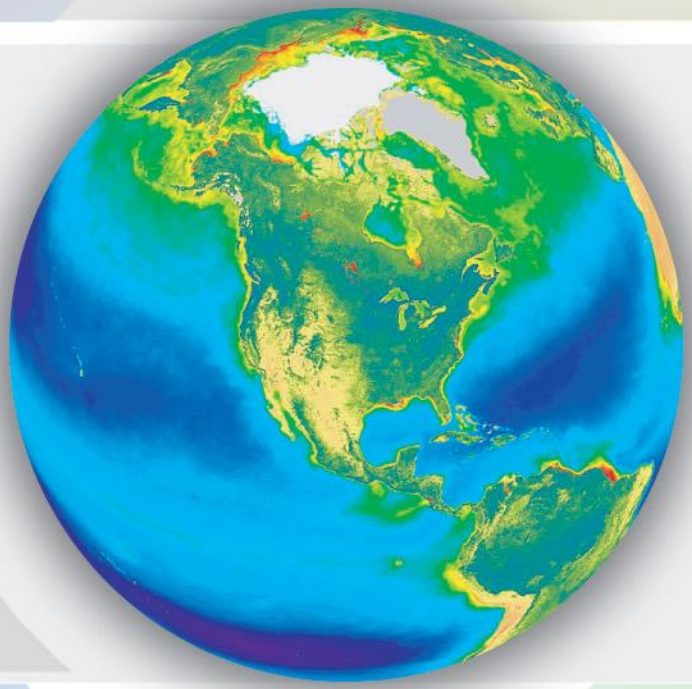
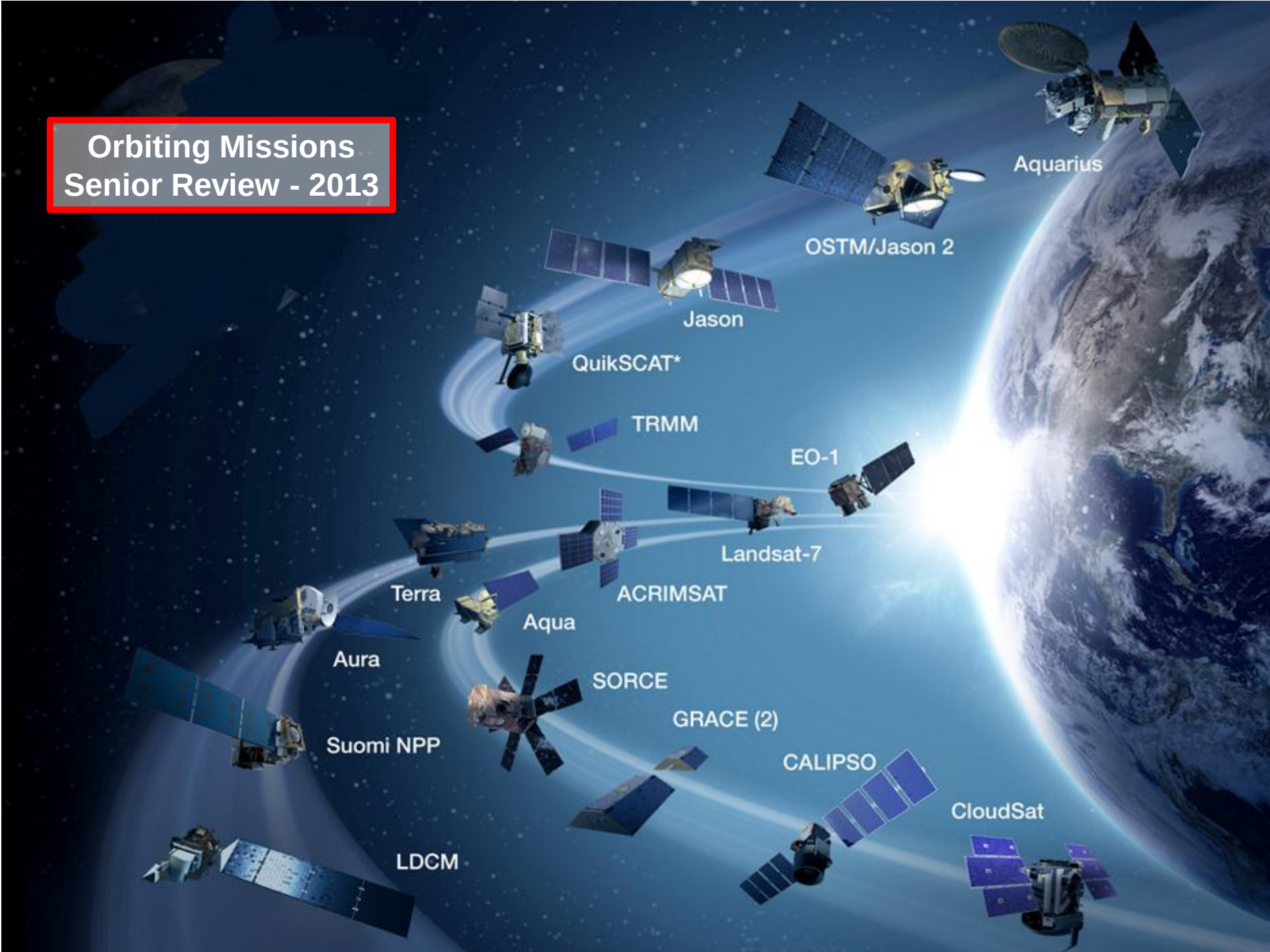
Future Directions for NASA Ocean Color Remote Sensing



Paula Bontempi
NASA Headquarters
International Ocean Color Science Team Meeting
6-8 May 2013


Orbiting Missions
Senior Review - 2013
Aquarius
OSTM/Jason 2
Jason
QuikSCAT*
TRMM
EO-1
Landsat-7
ACRIMSAT
Terra
Aqua
Aura
SORCE
GRACE (2)
Suomi NPP
CALIPSO
CloudSat
LDCM

Reinvigorate On-Orbit Constellation (1 of 2)

- OSTM/Jason-2 Launched 6/2008
- ~~OCO Launched 2/2009~~ (LV Failure)
- ~~Glory Launched 3/2011~~ (LV Failure)
- Aquarius/SAC-D Launched 6/2011
- Suomi NPP Launched 11/2011
- LDCM Launched 2/2013

- Global Precipitation Measurement (GPM)
  On Schedule for 2/15/2014 Launch
- Orbiting Carbon Observatory (OCO-2)
  On Schedule for 7/1-7/2014 Launch
- Soil Moisture Active Passive (SMAP)
  On Schedule for 10/31/2014 Launch
- Stratospheric Aerosol and Gas Experiment (SAGE-III/ISS)
  On Schedule for 3/2015 Launch

Reinvigorate On-Orbit Constellation (2 of 2)

- ICESAT-2 Confirmed for launch 12/2016
- Cyclone Global Navigation Satellite System (CYGNSS) (EVM) Formulation for launch late 2016/17
- GRACE-FO Formulation for launch 8/2017
- OCO-3/ISS Formulation for launch 2017
- Tropospheric Emissions: Monitoring of Pollution (TEMPO) (EVI) Formulation for instrument delivery 2017
- Pre-Aerosol, Cloud, ocean Ecosystem (PACE) Acquisition Strategy under evaluation, launch 2020
- Surface Water Ocean Topography (SWOT) Formulation for launch 2020

SeaWiFS (1997-2010)

132 SeaWiFS Authorized HRPT Stations (82 delivered data)

Code	Station
AAD	RSV Aurora Australis
ARG	CONAE, Buenos Aires
ARM	US Army Research Lab
AWI	R/V Polarstern
AZO	Faial, Azores
BAR	R/V Hesperides
BAS	Adelaide Island, Antarctica
BBS	Bermuda Biological Station
BGU	Negev, Israel
BHR	Bahrain
BIO	Dartmouth, Nova Scotia
BIU	Bar Ilan University
BOL	ABTEMA, Bolivia
BRL	Rio Grande, Brazil
CAL	IMARPE Callao, Peru
CAN	Gran Canaria, Spain
CAR	UCAR, Boulder
CHL	Santiago, Chile
CMR	Heraklion, Crete
CNR	IMGA-CNR - Bologna, Italy
CON	Concepcion, Chile
COS	Costa Rica
CRI	ACRI, France
CSC	Charleston, SC
DEN	University of Copenhagen
DLR	German Aerospace Center
DSF	*not available*
DUN	NERC Satellite Receiving Station
ECB	Gran Canaria, Spain
ECS	Elizabeth City, NC
FUN	Fortaleza, Ceara, Brasil
GAL	Charles Darwin Research Station
GOA	NIO Goa, India
GUA	Guam
GUY	Cayenne, French Guyana
HEL	R/V Alpha Helix
HIG	Male, Maldives
HIT	Hiroshima Inst. of Tech.
HOB	Hobart, Tasmania
IAM	Heraklion, Crete
ICM	Barcelona, Spain
IGP	University of Hawaii/HIGP
IMB	Heraklion, Crete
IMS	Inciralti-Izmir, Turkey
IOS	Sidney, British Columbia
IPR	R/V Shirase-Antarctica
IRE	Galway, Ireland
IRK	Irkutsk, Russia
IRM	MAZARA DEL VALLO
JMS	JAMSTEC, Yokosuka, Japan
KEN	Malindi, Kenya
KIT	Kitami, Japan
KOR	Korea Ocean R & D Inst.
KUS	Hong Kong, China
LSU	Louisiana State Univ.
MAL	Kuala Terengganu, Malaysia
MAS	Centro Espacial de Canarias
MBR	Moss Landing, California
MCM	Mcmurdo Station, Antarctica
MIR	R/V Mirai
MLI	Mont Joli, Quebec
MLT	University of Malta
MON	Ulaanbaatar, Mongolia
MSC	Matera,Italy
NAV	NRL-SSC, MS
NBP	R/V Nathaniel B. Palmer
NCS	Oman
NEA	New Caledonia
NEG	Negev, Israel
NFL	St. John's, Newfoundland
NGO	San Salvador de Jujuy, Argentina
NOA	Palea Penteli (Athens)
NOH	NOAA/NMFS Honolulu, Hawaii
NOL	La Jolla, California
NOR	Tromso, Norway
NPE	INPE, Sao Paulo, Brazil
NRI	Far Seas Fisheries, Tokyo, Japan
NSG	GSFC HRPT, NASA, MD
NTO	National Taiwan Ocean University
NTU	Taipei, Taiwan (Oceanography)
OMA	Muscat, Oman
ORS	Qingdao, China
PAL	Palmer Station, Antarctica
PEK	Peking University
POL	*not available*
POR	Funchal, Madeira Island
PRC	Hang Zhou, China
PRE	Pretoria, South Africa
PRM	Bremerhaven
RBN	R/V Ron Brown
RES	Resolute Bay
REU	La Reunion
ROC	Taipei, Taiwan (Fisheries)
ROM	ISAC - CNR, Rome, Italy
ROT	Rota
RUS	Yuzshno-Sakhalinsk
RUT	Rutgers University, New Jersey
SAM	American Samoa
SAN	Univ. of Santiago, Spain
SNG	National University of Singapore
SPZ	NATO, La Spezia
SSC	NRL-SSC
STR	GRTR Parc d'Innovation
SYO	Syowa Station, Antarctica
TAH	Papeete, Tahiti
TFI	Taiwan Fisheries Research Inst.
TNB	Terra Nova Bay, Antartica
TOK	Tokai University
TOW	Townsville, Australia
TUR	Middle East Technical Univ.
UAF	University of Alaska, Fairbanks
UKR	Sebastopol, Ukraine
UME	Univ. of Maine
TNB	Terra Nova Bay, Antartica
TOK	Tokai University
TOW	Townsville, Australia
TUR	Middle East Technical Univ.
UAF	University of Alaska, Fairbanks
UKR	Sebastopol, Ukraine
UME	Univ. of Maine
UMI	T/V Umitaka-Maru
UMX	Mexico City
UND	University of North Dakota
UNE	Univ. of Nebraska
UNY	MSRC SUNY
UOH	University of Hawaii, Honolulu
UPR	University of Puerto Rico
URG	Montevideo, Uruguay
URU	Carrasco, Canelones, Uruguay
USC	UC Santa Barbara
USF	Saint Petersburg, Florida
UST	Stockholm University
UTX	Univ. of Texas
VEN	Caracas, Venezuela
WAS	Perth, Australia
WFF	Wallops Flight Facility
WNZ	Wellington, New Zealand
YOK	Yokohama
ZTI	AZTI, Spain

SeaWiFS (1997-2010)

DigitalGlobe commits:

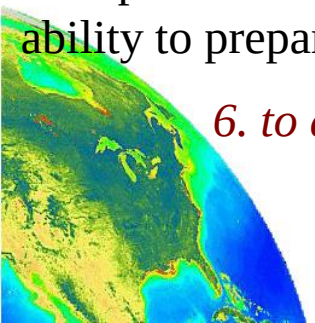
1. to provide to NASA in digital form via a mutually agreed upon distribution mechanism, access to all of the SeaWiFS HRPT data that currently reside in the DigitalGlobe digital archive from years 1997-2010 along with license for use & distribution as described below.

2. to provide to NASA a copy of DigitalGlobe's 8mm tape archive of HRPT data acquired during the OrbView-2 mission (as-is, in unknown format).

3. to allow NASA to request copies of all SeaWiFS HRPT data collected by remote ground stations (foreign and domestic) for incorporation into the NASA archive. These stations include those that were under contract to DigitalGlobe, those that were operating under the NASA research license and those that may have been operating independently

4. to allow all ground stations that may have collected data under contract to DigitalGlobe or who purchased a decryption license from DigitalGlobe, *to release their SeaWiFS data holdings to NASA without fear of violating the terms of their agreement with DigitalGlobe.*

5. to provide assistance to NASA with the decryption of HRPT data, or to supply NASA with the ability to prepare decryption keys (to the best of our current capacity).



6. to agree to place all of the OrbView-2 (SeaWiFS) data collected during the mission (1997 - 2010) in GAC, LAC or HRPT resolution into the public domain including those periods that are less than five years old.

****If you wish to contribute data: gene.c.feldman@nasa.gov**

MODIS Aqua and Terra

- Terra (12/1999-present) and Aqua (5/2002-present)
- Undergoing Senior Review (mission extension review) in 2013
- Partial reprocessing of MODIS Aqua (2011-2013 period only) recently completed to maintain instrument calibration.
- MODIS Terra reprocessing will follow, using MODIS Aqua as a calibration source.
- Updates at NASA Ocean Color Research Team splinter – Monday, 6 May @ 1330.

Suomi-NPP VIIRS (2011-present)

- VIIRS is performing well. Significant degradation of radiometric sensitivity in the NIR/SWIR has been observed, but is stabilizing.
- NASA is supporting the evaluation of the operational products from NOAA (Level-2:EDRs), while also evaluating the potential of the instrument to support continuity of ocean color science.
- To evaluate the instrument capabilities, the OBPG has:
  - developed a continuous instrument calibration based on the solar diffuser measurements (verified against lunar measurements).
  - applied a vicarious calibration based on MOBY.
  - generated a suite of products consistent in algorithm and format with MODIS and SeaWiFS standard products.
  - products available from oceancolor web for community evaluation.
  - Updates at NASA Ocean Color Research Team splinter – Monday, 6 May @ 1330

International Space Station: Hyperspectral Imager for the Coastal Ocean (HICO)

- imaging spectrometer based on PHILLS airborne imaging spectrometers
- HICO is the first spaceborne imaging spectrometer designed to sample the coastal ocean
- Sample selected coastal regions at 90 m with full spectral coverage (380 to 960 nm at 5.7 nm intervals) + a high signal-to-noise ratio
- Launched on the H-2 Transfer Vehicle (HTV) 10 September 2009 – mounted on the JEM-EF – first imagery September 25, 2009
- Turned over to NASA in late 2012
- NASA's goal is to create opportunity for international tasking and free and open data policy for everything collected (including the historical data)
- On 2 May 2013, NRL received concurrence from the Navy for the release of all HICO data collected since 1 January 2013 to the NASA oceancolor web
  - NASA is working with NRL to transfer the Level 0 data and processing software to NASA GSFC
- For all data taken prior to 2013, NRL/ONR have set up a systematic review of the archive to take place at a working meeting on 10 June 2013.
- Data and tasking policy is drafted, release is TBD.

- Planned instruments funded by NASA/HEOMD, ESD funding for analysis
  - *Hyperspectral Follow-on to HICO (under consideration)*

Pre-Aerosol, Cloud, and ocean Ecosystem (PACE) Mission

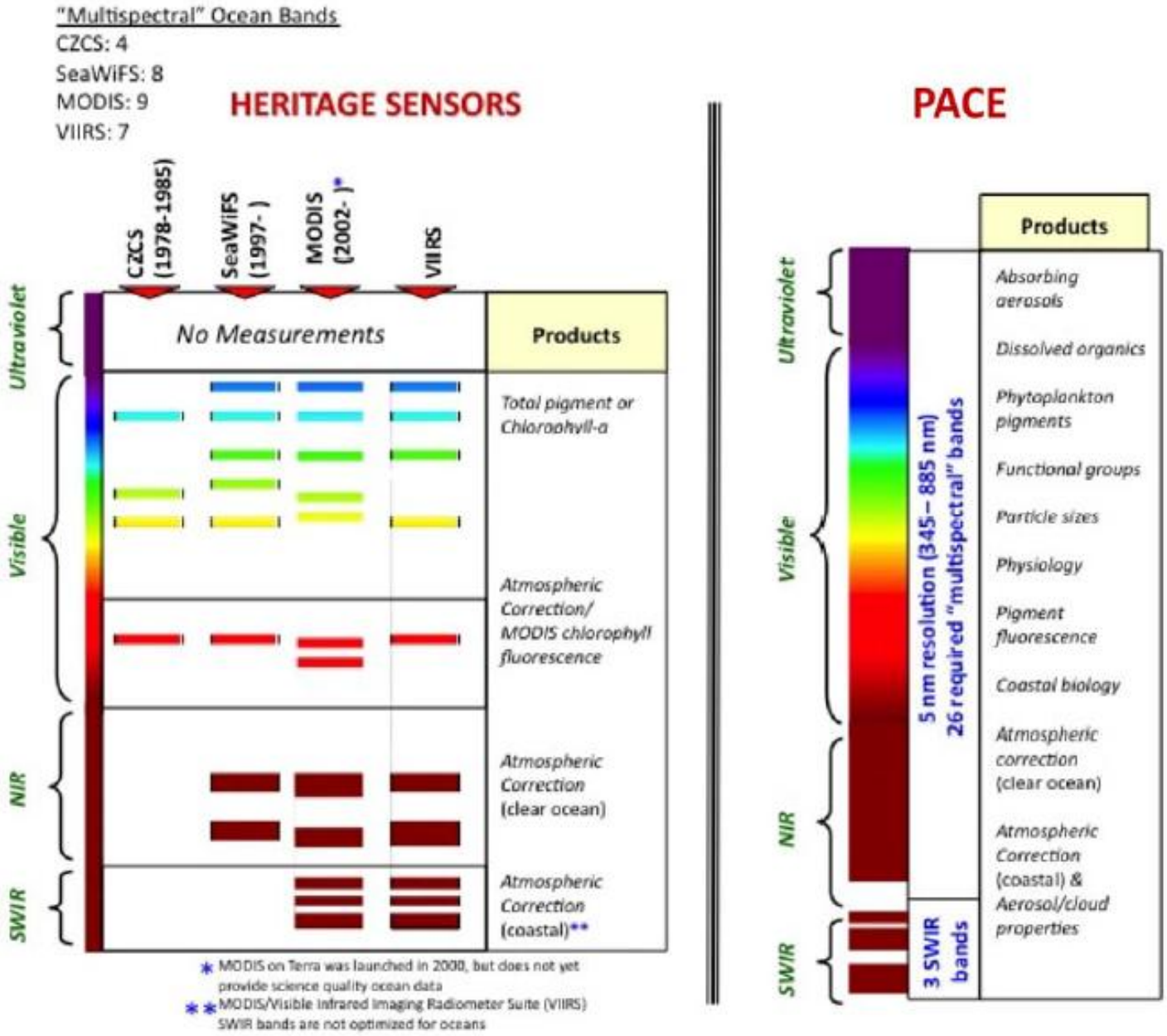
Pre-Aerosol, Cloud, and ocean Ecosystem (PACE) is an ocean color, aerosol, and cloud mission that follows the 2010 report – "Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space Science". It will use a global ocean color sensor for ocean ecology and biogeochemistry and, ultimately, improve the climate-carbon and climate-ecology model predictions.

Primary Science Objectives

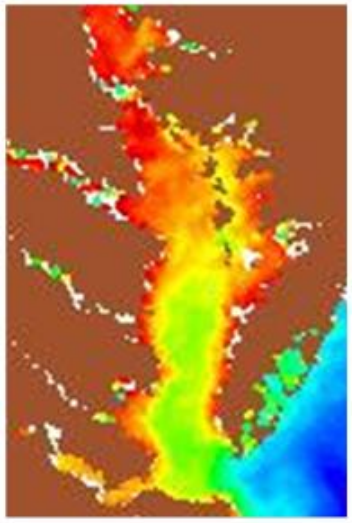
- Understand (and quantify) global biogeochemical cycling and ecosystem function in response to anthropogenic and natural environmental variability and change
- Understand (and quantify) the role of aerosols and clouds in physical climate (the largest uncertainty)
- Extend key Earth system data records on global ocean ecology, biogeochemistry, clouds, and aerosols

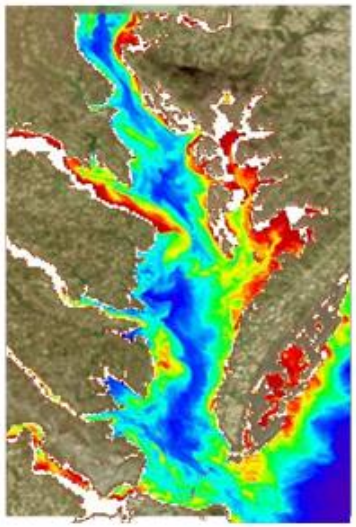
Partners	• TBD
Risk	• 8705.4 Payload Risk Class C
Launch	• 2019/2020
Orbit	• 97 deg inclination; 650 km altitude; sun synchronous
Duration	• 3 year
Payload	• Ocean color instrument; potential for a polarimeter
LCC	• $700 – 850M

Technical advancement in PACE



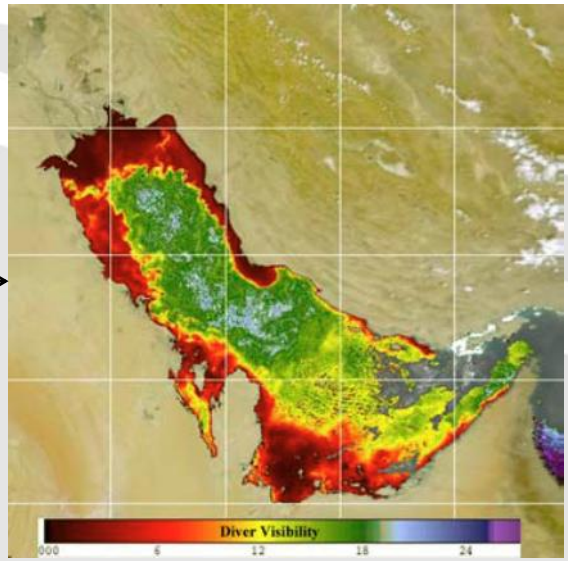
PACE Applied Science/Applications



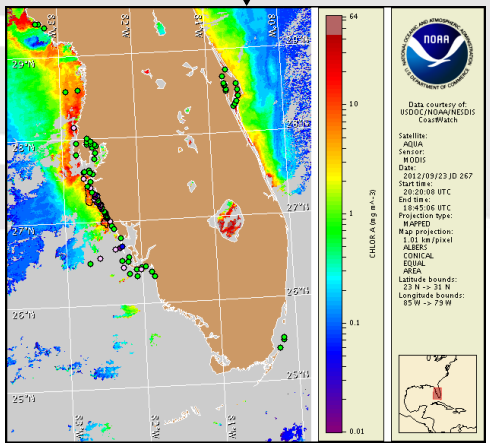


1 km

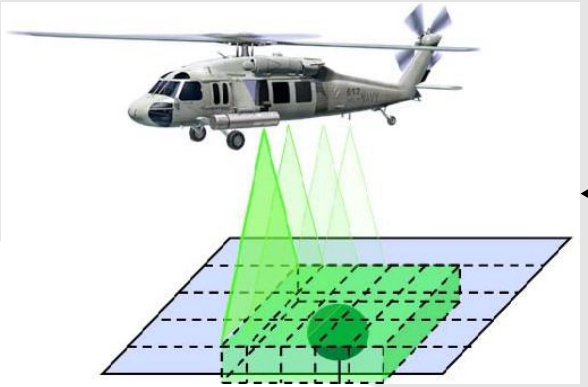
250 m



NRL Diver Visibility Product



Detection and Forecasting of HABs



Assessment of underwater LIDAR performance

PACE SDT Report

- In 2012 NASA competed a Science Definition Team (SDT) to define mission science requirements
- In some cases, the SDT is very prescriptive in technical requirements and instrumental approaches. This is based on the experience that the OC community has accumulated from CZCS through present.
- NASA accepts the SDT report as input, but not as programmatic requirements. We will consider the report and its recommendations as we prepare for the mission implementation.

Threshold Ocean Mission Requirements

Orbit	□ sun-synchronous polar orbit □ equatorial crossing time between 11:00 and 1:00 □ orbit maintenance to ±10 minutes over mission lifetime
Global Coverage	□ 2-day global coverage to solar zenith angle of 75° □ mitigation of sun glint □ multiple daily observations at high latitudes □ view zenith angles not exceeding ±60° □ mission lifetime of 5 years
Navigation and Registration	□ pointing accuracy of 2 IFOV and knowledge equivalent to 0.1 IFOV over the full range of viewing geometries (e.g., scan and tilt angles) □ pointing jitter of less than 0.01 IFOV between any adjacent spatial samples □ spatial band-to-band registration of 80% of one IFOV between any two bands, without resampling □ simultaneity of 0.02 second (to ensure co-registration of spectral bands to within 80% of one IFOV considering satellite along-track motion)
Instrument Performance Tracking	□ characterization of all detectors and optical components through monthly lunar observations through Earth-viewing port □ characterization of instrument performance changes to ±0.2% within the first 3 years and maintenance of this accuracy thereafter for the duration of the mission □ monthly characterization of instrument spectral drift to an accuracy of 0.3 nm □ daily measurement of dark current and observations of a calibration target/source, with knowledge of daily calibration source degradation to ~0.2%
Instrument Artifacts	□ Prelaunch characterization of linearity, response versus view angle (RVVA), polarization sensitivity, radiometric and spectral temperature sensitivity, high contrast resolution, saturation, saturation recovery, crosstalk, radiometric and band-to-band stability, onboard calibrator performance (e.g., bidirectional reflectance distribution of a diffuser, etc.), and relative spectral response □ prelaunch absolute calibration of 2% and on-orbit absolute calibration accuracy (before vicarious calibration) of better than 5% □ overall instrument artifact contribution to TOA radiance of <0.5% after correction □ image striping to < 0.1% in calibrated TOA radiances □ crosstalk contribution to radiance uncertainties 0.1% at L_{typ} □ polarization sensitivity of ≤1% and knowledge of polarization sensitivity to ≤ 0.2% □ no detector saturation for any science measurement bands at L_{max} □ RVVA of <5% for the entire view angle range and by <0.5% for view angles that differ by less than 1° □ Stray light contamination for the instrument < 0.2% of L_{typ} 3 pixels away from a cloud □ out-of-band contamination of <0.01 for all multispectral channels □ radiance-to-counts relationship characterized to 0.1% over full dynamic range (from L_{typ} to L_{max})
Spatial Resolution	□ Global spatial coverage of 1 km x 1 km (±0.1 km) along-track (nadir)
Atmospheric Corrections	□ retrieval of $[\square_w(\square)]_N$ for open-ocean, clear-water conditions and standard marine atmospheres with an accuracy of the maximum of either 5% or 0.001 over the wavelength range 400 – 710 nm □ Two NIR atmospheric correction bands (865 nm and either 820 or 940 nm) □ NUV band centered near 350 nm □ SWIR bands centered at 1240, 1640, and 2130 nm
Science Spectral Bands	□ 5 nm spectral resolution from 350 to 800 nm □ complete ground station downlink and archival of 5 nm data
Signal-to-noise	□ SNR at ocean L_{typ} of 1000 from 360 to 800 nm; 300 @ 350 nm; 600 @ NIR bands; 250, 180, and 15 @ 1240, 1640, & 2130 nm
Mission	□ full reprocessing capability of all PACE data at a minimum frequency of 1 – 2 times annually □ Integrated process studies, assessments, and cal/val studies □ Three-hour data latency and direct broadcast of aggregate spectral bands □ Robust data and results distribution system

http://decadal.gsfc.nasa.gov/pace.html

ESD Mission Development Path Forward

- Proposed Mission Science objectives provided by the SDT
- The PACE mission budget has been identified by the Earth Science Division, supporting a launch in 2019/2020
  - Budget is supported by multiple instrument and mission design lab cost studies
- Mission acquisition options are well understood and in discussion within NASA.
  - As a general rule within the ESD, competition is preferred if there are two or more viable mission and/or instrument developers interested.
  - It is one of the considerations as we decide on the approach.
- In FY2013/Q1 FY2014, NASA plans to:
  - Release an RFI for ocean color vicarious calibration approaches and instrumentation (21 responses, reviewed, next step underway)
  - Define the mission acquisition approach
  - Establish the expected partnership issues such as contributed instruments
  - Define the baseline mission science objectives
  - Release AO to the world, preceded by a draft AO for comment

Aerosol, Cloud, ocean Ecosystem (ACE) Mission Description

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 climate change
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 define the role of the oceans in the carbon cycle (e.g., uptake and storage).

The ocean ecosystem imager needs aerosol measurements to optimize their retrievals which is an important reason for the combined payloads.

FY11-12 Deliverables

Complete Draft Report including:
1.Scientific basis for selection of measurement requirements including Science Traceability Matrices for aerosols, clouds, ocean ecosystems, aerosol-cloud interactions and aerosol-ocean interactions
2.Instrument concept descriptions
3.Mission implementation options including the utilization of 1 and 2 spacecraft

Develop white paper proposals for short and medium term activities, including theory, data analysis and **field campaigns**, to better define ACE science and reduce instrument development risk

Mission Implementation and Challenges

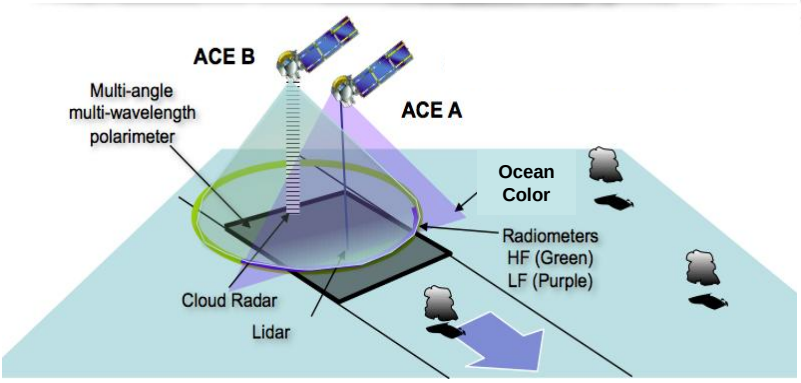
ACE Payload currently considers the following instrument candidates:

1. Lidar for assessing aerosol/cloud heights and aerosol properties. (TRL 4-6)
2. Dual frequency Doppler 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 over-guide instruments/measurements critical to the mission.

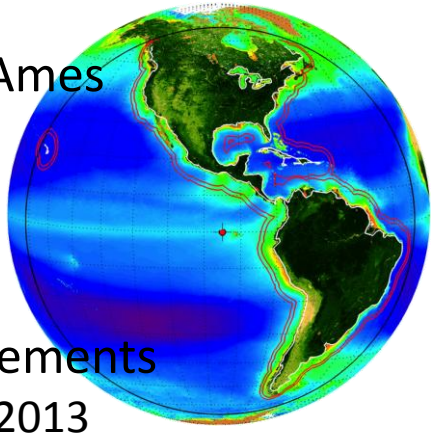
Mission Architecture



Current thinking: ACE in two parts flying in formation; the first launch a spacecraft with passive sensors (ocean color instrument and aerosol/cloud polarimeter), the second launch a spacecraft with active instruments (HSR Lidar and multi-frequency Doppler radar. Additional sensors (e.g., gray instruments from lower left quadrant) TBD.

GEO-CAPE

- GEOstationary Coastal and Air Pollution Events
- Recommendation to implement mission as secondary payloads hosted on commercial geostationary satellites (Fishman et al., BAMS, 2012)
- TEMPO (Tropospheric Emissions: Monitoring of Pollution) selected Nov. 2012 through NASA's Earth Venture Instrument solicitation
  - ~2019 launch on geo communications satellite (2-year operational mission)
  - UV-Visible grating spectrometer to provide hourly tropospheric ozone, NO2 and aerosol cycles (subset of GEO-CAPE atmosphere measurements)
- TEMPO selection does not imply acceleration of full GEO-CAPE mission
- GEO-CAPE is presently planned for launch no earlier than 2022
- Open Community workshop planned May 21-23, 2013 at NASA Ames
  - Planning GOCI-II and GEO-CAPE development workshop



<u>Ocean Color Mission Component</u>

- Focus on U.S. & other North and South American coastal waters
- Science studies guiding recommendations on ocean color requirements
  - Planning field campaign in northern Gulf of Mexico for September 2013
- Completed coastal oceans ecosystem white paper describing and justifying mission science and requirements; to publish as NASA TM (2013)
- Collaboration between KOSC GOCI team and NASA GSFC moving forward
- Plans to increase dialogue with international community in 2013

http://geo-cape.larc.nasa.gov/

NASA OB&B Research – Research Opportunities in Space and Earth Sciences

- ROSES 2013 - http://nspires.nasaprs.com/ - Released 14 February 2013
  - Carbon Cycle Science – 6 topics, four federal agencies, US$12M/yr – 386 proposals
  - NASA Data for Operation and Assessment – 4 topics, US$2M/yr –14 NOIs [15 May 2013]
    - Operational short-term weather prediction, climate projection assessment, ecological forecasting
  - The Science of Terra and Aqua – 3 topics ~US$11.5M/yr – 200 NOIs [20 May 2013]
    - Science Data Analysis + Multiplatform and sensor data fusion
    - Algorithms – New Data Products
    - Real- or Near-Real-Time Data Algorithms
  - Ocean Biology and Biogeochemistry ~US$500K/yr – 12 NOIs [30 May 2013]
    - Scoping proposals for field campaigns (e.g., ICESCAPE)
  - The Science of Terra and Aqua – Algorithms – Existing Data Products ~US$2.5M/yr [NOIs 15 May 2013, Proposals 1 July 2013]
  - PACE Science Team – TBD for 2013

- ROSES 2012 - http://nspires.nasaprs.com/ - Released 14 February 2012
  - Interdisciplinary Research in Earth Science – 5 topics, US$12M/yr, 145 proposals
    - Understanding Earth System Vulnerabilities to Climate Extremes
    - Impacts of Changing Polar Ice Cover
    - Water and Energy Cycle Impacts of Biomass Burning
    - Impacts of Population growth on watersheds and coastal ecology
    - Role of Permafrost in a Changing Climate