Colour, Climate, Carbon and Copernicus

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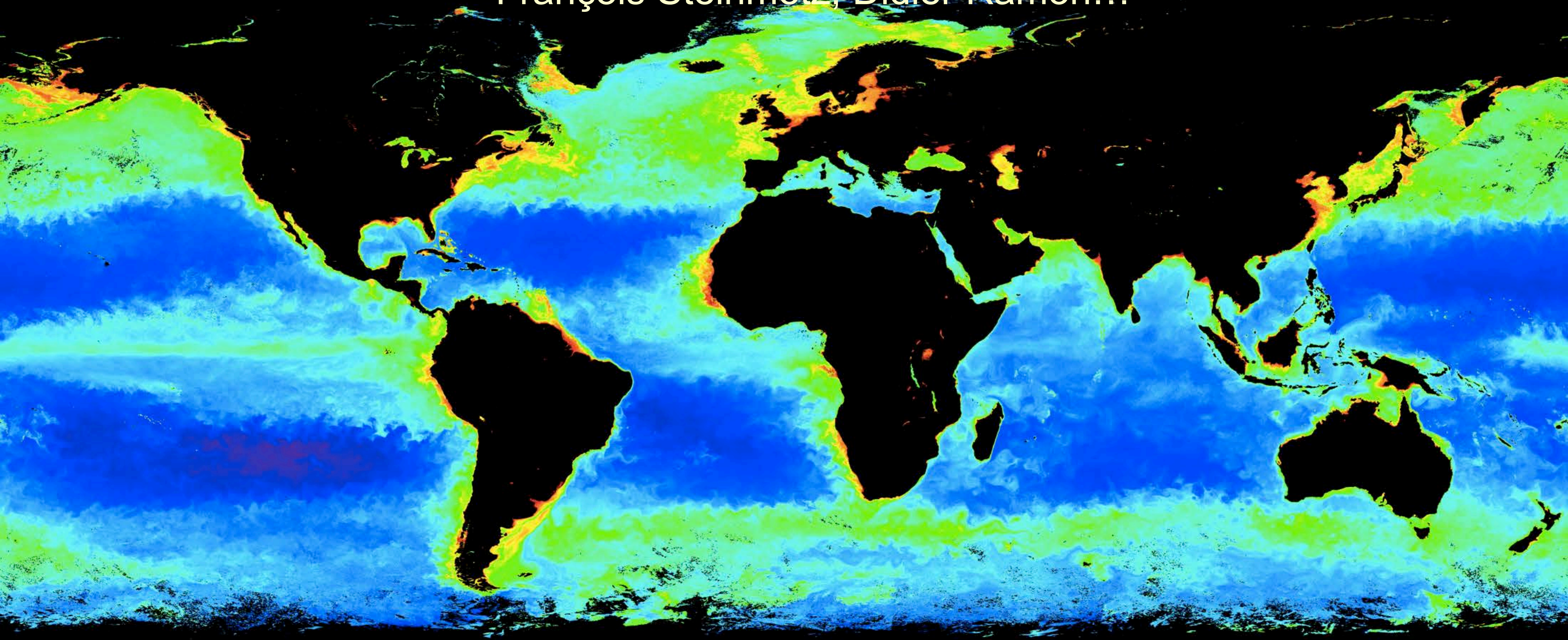
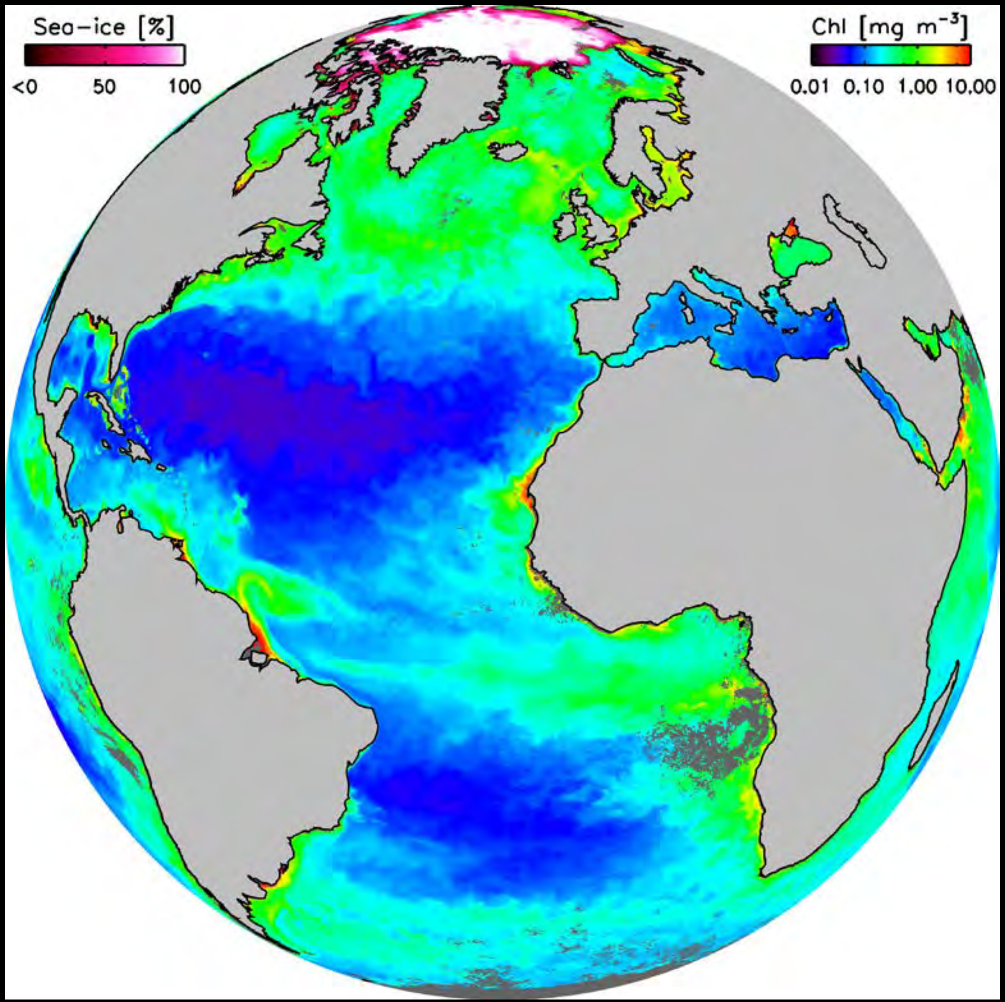
Plymouth Marine Laboratory

and many colleagues, including Carsten Brockmann, Andrei Chuprin, Tom Jackson, Dagmar Müller, Hajo Krasemann, Victor Martinez-Vicente, Mike Grant, Hayley Evers King, Andre Valente, Vanda Brotas, Steve Groom, Marco Zühlke, Nick Selmis, François Steinmetz, Didier Ramon…



OC-CCI Version 3 April 2003

Colour: where Light meets Life



ESA OC-CCI V3

Colour of the ocean tells us where and how the life-giving light is coupled to the ocean microflora. The more green the colour, the stronger the coupling.

It is the most fundamental phenomenon in the pelagic ecosystem: without it, the pelagic ocean would be sterile.

We can monitor this coupling through remote sensing. An ocean-colour image maps the strength of coupling between the ecosystem and its energy source.

Chlorophyll-a, a ubiquitous pigment contained in phytoplankton, is a major product.

Ocean-Colour Climate Change Initiative of the European Space Agency

As part of the larger Climate Change Initiative that deals with multiple Essential Climate Variables in the ocean, land, atmosphere and cryosphere, OC-CCI was charged with:

- Identifying user requirements
- Compare candidate algorithms and select suitable ones
- Establish uncertainties in products on a pixel-by-pixel basis
- Develop appropriate software for product generation
- Generate merged time series of ocean-colour products that meet user requirements
- Assess quality and validate products

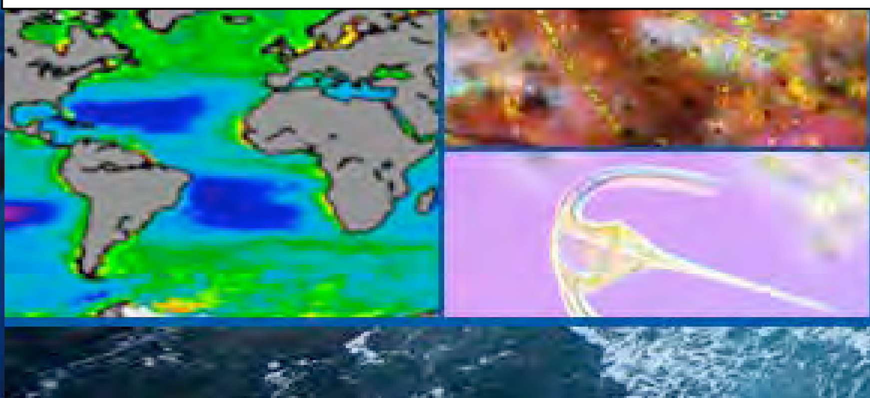
Work carried out in collaboration with, and a lot of help from, NASA

→ COLOUR AND LIGHT IN THE OCEAN FROM EARTH OBSERVATION WORKSHOP

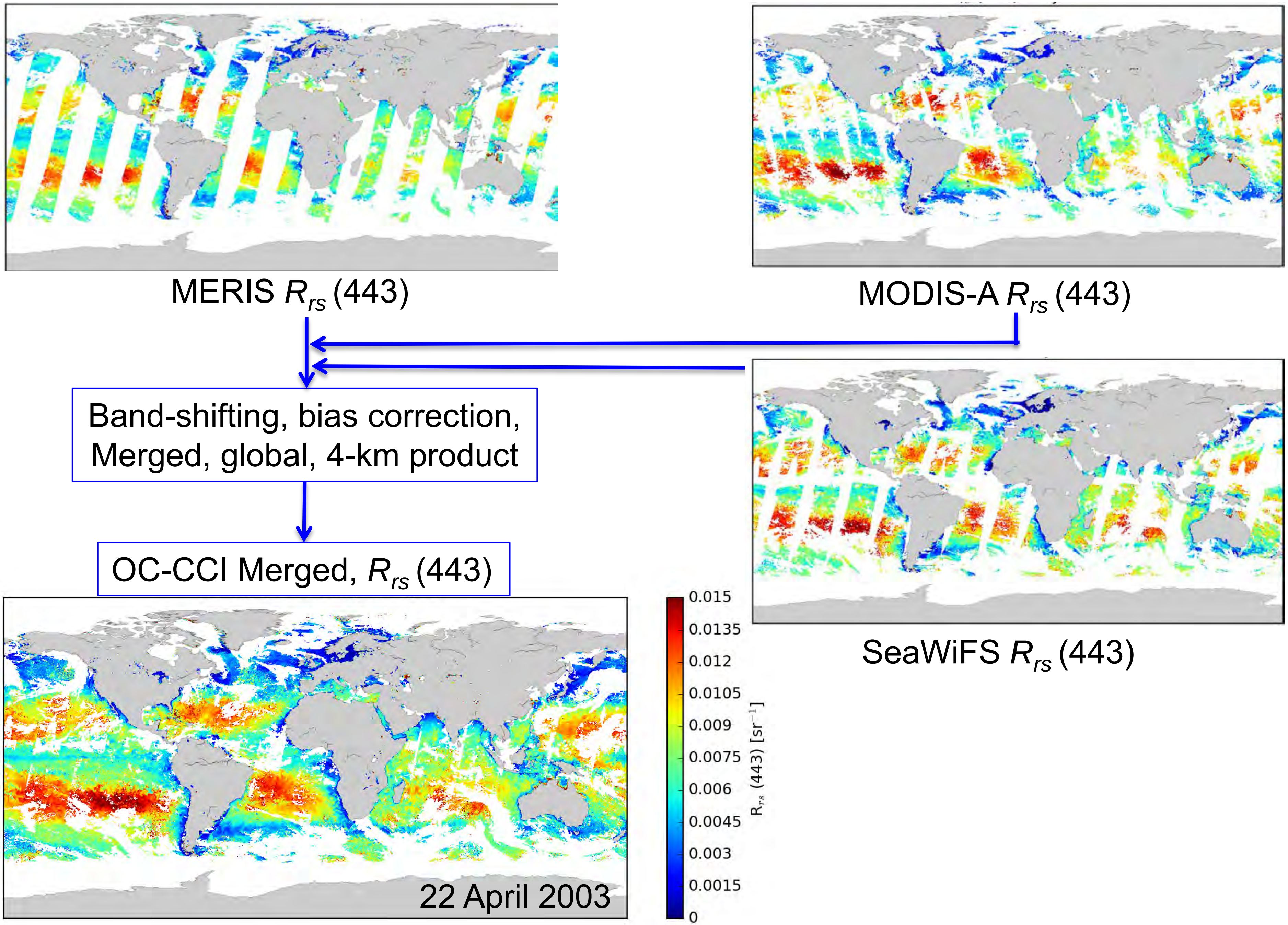
Relevance and Applications of Products from Space & Perspectives from Models

CLEO Workshop was the last of a series of community consultations that guided OC-CCI work

Some 160 participants



The Merged Product

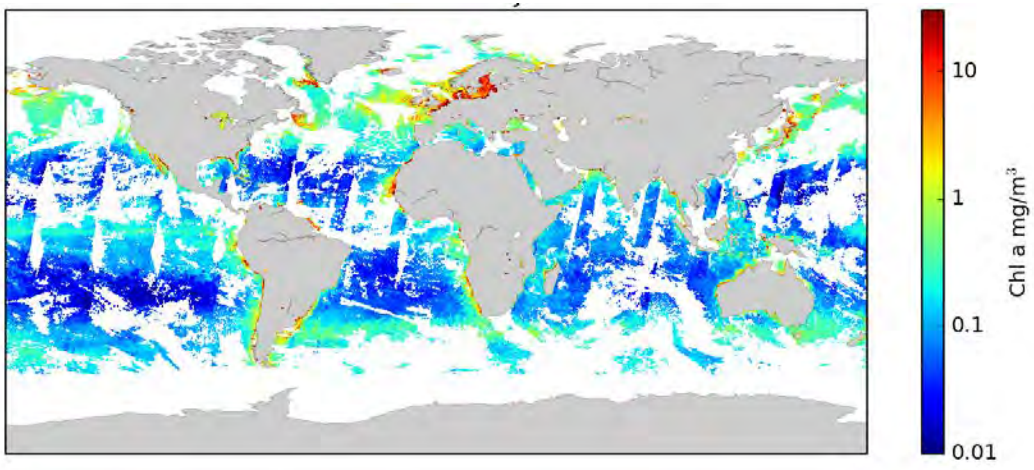


OC-CCI: (Version 3.1)

One of the advantages: Improved spatial coverage (User Requirement)

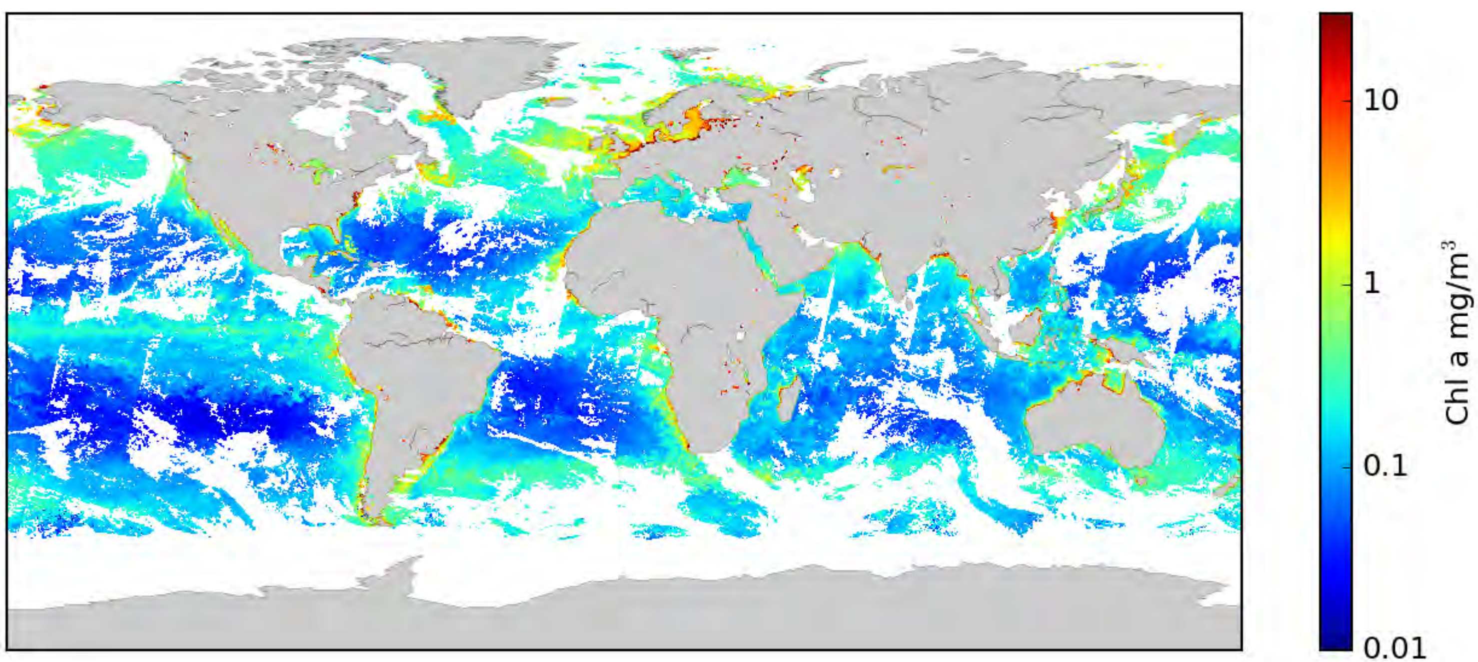
On sinusoidal grid, OC-CCI coverage is ~30% higher for this example

Note: CMEMS is using OC-CCI products as standard products

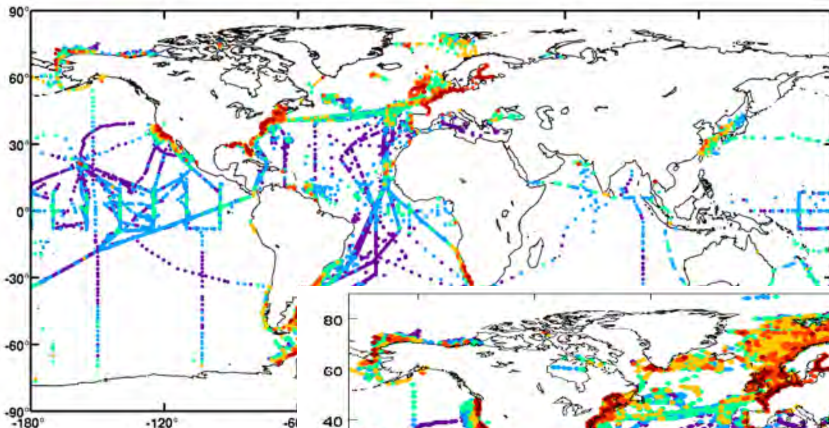


Another European merged product (GlobColour) for the same day, for comparison

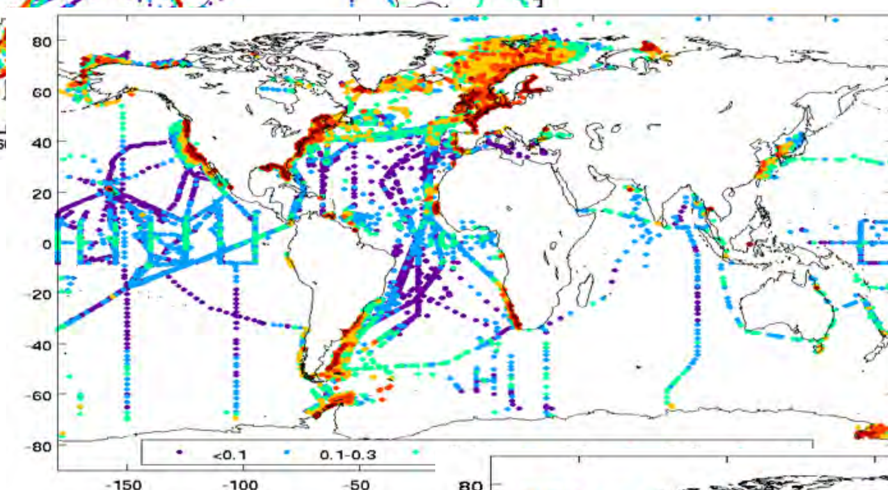
Example:
Daily Chlorophyll Concentration ($mg\ m^{-3}$) OC-CCI
22 April, 2003



In situ database

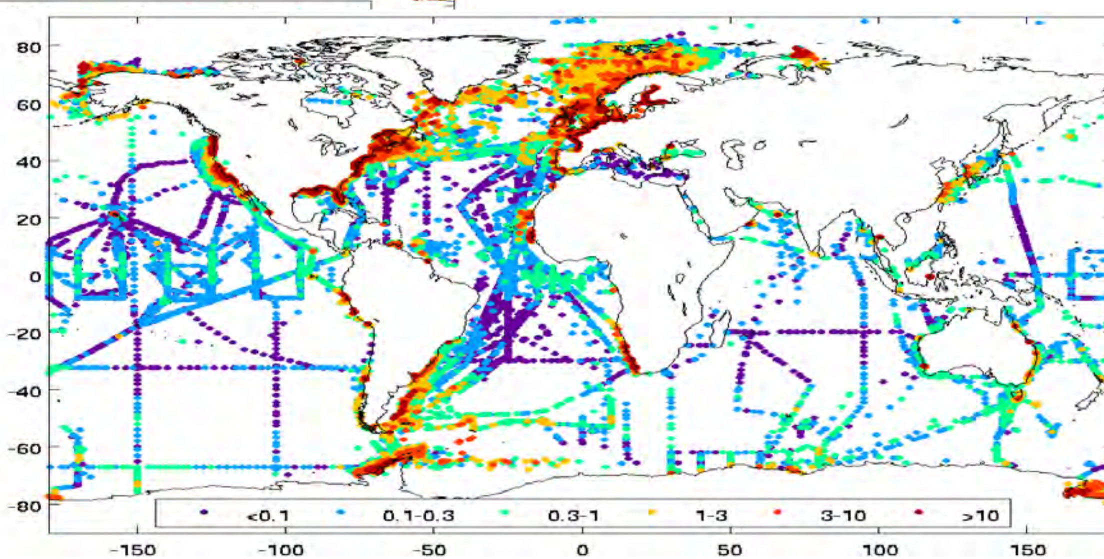


Chlorophyll database
Version 2:
39,849 observations



Chlorophyll database
Version 3:
66,226 observations

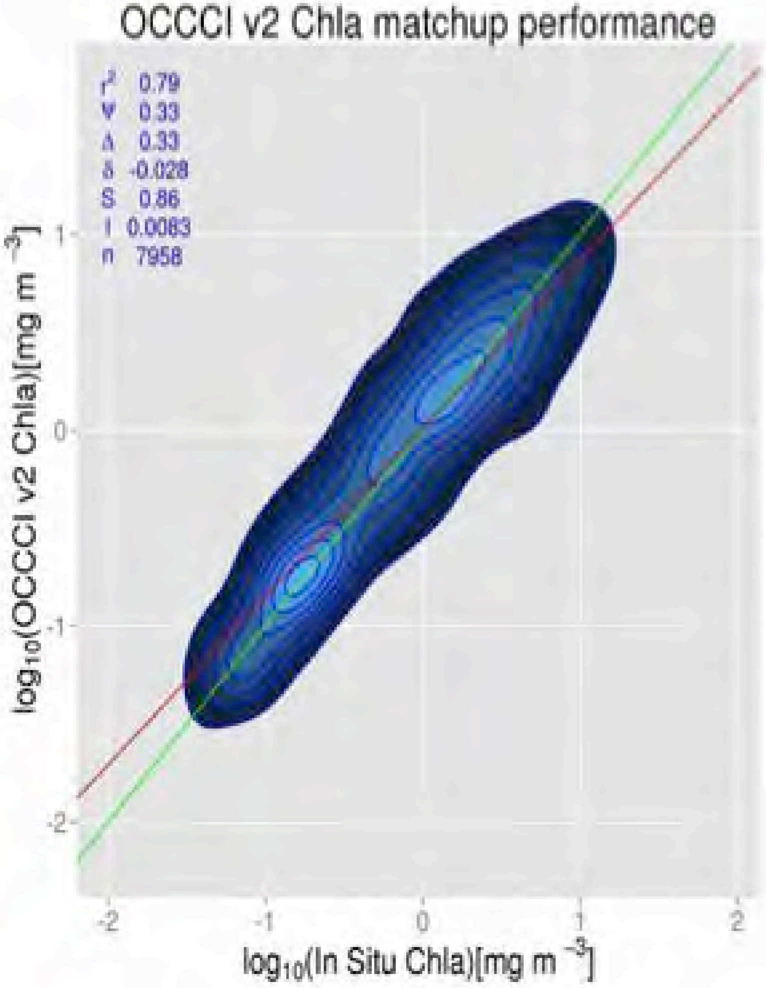
Note: Improved coverage
in the Arctic

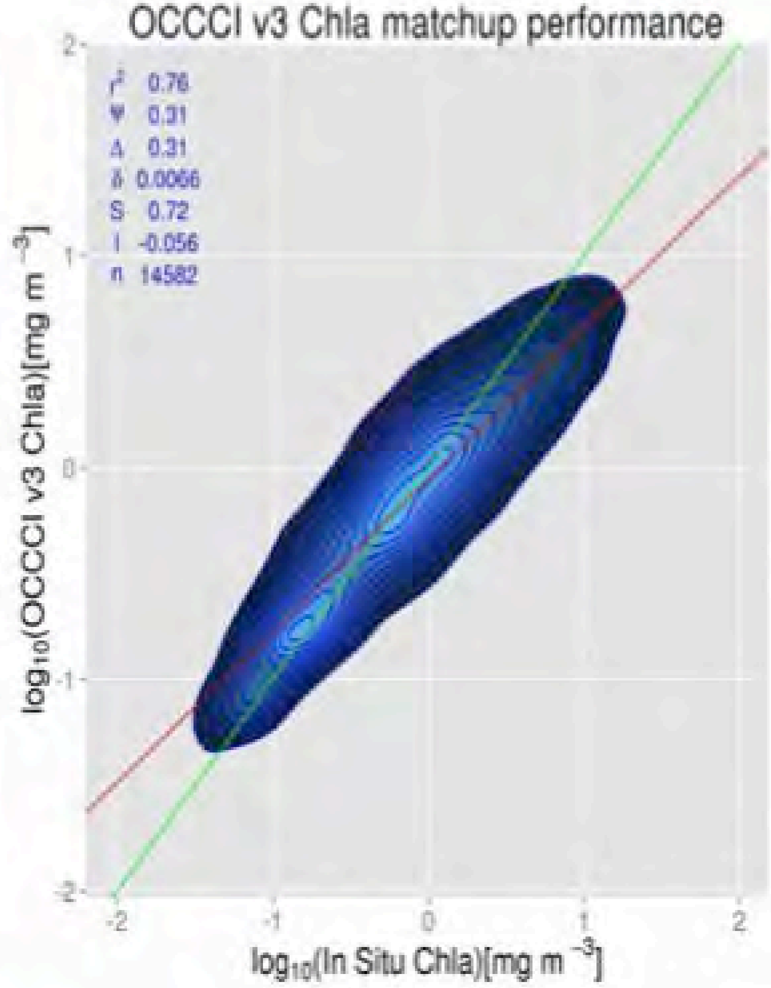


Chlorophyll database
Version 3.1:
79,924 observations

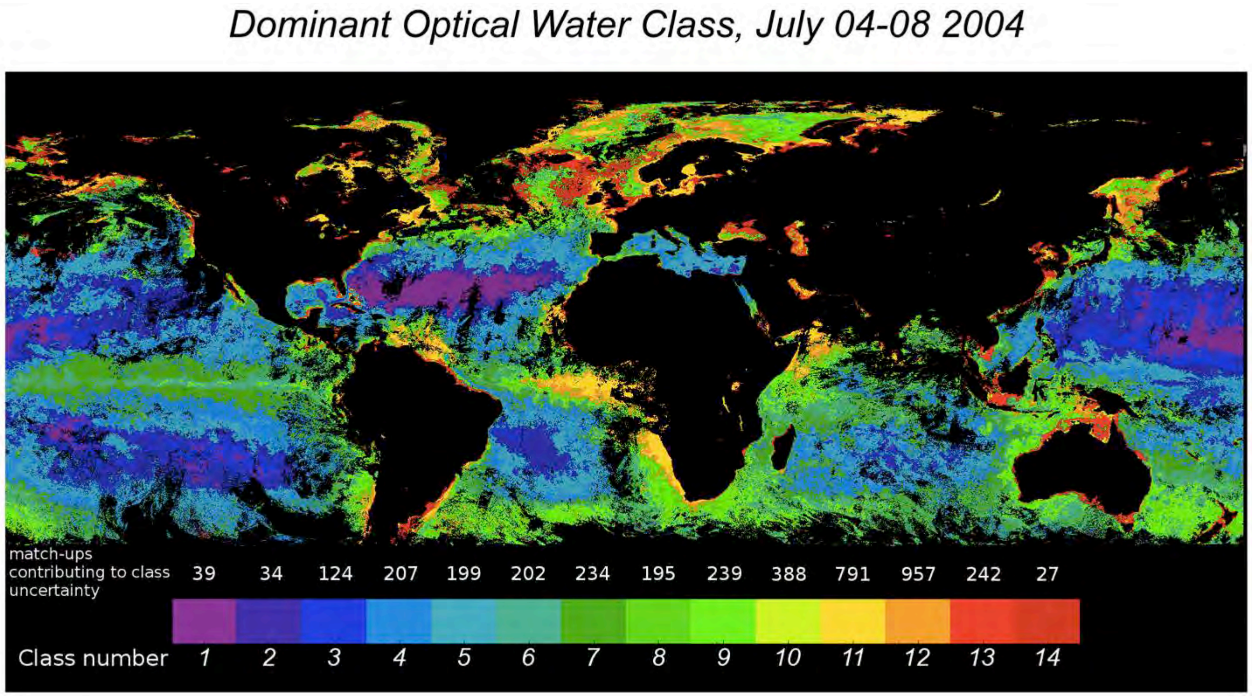
Note: Improved coverage
in the Southern Ocean

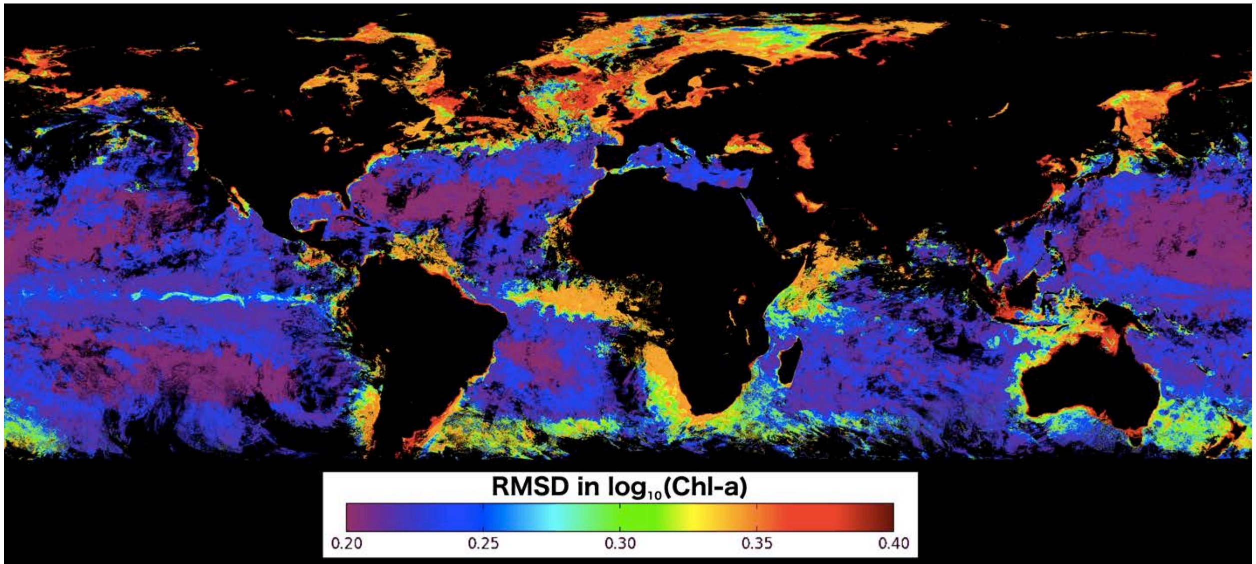
Match-up Data Analysis





From Optical Classes to Uncertainty Estimates

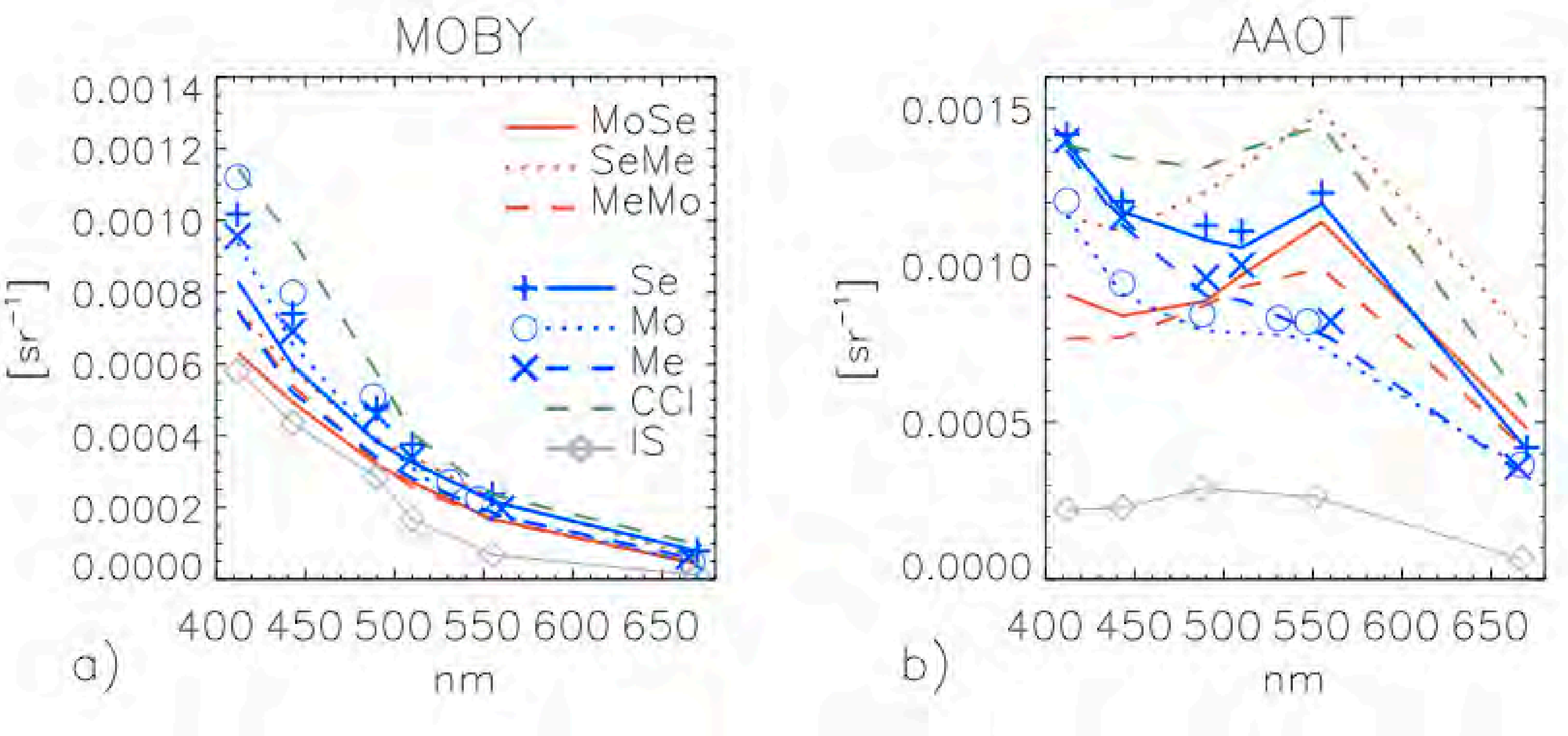




- The OC-CCI product suite includes data on optical water classes.
- Match-up in situ data are sorted according to optical classes to establish uncertainties (bias, RMSD) per optical class.
- At each pixel, uncertainties are weighted according to membership of optical classes at that pixel, to generate uncertainty characteristics per pixel.
- Thus, validation using match-ups underpin uncertainty estimates.

Moore et al. 2009
Jackson et al. 2017

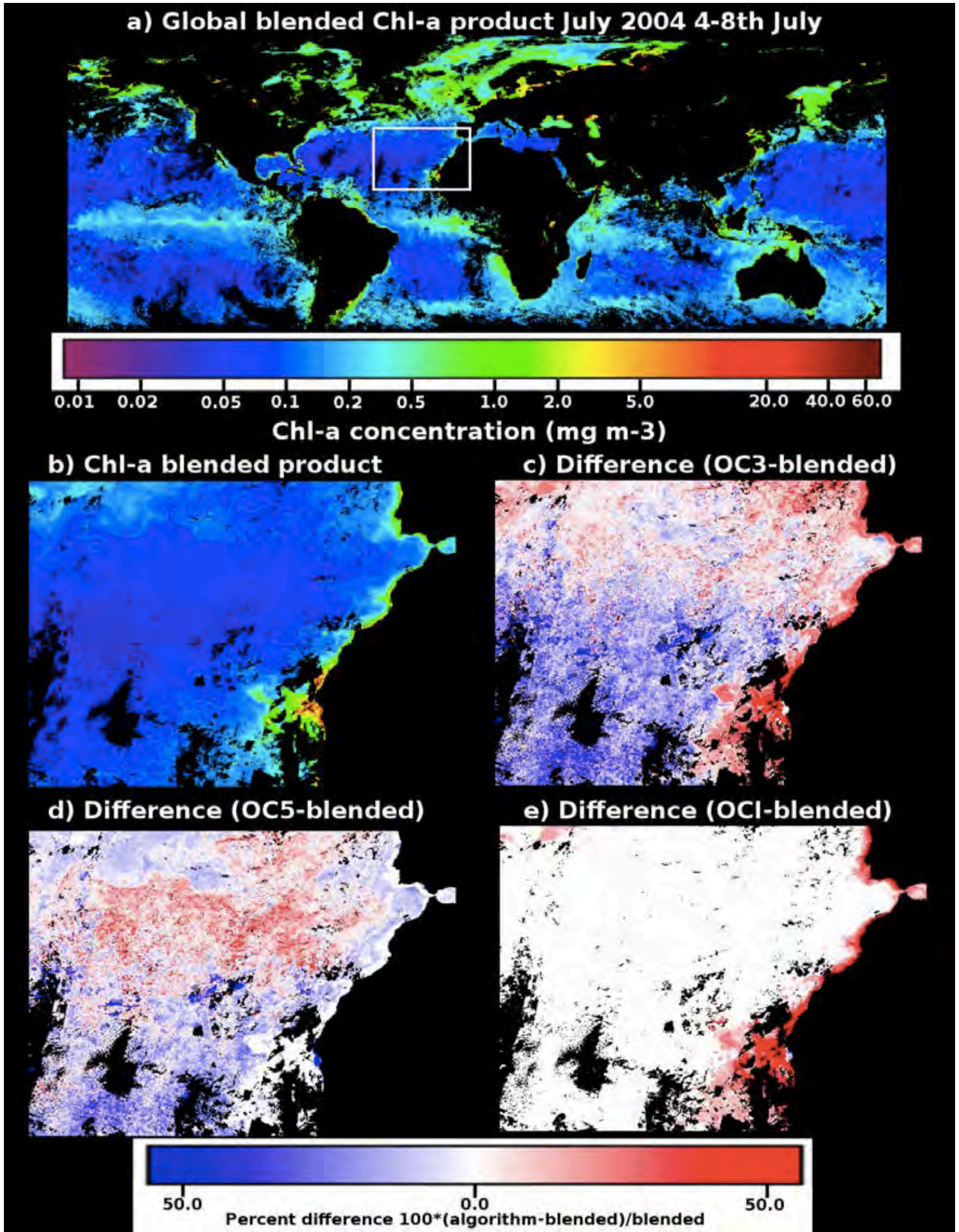
Assessment of the Rrs Uncertaities



Mélin et al. 2016

Version 3: Blended algorithm

- less noisy in oligotrophic waters, better performance in turbid coastal waters



Jackson et al. 2017

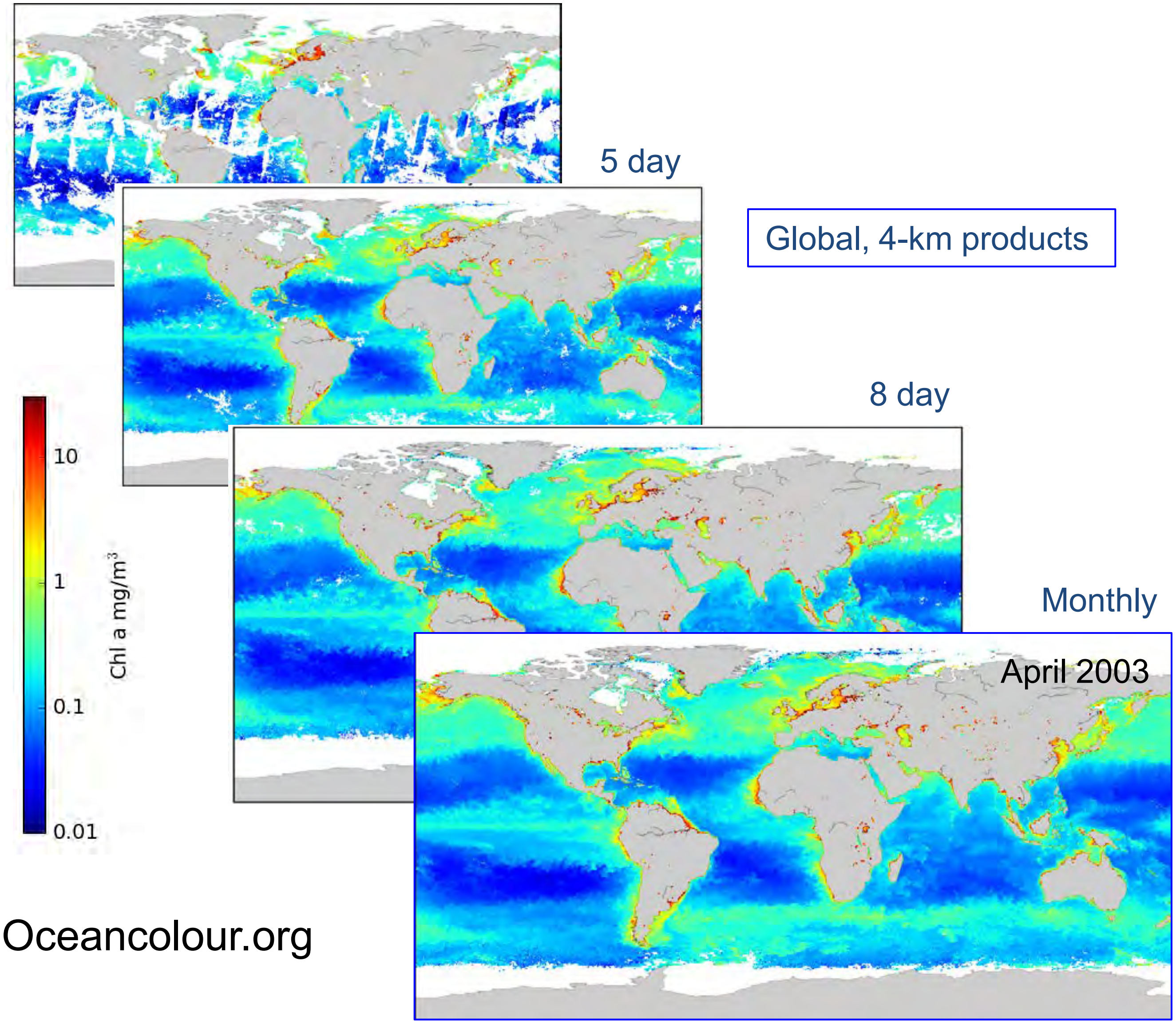
Ocean Colour CCI Products

Daily

5 day

8 day

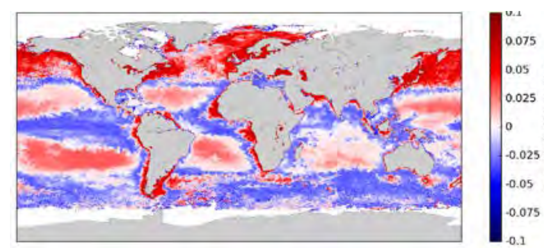
Monthly



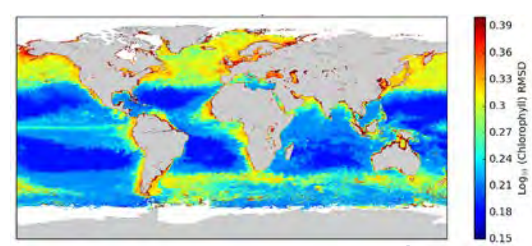
Global, 4-km products

Product suite includes Chl-a, K_d at 490 nm, R_{rs} and inherent optical properties at at SeaWiFS wavelengths, their uncertainty estimates and optical water classes.

Bias



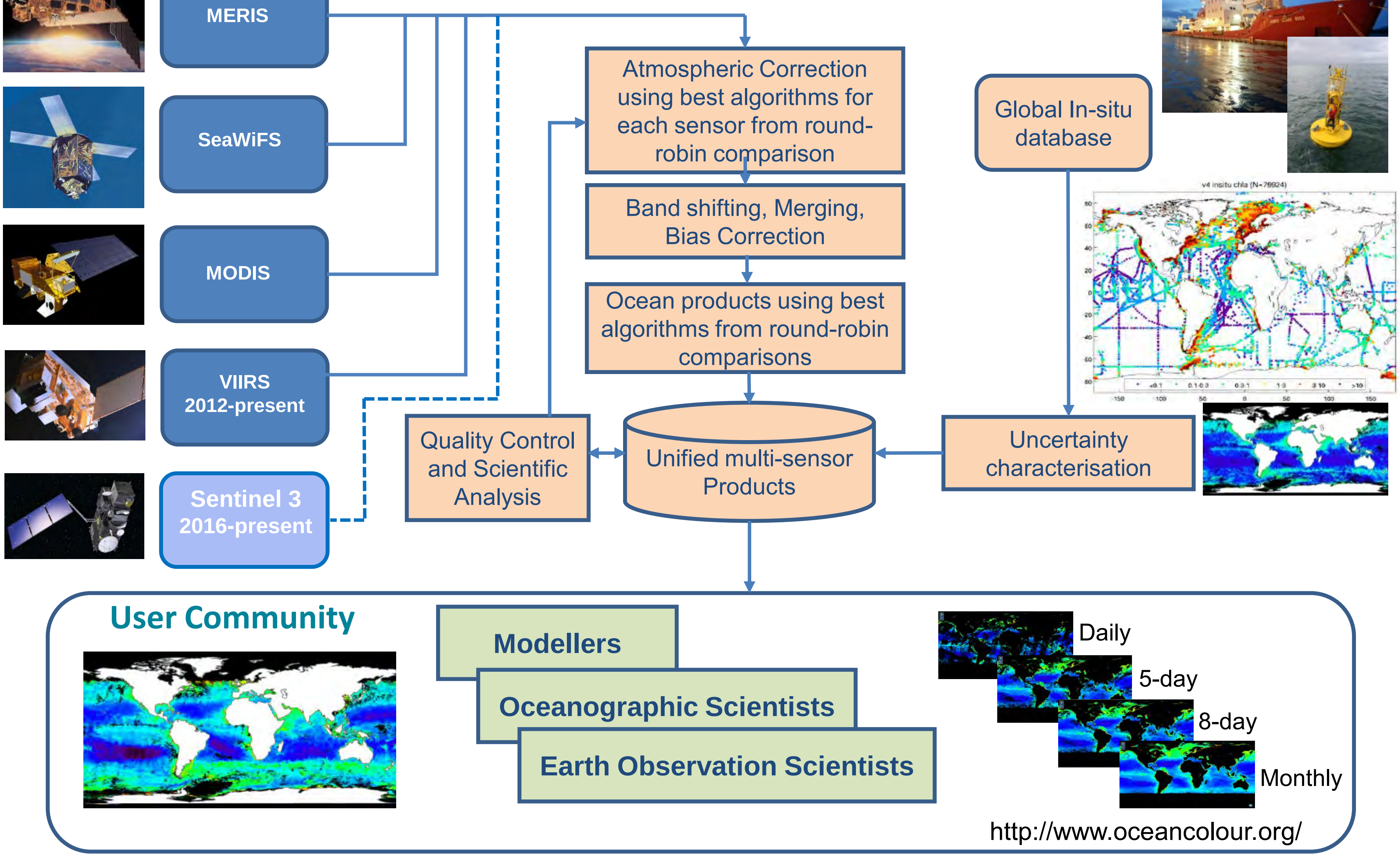
Uncertainty characterisation



RMSD

Oceancolour.org

OC-CCI data processing



Sensors currently contributing to OC-CCI merged product

SeaWiFS			412			443			490	510			555					670											765
MODIS-A				412.5		443		488			531						667				678						748		
MERIS				412.5	442.5				490	510				560	620	665						681.25	705					753.75	
VIIRS		410				443	486					551							671							745			

Consistency in ocean-colour band set in the Sentinel Era

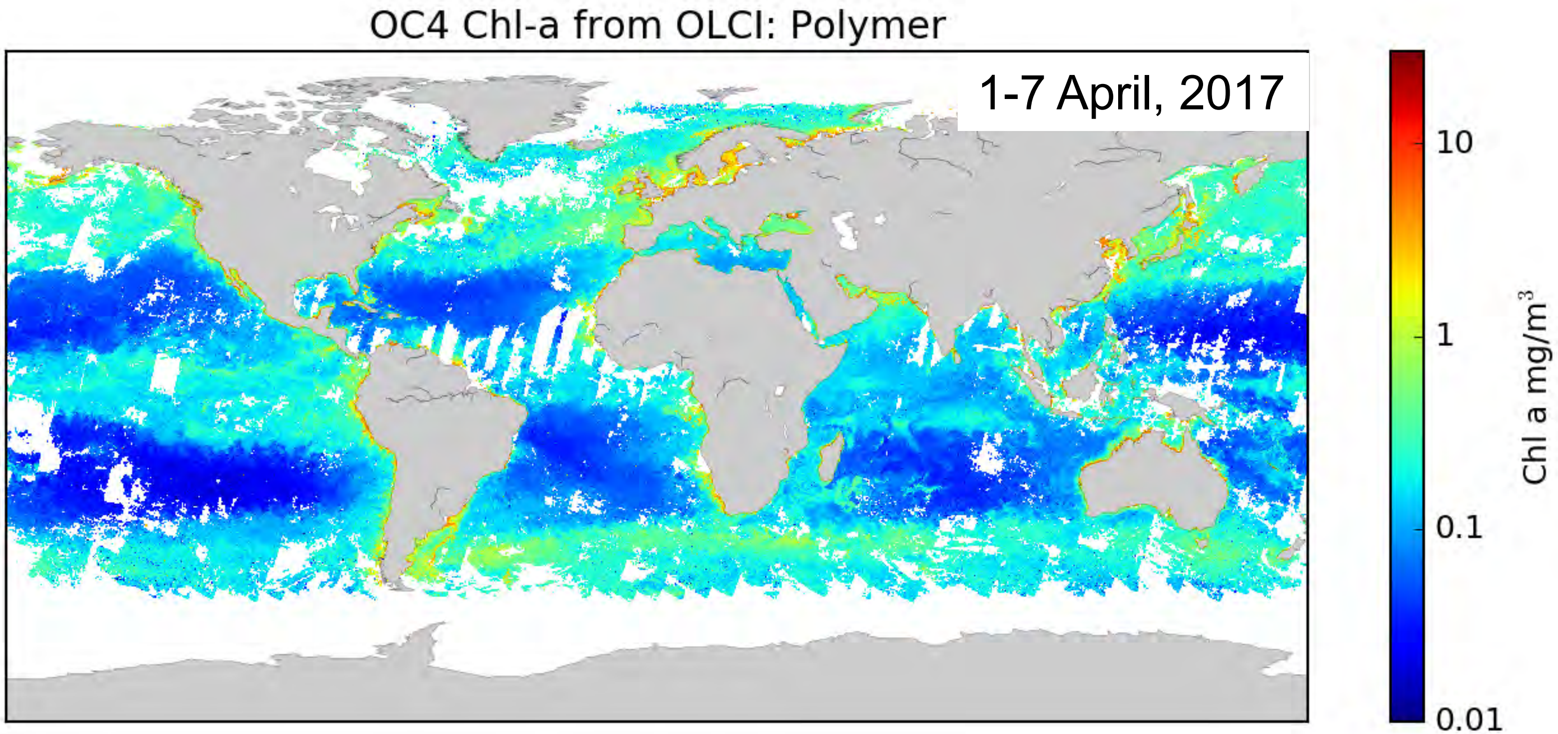
MERIS				412.5	442.5				490	510				560	620	665						681.25	705					753.75	
Sentinel-3A	400			412.5	442.5				490	510				560	620	665				673.75		681.25		708.75				753.75	
Sentinel-3B	400			412.5	442.5				490	510				560	620	665				673.75		681.25		708.75				753.75	
Sentinel-3C	400			412.5	442.5				490	510				560	620	665				673.75		681.25		708.75				753.75	
Sentinel-3D	400			412.5	442.5				490	510				560	620	665				673.75		681.25		708.75				753.75	

Sentinel-3 series of ocean-colour sensors (OLCI)

Considerable improvement over status quo for climate applications. Anticipated advantages include:

- Consistency in constellation of satellite sensors, consistency with MERIS
- Continuity: backwards to MERIS and forward with Sentinel-3 series (operational sensors)
- Coverage: at least two sensors in orbit at the same time
- Better spectral resolution – important for atmospheric correction, novel algorithms, new products
- Ground segment that includes high-quality in situ data acquisition for product validation

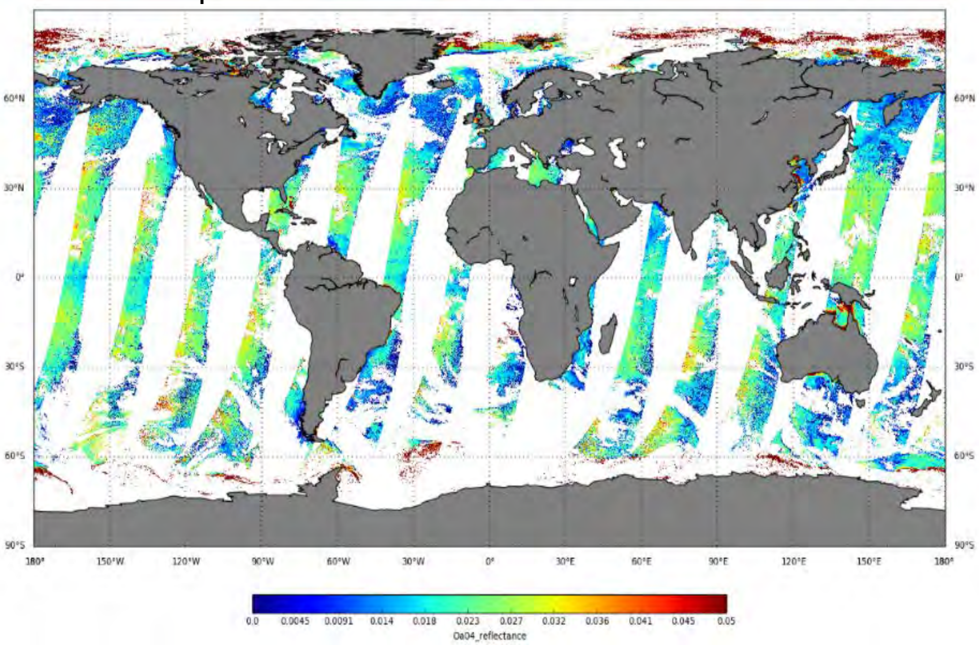
But: gap in time between MERIS and OLCI is a challenge



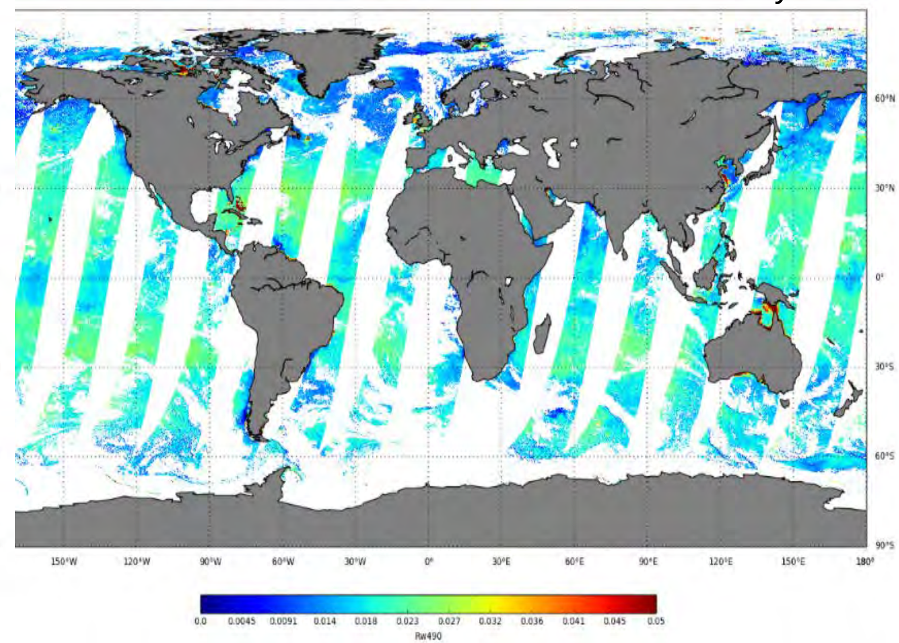
Comparison of daily composites

Daily Rw443 composites (22 September, 2016)

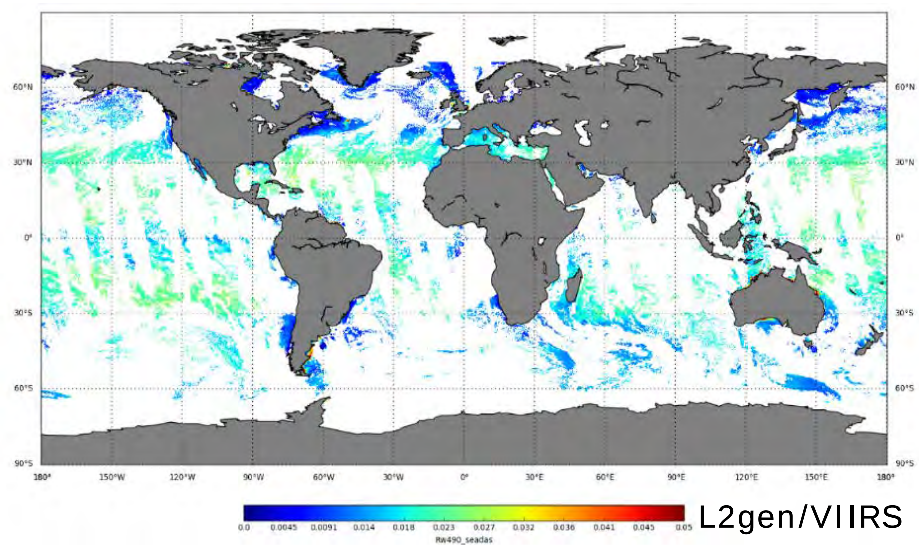
Standard product



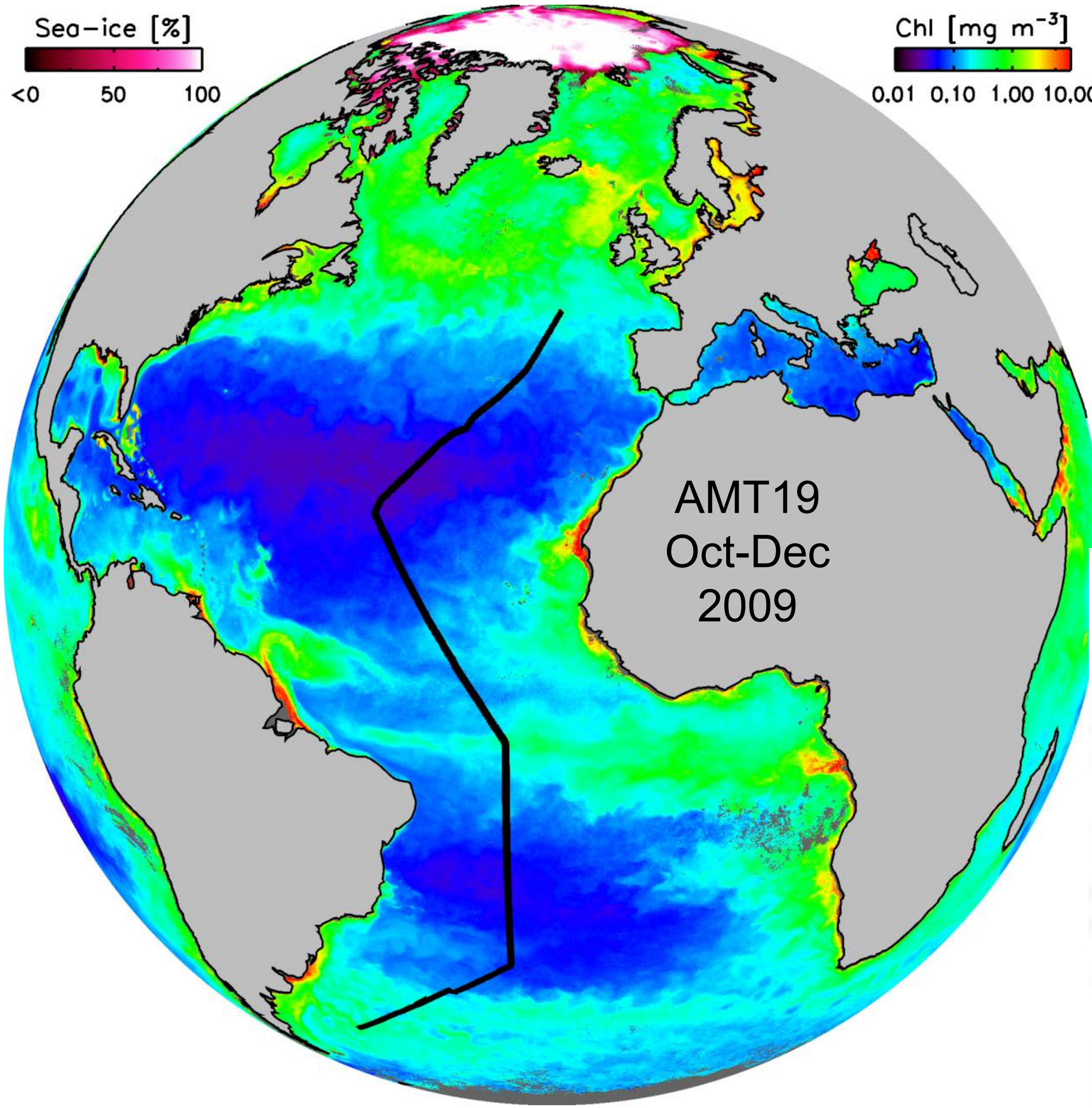
Polymer

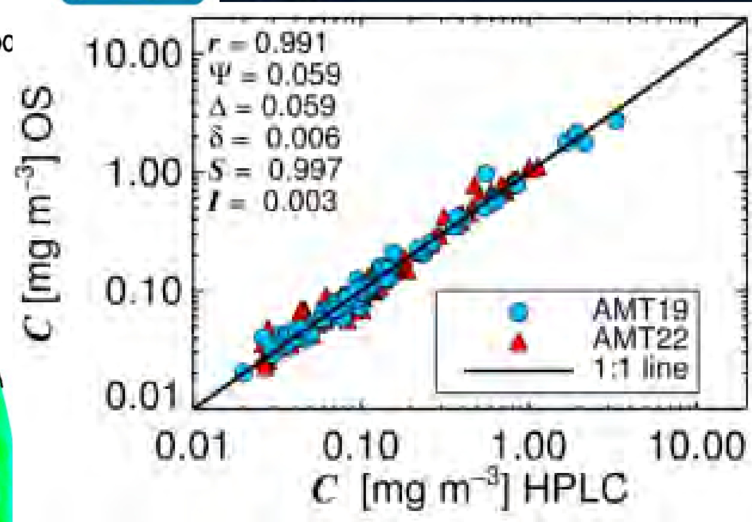


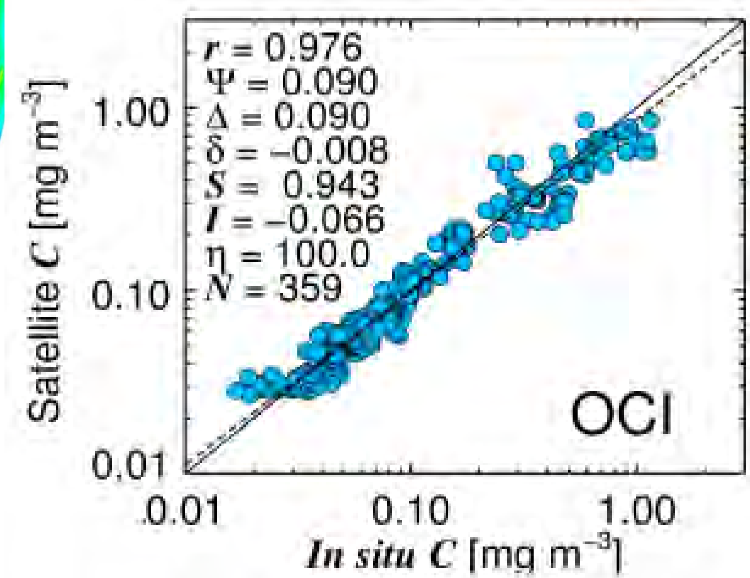
- Compared with VIIRS-only time series, the improved coverage from OLCI is remarkable.
- But quality assurance for climate products has to be undertaken meticulously, before merging with existing time series.
- Need to exploit the additional spectral coverage provided by OLCI.



L2gen/VIIRS



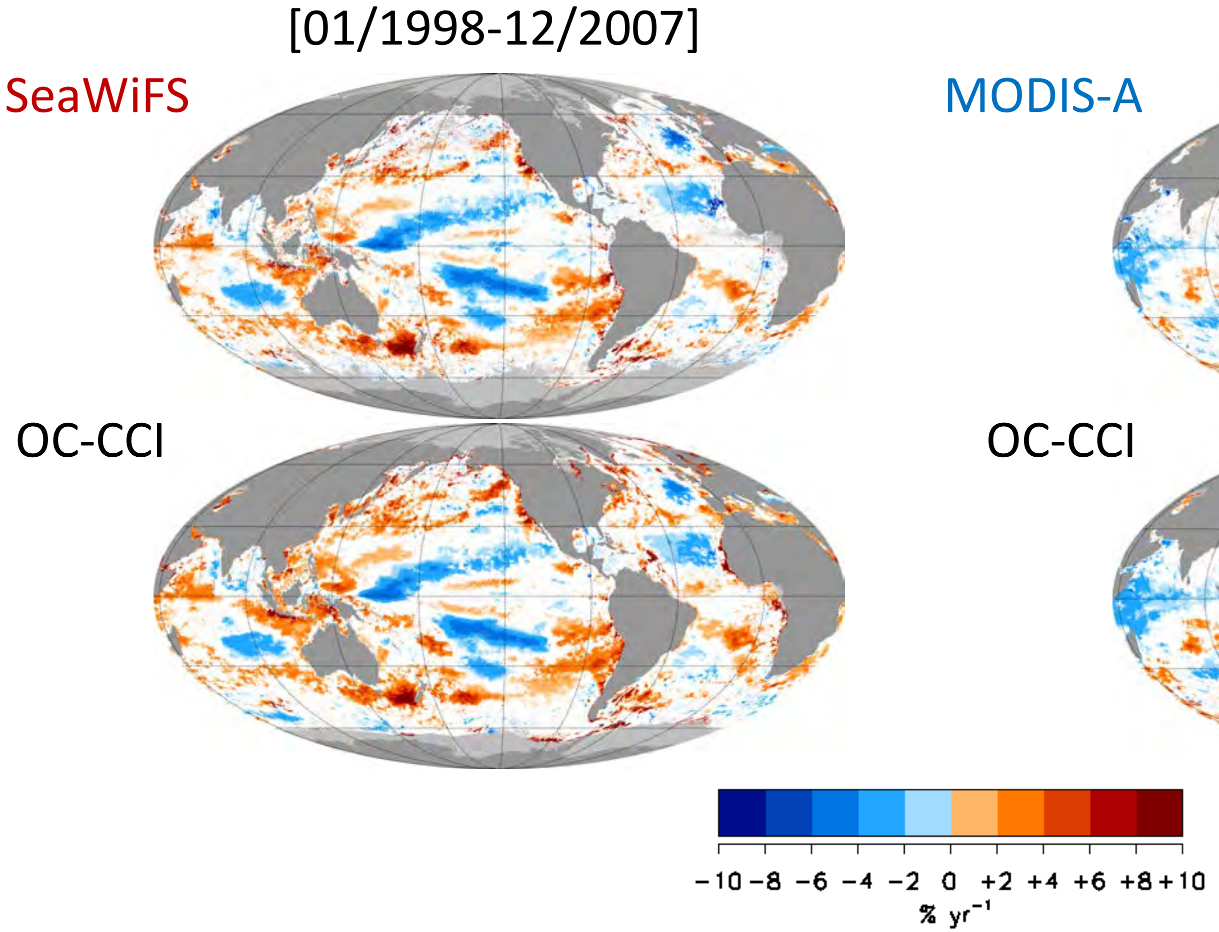




Workshop: Validating Copernicus Sentinel data using Fiducial Reference Measurements: 20-21 June 2017, Plymouth, UK

Dall'Olmo et al. (2012)
Brewin et al. (2016)

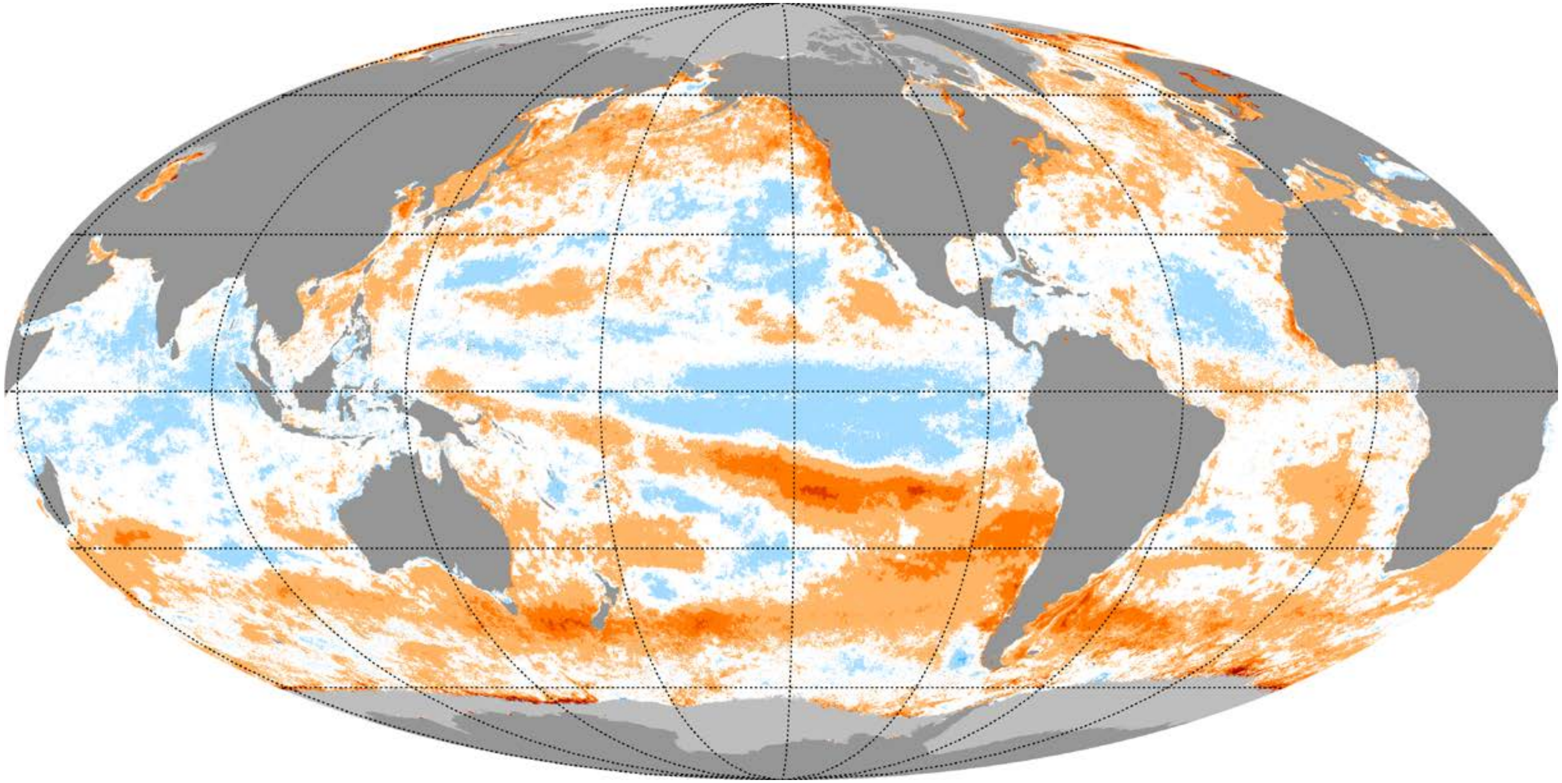
Comparison between trends in Chl*a* obtained over 10 years between OC-CCI and single-mission products:



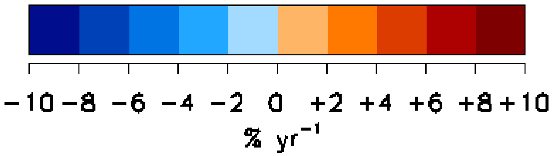
Mélin et al., *Remote Sens. Environ.*, 2017

OC-CCI: SeaWiFS+MERIS+MODIS-A+VIIRS

[10/1997-09/2015] (18 years)

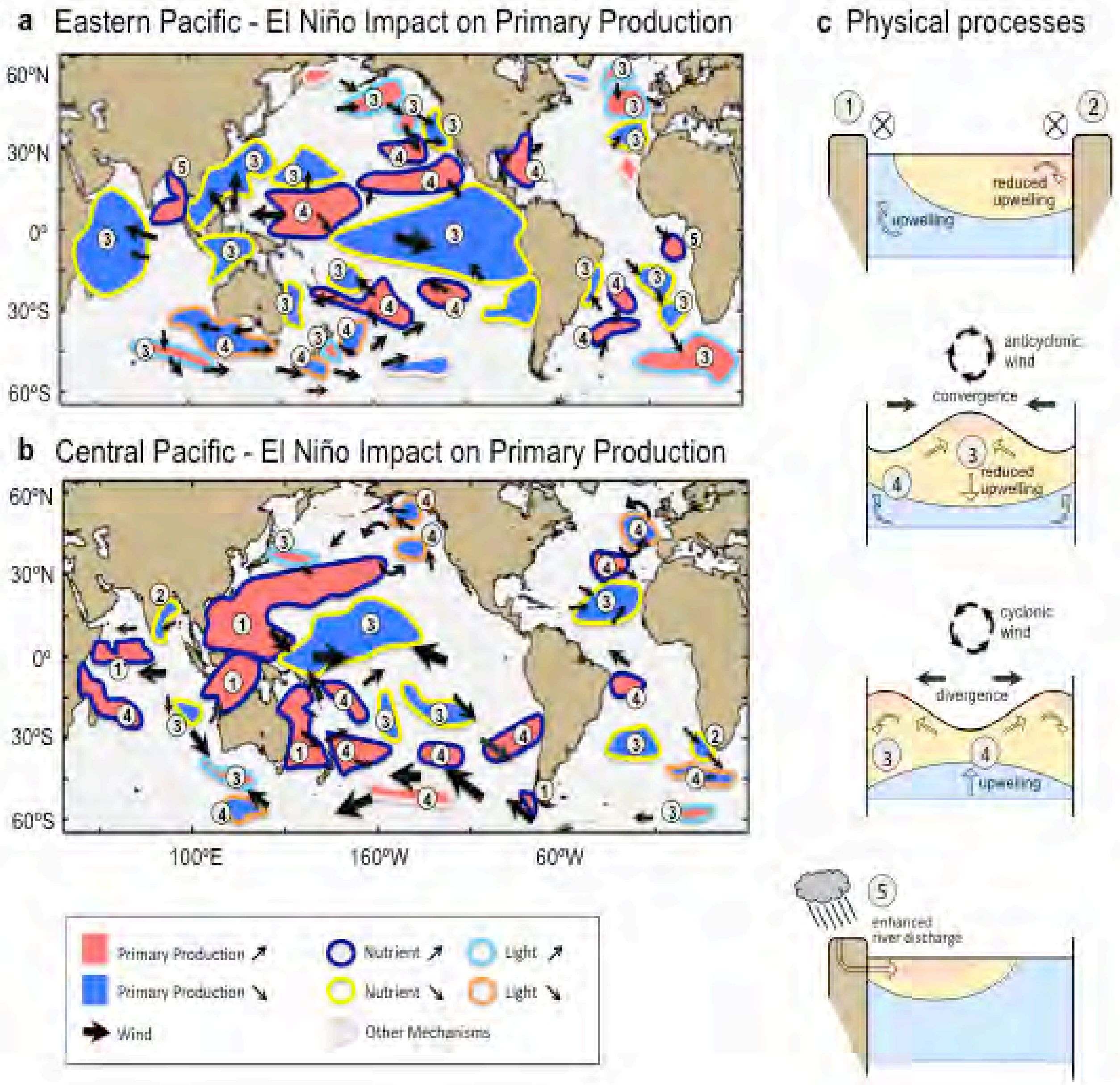


only significant (p<0.05) trends are shown



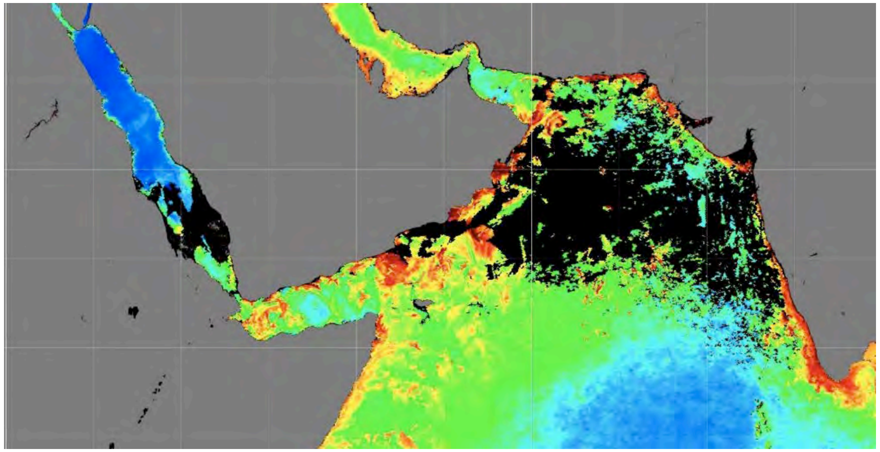
Mélin et al., *Remote Sens. Environ.*, 2017

Regionally-differentiated Impact of El Niño on Phytoplankton

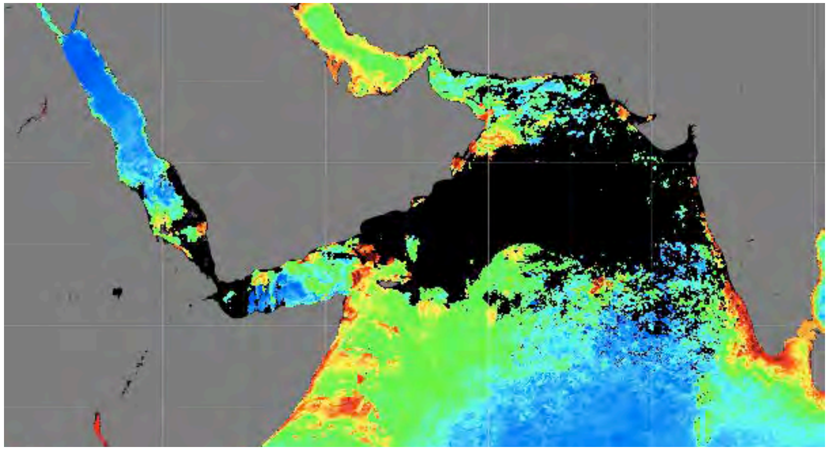


Racault et al. 2017

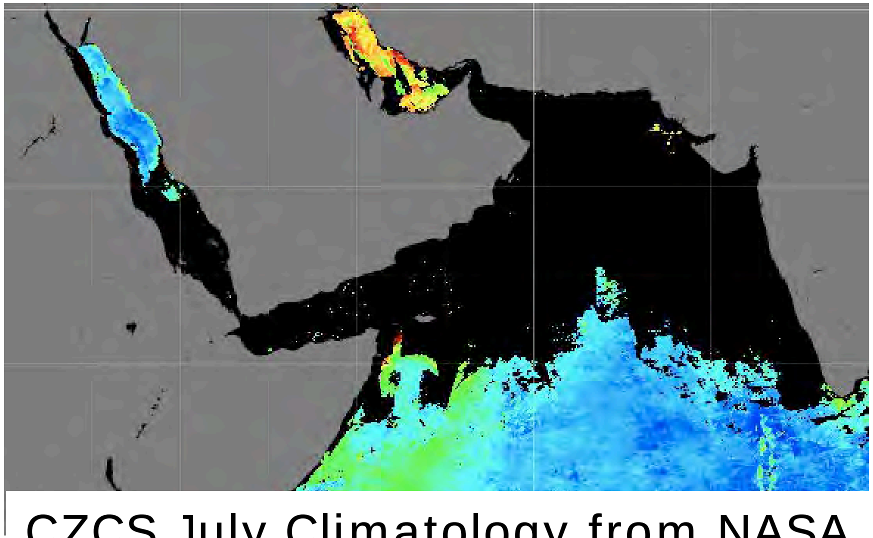
July Chlorophyll fields in the Arabian Sea



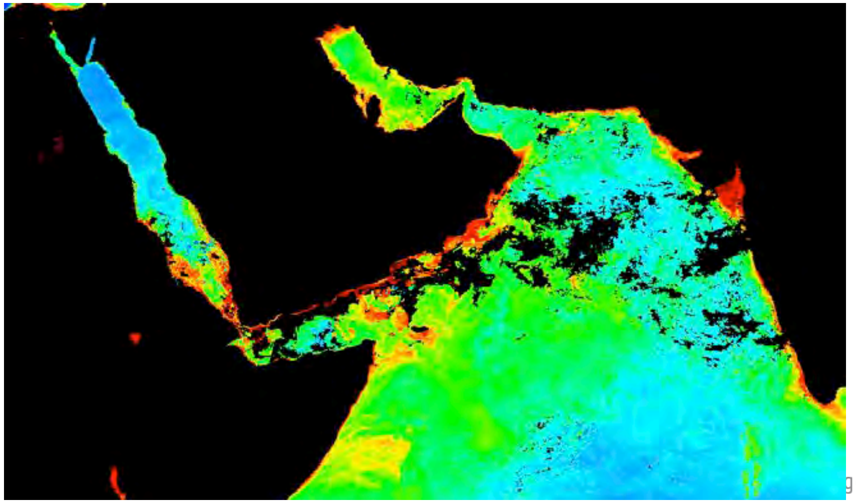
MODIS July Climatology from NASA



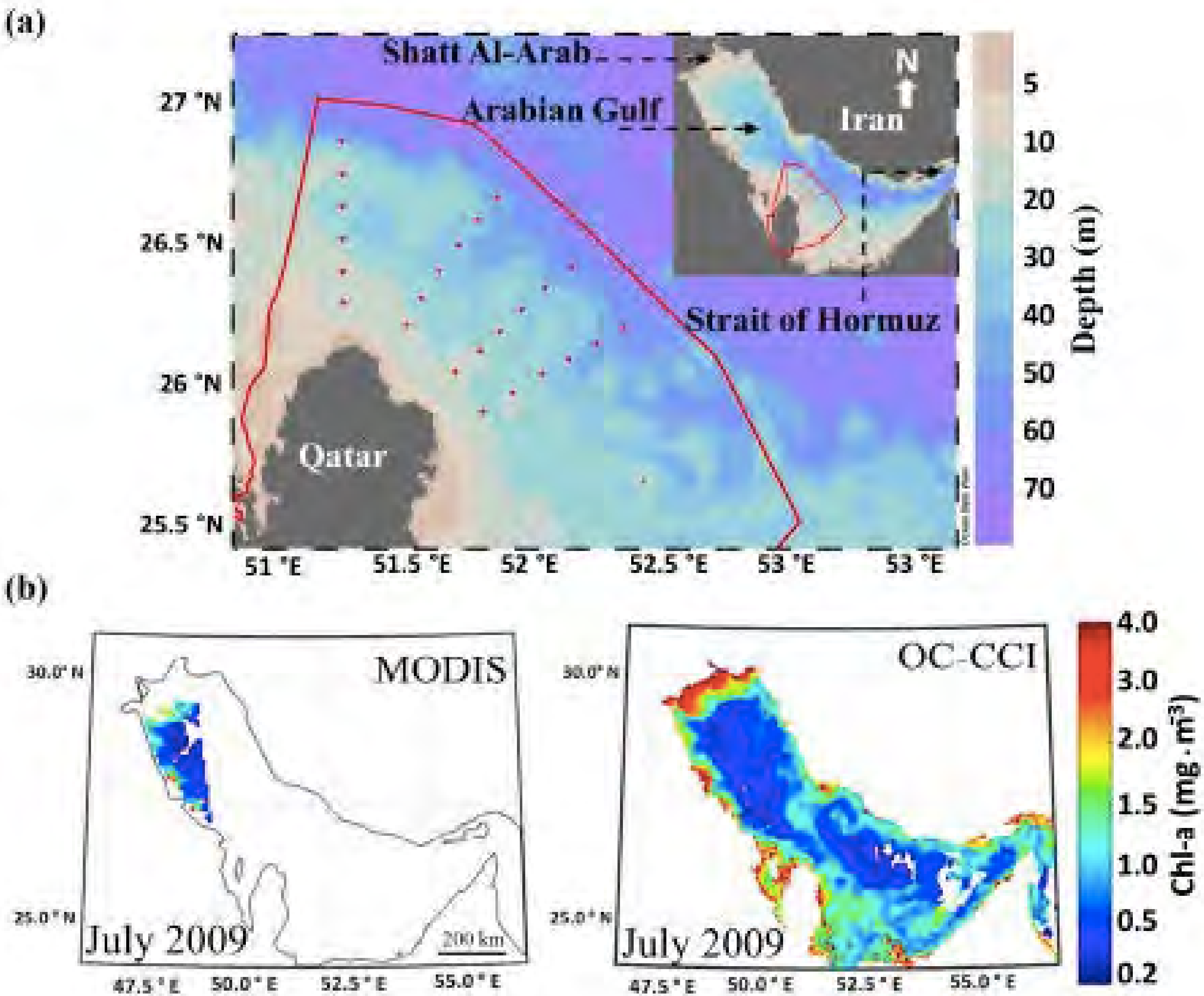
SeaWiFS July Climatology from NASA



CZCS July Climatology from NASA



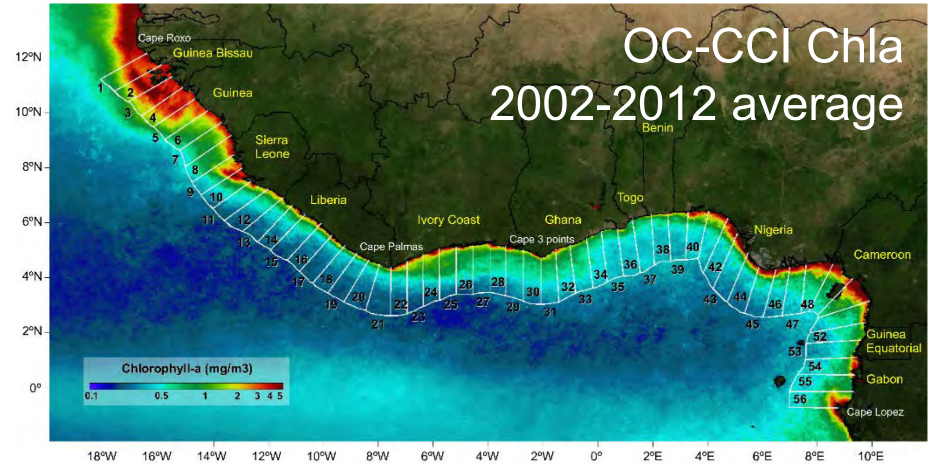
OC-CCI July 2003

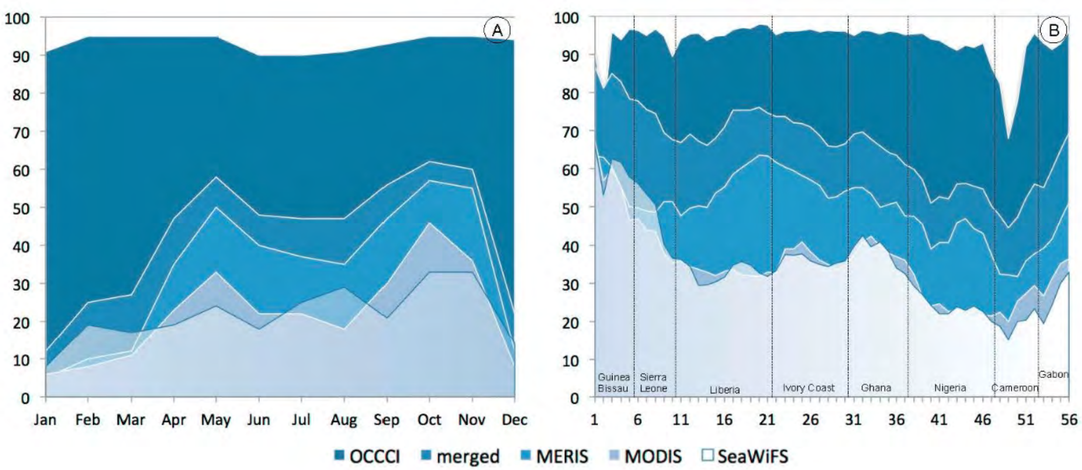


Al-Naimi et al. 2017

Application of OC-CCI data to the Gulf of Guinea

The Gulf of Guinea is a dynamic and complex ecosystem along the equatorial West African coasts. The use of ocean color data is extremely valuable to study this ecosystem but has been hampered so far by the poor coverage of satellite data (particularly in winter and the Niger delta).

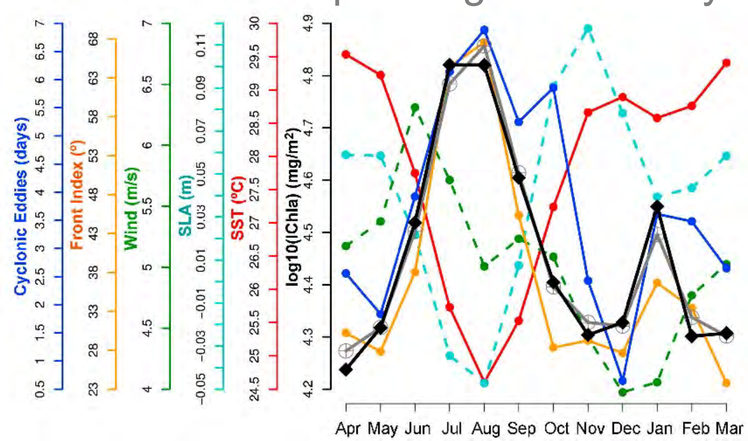




Coverage (%) of satellite products
as a function of time (A) and spatial cell (B)

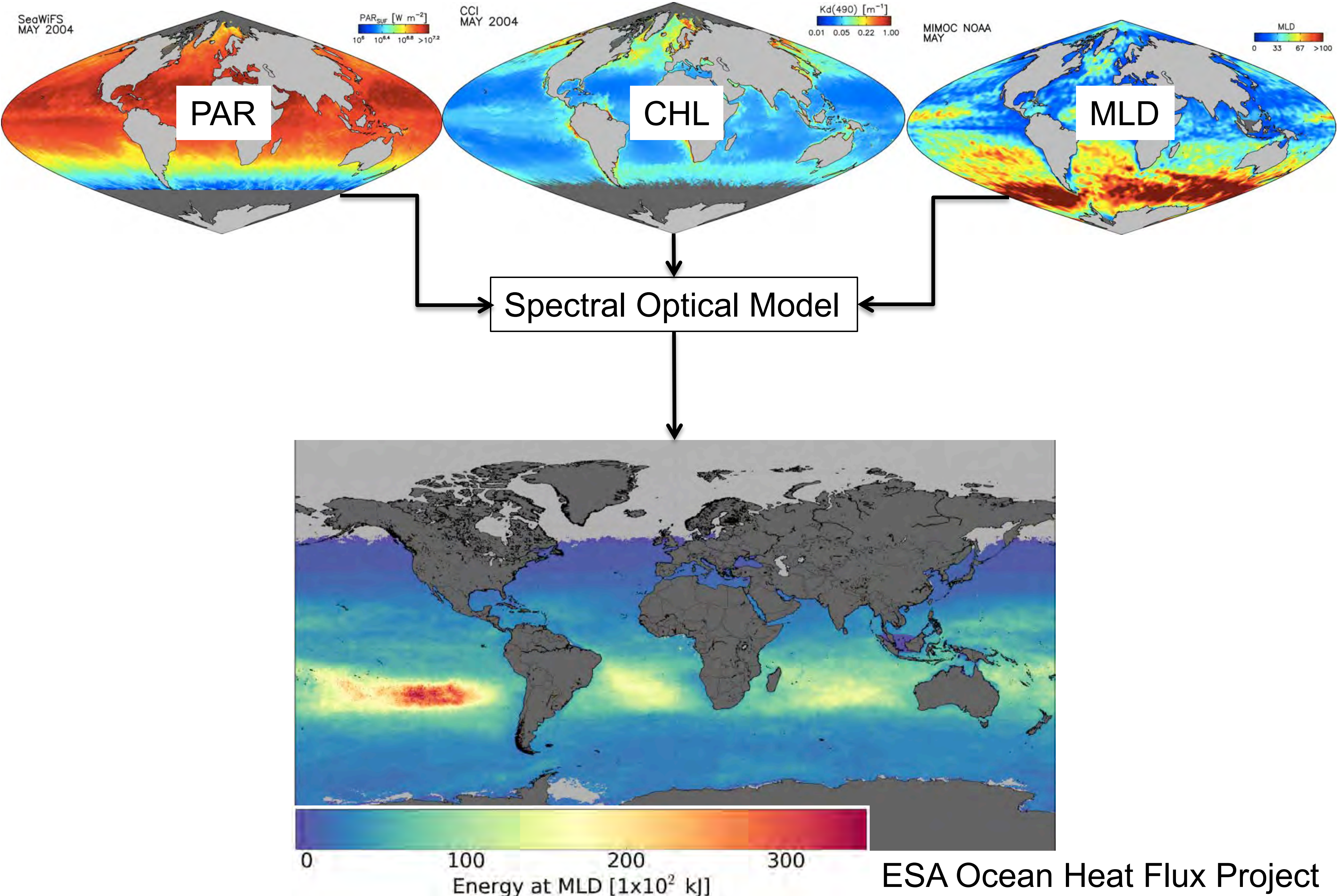
OC-CCI products allow a monthly coverage and reveal the relationships between Chla and physical variables.

Ex. of the Ghana upwelling seasonal cycle



Nieto and Mélin, *Prog. Oceanogr.*, 151, 97-115, 2017

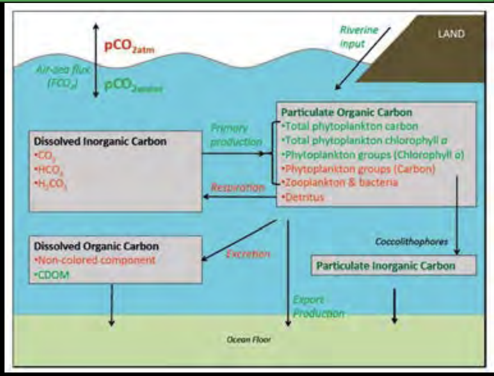
Contribution to Ocean Heat Budget



ESA Ocean Heat Flux Project

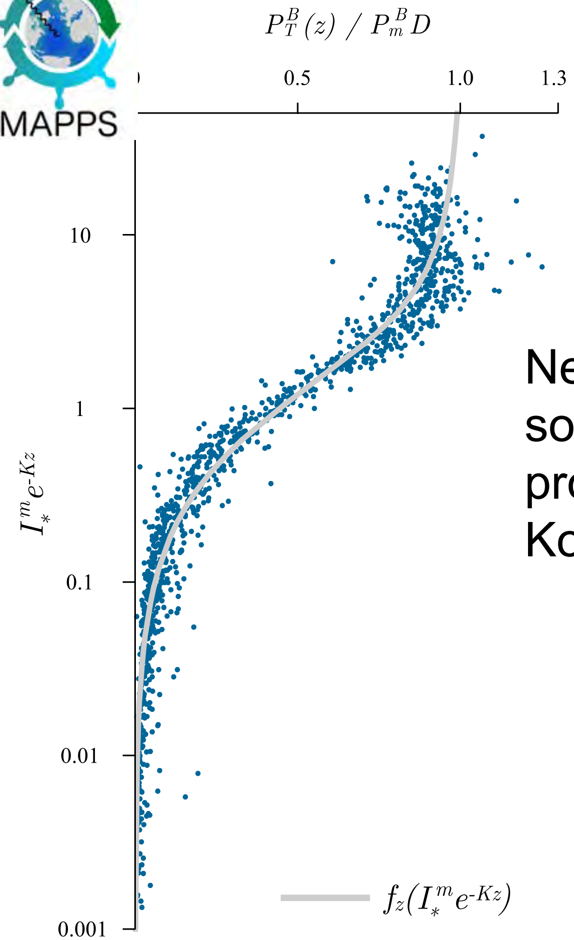
From ECV to Carbon Observations from Space

Sensor	Products
Ocean Colour	Chlorophyll, Absorption by coloured dissolved organic matter, Daily photosynthetically-available radiation, Particulate organic carbon, Phytoplankton carbon, Primary production, Particle size distribution, Primary production, New (export production, Phytoplankton functional types
Infra-red radiometer, passive microwave	Sea-surface temperature
Active and passive microwave sensors	Wind speed, vector wind, sea state, Sea ice extent, ice edge structure
Altimeter	Surface geographic currents and eddies

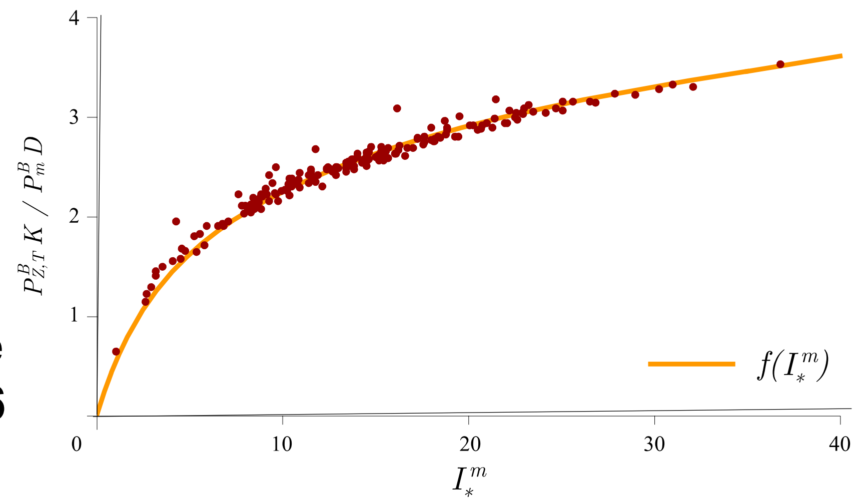


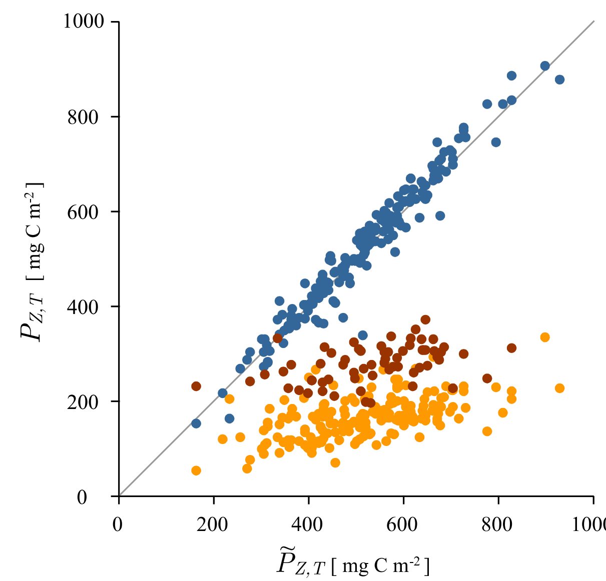
- Satellite requirements consistent with GCOS requirements
- But report emphasises the need for carbon products
- Requirements include both variables and fluxes

Modelling Primary Production



New analytic solutions to production profile Kovač et al. 2016



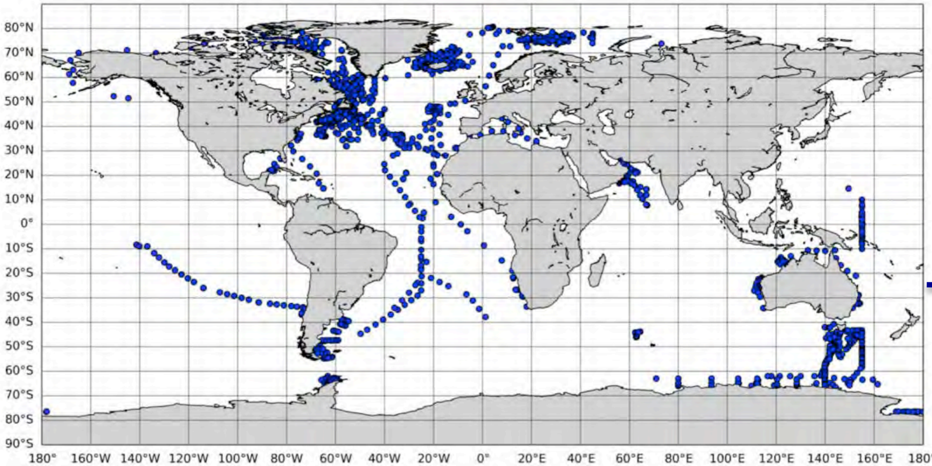


Models exist. New analytic solutions have been found for non-spectral case.
Data from Hawaii Ocean Time Series.
Key to model performance is the assignment of model parameters.
At HOT stations, province-based parameter assignment led to underestimation of production.

Kovač et al. 2015

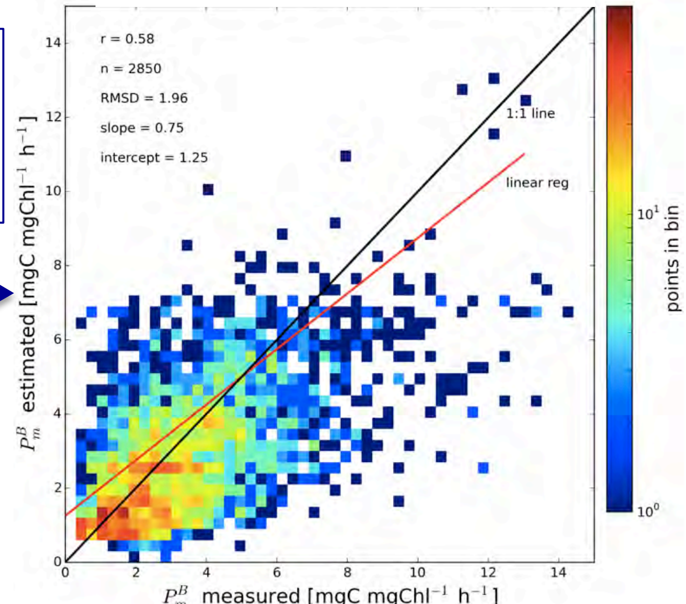
Photosynthesis Irradiance Parameters from Space

MAPPS



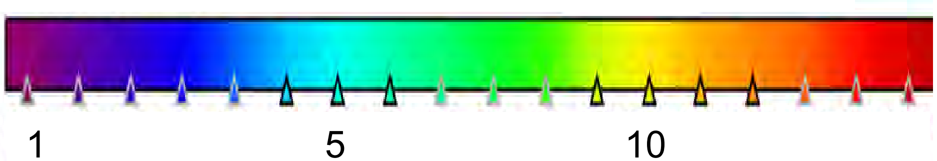
SST
PAR
Chl

Modelled Parameters



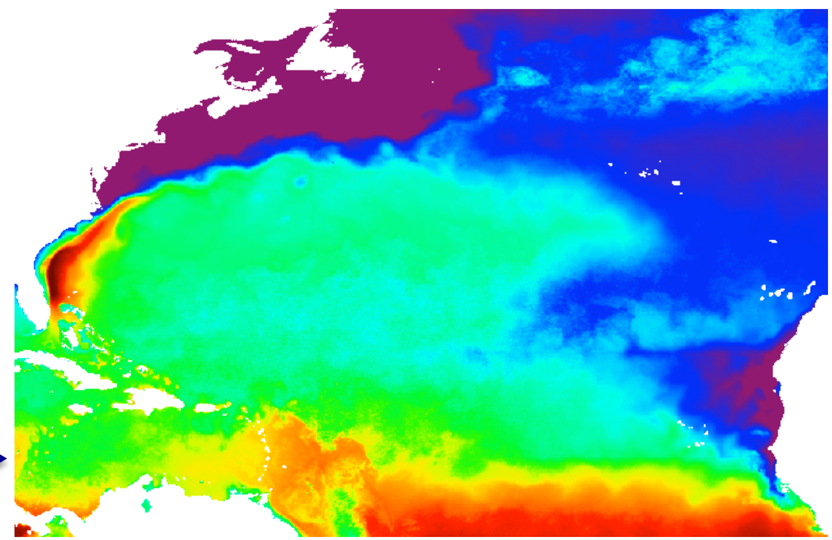
In situ database:
Bouman, Platt, Doblin,Gudmundsson, Hickman, Hiscock, Jackson, Lutz, Mélin, Rey, Pepin, Segura, Tilstone, Uitz, van Dongen-Vogels, Sathyendranath

Assimilation Number (mg C Chl^{-1} h^{-1})



Global satellite products of photosynthesis-irradiance parameters

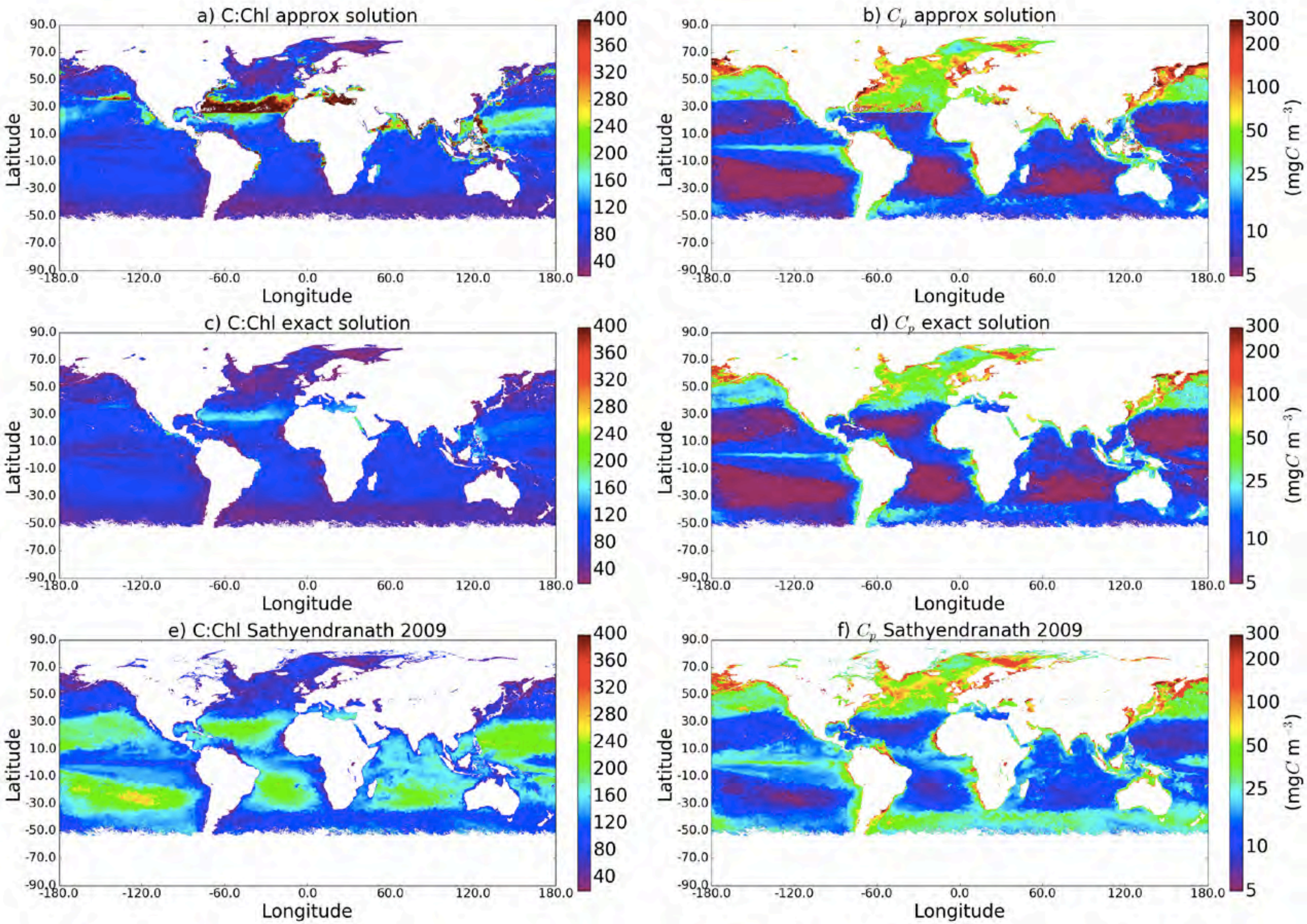
ESA MAPPS PROJECT



Phytoplankton Carbon and Carbon-to-Chlorophyll Ratio: Comparison of some empirical and physiological models

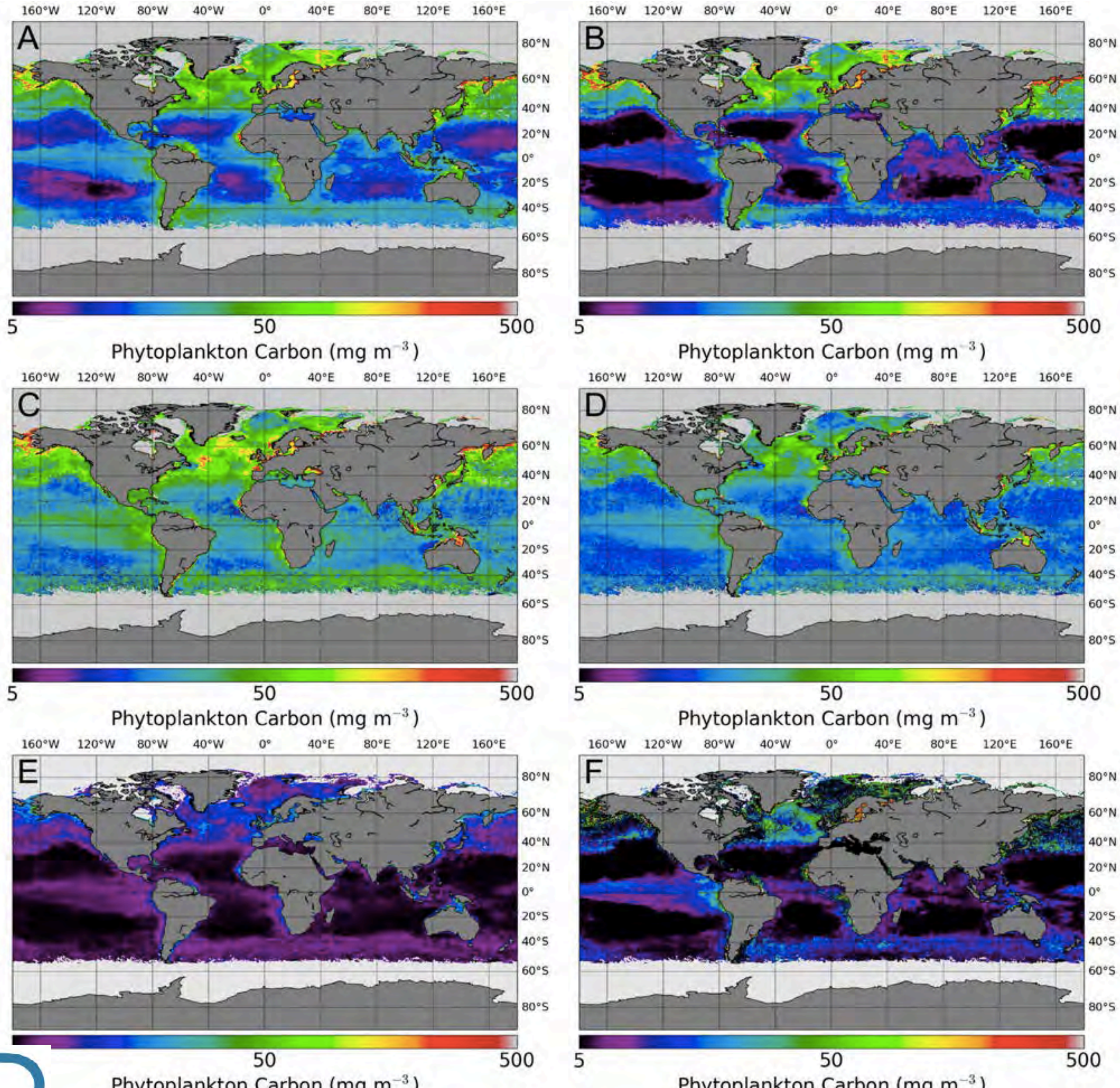
MAPPS

Carbon-to-Chlorophyll Ratio | **Phytoplankton Carbon**



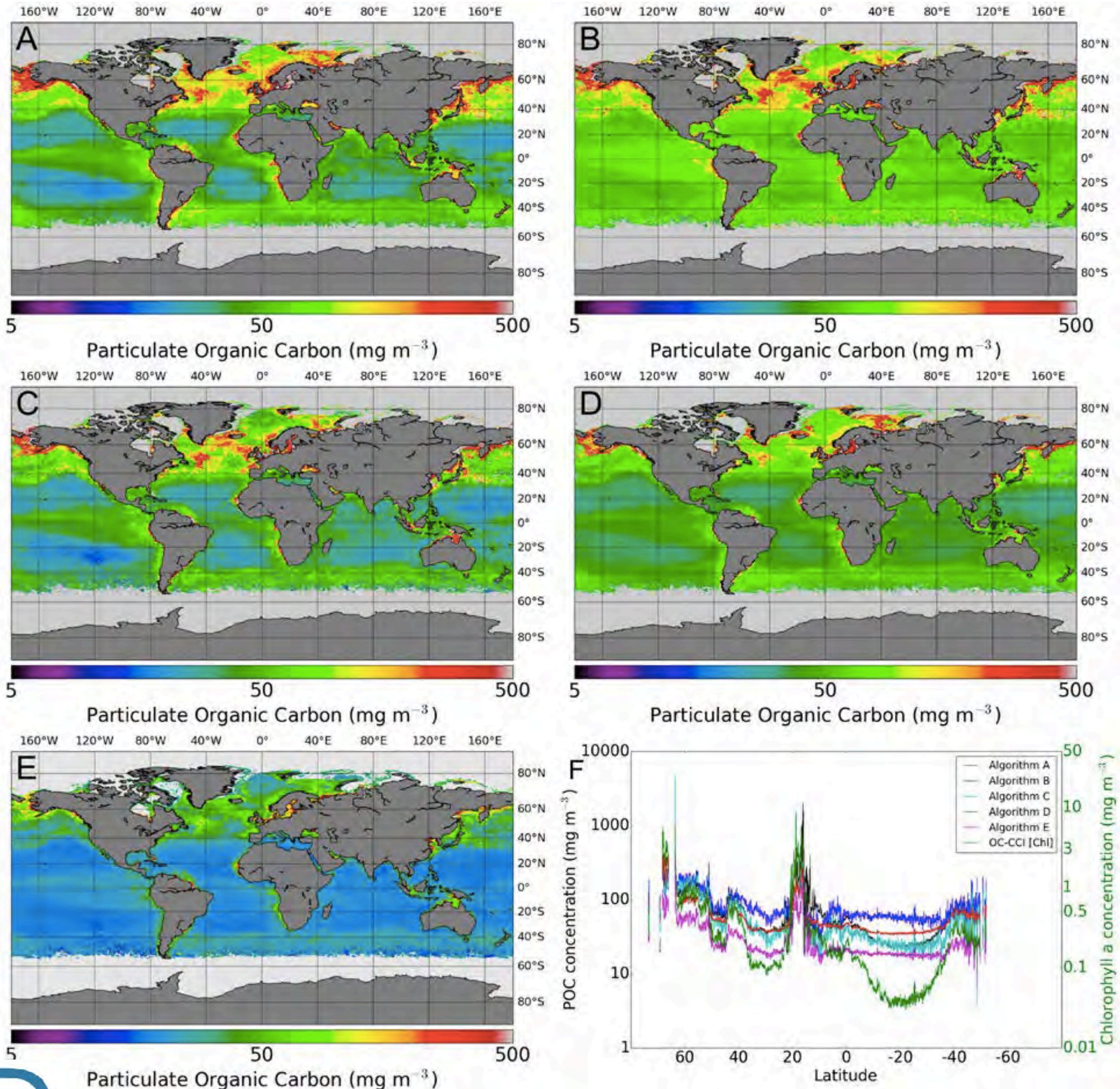
Jackson et al. (2017) CLEO Special Issue (under review)

Comparison of Algorithms for Phytoplankton Carbon (PC) from Ocean Colour



Martinez-Vicente et al. 2017 CLEO Special Issue (submitted)

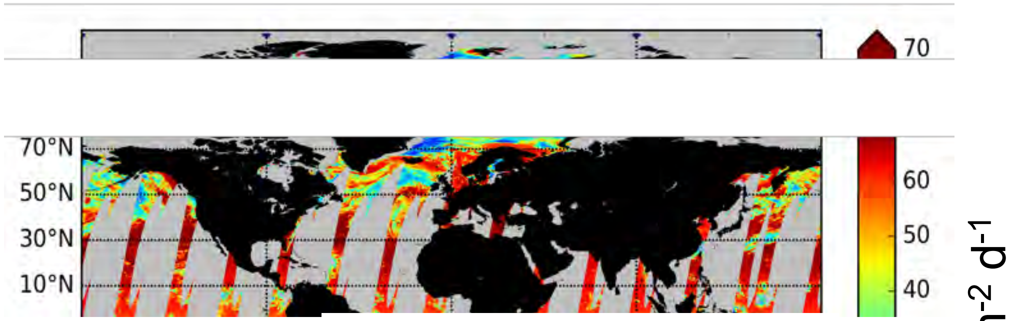
Comparison of algorithms for Particulate Organic Carbon (POC) from Ocean Colour



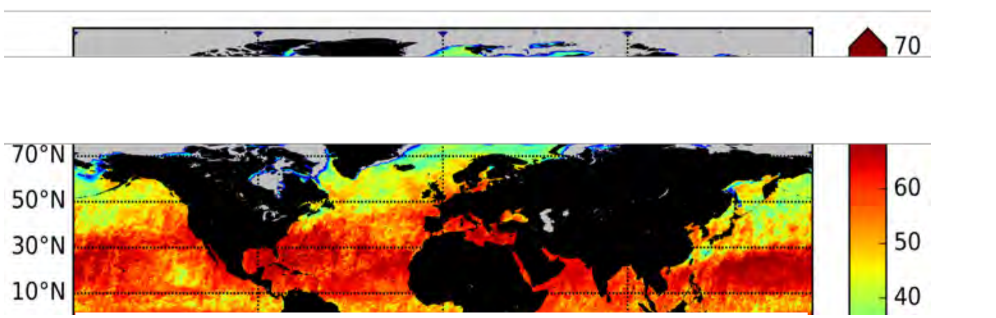
Evers-King et al. 2017 CLEO Special Issue (under review)

New PAR Product for MERIS

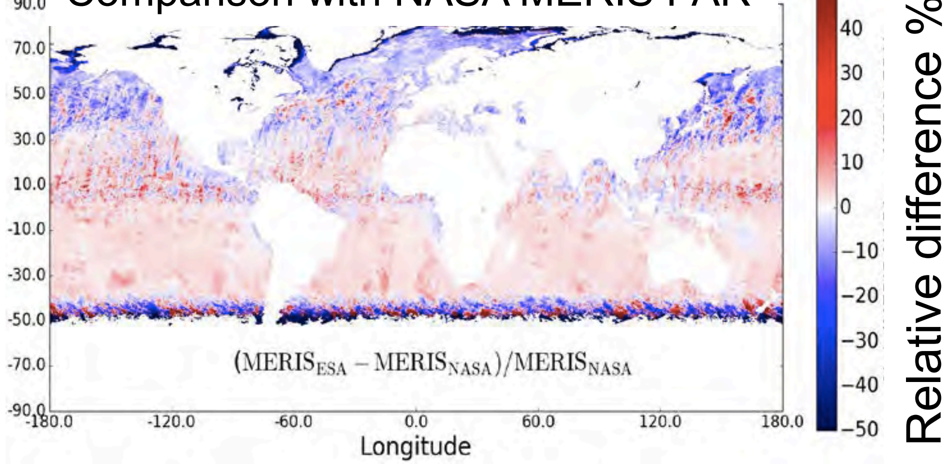
Daily: May 15, 2011



Monthly: May 1-31, 2011



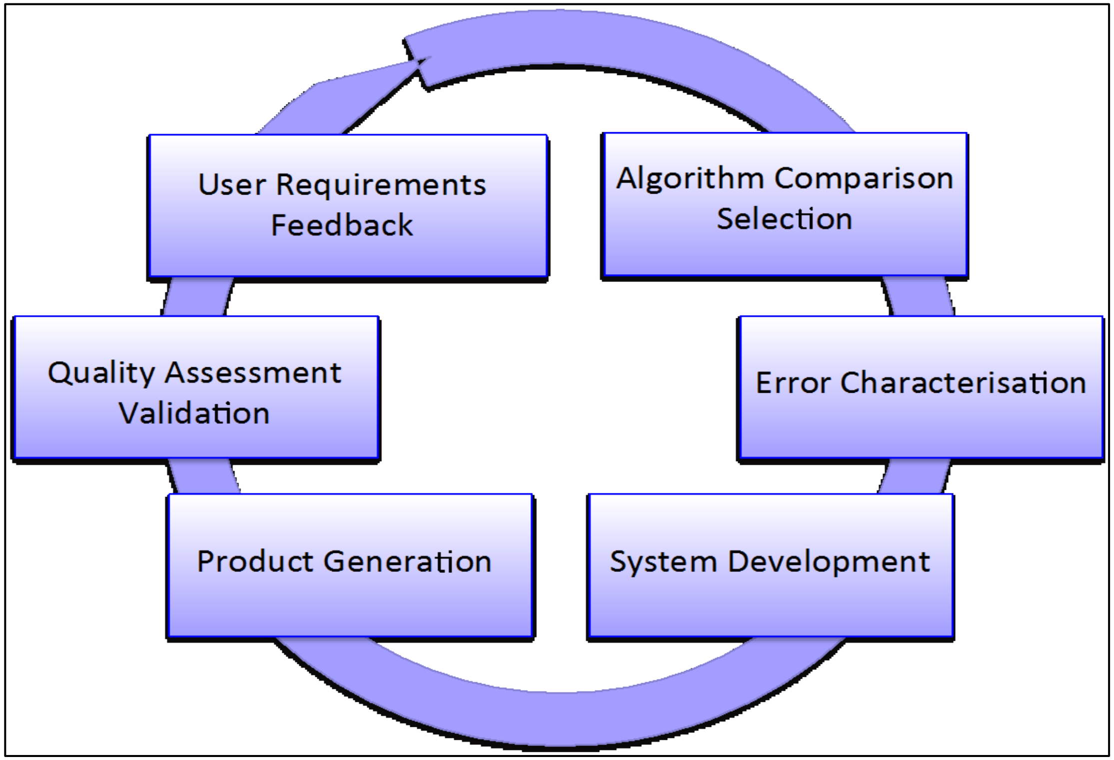
Comparison with NASA MERIS PAR



- Above-water PAR comparable to NASA MERIS PAR.
- Scalar PAR below surface, 0.1° spatial resolution derived from MERIS.
- Spectral an directional PAR can be derived from look-up-tables of clear and total overcast skies, latitude, date and wind speed.
- Being evaluated currently by some users
- Precursor for an OLCI product

Frouin et al. 2017, Platt et al. 2017, CLEO Special Issue

The future of OC-CCI



What sets OC-CCI apart from the perspective of the climate user?

- Improved coverage (studies of phenology)
- Uncertainty estimates on a per-pixel basis (data assimilation)
- Inter-sensor bias correction (trend analysis)
- Band-shifting (algorithm implementation)
- Rigorous, quantitative algorithm selection (all applications)

OC-CCI was conceived as a system in dynamic evolution.

Future lies with CCCS and CCI+

- Important to keep products up-to-date and current
- Coastal products have to be improved
- Sentinel series have to be incorporated
- Synergy with other ECVs has to be exploited
- Extension to inland water bodies important
- Extension of product line (primary production, carbon, PFTs) is crucial for user engagement
- In situ validation programmes have to keep pace with expanding products (e.g. photosynthesis parameters)

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