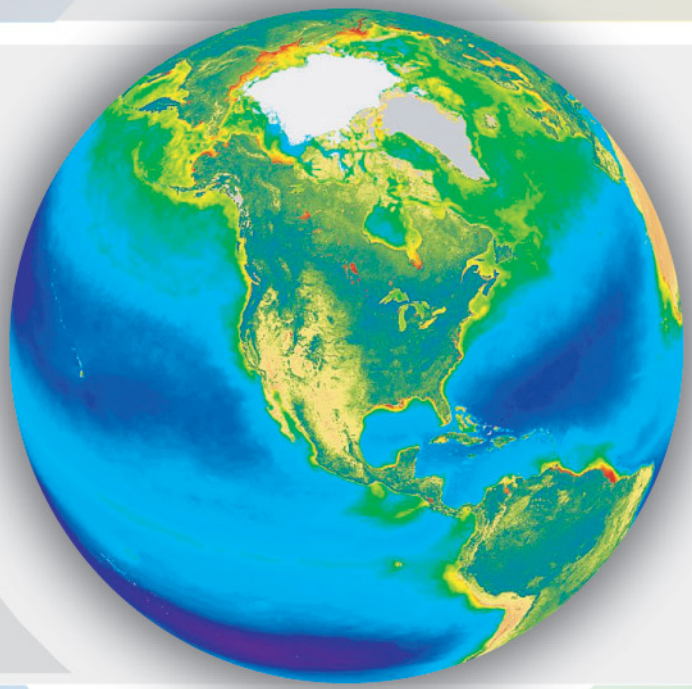
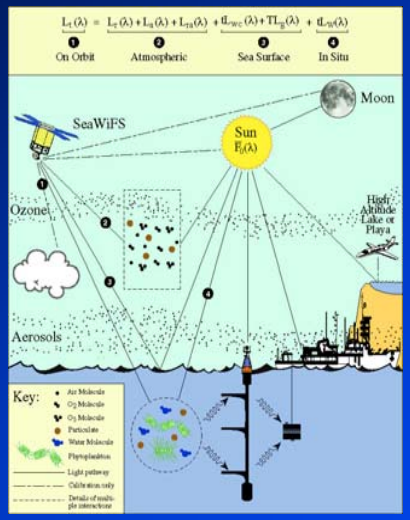
Future Ocean Color Research:

Ocean Biological and Biogeochemical Properties from Space



Paula Bontempi
NASA Headquarters
NOAA NMFS Seminar
11 December 2008

Ocean Biology and Biogeochemistry Research from Space



New Measurements/ DS Missions/New Initiative

Time Series, Vicarious Cal, Data Product Val, Field Campaigns (MOBY, HOT, BATS, BOUSSOLE, VT)

International Partnerships; Unrestricted data availability/use; Sharing of *in situ* Cal/Val data; Ship time; Models

Ocean/Coastal Processes from Space & Mod.

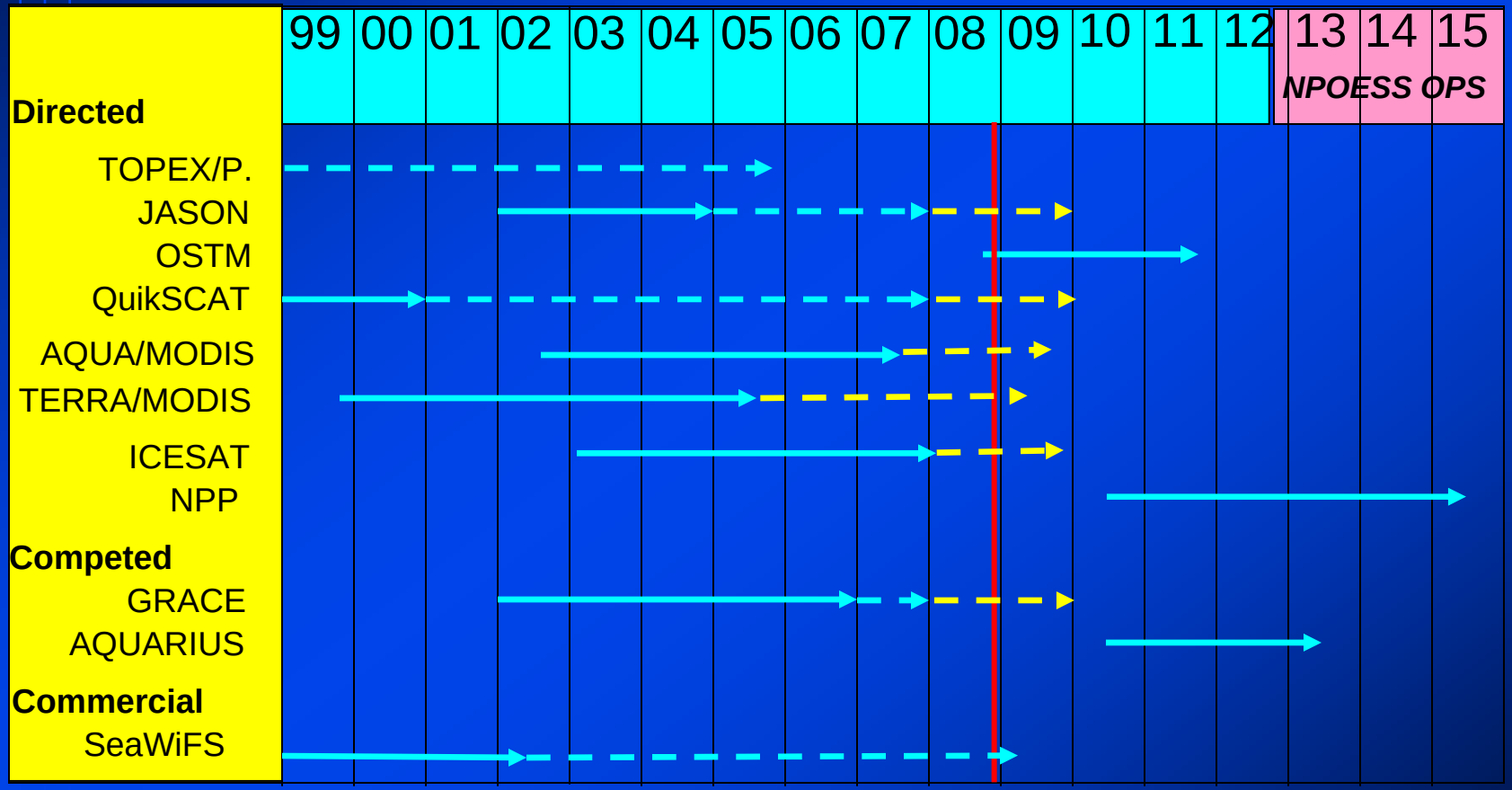
NACP/OCCC/ IMBER/SOLAS OCB

Carbon Cycle, Ecosystems Research

Systematic Measurements

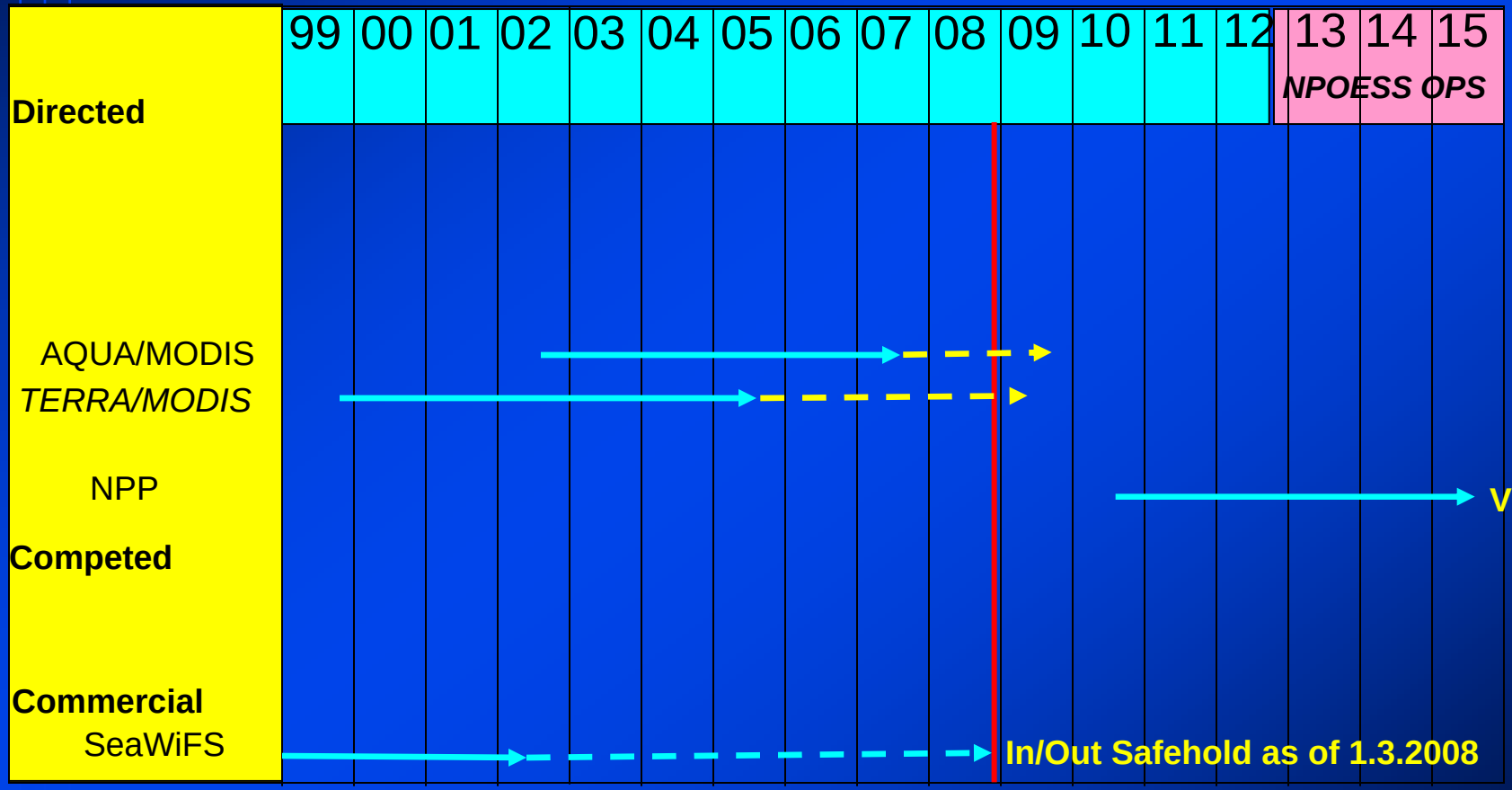
NASA Current and Approved Oceans and Ice Missions

Beyond Aquarius (2010) there are no approved NASA oceanographic satellite missions



NASA Current and Approved Oceans and Ice Missions

Beyond Aquarius (2010) there are no approved NASA oceanographic satellite missions



VIIRS Level 1 Requirements

Limits in NASA's role imposed by the Level-1 requirements (2003):

2.1.2.1 The SDS shall be designed with the assumption that the operational IPO IDPS generated NPP EDRs do not require reprocessing or re-computation in order to support climate research needs. Consequently, the SDS will not be designed to routinely generate climate data products which require long-term archival in ADS.

2.1.2.3 In developing the SDS, the Project shall assume that EDRs produced by the IDPS are climate quality and put in place the capability to test that hypothesis in order to contribute to improving the quality of future EDRs. The SDS shall provide suggested algorithm improvements to the IDPS.

Note:

1) The assumption underlying these requirements is demonstrably false, since no satellite sensor has ever produced research-quality data without reprocessing;

2) NASA NPP Project (SDS) funding will *not* support generation of better products (than the EDRs); and

3) Carder et al algorithm for chl *a* is behind the state of the science.

VIIRS Science Issues

- **List <u>not</u> in priority order:**
  1- VisNIR IFA Optical Crosstalk*
  2- VisNIR ROIC Static Electronic Crosstalk
  3- VisNIR Dynamic Crosstalk
  4- LWIR/SMWIR Static Crosstalk and/or Ghosting
  5- Gain Switch Noise and Linearity
  6- Stray Light Contamination
  7- Reflective Bands Uniformity
  8- Emissive Bands Calibration
  9- Relative Spectral Response (RSR) Measurements – characterization data receipt in a timely fashion
  10- End-to-End Calibration (SD-SAS-SDSM)
  11- Sensor Stability (Temperature, SC voltage, EMI/EMC)
  12- Response Versus Scan (RVS) Angle
  13- Characterization of Polarization Sensitivity
  14- Ambient to T/V to On-orbit Spatial Performance

- **March- delay in delivery of VIIRS FU-1 and launch for NPP (eight months)**

Need an assessment of the impact the IFA replacement would have on the new baseline; real technical risk associated with the replacement procedure; FU-1 ability to meet the ocean color and aerosol requirements is severely compromised.

VIIRS Science Issues & Feedback

NASA VIIRS Ocean Science Team Contributions

ALGORITHM

Action Item	AI No.	Last Date
Review of SDR calibration algorithm code	AI0025	5-Jan-2004
Review of ACO/OCC flags	AI0002	12-Apr-2004
Review Atm Corr algorithm code	AI0009	4-May-2004
Review Chl ATBD	AI0006	12-May-2004
Review VIIRS Rad Cal ATBD	AI0014	12-May-2004
Review Atm Corr ATBD v5r6	AI0007	15-May-2004
Review geolocation ATBD	AI0013	28-May-2004
Review Chl ATBD Update	AI0006a	3-Jun-2004
Review VIIRS Rad Cal ATBD update	AI0014a	3-Jun-2004
Review Chl ATBD v5r6	AI0006b	1-Jul-2004
Review Chl algorithm code	AI0008	29-Jul-2004
Review D36966 Update	AI0005a	20-Oct-2004
Review VIIRS Rad Cal ATBD update	AI0014b	10-Nov-2004
Review of Aerosol ATBD	AI0033	20-Dec-2004
Reason for ocean aerosol calculation	AI0035	6-Jan-2005
Response to NGST comments	AI0025a	8-Feb-2005
SDR Cal S/W review for L1 meeting	AI0047	21-Mar-2005
Comments on updated EDR flags	AI0054	2-Jun-2005
Comments on NGST Algorithm Work-Off List	AI0056	5-Aug-2005
SDR/RDR Code Complete Review	AI0059	16-Aug-2005
Review for ACO/OCC TIM	AI0058	17-Aug-2005
OC EDR issues list for NASA HQ	AI0063	26-Aug-2005
OC EDR algorithm ARB/ACCB	AI0067	6-Sep-2005
IPO Operational Algorithm Meeting	AI0077	18-Jan-2006
IPO Algorithm Division Risk Survey	AI0091	22-May-2006
IPO Algorithm Meeting	AI0094	20-Jun-2006
Simulated Data Effort	AI0097	12-Jul-2006
Overview of NPP Algorithm for PEATE PDR	AI0096	21-Jul-2006
ECR 139 OCC Algorithm Changes	AI0122	18-Feb-2008
ECR 677B CDFCB Changes	AI0124	10-Mar-2008

VIIRS Science Issues & Feedback

NASA VIIRS Ocean Science Team Contributions

GENERAL - SCIENCE

Action Item	AI No.	Last Date
Challenges for Ocean Color	AI0000	18-Mar-2004
VOAT Presentation -- 24 Aug 2004	AI0024	24-Aug-2004
OC EDR Whitepaper	AI0024a	28-Sep-2004
VOAT Presentation -- 3 Feb 2005	AI0040	27-Jan-2005
Rationale for open source distribution	AI0041	22-Feb-2005
Presentation for NASA HQ - 8 Apr 2005	AI0048	7-Apr-2005
Presentation for OCRT meeting -- 9-12 Apr 2005	AI0049	8-Apr-2005
Cloud dilation analysis	AI0050	25-Apr-2005
Comments on on-board and ground processing	AI0051	25-Apr-2005
NPP Science Team Meeting - 9-10 May 2005	AI0052	8-May-2005
Effects of opposite band pair errors on OC EDRs	AI0037a	9-May-2005
VOAT Presentation -- 26 Sept 2005	AI0064	26-Sep-2005
Sensitivity analysis of OC EDRs to radiometry	AI0037	8-Dec-2005
Poster and OC EDR sensitivity -- Fall AGU 8 Dec 2005	AI0065	8-Dec-2005
Analysis of partially cloudy pixel effects	AI0068	19-Feb-2006
Ocean Color Status Presentation for NASA HQ	AI0086	23-Mar-2006
VOAT Presentation -- 4 April 2006	AI0087	4-Apr-2006
VOAT Presentation -- 4-5 Oct 2006	AI0100	4-Oct-2006
NPP Presentation for OCRT - Contribution Slides	AI0105	6-Apr-2007
VOAT Presentation -- 11-12 Apr 2007	AI0103	12-Apr-2007
Comments on Sys Spec Changes	AI0102	30-May-2007
NPP Science Team Meeting - Aug 2007	AI0110	22-Aug-2007
Coccolithophorid Bloom Lt Analysis	AI0112	18-Sep-2007
IORD Specs Summary for GOCECP Presentation	AI0111	21-Sep-2007
JARG OCC Assessment	AI0108	26-Sep-2007
VOAT Presentation -- 17-18 Oct 2007	AI0117	18-Oct-2007
Manuever Meeting 20080213	AI0120	5-Feb-2008
VOAT Presentation -- 21-22 Feb 2008	AI0121	22-Feb-2008
IPO EDR Assessment Review	AI0126	26-Mar-2008
Sensitivity analysis manuscript	AI0072	in progress

VIIRS Science Issues & Feedback

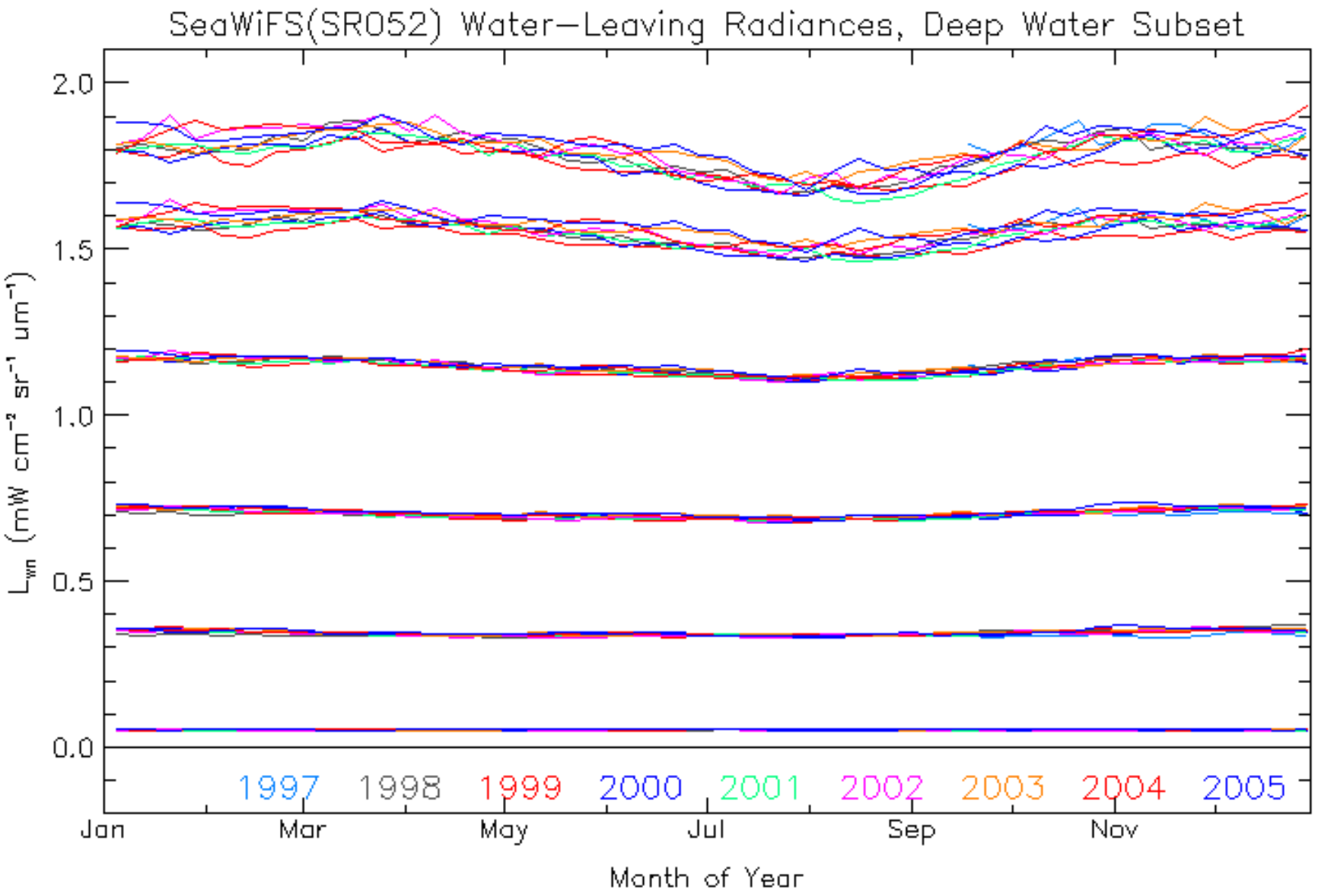
NASA VIIRS Ocean Science Team Contributions

INSTRUMENT Action Item	AI No.	Last Date
VIIRS test gap analysis	AI0004	5-Apr-2004
Review VIIRS Rad Cal Eqns (D36966)	AI0005	15-May-2004
Comments on reflective optic prescriptions	AI0012	18-May-2004
EDU Crosstalk effect on OC/EDR - define granules	AI0017	24-May-2004
Review list of Intermediate Products	AI0003	5-Jun-2004
EDU Crosstalk effect on OC/EDR - analysis	AI0017a	24-Aug-2004
IPO Presentation on Earthshine	AI0024b	17-Sep-2004
Inter-sensor SNR comparison	AI0026	28-Oct-2004
Dual gain switch point - impact analysis	AI0031	28-Oct-2004
Dual gain switch point - telecon	AI0032	7-Nov-2004
Earthshine TIM 7-8 Dec 2004	AI0034	7-Dec-2004
Comment on straylight	AI0039	3-Jan-2005
MODIS and VIIRS RSR and polarization	AI0036	28-Apr-2005
Evaluate SNR for bands M8 and M10	AI0053	18-May-2005
Review of FP-06 pt 1 (LSF in track direction)	AI0069	18-Nov-2005
Review of FP-11 (polarization insensitivity)	AI0070	19-Dec-2005
Review of EDU FP-10 (RVS)	AI0074	29-Dec-2005
Evaluation of EDU Near-Field Response (FP-14)	AI0085	5-Apr-2006
Analysis of Crosstalk (FP-03, FP-14, FP-04)	AI0089	24-May-2006
Analysis of RSR Sensitivities	AI0095	22-Jun-2006
Report on Extended Analysis of EDU Crosstalk	AI0093	26-Jun-2006
Lessons Learned Regarding VIIRS Crosstalk	AI0099	8-Aug-2006
EDU Test Assessment	AI0098	17-Aug-2006
OOB Crosstalk Mitigation	AI0114	10-Mar-2007
Crosstalk Requirements - Evaluation of Modifications	AI0104	29-Mar-2007
MODIS to VIIRS SWIR Radiometric Performance Comparison	AI0107	11-May-2007
Review of Waiver Requests	AI0106	25-May-2007
Crosstalk Analysis for OC EDR Impact	AI0101	1-Aug-2007
FU1 Polarization Characterization Analysis	AI0113	1-Oct-2007
NPP VIIRS Sensor Spec Comparison Input	AI0115	1-Oct-2007
Guenther Report on Crosstalk Mitigation - Review	AI0116	31-Oct-2007
VIIRS Calibration Workshop 20080131	AI0119	31-Jan-2008
Scaling Crosstalk to Ltyp	AI0123	6-Mar-2008
Gain_Switch_Anomalies_Analysis	AI0125	12-Mar-2008

NICST Memoranda Reviewed

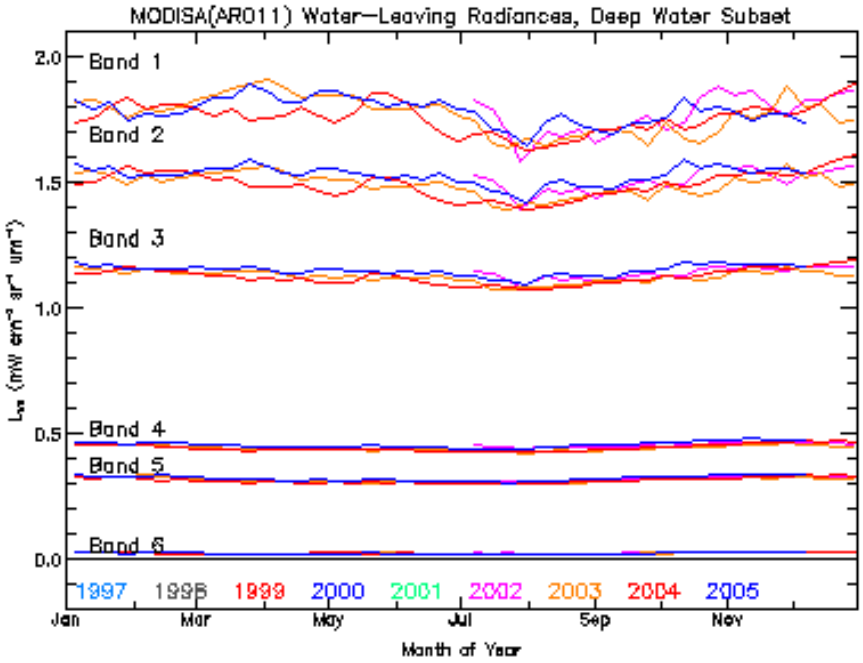
06_006	07_002	08_002
06_007	07_003	08_003
06_008	07_004	08_004
06_010	07_005	08_005
06_013	07_007	08_008
06_015	07_008	08_009
06_016	07_009	08_013
06_018	07_010	08_014
06_019	07_012	STR-358
06_020	07_016	
06_021	07_017	
06_023	07_018	
06_024	07_019	
06_025	07_020	
06_026	07_021	
06_027	07_023	
06_029	07_024	
06_030	07_025	
06_031	07_028	
06_032	07_030	
06_034	07_031	
06_035	07_032	
06_038		
06_040		
06_042		
06_043		

SeaWiFS Annual Lwn Cycles

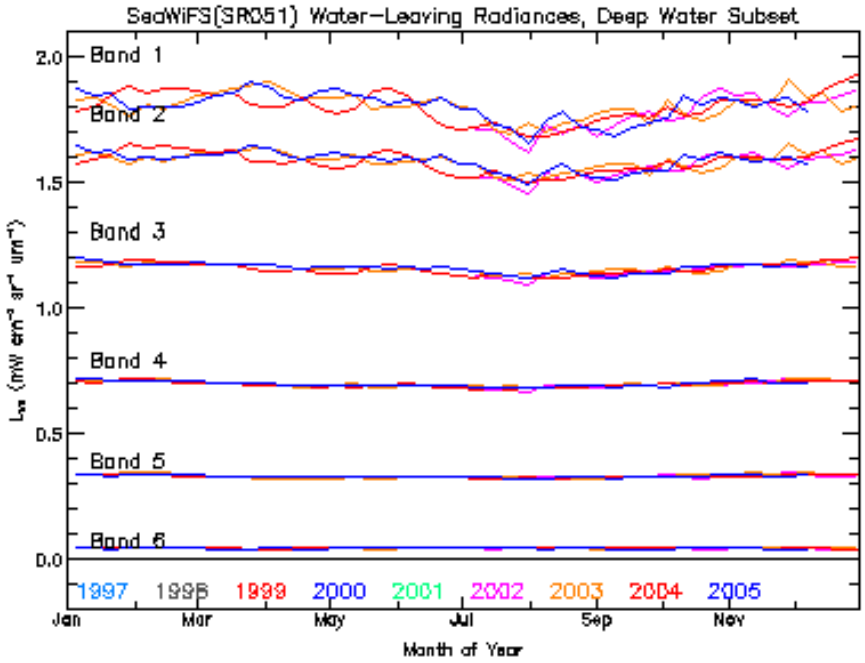


Comparison of Relative Temporal Stability in nLw Deep-Water, 8-Day Composites, Common Bins

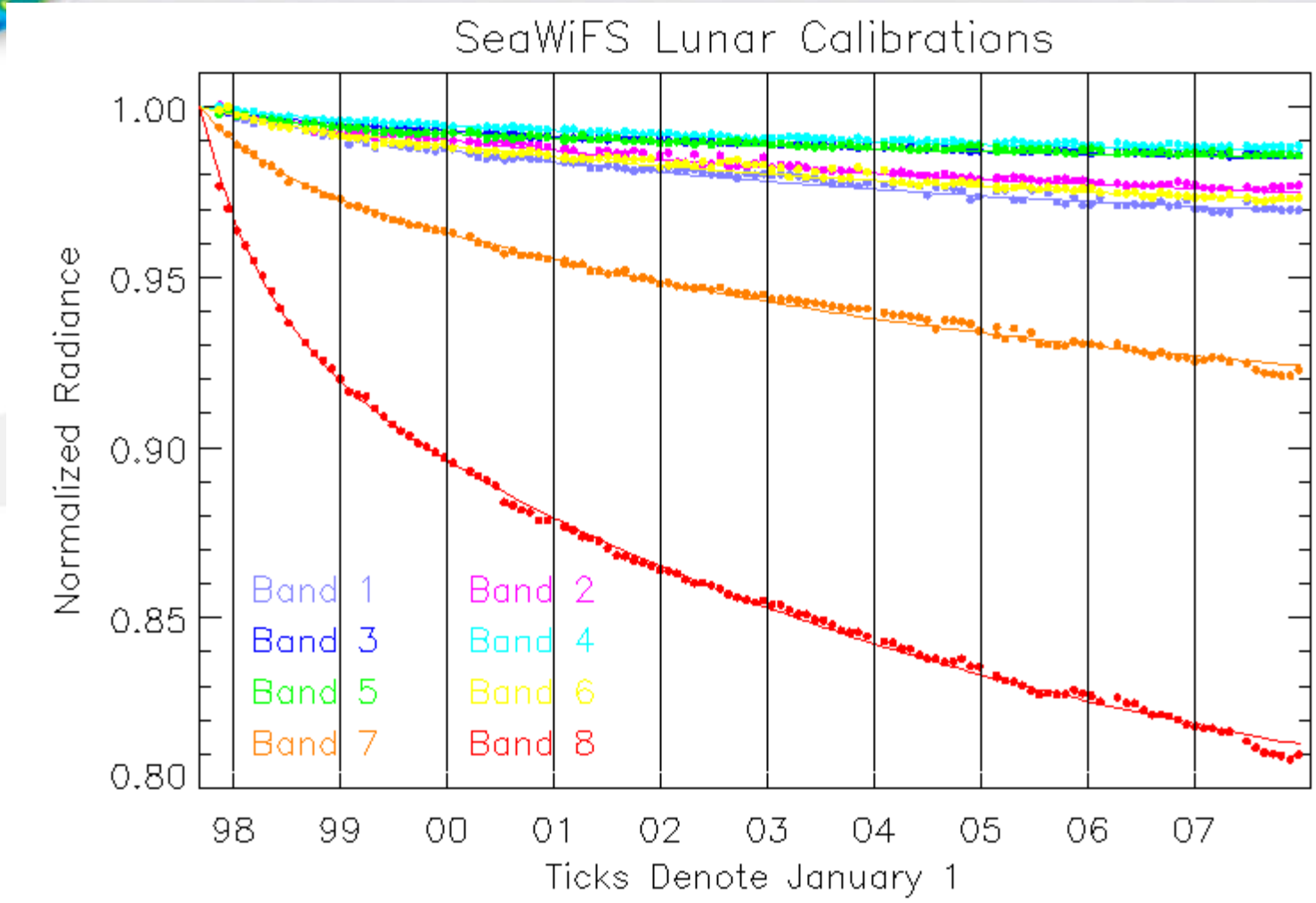
MODIS/Aqua



SeaWiFS



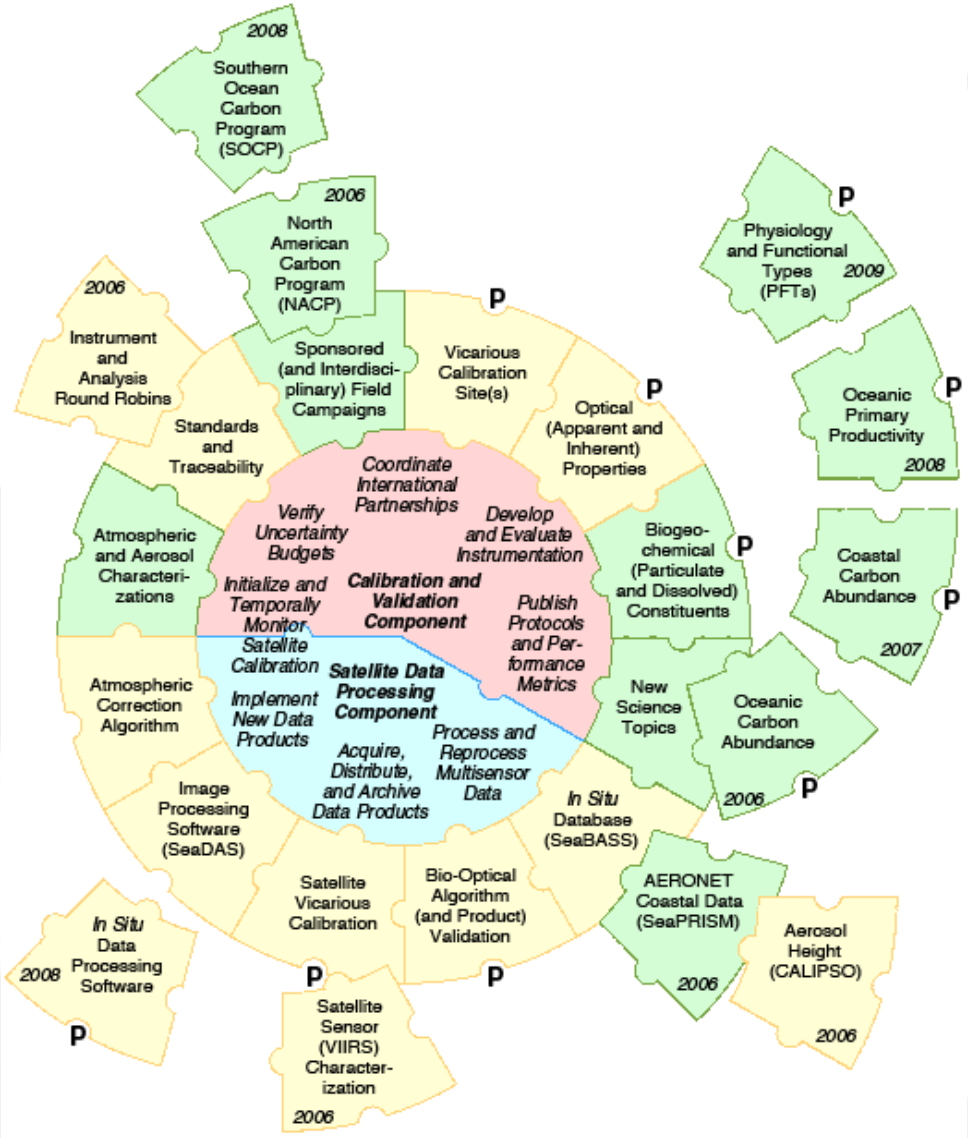
Requirement for On-Orbit Maneuvers (Lunar Cal)



Lunar Calibration Maneuvers are not even considered for NPOESS C1 and beyond: no lunar roll, SD yaw, or deep space pitch maneuvers

These may only be allowed for NPP, but not yet approved.

Requirement for Vicarious Calibration/Validation Activities



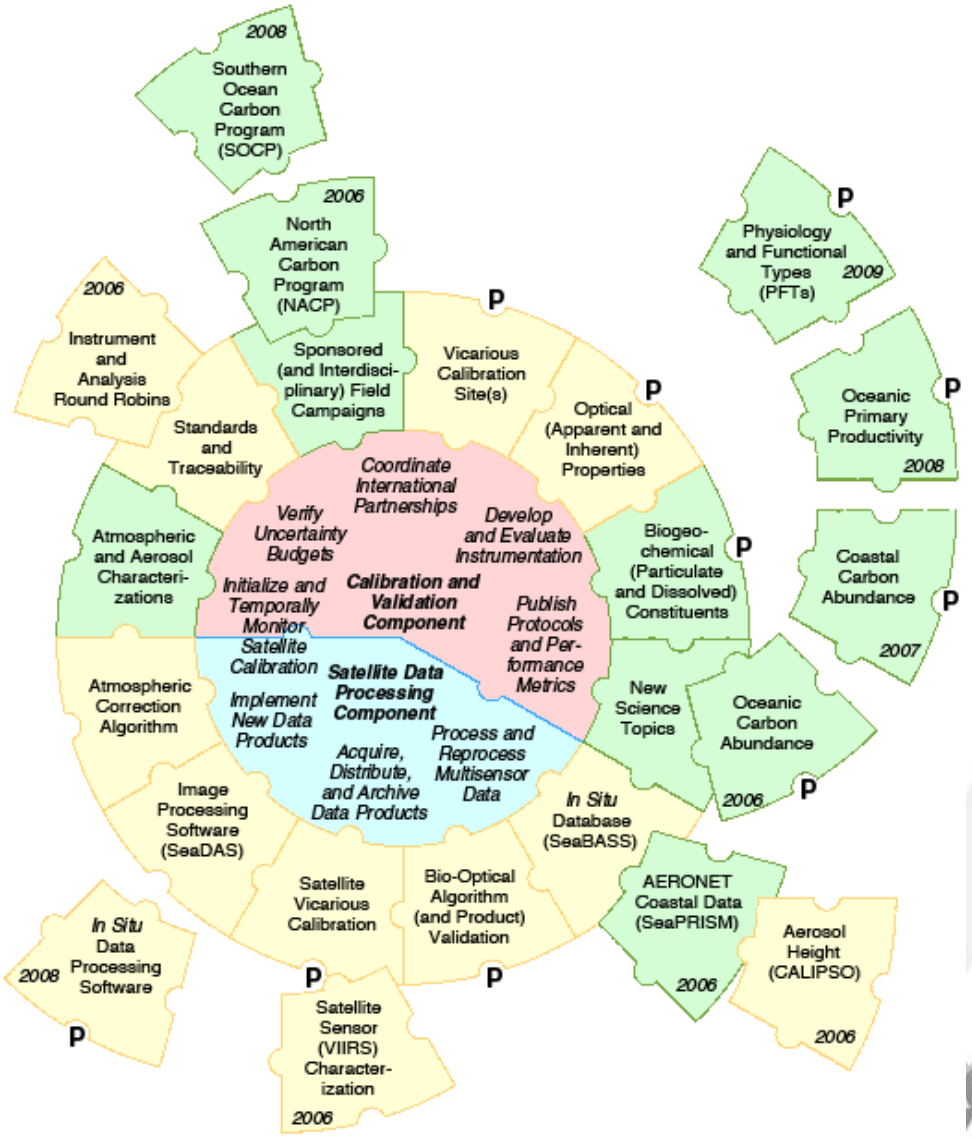
Requirement for Vicarious Calibration/Validation Activities

NOAA NESDIS support of MOBY beginning June 2007

Redirection of Ocean Biology and Biogeochemistry Funds to support new instrumentation in sensor development, ocean color sensor calibration, and data product validation (ORPP NT Priority #2): next generation research questions require equipment that does not exist; partnership with ESTO, Cal/Val Office at NASA GSFC

- Protocols
- QA/QC Procedures for Data
- Round robins – instruments, processing

Ultimately, the international agencies are going to have to implement guidelines for quality assurance as well



Vicarious Calibration/Validation Activities: Round Robins/Workshops

- Ocean Optics Protocols – on-going activity
  - Uncertainties with methods
- IOP Instrument Uncertainties – Sept 2008
  - how PIs measure instrument performance and uncertainties
  - data processing
  - review existing protocols
- HPLC Quantitation in Coastal Waters – SeaHARRE-4
  - Go beyond existing dynamic range of SH experiments (0.2-26.2 mg m^{-3})
- Common AOP Data Processing Interface – January 2009
  - Automatic interface for submitting data in common format
- Vicarious Calibration Site Selection + alternatives – NOPP, DS studies
  - Revisit site selection since 1980's, BOUSSOLE, BATS, HOT
  - Other approaches? – sync with ORION studies

*** PIs funded via ROSES required to participate in workshops and meetings***

- Workshops proposed by community members:
  - P. Coble on CDOM – Chapman Conference October 2008
  - Y. Gao on atmospheric deposition of iron to ocean – deferred until FY09

Published Community Reports on Ocean Color Requirements

The IOCCG web page (http://ioccg.org/) has the following available via pdf:

IOCCG Report Number 1 (1998): Minimum Requirements for an Operational Ocean-Colour Sensor for the Open Ocean. Edited by André Morel, pp.46.

IOCCG Report Number 2 (1999): Status and Plans for Satellite Ocean-Colour Missions: Considerations for Complementary Missions. Edited by James A. Yoder, pp. 43.

IOCCG Report Number 3 (2000): Remote Sensing of Ocean Colour in Coastal, and Other Optically-Complex, Waters. Edited by Shubha Sathyendranath, pp. 140.

IOCCG Report Number 4 (2004): Guide to the creation and use of ocean-colour, Level-3, binned data products. Edited by David Antoine, pp. 88.

IOCCG Report Number 5 (2006): Remote Sensing of Inherent Optical Properties: Fundamentals, Tests of Algorithms, and Applications. Edited by ZhongPing Lee, pp. 126.

IOCCG Report Number 6 (2007): Ocean-Colour Data Merging. Edited by Watson W. Gregg, pp. 68.
Revisit Level 1 requirements in 2009.

Published Community Reports on Ocean Color Requirements

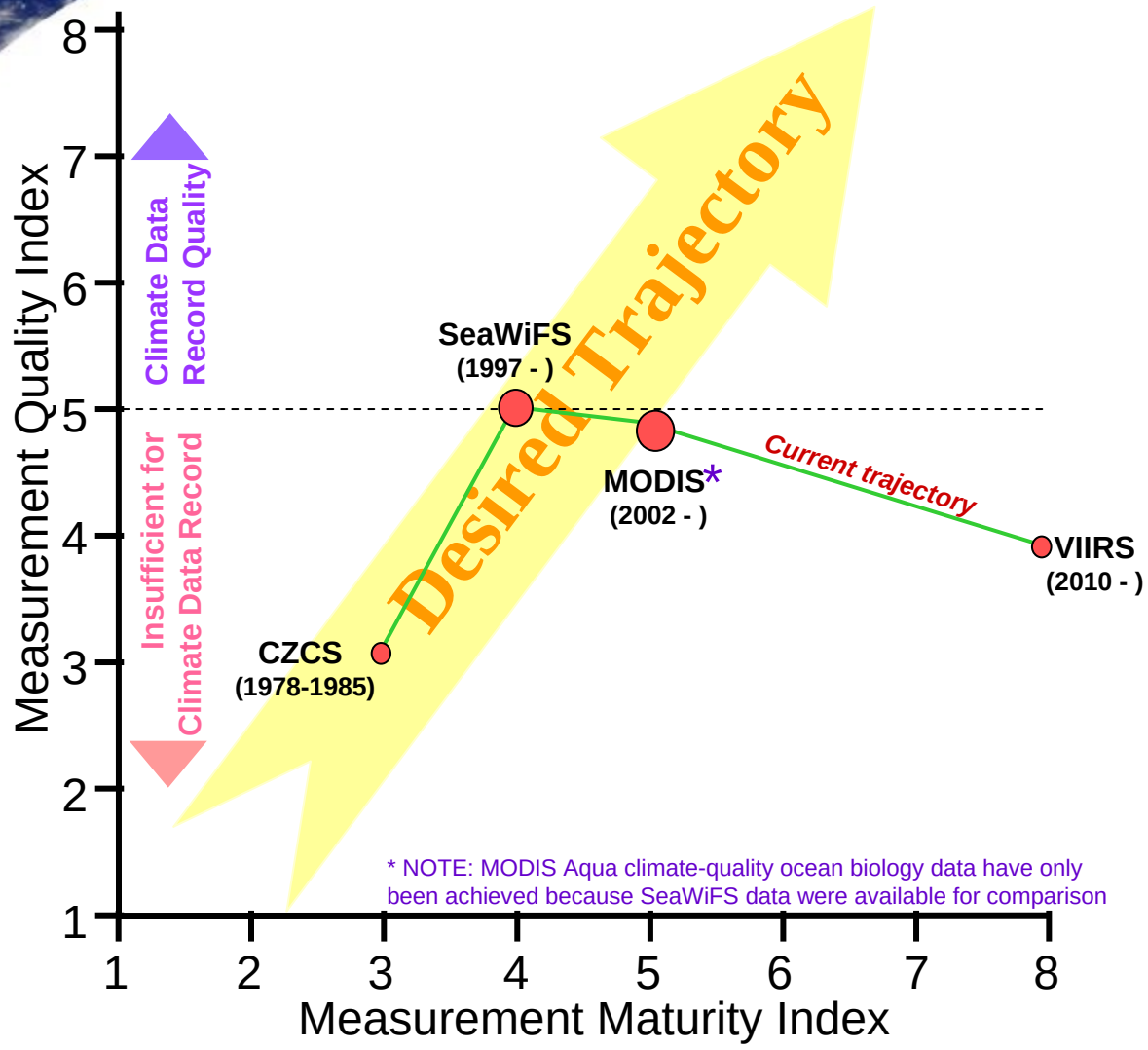
August 2006 - Updated minimum requirements based on SeaWiFS and MODIS lessons learned: Charles R. McClain, Stanford B. Hooker, Gene C. Feldman and Paula Bontempi (2006). Satellite Data for Ocean Biology, Biogeochemistry, and Climate Research. *EOS Transactions*, 87: (34) 337-343

August 2007 - VIIRS ocean color white paper

More detail on requirements, rationales, lessons learned, in ocean color remote sensing; technical memoranda that the NASA Ocean Biology Processing Group has published for SeaWiFS and MODIS, from pre-launch requirements to vicarious calibration: pdfs via the oceancolor web: http://oceancolor.gsfc.nasa.gov/DOCS/ under "Technical Memos".

NASA has publicly available Advance Plans for the next 30-years of Ocean Biology and Biogeochemistry research http://oceancolor.gsfc.nasa.gov/DOCS/ScienceTeam/OCRT_Apr2007/OBB_Report_03062007.doc and vicarious calibration science (under the aforementioned "Technical Memos“)

Heritage and Future Mission/Measurement Progress



Key

Few science products

Extensive science products

Maturity Index *

1= no known use for measurement

8= measured operationally

Quality Index *

1= potential science return

8= approaches limits on performance

"Use or disclosure of these data is subject to the restriction on the title page of this document"

Systematic Measurements

NASA's role in NPP Project ends Launch + 6 months

NASA's Science Data System will only evaluate standard products for use as climate research products; can make recommendations, but have no direct influence on program, no reprocessing, no data product(ion)

No lunar or vicarious calibration plan for NPP

No NASA NPP Science Team
(no ROSES element or budget line)

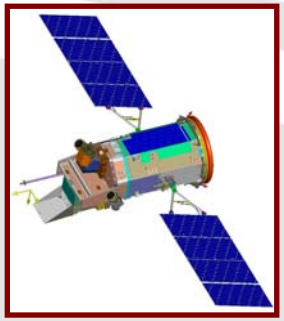
No role for NASA in NPOESS

New Measurements

Missions in Formulation and Implementation

OSTM
6/2008

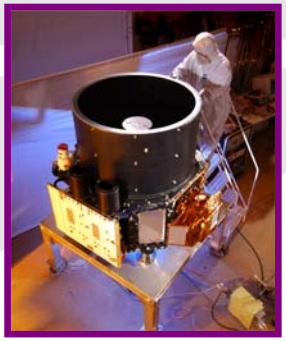
OCO
1/2009



GLORY
6/2009

AQUARIUS
5/2010

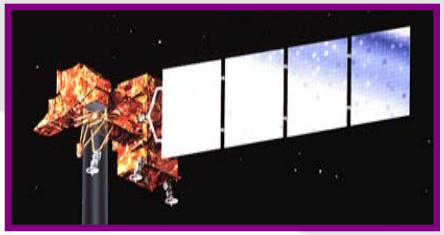
NPP
6/2010



ICESat-II
2015

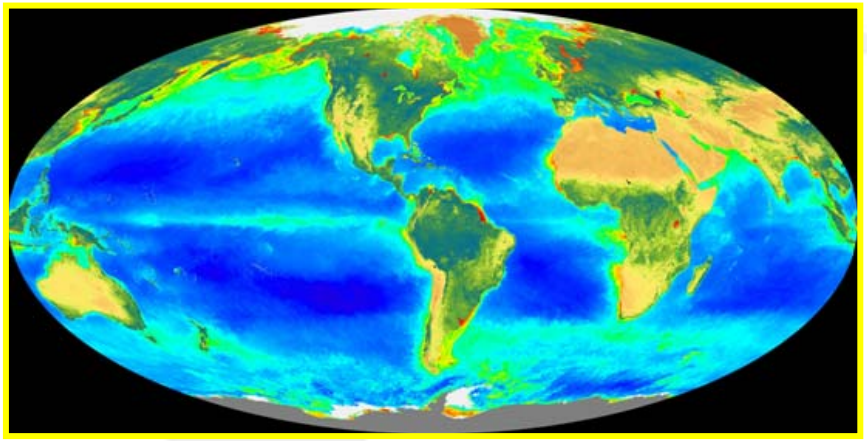
GPM
6/2013, 11/2014

SMAP
2012



LDCM
7/2011

Advance Plan:
Earth's Living Ocean: The Unseen World



NASA Ocean Biology and Biogeochemistry Program

Team from April 2005: Michael Behrenfeld, Heidi Dierssen, Paul DiGiacomo, Steve Lohrenz, Chuck McClain, Frank Muller-Karger, Dave Siegel, (Paula Coble)

May 2006-October 2006: Posted for Public Comment

Reviewers: Tony Freeman, Norm Nelson, Jim Yoder

March 2007: Briefed to NRC OSB

April 2007: Negotiations with NRC for review (OSB and SSB)

September 2007: Comments incorporated

April 2008: Briefed to NRC SSB

April 2008: Letter drafted for NASA SMAC review

December 2008: plan to have joint SSB/OSB (NASA-NOAA) sponsored review (TBD)

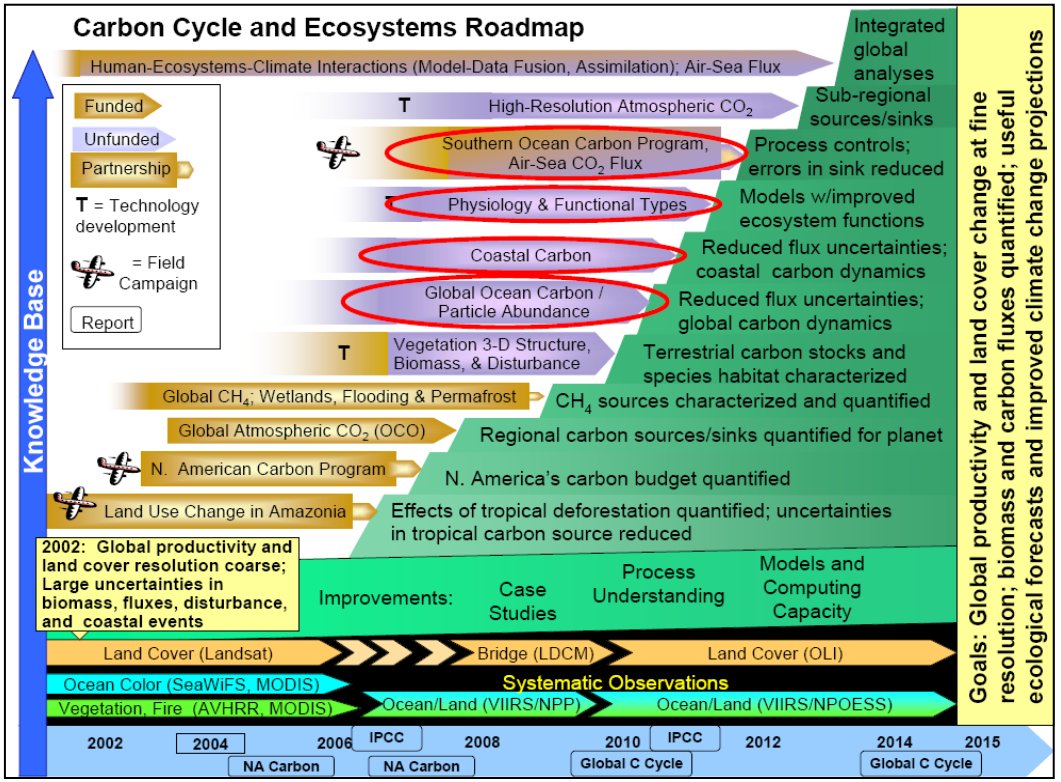
What have we learned?

- A close coupling exists between ocean climate and primary production. We know that the biologically productive ocean is extremely sensitive to vertical mixing.
- Verified the general Sverdrup/Riley concepts: that the combination of vertical mixing and light in a water column has major effects on the seasonal and temporal appearance of phytoplankton in the ocean.
- Satellite data of the ocean also allow ready identification of ocean and coastal fronts, which are key sites of high productivity and support tremendous upper trophic level biomass.
- Global ocean satellite data have also improved our understanding of important interactive relationships between coastal (e.g. squirts, jets, eddies) and oceanic waters, revealing a far greater influence of coastal processes on global ocean basins than anticipated.
- A global ocean view has additionally enabled previously unattainable synoptic estimates of primary production that can be resolved seasonally and decadally.

Future Science

Ocean Biology and Biogeochemistry Program planning document identifies a global ocean mission with enhanced spectral resolution from the UV to SWIR as the top priority future mission.

Measurements will contribute greatly toward achieving all four ocean-related science objectives identified in the NASA Carbon Cycle and Ecosystems roadmap (circled in red, right)



1. How are ocean ecosystems and the biodiversity they support influenced by climate and environmental variability and change, and how will these changes occur over time?

2. How do carbon and other elements transition between ocean pools and pass through the Earth System, and how do biogeochemical fluxes impact the ocean and Earth's climate over time?

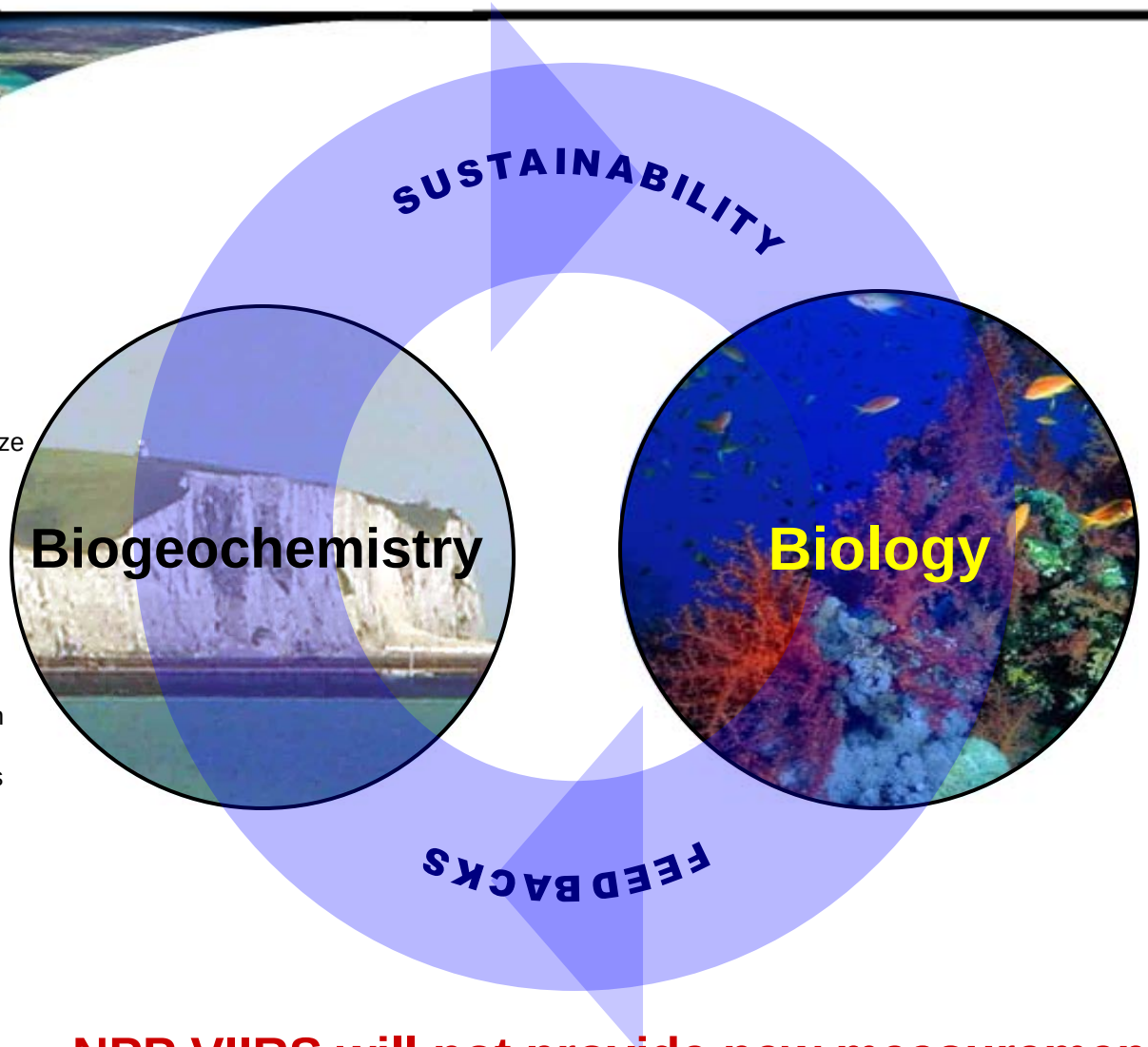
3. How (and why) is the diversity and geographical distribution of coastal marine habitats changing, and what are the implications for the well-being of human society?

4. How do hazards and pollutants impact the hydrography and biology of the coastal zone? How do they affect us, and can we mitigate their effects?

Future Science

Key Processes & Properties…

- Organic and inorganic particle abundance and size
- Plant species-specific bio- and chemical markers (e.g., calcite)
- Carbon species
- Export carbon
- Photosynthesis
- Coastal processes
- Land-ocean carbon transport
- Air-sea interactions



Key Processes & Properties…

- Photosynthesis
- Phytoplankton (plant) biomass
- Plant physiology/ growth rates
- Harmful algal blooms
- Plant functional groups
  - nitrogen fixers
  - carbon exporters
  - calcium carbonate
  - microbial loop
- Ecosystems and habitat health
- Climate-biology interactions

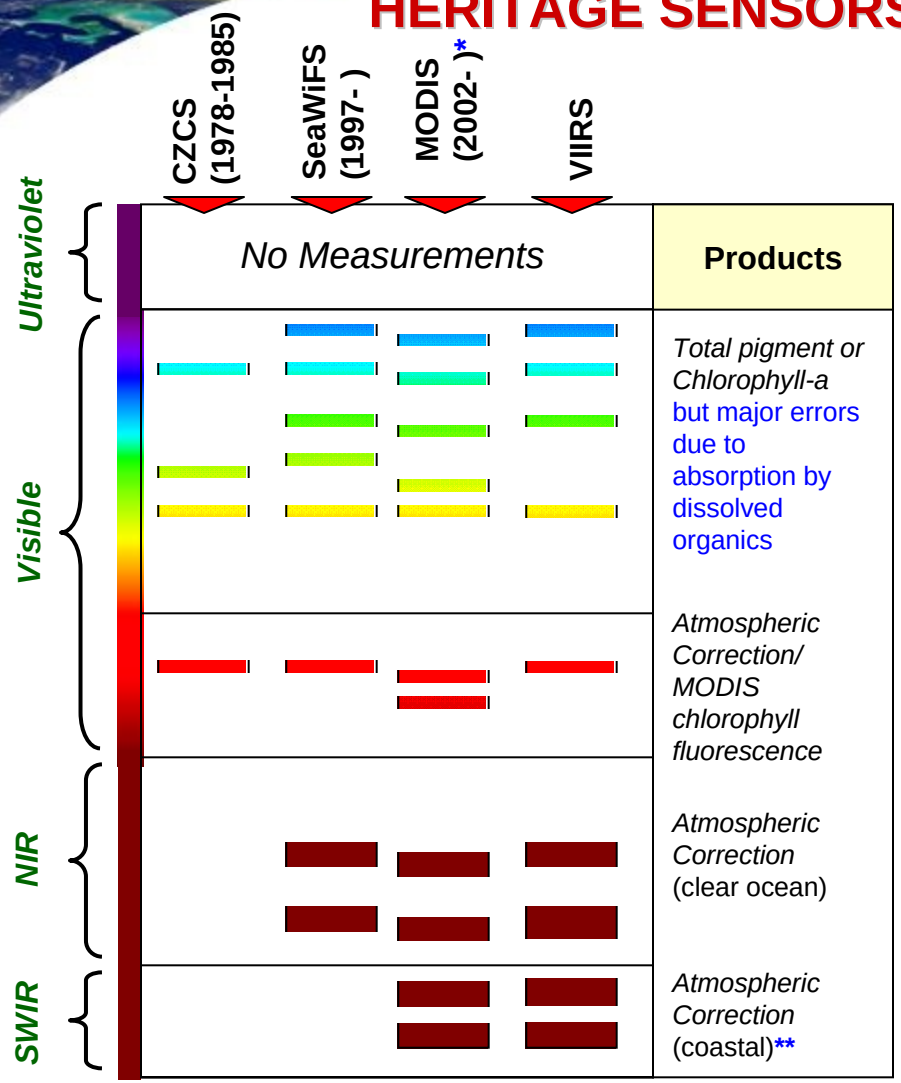
NPP VIIRS will not provide new measurements or core measurements that continue or advance ocean biology and biogeochemistry research

Timeline / Mission Themes	Immediate (1 – 5 Years)	Near-Term (5 - 10 Years)	Long-Term (10 - 25 Years)	Ecosystems	Biogeochemistry	Habitats	Hazards
Global Separation of In-water Constituents & Advanced Atmospheric correction	**Advanced radiometer & scattering lidar** • 5nm resolution from UV through visible • Ozone & extended NIR atmosphere bands • Atmosphere & subsurface particle scattering profiles	**Ocean radiance and atmosphere aerosols** • Advanced radiometer • Scattering lidar for aerosol speciation • Polarimeter for global aerosol coverage •500 m passive resolution	**Radiometry, aerosols, and physiology lidar** • Global radiometry system • Aerosol height & species • Midnight/noon obs of variable stimulated fluorescence				
High Spatial & Temporal Resolution Coastal	**GEO partnership** **Support analysis of current satellite data** **Landsat DCM partnership** **Development of suborbital sensor systems**	**High-res coastal imager** • 20 bands from UV - NIR • 10 m res – 100 km swath **GEO carbon mission** **Deployment of suborbital systems**	**Constellation of imaging spectrometers** • High temporal res • LEO, MEO or GEO • Include SAR **Continued deployment of suborbital systems**				
Plant Physiology & Functional Composition	**Support analysis of global passive data** • Assess functional groups using hyperspectral data • Estimate algal carbon & chlorophyll to characterize physiology	**Support analysis of global & GEO data**	**Variable fluorescence lidar constellation** •Map physiological provinces at different times of day • Dawn/dusk variable fluorescence lidar • Noon/midnight lidar				
Mixed Layer Depth	**Synthesis/analysis of observational forecast fields & on orbit remote sensing** **Mixed layer model development**	**Prototype mixed layer sensor development** • field testing of novel approaches for remote detection of mixed layer depth & light availability	**Mixed layer depth mission** •Space-borne proof-of-concept mission for global mixed layer depth mapping				

Bold Green Text Represents Satellite Missions
Bold Blue Text Represents Development Activities leading to Missions
Cross-hatch indicates secondary contribution to Mission Theme

Heritage Sensors and Potential Future Sensors

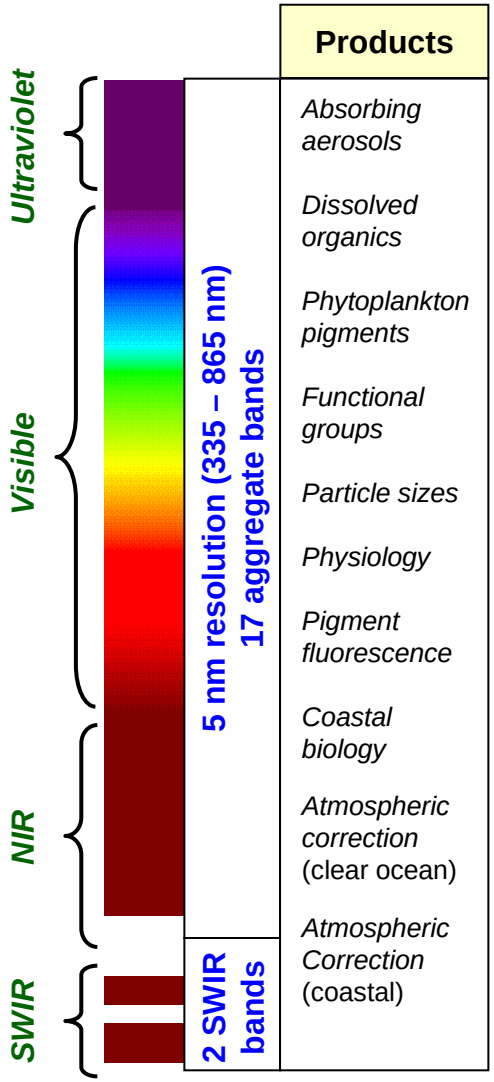
HERITAGE SENSORS



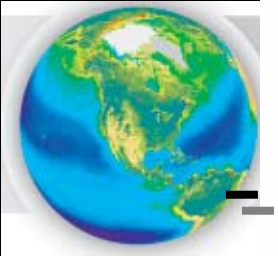
* MODIS on Terra was launched in 2000, but does not yet provide science quality ocean data

** MODIS/Visible Infrared Imaging Radiometer Suite (VIIRS) SWIR bands are not optimized for oceans

GOCECP



"Use or disclosure of these data is subject to the restriction on the title page of this document"



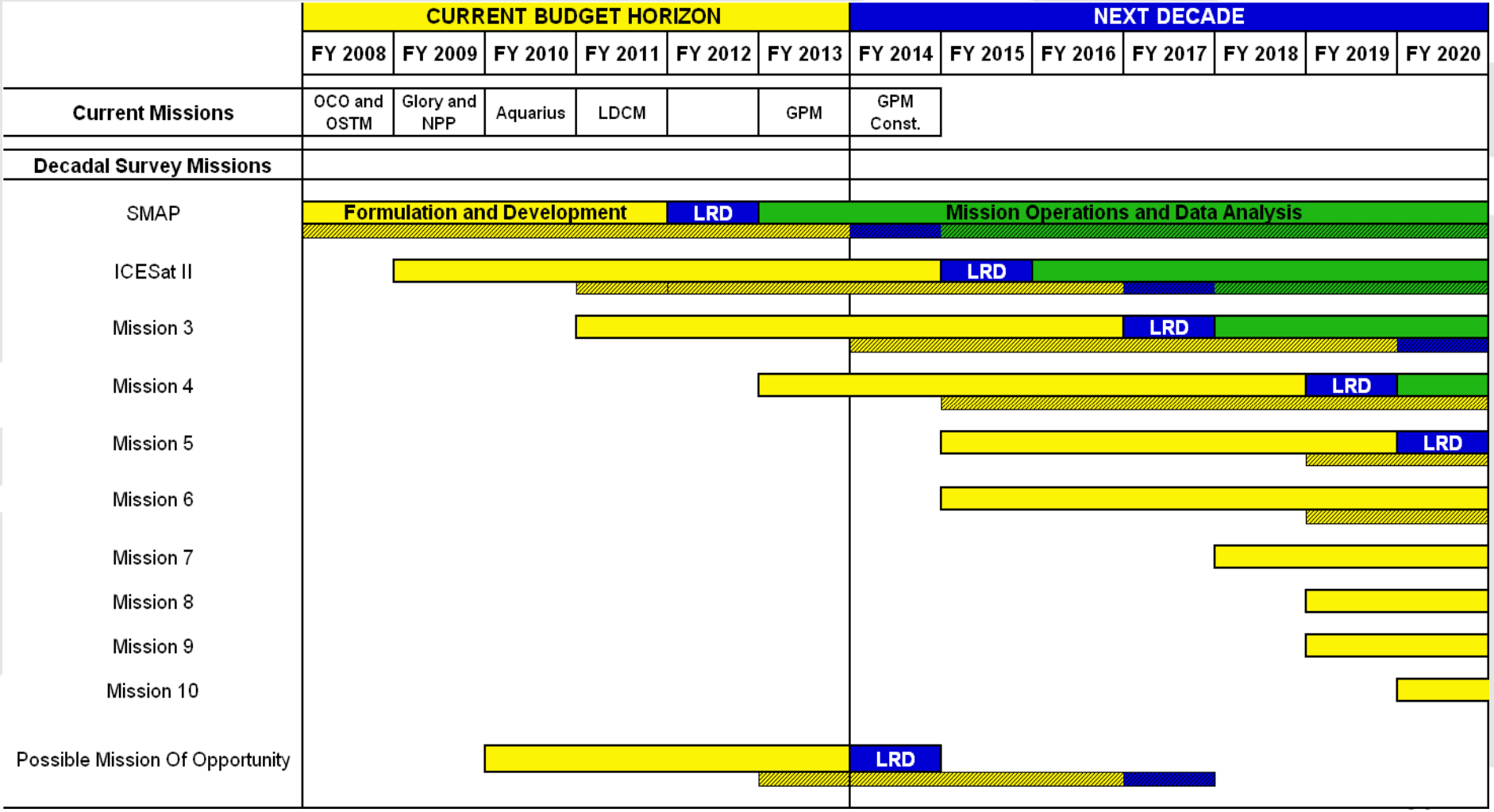
the missions are given in Part II, and Part III provides the foundation for selection.

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar and Earth 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

Earth Science New Initiative

NEW vs. PREVIOUS (hatched) MISSION PROFILE



ACE Mission Overview Quad

Mission Science

ACE is a aerosol-cloud and ocean ecosystem mission

"… to reduce the uncertainty in climate forcing in aerosol-cloud interactions and ocean ecosystem CO2 uptake" - Decadal Survey pg 4-4

Aerosol-cloud component science objectives are:

1. decrease the uncertainty in aerosol forcing as a component in global warming
2. quantify the role of aerosols in cloud formation, alteration of cloud properties and changes in precipitation.

Ocean ecosystem goals are to:

1. characterize and quantify changes in the ocean biosphere
2. quantify the amount of dissolved organic matter, carbon, and other biogeochemical species to characterize the role of the oceans in the carbon cycle (e.g., uptake and storage).

The ocean ecosystem imager needs aerosol measurements to improve their retrievals which is one of the reasons these payloads are combined.

FY09 Deliverables

Initiate early FY09 recommended studies including

1. OSSEs to address issues such as instrument capabilities, orbit, ...
2. IDLs for the potential instrument concepts

Late FY2009

1. IMDC / Team X runs to provide cost estimate
2. Final Report

Other activities:

- Three Science Definition Team Meetings – one open (June)
- Discussions with international partners on participation
- Field campaign/in situ measurement planning

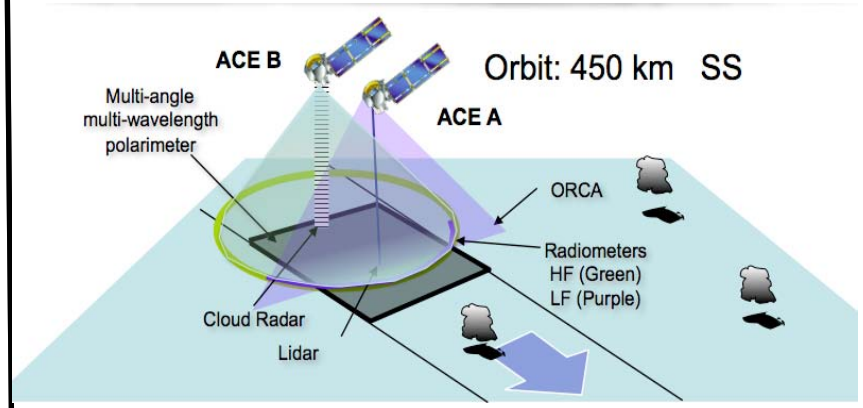
Mission Implementation and Challenges

ACE Payload currently considers the following instrument candidates:

1. Lidar for assessing aerosol/ cloud heights and aerosol properties. (TRL 4-6)
2. Dual frequency cloud radar for cloud properties and precipitation (TRL 4-6)
3. Multi-angle, swath polarimeter for imaging aerosol and clouds (TRL 4-6)
4. Ocean color multi-channel spectrometer for ocean ecosystems (TRL 5)
5. IR imager for cloud temperatures and heights (TRL 6)
6. High frequency swath radiometer for cloud ice measurements (TRL 6)
7. Low frequency swath radiometer for precipitation measurements (TRL 8)
8. Microwave temperature/humidity sounder (ATMS, TRL 9)

It is anticipated that all instruments will be openly competed. The payload may require more than one spacecraft.

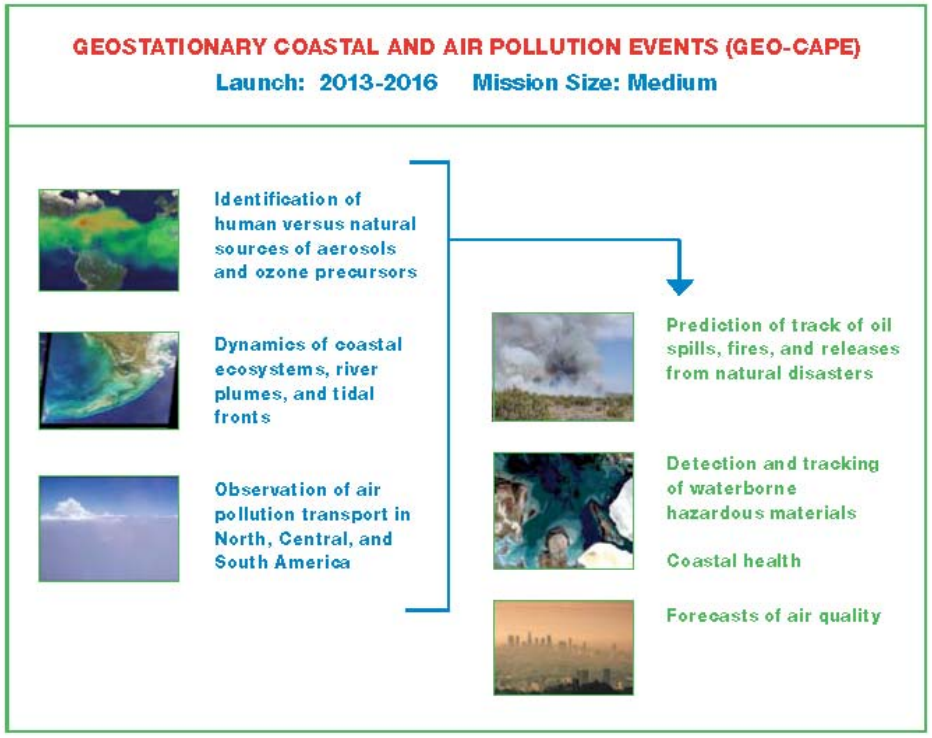
Instruments in gray were mentioned in the NAS DS ACE description. The Science Working Group considers these overguide instruments critical to the mission.



Current thinking: ACE follows ESA EarthCare 3 yr mission at 10:30 AM, 450 km (2013 LRD). EC payload has Doppler radar and single channel HSRL lidar but no swath imager in visible or µ-wave. ACE would provide continuity to EC and possibly overlap EC measurements for validation. ACE will have significantly improved radar, lidar and multi-wavelength imagers compared to EC and A-Train.

GEO-CAPE Overview

Many open science questions for air quality and ocean science require observations on temporal and spatial scales that reflect weather and ocean ecological and chemical dynamics



- **Science Working Group lead refinement of the Science Traceability Matrix (science questions, corresponding observations, measurement requirements, societal benefits)**
- **Program scientists lead refinement of list of tasks (e.g., refinement of the science traceability matrix, instrument synthesis and analysis laboratory runs) to be undertaken in next 12-14 months**
- **Workshop report target date of 1 January (covering overarching science and applications for the mission)**

HyspIRI Mission Overview Quad

Science

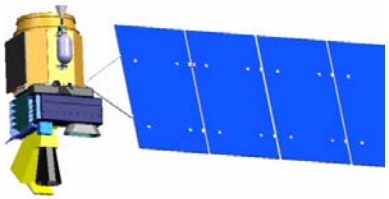
This mission provides global surface reflectance, surface temperature and surface emissivity at high spectral, spatial and temporal resolutions.

These data will be used to produce the first ever global measurements of ecosystem function and composition. Ecosystem function and composition are two of the three fundamental measurements which together with plant structure are required to understand terrestrial and coastal ecosystems.

The data will also be used to address key science questions related to volcanoes and wildfires, water use and availability, urbanization and land surface composition and change.

Architecture/structure:

Two Instruments on one spacecraft at 626 km 11 am sun sync orbit: (1) Imaging Spectrometer (VSWIR), (2)Thermal Infrared Multi-Spectral Imager (TIR)



VSWIR Science Measurement:
- 380 to 2500 nm in 10nm bands
- 60 m spatial resolution, 19 day revisit
- Global land and shallow water

TIR Science Measurement:
- 8 Bands (7 bands between 7.5-12 µm & 1 band at 4 µm)
- 60 m spatial resolution, 5 day revisit
- Global land and shallow water
- Day and night imaging

FY09 Objectives and Deliverables

-HyspIRI workshop report and whitepaper with science traceability and baseline architecture

-HyspIRI Level 1 requirements (baseline and minimal)

-Mission implementation schedule and other required products for transition to Phase A

-Risk reduction and margin increase investments

-August 2009 HyspIRI workshop

-Ready for transition to Phase A, Dec 2009

Mission Implementation Challenges:

-Science instruments are high heritage, low risk.

-HyspIRI is a high data rate mission. 700 Mbs dual polarization X-band downlink infrastructure will be needed at two polar ground stations.

-Data distribution and processing system for high volume products.

New Measurements

If ACE were to move to the top of the Tier II list of missions,
Launch Readiness Date (earliest) would be 2020.

Venture Class…

International Missions – a solution to global, climate research quality data?

1. NPP – 2010? 2011? Quality expected to be CZCS at best

2. VIIRS on NPOESS C1 (1330) must ensure radiometric performance for ocean color, pre-flight test data sets available in a timely/transparent manner (2011?).

3. European Space Agency (ESA) - easier access to MEdium Resolution Imaging Spectrometer (MERIS) data for U.S., resolve calibration, sensor performance, technical issues. ESA's Sentinel-3 OLCI (October 2012), for applications in coastal waters; narrow swath/long revisit time may limit utility.

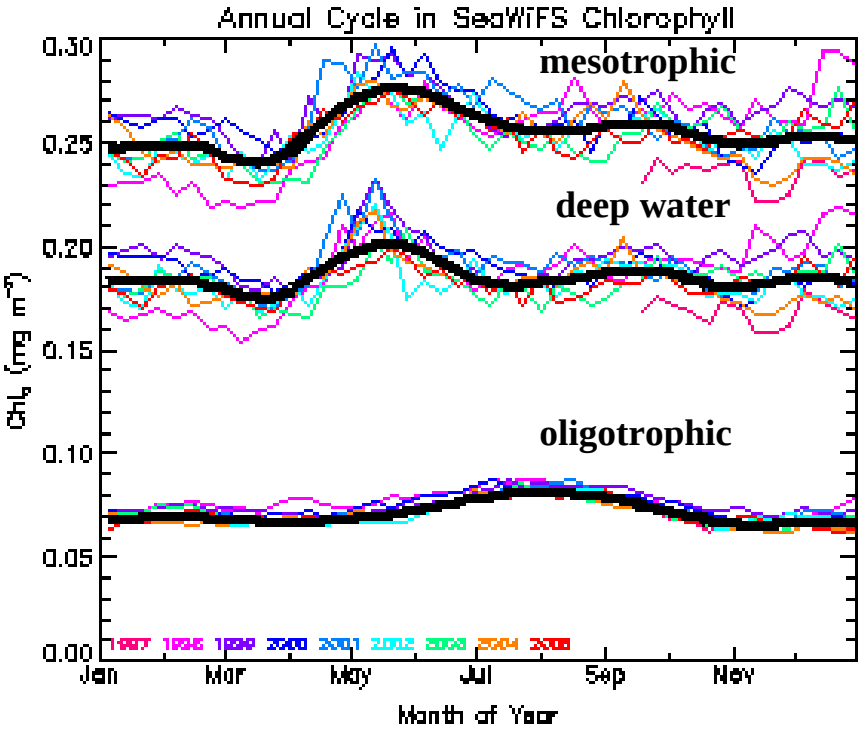
4. Indian Space Research Organization's (ISRO) Ocean Colour Monitor (OCM-II) OceanSat-2 (April 2009). NOAA-NASA to ISRO 21 January. Design of OCM-II potential for global climate research, details on sensor characterization and calibration

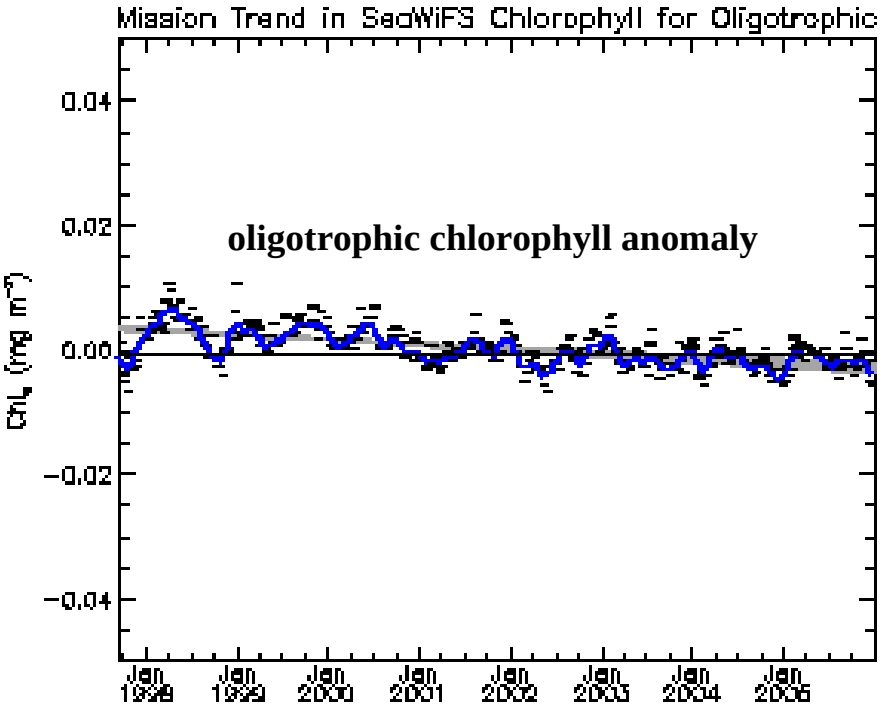
5. JAXA's SGLI – approved? Early 2014

6. Ocean color free-flyer as single agency mission, multi-agency mission, commercial partnership/data-buy. Foreign data streams as supplements to a U.S. capability for climate-quality ocean color observations (2012)

Recognize requirement for dedicated program for calibration/validation; algorithm development, evaluation; data processing, re-processing, distribution, archiving; support for research and operations

Geophysical vs. Instrument
SeaWiFS Temporal Trends: Chl Anomaly





Can we believe relatively small trends seen on decadal scales (relative to seasonal and short-term variabilities) without highly calibrated data?

NASA OB&B Research

- ROSES – Research Opportunities in Space and Earth Science
  - Omnibus solicitation with former Space Science
  - Released in February each calendar year w/rolling deadlines for NOIs, Proposal Due Dates
  - Updates to different sections in Table of Contents via Amendments by E-mail
- ROSES 2007 - http://nspires.nasaprs.com/ - "Solicitations"
  - Ocean Biology and Biogeochemistry/Airborne Science 2007 - ~$1.5M/yr [June 2008]
  - ECOHAB - ~$0.5M/yr [May 2008]
  - NOPP BAA on Sensors for Marine Ecology (NSF, NASA, NOAA, ONR) $7-9M/yr – [May 2008]
- ROSES 2008 - http://nspires.nasaprs.com/ - "Solicitations"
  - Ocean Biology and Biogeochemistry (~$2.5M/yr – 6.2.2008) up to 4 yrs
    - Research in Biological Oceanography (Multisensor observations of oceanographic phenomena; Impacts of a Changing Climate on Biological Oceanography; Research in support of the International Year of the Reef; Continuations of research projects selected under the 2004 NASA Res. Ann. entitled "Oceans and Ice," NRA-04-OES-02);
    - Synthesis and Integrative Science;
    - Providing the scientific basis for next generation ocean biology remote sensing technologies

NASA OB&B Research

- NASA Energy and Water Cycle Study – Water Quality – (up to $1.5M/yr – 8.19.2008)
  - Terrestrial Hydrology and Ocean Biology and Biogeochemistry
    - Algorithms to remotely sense inland and coastal water quality
    - Providing the scientific basis for next generation water quality remote sensing

- NOPP 2009 (up to $2.5M/yr with NSF and ONR) on Sensors for Marine Ecosystems topic out December 2008

- ROSES 2009 - http://nspires.nasaprs.com/ - Release Date 13 February 2009
  - Ocean Biology and Biogeochemistry and Cryospheric Sciences (~$3.0 M/yr) up to 4 yrs
  - Interdisciplinary Science (five topics) up to 3 yrs

Gap Analysis: Smallest Detectable Trend in Depth-Integrated Chlorophyll *a*

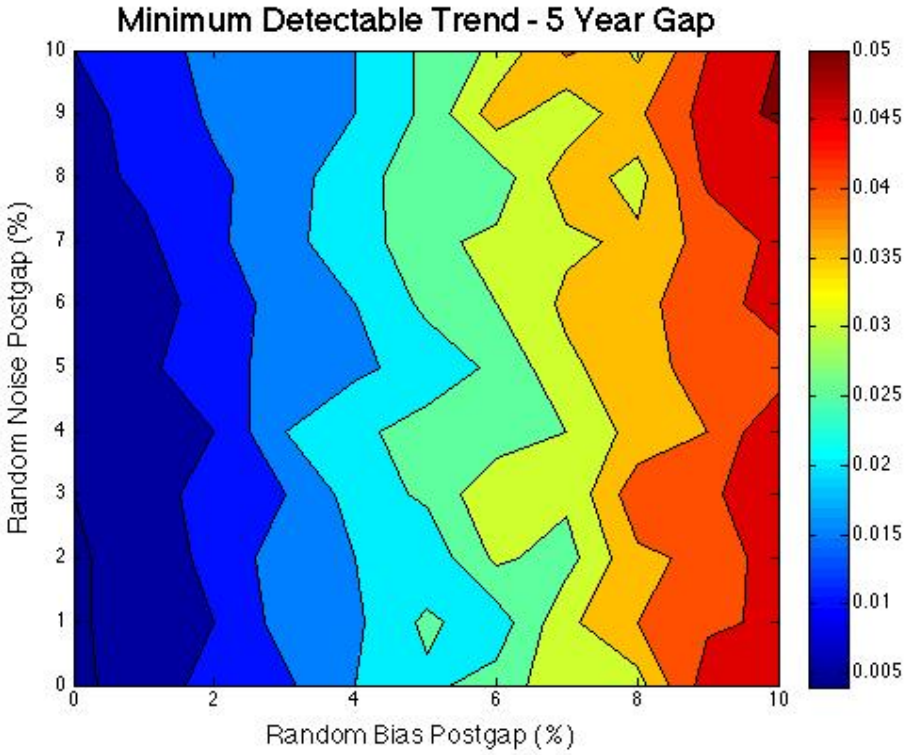
Assumptions:

- SeaWiFS obs used to model future (2009-2025) variability
- 5 year gap starting in 2008
- Random bias (calibration) & noise (stability) in post-gap

Results:

- With no random noise/bias between missions - trends as small as 0.005 Tg/y can be quantified
- Addition of any level of bias/noise significantly impacts size of the minimum detectable trend
- Random biases >>> random noise

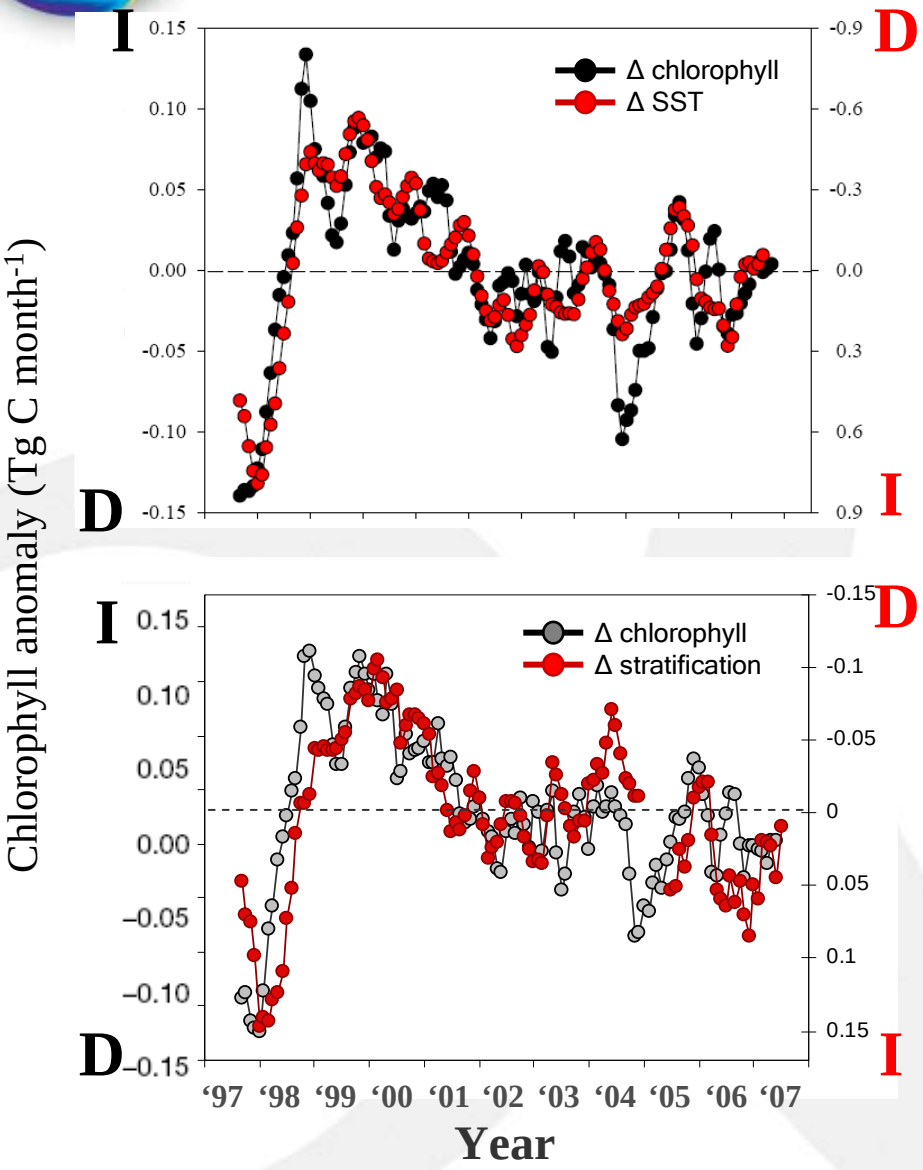
  Cross calibration matters!!!
- A gap of any length severely inhibits ocean color from achieving a CDR
- OC data record is only now starting to reach sufficient length to be considered a CDR



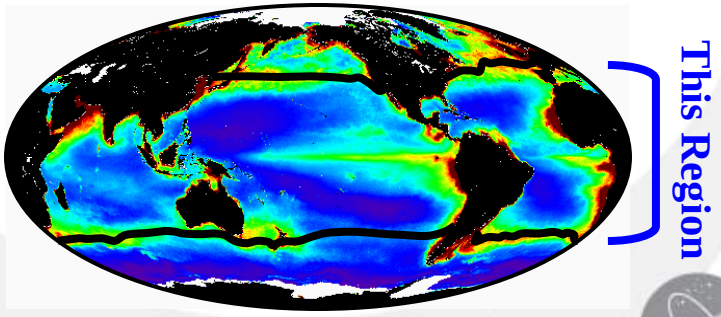
What's plotted:

- Smallest detectable trend in depth-integrated chl *a* as function of random bias & noise for the post-gap period

Stratified Oceans: 1997 - 2007



- Chlorophyll and temperature are inversely related
  - i.e., chlorophyll decreases as temperature increases
- Temperature-effect not direct
- Temperature related to stratification
- Stratification influences nutrients & light, which directly effect phytoplankton



(Behrenfeld et al, *Nature*, 2006)