

A composite space image featuring Earth, the Moon, Mars, Jupiter, a comet, a satellite, and a galaxy. The Earth is in the upper left, showing continents and clouds. The Moon is in the center, and Mars is in the lower center. Jupiter is in the lower right. A comet is streaking across the center. A satellite is orbiting Earth. A galaxy is in the upper right.

**Science Mission
Directorate**

**Climate-Related Research Carried Out
Under NASA's Earth Science Research
Program**

**Solar Variability, Earth's Climate and Space
Environment Workshop
June 6, 2008**

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Associate Director for Research
Earth Science Division





Overview of Talk

- Climate Variability and Change Research within Earth Science Program
- Recent Results
- NRC Decadal Survey and ESD Actions
- Summary





NASA's Science Goals

- ***Study Earth from space to advance scientific understanding and meet societal needs. (Earth Science)***
- Understand the Sun and its effects on Earth and the solar system. (Heliophysics)
- Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space. (Planetary Science)
- Discover the origin, structure, evolution, and destiny of the universe, and search for Earth-like planets. (Astrophysics)

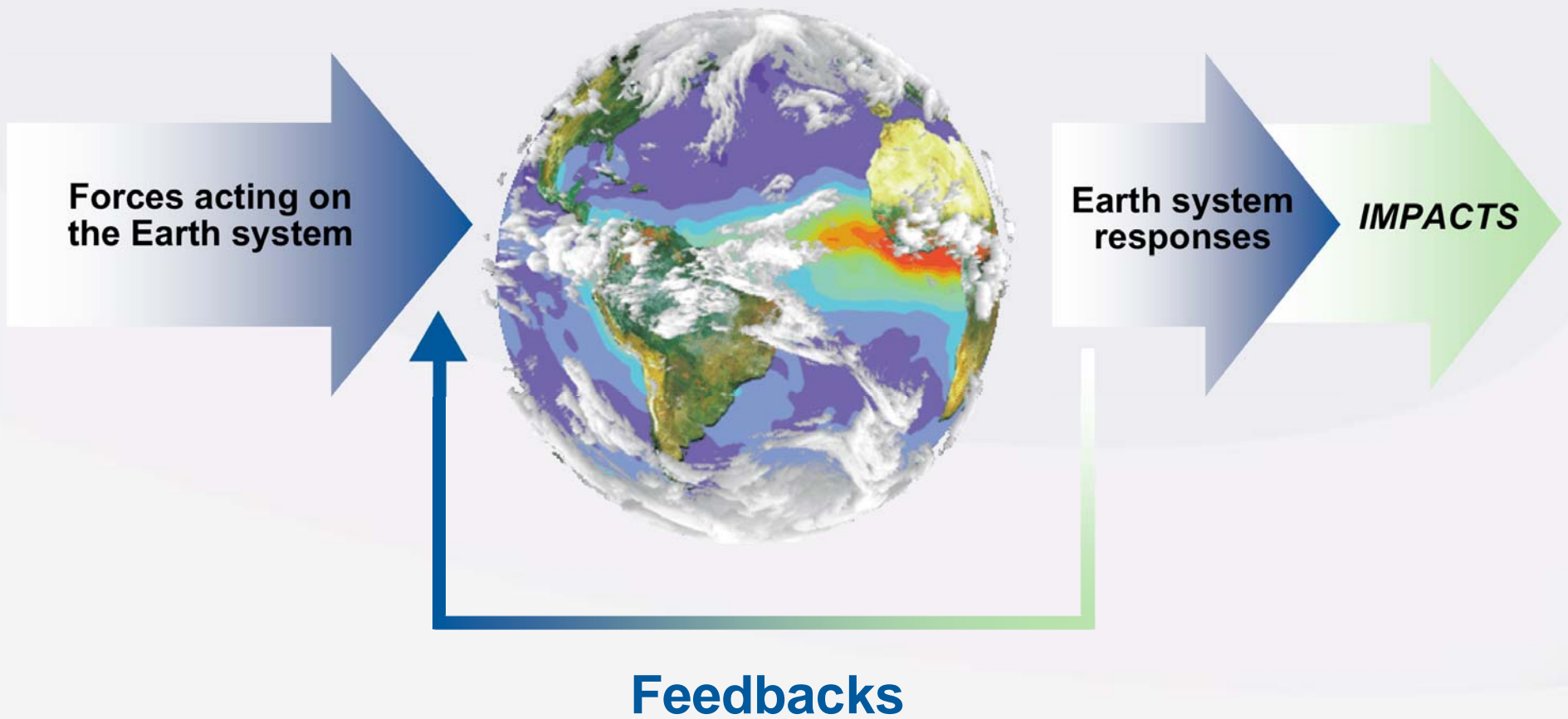


ESD Broader Governmental Context

- NASA Earth Science Supports Multiple Presidential Initiatives
 - Climate Change Science Program
 - Earth Observations
 - Ocean Action Plan
- Congressional Direction Addresses Several Aspects, most notably linkage between NASA and NOAA, but also other areas (ozone, land cover)
- NASA is part of NPOESS program, in particular through the NPOESS Preparatory Project (NPP) mission
- NASA supports several other CENR activities (Air Quality, Water Availability and Quality, Disaster Reduction, ...)



Earth as a Dynamic System



Earth System Science



Sun- Earth
Connection

Climate Variability
and Change

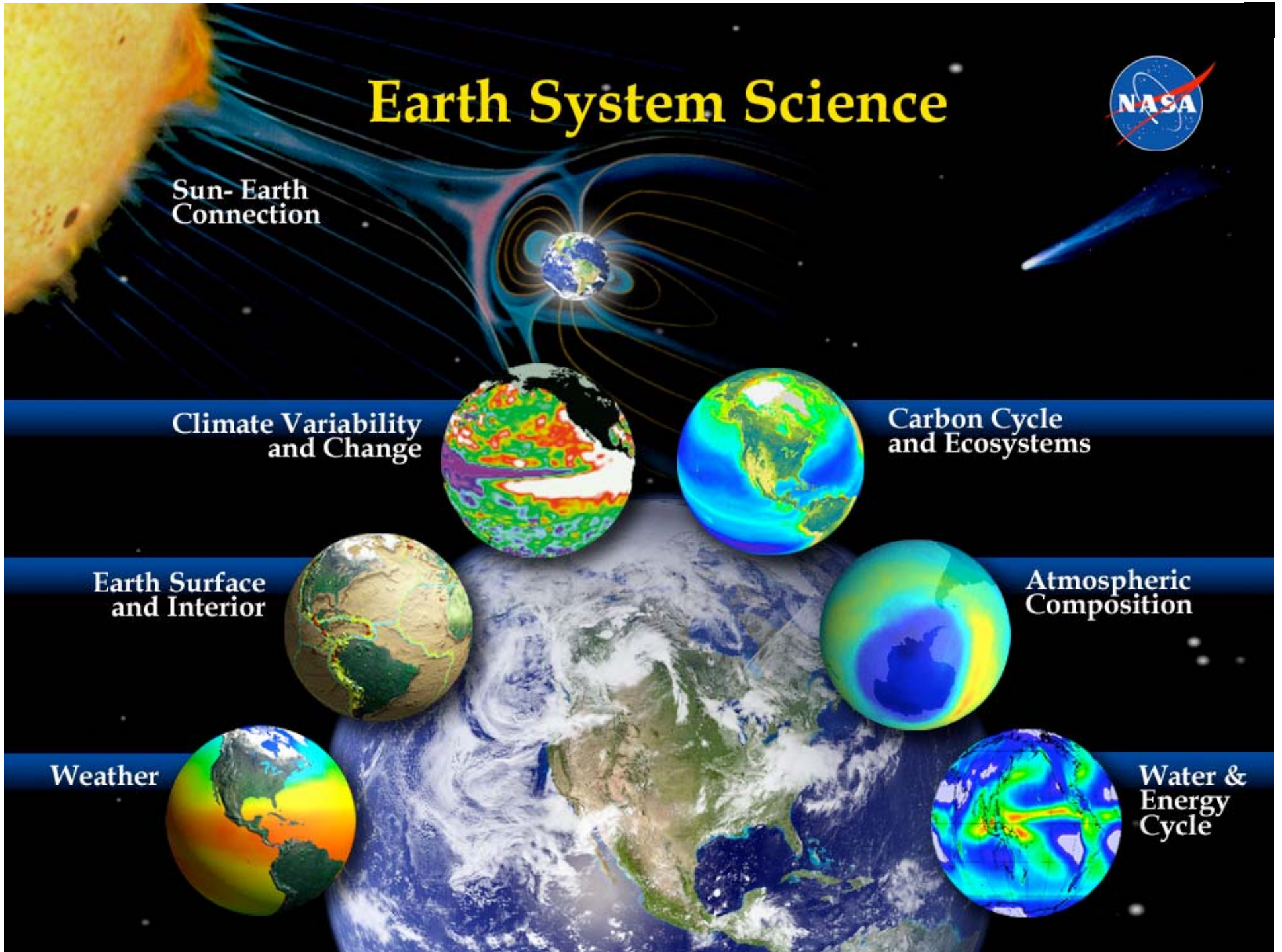
Carbon Cycle
and Ecosystems

Earth Surface
and Interior

Atmospheric
Composition

Weather

Water &
Energy
Cycle



Science Questions and Focus Areas

Variability

Precipitation, evaporation & cycling of water changing?



Global ocean circulation varying?



Global ecosystems changing?



Atmospheric composition changing?



Ice cover mass changing?



Earth surface transformation?



Forcing

Atmospheric constituents & solar radiation on climate?



Changes in land cover & land use?



Motions of the Earth & Earth's interior?



Climate Variability and Change
Carbon Cycle and Ecosystems
Water and Energy Cycle

Response

Clouds & surface hydrological processes on climate?



Ecosystems, land cover & biogeochemical cycles?



Changes in global ocean circulation?



Atmospheric trace constituents responses?



Sea level affected by Earth system change?



Atmospheric Composition
Weather
Earth Surface and Interior

Consequence

Weather variation related to climate variation?



Consequences of land cover & land use change?



Coastal region impacts?



Regional air quality impacts?



Prediction

Weather forecasting improvement?



Improve prediction of climate variability & change?



Ozone, climate & air quality impacts of atmospheric composition?



Carbon cycle & ecosystem change?



Change in water cycle dynamics?

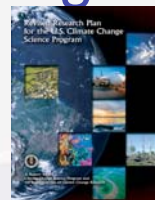


Predict & mitigate natural hazards from Earth surface change?

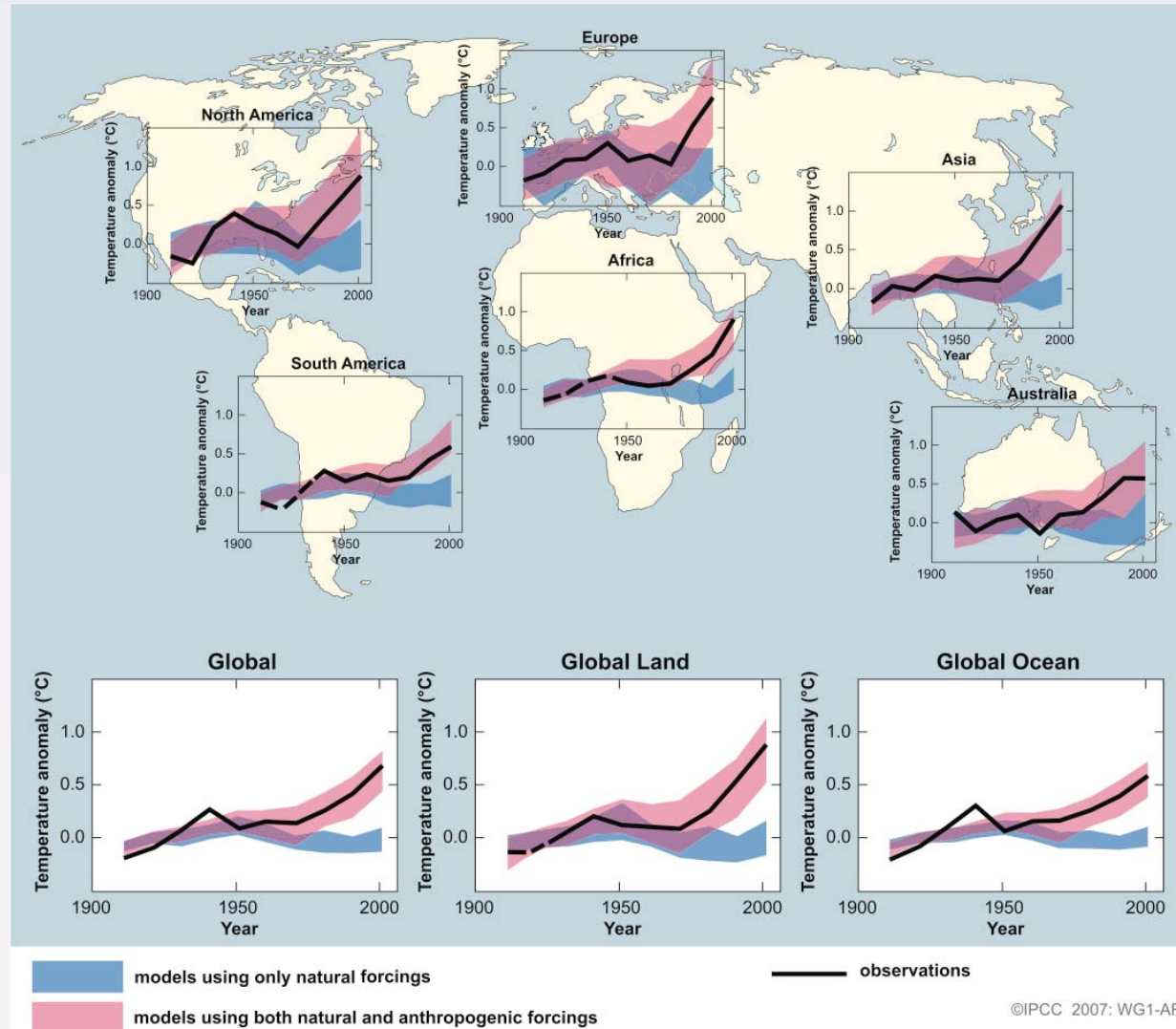


Recent Activity Affecting Climate Research in US

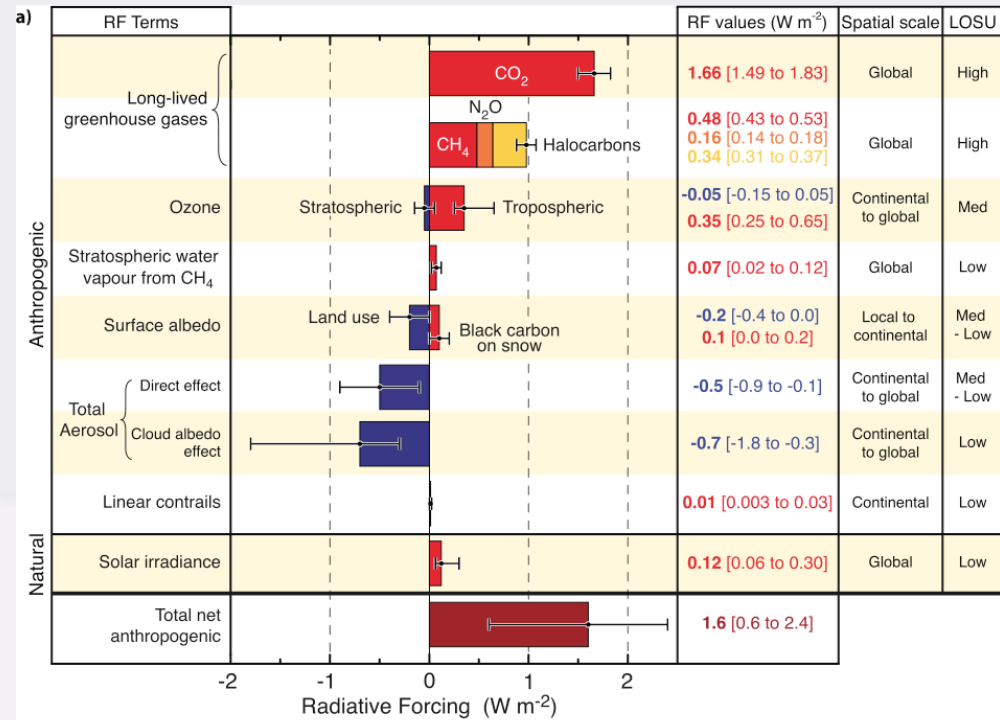
- NPOESS loses significant number of climate measurements for NPOESS, with some subsequently restored
- NRC releases first-ever Decadal Survey for Earth Science
- IPCC Report Released in 2007 - stronger statements about human contribution to climate change
- Particularly significant results involving polar regions
- CCSP releases increasing number of Synthesis and Assessment Products, including two court-ordered documents (5/29/08)



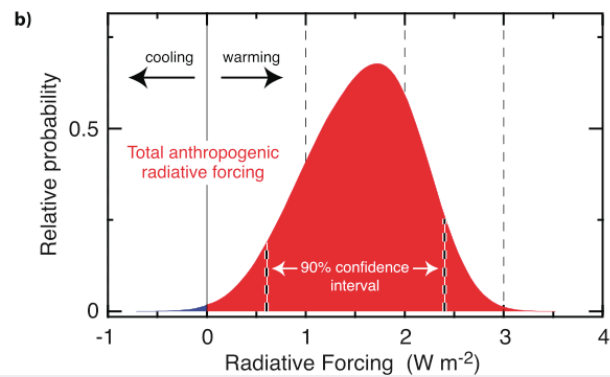
IPCC Modeling Results



IPCC Radiative Forcing



©IPCC 2007: WG1-AR4



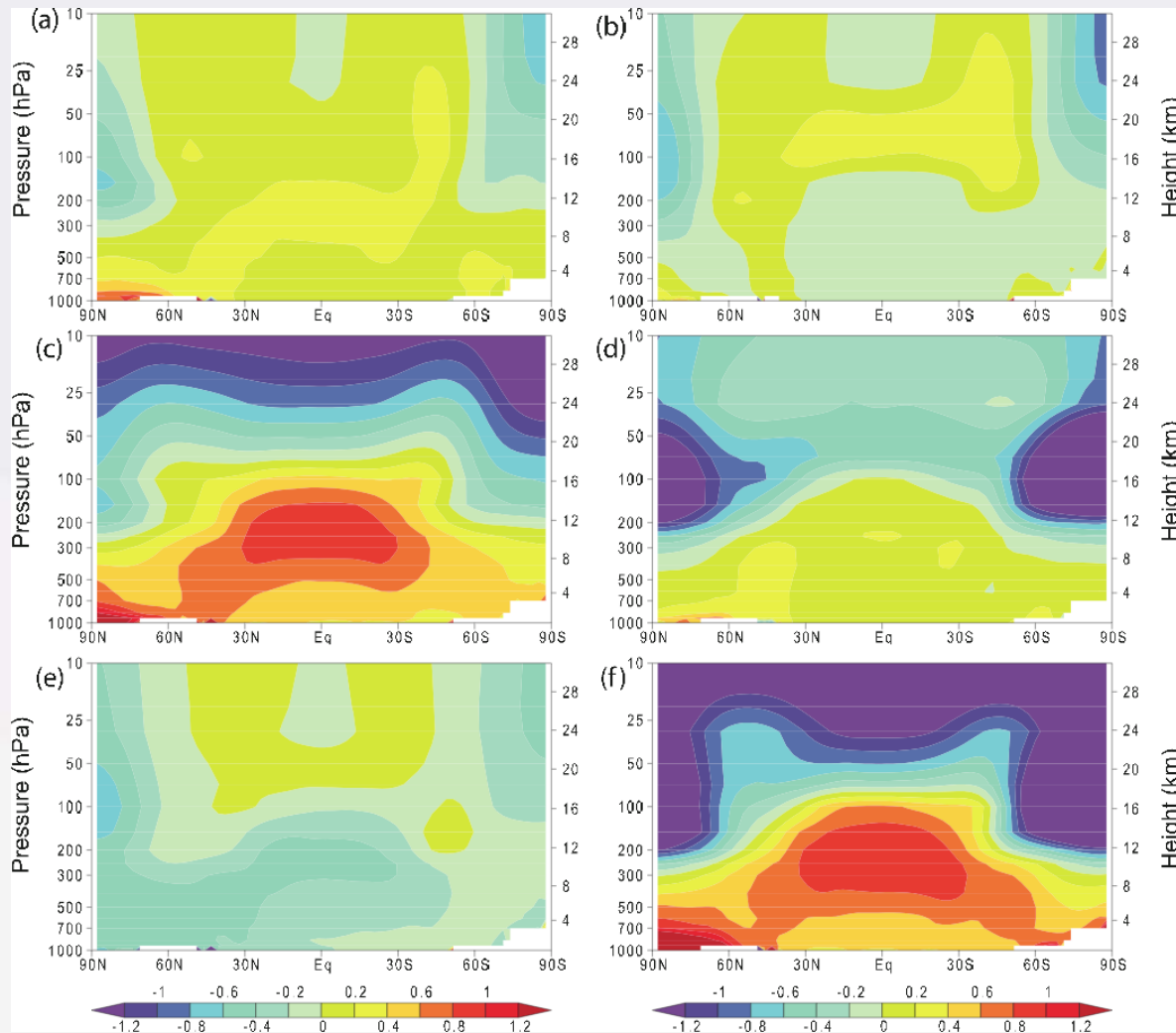
©IPCC 2007: WG1-AR4



IPCC 2-Zonal Means of T change - 1890-1999 (model)

Units: Deg
C/Century

- a) Solar Forcing
- b) Volcanoes
- c) Well-mixed GHGs
- d) Ozone changes
- e) Direct sulfate aerosol forcing
- f) Sum of all forcings

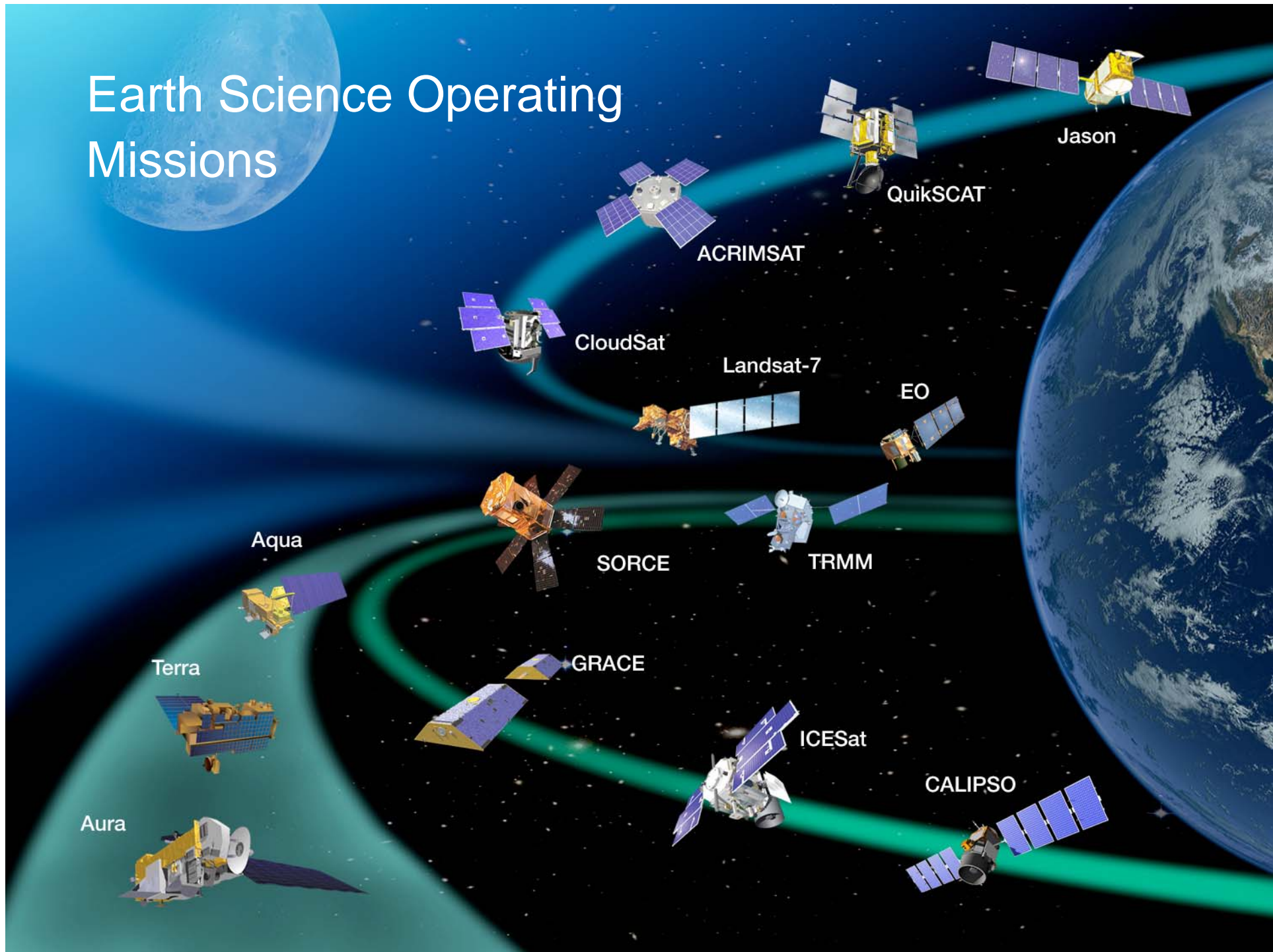


CCSP Synthesis and Assessment Products

- 1.1 Temperature trends in lower atmosphere (NOAA)
- 1.2 Past climate variability at high latitudes (USGS)
- 1.3 Reanalysis of historical climate data... (NOAA) [ends 29 May '08]
- 2.1 Updating scenarios of greenhouse gas emissions (DOE)
- 2.2 North American Carbon budget (NOAA)
- 2.3 Aerosol properties and their impacts on climate (NASA)
- 2.4 Trends in emissions of ozone-depleting substances (NOAA)
- 3.1 Climate models, sensitivity, uncertainty (DOE)
- 3.2 Climate projections (NOAA)
- 3.3 Climate extremes (NOAA)
- 3.4 Abrupt changes (USGS) [ends 16 June '08]
- 4.1 Coastal elevation and sensitivity to sea-level rise (EPA)
- 4.2 Thresholds of change for ecosystems and climate sensitive resources (USGS)
- 4.3 Relationship between ecosystems and climate change (USDA)
- 4.4 Review of adaptation options for ecosystems (EPA)
- 4.5 Effects of Climate Change on Energy Production and Use (DOE)
- 4.6 Impacts of climate variability (EPA)
- 4.7 Transportation sector / climate change linkages (DOT)
- 5.1 Uses and limitations of observations... in decision support systems (NASA)
- 5.2 Best practices approaches for uncertainty in decisionmaking (NOAA) [ends 9 June '08]
- 5.3 Decision support using seasonal-to-interannual forecasts (NOAA)



Earth Science Operating Missions



Jason

QuikSCAT

ACRIMSAT

CloudSat

Landsat-7

EO

Aqua

SORCE

TRMM

Terra

GRACE

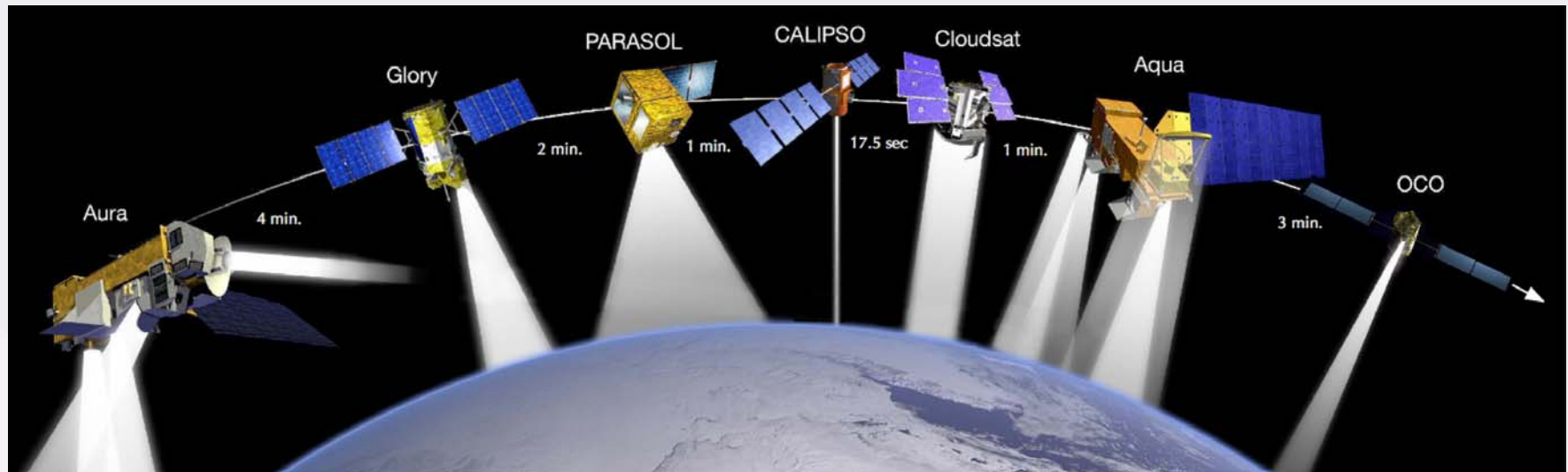
Aura

ICESat

CALIPSO

The "A-Train"

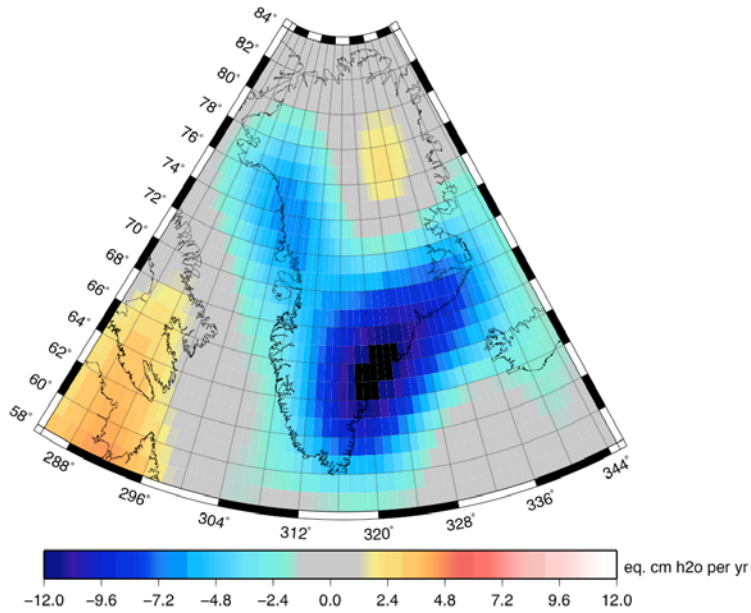
Moving Toward the Future of Integrated Earth Observation



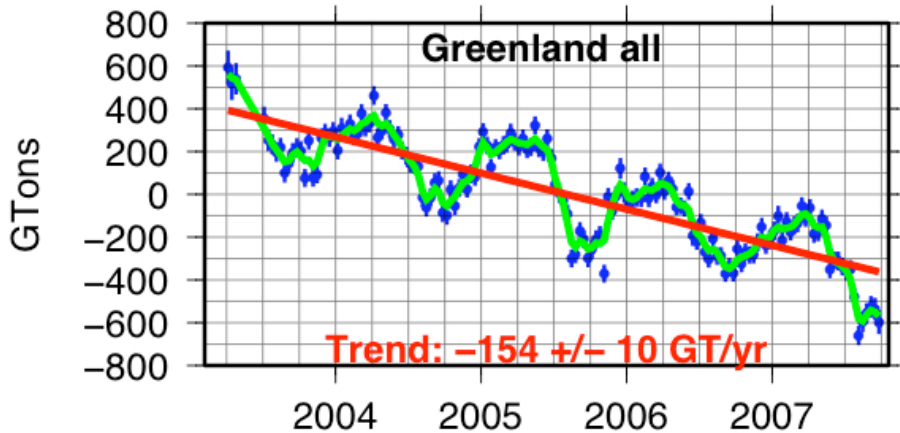
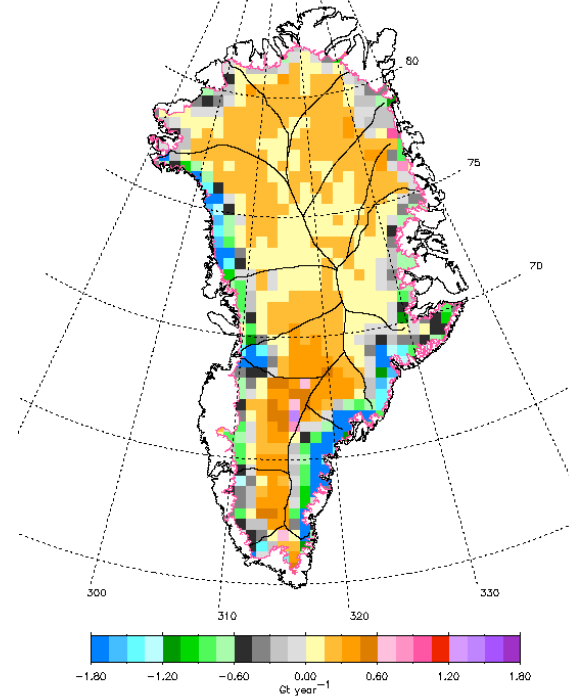


Greenland Mass Change from GRACE and ICESat

GRACE dM/dt Apr03-Apr07



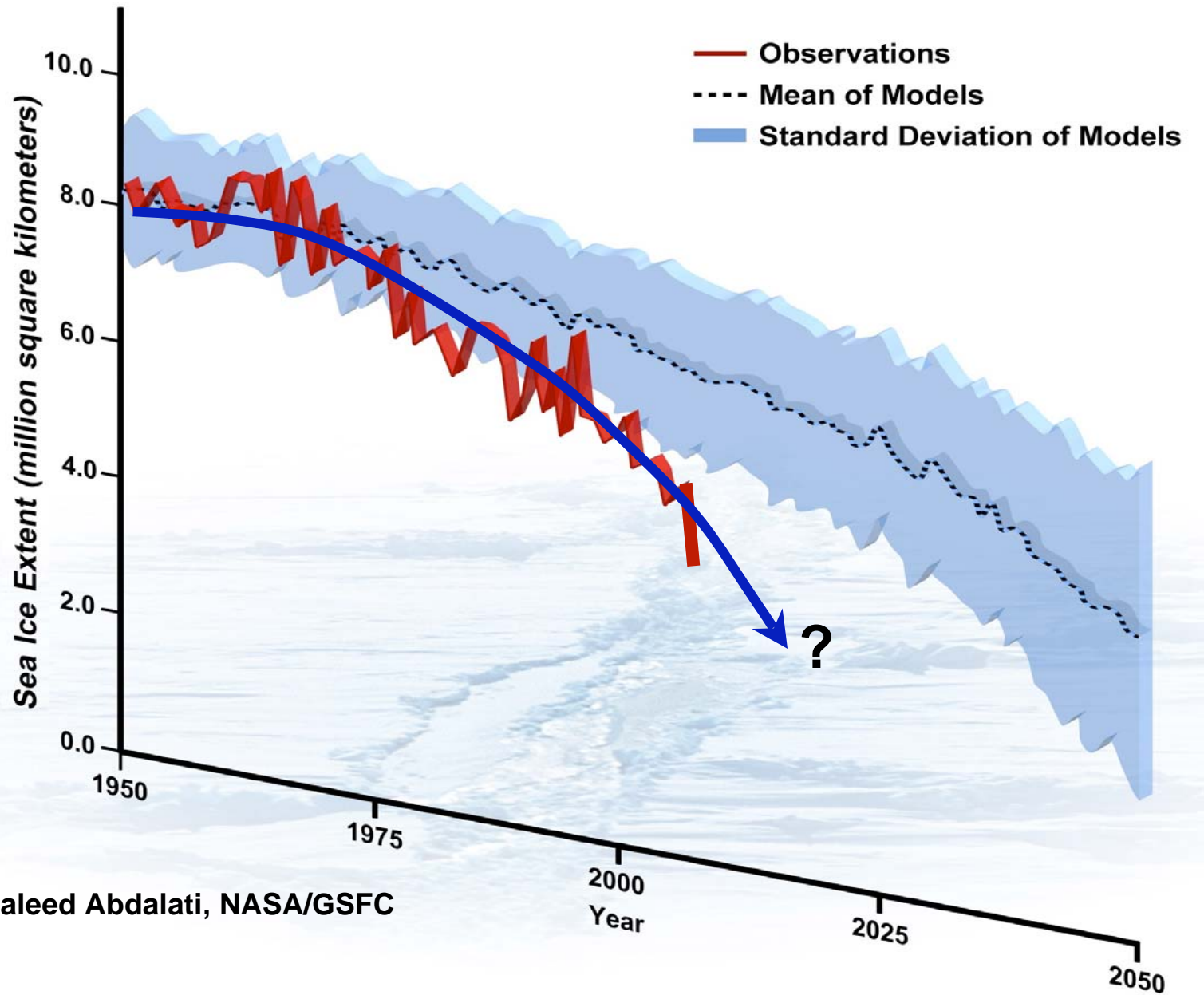
ICESat dM/dt Oct03-Nov07 (Zwally et al.)



ICESat Trend:
Oct03-Nov07: -137 Gt/yr

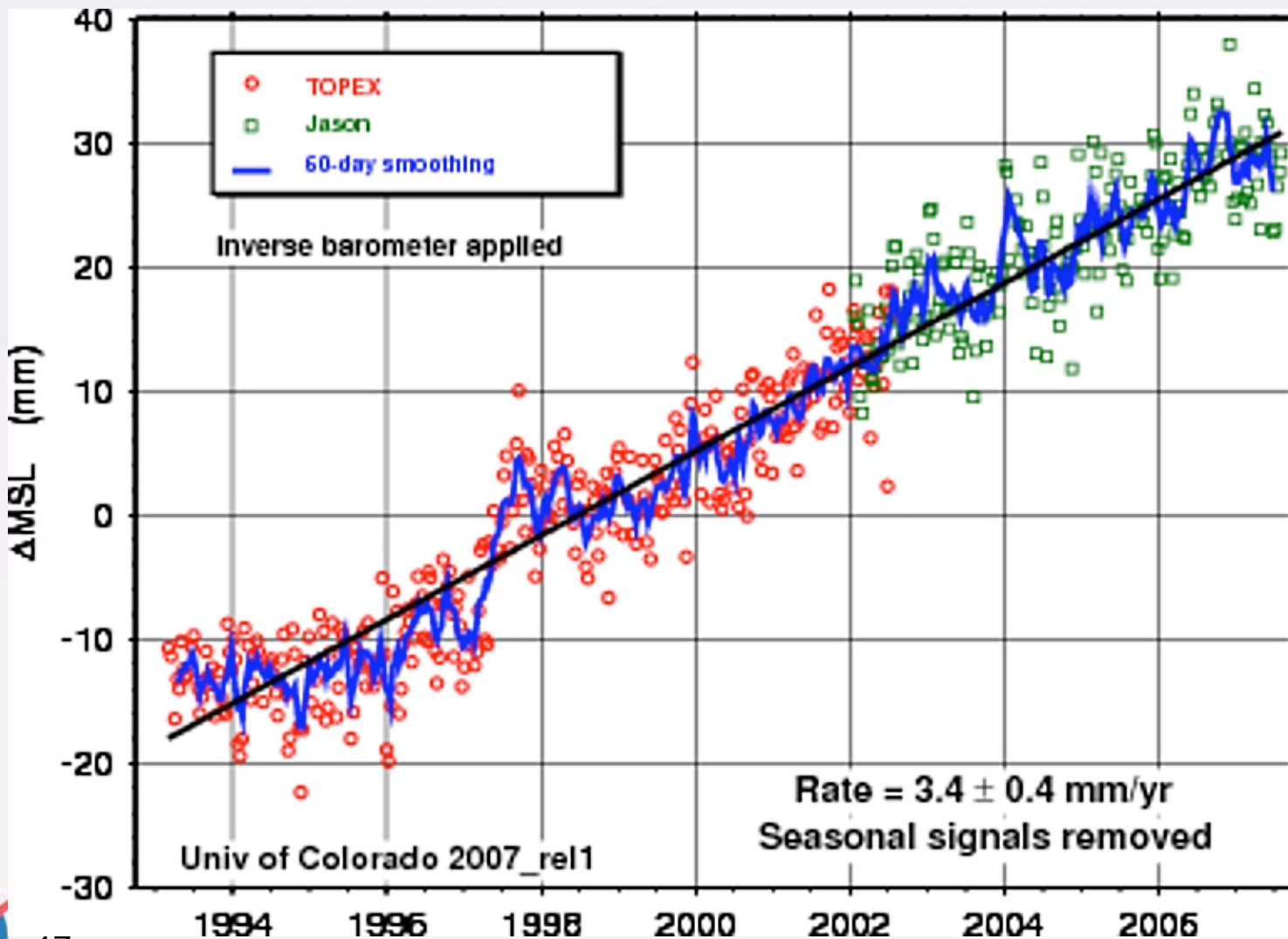
GRACE mascon Trend:
Sep03-Oct07: -161±10 Gt/yr

Disappearing Arctic Sea Ice

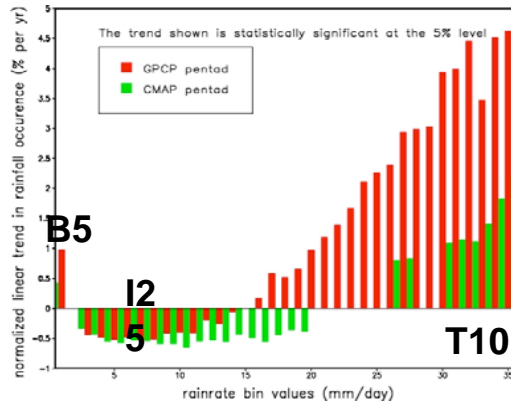
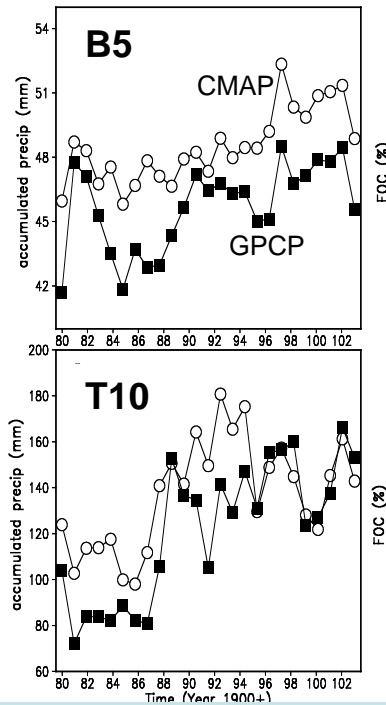


From Waleed Abdalati, NASA/GSFC

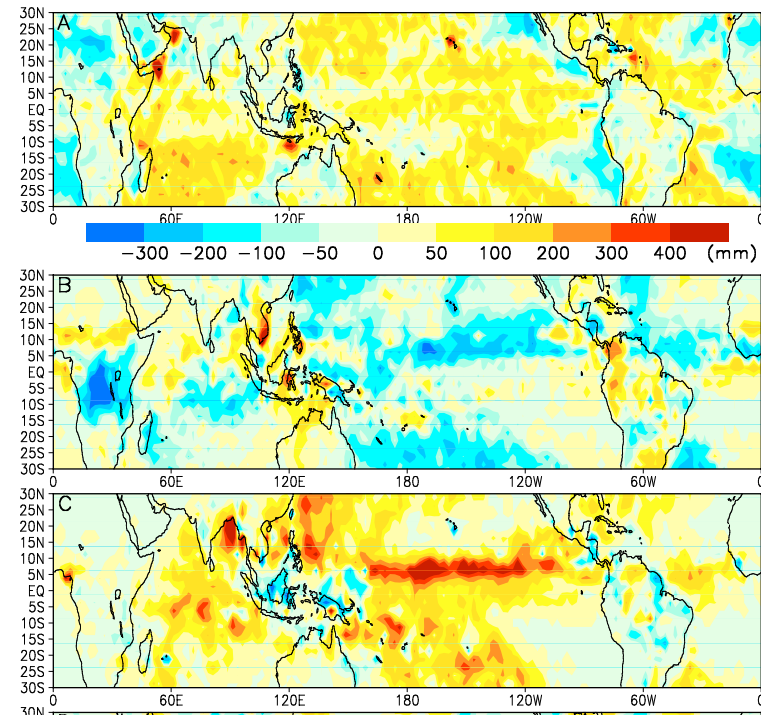
Global mean sea level variations from TOPEX/Poseidon and Jason altimeter measurements



Satellite rainfall data show long-term trend in rainfall characteristics



Linear shift in rainfall PDF 1979-2003. Only significant signals are shown



B5

I25

T10

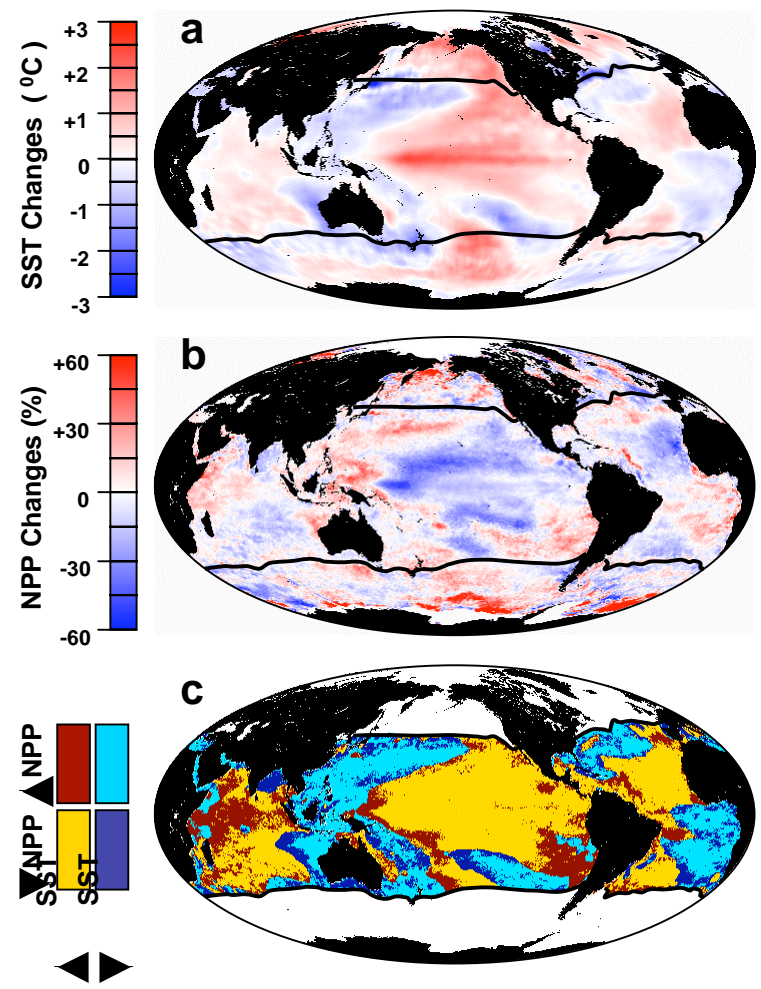
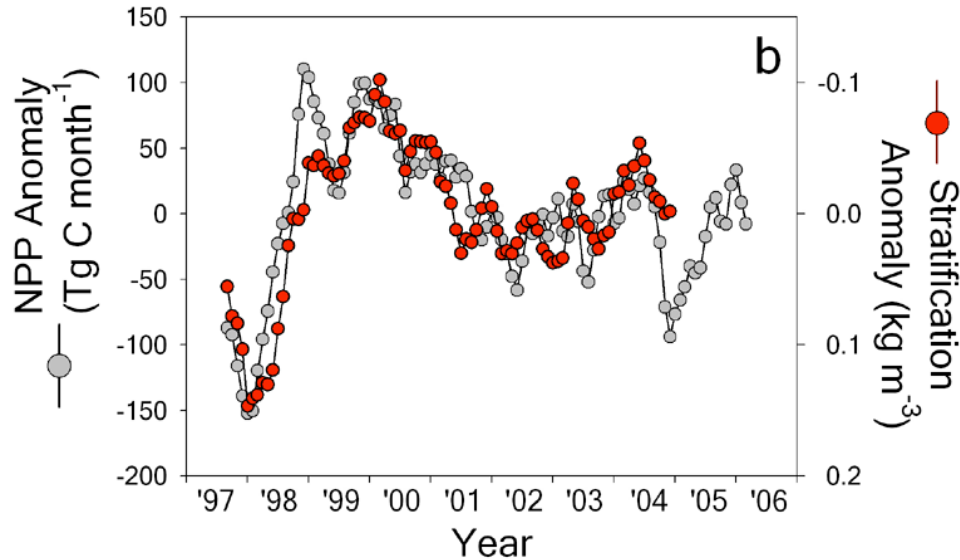
NASA study finds long-term shift in “probability distribution function” (PDF) in satellite-derived rainfall data showing a) an increasing trend in light rain (B5), b) a decreasing trend in moderate rain (I25) and c) an increasing trend in heavy rain (T10). Increase trends in B5 and T10 are shown as time series in left panels. Shift in PDF is shown in middle panel. Right panels show that a) light rain is increased almost uniformly over the ocean, except over continent and coastal regions, b) moderate rain is reduced over ITCZ and adjacent regions, and c) heavy rain is increased over the core of the ITCZ. B5, I25, and T10 have been identified as primarily contributed by warm rain (liquid phase), mixed-phase rain, and cold (ice-phase) rain respectively.

Ref: Lau and Kim, 2006 “ Detecting trends in tropical rainfall characteristics, 1979-2003” International. J. Climatology.



Climate-driven trends in contemporary ocean productivity

Michael J. Behrenfeld¹, Robert T. O'Malley¹, David A. Siegel³, Charles R. McClain⁴, Jorge L. Sarmiento⁵, Gene C. Feldman⁴, Allen J. Milligan¹, Paul G. Falkowski⁶, Ricardo M. Letelier² & Emmanuel S. Boss⁷



What do we *really* know?....

- Satellites measure neither NPP or chlorophyll, they tell us about optics
- SeaWiFS has recorded changes in ocean optical properties over vast regions
- These changes are clearly linked to effects of climate variability on upper ocean temperature and stratification - not instrument or atmospheric artifacts

alternative explanations: Nutrient-driven changes in NPP; Photo-oxidation of CDOM; Light-driven changes in photoacclimation

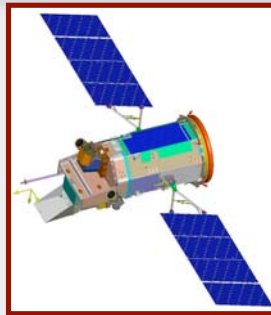
Missions in Formulation and Implementation



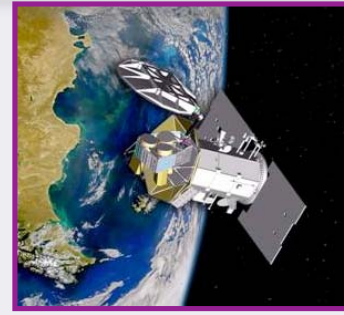
OSTM
6/2008



OCO
1/2009



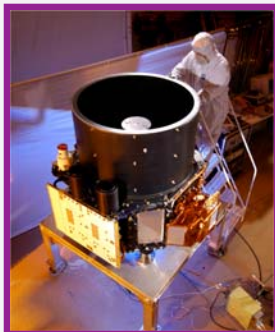
GLORY
6/2009



AQUARIUS
5/2010



NPP
6/2010



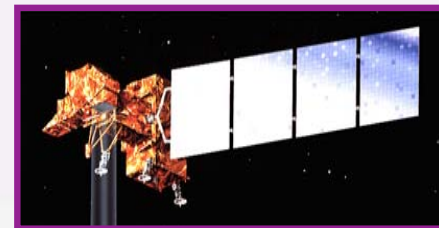
ICESat-II
2015



SMAP
2012



GPM
6/2013, 11/2014



LDCM
7/2011



Decadal Survey Recommendations

- 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.
- NOAA and NASA should undertake a set of 17 recommended missions, phased over the next decade
- NOAA research to operations
 - Vector ocean winds
 - GPS radio occultation temperature, water vapor and electron density profiles
 - Total solar irradiance/and Earth Radiation (NPP) and restored to NPOESS
- NASA
 - 15 missions in small, medium and large categories
 - Also need to invest in R&A, applied sciences, technology, ground networks, airborne science (including UASs)



NASA Near-Term Missions (4/15 total)

Decadal Survey Mission	Mission Description	Orbit	Instruments
CLARREO (NASA portion)	Solar and Earth radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter





CLARREO Impacts on Climate Science

- Improve assessment of climate predictions for public policy
 - CLARREO will measure solar reflected and infrared emitted high spectral resolution benchmark radiance climate data records that can be used to test climate model predictions, improve climate change fingerprinting, and attribution
- Provide climate-accuracy calibration for operational sensors
 - An orbiting calibration observatory that can be used to calibrate other solar and infrared space-borne sensors and thereby improve climate accuracy of a wide range of sensor measurements across the Earth observing system
- Dramatically reduce the effects of data gaps
 - The absolute accuracy of CLARREO, when used to calibrate other sensors in orbit can dramatically reduce the impact of data gaps on decadal change data records across many climate variables
- Provide the first space-based measurements of the Earth's far infrared spectrum
 - Opens a new window to 50% of Earth's IR spectrum with key information on water vapor feedback, cirrus radiative forcing, and the natural greenhouse effect



NASA Mid-Term Missions (5/15 total)

Decadal Survey Mission	Mission Description	Orbit	Instruments
HypIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer
ASCENDS	Day/night, all-latitude, all-season CO ₂ column integrals for climate emissions	LEO, SSO	Multifrequency laser
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar
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
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar



NASA Far-Term Missions (6/15 total)

Decadal Survey Mission	Mission Description	Orbit	Instruments
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar

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



Decadal Survey Ongoing Activities

- Completed “building block” calibrations of NRC missions
 - Ensure consistent, rational basis for costs
 - Full (LCC) mission cost (including NASA science teams/analyses, mission extension)
 - 2 additional independent cost-estimation efforts (Aerospace, LaRC IPAO)
- Developed joint (with NOAA) mitigation strategies for NPOESS climate sensors
 - NASA-NOAA study for OSTP
 - NRC/SSB Workshop (science impacts, priorities, approaches)
 - Limb Sensor restored to OMPS on NPP; CERES being restored to NPP
- Discussions with International Partners
 - Determine common interests, complementary capabilities
 - JAXA/METI, CNES, CSA, ESA, CEOS, WMO/SP, DLR meetings held
 - Bilateral new mission working groups initiating (CNES, JAXA, DLR)
- Implemented “Early Mission” workshops
 - Confirm/refine match between science objective and notional mission
 - Determine necessary “context” measurements for science objective
 - Community involvement, HQ led
 - Workshops completed Summer 2007 for SMAP, CLARREO, ICESat-II, DESDynI - reports available online
- Targeted Instrument Incubator Program (IIP) solicitation to Decadal Survey missions (all 3 tiers)
- Beginning to Move Out on SMAP and ICESat II with progressively smaller amounts for remainder of Tier I (CLARREO, DESDynI) and Tier 2 missions



ROSES 08 Summary

Element	Name	Due Date	Est. Am't/Yr (\$M)	Est. # Sel.	Funding period (yrs)
A.2	Terrestrial Ecology	TBD	TBD	TBD	TBD
A.4	Land Cover/Land Use Change	10/1/08	2	5 to 12	4
A.5	Biodiversity (new)	6/26/08	1.75	~7 to 10	3
A.6	Ocean Biology and Biogeochemistry	6/2/08	~2.5	~ 10 to 20	4 or shorter
A.7	Modeling, Analysis, and Prediction	5/23/08	~8	~ 30 to 40	4
A.8	Physical Oceanography	6/26/08	~1.5	~ 10	4
A.9	Ocean Salinity Science Team (new)	10/30/08	~2	~15	4
A.13	NASA Energy and Water Cycle Study - Water Quality (new)	8/19/08	~1.5	~7	4 or shorter
A.14	Atmospheric Composition: Laboratory Research	6/16/08	~ 3	~ 15 to 20	3
A.15	Atmospheric Composition: Surface, Balloon, and Airborne Observations	7/15/08	~ 8	~ 30 to 25	4
A.16	Hurricane Science Research	5/16/08	~ 1.6	~ 10 (+ 5 @\$20K)	4
A.17	Advanced Concepts in Space Geodesy	TBD (Y/N)	TBD	TBD	TBD
A.18	Decision Support Through Earth Science Research Results	8/13/08	~6	20 to 23	up tp 4
A.19	Earth Sciene Applications Feasibility Studies	8/27/08	~1	9 to 15	1 to 1.5
A.20	Advanced information Systems Technology	8/29/08	TBD	TBD	TBD
A.21	Adanced Component Technology	TBD	TBD	TBD	TBD



NRC Study: Earth Observations from Space - The First 50 Years of Scientific Achievement

- Report Conclusions (summarized)
 - Daily synoptic view of Earth from space has revolutionized Earth studies and helped society manage environment and resources
 - Long time series are required and the value of data sets increases with time
 - Scientific advances result from science-technology synergy, and societal benefit of measurements increases with increasing accuracy
 - Have indisputable benefit of multiple synergistic observations (satellite and non-satellite) linked with models
 - To achieve full benefit of observations, need infrastructure (models, computing, ground networks, personnel)
 - Full and open access to global data capitalizes on investment
 - Space observations have catalyzed interdisciplinary science and can be expected to lead to remarkable discoveries in the future
- *Summary Statement* : "The decadal survey and this committee both recommend that the nation's commitment to continue Earth observations from space be renewed."





Summary

- NASA Earth Science program addresses fundamental scientific questions and important societal objectives in support of Administration initiatives (climate, Earth observations, oceans)
- NASA research advances climate research and contributes to national and international assessments
- NASA results are proving critical in documenting changing climate and its global impacts, as well as supporting improvements of models
- NASA is moving forward with missions in formulation and development and beginning to move out on NRC decadal survey

