Continuity and Use of Ocean Color Radiometry Data: Operations = Research + Applications + Services + Users

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Center for Satellite Applications & Research (STAR)
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With contributions from:
Chris Brown, Steve Greb, Ewa Kwiatkowska, Veronica Lance, Mark Matthews, Lia Santoleri, Emily Smail, Rick Stumpf, Menghua Wang, Cara Wilson
Overview

Space-based ocean color radiometry measurements are becoming increasingly mature and transitioning into routine and sustained operations (more on that in a bit...)

- Coastal Zone Color Scanner in 1978
- First IOCCG Report Published in 1998; now 16 and counting!
- Diverse use for research, operational applications, and services
- Sustained measurements since 1997; continuity assured 2030+

Focus for this talk:
1) provision/continuity of OCR data in an operational context
2) facilitate usage of operational data & need to engage users
OLCI: mid-morning acquisitions

OLCI – Copernicus prime Ocean Colour sensor

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- **SAR Altimeter**
- **Sea and Land Surface Temperature Radiometer**
- **Ocean and Land Colour Instrument**

**Height of the surface**
**Temperature of the surface**
**Colour of the surface**
NOAA Polar Satellite Programs
Continuity of Weather Observations

VIIRS: early-afternoon acquisitions

Calendar Year

08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

← NOAA - 15
← NOAA - 18
NOAA - 19
Suomi NPP

Click on any bar for current status
NOAA-18

Fiscal Year

08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

JPSS - 1
JPSS - 2
PF0/JPSS - 3
PF0/JPSS - 4

In orbit and operating beyond design life
Planned Mission Life, from Planned Launch Date
Planned Mission Life Beyond 2036
Fuel-Limited Lifetime Estimate

Launched before Jan 2008

Note: Operations beyond design life are reflected through the next year based on current operating health.

Approved: Assistant Administrator for Satellite and Information Services
Challenge: Changing Perceptions

Operational = Near Real-Time
Challenge: Changing Perceptions

Operational = Near Real-Time (only)
Salmon Survival in 2011

Adult Chinook Returns – What happened in 2011?

Time series of average April-May chlorophyll concentrations in coastal Gulf of Alaska. The lowest value (2011) suggests that low productivity could have negatively influenced salmon survival that year.

Brian Burke
Fish Ecology Division
NWFSC, NOAA Fisheries
→ There is a prevailing perception that operational satellite missions, and the associated data generated by operational agencies, can only support near-real time applications

→ Another perception is that quality is not a primary driver for operational data.

→ Researchers are also frequently viewed as not being users of operational data, ostensibly falling into a different bucket.

→ None of the above are true....
Q: What does operational mean?
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A: Depends upon who you ask, but:

Per N. Smith & M. Lefebvre (1997) then Schiller et al. (2016), “whenever the processing is done in a routine predetermined systematic approach with embedded accuracy and constant monitoring. With this terminology, regular re-analyses may be considered as operational systems, as well as organized analyses and assessment of climate data.”
Q: What does operational mean?

A: Depends upon who you ask, but:

Per C. Brown, P. DiGiacomo et al. (manuscript in prep): Routine and sustained provision of accurate, consistent and fit for purpose quality oceanographic satellite observations spanning different time-scales (i.e., NRT to climate) and users (e.g., research, operational applications and services)
Q: What role does science play in the operational domain?
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A: Robust and fundamentally sound science provides an essential foundation and underpins the entire spectrum from research & development to robust operations, applications, and services. It is crucial at each and every step in the end-to-end process.
Q: Is mission level reprocessing part of the operational mission?

A: Yes! Many operational users require consistent, accurate time series data, e.g., fisheries management et al. As such this introduces crucial requirements for mission space and ground segments, including stability monitoring through on-orbit sensor calibration.
Operational missions must provide *routine and sustained* data of the highest possible quality supporting research and end user-driven applications and services, spanning NRT to climate-scales, unequivocally underpinned by fundamentally strong science.
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Operational missions therefore need to implement and maintain integral supporting space-based and ground system infrastructure and associated scientific and technical activities, e.g.,

- extensive pre-launch characterization,
- calibration/validation,
- on-orbit maneuvers,
- life of mission reprocessing
- On-going product development and refinement ensuring data are fit for purpose for all users (not just NRT apps)
Operational validation tools and activities

MERMAID Level 2 match-ups:
Time series, scatter plots and statistics

Inter-sensor comparisons at Level 3

Inter-sensor time series and scatter plots
Operational validation tools and activities

Running Level 3 inter-comparisons with contemporaneous global missions and climatologies (L3 binning for validation and monitoring)

- Band 490nm OLCI ratios with MODIS, VIIRS
- Band 560nm OLCI ratios with MODIS, VIIRS

No OC-SVC applied

Chlorophyll-a log difference OLCI – VIIRS June 2016

Level 2 in situ matchups with FRMs

OLCI and MOSBY Lw:

- 400 nm
- 412 nm
- 442 nm
- 490 nm
- 510 nm
- 560 nm

No OC-SVC applied

Cal/Val website
Report for the 2015 NOAA dedicated Cal/Val cruise has been published!

High quality MOBY daily in situ data are useful for on-orbit sensor performance monitoring!

https://www.star.nesdis.noaa.gov/sod/mecb/color/CalVal.php
Assessment of the OC products

Download the Quality Information Document from the CMEEMS website
NRT QUALITY CONTROL IN OPERATION

- inter-comparison between sensors and/or climatology
- computed operationally at daily basis
# VIIRS NRT and Science Quality Ocean Color Data

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Near-Real Time</th>
<th>Delayed-Mode/Science-Quality</th>
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<tbody>
<tr>
<td>Latency:</td>
<td>Best effort, as soon as possible (≈12-24h)</td>
<td>Best effort, on a 2-week delay</td>
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<tr>
<td>Processing System:</td>
<td>MSL.12</td>
<td>MSL.12</td>
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<tr>
<td>SDR:</td>
<td>IDPS Operational SDR</td>
<td>OC-improved SDR</td>
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<tr>
<td>Ancillary Data:</td>
<td>Global Forecast System (GFS) Model</td>
<td>Science quality (assimilated; GDAS) from NCEP</td>
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<tr>
<td>Spatial Coverage:</td>
<td>May be gaps due to various issues</td>
<td>Complete global coverage</td>
</tr>
<tr>
<td>Processed by:</td>
<td>CoastWatch, transferring to OSPO (operational) FY16</td>
<td>NOAA/STAR</td>
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<td>Distributed by:</td>
<td>CoastWatch, OSPO</td>
<td>CoastWatch, NCEI</td>
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<tr>
<td>Archive Plans:</td>
<td>Yes, from OSPO to NCEI</td>
<td>Yes, from CoastWatch to NCEI</td>
</tr>
<tr>
<td>Full Mission Reprocessing:</td>
<td>No</td>
<td>Yes, every ≈2-3 years or as needed</td>
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VIIRS Climatology Ocean Color Product Image (2012–2016)
Phytoplankton community composition in the Chesapeake Bay observed with satellite-derived algal light absorption spectra

- Seasonal climatology of diatom fraction (a–d) and [Chl-a] (e–h) in the Chesapeake Bay derived from VIIRS data during the period of 2012–2016. The diatom fraction is calculated from GSCM-derived \( a_{ph}(670)/a_{ph}(440) \) ratio.

- The [Chl-a] is calculated based on GSCM-derived \( a_{ph}(670) \)

G. Zheng and P. DiGiacomo, under review
Don’t let perfect be the enemy of the good (~Voltaire)
Make it simple. Make sure there is a payoff.
Enabling & Facilitating use of Ocean Color Data

The Skinner Box

Loudspeaker

Lights

Response lever

Food dispenser

Electrified grid

The Bernard Box

Get your DATA
DATA
DATA
Here!!!

Make it simple. Make sure there is a payoff. But a little “bling” does not hurt either!
Perspectives on addressing user needs (courtesy of a NOAA line office user):
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1. Users know what they need, but not what RS products they need.
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Enabling & Facilitating use of Ocean Color Data

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Enabling & Facilitating use of Ocean Color Data

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Enabling & Facilitating use of Ocean Color Data

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6. When they keep asking you for the product, or when they offer to commit their own time or find money to help with it, THEN you've created something useful.
7. When managers find the products useful for solving tough problems, researchers have the opportunity to do some really interesting science.
Enabling & Facilitating use of Ocean Color Data

End-to-End Value Chain in Support of User Needs

User needs → Data → Products → Information → Knowledge
Diagnose problem
Measure from satellite
Apply relevant guidelines
Inform decision makers and general public
Recommend safety for use

[Map Image with cyanolakes logo]
Coral Reef Watch
5-km Satellite-Based Products

Coral - specific

Bleaching Alert Area

http://coralreefwatch.noaa.gov
Enabling & Facilitating use of Ocean Color Data

End-to-End Value Chain in Support of User Needs
**Input OLCI data:**
- L2 global ocean data generated by EUMETSAT
- L1B data, to produce CMEMS OC regional products (if needed / under evolution)

**Sentinel-3 OLCI use by CMEMS OCTAC:**
- Production of OLCI global L3 and L4 products
- Production of OLCI tuned L3 and L4 regional products *(single Case1-Case2 Chl product with selected algorithm)*
- Integration in multi-sensor OC global and regional processing chains
- Integration in multi-sensor reprocessing system to produce consistent time series of OC products from 1997 to today

**Dissemination of OLCI data in CMEMS:**
- single sensor OLCI L3 regional and global products
- Variables: Chla, IOPs, attenuation coefficient, reflectances
- L4 OLCI regional and global products *(weekly, monthly)*
- Multi-sensors *(including OLCI)* L3 and L4 global and regional OC products *(L4 include daily Chl interpolated fields)*

**Use of OLCI data inside CMEMS:**
- Modelling quality assessment and data assimilation
- Indicators to monitor the marine environment *(eg. MSFD)*
Enabling & Facilitating use of Ocean Color Data

NOAA STAR Ocean Color (OC) Viewer

https://www.star.nesdis.noaa.gov/sod/mecb/color/about_ocview.php
• 3-day (free!) course aimed at NMFS or NOS participants (the “wet” side of NOAA) who want to learn how to access & use satellite data

• Objective is to help people access and use satellite data in the environment they are used to working in – a challenging task! Focus has been on GIS, Matlab and R applications.

• Participants bring projects to work on.

• Course initiated by funding from NOAA’s R&O project in 2006. The JPSS program has provided full or partial funding since 2013-2015.

• The learning experience goes two ways. From conducting these courses we get a better idea of users’ needs and wants, and therefore are better able to address those needs.

http://coastwatch.pfeg.noaa.gov/courses/satellite_course2017.html
Facilitating use of ocean color data by Coral Reef Managers

Comparing monthly imagery of $K_d(490)$ and Chl-$\alpha$ against the expected Normal levels (mean)

Red Box (circle) = Target A Guánica Watershed Outfall Puerto Rico, USA
Enabling & Facilitating use of Ocean Color Data

End-to-End Value Chain in Support of User Needs
Use of OCR within CMEMS

Use of OC products inside CMEMS:
- **modelling quality assessment**
- **data assimilation** in bio-geochemical models
- Quality check of in situ data
- **Indicators to monitor** the marine environment (e.g., MSFD)
- Indicators to monitor for management of marine resources
- **Ocean State Report**
Biogeochemical Med-MFC @ CMEMS

**Physical forcing**
U, V, T, S from Med-MFC
Physical component
NEMO 3.4 daily 3D fields at 1/16° and 72z levels

**Land & Atm. Forcings**
Yearly and monthly climatological data for rivers; seasonal estimates for atm.

**Boundary Conditions**
Seasonal profiles in the Atlantic buffer zone from MEDAR/MEDATLAS and CarbSys climatologies

**Initial Conditions**
MEDAR/MEDATLAS and 5-y hindcast spin-up + 17-y reanalysis

**BIOGEOCHEMICAL MODEL**
(resolution: 1/16°, 72z levels)
OGSTM - transport model

**Biogeochemical Flux Model – BFM**
51 variables; cycle of C, N, P, Si, O; carbonate system; Plankton Functional Types formulation

**Observations:**
NRT MODIS and OC Multi-REP regional Chlorophyll from CMEMS OC TAC
Daily Q/C 2D fields at 4km res resampled over model grid

**Assimilation**
3DVAR-BIO variational scheme; weekly assimilation cycle

**PRODUCTS**
8 variables: chlorophyll, nitrate, phosphate, primary production, phytopl. biomass, oxygen, pCO2, pH

Analysis & Forecast: daily since 1/1/2013
Reanalysis: monthly since 1/1/1999

Validation
Ocean Data Assimilation
(Navy Coupled Ocean Data Assimilation: NCODA)

Hae-Cheol Kim, NWS/NCEP
Enabling & Facilitating use of Ocean Color Data

Lake Erie Harmful Algal Bloom Bulletin
NOAA-NOS and OAR/GLERL

https://www.glerl.noaa.gov//res/HABs_and_Hypoxia/bulletin.html
HAB Operational Forecast System: Gulf of Mexico *Karenia brevis*

Padre Island National Seashore Closes Park to Dogs (December 9, 2009)

Gulf of Mexico Harmful Algal Bloom Bulletin
Region: Southwest Florida
Monday, 24 October 2016
NOAA National Ocean Service
NOAA Satellite and Information Service
NOAA National Weather Service
Last bulletin: Thursday, October 20, 2016

Conditions Report
Not present to high concentrations of *Karenia brevis* (commonly known as Florida red tide) are present along- and offshore portions of southwest Florida, and not present in the Florida Keys. *K. brevis* concentrations are patchy in nature and levels of respiratory irritation will vary locally based upon nearby bloom concentrations, ocean currents, and wind speed and direction. The highest level of potential respiratory irritation forecast for Monday, October 24 through Thursday, October 27 is listed below:

http://tidesandcurrents.noaa.gov/hab
Whale Watch

WhaleWatch: a dynamic management tool for predicting blue whale density in the California Current

Elliott L. Hazen,1,2, Daniel M. Palacios,3 Karin A. Forney,4, Evan A. Howell,5, Elizabeth Becker,6 Aimee L. Hoover,6 Ladd Irvine,3 Monica DeAngelis,7 Steven J. Bograd,1 Bruce R. Mate,3 and Helen Bailey,6

1Environmental Research Division, NOAA Southwest Fisheries Science Center, Monterey, CA 93940, USA; 2Department of Ecology and Evolutionary Biology, University of California Santa Cruz, Santa Cruz, CA 94073, USA; 3Marine Mammal Institute, Oregon State University, Hatfield Marine Science Center, Newport, OR 97365, USA; 4Marine Mammal and Turtle Division, NOAA Southwest Fisheries Science Center, Newport, OR 97366, USA; 5NOAA Pacific Islands Fisheries Science Center, Honolulu, HI 96818, USA; 6Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, MD 20688, USA; 7NOAA West Coast Regional Office, Long Beach, CA 90802, USA

Summary

1. Management of highly migratory species is reliant on spatially and temporally explicit information on their distribution and abundance. Satellite telemetry provides time-series data on individual movements. However, these data are underutilized in management applications in part because they provide presence-only information rather than abundance information such as density.

2. Eastern North Pacific blue whales are listed as threatened, and ship strikes have been suggested as a factor limiting their recovery. Here we developed a satellite-telemetry-based habitat model in a case-control design for Eastern North Pacific blue whales Balaenoptera musculus that was combined with previously published abundance estimates to predict habitat preference and densities. Further, we operationalized an automated, near-real-time whale density prediction tool based on up-to-date environmental data for use by managers and other stakeholders.

3. A switching state-space movement model was applied to 104 blue whale satellite tracks from 1994 to 2008 to account for errors in the location estimates and provide daily positions (case points). We simulated positions using a correlated random walk model (control points) and sampled the environment at each case and control point. Generalized additive mixed models and boosted regression trees were applied to determine the probability of occurrence based on environmental covariates. Models were used to predict 6-day and monthly resolution, year-round density estimates scaled by population abundance estimates that provide a critical tool for understanding seasonal and interannual changes in habitat use.

4. The telemetry-based habitat model predicted known blue whale hot spots and had seasonal agreement with sightings data, highlighting the skill of the model for predicting blue whale density.

http://www.westcoast.fisheries.noaa.gov/whalewatch/index.html
GEO AquaWatch

The AquaWatch Mission:
To improve water quality in coastal and inland waters through more effective monitoring, management and decision making.

The AquaWatch Goal:
To develop and build the global capacity and utility of Earth Observation-derived water quality data, products and information to support water resources management and decision making.
GEO AquaWatch

The AquaWatch Objectives:

• Facilitate effective partnerships between the producers, providers and users of water quality data, products and information.
• Improve analysis and integration of in situ and remote sensing water quality data.
• Develop and deliver fit-for-purpose water quality products and information services.
• Support technology transfer and access to water quality data products and information.
• Advocate for increased capacity for and use of water quality information for decision making.
The AquaWatch Water Quality Information Service

AquaWatch has developed a work plan consisting of a series of sequential work packages to construct the Water Quality Information Service.

1. **Work Package 1**: Initiation of GEO Water Quality CoP
2. **Work Package 2**: Ongoing and developing water quality project inventory
3. **Work Package 3**: Development of baseline global water quality products
4. **Work Package 4**: Local/regional end-to-end prototype project demonstration
5. **Work Package 5**: Develop initial demonstration global water quality monitoring service
6. **Work Package 6**: Transition to routine and sustained global water quality monitoring service
7. **Work Package 7**: Expand water quality monitoring service to include forecasting service

The seven work packages of AquaWatch. These are the "building blocks" of the Water Quality Information Service.

Increasing resources required
About GEO Blue Planet

- Oceans and Society: Blue Planet is an Initiative within the Group on Earth Observations

- GEO Blue Planet’s **mission** is to:
  - advance and exploit synergies among the many observational programmes devoted to ocean and coastal waters;
  - to improve engagement with a variety of users for enhancing the timeliness, quality and range of services delivered; and
  - to raise awareness of the societal benefits of ocean observations at the public and policy levels.

http://geoblueplanet.com/
Enabling & Facilitating use of Ocean Color Data

http://symposium.geobluueplanet.com/
Some additional thoughts…

- Facilitate more timely transitions *between* research & operations (R2O2R)
- Allow requirements to evolve as appropriate (not etched in stone!)
- Advance and encourage private sector use and transformation of OCR data
- Pursue measurement-based, source (i.e., mission) agnostic enterprise approach
- Fuse multi-sensor *color* data, especially across multiple time and space scales
- Facilitate better integration of OCR data w/other satellite & in situ measurements
- Accelerate modeling efforts & assimilation of OCR data for enhanced products/info
- Greater focus on the overarching, end-to-end value chain, moving from OCR observations and data to derived products & info that provides knowledge
- *Don’t let perfect be the enemy of the good*
Obrigado!