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

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With contributions from:
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Overview

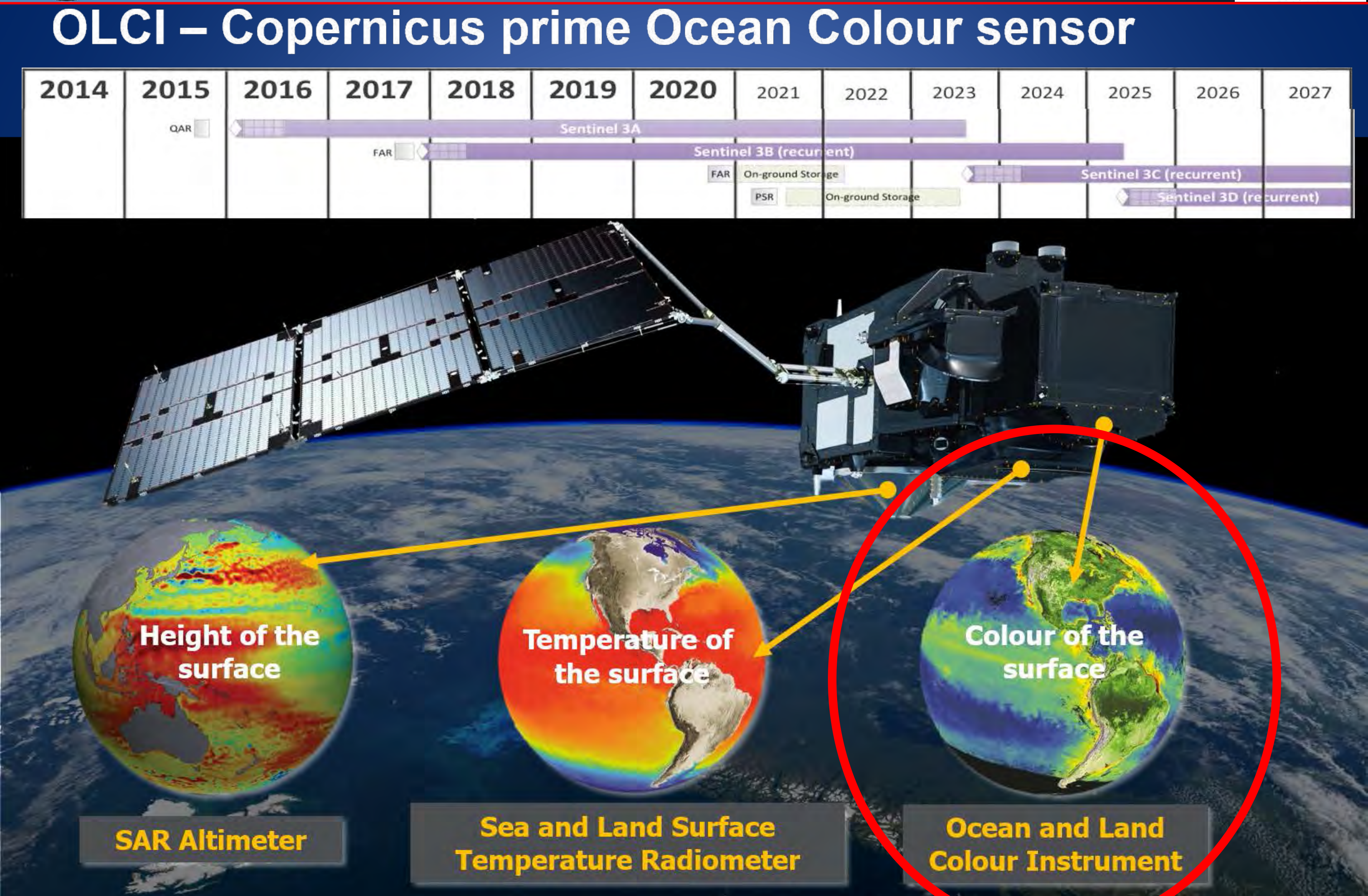
Space-based ocean color radiometry measurements are becoming increasingly mature and transitioning into routine and sustained operations (more on that in a bit…)

- 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

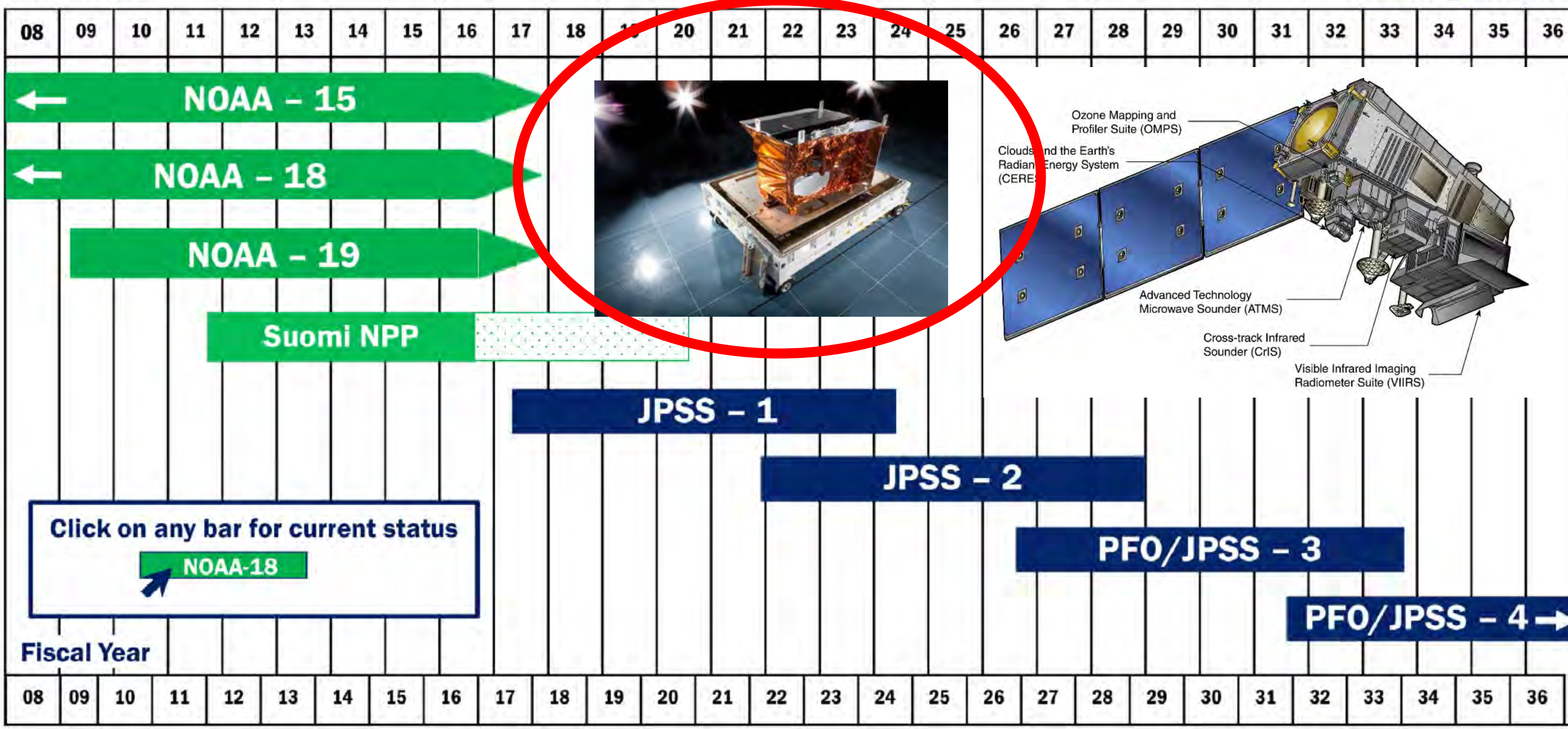


NOAA Polar Satellite Programs
Continuity of Weather Observations

VIIRS: early-afternoon acquisitions

Calendar Year

As of August 2016



Approved:

Assistant Administrator for Satellite and Information Services

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

In orbit and operating beyond design life

Launched before Jan 2008

Planned Mission Life, from Planned Launch Date

Planned Mission Life Beyond 2036

Fuel-Limited Lifetime Estimate

Challenge: Changing Perceptions

Operational = Near Real-Time

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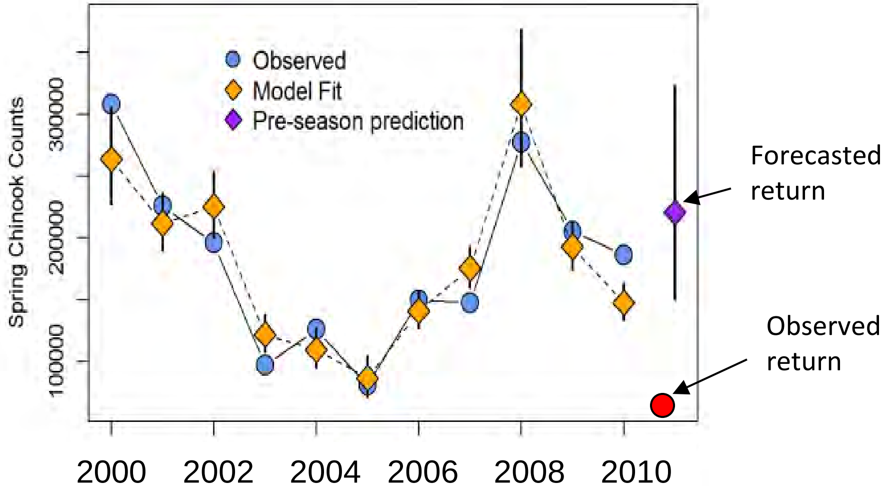
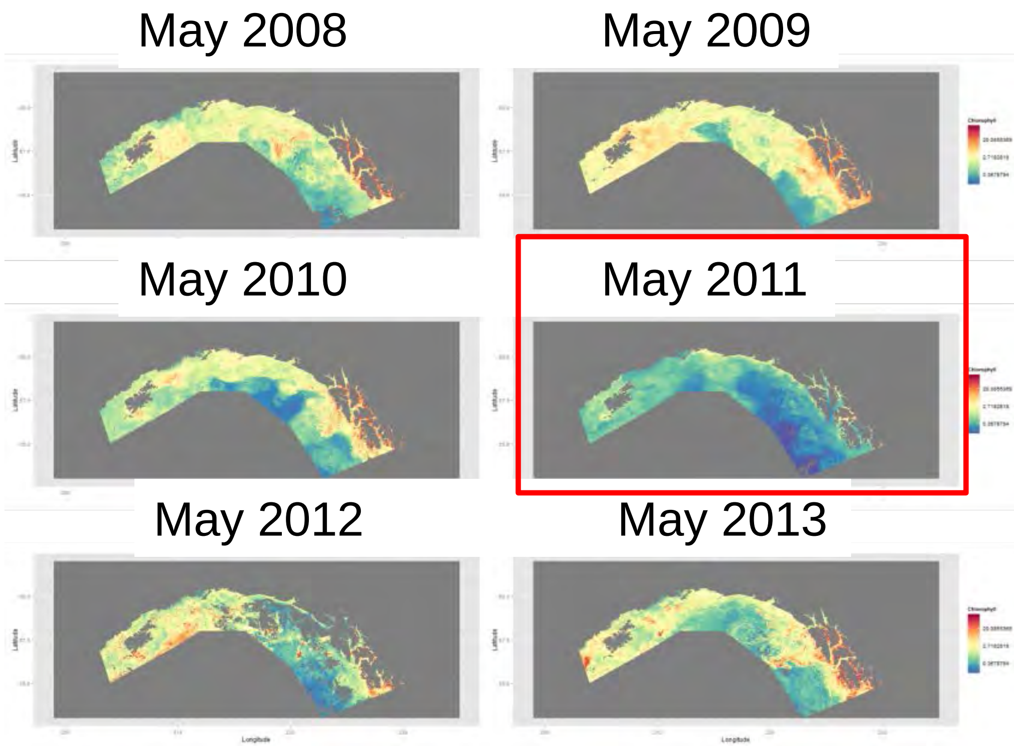
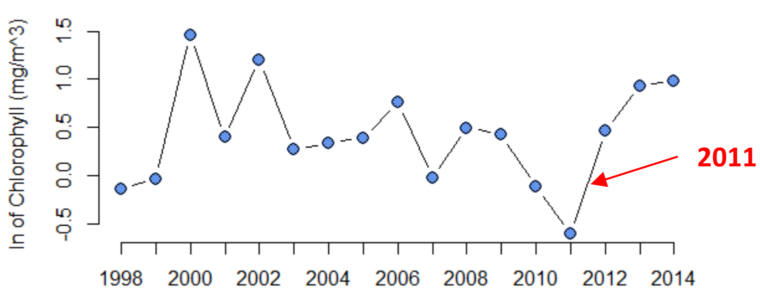
Operational (only) = Near Real-Time

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

Challenge: Changing Perceptions

→ 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….

Operational Definitions & Requirements

Q: What does operational mean?

Operational Definitions & Requirements

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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."

Operational Definitions & Requirements

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)

Operational Definitions & Requirements

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.

Operational Definitions & Requirements

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 Definitions & Requirements

- 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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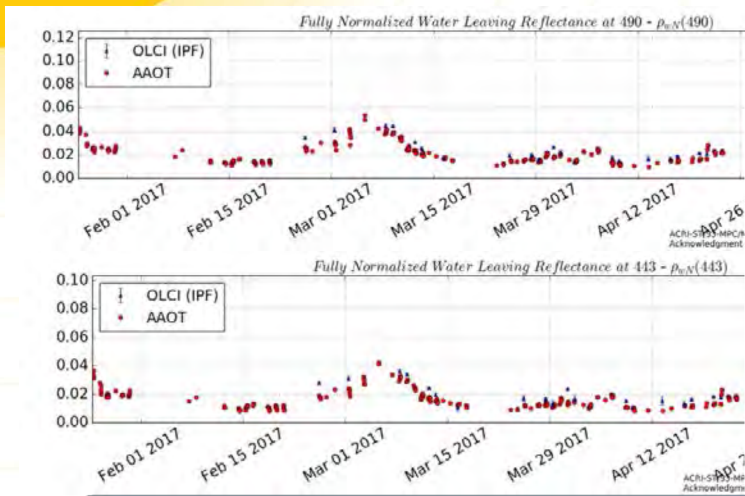
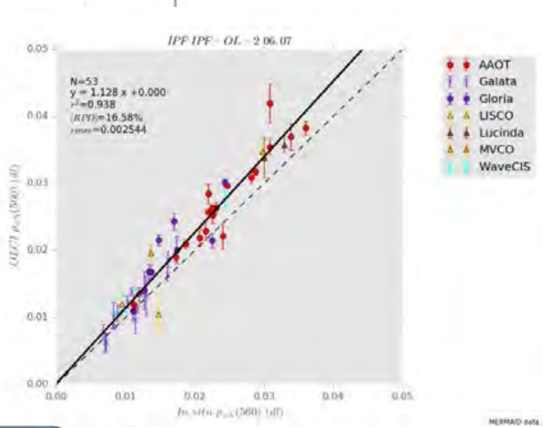
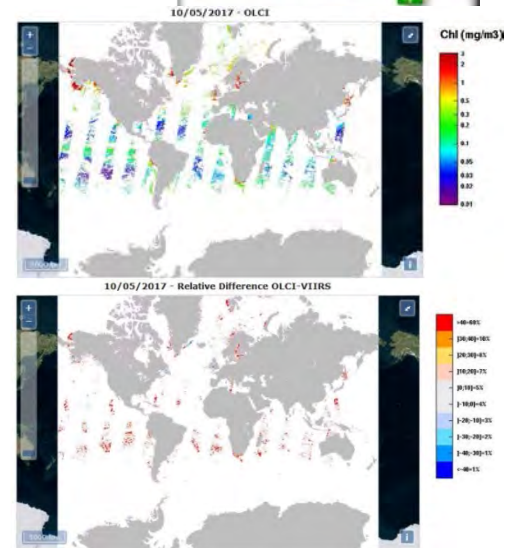
- Operational missions therefore need to implement and maintain integral supporting space-based and ground system infrastructure and associated scientific and technical activities, e.g.,
  - extensive pre-launch characterization,
  - calibration/validation,
  - on-orbit maneuvers,
  - life of mission 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



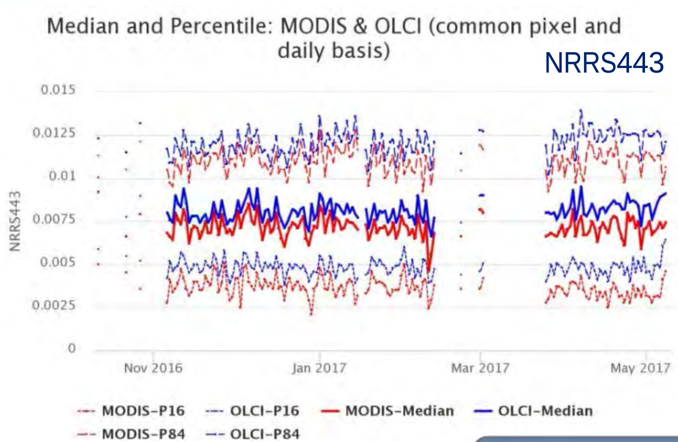


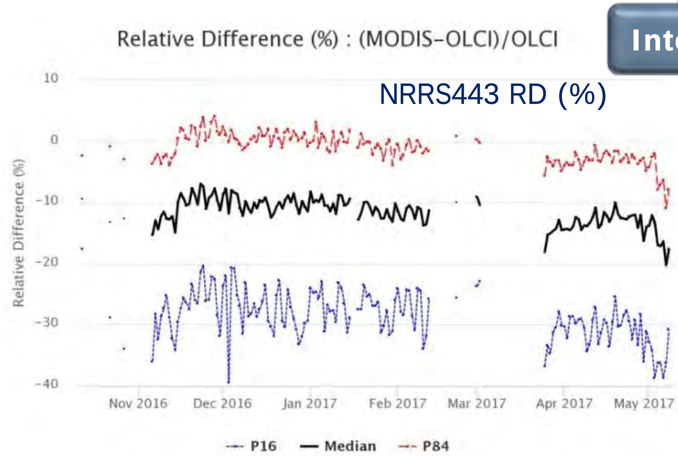


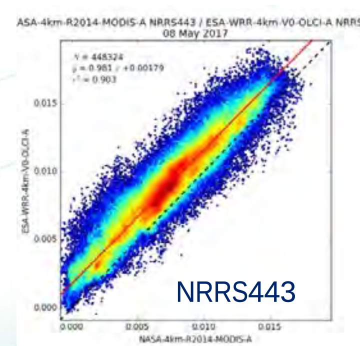
MERMAID Level 2 match-ups:

Time series, scatter plots and statistics

Inter-sensor comparisons at Level 3





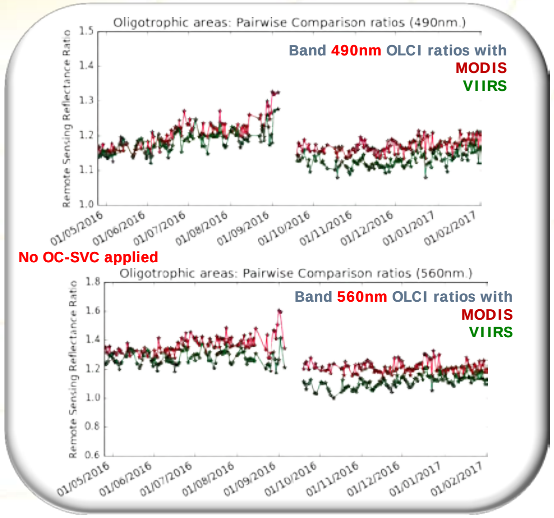


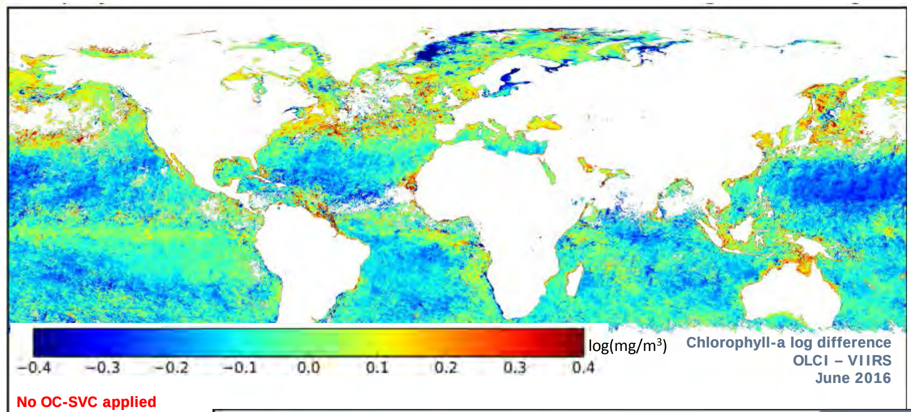
Inter-sensor time series and scatter plots

Operational validation tools and activities

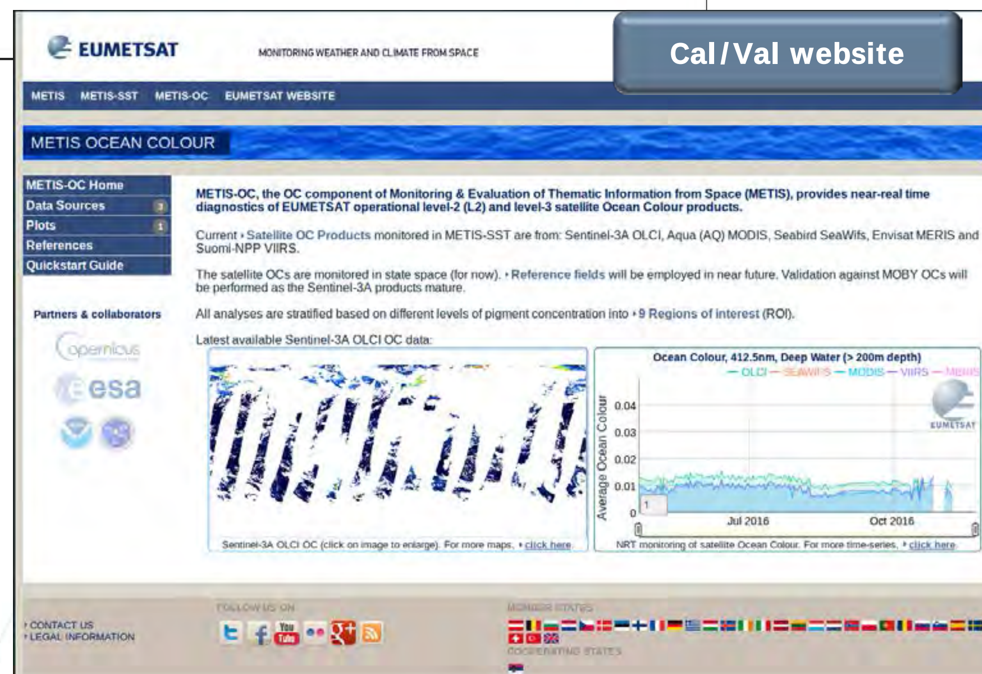
EUMETSAT

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

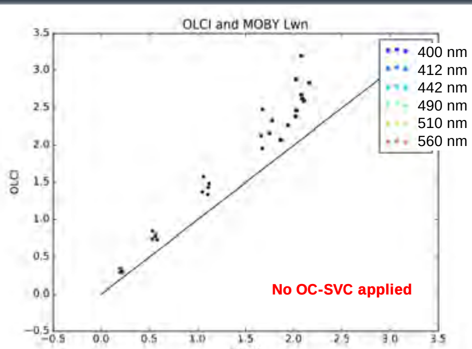




Cal/Val website



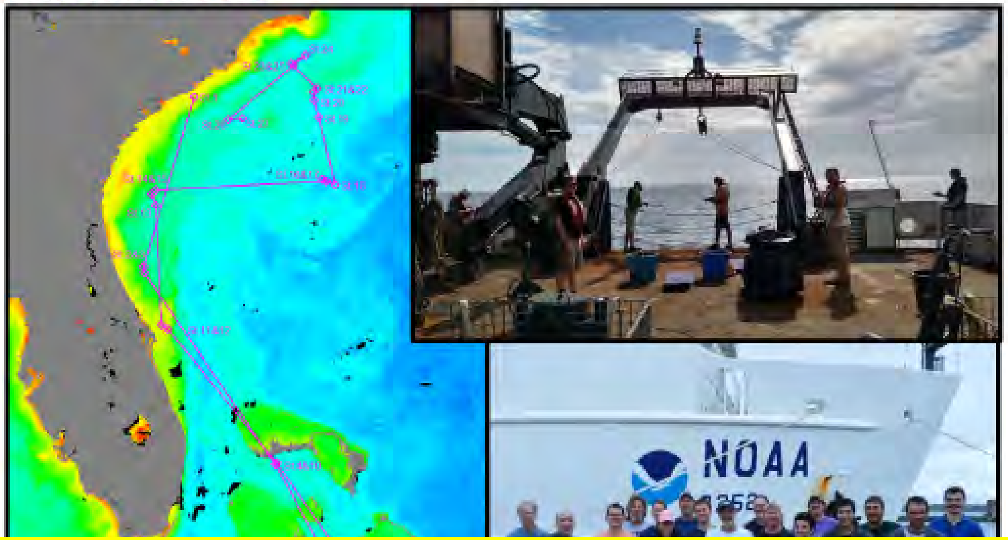
Level 2 in situ matchups with FRMs



NOAA Technical Report NESDIS 148

doi:10.7289/V5/TR-NESDIS-148

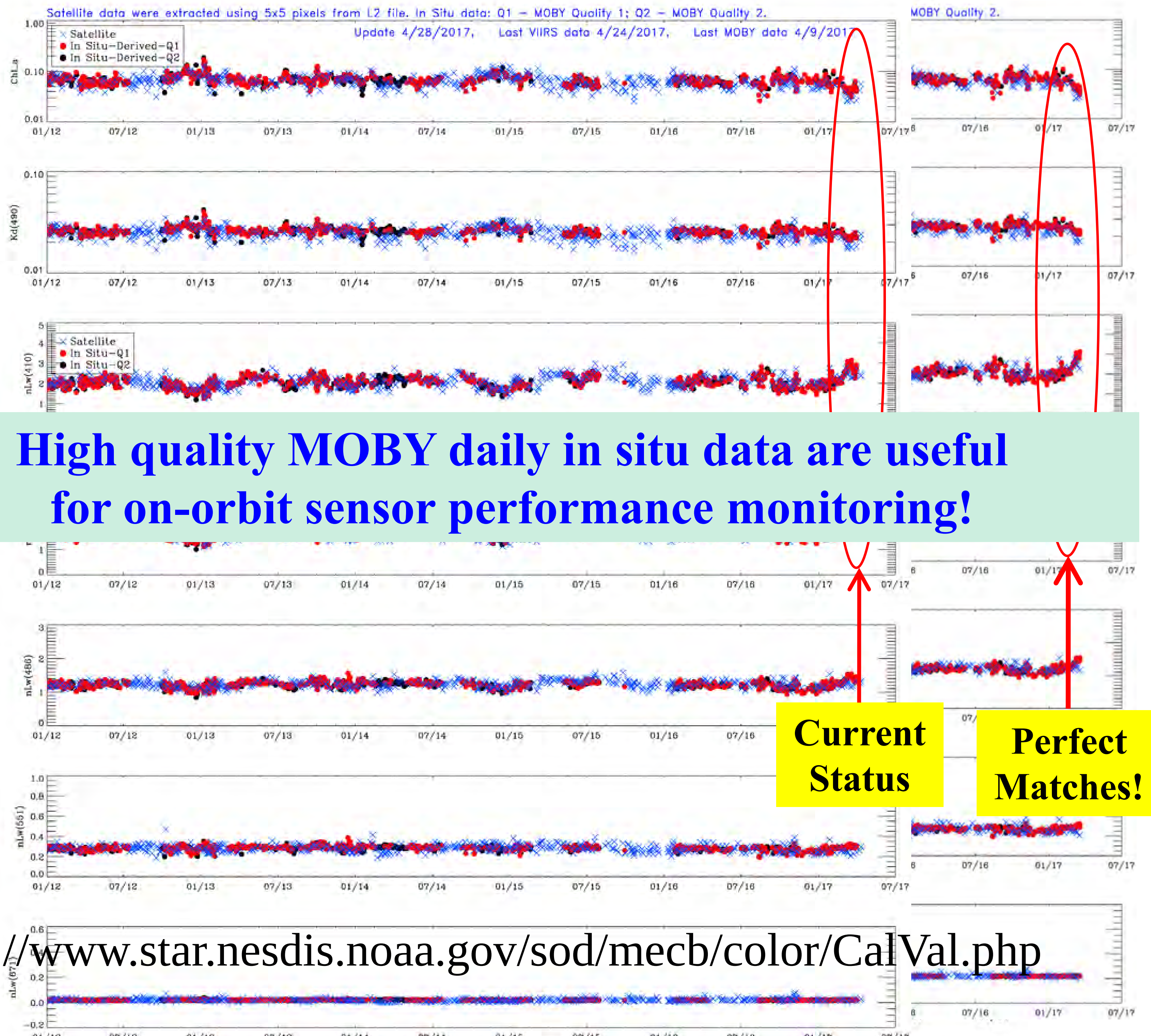
Report for Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise December 2015



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

Ondrusek, M., V. P. Lance, E. Stengel, M. Wang, R. Arnone, S. Ladner, W. Goode, R. Vandermeulen, S. Freeman, J. E. Chaves, A. Mannino, A. Gilerson, S. Ahmed, C. Carrizo, A. El-Habashi, R. Foster, M. Ottaviani, J. I. Goes, H. Gomes, K. McKee, C. Hu, C. Kovach, D. English, J. Cannizzaro, B. C. Johnson, Z. P. Lee, J. Wei, Q. Wang, J. Lin, N. Tufillaro, J. Nahorniak, C. O. Davis, and K. J. Voss, "Report for Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise December 2015," *NOAA Technical Report NESDIS 148*, V. P. Lance (ed.), NOAA National Environmental Satellite, Data, and Information Service, Silver Spring, Maryland, 2016. http://dx.doi.org/10.7289/V5/TR-NESDIS-148

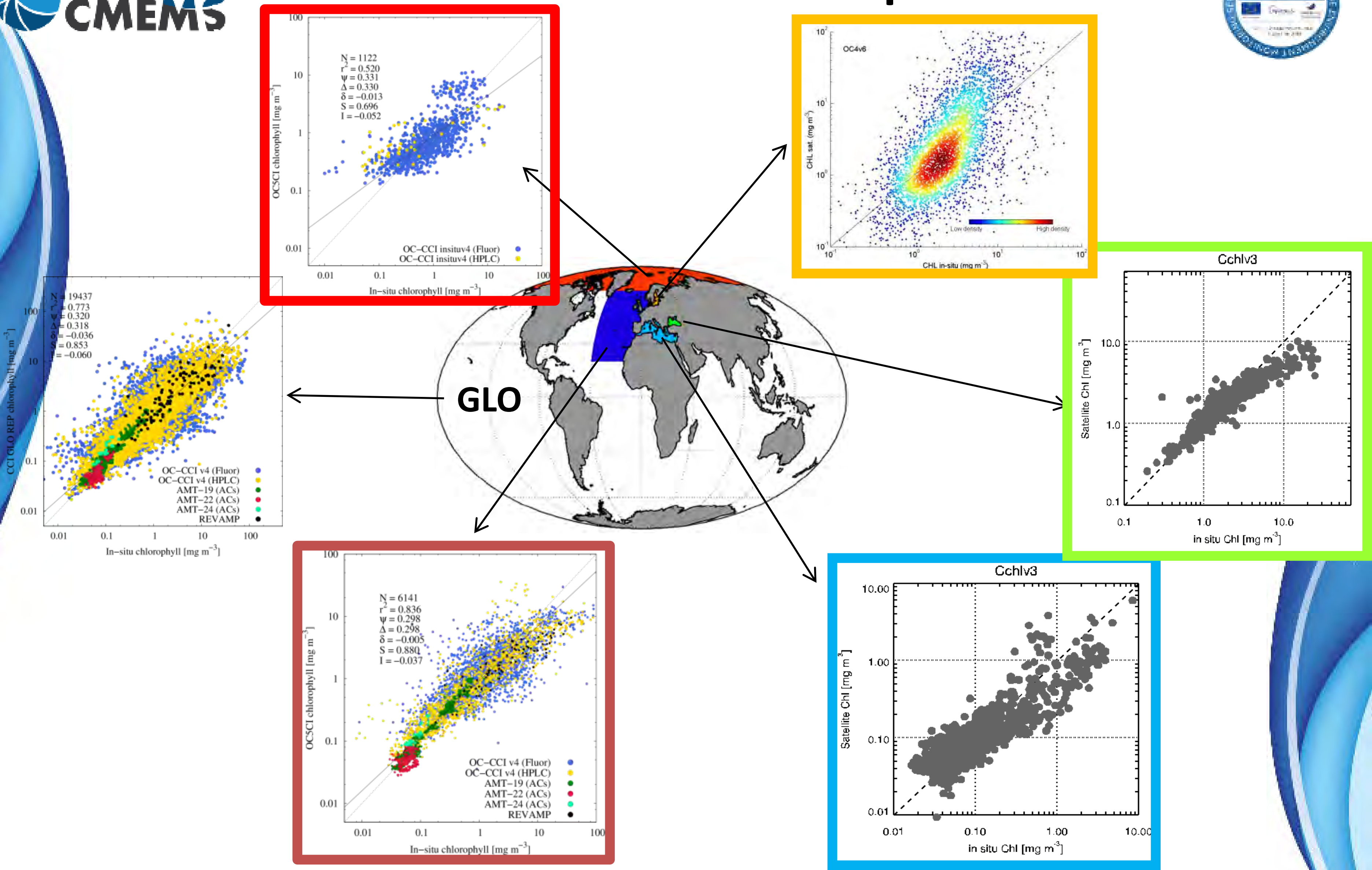
US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service



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

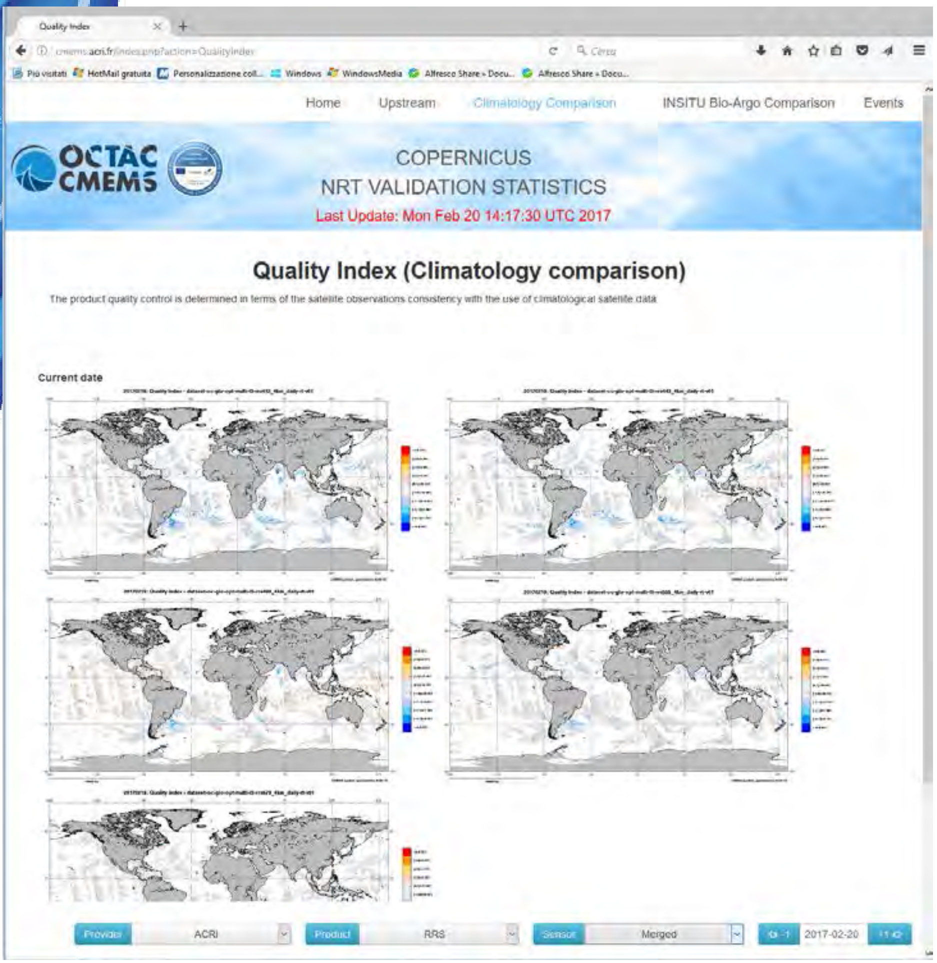
Assessment of the OC products

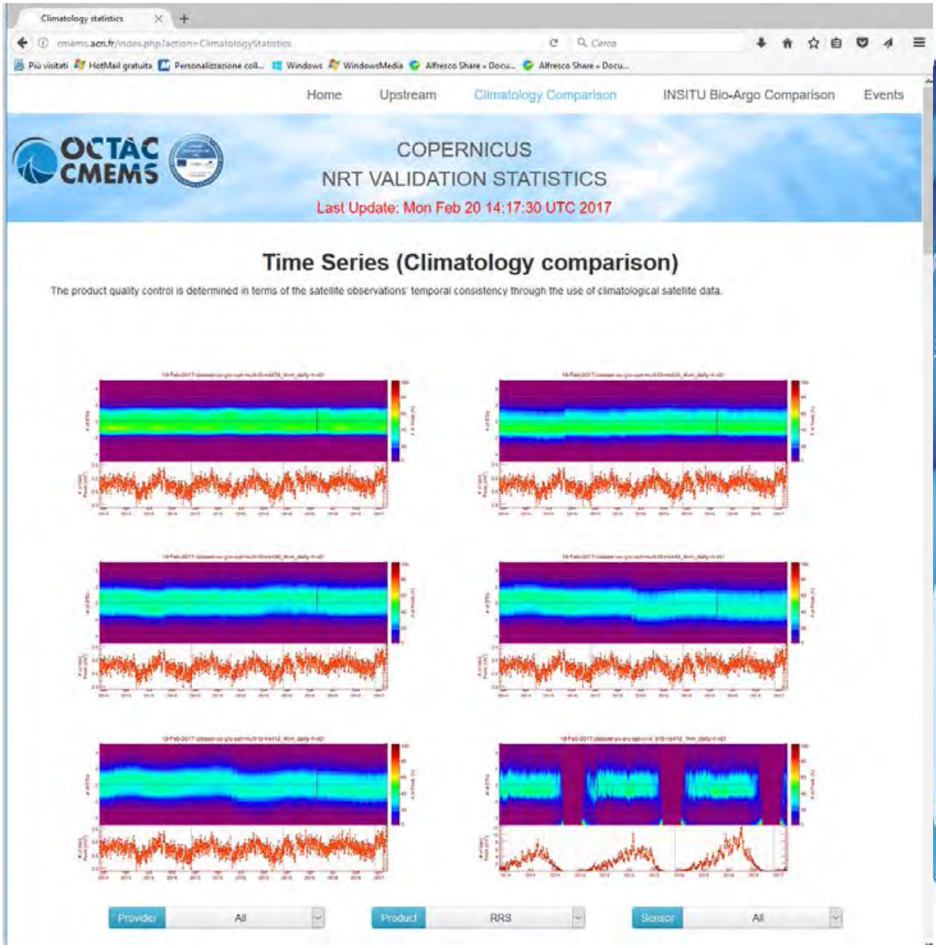


Download the Quality Information Document from the CMEMS website

NRT Quality Control in Operation

- inter-comparison between sensors and/or climatology
- computed operationally at daily basis

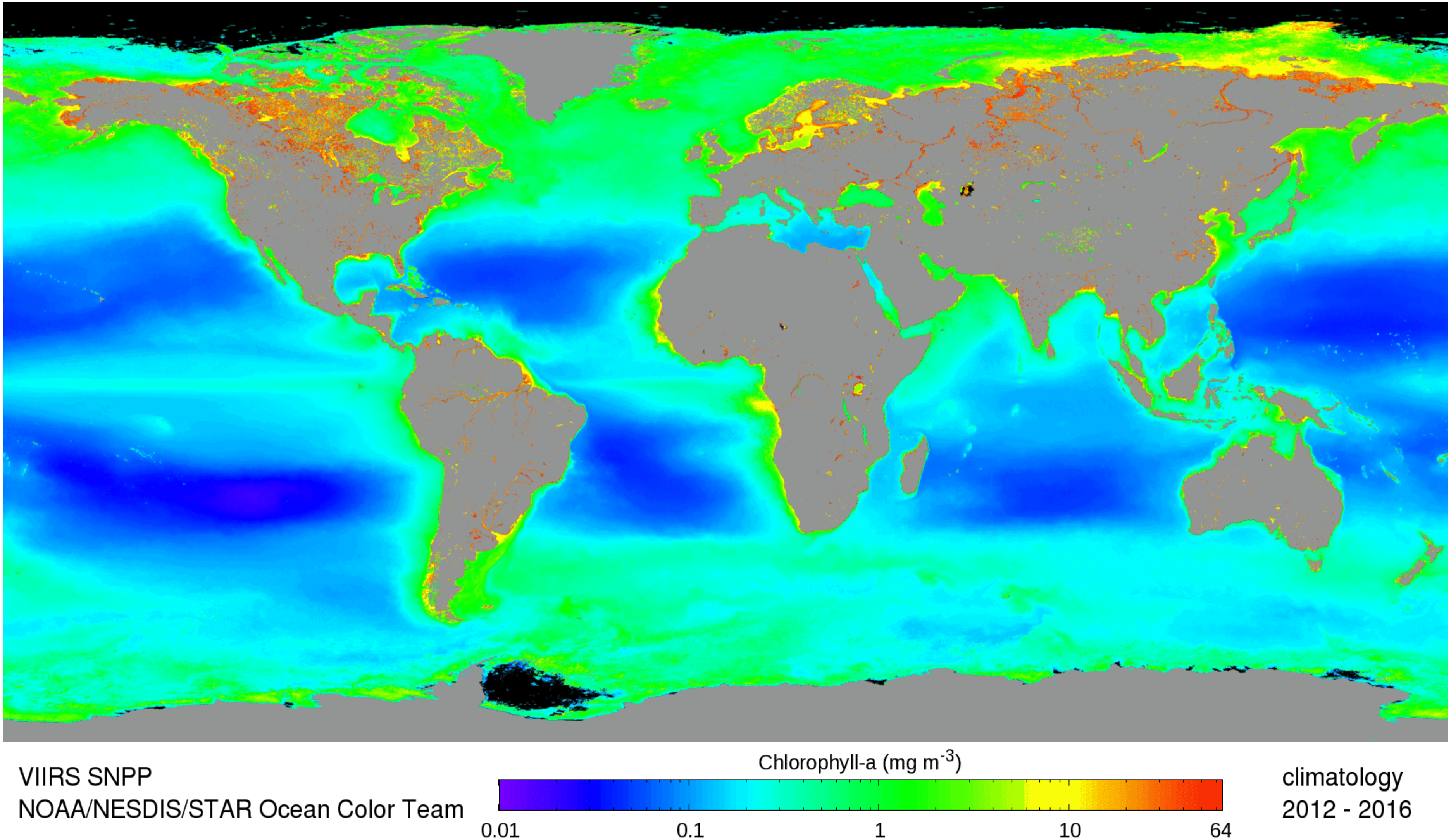




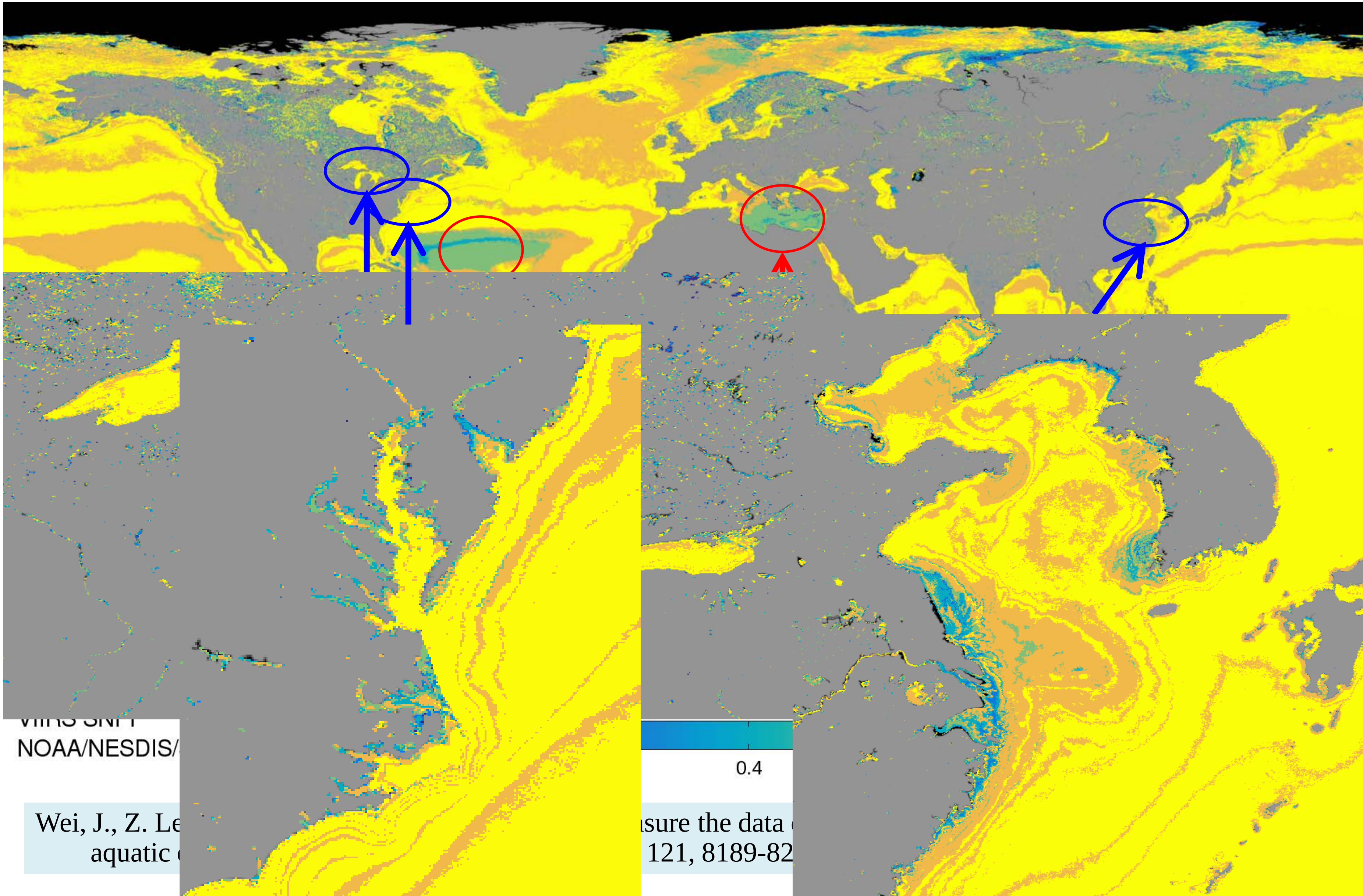
VIIRS NRT and Science Quality Ocean Color Data

Attribute	Near-Real Time	Delayed-Mode/Science-Quality
Latency:	Best effort, as soon as possible (~12-24h)	Best effort, on a 2-week delay
Processing System:	**MSL12**	**MSL12**
SDR:	**IDPS Operational SDR**	**OC-improved SDR**
Ancillary Data:	Global Forecast System (GFS) Model	Science quality (assimilated; GDAS) from NCEP
Spatial Coverage:	May be gaps due to various issues	Complete global coverage
Processed by:	CoastWatch, transferring to OSPO (operational) FY16	NOAA/STAR
Distributed by:	CoastWatch , OSPO	CoastWatch, NCEI
Archive Plans:	Yes, from OSPO to NCEI	Yes, from CoastWatch to NCEI
Full Mission Reprocessing:	No	Yes, every ~2-3 years or as needed

VIIRS Climatology Ocean Color Product Image (2012–2016)



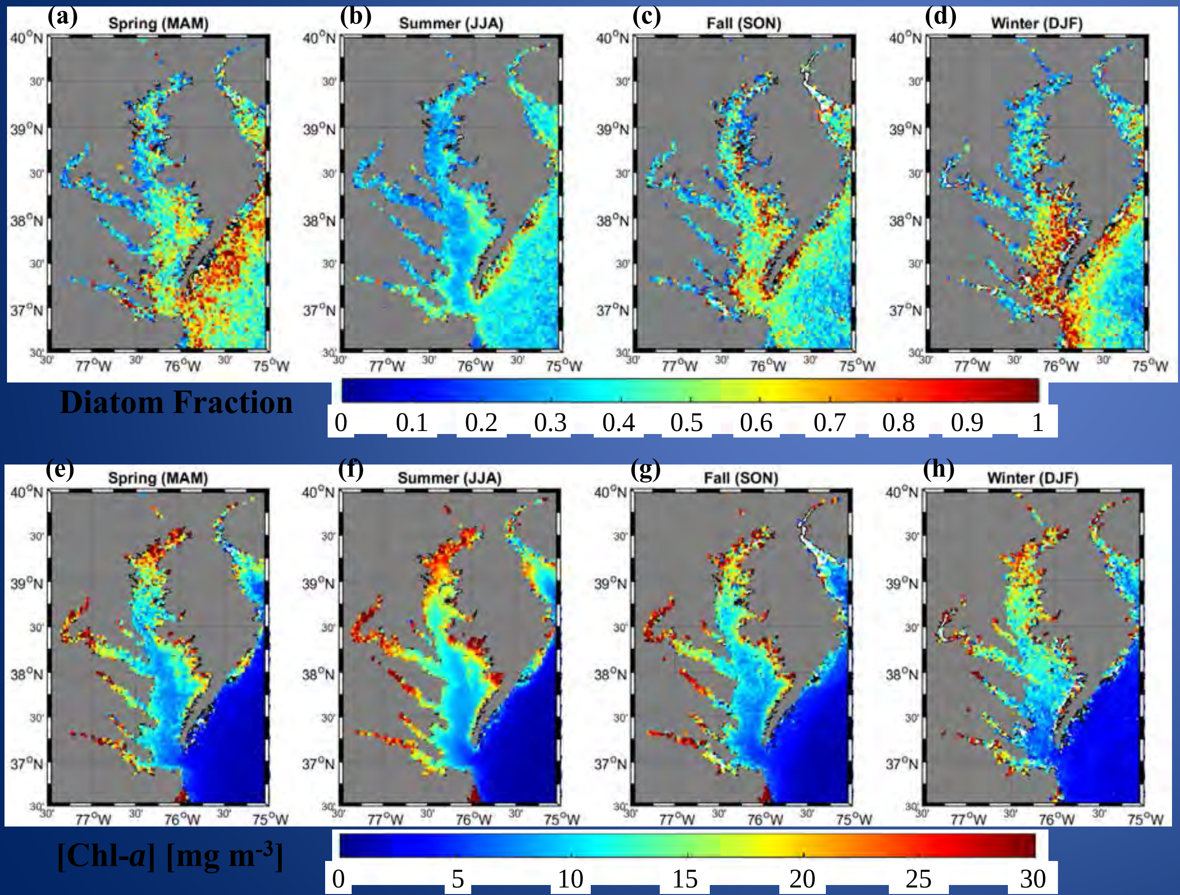
VIIRS Climatology $nL_w(\lambda)$ QA Score Image
(2012–2016)



Wei, J., Z. Le… …sure the data … aquatic … 121, 8189-82…

Product Research & Development Efforts

Phytoplankton community composition in the Chesapeake Bay observed with satellite-derived algal light absorption spectra



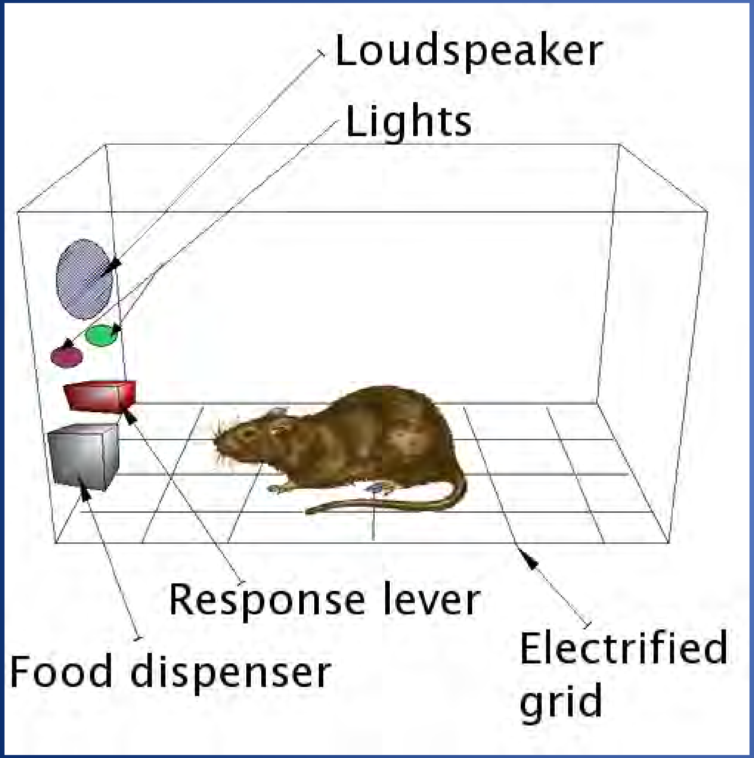
- Seasonal climatology of diatom fraction (**a**−**d**) and [Chl-*a*] (**e**−**h**) in the Chesapeake Bay derived from VIIRS data during the period of 2012−2016. The diatom fraction is calculated from GSCM-derived $a_{ph}(670)/a_{ph}(440)$ ratio
- The [Chl-*a*] is calculated based on GSCM-derived $a_{ph}(670)$

G. Zheng and P. DiGiacomo, under review

Don't let perfect be the enemy of the good (~Voltaire)

Enabling & Facilitating use of Ocean Color Data

The Skinner Box



Make it simple. Make sure there is a payoff.

Enabling & Facilitating use of Ocean Color Data

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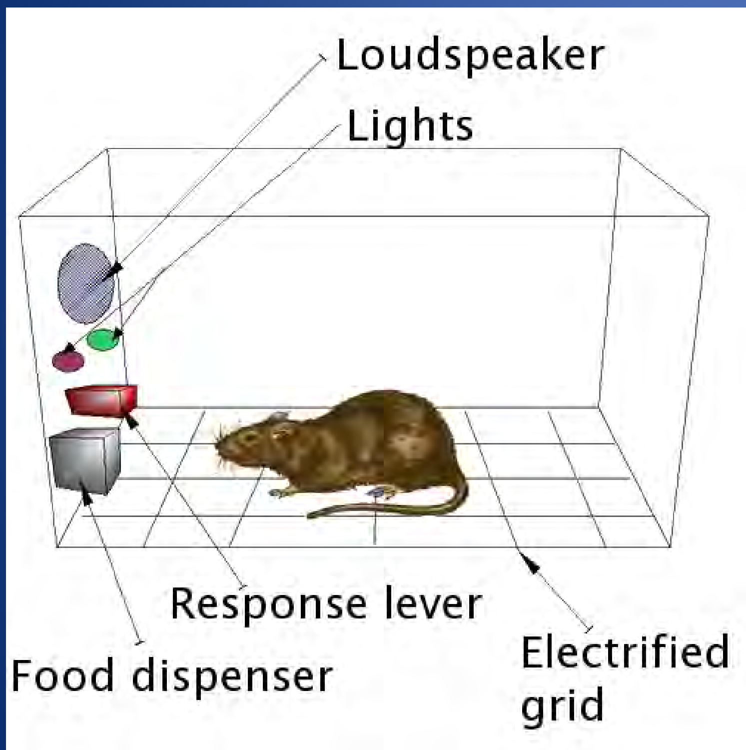

The Bernard Box

Make it simple. Make sure there is a payoff.
But a little "bling" does not hurt either!

Enabling & Facilitating use of Ocean Color Data

Perspectives on addressing user needs (courtesy of a NOAA line office user):

Enabling & Facilitating use of Ocean Color Data

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2. Remote sensors know what they can produce, but they don't usually know what users need.

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

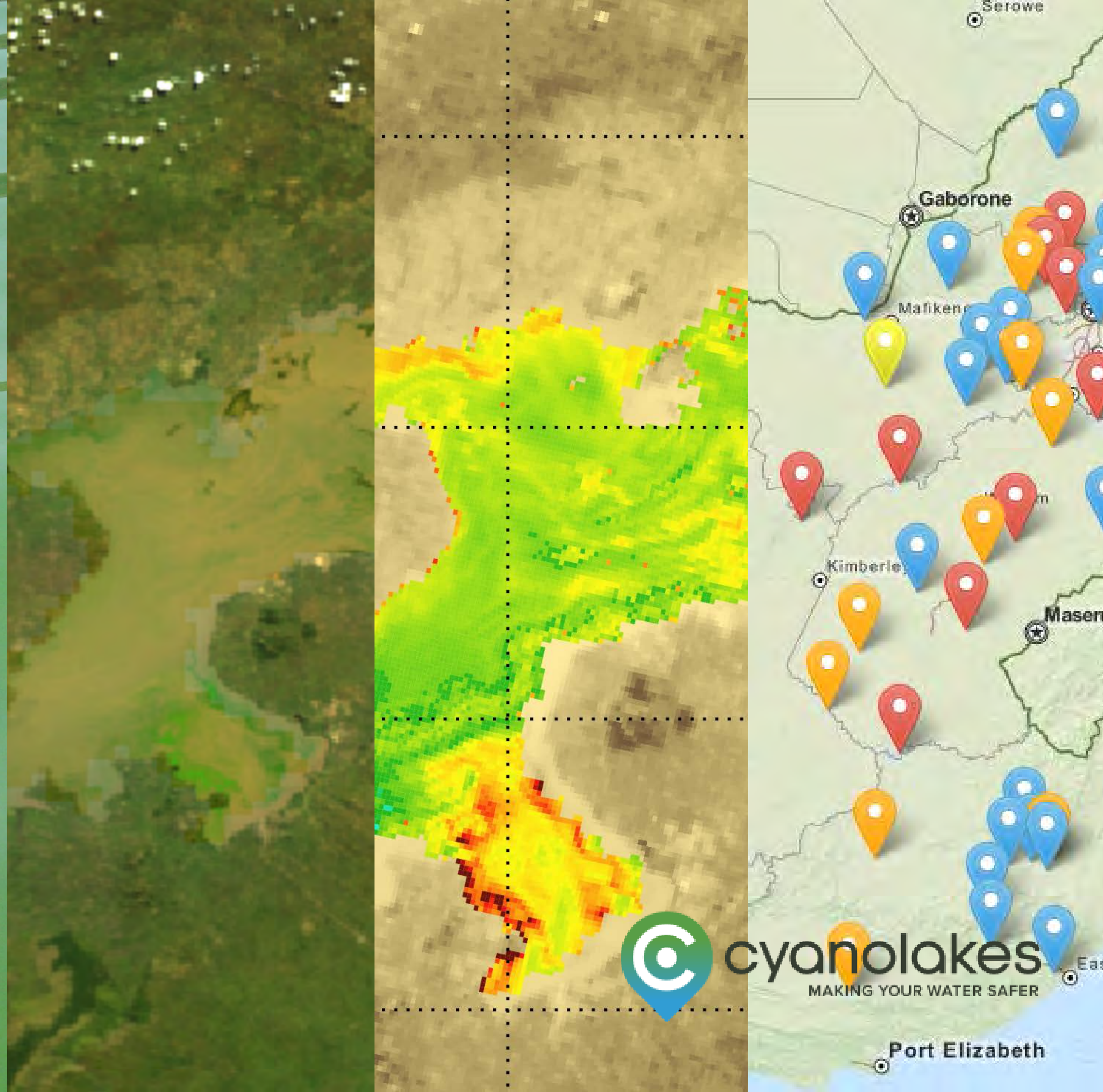
Diagnose problem

Measure from satellite

Apply relevant guidelines

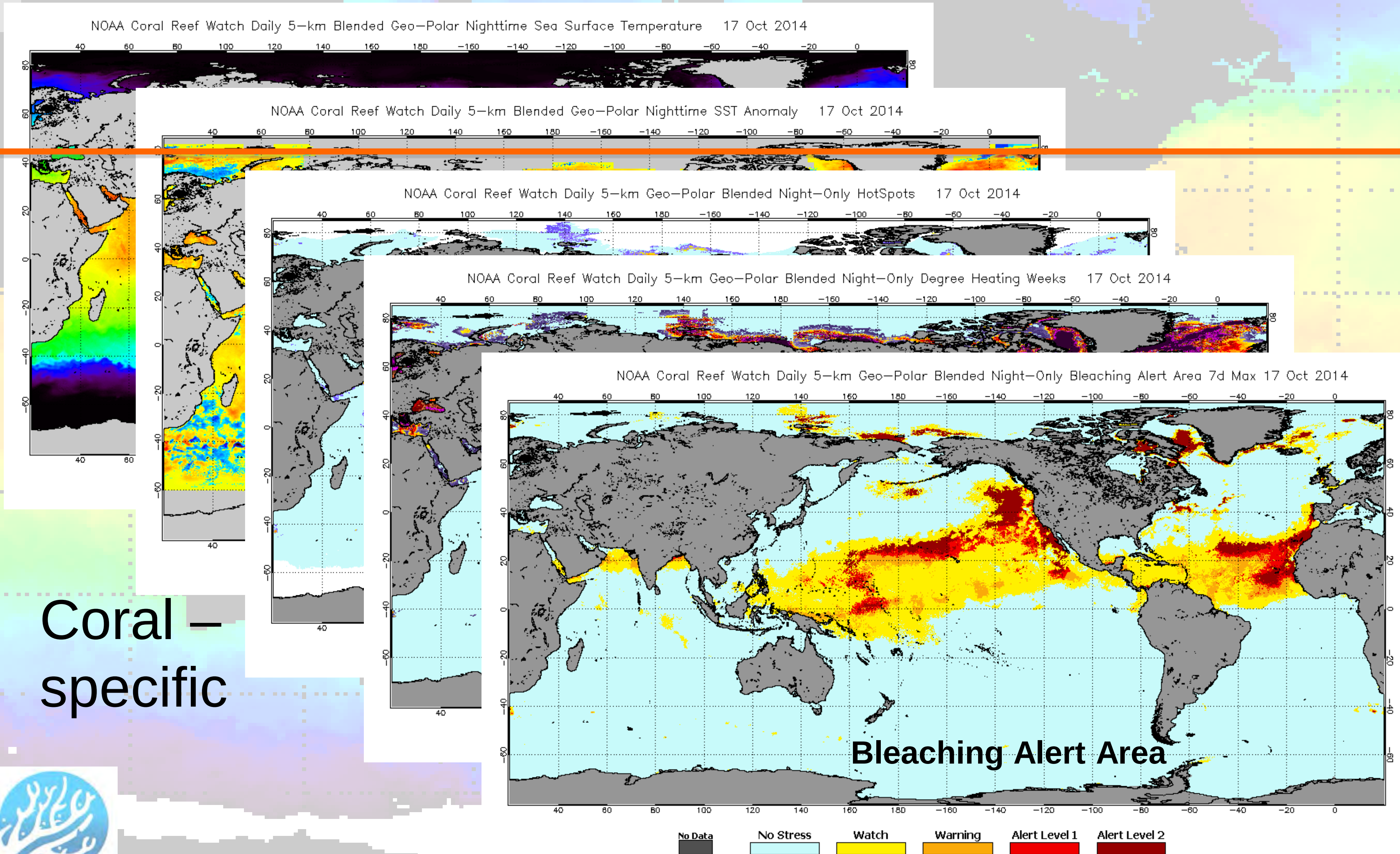
Inform decision makers and general public

Recommend safety for use



Coral Reef Watch
5-km Satellite-Based Products

Coral – specific

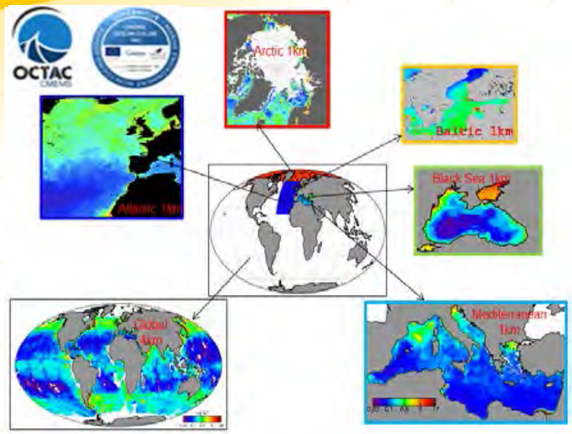


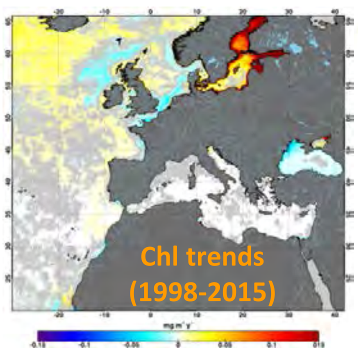
http://coralreefwatch.noaa.gov

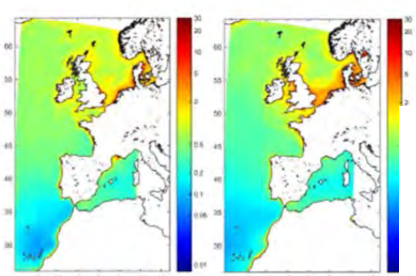
Enabling & Facilitating use of Ocean Color Data

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

Copernicus Marine Environment Monitoring Service







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

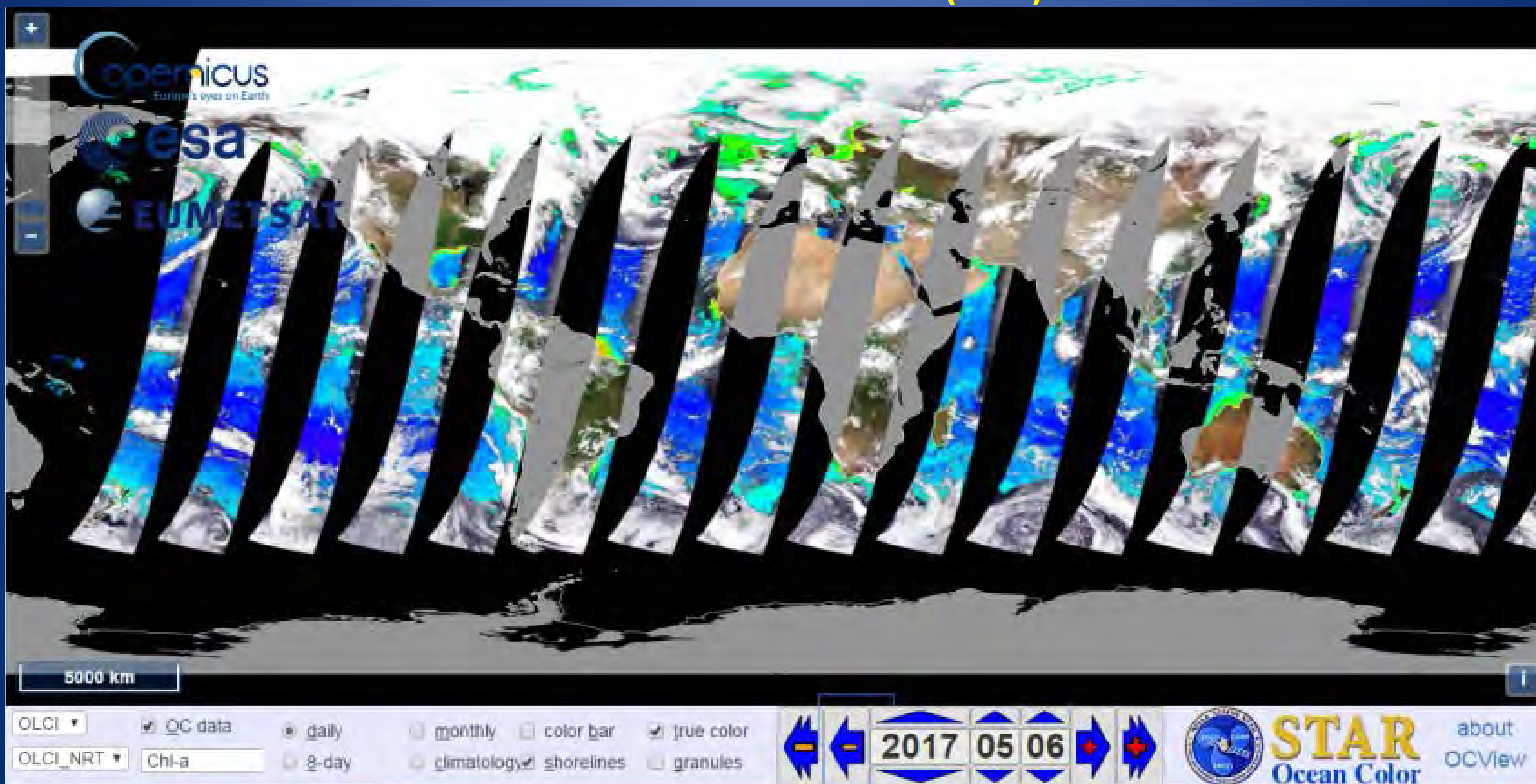
Dissemination of OLCI data in CMEMS:

- **single sensor OLCI L3 regional and global product**s
- 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:

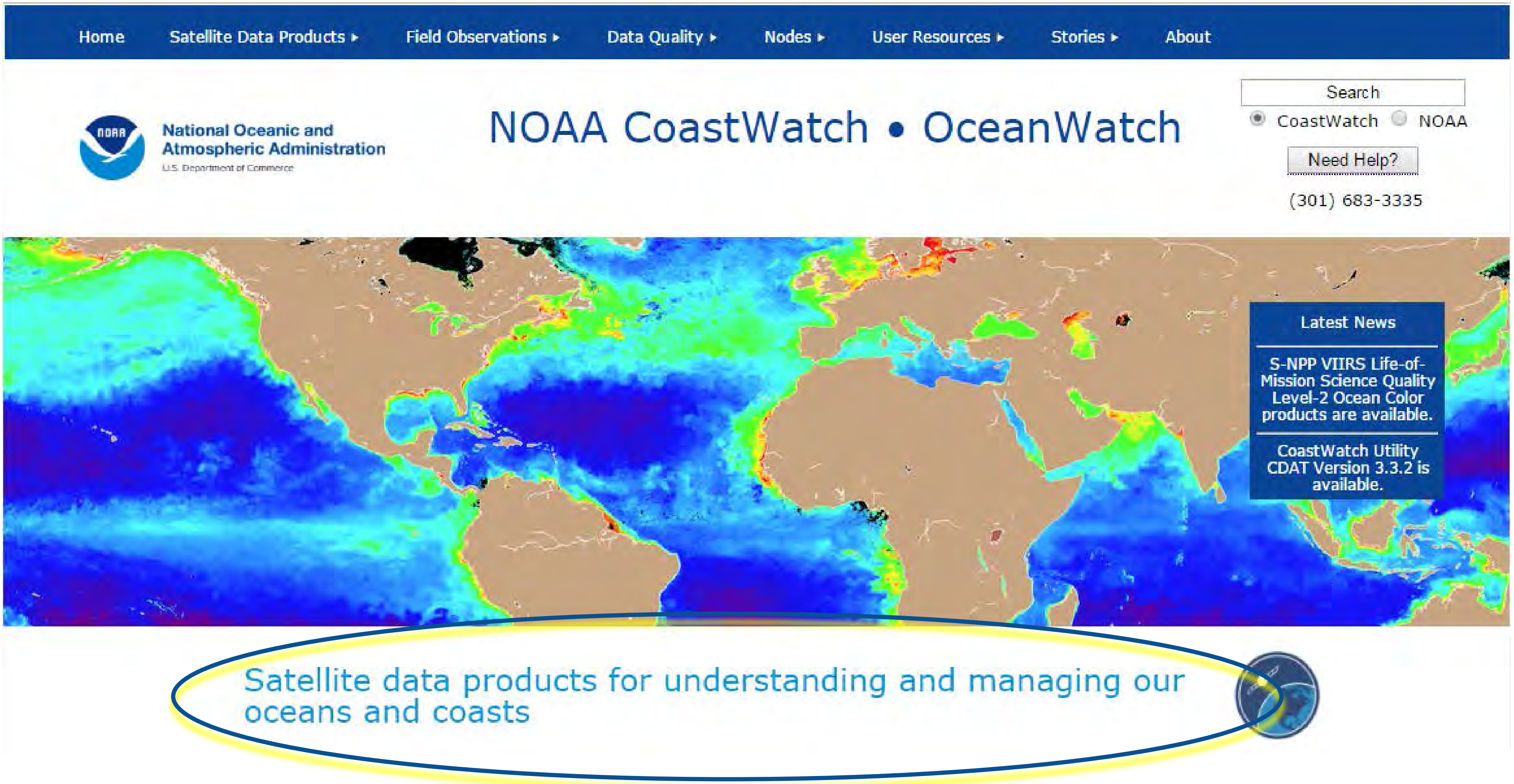
- **Modelling quality assessment and data assimilation**
- **Indicators** to monitor the **marine environment** (eg. MSFD)

NOAA STAR Ocean Color (OC) Viewer



https://www.star.nesdis.noaa.gov/sod/mecb/color/about_ocview.php

CoastWatch.NOAA.gov



NOAA Ocean Satellite Course

Aug 22-24, 2017
UW, Seattle, WA

•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.

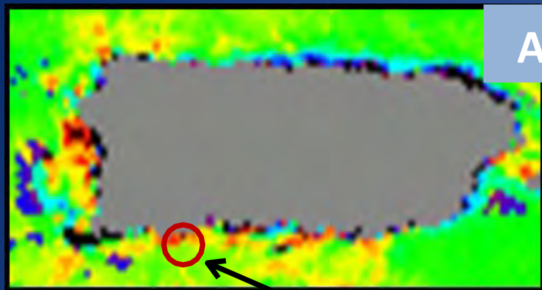
•Course initiated by funding from NOAA’s R&O project in 2006. The JPSS program has provided full or partial funding since 2013-2015.

•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.

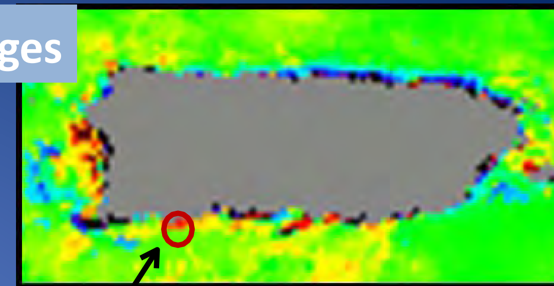
http://coastwatch.pfeg.noaa.gov/courses/satellite_course2017.html

Facilitating use of ocean color data by Coral Reef Managers

Aug 2014 Anomaly Images

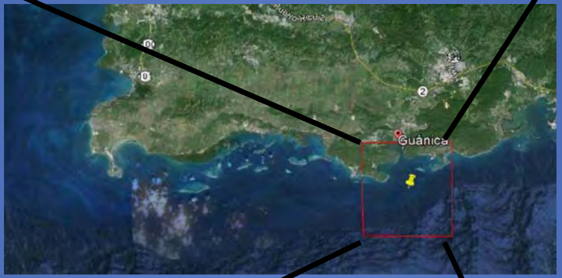


K_d(490) anomaly



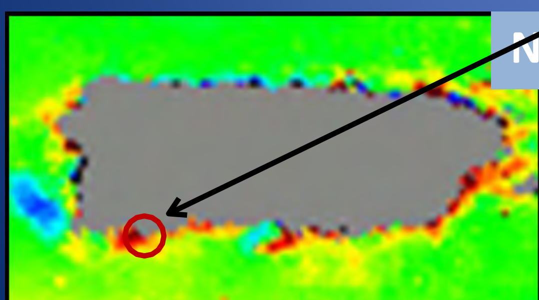
Chl-*a* anomaly

Comparing monthly imagery of K_d(490) and Chl-*a* against the expected **Normal levels (mean)**



Red Box (circle) = Target A Guánica Watershed Outfall Puerto Rico, USA

Nov 2014 Anomaly Images



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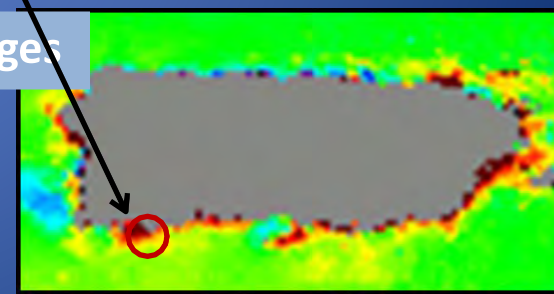


Chl-*a* anomaly

- 0.05 0 0.05

K_d(490) (m^{-1})

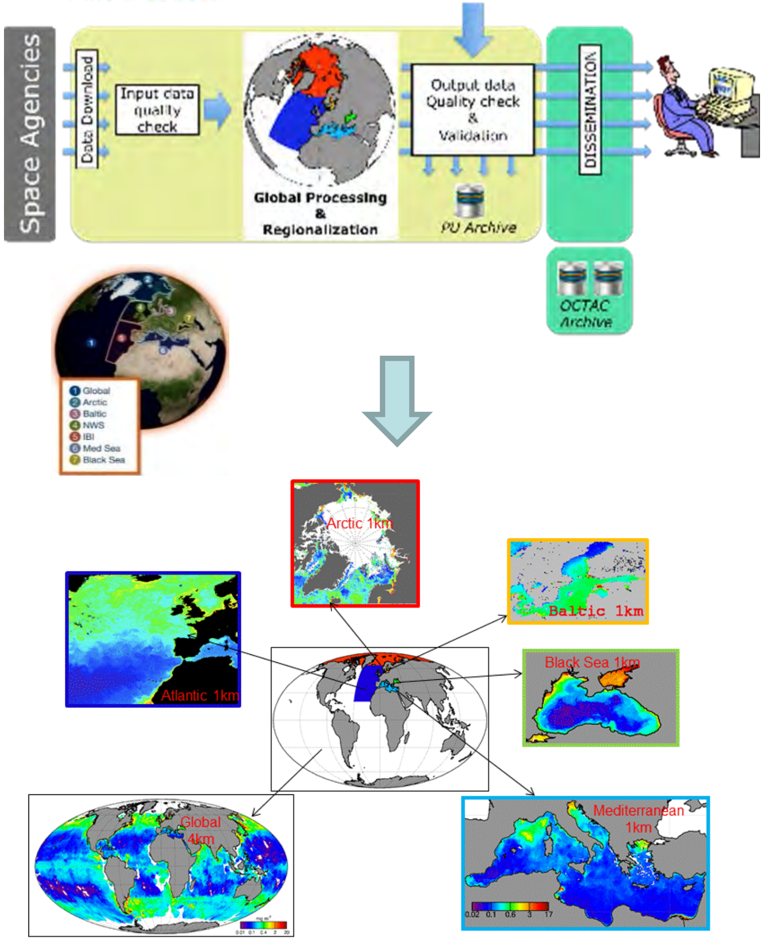
- 0.5 0 0.5

Chl-*a* (mg/m^3)

Enabling & Facilitating use of Ocean Color Data

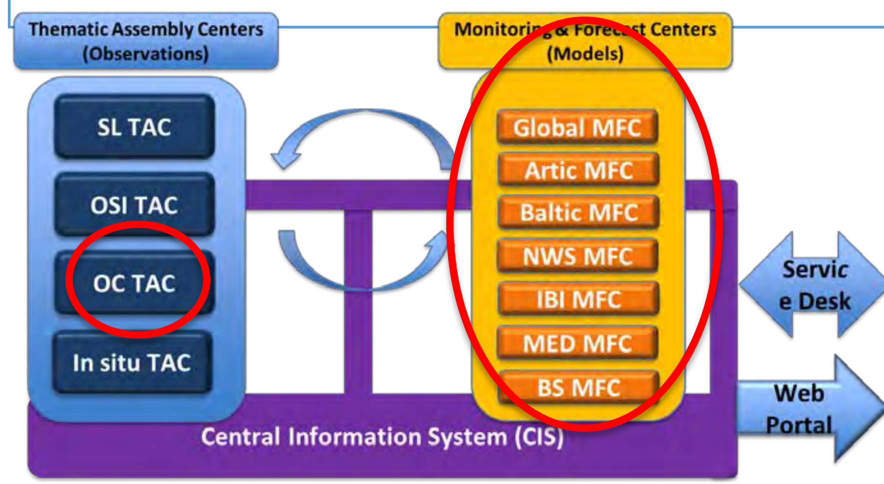
End-to-End Value Chain in Support of User Needs

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 (eg. MSFD)
- Indicators to monitor for management of marine resources
- **Ocean State Report**



European Commission | Copernicus Europe's eyes on Earth | MERCATOR OCEAN | OCTAC

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

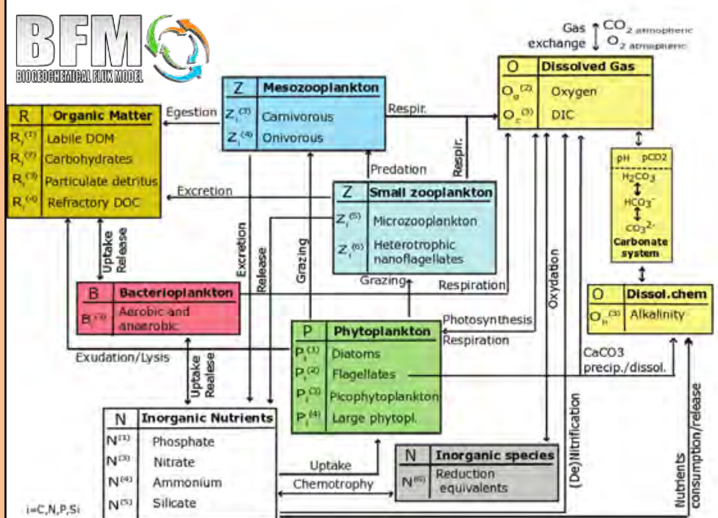
Initial Conditions
MEDAR/MEDATLAS and 5-y hindcast spin-up + 17-y reanalysis

BIOGEOCHEMICAL MODEL
(resolution: 1/16°, 72z levels)

OGSTM - transport model

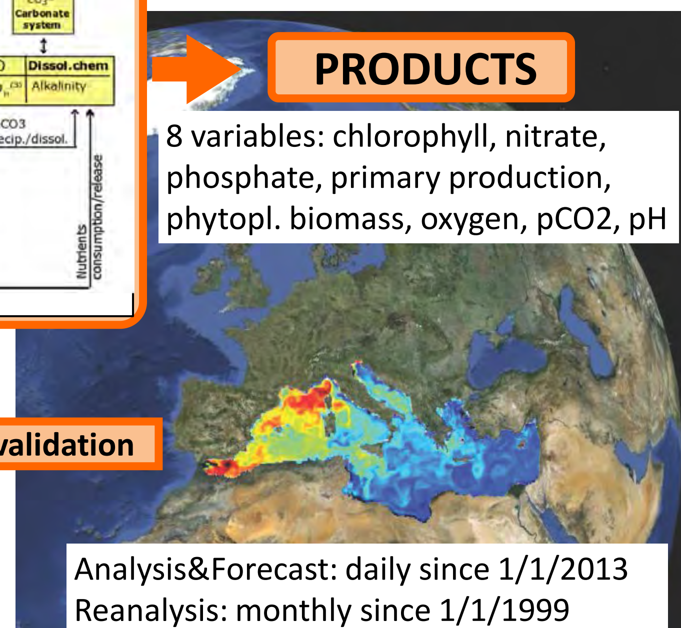
Biogeochemical Flux Model – BFM

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

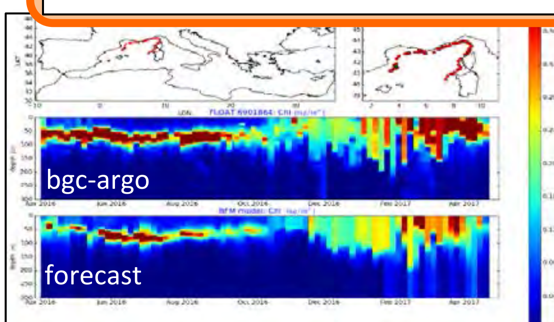


PRODUCTS

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

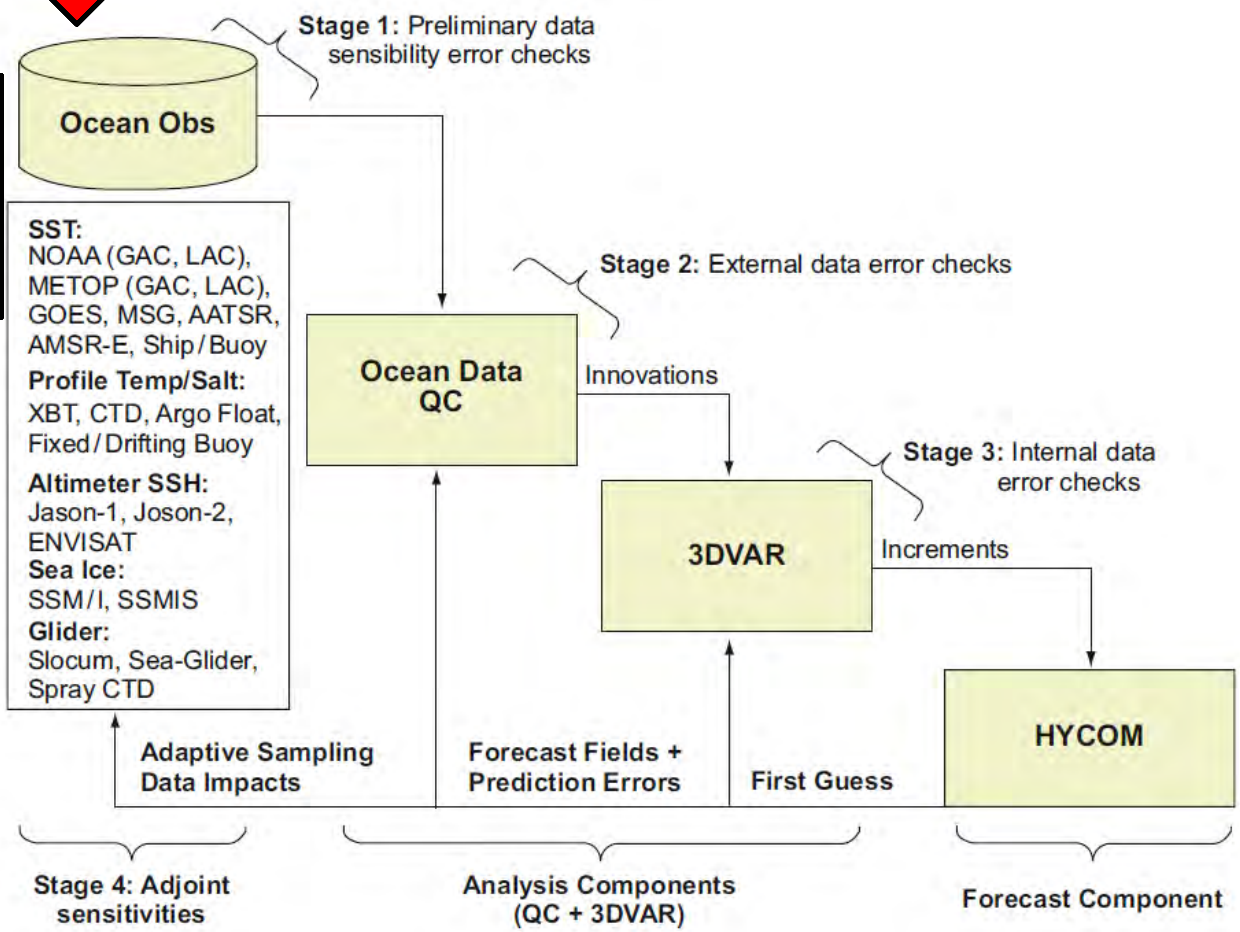


Ocean Data Assimilation

(Navy Coupled Ocean Data Assimilation: NCODA)

Hae-Cheol Kim, NWS/NCEP

VIIRS
NRT
Ocean Color
(K_{dPAR}, Chl-*a*)



Enabling & Facilitating use of Ocean Color Data

Experimental
Lake Erie Harmful Algal Bloom Bulletin
2011-019
13 October 2011
National Ocean Service
Great Lakes Environmental Research Laboratory
Last bulletin: 29 September 2011

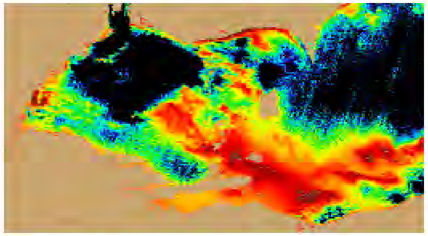


Figure 1. MERIS image from the European Space Agency. Imagery shows the spectral shape at 681 nm from October 11, where colored pixels indicate the likelihood of the last known position of the *Microcystis* spp. bloom (with red being the highest concentration). *Microcystis* spp. abundance data from shown as white squares (very high), circles (high), diamonds (medium), triangles (low) , + (very low) and X (not present).

Conditions: A large *Microcystis* bloom persists in Lake Erie, extending well past Cleveland to the east.

Analysis: Satellite imagery from Tuesday (10/11) indicates that the *Microcystis* bloom has now extended well past Cleveland to the east, and remains offshore. The eastern extent is just past Fairport Harbor. The bloom also hugs the northen shore in Ontario, to the Rondeau Provincial Park region. The forecast over the next three days indicates that the bloom will continue moving eastward as far as Geneva on the Lake, but will remain offshore. However, the northern portion of the bloom will dissipate. The wind stress is expected to increase dramatically on Oct 14, and will likely cause the surface bloom to decrease as mixing occurs. Water temperatures continue to remain stable.

NOTE: Please see pages 3 and 4 of this bulletin, as they show the MERIS image from 10/11/2011 (page 3) for the whole lake and the forecast for 10/16/2011 (page 4).

-Tomlinson, Wynne

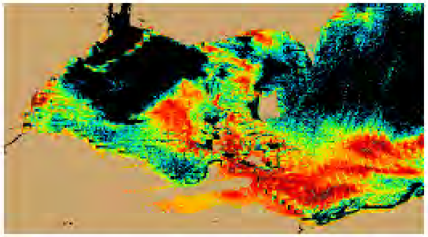


Figure 2. Nowcast position of *Microcystis* spp. bloom for October 13 using GLCFS modeled currents to move the bloom from the October 11 image.

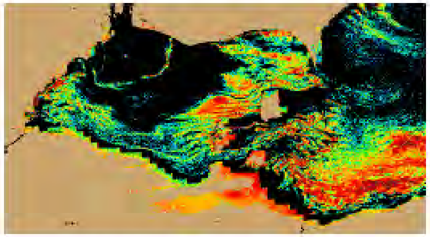


Figure 3. Forecast position of *Microcystis* spp. for October 16 using GLCFS modeled currents to move the bloom from October 11 image.

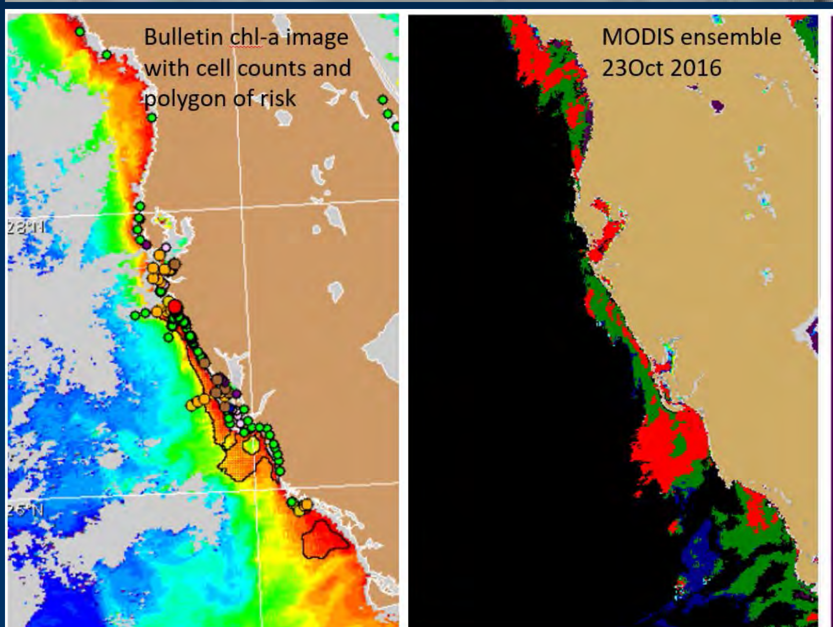
Please note:
- MERIS imagery was distributed by the NOAA CoastWatch Program and provided by the European Space Agency
- http://www.glerl.noaa.gov/res/Centers/HABS/lake_erie_hab/lake_erie_hab.html
- Cell counts were collected by the Great Lakes Environmental Research Laboratory
- The wind data is available through the National Data Buoy Center and the National Weather Service
- Modeled currents were provided through the Great Lakes Coastal Forecasting System

1

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*



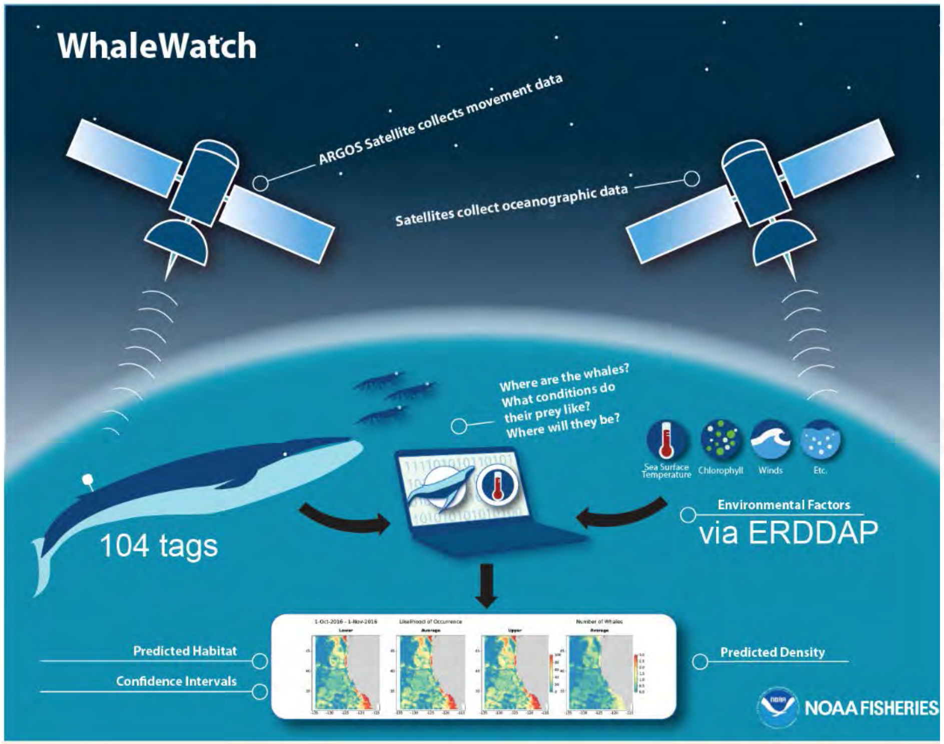
Gulf of Mexico Harmful Algal Bloom Bulletin
Region: Southwest Florida
Monday, 24 October 2016
NOAA National Ocean Service
NOAA Satellite and Information Service
NOAA National Weather Service
Last bulletin: Thursday, October 20, 2016

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



Journal of Applied Ecology

BRITISH ECOLOGICAL SOCIETY

Journal of Applied Ecology 2016 doi: 10.1111/1365-2664.12820

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**[4], **Aimee L. Hoover**[6], **Ladd Irvine**[3], **Monica DeAngelis**[7], **Steven J. Bograd**[1], **Bruce R. Mate**[3] **and Helen Bailey**[6]

[1]*Environmental Research Division, NOAA Southwest Fisheries Science Center, Monterey, CA 93940, USA;* [2]*Department of Ecology and Evolutionary Biology, University of California Santa Cruz, Santa Cruz, CA 94023, USA;* [3]*Marine Mammal Institute, Oregon State University, Hatfield Marine Science Center, Newport, OR 97365, USA;* [4]*Marine Mammal and Turtle Division, NOAA Southwest Fisheries Science Center, Santa Cruz, CA 95060, USA;* [5]*NOAA Pacific Islands Fisheries Science Center, Honolulu, HI 96818, USA;* [6]*Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, MD 20688, USA; and* [7]*NOAA 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 key 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 operationalize 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 8-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

Dead whale

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.

GROUP ON EARTH OBSERVATIONS

AquaWatch
The GEO Water Quality Community of Practice

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.

User needs → Data → Products → Information → Knowledge

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

GROUP ON EARTH OBSERVATIONS

AquaWatch
The GEO Water Quality Community of Practice

About GEO Blue Planet

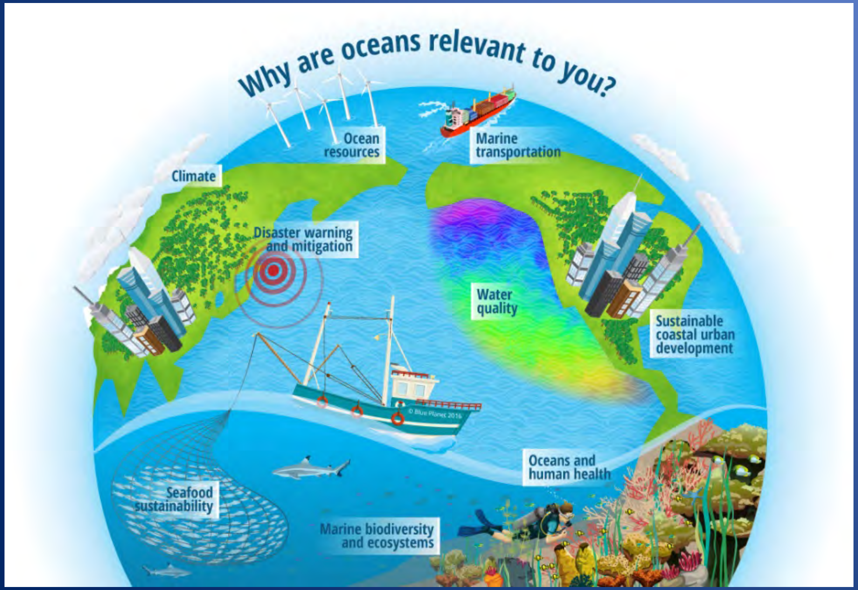
- Oceans and Society: Blue Planet is an Initiative within the Group on Earth Observations

http://geoblueplanet.com/

- 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.

Enabling & Facilitating use of Ocean Color Data

http://symposium.geoblueplanet.com/



BLUE PLANET
Oceans and Society
a GEO Initiative

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!