Earth Science and Applications from Space
National Imperatives for the Next Decade and Beyond

Briefing to Committee on Radio Frequencies

Dr. Arthur Charo, Space Studies Board

April 25, 2007

Pre-publication: http://www.nap.edu/catalog/11820.html

Organization of Study

- Executive Committee (18 members)
- Seven Thematically-Organized Panels (~12 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

Executive Committee

1. Rick Anthes, UCAR, co-chair, atmospheric science
2. Berrien Moore, U. New Hampshire, co-chair, biogeochemical cycling
3. Jim Anderson, Harvard, atmospheric science, chemistry
4. Bruce Marcus, TRW (ret), remote sensing
5. Bill Gail, Microsoft Virtual Earth, civil space and IT
6. Susan Cutter, U. South Carolina, hazards and risk
7. Tony Hollingsworth, ECMWF, weather forecasting
8. Kathie Kelly, U. Washington, physical oceanography/satellite obs
9. Neal Lane, Rice, policy
10. Warren Washington, NCAR, climate
11. Mary Lou Zoback, RMS, solid earth

Panel Chairs

12. Tony Janetos, PNL/U. Md., ecology and land remote sensing
13. Brad Hagar, MIT, solid earth
14. Ruth DeFries, U. Maryland, land cover change and remote sensing
15. Susan Avery, CIRES and CU, meteorology, space weather
16. Eric Barron, U. Texas, climate, paleoclimate
17. Dennis Lettenmaier, U. Washington, hydrology
18. Mark Wilson, U. Michigan, infectious disease and remote sensing

ESAS 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.
- Identify important directions that should influence planning for the decade beyond.

Sponsors: NASA SMD, NOAA NESDIS, USGS Geography

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)

Long ago and far away….

CHALLENGES

- Community Buy-in
  - First decadal survey
  - Breadth of interests
    - An organizational challenge was how to cover science/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 during the study at NASA and NOAA
  - Budgets
  - NPOESS
  - GOES

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

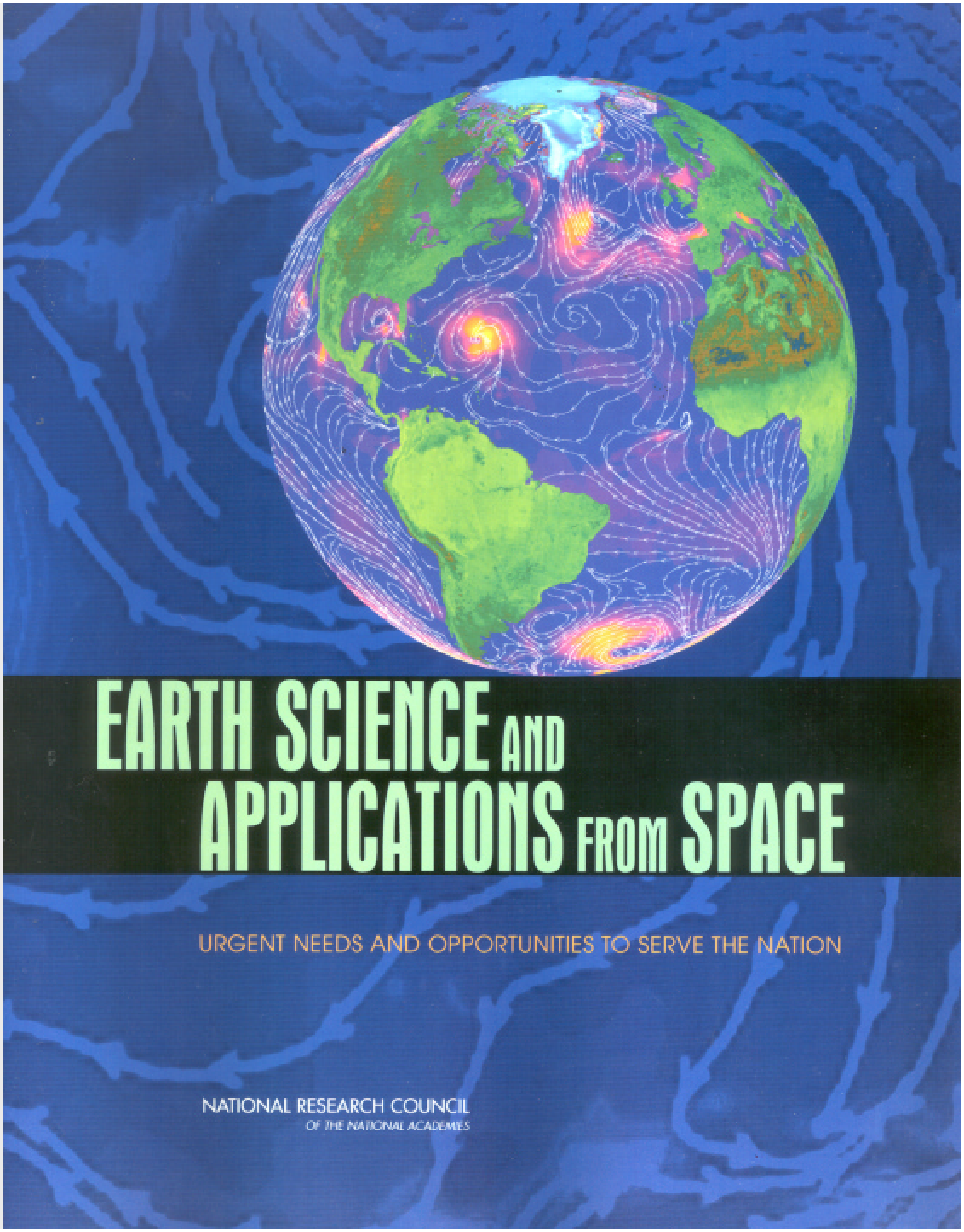
Extreme events, including severe storms, heat waves, earthquakes and volcanoes

VISION

A healthy, secure, prosperous and sustainable society for all people on Earth

"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."

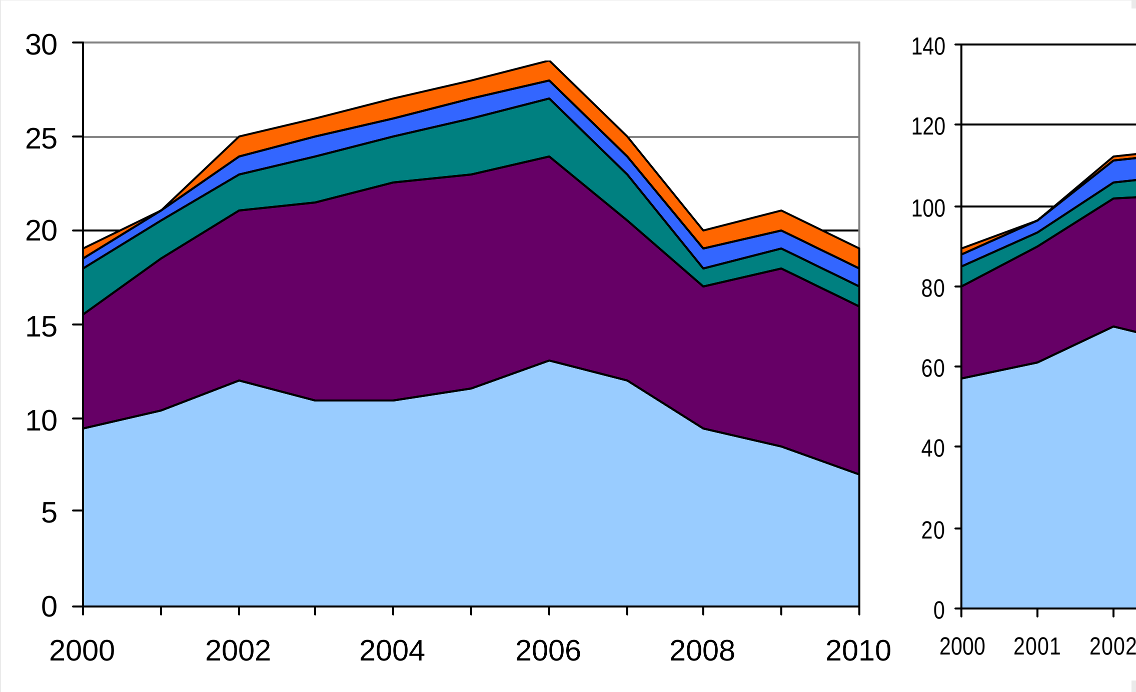
NRC (April 2005)

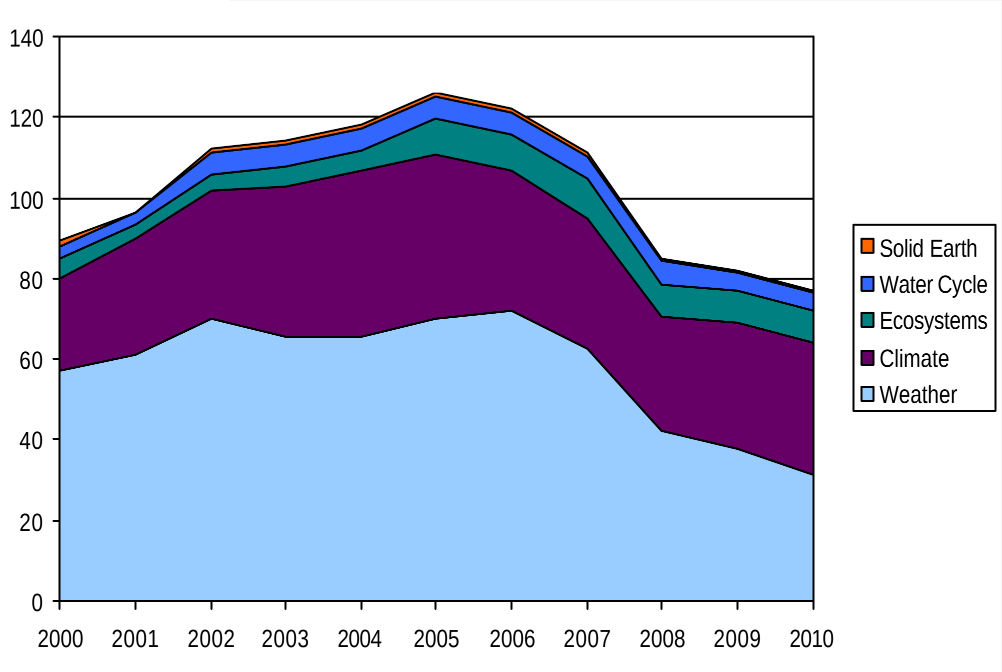


Interim Report

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

Trends In Earth Observations Missions From Space





Number of Missions **Number of Instruments**

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

Missions currently planned, taken from NASA/NOAA websites. Assumes ALL S/C last 4 years *past* design lifetime

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
  - Panel recommendations rolled-up
  - Missions sequenced
  - Overall cost matched to anticipated resources plus reasonable growth
- Highest Priorities of Each Panel Preserved
- Some Guidance on How To Handle Budget or Technology Development Problems

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 Scatteromenter)
  - 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

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

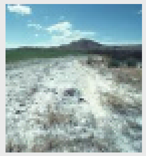
[1] Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high-accuracy SST measurement

Changes in carbon storage in vegetation

DESDynI
Launch 2010-2013

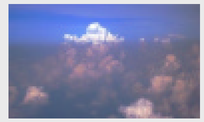
Pressure/ temperature/ water vapor profiles

GPSRO
Launch 2010-2013



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

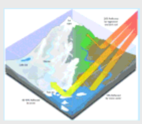
ICESat-II
Launch 2010-2013



Aerosol and cloud types and properties

ACE
Launch 2013-2016

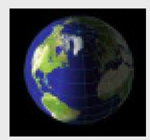
Absolute spectrally resolved IR radiance



Incident solar and spectrally resolved reflected irradiance

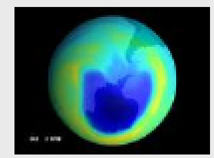
CLARREO
Launch 2010-2013

CO_2 measurements: Day/night, all seasons, all latitudes



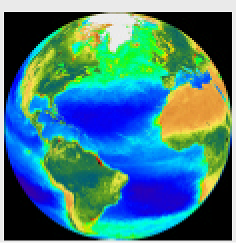
Connection between climate and CO_2 exchange

ASCENDS
Launch 2013-2016



Vertical profile of ozone and key ozone precursors

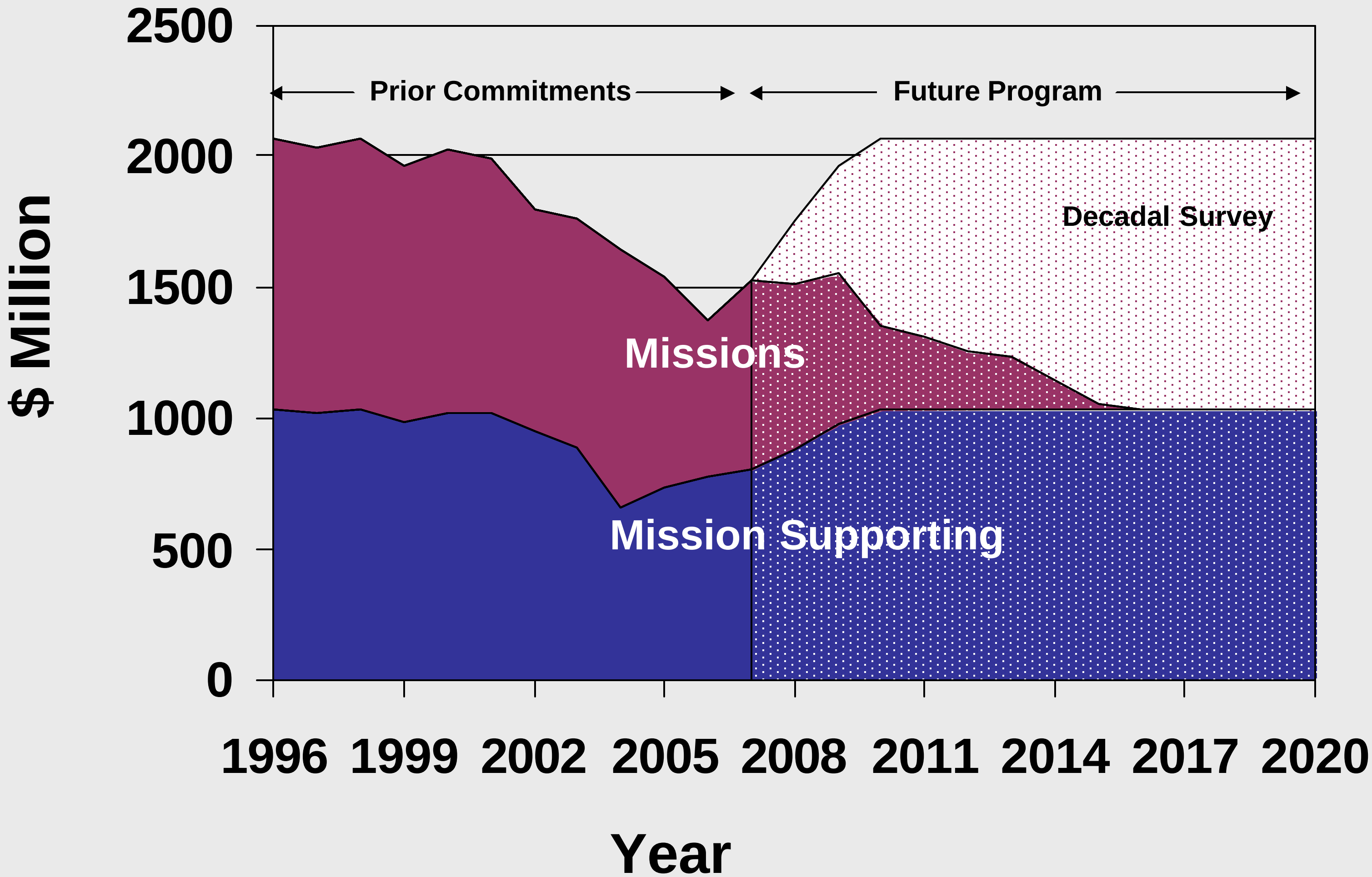
GACM
Launch 2016-2020



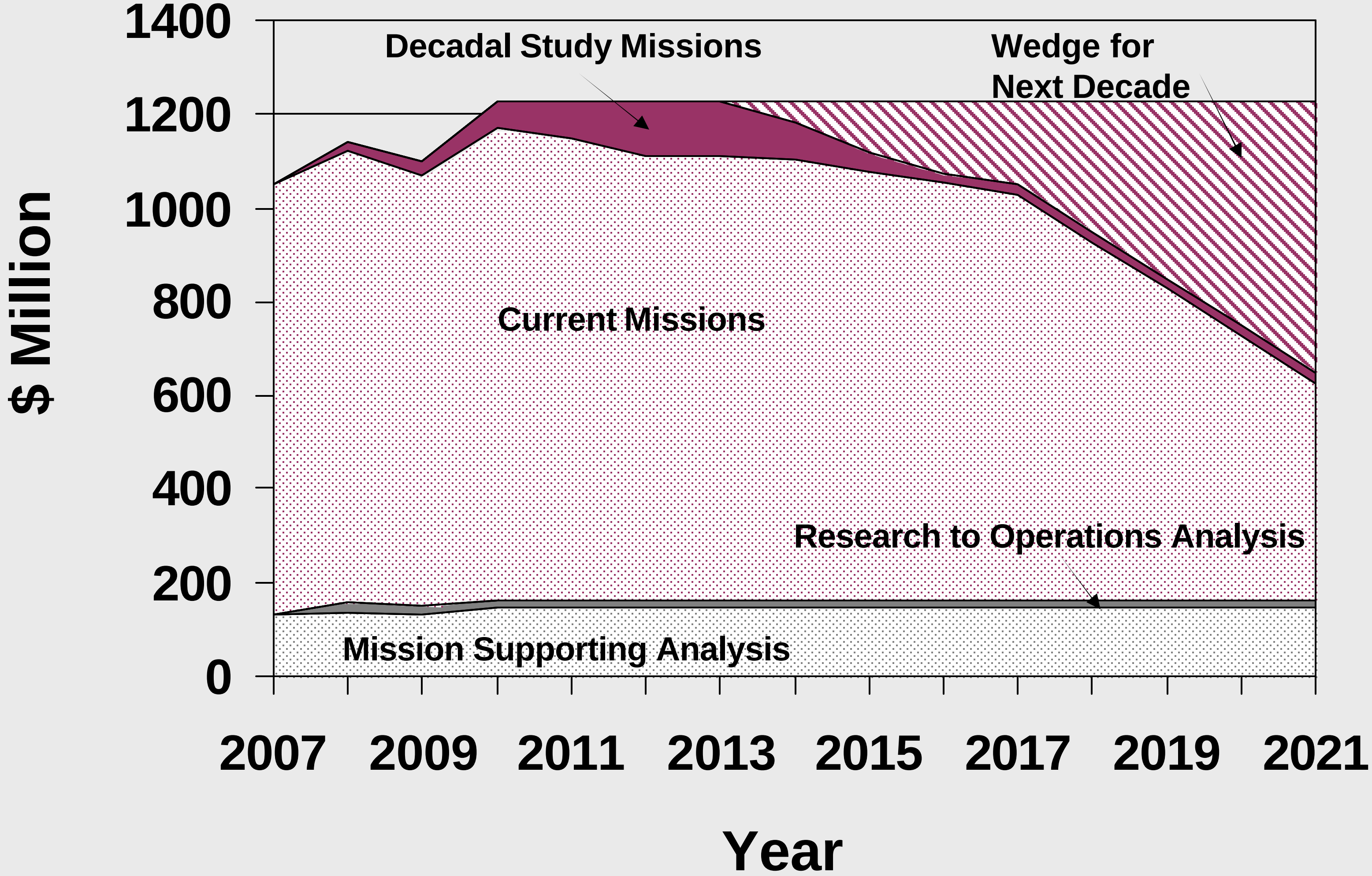
***Societal Challenge:* Climate Prediction**

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

Implementing the Survey (NASA Budget)



NOAA NESDIS Program: Next Decade (Decadal Survey Recommended)



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

RECOMMENDATIONS

- 12 additional recommendations related to turning observations into information (Chapter 3 of report)

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.

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

- **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

- ***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 descoping 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)...

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Prepublication version available now at

http://www.nap.edu/catalog/11820.html

Backup Slides

Contributions of Recommended Missions to Continuation or Expansion of EDRs--continued

EDR dependent on CMIS replacement	NPOESS Sensor	Relevant ESAS Contribution
Atmospheric vertical moisture profile	CrIS/ATMS/CMIS(replacement)	PATH, GPSRO, CLARREO
Atmospheric vertical temperature profile	CrIS/ATMS/CMIS(replacement)	PATH, GPSRO, CLARREO
Global sea surface winds	CMIS(replacement)	XOVWM
Imagery	VIIRS/CMIS(replacement)	HyspIRI
Sea surface temperature	VIIRS/CMIS(replacement)	PATH
Precipitable water/Integrated water vapor	CMIS(replacement)	ACE
Precipitation type/rate	CMIS(replacement)	PATH
Pressure (surface/profile)	CrIS/ATMS/CMIS(replacement)	GPSRO, CLARREO
Total water content	CMIS(replacement)	ACE
Cloud ice water path	CMIS(replacement)	ACE
Cloud liquid water	CMIS(replacement)	ACE
Snow cover/depth	VIIRS/CMIS(replacement)	SCLP
Global sea surface wind stress	CMIS(replacement)	XOVWM
Ice surface temperature	VIIRS/CMIS(replacement)	
Sea ice characterization	VIIRS/CMIS(replacement)	SCLP, ICESat-II

If currently planned missions *and* ESAS recommendations are executed…

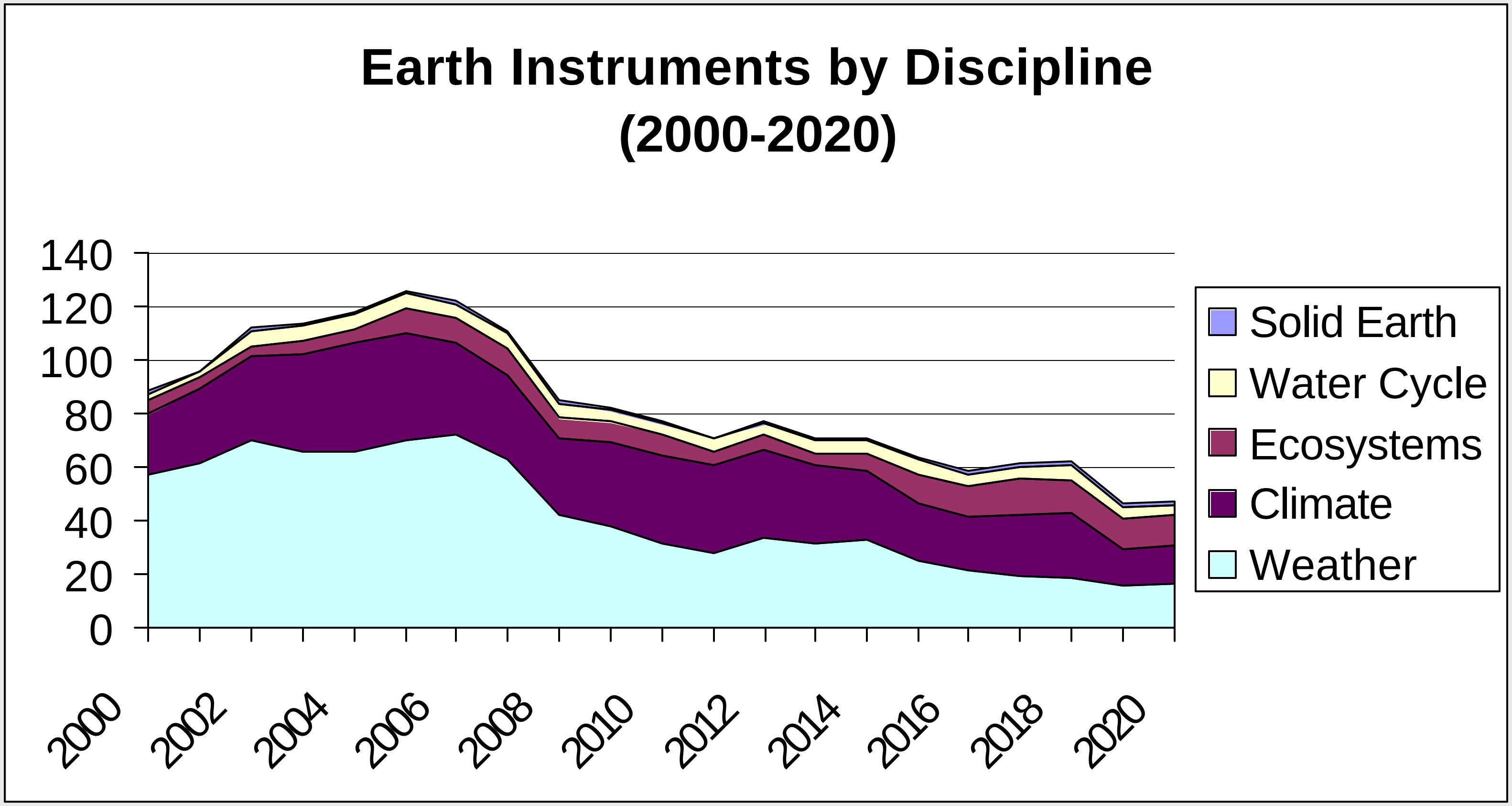
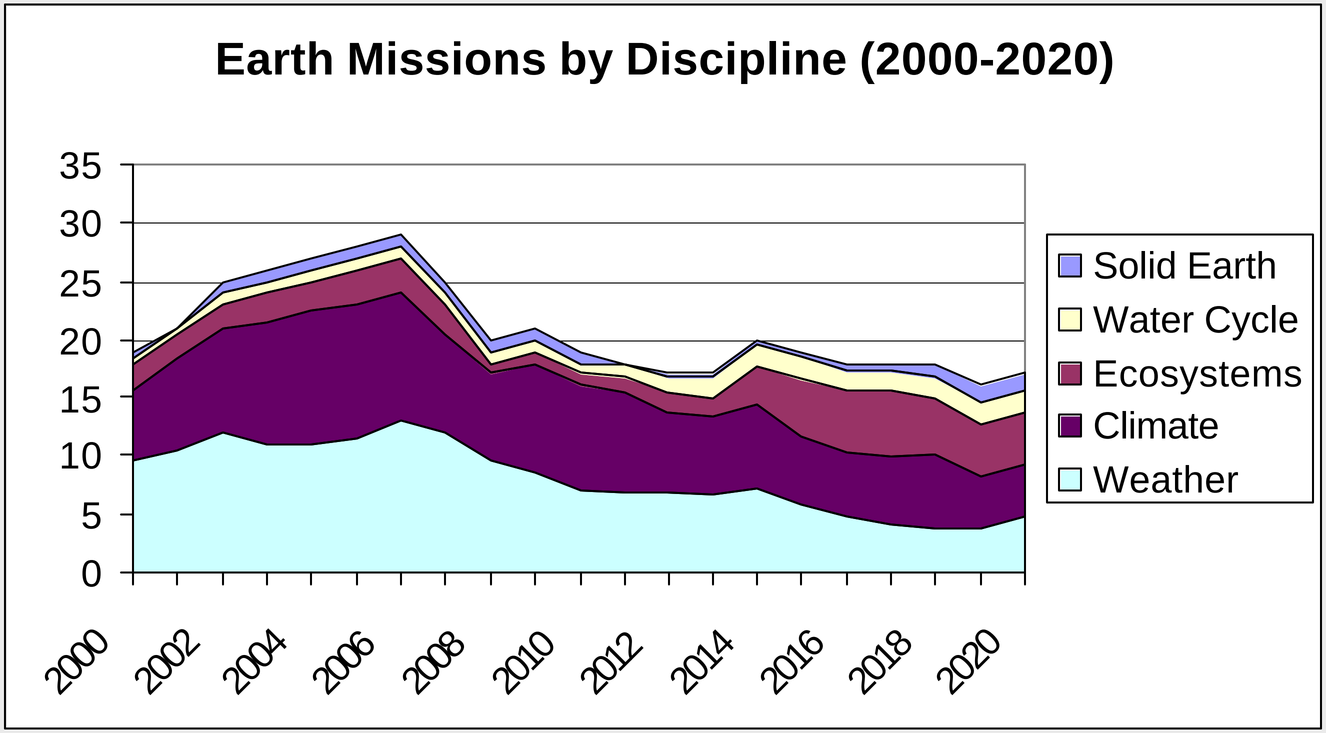
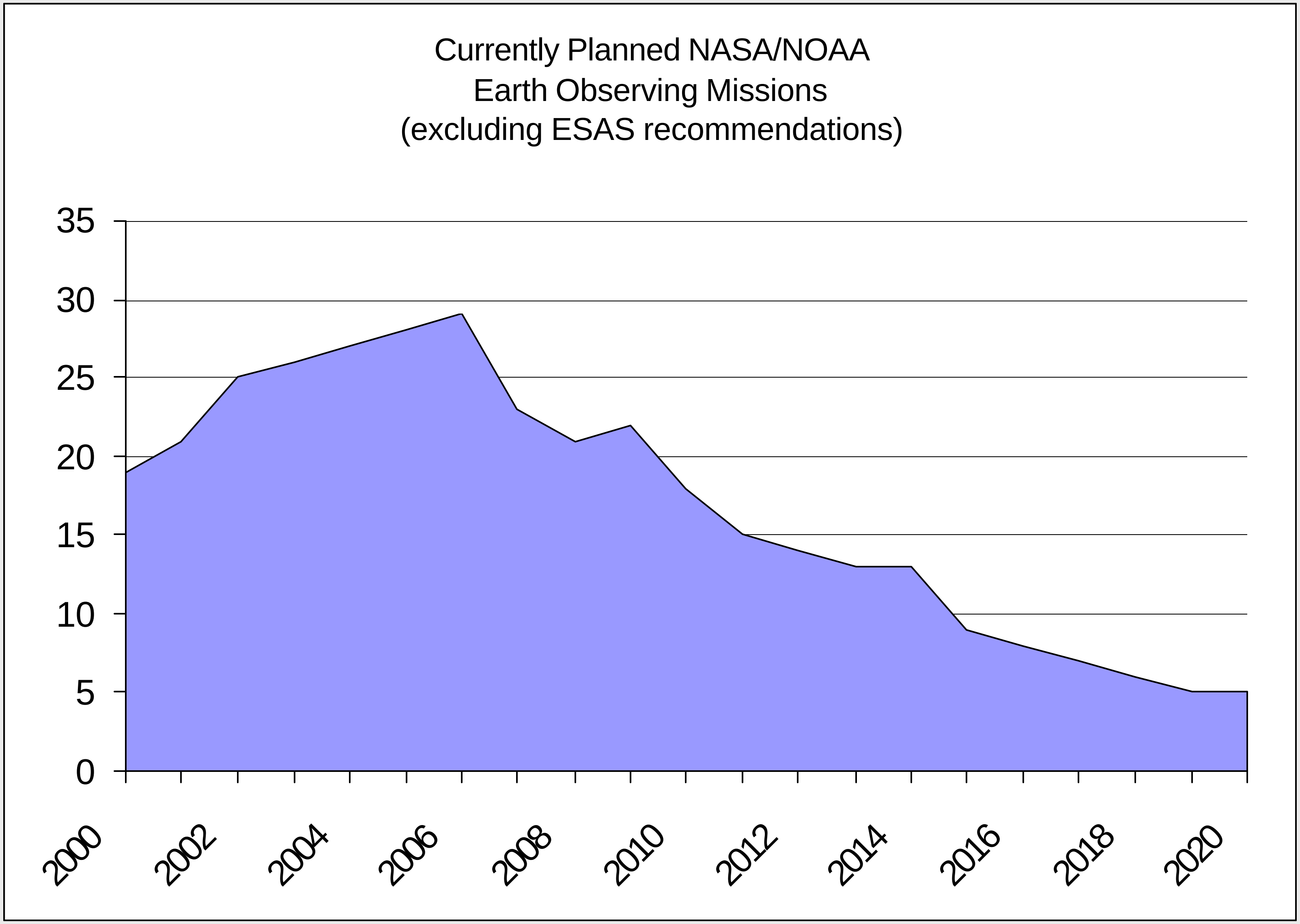


Figure in prepub – includes ESAS recommendations

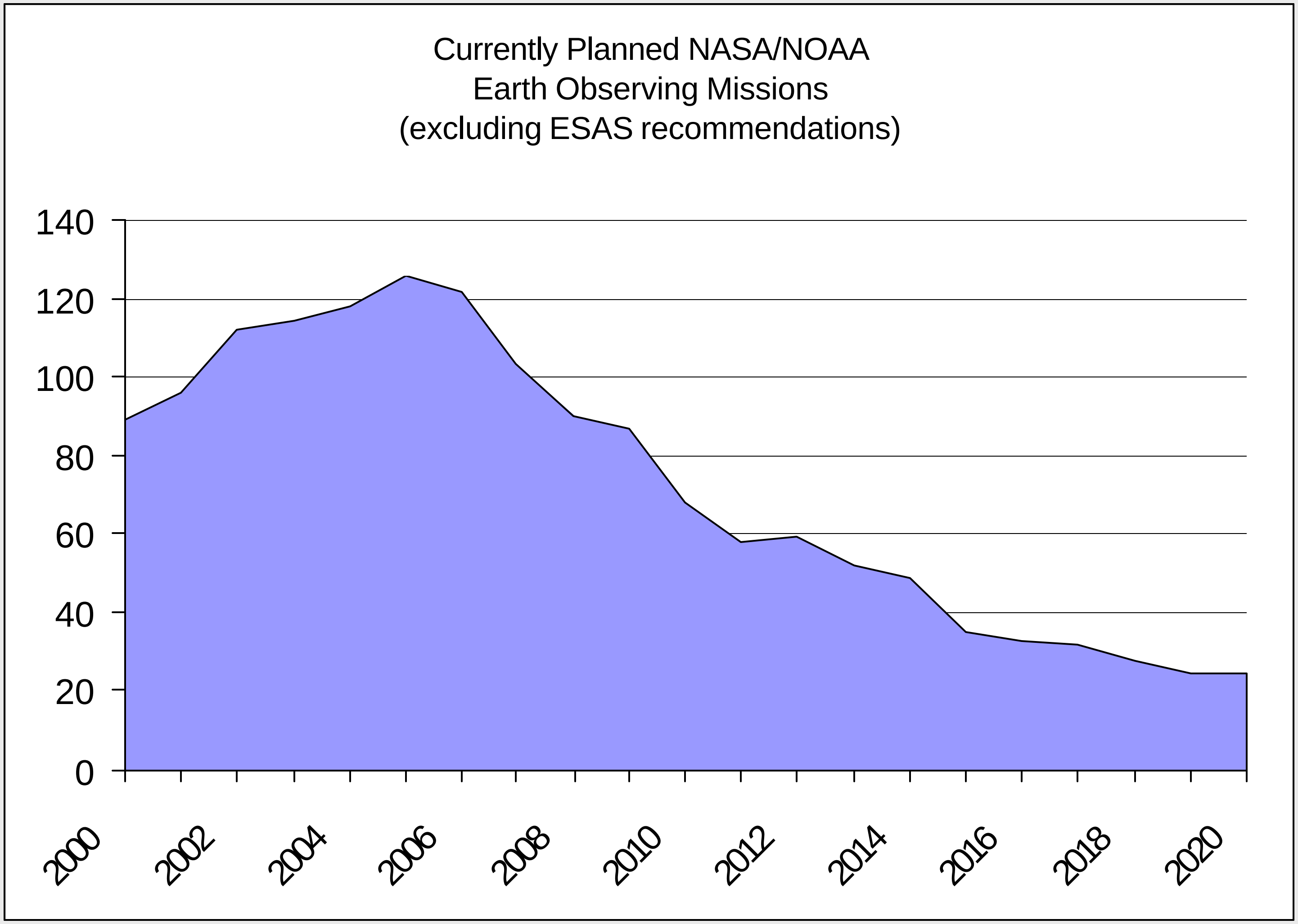


Prepub figure – includes ESAS recommendations

If nothing is done beyond what is currently planned..



New figure – updated to reflect all known NASA/NOAA changes, reconciles with NOAA plans as presented at AMS



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