**Title: The Need for a Climate Observing System**

**White Paper Description:** *The nation and the world need a rigorous climate observing system. Given the large societal issues related to climate change, filling this hole in our scientific approach represents one of the greatest challenges to the task of this Decadal Survey. While the Survey alone cannot solve this challenge, it can present the need and a vision forward.*

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***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?***

Climate change is well understood to be one of the major risks to modern society and one of the greatest science challenges of this century (IPCC, 2013, USGCRP, 2014). Yet we lack an adequate observing system designed to address the joint societal/scientific challenges of climate change (NRC, 2007; Trenberth et al., 2013; Dowell et al. 2013). While we have a wide range of Earth observations from surface to space, few have been designed to meet climate change requirements. No international agreements or commitments exist for designing, building, and maintaining a climate observing system. Yet the economic risks for climate change are measured in trillions of dollars. *Given this challenge, can the Decadal Survey (hereafter simply "Survey") put forth a vision of the need, the objectives, the priorities, and the scope of such a system?*

A pair of recent research studies (Cooke et al. 2014; 2015) estimated the economic value of such a system at ~ $10 trillion dollars to the world economy in today's value (known as "net present value" in economics and using a 3% discount rate). In the simplest sense, this is the economic value of moving climate science learning forward by 15 years using better observations, analysis, and modeling/predictions. The study further estimated that if the world tripled its current economic investments in climate research (observations, analysis, modeling) to achieve such an advanced observing system, the return on investment would be ~ $50 for every $1 invested by society. Few investments could approach such return. Compare that message to the current situation of a zero sum economic game in climate observations: one unresolved science question struggles for funding against another; yet both are critical to achieve. We need to change the question from "Which critical science climate observation is more important?" to "What climate science observations offer the highest value and return as a societal investment?"

Design of such an advanced and more rigorous international climate observing system would be a challenge in itself. Key elements of such a design can be taken from the recent NRC Continuity report (2015) and include:

1. *Define Quantified Earth Science Objectives (QESOs) for climate change.* Link their solution to more rapid progress in climate change prediction, understanding and thereby economic value through enabling improved societal decisions. *Rate the Importance of the QESOs*. We expect QESOs to be closely aligned with the USGCRP research goals, WCRP Grand Challenges, and IPCC major scientific uncertainties. This task is well suited to the Survey and its breadth of scientific expertise. Examples of QESOs can be found in the NRC Continuity report. Note that there will be many more highly important QESOs than NASA/NOAA/USGS current budgets can provide. This is exactly the point. This is why we currently don't have a climate observing system. We need to make clear how large the step is from where we are to where we ultimately need to go. The NRC Continuity report's proposed process can help with such selections.

2. *Identify the key geophysical variables needed to address each QESO.* Since some variables are more important than others, we must *rate their relative Utility to achieving the QESO.* While an evaluation of Utility has usually been performed qualitatively, only quantitative analysis is able to lead to measurable rankings of the variables as discussed in the NRC Continuity report (2015) and the NRC report on Quantifying Uncertainty in Complex Models (2012). The Survey could begin with qualitative discussion of Utility rankings and recommend that NASA/NOAA/USGS develop quantitative methodologies (e.g. OSSEs) for Utility ranking.

3. *Quantify the Quality of the measurement* needed to achieve the QESO. Quality as defined in the NRC Continuity report includes instrument accuracy, stability, time/space sampling, algorithms, and data availability. This task would require providing quantitative analysis beyond the capability of the Survey process; but *the Survey could call for such analysis.*

4. *Quantify the success probability of the measurement*. This step includes consideration of instrument risk (e.g. TRL level 6 vs 9), gap risk (and impact to Quality), and ability to cover gaps at the required Quality using other observations (e.g. international missions). This step is beyond the capability of the Survey to provide, but *the Survey could call for such analysis.*

5. *Estimate costs of the measurement approach*. This is a normal NASA/NOAA/USGS process.

The Survey clearly cannot design a complete observing system as part of its process. It can, however, present the need, the vision forward, and show that a true climate observing system would entail much larger resources than the current efforts by the U.S. or the international community. The Survey can also call for action to produce a more rigorous plan that might be developed by the U.S. Global Change Research Program (USGCRP) and its agencies. This vision cannot be produced by any of the current U.S. agencies, Congress, the Administration, or the public. It must come from the science community that best understands the magnitude of the challenges. The Survey and the USGCRP are the only two commissions capable of such a task in the U.S.

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

While existing systems are incredibly valuable and cost effective, they are far below the capabilities that even existing measurement technologies could achieve if applied to a climate observing system optimized for cost/benefit. Limits today are primarily economic and not technological. We struggle to achieve continuity of the observations we have already demonstrated such as total solar irradiance, radiation budget, radio occultation for temperature, cloud/aerosol lidar, cloud radar, precipitation radar, gravity for ice sheet mass, lidar for ice sheet elevation, ocean color, etc. In addition, a wide range of active remote sensing systems (e.g lidar, radar) as well as much higher accuracy and information content passive sensors (e.g. spectrometers) have been in technology development for 8 years since the last decadal survey and many are ready to be utilized. The 2007 Decadal Survey CLARREO benchmark climate change mission is an excellent example. CLARREO successfully passed Mission Concept Review in late 2010, and has since been delayed for lack of NASA resources to implement the concept. Limited resources also greatly reduced activity on all of the Tier 2 and Tier 3 missions.

*Space is expensive, but delaying climate change answers is much more expensive*.

It is in this sense that an improved climate observing system is primarily a discussion of investment value for society. Urgency is needed as observation delays are especially problematic given the long time scales of both climate change and societal policy actions. The Cooke et al (2015) study estimated a $650B per year cost to society for every year we delay an advanced climate observing system. At the same time, we must have a way to prioritize and estimate cost/benefit of improvements if society is to invest in an improved climate observing system as opposed to a zero sum game of "do the best you can", while hoping for a miracle breakthrough. This approach has failed to significantly narrow uncertainty in climate sensitivity even after 35 years of effort. This can be seen by simply comparing the discussion of climate sensitivity uncertainty in the Charney Report (NRC, 1979) to the recent IPCC AR5 (2013). Even more problematic, it remains unclear that the next 35 years of our current observations will solve this key challenge (Wielicki et al. 2013, Trenberth et al. 2013).

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

The primary logic for space observations is their unique ability to observe a wide range of critical climate variables covering the entire global climate system,. This is not to say that space observations can do all observations. In-situ (e.g. ARGO), aircraft (e.g. Ice Bridge), and surface observations are essential as well. But space observations are often the most complete and rigorous observations for many critical global climate variables.

The difficulty of achieving an optimized climate observing system should not be underestimated. One of the key challenges is coordination across disparate research communities with only modest overlap. These communities include surface/in-situ based climate observations, satellite climate observations, climate modeling/projection science, economics of climate change impacts, and climate policy. The USGCRP is currently the only major U.S. organization charged with such a broad charter, while internationally it is the World Climate Research Programme (WCRP). Ultimately a vision is required that can be effective at both national and international levels. The challenge is made more difficult by the fact that neither the USGCRP nor WCRP control any significant budgetary resources, so their influence (like the NRC studies) must be through providing a clear science vision to society.

*The primary mission of this Decadal Survey is to recommend to NASA/NOAA/USGS a portfolio that fits within its current budget. But the secondary goal should be to provide the scientific down payment on the longer-term vision of a true national and international climate observing system*.

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