



Future Earth Observations

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Outline

- Bringing it All Back Home: Thoughts on Earth vs. Planetary vs. Exoplanet Observations
- Prospects and Challenges for Future Earth Observations

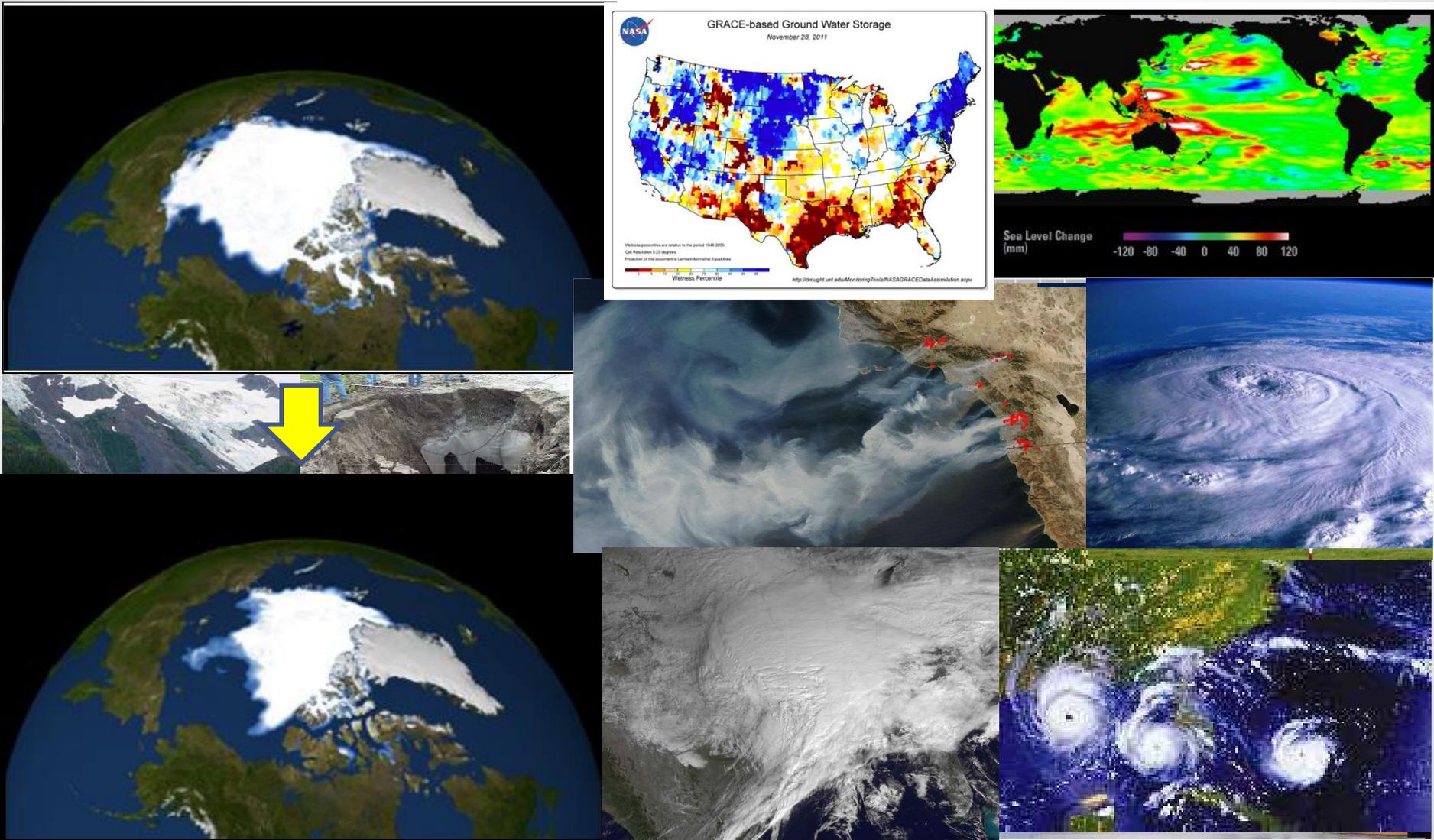
Detail vs. Discovery

- We know quite a bit about the Earth as a system
 - To add value today, Earth observations from space generally require high precision, fine spatial resolution, etc.
 - Often can/need to combine with in situ measurements, models, and/or algorithms to use the data that is collected (to extract information from data)
 - Models and algorithms can be quite sophisticated given extensive state-of-the-art knowledge of the Earth system
- We know less about exoplanets (remain in discovery phase)
 - No in situ measurements available
 - Can rely on first principles to make discoveries
 - Can also look for opportunities to leverage existing body of knowledge based on Earth observations (physics translates – but need to determine which aspects of models/retrievals can/should be used)
 - Use to test Earth models/algorithms in an unaltered-by-humans context?

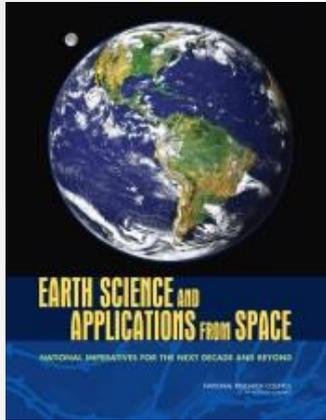
Observing Earth, Planets & Exoplanets from Space

	Earth	Planetary	Exoplanets
First space-based observations	1958: Explorer 1	1962: Mariner 2 Venus	2006: COROT (first discovery, 2007)
US Agencies involved	Many	One	One
Programmatic Emphasis	Earth System Science	Characterization	Discovery, Characterization
Types of observations	Research, Sustained, Operational	Research, Some Sustained...	Research
Example of a meaningful advance	Surface temperature to 0.1 K, CO ₂ concentration to 0.3%	Evidence for flowing liquid water on Mars	Is it in the habitable zone? Does it have an atmosphere or ocean?
In situ measurement availability	Extensive	Selected samples	None
Driving Measurement Requirements	High spatial (<1km) @ high spectral resolution (20,000) & high S/N ratio (300)	Entry, decent, landing. Global remote sensing coverage.	Quantify both primary and secondary eclipse

Space Based Observations Provide a Global Perspective on Changes in our Environment



Observing Priorities: NASA Earth Science's Guiding Documents

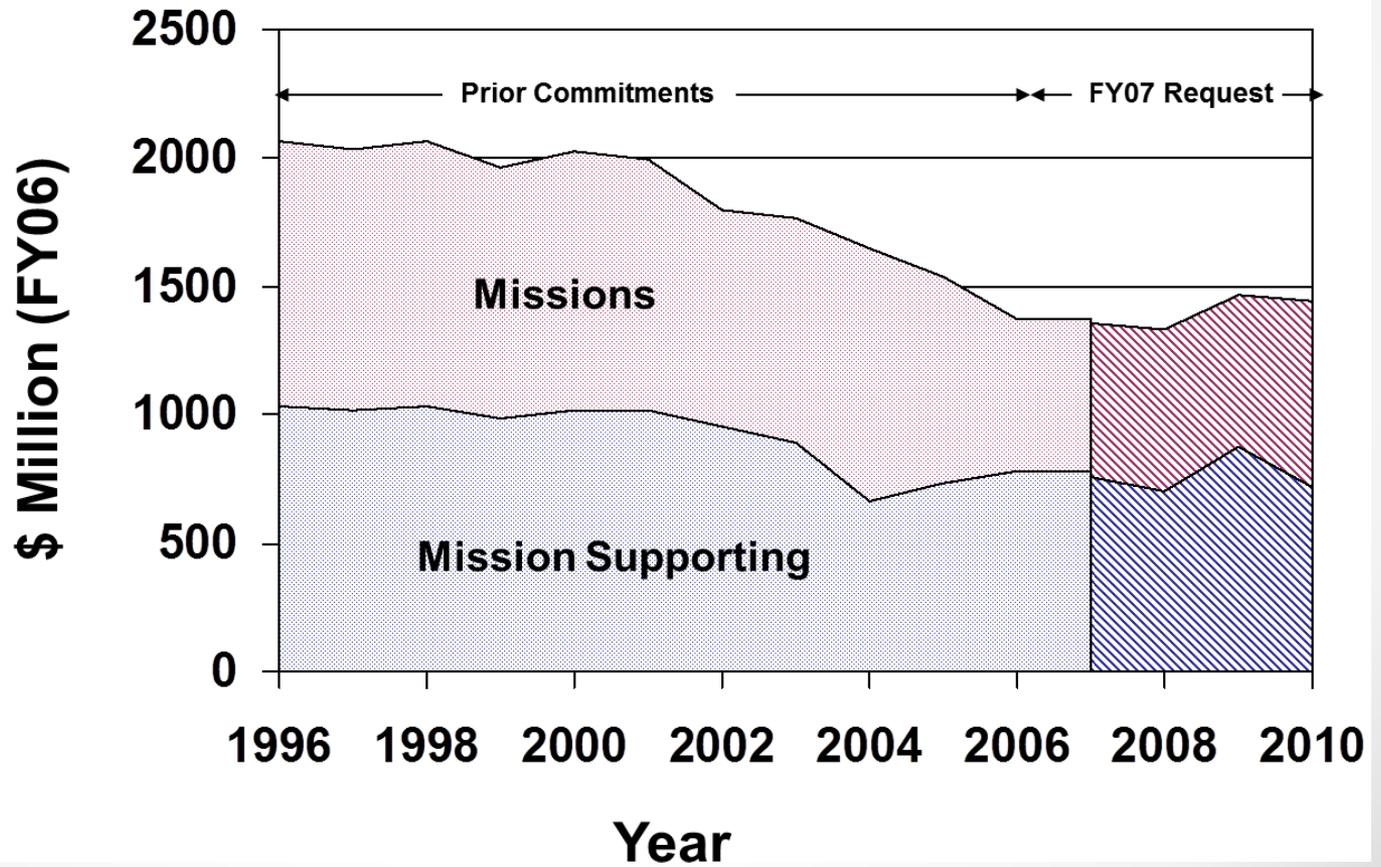
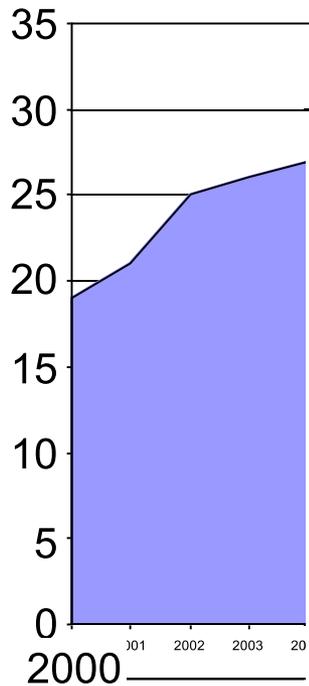


- Decadal Survey (2007)
 - Community consensus on observing priorities for Earth science and applications from space
 - Three agencies: NASA, NOAA (NESDIS), USGS (Geography)
 - Strong emphasis on Earth system science



- Climate-Centric Architecture (2010)
 - Combined decadal survey + administration's priorities
 - Considered implementable within President's FY11 budget
 - Added: \$2.1B, GRACE-FO, PACE, SAGE-3, OCO-3
 - Accelerated SWOT, ASCENDS, EV program

NASA Earth Missions (not including ESAS recommendations)

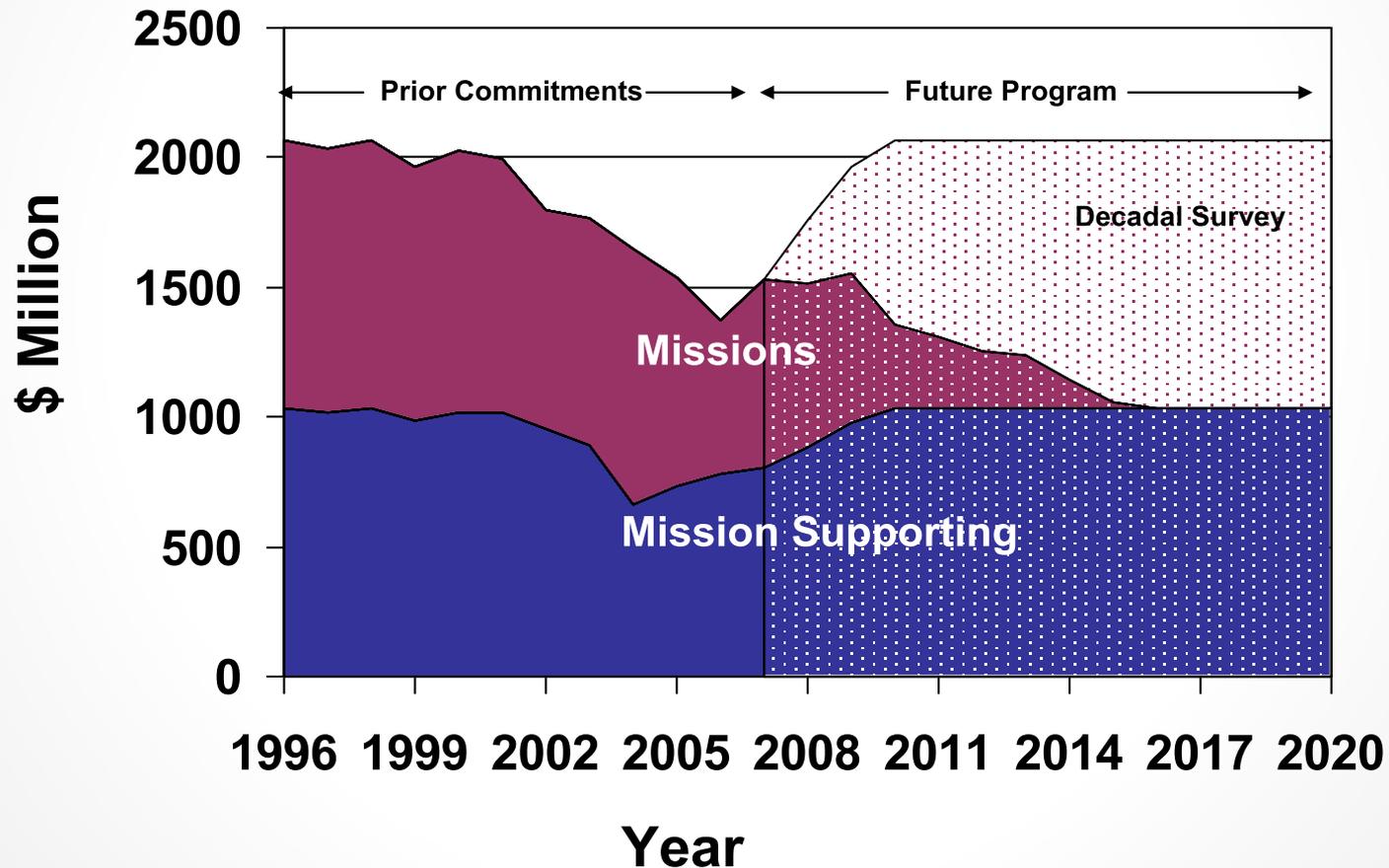


Decadal Survey Recommendations

- Emphasis on **Earth system science** for both research and applications
- Budget restoration to FY2000 level
- “Minimal yet Robust” set of Missions*
 - 17 new missions
 - 3 missions transferred from NASA research to NOAA operations (ocean vector winds, GPS RO, total solar irradiance & Earth radiation)
 - Plan needed for sustained observations (OSTP)
- Many other recommendations regarding program balance, other needed investments

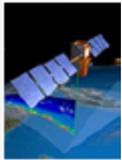
*Assumed all missions already in portfolio at the time would be completed

Budget Restoration Recommended

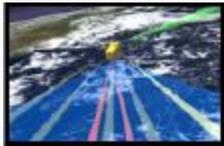


Mission Recommendations

3D-Winds*



ACE*



ASCENDS*

CLARREO*



DESDynI*

GACM*



- NOAA & NASA launch 17 missions from 2010-2020
- NOAA: Transition 3 research missions to operational
 - Extended Ocean Vector Winds Mission (XOVWM*)
 - GPS radio-occultation (GPSRO*) temperature, water vapor, & electron density sounding
 - Total solar irradiance via CLARREO* & NPOESS*

Geo-CAPE*



GPSRO*



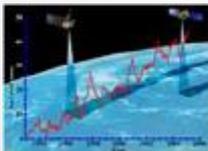
XOVWM*



SMAP



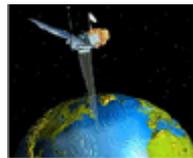
SWOT*



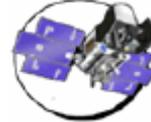
SCLP*



PATH*



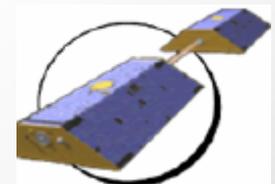
ICESat-II
& LIST*



HyspIRI*



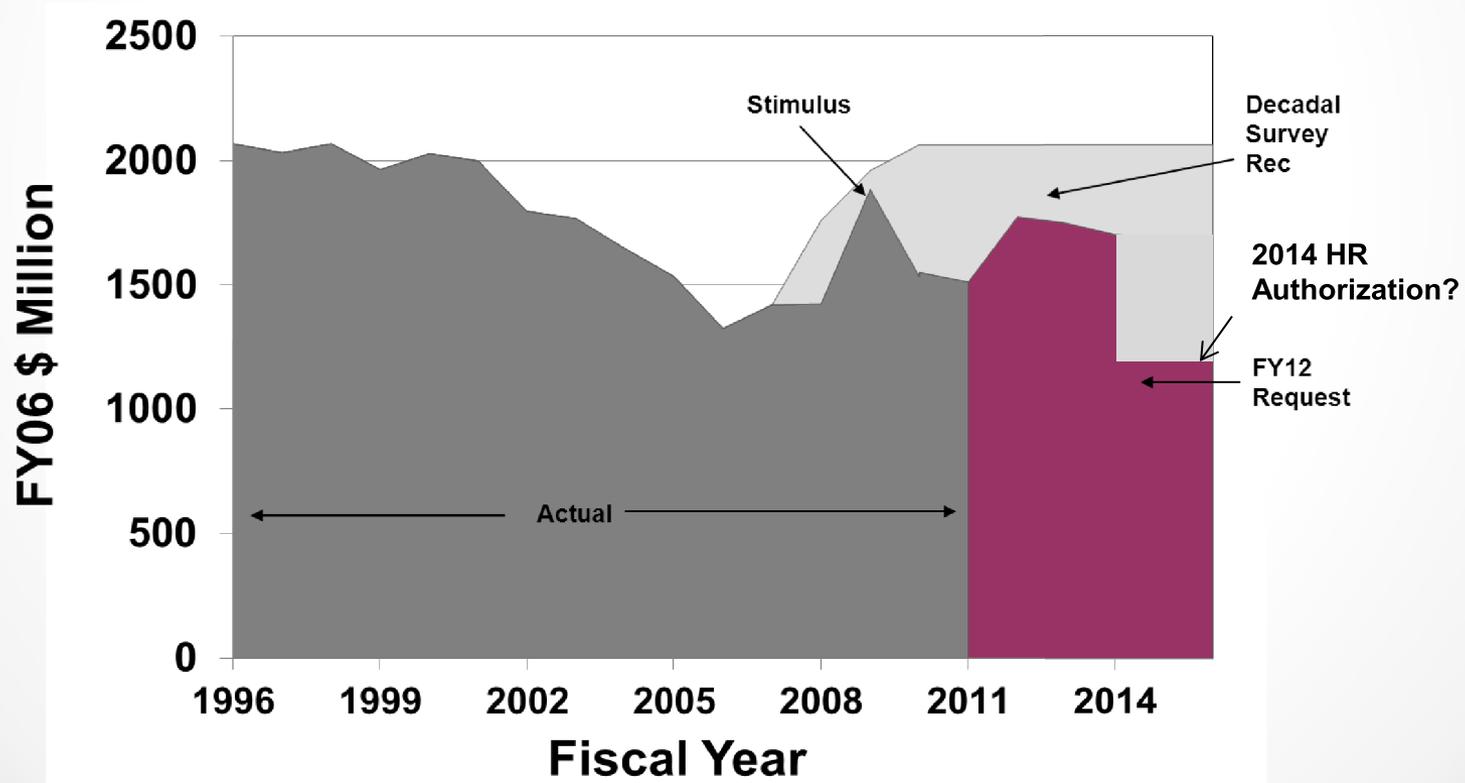
GRACE-II*



But...

- Per the 2012 Midterm Assessment, budgets to execute the Survey have not materialized

Comparison between President's **FY12** NASA Earth Science Request and NRC Recommendation



- The FY12 budget removed \$1.2B from the \$2.1B FY11 proposed Climate Initiative in FY12-15
- Explicit Administration-directed cuts:
 - GMI-2*/GPM LIO* cancelled; (GMI-2* was to be placed in a low-inclination orbit to provide more frequent samplings of precipitation events)
 - CLARREO* held in pre-formulation through FY2016;
 - DESDynI-Lidar* cancelled (full int'l provision required);
 - DESDynI-Radar* deferred until affordable;
 - Planned augmentations to non-flight (R&A, Applied Science, ESTO) reduced

Budget shortfalls considered the principal reason for the inability of NASA to realize the mission launch cadence recommended by the survey.

And...

- Mission cost estimates have grown dramatically:
 - Large cost increases in launch vehicles
 - Absence of medium-launch vehicle—survey assumed Delta II available
 - Addition of capabilities and/or extension of design life (e.g., ICESat-II)
 - Mission creep
 - Some missions more challenging than anticipated; others envisioned synergies that are not readily achieved via the suggested implementation
 - Changes at NASA:
 - Carry margins to provide 70% confidence in cost estimates;
 - Full-cost accounting
 - Missions executed as directed rather than competed/cost-capped
 - Stretch outs
 - Inflation (survey estimates in FY06\$)
 - Science costs included in mission budget (survey excluded R&A investments)

Pre-Decadal Survey Missions

- Finding: Progress in the pre-decadal survey missions has fallen short of expectations because of launch failures, delays, and changes in scope. NASA's primary programmatic emphasis remains on flying out its pre-decadal survey mission queue

TABLE 2.1 Current Status of Pre-Decadal Survey Missions

Mission	Launch Date	Status
OSTM/Jason-2 (Ocean Surface Topography Mission)	June 2008	Operating
OCO (Orbiting Carbon Observatory)	February 2009	Launch failure
Glory	March 2011	Launch failure
Aquarius	June 2011	Operating
NPP (NPOESS Preparatory Project)	October 2011	Operating
LDCM (Landsat Data Continuity Mission)	Targeting December 2012	Implementation
GPM Core (Global Precipitation Mission)	Targeting July 2013	Implementation
GPM LIO (Global Precipitation Mission—low inclination orbiter)	—	Canceled

**Notable Changes
Since Survey:**
OCO-2 Approved
TIRS added to LDCM

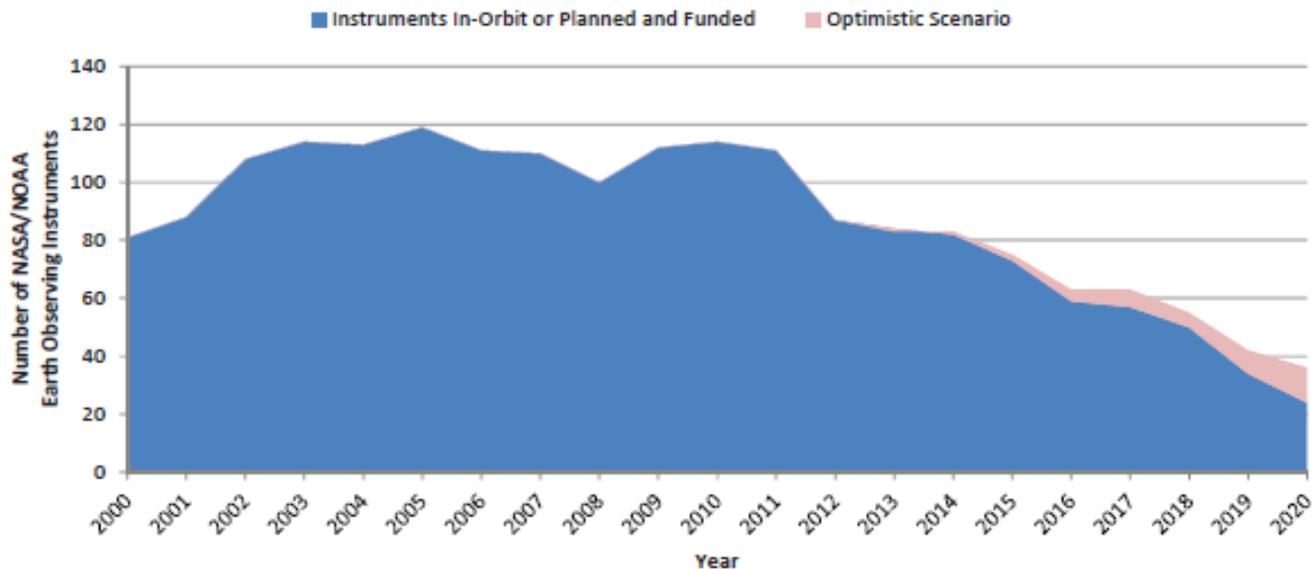
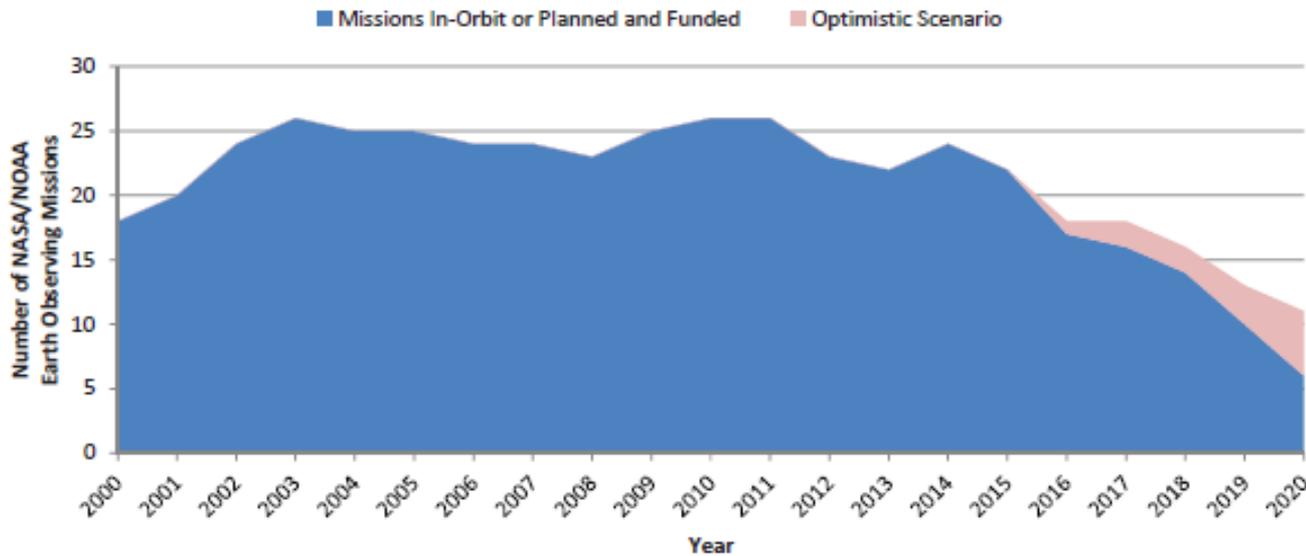
Status of Earth Science Decadal Survey Recommended Missions*

	Recommended		
	Launch Period	Planned Launch Date	Status
CLARREO *(NASA portion)	2010-2013	None	Formulation (Pre-Phase A)
CLARREO *(NOAA portion)	2010-2013	None	Not in NOAA Budget or Plans
DESDynI*	2010-2013	None	Formulation (Pre-Phase A)
GPSRO *(NOAA)	2010-2013	None	Not in NOAA Budget
ICESat-II	2010-2013	10/2015	Implementation Phase (Phase A)
SMAP	2010-2013	11/2014	Implementation Phase (Phase B)
ACE*	2013-2016	None	Formulation (Pre-Phase A)
ASCENDS*	2013-2016	None	Formulation (Pre-Phase A)
GEO-CAPE*	2013-2016	None	Formulation (Pre-Phase A)
HyspIRI*	2013-2016	None	Formulation (Pre-Phase A)
SWOT*	2013-2016	None	Formulation (Pre-Phase A)
XOVWM *(NOAA)	2013-2016	None	Not in NOAA Budget or Plans
3D-WINDS *(Demo)	2016-2020	None	Formulation (Pre-Phase A)
GACM*	2016-2020	None	Formulation (Pre-Phase A)
GRACE-II*	2016-2020	None	Formulation (Pre-Phase A)
LIST*	2016-2020	None	Formulation (Pre-Phase A)
PATH*	2016-2020	None	Formulation (Pre-Phase A)
SCLP*	2016-2020	None	Formulation (Pre-Phase A)

*Proposed Mission - Pre-decisional - for Planning and Discussion Purposes Only

What's the Outlook?

- Finding: The nation's Earth observing system is beginning a rapid decline in capability as long-running missions end and key new missions are delayed, lost, or canceled.
- This jeopardizes ability to advance Earth *system* science
 - Earth system science requires observations of many elements of the Earth system (vs. advancing individual disciplines)



Optimistic Scenario assumes Climate Centric Architecture implementation (GRACE-FO* in 2016, PACE* in 2019, SWOT* in 2020, ASCENDS* in 2020, EVM-1* in 2017, SAGE-3 in 2014, OCO-3 in 2015, EVI* every year starting 2017)

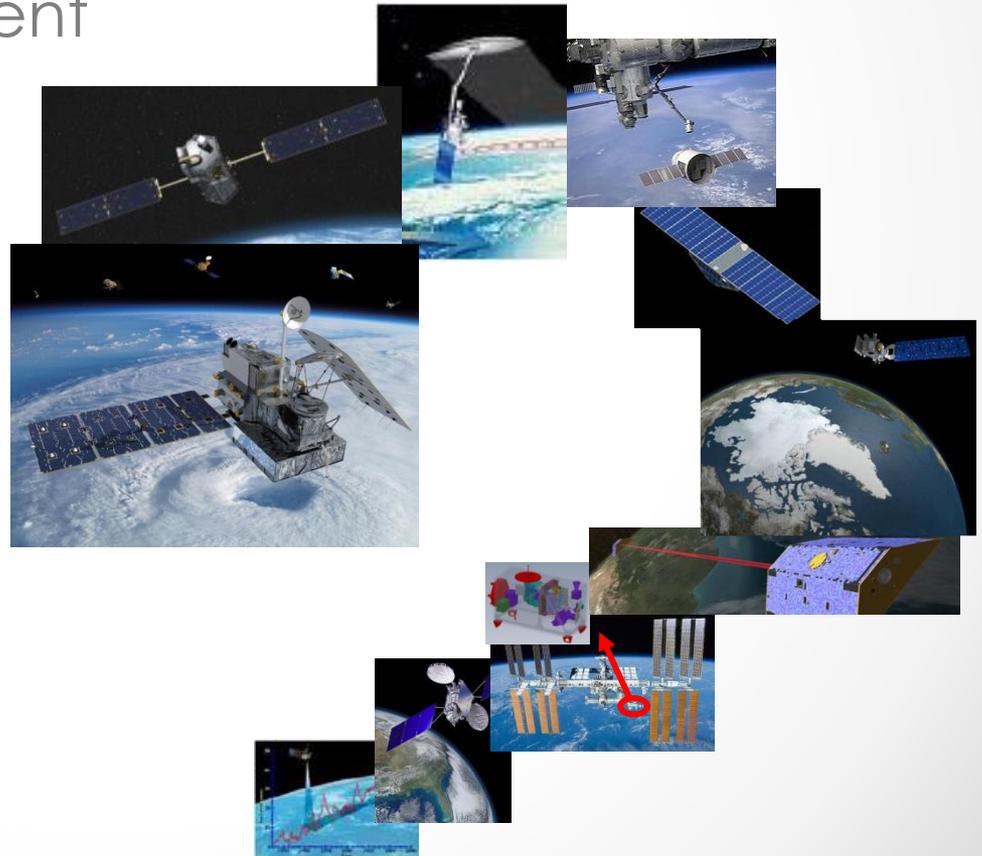
*Proposed Mission - Pre-decisional - for Planning and Discussion Purposes Only

What is NASA doing?

- Executing the program that has been funded
 - Falls short of recommended program but the glass isn't entirely empty

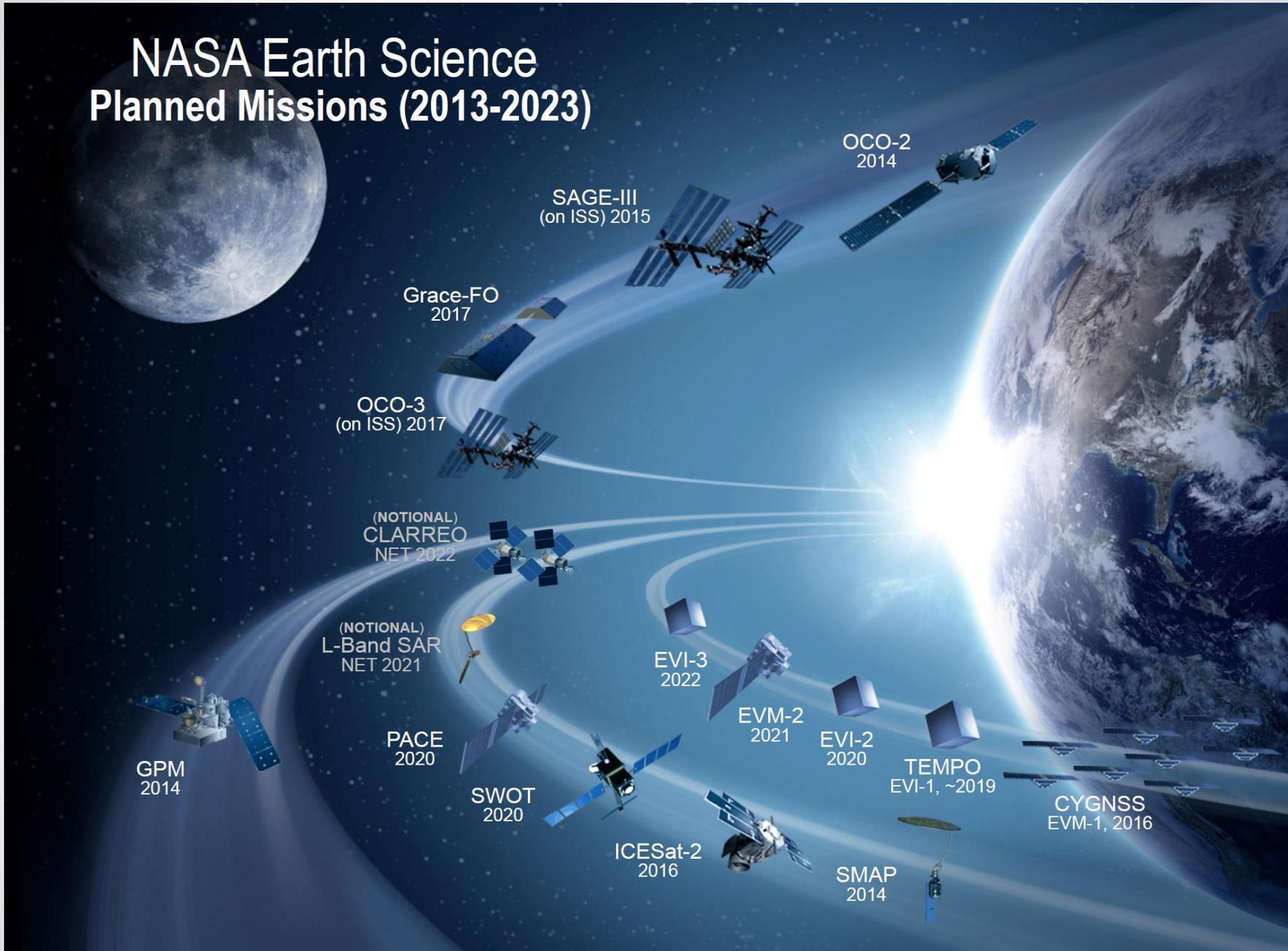
- Missions in Development

- GPM (Feb 2014)
- OCO-2 (July 2014)
- SMAP (Oct 2014)
- SAGE III (2015)
- CYGNSS* (2016)
- ICESat-2 (Dec 2016)
- GRACE FO* (Aug 2017)
- OCO-3 (2017?)
- TEMPO* (~2019)
- SWOT* (2020?)



*Proposed Mission - Pre-decisional - for Planning and Discussion Purposes Only

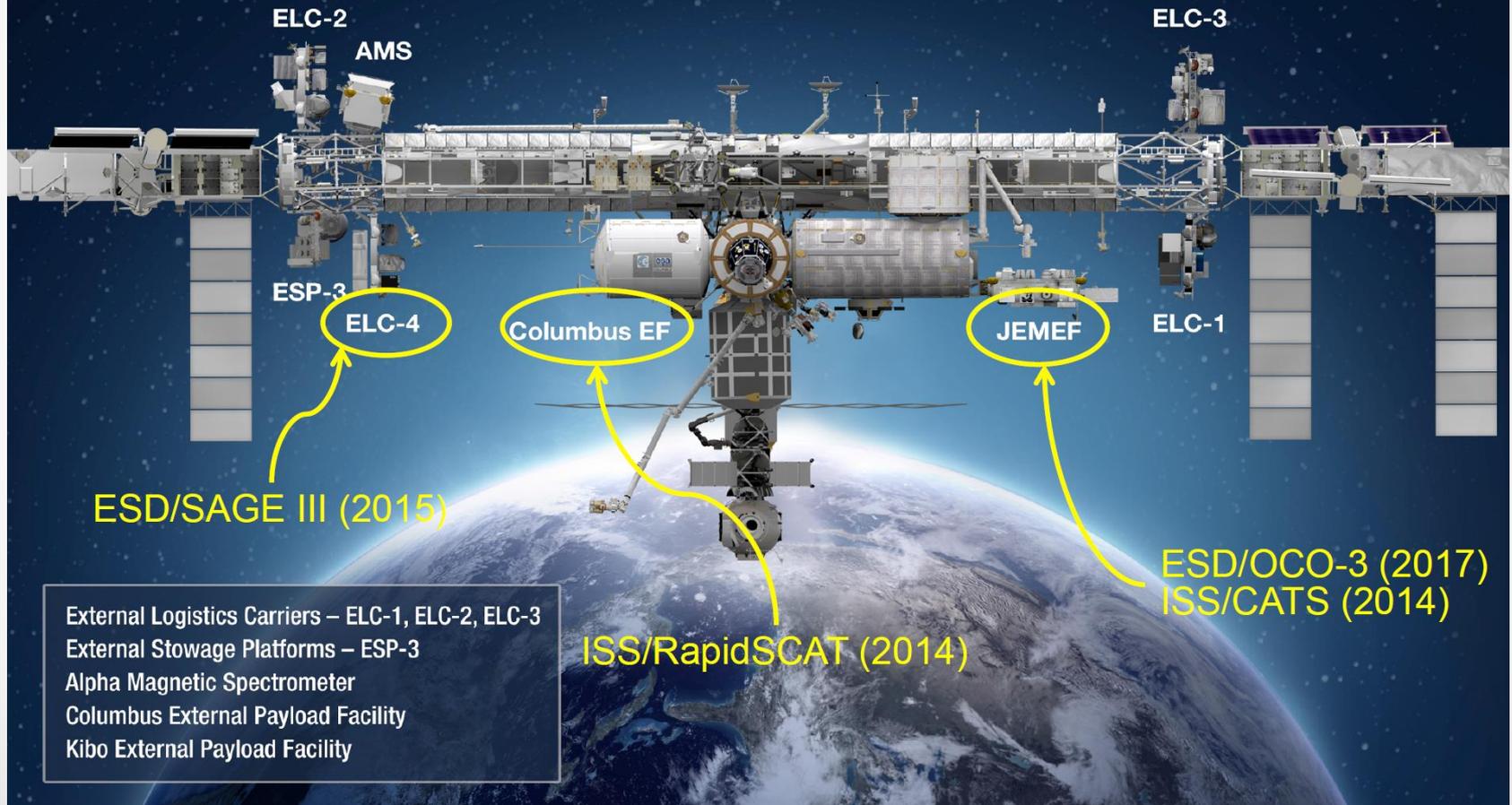
NASA Earth Science Planned Missions (2013-2023)



*Proposed Mission - Pre-decisional - for Planning and Discussion Purposes Only

International Space Station

Earth Science Instruments





Decadal Survey Venture Line

EVS
Sustained Sub-Orbital Investigations

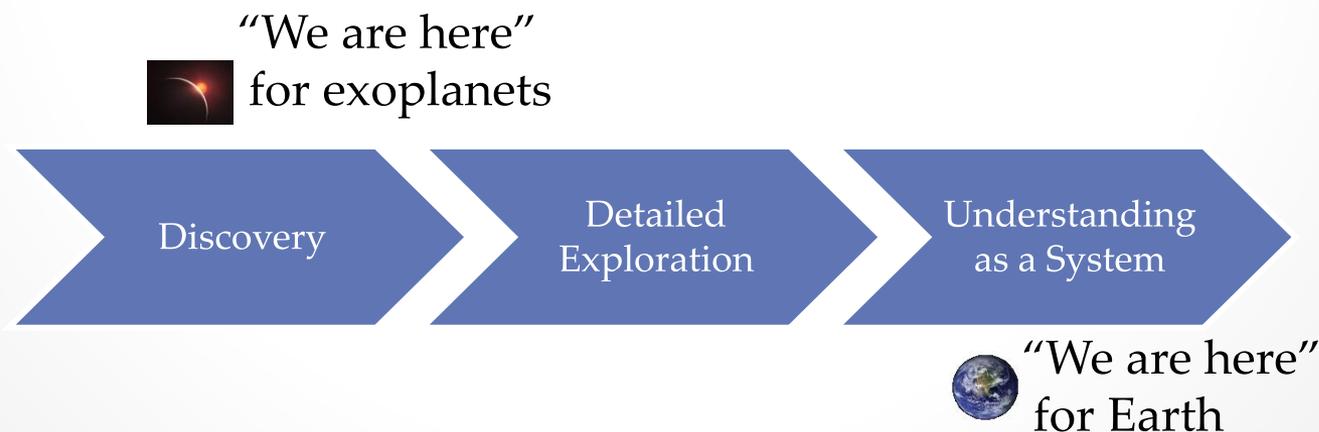
EVM Complete,
self-contained,
small missions

EVI
Full function,
facility-class
instruments
Missions of
Opportunity (MoO)

Mission	Mission Type	Release Date	Selection Date	Major Milestone
EV-1, aka EVS-1	Suborbital	2009	2010	N/A
EVM-1, CYGNSS	Full Orbital	2011	2012	Launch ~2017
EVI-1	Instrument Only	2011	2012	Delivery NLT 2017
EVI-2	Instrument Only	2013	2014	Delivery NLT 2019
EVS-2	Suborbital	2013	2014	N/A
EVI-3	Instrument Only	2014	2015	Delivery NLT 2020
EVI-4	Instrument Only	2015	2016	Delivery NLT 2021
EVM-2	Full Orbital	2015	2016	Launch ~2021
EVI-5	Instrument Only	2016	2018	Delivery NLT 2023
EVI-6	Instrument Only	2017	2019	Delivery NLT 2024

Looking forward

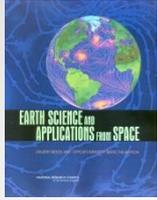
- Using space-based Earth observation as an analogy, we expect evolution of planetary and exoplanet observations from discovery to detailed systematic exploration towards an understanding of exoplanet system science



Acknowledgments

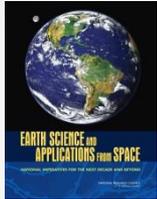
- NRC committees involved in preparing many of these graphics (decadal survey, midterm assessment)
- Steve Volz (NASA HQ) for future mission summary graphics

Further Reading



Interim Report

www.nap.edu/catalog.php?record_id=11281



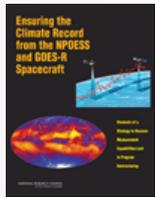
Decadal Survey

www.nap.edu/catalog.php?record_id=11820



Midterm Assessment

www.nap.edu/catalog.php?record_id=13405



Ensuring the Climate Record from the NPOESS and GOES-R Spacecraft

www.nap.edu/catalog.php?record_id=12254



Assessment of Impediments to Interagency Collaboration on Space and Earth Science Missions

www.nap.edu/catalog.php?record_id=13042



Responding to the Challenge of Climate and Environmental Change:

NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space

http://science.nasa.gov/media/medialibrary/2010/07/01/Climate_Architecture_Final.pdf

Earth Science and Applications from Space

A Midterm Assessment of NASA's

Implementation of the Decadal Survey

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