National Oceanic and Atmospheric Administration
Responses to the 2019 Annual Report of the
Environmental Information Services Working Group

General Comments

The National Oceanic and Atmospheric Administration Science Advisory Board's Environmental Information Services Working Group (EISWG) 2019 annual report contained two sets of recommendations for the National Oceanic and Atmospheric Administration (NOAA), based on reviews provided by EISWG of: 1) the use of Observing Systems Simulation Experiments (OSSE) in NOAA; and 2) the NOAA report to Congress, *Tornado Warning Improvement and Extension Program Plan* produced by the NOAA Office of Oceanic and Atmospheric Research.

(c) ANNUAL REPORT.—Not less frequently than once each year, the Working Group shall transmit to the Science Advisory Board for submission to the Under Secretary a report on progress made by National Oceanic and Atmospheric Administration in adopting the Working Group's recommendations. The Science Advisory Board shall transmit this report to the Under Secretary. Within 30 days of receipt of such report, the Under Secretary shall submit to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives a copy of such report.

Recommendations on Potential NOAA Actions Related to OSSEs

Recommendation 1: "OSSE, OSE, FSO, EFSO research efforts should be coordinated nationally (e.g., sharing of software tools) to avoid duplication of effort (e.g., via the QOSAP program). These methods each have their pros and cons, and should all be used to assess the relative benefit of different observing systems. Besides full-scale OSSE experiments, simple experiments could also be very powerful (e.g., for sampling strategies and data value evaluation)."

NOAA Response: NOAA concurs with this recommendation and will work through appropriate mechanisms to avoid duplication.

Recommendation 2: "The OSSE development for earth system models (e.g., for sea ice prediction) needs to be accelerated. Furthermore, global 5 km (and preferably 3 km) Nature Run based on earth system models should be developed as the basis for a variety of OSSEs. This may require the purchase of new high-performance computers or the partnership with other agencies."

NOAA Response: NOAA concurs with the recommendation to accelerate OSSE development and increasing the Nature Run resolution to 5 km. However, the agency notes that this activity will be well suited for cloud computing and may not require adding additional high performance computing capacity to existing NOAA assets.

Recommendation 3: "NCEP data assimilation and prediction system will continue to improve. OSSEs are used to evaluate the observational network likely decades ahead. Therefore, the choice of observations and investment decisions based on OSSEs need to explicitly consider the potential impact of deficiencies in the current data assimilation and prediction system."

NOAA Response: NOAA concurs with this recommendation.

Recommendation 4: "Besides existing OSSE activities at NOAA, OSSEs should also be used to:

- assess the value of NOAA partnership in satellite remote sensing with foreign agencies (e.g., India) and the private sector (e.g., purchasing data from privately-launched satellites),
- assist the exploration of strategies for the most effective and efficient way to do sea ice prediction (observations, models, data assimilation). Should NOAA request ice-breakers? How many?
- compare the value of (polar, geostationary, small/cube) satellite network strategy (e.g., small number of large satellites versus large number of small and cube satellites) for weather and climate prediction, and
- do a gap analysis in NOAA; i.e., what are the greatest new observational needs? What combination of old and new systems will work best?"

NOAA Response: NOAA agrees with this recommendation.

Recommendation 5: "OSSEs have been primarily used to evaluate the impacts of observing systems and/or observation denial on forecast performance per se, that is, on the physical parameters, and treating all forecast locations, times, and circumstances as equal. But this idea should be extended to societal impacts, whether monetizable, or in terms of lives at stake, etc. In other words, there are national priorities (e.g., saving human race) where money does not matter, and there are priorities depending upon the constraint of financial resources. This could be a possible additional avenue of research. In an Earth system model where social systems and the built environment are included, one can imagine collecting human data or propagating just the physical earth system information through the social systems as well.

Indeed, while OSSEs provide quantitative analyses of future observing system impacts for a specific model, the effects on products that rely on that model can only be estimated qualitatively. The NOAA/NESDIS Technology, Planning and Integration for Observation (TPIO) division has developed a qualitative tool for assessing supporting investment decisions, called the NOAA Observing System Integrated Analysis (NOSIA-II), also known as NOAA's Value Tree. This Value Tree is based on a survey of subject matter experts across all NOAA Line Offices to gauge the impacts of Earth observation investments on NOAA's key products and services. Therefore the aforementioned OSSE, OSE, FSO, EFSO and PQC tools should be used in concert with the current NOSIA-II system to determine NOAA's future observing needs."

NOAA Response: As the EISWG reports states, an OSSE modeling experiment is used to evaluate the impact of new observing systems on operational forecasts when actual observational data are not available. While NOAA acknowledges the value of OSSEs as a quantitative analysis tool, there are certain assumptions made when using a simulated dataset, and the agency is concerned that extending this tool to also evaluate societal impacts could potentially compound any assumptions or errors in the simulated dataset.

However, observing system investments can be assessed by combining Observing System Experiments (OSE)/OSSE results with NOSIA model data to assess mission service impacts such as hurricane warnings and fisheries stock assessments. Using OSE/OSSE and NOSIA data in concert facilitates decision making before acquiring substantial observing systems to minimize risk, manage costs, and maximize impact. Additionally, economists have used NOSIA mission service impacts to estimate the return-on-investment from NOAA observing systems.

Recommendations on Potential NOAA Actions Related to the Tornado Warning Improvement and Extension Program Plan

With respect to technological objectives, the EISWG notes that some of the challenges could be accomplished with currently deployed technologies through software or hardware upgrades, or the deployment of readily adaptable commercial-off-the-shelf technologies. In particular, NOAA should recognize the following:

(1) While convection-allowing models have made great progress, they still do not capture every important mesoscale feature. Timing and position of thunderstorms can be off in time by an hour or two and in space by a county or more. Model forecasts seem less accurate when storms are already present when the model is initialized.

Recommendation 1: "In its development of Warn on Forecast (WoF) procedures, NOAA should include pattern recognition and artificial intelligence algorithms that take into account and adapt for the various known shortcomings in explicit computer model forecasts."

NOAA Response: NOAA agrees with this recommendation and notes that the agency is already doing this in a research and development environment. The WoF research program uses statistical techniques to pull probabilistic information out of model ensembles (rather than using explicit/deterministic model forecasts). The ensemble forecast output provides a range of possible outcomes based on variations in model physics and initial conditions that represent the variability of the atmosphere. The resultant probabilistic information can provide forecasters with a better understanding of the potential for severe weather, given that storms develop within the area. Output from the WoF research program have been tested and evaluated in the NOAA Hazardous Weather Testbed and have shown promising capability to assist forecasters with advance notifications to the public. In addition, NOAA is actively researching the use of machine learning methods as a way of post-processing the ensemble output from the WoF system and hopes to test these forecaster tools from the new methods in the Hazardous Weather Testbed with forecasters within the next several years.

(2) The greatest successes with tornado warnings come in supercell situations; skillful warnings for non-supercell tornadoes remain a serious challenge.

Recommendation 2: "NOAA should focus more strongly on reducing the false alarm rate (FAR) and other metrics of skill in current generation tornado warnings. Polygon-based warnings challenge the way FAR is determined and so demand new methods to quantify true positive, false positive, true negative, and false negative for precision, recall, and accuracy. As warning polygons are now updated as severe storms evolve, FAR measures will need to be assessed over space and time. The ways these metrics are computed should be transparent. National metrics are nearly meaningless by themselves; NOAA should compute and release metrics by Forecast Office. Importantly, while the focus should be on reducing the FAR, such reductions cannot come at the expense of affecting negatively other tornado warning-based metrics, such as the probability of detection (POD). In other words, reducing the FAR while decreasing the POD would not be a positive outcome. These are related metrics, both very important and clearly improving the quality of tornado warnings will require a balance between these two important metrics to provide people with more accurate warnings to support decision making."

NOAA Response: NOAA agrees with this recommendation, and we are already working to revise how FARs are calculated. We disagree, however, that "... national metrics are nearly meaningless by themselves." They provide the national perspective on warning performance. Also, the NOAA National Weather Service (NWS) Performance Management website already provides warning statistics for each Workforce Management Office (WFO), multiple WFOs, NWS Regions, and nationally. NOAA concurs that FAR needs to be improved without negatively impacting POD. NOAA is continuing its research and development activities to better understand the tendencies that lead to FAR and how to address them.

Recommendation 3: "As a means for obtaining greater low-level radar coverage of non-supercell tornadic circulations and so significantly aiding in the warning of tornadoes, NOAA should consider ...

a) ... reducing the lowest allowable elevation angle on all NEXRAD/WSR88D radars to the minimum possible value, consistent with ground clutter and local environmental considerations, and
b) ... adding one or two tower sections to selected existing NEXRAD to reduce ground clutter, increase the radar horizon, and allow better overall coverage."

NOAA Response:

a) NOAA notes that we have done this already in several locations; however, it is not practical in all locations due to terrain blockage and other environmental impacts. NOAA has lowered the angle for the Next Generation Weather Radar (NEXRAD) at 10 sites so far – Langley Hill, Washington; Monterey, California; Cedar City, Utah; Medford, Oregon; Buffalo, New York; Minot, North Dakota; Greenville-Spartanburg, South Carolina; Raleigh, North Carolina; Jackson, Mississippi; and Shreveport, Louisiana. The NWS Regions are prioritizing NEXRAD sites where lowering the angle

will provide maximum benefits. Lowering the angle costs about $100,000 per site to conduct the environmental assessment and make the software changes in the NEXRAD unit and also to the WFO's Advanced Weather Interactive Processing System (AWIPS) to be able to use the data from the lower angles.

b) NOAA disagrees with the recommendation. While increasing radar height could reduce blockage from nearby terrain, trees, and buildings, it will further extend the range of ground clutter. Furthermore, it is very expensive to raise the tower, and benefits are limited except in very few locations. NOAA considers raising the tower as a last resort when beam blockage has increased since the radars were installed, and lowest angles of data are no longer available. To date, we have raised the tower at only one site. Furthermore, the maximum height of the radar is 30 meters. It is not feasible to raise the tower greater than 30 meters due to the resultant degraded data quality related to distance between the feedhorn and signal processor, as well as the increased potential for high wind damage.

Recommendation 4: "To aid in the warning of short-lived tornadoes, NOAA should build on the experiences in south-central Oklahoma and across the multicounty Dallas-Fort Worth metropolitan area and include networked X- or C-band as gap-filling radars to obtain greater low-level coverage of non-supercell circulations and strong winds."

NOAA Response: NOAA notes that this is technically feasible, but not cost effective at this time. The proven benefits of such systems have not been categorically demonstrated to have a significant impact on NWS warnings. In the Dallas-Fort Worth area, the NEXRAD coverage is excellent. Via the National Mesonet program, NWS provides support to Collaborative Adaptive Sensing of the Atmosphere (CASA), a network of commercial X-band radars supplementing NEXRAD coverage in the DFW region. Given the NEXRAD coverage, the CASA data are supplemental and most useful in determining where to conduct post-storm surveys, rather than to warn for tornadoes. Forecasters appreciate having the CASA data, but still rely predominantly on the NEXRAD for issuing warnings in the Dallas-Fort Worth area. The real challenge remains to better understand these short-lived tornadoes and be able to warn before they form.

Recommendation 5: "The NEXRAD processing software used to detect mesocyclone and tornado vortex signatures should be modernized/upgraded to reflect the best science now available. An example is provided by the Mesocyclone Detection Algorithm (MDA), which currently uses only a portion of the available shear information. A modernization of this key algorithm might allow circulations of (weak) intensity levels 1 and 2 to be detected sooner and utilized with some confidence. This could make possible earlier (by several minutes, or equivalently two or three volume scans) detection of the earliest stages of formation of long-lived tornadoes, and allow tracking of at least a portion of the life cycle of short-lived tornadoes."

NOAA Response: In regards to NEXRAD software, NOAA is currently working to update both the Mesocyclone Detection Algorithm (MDA) and the Tornado Detection Algorithm (TDA), the latter of which identifies the Tornado Vortex Signature. NOAA is researching advanced algorithm technologies to track storm-scale circulation features of all intensities. These Rotation Track products are implemented on the Multi-Radar Multi-Sensor system which is available to

forecasters. Additionally, new MDA and TDA are being developed that also includes dual polarization variables as well as shear estimates. The new TDA will be evaluated in the Hazardous Weather Testbed in spring 2020.

With respect to the sociological objectives, NOAA should recognize that the protection of life and property from the impact of tornadoes is not only a meteorological challenge, but also a sociological one. For example, to justify the costs and effort involved in developing and deploying WoF systems that may provide people advance skillful warnings of an hour or more, NOAA needs to understand better if people will take appropriate actions upon receipt of such lengthy advance warnings.

Recommendation 6: "Given the limited number of federal social science positions within the agency, NOAA should utilize its set of joint and cooperative institutes to access social science expertise in the national university community."

NOAA Response: NOAA concurs with this recommendation and is beginning discussions to implement this action with the cooperative institutes. For example, NWS is working with the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) and the Center for Risk and Crisis Management (CRCS) on the conveyance of uncertainty and probabilistic forecasts.

Recommendation 7: "NOAA should have social science programs charged with investigating questions such as the following: Will people take action more than a few minutes in advance, even if given warnings an hour in advance? Where is the balance between lead-time and good decision-making? If actions are taken based upon lead times an hour or longer than at present, will this include fleeing and, if so, will road infrastructure and traffic management suffice? Will the public take action based upon probabilistic tornado warnings? How should the public best receive such warnings? Will the public be responsive to repeatedly updated warnings (N.B., The Report (see Attachment 1), p. 7 suggests that such warnings could be updated every 2 minutes), or simply confused by such frequent updates, and so waiting until the last minute to attempt to take action?"

NOAA Response: NOAA agrees with this recommendation and notes that we are doing this now, however, expanding these efforts merits additional consideration. As an example, the National Weather Service is working with CIMMS and CRCS on the conveyance of uncertainty and probabilistic forecasts. Both WoF and the Forecasting a Continuum of Environmental Threats (FACET) programs have social science based research initiatives focused on the public response to these new warning techniques.

Recommendation 8: "To reduce impacts in terms of minimizing property losses (as well as improve life safety measures), it will be necessary to implement stronger building codes. NOAA should develop and implement - in partnership with NIST, universities such as Texas Tech, and entities such as the Institute for Business and Home Safety - a weather-ready home certification program as an extension of its StormReady community and Weather-Ready Nation program,. This could encourage in-home shelters, hurricane clips to hold on roofs, etc."

NOAA Response: While this may be beyond the scope of the agency's mission, it is a good idea and NOAA will continue to build partnerships with other Federal agencies, non-governmental organizations, and industry to marry weather, water, and climate information from NOAA with structural information to help save lives and protect property. For example, NOAA works with NIST as they are the lead agency for the National Windstorm Impact Reduction Act. The NIST National Windstorm Impact Reduction Program was created to improve the understanding of windstorms and their impacts and to develop measures to reduce the damage they cause. In various storm areas (i.e., Great Plains, Southeast U.S.), or within regions associated with land-falling hurricanes, NOAA has deployed mobile observation platforms to better understand the winds embedded within the tornadoes.

In closing, the EISWG notes the resources portion of the plan seems generic. This leads to questions such as, "Has a detailed action plan been produced?" "If so, what are the detailed timelines?" "Has a detailed cost/benefit analysis been performed?" Such information is needed by the EISWG to know if NOAA is tracking favorably against the intended deliverables when reviewing subsequent reports.

NOAA Response: Resource requirements are still being considered within the agency and will be reflected in NOAA's future year budget requests, as well as in the annual budget plan required by Section 103 of the Weather Act.

Environmental Information Services Working Group

A working group of the National Oceanic and Atmospheric Administration Science Advisory Board

3 July 2019

To: Lynn Scarlett, Chair, NOAA Science Advisory Board

CC: Robert Winokur, SAB Liaison to the Environmental Information Services Working Group

Everette Joseph, SAB Liaison to the Environmental Information Services Working Group

Cynthia Decker, NOAA SAB Executive Director

SUBJECT: Second NOAA SAB EISWG report to the US Congress, as required by the Weather Research and Forecasting Innovation Act of 2017 (P.L. 115-25, 18 April 2017), as amended (P.L. 115-423, 7 January 2019)

Dear Ms. Scarlett:

This is the second report to the United States Congress from the Environmental Information Services Working Group (EISWG), a working group of the Science Advisory Board (SAB) to National Oceanic and Atmospheric Administration (NOAA). It is made in accordance with Title IV, Sec. 401(c) of the Weather Research and Forecasting Innovation Act of 2017 (P.L. 115-25, signed 18 April 2017), as amended (P.L. 115-423, 7 January 2019) (hereafter, the Weather Act), which assigns EISWG the following responsibility:

> *"ANNUAL REPORT.—Not less frequently than once each year, the Working Group shall transmit to the Science Advisory Board for submission to the Under Secretary a report on progress made by National Oceanic and Atmospheric Administration in adopting the Working Group's recommendations. ..."*

The limited time and resources available to the EISWG require that it maintain a collaborative and consultative annual process with NOAA Line Offices in order to carry out its assigned role in the attainment of the objectives of the Weather Act. While it is clear there are limits on what the working group can do based on resourcing, the EISWG is addressing topics in the Weather Act systematically as it works through priorities with NOAA.

In the first year (2018), the EISWG's efforts focused on the implementation of a reactive review process for the series of reports required of NOAA by the Weather Act. In this second year, the EISWG realized this was going to be a slow process because many of

the reports are complex, requiring extended periods for development and internal review within NOAA and the Executive Branch..

Therefore, in addition to reviewing the required reports as they become available from the NOAA Line Offices, the EISWG is developing its own assessments of key Weather Act topics based on presentations by both NOAA staff and external experts, and extended discussions at EISWG meetings with these presenters. The presentations and discussion are summarized by a small task group into a brief report that outlines the state of the topic within NOAA, followed by any necessary recommendations. After review by the full EISWG membership, the report is forwarded to the NOAA SAB for its consideration and transmittal to NOAA leadership.

The EISWG used this proactive process in fall 2018 to review the use of Observing Systems Simulation Experiences (OSSE) within NOAA, a prominent topic in the Weather Act. This has resulted in a report with several recommendations that was forwarded to the SAB in April 2019. The SAB subsequently reviewed the report and transmitted it to NOAA leadership in May 2019. The EISWG OSSE report with its recommendations is at Attachment 1. N.B.: A slightly modified version of this report has been submitted to the Bulletin of the American Meteorological Society for publication.

As of this writing, EISWG has received four of the reports NOAA is required to deliver to the Congress under the Weather Act. One of these is the "Report to Congress – Tornado Warning Improvement and Extension Program Plan." The EISWG has reviewed this report and developed a number of recommendations for NOAA's consideration. The review and recommendations were forwarded in early July 2019 to the NOAA Science Advisory Board for its review and transmittal to NOAA leadership. A copy of the EISWG's review and recommendations is at Attachment 2.

On behalf of the members of the EISWG,

John T. Snow
EISWG Co-Chair, and Dean Emeritus and Regents' Professor
Emeritus of Meteorology, The University of Oklahoma,
Norman, OK

Brad Colman
EISWG Co-Chair, and Director of Weather Strategy, Bayer Crop
Sciences - The Climate Corporation, Seattle, WA

Dated: 3 July 2019
Letter to: Lynn Scarlett, Chair, NOAA SAB
Subject: Second NOAA SAB EISWG report to the US Congress, as required by the
Weather Research and Forecasting Innovation Act of 2017 (P.L. 115-25, 18
April 2017), as amended (P.L. 115-423, 7 January 2019

Attachments:

1) An EISWG review and recommendations on the use of Observing Systems
Simulation Experiences (OSSE) within NOAA.

2) An EISWG review and recommendations concerning the "Report to Congress
– Tornado Warning Improvement and Extension Program Plan."

Attachment 1: An EISWG review and recommendations on the use of Observing Systems Simulation Experiences (OSSE) within NOAA.

NOAA Science Advisory Board Report: Use of Observing System Simulation Experiments (OSSEs) at NOAA

Prepared by the Environmental Information

Services Working Group

April 2019

Use of Observing System Simulation Experiments (OSSEs) at NOAA
9 April 2019
Prepared by the OSSE Task Force

1. Introduction

The NOAA Scientific Advisory Board (SAB) identified the review of the use of Observing System Simulation Experiments (OSSEs) as one of its key activities, and tasked its Environmental Information and Service Working Group (EISWG) to lead this effort in collaboration with the Climate Working Group (CWG). EISWG submitted the OSSE work plan to SAB in August 2018 and finalized the team membership in December 2018, including

- EISWG Members: Bill Hooke, Ron Birk, Bob Weller, Xubin Zeng (Chair)
- SAB members: Eugenia Kalnay and Susan Avery (SME)
- CWG members: Joellen Russell, Fuqing Zhang, Raghu Murtugudde
- NOAA liaison: Lidia Cucurull and Bob Atlas, NOAA AOML
- Domain experts: Fred Carr (note that other people mentioned here, such as Bob Atlas and Eugenia Kalnay, are also domain experts)
- External Agency Partners: Derek Posselt (NASA JPL)

While we don't have a member from Naval Research Laboratory (NRL), Dan Tyndall and his colleagues (N. Baker, D. Flagg, C. Barron, M. Carrier, S. Smith, D. Allen, and K. Hoppel) helped us by providing the summary of OSSEs at NRL (see the Supplementary Material).

The objectives of this report are:

- to review the use of OSSEs in NOAA, Navy, NASA, and elsewhere
- to develop options for NOAA to consider current and future research and development (R&D) work in this area, such as the combination of OSSEs with EFSO (which is being carried out at AOML with University of Maryland collaboration, and is expected to strongly enhance and accelerate the current abilities of OSSEs).

The deliverable is:

- a short white paper that will review the use of OSSEs in NOAA, Navy, NASA, and elsewhere; and develop recommendations for NOAA to consider and provide rationales for each recommendation made.

Individual write-ups were provided by team members from late December 2018 to early February 2019 (see Supplementary Material), and a face-to-face meeting (with X. Zeng, J. Snow, B. Hooke, R. Birk, J. Russell, F. Carr, and D. Posselt present) was held in January 2019. Initial thoughts from the preliminary report were presented to the SAB telecon in late February 2019, and the draft white paper was presented to the EISWG in early April 2019. The White Paper was finalized through several iterations among the OSSE Task Force members and with input from EISWG members, and it was submitted to SAB in late April 2019.

2. Findings on the use of OSSEs at NOAA and elsewhere

An OSSE is a modeling experiment used to evaluate the impact of new observing systems on operational forecasts when actual observational data are not available. OSSEs are done:

- to find out if a new observing system will add value to NWP analyses and forecasts;
- to make design decisions for a new observing system; and

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- to investigate the behavior of data assimilation systems in an environment where the system's behavior is known.

Since 1980s, the current methodology used for rigorous OSSEs has been accepted nationally and internationally as the way in which OSSEs should be conducted in order to provide credible results. Since that time, extensive OSSEs have been conducted, first at NASA/GSFC, and later at NOAA/AOML in collaboration with operational data assimilation centers, private enterprise, and academic partners. These OSSEs determined correctly the quantitative potential for several proposed satellite observing systems to improve weather analysis and prediction prior to their launch, evaluated trade-offs in orbit configurations, coverage and accuracy for space-based observing systems, and were used in the development of the methodology that led to the first beneficial impacts of satellite surface winds on numerical weather prediction. Today, OSSEs and related capabilities exist at NOAA, NASA, NRL, universities, the private sector, and the Federally Funded Research and Development Centers (FFRDCs) (see the partial list in the Supplementary Material).

Since 2014, OSSEs in NOAA have been performed under NOAA's Quantitative Observing System Assessment Program (QOSAP). QOSAP coordinates the assessment of the impact of current and new observations across the different NOAA Line Offices and it uses observing system experiments (OSEs, to test value of existing, rather than future, observing systems), forecast sensitivity observation impact (FSOI) and ensemble FSOI (EFSOI), and OSSEs as effective techniques to evaluate the impact of the different observation types. QOSAP's primary objective is to improve quantitative and objective assessment capabilities to evaluate operational and future observation system impacts and trade-offs to assess and to prioritize NOAA's observing system architecture. More specifically, QOSAP's main focuses are (1) to increase NOAA's capacity to conduct quantitative observing system assessments, (2) to develop and use appropriate quantitative assessment methodologies, and (3) to inform major decisions on the design and implementation of optimal composite observing systems.

Under QOSAP, a state-of-the-art global OSSE system, an advanced Hurricane OSSE System, and an internationally recognized first of its kind rigorous Ocean OSSE System were developed. For global NWP, a state-of-the-art global OSSE system based on the NASA Cubed Sphere (FV3) at 7 km resolution nature run (with the model output assumed to closely represent the true environmental conditions) was developed to allow observation impact assessments at higher horizontal resolution. QOSAP also began acquisition and initial testing of a new 9-km horizontal resolution global nature run provided by ECMWF. Development of regional OSSE systems for high impact weather and air quality were initiated, and a 2-km state-of-the-art basin scale nature run has been developed.

Using these systems, a significant number of OSEs and OSSEs in both global and regional (tropical cyclone) systems for multiple existing and proposed observing systems were performed and many of these have since been published in the refereed literature. Additionally, QOSAP conducted OSSEs related to the role of ocean observations in hurricane prediction. In particular, QOSAP met the deadlines to complete OSSEs with GNSS-RO and Geo-HSS required by U.S. Congress under the Weather Law H.R. 353. Finally, QOSAP began the process to develop the quantitative assessments capability to meet the needs of NOS and NMFS, and OSSE capabilities for other ocean basins, coastal oceans, and for climate are under development. These capabilities are summarized in Figure 1.

Besides NOAA, NASA has been conducting OSSEs for decades, primarily by the Global Modeling and Assimilation Office (GMAO) at NASA Goddard Space Flight Center (GSFC). The goal is to determine how much additional information is provided by a new set of measurements, relative to the current global observing system. This is consistent with NASA's aim of providing accurate and complete characterization of the state of Earth's atmosphere, oceans, land surface, and cryosphere. The primary product produced by NASA's modeling and data assimilation infrastructure is the Modern-Era Retrospective-analysis for Research and Applications (MERRA). GMAO also conducts research into how to properly calibrate an OSSE and has also produced a global mesoscale-resolving Nature Run (also used by NOAA). The GMAO OSSE system consists of the NASA Global Earth Observing System (GEOS)

model and the Gridpoint Statistical Interpolation (GSI) data assimilation system. Note that the GSI is also used in the NOAA NCEP operational forecast system.
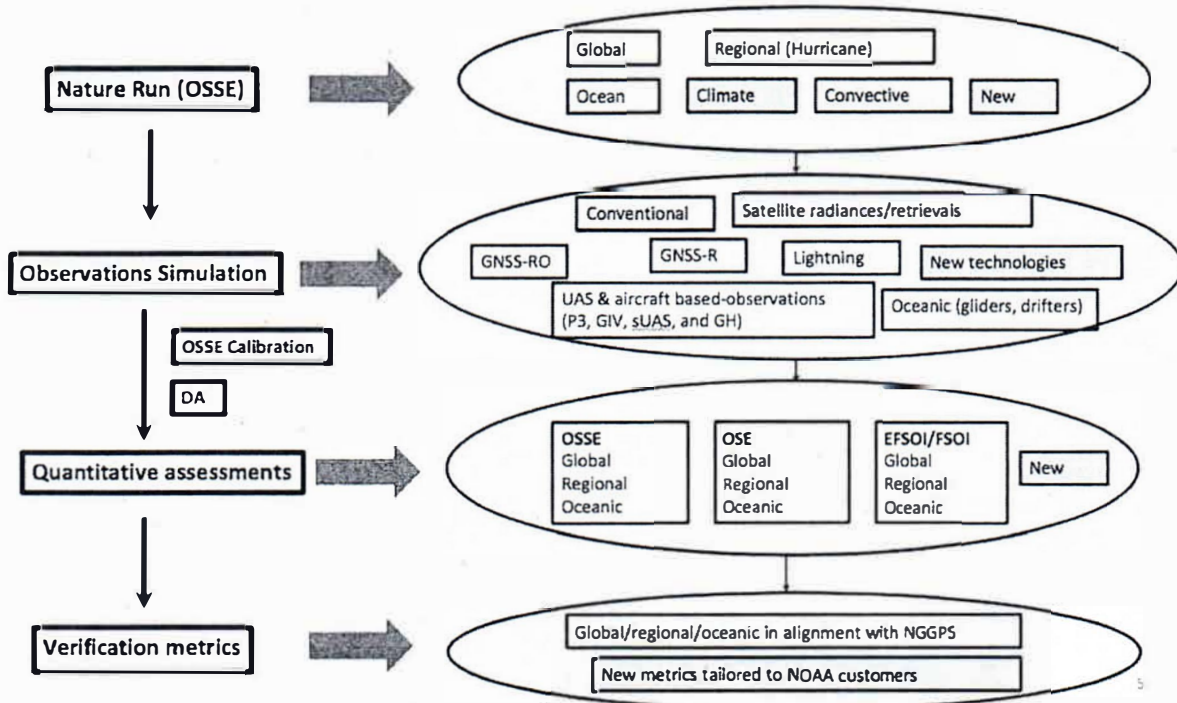

Figure 1. Diagram showing the different components of the OSSE system at NOAA AOML.

In general, Earth observations from NASA have two purposes: (1) accurate characterization of the Earth's atmosphere, oceans, cryosphere, and land surface, and (2) scientific discovery of the processes that drive the evolution of the Earth system, and the linkages among the components of the system. Besides traditional forecast OSSEs, NASA has also done sampling OSSE (to address the question of whether a set of measurements is able to see a feature of interest) and retrieval OSSE (to quantify the degree to which prospective measurements provide information on a geophysical quantity of interest).

The U.S. Navy requires meteorological and oceanographic information to characterize the environment to support global, regional, and tactical scale operations on time scales ranging from minutes to weeks. Because the battlespace environments the Navy operates in are often data sparse, investments in new observation types addressing insufficiently-sampled properties are critical. Recently, the Navy has requested estimates of impacts that potential observing systems would have on NWP forecasts and tactical decision aids before fully investing in the systems.

These estimates can be computed using an OSSE; however, the traditional OSSE methodology can be costly in both personnel and computational resources associated with the production of a nature run as well as the simulation of both new observations and existing observations from the global observing system. Instead of running traditional OSSEs to estimate observation impacts, the Naval Research Laboratory (NRL) has run several variants of the methodology in recent years to derive similar statistics (Fig. 2) for

- the Coupled Ocean-Atmosphere Mesoscale Prediction System using the NCEP Global Forecast System (GFS) analysis fields (to replace the Nature run),
- the Navy Coastal Ocean Model (NCOM) (by simulating observations from a Nature run or using NCOM model data from a different year - but the same month and day), and
- the Navy Global Environmental Model to study impacts of potential observations (e.g., stratospheric ozone) on middle atmosphere prediction.
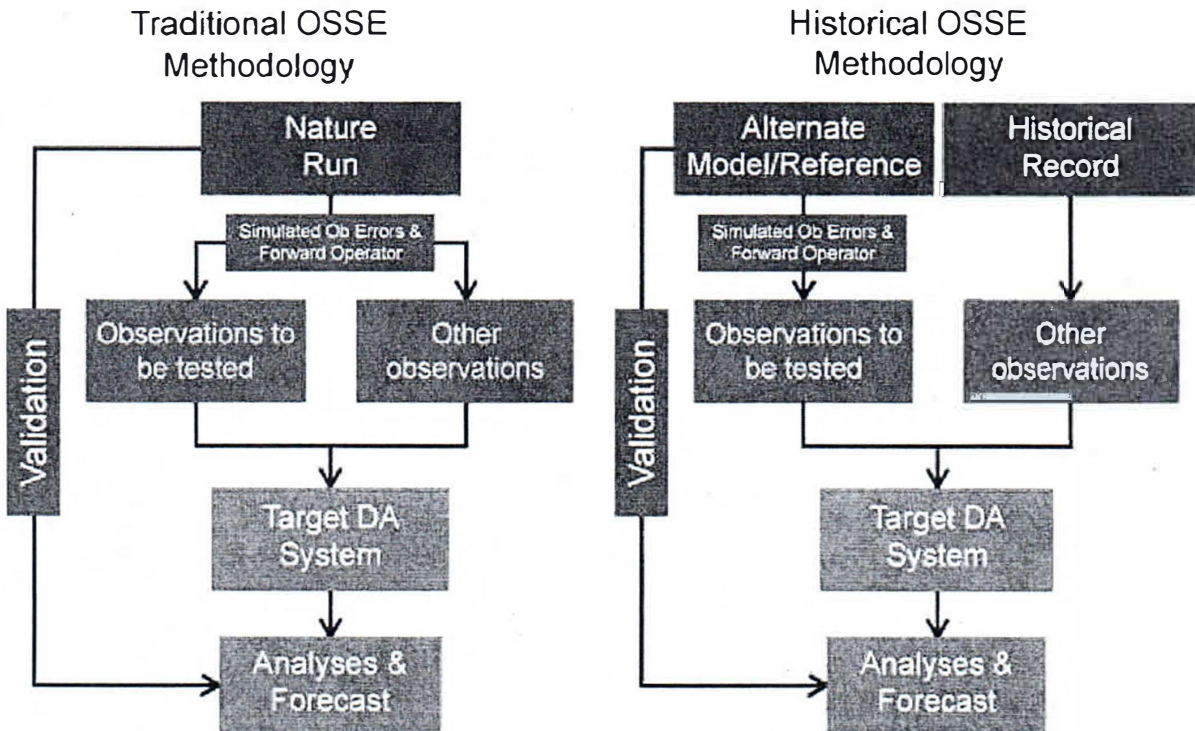
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Figure 2. Schematic depiction of traditional OSSE methodology (left) and the historical OSSE methodology (right)

The private sector recognizes the value of developing, evolving, and applying OSSEs to inform decisions on investments in observing system capabilities. Assessments are conducted to inform plans and designs for commercial sector observing systems, including making the case to investors for the value of the remote sensing systems. Assessments are also used to inform decisions on design alternatives for government systems, by both private sector developers and FFRDCs assessing the value of alternatives. A representative list of private sector organizations engaged in OSSEs is provided in the supplemental material.

Besides OSSEs, operational or research data assimilation systems (e.g., at NCEP) can provide real-time assessments of the sensitivity of the final analysis to the individual observations used in the analysis (although they are usually grouped by observation system). This is known as the Forecast Sensitivity to Observations (FSO) method. This was first done with adjoint data assimilations systems – because of the use of the tangent linear model, this approach is limited to short-range forecast (1-2 days) impacts. FSOs can also be done using Ensemble Kalman Filter data assimilation systems, known as EFSOs (e.g., at the University of Maryland). EFSO uses ensemble perturbations to evaluate during the 6hr forecasts whether each observation is beneficial or detrimental. Proactive Quality Control (PQC) then deletes, for example, the 10% most detrimental observations, resulting in large forecast improvements, and a collection of detrimental observations that can facilitate improving the observation algorithms. Therefore, combining OSSEs with EFSO will provide much more information about each observing system, make OSSE+EFSO/PQC much more effective and useful than OSSE alone.

3. Discussions on the values and limitations of OSSEs

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As discussed in Section 2, the values of OSSEs have been demonstrated at NOAA, NASA, and NRL in evaluating the impact of new observing systems on operational forecasts when actual observational data are not available. OSSEs are also valuable for testing new data assimilation methodologies and for observation targeting strategies. They can be further enhanced by

- combining OSSEs with EFSO (or FSO) – as OSSEs can see the forecast impact of one particular (proposed) observing system, but it won't see the individual impact of all the other (simulated) observing systems, which EFSOs and FSOs can do,
- using different approaches to replace the Nature run – as Nature run may have specific deficiencies,
- using variety of OSSEs (for forecasting, sampling, and retrievals) – as forecast OSSEs may not be able to address the impact of observations in answering specific science questions, and
- using OSEs for current observation systems.

While most OSSEs are done for global satellite systems, they can be used to assess new observing systems for regional scales as well. For instance, on the storm-scale, OSSEs have been done at University of Oklahoma to assess the value of using dual-polarization radar data in NWP, as well as to assess different scanning strategies and network configurations. On the continental U.S. scale, OSSEs can be used to assess the value of increasing the density of vertical profiling systems, as recommended by the National Academies "Network of Networks" Report. Besides OSSEs/OSEs, several National Academies reports have recommended that new observing systems be deployed in regional testbeds for evaluation (including urban testbeds) for evaluation, before investing in a nation-wide system.

However, the reliability and effectiveness of OSSEs depend critically on the data assimilation methodology and the forecast models. In particular, the relative impacts of different observation systems may depend critically on the data assimilation system. For example, the current NCEP operational data assimilation system has demonstrated no quantifiable impacts of any all-sky (cloudy/rainy) satellite radiances in the operational model performance (based on the recent NCEP presentations) while the more advanced ECMWF data assimilation and prediction system now puts all-sky radiance (minus clear-sky) as the most impactful sources of observations (based on the ECMWF presentation at the AMS Annual Meeting in January 2019). Furthermore, OSSEs should state the time period for which the results are valid, depending on the use of current or future observing systems.

The use of extreme events (e.g., a major hurricane event) or their nature runs as truth for OSSEs should be avoided, as the skill scores for any operational NWP models are judged by a large number of cases or seasons, and by many metrics, not a single event. In general, individual events in real world or in nature runs can have case-dependent and flow dependent predictability, which will have significant impacts on using certain observing systems. A continuous long "nature" run, on the other hand, is likely to be drifting away from the true nature, given the unavoidable yet still significant errors in the model physics or in the boundary conditions or forcings.

While OSSEs for the global atmosphere are relatively mature, further development for ocean OSSEs is needed. Despite its major role in the earth system, the ocean is sparsely observed. The lack of observations stems in part from the technical challenges of sustaining observations of the ocean and also from the cost of maintaining observing arrays and networks across the ocean basins. In this context, OSSE, especially combined with EFSO, are a valuable tool that can be used to inform those that fund ocean observations about the impact that specific observing elements have on model fields. Additional OSE efforts are also valuable. For instance, the large, cooperative European Union project AtlantOS will focus on a forward design for basin-scale in situ observations, with a quantitative focus informed by OSE/OSSE work.

However, a basic challenge for ocean OSEs and OSSEs is that because the ocean is sparsely sampled and since the ocean models do not capture all the modes and variability present, the realism of the models and conclusions about the impacts of observing system elements need to be questioned and considered with care. For instance, recent community efforts indicate that tropical Pacific OSE/OSSE studies are

expensive (usually) and often inconclusive, in large part due to the large systematic errors in models and dependence on parameterization assumptions. Therefore, multiple lines of evidence are encouraged to support detected sensitivity.

As mentioned earlier, OSSEs have great power for inexpensively and rapidly exploring the impact of the relative contributions made to NWP by a wide range of observing technologies -- and indeed providing insights into a number of observing configurations that might be prohibitively expensive and time consuming to develop by any other means. On the other hand, attention shouldn't be confined to OSSEs to the exclusion of other R&D, such as

- actual deployment and use of observing technologies in pilot programs and demonstration projects;
- complementing advances in NWP per se with corresponding improvements in mass risk communication and the use of new technologies such as data analytics and artificial intelligence;
- basic social science research toward similar ends;
- R&D in valuing weather information; and
- other avenues.

The opportunities – and the public stakes (with respect to health and safety and building resilience to hazards; development of renewable natural resources; and protecting the environment and ecosystems) – are so high and so urgent as to demand a national pursuit of all these diverse R&D and technology transfer paths in parallel, rather than in sequence or in isolation. More attention to OSSEs and development of their potential is needed, but in a manner balanced by additional attention to other opportunities across the board.

4. Recommendations on potential NOAA actions related to OSSEs

NOAA is mandated by the Weather Research and Forecasting Innovation Act of 2017 Section 107 to perform OSSEs. Indeed OSSEs have been successfully used in major decision-making in the past. For instance, there was a proposed data buy where NASA and NOAA were each required to spend $150M to buy a particular type of data. A joint NOAA/NASA OSSE was performed to determine the data requirements for this observing system. It was determined that the minimum requirements to ensure a beneficial impact on weather prediction for this observing system could not be met, and the nation did not have to make this unnecessary expenditure.

Based on the findings in Section 2 and discussions in Section 3, here are our recommendations on potential NOAA actions related to OSSEs.

Recommendation 1: OSSE, OSE, FSO, EFSO research efforts should be coordinated nationally (e.g., sharing of software tools) to avoid duplication of effort (e.g., via the QOSAP program). These methods each have their pros and cons, and should all be used to assess the relative benefit of different observing systems. Besides full-scale OSSE experiments, simple experiments could also be very powerful (e.g., for sampling strategies and data value evaluation).

Recommendation 2: The OSSE development for earth system models (e.g., for sea ice prediction) needs to be accelerated. Furthermore, global 5 km (and preferably 3 km) Nature Run based on earth system models should be developed as the basis for a variety of OSSEs. This may require the purchase of new high-performance computers or the partnership with other agencies.

Recommendation 3: NCEP data assimilation and prediction system will continue to improve. OSSEs are used to evaluate the observational network likely decades ahead. Therefore, the choice of observations and investment decisions based on OSSEs need to explicitly consider the potential impact of deficiencies in the current data assimilation and prediction system.

Recommendation 4: Besides existing OSSE activities at NOAA, OSSEs should also be used to:

- assess the value of NOAA partnership in satellite remote sensing with foreign agencies (e.g., India) and the private sector (e.g., purchasing data from privately-launched satellites),
- assist the exploration of strategies for the most effective and efficient way to do sea ice prediction (observations, models, data assimilation). Should NOAA request ice-breakers? How many?
- compare the value of (polar, geostationary, small/cube) satellite network strategy (e.g., small number of large satellites versus large number of small and cube satellites) for weather and climate prediction, and
- do a gap analysis in NOAA; i.e., what are the greatest new observational needs? What combination of old and new systems will work best?

Recommendation 5: OSSEs have been primarily used to evaluate the impacts of observing systems and/or observation denial on forecast performance per se, that is, on the physical parameters, and treating all forecast locations, times, and circumstances as equal. But this idea should be extended to societal impacts, whether monetizable, or in terms of lives at stake, etc. In other words, there are national priorities (e.g., saving human race) where money does not matter, and there are priorities depending upon the constraint of financial resources. This could be a possible additional avenue of research. In an Earth system model where social systems and the built environment are included, one can imagine collecting human data or propagating just the physical earth system information through the social systems as well.

Indeed, while OSSEs provide quantitative analyses of future observing system impacts for a specific model, the effects on products that rely on that model can only be estimated qualitatively. The NOAA/NESDIS Technology, Planning and Integration for Observation (TPIO) division has developed a qualitative tool for assessing supporting investment decisions, called the NOAA Observing System Integrated Analysis (NOSIA-II), also known as NOAA's Value Tree. This Value Tree is based on the survey of subject matter experts across all NOAA Line Offices to gauge the impacts of Earth observation investments on NOAA's key products and services. Therefore the aforementioned OSSE, OSE, FSO, EFSO and PQC tools should be used in concert with the current NOSIA-II system to determine NOAA's future observing needs.

Finally, it should be emphasized that perhaps the greatest benefit of R&D on OSSEs is not so much the guidance they can provide by themselves with respect to any particular observing system development and deployment decision. Instead it's about the enriched perspective they provide about strategic approaches to investment in Earth observations, science, and services in support of the national agenda. There is an analogy to the famous Eisenhower quote "individual plans are worthless, but planning is vital."

Attachment 2: An EISWG review and recommendations concerning the "Report to Congress - Tornado Warning Improvement and Extension Program Plan."

NOAA Science Advisory Board Report Review and Recommendations to NOAA of the "Report to Congress – Tornado Warning Improvement and Extension Program Plan"

Prepared by the Environmental Information

Services Working Group

July 2019

Environmental Information Services Working Group

A working group of the National Oceanic and Atmospheric Administration Science Advisory Board

3 July 2019

To: Lynn Scarlett, Chair, NOAA Science Advisory Board

CC: Robert Winokur, SAB Liaison to the Environmental Information Services Working Group

Everette Joseph, SAB Liaison to the Environmental Information Services Working Group

Cynthia Decker, NOAA SAB Executive Director

Subject: EISWG Review and Recommendations to NOAA of "Report to Congress – Tornado Warning Improvement and Extension Program Plan"

Dear Ms. Scarlett:

In response to the requirements of Title I, Section 103 of the Weather Research and Forecasting Innovation Act of 2017 (P.L. 115-25, signed 18 April 2017), as amended (P.L. 115-423, 7 January 2019) (hereafter, the Weather Act), the National Oceanic and Atmospheric Administration (NOAA) has prepared and submitted a "Report to Congress – Tornado Warning Improvement and Extension Program Plan" (hereafter, the Report). See Attachment 1. In accordance with Title IV, Section 401(c) of the Weather Act, the Environmental Information Services Working Group (EISWG), a working group of the NOAA Science Advisory Board (SAB), has reviewed the Report and prepared the following comments and recommendations.

To aid the working group in its review, the EISWG requested comments on the Report from Dr. Greg Forbes, formerly a senior faculty member in the Department of Meteorology, Penn State University, and now a semi-retired severe convective weather expert and broadcast meteorologist at The Weather Channel.

In general, the EISWG finds that the Report is comprehensive and responsive to the requirements of the Weather Act. It provides a good assessment of the technological and social/behavioral challenges that are essential to address in parallel to increase both the skill of NOAA's monitoring and forecasting, and the effectiveness of its warnings of tornadoes (and other destructive phenomena, such as microbursts, associated with severe thunderstorms). The Report describes the several efforts that NOAA has either underway or planned to address these technological and social challenges. The EISWG was pleased to see the many mentions of working in

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partnership with the entire Weather Enterprise to achieve jointly the shared goals of saving lives, protecting property, and reducing the economic impact from tornadoes.

Given the budget and other resources likely to be available to NOAA over the next five or so years, the EISWG is concerned that NOAA's ambitions may exceed its capabilities to accomplish the goals it has set for itself. This further highlights the importance of working with and leveraging the capabilities of the national Weather Enterprise.

With respect to technological objectives, the EISWG notes that some of the challenges could be accomplished with currently deployed technologies through software or hardware upgrades, or the deployment of readily adaptable commercial-off-the-shelf technologies. In particular, NOAA should recognize the following:

(1) While convection-allowing models have made great progress, they still do not capture every important mesoscale feature. Timing and position of thunderstorms can be off in time by an hour or two and in space by a county or more. Model forecasts seem less accurate when storms are already present when the model is initialized.

> **Recommendation 1:** In its development of Warn on Forecast (WOF) procedures, NOAA should include pattern recognition and artificial intelligence algorithms that take into account and adapt for the various known shortcomings in explicit computer model forecasts.

(2) The greatest successes with tornado warnings come in supercell situations; skillful warnings for non-supercell tornadoes remain a serious challenge.

> **Recommendation 2:** NOAA should focus more strongly on reducing the false alarm rate (FAR) and other metrics of skill in current generation tornado warnings. Polygon-based warnings challenge the way FAR is determined and so demand new methods to quantify true positive, false positive, true negative, and false negative for precision, recall, and accuracy. As warning polygons are now updated as severe storms evolve, FAR measures will need to be assessed over space and time. The ways these metrics are computed should be transparent. National metrics are nearly meaningless by themselves; NOAA should compute and release metrics by Forecast Office. Importantly, while the focus should be on reducing the FAR, such reductions cannot come at the expense of affecting negatively other tornado warning-based metrics, such as the probability of detection (POD). In other words, reducing the FAR while decreasing the POD would not be a positive outcome. These are related metrics, both very important

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and clearly improving the quality of tornado warnings will require a balance between these two important metrics to provide people with more accurate warnings to support decision making.

Recommendation 3: As a means for obtaining greater low-level radar coverage of non-supercell tornadic circulations and so significantly aiding in the warning of tornadoes, NOAA should consider …
  a) … reducing the lowest allowable elevation angle on *all* NEXRAD/WSR-88D radars to the minimum possible value, consistent with ground clutter and local environmental considerations, and
  b) … adding one or two tower sections to selected existing NEXRAD to reduce ground clutter, increase the radar horizon, and allow better overall coverage.

Recommendation 4: To aid in the warning of short-lived tornadoes, NOAA should build on the experiences in south-central Oklahoma and across the multi-county Dallas-Fort Worth metropolitan area and include networked X- or C-band as gap-filling radars to obtain greater low-level coverage of non-supercell circulations and strong winds.

Recommendation 5: The NEXRAD processing software used to detect mesocyclone and tornado vortex signatures should be modernized/upgraded to reflect the best science now available. An example is provided by the Mesocyclone Detection Algorithm (MDA), which currently uses only a portion of the available shear information. A modernization of this key algorithm might allow circulations of (weak) intensity levels 1 and 2 to be detected sooner and utilized with some confidence. This could make possible earlier (by several minutes, or equivalently two or three volume scans) detection of the earliest stages of formation of long-lived tornadoes, and allow tracking of at least a portion of the life cycle of short-lived tornadoes.

With respect to the sociological objectives, NOAA should recognize that the protection of life and property from the impact of tornadoes is not only a meteorological challenge, but also a sociological one. For example, to justify the costs and effort involved in developing and deploying WOF systems that may provide people advance skillful warnings of an hour or more, NOAA needs to understand better if people will take appropriate actions upon receipt of such lengthy advance warnings.

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Recommendation 6: Given the limited number of federal social science positions within the agency, NOAA should utilize its set of joint and cooperative institutes to access social science expertise in the national university community.

Recommendation 7: NOAA should have social science programs charged with investigating questions such as the following: Will people take action more than a few minutes in advance, even if given warnings an hour in advance? Where is the balance between lead-time and good decision-making? If actions are taken based upon lead times an hour or longer than at present, will this include fleeing and, if so, will road infrastructure and traffic management suffice? Will the public take action based upon probabilistic tornado warnings? How should the public best receive such warnings? Will the public be responsive to repeatedly updated warnings (N.B., The Report (see Attachment 1), p. 7 suggests that such warnings could be updated every 2 minutes), or simply confused by such frequent updates, and so waiting until the last minute to attempt to take action?

Recommendation 8: To reduce impacts in terms of minimizing property losses (as well as improve life safety measures), it will be necessary to implement stronger building codes. NOAA should develop and implement - in partnership with NIST, universities such as Texas Tech, and entities such as the Institute for Business and Home Safety - a weather-ready home certification program as an extension of its StormReady community and Weather-Ready Nation program,. This could encourage in-home shelters, hurricane clips to hold on roofs, etc.

In closing, the EISWG notes the resources portion of the plan seems generic. This leads to questions such as, "Has a detailed action plan been produced?" "If so, what are the detailed timelines?" "Has a detailed cost/benefit analysis been performed?" Such information is needed by the EISWG to know if NOAA is tracking favorably against the intended deliverables when reviewing subsequent reports.

On behalf of the members of the EISWG,

John T. Snow
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Attachment:

1) NOAA, 2019: "Report to Congress – Tornado Warning Improvement and
Extension Program Plan."