RFI in April 1998 outlined that the primary objective was to provide an image of Earth for educational outreach opportunities, with a secondary goal of using the observations for meteorological and environmental monitoring in support of current missions. However, when NASA released the AO, the perspective of the mission had changed, with the educational goal listed as secondary to Earth remote sensing.
4. **Lack of Incorporation of Commercialized Technology** – NASA originally touted the development of new technologies and commercial participation as possible benefits, but the use of new technologies was absent from the AO goals and the spacecraft did not incorporate any significantly new technologies.

Of note is that Triana was slated to be launched on a space shuttle to save NASA from having to buy a commercial launch, and at some point during development, the satellite was scheduled to be launched on the ill-fated STS-107 Columbia Space Shuttle mission, originally set to launch on January 11, 2001. The STS-107 mission eventually launched on January 16, 2003, without Triana (which was replaced by the FREESTAR payload), and the uncertainty of Triana partly contributed to the delay in launch.

Table 3 The Evolution of the Triana Mission Design

	Original Concept (March 1998)	Request for Information (April 1998)	Announcement of Opportunity (July 1998)	Proposal Selected (October 1998)	Assessment by Review Board (August 1999)
Budget	$20-$50 Million	Less than $50 Million (including launch and operations)	$50 Million (not including launch or education NRA)	$77 million (not including launch or education NRA)	$77 million (not including launch or education NRA)
Mass	330 pounds	330 pounds	484 pounds	>550 pounds	986 pounds
Primary Goal	Inspiration, Education,	Educational Outreach	Applications and Science	Applications and Science	Applications and Science
Secondary Goal	Applications and Science	Applications and Science	Educational Outreach	None	None

The House Science Committee, and then the House itself, voted in May 1999 to remove financing from Triana, mainly citing poor financial circumstances, but also revealing partisan influences in their decisions, with Republicans remarking several times in the session that the mission was only fulfilling the dream of a Democratic vice president to launch a multimillion-dollar screensaver, and Democrats countering that canceling the mission would waste over $35 million already allocated in the prior year and forego valuable science. However, later that year the House issued a report (House Report 106-379) on October 13th in which they outlined and questioned the goals of the mission, but did not terminate the mission altogether, instead instructing NASA to suspend development efforts. In response, the NASA Associate Administrator for Earth Science issued a letter to the NRC [18] on October 14th requesting that they evaluate the following scientific themes addressed by Triana:

1. Solar Radiation and Climate (including cloud radiative properties)
2. Ozone, Aerosols, and Ultraviolet Radiation
3. Stratospheric Dynamics
4. Vegetation Canopy Structure
5. Solar Wind and Space Weather

The report by the NRC found substantial reason that Triana would contribute positively in both Earth Science and Space Weather measurements, noting that it had the potential to provide predictive capabilities for solar phenomena, stating that “if the ACE spacecraft is lost or its plasma or magnetometer instrument fails, then Triana as the only upstream monitor of solar wind and interplanetary magnetic fields could be critical to the Space Environment Center’s mission.” [18] The report noted that space weather measurements from a 3-axis stabilized spacecraft such as Triana could yield an improvement in the time resolution of the solar wind ion measurements that would be approximately 30 times better. In general, the case for implementing Triana solely on the basis of a replacement for ACE were remarkably strong at the time:

> The Plasma-Mag on Triana at Ll is designed to provide in near real time and on a continuous basis the primary set of measurements required by the Space Environment Center of NOAA to monitor and forecast Earth's solar environment and provide accurate, reliable, and useful warnings of solar-terrestrial interactions. The required primary measurements are the solar wind plasma ion density, velocity, and temperature, and the magnetic field vector in standard coordinates. The Plasma-Mag instrument package is intended to take the measurements and compute on-board averages of solar wind and magnetic field parameters in real time once per minute. The launch of Triana in 2001 or later will provide overlap with ACE for many years, allowing for cross-calibration. The availability of real-time solar wind data from Ll spacecraft at two separate points in space would enhance the reliability of detecting the geoeffectiveness of disturbances not directly on the Sun-Earth line by providing additional information about the irregularities in the solar wind. [18]

The findings were that the goals and objectives of the mission ultimately fell into two separate categories:

A. To launch a modest exploratory mission to demonstrate value in Earth Science from L1
B. To gather global climate data and meet operational needs related to solar weather and global change

The NRC also noted that implementing the Triana mission would meet the needs requested by previous reports, such as well-calibrated observations in multiple perspectives and approaches, fulfilled by the use of L1 as an observation point (see Fig. 15), and technical innovation. “Triana is an exploratory mission that may open up the use of deep-space observation points such as L1 for Earth science. The task group believes that the potential impact is sufficiently valuable to Earth science that such a mission might well have been viewed as an earlier NASA priority had adequate technology been available at reasonable cost." [18] In summary, the report recommended the continuance of the mission, arguing that although Triana was an exploratory mission, focusing on the development of new observing techniques rather than a specific scientific investigation, the potential goals and objectives were consistent with published strategies and priorities, as well as the need for new technology and perspectives, and that the mission would meet its goals and contribute positive value based on this new perspective.

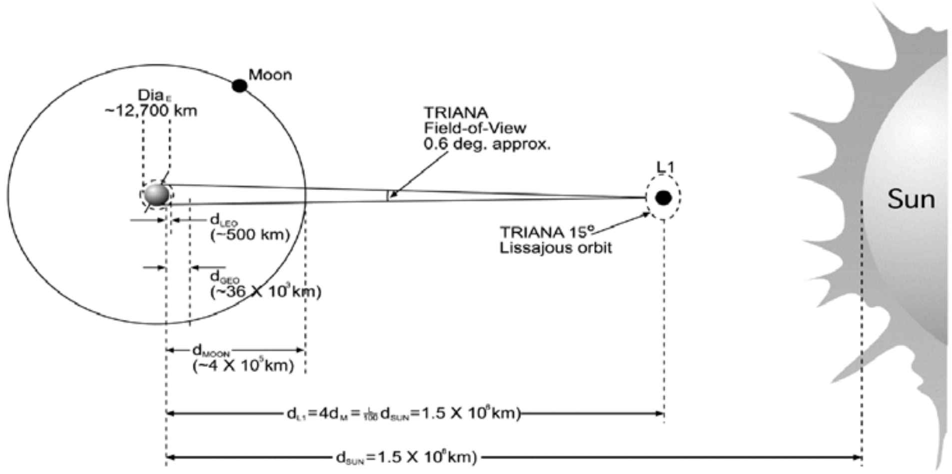


Fig. 15 The New Perspective of Triana's Location

Unfortunately, not everyone shared this promising perspective, including the NASA OIG, who primarily focused on the cost overruns and the deviation from the primary mission structure as announced initially, and recommended that the mission either be re-scoped and redesigned, allowed to proceed with significant modifications, or be canceled in lieu of a "Virtual Triana". The last recommendation would enhance the original educational intent of the mission by dedicating a portion of the Triana budget to developing software and a website to integrate pictures of the Earth already publicly available from existing satellites. Lost in the OIG's analysis was what was to be gained by utilizing a new perspective of an L1 location, as well as the contribution Triana would make toward continuing solar measurements used by other agencies.

Ultimately, proponents of Triana would be defeated by an apparent politically driven motive, despite the promises it held to provide new perspectives. Although the mission was at an advanced stage of development, fully integrated and qualified within a full environmental test program, with most components tested between 1500-2000 hours, the White House canceled the mission. Shortly after George W. Bush took office, plans were quickly set into motion to shut down all progress on the mission. Most of Triana, except the flight transponder, star tracker, gyros, and reaction wheels (which were moved to multiple locations at GSFC) was placed into storage in "stable suspension" in a cleanroom under nitrogen purge on March 9, 2001, its fate uncertain, but with hope that someday the tiny satellite could overcome the huge hurdles of politics and let science prevail.

B. DSCOVR: A New Name on a Familiar Face

Triana remained quietly abandoned for almost two years after it was placed into stable suspension, until January 2003, when NASA renamed it DSCOVR, in an attempt to reflect the changes the mission had undergone since it was first proposed, and also to regain support for the project. However, the mission was formally canceled again in January 2006 without any forward progress. On June 22, 2007, DSCOVR GSFC scientists presented a restart estimate to NASA Headquarters (HQ), outlining what it would take to resume mission development. Subsequently, the NASA Authorization Act of 2008 recommended that NOAA take the lead on ensuring continuance of solar measurements, and work with NASA to research implementing DSCOVR as a replacement for ACE by taking advantage of the solar instruments that were appended as a secondary mission to the original Triana framework. NOAA and NASA signed the MOU on September 4, 2008 to implement this work.

Shortly after the election of President Barack Obama on November 4, 2008, GSFC scientist removed the spacecraft from storage, performed a static swing test on December 15, and issued the "Serotine Report" on January 14, 2009. This report contained a case study of reconfiguring the spacecraft to perform a specific weather application for NOAA, targeting a launch in 2012, and a proposal that outlined a total cost, including observatory, instrument accommodations, and mission operations, of $62 million. The study outlined the findings of a spacecraft aliveness test that was performed; the findings related to major changes or deficiencies are outlined in Table 4. The test focused on determining the status of the Ground Support Equipment (GSE), the payload (not including the Earth science instruments) and spacecraft status, as well as the documentation, and the connectivity between the spacecraft and the ground system itself. Two main risks were noted, the first being possible solar cell adhesive oxidation, and the second the availability of replacement parts due to the age of the spacecraft.

Table 4 Assessment of DSCOVR Components after Stable Suspension

Component	Findings and/or Changes
Documentation	Data stored on various computers was not transferred to a central repository. Hard copies of documentation for spacecraft not properly stored.
Hardware	Instruments removed for refurbishment. Avionics had to be de-integrated for refurbishment. Electron Electrostatic Analyzer (ESA) relocated from end of boom to the propulsion module. Extension added to end of boom to host magnetometer. RWAs had magnetic shields added to meet new science requirements. Choke rings added to Omni antennas. New lithium ion battery installed. Struts added to strengthen instrument deck. Star Tracker and HGA returned to Ball Aerospace for refurbishment.
Propulsion	Propulsion Line Zone 5 below minimum during testing (also noted during Triana testing). Auxiliary dual element heater installed over the existing line 5 heater. Structural analysis performed to assure no impact due to the added thermostat, heater, and aluminum tape masses. Wires run to bottom of propulsion module to power flight auxiliary heater. HGA and prop module access panel removed to gain access to inside of prop module for wire routing. Several mli blankets removed to install the auxiliary heater.
Thermal Vacuum Testing	Several power inconsistencies between test data and systems level power budget identified. Current monitors for RWAs incorrect. Current monitoring system had multiple components on a single current monitor. Several monitors included both a heater service and multiple power dissipating components. Several thermocouples installed on various internal propulsion components. Ends of thermocouple wires were cut such that labels (numbers) were not preserved.
Thermal Blankets and Coatings	Germanium missing from most areas of germanium black Kapton MLI; replaced outer layers. Several blankets totally missing. Uncertainty in original location of other thermal blankets. Most thermal control surfaces showed damage due to mishandling. The optical properties had not changed during storage.
Flight Software	Launch/separation/deployment requirements for the new launch vehicle. New trajectory and removal of the shuttle launch based propulsion systems.

In 2009, NASA and NOAA had yet to finalize the composition of the payload on DSCOVR. The inclusion of the Earth Science instruments, NISTAR and EPIC, was undetermined. Additionally, NOAA wanted to add an additional instrument to the spacecraft called the Coronal Mass Ejection (CME) imager, which would be mounted on top of the spacecraft, have a recommended mass of about 6.5 kg and use less than 12 Watts of power. The cost of the CME was not included in the cost estimate outlined above. Additionally, to accommodate the inclusion of the CME, it would be located in the space vacated by the EPIC instrument, so the absence of the EPIC instrument was a precursor to the addition of the CME. The specific assumptions used for the CME cost estimation, originally below $3 million, were that the instrument would be Government Furnished Equipment (GFE) from NOAA, and that NOAA would be responsible for the design, build, and test of the instrument. GSFC would participate in design reviews, and interface development and test. The instrument would use existing DSCOVR electrical interfaces, supply its own command and control system, as well as thermal blankets, and be mounted on a gimbal controlled by the instrument to enable sun tracking. The spacecraft, which would supply ephemeris and attitude information to the instrument, as well as power, would have its thermal blankets on the upper deck modified to accommodate the instrument.

Also in flux at the time was the physical location of the Operations Center; options included the NOAA Satellite Operations Facility (NSOF), as well as two locations at GSFC. The leading assumption at the time was that it would be located at GSFC, despite guidance that NOAA should assume operations for space weather satellites at L1. Additionally, the proposal assumed that the existing Real-Time Solar Wind Network (RTSWnet) stations that were being used for ACE would be allocated to support DSCOVR, but also proposed using a Near-Earth Network (NEN)

White Sands station pass once per day to downlink data stored during the RTSWnet passes (since those stations would only support real-time data); the study did not investigate using NOAA antenna resources in lieu of NEN stations.

After GSFC issued the Serotine Report, progress on the mission stalled for about a year, as NOAA FY2011 funding for refurbishment effort and instrument development was pending Continuing Resolution (CR). Regardless, NOAA scientists continued to develop their plans for the addition of the CME Compact Coronagraph (CCOR) (see Fig. 16) that would provide CME imagery for issuing 1-4 day storm alerts, and improve upon the imaging provided by the SXI instruments on the GOES series.

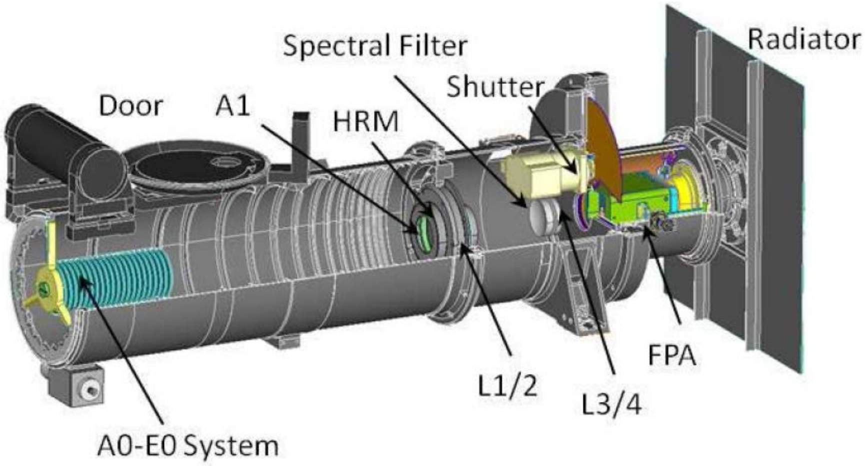


Fig. 16 Proposed Coronal Mass Ejection (CME) Compact Coronagraph (CCOR)

Developers conducted Phase A for the CCOR development from April 2010 through December 2010, but the CR delayed the implementation of Phase B. As such, the inclusion of the CCOR on DSCOVR altogether became questionable, just as questionable as the status of the Earth Science instruments, even though SWPC stressed the need to transfer better technology into operational use to provide solar images for weather forecasting. To allow its inclusion, cost trade analyses performed at the time by SWPC included de-scoping the CCOR or reducing support for existing instruments, such as the space weather instruments (SEM and SXI) on the GOES satellites.

> Numerous research instruments and observations are required to provide the basis for modeling interactions between the solar-terrestrial environment and technical systems and for making sound technical design decisions that take such interactions into account. Transitioning of programs and/or their acquisition platforms or instruments into operational use requires strong and effective coordination efforts among agencies. Imaging of the Sun … will play a central role in operational space forecasting in the future. [22]

Ultimately, the long delay in the FY2011 funding resulted in the removal of the CME CCOR from the DSCOVR payload altogether, and NOAA pushed forward with implementing the PlasMag space weather capabilities, which were deemed more important to have operational immediately. However, the failure to include an operational coronagraph did not go unnoticed by review panels, as the NRC noted in 2011 when they stated

> ...problems in executing the transition to operations are not confined to Earth science missions. The importance of ensuring critical measurements of the solar wind upstream from Earth is noted. A similar problem in the development of operational capabilities for space weather prediction is evident in the failure to develop an operational coronagraph, which is required to provide advanced warning of the effects of a coronal mass ejection. [11]

However, because of funding issues, the promise of the CCOR had to be reconsidered at a later time for inclusion on any DSCOVR follow-on missions in the future.

Eventually, in February 2011, the Obama administration began the process to secure funding to re-purpose the DSCOVR spacecraft, and Congress appropriated $30.1 million in NOAA’s 2012 budget to resurrect the DSCOVR program. On NASA’s side, by 2011, the Earth Science instruments were refurbished and integrated on the satellite, but as late as 2012 it was unclear if there would be financial support to operate the instruments. The instruments, with their function of monitoring climate change, had not lost their cloud of financial uncertainty and susceptibility to political opinions, even ten years later. At one point during development, developers considered launching and operating the satellite with the instruments inactive. They also proposed replacing the instruments with non-functioning structures of equivalent mass and maintaining the instruments in storage on the ground. In the end, the potential science prevailed, and the two original instruments, EPIC and NISTAR, were officially included back on the DSCOVR payload.

In their FY12 budget, the Air Force proposed to fund a launch of DSCOVR in order to provide competition for potential new entrants to the rocket market, deviating from the original plan of Triana to specifically use a government launch vehicle. Though the satellite would provide scientific data to government users, it was not considered a critical payload, so it was suitable for boost in a test launch, which posed higher risk than other launches. In December 2012, NASA selected a Falcon-9 v1.1 rocket to launch DSCOVR, and in September 2013 NASA cleared DSCOVR to proceed to the implementation phase targeting an early 2015 launch. After a tumultuous and uncertain path, faced with different, often conflicting, perspectives of its value and purpose, Triana, albeit it with a new name and primary mission, finally found its way off of Earth and into deep space, to provide Earth's inhabitants with a greater perspective of Earth and stronger protection from the Sun.

VI. DSCOVR Mission Overview

In its final form, despite the lack of the CCOR, DSCOVR, shown in Fig. 17, represented a generational change in solar, space weather and meteorological observation to meet space weather forecasting requirements, while enhancing Earth environmental data collection for analysis and Earth Science research. The DSCOVR mission provided the first major improvement in instrument technology since NASA launched ACE in 1997, introduced other new technologies in both the Space and Ground Segments, and provided NOAA with its first deep space mission. The spacecraft was supported by a ground system, consisting of a global suite antennas, networks, and a mission operations center for telemetry and command functions. A brief overview of the space and ground segments is provided below to provide context to the collaboration efforts that were required; more detailed descriptions of the spacecraft and its components as well as the ground system are available in other documentation.

Fig. 17 The Deep Space Climate Observatory (DSCOVR)

A. Spacecraft Segment Overview

The Space Segment (SS) consists primarily of the satellite and its payload (see Table 5). The satellite is based on the Small Explorers (SMEX)-Lite spacecraft bus architecture, which was a predominantly single-string system developed by NASA/GSFC and derived from proven concepts utilized on prior GSFC SMEX missions. It is a three-axis stabilized spacecraft that utilizes a typical complement of sensors and actuators, i.e., Star Tracker (ST), Inertial Reference Unit (IRU), Coarse and Digital Sun Sensors (CSS and DSS), and Reaction Wheel Assemblies (RWAs), to maintain the desired attitude. The attitude is also maintained through the use of the propulsion system, which is used to unload excessive momentum that builds up in the RWAs, and perform orbit maintenance, with ten thrusters.

The Earth-Side (+X) of the spacecraft is shown in Fig. 18 (Left) and the Sun-Side (-X) of the spacecraft is shown in Fig. 18 (Right). The main mechanical components of the spacecraft are the Upper Structure, the SMEX-Lite spacecraft bus, the deployables, and the propulsion module. The Upper Structure supports the instrument deck, electronic boxes, and other subsystem components such as the Star Tracker. The SMEX-Lite bus supports the electronic boxes and other subsystem components such as the reaction wheels and provides the infrastructure needed to support the instruments and the mission, which includes power, thermal control, data, communications, and attitude and orbit control. The deployables consist of a pair of symmetrically mounted solar arrays and a deployable boom, which carries the PlasMag Magnetometer. The propulsion system houses a 28-inch diameter hydrazine tank and other propulsion system components. Certain maneuvers, and calibration activities that require off pointing, necessitate a battery, so NASA provided a battery that will supply ample power throughout the mission.

Table 5 DSCOVR Subsystem Overview

Subsystem	Function
Propulsion (PROP)	Maintains Lissajous orbit and to manage the system momentum via thrusters
Safety Inhibit Unit (SIU)	Prevented energizing components deemed hazardous while attached to the LV
Electrical Power (EPS)	Provides primary (solar array) and backup (battery) power
Thermal (THERM)	Maintains temperature via thermal blankets and thermistors
Communications (COMM)	Permits telemetry, command and ranging operations via antennas
Magnetometer (MAG)	Supports primary mission by measuring magnetic field
Faraday Cup (FC)	Supports primary mission by measuring solar wind parameters
Electron Electrostatic Analyzer (ESA)	Provides tertiary measurements of 3-D solar wind velocity distributions
Data Processing Unit (DPU)	Data interface to/from the PlasMag instruments
NIST Advanced Radiometer (NISTAR)	Supports secondary mission by measuring Earth's irradiance
Earth Polychromatic Imaging Camera (EPIC)	Supports secondary mission by measuring Earth's wavelengths
Pulse Height Analyzer (PHA)	Provides tertiary measurements by detecting solar flare conditions
Command and Data Handling (CDH)	Manages data sent to and received from the spacecraft
Guidance, Navigation and Control (GNC)	Provides attitude pointing and maneuver capabilities via sensors and actuators
Flight Software (FSW)	Manages on-board coded operations for storage, operations and maintenance
Spacecraft Bus (BUS)	Supports the electronic boxes and other subsystem components

The uplink data rate is 2 kbps. The downlink data rate is variable and dependent on the capability of the ground antenna. To ensure a 3 dB link margin at the ground stations designated for DSCOVR, on-orbit operations rely on four rates: 1kbps (4ksps), 20 kbps (80 ksps), 50 kbps (200 ksps) and 138 kbps (551 ksps). Nominal operations use the higher rates, with 138 kbps used primarily at the Command and Data Acquisition Stations (CDAS) and the 20 kbps used at all other stations, while the low rate data (1 kbps) is used primarily for contingency operations with the Deep Space Network (DSN).

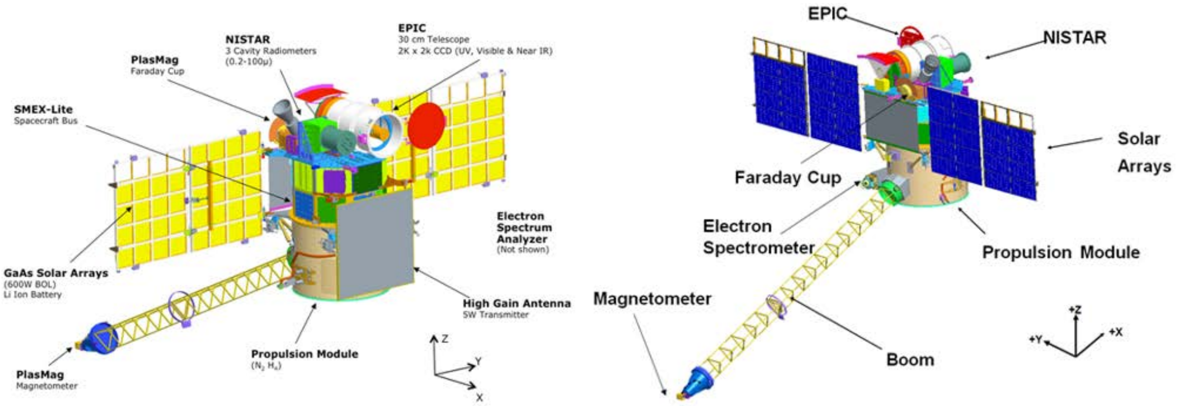


Fig. 18   Earth-Facing (Left) and Sun-Facing (Right)

The DSCOVR instruments are the components of the SS that provide the data to fulfill the primary and secondary mission objectives. The Plasma Magnetometer (PlasMag) suite's Magnetometer (MAG) and Faraday Cup (FC) serve as the primary instruments, providing data for NOAA. The Earth Polychromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology (NIST) Advanced Radiometer (NISTAR) are part of the secondary payload, supplying data to NASA. The Pulse Height Analyzer (PHA), and the third PlasMag component, the Electron Electrostatic Analyzer (ESA), are part of a tertiary mission objective, as data from these instruments are not used for Earth Science or for space weather predictions.

1. *Primary Mission and Instruments: Space Weather for NOAA*

The primary goal of DSCOVR is to provide up to an hour's warning of solar-related disturbances and geomagnetic storm activity using the PlasMag FC and MAG instruments. The instruments are capable of taking faster measurements than previous instruments that study the solar wind. The FC observes solar wind protons and helium ions traveling at velocities of 200 km/s to 1250 km/s with a time resolution of 1 second per distribution. The MAG measures interplanetary magnetic field vectors at 50 samples per second and also aids in the interpretation of the other measurements, and measures the magnetic field at L1 within a dynamic range of ± 1 nT (± 0.2 nT) to ± 65,536 nT in frequencies ranging from static to 25 Hz. The MAG sensor is mounted on a 3.5 meter deployable boom to alleviate some of the effects of the static and dynamic magnetic fields generated by the spacecraft on the magnetic field measurements.

Table 6 NOAA Level-1 Space Weather Measurement Objectives and Requirements

Type of Measurement	Range	Cadence	Accuracy
Vector Magnetic Field	0.1 -100 nT	1 minute	± 1 nT
Solar Wind Proton Speed	200-1250 km/s	1 minute	20%
Solar Wind Proton Density	1-100 /cm^3	1 minute	20%
Solar Wind Proton Temperature	40,000 – 2,000,000 K	1 minute	20%

Table 6 outlines the NOAA Level-1 space weather measurement requirements that are fulfilled through the use of the FC and MAG. It is required that DSCOVR measure the listed parameters with a cadence of 1 sample per minute or better, and deliver the measurements with a system latency of no more than 5 minutes. The goal for continuous space weather data flow is for 96% uptime of the system per day except during orbit maintenance maneuvers and instrument calibration activities. On any day declared as a Critical Space Weather Day, solar wind data available to SWPC must meet a 96% daily duty cycle; any planned activities that would violate this must be coordinated with and approved by SWPC, except where health and safety of the spacecraft and/or instruments is in question. Space weather data must be of useable quality during all levels and types of disturbed space weather measured at the Sun-Earth L1 location permitting approximately 15-60 minute alert time. All gaps that exceed these requirements must be actively worked to minimize the impact.

2. *Secondary Mission and Instruments: Earth Science for NASA*

The two legacy Earth Science instruments developed for the Triana mission provide data for the secondary mission, which is to support Earth Science by collecting images and radiometric data for NASA using the Earth Poly-Chromatic Imaging Camera (EPIC) and National Institute of Standards and Technology (NIST) Advanced Radiometer (NISTAR). Data that are part of the secondary mission are retrieved on a best effort basis as to not interfere with data collection in support of the primary mission. The secondary objectives of DSCOVR are to:

- Measure Earth radiation data in visible to far infrared wavelengths (0.2-100 µm) to calculate total radiant power in Ultraviolet (UV), visible, and infrared wavelengths
- Measure reflected solar radiance in UV, visible and near infrared wavelengths (0.2-4 µm)
- Measure reflected IR solar radiance in Near infrared (0.7-4 µm) wavelengths
- Provide global spectral images of the sunlit side of the Earth

The EPIC instrument observes the Earth at wavelengths ranging from 317 to 779 nm, a range that spans from the near Ultraviolet (UV) into the near-infrared (as shown in Table 7). EPIC periodically collects a full set of science quality images of the entire sunlit side of the Earth, which is stored onboard for transmission during a high-data rate downlink opportunity. The EPIC telescope is a classical Cassegrain design that consists of a two-mirror system. The primary mirror is parabolic-shaped and remains fixed within the telescope. The secondary mirror is hyperbolic shaped and is connected to a focus mechanism that allows for fine focus adjustment. The camera consists of dual filter wheels that permit the selected wavelengths to enter the camera for imaging. A shutter controls the length of the exposure and is capable of multiple exposures ranging from 2 ms for narrow exposure to a minimum of 44 ms for a wide exposure. The camera is capable of performing longer dwell exposures in the wide position with a minimum of 100 ms exposure duration and a maximum limited by software (on the order of days).

Table 7 EPIC Channel Parameters

Wavelength (nm)	Type	Observation
317.5	Near Ultraviolet	Ozone, Volcanic SO_2
325	Near Ultraviolet	Ozone, Volcanic SO_2
340	Near Ultraviolet	Ozone, Volcanic SO_2, Aerosols, Clouds
388	Near Ultraviolet	Aerosols, Clouds
443	Visible [Blue]	Aerosols
551	Visible [Green]	Aerosols, Vegetation
680	Visible [Red]	Aerosols, Vegetation, Cloud, O_2 B-Band Reference
687.75	Visible [Red]	O_2 B-Band Cloud Height
764	Near Infrared	O_2 A-Band Cloud Height, Aerosol Height
779.5	Near Infrared	O_2 A-Band Reference, Vegetation

The NISTAR instrument measures the Earth's energy balance, and takes irradiance measurements of the reflected solar energy and thermally emitted light coming from the full Earth disk. The NISTAR radiometer has a Field of View (FOV) of 1°, which is co-aligned with the EPIC camera boresight, and Field of Regard (FOR) of 7°. Three radiometers are used to make simultaneous measurements in three bands:

- Band-A (0.2 to 100µm): Visible plus far IR channel to measure total radiant power from Earth
- Band-B (0.2 to 4µm): Solar channel to measure reflected solar radiation
- Band-C (0.7 to 4µm): Near infrared channel to measure reflected infrared solar radiation

3. Tertiary Mission and Instruments: Additional Solar Weather Monitoring

The goals of the tertiary instruments are to monitor the effects of high energy particles using the Pulse Height Analyzer (PHA), and solar wind electrons via the Electron Electrostatic Analyzer (ESA) component of the PlasMag suite. The ESA is mounted to the side of the Propulsion Module and detects and measures electrons in the solar wind to yield 3-dimensional (3-D) velocity distribution functions and moments of the measured electrons. The resulting measurements provide data on the bulk speed, density, and other parameters every second. The ESA has a time resolution of 0.25 seconds per distribution. The PHA is an engineering experiment that detects possible flare conditions by measuring proton counts and comparing the count to a flare threshold value. If the proton count exceeds the flare threshold for five consecutive measurements, the PHA uses a spacecraft event message to notify the ground that a flare condition has occurred. The tertiary objectives of DSCOVR are to:

- Measure the time-resolved 3D distribution function of the alpha components of the solar wind plasma
- Provide real-time insight into particle events that may impact DSCOVR
- Measure the full 3-dimensional distribution of solar wind electron activity

B. Ground Segment Overview

The Ground Segment (GS) consists of all components of the mission not part of the SS that are used to support communication and data transfers between ground facilities and components, as well as with the components of the SS. Objectives of the GS, which includes supporting personnel, are to ensure facility readiness, maintain command uplinks and downlinks, coordinate antenna scheduling to ensure reception and transmission of commands and data, data processing, storage and distribution, and ground system monitoring. The readiness and integration of the DSCOVR GS was a major part of mission development. While the SS, i.e., the spacecraft itself, is discrete and separate from existing components, the GS, specifically the mission operations ground system, consisted of new components, but also used or modified existing components. Its development and integration into an operational framework, without the disruption of existing ones, required extensive planning and collaboration with internal and external entities. The major DSCOVR GS components are listed in Table 8 and represented in Fig. 19.

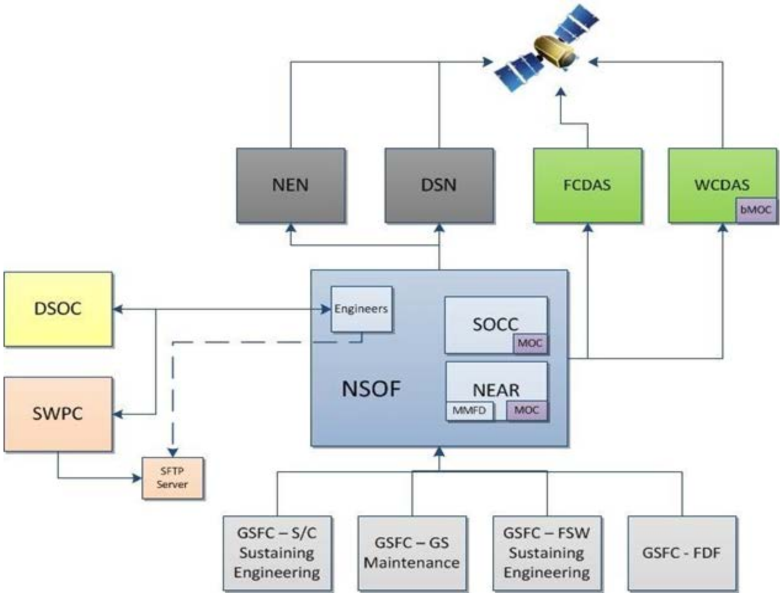


Fig. 19 DSCOVR Ground System Agencies (RTSWnet and AFSCN Not Shown)

Mission operations and commanding are performed from NOAA Satellite Operations Facility (NSOF) in Suitland, MD, Wallops Command and Data Acquisition station (WCDAS) in Wallops Island, VA, and Fairbanks Command and Data Acquisition Station (FCDAS) in Fairbanks, AK. Together, the NSOF and WCDAS constitute the “primary” sites for DSCOVR operations and may be considered in certain respects as a single system, with WCDAS providing the Earth-Space communications functions, and NSOF providing most of the higher level mission operations functions. The NSOF is the primary operations site that houses the DSCOVR Mission Operations Center (MOC), which NASA integrated into its multi-mission operations center, and personnel who execute the Mission Management (MM) and Enterprise Management (EM) functions. All DSCOVR mission operations, from launch verification through sustaining operations, have been performed from NSOF. The Satellite Operations Control Center (SOCC) is the primary location in the NSOF where real time monitoring and commanding occurs. DSCOVR real-time operations have been incorporated within the framework of the SOCC, which is staffed 24/7 with NOAA Flight Operators (FOs), and is where all commanding requests are executed and health and safety is monitored in real-time. The FCDAS serves as a backup support site to WCDAS during the portion of the year when visibility with the spacecraft can be maintained, and when the antenna is not needed to support GOES-W backup operations.

Other primary entities in the ground segment help support the mission, including the NOAA National Centers for Environmental Information (NCEI) (formally the National Geophysical Data Center [NGDC]), SWPC, as well as GSFC and its components. SWPC is the primary user of DSCOVR space weather data and is responsible for ensuring customers receive timely and accurate space weather watches, warnings and alerts. SWPC receives DSCOVR PlasMag data in real-time directly from all ground networks used for normal operations. SWPC extracts the PlasMag and ancillary data and processes it to create Space Weather products for distribution to the Space Weather User Community. SWPC transfers the data files and products to the NCEI for archiving.

GSFC in Greenbelt, MD is the NASA facility that handled all NASA oversight and operations for spacecraft and ground system support for the DSCOVR program during launch and prior to handover. After handover, GSFC has provided and/or coordinated sustaining engineering support for the spacecraft and most ground system components that were delivered to NOAA. The primary interfaces at GSFC that have been involved with the DSCOVR mission are the Multi-Mission Flight Dynamics Facility (FDF), which provides orbital solutions, the Flight Software Systems Branch (FSSB), which currently provides FSW support via the FSW Sustaining Engineering Team (FSSE), and the DSCOVR Science Operations Center (DSOC), which processes data from the EPIC and NISTAR, and submits any operations requests for those instruments.

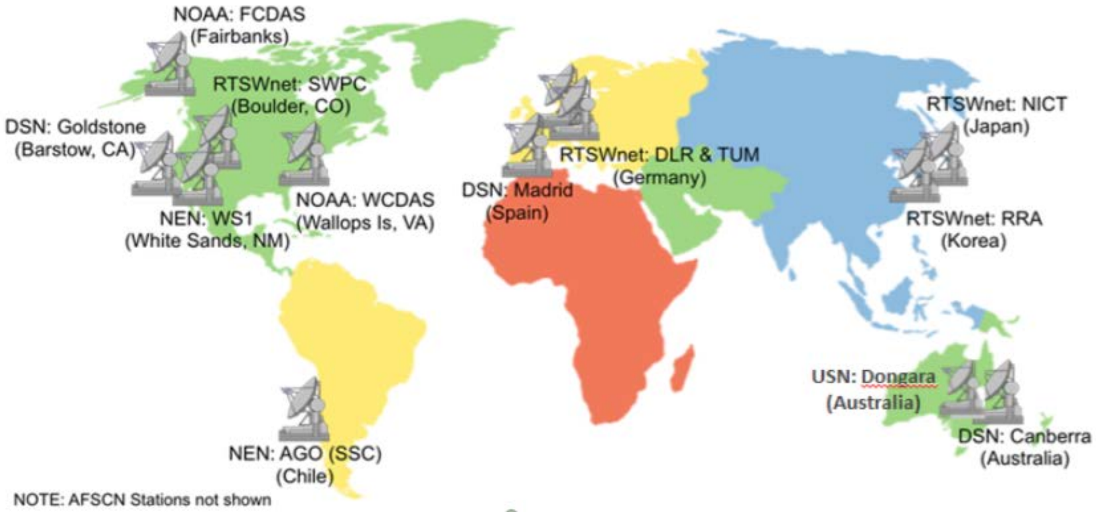
In addition to the NOAA and NASA facilities outlined above, various additional partners constitute a vast global ground station network that supports nominal and anomaly operations. Nominal daily WCDAS ground station passes are supplemented by the Real-Time Solar Wind Network (RTSWnet) and the NASA Near-Earth Network (NEN); these are shown relative to their global position as part of the entire Ground Station Network in Fig. 20.

RTSWnet stations are scheduled by SWPC to collect a continuous stream of Space Weather data to be throughput directly to SWPC; the RTSWnet augments ground station coverage for periods of time not covered by WCDAS. However, there is no command capability at RTSWnet stations, and while utilizing the RTSWnet stations, the Observatory is only capable of downlinking Space Weather data at a rate of 20 kbps.

Table 8 Major Ground System Facilities and Components

Component	Function	Owner
NOAA Satellite Operations Facility	Satellite engineering mission support	NOAA/OSPO
Goddard Space Flight Center	GS and spacecraft sustaining engineering	NASA
Multi-Mission Flight Dynamics Facility	Orbital product generation	NASA/GSFC
DSCOVR Science Operations Center	Earth Science data processing	NASA/GSFC
Flight Software Systems Branch	FSW sustaining engineering	NASA/GSFC
Mission Operations Center	Spacecraft command and data processing	NOAA/NSOF
Wallops Command and Data Acquisition Center	Primary telemetry and command antenna	NOAA
Fairbanks Command and Data Acquisition Center	Backup telemetry and command antenna	NOAA
Space Weather Prediction Center	Space Weather data processing	NOAA
National Centers for Environmental Information	Space Weather data archiving	NOAA
Near-Earth Network Ground Stations	Tracking and ranging antennas	NASA
Deep Space Network Ground Stations	Anomaly telemetry and command / ranging	NASA/JPL
Real-time Solar Wind Network	Prime Space Weather data collection antennas	NOAA/SWPC
Air Force Satellite Control Network	B/U Space Weather data collection antennas	DOD

The NEN is the global ground station network that is used for the acquisition of tracking and ranging data daily via White Sands (WS1) and/or Santiago (AGO) stations. The Universal Space Network (USN) is a corporate ground station network that provides tracking and ranging services to NASA NEN, primarily the Dongara and Hawaii stations. The NASA Deep Space Network (DSN) and the Air Force Satellite Communications network (AFSCN) are used for anomaly operations, or in the case of the DSN, for periodic maneuvers and ranging once a week.



NOTE: AFSCN Stations not shown

Fig. 20   CDAS, RTSWnet, NEN and USN Ground Stations (USN Hawaii Not Pictured)

The Mission Operations Center (MOC) system, designed by Omitron, Inc., is the main component of the DSCOVR ground system that supports and maintains mission operations. The MOC helps to support command and control, telemetry processing, spacecraft script creation and management, maneuver planning, attitude and instrument calibrations, data distribution and archiving, and trend analysis. The components of the MOC are located throughout the NSOF, connected by a common internal network. Detailed descriptions of the MOC components are available in other documentation.

Incorporating a space segment into an existing operational framework typically yields minimal to no disruption to the existing framework; the satellite is inherently separate and isolated and therefore no assessment of existing components is required to ensure a smooth transition. The design and integration of the DSCOVR ground segments and its components, as well as spacecraft operations, into the OSPO framework required substantial oversight and collaboration, beginning very early in the mission development process. The diversity of the DSCOVR mission objectives between two discrete agencies with often counterproductive perspectives and a mixed history of collaboration made for a challenging integration process. The dynamic of the relationship, and the roles and responsibilities for both agencies had to be outlined immediately to ensure the agencies could establish a clear and solid foundation. “The relationship involving dynamic, positive feedback between research and operations highlights the importance of a strong cooperative relationship between NASA (and) NOAA.” [19] Throughout each phase of mission development, technical, programmatic, and even personal difficulties were encountered, but by maintaining open communication, differences of opinions and perspectives were addressed and overcome in order to ensure the success of the mission.

VII. Establishing an Advanced Cooperation Dynamic for DSCOVR Implementation

The DSCOVR mission was a collaboration between NASA and NOAA, specifically between the OSPO Operations and Sustainment (O&S) Team and the GSFC DSCOVR Project (GDP) Systems and Development (S&D) team, another in the line of collaborative endeavors, but unique because of the diversity of the payload and mission goals and the breadth and scope of the required interaction between the two agencies. Previous collaborations typically involved NASA/GSFC delivering extensions of operational frameworks that already existed, i.e., additional POES or GOES satellites, that were already familiar to NOAA/OSPO operational staff, and therefore required little to no familiarization or training. By contrast, the DSCOVR mission was entirely new territory for NOAA, both literally and figuratively, because of its spacecraft mechanics, its physical location, its orbital dynamics, and its operations concept. Therefore, while the required collaboration approach for DSCOVR could borrow some aspects from previous NASA-NOAA endeavors outlined earlier, the overall framework of the management approach for the mission needed to be developed from scratch, after performing a careful analysis of the intended goals and interlocking components.

The DSCOVR collaboration formally began on September 1, 2011 when the two agencies signed an Interagency Agreement (IAA) for Mission Studies and Planning. The agreement established the terms and conditions under which NASA and NOAA coordinated to implement the mission. Under the terms of the IAA, NASA provided the Implementation Phase IAA, various documentation, designed and tested the spacecraft, operated launch sites, and coordinated launch operations, while NOAA collaborated with NASA in project planning and implementation, approved all selection plans and processes, and developed DSCOVR mission requirements.

While the IAA, and subsequent agreements, addressed financial allocations and outlined and facilitated top-level responsibilities and coordination, they did not contain any details for how to develop and implement the mission at the lower operational level as a collaborative effort between development and operations engineers within OSPO and GSFC, two teams mutually invested in the success of the mission, both in pre-launch preparations and post-launch operations.

> Interagency collaboration is not the norm for federal agencies pursuing Earth or space science missions. However, when agencies do collaborate, grassroots collaboration is preferred because it is based on technical necessity and a desire to work together. (T)here may be national policy reasons to require collaboration in certain situations, but top-down collaboration will be burdened from the beginning with a lack of working-level buy-in. Teams that want to work together far outperform those that are forced together, and they also facilitate the application of the tools and techniques associated with good program and project management. Successful collaboration is more likely when each agency considers the partnership one of its highest priorities. [19]

Ensuring a common approach at the working level between the S&D Team and the O&S Team was essential and required in order to establish a solid working relationship that functioned independent of the higher level management structure to facilitate the transition process, yet maintained the communication and reach back mechanism. Without proper awareness and preparation given to the transition process, “(t)he process (can be) hindered by a variety of obstacles, including cultural differences between the research and operational communities, organizational issues, poor communication and coordination … lack of adequate … educated human resources, (and) absence of effective long-range planning.” [19] Unlike other collaborative missions, NASA had a vested interest in a portion of the payload data that would come from DSCOVR once operational, which played heavily into the collaborative relationship during development in all mission phases. This also factored heavily into the determination of the ***Category of Implementation*** and ***Type of Collaboration*** for DSCOVR, which OSPO used to shape the approach for structuring and managing the transition framework, including the transition pathways.

Transition pathways are end-to-end processes assembled for achieving successful transitions and are characterized by ***Four Transition Pathway Elements***: *Objectives*, *Organizational Structure*, *Procedures*, and *Resources*. For the DSCOVR mission, the GDP coordinated spacecraft integration, requirements testing and launch preparations, and OSPO operated the spacecraft and ground system after Handover. However, there was discontinuity and ambiguity on the transition pathway between the pre-launch and post-launch operations that required resolution via systems engineering at the working level in order ensure an efficient transition.

> Many of the impediments to interagency collaboration, both internal and external, manifest themselves as impediments to good systems engineering. Good systems engineering and project management techniques are important in any space mission, but especially when multiple organizations are involved. The inevitable creation of seams (i.e., divisions of responsibility and/or accountability between participants for planning, funding, decision making, and project execution) as a result of interagency collaboration is a source of technical and programmatic risks. Such risks could include failure to meet agreed-upon technical performance requirements, compromised system reliability, unacceptable schedule delays, or cost overruns, and mitigating such shortfalls requires proactive management and attention. [19]

In general, a definitive, but flexible, plan for a transition pathway should be developed early, reviewed regularly, and updated as necessary in order to tighten and maintain a seamless transition. The primary focus of this paper is on the transition from research to operations, shown as Transition Pathway (TP) One (TP1) in Fig. 21. For the DSCOVR mission, TP1 was divided into a primary transition pathway, and two secondary pathways that facilitated unilateral coordination between NASA and NOAA for the GS (TP1G) and the SS (TP1S). Transition Pathway Two (TP2) represented the push/pull dynamic between OSPO and the users of the data, primarily SWPC and DSOC; this dynamic is not addressed in detail here, but partially contributed to how OSPO formulated the TP1 dynamic. Each valley can be measured in several areas, including those of organizational structure and culture, mission objective and design, planning and coordination, communication, and financial and human resources, as well as that of the limitations associated with scientific understanding and technical capability. By executing successful mission operations systems engineering, OSPO ensured that everything remained within the required Transition Pathway, and that no information was lost into the valley of death and lost opportunities.

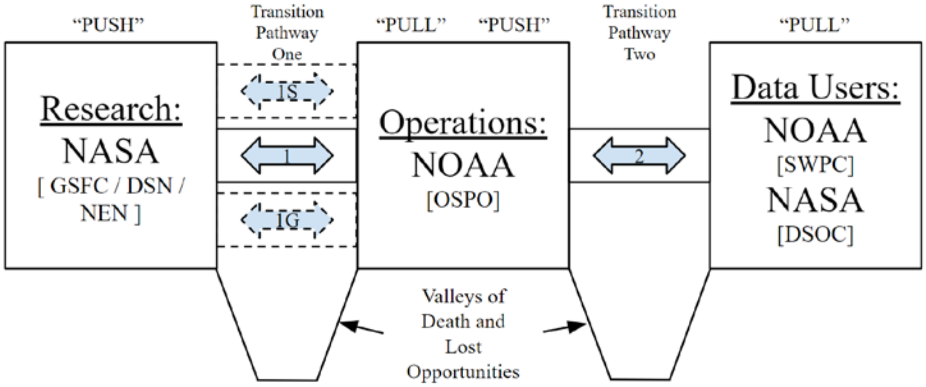


Fig. 21 Research, Operations and Data Users Transition Pathways

OSPO could not formulate the elements and design of the pathways for the DSCOVR mission without first reviewing and applying the ***Categories of Implementation*** outlined earlier to determine the context of application. Subsequently, OSPO determined that more than one ***Category of Implementation*** was applicable due to the duality of the mission structure; for the primary mission, the implementation was a NASA systematic measurement that ultimately transitioned to NOAA operational measurements, while for the secondary mission, it was a combination of a NASA exploratory measurement and technology demonstration that ultimately transitioned to NASA operational measurements. Therefore, OSPO required more than one transition pathway to coordinate two discrete missions within the overall DSCOVR mission itself; these were managed independently as sub-pathways within TP1, TP1S and TP1G.

OSPO performed analysis of the ***Types of Collaboration*** to determine how to structure the transition and operations management frameworks. Since both agencies relied on each other for mission success (i.e., NOAA needed NASA to launch and validate the space weather instruments, and NASA needed NOAA to successfully operate and monitor the earth science instruments), the collaboration was at least one of Cooperation. Furthermore, because of the atypical dynamic and dependencies required due to the duality of the payload and mission goals, OSPO qualified the collaboration as *Advanced Cooperation* (see Fig 22).

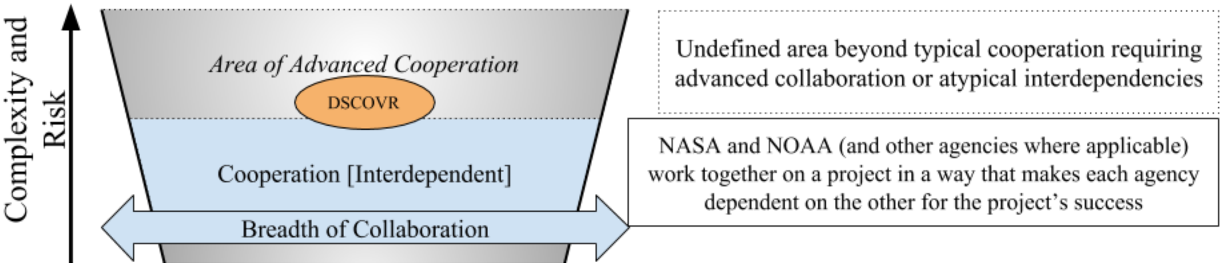


Fig. 22 Placement of DSCOVR on the Scale of Collaboration

Based on these qualifiers, summarized in Table 9, the GDP and OSPO worked together to strengthen the planning, coordination, and management components of the mission using teams of people with appropriate research and operational expertise focused on defining and strengthening cooperative efforts on the required transition pathways.

Table 9 DSCOVR Categories of Implementation and Type of Collaboration

Categories of Implementation	Rationale	Type of Collaboration	Rationale
NASA Systematic Measurements that Transition to NOAA Operational Measurements	Primary mission instruments designed by NASA transition to NOAA	Advanced Cooperation	There is a reliance of NASA on NOAA after Handover for data that is beyond a standard "Cooperation" collaborative relationship.
NASA Exploratory Measurements and Technology Demonstrations that Transition to Operational Measurements	Secondary exploratory instruments are technology demonstrations that transition to NOAA to operate, but data are used by NASA		

When the decision is made to engage in a collaborative space mission beyond the "Use of Resources" level, there are areas in which agencies must mitigate risks. The mitigation strategy created for DSCOVR development was the ***MOPS Approach***, which managed the ***Four Transition Pathway Elements*** through four focused mitigation practices:

- **Management (of *Organization Structure*)** - One of the collaborating agencies was designated as the lead agency. Ultimate responsibility and accountability for executing the mission rested with the lead agency. Since there was a transition of major responsibility at a point in time, and the single lead agency changed, coordination between the two was required.
    - ***Relevant Pillar of Successful Transition***: *Strong Management*
- **Operations (of *Objectives*)** - There was a common, agreed-upon concept of operations, which evolved with time and experience, but had an explicit agreement on an initial operational approach. The operations of objectives set definitive strategies and quality checks for meeting a set of milestones in the most efficient manner, and established the principles of continuity between mission objectives.
    - ***Relevant Pillar of Successful Transition***: *Well-defined Transition Objectives and Plans*
- **Policy (of *Resources*) -** There was a single, clear memorandum of understanding (MOU) and other agreements between the agencies that defined the chain of command. As an extension of the MOU, the agencies established a joint policy that addressed how available assets (i.e., finances, materials, services, and staff) were used to produce shared benefits.
    - ***Relevant Pillar of Successful Transition***: *Adequate Human and Fiscal Resources*
- **Systems Engineering (of *Procedures*) -** There was a single, well-defined, established systems engineering process with a single chief systems engineer and no duplicate milestone reviews. The Systems Engineering of procedures was the general method for implementing processes using standard approaches.
    - ***Relevant Pillar of Successful Transition***: *Effective Processes for Performing the Transition*

Furthermore, agencies who engage in an *Advanced Cooperation* dynamic can enhance and sustain their collaborative efforts by engaging in the ***Eight Practices in a Successful Advanced Cooperation Relationship*** outlined in Table 10 while implementing the *MOPS Approach*. Common in these practices are leadership, trust, and a respected organizational culture that are necessary elements for a collaborative working relationship.

Table 10 Eight Practices in a Successful Advanced Cooperation Relationship

Practice	Result	Description
Define and Articulate a Common Outcome	Target Goal	Define goals that benefit both NASA and NOAA
Establish Mutually Reinforcing or Joint Strategies	Strategy	Manage mission objectives in a way that are mutually beneficial for both NASA and NOAA objectives
Agree on Roles and Responsibilities	Roles	Determine how NASA and NOAA will work together early in the mission in order to establish staffing framework and levels of support that are needed
Identify and Address Needs by Leveraging Resources	Needs	Utilize and share personnel and technological resources between agencies.
Establish Compatible Policies that Span Agency Boundaries	Policies	Acknowledge, respect and resolve cultural differences between the two agencies and utilize common ground
Develop Mechanisms to Monitor, Evaluate and Report Results	Quality Checks	Maintain awareness of and report mission status
Reinforce Agency Accountability through Plans and Reports	Reporting	Maintain civil cross-agency checks and balances
Reinforce Individual Accountability through Evaluation Processes	Evaluation	Evaluate and support and individual progress

VIII. NASA-NOAA Collaboration: Transitioning from Research to Operations

The execution of mission activities throughout all phases relied on several teams at various management levels within both agencies to ensure success, but OSPO formed a dedicated team at the working level that applied the *MOPS Approach* at every point from pre-launch planning and development, through launch, orbit insertion, and post-launch testing, and finally during transition to normal and sustaining operations. OSPO formed the NOAA DSCOVR Operations Team (DOT) to coordinate, implement and manage all activities relevant to transition and operations on behalf of NOAA. This structure was necessary because it established a core set of individuals dedicated to connecting NOAA to NASA components to facilitate transition efforts, and allowed the respective agencies to continue executing their internal responsibilities independent of the transition efforts.

> (T)he organizational structure of the research and operational agencies would be efficiently aligned to support technology transfer across the transition pathway. Staff would be highly educated, trained, and motivated. The cultures would be open to new ideas from other organizations, as well as being cooperative, team-oriented, and supportive of the technology-transfer process. Planning for technology transfer would occur from the very beginning of a research mission and would be updated continuously as the mission progressed. Communication and coordination would occur between the researchers and the operational personnel throughout the mission. The necessary scientific and technological underpinnings of the mission would be solid, including the scientific understanding required to use the mission results effectively to improve operational products and services. And finally, adequate financial and human resources would be available, not only to the research and operational sides but also to the transitioning process that bridges the gap. [19]

Therefore, a key feature of the DSCOVR transition approach was the inclusion of a small number of NOAA staff, i.e., the NOAA DOT, dedicated to DSCOVR mission operations since the early stages of pre-launch development that worked closely with NASA since “there needed to be a ‘spannable distance’ between the research and operational communities, as well as a mechanism that bridged this distance and connected the researchers to the end users of the data and technologies.” [19]

OSPO established a streamlined management dynamic, shown in Fig. 23, to execute the *MOPS Approach* for the DSCOVR mission. This DSCOVR management approach utilized the same rationale that was behind the formation of DMSP program transition model, where “an efficient, compact management structure and process allowed the program to far exceed expectations and outpace parallel efforts in NASA. The novel management scheme was made possible by … a few key energetic people with strong ties to the user and the research community that exercised technical direction. It could make decisions and act quickly.” [19] Therefore, to efficiently execute mission development using the *MOPS Approach* for DSCOVR, OSPO envisioned and implemented this mirrored team structure that spanned both agencies to facilitate transfers between a singular membrane of transition; by having counterparts within each agency, the agencies more effectively coordinated the sharing and dissemination of information.

> Due to the complexity of the systems and the multiple communities involved, some level of redundancy between agencies must be included. The establishment of clear roles for one agency should not be interpreted to preclude the other agency from pursuing activities that complement its mission. [11]

This dynamic permitted OSPO staff to participate not only as end users, but also as facilitators of mission integration, for both NASA staff supporting launch activities, as well as for NOAA staff supporting normal operations. The success of this dynamic illustrated the importance of involving the operational team early in the DSCOVR mission development process, a concept that at first required some perspective resolution between both agencies.

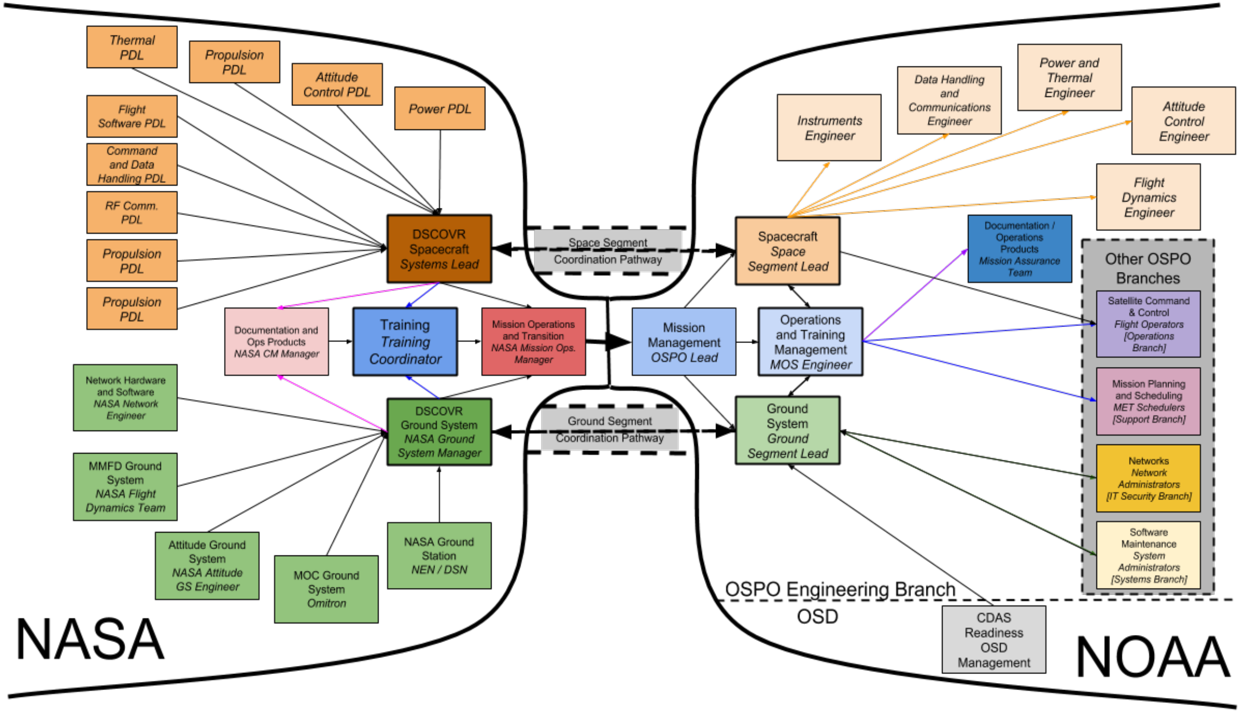


Fig. 23 NASA [GSFC, NEN and DSN] and NOAA [OSPO and OSD] Transition Dynamic: Final Version

Although the DSCOVR collaboration formally began in writing on September 1, 2011 when NASA and NOAA/NESDIS signed the IAA for Mission Studies and Planning, the collaborative effort at the S&D and O&S level, between the GDP and OSPO, respectively, was where personnel implemented the detailed engineering work to facilitate the transition from research to operations. Systems Engineering (SE) and Operations Engineering (OE) efforts at this level required more intensive technical and management interactions in order to carry out the actual planning and execution needed to fulfill the requirements outlined between upper management. All phases of mission development required multiple levels and types of teamwork, which needed to be documented and agreed upon to ensure coordinated efforts between both parties.

> For each identified transition project, establish a NASA-NOAA Project Transition Plan (which should) describe (in detail appropriate to the time frame of the activity) how each activity is to be accomplished; it should include (a) … schedule of transition activities, to include the training and education necessary for full operational capability, and (a) description of the … human resources required for each transition activity, as well as an estimate of expected resources required for operations and maintenance after the acceptance of initial operational capability. [19]

The following is a synopsis of how the launch of DSCOVR and the subsequent transition of operations, spacecraft and ground system from NASA/GDP to NOAA/OSPO were implemented using the methods previously outlined. Using a dynamic structured by the practices in Table 10, OSPO personnel managed preparations for the DSCOVR mission from two fronts:

1. **NASA Launch Support:** Facility and Personnel Readiness to Support Launch, and
2. **NOAA Operations Support:** Infrastructure and Management Structure Readiness to Operate the Mission

Within each front the agencies divided the management of the mission elements into three categories to fit within the management dynamic and transition pathways outlined in Fig. 23:

1. **Ground Segment:** Coordination of Ground System and Antenna Functionality
2. **Space Segment:** Management of Spacecraft and Instrument Operations
3. **Operations Management:** Personnel Training and Readiness

OSPO coordinated with the GDP to outline the top-level goals for the upcoming transition, resulting in the following list of ***Five Requirements for Transition*** fulfilled during the period of common transition activities (shown by the gray area in Fig. 24):

- **Established Management and Operations Plan:** NOAA (Staff and Facility) Ready to Operate
- **Certified Operational Resources:** Operations Products and Documents Delivered
- **Functional Space and Ground Assets:** Spacecraft On-Orbit and Functional and GS Validated
- **Established Sustainment Plan:** Sustaining Engineering Agreements Finalized
- **Validation of Success:** Readiness Reviews Conducted

All requirements had to be sufficiently completed in order to permit a successful transition of operations from NASA to NOAA, and the manner in which each requirement was managed and fulfilled is outlined in subsequent sections. Each requirement was governed by one or more ***Transition Pathway Elements***, and was facilitated by a specific mitigation strategy and ***Pillar of a Successful Transition*** within the *MOPS Approach*.

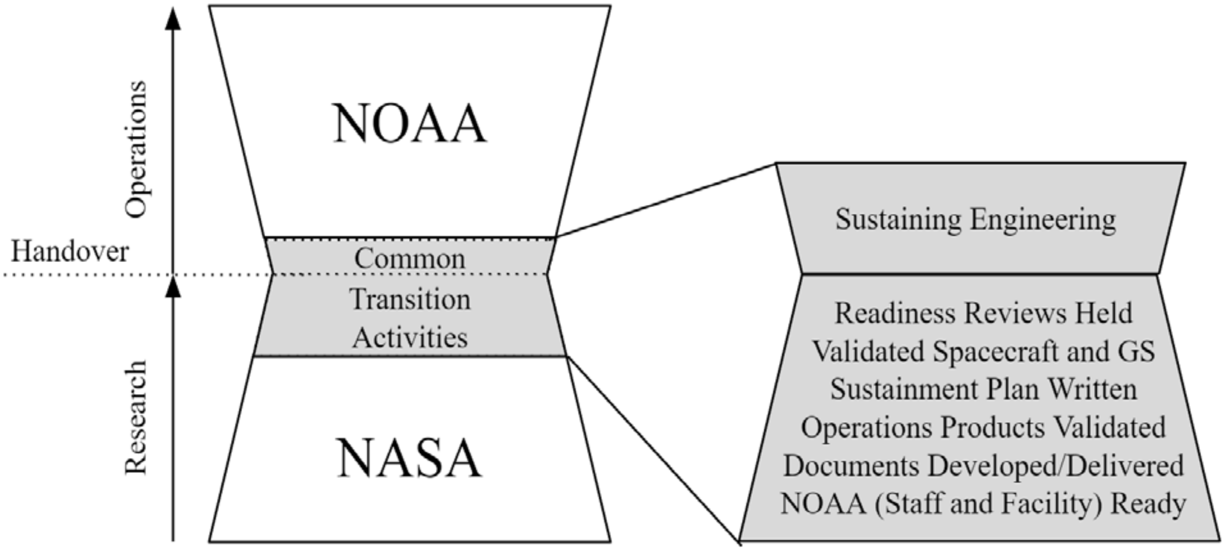


Fig. 24 Expansion of Common Transition Activities

The DOT, led by the Mission Operations Systems Engineer (MOSE), coordinated the *Advanced Cooperation* dynamic with NASA using the ***Eight Practices in a Successful Advanced Cooperation Relationship,*** applied the *MOPS Approach* within the *Operations and Sustainment (O&S) Lifecycle* to fulfill the ***Five Requirements for Transition***, and executed a *Coordinated Integration* of DSCOVR into the NOAA framework. Once integrated, DSCOVR operations were managed using the ***Areas of Focus*** to meet measurable objectives and maintain mission requirements. The MOSE functioned as the lead coordinator for both Systems Engineering (SE) and Project Management (PM) for the DSCOVR mission, two important processes that needed to work together to facilitate a successful transition. For DSCOVR, SE was the process by which the performance requirements, interfaces, and interactions of all the DSCOVR spacecraft and ground system elements were integrated and operated so as to meet the overall requirements of the total system, and PM facilitated schedule coordination, performance requirements, and assignments of team member roles and responsibilities.

A. Establishing a Baseline and Incorporating Requirements and Participation of the End Users

Any project is the most successful if the desired result or outcome is understood completely as early as possible. For projects that produce a specific product, understanding how the target user intends to use that product is imperative in producing something useful that will fulfill the needs of the target audience. "The key (to success) is effective and clear coordination between the operational and research entities." [19] For DSCOVR, NASA had two types of customers: first, the operational user (OSPO) who would operate and maintain the ground system and spacecraft, and second, the end users (SWPC and DSOC) who would utilize the data from the spacecraft. Typically, the process to ensure the data meet requirements via instrument operations has been scientific and utilized a very straightforward approach, but for transitions that occur on a moderate time scale of around 2-5 years,

> … the technical and administrative issues become more complicated. The process is analogous to "product development," during which a research and development (R&D) center is attempting to develop and refine a potential product and bring it to market. The product requirements may not be well understood, and the operational/ production side may be skeptical … Time schedules may be poorly defined, and the project may run late, thus incurring more costs. The transfer of programmatic responsibility for a research satellite mission to an operational agency is an example of such a midrange transition. [19]

The DSCOVR mission timeline fell within this range and met these qualifications. In the example provided above, the R&D Center (the GDP) was refining the product (the DSCOVR spacecraft and the supporting ground system) and bringing it to market (within and for OSPO). Involving the market users (OSPO O&S engineers) in the product development phase reduced the risk of producing a product that was not in line with user expectations. Once this dynamic was identified, the next step was optimization of the dynamic itself.

> Successful transitions from R&D to operational implementation always require: (1) an understanding of the importance (and risks) of the transition, (2) development and maintenance of appropriate transition plans, (3) adequate resource provision, and (4) continuous feedback (in both directions) between the R&D and operational activities. In the case of the atmospheric and climate sciences, inadequacies in transition planning and resource commitment can seriously inhibit the implementation of good research … [17]

The risks and benefits of the transition (1) were established at the onset of the collaboration, and formalized in signed agreements. Adequate resources (3) within the collaborative framework translated into providing sufficient personnel in both agencies that could facilitate an efficient unilateral feedback loop (4) between them. Most of the optimization was pursued through the formulation and enforcement of transition planning (2). Therefore, the solution to the most efficient optimization process was to partner OSPO personnel in an equivalent capacity with GDP personnel in all mission development phases, which fell in line with previous studies that found that "... successful interagency space mission collaborations are characterized by… well-understood participation incentives for each agency and its primary stakeholders (where) early and frequent stakeholder involvement throughout the mission keeps all stakeholders informed, manages expectations, and provides appropriate external input." [11]

Representation of the end operational users is also important when the designer and the intended user come from agencies with different perspectives and approaches. "The mismatch between a NOAA planning process that requires a well-defined set of exploratory measurements and the unpredictability of the NASA research peer-review process is an impediment to this transition." [19] The MOSE recognized this impediment, and resolved to mitigate the risk introduced by the mismatch by implementing a solid systems engineering and project engineering approach, since "good systems engineering and project management techniques are important in any space mission, but especially where multiple organizations are involved." [11]

In a joint collaborative effort it is important to establish the framework and trajectory of the dynamic at the onset. In an *Advanced Cooperation* relationship, applying the ***Eight Practices in a Successful Advanced Cooperation Relationship*** in a natural progressive format based on the objective of each practice can guide the trajectory. The first four practices should be executed at the initial meeting in order to yield the following results that define the team dynamic: the *Target Goal* (What), the *Strategy* (How), the *Roles* (Who), and any gaps in resources that prevent initial progress, i.e., the *Needs*. Once those are established, then the second half of the practices can be implemented, which produce results to reinforce the dynamic, guide the trajectory, and gauge progress execution: *Policies, Quality Checks, Reporting* and *Evaluations*.

> (A) flexible plan or architecture for a seamless transition pathway, including the necessary financial and human resources, should be developed, regularly reviewed, and updated as necessary. NASA and NOAA should work together to strengthen the planning, coordination, and management components of the mission. Teams of people with appropriate research and operational expertise should be assigned to the mission. [19].

The operational working-level partnership between the GDP and the DOT counterparts officially began on December 7, 2012, when engineers from each agency met for the first time to establish a working baseline. At this meeting, the MOSE outlined NOAA's interpretation of how the working relationship should be developed (i.e., *Strategy*) using the concept of a shared organizational structure (i.e., *Roles*) based partly on an existing Mission

Operations Support Team (MOST) model that had been developed for the recent GOES-R mission integration, but on a smaller scale and with a redesigned approach. Fig. 25 depicts the fluid concept of mission management that the MOSE presented to GSFC at this initial meeting. Under this model, there was a dual-agency "Core" MOST comprised of personnel from the GDP and the DOT including discipline engineers, systems engineers, flight and ground controllers, mission planners and schedulers, and ground systems engineers. This model also proposed that OSPO, specifically the DOT, would become progressively more involved in mission activities toward Launch, leading into a Handover phase, the timing of which was vague and undefined at the time of the meeting. In general, the idea was that the GSFC MOST personnel's involvement dropped off at Handover then diminished, although a "Gradual Handover" through Cruise Phase up to L1 Orbit Insertion (LOI) was posited, where GSFC MOST support tapered off instead of dropping completely.

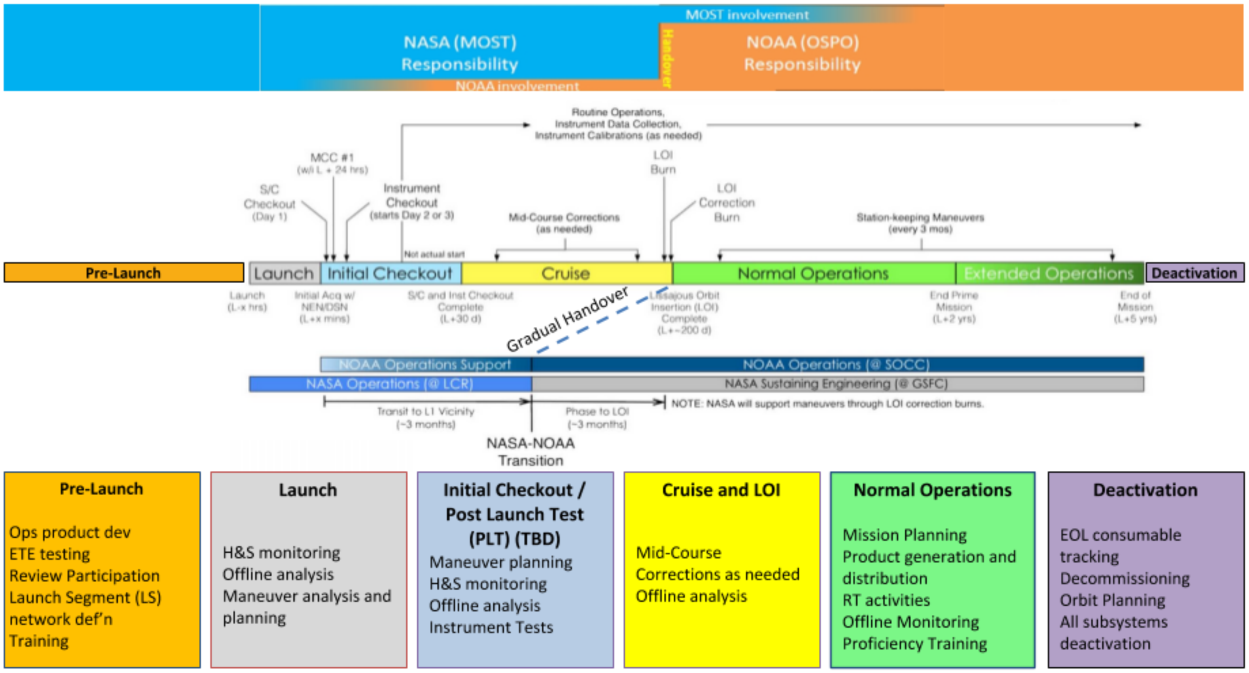


Fig. 25 Initial Mission Operations Support Team (MOST) Dynamic Proposal - December 2012

The *Target Goals* of the MOST were addressed as well. For OSPO specifically, the goals were to acquire in-depth engineering expertise of the DSCOVR satellite and ground systems necessary to operate the DSCOVR mission, including anomaly response and recovery. The MOSE proposed that both agencies would collectively develop a comprehensive set of mission plans, procedures, tools, training programs, and data necessary to operate the DSCOVR mission from launch through end-of-life decommissioning, and deliver to OSPO a functionally-verified and performance-optimized DSCOVR satellite and ground system.

At this meeting, the MOSE firmly asserted that NOAA expected to serve as equal partners in the management structure for all phases of the mission, and by the end of the meeting, the agencies established a collaborative baseline. Although a few open issues (i.e., *Needs*) were identified, including timing of the Handover with respect to LOI, operational product and documentation lists, team size and framework, and training approaches, overall the meeting established baseline expectations among both agencies. More importantly, the meeting allowed the MOSE to assert that OSPO was willing and able to go above and beyond to ensure NOAA's perspective and operational requirements were considered from the very beginning of mission development, to resolve that perspective with NASA's approach, and to facilitate open and honest communication between agencies throughout the endeavor.

> Communication is important in any space mission, but even more important when organizations with different cultures, procedures, vocabularies, and roles come together to achieve a common goal. Differences of culture, language, and procedures are expected in international space cooperation but are often underestimated in interagency collaborations until problems become quite obvious. [11]

Using lessons learned from previous collaborations, and taking the suggestions of the MOSE under consideration, engineers from each agency held the first Mission Operations Working Group (MOWG) on January 15, 2013. In attendance were engineers from NASA (and supporting contractors), NOAA (OSPO, OSD and EMOSS engineers), as well as SWPC and DSOC personnel, ensuring that members from all three areas (Research, Operations and End Data Users) in Fig. 21 were represented and had input into the planning process from the start.

Shortly after the first MOWG meeting, at the Mission Baseline Review (MBR) on June 5, 2013, one of the first of many *Quality Checks*, the GDP presented their intended approach for training and commissioning. The Chair of the review submitted an Action Request Form (ARF) on the topic of training and commissioning, recommending that technical criteria be established for handover, instead of applying a time-based handover, and that the GDP should consider bringing members of the operations team onto the development team as test conductors in the Integration and Test (I&T) activities. The recommendation noted that the GDP exacerbated the risk of inadequate training by only presenting the training development and participation of the operations team at a high level, and that early involvement of operations teams has proven to be a key ingredient for mission success, especially in highly-integrated Class D missions such as DSCOVR. This advice was in line with previous findings which noted that "… successful transitions require an understanding of the importance and risks of transition, the development of appropriate transition plans, adequate resources for the transitions, and continuous communication and feedback between the research and operational communities." [19] Although members of the DOT were not brought into the I&T process, their involvement in the S&D process expanded based on the recommendation from the Chair.

Following the MBR, the concept of the MOST structure evolved, as the MOSE split the organization framework into the Flight Operations Team (FOT) [on the GSFC side] and the DOT [on the OSPO side]. The DOT was the "Core" DSCOVR team for NOAA, and consisted of the NOAA Flight Operators (FOs) and the NOAA Mission Engineering Team (MET); the MOSE further divided the MET into the Scheduling Group and the Engineering Group to better facilitate mission planning and execution. The DOT worked closely with the FOT, but also with NASA spacecraft, instrument, and ground system personnel, to acquire all information and/or materials required to fulfill mission operations goals. The MOSE funneled and distributed these data back into the NOAA framework among the five branches, i.e., members of the "Extended DOT", in a digestible format; once reviewed, the MOSE returned any comments or suggestions back to the GDP, thereby implementing an information feedback loop through the transition pathways shown in Fig. 23.

Building on the mirrored transition structure shown in Fig. 23, and to establish a compatible management policy that spanned agency boundaries, the MOSE established the DOT Space Segment Lead (SSL) position to coordinate with the GDP Spacecraft Systems Lead (SCSL) on spacecraft matters and the DOT Ground Segment Lead (GSL) position to work with the GDP Ground Systems Manager (GSM) on ground system issues. The MOSE coordinated with the GDP Mission Operations Manager (MOM) to manage overarching transition activities, and also served in the role of SSL due to the condensed staffing profile. This dynamic ensured the continuous and coordinated flow of information across agency boundaries, and facilitated progress on multiple fronts on transition sub-pathways.

The MOSE and GSL not only had to ensure they were ready to receive the mission as operators, and monitor the progress of the GDP S&D team, but also had the responsibility of establishing physical and operational readiness for the DSCOVR mission within the NSOF to support both launch and normal operations. The MOSE needed to develop mechanisms to monitor, evaluate, and report results across all fronts of mission development, and reinforce both NASA and NOAA accountability through plans, action items and weekly reports. To facilitate a coordinated attack on issues in a wide range of areas, the MOSE formed and ran the DSCOVR Working Group (DWG) to track progress and action items related to NSOF development.

As the early mission development progressed, the overarching concern of the MOSE was ensuring that the role of OSPO, and the NOAA perspective, was always clearly defined and maintained at the developmental and operational level in all mission stages, but in an non-intrusive way that still allowed the GDP to perform in their capacity as the primary lead for the DSCOVR project. The GDP was responsible for launching the satellite and establishing a working ground system, i.e., delivering an operational system to NOAA. However, part of that functional operational system was a well-trained staff within NOAA, comprised of personnel with knowledge of relevant GS and/or SS components.

Despite the collaborative progress for the mission as a whole, the individual efforts of the GDP and the DOT were too disjoined and independent, and progressed as two separate paths instead of a collective approach on the same transition pathways. As an *Advanced Cooperation* partnership, this disconnect between joint agencies was counterproductive; the dynamic required interdependency in order to facilitate the sharing of vital information needed to launch and operate the mission by NASA and NOAA, respectively. This disjointed implementation of mission development created a contentious atmosphere among agencies approaching the mission with two very different perspectives. While NOAA viewed DSCOVR as a flagship for their expanding fleet of satellites, the history of Triana was still present on the minds of the GDP. The fact that NASA's Earth Science instruments were now secondary to NOAA's Space Weather instruments was something that had the potential to create a level of contention that could hinder the collaborative effort. Additionally, NOAA would be operating DSCOVR, while

NASA had been operating ACE (and had even been briefly considered as the agency that would be operating DSCOVR once operational).

There could have been a resurgence of the old perspective that contributed to the disbandment of the OSIP, when the two agencies were partners in building the operational weather satellite system (with NOAA in the role of junior partner) and the potential existed for NASA management to view the DSCOVR mission as “theirs” (i.e., NOAA’s) and not “ours”, which could hinder their commitment to fully supporting transition efforts. Under the arrangement as it existed for the DSCOVR mission, this mentality was just as applicable as it was then and had to be addressed and resolved before any forward progress could be made.

> As agencies bring diverse cultures to the collaborative effort, it is important to address these differences to enable a cohesive working relationship and to create the mutual trust required to enhance and sustain the collaborative effort. Frequent communication among collaborating agencies is another means to facilitate working across agency boundaries and prevent misunderstanding. Collaborating agencies may also need to find common ground while still satisfying their respective operating needs. The ability to work collaboratively requires mutual trust among the respective parties—a shared belief that the partners will carry out their part of the joint agreement. Fostering an interagency culture … can help facilitate collaborative efforts across agency boundaries and enhances a cohesive working relationship among staff. [3]

NASA was, and has been, the leader in spacecraft development and launch, and now had to share that role with a NOAA operations staff eager to ensure they were prepared to take over and operate the mission. What resulted was a delicate balance of “staying out of the way” to let NASA do their job and “getting in the passenger seat” to learn how to operate.

> (A)gencies face a range of barriers when they attempt to collaborate with other agencies. One such barrier stems from missions that are not mutually reinforcing or that may even conflict, making reaching a consensus on strategies and priorities difficult. Another significant barrier to interagency collaboration is agencies’ concerns about protecting jurisdiction over missions and control over resources. [3]

From the beginning of the DSCOVR mission, the GDP was under pressure to meet mission deadlines, as they usually are in any RTO project. However, in addition to factoring in standard delays and issues, they had to also account for not only working with but also training a collaborative partner, which placed an additional strain on the required *Advanced Cooperation* dynamic. In this respect, NOAA was more than just a partner; the DOT was another ground system component that required testing, validation, and operational certification before Handover.

The collaborative effort between the agencies was sometimes contentious, but always professional, and the involvement of the operational personnel in the process was essential to its successful conclusion, regardless of the perspective each agency held on that inclusion. The MOSE was always cognizant of NOAA’s requirements, and executed the last three of the ***Eight Practices in a Successful Advanced Cooperation Relationship*** to develop *Quality Checks*, initiate *Evaluations*, and institute a *Reporting* process in order to reinforce the GDP’s accountability by continually addressing risks before they became unresolvable. In order to maintain awareness of mission progress and relay updates, MET Engineers continued supporting DSCOVR mission readiness reviews to track *Quality Checks* and provided *Reporting* back to OSPO management. To reinforce individual accountability within the GDP team via *Evaluations*, the MOSE met regularly with OSPO Management to discuss high level mission implementation plans, including OSPO branch integration, planned personnel training, and sustaining engineering agreements, as well as any personnel issues or conflicts that were impacting mission development.

Throughout the collaborative process, the MOSE tracked key issues, and a few months before handover, the MOSE outlined to the Director of OSPO the top-level risks (shown in Table 11) that jeopardized mission success after Handover. Evaluation of these risks were based on the status progress, the perceived resolution given the efforts and plans at the time, and the resulting impact to supporting operations and meeting mission requirements. The risks were addressed in detail to NOAA and NESDIS management, and outlined key areas that should be monitored early and closely in any *Advanced Collaboration* relationship, including documentation, mission continuity, IT security, and concept of operations formation. Since the MOSE identified these risk with sufficient time to obtain resolution, many of the risks were resolved prior Handover, and others, such as Safe Hold events and Earth Science instrument operations, were accounted for during transition planning to ensure they could be accurately managed during Normal Operations. Maintaining this awareness of potential show-stoppers ensured that they were mitigated quickly and permitted development in essential areas.

Table 11 Collaborative Mission Risks Leading into Handover

Risk ID	Title	IF …	THEN …
DSCO-1	Quality of Documents to Support Operations	… the documentation delivered by the GDP does not meet NOAA standards for documents required to support DSCOVR Operations, and lacks guidelines and information required to execute and/or recover from known or predicted nominal and contingency scenarios…	… there will be a significant amount of work and staffing required by the NOAA DSCOVR Operations staff to update operational documentation, which, given that the GDP are the subject matter experts, may lead to errors and discrepancies and negatively impact the mission elements, including the satellite.
DSCO-2	Earth Science Operations and Staffing Requirements	… the Earth Science instrument operational requests are to be executed as planned during Normal Operations, considering the offline planning and real-time activities required to plan for and execute these activities …	… the current staffing levels may be insufficient to support the increased Normal Operations workload.
DSCO-3	Potential Frequent Safe Hold Events	… the DSCOVR satellite continues to regularly trip into boot mode / Safe Hold …	… the level of workload required to support operations is increased, the purpose of the mission is jeopardized, and the ability to meet mission requirements is reduced, especially without thorough supporting documentation delivered by the GDP.
DSCO-4	USB Process for Use During Operations	… USB devices are not available for the Mission Engineering Team (MET) Scheduling and Engineering staff …	… operational products needed to meet mission requirements cannot be transferred into and out of the MOC System.
DSCO-5	White Sands (WS1) Availability for Northern Ranging	… WS1 is not regularly available to support DSCOVR ranging …	… the Flight Dynamics Facility (FDF) will not be able to perform accurate orbital calculations and deliver quality products to NOAA to support maneuver planning since the WS1 ground station is the only northern hemisphere ranging station.
DSCO-6	No Week-Long ATS Loads and Increased Work for Schedulers	… the spacecraft is unable to accommodate week-long on-board command loads (ATSs) …	… the workload required for the scheduling staff will be increased, and may require increased staffing support.
DSCO-7	Ground Connectivity to Primary User from Backup Ground Station	… the connection between FCDAS and SWPC is not finalized/tested …	… the data transfer from the backup station to the primary DSCOVR user will be not be available and will impact mission requirements.

B. NOAA Satellite Operations Facility: Launch and Operational Readiness

One of the first tasks that needed to be accomplished in the mission development process was establishing a framework that would accommodate both launch services for NASA and operational activities for NOAA. To manage this effort, the MOSE (for launch staffing and operations) and GSL (for facility and ground readiness) were required to divide their time to implement both efforts, coordinating with each agency to facilitate communication and establish resources. Internal NOAA coordination was also required to ensure the appropriate personnel were available to provide support to NASA for launch and/or receive products from NASA to execute operations.

1. Establishing Facility Readiness to Support Launch

To support launch activities, OSPO provided the GDP with space in the NSOF Launch Control Room (LCR). From the beginning of this effort, the MOSE utilized used the working group forum to coordinate the readiness of the NSOF to support launch. This work involved heavy reliance on the Support Branch Facilities personnel and the ITSB personnel to ensure room readiness and the functionality of required connectivity, and the GSL worked closely with the NSOF personnel, as well as the GDP Networking Team and Ground Systems Manager, to establish communication lines, workstation connections, and coordinate other facility logistics. The MOSE provided a NOAA Support Assessment to MOD Management in January 2013, outlining the resources required to support DSCOVR launch preparations, while the GSL managed the installation of DSCOVR operational hardware within the NSOF server room. In February 2013, the GDP provided an LCR Readiness Date of September 12, 2013, at which point the GDP would begin installing their equipment and targeted a release date of November 2013 to begin testing their operational ground system, i.e., the Mission Operations Center (MOC).

OSPO Support Branch and ITSB personnel performed all of the LCR preparations while the MOSE and GSL coordinated with existing and/or developing OSPO missions to avoid resource conflict and disruptions to schedules, including GOES-R, DMSP F19, and JPSS launch activities, which required managing shared LCR space on overlapping mission timelines using strict schedule monitoring (see Fig. 26). Since the JPSS schedule was in direct conflict with the DSCOVR schedule, the MOSE met with JPSS leadership frequently to outline DSCOVR requirements for their physical footprint in LCR-A, negotiating shared space within that room. As part of this effort, the MOSE coordinated with the Support Branch to convert an adjacent maintenance room into a usable operations swing space, known as the LCR Side Room (LSR) or Room 4001, to avoid resource conflicts. OSPO initially configured the room as a backup space from which to perform launch activities, in case of a slip in the DMSP launch schedule. MOC equipment was set up in the LSR on October 2, 2013 until JPSS finished utilizing LCR-A. DSCOVR moved into LCR-A on May 2, 2014. The GDP then used the LSR as a space for offline meeting and anomaly resolution discussion, and it is still used today by missions preparing for upcoming launches. Additionally, GOES-R occupied LCR-B, which is only separated from LCR-A by a four foot divider, so it required coordination since activities could not be conducted at the same time due to noise interference between both sides.

In addition to fulfilling the duty of ensuring NSOF ground system readiness, the GSL also coordinated readiness and development efforts at the two NOAA ground stations slated to provide antenna support for DSCOVR during launch and normal operations, WCDAS and FCDAS. This permitted NASA launch activities to proceed on schedule by facilitating the completion of much needed CDAS development activities and required efficient communication between all DSCOVR personnel to ensure complete understanding of the state of CDAS readiness. The GSL enabled consistent communication by holding weekly CDAS Working Group (CDASWG) meetings and additional project level CDAS meetings to ensure complete understanding of the technical issues that would remain open at Handover, and developed a plan for addressing these issues with the NASA review board. Through this coordination, the GSL formulated a clear test plan to demonstrate CDAS compliance with the NASA Level 3 (L3) project requirements, and ultimately, demonstrate CDAS readiness to support DSCOVR in day-to-day operations. Earlier verification of the CDAS, through earlier involvement of CDAS and OSD personnel, is recommended to ensure ground station readiness for future NOAA missions and prevent CDAS readiness from becoming a lien on transition.

In general, the overall correspondence with the GDP in regards to NSOF readiness was often inefficient, in that the GDP would outline their requirements, but would not provide the MOSE with information needed to fulfill those requirements. The MOSE insisted on documentation outlined the resources needed, and the responsible entities. One of the issues encountered was obtaining a comprehensive Launch Management Plan (LMP) document from the GDP, which OSPO needed to accurately accommodate the GDP personnel physically within the NSOF, specifically the LCR. The MOSE assigned NASA an action item on February 13, 2013 which required them to provide NOAA by June 30, 2013 with an LMP that included requirements for LCR use, and a timeline of occupancy requirements. The GDP insisted that due to the small size of the mission, and the minimal funding available, that the LMP, among other documentation, could not be feasibly written, nor was it needed. In the end, the GDP did not submit an LMP to OSPO, and without an LMP, the MOSE was unable to accurately account for the required resources in the LCR, which caused delays in readiness.

Furthermore, the MET attempted to negotiate a presence of their own in the LCR to support pre-launch and launch activities as part of training. At the Mission Operations Review (MOR) on January 9, 2014, the two agencies agreed that the GDP would temporarily allocate two of the terminals from the SOCC for installation in LCR-A for the MET Engineers to use to participate in rehearsals, launch and post-launch checkout activities. However, once the terminals were installed, the GDP MOM informed the MOSE on June 6, 2014 that after developing a seating chart for launch and looking at personnel requirements, those two workstations would instead be allocated to additional GDP launch personnel. Had the GDP developed an accurate LMP early in the development phase when requested, this conflict could have been avoided. The MOSE had orchestrated the inclusion of additional workstations, yet once installed, the GDP realized they did not have enough resources and commandeered them as part of their launch and checkout design. If those terminals not been moved, the GDP would have developed a launch plan with the terminals that were originally allocated. Nevertheless, OSPO established the launch space in time to support all rehearsals, launch and checkout, and although they did not have their own workstations, MET Engineers were able to shadow the GDP FOT and spacecraft subsystem Project Design Leads (PDLs) while they were on terminal during rehearsals and post-launch checkout activities.

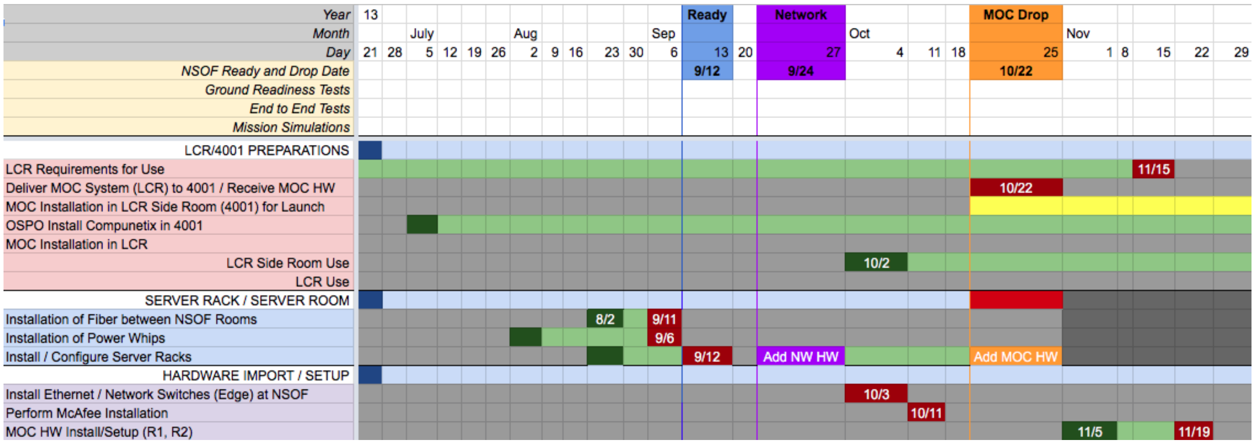


Fig. 26 Launch Control Room Readiness Schedule

Managing space allocation to support the GDP's efforts during launch posed many challenges. The GDP was understandably concerned that the facility be ready to support their needs for launch services. Additionally, the personnel attempting to establish facility readiness were also trying to facilitate their own inclusion, as well as that of the other operational staff, in DSCOVR launch activities as part of training and familiarization. The two efforts often seemed in conflict, and when the GDP's resources were strained, they were allocated to launch readiness instead of incorporating any potential training opportunities. To avoid these conflicts in future collaborations, an LMP needs to be developed early that considers the needs of both agencies, outlines roles and responsibilities, and accounts for participation of OSPO personnel that are slated to operate the mission after Handover. A balance between executing launch readiness activities and incorporating personnel training within those activities needs to be maintained; although launch readiness take precedence, the need for sufficient training cannot be overshadowed to the extent that training opportunities are ignored. Launch efforts were further complicated due to the work required by OSPO personnel to manage conflicting schedules with other missions scheduled to launch as well as the work required to establish an operational framework within the same facility, so all mission schedules should be reviewed early and often to ensure that adequate time and personnel are allocated to mitigate schedules and resources.

2. *Development of an Operational Framework through Coordinated Integration*

A satellite operational framework is a common system architecture, consisting of hardware and software, as well as supporting personnel, upon which a given mission or enterprise is built. The framework selectively constrains the design of the enterprise overall and the individual elements or missions within it. The primary advantage of the framework approach for satellite command and control is that it accommodates a flexible ground infrastructure to support rapid deployment of assets. The NOAA/OSPO satellite operations framework has been successful overall at maintaining satellite missions, and implementing new ones. However, although "(t)he upgrade process has worked well for incremental upgrades … it has been less successful with major advances … that require the introduction of new systems or significant changes to … mission systems." [19] The potential methods for the facilitation of the DSCOVR mission needed to be evaluated to determine the best and most efficient manner in which to incorporate mission operations. In order to provide a more coherent and complete level of mission integration and operation support, the MOSE divided the DSCOVR integration and operations support framework into two components: Mission Management (MM) and Enterprise Management (EM).

MM encompassed all operational functions of the DSCOVR SS with respect to GS operations. These functions included space-ground communications (uplink & downlink), command generation and telemetry data processing, mission operations (including real-time console operations, offline engineering and trending, anomaly detection & resolution, procedure development, special operations planning & execution), monitoring of payload services, mission scheduling and planning, orbit determination and maneuver planning, and flight software (FSW) verification. EM supported all operational functions by supervising the elements that comprised the operational systems and networks for the DSCOVR GS. EM functions underpinned the infrastructure that linked the MM function and supported automation and provided a high-level layer of supervision over the end-to-end GS. Some specific functions and capabilities of EM were to monitor and report the end-to-end status and performance of all GS elements (hardware and software), networks, communication links and antennae operations, supervise all GS networks and interfaces to external systems, supervise all primary and backup site functions, and supervise IT enterprise security.

The Systems and Development (S&D) Life Cycle model used for new and developing missions at OSPO to execute Systems Engineering (SE) processes is shown in Fig. 27. Operations Engineering (OE) is a segment of SE focused on incorporating operational experience, knowledge, and insight into the development process to reduce impact and increase efficiency through development, testing and operations of a system or systems in order to improve performance and operability. While the majority of the daily work performed by OSPO Engineering personnel typically falls within the Operations & Sustainment (O&S) portion (Phase E) of the *S&D Life Cycle Engine*, for new missions being developed by NASA/GSFC, such as DSCOVR, personnel are embedded and involved with Systems Development, Integration, and Testing (Phases A-D). The MOSE embraced the inherent soundness of the Mission-Level *S&D Life Cycle Engine* and applied it in directly analogous sub-phases to the Operations Phase E, to develop the *O&S Life Cycle Engine* for DSCOVR integration. The MOSE utilized the *Applied O&S Lessons Learned* path to provide the GDP lessons learned from the incorporation of previous mission in order to give them insight into what successful methods have worked. Simultaneously, the MOSE applied the *New Systems & Modified Systems* path internally among existing staff to execute the sub-Phase-E stages via the *Operations & Sustainment (O&S) Life Cycle Engine*. In either Life Cycle Engine, during each phase of the development cycle, the operations engineers participated in the activities particular to that phase, carrying through the knowledge of each previous phase and maintaining a focus on operability and overall impact. The MOSE utilized this approach for integrating operations engineers into the DSCOVR mission life cycle to ensure operational and launch readiness.

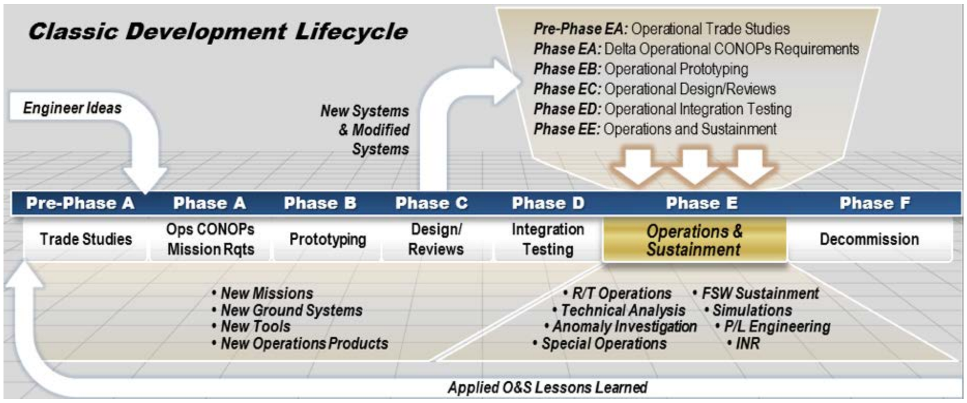


Fig. 27 Classic Mission Development Lifecycle

In general, the purpose and output of each phase in both the overall *S&D Life Cycle Engine* and the *O&S Life Cycle Engine* varies depending on whether its application is toward the implementation of a new mission, or toward the modification to an existing mission, as shown in Table 12. DSCOVR had qualities that placed it within both Life Cycle Engines depending on the responsible party, and, responding to a recommendation that "NASA and NOAA should jointly work toward … an *adaptive* and *flexible* operational system in order to support the rapid infusion of new satellite observational technologies, the validation of new capabilities, and the implementation of new operational applications" [12], the MOSE utilized this systems and operational engineering model such that NOAA personnel applied each relevant step of the *O&S Life Cycle Engine* while assisting NASA personnel with executing the *S&D Life Cycle Engine*, as follows:

1. NOAA involvement in requirements definition and analysis during the ***Operations Concept and Mission/Operations Requirements (Phase EA)*** phase was primarily to ensure that the general areas of concern were addressed in the requirements and accounted for in development planning. At this point, the NOAA MOSE developed the operations concept, projected staffing profiles, and operational scenarios, and derived operational requirements as driven by the operations concept.
2. During ***Operational Prototyping (Phase EB)***, the MOSE ensured consideration of identified operational requirements and guided initial design trades toward more operationally appropriate options.
3. At the ***Operational Design/Review (Phase EC)***, the MOSE assumed the role of assisting NASA with interpreting NOAA operational requirements, and began production of preliminary end user products such as documentation, which served as a bottom up approach to engineering, bringing to light any additional derived operational requirements.

4. During the ***Operational Integration Testing (Phase ED)*** phase, the DOT became involved and performed all functions intended for normal operations, such as operating the spacecraft and performing ground system responsibilities. This process served as hands-on training, facilitated by the MOSE. Activities during this phase included assisting in the development of predicted operational scenarios, observing system operations, translating the operational scenarios into users' guides, training plans and operational procedures, and developing any needed operational workarounds required in response to issues identified during testing.
5. Once in the ***Operations and Sustainment (Phase EE)*** phase, the DOT assisted operations personnel in using the system, developed workarounds, and identified unanticipated mission characteristics and system requirements to feed into system upgrades and enhancements. In support of sustaining engineering, the DOT assisted in the identification of areas representing the best potential for new technology or method insertion, which led to the Continuous Improvement cycle implemented during Normal Operations, supported by NASA through reach back support.

In Systems Engineering, the V-model is a graphical representation of a systems development life cycle and summarizes the main activities that need to be performed during the process, the documentation needed to facilitate the transfer between stages, and the direction of progress. Fig. 28 was the model developed for the DSCOVR mission to facilitate implementation of the *S&D Life Cycle Engine* and *O&S Life Cycle Engine*, overlaid with representation from NOAA/OSPO, NASA/GDP, and a collaborative team from both agencies where applicable. On the left stream, the initial Management Plan and Operations Concept included collaboration from NASA and NOAA upper management to ensure that the design and approach fulfilled mission requirements. As the stream progressed downward into systems requirements, design, and implementation, the GDP worked independently to create both a SS and GS that met those requirements, and created documentation to support these efforts. Entering the right stream, once the GDP completed unit testing, and neared conclusion in the subsystem verification stage, the DOT joined the process to confirm that the system validation produced results that met their operational needs. The majority of the involvement from the DOT occurred during System Verification and Validation, when the MOSE provided NOAA's perspective on how the system functionality, operations design, and sustainment support should be finalized to fit within NOAA's concept of operations and operational requirements and also captured within the appropriate operational documentation (i.e., the Concept of Operations, and Sustainment Plan).

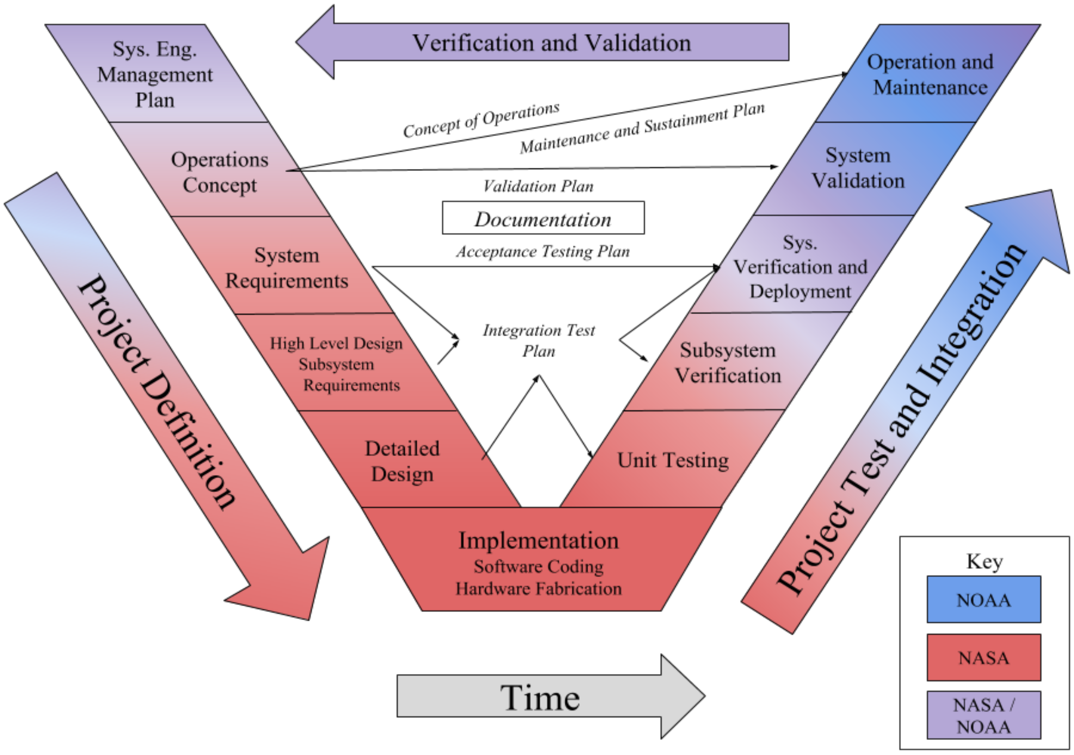


Fig. 28 Systems Engineering Process for DSCOVR Development and Integration

Table 12 Systems & Development and Operations & Sustainment Engineering Lifecycle Engines

	NASA		NOAA	
Phase	**S&D Life Cycle: Purpose**	**S&D Life Cycle: Output**	**O&S Life Cycle: Purpose**	**O&S Life Cycle: Output**
Operations Concept and Requirements	Determine new system feasibility, establish initial baseline compatible with NOAA's strategic plan	System Operations Concept definition, Mission and System Requirements documents	Determine operational feasibility of proposed change and establish baseline compatibility.	Engineering develops Concept of Operations. Updates requirements documentation as needed
Prototyping	Define project to establish initial baseline that meets mission needs.	End products: mockups, trade study results, specification and interface documents	Establish initial baseline that meets operational needs.	End products: demonstrations, detailed requirements specifications and updated interface documents
Design/Reviews	Complete detailed system design	End products: detailed designs, software	Operations engineer assumes role of assisting developers in interpreting operational requirements and begin end user product development	End products: documentation from bottom-up engineering approach
Integration Testing	Integrate and release system and build confidence that it meets requirements.	Fully launched, operations-ready system end product with supporting related enabling products	Integrate and release updated system. Operations personnel used to perform all functions intended for normal operations	Operations-ready system end product with supporting related enabling products
Operations (NOAA) and Sustainment (NASA)	Conduct mission and meet initially identified need; maintain support	Desired system and sustainment	Conduct operations, meet identified need, maintain operational support; implement mission operations plan	Desired new operations baseline and/or changes

Since DSCOVR qualified as not only a new mission, but also a modification to an existing mission, this complicated its integration into the NOAA operational framework, and required careful coordination. "Key issues for an operational forecast system are to ensure that transitions do indeed result in improvements and that the effort required for the transition is not disruptive." [17] The MOSE uniquely incorporated DSCOVR into the pre-existing framework of operations within the NSOF. The small size of the DSCOVR mission, the low-level of spacecraft interaction required to fulfill mission goals, and the similar characteristics of operational necessities that already existed within the OSPO satellite operations environment, allowed for the absorption of the mission within the context and operational framework of pre-existing NOAA constellations where possible. DSCOVR operates within the existing NOAA framework under the OSPO five-branch system. This design addresses mission requirements and facilitates the execution of activities to fulfill mission goals by dividing efforts through shared and coordinated efforts. The members of the DSCOVR team have operated with guidance, oversight, and support from the branches of the pre-existing OSPO architecture, and the DSCOVR mission has been executed in conjunction with and/or within pre-existing NOAA missions.

Independence versus Integration

The functional architecture and concept of operations of the NSOF has facilitated the operation of independent missions, yet also permitted integrated operations where possible or when it is more efficient. Three models of facilitation for the DSCOVR mission were considered when developing the OSPO concept of operations and DSCOVR framework:

1. *Segregated Operations:* Operations which would normally impact the mission but the characteristics of the mission operations location and functionality meant that direct interaction with the mission by non-mission personnel was required and the mission could work independently from NSOF operations.

> **NOTE**: This was not possible since the framework needed to be integrated within a multi mission operations center within the NSOF, where each individual satellite mission shared a common infrastructure. Each mission had its own unique piece, but all missions used shared services provided in and by the NSOF for certain functions, so complete segregation was not feasible.

2. *Coordinated Operations:* Operations where interaction with the mission was required as determined through assessment of the characteristics of the mission operations location and equipment levels and capability of the NSOF.
3. *Integrated Operations*: Operations where the equipment levels and capability of the mission were highly reflective of existing satellites, ground systems, and operations, and could largely be managed through pre-existent systems and processes.

The operational framework for DSCOVR had to be *coordinated* into overall NSOF operations, represented notionally in Fig. 29, because it contained its own discrete new components, but also had to be *integrated* because there were components of the DSCOVR framework that were to be maintained through pre-existing NSOF procedures using current resources. Therefore, the MOSE brought DSCOVR into the NSOF framework through a *Coordinated Integration* process.

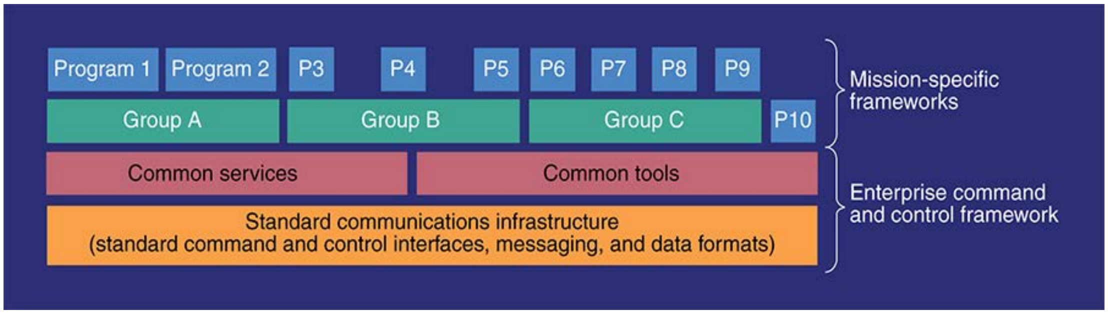


Fig. 29 NSOF Framework Representation

When a single satellite mission is implemented within its pre-developed infrastructure and set of core services, additional development of only the mission-unique portion of the ground-control software is required. It does not constrain satellite missions to specific services; rather, it enables a program to tailor its uses of the overall framework to best meet its specific requirements. To fit into the NSOF framework, a satellite mission must adhere to certain standards for operations relative to the command and control functions it creates. Fortunately, the overall command and control framework of the NSOF accommodates multiple concepts of operation without changing its fundamental standards.

> A … space center with decades of mission operations experience can approach future space missions of a similar kind easier than a new competitor. The effort is less because many concepts, processes, and tools do already exist in flight-proven configurations. This depends, however, strongly on the nature of the mission; it cannot be generalized because the requirements of space missions can be of considerable difference. [29]

Although the concept of operations for DSCOVR was unique, its structure and planned approach permitted the merging of the mission with existing resources and methods of operation. As OSPO’s first deep space mission, NOAA could have used this opportunity to create a third, independent framework in which to execute DSCOVR operations. However, this would have taken substantial resources, specifically in the area of IT Security, and NOAA was unwilling to pursue this route at the time, choosing instead to use portions of current POES and GOES operational frameworks, personnel, and ground system components, as indicated by Fig. 30, to create a framework in which to implement the DSCOVR concept of operations.

To outline and facilitate the *O&S Life Cycle Engine*, the MOSE developed and released the *OSPO DSCOVR Concept of Operations (CONOPS)* document that explained the methods by which the mission requirements, as captured in the GDP *Operations Concept (OPSCON)* document, were fulfilled using the *MOPS Approach*. The CONOPS described the OSPO management structure and responsibilities for executing the mission, the supporting ground system infrastructure, the objectives of operations, and the chain of command and authorization of operations. It also explained the systems engineering processes that were implemented using *Areas of Focus* to meet the measurable objectives of ensuring spacecraft health and safety and continued data delivery to required end users. The document outlined plans for meeting mission objectives by efficiently balancing workload demands against personnel abilities between various groups for both the GS and the SS.

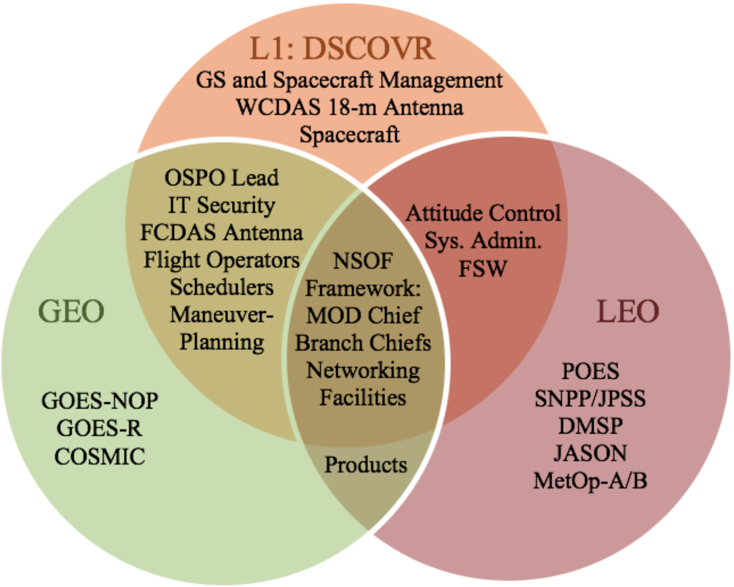


Fig. 30 Coordinated Integration of DSCOVR into NSOF Operations

C. NOAA OSPO Staff Readiness: Establishing and Training a Streamlined Operations Team

The MOSE, under the EMOSS contract, was one of two full time engineers provided by OSPO to support DSCOVR development within the NSOF, and was the lead individual coordinating the operational and engineering interests for OSPO. In addition to executing facility readiness responsibilities, the MOSE coordinated internally with NSOF personnel to formulate a mission staffing and operations approach that was compatible with the existing five-branch framework, minimizing the operational workloads to a scaled-down design without sacrificing the operational needs of the mission. The MOSE coordinated with NSOF personnel to establish readiness, without disrupting the needs of current operational missions, and developed and presented OSPO facility and staff readiness at the Mission Operations and Operational Readiness reviews. Additionally, the MOSE fulfilled the duties of the SSL position, which were to coordinate and implement changes to the spacecraft and/or payload under the guidance of the GDP, and ensure MET Subsystem Engineers received appropriate training and materials to fulfill their subsystem responsibilities. As the Spacecraft Systems Engineer, the SSL worked closely with the GDP Systems PDL to capture all applicable spacecraft knowledge. The DSCOVR GSL was the other full time engineer dedicated to DSCOVR development, also under the EMOSS contract, and supplemented the MOSE by working with NASA GS counterparts to establish and validate ground system requirements, build GS training plans and materials, and coordinate training of GS personnel.

1. Navigating Staffing Restrictions and Optimizing Shared Resources

The MOSE and GSL worked together, under the guidance of a government OSPO DSCOVR Lead, to co-manage the MET and establish a core team of MET Engineers and MET Schedulers dedicated to coordinating and implementing the primary functions of the DSCOVR mission during Normal Operations. As depicted in Fig. 31, the MOSE led a team of four part-time MET Engineers, each allocating ¼ of their time to support DSCOVR. A Configuration Management (CME) provided configuration management services for multiple missions in addition to DSCOVR. A Flight Dynamics Engineer (FDE) supported DSCOVR maneuver planning and execution while performing GOES flight dynamics responsibilities as well. The remaining two engineers, an Attitude Control Engineer (ACE) and a Flight Software Engineer (FSE), worked the remainder of their time providing similar support for POES operations. The GSL coordinated with the MET Schedulers in the Support Branch, who also worked ¼ time on DSCOVR and ¾ time conducting GOES scheduling responsibilities. The MOSE and GSL interfaced with personnel from the remaining branches as indicated in Fig. 31; the MOSE coordinated with the DSCOVR Flight Operators (FOs), who also monitored GOES satellite operations, and the GSL worked with network engineers in the IT Security Branch (ITSB) and the System Administrators (SAs) in the Systems Branch, as well as with both the CDASs, all of whom supported other OSPO missions.

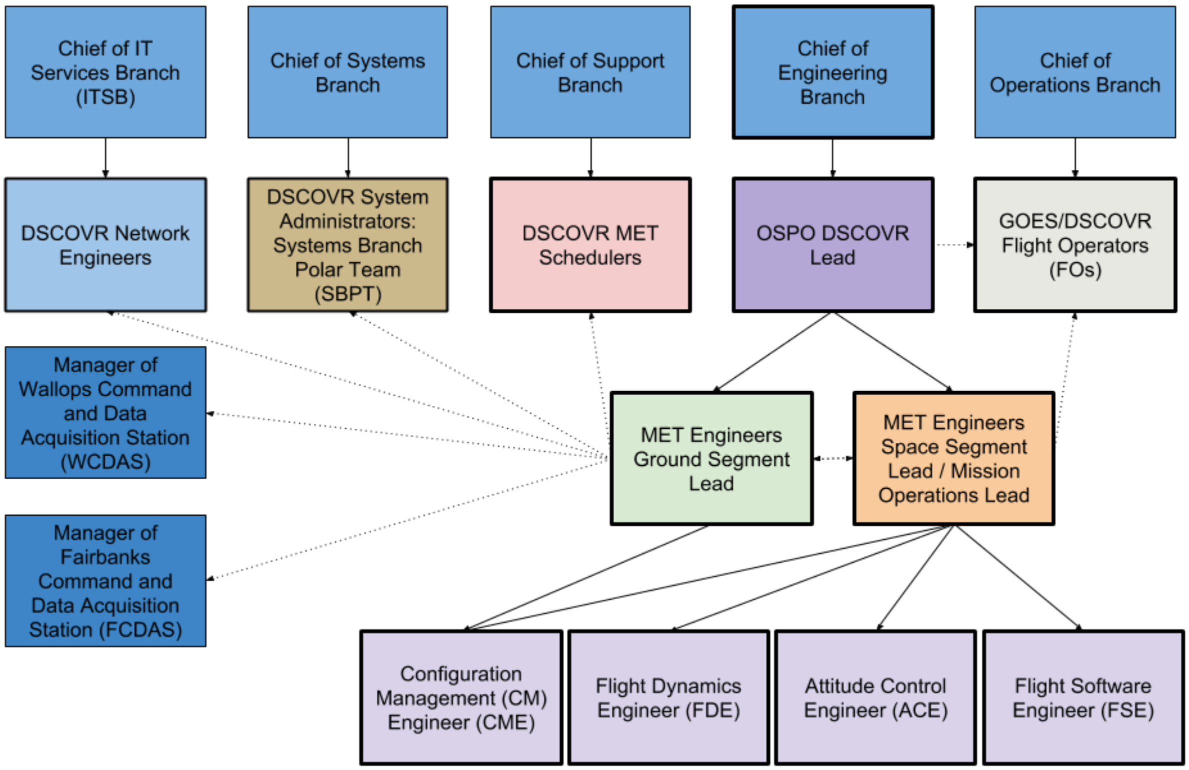


Fig. 31 OSPO Framework Coordination

As noted earlier, the DOT consisted of the MET (Engineering Group and Scheduling Group), the OSPO DSCOVR Lead, and the Flight Operators (FOs), since they executed the majority of required operations, as indicated in Table 13. This management approach created a highly efficient, well organized team led by the Engineering Branch that could execute and/or coordinate DSCOVR mission engineering tasks as shown in Fig. 32 (for Offline Operations) and Fig. 33 (for Real-Time Operations), extracting resources from additional branches when needed.

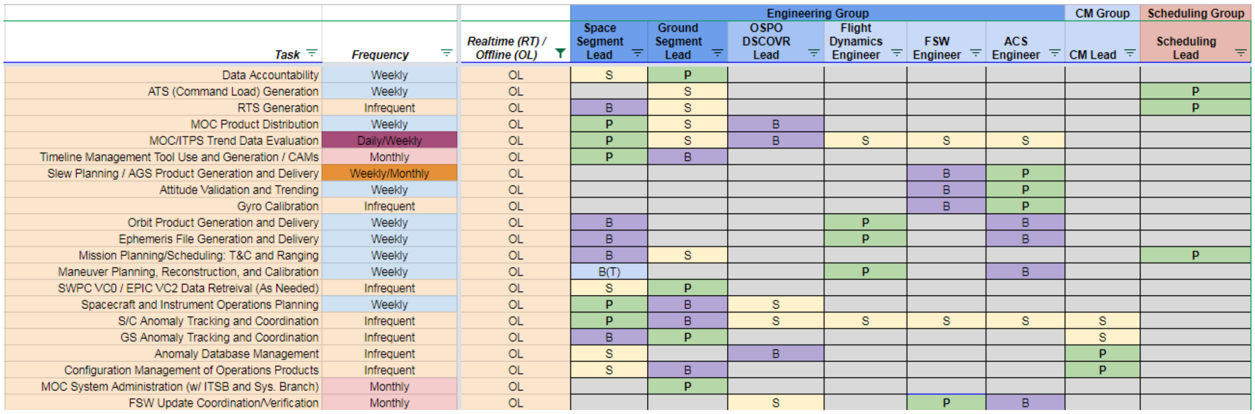
The Support Branch provided the MET Schedulers, who were responsible for generating ground station integrated contact schedules, including ranging operations with the Near-Earth Network (NEN) and Deep Space Network (DSN) ground stations. Schedulers coordinated support with WCDAS (and FCDAS when needed) to ensure complete coverage by all ground stations. Schedulers also generated a stored command load (i.e., Absolute Time Sequence (ATS)) that contained transmitter on/off commands and transmitter rate configurations (high or low) that corresponded to the ground station contact windows and antenna capabilities, as well as any commands for instrument activities and data management. The Operations and Engineering Branch uploaded the stored command load to the spacecraft once per week and covered a duration of one week. The Support Branch also provided telecommunication and hardware support for DSCOVR, and worked with the Engineering Branch MOSE and CMEs to keep training packages current.

The Operations Branch provided the Flight Operators (FOs) and the Shift Supervisor to support DSCOVR real-time monitoring and operations. The Shift Supervisor oversaw the DSCOVR Operations area in the SOCC and the operations of all missions contained therein, updated and sent daily reports of mission activities to management, and ensured proper notification of any anomalies. The FOs monitored the health and safety of DSCOVR 24/7 on-console in a real-time satellite operations environment, and ensured that real-time data collection was uninterrupted. They also oversaw all real-time commanding to the satellite as requested by Engineering and the execution of commands via the stored command schedules.

Table 13 OSPO DSCOVR Operations and Maintenance Support Personnel

DOT: Prime (Full Time) MET Engineers	**Branch**	**Role**
1.0: Mission Operations Sys. Eng. (MOSE)	Engineering	Space Segment Lead, Operations Management
1.0: Ground Systems Lead (GSL)	Engineering	Ground Segment Lead, Scheduling Coordinator, Ground Station Management
DOT: Secondary (Part Time) MET Engineers	**Branch**	**Role**
0.25: Flight Dynamics Engineer (FDE)	Engineering	Maneuver Planning and Execution, Propulsion
0.25: Flight Software Engineer (FSE)	Engineering	FSW Monitoring and Maintenance
0.25: Attitude Control Engineer (ACE)	Engineering	Momentum Mgmt., Guidance and Navigation
0.25: Configuration Management Eng. (CME)	Engineering	
DOT: Government: Lead, FOs & Schedulers	**Branch**	**Role**
0.25: OSPO DSCOVR Lead Engineer	Engineering	Management & Oversight, NASA Reach Back
0.5: Flight Operator (FO)	Operations	Health and Safety (H&S) Monitoring, Station Handovers, Commanding, Data Capture
MET Schedulers – 0.5: Lead Scheduler 0.25: Assistant Scheduler 0.25: Assistant Scheduler	Support	Integrated Contact Schedule (ICS) Generation Absolute Time Sequence (ATS) Generation Ground Station Scheduling
Supporting Personnel	**Branch**	**Role**
As Needed: Support Branch Team (SBT)	Support	Facilities and Communication
As Needed: System Administrators (SAs)	Systems	On-Call Ground System O&M
As Needed: Network Engineers (NEs)	ITSB	IT Security, Networking, System Patching

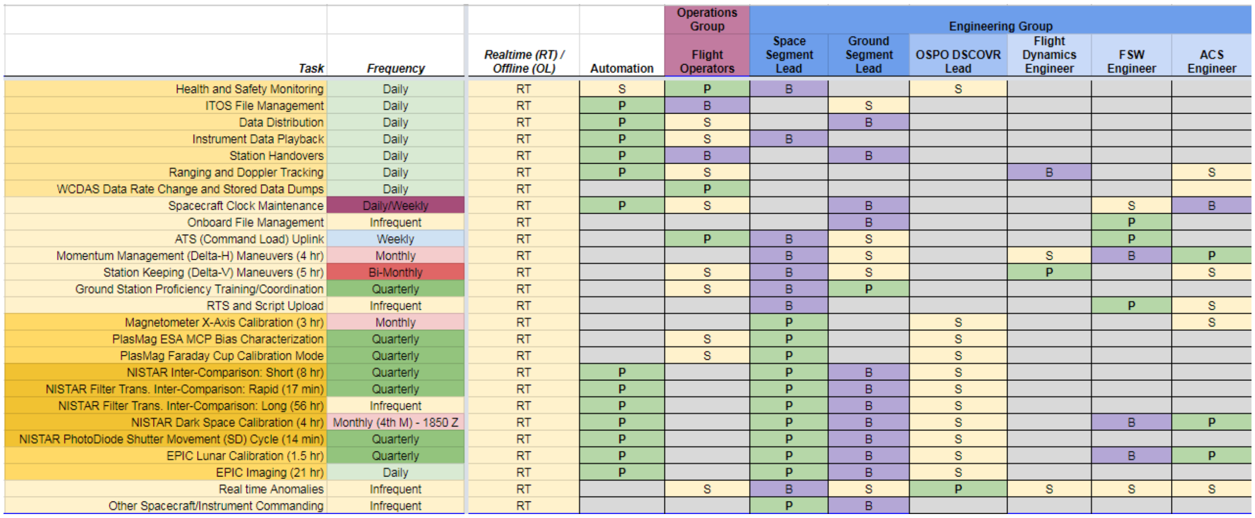
The FOs provided notification of anomalies and out-of-limit violations, or, in some cases, responded to anomalies using immediate contingency responses, executing necessary procedures and steps as previously defined by the Engineering Branch in order to place the satellite into a safe configuration until an analysis could be performed. Where some processes were automated, operators oversaw proper execution of the automated process and responded to automated warnings. Within the SOCC, the DSCOVR mission operations were absorbed within the GOES mission. Operations were executed and monitored in real-time by the FOs utilizing a real-time monitoring MOC System workstation (1 prime and 1 backup), with 2 additional MOC System workstations available for use by supporting engineers. On the ground, the FOs monitored the state of ITOS to ensure proper data connections and data deliveries to offline systems, archives, and appropriate outside users. They also monitored station handovers to ensure constant coverage and data acquisition, and coordinated ground station proficiency training with each backup station/network.



			Engineering Group						CM Group	Scheduling Group
Task	*Frequency*	*Realtime (RT) / Offline (OL)*	Space Segment Lead	Ground Segment Lead	OSPO DSCOVR Lead	Flight Dynamics Engineer	FSW Engineer	ACS Engineer	CM Lead	Scheduling Lead
Data Accountability	Weekly	OL	S	P						
ATS (Command Load) Generation	Weekly	OL		S						P
RTS Generation	Infrequent	OL	B	S						P
MOC Product Distribution	Weekly	OL	P	S	B					
MOC/ITPS Trend Data Evaluation	Daily/Weekly	OL	P	S	B	S	S	S		
Timeline Management Tool Use and Generation / CAMs	Monthly	OL	P	B						
Slew Planning / AGS Product Generation and Delivery	Weekly/Monthly	OL					B	P		
Attitude Validation and Trending	Weekly	OL					B	P		
Gyro Calibration	Infrequent	OL					B	P		
Orbit Product Generation and Delivery	Weekly	OL	B			P		B		
Ephemeris File Generation and Delivery	Weekly	OL	B			P		B		
Mission Planning/Scheduling: T&C and Ranging	Weekly	OL	B	S						P
Maneuver Planning, Reconstruction, and Calibration	Weekly	OL	B(T)			P		B		
SWPC VC0 / EPIC VC2 Data Retreival (As Needed)	Infrequent	OL	S	P						
Spacecraft and Instrument Operations Planning	Weekly	OL	P	B	S					
S/C Anomaly Tracking and Coordination	Infrequent	OL	P	B	S	S	S	S	S	
GS Anomaly Tracking and Coordination	Infrequent	OL	B	P					S	
Anomaly Database Management	Infrequent	OL	S		B				P	
Configuration Management of Operations Products	Infrequent	OL	S	B					P	
MOC System Administration (w/ ITSB and Sys. Branch)	Monthly	OL		P						
FSW Update Coordination/Verification	Monthly	OL			S		P	B		

Fig. 32 DOT Offline Operations Delegations

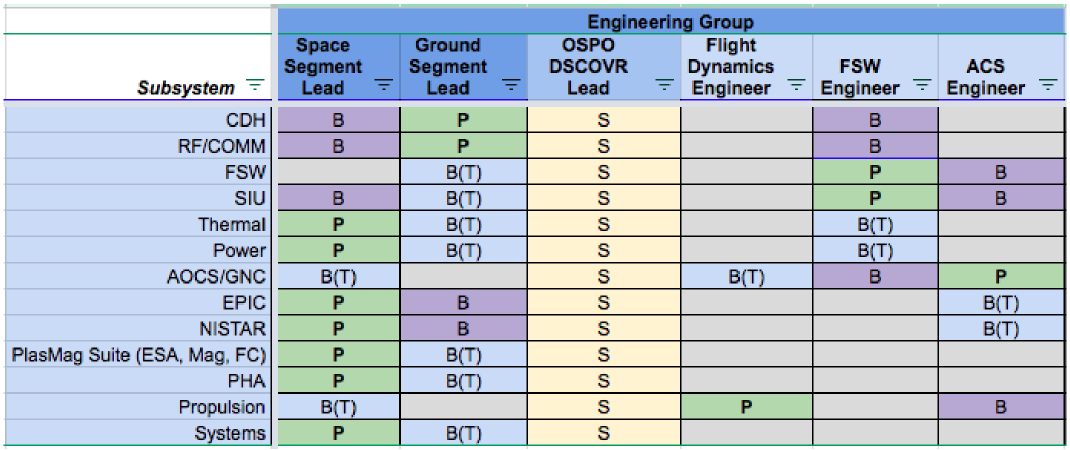
The Systems Branch was responsible for maintaining DSCOVR system software, supporting new system development, testing and deployment, and integrating and testing software system updates in support of the mission. OSPO also tasked this branch with software and data archiving, hardware support, and assisting Engineering with regression testing of operational system components, and performed initial anomaly response support for the ground system and configuration adjustments. Personnel were responsible for software installations when needed, system restarts and reboots, fault isolation and initiated quick responses for restoral of service as needed. The DSCOVR IT components and operations were incorporated into the existing GOES Information Technology (IT) security system and infrastructure, and the Information Technology Services Branch (ITSB) was responsible for ensuring DSCOVR continually met all IT Security requirements. The ITSB also provided support for networks within the NSOF, and between the NSOF, WCDAS and FCDAS.



				Operations Group	Engineering Group					
Task	*Frequency*	*Realtime (RT) / Offline (OL)*	Automation	Flight Operators	Space Segment Lead	Ground Segment Lead	OSPO DSCOVR Lead	Flight Dynamics Engineer	FSW Engineer	ACS Engineer
Health and Safety Monitoring	Daily	RT	S	P	B		S			
ITOS File Management	Daily	RT	P	B		S				
Data Distribution	Daily	RT	P	S		B				
Instrument Data Playback	Daily	RT	P	S	B					
Station Handovers	Daily	RT	P	B		B				
Ranging and Doppler Tracking	Daily	RT	P	S				B		S
WCDAS Data Rate Change and Stored Data Dumps	Daily	RT		P						
Spacecraft Clock Maintenance	Daily/Weekly	RT	P	S		B			S	B
Onboard File Management	Infrequent	RT				B			P	
ATS (Command Load) Uplink	Weekly	RT		P	B	S			P	
Momentum Management (Delta-H) Maneuvers (4 hr)	Monthly	RT			B	S		S	B	P
Station Keeping (Delta-V) Maneuvers (5 hr)	Bi-Monthly	RT		S	B	S		P		S
Ground Station Proficiency Training/Coordination	Quarterly	RT		S	B	P				
RTS and Script Upload	Infrequent	RT			B				P	S
Magnetometer X-Axis Calibration (3 hr)	Monthly	RT			P		S			S
PlasMag ESA MCP Bias Characterization	Quarterly	RT		S	P		S			
PlasMag Faraday Cup Calibration Mode	Quarterly	RT		S	P		S			
NISTAR Inter-Comparison: Short (8 hr)	Quarterly	RT	P		P	B	S			
NISTAR Filter Trans. Inter-Comparison: Rapid (17 min)	Quarterly	RT	P		P	B	S			
NISTAR Filter Trans. Inter-Comparison: Long (56 hr)	Infrequent	RT	P		P	B	S			
NISTAR Dark Space Calibration (4 hr)	Monthly (4th M) - 1850 Z	RT	P		P	B	S		B	P
NISTAR PhotoDiode Shutter Movement (SD) Cycle (14 min)	Quarterly	RT	P		P	B	S			
EPIC Lunar Calibration (1.5 hr)	Quarterly	RT	P		P	B	S		B	P
EPIC Imaging (21 hr)	Daily	RT	P		P	B	S			
Real time Anomalies	Infrequent	RT		S	B	S	P	S	S	S
Other Spacecraft/Instrument Commanding	Infrequent	RT			P	B				

Fig. 33 DOT Real-Time Operations Delegations

The Engineering Branch provided the MET Engineers under the EMOSS contract, who were primarily responsible for ensuring and maintaining the health and safety of the SS and corresponding GS through the *Areas of Focus* and measurable objectives previously outlined. MET Engineers were allocated responsibilities for ensuring the health and safety of DSCOVR subsystems as outlined in Fig. 34, which indicated who was prime (P) and who was backup (B) when the prime engineer was unavailable; B(T) indicated that the position had the option to actively train to cover that subsystem (if resources permitted). The MET Engineers worked with the Support Branch to provide training support to Flight Operators and new employees, and updates to training packages when needed, to guarantee that the appropriate personnel had the most up-to-date and complete information regarding the status of the mission. They also developed and maintained command procedures and scripts that were utilized to execute operations on the spacecraft and its payload, and provided the MET Schedulers with scheduling requirements for maneuvers, seasonal events, and other recursive events for timely execution. Data review via daily, monthly and yearly telemetry analysis, in conjunction with anomaly support and investigation, guaranteed that OSPO remained constantly aware of the condition of the satellite and of any possible changes in telemetry behavior. Additionally, the MET Engineers helped facilitate and implement changes to the spacecraft and instruments based on requests from the manufacturer, or other GS elements.



	Engineering Group					
Subsystem	**Space Segment Lead**	**Ground Segment Lead**	**OSPO DSCOVR Lead**	**Flight Dynamics Engineer**	**FSW Engineer**	**ACS Engineer**
CDH	B	**P**	S		B	
RF/COMM	B	**P**	S		B	
FSW		B(T)	S		**P**	B
SIU	B	B(T)	S		**P**	B
Thermal	**P**	B(T)	S		B(T)	
Power	**P**	B(T)	S		B(T)	
AOCS/GNC	B(T)		S	B(T)	B	**P**
EPIC	**P**	B	S			B(T)
NISTAR	**P**	B	S			B(T)
PlasMag Suite (ESA, Mag, FC)	**P**	B(T)	S			
PHA	**P**	B(T)	S			
Propulsion	B(T)		S	**P**		B
Systems	**P**	B(T)	S			

Fig. 34 OSPO DSCOVR Operations and Maintenance Support Personnel

2. *The Development and Implementation of an Optimal Training Approach*

Even before OSPO engineers met with their GSFC counterparts in December of 2012, they maintained the perspective that the most important aspect of any collaboration with NASA in which NOAA was the final user, aside from respect and cooperation, was a solid foundation based on a thorough training plan developed early and updated frequently. “It takes time to develop the necessary human resources through education and training, so the human resource needs must be anticipated explicitly throughout the process. Well trained people are, therefore, one of the most important components of the remote sensing technology transfer process.” [19] The initial plan was that the GDP would organize the training of the OSPO counterparts who would eventually be operating the SS and GS after handover. However, the MOSE discovered that the GDP and OSPO maintained training approaches that were diametrically asymmetric and created an unproductive asymmetric engagement. Since the two agencies inherently had different operational structures, and management perspectives, it complicated the training, and the approach needed to be dissected and reconstructed. The training that the GDP first offered lacked the cohesiveness that tends to come from an operational perspective. The GDP, and NASA in general, uses a systematic approach, presenting information as separate discrete pieces, so the GDP designed and delivered the training in compartmentalized sessions without referencing the means or methods by which the pieces would be reconstructed in different operational situations.

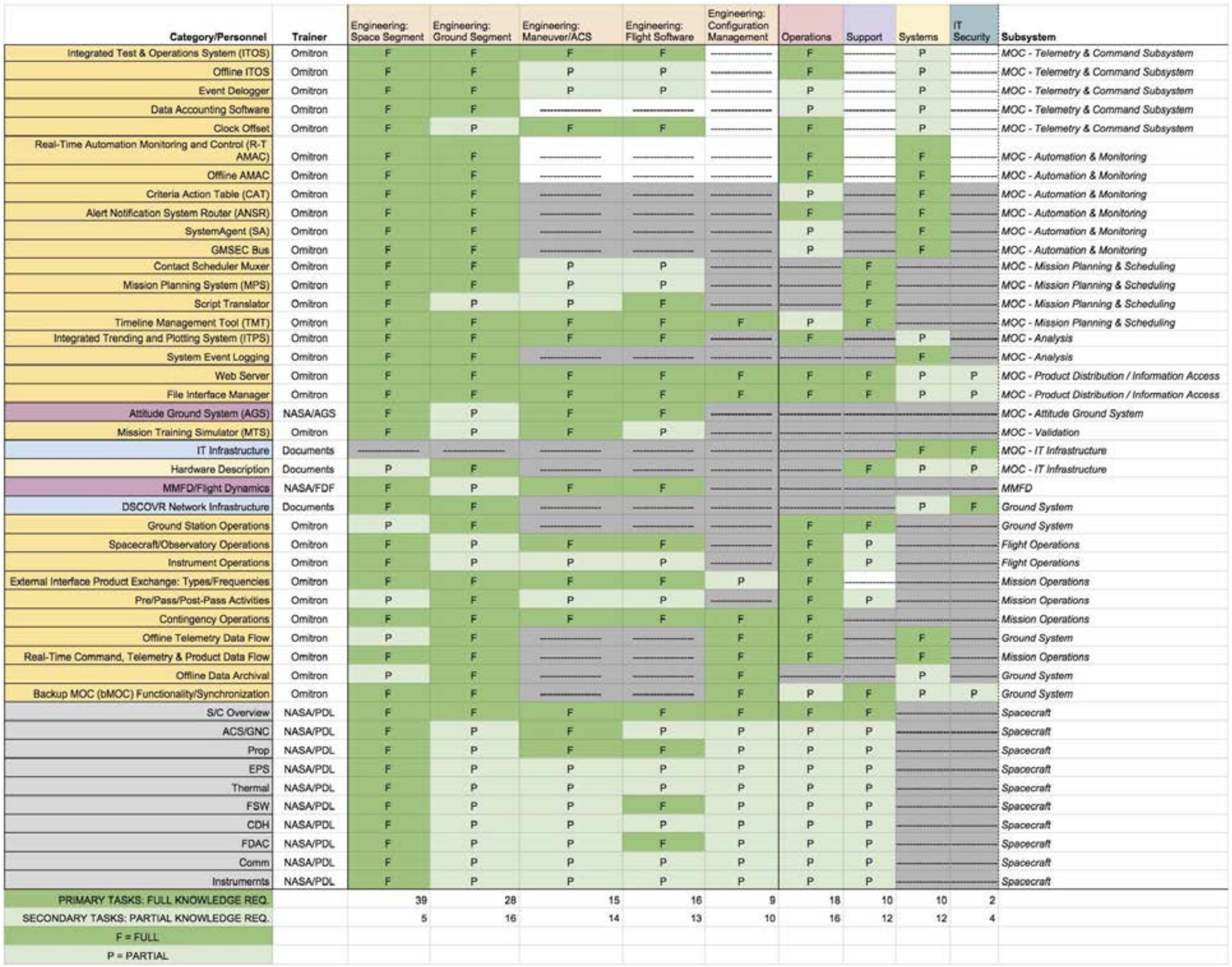
Incorporating training accurately was one of the primary recommendations of transition operations under the ITO model. “An important aspect of … operational programs (is) how the research programs of NASA … can serve both to provide the operational tools of agencies such as NOAA … and to provide training for future expert staff for those agencies.” [22] In general, any training that NASA intends to provide to NOAA should be analyzed and reformatted to fit NOAA’s operational approach. NASA utilizes a systematic training approach which needs to be re-scoped from the operational perspective, as it will most likely be disjointed and lack the end-to-end cohesiveness required for operations. “For safe and robust mission operations, the (operations personnel) need to know the functionality of the space segment and must be trained for situations that are typical or likely to occur. This is facilitated through training and technical documentation, which must be available on time, i.e., before training and operational validation phase.” [29] The GDP initially developed the DSCOVR Operations Training Plan (OTP) (DSCOVR-PLAN-002432) which provided training and certification criteria, and delineated responsibilities for the training approach, but it lacked a timeline that was realistically aligned with the training material.

> The long duration of the mission, and in particular of the cruise before reaching the target and starting the actual ‘productive’ phase of the mission, present severe managerial challenges (such as) keeping the motivation and the knowledge base in the team throughout the low activities cruise, to preserve it for future science operations at the target. Very important to tackle this problem is the organization of a plan of cross training and proficiency training activities (especially since) a significant problem is presented by the natural turnover in the flight control team composition. [29]

Since the GDP planned to devote the majority of their time and resources to support system readiness, launch, and on-orbit commissioning, they planned to conduct the majority of the training during the three month Cruise Phase (between Launch and LOI). However, the original training schedule, which the GDP initially developed without input from the end user (OSPO), assumed that commissioning activities would be completed within 45 days, but faced compounding delays and content expansion due to additional commissioning activities and anomalies that occurred during the Cruise Phase.

Training coordination was one of the primary uses of the feedback loop outlined in Fig. 23, but under the initial plan, the flow lacked clear direction from the GDP and often had a discontinuous flow, or incomplete content. The original training that the GDP proposed was minimal, focused only on MOC operations, and lacked spacecraft and payload information and operations, or GDP ownership. The GDP MOM was preoccupied with launch readiness activities, so the NOAA MOSE pressured the MOM to not only allocate additional resources to re-evaluate the training plan and timeline, but to also strongly consider and incorporate NOAA’s perspective on what knowledge was required to ensure successful operations after transition. In response, the GDP hired a Training Coordinator (TC) to manage training materials and schedules. The TC instructed the NASA Spacecraft Project Design Leads (PDLs) to contribute training materials, which required substantial effort in some cases since the PDLs were not accustomed to acting in a training capacity. Similarly, the GS Subject Matter Experts (SMEs) prepared materials relative to their GS elements and provided them to the TC. During the process, the PDLs and SMEs provided their training materials to the GDP Spacecraft Systems Lead (SSL) and NASA Ground System Manager (GSM), respectively, who then organized the materials and provided them to the TC. The TC then worked with the MOM to coordinate a training schedule with the MOSE (including the OSPO Lead for coordination or government oversight when necessary). The MOSE coordinated with required OSPO personnel (depending on the subject of the training) to determine availability for scheduling training sessions, and relayed back to the GDP any requests for specific training.

It was at this point that the MOSE position evolved by necessity into a training manager position to coordinate with the GDP TC to restructure the approach. The MOSE re-scoped the GDP's training plan to address end-to-end processes (including both offline planning and real-time execution) to meet OSPO needs and approach for Normal Operations, and took the lead on defining the training schedule, scope, as well as tracking progress in order to ensure completeness. The MOSE developed a NASA-to-NOAA Training Matrix (see Fig. 35), designating required areas of training to sectors of personnel across all OSPO branches, and the contents were incorporated into a Training Schedule (see Fig. 36) in order to maximize the training opportunities based on the availability of the GDP trainers and the OSPO personnel. Since the entire NOAA DSCOVR operational personnel consisted of several discrete, but intersecting, groups at OSPO, each segment had to be trained according to their function. Detailed descriptions of operations functions served as the basis for identifying topics, and each function had a list of associated certification criteria. The MOSE and GSL assisted the GDP FOT in their certification of the FOs using the same process as the GDP FOT. The MOSE coordinated availability and the GSL took the lead to supplement the certification process by establishing an On-The-Job (OTJ) Training Schedule for the FOs using the Simulator and extensive FOP Review.



Category/Personnel	Trainer	Engineering: Space Segment	Engineering: Ground Segment	Engineering: Maneuver/ACS	Engineering: Flight Software	Engineering: Configuration Management	Operations	Support	Systems	IT Security	Subsystem
Integrated Test & Operations System (ITOS)	Omitron	F	F	F	F	—	F	—	P	—	*MOC - Telemetry & Command Subsystem*
Offline ITOS	Omitron	F	F	P	P	—	F	—	P	—	*MOC - Telemetry & Command Subsystem*
Event Delogger	Omitron	F	F	P	P	—	P	—	P	—	*MOC - Telemetry & Command Subsystem*
Data Accounting Software	Omitron	F	F	—	—	—	P	—	P	—	*MOC - Telemetry & Command Subsystem*
Clock Offset	Omitron	F	P	F	F	—	F	—	P	—	*MOC - Telemetry & Command Subsystem*
Real-Time Automation Monitoring and Control (R-T AMAC)	Omitron	F	F	—	—	—	F	—	F	—	*MOC - Automation & Monitoring*
Offline AMAC	Omitron	F	F	—	—	—	F	—	F	—	*MOC - Automation & Monitoring*
Criteria Action Table (CAT)	Omitron	F	F	—	—	—	P	—	F	—	*MOC - Automation & Monitoring*
Alert Notification System Router (ANSR)	Omitron	F	F	—	—	—	F	—	F	—	*MOC - Automation & Monitoring*
SystemAgent (SA)	Omitron	F	F	—	—	—	P	—	F	—	*MOC - Automation & Monitoring*
GMSEC Bus	Omitron	F	F	—	—	—	P	—	F	—	*MOC - Automation & Monitoring*
Contact Scheduler Muxer	Omitron	F	F	P	P	—	—	F	—	—	*MOC - Mission Planning & Scheduling*
Mission Planning System (MPS)	Omitron	F	F	P	P	—	—	F	—	—	*MOC - Mission Planning & Scheduling*
Script Translator	Omitron	F	P	P	F	—	—	F	—	—	*MOC - Mission Planning & Scheduling*
Timeline Management Tool (TMT)	Omitron	F	F	F	F	F	P	F	—	—	*MOC - Mission Planning & Scheduling*
Integrated Trending and Plotting System (ITPS)	Omitron	F	F	F	F	—	F	—	P	—	*MOC - Analysis*
System Event Logging	Omitron	F	F	—	—	—	—	—	F	—	*MOC - Analysis*
Web Server	Omitron	F	F	F	F	F	F	F	P	P	*MOC - Product Distribution / Information Access*
File Interface Manager	Omitron	F	F	F	F	F	F	F	P	P	*MOC - Product Distribution / Information Access*
Attitude Ground System (AGS)	NASA/AGS	F	P	F	F	—	—	—	—	—	*MOC - Attitude Ground System*
Mission Training Simulator (MTS)	Omitron	F	P	F	P	—	—	—	—	—	*MOC - Validation*
IT Infrastructure	Documents	—	—	—	—	—	—	—	F	F	*MOC - IT Infrastructure*
Hardware Description	Documents	P	F	—	—	—	—	F	P	P	*MOC - IT Infrastructure*
MMFD/Flight Dynamics	NASA/FDF	F	P	F	F	—	—	—	—	—	*MMFD*
DSCOVR Network Infrastructure	Documents	F	F	—	—	—	—	—	P	F	*Ground System*
Ground Station Operations	Omitron	P	F	—	—	—	F	F	—	—	*Ground System*
Spacecraft/Observatory Operations	Omitron	F	P	F	F	—	F	P	—	—	*Flight Operations*
Instrument Operations	Omitron	F	P	P	P	—	F	P	—	—	*Flight Operations*
External Interface Product Exchange: Types/Frequencies	Omitron	F	F	F	F	P	F	—	—	—	*Mission Operations*
Pre/Pass/Post-Pass Activities	Omitron	P	F	P	P	—	F	P	—	—	*Mission Operations*
Contingency Operations	Omitron	F	F	F	F	F	F	—	—	—	*Mission Operations*
Offline Telemetry Data Flow	Omitron	P	F	—	—	F	F	—	F	—	*Ground System*
Real-Time Command, Telemetry & Product Data Flow	Omitron	F	F	—	—	F	F	—	F	—	*Mission Operations*
Offline Data Archival	Omitron	P	F	—	—	F	—	—	P	—	*Ground System*
Backup MOC (bMOC) Functionality/Synchronization	Omitron	F	F	—	—	F	P	F	P	P	*Ground System*
S/C Overview	NASA/PDL	F	F	F	F	F	F	F	—	—	*Spacecraft*
ACS/GNC	NASA/PDL	F	P	F	P	P	P	P	—	—	*Spacecraft*
Prop	NASA/PDL	F	P	F	F	P	P	P	—	—	*Spacecraft*
EPS	NASA/PDL	F	P	P	P	P	P	P	—	—	*Spacecraft*
Thermal	NASA/PDL	F	P	P	P	P	P	P	—	—	*Spacecraft*
FSW	NASA/PDL	F	P	P	F	P	P	P	—	—	*Spacecraft*
CDH	NASA/PDL	F	P	P	P	P	P	P	—	—	*Spacecraft*
FDAC	NASA/PDL	F	P	P	F	P	P	P	—	—	*Spacecraft*
Comm	NASA/PDL	F	P	P	P	P	P	P	—	—	*Spacecraft*
Instrumernts	NASA/PDL	F	P	P	P	P	P	P	—	—	*Spacecraft*
PRIMARY TASKS: FULL KNOWLEDGE REQ.		39	28	15	16	9	18	10	10	2	
SECONDARY TASKS: PARTIAL KNOWLEDGE REQ.		5	16	14	13	10	16	12	12	4	
F = FULL											
P = PARTIAL											

Fig. 35 DSCOVR Team Training Matrix: Full and Partial Training Allocations

The MOSE coordinated four separate groups within the GDP to provide spacecraft and operations training:

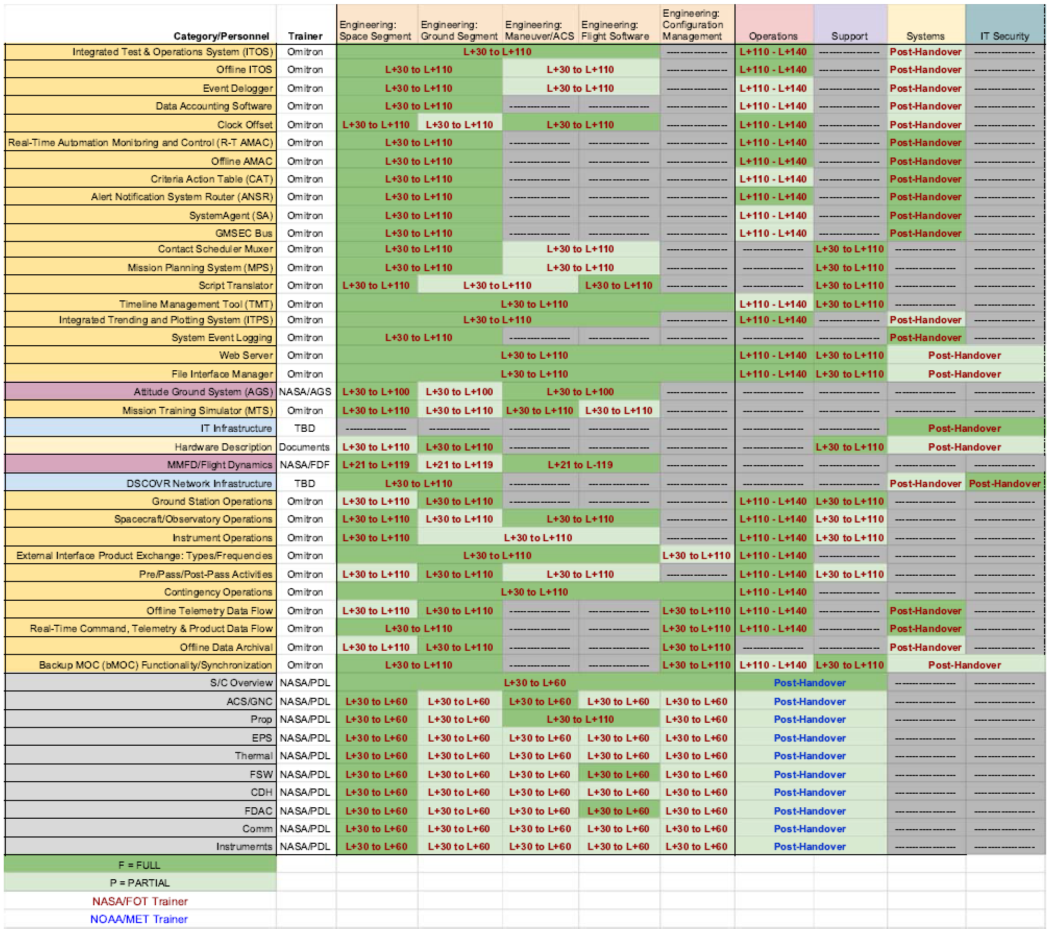
1. **The NASA Flight Operations Team (FOT):** The GDP FOT provided the training for the MOC Ground System, the operations processes, and procedures to conduct the daily operations, including operation of the Mission Training Simulator (MTS):
    a. The MOSE worked with the MET Engineers to provide them with subsets of the training material related to their responsibilities for the ground system and spacecraft operations

b. The MET Schedulers worked directly with and shadowed the GDP FOT to plan mission timelines, ground station contacts, and generate on-board schedules.
c. The MOSE coordinated with a subset of the FOs so they could receive tailored training that familiarized them with the relevant portions of the ground system and with required DSCOVR spacecraft health and safety monitoring and operations.

2. **The Attitude Ground System (AGS) Team:** The team that provided the attitude support, slew planning and product generation support to the GDP provided the AGS training.
3. **The Multi-Mission Flight Dynamics (MMFD) Team:** The MMFD team that provided the support to the Project throughout the commissioning provided the MMFD training, which included L1 orbit fundamentals, ephemeris and orbit product generation, station keeping maneuver planning, and operational use of the supporting ground system.
4. **The Project Design Leads (PDLs):** The PDLs provided training on the DSCOVR spacecraft and all subsystems outlined earlier.

Two groups provided the GS training:

1. **NASA Ground System Engineers:** NASA Ground System Engineers provided:
    a. NSOF Support Branch Facilities Group hardware training
    b. NSOF ITSB IT and network training
    c. NSOF Systems Branch system administration training
    d. WCDAS and FCDAS Front End Processor ground system training
2. **Hammers Company:** The Hammers Company, the designer of the DSCOVR command and control software, provided classroom training sessions for the MET GSL and systems branch personnel



Category/Personnel	Trainer	Engineering: Space Segment	Engineering: Ground Segment	Engineering: Maneuver/ACS	Engineering: Flight Software	Engineering: Configuration Management	Operations	Support	Systems	IT Security
Integrated Test & Operations System (ITOS)	Omitron	L+30 to L+110				-------------	L+110 - L+140	-------------	Post-Handover	-------------
Offline ITOS	Omitron	L+30 to L+110		L+30 to L+110		-------------	L+110 - L+140	-------------	Post-Handover	-------------
Event Delogger	Omitron	L+30 to L+110		L+30 to L+110		-------------	L+110 - L+140	-------------	Post-Handover	-------------
Data Accounting Software	Omitron	L+30 to L+110		-------------	-------------	-------------	L+110 - L+140	-------------	Post-Handover	-------------
Clock Offset	Omitron	L+30 to L+110	L+30 to L+110	L+30 to L+110		-------------	L+110 - L+140	-------------	Post-Handover	-------------
Real-Time Automation Monitoring and Control (R-T AMAC)	Omitron	L+30 to L+110		-------------	-------------	-------------	L+110 - L+140	-------------	Post-Handover	-------------
Offline AMAC	Omitron	L+30 to L+110		-------------	-------------	-------------	L+110 - L+140	-------------	Post-Handover	-------------
Criteria Action Table (CAT)	Omitron	L+30 to L+110		-------------	-------------	-------------	L+110 - L+140	-------------	Post-Handover	-------------
Alert Notification System Router (ANSR)	Omitron	L+30 to L+110		-------------	-------------	-------------	L+110 - L+140	-------------	Post-Handover	-------------
SystemAgent (SA)	Omitron	L+30 to L+110		-------------	-------------	-------------	L+110 - L+140	-------------	Post-Handover	-------------
GMSEC Bus	Omitron	L+30 to L+110		-------------	-------------	-------------	L+110 - L+140	-------------	Post-Handover	-------------
Contact Scheduler Muxer	Omitron	L+30 to L+110		L+30 to L+110		-------------	-------------	L+30 to L+110	-------------	-------------
Mission Planning System (MPS)	Omitron	L+30 to L+110		L+30 to L+110		-------------	-------------	L+30 to L+110	-------------	-------------
Script Translator	Omitron	L+30 to L+110	L+30 to L+110		L+30 to L+110	-------------	-------------	L+30 to L+110	-------------	-------------
Timeline Management Tool (TMT)	Omitron	L+30 to L+110					L+110 - L+140	L+30 to L+110	-------------	-------------
Integrated Trending and Plotting System (ITPS)	Omitron	L+30 to L+110				-------------	L+110 - L+140	-------------	Post-Handover	-------------
System Event Logging	Omitron	L+30 to L+110		-------------	-------------	-------------	-------------	-------------	Post-Handover	-------------
Web Server	Omitron	L+30 to L+110					L+110 - L+140	L+30 to L+110	Post-Handover	
File Interface Manager	Omitron	L+30 to L+110					L+110 - L+140	L+30 to L+110	Post-Handover	
Attitude Ground System (AGS)	NASA/AGS	L+30 to L+100	L+30 to L+100	L+30 to L+100		-------------	-------------	-------------	-------------	-------------
Mission Training Simulator (MTS)	Omitron	L+30 to L+110	L+30 to L+110	L+30 to L+110	L+30 to L+110	-------------	-------------	-------------	-------------	-------------
IT Infrastructure	TBD	-------------	-------------	-------------	-------------	-------------	-------------	-------------	Post-Handover	
Hardware Description	Documents	L+30 to L+110	L+30 to L+110	-------------	-------------	-------------	-------------	L+30 to L+110	Post-Handover	
MMFD/Flight Dynamics	NASA/FDF	L+21 to L+119	L+21 to L+119	L+21 to L-119		-------------	-------------	-------------	-------------	-------------
DSCOVR Network Infrastructure	TBD	L+30 to L+110		-------------	-------------	-------------	-------------	-------------	Post-Handover	Post-Handover
Ground Station Operations	Omitron	L+30 to L+110	L+30 to L+110	-------------	-------------	-------------	L+110 - L+140	L+30 to L+110	-------------	-------------
Spacecraft/Observatory Operations	Omitron	L+30 to L+110	L+30 to L+110	L+30 to L+110		-------------	L+110 - L+140	L+30 to L+110	-------------	-------------
Instrument Operations	Omitron	L+30 to L+110	L+30 to L+110			-------------	L+110 - L+140	L+30 to L+110	-------------	-------------
External Interface Product Exchange: Types/Frequencies	Omitron	L+30 to L+110				L+30 to L+110	L+110 - L+140	-------------	-------------	-------------
Pre/Pass/Post-Pass Activities	Omitron	L+30 to L+110	L+30 to L+110	L+30 to L+110		-------------	L+110 - L+140	L+30 to L+110	-------------	-------------
Contingency Operations	Omitron	L+30 to L+110					L+110 - L+140	-------------	-------------	-------------
Offline Telemetry Data Flow	Omitron	L+30 to L+110	L+30 to L+110	-------------	-------------	L+30 to L+110	L+110 - L+140	-------------	Post-Handover	-------------
Real-Time Command, Telemetry & Product Data Flow	Omitron	L+30 to L+110		-------------	-------------	L+30 to L+110	L+110 - L+140	-------------	Post-Handover	-------------
Offline Data Archival	Omitron	L+30 to L+110	L+30 to L+110	-------------	-------------	L+30 to L+110	-------------	-------------	Post-Handover	-------------
Backup MOC (bMOC) Functionality/Synchronization	Omitron	L+30 to L+110		-------------	-------------	L+30 to L+110	L+110 - L+140	L+30 to L+110	Post-Handover	
S/C Overview	NASA/PDL	L+30 to L+60					Post-Handover		-------------	-------------
ACS/GNC	NASA/PDL	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	Post-Handover		-------------	-------------
Prop	NASA/PDL	L+30 to L+60	L+30 to L+60	L+30 to L+110		L+30 to L+60	Post-Handover		-------------	-------------
EPS	NASA/PDL	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	Post-Handover		-------------	-------------
Thermal	NASA/PDL	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	Post-Handover		-------------	-------------
FSW	NASA/PDL	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	Post-Handover		-------------	-------------
CDH	NASA/PDL	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	Post-Handover		-------------	-------------
FDAC	NASA/PDL	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	Post-Handover		-------------	-------------
Comm	NASA/PDL	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	Post-Handover		-------------	-------------
Instrumemts	NASA/PDL	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	L+30 to L+60	Post-Handover		-------------	-------------
F = FULL										
P = PARTIAL										
NASA/FOT Trainer										
NOAA/MET Trainer										

Fig. 36 DSCOVR Team Training Matrix: Training Schedule

To ensure training was successful and that OSPO could execute mission operations, there needed to be a manner in which the retention and application of the information could be assessed and confirmed as successful. Therefore, prior to Transition, the MOSE coordinated with the GDP to implement an *Interim Transition Period* (ITP) from August 10 - October 27, 2015, which supplemented the training material by allowing the DOT to perform offline mission operations tasks (i.e., mission planning and scheduling) and real-time spacecraft activities (i.e., monitoring, commanding and maneuvering) with the GDP in a supervisory capacity. Operations partly moved from the LCR to the prime operations location for normal operations (the SOCC) (although the GDP maintained a presence in the LCR for anomalies and larger operations). At this point, the MET (Engineers and Schedulers) began planning and executing Normal Operations activities and the SOCC FOs began passive (secondary) Health and Safety monitoring with FOT (prime) support. After a month into the ITP, DSCOVR operations moved completely to the SOCC on September 18th; the MET continued planning operations for all required Normal Operations, and the FOs assumed prime responsibility for health and safety monitoring with the GDP FOT as secondary.

In short, the GDP had not accurately calculated and accounted for the resources and time required to completely train the OSPO personnel because they failed to consult with OSPO on the plan, nor did they consider the OSPO operational staff as a GS component that required verification and validation before Handover. “A ground segment (not only) comprises a ground system, i.e., infrastructure, hardware, software, and processes, (but also) a team that conducts the necessary operations on the space segment.” [29] In the end, the required DOT personnel received enough training to permit them to successfully take over operations after Handover. Although the implementation of training was not ideal, and training plans should have been established with OSPO input from the beginning, the end result produced the required outcome. The primary lesson is that the operational team should be considered a mission-essential ground system component, with a validation and verification approach and plan to confirm readiness to transition to normal operations. By considering the personnel as an essential GS component, and not an afterthought, they can be given more detailed attention and consideration, thereby generating a more complete training plan and approach.

D. Operational Documentation and Products: Ensuring the Delivery of Certified Operational Resources

The conflicting perspectives between NASA and NOAA were most evident during the documentation development phase, as OSPO struggled with the GDP to ensure they developed documents that accurately outlined transition requirements, and delivered documentation that contained the operational support needed to perform normal operations. “The set of organizational procedures or way of operating is the “machinery” that must be run, maintained, and occasionally redesigned to enable an organization to produce research results for transition or to create products for particular applications.” [19] The approach for documentation development undertaken by the GDP focused primarily on developing documents to support launch and checkout activities; at first, the GDP had minimal consideration for operational documents that complied with the OSPO operational framework. The GDP initially insisted on developing the documentation without major input from OSPO, so to assist with development, the MOSE provided the GDP with previous examples of documentation that were delivered to NOAA by other missions, including GOES-R, to help them understand the typical types of materials NOAA was accustomed to receiving from NASA in collaborative endeavors. Soon after, the MOSE performed an assessment of the documentation slated to be delivered to OSPO and noted that the GDP had failed to resolve the technical background required to understand the mission elements with the operational approach that would be implemented by the DOT. So the MOSE attempted to impose upon the GDP the value of capturing the information in the documents, but with minimal success.

The GDP management often insisted that the transition efforts would be successfully executed absent of any supporting documentation, and that outlining specific transition requirements in documentation was not as important as actually executing the efforts to meet those requirements. Additionally, they often argued that the DOT only needed more comprehensive operational documentation because they did not have the mission knowledge required to operate the mission, yet they continuously fell short on their training responsibilities that would have provided the DOT with that very knowledge. The MOSE was persistent in convincing the GDP that thorough documentation was required to ensure agreements were upheld and that normal operations could be performed successfully, and often reminded the GDP that with two instruments of their own on DSCOVR, it was in their best interest to provide OSPO with the best operational materials.

The most important documents required by OSPO, the ones that required the most detail, and the ones that created the most contention between the DOT and the GDP, were the Flight Operations Procedures (FOPs) and specifically the Contingency Operations Procedures (COPs).

> (FOPs and COPs) are developed for ground and for flight processes and increase mission operations considerably as they reduce the risk of operational mistakes. (These procedures) describe a validated workflow step by step, together with the

> required initial conditions, the commands to be sent, the expected response of the space segment, timing conditions, and explaining comments. Such procedures are primarily developed for routine operations (but) it is important to cover also potential contingency situations with respective procedures. The drop into safe mode is a prominent example of a contingency situation, and the respective procedure should describe the analysis and recovery actions to bring the spacecraft back into normal operations mode. [29]

NOAA's perspective has been that to maintain mission success "intense training of the FOPs, the finalization of flight and ground procedures, as well as their validation must be achieved." [29] The GDP initially insisted that they would develop the FOPs and COPs and then deliver the final products to OSPO, but the MOSE insisted on being a part of the development process, not only as an extension of training, but to also guide their content and structure. "One-of-a-kind missions like scientific satellites or new models … require substantially more work to be done on flight procedure development and the control center may be asked to contribute in that work." [29]

The GDP initially intended to deliver FOPs and COPs in a very simplistic format, but the MOSE required that the FOPs and COPs contain explicit instructions, and supporting information on expected telemetry signatures as suggested above. The NSOF has established itself as a high-pressure operational facility, delivering satellite data that are used to save lives, and therefore OSPO has maintained a high standard for acceptability in operational documents, especially those used for spacecraft emergencies.

> Safe and reliable operations of a spacecraft in orbit require sufficient knowledge about how to fly the spacecraft. Detailed information about the spacecraft itself and the ground system used for the operations is provided by handbooks, telemetry and telecommand databases, and other reference lists, but the basis for the operations is built on the … FOP. [29]

OSPO wanted to ensure that all of the basic foreseeable topics were addressed and covered in COPs, but the GDP continually reminded the MOSE that NASA Sustaining Engineering support would be available after Handover to assist with anomalies. The MOSE countered that the GDP should deliver to OSPO the full gauntlet of supporting documentation and operational products required to safely and completely operate the mission. The MOSE claimed that the transition of operations should not rely heavily on the notion that sustaining engineering will be the immediate default solution; sustaining engineering is a valuable resource, but OSPO should be able to reasonably resolve a good portion of the issues that arise based on the training and materials given to them by the GDP. As such, knowing the importance that the FOPs and COPs played during operations, the MOSE instituted a rigid document development and review schedule that included a strict auditing and reporting process. This involved coordinating with NASA PDLs for content, tracking the progress of FOP and COP development and reporting it to OSPO management, and ensuring that the final versions met the NOAA standards of operational documentation. Through this effort, the GDP was held more accountable for the content of the handover material, and the content of the procedures met all NOAA requirements.

The collaborative effort on documentation development was also applied to the Transition Plan. The MOSE provided a draft Transition Plan to the GDP immediately after their initial meeting in December 2012 to establish the document framework, create a starting point for a comprehensive document, and establish expectations for transition requirements early, since "there is a need for transition plans, developed jointly by the research and operational community for all appropriate NASA missions." [19] As the recipient of the content found within the document, input by the operational user into the Transition Plan was essential, yet the GDP rejected this initial version of the Transition Plan, as well as the collaborative offer, and decided to write the document on their own. However, versions of the document that were delivered for review by the GDP lacked significant details, milestones, and training details and requirements, so the MOSE applied the same development and review process that was applied to the FOPs and COPs to the Transition Plan development. Through this development process, the MOSE recognized that training was not being addressed in enough detail, and recommended that training be covered at length in a separate document, i.e., the OTP. As mentioned earlier, the MOSE guided the development of the OTP as well, deconstructing the training material and overlaying a timeline on the material to facilitate the training process.

The GDP also provided GS documentation, which included procedures to manage standard nominal operations tasks, as well as backup contingency scenarios. The GS FOPs were reviewed by the GSL and provided to the Systems Engineering Branch and the ITSB when necessary to confirm they met their standards for usability and clarity. Supplementing the transition and operational documentation were reference documentation, which were already developed, and contained technical documents and schematics, problem reports from Observatory Integration and Test (I&T), commissioning results, and all other reference materials not labeled as operational, including Triana documents. All documents were delivered electronically without issue, and ingested into OSPO's library for future reference. Operational products were also provided, which included all verified and validated commanding procedures, telemetry pages, and databases. MET Engineering assisted the FOT with developing telemetry pages and layouts that accommodated the monitoring capabilities of the FOs. Other operational products included software that created pages with a list of executable procedures for major events such as maneuvers, and limit monitoring and audible tools that were designed to facilitate reduced real-time monitoring, as the FOs divided their time between GOES and DSCOVR activities.

With staffing turnaround, operational documentation tend to outlast personnel, in both NASA and NOAA staffing structures, so it was imperative that the documentation that was provided be thorough and capture all applicable input from current knowledgeable staff. GSFC personnel tend to move on to other projects, and although sustaining engineering agreements were established, the information that resided with that personnel could be unattainable months or years after Handover. For future *Advanced Cooperation* endeavors, the operational perspective needs to be incorporated into the content and structure of all documents intended to directly support mission operations. Inserting the end user of the documents in the development process early will save time in document revisions, and assist with document clarity and usability.

E. Sustainment Plans: Ensuring Post-Handover Support

Agreements for NASA/GSFC support after Handover were outlined by NOAA and NASA management, and NOAA NESDIS and GSFC signed a Memorandum of Agreement (MOA) for DSCOVR for Sustaining Engineering Support. The MOSE coordinated regular meetings to establish which components would be maintained by NASA, and which would be covered by NOAA in-house personnel, primarily with respect to networking and other GS hardware. The Front End Processors (FEPs) which directed real-time telemetry and commands to/from the antennas at both WCDAS and FCDAS were part of a separate transition effort, but were accounted for in the overall sustaining engineering management approach. The scope of the MOA covered Mission Operations Center (MOC) maintenance, Flight Software (FSW) maintenance, spacecraft anomaly support, Flight Dynamics support, and Attitude Ground System (AGS) maintenance.

The MOC developer, Omitron, Inc., performs MOC maintenance, including maintaining ground system development lab and ground system software at their development lab, ground system updates/bug fixes for software, integration of all ground system software updates into the NSOF, patching and testing of all identified vulnerabilities at the development lab and implementing and testing solutions at the NSOF MOC. The GSFC Flight Systems Software Branch provides FSW sustaining engineering, including maintaining the DSCOVR FSW test bed, reflecting the most recent configuration of the spacecraft, supporting spacecraft anomaly investigations and script generation, and generating, testing and delivering FSW updates as required. Flight Dynamics Facility (FDF) sustaining engineering includes providing orbit determination, generating acquisition data, and providing ephemeris products. The GSFC Attitude Control Systems Branch provides AGS sustaining engineering, and includes maintaining the AGS, reflecting the most recent configuration of the spacecraft, supporting spacecraft anomaly investigations, and generating, testing and delivering AGS updates as required. The GSFC Applied Engineering and Technology Directorate provides spacecraft sustaining engineering which includes supporting spacecraft anomaly investigations, and contacting subsystem manufactures (where applicable) for support.

As outlined earlier, sustaining engineering agreements should not preclude training topics or hinder the development of thorough documentation. Sustaining engineering is an important aspect of mission longevity, ensuring that the research and development personnel are readily available to address unforeseen issues, but is secondary to a comprehensive training plan supported by thorough documentation that cover all foreseeable events and situations that the operational team should be able to manage.

F. Space Segment and Ground Segment Validation: Acquiring Functional Space and Ground Assets

NOAA required completion of all spacecraft commissioning activities, with the instruments calibrated, and the spacecraft stationed in orbit and ready for normal operations, before the GDP could deliver the spacecraft. DSCOVR was successfully launched on February 11, 2015, and a Mid-Course Correction (MCC) burn was performed 32 hours after launch to correct the DSCOVR trajectory toward L1. The GDP performed nominal checkout activities and functional tests as planned during the cruise phase. The L1 Orbit Insertion (LOI) maneuver burn was performed nominally, as was a follow up LOI Correction (LOI-C) maneuver, placing the satellite in its final orbit. Final instrument calibration were performed to ensure readiness for data collection.

Regular commissioning activities were conducted nominally, and are not covered here, but several anomalies or deviations from the operational baselines were encountered during the Cruise phase that modified the intended post-Handover concept of operations:

1. **Faraday Cup Settings –** The GDP had not optimized the Faraday Cup before they delivered it to NOAA and required additional collaboration with the GDP to implement patches and parameter changes.
2. **NISTAR Calibrations –** NISTAR required additional calibrations and optimization when the GDP delivered it to NOAA, and also required additional collaboration.

3. **Safe Hold Mode –** The entire spacecraft had experienced six unexpected and unexplained reboots (i.e., Safe Hold mode entries) beginning in July 2015, requiring a full system recovery that became a regularly occurring anomaly which needed to be accounted for in staffing levels.

NOAA/OSPO accepted the spacecraft with these conditions, and a plan for sustained support from GSFC to support them, and confirmed that the orbit and attitude maintenance were well understood and instrument activities (planning and operations) would be prioritized and regularly performed.

OSPO SAs assumed system administration responsibilities for the MOC and supporting ground system on September 1, 2015, prior to official handover, as part of extended hands-on training. The GDP confirmed that the real-time MOC system was stable and proven suitable for the Normal Operations phase, and all offline MOC components operations were stable. Real-time telemetry and commanding network links between all ground system elements were proven stable with no major issues. All backup systems in the offsite backup MOC at WCDAS were confirmed stable and configured to match the primary systems, with synchronization schedules set up. As part of the ground system validation, and training, the DOT exercised a Continuity of Operations Plan (COOP) failover where they deployed to WCDAS to activate the backup components and conduct operations from WCDAS; all real-time and offline systems were demonstrated successfully with no major impacts. The DOT worked with the GDP to establish automated telemetry limits for the spacecraft and instruments, as well as automated configuration monitors for mnemonics with no database limits, including an audible alert system that would notify the FOs of any abnormal behavior. Trending report profiles were established for daily, weekly, and monthly monitoring.

One issue within the GS at Handover was that the GDP had designed the system to use IronKey (USB) devices to transport required operational products into and out of the MOC Ground System to facilitate mission planning. However, the NOAA System Owner prohibited the use of IronKey devices between the NSOF administrative network and the MOC System network, preventing the ability to import critical products (e.g. contact schedules) from the internet into the MOC System. This resulted in numerous instances requiring GDP intervention to complete the transfers for the MET (utilizing NASA admin LANs as a workaround), so without NASA presence, the MET would not be able to complete all critical offline activities. Eventually, NOAA mitigated this risk through coordinated management of USB devices, ensuring mission continuity via ground system transfers.

Confirming SS and GS functionality prior to Handover is more straightforward than other transition requirements, as the validations are discrete and follow a standard checklist for verification. However, the important part of receiving a SS and GS architecture, as the operational user, is not so much confirming that they are operating as expected, but accounting for any deviations and ensuring that personnel staffing and knowledge is sufficient to manage the deviations. The DSCOVR spacecraft presented several deviations from the operational standard configurations, and through awareness, involvement, and accountability, they were successfully managed to ensure mission continuity.

G. Readiness Reviews: Confirming Readiness to Transition and Operate DSCOVR

In all NASA/NOAA collaborative endeavors, readiness reviews serve as *Quality Checks* at various times during mission development. They are conducted to ensure that schedules are being maintained, mission goals remain attainable, and all parties are in agreement with respect to the next steps to be taken. Several reviews were conducted throughout all of mission development phases, with NOAA personnel participating in varying degrees. Some reviews were unrelated to transition and operations, such as the Pre-Environmental Review (PER) on January 28, 2014 and the Pre-Ship Review (PSR) on November 12, 2014, which are not addressed in detail here, while others required the MOSE to present facility, staff, and operational readiness to support both launch and normal operations, and are explained from the operational perspective.

1. Mission Operations Review (MOR)

On January 9, 2014, the MOSE presented NSOF readiness to support launch operations, and initial plans for Normal Operations at the Mission Operations Review (MOR). The MOR was the first opportunity for NOAA to present as a partner in the collaboration. The MOSE outlined the status of physical space readiness for the ground system, noted how schedules and spaces were coordinated around launch activities from other missions, and explained how the GSL worked with NSOF personnel to procure connectivity throughout the facility. At the MOR, the MOSE first presented an overview of the launch backup space (i.e., Room 4001) as the prime launch space in the event that DMSP had a launch slip.

The MOSE also presented the plans for operating the mission after Handover for the first time at the MOR. It was here that the MOSE first outlined the staffing approach, consisting of primary support from the MOSE/SSL and GSL, and secondary support from other staff, including the Flight Operators and cross-trained EMOSS engineers for maneuver planning, attitude control, and configuration management. The MOSE noted that the staffing was structured to support the highly-automated MOC System design that the GDP had developed and presented to NOAA, with automated ground station pass execution, automated data processing and automated notification and system alerts. The MOSE outlined all required real-time and offline operations tasks and assigned primary and secondary mission personnel to execute all tasks during normal operations. The MOSE also presented the envisioned training approach, noting that the MOSE/SSL and GSL were involved full-time for all activities receiving primary training, and additional personnel would be joining to receive secondary training in subsets of activities relevant to their positions and intended responsibilities. The early presentation of the OSPO staffing and management approach, which was constructed based on strict analysis of perceived responsibilities at the time, was provided to guide the GDP in structuring their approach for training and the normal operations dynamic.

2. Operations Readiness Review (ORR)

On November 14, 2014, the MOSE presented the current status of NSOF readiness to support launch, and the further development of plans for Normal Operations, at the Operations Readiness Review (ORR). At the ORR the GDP demonstrated to the review panel that all flight and ground system verification activities were successfully completed, the system was ready for final processing prior to launch and mission operations, and all system and support (flight and ground) hardware, software, personnel, procedures, and user documentation accurately reflected the deployed state of the system.

During the presentation, the GDP noted that the majority of training would occur during the Cruise phase, with all training to be completed by May 2015. The out brief from the review noted that the approach for the Class D mission relied primarily on OTJ training, as opposed to intense class room training, where the OSPO operators assumed responsibility at the consoles during commissioning under the mentorship of the GDP operators, and that this required early participation and coordination from OSPO. The reviewers noted that the GDP team was well trained to execute their responsibilities, and that the interaction with the OSPO team scheduled to take over operations was healthy. However, the reviewers noted that the GDP team needed to pay particular attention to the availability of personnel and the measures of proficiency as they progressed with this training approach. The MOSE also suggested two advisories with respect to training, noting that the AGS training outline lacked specific material, and the MMFD training did not cover Solar Exclusion Zone (SEZ) maneuvers that would need to be conducted starting in 2019.

The reviewers also found that two major and two minor issues hindered an otherwise perfect ORR. For the major issues, the review board recommended that OSPO and the GDP conduct a thorough assessment of the circumstances that led to each of the following situations, and address the apparent miscommunication as to what was needed when:

1. **Major – IT Security Authority to Operate (ATO)** - As of the ORR, the GDP had not received Authority to Operate (ATO) from NOAA because of patches required to the MOC software. The GDP had planned to implement these patches after launch during the MOC patch release in March 2015, an approach not supported by NOAA. Had this been considered a lien, it could have delayed launch. Reviewers recommended that the GDP conduct an independent review of the solution to this issue before launch to ensure verification of the integrity of the system. The review board recommended that the IT security architecture expectations should be captured early in the system requirements for future missions, and that the budget should reflect those requirements.

2. **Major – Readiness of NOAA Antennas (WCDAS and FCDAS)** - The ability of NOAA to take over operations was fully contingent upon having their antennas capable of command uplink and data downlink of the DSCOVR data. It was not clear to the review board that WCDAS would be ready on time to support Handover. Further, reviewers noted the limitations in coverage at FCDAS during the winter months, making it a poor back up antenna. OSPO nor the GDP had presented any viable alternatives or plans outside of an implied possibility for extended NASA support using their antenna assets. The readiness of these stations appeared to be the biggest risk to readiness for transition.

3. **Minor – Flight Software Lab Issues** - Unexplained communication card watchdog resets had been occurring in the FSW lab. The GDP reported that these events had been occurring randomly, averaging 1 or 2 resets per week, but the software facility lab had not fully verified the root cause of this issue. It was recommended that the GDP make use of the remaining long duration simulations to further test the system, gaining additional time with the FSW on the spacecraft prior to launch to further mitigate any risk.

4. **Minor – Contingency Operations Failover on Backup MOC (bMOC) –** The GDP had not planned a failover contingency operations deployment of the operations team to the bMOC at WCDAS prior to Handover. While the status of the bMOC equipment was observable and remotely operable from the MOC, the reviewers recommended a failover using a deployed team (possibly the DOT).

The MOSE conducted and presented a staffing analysis based on the GDP OPSCON, and expanded on the staffing structure outlined at the MOR. The MOSE provided additional responsibility allocations, and reviewed a more descriptive approach for mission task execution. By this review, the MOSE had developed a detailed training matrix and taken ownership and responsibility for ensuring successful training execution.

3. Post-Launch Acceptance Review (PLAR)

The Post-Launch Acceptance Review (PLAR) was the first review after launch, and was held on September 29, 2015, after all commissioning activities were completed. The PLAR was primarily a review by the GDP where they presented the readiness of the mission to be accepted at Handover, although OSPO had an opportunity to provide their perspective on GDP readiness. At the PLAR, the MOSE presented the status of training and certification, noting that while some sections of training had been completed, there were still areas that had not been finished due to lack of documentation, or required additional shadowing to complete, but stated that all training was expected to be completed before Handover. The MOSE outlined how offline, real-time and special activities would be conducted, and how anomalies would be managed. At the conclusion of the PLAR presentation, the MOSE outlined remaining activities needed to ensure a successful Handover, including ensuring readiness of FOs to support unsupervised SS operations, finalizing readiness of SA personnel to support unsupervised GS operations, and successfully conducting all regular Normal Operations activities under the supervision of the GDP. Once the presentation was complete, the satellite went into safe hold mode, and the NOAA engineers conducted the recovery efforts.

4. Operations Acceptance Review (OAR)

OSPO was responsible for confirming readiness to take over of operations before handover could be performed, and the Operations Acceptance Review (OAR) was a venue devoted entirely to this purpose. Just as the PLAR was primarily for the GDP to present their status, the OAR was OSPO's opportunity to present readiness from their perspective. The MOSE presented the following material at the OAR on October 27, 2015 to demonstrate NOAA's operational readiness:

- OSPO Organization and Staffing: Mission Operations Structure, Training and Certification, Staff Readiness
- Normal Operations Approach: Real-Time Operations, Offline Operations, External Interface Management
- Anomaly Response and Resolution
- Flight and Ground System Stability Assessment
- Post-Handover NASA Operations Support
- Summary, Plans Forward, and Risks

The MOSE explained how the training approach had been re-scoped to address end-to-end processes to meet OSPO needs and approach for Normal Operations, and that the MOSE took the lead on defining training schedule and scope, and tracking completion. At the OAR, the MOSE demonstrated that an anomaly reporting plan (method and tools) had been established, a fully defined approach to mission planning and scheduling was in place, and a comprehensive approach for offline parameter trending existed. The MOSE also explained that the staff had an understanding of confirmed Sustaining Engineering Agreements, and had confirmed that GS connectivity had been tested and verified, since the DOT had been using the GS since April 2015 (for training) and since August 2015 (for operations). Prime and backup roles and responsibilities were defined, and the SS and GS operations at the system and subsystem levels were shown as understood for routine, special and contingency operations modes. The MOSE explained that the personnel had been trained and certified, all documents had been received at Handover or developed in-house, and the CM process of all operations procedures were defined.

At the OAR, the MOSE addressed the increased requirements for the Earth Science instruments, including additional slew calibrations and commanding requirements that were being levied, and raised a concern that if implemented, current OSPO staffing levels would be strained, especially considering that Faraday Cup commissioning activities were still being conducted, and the spacecraft was experiencing sporadic reboots that required extensive support for recovery. The MOSE outlined mitigation steps (i.e., increased staffing), and confirmed planned negotiations to discuss scaling back the calibration requirements for the Earth Science instruments during normal operations. At the conclusion of the OAR, NASA/OSPO and NOAA/GSFC confirmed that the transition to operations could be conducted, and NOAA officially took over operations of the DSCOVR spacecraft and ground system at 0000z on October 28, 2015.

IX. Normal Operations: Enhancements and Modifications

The DOT began operating the DSCOVR spacecraft and ground system on October 28, 2015, and performed their first major spacecraft operation on October 29, 2015, the first station keeping maneuver, which was executed nominally. Since the same personnel were involved with operations before handover, the implementation of Normal Operations activities was seamless and transparent to the end users. To ensure disruption or discontinuities, there were no initial modifications to the cadence of activities performed, but the MET began assessing how the GS and operational approach could be optimized to streamline mission execution, utilizing the sustaining engineering support in place to continue using available resources from the GDP, as depicted in Fig. 24.

The GSL coordinated with Omitron sustaining engineers to investigate potential optimizations to automated features within the MOC System that could further alleviate FO workload responsibilities, reduce the potential for human error, and streamline the capture and distribution of data. The GSL implemented enhancements to the Graphical User Interface (GUI) used by the FOs in the MOC to assist them with quickly identifying and responding to audible alerts, and fostered greater situational awareness by updating MOC System layouts to comply more with OSPO standards for operator responsibilities. The SSL continued coordinating with the GDP instrument PDLs to optimize instrument operations and reduce workload for offline planning and real-time commanding and support. There were several spacecraft modifications outside of normal operations still being performed when the GDP handed off the spacecraft to NOAA, such as optimization of the primary instrument, the Faraday Cup, and the establishment of the operational configuration of NISTAR.

The optimization of NISTAR and EPIC caused a continual fluctuation in the required duration and frequency of the calibrations shown in Fig. 38, with some calibrations requested more frequently, and others removed to an as-needed basis. NISTAR had not been optimized by the time the GDP delivered the spacecraft, partly due to GDP staffing issues, in that they did not have the relevant required experience on their team during the commissioning phase to ensure all tests were performed to obtain the optimal instrument configuration. Once the cadence and implementation approach for the dark space calibrations had been set, there were modifications to the duration of the calibration, as well as the filters used during alternating calibration, and the NASA NISTAR PDL added additional dark space calibration to the end of the Short Intercomparison calibration. The NASA NISTAR PDL also frequently adjusted intercomparison schedules, requiring multiple changes in the MOC System and within operational products.

The MOSE made continuous efforts to determine and quantify the DSCOVR Normal Operations tasks to ensure they fit within the intended operational structure, but this effort was hindered by ambiguous outlines from the GDP on the expected tasks required during Normal Operations, primarily those related to the Earth Science instruments. The agreed operational approach for the Earth Science instruments was that they would be mostly hands-off and require very little interaction, yet their nominal and anomalous operations soon expanded the required involvement beyond the initial required support levels. The implementation plan for secondary instrument activities during Normal Operations were heavily debated between the GDP and OSPO. Level 2 (L2) mission requirements stipulated that the Observatory was to perform lunar calibration activities for EPIC and NISTAR concurrently (L2SRD 2.4-05), that the Observatory was to perform the lunar calibration for EPIC and NISTAR at least once after the spacecraft was on-station in the final orbit (L2SRD 2.4-06), and the Observatory was to perform the deep space calibration with NISTAR at least once after insertion into the final orbit (L2SRD 2.4-08). Yet the GDP recommended and requested weekly calibrations for NISTAR, and monthly calibrations for EPIC, which were not in line with the staffing levels provided to support DSCOVR Earth Science operations, and were far beyond the requirements. Since slews and calibrations had been redesigned such that they would not interrupt the delivery of space weather data, it opened up more operational possibilities, and as such, the GDP had expanded their requests for calibration activities.

Negotiations were held to discuss scaling back the calibration requirements for the Earth Science instruments during normal operations. The GDP proposed an approach to the NISTAR Dark Space Calibration that involved multiple slews to and from Earth in order to accommodate EPIC imaging. The MOSE objected, noting that performing any slew has an inherent risk of leaving the spacecraft in a non-nominal configuration, and this approach needed to be reconsidered as it was outside the scope of the original L2 requirements for Earth Science instrument operations. This approach also strained the offline effort required to generate the slew products that needed to be incorporated into the ATS. The end result was that the NISTAR Dark Space Calibration was performed weekly for a few months, and then switched to monthly, with one slew out to dark space, and then a slew back to Earth after a period of dwelling; EPIC imaging continued throughout the calibration.

Similarly, the GDP proposed monthly EPIC Lunar Calibrations, but the MET negotiated reducing this to quarterly once the GDP had conducted a few monthly calibrations. EPIC imaging operations were generally automated, although the DSOC requested periodic special imaging requests or tests. DSOC requested additional EPIC imaging, which needed to be coordinated between regular imaging, and also needed to be calculated by the MET FSW Engineer to ensure the imaging did not violate on-board storage limitations. These special requests included lunar transits on July 16, 2015 and July 5, 2016 (see Fig. 37), a lunar occultation in 2015, solar eclipses on March 9, 2016 and August 21, 2017, imaging of Jupiter on March 15, 2016, and an annular eclipse on February 26, 2017. Imaging requests were managed using request authorization forms, and provided NASA with additional data that they needed, as well as public images for release on their website (https://epic.gsfc.nasa.gov).

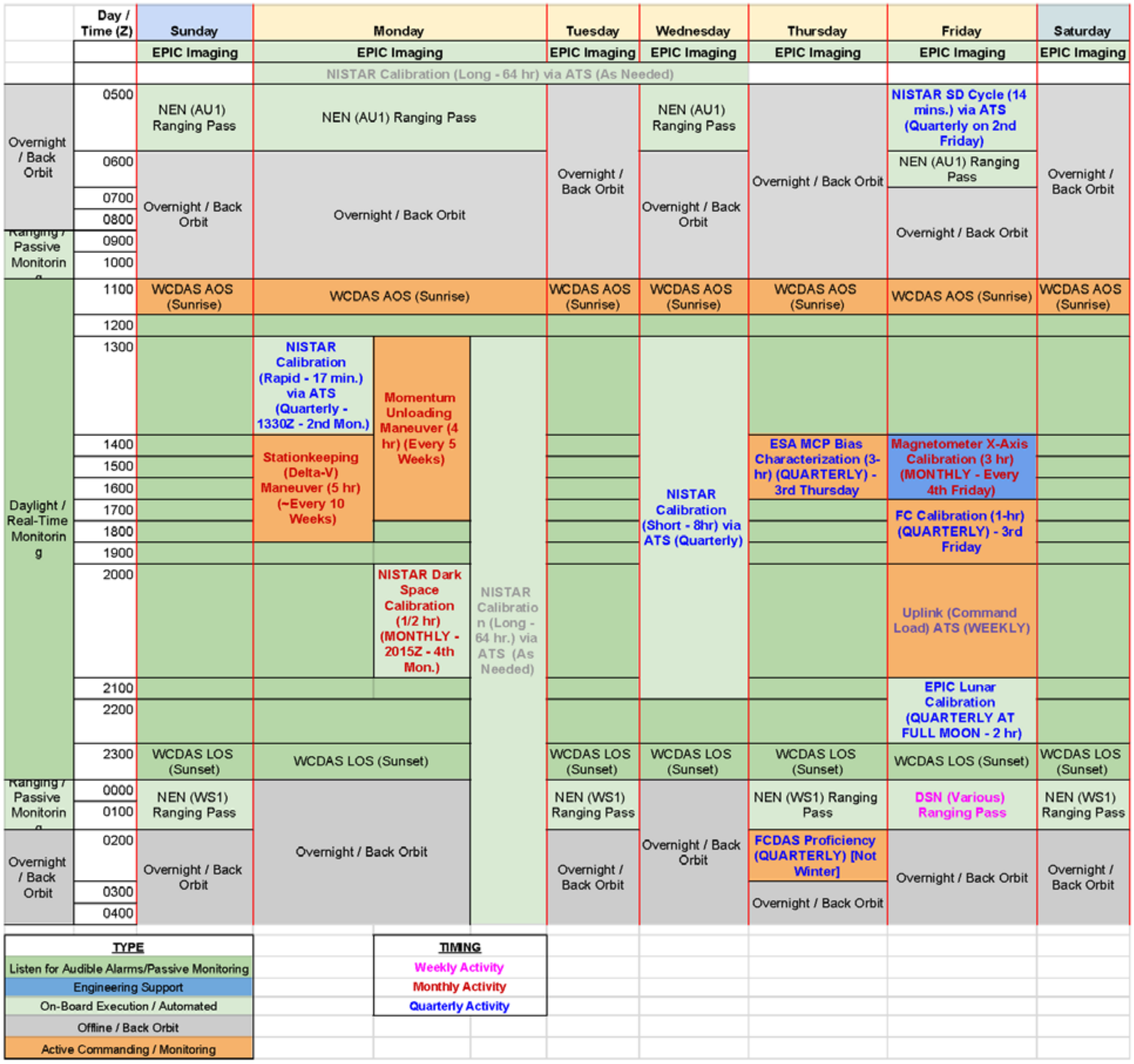
Fig. 37 Earth and the Dark Side of the Moon

During Normal Operations, the MOSE maintained a robust training program to ensure safe and efficient mission operations and to ensure that DSCOVR data users can fully access the data available to them. The training included spacecraft and instrument engineering and operations, all DSCOVR routine and contingency operations, and GS software and hardware maintenance. Three separate types of training were identified and implemented, which were:

1. Spacecraft Manufacturer/NASA to NOAA (i.e., Sustaining Engineering Support),
2. Internal MET Training (i.e., OTJ Training), and
3. MET to Flight Operator Training (i.e., Chalk Talks)

Continuous training sessions and frequently updated materials were essential for maintaining an efficient DSCOVR operational framework during Normal Operations.

As DSCOVR was a mission with dual purposes, providing data via an *Advanced Collaboration* dynamic, the management of operations required a delicate balance to ensure all requirements were maintained. Although SWPC and space weather had priority, the DOT worked to ensure that the earth science instruments, as the original legacy payload, performed above and beyond minimal requirements. Fig. 37 depicts the week-in-the-life for DSCOVR real-time operations, with all regular activities shown in the span of one week; although these events did not typically all occur within the same week, the visual provides a good overview of the required operations that the DOT was responsible for executing in order to support the spacecraft and payload operations. This depiction was the result of months of negotiations, instrument modifications, and cadence updates that occurred after Handover. Through continued involvement, and persistent input, the MOSE was able to ensure that OSPO could operate the DSCOVR mission as delivered and designed. Unfortunately, part of that operational design involved incorporating frequent anomalies into the structure of Normal Operations.



	Day / Time (Z)	Sunday	Monday			Tuesday	Wednesday	Thursday	Friday	Saturday
		EPIC Imaging	EPIC Imaging			EPIC Imaging	EPIC Imaging	EPIC Imaging	EPIC Imaging	EPIC Imaging
			NISTAR Calibration (Long - 64 hr) via ATS (As Needed)							
Overnight / Back Orbit	0500	NEN (AU1) Ranging Pass	NEN (AU1) Ranging Pass			Overnight / Back Orbit	NEN (AU1) Ranging Pass	Overnight / Back Orbit	NISTAR SD Cycle (14 mins.) via ATS (Quarterly on 2nd Friday)	Overnight / Back Orbit
	0600	Overnight / Back Orbit	Overnight / Back Orbit				Overnight / Back Orbit		NEN (AU1) Ranging Pass	
	0700								Overnight / Back Orbit	
Ranging / Passive Monitorin	0800									
	0900									
	1000									
Daylight / Real-Time Monitoring	1100	WCDAS AOS (Sunrise)	WCDAS AOS (Sunrise)			WCDAS AOS (Sunrise)	WCDAS AOS (Sunrise)	WCDAS AOS (Sunrise)	WCDAS AOS (Sunrise)	WCDAS AOS (Sunrise)
	1200									
	1300		NISTAR Calibration (Rapid - 17 min.) via ATS (Quarterly - 1330Z - 2nd Mon.)	Momentum Unloading Maneuver (4 hr) (Every 5 Weeks)	NISTAR Calibration (Long - 64 hr.) via ATS (As Needed)		NISTAR Calibration (Short - 8hr) via ATS (Quarterly)			
	1400		Stationkeeping (Delta-V) Maneuver (5 hr) (~Every 10 Weeks)					ESA MCP Bias Characterization (3-hr) (QUARTERLY) - 3rd Thursday	Magnetometer X-Axis Calibration (3 hr) (MONTHLY - Every 4th Friday)	
	1500									
	1600									
	1700								FC Calibration (1-hr) (QUARTERLY) - 3rd Friday	
	1800									
	1900									
	2000			NISTAR Dark Space Calibration (1/2 hr) (MONTHLY - 2015Z - 4th Mon.)					Uplink (Command Load) ATS (WEEKLY)	
	2100								EPIC Lunar Calibration (QUARTERLY AT FULL MOON - 2 hr)	
	2200									
	2300	WCDAS LOS (Sunset)	WCDAS LOS (Sunset)			WCDAS LOS (Sunset)	WCDAS LOS (Sunset)	WCDAS LOS (Sunset)	WCDAS LOS (Sunset)	WCDAS LOS (Sunset)
Ranging / Passive Monitorin	0000	NEN (WS1) Ranging Pass	Overnight / Back Orbit			NEN (WS1) Ranging Pass	Overnight / Back Orbit	NEN (WS1) Ranging Pass	DSN (Various) Ranging Pass	NEN (WS1) Ranging Pass
	0100									
Overnight / Back Orbit	0200	Overnight / Back Orbit				Overnight / Back Orbit		FCDAS Proficiency (QUARTERLY) [Not Winter]	Overnight / Back Orbit	Overnight / Back Orbit
	0300							Overnight / Back Orbit		
	0400									

TYPE
Listen for Audible Alarms/Passive Monitoring
Engineering Support
On-Board Execution / Automated
Offline / Back Orbit
Active Commanding / Monitoring

TIMING
Weekly Activity
Monthly Activity
Quarterly Activity

Fig. 38 Representation of Required Normal Operations

X. Periodic Reboot: Incorporating Known Anomalies into Normal Operations

An anomaly is defined as something that deviates from what is normal, standard, or expected. If an anomaly continues to happen regularly, it becomes less anomalous, and more part of standard operations. Therefore, consideration needs to be given to that reoccurrence, and it must be approached as something that can be recognized quickly, and responded to using established procedures. For DSCOVR, there were anomalies that occurred frequently enough to become incorporated as part of regular operations, requiring a dedicated recognition and response team and approach for resolution.

The MOSE formed the DSCOVR Anomaly Response Team (DART) under the direction of the OSPO DSCOVR Lead Engineer and included members of the MET and the FOs. The DART was convened once an anomaly was identified on the SS or the GS either by notification from SWPC, or by confirmation in real-time telemetry, and instituted the anomaly process (as indicated in Fig. 39). Using the process shown in Fig. 40, the role of the DART was to assure the SS and/or GS was in a safe state, and take action if needed. The DART assessed the state of the observatory (or ground system) with the aim of restoring nominal operations as soon as possible without incurring additional risk, and utilized delivered FOPs and/or COPs to perform corrective actions as directed. As part of analysis, the DART reviewed mission material from previous occurrences and requested additional resources as needed (e.g. NASA PDLs, manufacturers). The DART attempted to identify the root cause and initiated steps and processes to eliminate or mitigate the risk of re-occurrence of the anomaly, and at its discretion, dissolved and turned root cause/corrective actions over to a DSCOVR Flight/Ground Anomaly Review Board (ARB). As part of anomaly resolution, the DART recommended and/or executed corrective actions, updating existing documents as needed, and issued anomaly reports.

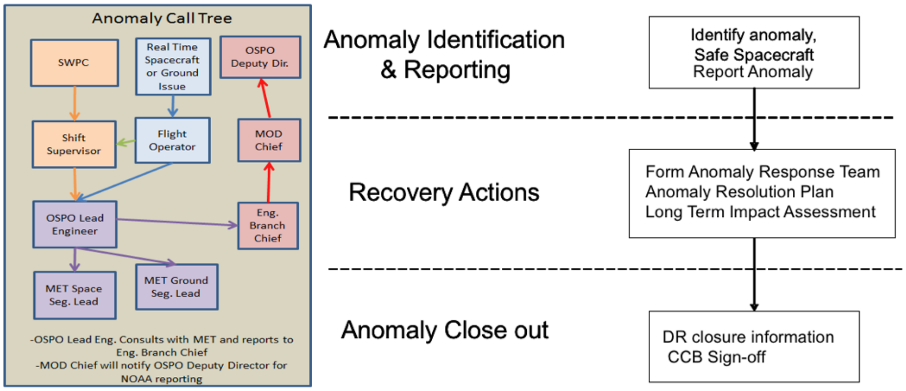


Fig. 39 Anomaly Call Tree and Top-Level Response Process

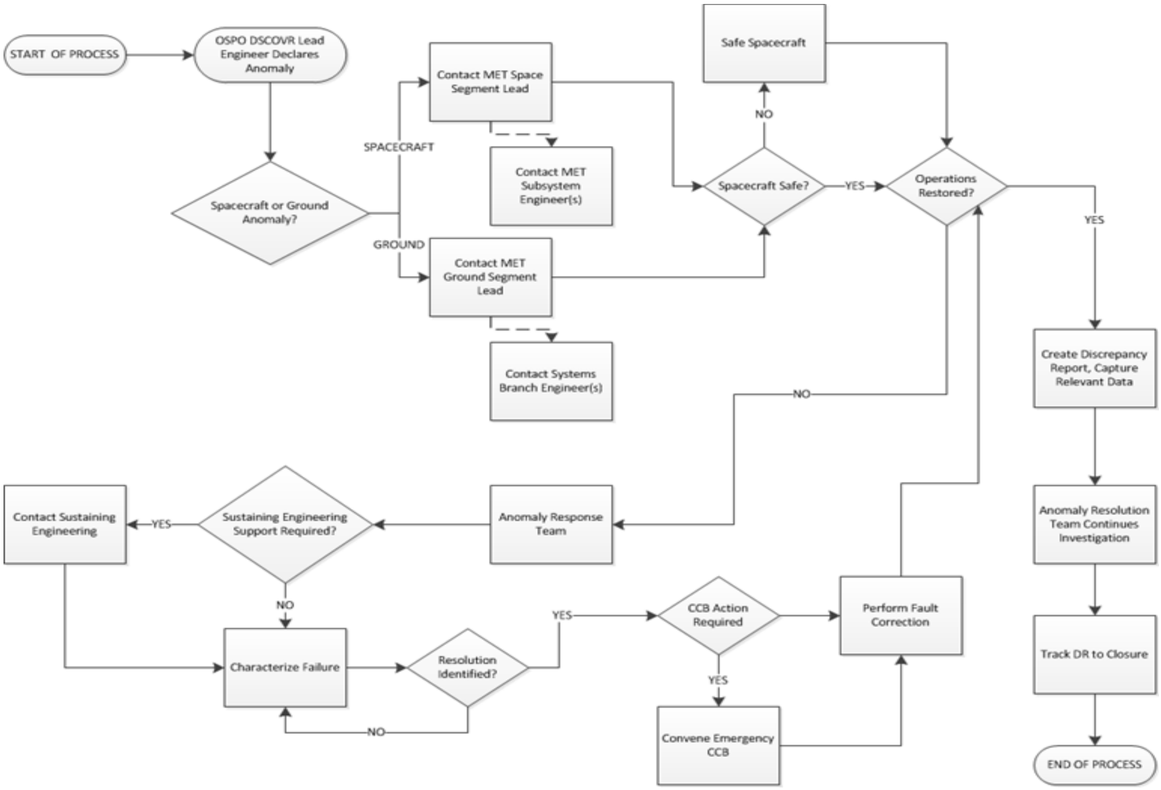


Fig. 40 Detailed DART Anomaly Recognition and Response Process

At Handover, NASA delivered the spacecraft with known anomalies affecting the primary instrument (**Faraday Cup Loss of Peak Tracking),** an Earth Science instrument (**NISTAR Built-In-Test (BIT) Receiver Cavity (RC) Calibration Failures)**, and a major anomaly in which the spacecraft sporadically rebooted into a safe mode configuration equivalent to a factory reset (**Safe Hold Spurious Reboots**). Each of these anomalies created additional workload for an O&S team that the MOSE formulated based on a specific concept of operations with surge support for a low threshold of anomalies. While the Faraday Cup (FC) and NISTAR anomalies had minimal impact, and were absorbed quickly within the responsibilities of the instrument engineers, the Safe Hold Reboots were a major addition to the workload that required support from a majority of the DOT staff.

A. Faraday Cup Anomaly Operations

The Faraday Cup was in the process of being slowly increased to its operational setting (Step 63), and monitored closely due to abnormal behavior, when the GDP delivered the spacecraft to OSPO at Handover. The FC has three collector plates (A, B, and C), and NASA noted that Collector "C" was not performing up to specifications. Additionally, software patches had been implemented to limit both the step function of the instrument, as well as to limit the range of the instrument operational current. On September 21, 2015, engineers increased the voltage to Step 58 (6002V), then Step 59 (6269V) a week later on September 28th, and then Step 60 (6638V) on October 19th. The MET SSL developed FC operational monitoring and reaction guidelines for the FOs to ensure they reacted appropriately to specific violations for voltages, currents and temperatures. The SSL coordinated with the GDP FC PDL to carefully increase the voltage levels and optimize the operational parameters to ensure SWPC received the most accurate space weather data. The SSL and the GDP FC PDL performed commanding to increase the voltage to Step 61 (7146V), Step 62 (7560V) and finally Step 63 (8011V) on November 9th, November 16th, and December 7th, respectively. Once the operational voltage had been reached and confirmed stable, Faraday Cup parameter testing was performed starting on February 5, 2016. Engineers tested various settings for modulator voltage, clock delay, retrace intervals, integration time, and peak offset to determine the settings that would provide SWPC with optimal data while alleviating some of the performance issues observed during initial commissioning activities.

As part of modified operations after Handover, two issues had to be regularly mitigated: a software bug that caused the peak tracking to lose the peak value, and abnormal readings in low density and temperature values following a full scan that had to be removed. To address these issues, the MET SSL and FSW Engineer worked with the FC PDL to write and update software patches to modify the instrument behavior, including a patch that excluded data acquired during retrace intervals from the peak tracking algorithm, and another that eliminated the performance of regular full scans since abnormal data was being collected at the end of each scan and affecting the usable data. To reduce instrument data outage time, the SSL implemented a procedure whereby the instrument software was quickly recycled to correct measurements. When SWPC notified the SOCC that the instrument had locked onto abnormal data in low solar wind density conditions, the FOs forced a full scan of the instrument via commanding, returning the instrument back to a nominal tracking configuration.

To maintain an optimal calibration baseline, the SSL implemented a quarterly low voltage calibration schedule, while the NASA and the instrument vendors recommended additional software patches. The FC PDL and the MET FSW Engineer wrote and implemented these patches, including one that extended the width of the peak tracking scan. The SSL developed a description of all active patches distributed it to FOs and NOAA management to provide awareness of the actions each patch took in the event of a violation, and outlined investigation procedures if the instrument software halted because of any action:

A. *IDPU Ram Code Scrubber Software Patch* – Performs EDAC functions on the EEPROM image
B. *Faraday Cup Limiter Software Patch* – Checks modulation voltage to ensure steps are incremented by no more than one count per step; if so, it halts the instrument software.
C. *Faraday Cup Current Limiter Software Patch* – Checks that current is below threshold of 407.0mA; if greater that threshold for more than four counts, it halts the instrument software.
D. *Faraday Cup Retrace Interval Software Patch* – Excludes retrace intervals measurements from algorithm.
E. *Faraday Cup Extended Range Patch* – Extends width of peak tracking scan on the low end.
F. *Faraday Cup Full Scan Disable Patch* – Disables all full scans.
G. *Faraday Cup KLAST Correction Software Patch* – Permits software to maintain total number of steps in a peak tracking scan when the peak location is too close to the end of the modulator table.
H. *Faraday Cup Jump Correction Software Patch* – Forces instrument to no longer track highest energy peak signal when multiple peaks of the same magnitude are measured in the same cycle.

With all these modifications, the Faraday Cup now delivers usable data to SWPC to meet all requirements, and provides them with the information they need to issue space weather forecasts and warnings. The instrument performance is still being analyzed, and instrument vendors are working with SWPC to determine additional modifications that can be made to further optimize the instrument, including a method to use ESA as supplemental input to FC data.

B. NISTAR Anomaly Operations

Once operational NISTAR experienced frequent anomalies that strained the resources of the Engineering personnel who were also working to optimize the configuration of the instrument itself. The instrument has mechanical shutters located at the top of each Receiver Cavity (RC) and Silicon PhotoDiode (PD). Shutters can be manually calibrated, allowing software to determine and track the shutter's position. The Shutter Task controls movement of the shutters and has a Built in Test (BIT) that has a value of 'PASS' unless a shutter calibration fails or limit switch is hit. Periodically, the calibration failed in one of the RCs, causing a BIT failure, and left the instrument in an uncalibrated position. Once this occurred, the instrument remained inoperative until it could be recalibrated and returned to its nominal configuration.

When the instrument optimization process changed the auto cycle setting of the instrument from 30 minutes to 4 minutes, the frequency of BIT failure occurrences increased, due to the increased frequency of shutter commands in a 4-minute auto cycle configuration. Engineers were responding to at least one BIT failure every week, which required 30 minutes of command time to recover the instrument, as well as pre-commanding authorization paperwork, and post commanding Spacecraft Event Report (SER) generation.

To minimize the effort, the MET Engineers developed a Relative Time Sequence (RTS) that was loaded onto the spacecraft, and executed with a single command. This RTS then automatically executed the additional commands needed to re-calibrate NISTAR and configure it back to its operational setting. With this implementation, the MET Engineers reduced the time for recovering NISTAR to a few seconds. Additionally, with the operational automation as part of normal operations, all paperwork requirements were eliminated as well. In the end, the MET Engineers were able to turn a 2-hour operation into something that could be completed in a matter of seconds.

C. Spurious Reboots: Safe Hold Anomaly Operations

By the time the GDP delivered the spacecraft to NOAA, the spacecraft had experienced six unexpected and unexplained reboots (i.e., Spurious Safe Hold [SH] mode entries) beginning in July 2015, requiring a full system recovery that became a regularly occurring anomaly. Currently, the DART, specifically the Mission Manager, the FSW Engineer, the RF/Communications Engineer, and the SSL, performs SH recovery operations. The DART uses the NASA FSW Sustaining Engineering support to determine actual spacecraft FSW down-time via FSW log analysis. The DSCOVR spacecraft has experienced eighteen spurious reboots (and one Processor Exception [PE]) since June 2015, with twelve occurring after Handover from NASA on October 28, 2015, as shown in Table 14.

Table 14 Spurious Safe Hold Anomalies

DSCOVR Safe Hold Anomalies	
SH1 – 2015/174/1715UTC – June 23, 2015	SH2 – 2015/178/1800UTC – June 27, 2015
SH3 – 2015/196/0620UTC – July 15, 2015	SH4 – 2015/216/2115UTC – August 4, 2015
SH5 – 2015/272/1900UTC – September 29, 2015 [PE]	SH6 – 2015/281/1811UTC – October 8, 2015
---HANDOVER (October 28, 2015) ---	
SH7 – 2016/006/0733UTC – January 6, 2016	SH8 – 2016/014/0648UTC – January 14, 2016
SH9 – 2016/145/1446UTC – May 24, 2016	SH10 – 2016/261/0849UTC – September 17, 2016
SH11 – 2016/285/0412UTC – October 11, 2016	SH12 – 2016/304/0950UTC – October 30, 2016
SH13 – 2017/236/1645UTC – August 24, 2017	SH14 – 2017/283/1707UTC – October 10, 2017
SH15 – 2018/014/2357UTC – January 14, 2018	SH16 – 2018/066/2201UTC – March 7, 2018
SH17 – 2018/068/1844UTC – March 9, 2018	SH18 – 2018/081/1006UTC – March 22, 2018

After the first two instances occurred within the span of a week in June 2015, the GDP convened an Anomaly Review Board (ARB) to conduct an investigation into the probable causes of the anomaly. The ARB reviewed space weather conditions at the time of the event but could find no direct correlation, and also considered potential hardware anomalies; the technical investigation is not discussed here, as it is still ongoing, and is not relevant to the discussion. The GDP executed the COP that they had developed for this anomaly to recover from the first few Safe Holds, and once it became evident that they were going to be a regular occurrence, the MOSE coordinated with the GDP to better define the recovery procedure to be more in line with a standard Normal Operations procedure. As an extension of training, the MET Engineers and FOs led the SH5 and SH6 recovery efforts, with support from the GDP, to ensure they could identify the signatures and accurately execute the recovery procedures.

After Handover, the MOSE worked internally with the team, and with external entities as required, to efficiently streamline the recognition and recovery process. The GSFC Flight Software Sustaining Engineering (FSSE) group provided analysis of Safe Hold diagnostic files to determine the exact time of the anomaly and the duration and reason of the reboot, and assisted with implementing additional diagnostic tools on board the spacecraft. The MET also coordinated with SWPC to enhance anomaly recognition procedures. When the spacecraft is outside the view of the OSPO ground stations (WCDAS or FCDAS) and not in a ranging pass (with NEN or DSN), the satellite is providing continuous real-time telemetry to SWPC via the RTSWnet ground stations. However, during these times, SWPC nor OSPO have insight into the state of the spacecraft, so when SWPC stops receiving data, the reason is not immediately clear. SWPC has to first determine if the outage is due to an issue with their ground system. The MOSE worked with SWPC to help them improve their ground system troubleshooting procedures so they could quickly eliminate the ground system as the source of the outage, and confirm that it was a spacecraft issue so OSPO could proceed with implementing recovery procedures. By reducing the time between event occurrence and event recognition via telemetry, shown as the blue bar in Fig. 38, the recovery procedure was implemented more quickly.

The MOSE developed ready-to-go recovery pages in the MOC System with the required commanding to further expedite the execution of the recovery efforts. The MOSE converted the COP delivered by the GDP into a Control Room Operations Handbook (CROH) procedure, with more detailed instructions, page references, execution times, and special notes for streamlining the implementation of the recovery. Lessons learned were incorporated after each recovery effort, continually improving the process and reducing the duration of the recovery. The MOSE streamlined the process for establishing ground station support for recovery efforts as well by establishing standard procedures for requesting DSN support in the event that the primary antenna (WCDAS) or backup antenna (FCDAS) were unable to support recovery commanding.

The MET FSW engineer worked with the GDP FSW PDL to coordinate the burn of specific recovery steps to the EEPROM memory so they would not have to be performed every time the spacecraft reboot, thereby reducing the recovery time. Instrument recovery procedures were optimized to give Space Weather instruments, primarily the Faraday Cup, priority in recovery. The SSL worked with the FC PDL to streamline the FC recovery procedure by removing unneeded calibration activities, resulting in a reduction of over an hour. EPIC recovery was reduced significantly to a matter of minutes, with imaging resuming automatically via the ATS at 00:00z on the next DOY, and the NISTAR recovery, which was done in three parts after 24 hour and 48 hour waits were streamlined by implementing automated thermal assessments that permitted wait time reductions to 18 hours and 36 hours. The optimized recovery times are shown in Table 14, which shows the Faraday Cup returned to normal operations within five hours of event recognition.

Table 15 Optimized Safe Hold Recovery Procedure Duration

Milestone	**Expected Duration**
Readiness to Begin Recovery (RBR)	**30 minutes → 2.5 hours** (if DSN is being used)
Recovery to Science Mode and HGA (SMHGA)	RBR + 1 hour = **1.5 → 3.5 hours**
Faraday Cup Recovery to Normal Operations (FCRNO)	SMHGA + 1.5 hour = **3 → 5 hours**
ESA Recovery to Normal Operations (ERNO)	FCRNO + .5 hours = **3.5 → 5.5 hours**
SC Ready for Normal Ops (no Earth Sci. Insts.) (SRNO)	ERNO + 0.5 hours = **4 → 6 hours**
EPIC Ready for Operation (ERO)	SRNO + 0.1 hours = **4.1 → 6.1 hours**
NISTAR Ready for Operations: (NRO)	ERO + 0.1 hr+18 hr.*+0.5 hr+36 hr.*+0.1 hr. = **58→ 60* hrs.**
***NOTE:** NISTAR waits (18 hours and 36 hours) are maximum times between Part II and Part III; recovery may be expedited if telemetry verifications and ground station contacts permit	
Total Active Operations/Commanding Time Required: 4.1 hours (on CDAS) → 6.1 hours (on DSN) [Wait times between NISTAR Part I and Part II (18+ hours) and Part II and Part III (36+ hours) not included.]	

The optimization of the recovery procedure significantly reduced the outage times for the primary space weather instruments, as shown in Fig. 41. In general, after Handover, recovery times were reduced by over 50%, with any delays in recovery mostly attributed to ground system issues (i.e., loss of telemetry, antenna issues, and poor link margins). Due in part to the reduced recovery times, yearly metrics for instrument data continuity remained well below Level 1 requirements even with the SH events.

An anomaly that continues to occur becomes less of anomaly and more a part of normal operations. When NOAA accepted a satellite with a known abnormality that caused it to reset sporadically, there were doubts as to the value that DSCOVR had as a replacement for ACE, especially considering the operational inconsistencies of the primary instrument, the Faraday Cup. Despite these unplanned deviations, and due to the diligence of a NASA team committed to delivering an optimal product, and the ingenuity and efficiency of a NOAA operational team devoted to the success of OSPO's flagship deep space mission, DSCOVR has continued to provide important predictive space weather data and valuable earth science measurements.

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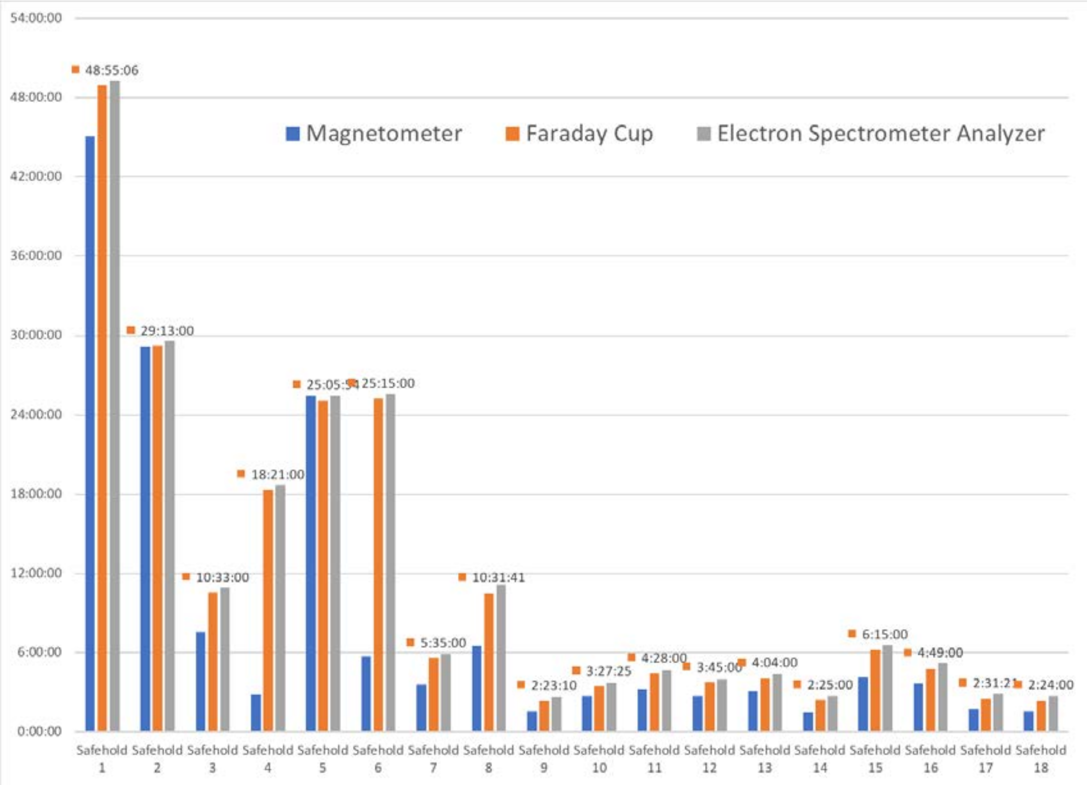

Fig. 41 Space Weather Instrument Recovery Times (in hours)

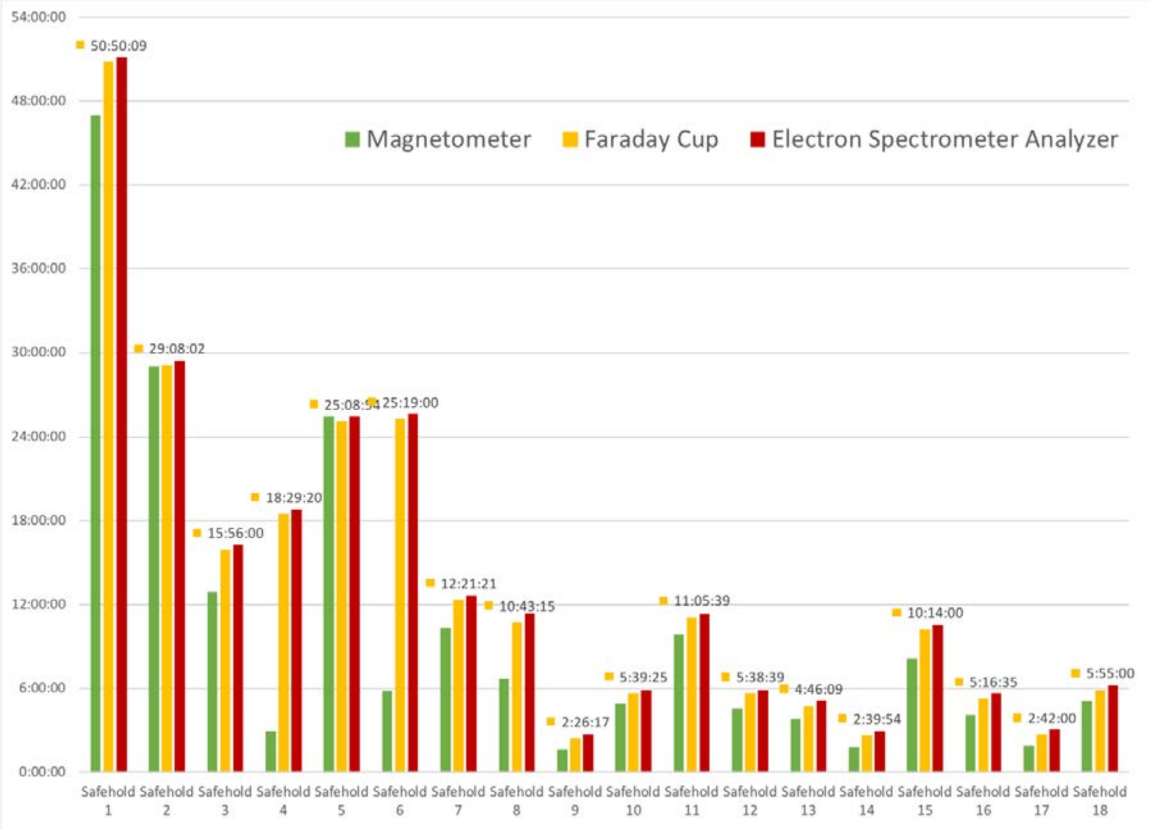

Fig. 42 Space Weather Instrument Outage Times (in hours)

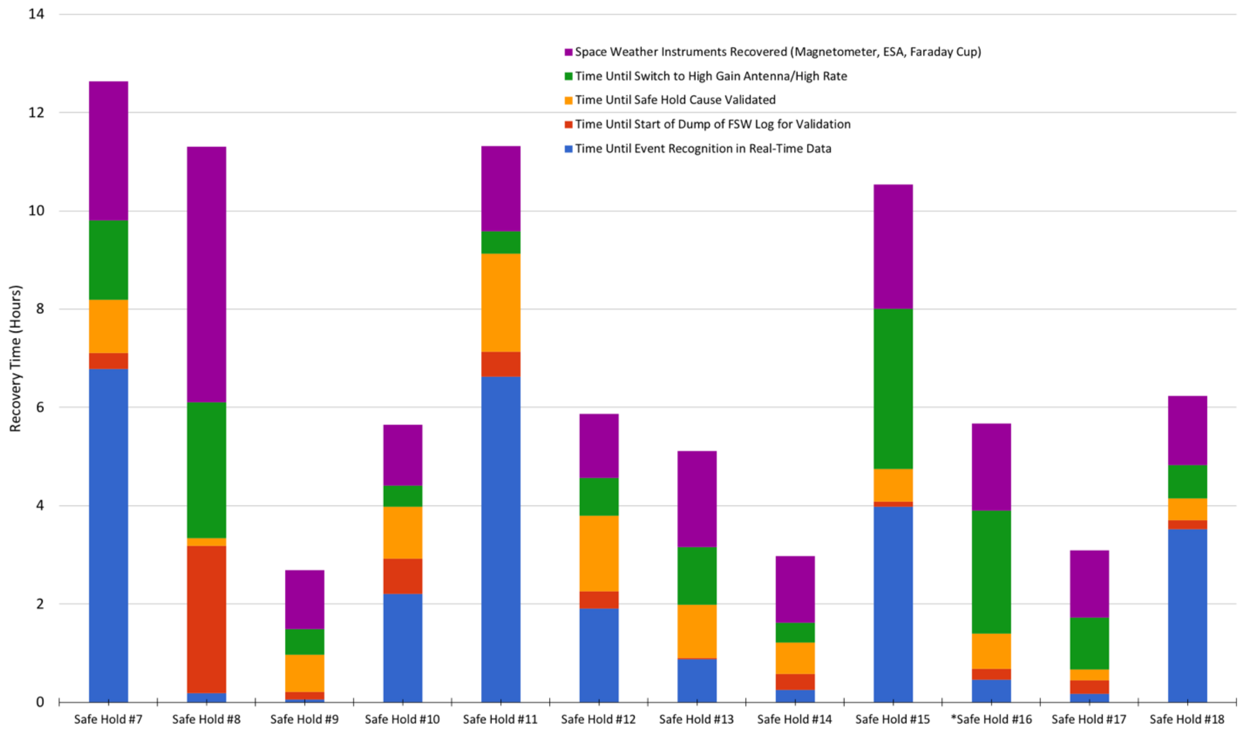

Fig. 43 Safe Hold #7-#18 Segmented Recovery Times (Space Weather Instruments Only)

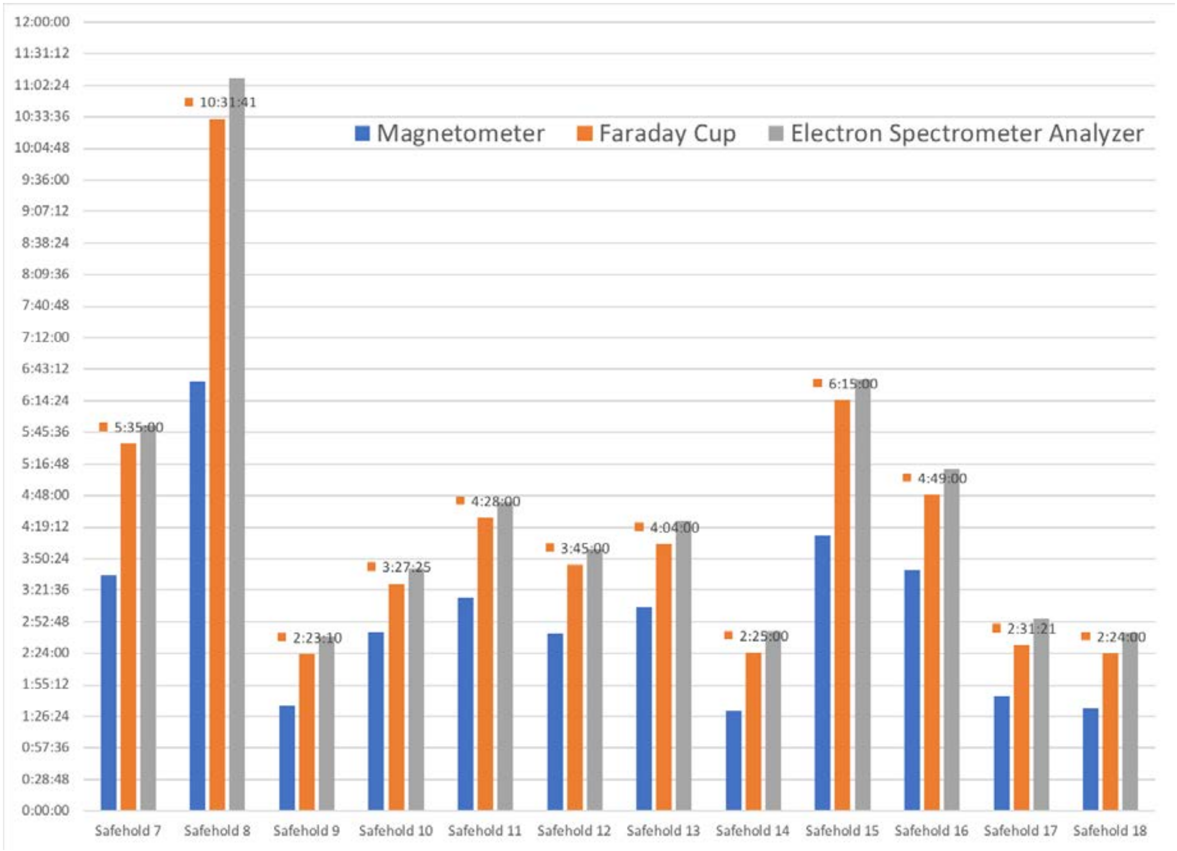

Fig. 44 Space Weather Instrument Recovery Times [After Handover] (in hours)

XI. Expanding the Lagrangian Constellation: Future OSPO Deep Space Missions

The DSCOVR mission is the flagship for an expanding NOAA footprint in satellite operations, and with its success, OSPO has proven it is capable of evolving beyond LEO and GEO satellite management. As outlined earlier, OSPO integrated DSCOVR as an entity separate from existing operations, but also merged with existing components; DSCOVR operates both on its own, almost as an independent OSPO entity, often excluded in conversations about OSPO's mission, yet part of a larger framework on paper and in practice. However, given current data and prediction requirements, deep space satellite operations need to be embraced and the growth of this market needs to be accounted for in the immediate future. Just as DSCOVR succeeded ACE, future missions at L1 (and possibly L5) will surpass DSCOVR for space weather prediction. In 2014, while DSCOVR was in its final preparations for launch, NASA received direction to perform studies with NOAA to determine the path forward for maintaining space weather measurement continuity:

> The Director of the Office of Science and Technology Policy, in consultation with the Administrator, the Administrator of (NOAA), the Director of the National Science Foundation (NSF), and heads of other relevant Federal agencies, shall enter into an arrangement with the National Academies to provide a comprehensive study that reviews current and planned ground-based and space-based space weather monitoring requirements and capabilities, identifies gaps, and identifies options for a robust and resilient capability. The study shall inform the process of identifying national needs for future space weather monitoring, forecasts, and mitigation. The study shall also review the current state of research capabilities in observing, modeling, and prediction and provide recommendations to ensure future advancement of predictive capability. [9]

The Space Weather Action Plan (SWAP) directed the DOC, in coordination with NASA, DOD, and NSF, to produce a plan for the deployment of new operational space-weather-observing assets, and stressed the need for the inclusion of a solar coronagraph to replace the SOHO/LASCO coronagraph capability, which had been excluded from the DSCOVR payload.

NOAA conducted the NOAA Satellite Observing Systems Architecture (NSOSA) study to research and outline possible future space-based implementation concepts to fulfill measurements required by the SWAP. The study allocated observation functions to specific orbits, analyzed the legacy architecture, and made recommendations for improvements in existing observation functions. Beyond L1, possibilities for expansion also included missions at L5 to independently support space weather forecasting, or to work in tandem with L1 missions.

> Essential components of a robust space environment operational program that will complement what exists today or, in some cases, provide much needed continuity of critical capabilities, include (satellites that) monitor the variable solar-heliospheric photon, particle, and magnetic field inputs with satellites at L1 and L5. To sample solar wind structures 5 days before they reach Earth and to provide global coverage of disturbances moving Earth-ward through the inner heliosphere, a spacecraft could be located at L5, the gravitationally stable location approximately 60 degrees behind Earth in its orbit as seen from the Sun. From L5, solar activity behind the limb rotating Earth-ward could be observed; in addition, in situ sampling of solar wind structure at a longitude distinct from that accessible at L1 and rotating Earth-ward is possible. An L5 mission would build on experience using … coronagraph measurements for space weather forecasting. [20]

A continuation of the NOAA"s current architecture would maintain the use of L1, while additions would add mission functionality at L5, and the study found that the "highest cost-benefit addition to space weather is off-axis measurements, most likely from L5." [4]. Regardless of Lagrangian location, OSPO has the responsibility to ensure they are prepared to incorporate additional deep space missions. More immediately, OSPO has to be cognizant of current plans to launch and implement a pair of satellites by 2022 to take over for DSCOVR operations just as the satellite is schedule to reach End-of-Life (EOL).

A. Space Weather Follow On Mission

The U.S. Government issued directives that dictated that there be no discontinuity in space weather measurements. Executive Order, Section 4(e), directed the Secretary of Homeland Security to ensure the timely redistribution of space weather alerts and warnings that support national prepare preparedness, continuity of government, and continuity of operations.

> Solar wind measurements from L1 should be continued, because they are essential for space weather operations and research. The DSCOVR L1 … mission (is) recommended for the near term, but plans should be made to ensure that measurements from L1 continue uninterrupted into the future. (A) space-based coronagraph and solar magnetic field measurements should likewise be continued. DSCOVR (does) not carry the coronagraph that is needed to replace observations from the SOHO spacecraft, which NASA launched in 1995. Moreover, instruments on DSCOVR, like those currently on ACE, have significant limitations in monitoring the highest-velocity events. [20]

Furthermore, the SWAP clarified that NOAA should execute plans to ensure data are collected to support these alerts, and that the data should continue to be collected from L1. The directive also stated that NOAA should implement the use of a coronagraph, since SWPC was presently using a NASA resource (i.e., SOHO CME images) to define the inner boundary of the operational CME propagation code and issue 1-3 day warnings of Earth arrival of CMEs, including shape, density, velocity and direction. In the current configuration, L1 solar wind measurements are a “single point of failure” for SWPC’s geomagnetic activity prediction system.

> A space weather and climatology program would encompass long-term planning for critical measurements, such as the L1 solar and solar wind measurements currently acquired from ACE and SOHO. The survey committee endorses DSCOVR as a temporary interagency solution to the current lack of continuity beyond ACE, which was launched in August 1997, of L1 plasma and field measurements essential to current space weather models, while advocating the need to have a plan beyond DSCOVR for continuous and comprehensive L1 coverage. [20]

Although NOAA investigated gap mitigation possibilities, including technical demonstration coronagraph missions and inclusion on commercial satellites, the leading candidate for a DSCOVR replacement is the Space Weather Follow-On (SWFO), shown in Fig. 45. The goal of SWFO is to maintain space weather measurement requirements, assuming that SOHO and DSCOVR will operate until late 2022. SWFO will provide long term continuity of space weather observational requirements with two satellites phased five years apart, with the first launch slated for October 1, 2021, and then in 2027, although a study is being conducted to consider launching SWFO-2 with SWFO-1 and storing it in space until needed operationally. Components for both satellites will be purchased together, but they will be assembled in succession. Goals and objectives are noted in Fig. 46; the primary operational objectives of the SWFO duo are to observe coronal mass ejection initiation and direction, produce CME images for input into heliospheric propagation code and measure solar wind thermal plasma, energetic particle, and magnetic field to enable space weather forecasting.

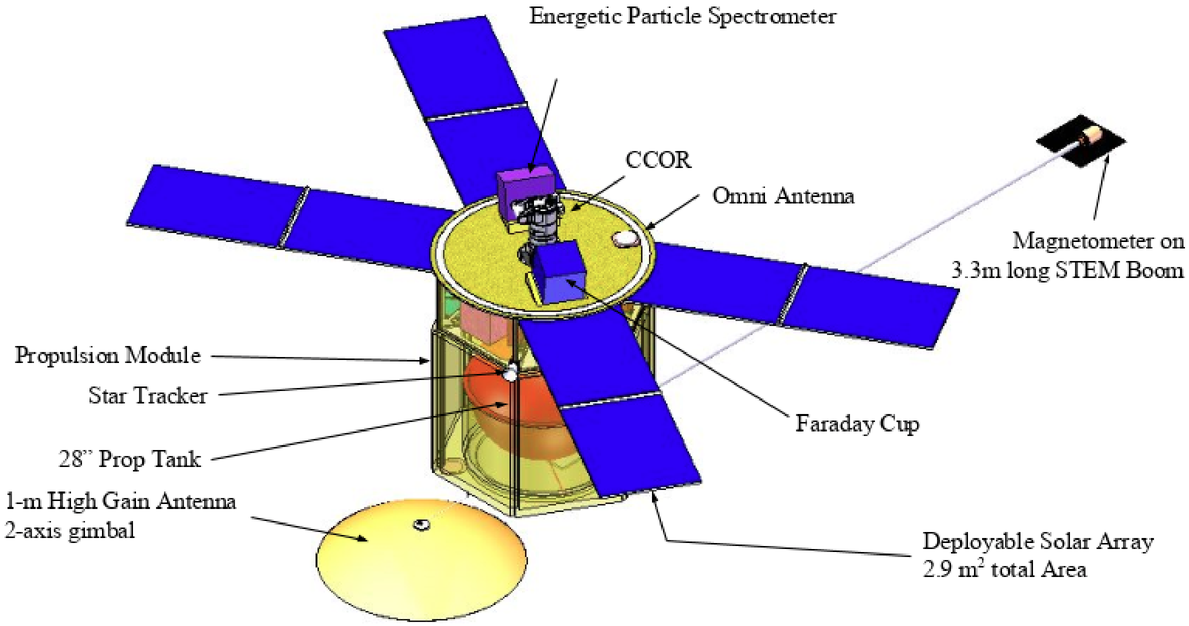

Fig. 45 Space Weather Follow On (SWFO)

Multiple studies in addition to the SWAP, principally the Committee on Space Environmental Monitoring (CESMO) 2009 and CCOR Request for Information (RFI) 2017, established that solar wind must be measured at L1 (or closer to the sun). Coronagraphic imagery requirements could be met in a variety of orbits in addition to L1, but no non-dedicated opportunity currently exists to fully meet the operational need. Also, research missions partially meeting the above requirements have exceeded their mission lives, and no advanced propulsion yet exists to allow sub-L1 missions. Therefore, SWFO will be launched and placed into an L1 Lissajous orbit just as ACE and DSCOVR were. Current conceptual instruments that will be designed to meet SWFO mission and data requirements will include a bulk plasma detector, a magnetometer, and low energy ion spectrometer, and the CCOR. The mission will have a five year mission life, with 10 years of consumables, and hardware similar to that currently on DSCOVR. The GS design will support data latency requirements, and the mission operations concept will be similar to DSCOVR, making it an optimal candidate for OSPO integration and tandem operations with DSCOVR in the NSOF.

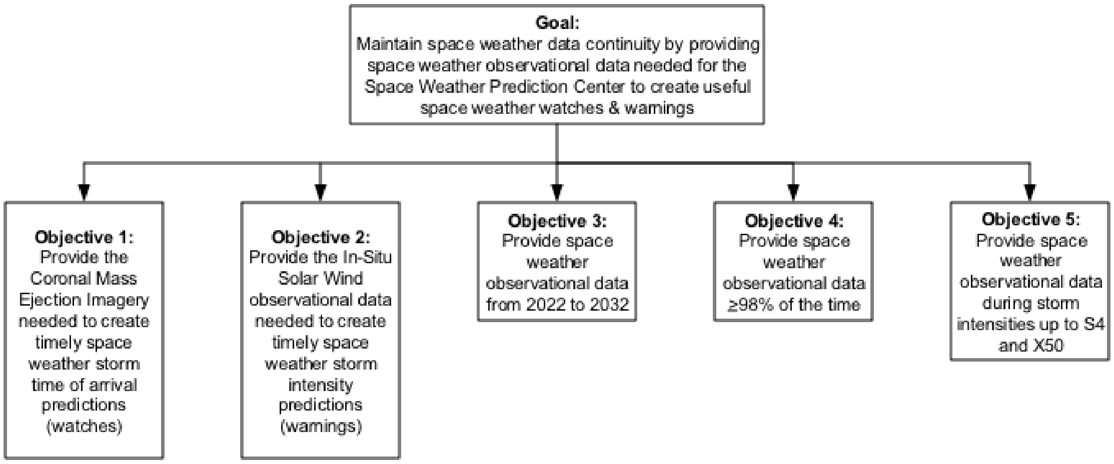

Fig. 46 Space Weather Follow On (SWFO) Goals and Objectives

The FY18 federal budget was signed on March 23, 2018 to support the development schedule shown in Fig. 47. The budget provided $8,545,000 for the Space Weather Follow-On program, for which the administration sought just $500,000 in its original 2018 request. The report accompanying the omnibus bill also directed NOAA to provide a full assessment of launch options for a coronagraph, and a plan to address non-coronagraph space weather requirements, within 180 days of enactment. It directed NOAA to coordinate with NASA and the Department of Defense to ensure that NOAA provide cost-effective operational space weather assets and NASA provide technology development, in accordance with the SWAP.

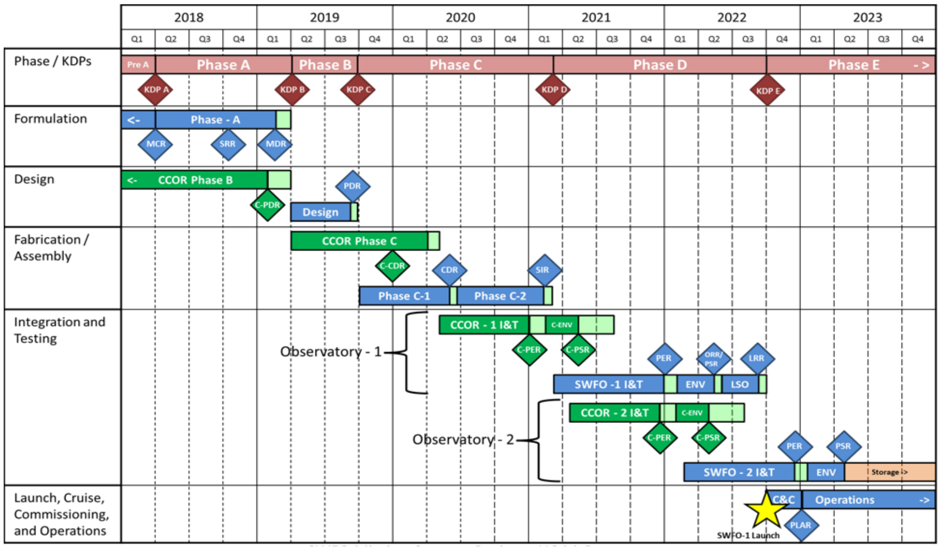

Fig. 47 SWFO Development and Launch Schedule

The following Key Performance Parameters (KPP's) are defined for SWFO:

- Solar wind magnetic field vector
- Solar wind plasma ion velocity
- Solar wind plasma ion density
- Solar wind plasma ion temperature
- Coronal mass ejection imagery

The SWFO Program minimum success criteria is defined as delivering to SWPC the SWFO KPPs during the SWFO operational time period. SWFO will be launched and commissioned in a manner similar to DSCOVR, and would be delivered to OSPO to be integrated into the OSPO operational framework. To ensure a successful integration, preparations need to be made well in advance of the projected launch date.

B. Modifications to an Integrated Framework

NOAA added DSCOVR to the OSPO framework through *Coordinated Integration*, and as such, was not given a discrete operational framework disconnected from GOES operations. A growing Lagrangian operational environment needs to be disjointed in all aspects from any existing operational components. "NESDIS has also identified other key problem-space areas that must be addressed … (including how to) balance mutually exclusive collection needs from a disparate stakeholder base, such as space weather from distant orbits like the L1 halo versus terrestrial weather from LEO" [34] Even with the addition of DSCOVR to the OSPO family, space weather measurements are still a small percentage of the data that are collected and distributed, although space weather is an important aspect of operations for the GOES-R series. The GOES-R program previously attempted inclusion of the coronagraphic imagery requirement but it was transferred to the solar wind program because the large mass and envelope of a standard coronagraph proved too costly to accommodate on GOES-R. NOAA embarked on a multi-year program to develop a smaller, lighter coronagraph, but the GOES-R series schedule did not permit inclusion of CCOR. However, the GOES-R series continued the 43-year record of solar observations from GEO, providing solar disk images from X-ray to EUV wavelengths, flare location, broader spectral coverage with higher spectral resolution for more accurate inputs into atmosphere/ionosphere models. The GOES-R series also monitors high energy particles with expanded energy range for improved analysis of spacecraft surface charging and to diagnose satellite internal charging, solar protons for improved Solar Radiation Storm characterization, and heavy ions for improved diagnosis of satellite single event upsets. Disconnecting DSCOVR from the GOES framework would still permit both missions to provide critical space weather data. Fortunately, the NSOSA study examined conceptual designs of around 50 specific satellite concepts that equally weighed GEO, small and large LEO, and solar orbiting systems, and presented a new opportunity to redesign the OSPO framework in the coming years.

Ground station tracking needs for future L1 missions are already available, with certain caveats, and depending on any L5 mission design, it seems likely that new capabilities will be needed to ensure continuous data reception. In January 2016, NESDIS presented their plan for conducting the NSOSA study to determine the most cost effective space segment architectures for NOAA weather, space weather, and environmental remote sensing missions, beyond the Program of Record to 2050. NESDIS referenced the preexisting Decadal study, stating that "while the decadal will provide a prioritized list of science and applications objectives, the NESDIS architecture studies will provide implementation options for operational services" [33]. Their presentation addressed preliminary findings that "NOAA's portfolio for large missions is well established for the next 10+ years, with JPSS and GOES constellations well underway, (but) smaller missions are not as well established, and new starts require new funding." [33]

There have been three independent reviews of NOAA/NESDIS activities. The first was an assessment of the NOAA satellite enterprise, and was conducted in 2012, with a report documenting findings and recommendations dated July 20, 2012. A follow-up review, to assess progress on recommendations from the 2012 Independent Assessment, was conducted in 2013 with the results presented in a report dated November 8, 2013. A third review, conducted in 2016-17, was another Independent Assessment of the NESDIS path forward and the capability of the enterprise to embark on that path. While the focus of the 2016-17 review was the future, it examined past and present activities to have a valid initial condition for the assessment of the future. The findings of this third review noted that NESDIS has been predisposed toward a future architecture based on multiple small, low-cost satellites and/or commercial solutions, but commented that any decisions in this regard cannot be made before a thorough analysis was completed, and that no specific operational architecture should be discounted. A final note in the review remarked that when NOAA was asked the question of whether NASA was a partner or a "contractor" to NOAA, no definitive answer to this question emerged, and the reviewers concluded that in fact NASA has played both roles, depending on the activity, reinforcing the ambiguity and complexity of the relationship dynamic.

NESDIS is currently faced with challenges such as what path to follow beyond established programs (particularly GOES-R and JPSS), how to successfully integrate and manage several stand-alone ground programs, including programs soon to be transferred from NASA, how to deal with an emerging commercial marketplace for weather and environmental data, and how to progress in the long term given the significant changes underway in the space industry. NESDIS recently established its OSAAP (Office of Systems Architecture and Advance Planning) office with the responsibility of examining current and future requirements and assessing space and ground capabilities for the future. They have formed a small joint team of experienced NOAA and NASA engineers to evaluate the current space environment and to map plans for the future. NESDIS, through its OSAAP team, is working to respond to the NOAA Administrator 2017 Guidance memorandum which directs them to develop a space based observing enterprise that is flexible, responsive to evolving technologies, and economically sustainable.

XII. Lessons Learned and the Path Forward

The integration of DSCOVR, as the first L1 mission for NOAA, and as an *Advanced Collaboration* between NASA and NOAA, brought many new experiences and provided several lessons that can be used to assist with the integration of similar missions in the future. At the conclusion of the collaboration, NASA requested feedback to incorporate into a Lessons Learned document, and the MOSE sought input from all OSPO personnel who were heavily involved in the process. These lessons are listed in Table 16.

Table 16 OSPO Lessons Learned Provided to the GSFC DSCOVR Project

Title	Observation	Lesson	Recommendation
FISMA IT Security Requirements Integration into Systems Development Lifecycle	NOAA experienced inconsistent IT Security support and coordination. IT Security Requirements were overshadowed by project schedule challenges. Implementing high IT Security Controls under a lower budget and integrating a new GS within a Legacy command and control system boundary prevented security controls from being implemented, such as having the GS patched at each phase.	Early planning for FISMA IT Security is imperative, no matter the phase of the project.	Fully investigate requirements for IT Security and gauge the level of support involved from IT Security personnel in order to avoid jeopardizing schedule.
Requesting NOAA Support Branch (Facility and Comm.) Personnel Support	NOAA Support Branch requested at least 1 month coordination prior to each pre-launch/launch event that required personnel support. There were events that were scheduled for which NOAA did not receive a staff support request until a week or less in advance. NOAA works around schedule slips, but there cannot be an expectation that NOAA staff can support short notice requests for dev/test activities beyond normal working hours.	Early notification and expectations for pre-launch events that require personnel support from NOAA staff is important to ensure staff can support activities.	NOAA staff members support multiple missions and are not always readily available to support launch efforts, so NASA should outline required NOAA staffing resources for each scheduled event well in advance (1+ month).
Equipment Security and Accessibility in NSOF Server Room	There was equipment locked in the server room racks that were inaccessible by NSOF Facilities personnel. NOAA understands the need of a mission to control their equipment.	Locked equipment racks with no known expedient way to access them in an emergency is a safety issue.	Recommend tamper tags or the like for future missions.
Early a Launch Management Plan Development	Allocation of space to DSCOVR equipment, specifically terminals supporting launch in the LCR, was not tailored to any specific launch requirement, but instead was allocated based on perceived available space. Once it was noted that there was insufficient space for the number of terminals/seats needed for launch, multiple reconfigurations were required, inconveniencing JPSS planning and installations, and straining Support Branch resources.	Having a detailed analysis of support required for launch can detect deficiencies early on, and can prevent late adjustments in launch resources.	Develop a Launch Management/Configuration Plan early in development, and write the requirements for seating based on a logical need to support launch instead of on perceived available space.
Early Involvement of Operational Personnel in Development Phase	NASA was in charge of the development of the mission, for both the GS and the SS. NOAA Operational staff was mostly left out of the product development, SS testing, and other developmental activities. These were prime opportunities to provide training to the staff that would be operating the mission after Handover. Since a portion of the R&D personnel will be providing sustaining engineering support after handover, early collaboration with operational personnel could lend itself to streamline the collaboration after handover.	Relying on post-launch training as the sole training opportunity is risky. If any portion of launch and checkout is non-nominal, time may be taken away from training opportunities.	Involve operational personnel in development phase of mission, to provide insight to the ground system, supporting products, and spacecraft. Allowing non-intrusive collaboration between R&D and operational personnel provides additional training.
Early Involvement in Development Phase of CDAS Personnel	NOAA, specifically OSD, was in charge of ensuring FCDAS and WCDAS readiness to support operations, and in the latter case, launch as well. Readiness efforts were not consistently reported to OSPO and the DOT, causing discontinuities and delays in readiness.	Involving the CDAS personnel in OSPO readiness meetings ensured schedules were maintained and progress reports were conveyed.	CDAS and OSD should allocate personnel in a mirrored fashion to coordinate with OSPO personnel. OSPO should provide a dedicated CDAS readiness engineer to assist.

The author of this paper, as the DSCOVR MOSE, has two primary recommendations for NOAA, and OSPO, to ensure continued mission success, and facilitate an expanding satellite operations framework:

1. **Assessment of Requirements and Readiness for DSCOVR Follow-on Missions** – With the success of the DSCOVR mission, and given that follow-up missions will be required, OSPO needs to establish, by the end of the decade, an operational path forward for the next Space Weather forecasting satellites. The operational framework should be established early to ensure that steps are taken to permit readiness when requested for the next, and subsequent, space weather missions. Just as these replacement and implementation plans have been established for LEO and GEO missions, so should they be formed for L1 (and possibly other Lagrangian) missions. The Senate Appropriations committee has, in the past, directed NOAA to maintain a multi-year schedule to ensure readiness, and accelerate the development of advanced technologies and an architecture study for a series of space weather follow on missions to implement OSTP's strategy and action plan.
2. **Development of an Independent Lagrangian Orbit Environmental Satellite (LOES) Framework** – The current implementation of DSCOVR operations has injected DSCOVR within portions of GOES operations in many areas, including staffing, IT security, and ground system elements. This implementation has marginalized the independence of DSCOVR, and other deep-space operations, and does not easily permit Deep-Space/Lagrangian mission expansion. Disconnecting DSCOVR from GOES and forming an independent Lagrangian Orbit Environmental Satellite (LOES) framework, separate from POES and GOES, will allow for additional missions to be incorporated within their own orbit-specific operational framework. OSPO has the potential for growth beyond Polar and Geostationary missions, and using DSCOVR as its flagship, this separation and expansion should be implemented to allow for the incorporation of additional Lagrangian (Deep-Space) missions.

NASA and NOAA launched DSCOVR as a two-year mission, with a fuel budget of five years. At just over three years in operations, and with an efficient operational framework and a fuel management plan that places the end of life no earlier than 2029, there is a solid expectation that DSCOVR will continue to fulfill its mission requirements far beyond its formal mission lifetime. NASA launched ACE on August 25, 1997, and over twenty years later, is still serving as a reliable backup to DSCOVR. The hope is that with SWFO-1 and SWFO-2 expected to be operational by 2027, and optimizing fuel usage in a manner similar to ACE, DSCOVR will still be in a state to serve as an operational backup for the SWFO series. To ensure a smooth integration of SWFO-1 and SWFO-2, many of the guidelines in this paper should be followed and/or implemented, and OSPO should work to ensure that their operational framework is ready to incorporate the satellites into an expanding deep space operational framework.

The world continues to benefit from a satellite mission unlike any other, as DSCOVR continues to provide critical space weather data, and valuable earth science products from a spectacular perspective. The mission represents the benefits of a continued partnership between NOAA and NASA, and is proof that the partnership can extend beyond that of a simple RTO dynamic. Future missions with shared payload, diverse mission goals, and joint responsibilities can benefit from the methods outlined in this paper to implement a streamlined launch readiness and transition to operations process. The DSCOVR mission exemplifies the possibilities that exist when expanding the operational frontier for NOAA satellite operations beyond the local neighborhood. New perspectives produce value and insight, and endless possibilities for scientific discovery.

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Appendix A: Accounting for Payload Uncertainty - An Overview of EPIC Repurposing Options

The Earth Science instruments on DSCOVR have been stigmatized from the beginning since their manifestation as the Triana primary payload. Their science of their intended purpose, to provide data for interpreting trends related to climate change, was often overshadowed by political agendas, as was the case when their inclusion on the DSCOVR mission was up for consideration. Just as DSCOVR gained a new life at the onset of a Democratic White House in 2008, the fate of EPIC and NISTAR became questionable at the beginning of a new Republican White House in 2016. Despite the fact that the instruments were fully operational without any significant anomalies, conducting measurements via highly automated processes that required little to no manual intervention, the NASA funding for their continued use was not included in the White House's FY 2018 budget request. However, the final fiscal year 2018 spending bill released by House and Senate appropriators on March 21, 2018 provided NASA more than $20.7 billion, far above the administration's original request, and restored funding for Earth Science and education programs slated for cancellation by the White House, including $1,700,000 for the DSCOVR Earth Science instruments.

In preparation for potential deactivation, the MOSE conducted an assessment of what the impact would be if the Earth Science instruments were turned off, or left in another non-operational configuration, and concluded that there was more risk involved in turning them off, destabilizing a long-trended thermal and power profile, than there was in leaving them operational and performing their intended functions, even if NASA had no funding to process the data. Additionally, if the instruments' operations were halted, if and when they were turned back on, there would be no guarantee of operation, and there would be significant gaps in archived data, as well as a loss in calibration baselines.

As part of the MOSE's assessment, alternate uses for the instruments were considered that would contribute positively to the overall mission, including revisiting the use of EPIC as an attitude control mechanism, and using the Earth Science instruments as forecasting tools to supplement existing Earth forecasting data provided by NOAA's LEO and GEO missions. Although these options were not pursued beyond an initial hypothesis, short descriptions of these two ideas are provided below as a starting point for any possible future work.

A. EPIC as an Attitude Control Mechanism

DSCOVR is a three-axis stabilized spacecraft that utilizes a typical complement of sensors and actuators, i.e., Star Tracker (ST), Inertial Reference Unit (IRU), Coarse and Digital Sun Sensors (CSS sand DSS), and Reaction Wheel Assemblies (RWAs), to maintain the desired attitude. Operationally, the ST has shown some flaws and deficiencies, and while many missions operate with at least two star trackers, DSCOVR has only one, so considerations should be made for backup alternatives for attitude control. To enhance attitude control efficiency, and supplement the sole ST, it has been proposed that EPIC, which has a 0.62-degree FOV and takes full images of Earth on a regular cadence, has the capability to be used in an attitude-control capacity using an image-based attitude control technique.

The MET Engineers noticed the first indication of ST issues on December 08, 2015, after observing multiple instances of poor centering of the earth in the EPIC images. The investigation intensified when an on-board safing script was triggered due to high star tracker rates and autonomously aborted a momentum unloading burn on December 17, 2015. Analysis showed that the FSW initiated the transition to Sun Acquisition (SUNACQ) mode in response to the Fault Detection Handling (FDH) ST rate monitoring function that is active while in Delta-H (DH) and Delta-V (DV) modes. This FDH derives the spacecraft body rate by differentiation between successive ST quaternions. When an excessive rate is indicated (above 0.5 deg. /sec.) for five consecutive 10 Hz. control cycles, the SUNACQ mode is commanded. The purpose of this FDH is to guard against an otherwise undetected anomaly in MIMU performance, as DH and DV modes rely on that device to sense attitude for the ACS controller. The likelihood of such failure during the very limited time in DH and DV modes (nominally < 1 minute) is minimal, and the execution of DH and DV is mandatory to continue the mission, so until the star tracker performance is resolved and the sensitivity of the FDH function is reconsidered, the star tracker rate FDH has been disabled.

Attitude control performance degraded over subsequent days, but soon recovered to a more nominal state. Following additional analysis, MET Engineers determined that all elements of DSCOVR hardware and software were functioning nominally, and that the observed abnormal performance was inherent to the system design; while the ACS performance does not meet requirements, the actual performance primarily affects the EPIC, with marginal impact on NISTAR, and is satisfactory for DSCOVR's primary space weather mission. Data showed that episodes of poor pointing were directly correlated with jitter in the ST attitude solution, which in turn was related to the star density in the ST scene, and attitude solutions based on fewer than the desired full complement of 5 stars. At this point, the ST scene provided only 4, and at times as few as 3 stars, of sufficient magnitude (the limiting magnitude of the Ball CT-633 star tracker is ~5.0). Not only is the accuracy of attitude solution degraded with fewer stars, but "jitter" is introduced as the ACS system responds to transitions between 5, 4 and 3 star solutions. This is particularly an issue for DSCOVR, as the ACS system does not employ any type of Kalman filtering. Although the star tracker is functioning nominally, it is not clear that its performance fully meets the specification upon which the observatory ACS design was predicated. The TRIANA Attitude and Control System (AOCS) Hardware Coordinate System document states that the star tracker will maintain 5 or more stars in the FOV over the entire celestial sphere with 98% probability for the star catalog which contains 2000 stars. This specification has not been confirmed with Ball, and it does not speak to the probability of maintaining 4, 3, and 2 stars.

In the course of the ST performance investigation, MET Engineers questioned the effect of the EPOXI patch, which the GDP loaded to the ST software early in the mission. The GDP installed the EPOXI patch when they noticed that when tracked stars were near the edge and comers of the tracker FOV (nominally 17.5 deg. square) there was more variation (noise) between successive tracker quaternions. Ball had developed the EPOXI patch, which limits the FOV to a 16 deg. circle, where the instruments optics and ground calibration are optimal, in response to a similar concern for an early mission. The concern was that this may be a handicap when operating with a sparse scene. However, in consultation with Ball Aerospace, it is now understood that this FOV limit is qualified such that 16 deg. circle is the preferred area. If there are 4 or 5 viable stars within this area, the tracker will compute the attitude solution based only on those stars. If this is not the case, the tracker will use any available stars within the larger square FOV.

The DSCOVR AOCS pointing requirements were carried forward from the TRIANA baseline design. In examining early Triana documentation the MET Engineers discovered that in this baseline design, the FSW AOCS function included a fine targeting function in which an earth centroid quaternion, received from the EPIC, was used to adjust the "Coarse Target" quaternion from the star tracker. Although Triana developers considered a six-state Kalman filter (estimating attitude errors and gyro biases), since Science mode was meeting all performance requirements without a Kalman filter, the gyros were very stable, and not including the Kalman filter saved both analysis and software schedule, one was not included. Given the actual ST and AOCS design/performance and DSCOVR's orbital dynamics, occasional episodes of poor ST scene are unavoidable. Fundamentally, this issue could only have been addressed during the design stage by incorporating a second ST mounted in a different orientation, or perhaps a ST of a different design. While not a substitute for a continuously valid ST attitude solution, an on-board Kalman filter implementation would serve to mitigate the impact of degraded ST attitude solution in poor scene conditions and Lost in Space (LIS) conditions of moderate duration (minutes-hours). Attitude jitter between ST solutions would be greatly reduced, and the final state before falling to LIS would be more accurate. Also, the dynamic computation of gyro biases would improve performance when propagating during the LIS condition. Of course, a hardware solution is now impossible, and the development and implementation of a Kalman filter would be a major effort.

Alternatively, if the EPIC was not being used for its intended purpose, it could theoretically be implemented as a tool to provide image-based attitude control for DSCOVR. The EPIC flight software is divided into 3 tasks:

- EPIC Control (EC) - Performs most of the nominal activities such as taking pictures.
- EPIC Data Processing (ED) - Processes image files created by EC task to output compressed and/or “processed” files.
- EPIC Housekeeping (EH) - Performs most of the behind-the-scenes work with the hardware.

Within the EPIC coding for the ED task are the technical specifications for the centroid. When the image acquisition sequence is complete, the raw image file is handed off to the ED task for processing, centroiding, and/or data compression. Documentation provided by the GDP at Handover indicates that:

1. EPIC is capable of calculating the center of the earth area, or centroid, for a given image,
2. This capability (i.e. Gibbous-phase Correction [i.e., earth centroiding]) was originally designed to provide input information to the spacecraft’s Attitude Control System, and
3. The functionality remains in the EPIC flight software even though the need for this function disappeared.

The analysis provided below is for information purposes only, and describes the calculations behind the potential implementation of this function. The actual application of this feature would require extensive work, including flight software modifications.

The output of the EPIC camera is a U and V coordinate measurement of the estimate of the earth’s centroid as shown in Fig. 48.

FOV: 0.62° (Earth is nominally _Pointing: ±0.05° ([0.62°-0.52°]/2)

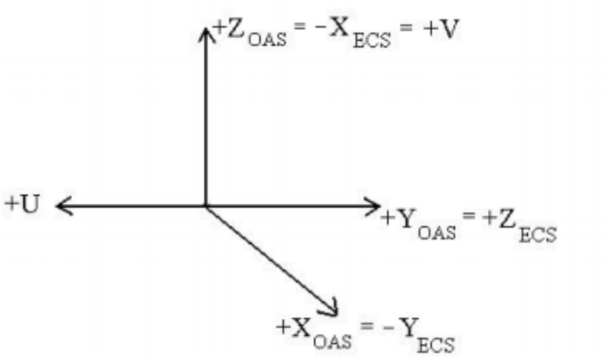

Fig. 48 EPIC Coordinate System and Observatory Axis System

The EPIC Coordinate System (ECS) is aligned with the Observatory Axis System (OAS) axis as shown in Fig. 48. Therefore, the transformation from OAS-to-ECS is given by a 2-1-3 rotation of [Θ, Φ, Ψ] = [90.0°, -90.0°, 0.0°] respectively, or

$$[A]_{OAS-ECS} = \begin{bmatrix} 0 & 0 & -1.0 \\ -1.0 & 0 & 0 \\ 0 & 1.0 & 0 \end{bmatrix} \quad (1)$$

The ECS-to-OAS matrix is the inverse, or

$$[A]_{ECS-OAS} = \begin{bmatrix} 0 & -1.0 & 0 \\ 0 & 0 & 1.0 \\ -1.0 & 0 & 0 \end{bmatrix} \quad (2)$$

Coarse Targeting (CT) is where a quaternion rotation $\bar{q}_{I\rightarrow CT}$ is derived from a Geocentric Inertial (GCI) reference frame to a coarse target based only on the on-board ephemeris model and a defined clock angle. Fine Targeting (FT) is when a quaternion rotation $\bar{q}_{I\rightarrow FT}$ is derived using the same methods as CT, but also uses data from the EPIC camera as input. For Science mode, the target quaternion is generated on board, so for an Earth point quaternion calculation, CT would be used based on ephemeris if there is no centroid data available. Else, if the centroid is available, FT would be used to improve the CT. The target quaternion would be set to this Earth pointing quaternion, with a subsequent rotation through a ground commanded offset quaternion (nominally set to [0, 0, 0, 1]).

Coarse Targeting: In general, CT is a two-step process, where first the earth-pointing quaternion is derived based on sun and spacecraft ephemerides, and then the spacecraft is rotated about the earth-pointing axis by the clock angle, Θ, to place the sun vector in a position specified by thermal requirements. The orientation of the spacecraft with the clock angle equal to zero is shown in Fig. 46. This default position places the component of the sun vector $\hat{S}_{Gci}$ in the $Y_B{-}Z_B$ plane ($\hat{S}_{YZ-Body}$) parallel to Z_B, with the star tracker pointing along Z_B.

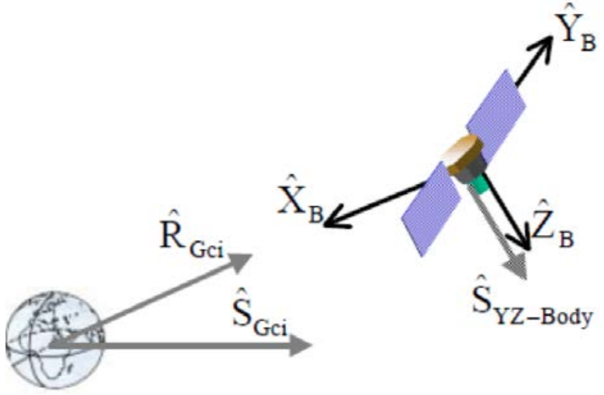

Fig. 49 DSCOVR Orientation with Clock Angle of Zero

The quaternion $\bar{q}_{I\rightarrow TargetA}$ is extracted from the following matrix:

$$A_{I\rightarrow TargetA} = \begin{vmatrix} -\hat{R}_{Gci} \\ \dfrac{\hat{S}_{Gci}\, X - \hat{R}_{Gci}}{|\hat{S}_{Gci}\, X - \hat{R}_{Gci}|} \\ \dfrac{-\hat{R}_{Gci}\, X\,(\hat{S}_{Gci}\, X - \hat{R}_{Gci})}{|-\hat{R}_{Gci}\, X\,(\hat{S}_{Gci}\, X - \hat{R}_{Gci})|} \end{vmatrix} \Rightarrow \begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} \tag{3}$$

Rotate counterclockwise about the earth-pointing axis (X_B) as shown in Fig. 47, and then

$$\bar{q}_{TargetA\rightarrow TargetB} = \begin{vmatrix} \sin\frac{\Theta}{2} \\ 0 \\ \cos\frac{\Theta}{2} \end{vmatrix} \tag{4}$$

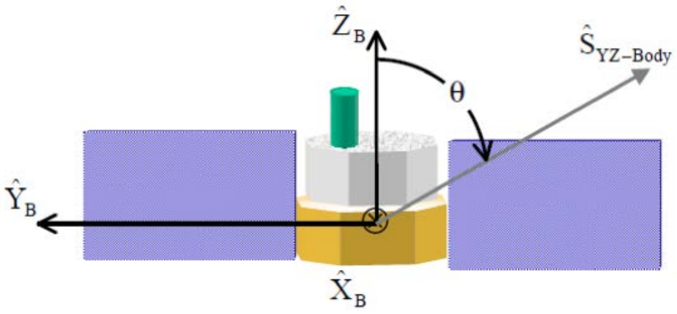

Fig. 50 Counterclockwise Rotation about X_B by Θ

The overall course target quaternion ($\bar{q}_{I\rightarrow CT}$) is then given by:

$$\bar{q}_{I\rightarrow CT} = \bar{q}_{I\rightarrow TargetB} = \bar{q}_{I\rightarrow TargetA} \otimes \bar{q}_{TargetA\rightarrow TargetB} \tag{5}$$

Fine Targeting: Whenever the AOCS receives a new centrum (H, V) from EPIC, the rotation from the current measured attitude to the centroid attitude ($\bar{q}_{adj}$)is calculated as:

$$\bar{q}_{adj} = \bar{q}_{Body,mea\rightarrow Centroid} \tag{6}$$

The offset ($\bar{q}_{bias}$) is calculated as:

$$\bar{q}_{bias} = \bar{q}_{Gci\rightarrow Gci'} \tag{7}$$

$\bar{q}_{adj}$ is used to calculate the fine target for the current cycle and then once propagating, $\bar{q}_{bias}$ is used to correct the coarse target quaternion based on the most recent centroid information. So the quaternion definition becomes $\bar{q}_{I\rightarrow Body,mea}$ as the best estimate of current attitude, where $\bar{q}_{Body,mea\rightarrow I}$ is the conjugate. From the current attitude and using the coarse target, the small angle rotation (R) about the EPIC boresight (X_B) can be calculated from the first element of the quaternion:

$$R = \left(\bar{q}_{Body,mea\rightarrow CT}[1]\right) = \left(\bar{q}_{Body,mea\rightarrow I} \otimes \bar{q}_{I\rightarrow CT}[1]\right) \tag{8}$$

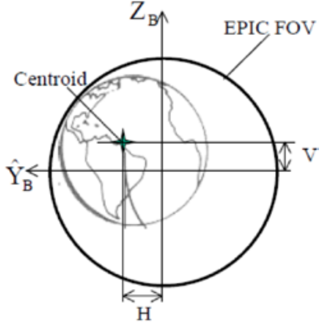

Fig. 51 Centroid and EPIC Field of View (FOV)

The centroid (H, V) is used to define the small angle rotations about Z_B and Y_B required to place the centroid at the center of the EPIC Field of View (FOV) (as shown in Fig. 48):

$$\bar{q}_{adj} = \bar{q}_{Body,mea \to Centroid} = \left| \begin{array}{c} {}^{R}\!/_{2} \\ -{}^{V}\!/_{2} \\ {}^{H}\!/_{2} \\ \hline\hline \sqrt{1-({}^{R}\!/_{2})^2-({}^{Y}\!/_{2})^2-({}^{H}\!/_{2})^2} \end{array} \right| \tag{9}$$

Using this centroid update, the fine target quaternion is calculated:

$$\bar{q}_{Gci \to FT} = \bar{q}_{Gci \to Body,mea} \otimes \bar{q}_{Body,mea \to Centroid} = \bar{q}_{Gci \to Body,mea} \otimes \bar{q}_{adj} \tag{10}$$

The corresponding offset between the fine target quaternion based on the current centroid update and the current coarse quaternion is calculated, and used to propagate the fine target quaternion between centroid updates, as indicated in Fig. 49. Therefore, $\bar{q}_{bias} = \bar{q}_{Gci \to Gci'} = \bar{q}_{Gci \to FT} \otimes \bar{q}_{CT \to Gci'}$

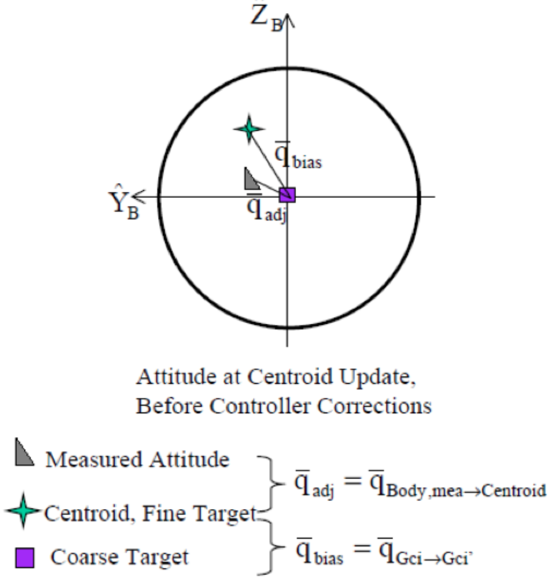

Fig. 52 Propagation of Fine Target Quaternion

Between centroid updates, the offset quaternion that is calculated with the most recent centroid information is used to correct the current coarse target quaternion:

$$\bar{q}_{Gci \to FT} = \bar{q}_{bias} \otimes \bar{q}_{Gci \to CT} = \bar{q}_{Gci \to Gci'} \otimes \bar{q}_{Gci \to CT} \tag{11}$$

It should be noted that although the GDP stated that this function was not fully proven through extensive testing, and should currently not be used operationally, the potential exists to implement this feature in the future if NOAA management determines it is needed.

B. EPIC and NISTAR as Earth Weather Forecasting Tools

Since launch, both EPIC and NISTAR have been established as highly functional instruments that have provided NASA with measurements and perspective unlike any previous Earth Science instruments. The information and products that they have provided are valuable, and justify their initial classification as the primary mission of Triana. To shutter their operations based on politics and finances, and not due to technical failures or limitations, would be a waste of valuable science.

Faced with the threat of the loss of finances that would have eliminated EPIC and NISTAR operations, the MOSE investigated the possibility of integrating their data, and their scientific value, into the existing Earth Monitoring and Forecasting framework already established within NOAA. EPIC provides Earth-reflected radiances that are transformed into data products, including ozone, aerosols, cloud characteristics (fraction, thickness, optical depth, and height), sulfur dioxide, water vapor, volcanic ash, and UV irradiance, at 8-14 km surface resolution. These observations are taken between 13 and 22 times per day, depending on the time of the year, although this cadence could be modified with enhanced ground station capabilities. NISTAR provides measurements of the entire Earth's reflected and emitted radiation at the retro-reflection angles. These instruments and could fill in important missing data not obtainable by any Earth-orbiting satellite.

EPIC data could be used to determine the daily cycles in total ozone, aerosols, and column water vapor at high temporal and spatial resolution, complimenting similar data from other NOAA missions. The NOAA Ozone and Water Vapor Group (OZWV) conducts research, using balloon-borne, cryogenic frost point hygrometers, on the nature and causes of the depletion of the stratospheric ozone layer and the role of stratospheric and tropospheric ozone and water vapor in forcing climate change and in modifying the chemical cleansing capacity of the atmosphere. This is accomplished through long-term observations and intensive field programs that measure total column ozone, ozone vertical profiles, ground level ozone, and water vapor vertical profiles in the upper troposphere and stratosphere. Data from EPIC could provide this group with supplemental information to assist with this research.

Other dynamical processes such as the polar vortex structure, near-tropopause circulations, and jet stream winds can be observed by DSCOVR. The NOAA GEOS-5 Wind Model creates a dynamic portrait of the Earth through numerical experiments that simulate the current knowledge of the dynamical and physical processes governing weather and climate variability using data from NASA GSFC. DSCOVR data could be integrated into these models, or replace them completely, providing NOAA with the ability to develop the models using their own data source. Arctic ozone depletion events can also be detected to assess their ecological threats through enhanced UV radiation. The ozone, cloud, and aerosol data can be used to compute surface UV irradiance every few hours so that exposures and health risks can be more accurately determined. The NOAA Climate Prediction Center (CPC) delivers real-time products and information that predict and describe climate variations on timescales from weeks to years thereby promoting effective management of climate risk and a climate-resilient society, and could benefit from the data provided by EPIC to assist with their studies on the nature of UV radiation.

EPIC's combination of wavelengths permits determination of optical depth, single scattering albedo, and particle size. This information, provided at high spatial and temporal resolution, could be extremely useful for understanding and modeling the processes that disperse and deplete aerosols, allowing for better assessment and prediction of their chemical, cloud, and radiative impacts. The ability to detect aerosols every few hours or sooner at high spatial resolution can be exploited, in combination with NOAA's current global network of Volcanic Ash Advisory Centers (VAACs), to provide timely warnings of volcanic ash events and visibility anomalies (smoke and dust plumes) to the air transportation industry (through the FAA), the US Park Service, and the EPA.

The NOAA Earth System Research Laboratory (ESRL) Global Monitoring Division (GMD) Aerosols Group (AERO) utilizes baseline and regional stations worldwide that provide information about long-term changes in background aerosol properties and the influence of regional sources on aerosol optical properties statistics and trends. GMD's measurements of aerosol optical properties provide information about the trends and factors that influence the climate forcing effect of aerosol particles. The study of aerosol properties on various spatial and temporal scales yields information about trends in aerosol distributions. Data from the aerosol monitoring stations are updated several times a day, and the aerosol data provided by EPIC could be valuable by providing input from another perspective throughout the day.

Since LEO/GEO satellites are being used to develop comprehensive climatologies of cloud properties at high spatial and temporal resolution, the unique viewing geometry of EPIC can be exploited in conjunction with these other satellites to determine cloud phase and particle shape, and provide ESRL with additional data. Cloud particle habit (shape) is an assumed parameter in current retrieval methods and in mesoscale models and general circulation models (GCMs). Retrieval of this parameter on a global basis could reduce the uncertainties in cloud and radiation modeling as well as in the retrievals of cloud particle size and ice water path, assisting ESRL with cloud, radiation, and precipitation climatologies from observations. The atmospheric column water vapor can be derived from reflected measurements over all surfaces every few hours and could complement similar estimates from infrared retrievals of upper tropospheric water vapor column. The near retro-reflection geometry of the EPIC view can also be used to determine anisotropic reflectance properties of various types of vegetation and to improve characterization of canopy structure and plant condition.

Land surface albedo (LSA), defined as the ratio between solar radiation reflected by Earth's land surface and solar radiation incident at the surface, is a function of both solar illumination and the reflective properties of land. Diurnal variations of surface spectral albedo could also be derived to provide more accurate models for radiation calculations in GCMs and other atmospheric models. LSA is an essential variable linking the land surface and the climate system, and modelers in many fields need the LSA data, including NOAA's NWS Environmental Modeling

Center, Center for Satellite Applications and Research (STAR) and National Climatic Data Center (NCDC) and USDA's Agricultural Research Services and Forest Service, as well as universities and other research institutions throughout the world. JPSS provides this data, and DSCOVR could supplement these readings from a different perspective.

The GEO satellite is the one satellite platform that can duplicate part of DSCOVR's global view. Current weather satellites produce a global view that excludes all areas poleward of 72° every 3 hours. Complete longitudinal coverage could be achieved using 5 of the current GEO satellites, but this stitched view introduces discontinuities in the viewing and illumination conditions as well as discontinuities in time and spatial resolution at the boundaries between each GEO satellite. A major source of uncertainties related to the use of GEO satellites is the lack of on-board calibration of their spectral instruments. This problem is exacerbated when one attempts to use multiple GEO satellites to produce a global view, since the calibration problem becomes one of cross- calibration of multiple, different instruments in five different satellites.

Useful angle coverage problems also affect DSCOVR, but since DSCOVR sees points on the surface and atmosphere from sunrise to sunset, this effect is reduced in the longitudinal direction as the Earth rotates. The DSCOVR algorithms have been developed to work up to about 80 degrees in either solar zenith angle or satellite view angle, giving a view to within 20 minutes of sunrise or sunset. Unlike GEO satellites, for DSCOVR the two angles are approximately equal, which permits viewing closer to the poles. For example, when DSCOVR is in the ecliptic plane, a point at 70 degrees latitude will be viewed at a View Zenith Angle (VZA) of 70 degrees at local noon, whereas it would be almost at the tangential point for a GEO satellite all of the time. Additionally, the combination of the Lissajous orbit of DSCOVR around L1 and the seasonal change in relative Earth orientation, enables the periodic view of the higher latitudes including full view of the polar regions for periods close to the summer solstice in each hemisphere.

Most GEO satellites carry spectral imagers that are unique to the particular satellite. While all of them may have some channels in common, there are usually distinct differences in the specific filter functions even for the common channels. There is only one channel (visible) in the solar spectrum that is common to all of the satellites. For example, the GOES-I series of satellites has a visible (0.65 μm) channel but its filter function is slightly different than the previous series of GOES instruments and differs markedly from the broad Meteosat visible channel that extends to 1.1 μm. The one common visible channel can be used to produce a discontinuous, near-global, black and white view of the Earth. DSCOVR views all areas from continuously changing viewing and illumination conditions with a single set of instruments including broadband radiances in four channels covering the range from 0.2 to 100 μm and images in the ultraviolet, red, green, blue, and two near-infrared channels. Each GEO series has a different spatial resolution and its own imaging schedule such that full-disc views are only available from all satellites only once every 3 hours. Satellites begin at the north and scan to the south taking 15-18 minutes to complete a single multispectral image. Every few hours, or sooner if needed, DSCOVR images the entire Earth in 10 channels within 2 minutes with a single resolution that is dependent on the position of the pixel in the array. At the Earth's surface, the spatial resolution varies gradually and continuously. LEO satellites carry some of the same channels as DSCOVR at different spatial resolutions but with much less geographic coverage. A single track of the AVHRR instrument on the POES satellites includes the 645 and 870 nm channels and takes over 50 minutes to cover the ground (atmosphere) track. While one can merge images of the whole planet from LEO spectral images, these images lack the scientific value provided by the combination of simultaneous global view, high time resolution and sunrise to sunset continuous coverage.

DSCOVR is just the first step in an effort to incorporate deep space observatories of the Earth to acquire data, which, although similar in spectral composition to that retrieved from existing satellites, can provide a space-time coverage not presently available. Future deep space Earth observatories, for example at L2, would allow observations of the "night-side" of the planet and complement the "sunlit" view. As the first step in an emerging multi-perspective (LEO, GEO, and L1) approach to understanding and observing all elements of the Earth system, the DSCOVR vantage point offers several opportunities for examining aspects of the Earth not presently accessible. Indeed, armed with remote sensing instrumentation, DSCOVR provides never before available observations and perspectives of dynamic aspects of atmospheric aerosols and clouds, ozone, regional ecological responses on short time scales. There are many scientific advantages of the synoptic, constant-illumination, DSCOVR vantage point that could be exploited to add further scientific and human value and protection to deep space observatories. In this aspect, DSCOVR could be a stepping stone to a much more robust future distributed Earth Sensing System.