

Earth Science and Applications from Space

National Imperatives for the Next Decade and Beyond



Study “Vision”

“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 for society as it seeks to achieve prosperity and sustainability.”

Background and Organization

- Sponsors: NASA, NOAA, USGS
- Charge: *Recommend a prioritized list of flight missions and supporting activities to support national needs for research and monitoring of the dynamic Earth system during the next decade and beyond.*
- Organization:
 - Steering Committee (18 members)
 - Seven Thematically-Organized Study Panels (~12 members each)
 1. Earth Science Applications and Societal Needs
 2. Land-use Change, Ecosystem Dynamics and Biodiversity
 3. Weather (incl. space weather and chemical weather)
 4. Climate Variability and Change
 5. Water Resources and the Global Hydrologic Cycle
 6. Human Health and Security
 7. Solid-Earth Hazards, Resources and Dynamics

Panel Objectives

- Identify general needs and opportunities for space borne observations to advance our science in next 10 years
- Propose program or missions to meet those needs
- Rank proposed programs or missions in priority order
- Describe each mission in terms of science payoff, cost, benefits to society
- Identify observations that cannot be made from space but needed to complement space-based data
- Identify other essential components (telemetry, data management)

Scientific and Societal Imperatives

Climate change and impacts

Ice sheets, sea level, and ocean circulation

Shifts in precipitation and water availability

Transcontinental Air Pollution

Shifts in ecosystems response to climate change

Human health and climate change

Extreme events, including severe storms, heat waves, earthquakes and volcanoes

Challenges

- Community Buy-in
 - First decadal survey
 - Breadth of Earth science community
 - An organizational challenge was how to cover science and application themes as well as scientific disciplines. In retrospect, having additional discipline-focused subgroups would have been useful.
- Multi-Agency Issues
 - Transition to Operations
 - Sustained Research Operations
- Important changes in baseline assumptions during the study
 - Budgets for Earth science decline dramatically at NASA
 - NPOESS program debacle and elimination of GOES-R advanced sounder/coastal waters imager

Interim Report – April 2005

- “Today, this system of environmental satellites is at risk of collapse.”
- Since then more delays, descoping and cancellations of missions at NOAA and NASA

Final Report — January 2007

- NOAA and NASA should undertake 17 recommended missions, phased over the next decade.
 - Restores U.S. leadership in Earth science and applications from space and averts the potential collapse of the system of environmental satellites
- Presents an Integrated Suite of Missions
 - Panel recommendations rolled-up
 - Missions sequenced
 - Overall cost matched to anticipated resources plus reasonable growth
 - Highest priorities of each panel are preserved
- Some Guidance on How To Handle Budget or Technology Development Problems

FINAL REPORT

- Recommends a Path Forward that Restores US Leadership in Earth Science and Applications and averts the Potential Collapse of the System of Environmental Satellites
- Presents an Integrated Suite of Missions
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RECOMMENDATIONS

- 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.

KEY AGENCY RECOMMENDATIONS

(for currently planned observing system)

- NASA-continuity of precipitation and land cover
 - Launching GPM by 2012
 - Obtaining a replacement to Landsat 7 data before 2012.
- The committee also recommends that NASA continue to seek cost-effective, innovative means for obtaining land cover change information.

MAIN RECOMMENDATION

(for next decade)

- NOAA and NASA should undertake a set of 17 recommended missions, phased over the next decade

MAIN RECOMMENDATION

(for next decade)

- NOAA research to operations
 - Vector ocean winds (CMIS-LITE plus Scatterometer)
 - GPS radio occultation temperature, water vapor and electron density profiles
 - Total solar irradiance and Earth Radiation (CERES on NPP also) restored to NPOESS
- NASA
 - 15 missions in small, medium and large categories

RECOMMENDATIONS

- Technology development in support of missions
 - NASA-invest in both mission-focused and cross-cutting technology development to decrease risk in missions and promote cost reduction across multiple missions
 - NASA-create new Venture class of low cost (\$100-\$200M) missions to foster innovation and train future leaders
 - NOAA-increase investment in research to operations

PROGRAMMATIC DECISION STRATEGIES AND RULES

- **Manage Technology Risk**
 - Sequence missions according to technological readiness and budget risk factors... technological investments should be made across all recommended missions.
 - If there are insufficient funds to execute the missions in the recommended timeframes, it is still important to make advances on the key technological hurdles.
 - Establish technological readiness through documented technology demonstrations before mission development phase...

PROGRAMMATIC DECISION STRATEGIES AND RULES

Leverage International Efforts

- Restructure or defer missions if international partners select missions which meet most of the measurement objectives of recommended missions, then a) establish data access agreements, and b) establish science teams
- Where appropriate, offer cost-effective additions to international missions that help extend the values of those missions.

PROGRAMMATIC DECISION STRATEGIES AND RULES

- *Respond to Budget Pressures and Shortfalls*
 - Protect the overarching observational program by canceling missions that substantially overrun...
 - Maintain a broad research program under significantly reduced agency funds by accepting greater mission risk rather than descope missions and science requirements...
 - Aggressively seek international and commercial partners to share mission costs...
 - In the event of budget shortfalls, re-evaluate the entire set of missions given an assessment of the current state of international global Earth observations, plans, needs, and opportunities. Seek advice from the broad community of Earth scientists and users and modify the long terms strategy (rather than dealing with one mission at a time)...

17 Missions

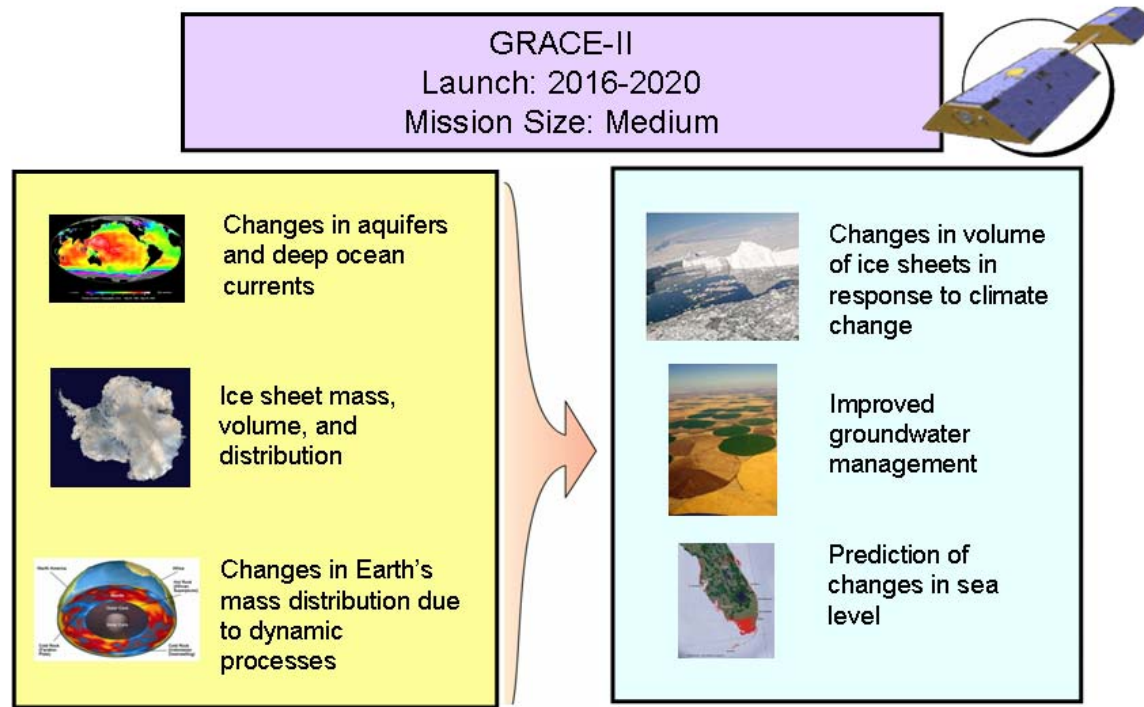
(Red = <\$900 M; Green = \$300-\$600 M; Blue = <\$300 M)

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 - 2013—Missions listed by cost				
CLARREO (NOAA portion)	Solar and Earth radiation characteristics for understanding climate forcing	LEO, SSO	Broadband radiometer	\$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

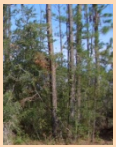
Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	\$200 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	Ku-band radar Ku-band altimeter Microwave radiometer	\$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High spatial resolution hyperspectral spectrometer Low spatial resolution imaging spectrometer IR correlation radiometer	\$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

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



GRACE-II would provide information about variations in groundwater storage at spatial resolutions sufficient to help improve resource characterization and management in those portions of the world (which include most underdeveloped countries) where groundwater is not actively managed. A more indirect benefit will be improved characterization of water storage in the subsurface, which affects weather and climate model estimates of water recycling to the atmosphere, and hence precipitation prediction at both weather and climate time scales. At present, the dynamics of water storage in surface soils vs. deeper storage as groundwater is not discriminated in land surface models, as there is little observational basis for doing so. Hence, essentially all variations in subsurface storage are attributed to soil moisture, and the lower frequency variations associated with groundwater are ignored. GRACE-II data would help foster a new generation of land surface models, which would better represent subsurface moisture variations, and, in turn, the recycling of moisture to the atmosphere.



Changes in
carbon storage
in vegetation

DESDynI

Launch 2010-2013

Pressure/
temperature/
water vapor
profiles



GPSRO

Launch 2010-2013



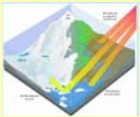
Estimate of
flux of low-
salinity ice
out of Arctic
basin

ICESat-II

Launch 2010-2013



Absolute spectrally
resolved IR radiance



Incident solar and
spectrally resolved
reflected irradiance

CLARREO

Launch 2010-2013



Aerosol
and cloud
types and
properties

ACE

Launch 2013-2016



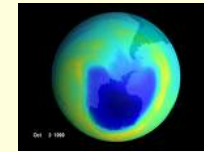
CO₂ measurements:
Day/night, all
seasons, all latitudes



Connection between
climate and CO₂
exchange

ASCENDS

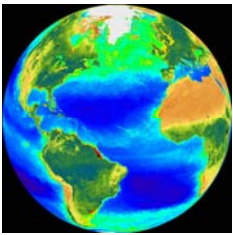
Launch 2013-2016



Vertical profile
of ozone and
key ozone
precursors

GACM

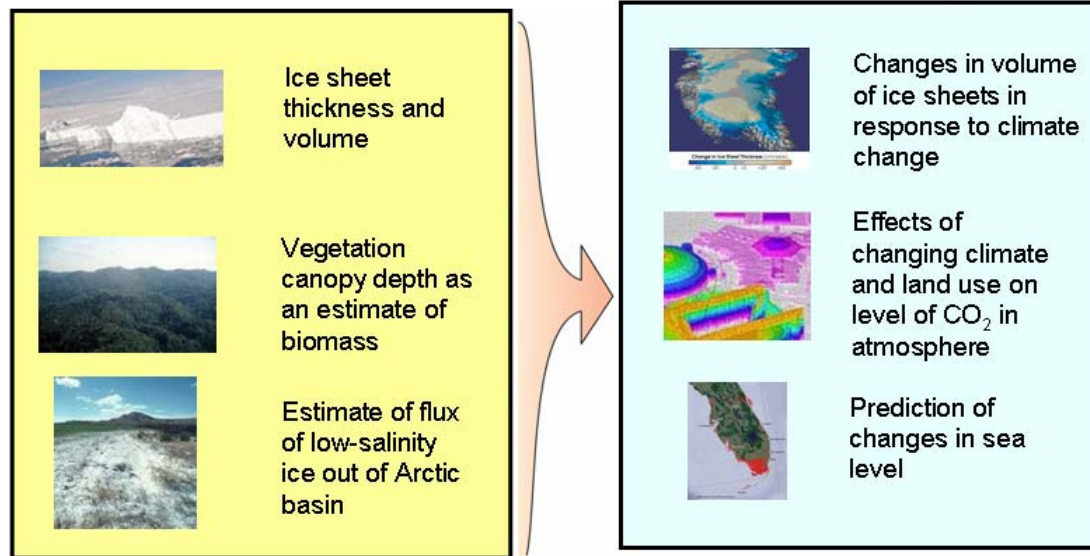
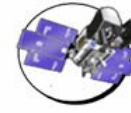
Launch 2016-2020



Societal Challenge: Climate Prediction

Robust estimates of primary climate forcings for improved climate forecasts, including local predictions of the effects of climate change

ICESat-II
Launch: 2010-2013
Mission Size: Medium



Mission and Payload: The proposed mission is to deploy an ICESat follow-on satellite to continue the assessment of polar ice changes and to complement vegetation canopy studies. The satellite will fly in low earth, non-sun-synchronous orbit.

The payload will include a single channel lidar with GPS navigation and pointing capabilities sufficient for acquiring high accuracy repeat elevation data over ice and vegetation. The proposed ICESat-II mission will address technical issues uncovered during the ICESat mission. Limitations of the lasers on ICESat are understood and will be readily corrected for ICESat-II.

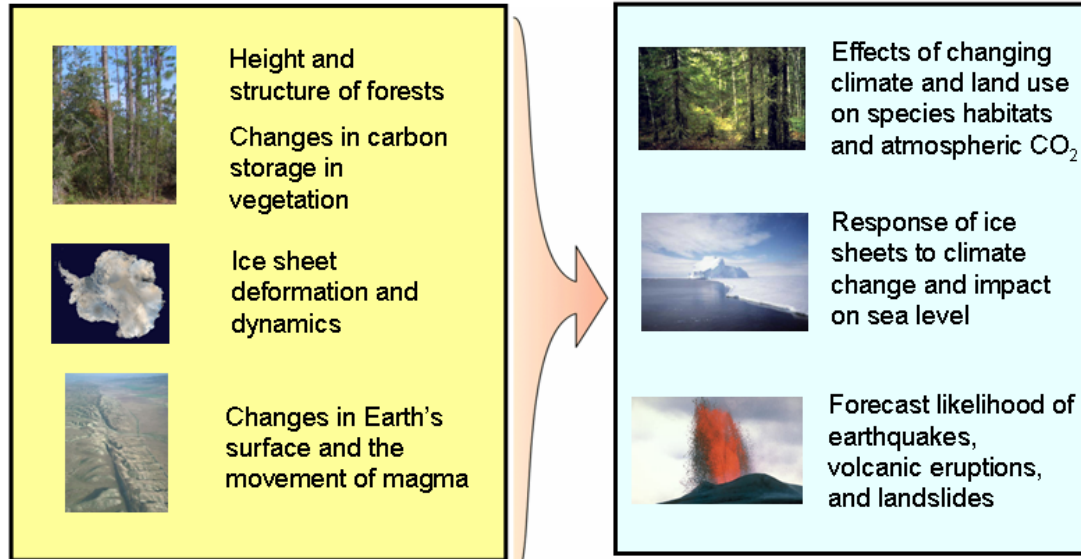
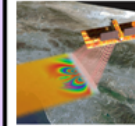
Some Numbers – not including ESAS recommendations

	2006	2010	2015
Number of NASA/NOAA missions (currently flying + planned)	29	18	9
Number of NASA/NOAA instruments (currently flying + planned missions)	122	68	35

Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI)

Launch: 2010-2013

Mission Size: Large

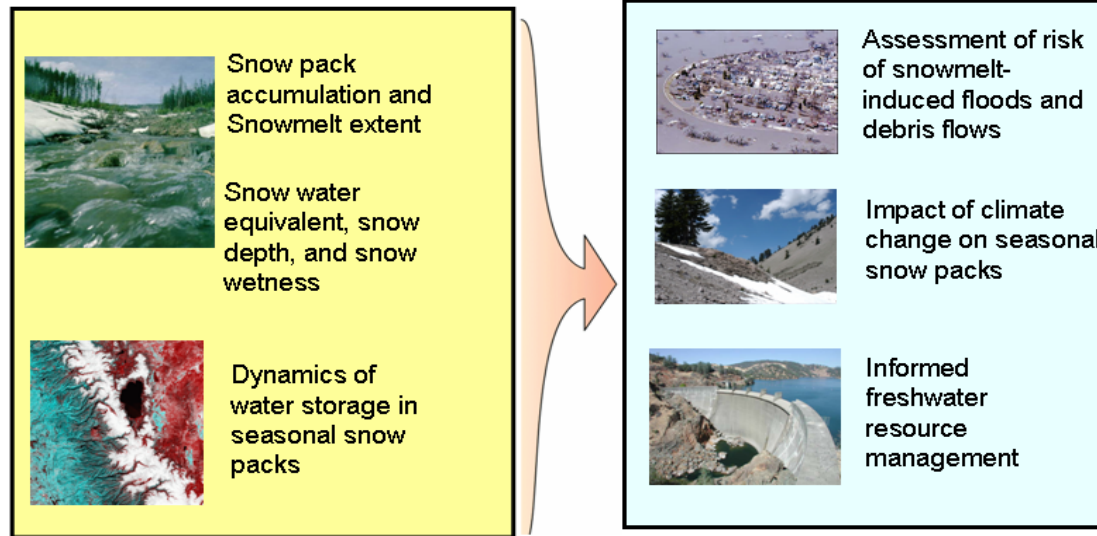
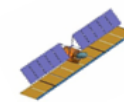


Mission and Payload: This mission combines two sensors that, taken together, provide observations important for solid-Earth (surface deformation), ecosystems (terrestrial biomass structure) and climate (ice dynamics). The sensors are: 1) an L-band Interferometric Synthetic Aperture Radar (InSAR) system with multiple polarization, and 2) a multiple beam lidar operating in the infrared (~ 1064 nm) with ~ 25 m spatial resolution and 1 m vertical accuracy. The mission using InSAR to meet the science measurement objectives for surface deformation, ice sheet dynamics, and ecosystem structure has been extensively studied. It requires a satellite in 700-800 km sun-synchronous orbit in order to maximize available power from the solar arrays. An eight day revisit frequency balances temporal decorrelation with required coverage. Onboard GPS achieves cm-level orbit and baseline knowledge to improve calibration. The mission should have a 5 year life time to capture time-variable processes and achieve measurement accuracy.

Snow and Cold Land Processes (SCLP)

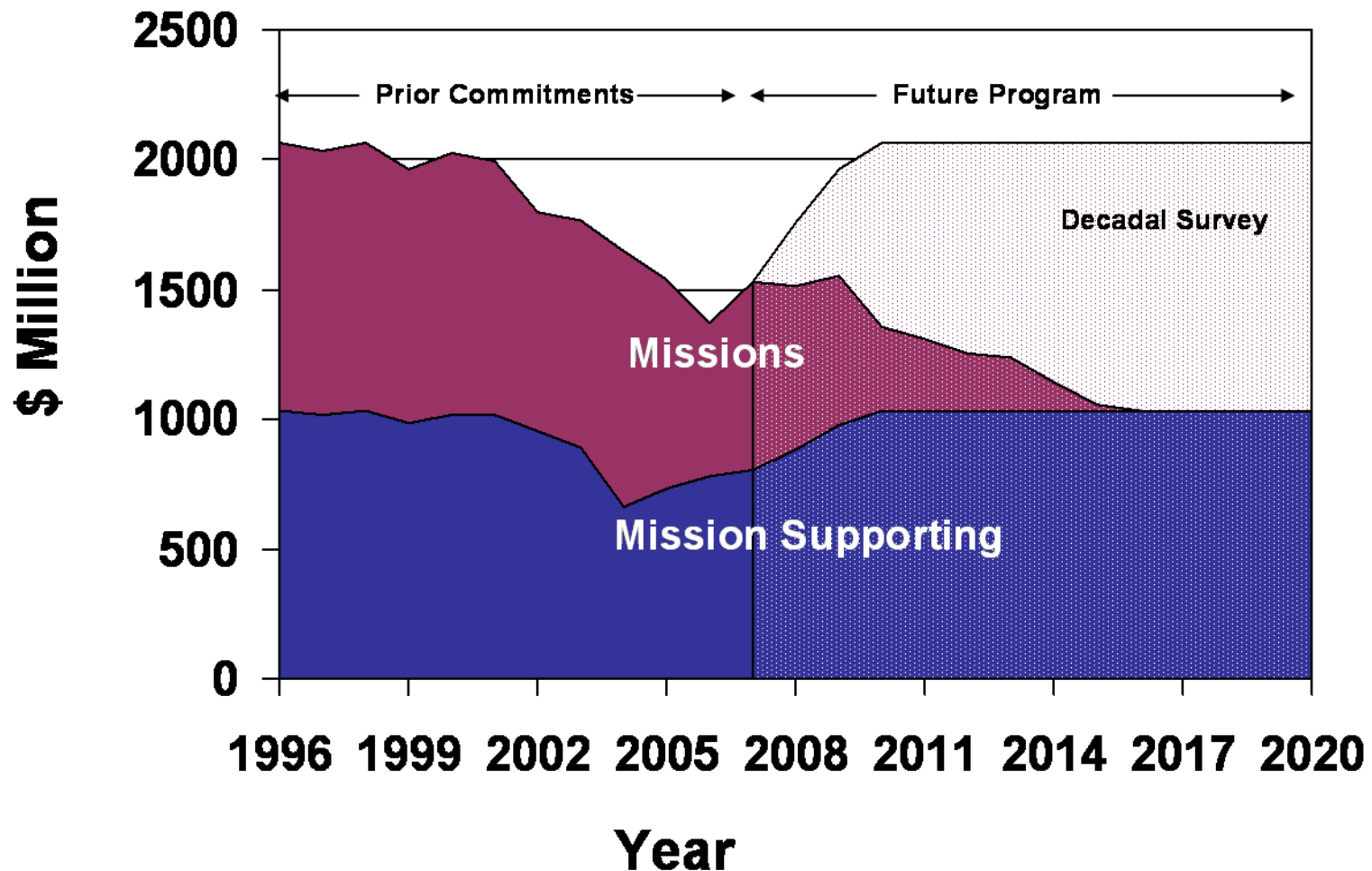
Launch: 2016-2020

Mission Size: Medium



Mission and Payload: A mission consisting of a dual mode high frequency (X-, Ku-band, with VV- and VH-polarization) SAR and high frequency (K-, Ka-band with H-polarization) passive microwave radiometry in low earth orbit (LEO) would meet the science objectives. Microwave sensors are best suited for the measurement objectives. A combination of active and passive microwave instruments will provide the needed spatial resolution and heritage for key climate data records, respectively. The two high frequency SAR channels are sensitive to volumetric scattering in snow, but sample a range of depths and so are capable of characterizing both deep and shallow snowpacks. The X-band SAR would also be used to create a reference image thereby accounting for substrate emissivity. The dual polarization mode SAR enables discrimination of the radar backscatter into volume and surface components. The dual frequency passive microwave radiometer would provide additional information to aid the radar retrievals and would also provide a link to snow measurements from previous, recent and planned passive microwave sensors. A multi-resolution configuration would provide spatial resolution on the order of 50-100 m for spatial variability at the hillslope scale. However, it is not essential to have this resolution everywhere all of the time. Sub-kilometer spatial resolution would often be sufficient as long as 50-100 m observations were regularly available to link to finer-resolution local and hillslope-scale processes. Dual temporal resolution is also proposed with 15-day temporal resolution to capture intra-seasonal variability and a shorter repeat interval of 3-6 days to resolve the effects of synoptic weather events.

Implementing the Survey (NASA Budget)



NOAA NESDIS Program: Next Decade (Decadal Survey Recommended)

