NORTHROP GRUMMAN

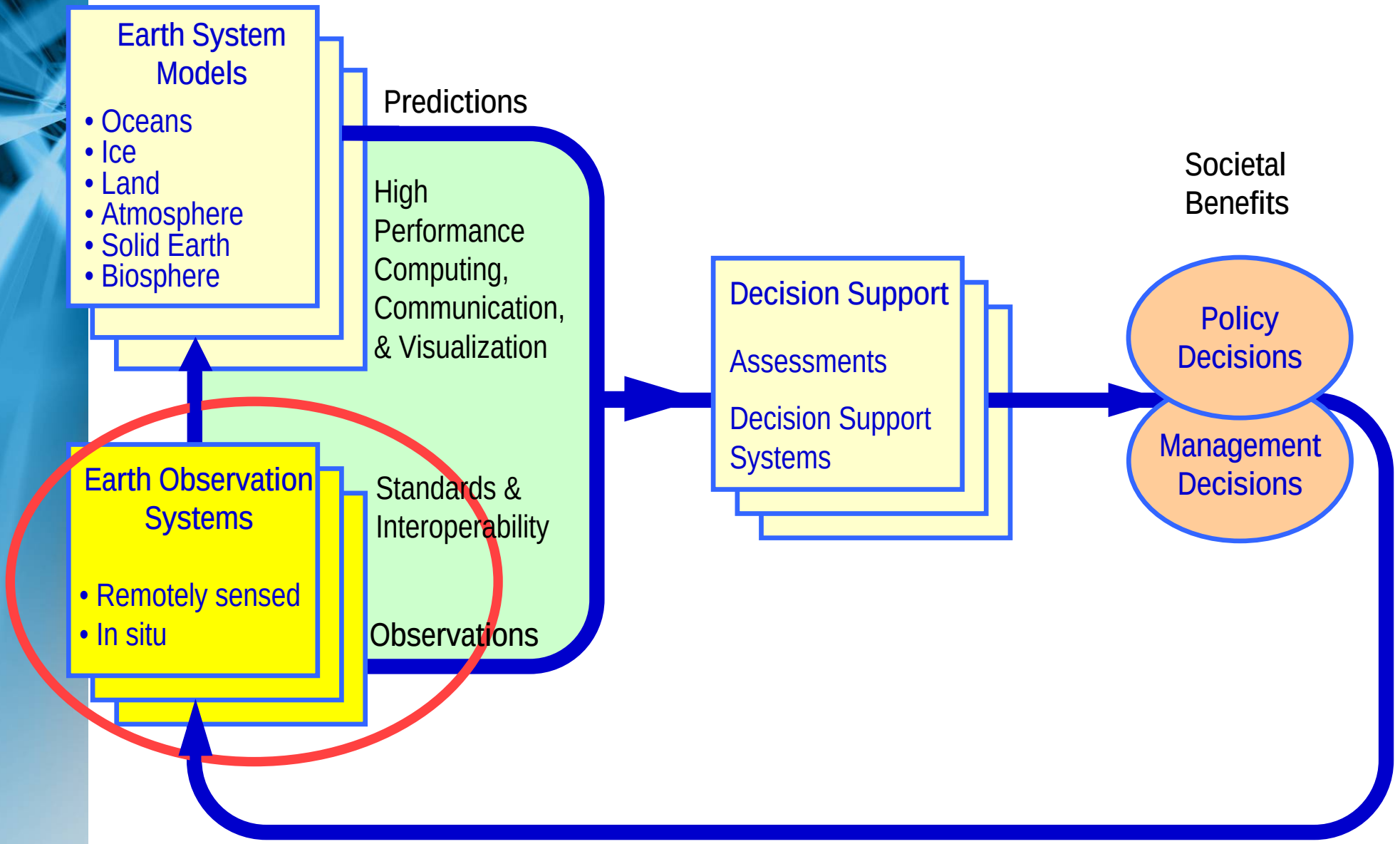
DEFINING THE FUTURE

Global Change Monitoring System

September 21, 2007

Northrop Grumman Corporation

System of Systems Framework



From: The Architecture of GEOSS (GEO4DOC 4.1 [2]; April 5, 2004)

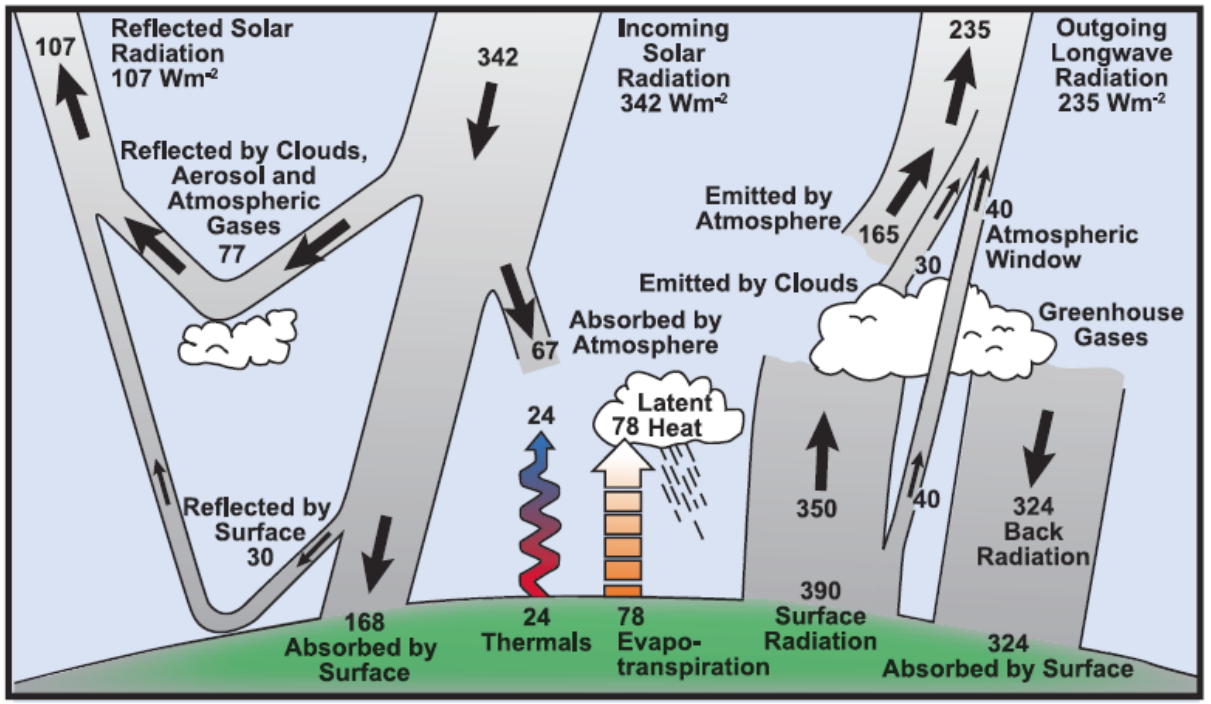
Framework for Future Earth Observations

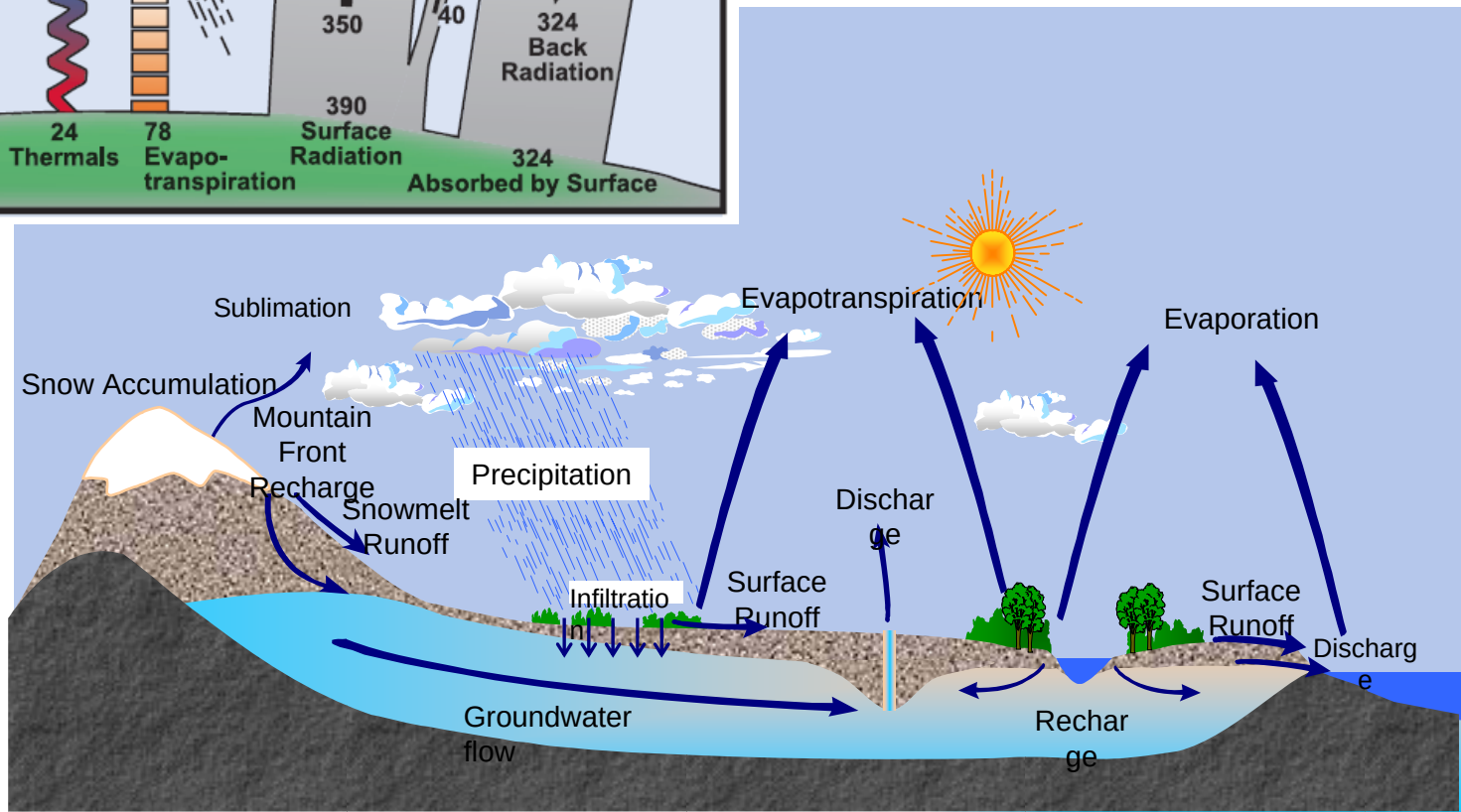
- **Targets** - Establish, evolve, and optimize a target set of observations to support the user community and society
- **Operational Views** - Establish, evolve, and optimize operational views of an overall system to deliver the target set of observations with a time-phased view looking forward 40 years to include guidance for research for future generations of operational systems
- **Architecture** - Evolve an Integrated Earth Observation System (IEOS) architecture developed on the principles of the Federal Enterprise Architecture
- **Blueprint for Solutions** - Establish, evolve, and optimize blueprints for implementing the components needed for integrated approach to address applications of national priority

Pathway to Future Earth Observations

- **Target Observables**
  - **55 Environmental Data Records (EDRs)**
  - **26 Essential Climate Variables (ECVs)**
  - **Gap Analyses**
- **Operations Concepts**
  - Operations View
  - Whole Earth Simulator
- **Evolving Architecture**
  - GEOSS and IEOS Framework
  - Multi-System Configurations
- **Blueprint for Solutions**
  - Integrated System Solutions
  - Prospective Next Generation Monitoring/Measurement Systems

Earth Energy and Water Budget





26 GCOS Essential Climate Variables (ECV)

3.1. Atmosphere

- 3.1.1. Surface Wind Speed and Direction
- 3.1.2. Upper-air Temperature
- 3.1.3. Water Vapour
- 3.1.4. Cloud properties
- 3.1.5. Precipitation
- 3.1.6. Earth Radiation Budget
- 3.1.7. Ozone
- 3.1.8. Atmospheric reanalysis (multiple ECVs)
- 3.1.9. Aerosols
- 3.1.10. Carbon Dioxide, Methane and other Greenhouse Gases
- 3.1.11. Upper-air Wind

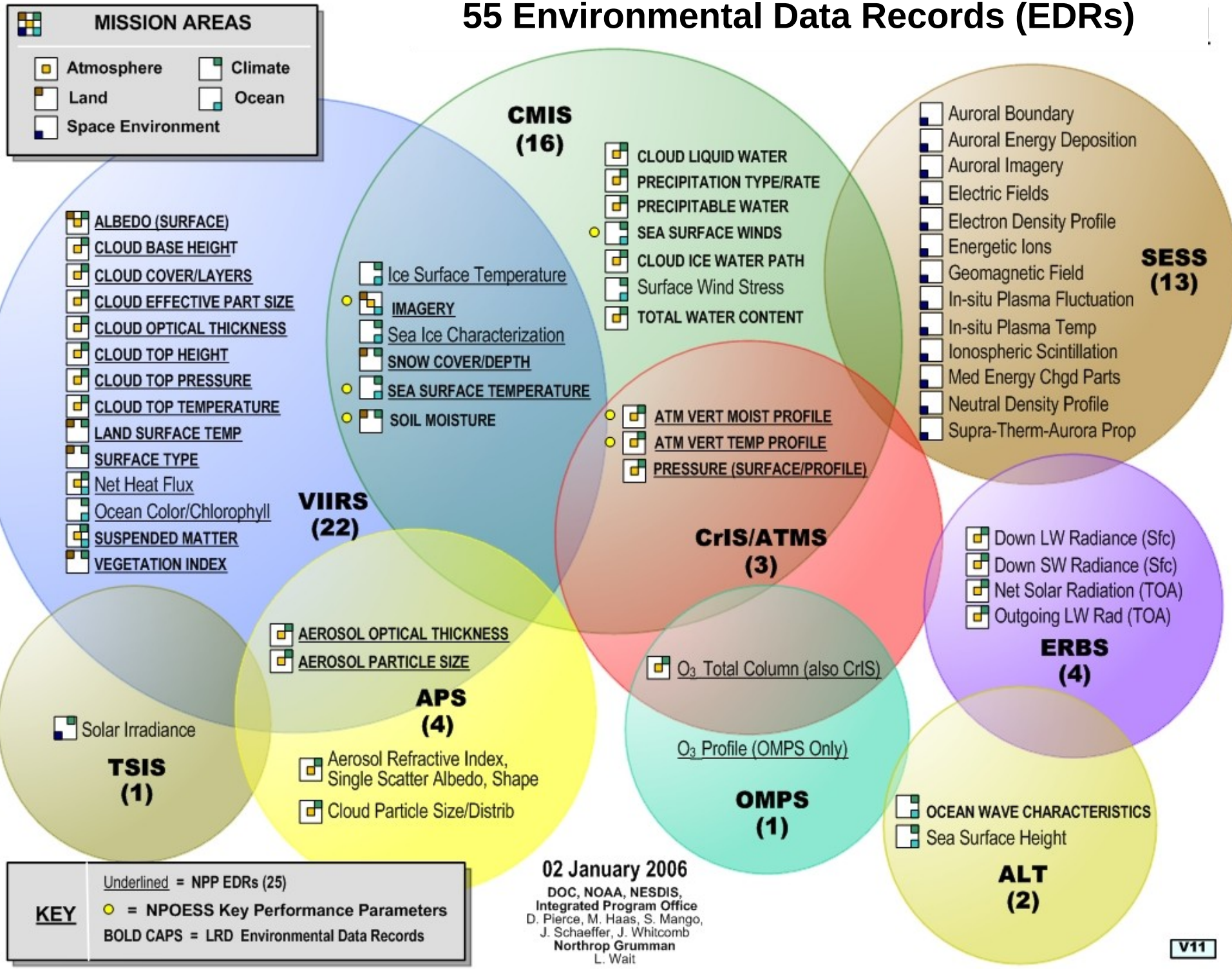
3.2. Oceans

- 3.2.1. Sea Ice
- 3.2.2. Sea Level
- 3.2.3. Sea Surface Temperature
- 3.2.4. Ocean Colour
- 3.2.5. Sea State
- 3.2.6. Ocean Reanalysis
- 3.2.7. Ocean Salinity

3.3. Terrestrial

- 3.3.1. Lakes
- 3.3.2. Glaciers and Ice Caps, and Ice Sheets
- 3.3.3. Snow Cover
- 3.3.4. Albedo
- 3.3.5. Land Cover
- 3.3.6. fAPAR
- 3.3.7. LAI
- 3.3.8. Biomass
- 3.3.9. Fire Disturbance
- 3.3.10. Soil moisture

55 Environmental Data Records (EDRs)

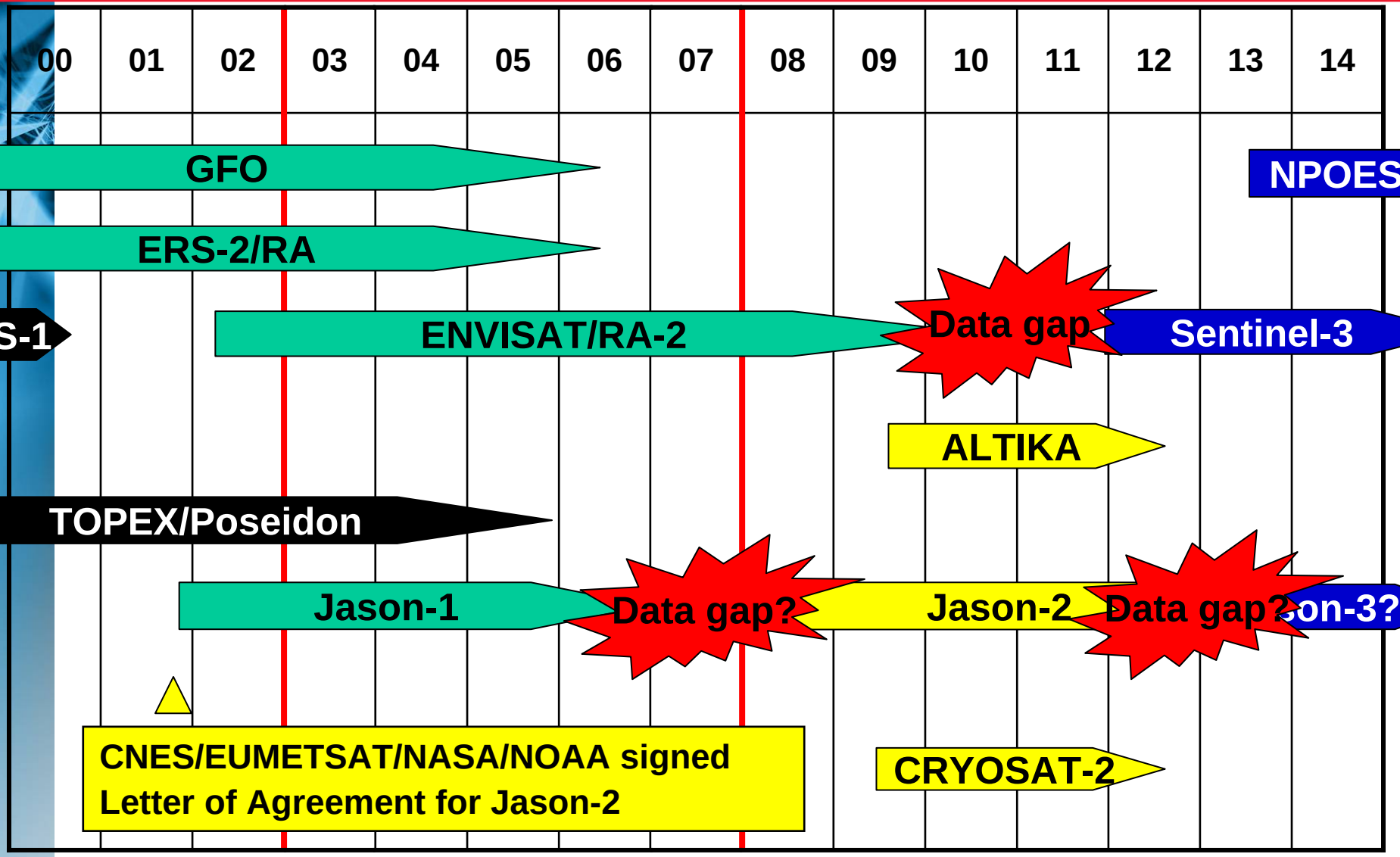


Global Essential Climate Variables out through 2050

Gap Analyses

- Precipitation (TRMM - GPM)
- Terrestrial Variables (Landsat 5,7 – LDCM)
- Altimetry (JASON 2 – JASON 3)
- Solar Irradiance (SORCE - NPOESS)
- Space Weather (ACE - SESS)
- Climate Variables (EOS - NPP - NPOESS)
- Unprecedented Environmental Variables

“Known Altimetry Missions”

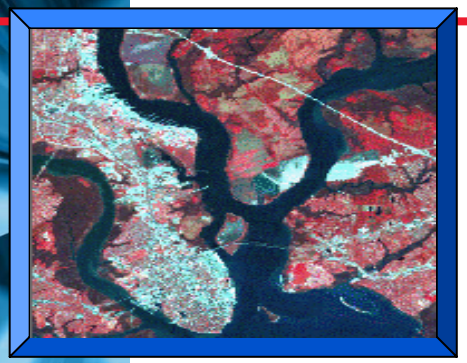


Decadal Survey Recommendation to NASA

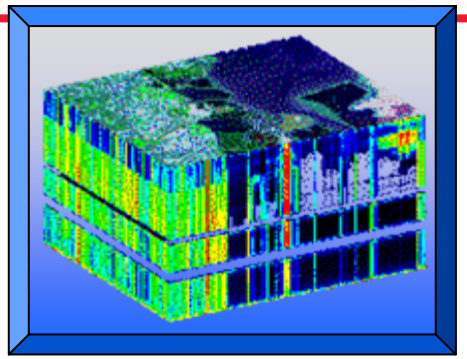
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	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	Ka-band wide swath radar C-band radar	$450 M
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	$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

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

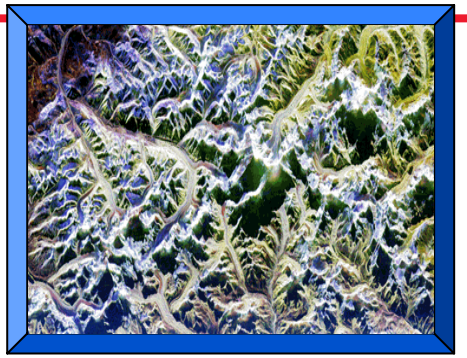
Remote Sensing Technologies



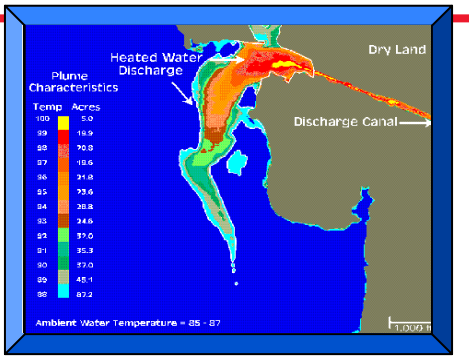
Multispectral



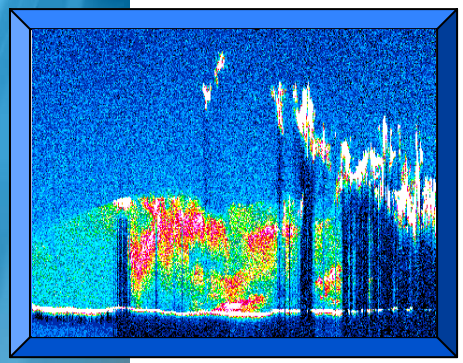
Hyperspectral



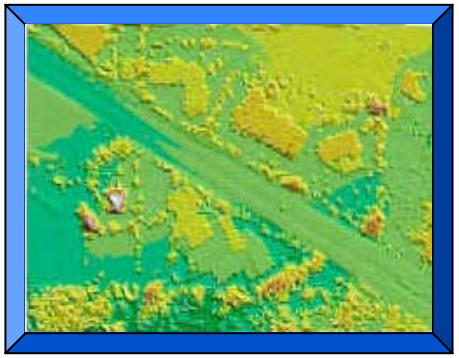
RADAR / SAR



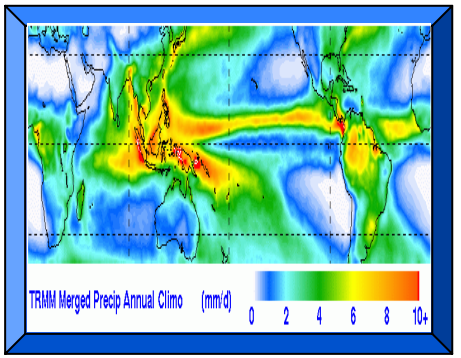
Thermal



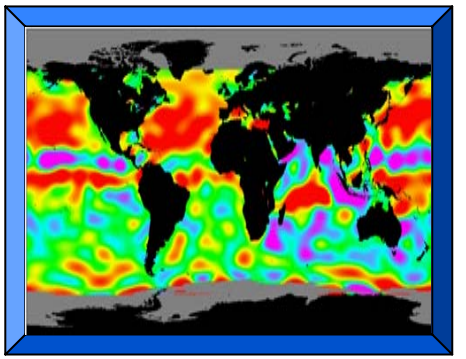
Atmospheric LIDAR



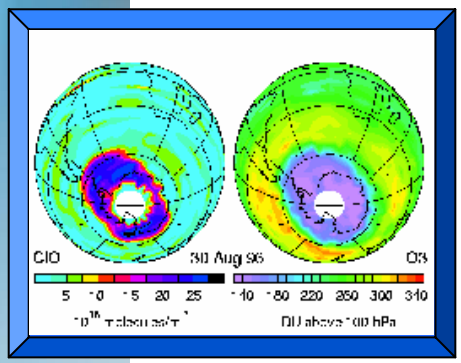
Surface LIDAR



Passive Microwave

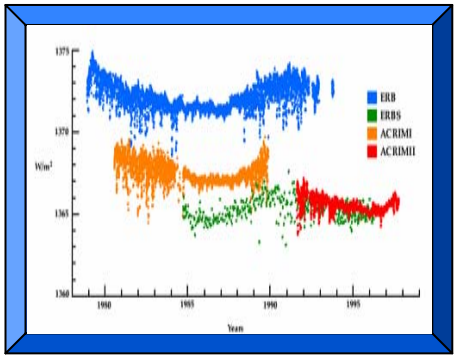


RADAR Altimetry

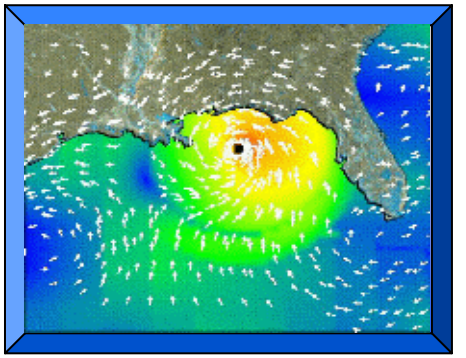


Limb Sounding

Laser Ranging



Irradiance/Photometry



Scatterometry

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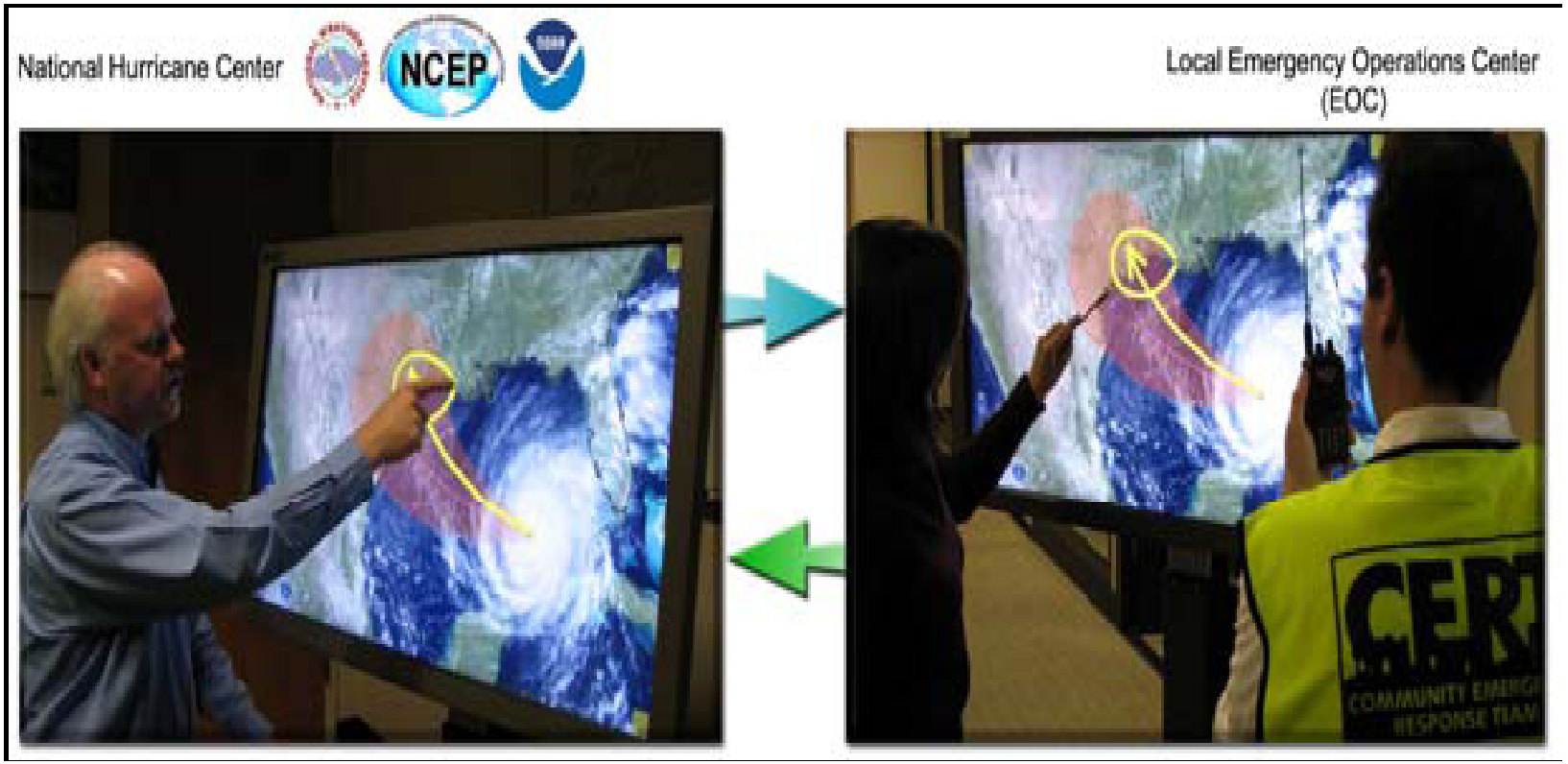
Operating Principles

- **Mission Focused - Continuously evolve existing and planned Earth observation systems to be optimally useful**
- **User Oriented - Optimize use of heritage capacity and continuous innovation in response to meeting civilian and economic needs**
- **Science and Technology Enabled - Apply research, technology, and credentialed science as the basis of assuring optimal capacity to place the right capabilities in the right place at the right time**
- **Innovation Driven - Maintain commitment to the innovation and discovery process to continue to provide the advantages of Earth observation systems and their applications to our national interests**

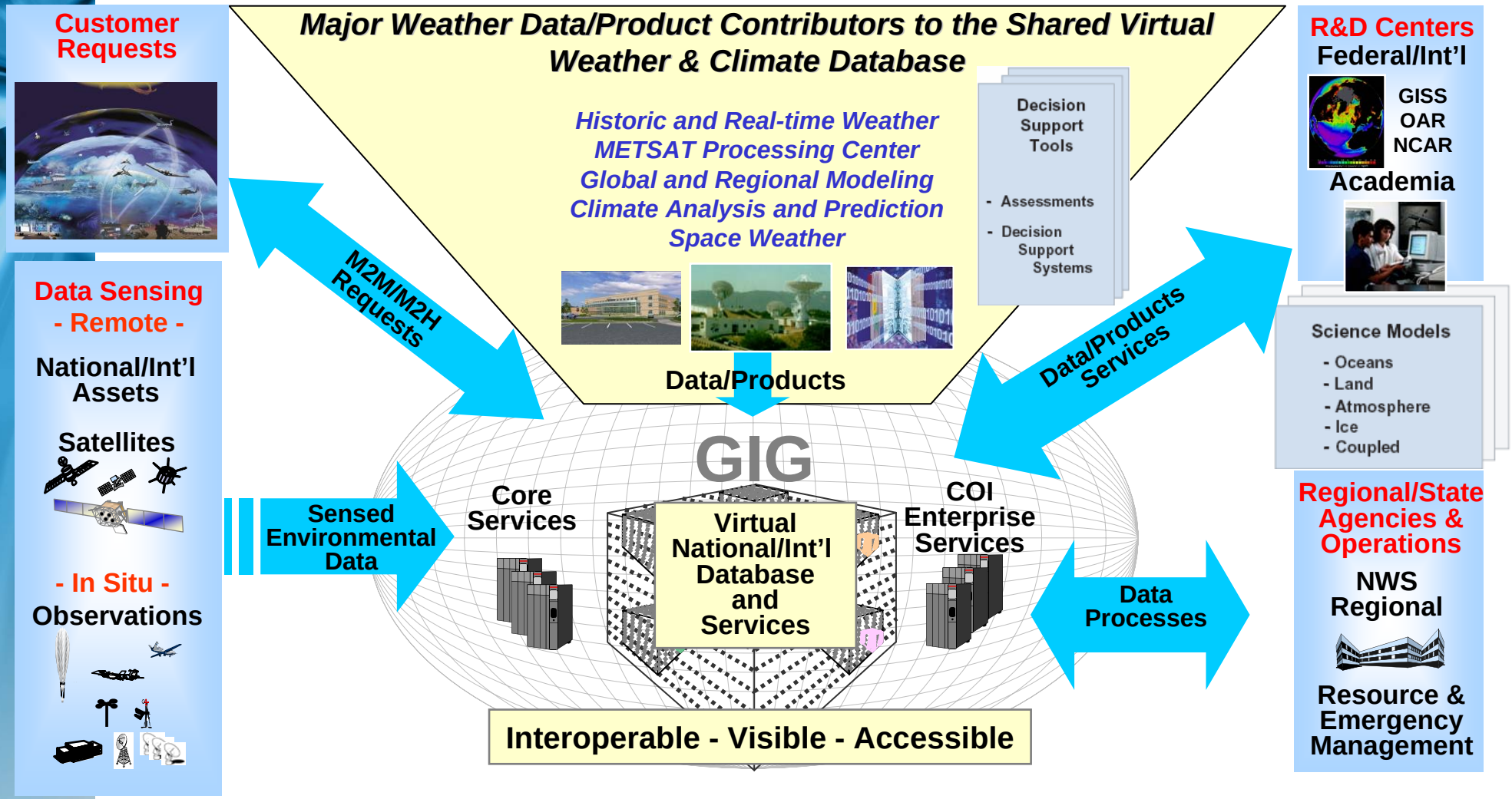
20 MegaPixel Workstations

Collaborative Engineering Tools



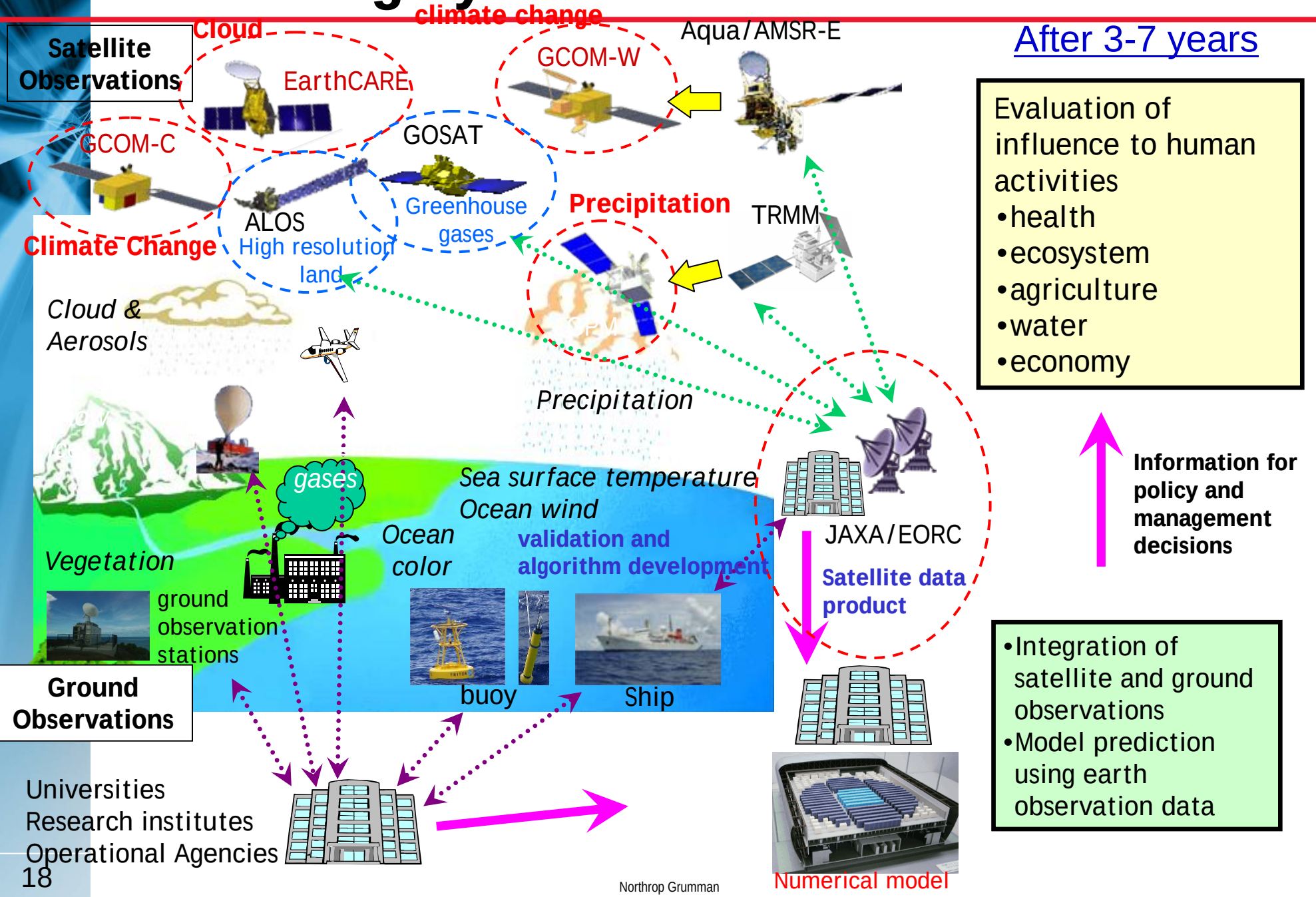
- **Enables integration of observations and decision support tools**
- **Enables scientists and decision makers to collaborate on common views**
- **TouchTable approach can be distributed around country and world**

Operations View Example - U.S. Global Environmental Monitoring System Components



Net-centric architecture where observed and forecast weather and climate are available in standardized formats enabling machine-to-machine (M2M) and human-to-machine interfaces

Proposed JAXA Earth Environmental Monitoring System



After 3-7 years

Evaluation of influence to human activities
- health
- ecosystem
- agriculture
- water
- economy

Information for policy and management decisions

- Integration of satellite and ground observations
- Model prediction using earth observation data

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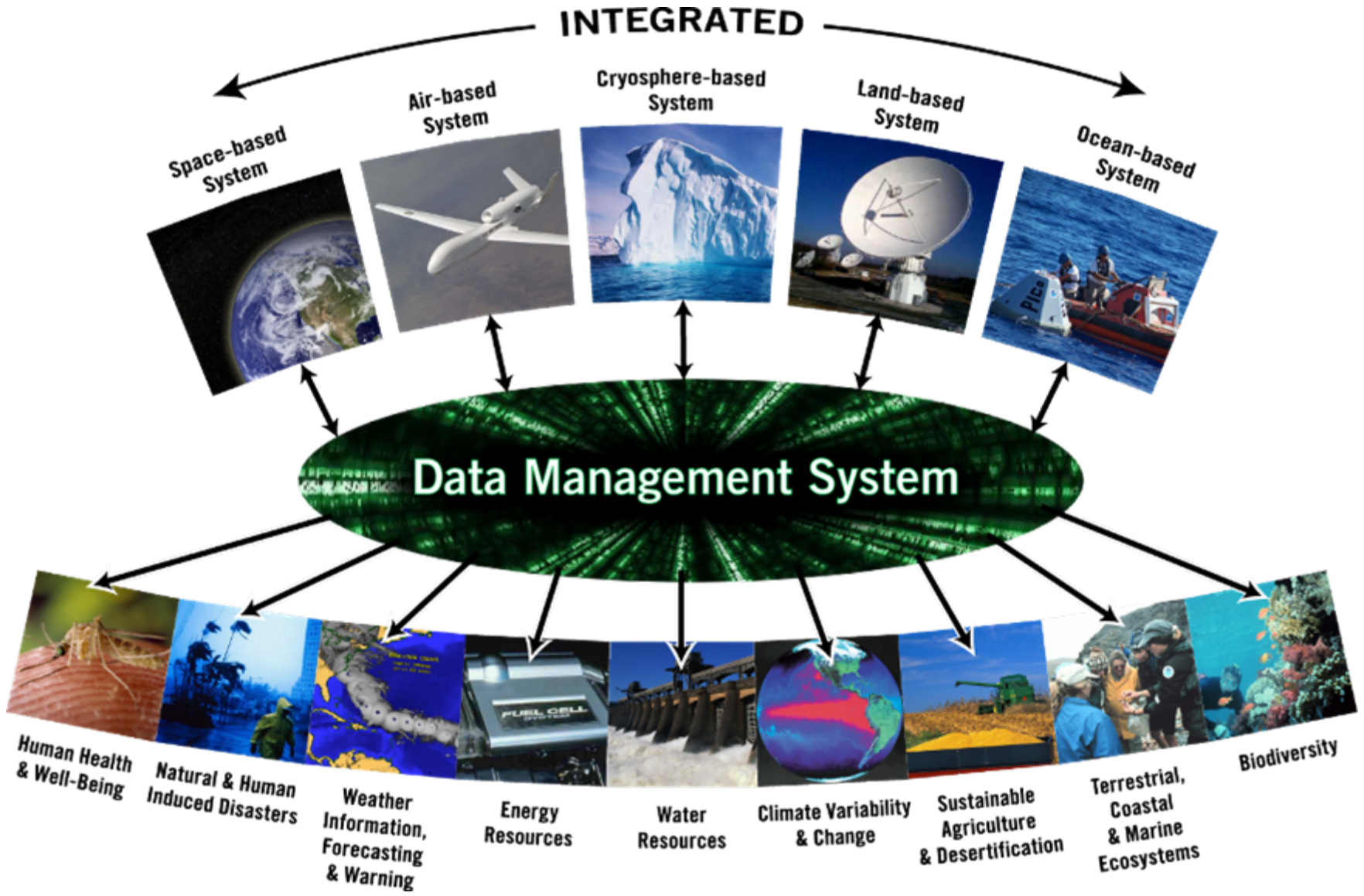
GEOSS Construct



GEOSS Scope

Value Chain

OBSERVATIONS
- Remote
- In Situ

DATA
- Processing
- Archive
- Metadata

INFORMATION
- Interpret
- Predict
- Tailor

DECISION SUPPORT
- Actionable Information
- C3, Networked
- Individual

Collection Regimes

SUBSURFACE
- Undersea
- Land
- Chemistry

SURFACE
- Hydrology
- Biology
- Vegetation

ATMOSPHERE
- Boundary
- Troposphere
- Stratosphere

SUBORBITAL
- 65kft to 325kft

SPACE
- Solar Wind
- Magnetosphere
- Plasma

Platforms

- Buoys
- Seismic
- UAV's

- Buoys
- Ships
- Stations

- Airborne
- Balloon
- Rockets
- UAVs

- Airborne
- Balloons

- LEO
- MEO
- GEO

Models

WORLDWIDE | REGIONAL | STARING | SITE

Synergy

INTERDISCIPLINARY | INTERAGENCY | INSTITUTIONS | INTERNATIONAL

Life Cycle

REQUIREMENTS
- Near Term
- Long Term

ACQUISITION
- Stovepipes
- System-of-Systems

DEVELOPMENT
- Users
- Multi-Use

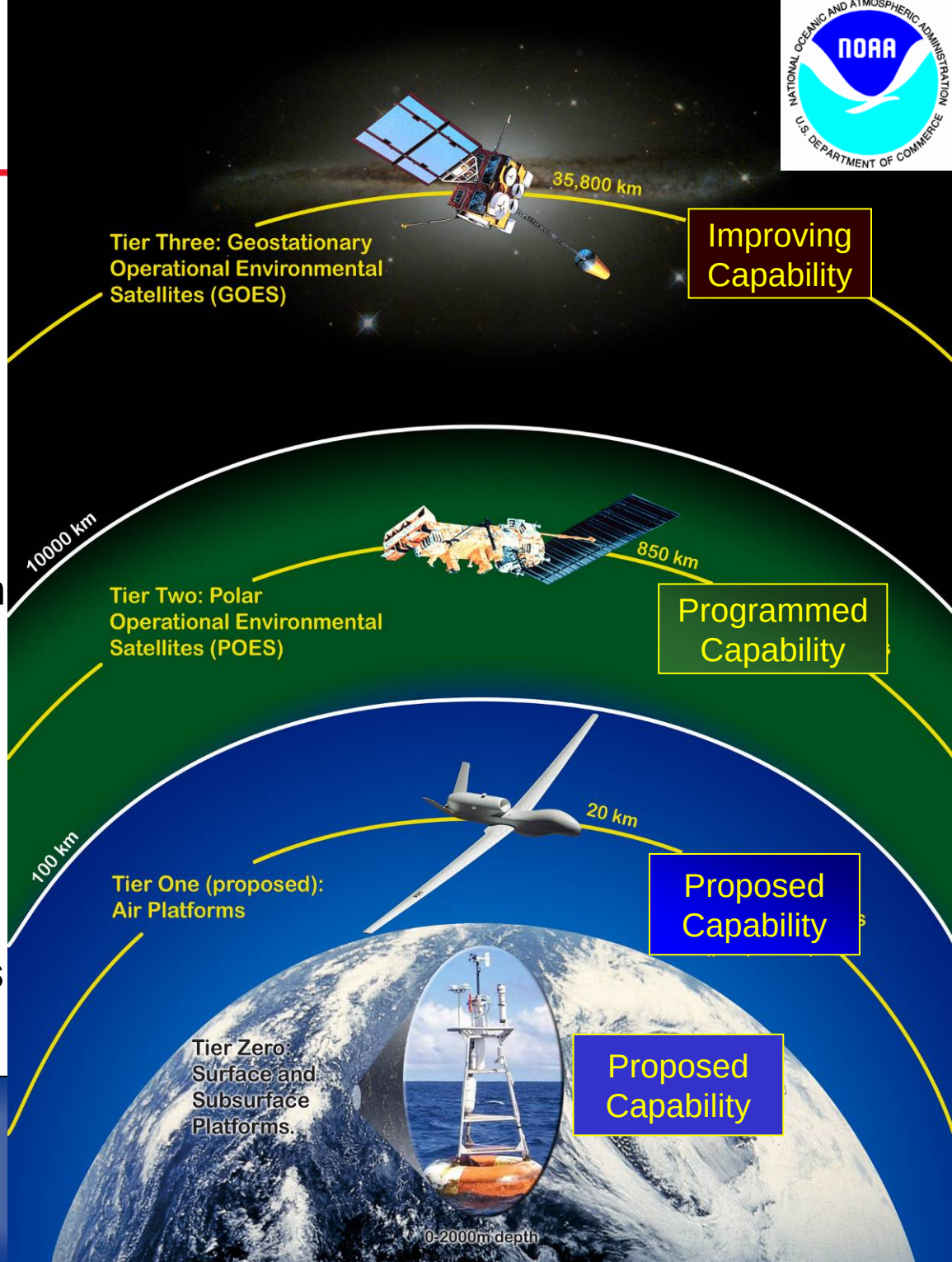
OPERATIONS
- Mission Op
- Prediction
- Alarm

REPLACEMENT
- Next Gen
- Integrated

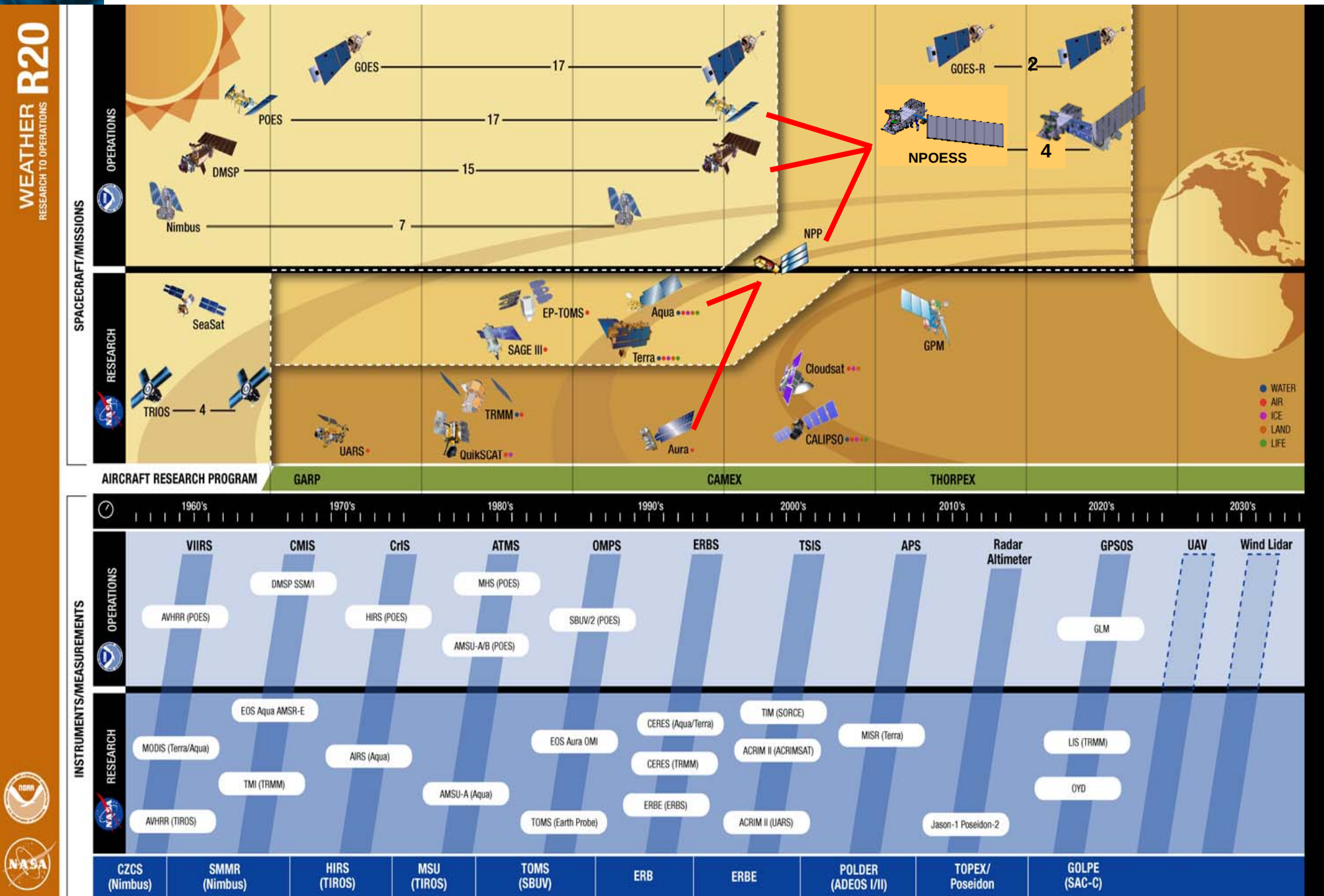
Integrated Global Weather and Climate Observing System

- **Global Observing System**
  - ✓ Supports real-time weather data collection
  - ✓ Supports scientific prediction of long-term climate change
  - ✓ GH provides In-situ ground truth for new space sensors
  - ✓ Routine Systematic Reporting
  - ✓ Global coverage over Oceans

Strategic triad for global observing: ***Satellites, UAVs & Buoys***



U.S. Weather System

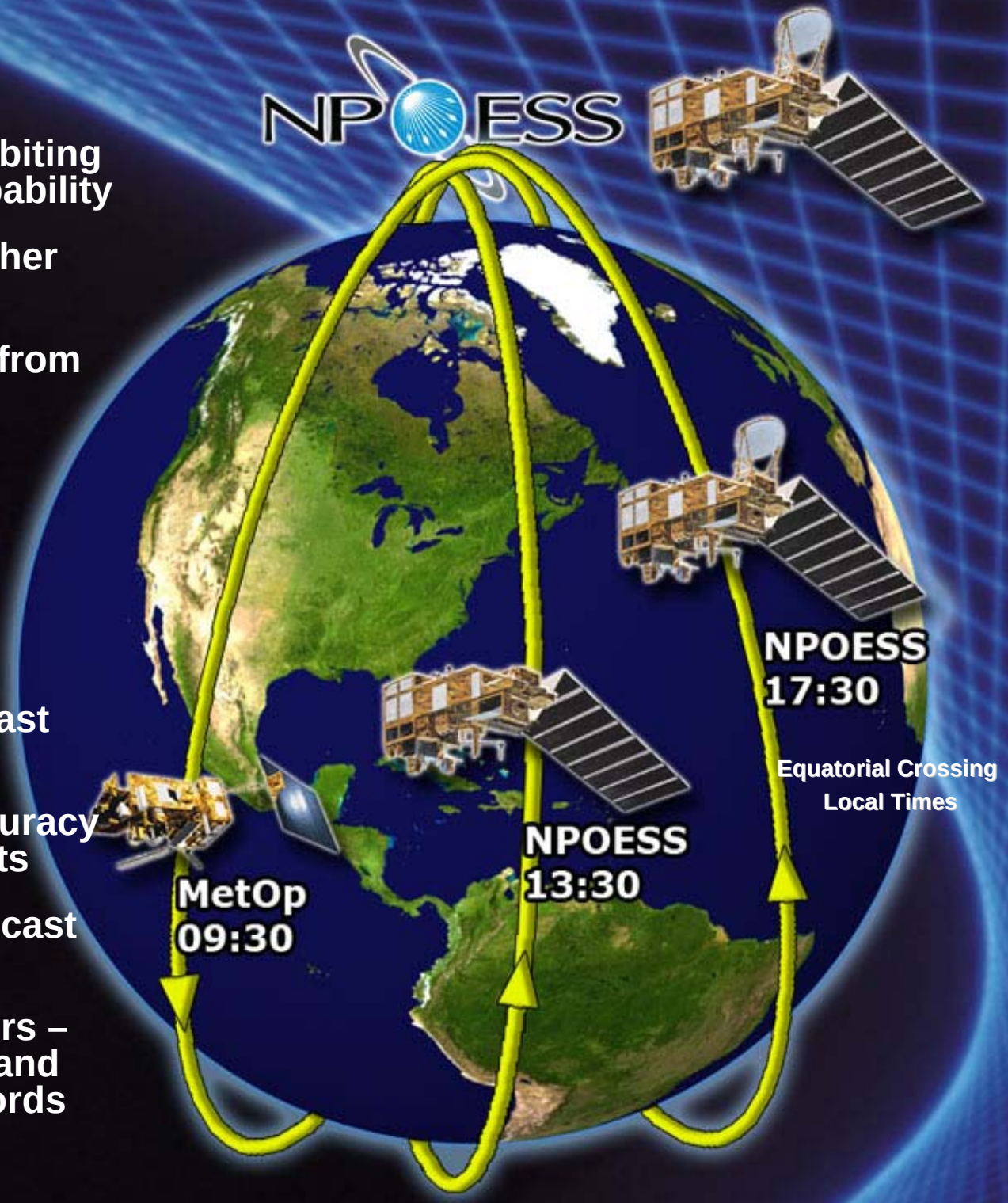


NPOESS Mission

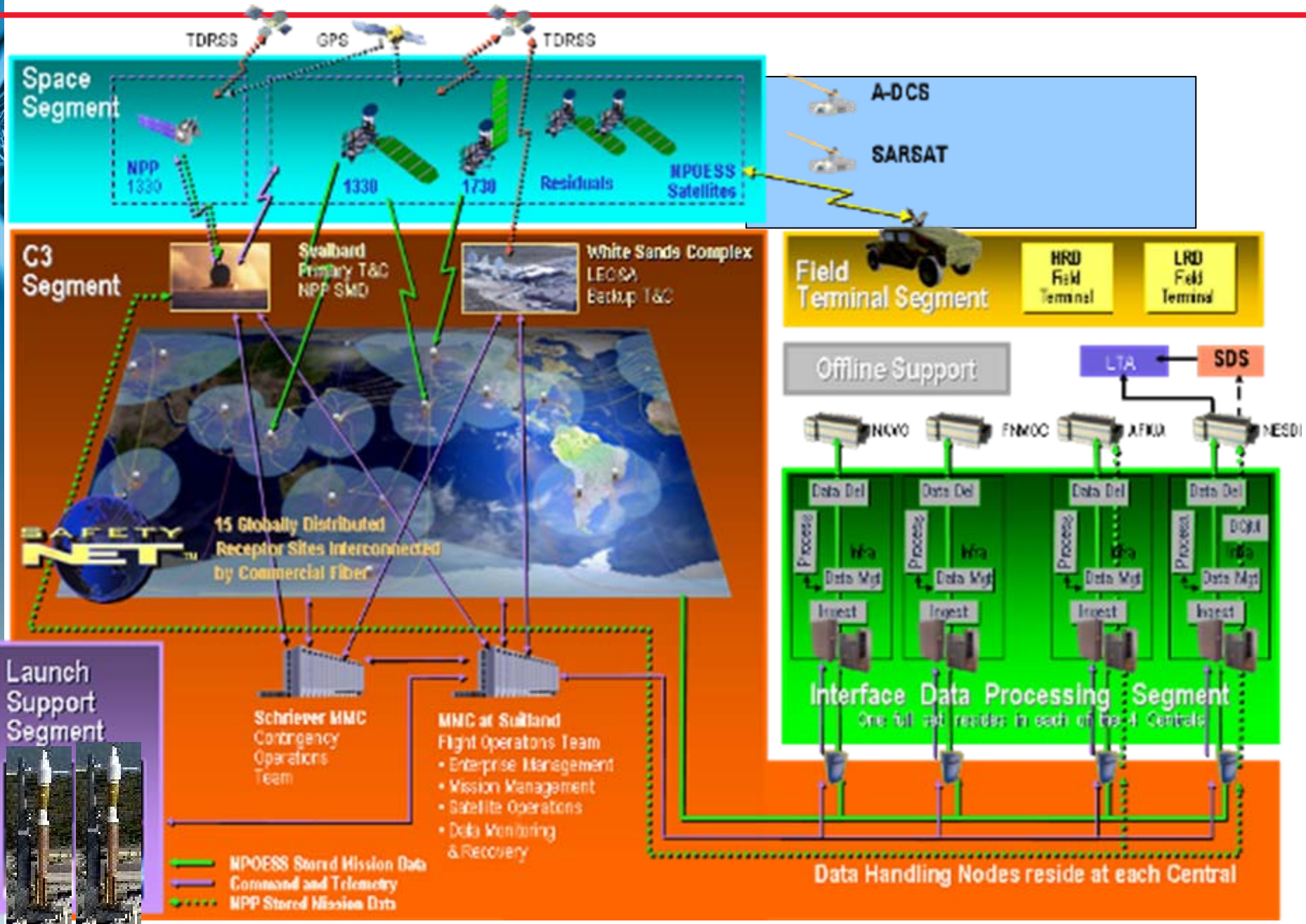
- National, operational, polar-orbiting environmental monitoring capability
- Converges DoD & NOAA weather satellite programs
- Incorporates new technology from NASA programs
- International cooperation with European MetOp satellite

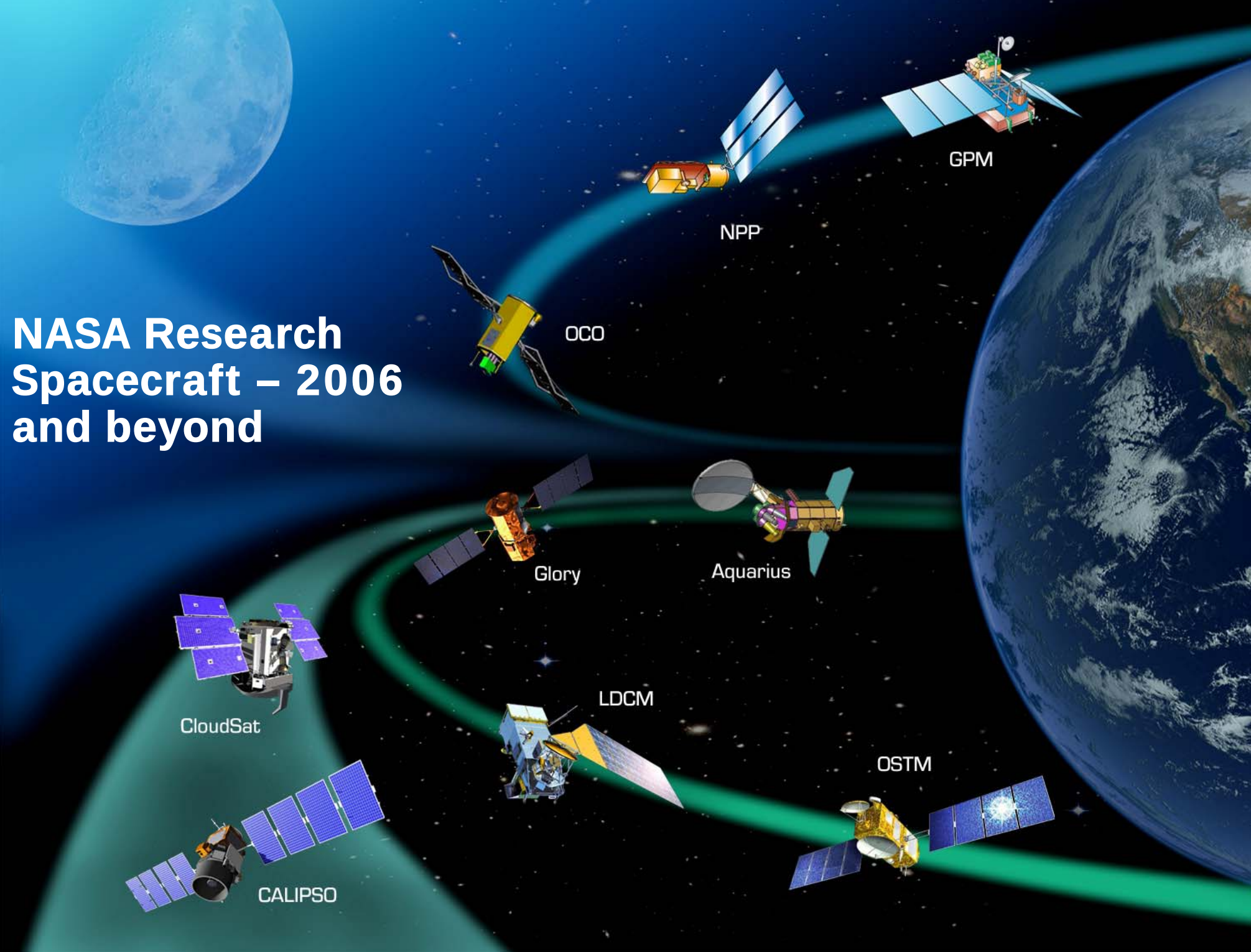
NPOESS Benefits

- Critical input to weather forecast models
  - NPOESS will improve accuracy and expedite data products
- Greatly improved direct broadcast data to users worldwide
- Science-quality data to all users – including research scientists and continuity of climate data records



NPOESS Mission Configuration




NASA Research Spacecraft – 2006 and beyond
GPM
NPP
OCO
Glory
Aquarius
CloudSat
LDCM
OSTM
CALIPSO

GH for Earth Environment and Climate

Global Hawk operates above problematic winds and weather at medium altitudes

Global Hawk operates above ALL other traffic

Global Hawk's sensors range further from high altitude

60,000 ft

45,000 ft

Benefits of High Altitude Flight

- Greater responsiveness
- Less aircraft attrition
- Fewer flight path deviations
- Negligible icing impacts

- Increased safety
- Reduced requirements for coord with ATC
- Eases FAA Certification

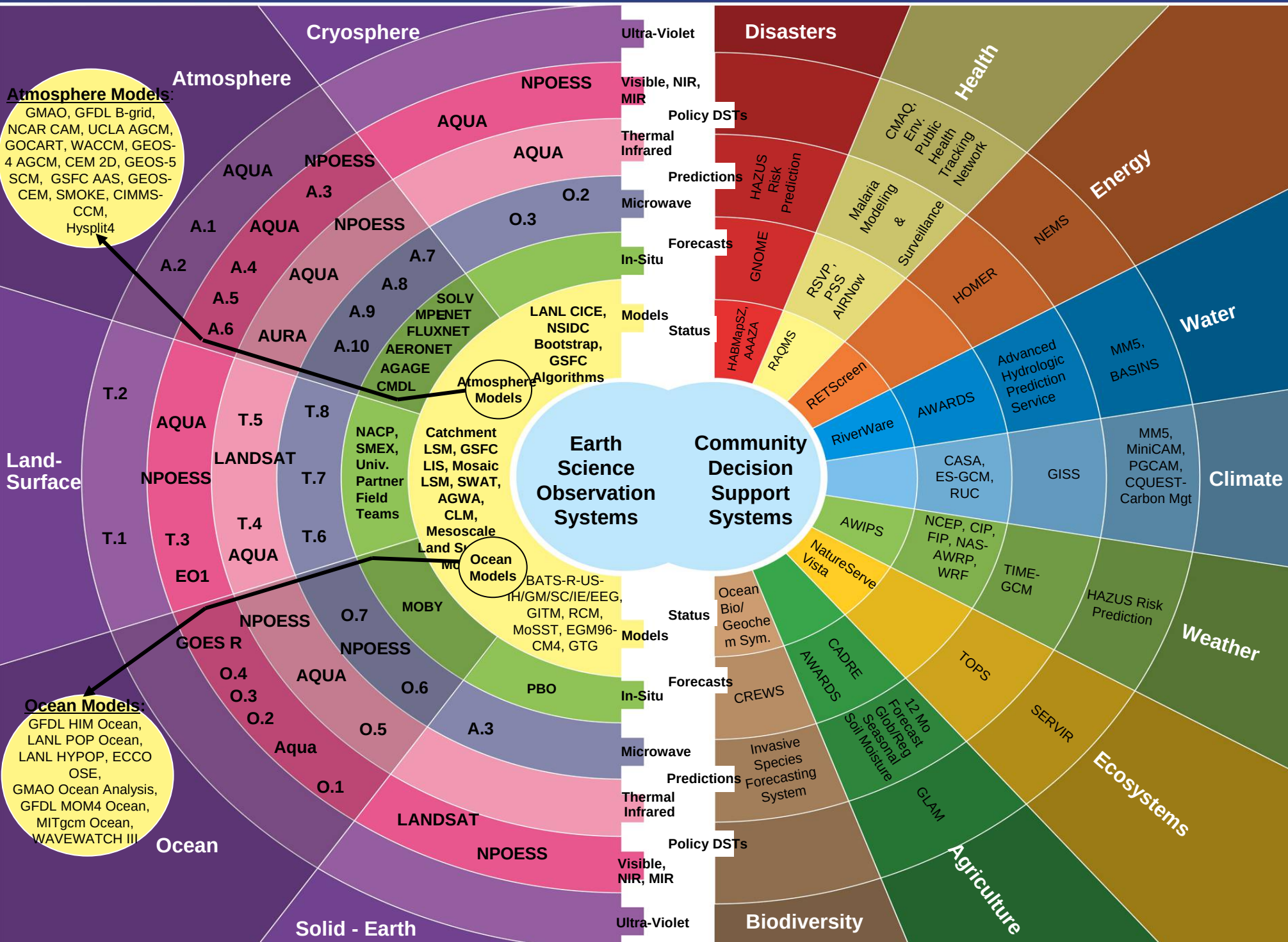
- Terrain masking less problematic
- Greater reach into Areas of Interest
- Greater line of sight connectivity
- Greater Range = Earlier Detection = Increased Warning
- Reduced impact of haze

Calibration / Validation for Global System

Global Hawk Instruments to Cal/Val GOES R ABI	
GOES-R ABI range (μm) (resolution 0.64 μm vis, >2 μm vis/NIR)	**NAST-I range (μm) (resolution 1.4 nm)**
0.45-0.49	
0.59-0.69	
0.846-0.885	
1.371-1.386	
1.58-1.64	
2.225-2.275	
3.80-4.00	3.7-5.05
5.77-6.6	
6.75-7.15	5.0-7.775
7.24-7.44	
8.3-8.7	7.69-15.5
9.42-9.8	
10.1-10.6	
10.8-11.6	
11.8-12.8	
13.0-13.6	

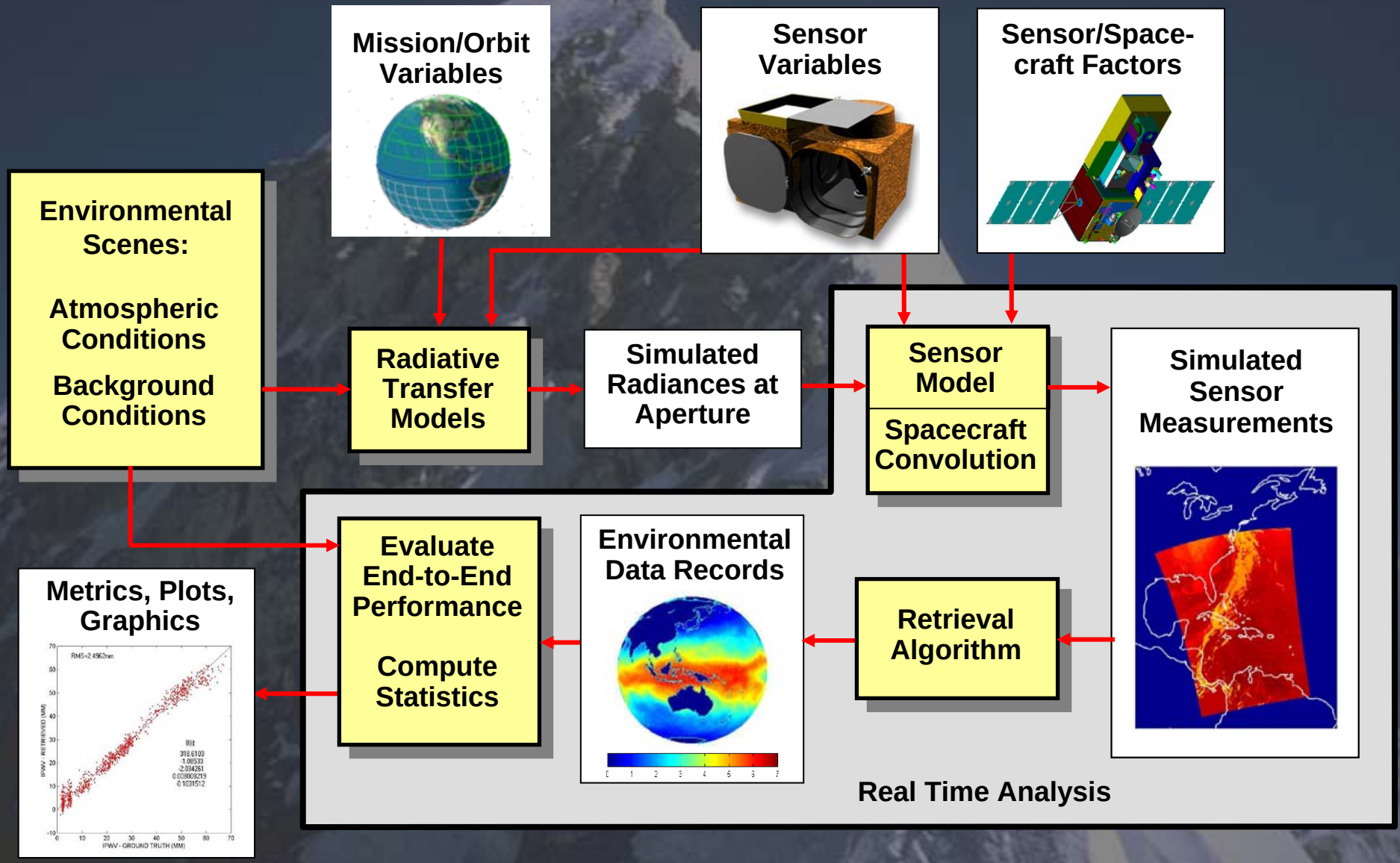
Architecture for IEOS Climate Variability & Change

DRAFT- WORKING DOCUMENT 12/19/06



Analysis of Alternatives

Flexible Set of Tools Supports Multiple Sensors / Missions



Recommendation: Establish National Board on Earth Observations

- **Inclusive**: Embrace cross-community, national perspectives on a target vision and on capabilities and capacities to achieve that target vision
- **Responsive:** Produce value-added targets (measurements, architectures, solutions) to enable timely decisions on investments
- **Objective:** Act as an "honest broker" with broad, analytically based perspectives
- **Accountable:** Serve the needs of the nation by taking into account the needs of the agencies, state, regional, local, tribal, and private sectors using OMB's Program Assessment Rating Tool (PART)
- **Effective:** Capitalize on agency &private sector activities and expertise; including use of existing investments in Earth observations that can be leveraged to meet additional target observations

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Essential Decisions are enabled by Essential Data

INPUTS	OUTPUTS	DECISIONS	IMPLEMENTATION
Observations	Predictions / Forecasts	Partnerships	Value / Benefits to Users

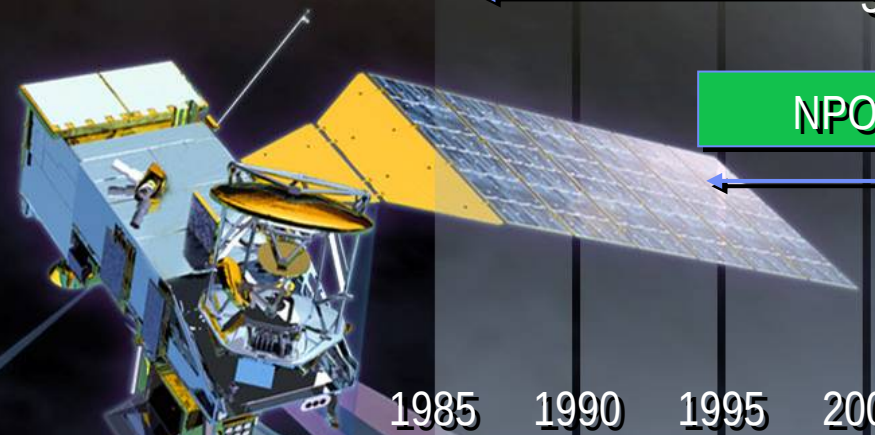
Surface, Airborne & Space Observations

Weather and Climate Models

Decision Tools

Policy

Management



Mission to Planet Earth EOS

30 yrs

NPOESS Restructured NPOESS

30 yrs

U.S. Integrated Earth Observation System

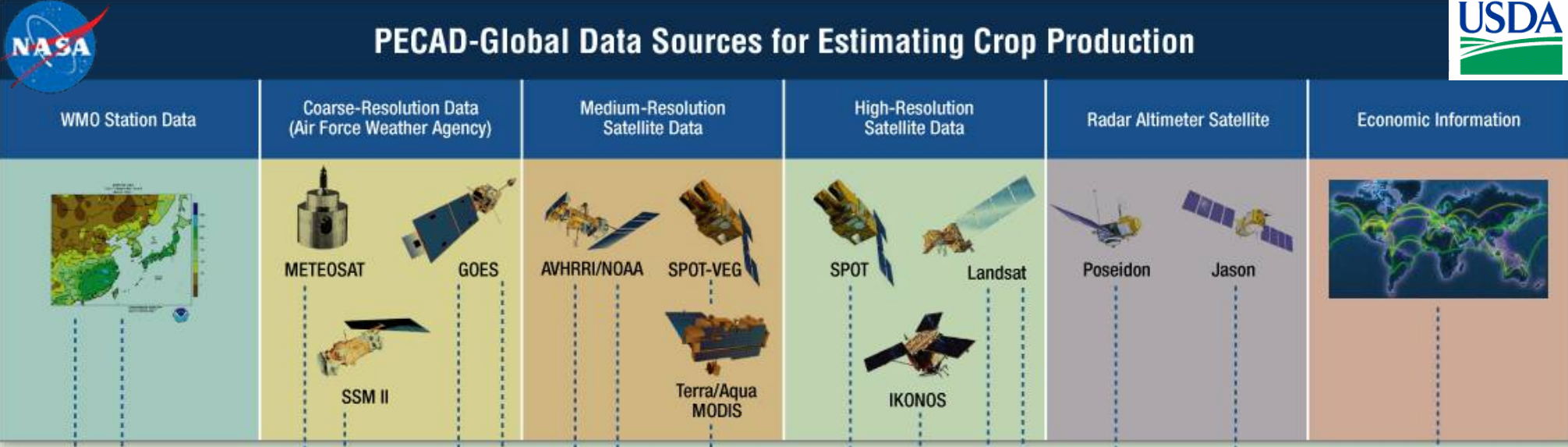
1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 203

It's Time for a Blueprint for Solutions

NORTHROP GRUMMAN

National Application	Partner Organizations	Decision-Support Systems
Agricultural Efficiency	USDA,NOAA	CADRE—Crop Assessment Data Retrieval and Evaluation (USDA)
Air Quality	EPA,NOAA,USDA	CMAQ—Community Multiscale Air Quality Modeling System AIRNow AQI—Air Quality Index
Aviation	DOT/FAA,NOAA	NAS-AWRP—National Air Space-Aviation Weather Research Program
Carbon Management	USDA,DOE,NOAA	CQUEST—Support to the Energy Act of 1992,Section 1605b
Coastal Management	NOAA,EPA,NRL	HAB—Harmful Algal Bloom Bulletin/Mapping System CREWS—Coral Reef Early Warning System
Disaster Management	DHS/FEMA,NOAA,USGS,USFS	AWIPS—Advanced Weather Interactive Processing System HAZUS-MH—Hazards U.S.—Multi-Hazards
Ecological Forecasting	USAID,NOAA,NPS,CCAD,USGS	SERVIR—Regional Visualization and Monitoring System
Energy Management	DOE,UNEP,NOAA,NRC	RETScreen—Energy Diversification Research Laboratory (CEDRL) NEMS—National Energy Modeling System
Homeland Security	DHS,USGS,NOAA,NGA,DOD	IOF—Integrated Operations Facility IMAAC—Interagency Modeling and Atmospheric Assessment Center
Invasive Species	USGS,USDA,NOAA	ISFS—Invasive Species Forecasting System
Public Health	NIH,CDC,DOD,EPA	PSS—Plague Surveillance System EPHTN—Environmental Public Health Tracking Network MMS—Malaria Monitoring and Surveillance RSVP—Rapid Syndrome Validation Project
Water Management	EPA,USDA,USGS,BoR	RiverWARE—Bureau of Reclamation decision-support Tool AWARDS—Agricultural Water Resources and decision-support Tool BASINS—Better Assessment Science Integrating Point and Nonpoint Source

PECAD-Global Data Sources for Estimating Crop Production



GRIB (Raster)

Data Processed by NASA/GIMMS

AGRMET (Grid Cells)

PCWORKS (Image analysis)

Archive Explorer for all USDA agencies

Automated lake elevation (176) every 10-days

PECAD Regional Crop Assessment Analysis

CADRE DBMS

Automated Products on Web

PCWORKS (Image analysis)

GeoCover (Global Landsat LandCover & Mosaics DBMS)

Crop Explorer
http://151.121.3218
(Maps & time-series graphs over major crop regions)

Convergence of Evidence Analysis
Production=Yield * Area

CADRE EX-PLOT

ArcGis
(Images, shape files, & graphs)

Interactive Data Extraction

ARCVIEW/CADRE

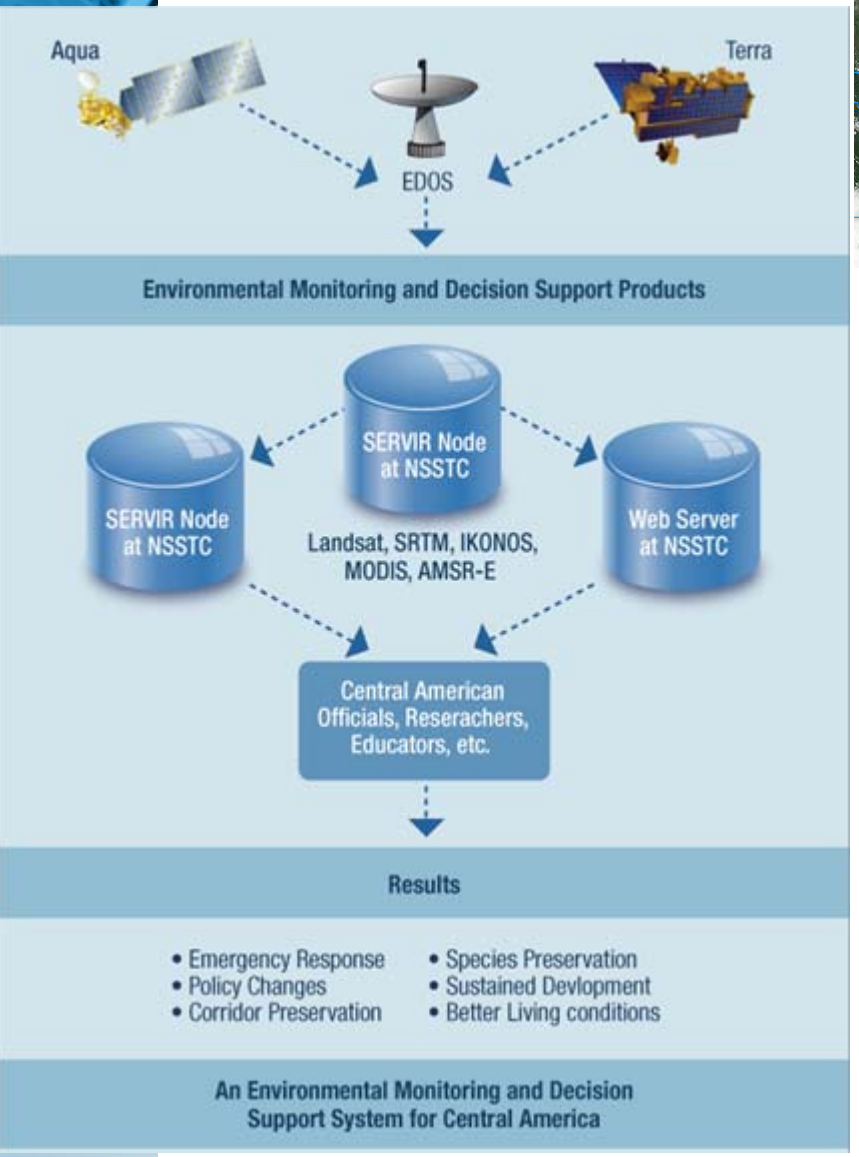
Baseline Reference Data

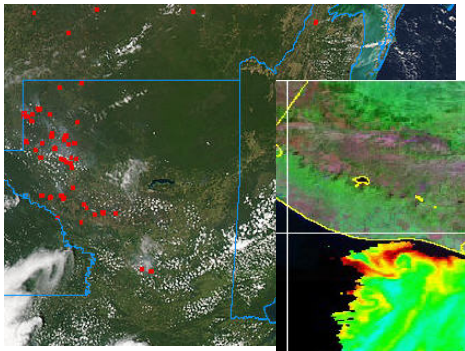
Crop Procuction Estimates

2-Layer Soil Moisture Model

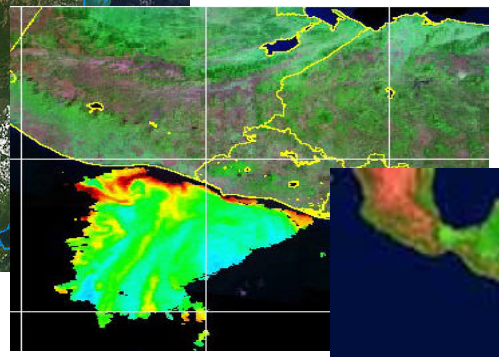
Crop Models

SIAM-SERVIR with CCAD





Wildfires



Red Tide

Land Cover/Use/Change

Central American Officials, Researchers Educators, etc.

Results

Emergency Response
Policy Changes
Corridor Preservation
Species Preservation
Sustained Development
Better Living

Next Generation Systems

- **Optimized to**
  - cover essential variables and coverage
  - be interoperable with Earth Science System models
  - be interoperable with decision support tools of national and global priority
  - effectively transition from research to operations
- **Optimized for**
  - sustainability and operational use
  - adaptability and flexibility with evolving knowledge of science and technology
  - cost, schedule, performance and risk mitigation
  - national collaboration
  - international collaboration

Over 6.5 billion people to serve….