Earth Science Missions: What They Measure and How They Apply to the Real World

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PURPOSE

The purpose of this document is to inform decision makers about the harm many of the Administration's budget cuts will do to our national security. The budget cuts call for the termination of 5 NASA space based missions and reduced funding of one NOAA mission series. These space based missions are critical to provide climate and Earth data for real time observation and for developing and validating near-term, medium-term, and long-term climate models to predict future weather and climate conditions for planning and decision-making purposes.

Additional harm will accrue as the nation loses its technological edge in developing military reconnaissance systems. Many of our most powerful and technologically complex systems utilize technology developed in unclassified NASA and NOAA systems.

INTRODUCTION AND BACKGROUND

This report describes the detrimental consequences of the budget cuts proposed by the Trump administration to Earth Observation Systems. It is an expansion on a March 2017 report by securethefuture2100.org [1], which documented the cuts to 5 NASA Earth Science Missions and 2 NOAA spacecraft [2]. A second report dated July 2017 by securethefuture2100.org defined how climate change affects South Asia and threatens global security [3]. This current report defines in more detail the jeopardized missions and satellites, and the use of their data in the real world to monitor climate parameters, and gather and archive climate data for public use in US Government databases. The National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) develop, implement, and operate ground, ocean, atmospheric, and space based instruments and satellites used to measure Earth's weather and climate variables.

In summary, data from these instruments document what the weather and climate are actually doing around the globe as measured by a uniform technique and set of sensors. These data along with data from other instruments can then be used to:

- Validate weather predictions (near term) by comparing measured data to model data over the same past time period. Agreement increases confidence in model results, whereas differences indicate where model improvements are needed.
- Measured data provide essential inputs to initialize (i.e., specify the initial state for) future predictions of tomorrow's weather. Examples include predictions of hurricane tracks (spaghetti lines) in the Western Atlantic and monsoon tracking in South Asia.
- Validate climate prediction models (over the long term) by comparing measured data to model data over the same past time period. Again, agreement increases confidence in model results, whereas differences indicate where model improvements are needed.
- Measured data provide essential initializations to predict future climate conditions.

Near term weather predictions and longer-term climate model predictions can potentially help:

- Rice farmers in Bangladesh on the critical timing of planting their rice according to the current monsoon season;
- The energy company researching where to place their solar and wind farms over the long term;
- City and state coastal planners deciding on adaptation approaches with sea level rise and potential disasters like Sandy, Katrina, Harvey and Irma;
- The US government in planning for both military and humanitarian operations.

Note: Refer to Earth Sciences Mission – Summary Chart at end of report

BUDGET UPDATE

NASA Missions ($191M Cut) [4]:

1) The Pre-Aerosol, Cloud, ocean Ecosystem (PACE) satellite (also called the Plankton Aerosol, Cloud, ocean Ecosystem satellite)
2) The Orbiting Carbon Observatory-3 (OCO-3)
3) The Earth-viewing instruments aboard the Deep Space Climate Observatory (DSCOVR) spacecraft (i.e., Earth Polychromatic Imaging Camera (EPIC) and the National Institute of Standards & Technology Advanced Radiometer (NISTAR))
4) The Climate Absolute Radiance and Refractivity Observatory Pathfinder (CLARREO-PF) Mission

The President's Budget Blueprint for FY2018 dated March, 2017 [2]: Above 4 missions terminated.

NASA FY2018 Budget Estimates dated May, 2017 [5]: Above 4 missions terminated, and in addition a fifth also terminated:
5) The Radiation Budget Instrument (RBI) (aboard the Joint Polar Satellite System 2 (JPSS-2)) – a much improved instrument over a similar instrument on JPSS 1.

The President's Budget Blueprint for FY2018 dated March, 2017 2: RBI not called out.

NASA FY2018 2018 Budget Estimates dated May, 2017: RBI terminated.

NASA grants and research ($69M Cut):
The NASA budget request also cuts funding for Earth science research grants by $59M and terminates the Carbon Monitoring System ($10M). NASA's Carbon Monitoring System (CMS) was begun by congressional mandate in 2010 to develop methods for assessing the greenhouse gas emissions from forests and other natural carbon stocks. Although much of the work is focused on the United States, it also supports pilot technologies for eventual use in countries such as Colombia, Cambodia, Mexico, and Peru [6].

NOAA Spacecraft ($394K Cut):
Polar Follow On Program
Joint Polar Satellite System 3 (JPSS-3)
Joint Polar Satellite System 4 (JPSS-4)

The President's Budget Blueprint for FY2018 dated March 2017 [2]:
Unclear at the time on amount of funding cuts. We interpreted as terminated but with the submission of the FY 2018 NOAA Budget Summary dated May 2017 [7] we have a better understanding of the FY 2018 funding and basic scope of the Polar Follow On program.

FY 2018 NOAA Budget Summary dated May 2017 [7]:
> Reduction of out-year request for FY 2018 in FY 2017 budget from $586K to $180K (-$394K).

The Polar Follow On program is funded but at a lower level. The purpose of the budget cut is for NOAA to initiate a re-plan of the Polar Follow On program and work to improve its constellation strategy considering all the polar satellite assets to ensure polar weather satellite continuity while seeking cost efficiencies, managing and balancing system technical risks, and leveraging partnerships. Congress needs to ensure that funding is consistent with the viability and integrity of the US Polar Satellite System mission.

NOAA climate change grants and programs – cancelled [2] ($250M)

- Terminates NOAA grants and programs for coastal and marine management, research, and education including Sea Grant [8].
- Programs help U.S. coastal communities prepare themselves for rising sea levels.
- Industry, states, and communities are on their own.

NASA Mission Descriptions: (NOTE – See Flow Chart at end of document summarizing NASA Mission information.)

1) The Pre-Aerosol, Cloud, Ocean Ecosystem (PACE) Satellite:
PACE has been planned to use advanced technologies to provide unprecedented insight into Earth's ocean and atmosphere, which impact our everyday lives by regulating climate and making our planet habitable. Our oceans teem with life, supporting many of Earth's food chains and economies. PACE, now entering its design phase, is expected to use global observations to make new discoveries in Earth's living ocean, such as the diversity of organisms fueling marine food webs and how ecosystems respond to environmental change. PACE will observe our atmosphere to study clouds along with the tiny airborne particles known as aerosols. Looking at the ocean, clouds, and aerosols together will improve our knowledge of the roles each plays in our changing planet.

PACE's data are expected to reveal interactions between the ocean and atmosphere, including how they exchange carbon dioxide and how atmospheric aerosols might fuel phytoplankton growth in the surface ocean. By extending and expanding NASA's long record of satellite observations of our living planet, PACE is planned to take Earth's pulse in new ways for decades to come [9,10].

Application of PACE Mission to Real World:
The PACE mission will provide a combination of high-quality global atmospheric and oceanic observations that provide direct benefits to society in areas such as water resources monitoring, fisheries management, air quality forecasting, and disaster monitoring.

> Water Resources Monitoring - Harmful Algal Blooms:
To better understand the causes and impacts (economic, cultural, environmental, human health) of Harmful Algal Blooms (HABs), and how to improve monitoring and forecasting of the location and extent of HABs using ocean observations from space. Help prevent illnesses and deaths from HABs. Forecasting HABs is critical to the fish and shellfish industry since fish and shellfish exposed to HABs are generally considered poisonous [11].

> Fisheries Management:
Improve monitoring of our global ocean resources and their habitat, as needed for implementing ecosystem-based management approaches for productive and sustainable fisheries, safe sources of seafood, the recovery and conservation of protected resources, and healthy ecosystems. Help maintain and/or improve fish harvest globally in the long term [11].

> Air Quality Forecasting:
Forecasting of air quality particulate matter concentration that can impact health. Individuals and communities can take action accordingly [11].

> Disaster Monitoring
Improving Hazard Assessment and Aviation Safety: Knowledge of the location, amount, and evolution of volcanic plumes and their ash and SO_2 content will enable timely and accurate hazard assessment/avoidance and enhance aviation safety after volcanic eruptions.
Monitoring and tracking oil spills: Monitoring and tracking oil spills will provide information for spill clean-up and information that can be used for environmental, wildlife, and community damage assessment [11].

> **Modeling**
Productivity And Biodiversity Of Coastal Ecosystems: PACE satellite-derived optics and biogeochemical variables may be assimilated into operational seasonal-to- inter-annual climate computer models. As a result, PACE data may improve model skills and climate forecasting capabilities of the Global Ocean Data Assimilation System / Coupled Forecast System (GODAS/CFS) and Real- Time Ocean Forecast System (RTOFS) [11].
Modeling Improvement: Data from PACE will improve climate-carbon and climate-ecology model predictions [12].

> Weather Monitoring: Pace will be used to provide data to GODAS to monitor and understand El **Niño**-Southern Oscillation (ENSO) in near–real time [11, 13].

2) The Orbiting Carbon Observatory-3 (OCO-3):
OCO-3, like the currently-flying OCO-2, is designed to investigate important questions about the distribution of carbon dioxide on Earth as it relates to growing urban populations and changing patterns of fossil fuel combustion [15]. OCO-3 is a complete stand-alone payload built using the spare OCO-2 flight instrument, with additional elements added to accommodate installation and operation on the International Space Station (ISS) [14] [16].

- OCO-2 can observe most of the Earth's surface in just 16 days, allowing for continuous modeling to identify patterns and trends by studying how CO_2 moves throughout the atmosphere [18]. Recent examples of the use of OCO-2 data are a published study of the effect of El Nino (an ocean and atmosphere cycle that impacts global weather) on CO_2 [19]and another study [NEW REF 2] demonstrating OCO-2's ability to detect the impact of individual power plants on CO_2 [20].
- OCO-3 is a critical element in the continuation of global carbon dioxide (CO_2) measurements focused on understanding the regional sources and sinks (land and ocean) of CO_2 [17] [18] [21]
- OCO-3 can also contribute to focused study of how space based measurements can constrain rapidly changing CO_2 emissions. Human-made CO_2 emissions could be the largest source of uncertainty in the global carbon budget as OCO-3 measurements reduce uncertainty of natural fluxes [21].
- OCO-3 measurements can be combined with evapotranspiration and biomass measurements to study process details of the terrestrial ecosystem [21].

The OCO-3 instrument has a planned operational life of 3 years. Operation on ISS allows latitude coverage from 51 deg N to 51 deg S (approximately from the western Canada/US border to the southern tip of Argentina). OCO-2, which was launched in July 2014, is now beyond its prime mission lifetime of two years [22] [23]

Application of OCO-3 Mission to Real World:
The OCO-3 mission will provide a key measurement that will be combined with other ground and aircraft measurements and satellite data to answer important questions about the processes that regulate atmospheric carbon dioxide and its role in the carbon cycle and climate. OCO-3 will allow continuous modeling to identify patterns and trends by studying how CO2 moves throughout the atmosphere [22]. From the use of data captured by OCO-3 for development of models, this information could help policymakers and business leaders make better decisions to aid climate stability and protect our quality of life.

3) Earth-viewing instruments aboard the Deep Space Climate Observatory (DSCOVR): [24] [25] a) The Earth Polychromatic Imaging Camera (EPIC), b) The National Institute of Standards & Technology Advanced Radiometer (NISTAR)

DSCOVR is a NOAA-operated spacecraft currently orbiting the neutral-gravity point (Lagrange-1 (L1)) between the sun and Earth (about 930,000 miles from Earth and 94,000,000 miles from the sun). At this location DSCOVR has a continuous view of the Sun and the sunlit side of the Earth.

The sun view enables instruments to monitor the solar wind and to forecast space weather at Earth -- effects from the material and energy from the sun that can impact satellites and technological infrastructure on Earth. These sun-viewing instruments are not affected by the budget cut.
The earth view is monitored by EPIC and NISTAR having a continuous "big picture" view of the illuminated Earth in contrast with Earth-orbiting satellites alternating between "day time" and "night time" views. The budgets for these instruments have been terminated.

3a) The Earth Polychromatic Imaging Camera (EPIC:

EPIC, on DSCOVR, takes images of the sunlit side of Earth for various Earth sciences purposes, in 10 different channels from ultraviolet to near infrared. From these data it monitors changes in ozone, aerosols, dust and volcanic ash, cloud height, vegetation cover and climate. EPIC takes full-Earth pictures about every two hours and processes them faster than other Earth observation satellites. EPIC fills in a missing piece of energy information not observed by other satellites [25] [26] [27]. For example, one unique feature of EPIC on DSCOVR is its ability to provide frequent observations of every region of the Earth in near-backscatter directions (163°-176°), an ability that the existing Low-Earth-Orbiting and Geostationary satellites do not have[31]. It has been widely recognized that these near-backscatter directions contain the most information-rich directions in the directional distribution of canopy reflected radiation[32]. This canopy reflected radiation is used to derive Leaf Area Index (LAI) and its sunlit portion, important descriptors of vegetation cover that are key state parameters in most ecosystem productivity models. [STAN--I TRIED TO INSERT FOOTNOTE 26 TWICE JUST ABOVE HERE, BUT IT CAME OUT AS 29 & 30. PLEASE FIX.]

The first DSCOVR EPIC image released by NASA, showing the full sunlit Earth from one million miles away, showing the Americas.

Application of EPIC Mission to Real World:

Real time climate information and collection of data that can be used to validate climate prediction models, provide essential inputs to predict storms, models to monitor global vegetation coverage, future climate conditions, and have a better understanding of vegetation, aerosols, ozone and other features of Earth and its atmosphere [28] [29] [30].

3b) The National Institute of Standards and Technology Advanced Radiometer (NISTAR) [33 34 35]:

NISTAR, on DSCOVR, measures irradiance of the sunlit face of the Earth. The data are used to study changes in Earth's radiation budget caused by natural and human activities. The radiometer measures in four channels:

- For total radiation in ultraviolet, visible and infrared in range of 0.2-100 μm.
- For reflected solar radiation in ultraviolet, visible and near infrared in range of 0.2-4 μm.
- For reflected solar radiation in infrared in range of 0.7-4 μm.
- For calibration purposes in range of 0.3-1 μm.

NISTAR's energy balance measurements, unique because of both their vantage point and their accuracy (see below), will improve our understanding of the effects of changes to Earth's radiation budget caused by human activities and natural phenomena. The Earth's radiation budget (i.e., the amounts of incoming and outgoing radiant energy, and the difference between incoming and outgoing) is the fundamental driver of Earth's climate.

The data collected by NISTAR on Earth's albedo, incoming short- and long-wave radiation, and outgoing long-wave radiation has never been measured from this position before. DSCOVR's location at the L1 observing position permits long integration times because no scanning is required. Radiometric accuracy of 0.1–1.5% (varies with band) is expected, which is up to a 10-fold improvement in accuracy over current Earth-orbiting satellite data.

Application of NISTSR Mission to Real World:

The information from NISTAR can be used for climate science applications. Measurements of the reflected sunlight and the thermal radiation of Earth back towards the sun are quantities that are key factors of current climate models [35].
Similar to RBI—see below.

4) The Climate Absolute Radiance and Refractivity Observatory Pathfinder (CLARREO-PF):

CLARREO Pathfinder (CPF) mission is a precursor to the full CLARREO mission which is intended to demonstrate essential measurement technologies: measuring the energy from the Sun reflected back from the Earth. CLARREO is a Tier 1 mission recommended by the National Research Council (NRC) Decadal Survey of 2007. The foundation of CLARREO is the ability to produce highly accurate climate records to test climate projections in order to improve models and enable sound policy decisions. The CLARREO mission accomplishes this critical objective through accurate decadal observations that are sensitive to many of the key climate parameters such as radiative forcings, climate responses, and feedbacks. A key goal of CLARREO is to make these observations traceable to international standards (specifically, SI, or Système International d'Unités (International System of Units)). Uncertainties in these parameters drive uncertainty in current climate model projections [36 37].

CLARREO Pathfinder (CPF) funds allocated in 2016 support the flight of a Reflected Solar (RS) spectrometer, hosted on the International Space Station (ISS) in the 2020 time frame. The CPF is a Class D mission with 1 year of operations on orbit and 1 year for analysis of acquired data [36].

Application of CLARREO Mission to Real World:
CLARREO will produce highly accurate climate records to validate and improve climate prediction models and provide essential inputs to predict future climate conditions [37].

5) The Radiation Budget Instrument (RBI):
RBI will extend the unique global climate measurements of the Earth's radiation budget currently provided by the Clouds and the Earth's Radiant Energy Systems (CERES) flying on the Suomi NPP satellite mission and on JPSS-1 [38].

RBI is planned to be one of five instruments to operate on the Joint Polar Satellite System 2 (JPSS-2, see below). RBI's goal is to provide an independent measurement of Earth-reflected solar radiation and Earth-emitted thermal radiation. These are important components of Earth's radiant energy budget, i.e., the budget that accounts for Earth's incoming and outgoing energy, including the components of each, and the difference between incoming and outgoing. That energy difference is the primary driver of climate change. -- In this way, RBI's measurements, when combined with measurements of incoming radiation from the sun, are used to show whether Earth's incoming and outgoing radiant energy are in balance. When outgoing energy is too small to balance incoming energy, as is currently caused by increases in greenhouse gases blanketing Earth's surface, Earth temperature rises. Thus, RBI's measurements are fundamental to monitoring the basic driver of Earth's temperature and resultant climate change. RBI was planned to extend two decades of NASA measurements of Earth's energy budget [39] [40] [41] [42] [43] [44] [43].

Application of RBI Mission to Real World:
RBI's data on Earth's reflected sunlight and emitted thermal radiation will help document the effect of clouds on the Earth's energy budget, which strongly influences both weather and climate. Long-term satellite data from RBI will help scientists and researchers understand the links between the Earth's incoming and outgoing energy, and properties of the atmosphere that affect it. The data from RBI will provide fundamental inputs to extended range --10-day or longer -- weather forecasting, and help develop a quantitative understanding of the links between Earth's radiation budget and the properties of the atmosphere and surface that define that budget. This improved understanding, benefitting from comparisons between measured and model-predicted results, is used to improve climate models [38] [45].

NOAA Mission Description: (NOTE – See Flow Chart at end of document summarizing NOAA Mission information.)

NOAA / NASA Joint Polar Satellite System Program (JPSS): Includes Polar Follow-On (PFO) [46 47 48] :

- Polar orbit crossing Earth's equator about 14 times per 24 hrs
- High Resolution instrumentation
- Launch at ~ 5 year intervals for continuity of Earth monitoring
- Provides continuous critical global Earth observations through 2038.
- Gather global measurements of atmospheric, terrestrial and oceanic conditions, including sea and land surface temperatures, vegetation, clouds, rainfall, snow and ice cover, fire locations / smoke plumes, Gulf oil tracking, atmospheric temperature, water vapor and ozone.

Application of JPSS Mission to Real World:

JPSS delivers key observations for the Nation's essential products and services, including reliable, regularly updated forecasts that often include severe weather like hurricanes, tornadoes and blizzards days in advance[49], and assessing environmental hazards such as droughts, forest fires, poor air quality and harmful coastal waters [46 47]. Further, JPSS will provide continuity of critical, global Earth observations— including our atmosphere, oceans and land through 2038.

JPSS data are critical to the National Weather Service (NWS) ice operations, which use imagery to monitor ice extent as well as potential hazards throughout the region. Forecasters produce graphic analyses of sea surface temperature, sea ice and five-day sea ice forecasts year-round as a public service to public and private maritime operations. This ice forecast assists fishing and commercial vessels in determining the safest and most efficient route, including the economically advantageous but hazardous route through the Northwest Passage between the Atlantic and Pacific Oceans [46 47 48].

JPSS data are invaluable to NWS and other operations, in part because in the arctic winter, they provide Day/Night Band imagery at night using the light of the moon. This type of high- resolution satellite imagery is not available from any other satellite. Imagery from the Day/Night Band on the VIIRS instrument enables Weather Forecasting Offices in Alaska to clearly see high-resolution features throughout the year without sunlight [46].

Alaskan and other lives and livelihoods are dependent upon accurate forecasting of oceanic conditions.

TECHNOLOGICAL INNOVATIONS REQUIRED BY MILITARY SURVEILLANCE SYSTEMS.

Many of our military reconnaissance systems have relied on technology first developed for unclassified satellites such as the NASA and NOAA systems. The technological advances occurred in optical and radio wave sensing, space-based radar, communication, space-environment heat management, and other technological challenges.

The first successful weather satellite was the TIROS-1, launched by NASA on April 1, 1960 [51]. This satellite provided low-resolution images that were capable of monitoring weather conditions. The senor mix included the detection of thermal radiation. The first Landsat satellites were launched on July 23, 1972 [53]. The satellite provided moderate resolution imagery that was of immense use in agriculture, cartography, geology, forestry, regional planning, surveillance and education. One of the important advances was in the detection of thermal radiation with the Landsat Thematic Mapper Scanner at moderate resolution.

The first space-based radar systems were the Seasat developed by NASA's Jet Propulsion Laboratory and launched in June 27, 1978. NASA later developed the Venus Radar Mapper in May 4,1989. This allowed further refinement of space-based radar systems. Space-based radar systems require the effective dissipation of heat from the radar transmitter. This important technology was developed in these unclassified systems.

Space-based communication requires the perfection of the capability to make an antenna collapsible into the small volume of a launch vehicle and then unfurl flawlessly in space. Large space antennas have a metallic net that is attached to thin ribs. The antenna is folded up so it can be inserted into the launch vehicle. Once the ribs unfold the antenna mesh position must be accurate to very small tolerances depending on the operating wavelength. The need to develop large space antenna structures was identified in an early NASA document [55]. An inadequate deployment of the antenna can destroy the entire mission.

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Earth Sciences Missions – Summary Chart