Establishment of Space-Based Climate Change Measurement as a Prime Objective for Earth System Science

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White Paper Description: We describe the imperative for accurate measurement of climate change from space as a crucial objective of Earth System Science in the 2017 Decadal Survey (DS). Existing observations do not meet climate accuracy. We advocate appointment of a Panel as part of the DS to develop a strategy to promptly initiate measurement of climate change from space.

1. ***What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, and/or operations in the coming decades?***
NASA, NOAA, the USGS and the government of the United States face a daunting task with respect to deciding appropriate investments to make in the study of the Earth, its atmosphere, and its climate. At no time in our history have weather and climate played such a large role in everyday life, in our economy, and in national security. The examples of Hurricane Katrina in 2005 and Superstorm Sandy in 2012 show how just one event can lead to billions of dollars in damages and disruption of local communities and economies for years afterwards. These events are arguably minor in comparison with the anticipated disruptions on a global scale from climate change. An example of implications of climate change for national security can be found at:

http://www.nap.edu/catalog/12914/national-security-implications-of-climate-change-for-us-naval-forces

The 2017 Decadal Survey (DS) must therefore confront and address the specific observational needs and challenges associated with advancing knowledge of climate change. This will require outlining an integrated and complimentary set of rigorously quantified, definitive measurements that will continue for decades. Such measurements are, by necessity, distinct from those that may only need to occur for a single mission to study the processes that influence weather and climate and the Earth system.

Adding to the challenge of developing a viable Survey is the anticipated economic and funding environment of the next decade and beyond. International economies (the United States, Japan, the United Kingdom, China, and the European Union) are still responding to the financial crisis of 2007-2009 with unprecedented economic stimulus measures. These countries are also dealing with continued growth of sovereign debt and ageing populations. These economic conditions have resulted in constraints on discretionary spending from which scientific endeavors such as space flight projects are funded. To be viable the 2017 Earth Science Decadal Survey must confront this economic reality by assessing which missions offer the potential for the most significant economic impact in the near and long terms, rather than solely from the perspective of how many missions can fly for the anticipated funding.

We therefore propose that this new Decadal Survey seriously consider the distinct needs of climate change missions by not viewing them as simply missions in a long queue that also includes process study missions. The continuing lack of quantitative assessment of climate change and appropriate societal response, increases daily the risk of continued accumulated economic consequences. The only way to assuage this is to begin a climate record of known high accuracy that will be continued well into the future, until, as described below, the advantage of high accuracy is realized through earlier detection of climate change.

We therefore advocate that as part of its deliberations, the new DS establish a Panel to study and recommend a strategy for initiating measurements of climate change from space in concert with other Panels recommending the more traditional process oriented missions.

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

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

Measurement of climate change inherently involves the reliable determination of trends of atmospheric parameters such as temperature, moisture, cloud properties and extent, trace species, etc., over multi-decadal timescales. This challenge involves assessing measurements that necessarily will be made by different instruments built by different engineers and analyzed by different generations of scientists. The necessary link to enable quantitative information on climate change to be drawn from these long-term datasets is very high absolute calibration, measured on-orbit for the life of each mission, to known (Systeme International, SI) standards. Process study missions typically do not require stringent absolute calibration nor do they typically need to be conducted over decades. Thus there is a real difference in approach and requirements to measuring climate change and to conducting traditional process study missions that NASA in particular has undertaken. Measurements from space are essential to quantify the extent of *global* climate change.

To achieve accurate measurement of climate change, the scientific community embarked over a decade ago to define the approach to achieving high accuracy, SI traceable measurements on-orbit. Two community workshops, the first held in 2002 and titled "Satellite Instrument Calibration for Measuring Global Climate Change," and the second held in 2006 and titled "Achieving Satellite Instrument Calibration for Climate Change" outlined these approaches. The community reports are available online at:

http://www.nist.gov/pml/div685/pub/upload/nistir7047.pdf

http://www.star.nesdis.noaa.gov/star/documents/ASIC3-071218-webversfinal.pdf

These approaches were the basis of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission recommended as a Tier 1 mission in the 2007 Decadal Survey. These principles have been rigorously matured into concrete measurement objectives (e.g., absolute accuracy, time and space sampling, etc.) in the interim, as described in detail by *Wielicki et al*. [2013]. The CLARREO mission principles of high accuracy, tied on-orbit to SI standards, so that they may be trusted for decades to come, exemplify the needed climate change measurement. The CLARREO mission, however, remains in pre-formulation as of this writing.

The major question in response to climate change is, how much to mitigate and when? To answer this question the need is urgent to embark on dedicated climate change measurements from space. As noted in the Introduction to this White Paper, climate change carries enormous economic impact. *Burke et al*. [2015] noted that "unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100 and widening global income inequality, relative to scenarios without climate change."

Only with accurate climate measurements from space will policy makers assuredly know how and when to mitigate and the economic advantage of doing so. As shown by *Cooke et al*. [2014], highly accurate climate change measurements allow the determination of climate trends sooner than existing measurement systems, moving forward in time ***by decades*** our knowledge of climate change and climate sensitivity. This knowledge allows for society to make decisions earlier and with higher confidence, thus averting future damages from climate change. These averted damages can amount to trillions of (US) dollars. *Cooke et al*., [2015] have shown that the economic savings from accurate climate measurements are still in the trillions of dollars even when mitigation costs are considered. The enormous economic benefit of early detection afforded by highly accurate measurements is due to the non-linear effects of climate change, particularly temperature, on the global economy. In essence, these accurate measurements serve as early warning sentinels for the climate system, thus enabling tangible economic benefits.

A similar focus on quantitative climate change goals, high accuracy observations, and using accuracy to minimize the delay in societal climate change information is contained in the recent NRC report "*Continuity of NASA Earth Observations from Space: A Value Framework"* (2015). The need for accuracy as the foundation of long-term climate observations is also called for in the 2012 WMO-CEOS report " *Strategy Towards an Architecture for Climate Monitoring from Space*" (2012). These reports may be found online at:

http://www.nap.edu/catalog/21789/continuity-of-nasa-earth-observations-from-space-a-value-framework

http://ceos.org/ourwork/workinggroups/climate/current-activities/

NASA and other domestic and international Agencies must begin true climate change missions. These missions do not fit existing paradigms of missions undertaken for scientific curiosity or process studies, or for operational or continuity missions such as weather forecasting. The high accuracy required and the commitment to decadal measurements are not consistent with current NASA flight mission solicitations such as the successful Earth Venture (EV) program initiated at the recommendation of the 2007 Decadal Survey. Specifically, EV mission budgets typically admit no more than 2 years of on-orbit data and thus EV mission length and cost constraints preclude even the initiation of an accurate climate change record.

4. *Summary*

We believe it is incumbent on the new Decadal Survey to convene a Panel specifically devoted to investigating and recommending a strategy of climate change measurements from space for NASA and other Agencies to initiate at the earliest possible time. This Panel should be tasked with recommending how these missions will be initiated, budgeted, and ultimately maintained throughout many decades to come. Data stewardship will be a key issue as well. In order to recommend those missions technically ready to initiate now, the Panel would also work closely with technology readiness Panel(s) normally convened under the new DS.

In summary, we believe that starting an accurate climate change record is of the highest national priority – every day that passes tacitly accumulates more economic damages from climate change due to lack of concrete knowledge on specific actions to take. In delay, there is also the risk in over-regulating and under-regulating because of the absence of concrete knowledge, which is precisely what is now limiting international progress on agreements to reduce greenhouse gas emissions. We therefore strongly advocate that the 2017 Decadal Survey convene a Panel to address the issue of accurate climate change measurements from space and to ultimately recommend a sound strategy for their prompt initiation. No other measurements have the potential to profoundly impact the future of humanity, both scientifically and economically.

References:

Note: The Cooke et al. (2015) paper was accepted by the journal *Climate Policy* on October 18, 2015. A reprint may not be available immediately online but the accepted manuscript is available by contacting the Principal Author of this White Paper.

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