White Paper for
2017-2027 NRC Decadal Survey in Earth Science and Applications from Space

Title (150 character limit): A rigorous, independent observing system simulation experiment capability to establish the science value of future satellite missions.

White Paper Description (350 character limit): In the next decade, it will be critical to develop observing system simulation experiments to estimate the science value of new observations. This capability should be formal, independent and intramural, building off established techniques while recognizing the challenges of such simulation for novel measurements.

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White Paper Text:

1. *What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?*

One of the key challenges for Earth System Science is to develop and implement space-based observing systems that will confront the climate modeling community in such a way that will result in reduced uncertainty both in climate change projections and vexing metrics such as climate sensitivity and societally-relevant temperature, humidity, wind, and precipitation trends and extremes.

Given the complexity, time, and cost associated with the development of new satellite observations, it is incumbent upon the Earth System Science community to estimate the scientific and societal value of new observations prior to their development or launch, and use this as a basis for prioritizing the implementation of novel observations.

The use of observing system simulation experiments (OSSEs), whereby model outputs are used as a basis to emulate the signals that would be observed by a novel instrument, can provide a path towards estimating that value. OSSEs can also allow those with expertise in the development of new observations and those with expertise in model development to converge in order to design observing systems in such a way as to interrogate models and test hypotheses regarding key sources of uncertainty in model design or implementation. Although it is not developed as an OSSE experiment, the widespread adoption of inline instrument emulation through the CFMIP Observational Simulator Package (COSP) and recent use of Obs4MIPS satellite data, indicate that the climate model community is highly motivated to confront climate model output with a suite of existing measurements. A similar level of participation in the mission-planning process is warranted.

As a tool for satellite instrument development, OSSEs techniques have significant heritage in the numerical weather prediction (NWP) community, whereby a key metric for proposed new observations is the OSSE-generated improvement in forecasting skill derived from the addition of the proposed measurement system and assimilation of its data.

Still, it must be recognized that the OSSEs are an insufficient substitute for actual observations, because systematic errors in the model data and overly optimistic instrument error estimations, both of which serve as inputs to the OSSE, could bias simulations. Furthermore, it is difficult to estimate how errors in the actual data will propagate into novel instrument science and societal value. Therefore, results of analysis performed with OSSEs should be considered as a best-case scenario, rather than a best estimate, for answering the specific question posed by the OSSE.

For NWP, the existence of an established forecast model and the incremental increase in skill from new observations has mitigated the abovementioned risks associated with OSSE technique. The challenges for OSSE development for non-incremental, more transformative measurements are more serious, but should be considered in a hypothesis-testing framework, rather than NWP operational forecast perspective of OSSEs. That is, where model representations and parameterizations disagree, OSSEs may be able to illuminate those measurements that would lead to constraints. For climate change and climate change process observations, the mismatch of time-scales between the nominal observing system lifetimes and the time-scales of secular trends and natural variability, OSSEs are even more central to assessing the science value of a proposed mission. Reinforcing this point, the NRC report "Continuity of NASA Earth Observations from Space: A Value Framework" (2015) has recommended that NASA increase its OSSE capability in order to more quantitatively evaluate the "Utility" of future observations to addressing Quantitative Earth Science Objectives or "QESOs". The examples given in that report specifically apply to climate change QESOs.

For space-based observations, there is a pressing need for NASA to utilize OSSEs, but the OSSE capability must be developed judiciously and be free from conflicts of interest. The development of OSSE capability is relatively straightforward, though non-trivial in scope, requiring expertise in remote sensing technology, orbital mechanics, instrument emulation, the underlying model inputs, and advanced computer resources and architectures, all of which are necessary for an OSSE. However, given the competitive scientific and financial landscape for new satellite instrument missions, it is important for the Earth System Science community to consider the implementation of OSSEs by research teams that are independent from the teams and/or NASA centers that are implementing the missions. This is necessary because myriad assumptions are inherent in the development of the OSSE, and if OSSEs are to be used as a tool to evaluate mission science and societal value, the community must accept the impartiality of the OSSE results. OSSE results derived from (preferably multiple) independent investigations, as opposed to those arising from within a science team, will be free of real and perceived conflicts of interest. Policies to establish conflict-of-interest-free OSSE capability should be developed and should consider expertise both inside and outside NASA centers. Furthermore, by entraining the expertise of major modeling groups from the U.S. Department of Energy, the National Science Foundation, the Environmental Protection Agency, and the National Oceanic and Atmospheric Administration, along with Universities, there will be more community-wide interest in the novel observations simulated by the OSSE efforts. This should dovetail the effort to develop an independent capability for NWP OSSEs for NASA through the GMAO program.

2. *Why are these challenge/questions timely to address now especially with respect to readiness?*

It is timely to formalize the methods by which the science and societal value are assessed for novel satellite-based observations, because this will create a more rigorous process to tie modeling uncertainties to observation priorities. This will help span the persistent gulf between model and observation development by entraining the modeling community to establish a set of observational priorities, rather than developing tools only to utilize the data that currently exist. The current, informal nature for determining science and societal value may lead to mission decisions based on qualitative assessment. The observations to date, while vastly improving the scientific community's understanding of Earth system processes, have evidently not led to reduced uncertainty in the models even in fundamental metrics of climate change, such as climate sensitivity, and trends in temperature, humidity, winds and precipitation means and extremes. Only coordinated, hypothesis-driven research, which can be assisted with OSSEs, will bring the relevant communities together to plan for future observational systems that can systematically reduce errors in model projections for our changing planet.

3. *Why are space-based observations fundamental to addressing these challenges/questions?*

The comprehensive nature of space-based observations enables both large- and small-scale comparisons with model outputs. For this reason, they are particularly relevant to model confrontation. However, a comprehensive, independent OSSE capability within or exterior to NASA currently does not exist and will require additional planning and investment. Specifically, planning should focus on viable strategies to advance OSSE capability as a service to NASA mission evaluation while mitigating conflicts of interest, through the promotion and incentivizing of impartiality. Consequently, investment should consider strategies to promote OSSE expertise across multiple NASA centers and with model development stakeholders. This could take the form of a super-center OSSE capability and/or the promotion of OSSE capability at major modeling centers with scientific and programmatic priorities that are quite independent of NASA mission development.