IOCCG Working Group on “Mission Requirements for Future Ocean Color Sensors”

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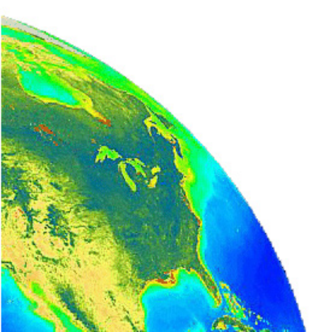
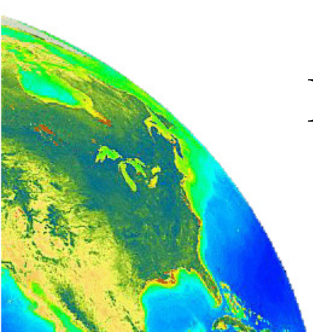


PACE SDT, November 17th, 2011

Report Structure:

- Chapter 1: Introduction (4 pages)
- Chapter 2: Science Questions and Applications (10 pages)
- Chapter 3: Approaches and Data Product Requirements (14 pages)
- Chapter 4: Space Measurement and Mission Requirements (33 pages)
- Chapter 5: International Cooperation (8 pages, almost finished)
- Chapter 6: Conclusions (in progress)



Expected completion date: December 2011

Background

- Main objective of International Ocean-Colour Coordinating Group (IOCCG, associate member of CEOS) is to develop consensus for OC
- Why a follow-on to IOCCG Report 1 (A. Morel) "Minimum Requirements for an Operational Ocean Color Sensor for Open Ocean" ?
  - Report 1 focused on chlorophyll
  - New products are available
  - New science questions
  - Technological progress
- Report is built around a Science Traceability Matrix (STM)

Global Ocean and Climate Change STM

IOCCG International Ocean Colour Coordinating Group

Category: Global Ocean Science and Climate Change

No.	Scientific Questions
1	What are the phytoplankton standing stocks, composition, & productivity of ocean ecosystems? How and why are marine ecosystems changing and what changes are expected in the future? How are these changes related to human activities (e.g., climate change) and what are the feedbacks to the climate system?
2	How and why are ocean biogeochemical cycles changing? How do they influence the Earth system? How to monitor them?
3	How are the material exchanges between land & ocean varying and changing? How do they influence coastal ecosystems, biogeochemistry & habitats? How are they changing?
4	How do aerosols & clouds influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere and Earth system?
5	How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics?
6	What are the distributions and magnitudes of algal blooms? How do human activities, such as eutrophication, and climate change, affect blooms. Can harmful blooms be differentiated from other blooms?
7	How can satellite remote sensing be used to investigate and monitor coastal ecosystems (e.g., water quality and coral reef health)?
8	How are changes in marine ecosystems and habitat affecting fisheries.
9	Can ocean dumping be observed using satellite ocean color radiometry and can aggregation zones be identified?

Approach using space OC data	Maps to Science Question
Quantify phytoplankton biomass, pigments, optical properties, key groups (functional/HABS), and productivity using bio-optical models & chlorophyll fluorescence. Quantify relationship between physiological state and bio-optical properties.	1, 2, 6
Measure particulate and dissolved carbon pools, their characteristics and optical properties.	2, 3
Quantify ocean photobiochemical and photobiological processes.	2, 4
Estimate particle abundance, size distribution (PSD), & characteristics.	1, 3, 2
Assimilate observations into ocean biogeochemical model fields of key properties (cf., air-sea CO_2 fluxes, carbon export, pH, etc.).	2
Compare observations with ground-based and model data of biological properties, land-ocean exchange in the coastal zone, physical properties (e.g., winds, SST, SSH, etc), and circulation (ML dynamics, horizontal divergence, etc).	3, 4, 5, 6
Combine ocean & atmosphere observations with models to evaluate (1) air-sea exchange of particulates, dissolved materials, and gases and (2) impacts on aerosol & cloud properties.	4
Assess ocean radiant heating and feedbacks.	5
Correlate fish stocks, year class survival rates, and life cycles with bloom concentrations, timing and taxonomic composition.	8
Evaluate anomalous ocean reflectance signatures due to floating debris and refuse.	9

Space Product Requirements

1km spatial resolution grid
Global 2-day coverage
Level 2 and Level 3

▸ Intermediate products:
Aerosol optical thickness, Angstrom exponent

▸ Basic product :
nLw (normalized water-leaving radiances) or Rrs (remote sensing reflectances) in UV, VIS, and NIR (μW/cm²/μm/sr) at either a set of spectral bands or hyperspectral data depending on mission objectives

▸ Derived products:
- Chl (mg/m3) Chlorophyll concentration for case-1, case-2 and merged cases
- Primary production (gC/m^2d)
- YSBPA (m^{-1}) Yellow substance and bleached particle absorption
- DOM (m^{-1}) Dissolved organic matter absorption
- CDOM (m^{-1}) Colored dissolved organic matter absorption
- TSM (g/m^3) Total suspended matter
- Kd(490) diffuse attenuation coefficient at 490nm (m^{-1})
- PAR (μEin/m²) daily photosynthetic available radiation (about iPAR ?)
- iPAR (μEin/m²) instantaneous photosynthetic available radiation
- a, absorption coefficient (m^{-1}): total, CDM, CDOM, phytoplankton, nonalgal detritus
- bb, backscattering coefficients (m^{-1}): total, particulate (small, large)
- FLH Fluorescence Line Height
- PIC/POC Particle inorganic/organic carbon ($moles/m^3$)
- Eutrophic depth (m), Secchi depth (m)
- Phytoplankton physiological parameters: Growth rate, C:Chl, Chlorophyll fluorescence efficiency & quantum yields
- Classification : Phytoplankton type (PHYSAT)
- Particle size distribution

Mission Measurement Requirements

1. Ocean Radiometer
Total radiances in UV, VIS, NIR, & SWIR. For example:
Bio-optical bands: 360, 385, 412, 443, 460, 490, 510, 555, 583, 617, 640, 665, 678, 710 nm
Atmospheric correction bands: 748, 765, 865, 1245, 1640 nm
Prelaunch characterization data & documentation

2. Field validation program

3. Vicarious calibration program

4. Data system
Latency: 3 hrs – operational
2 weeks – science
Reprocessing capacity

5. Ancillary data
Ozone
Surface vector winds
NO_2
Surface pressure
Water vapor concentration
Relative humidity

Science Questions (1/3):

- ## 1. Marine Ecosystems

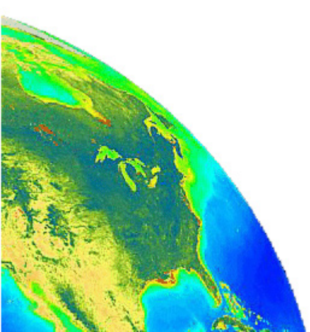
What are the phytoplankton standing stocks, composition, and productivity of ocean ecosystems? How and why are marine ecosystems changing and what changes are expected in the future? How are these changes related to human activities (e.g., climate change) and what are the feedbacks to the climate system?

- ## 2. Biogeochemical Cycles

How and why are ocean biogeochemical cycles changing? How do they influence the Earth system? How to monitor them?

- ## 3. Land-Ocean Interactions

How are the material exchanges between land & ocean varying and changing? How do they influence coastal ecosystems, biogeochemistry and habitats? How are they changing?



Science Questions (2/3):

- 4. Ocean-Atmosphere Biogeochemical Interactions

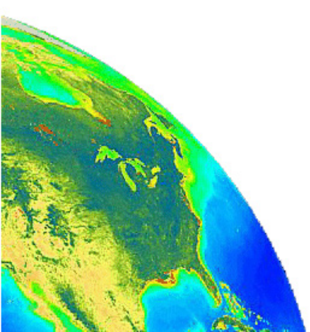
  How do aerosols and clouds influence ocean ecosystems and biogeochemical cycles? How do ocean biological and photochemical processes affect the atmosphere and Earth system?

- 5. Biological-Dynamical Interactions

  How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics?

- 6. Algal Blooms

  What are the distributions and magnitudes of algal blooms? How do human activities, such as eutrophication, and climate change, affect blooms? Can harmful blooms be differentiated from other blooms?



Science Questions (3/3):

- ## 7. Coastal and Estuarine Ecosystem Health

  How can satellite remote sensing be used to investigate and monitor coastal ecosystems (e.g., water quality and coral reef health)?

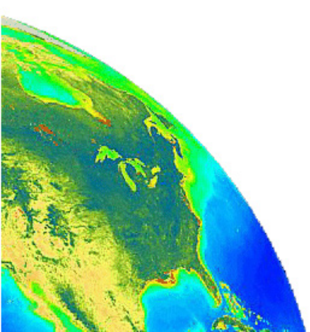
- ## 8. Fisheries

  How are changes in marine ecosystems and habitat affecting fisheries?

(see IOCCG Report Number 8, *Remote Sensing of Fisheries and Aquaculture,* 2009)

- ## 9. Ocean Pollution

  Can ocean dumping be observed using satellite ocean color radiometry and can aggregation zones be identified?



Recommended Spectral Bands (26)

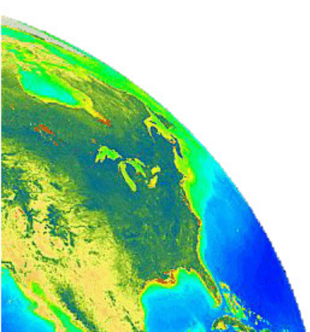
l [nm]	dl [nm]	SNR		l [nm]	dl [nm]	SNR
350	15	300		617	15	1000
360	15	1000		640	10	1000
385	15	1000		655	15	1000
412	15	1000		665	10	1000
425	15	1000		678	10	1400
443	15	1000		710	15	1000
460	15	1000		748	10	600
475	15	1000		765	40	600
490	15	1000		820	15	600
510	15	1000		865	40	600
532	15	1000		1245	20	250
555	15	1000		1640	40	180
583	15	1000		2135	50	100

Other Design Recommendations:

- Spatial resolution (1km)
- Tilt capability (to avoid sun glint)
- Stability monitoring with lunar measurements (preferred) and/or solar diffuser
- Polarization scrambler
- Reduce straylight
- Temperature control
- Life time of at least 5 years

Prelaunch Sensor Characterization Recommendations:

- Total uncertainty of 0.5% requires individual uncertainty components of 0.2% or less (e.g. polarization, straylight, temperature, linearity, etc.)
- Exception: Absolute calibration prelaunch can be higher (e.g. 2%) because of vicarious calibration
- Accurately characterize relative spectral response
- Develop instrument model

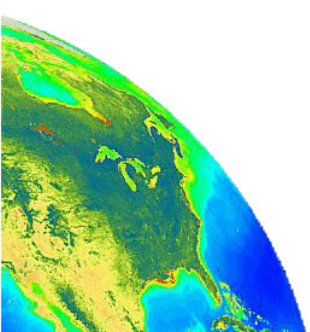


On-Orbit Sensor Calibration Recommendations:

- Trend sensor radiometric degradation with lunar measurements (preferred) and/or solar diffuser measurements
  - Small size of lunar image difficult to accommodate for certain sensor types
  - Solar diffuser can provide larger image to fill instrument aperture, but requires trending of solar diffuser reflectance
  - Irradiance variations of moon can be accurately predicted with USGS ROLO model (0.1%), but absolute calibration has uncertainty of several percent
  - Need for absolute calibration "under discussion"

On-Orbit Sensor Characterization Recommendations:

- Consider alternative calibration methods (deep convective clouds, Rayleigh method, etc., see IOCCG calibration report (unpublished))
- Measure on-orbit spectral drift (for hyperspectral instruments)
- Trend signal-to-noise ratio



Spacecraft/Orbit Considerations:

- Data transmission: on-board storage and transmission to dedicated high latitude ground station AND Direct Broadcast
- Choose orbit altitude such that 2-day global coverage is possible (depends on swath width/maximum scan angle)
- Maintain orbit (SeaWiFS equator crossing time varied from noon to 2:30PM, MERIS has started to drift in October 2010)

Field Programs

- Vicarious calibration needed for visible bands, each mission should identify vicarious calibration source
- NIR vicarious calibration uses assumption about typical aerosol type
- Validation needed at least for water-leaving radiances

Ancillary data:

- Total column atmospheric water-vapor
- Sea surface wind speed
- Total ozone in atmospheric column
- Atmospheric pressure
- Atmospheric NO2
- Relative humidity (for aerosol selection, Ahmad et al., 2010)

Data Processing and Distribution:

- Data delivery:
  - start 3 months after launch
  - then <24 hours after acquisition
- Data accessibility:
  - open for research, restrict for commercial applications if needed
  - provide L1 and L2 data online

  Data management:
  - Scope data system to allow full archiving (L1, L2, whole mission) and reprocessing (every 2 years)

Parallel activity: NASA/TM-2011-215883

“Requirements for an Advanced Ocean Radiometer”

October 2011

Authors: Meister, McClain, Ahmad, Bailey, Barnes, Brown, Eplee, Franz, Holmes, Monosmith, Patt, Stumpf, Turpie, Werdell

Requirements for an Advanced Ocean Radiometer:

- Not connected to IOCCG report (except for two common authors), not from ACE team
- NASA TM by OBPG (and NIST, NOAA, engineers)
- Starting point: ACE Ocean Biology White paper (neptune.gsfc.nasa.gov/osb/index.phb?section=241)
- Goal: testable requirements (more detailed than AOBWP or IOCCG report)
- Considered heritage requirements (SeaWiFS, MODIS, VIIRS) and our experience with them
- Available at: dsm.gsfc.nasa.gov/pace-2011sdtdocuments.html (or by request)

Requirements for an Advanced Ocean Radiometer:

- Example in AOBWP:
  "Polarization: <1.0% sensor radiometric sensitivity, 0.2% prelaunch characterization accuracy"
- 2 paragraphs in TM: two paragraphs, provide equation:
  $dn(b) = dn_0(1+p_a \cos(2b-2d))$
  $p_a<0.01$, no target value for d, 0.2% accuracy requirement relates to above equation, cite relevant literature, define scan angles for evaluation

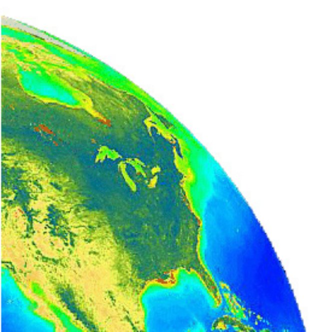
Requirements for an Advanced Ocean Radiometer:

- Spacecraft and Global Coverage Specifications: 8 requirements (scan angle range, tilt, lunar cal., etc.)
- Instrument Specifications:
  - Radiometric: 15 requirements (dynamic range, linearity, polarization, saturation, crosstalk, etc.)
  - Spectral: 6 requirements (RSR, spectral stability, center wavelength, etc.)
  - Spatial: 6 requirements (IFOV, band-to-band registration, pointing knowledge, etc.)

Backup slides:

Ideal Sequence to determine performance requirements

1. Science objectives & questions
2. Products & product accuracy requirements
3. Algorithms & spectral band selection
4. Bio-optical algorithm accuracy requirements
5. Lwn or Rrs accuracy requirements
6. TOA radiance accuracy requirements
7. Single set of "most stringent" spectral accuracy requirements
8. Sensor spectral calibration & characterization requirements & test specifications



Relating Satellite Products to Approaches and Science Questions (1/3)

Table 1. Correspondence between approaches for addressing scientific questions and ocean color satellite data products.

Approach	Satellite Products
Quantify phytoplankton biomass, pigments, optical properties, key groups (functional/HABS), and productivity using bio-optical models & chlorophyll fluorescence. Quantify relationship between physiological state and bio-optical properties. Scientific questions 1, 2, and 6.	Chlorophyll-a, other phytoplankton pigments, primary production, particulate inorganic carbon, dissolved organic matter/carbon, taxonomic groups (e.g., coccolithophore and Trichodesmium concentrations), physiological properties, particle size distribution, normalized water-leaving radiances (or remote sensing reflectances)

Relating Satellite Products to Approaches and Science Questions (2/3)

Table 2. Mapping of scientific questions to satellite data products needed to address the questions.

Scientific Question	Satellite Data Products
1. What are the phytoplankton standing stocks, composition, & productivity of ocean ecosystems? How and why are marine ecosystems changing and what changes are expected in the future? How are these changes related to human activities (e.g., climate change) and what are the feedbacks to the climate system?	Chlorophyll-a, other phytoplankton pigments, primary production, particulate inorganic carbon, dissolved organic matter/carbon, taxonomic groups (e.g., coccolithophore and Trichodesmium concentrations), physiological properties

Relating Satellite Products to Approaches and Science Questions (3/3)

Table 3. A reverse mapping from Table 2 of satellite data products to relevant scientific questions.

Satellite Data Products	Scientific Questions
Normalized water-leaving radiances or remote sensing reflectances	6, 9 (Note: all products are derived using Lwn's or RSR's)
Chlorophyll-a	1, 5, 6, 8

Satellite Product Definitions

- Example (22 products):
  3.2.20 Total Suspended Matter (TSM): the dry weight of particles in a unit volume of water (mg/L, or g/m^3)

Table 4. Range of observed geophysical parameter values.

Geophysical Parameter	Geophysical Range
Normalized water-leaving radiances	0 - 2.5 mW/cm^2 µm str
Remote sensing reflectances	0 - 0.2/str
Chlorophyll-a	0 - 500 mg/m^3
Diffuse attenuation	0 - 0.5/m

Recommended Spectral Bands (1/2)

Table 5. A set of recommended minimum spectral bands required for addressing **all** the STM science questions. The missions listed below are the global missions. Note that some instruments have some of the bands listed but only those bands specifically designed for ocean color applications are indicated, e.g., the MODIS SWIR bands have been used for turbid water aerosol corrections, but the signal-to-noise ratios are very low and would not meet an ocean color specification.

CZCS	POLDER	OCTS	SeaWiFS	MODIS	MERIS	GLI	VIIRS	SGLI	OLCI	PACE	Application	Comments
										350	Absorbing aerosol detection	
										360	CDOM-chlorophyll separation	Strong NO2 absorption
						380		380		385	CDOM-chlorophyll separation	Strong NO2 absorption; avoid precipitous drop in solar spectrum at 400 nm