Statement of

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National Research Council
The National Academies

before the

Committee on Science and Technology
The U.S. House of Representatives
Hearing on *National Imperatives for Earth and Climate Science Research and Applications Investments over the Next Decade*

Mr. Chairman, Ranking Minority Member, and members of the committee: thank you for inviting me here to testify today. My name is Richard Anthes, and I am the President of the University Corporation for Atmospheric Research, a consortium of 70 research universities that manages the National Center for Atmospheric Research, on behalf of the National Science Foundation, and additional scientific education, training and support programs. I am also the current President of the American Meteorological Society. I appear today in my capacity as co-chair of the National Research Council (NRC)'s Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future.

The National Research Council is the unit of the National Academies that is responsible for organizing independent advisory studies for the federal government on science and technology. In response to requests from NASA, NOAA, and the USGS, the NRC has recently completed a "decadal survey" of Earth science and applications from space. ("Decadal surveys" are the 10-year prioritized roadmaps that the NRC has done for 40 years for the astronomers; this is the first time it is being done for Earth science and applications from space.) Among the key tasks in the charge to the decadal survey committee were to:

- Develop a consensus of the top-level scientific questions that should provide the focus for Earth and environmental observations in the period 2005-2020; and
- Develop a prioritized list of recommended space programs, missions, and supporting activities to address these questions.

The NRC survey committee has prepared an extensive report in response to this charge, which I am pleased to be able to summarize here today. Over 100 leaders in the Earth science community participated on the survey steering committee or its seven study panels. It is noteworthy that this was the first Earth science decadal survey, and the committee and panel members did an excellent job in fulfilling the charge and establishing a consensus – a task many previously considered impossible. A copy of the full report has also been provided for your use.

The committee's vision is encapsulated in the following declaration, first stated in the committee's interim report, published in 2005:

> “Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important challenges for society as it seeks to achieve prosperity, health, and sustainability.”

As detailed in the committee’s final report, and as we were profoundly reminded by the latest report from the International Panel on Climate Change (IPCC), the world faces significant and profound environmental challenges: shortages of clean and accessible freshwater, degradation of terrestrial and aquatic ecosystems, increases in soil erosion, changes in the chemistry of the atmosphere, declines in fisheries, and above all the rapid pace of substantial changes in climate. These changes are not isolated; they interact with each other and with natural variability in complex ways that cascade through the environment across local, regional, and global scales. Addressing these societal challenges requires that we confront key scientific questions related to ice sheets and sea level change, large-scale and persistent shifts in precipitation and water availability, transcontinental air pollution, shifts in ecosystem structure and function in response to climate change, impacts of climate change on human health, and occurrence of extreme events, such as hurricanes, floods and droughts, heat waves, earthquakes, and volcanic eruptions.

Yet at a time when the need has never been greater, we are faced with an Earth observation program that will dramatically diminish in capability over the next 5-10 years.

Last April, my co-chair, Dr. Berrien Moore, came before Congress to testify in response to release of the committee’s 2005 interim report. His testimony highlighted the key roles played by NASA and NOAA over the past 30 years in advancing our understanding of the Earth system and in providing a variety of societal benefits through their international leadership in Earth observing systems from space. He noted that while NOAA had plans to modernize and refresh its weather satellites, NASA had no plans to replace its Earth Observing System platforms after their nominal six year lifetimes end. He also noted that NASA had cancelled, scaled back, or delayed at least six planned missions, including a Landsat continuity mission. This led to the main finding in the interim report, which stated “this system of environmental satellites is at risk of collapse.”

Since the publication of the interim report, the Hydros and Deep Space Climate Observatory missions were cancelled; the flagship Global Precipitation Mission was delayed for another two and a half years; significant cuts were made to NASA’s Research and Analysis program: the NPOESS Preparatory Project mission was delayed for a year and a half; a key atmospheric profiling sensor planned for the next generation of NOAA geostationary satellites was canceled; and the NPOESS program breached the Nunn-McCurdy budget cap. As you have all heard, the certified NPOESS program delays the first launch by 3 years, eliminates 2 of the planned 6 spacecraft, and de-manifests or de-scopes a number of instruments, with particular consequences for measurement of the forcing and feedbacks that need to be measured to understand the magnitude, pace, and consequences of global and regional climate change. It is against this backdrop that I discuss the present report.

As you will see in the report, between 2006 and the end of the decade, the number of operating missions will decrease dramatically and the number of operating sensors and instruments on NASA spacecraft, most of which are well past their nominal lifetimes, will decrease by some 35 percent, with a 50% reduction by 2015 (see Figure 1 below). Substantial loss of capability is likely over the next several years due to a combination of decreased budgets and aging satellites already well past their design lifetimes. **This will result in an overall degradation of the system of Earth observing satellites, with the following potential consequences**:

- After decades of steady improvement, weather forecasts, including those of severe weather such as hurricanes, may start becoming less accurate, putting more people at risk and diminishing the proven economic value of accurate forecasts.
- The ozone hole in the stratosphere has apparently reached its maximum intensity. Models predict it will start to slowly recover. Without observations we may not be able to verify its recovery or explain why it is occurring.
- Earth is warming because of a small imbalance between incoming solar radiation and outgoing radiation from Earth. Measuring this small imbalance is critical to determining how fast Earth is warming and when the warming will stop. Without the measurements we are recommending will not be able to quantify how this net energy imbalance is changing.
- Climate models have improved steadily over the years, but are far from perfect. We need observations of the Earth system, the atmosphere, oceans, land and ice to verify and improve the climate models. These models have real impact on the U.S. economy, in predicting El Nino and other seasonal fluctuations in climate, which are used in energy, water and agriculture management.
- Sea level is rising and ice around the world is melting, yet there is uncertainty in how fast these are occurring and whether or not they are accelerating or decelerating. Without the observations we are recommending, we will be unable to know for sure how these rates are changing and what the implications will be for coastal communities.
- There is controversy about whether the frequency and intensity of hurricanes are increasing as the climate warms; observations of the atmosphere and oceans are required to resolve this important issue.
- The risk of missing early detection of Earthquakes, tsunamis, and volcanic eruptions will increase.
- Air quality forecasts, which require the global perspectives of satellites to identify pollution transport across borders, will become less accurate, with negative implications for both human health and urban pollution management efforts.
- Earth science is based fundamentally on observations. While it is impossible to predict what scientific advances will not occur without the observations, or what surprises (like the ozone hole) we will miss, we can be sure the rate of scientific progress will be greatly slowed without a robust set of Earth observations.

In its report, the committee sets forth a series of near-term and longer-term recommendations in order to address these troubling trends. It is important to note that this report does not “shoot for the moon,” and indeed the committee exercised considerable constraint in its recommendations, which were carefully considered within the context of challenging budget situations. Yet, while societal applications have grown ever-more dependent upon our Earth observing fleet, the NASA

Earth science budget has declined some 30% in constant-year dollars since 2000 (see Figure 2 below). This disparity between growing societal needs and diminished resources must be corrected. This leads to the report's overarching recommendation:

"The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth observing systems and restore its leadership in Earth science and applications."

The report outlines near-term actions meant to stem the tide of capability deterioration and continue critical data records, as well as forward-looking recommendations to establish a balanced Earth observation program designed to directly address the most urgent societal challenges facing our nation and the world (see Figure 3 below for an example of how nine of our recommended missions support in a synergistic way one of the societal benefit areas—extreme event warnings). It is important to recognize that these two sets of recommendations are not an "either/or" set of priorities. Both near-term actions and longer-term commitments are required to stem the tide of capability deterioration, continue critical climate data records, and establish a balanced Earth observation program designed to directly address the most urgent societal challenges facing our nation and the world. It is important to "right the ship" for Earth science, and we simply cannot let the current challenges we face with NPOESS and other troubled programs stop progress on all other fronts. Implementation of the "stop-gap" recommendations concerning NPOESS, NPP, and GOES-R are important—and the recommendations for establishing a healthy program going forward are equally as important. Satisfying near-term recommendations without placing due emphasis on the forward-looking program is to ignore the largest fraction of work that has gone into this report. Moreover, such a strategy would result in a further loss of U.S. scientific and technical capacity, which could decrease the competitiveness of the United States internationally for years to come.

Key elements of the recommended program include:

1. Restoration of certain measurement capabilities to the NPP, NPOESS, and GOES-R spacecraft in order to ensure continuity of critical data sets.
2. Completion of the existing planned program that was used as a baseline assumption for this survey. This includes (but is not limited to) launch of GPM in or before 2012, securing a replacement to Landsat 7 data before 2012.
3. A prioritized set of 17 missions to be carried out by NOAA and NASA over the next decade (see Tables 1 and 2 below). This set of missions provides a sound foundation for Earth science and its associated societal benefits well beyond 2020. *The committee believes strongly that these missions form a minimal, yet robust, observational component of an Earth information system that is capable of addressing a broad range of societal needs.*
4. A technology development program at NASA with funding comparable to and in addition to its basic technology program to make sure the necessary technologies are ready when needed to support mission starts over the coming decade.
5. A new "Venture" class of low-cost research and application missions that can establish entirely new research avenues or demonstrate key application-oriented measurements, helping with the development of innovative ideas and technologies. Priority would be

given to cost-effective, innovative missions rather than ones with excessive scientific and technological requirements.

6. A robust NASA Research and Analysis program, which is necessary to maximize scientific return on NASA investments in Earth science. Because the R&A programs are carried out largely through the Nation's research universities, such programs are also of great importance in supporting and training next generation Earth science researchers.
7. Suborbital and land-based measurements and socio-demographic studies in order to supplement and complement satellite data.
8. A comprehensive information system to meet the challenge of production, distribution, and stewardship of observational data and climate records. To ensure the recommended observations will benefit society, the mission program must be accompanied by efforts to translate raw observational data into useful information through modeling, data assimilation, and research and analysis.

Further, the committee is particularly concerned with the lack of clear agency responsibility for sustained research programs and the transitioning of proof-of-concept measurements into sustained measurement systems. To address societal and research needs, both the quality and the continuity of the measurement record must be assured through the transition of short-term, exploratory capabilities, into sustained observing systems. The elimination of the requirements for climate research-related measurements on NPOESS is only the most recent example of the nation's failure to sustain critical measurements. Therefore, our committee recommends that the Office of Science and Technology Policy, in collaboration with the relevant agencies, and in consultation with the scientific community, should develop and implement a plan for achieving and sustaining global Earth observations. This plan should recognize the complexity of differing agency roles, responsibilities, and capabilities as well as the lessons from implementation of the Landsat, EOS, and NPOESS programs.

Mr. Chairman, the observing system we envision will help establish a firm and sustainable foundation for Earth science and associated societal benefits through the year 2020 and beyond. It can be achieved through effective management of technology advances and international partnerships, and broad use of satellite science data by the research and decision-making communities. Our report recommends a path forward that restores U.S. leadership in Earth science and applications and averts the potential collapse of the system of environmental satellites. As documented in our report, this can be accomplished in a fiscally responsible manner, and I urge the committee to see that it is accomplished.

Thank you for the opportunity to appear before you today. I am prepared to answer any questions that you may have.

Supporting Tables and Graphics

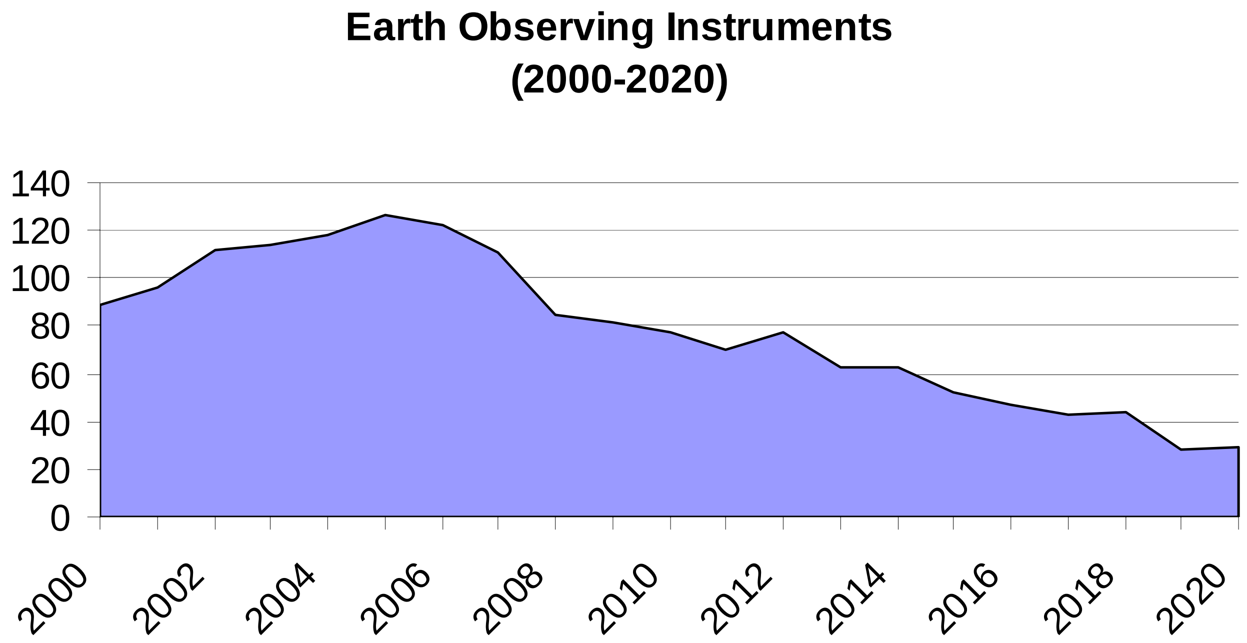


Figure 1. Number of current and planned U.S. space-based Earth Observations instruments, <u>not</u> counting the recommended missions in the Committee's report. For the period from 2007 to 2010, missions were generally assumed to operate for four years past their nominal lifetimes. SOURCE: Information from NASA and NOAA websites for mission durations.

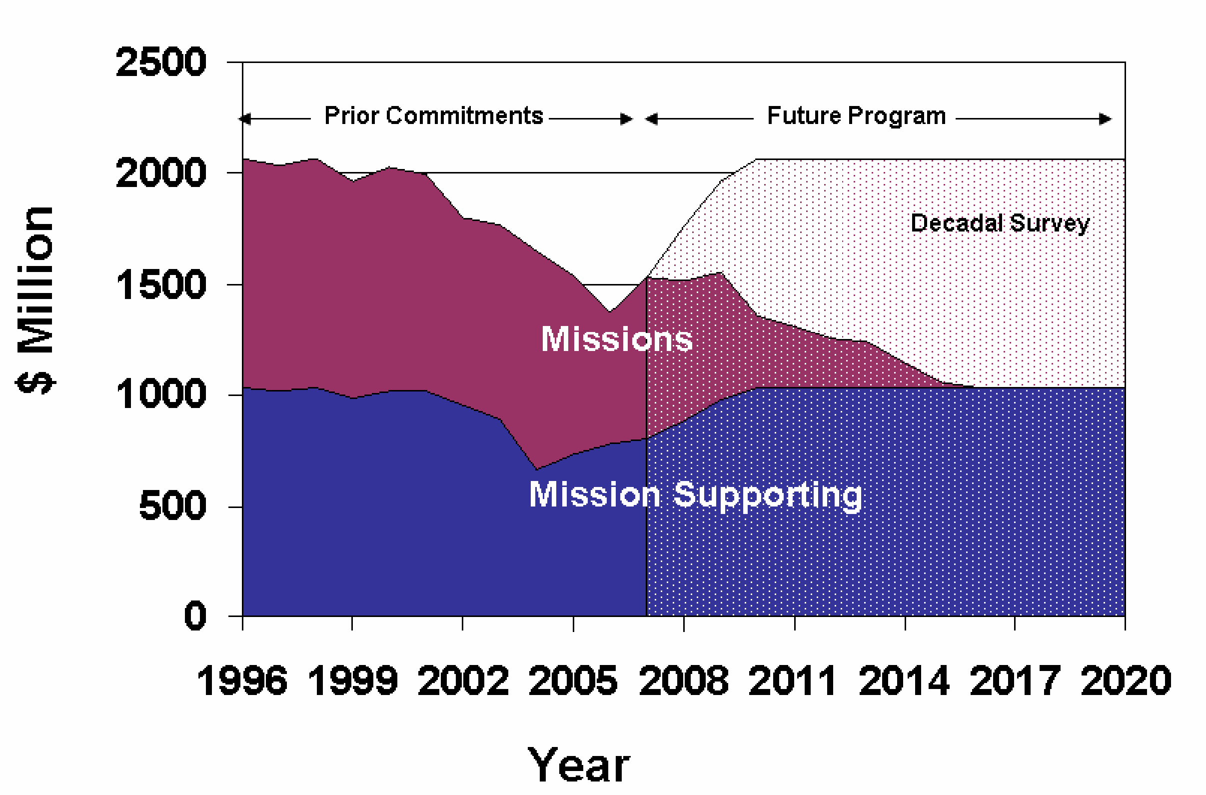
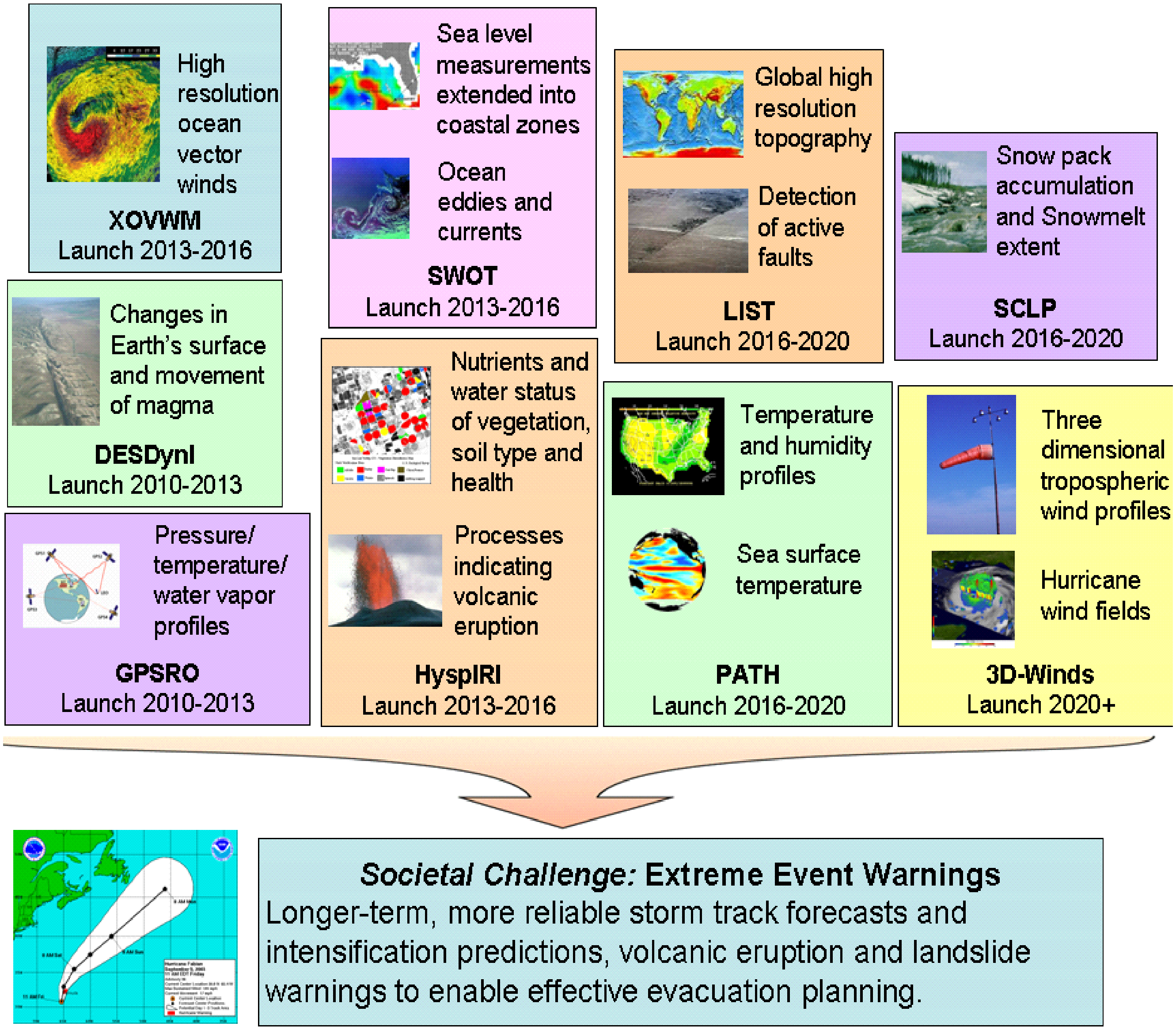


Figure 2. NASA budget for Earth Sciences adjusted to constant FY 2006 dollars and adjusted for the effects of full-cost accounting.



High resolution ocean vector winds

XOVWM
Launch 2013-2016

Sea level measurements extended into coastal zones

Ocean eddies and currents

SWOT
Launch 2013-2016

Global high resolution topography

Detection of active faults

LIST
Launch 2016-2020

Snow pack accumulation and Snowmelt extent

SCLP
Launch 2016-2020

Changes in Earth's surface and movement of magma

DESDynI
Launch 2010-2013

Nutrients and water status of vegetation, soil type and health

Processes indicating volcanic eruption

HyspIRI
Launch 2013-2016

Temperature and humidity profiles

Sea surface temperature

PATH
Launch 2016-2020

Three dimensional tropospheric wind profiles

Hurricane wind fields

3D-Winds
Launch 2020+

Pressure/ temperature/ water vapor profiles

GPSRO
Launch 2010-2013

***Societal Challenge:* Extreme Event Warnings**
Longer-term, more reliable storm track forecasts and intensification predictions, volcanic eruption and landslide warnings to enable effective evacuation planning.

Figure 3. Illustration showing how recommended missions work together to address societal challenges. Numerous additional examples are available in Chapter 2 of the final report.

TABLE 1. Launch, orbit, and instrument specifications for the recommended NOAA missions. Shade colors denote mission cost categories as estimated by the NRC committee. Green and blue shadings represent medium ($300 million to $600 million) and small (<$300 million) missions, respectively. Detailed descriptions of the missions are given in Part II of the final report, and Part III provides the foundation for selection.

Decadal Survey Mission	**Mission Description**	**Orbit**	**Instruments**	**Rough Cost Estimate**
Timeframe 2010 - 2013—Missions listed by cost				
CLARREO (Instrument Re-flight Components)	Solar and Earth radiation characteristics for understanding climate forcing	LEO, SSO	Broadband radiometers	$65 M
GPSRO	High accuracy, all-weather temperature, water vapor, and electron density profiles for weather, climate and space weather	LEO	GPS receiver	$150 M
Timeframe 2013 – 2016				
XOVWM	Sea surface wind vectors for weather and ocean ecosystems	LEO, SSO	Backscatter radar	$350 M

TABLE 2. Launch, orbit, and instrument specifications for the recommended NASA missions. Shade colors denote mission cost categories as estimated by the NRC ESAS committee. Pink, green, and blue shadings represent large ($600 million to $900), medium ($300 million to $600 million), and small (<$300 million) missions, respectively. Missions are listed in order of ascending cost within each launch timeframe. Detailed descriptions of the missions are given in Part II of the final report, and Part III provides the foundation for selection.

Decadal Survey Mission	**Mission Description**	**Orbit**	**Instruments**	**Rough Cost Estimate**
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar and Earth radiation, spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M

ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M
Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST[a]	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

[a] Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high accuracy SST measurement.