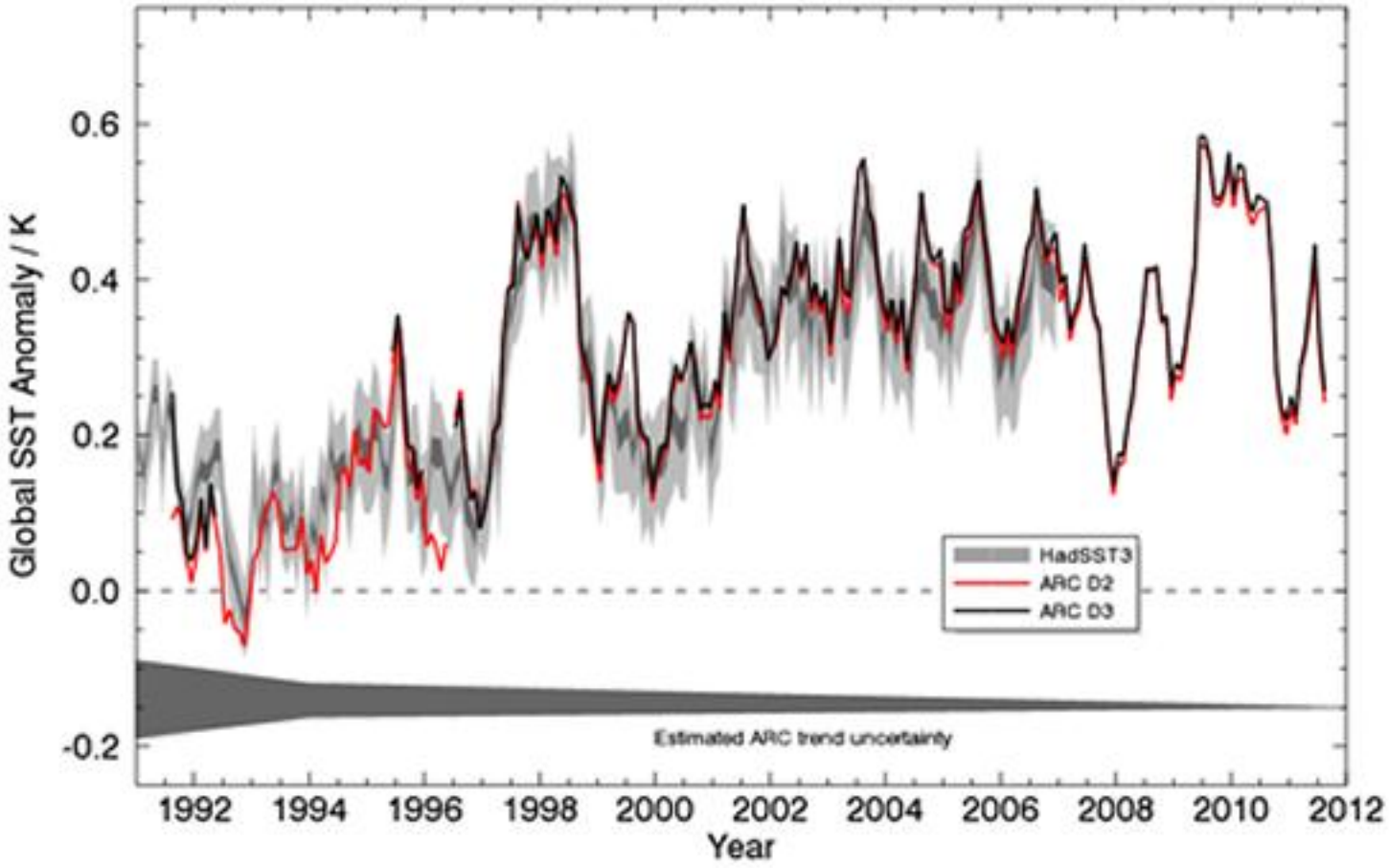
Ocean Colour and Climate

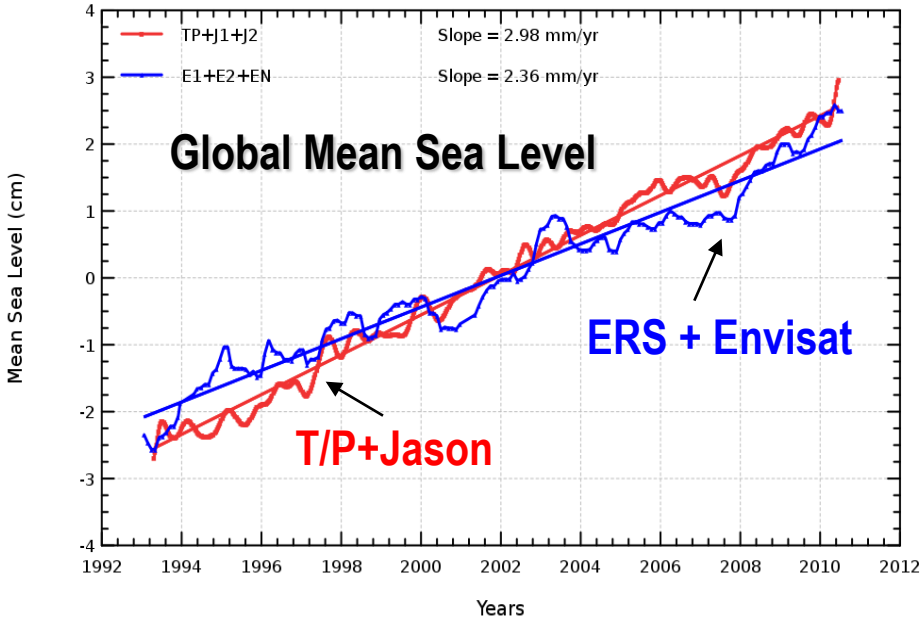
Shubha Sathyendranath and Trevor Platt

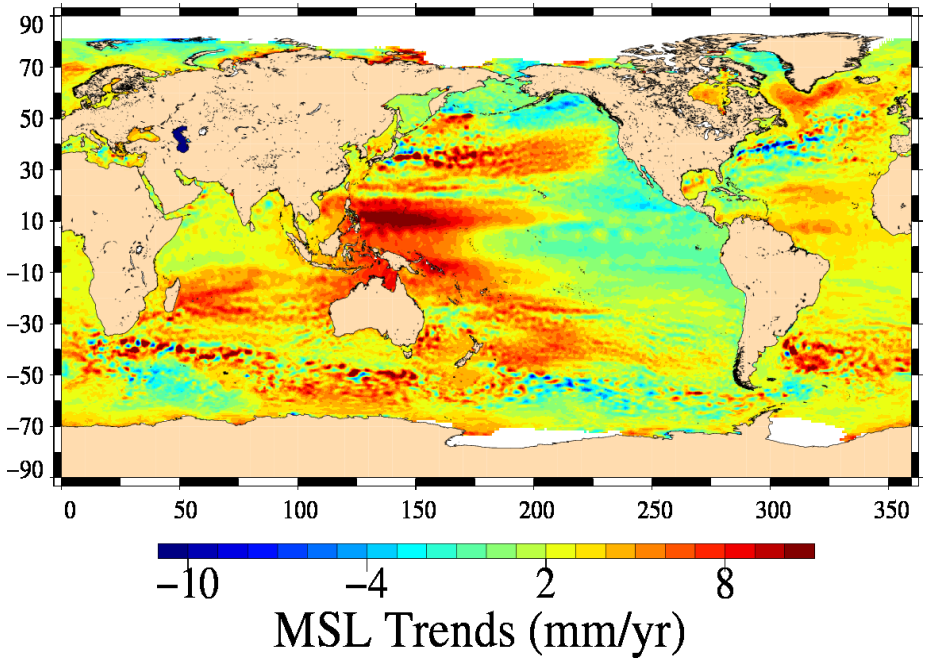
SST Trends



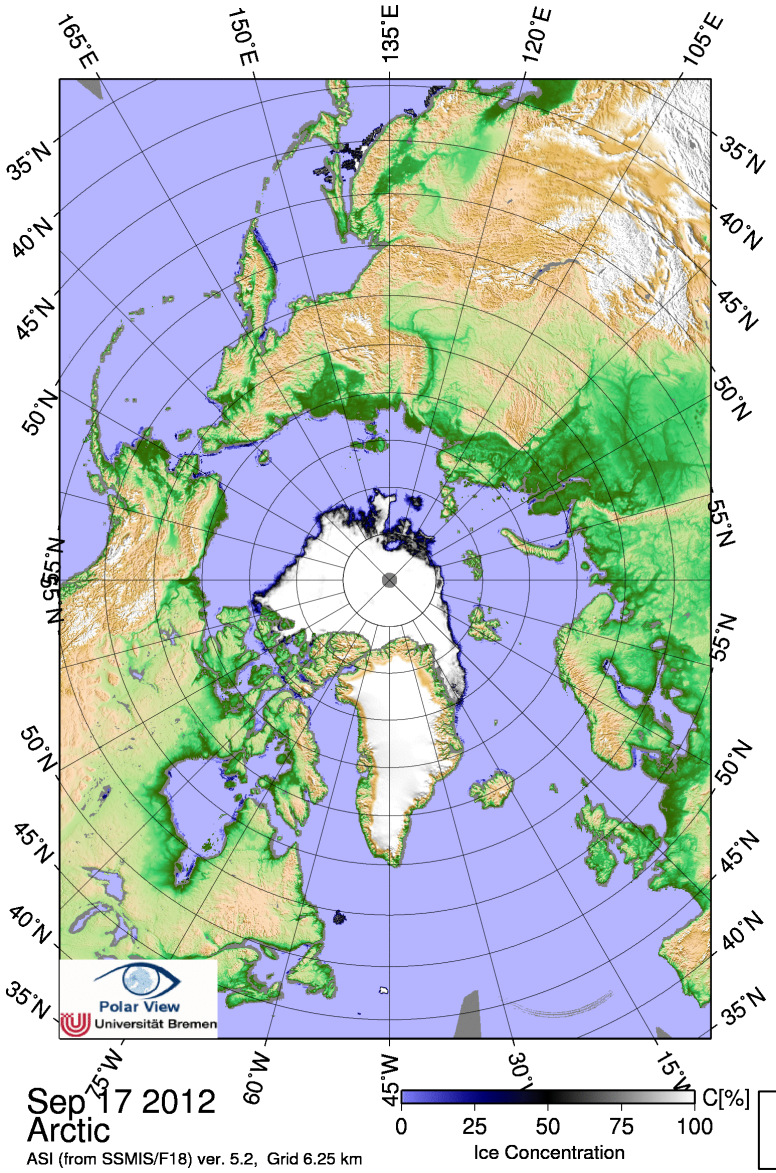
From SST CCI website

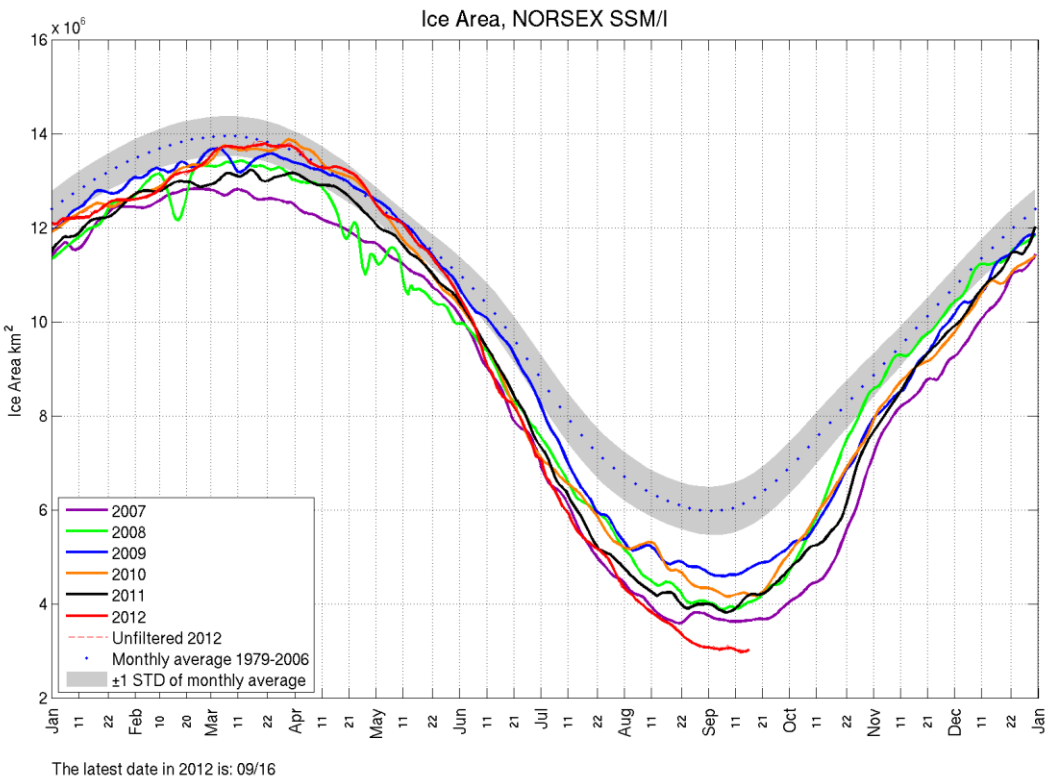
Results from SL-CCI Project





Record low Arctic sea ice extent in September 2012





September shows the lowest ice area in the Arctic since satellite observation started in 1979.

Figure courtesy NERSC and http://arctic-roos

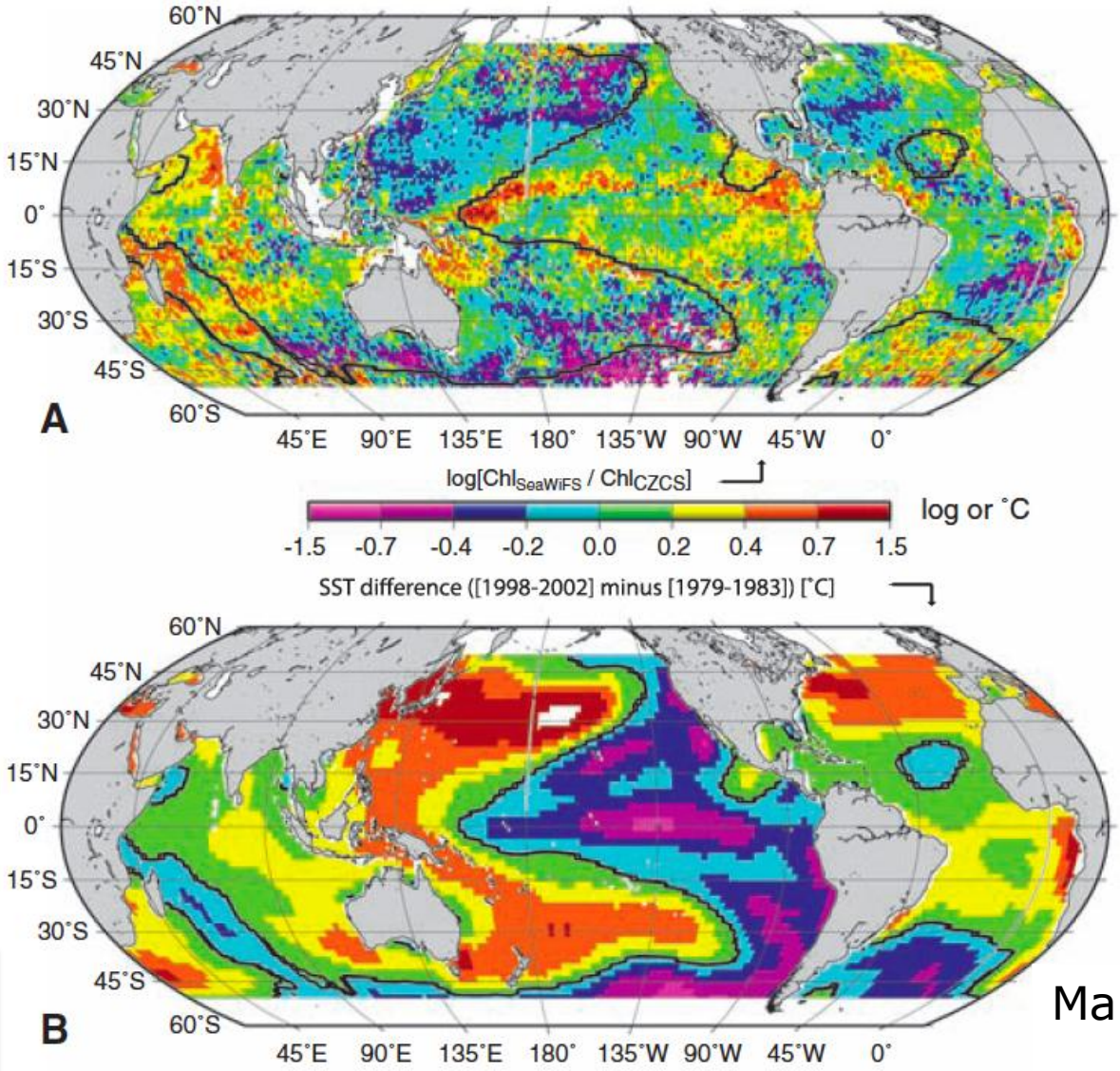
Ocean colour sensors are designed to study the marine ecosystem

What are the key properties of the marine ecosystem that are vulnerable to climate change and can be detected using satellite data?

Can we design a time series fit for purpose?

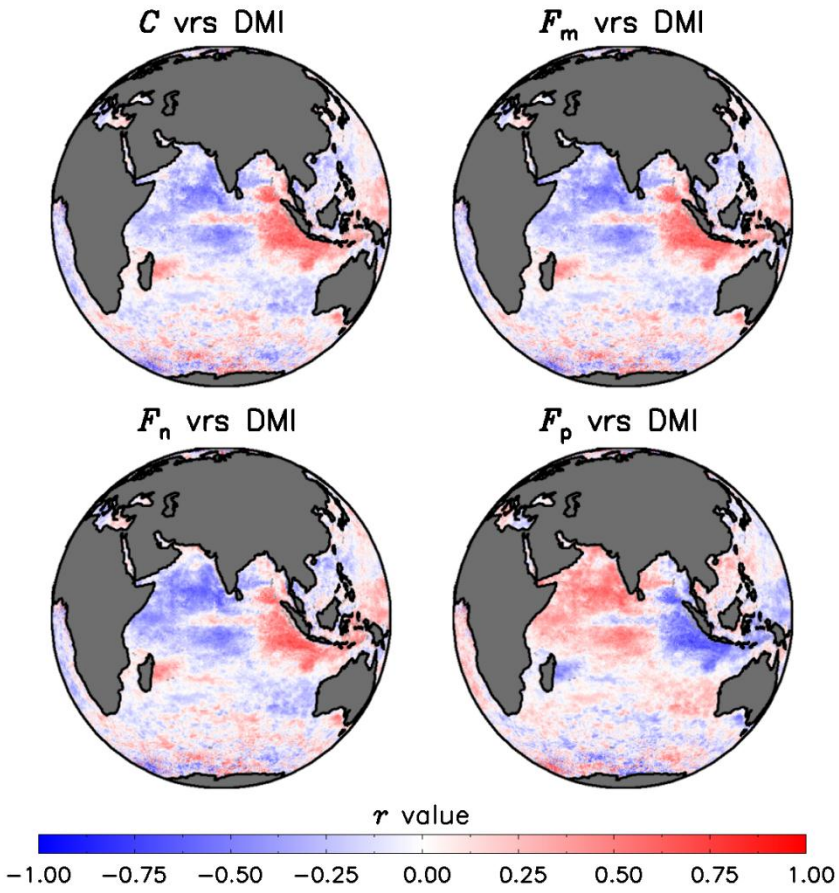
Results from the Ocean-Colour Climate Change Initiative of the European Space Agency

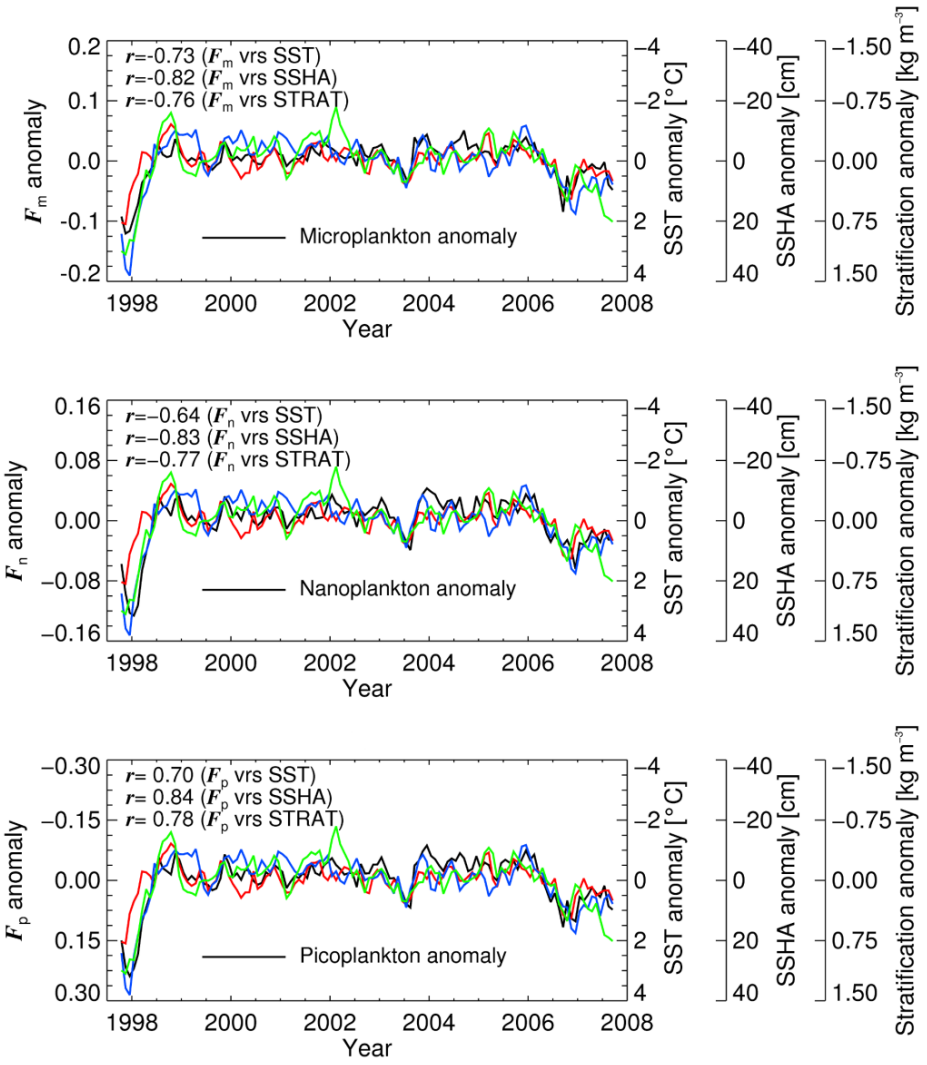
Multi-decadal changes in chlorophyll concentration related to changes in SST



Martinez et al. (2009)

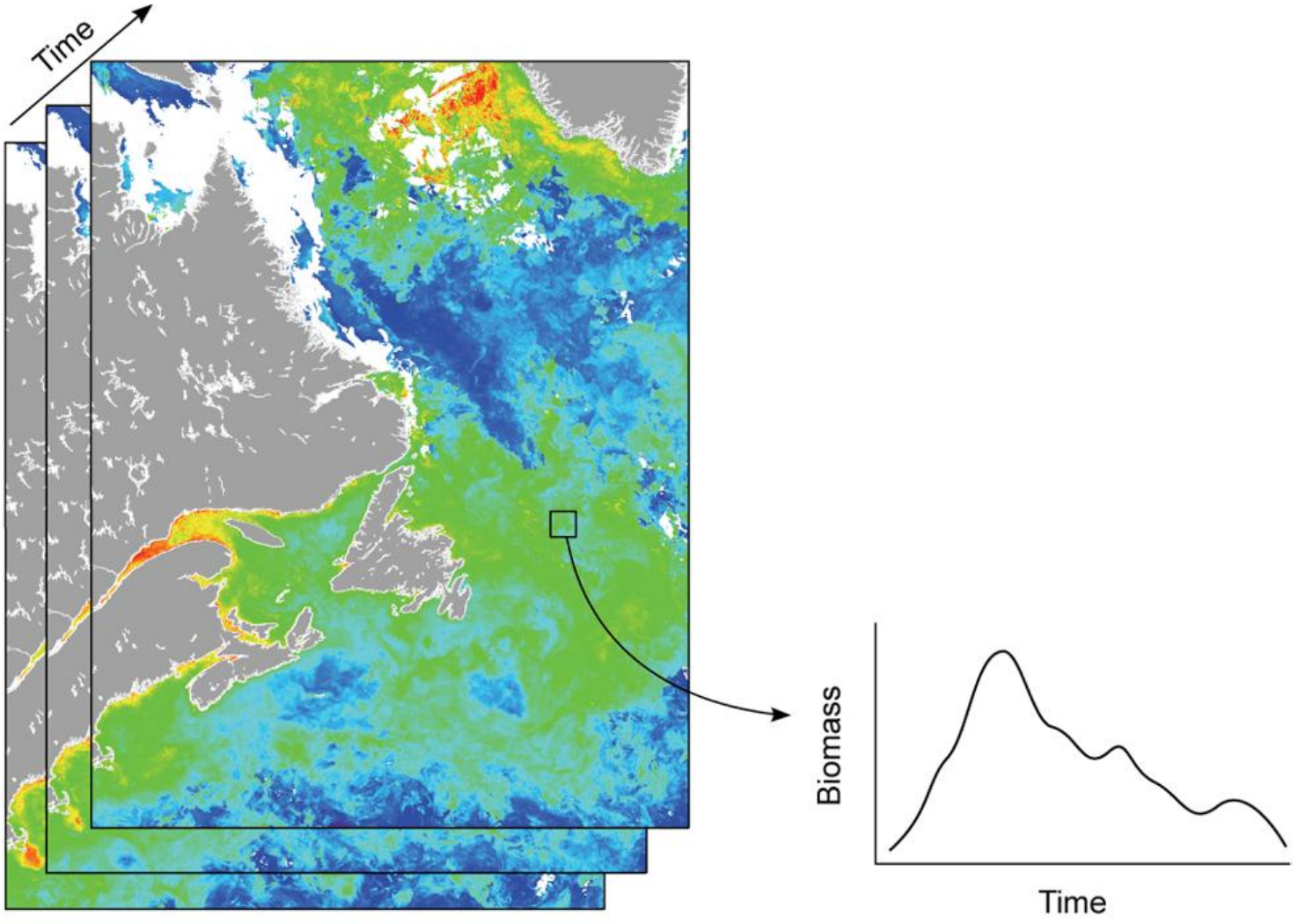
Diagnose changes in phytoplankton size structure using EO

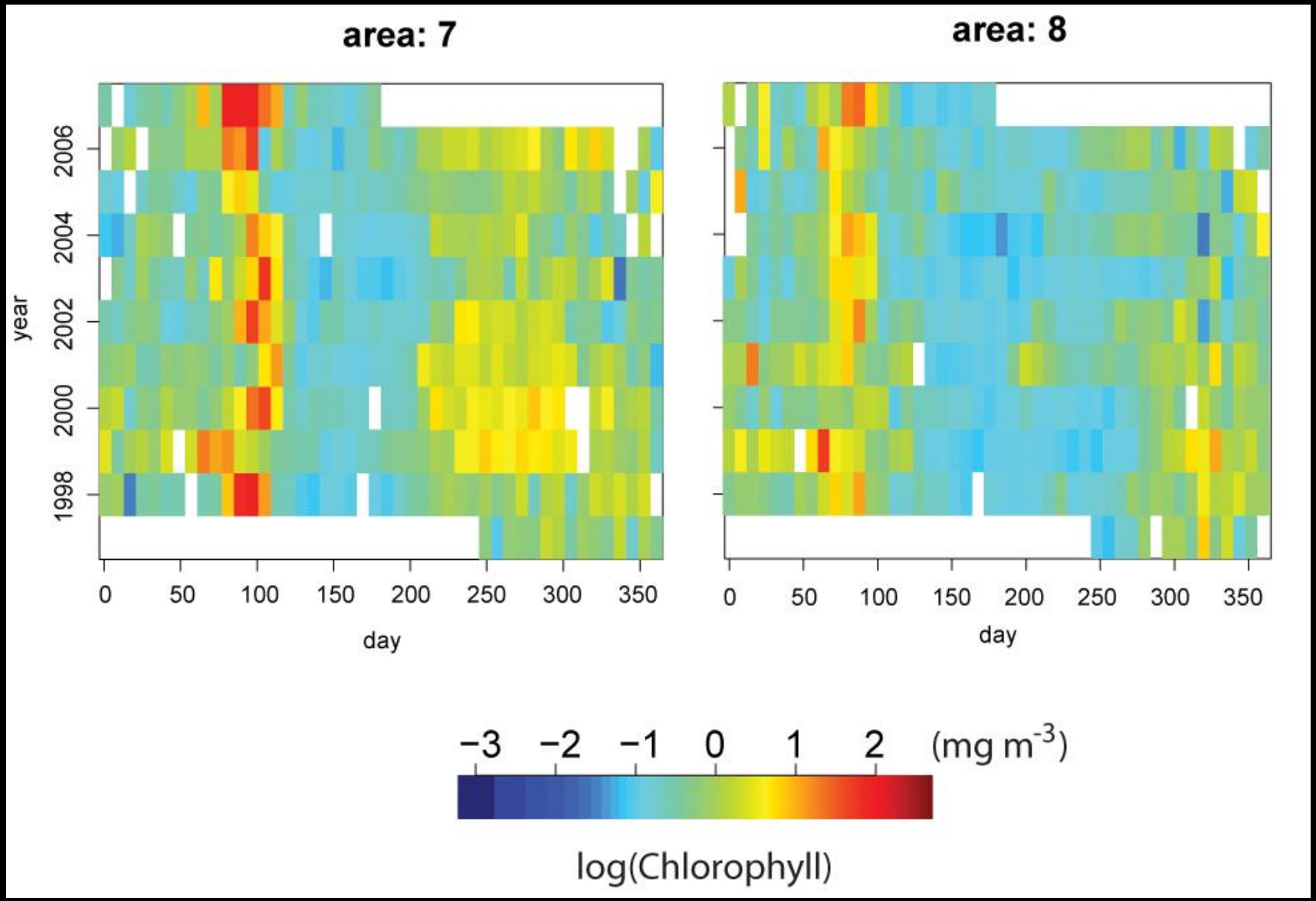




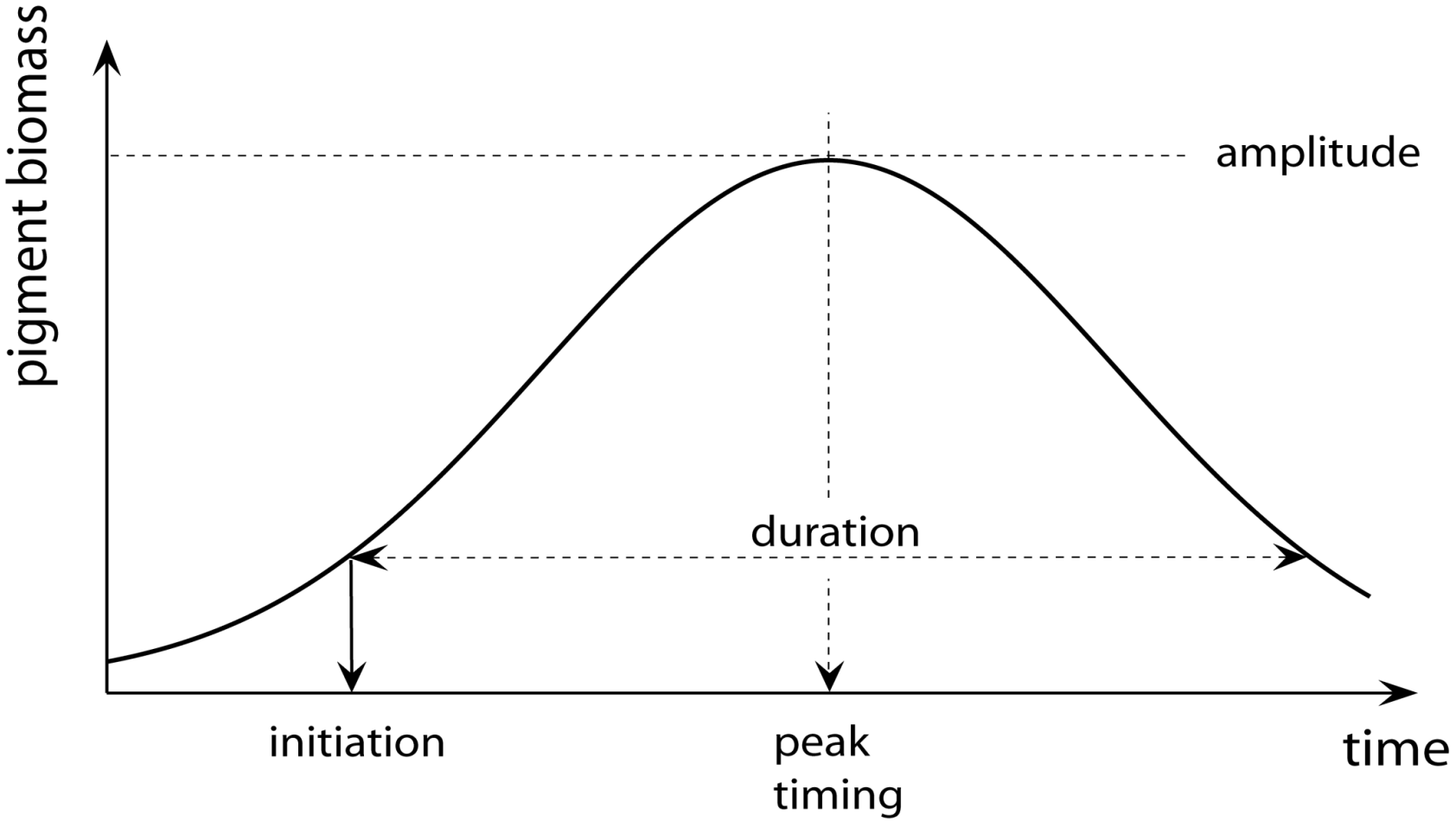
Brewin et al. (DSR 2012)

Construction of time series possible at any chosen scale of spatial averaging




area: 7
area: 8
year
1998
2000
2002
2004
2006
0
50
100
150
200
250
300
350
day
−3
−2
−1
0
1
2
(mg m-3)
log(Chlorophyll)

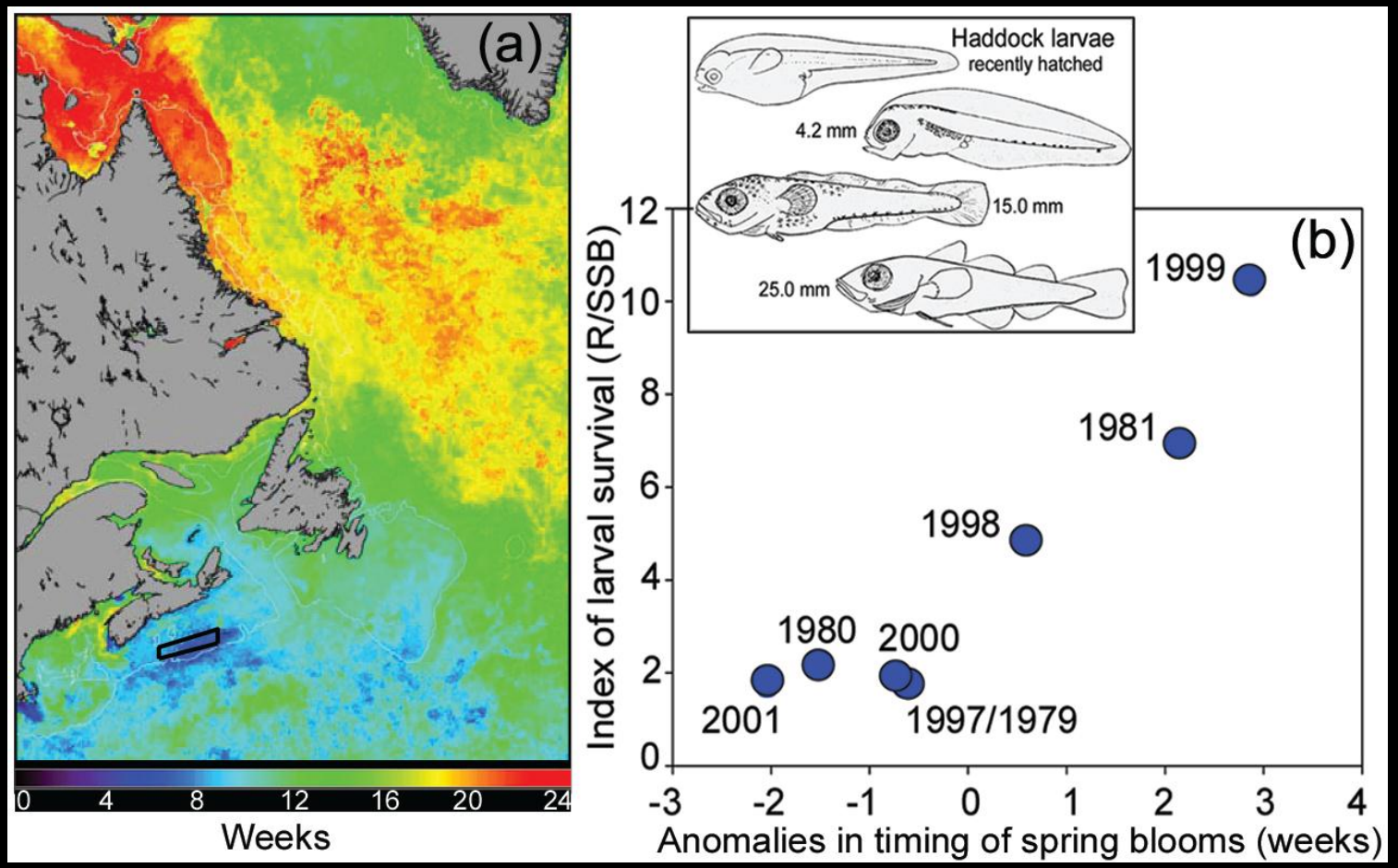
Quantifying the Seasonality



Any or all of these indices may vary between years
(at any or all of the pixels in the region of interest)

Platt, Sathyendranath & Fuentes-Yaco, 2007

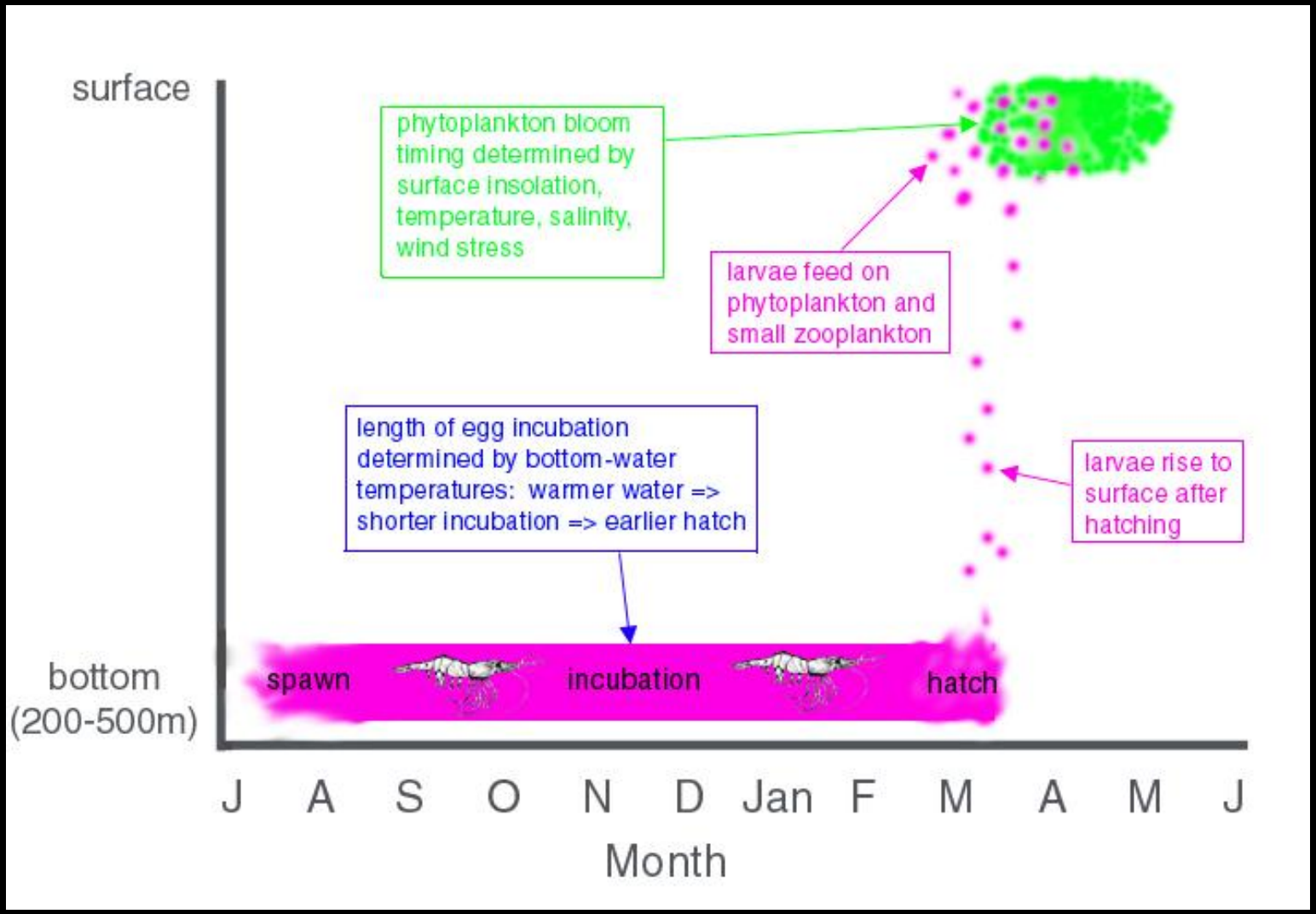
Inter-annual variations in the timing of the spring bloom impacts survival of larval fish (Platt *et al.* 2003)



Unusually early spring blooms in 1981 & 1999 resulted in exceptional haddock year-classes

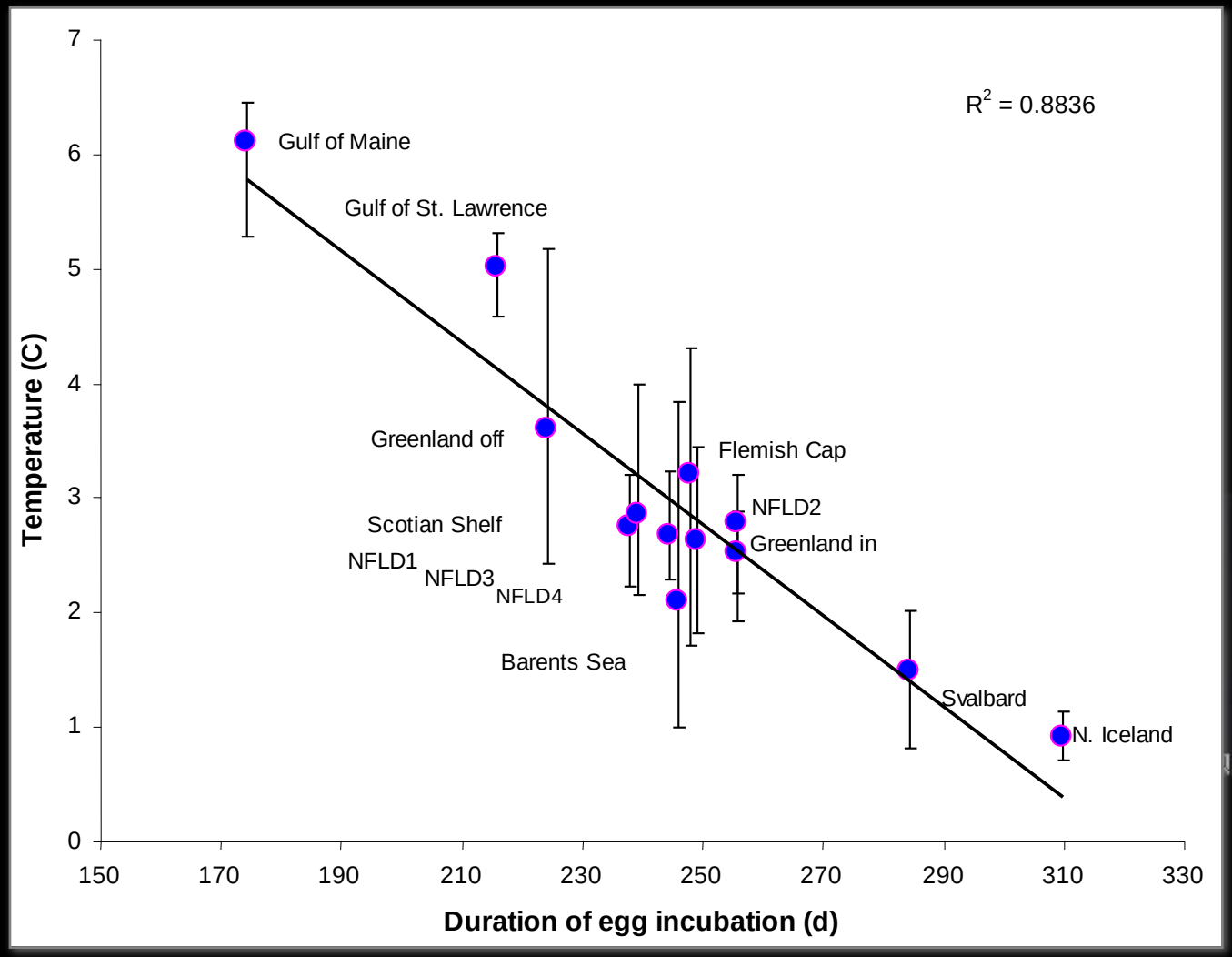
Application of time-series data applied to study growth, survival and distribution of Northern shrimp

Life Cycle of Northern Shrimp

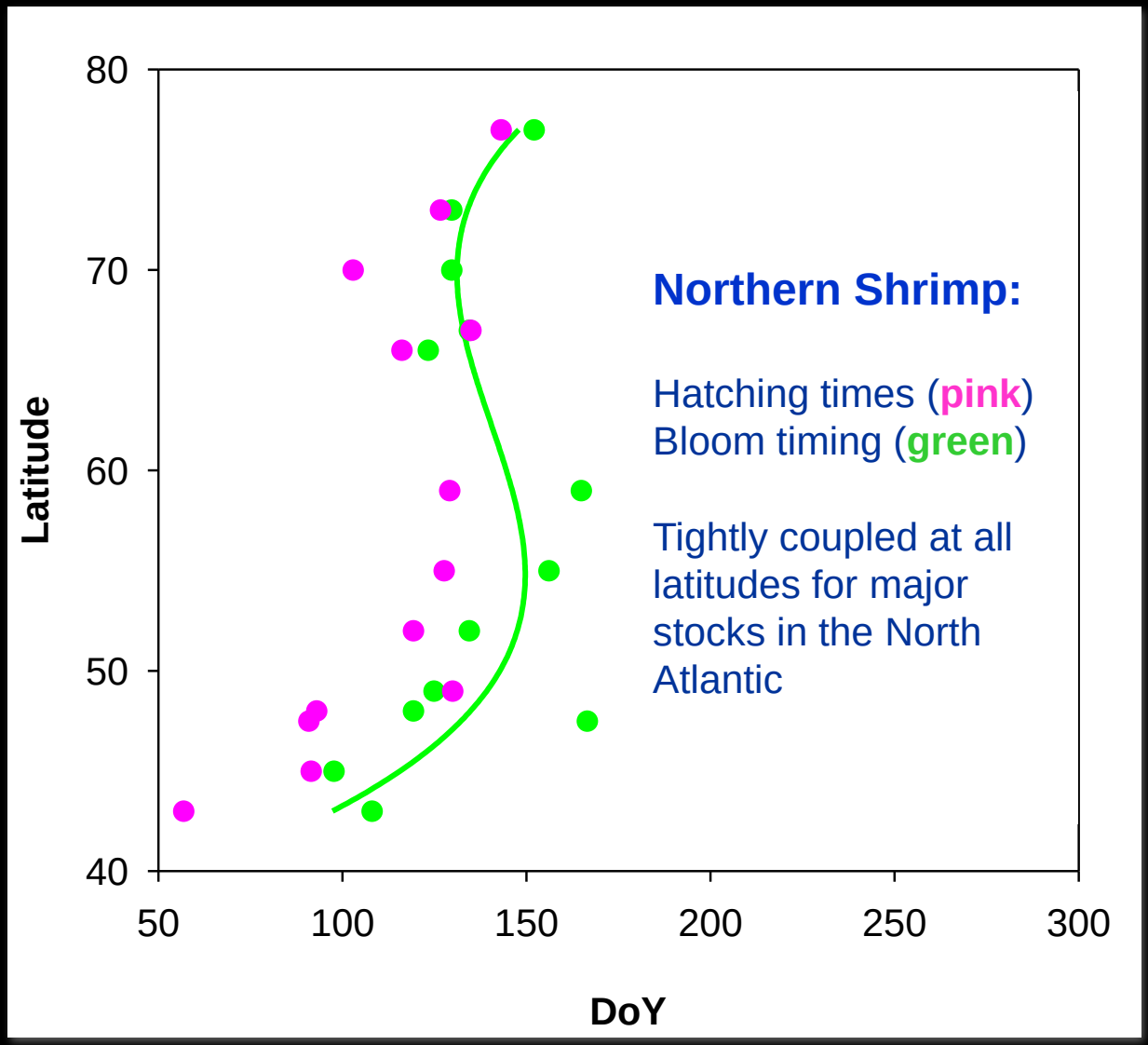


Koeller *et al*. 2006; Fuentes-Yaco *et al*. 2006; Koeller *et al*. 2009

Northern Shrimp: Duration of egg incubation time related to bottom-water temperature for major stocks in North-West Atlantic



Koeller, Fuentes–Yaco, Platt, Sathyendranath and others (submitted)



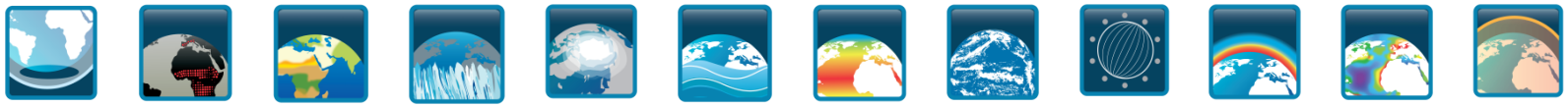
Koeller, Fuentes-Yaco, Platt, Sathyendranath and others. Science. 2009

Potential Responses of the Marine Ecosystem to a Changing Climate

We see that, in a changing climate,

- Total amount of phytoplankton (as indexed by chlorophyll-a concentration) might change
- The community structure associated with the chlorophyll concentration might change
- Other substances that absorb and scatter light in the visible domain might change, relative to chlorophyll-a
- The phenology might change (e.g. timing, amplitude and duration of blooms)

These considerations guided the algorithm selection process in the Ocean Colour Climate Change Initiative.

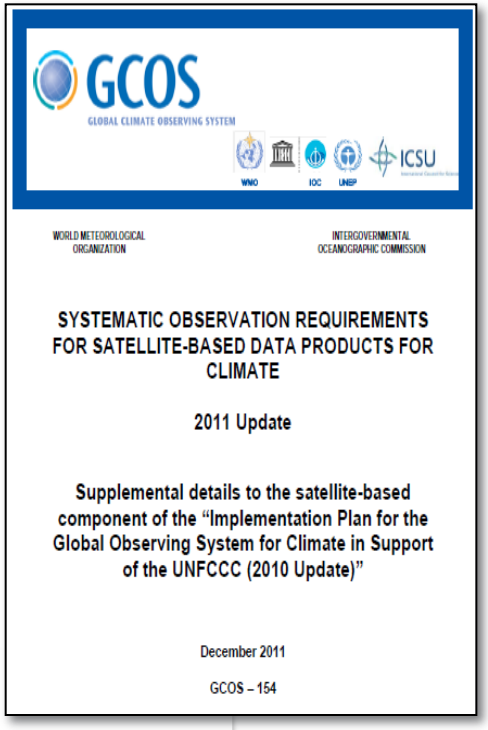


GCOS Ocean Colour requirements: a major challenge

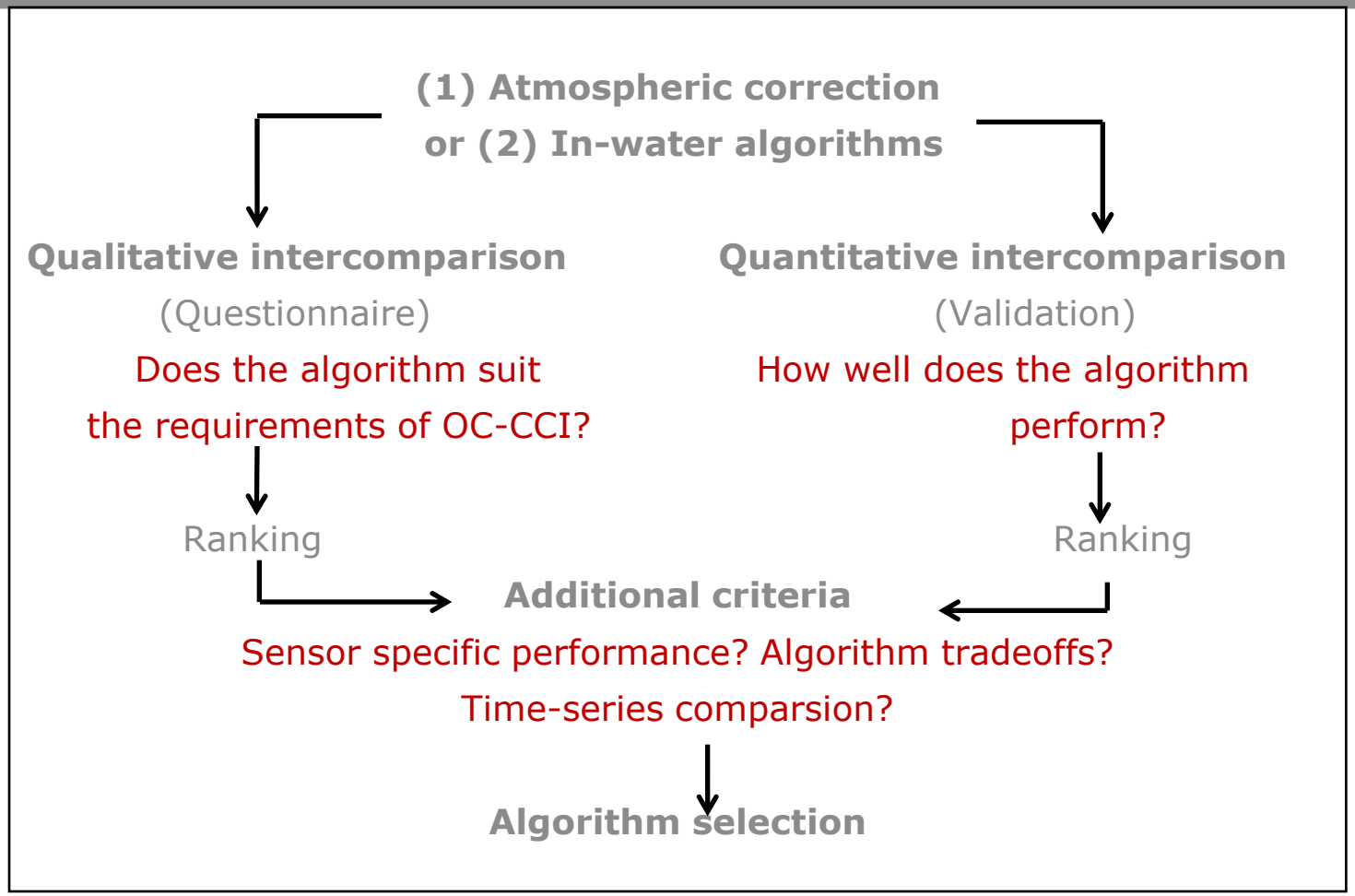
Goal: create the most complete and consistent possible error-characterized time series of multi-sensor global satellite ECV products for climate research and modeling meeting GCOS requirements

GCOS-154 updated December 2011					
Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
Water Leaving Radiance	**4km**	**N/A**	**daily**	**5%**	**0.5%**
Chlorophyll-a concentration	**30km**	**N/A**	**weekly averages**	**30%**	**3%**

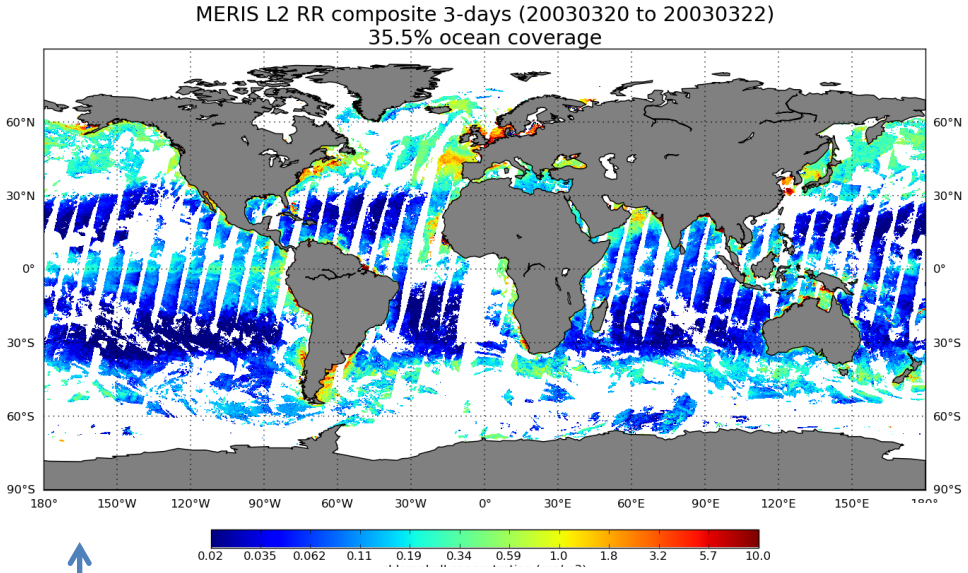
Note: OC-CCI to create time series of inherent optical properties as well.


GCOS
GLOBAL CLIMATE OBSERVING SYSTEM
WMO IOC UNEP ICSU
WORLD METEOROLOGICAL ORGANIZATION
INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED DATA PRODUCTS FOR CLIMATE
2011 Update
Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)"
December 2011
GCOS – 154

Intercomparison Criteria



Atmospheric correction algorithm



Chlorophyll concentration (mg m^{-3})

MEGS ocean coverage:35.5%
POLYMER ocean coverage: 73%

Example: Three-day composite Chlorophyll concentration (20-03-2003 to 22-03-2003)

Note: Verification on-going. For example, are all high-latitude values reliable?

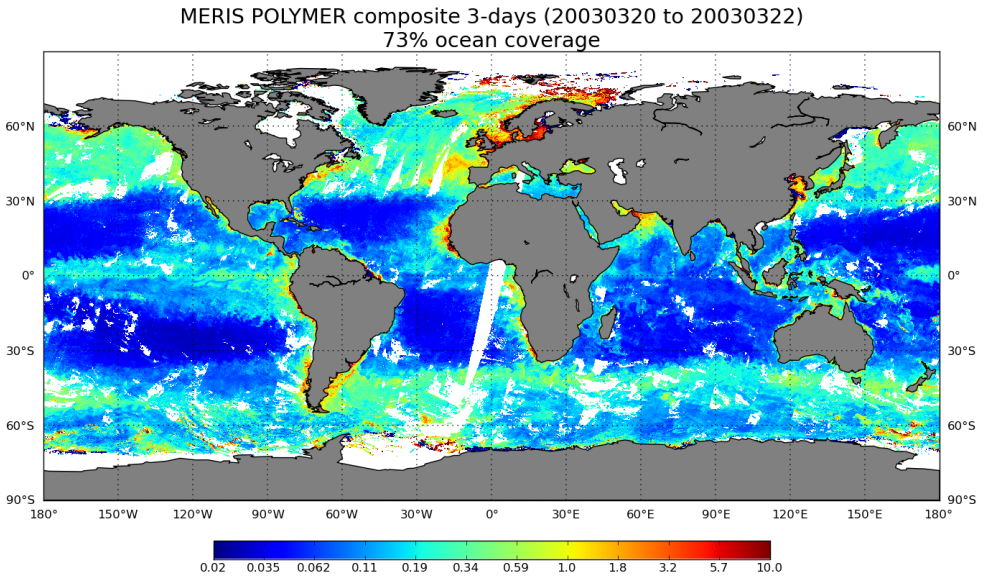
POLYMER:

Selected Atmospheric Correction Algorithm for MERIS

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

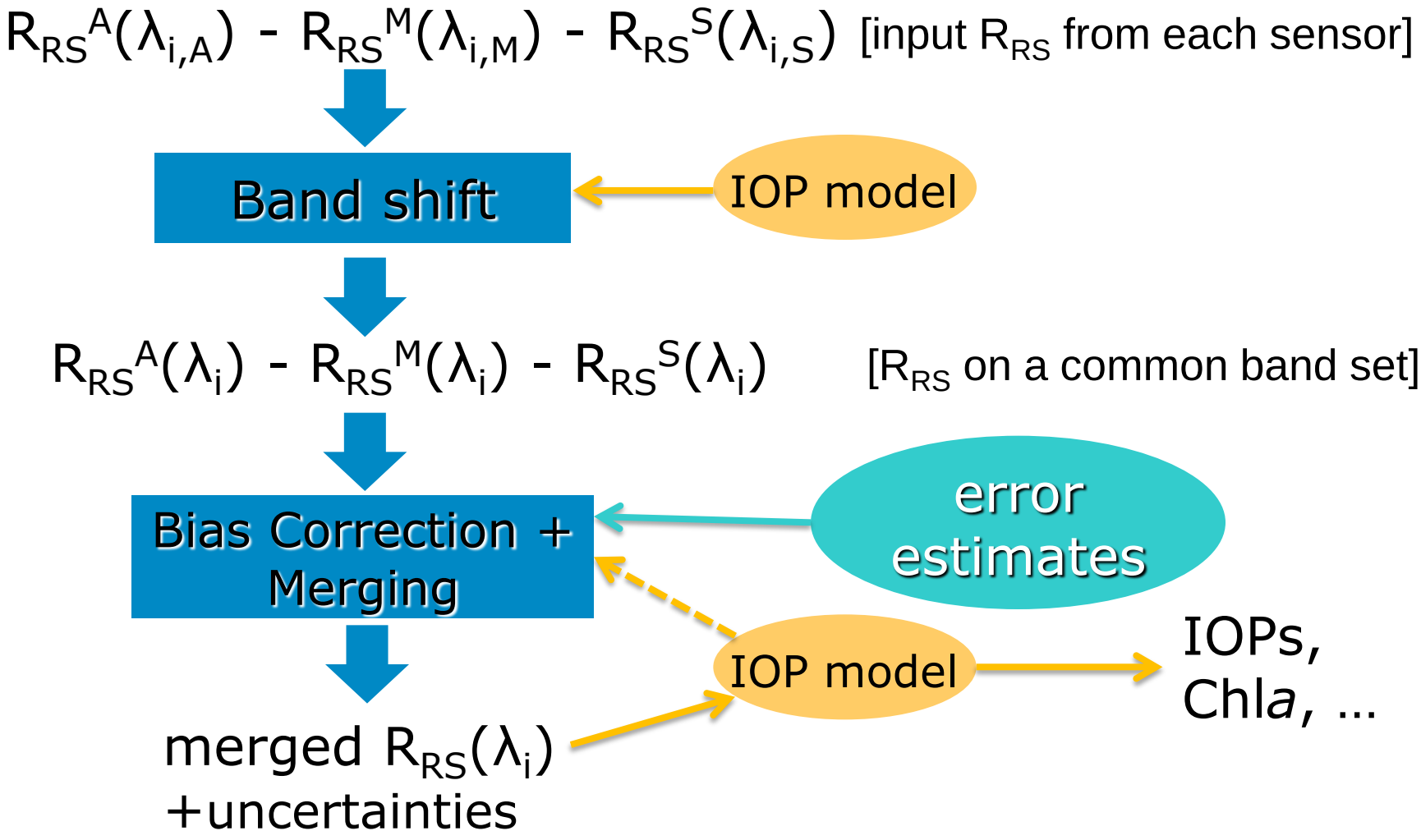
Note: MyOcean will be using OC-CCI products as standard products

Directly applicable to Sentinel-3 OLCI

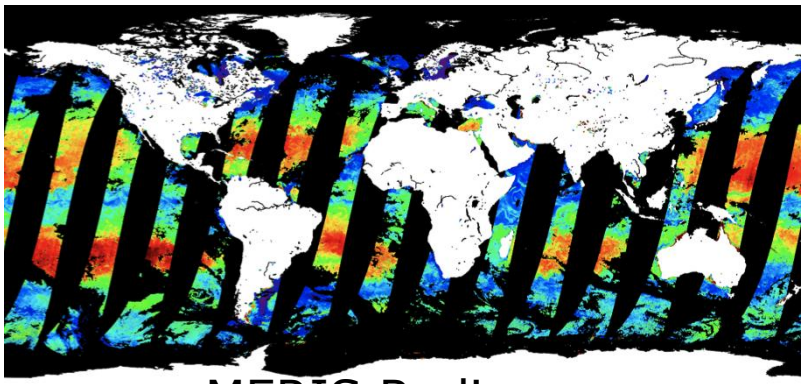


Chlorophyll concentration (mg m^{-3})

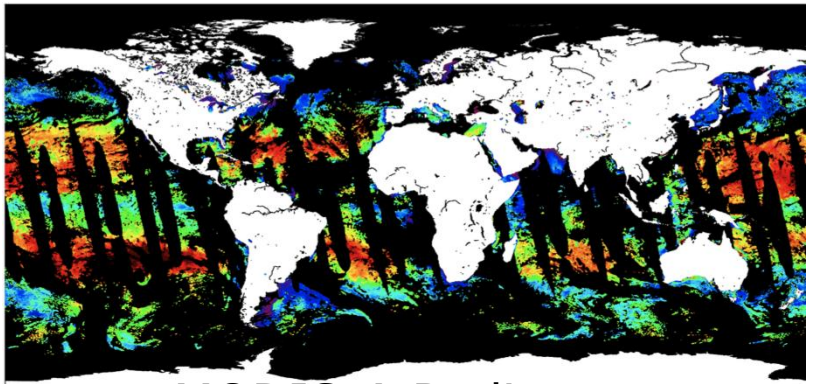
OC-CCI Data Merging: Approach



The Merged Product

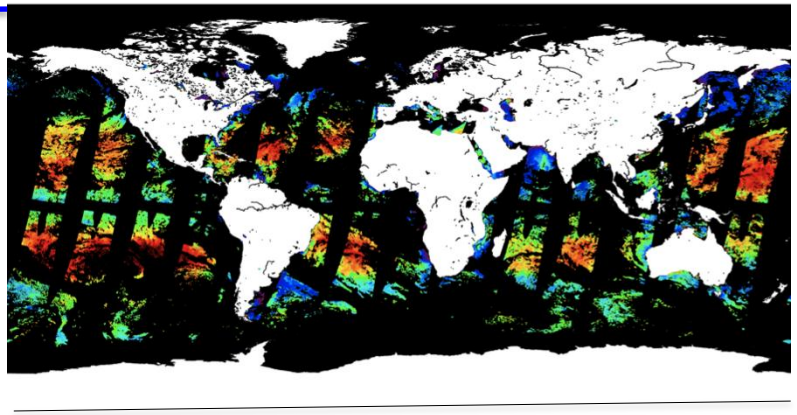


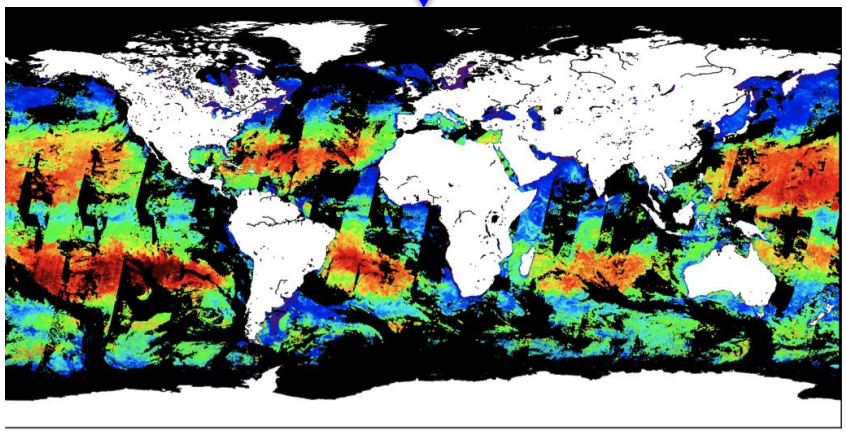
MERIS Radiance



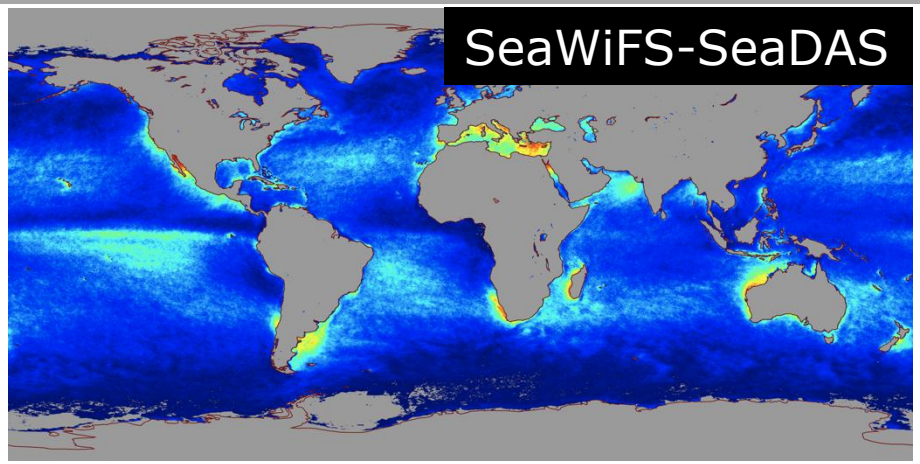
MODIS-A Radiance

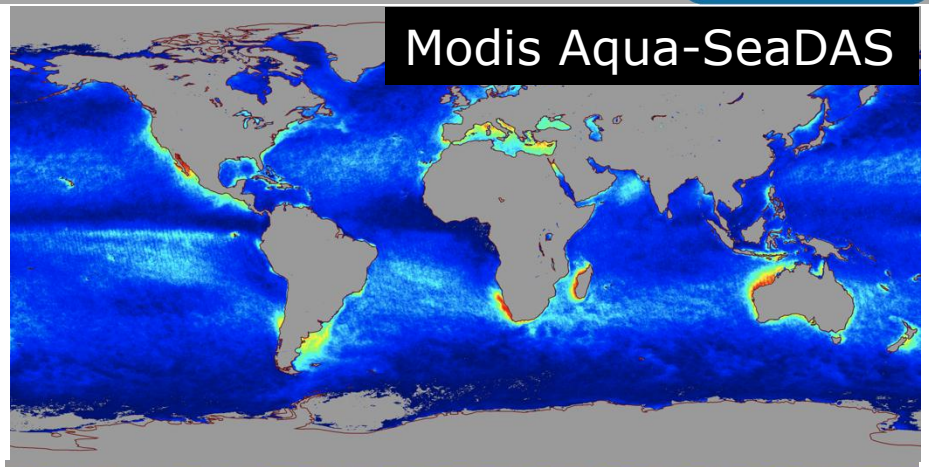
Band-shifting, bias correction,
Merged product

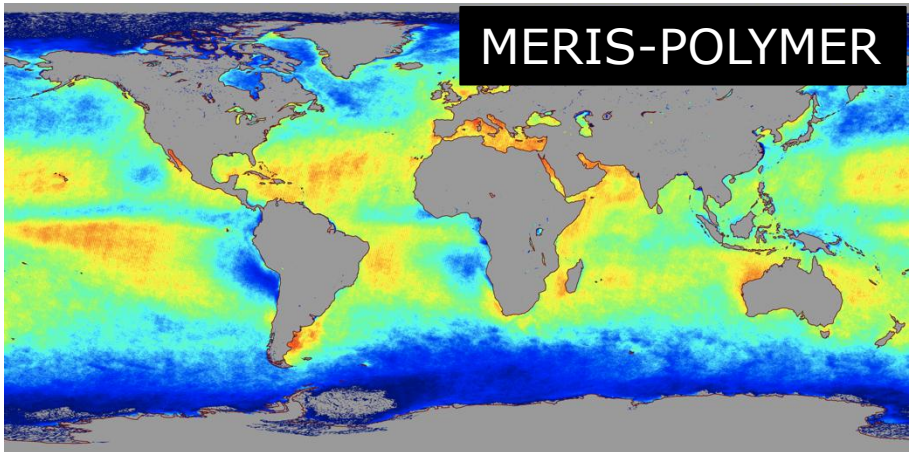


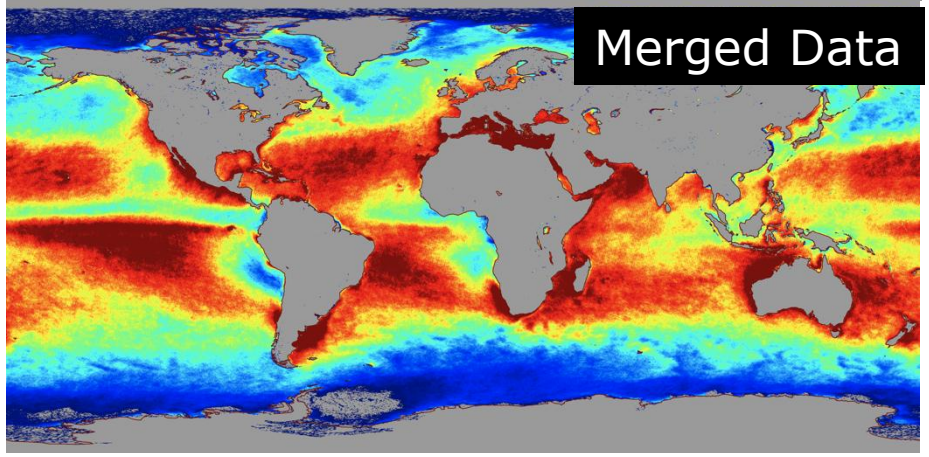


Geographic distribution of frequency of coverage of retrieved data

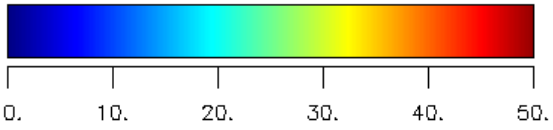




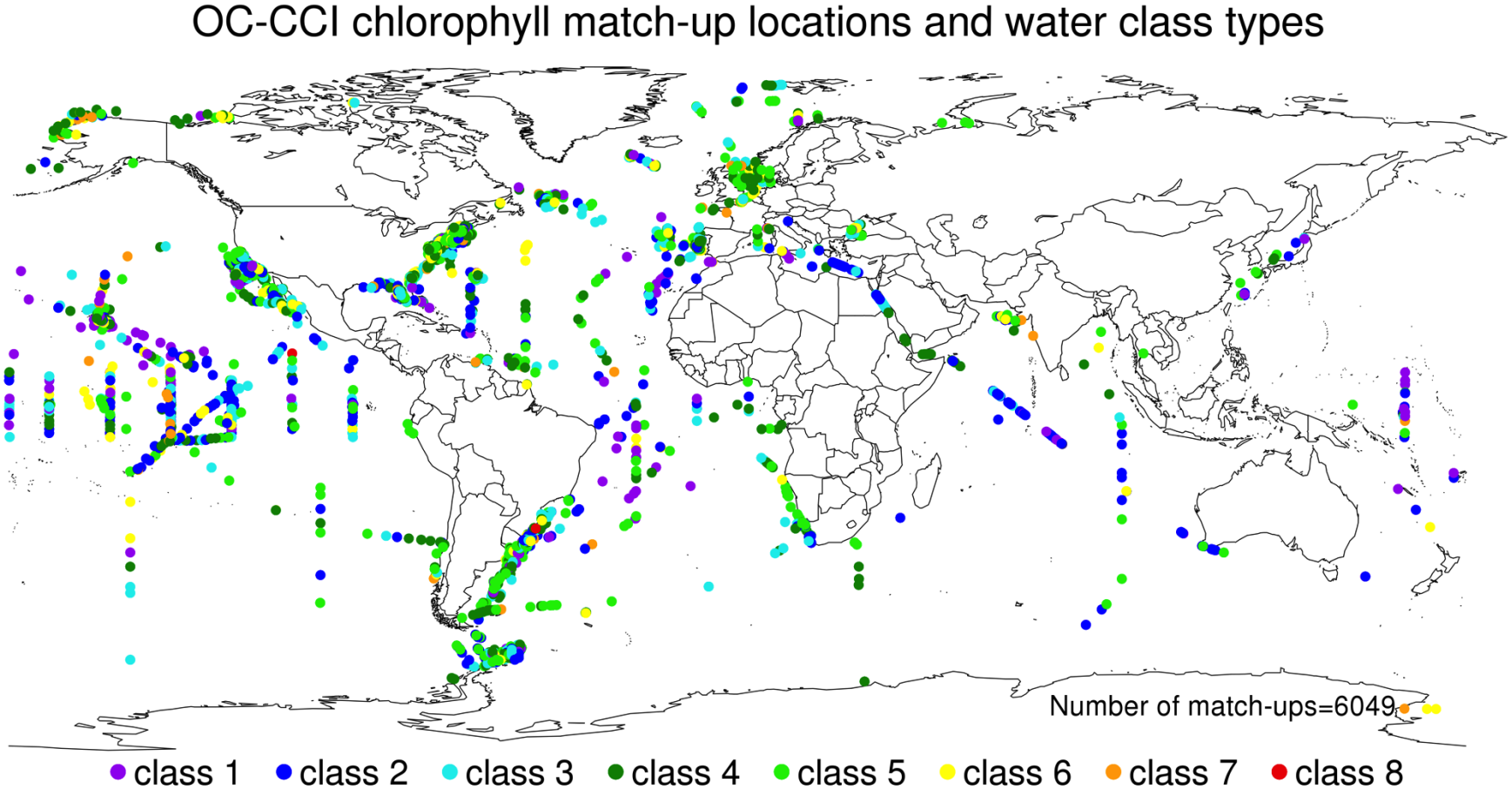




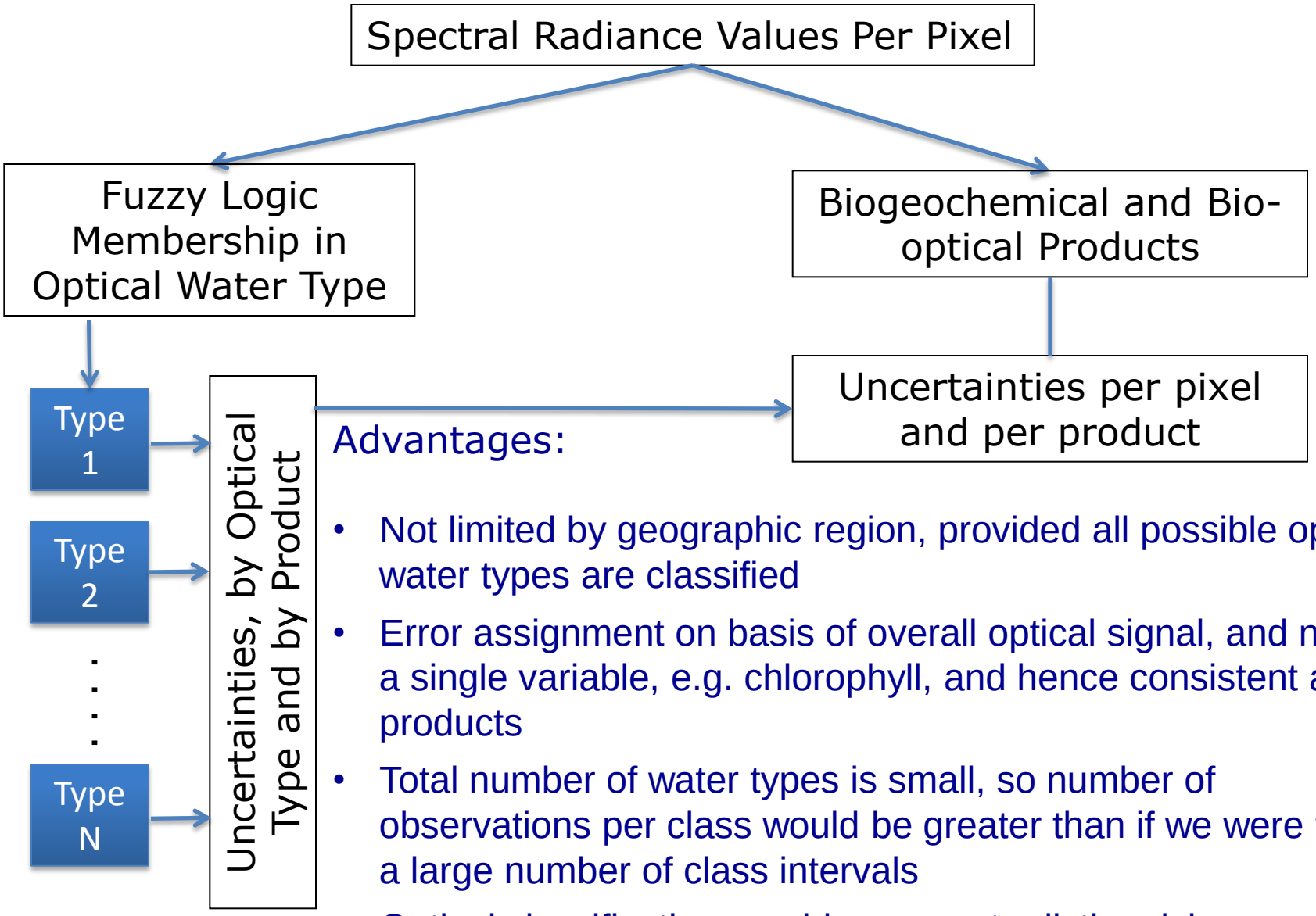
- Inter-sensor bias corrected prior to merging, to avoid spurious trends in merged data
- Band-shifted to produce consistency in data across sensors
- Enhanced contribution from MERIS due to POLYMER capability to deal with sun glint and thin clouds



Daily coverage in %


OC-CCI chlorophyll match-up locations and water class types
Number of match-ups=6049
class 1
class 2
class 3
class 4
class 5
class 6
class 7
class 8

Error Specification according to Optical Water Type

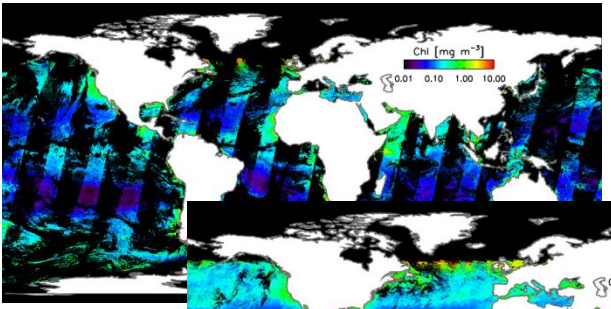


Advantages:

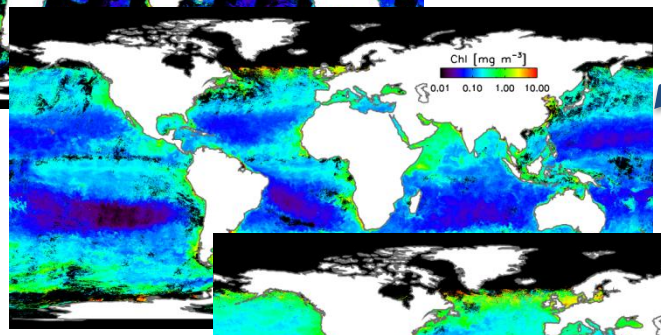
- Not limited by geographic region, provided all possible optical water types are classified
- Error assignment on basis of overall optical signal, and not on a single variable, e.g. chlorophyll, and hence consistent across products
- Total number of water types is small, so number of observations per class would be greater than if we were to use a large number of class intervals
- Optical classification provides a way to distinguish case-1 and case-2 waters

Ocean Colour CCI Products

Daily

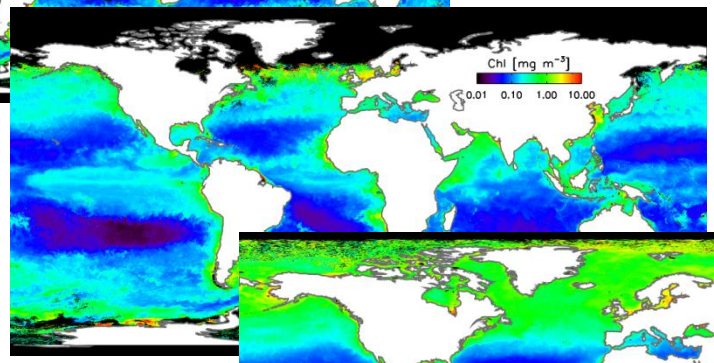


Weekly

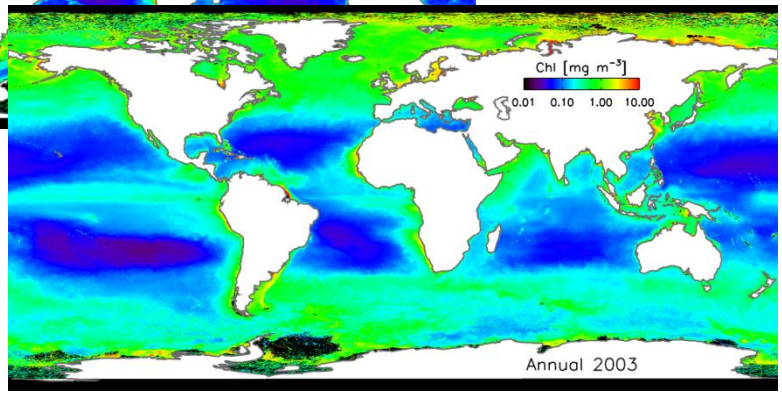


Improved spatial coverage, even at weekly scale

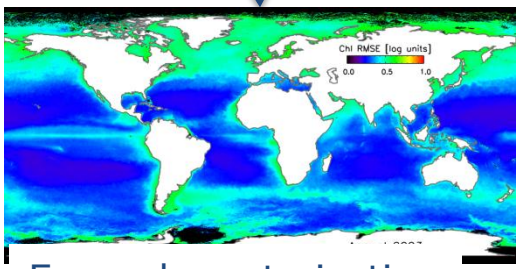
Monthly



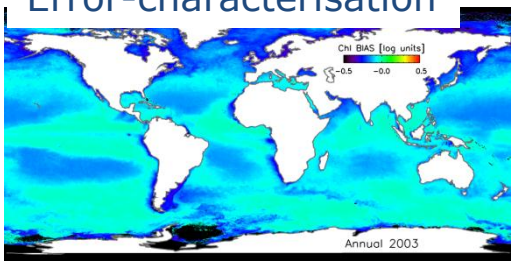
Annual



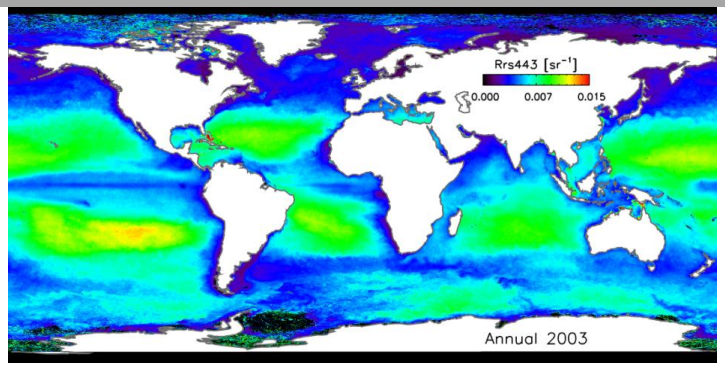
Error specification (RMSE and bias) based on comparison with match-up in situ data & extrapolation to global ocean

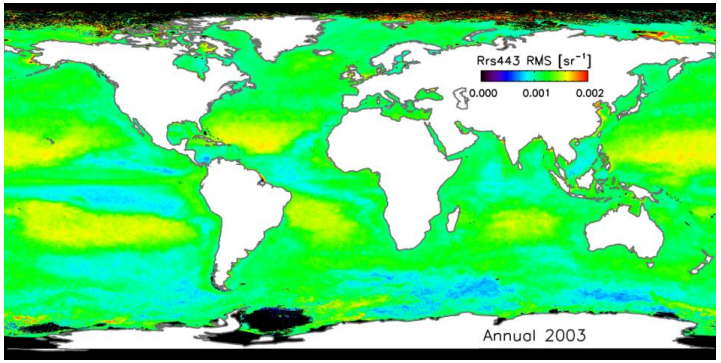


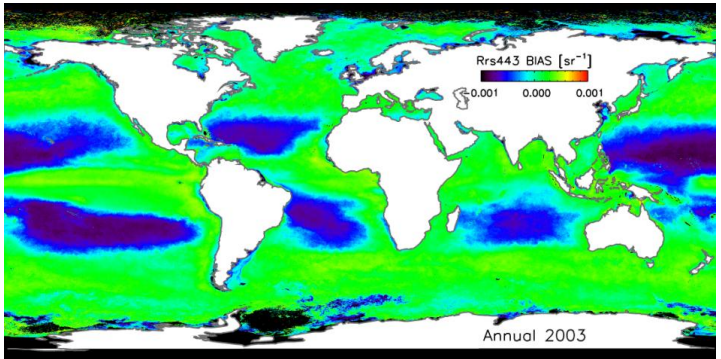
Error-characterisation



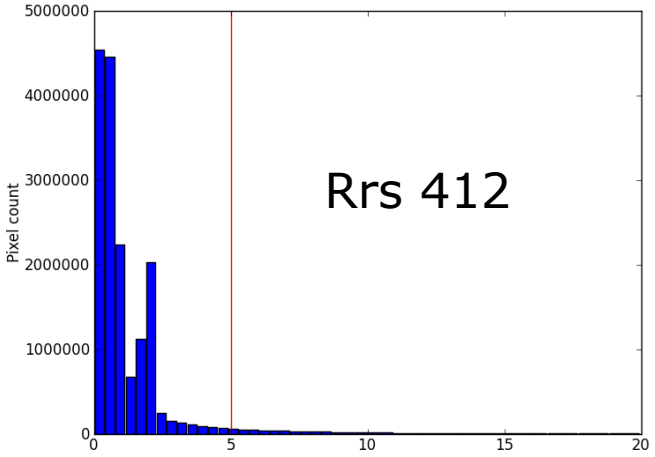
Ocean Colour: Uncertainties and GCOS Requirements

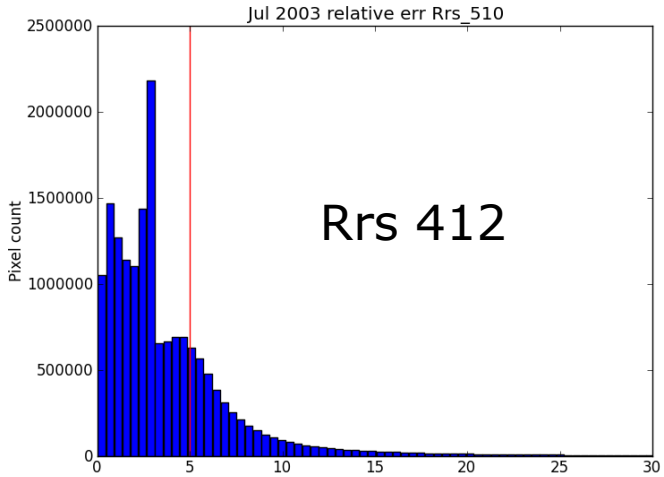






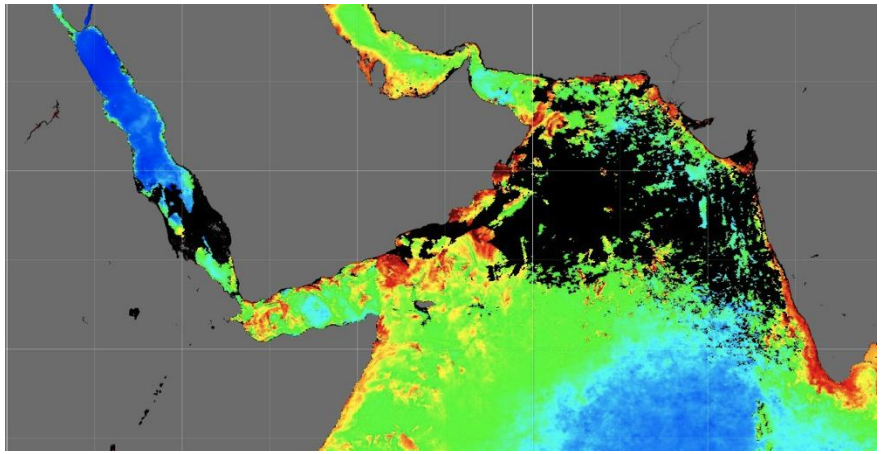
Relative Error



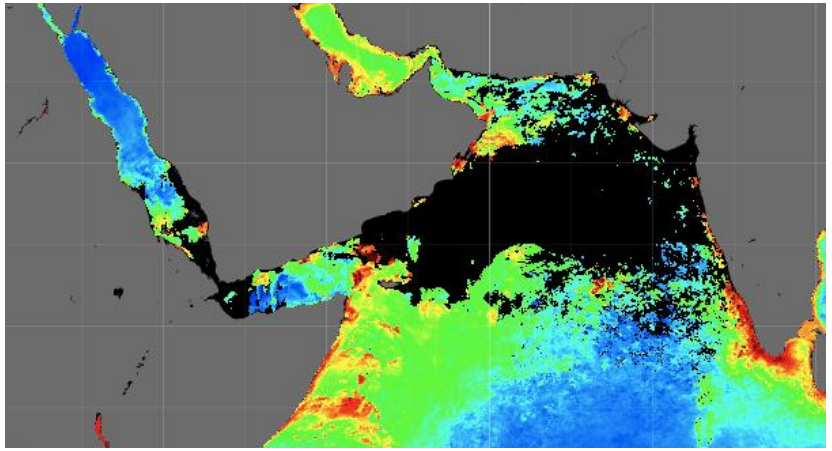


First of its kind, based on user feedback, according to a method that uses optical water classification (Moore et al. 2009).

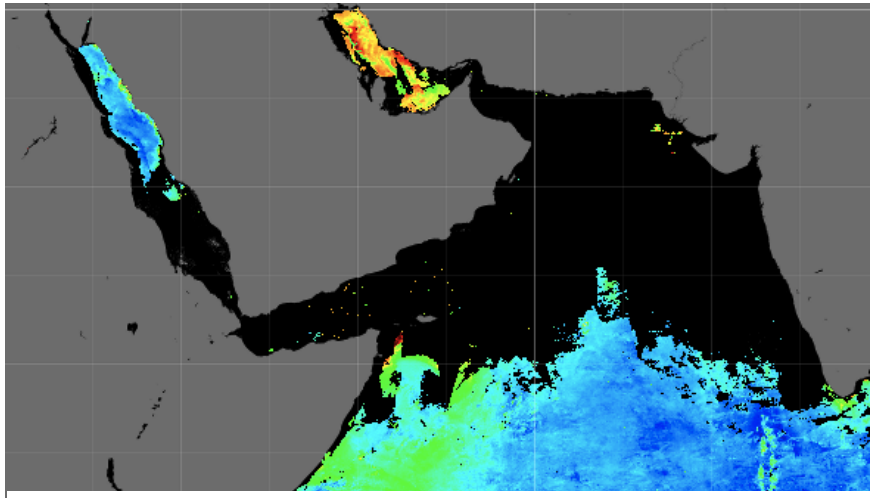
July Chlorophyll fields in the Arabian Sea



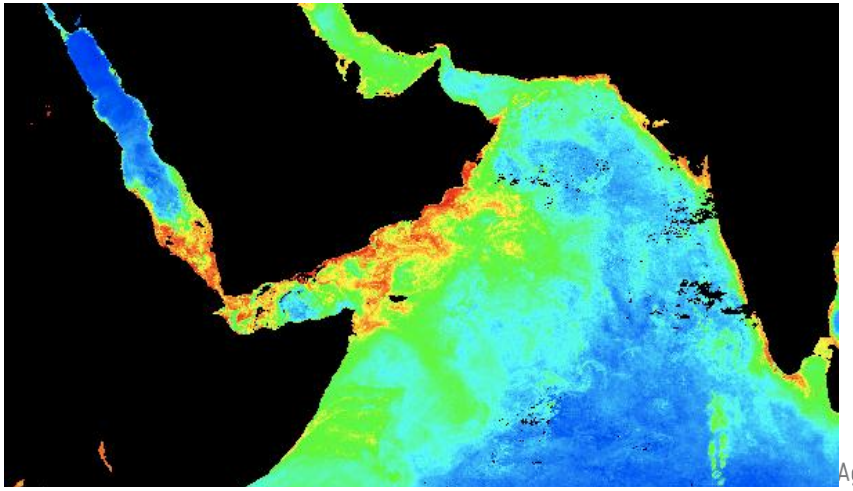
MODIS July Climatology from NASA



SeaWiFS July Climatology from NASA

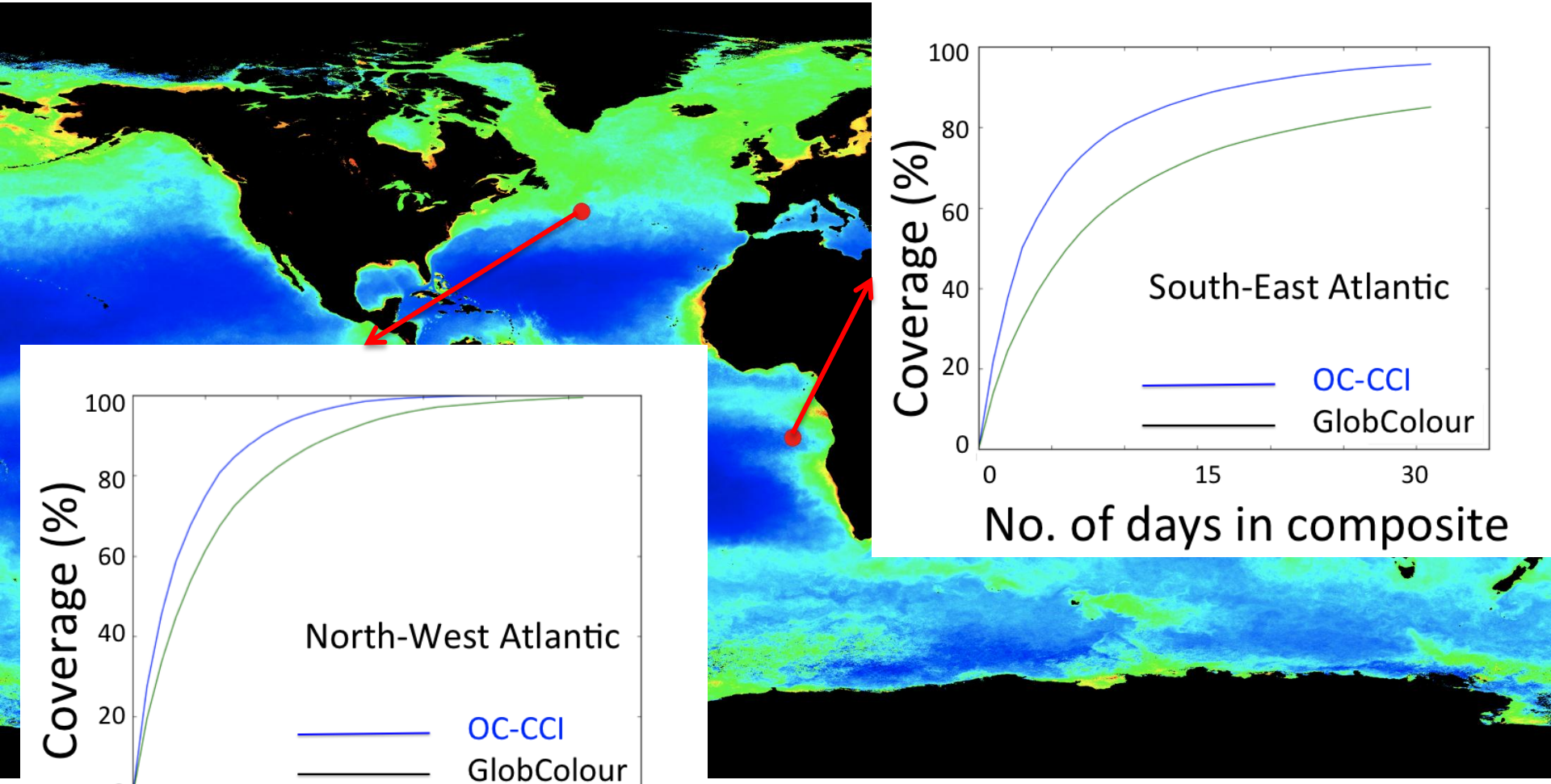


CZCS July Climatology from NASA

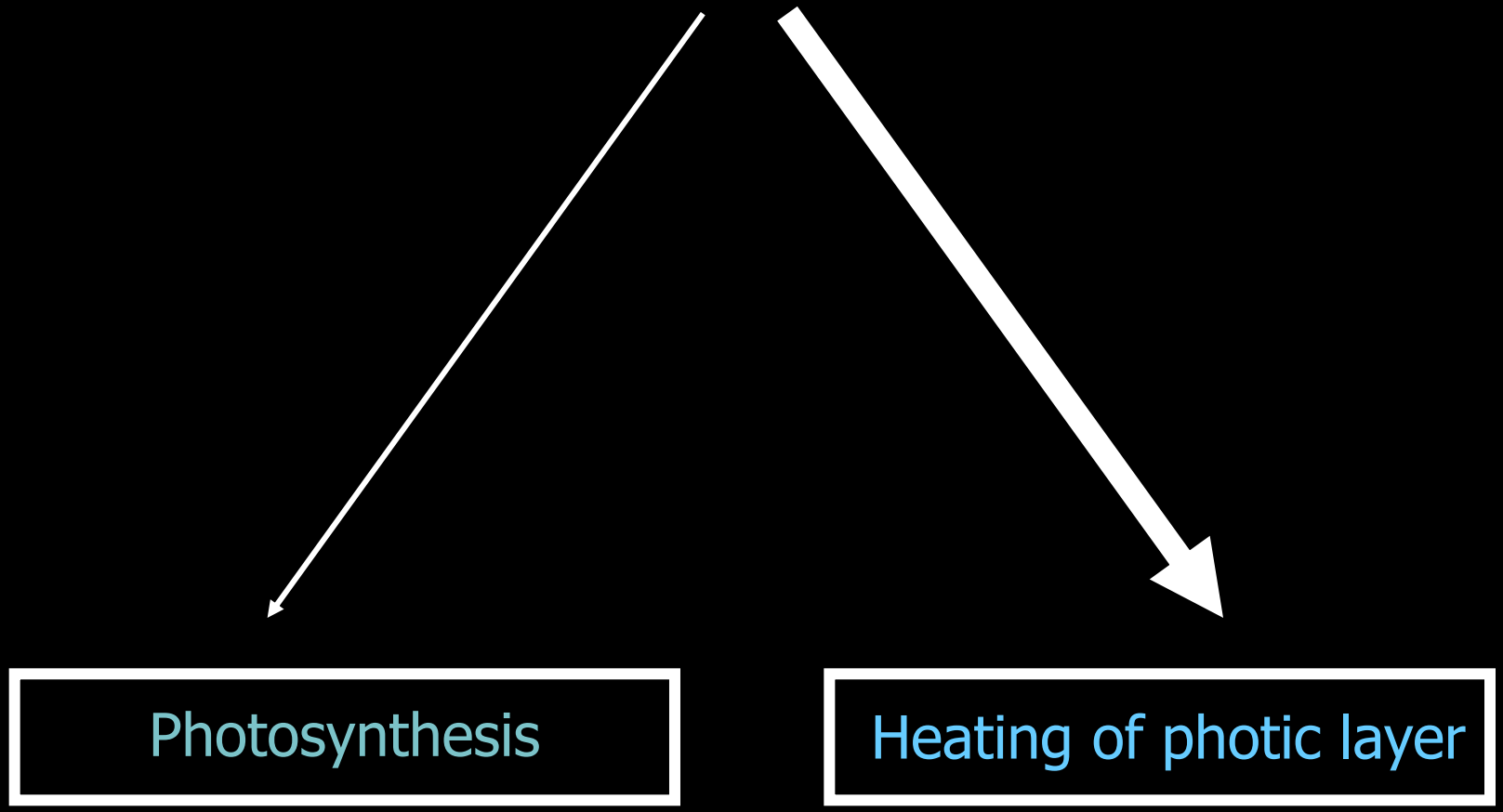


OC-CCI July 2003

Agency

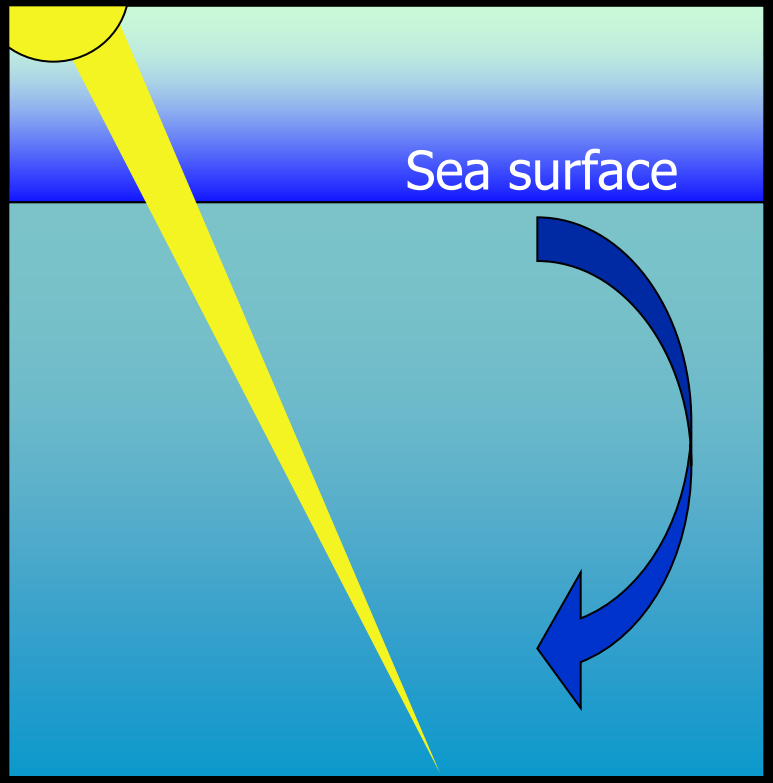

Coverage (%)
100
80
60
40
20
0
0
15
30
South-East Atlantic
OC-CCI
GlobColour
No. of days in composite
Coverage (%)
100
80
60
40
20
0
0
15
30
North-West Atlantic
OC-CCI
GlobColour
No. of days in composite

Dual Role for Light Absorbed by Phytoplankton



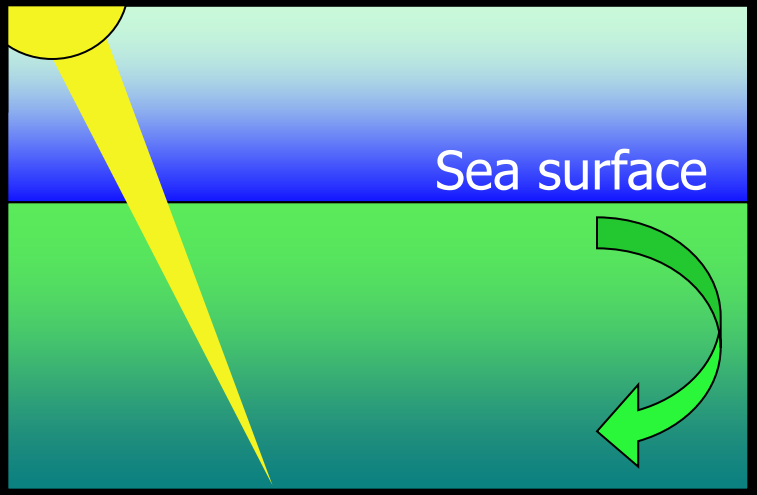
Diffuse attenuation coefficient *K* and mixed-layer depth

Low *K*



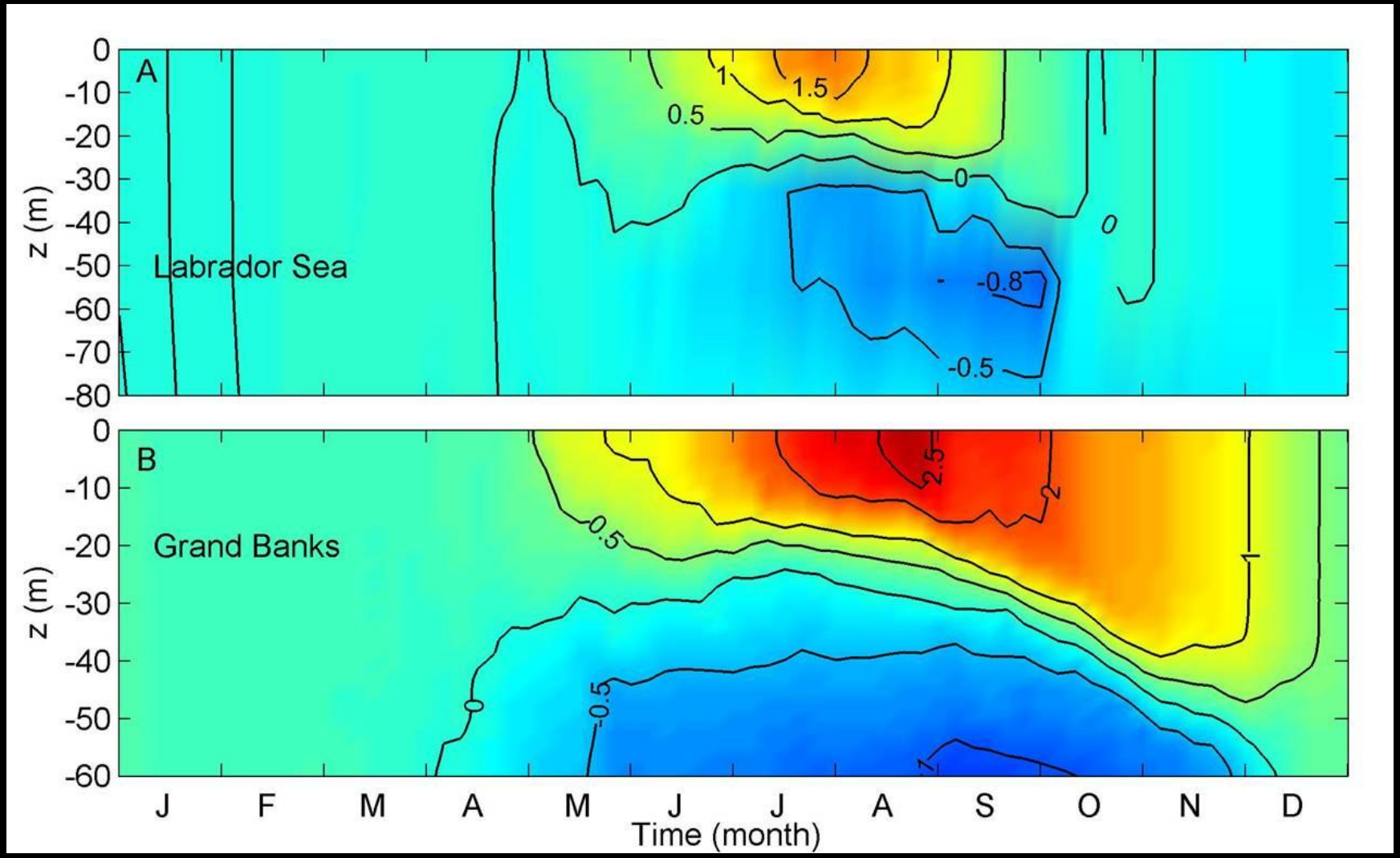
Deep photic layer
Favours deep mixed layer

High *K*



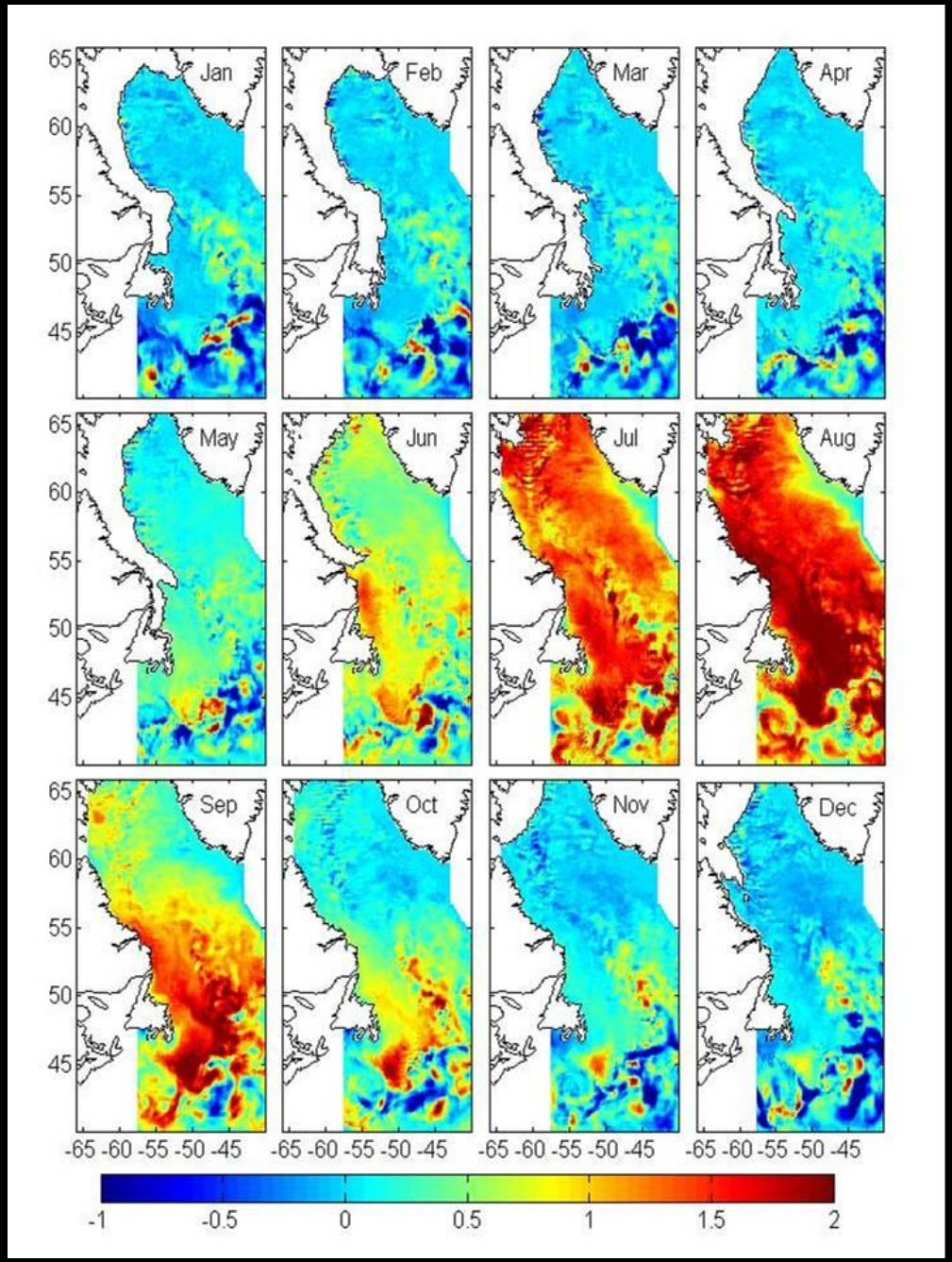
Shallow photic layer
Favours shallow mixed layer

Biologically-induced temperature differences in the ocean

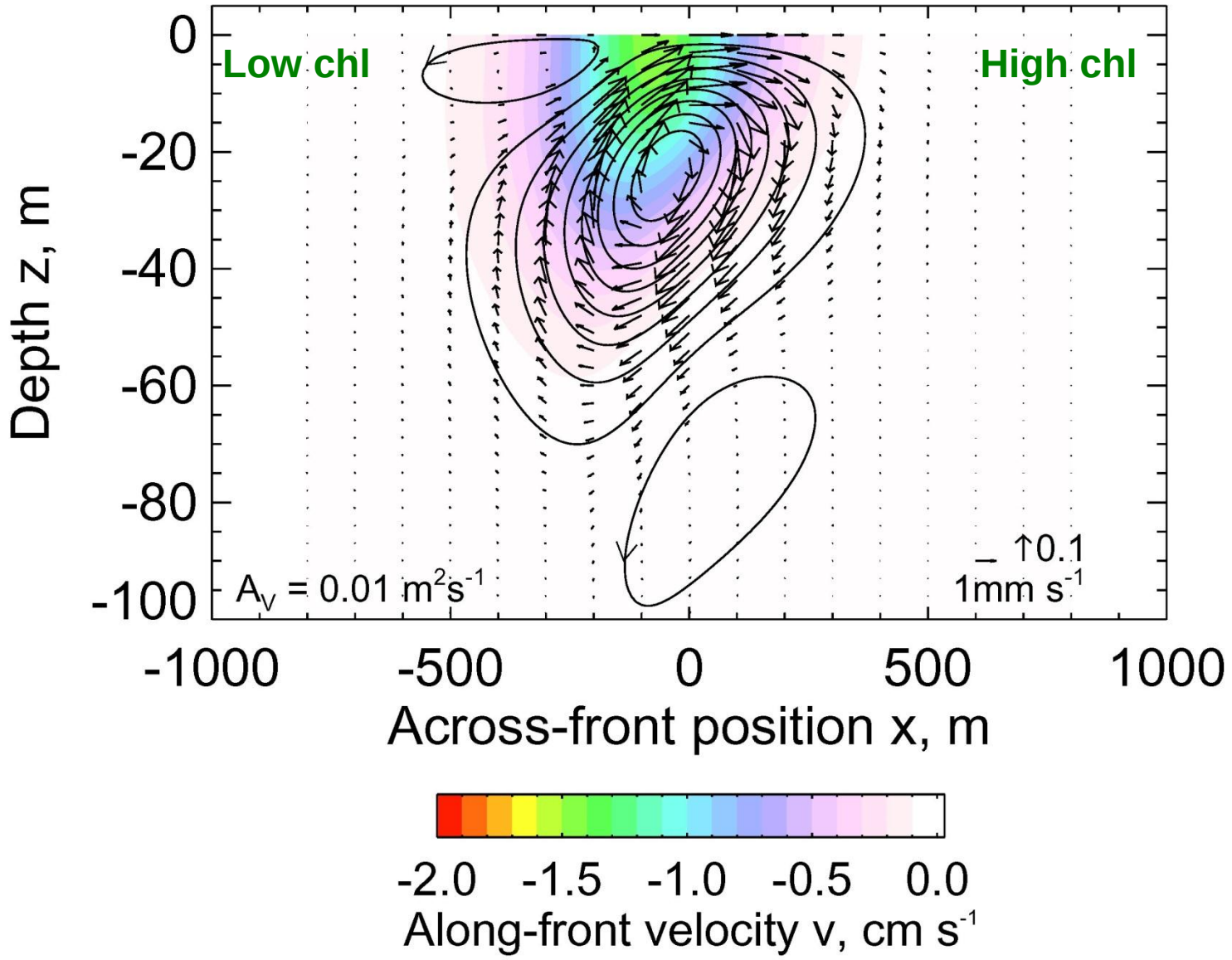


Wu et al. 2007, Deep-Sea Res. II

Difference in SST due to biologically-induced change in *K*



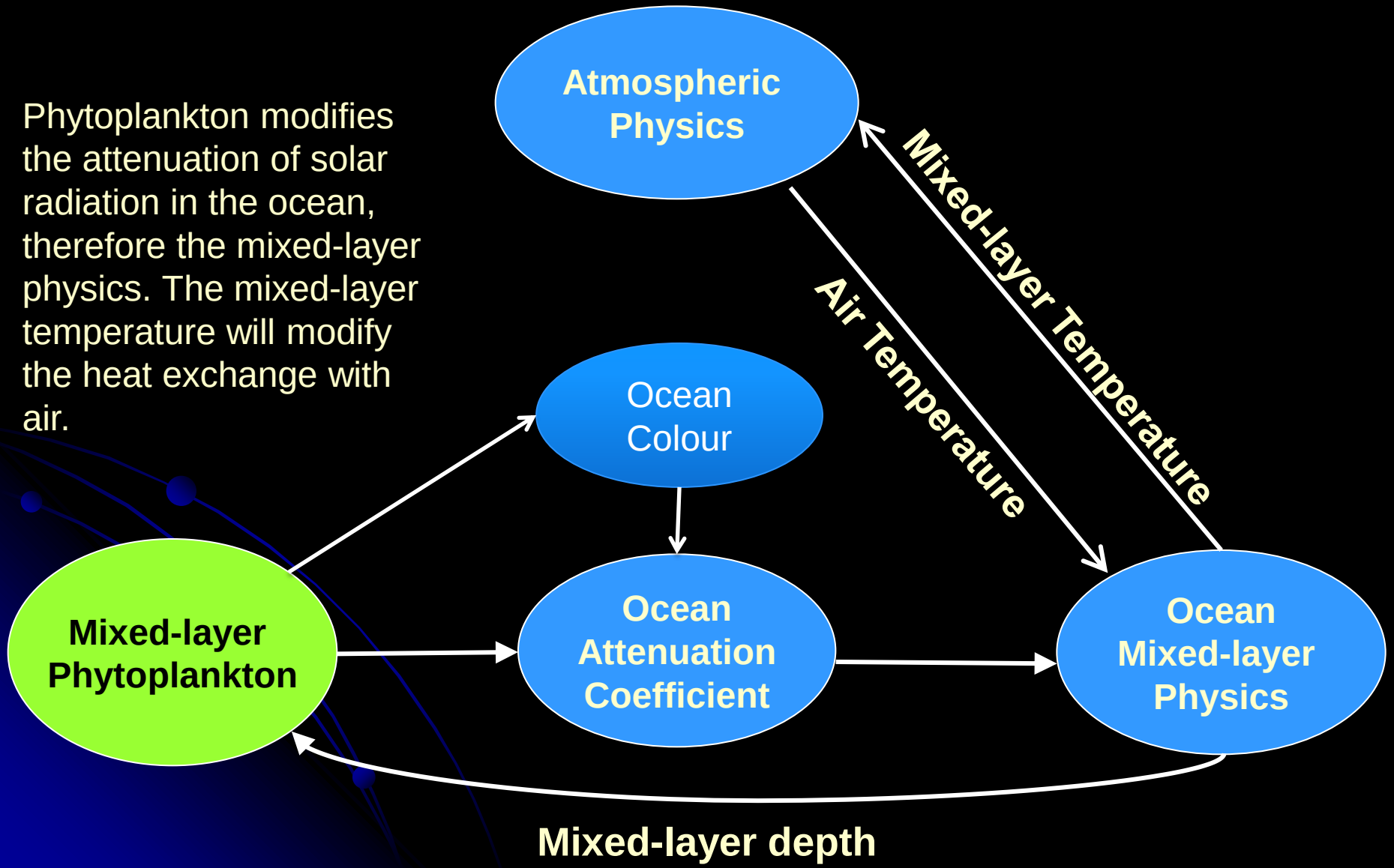
Wu et al. 2007, Deep-Sea Res II



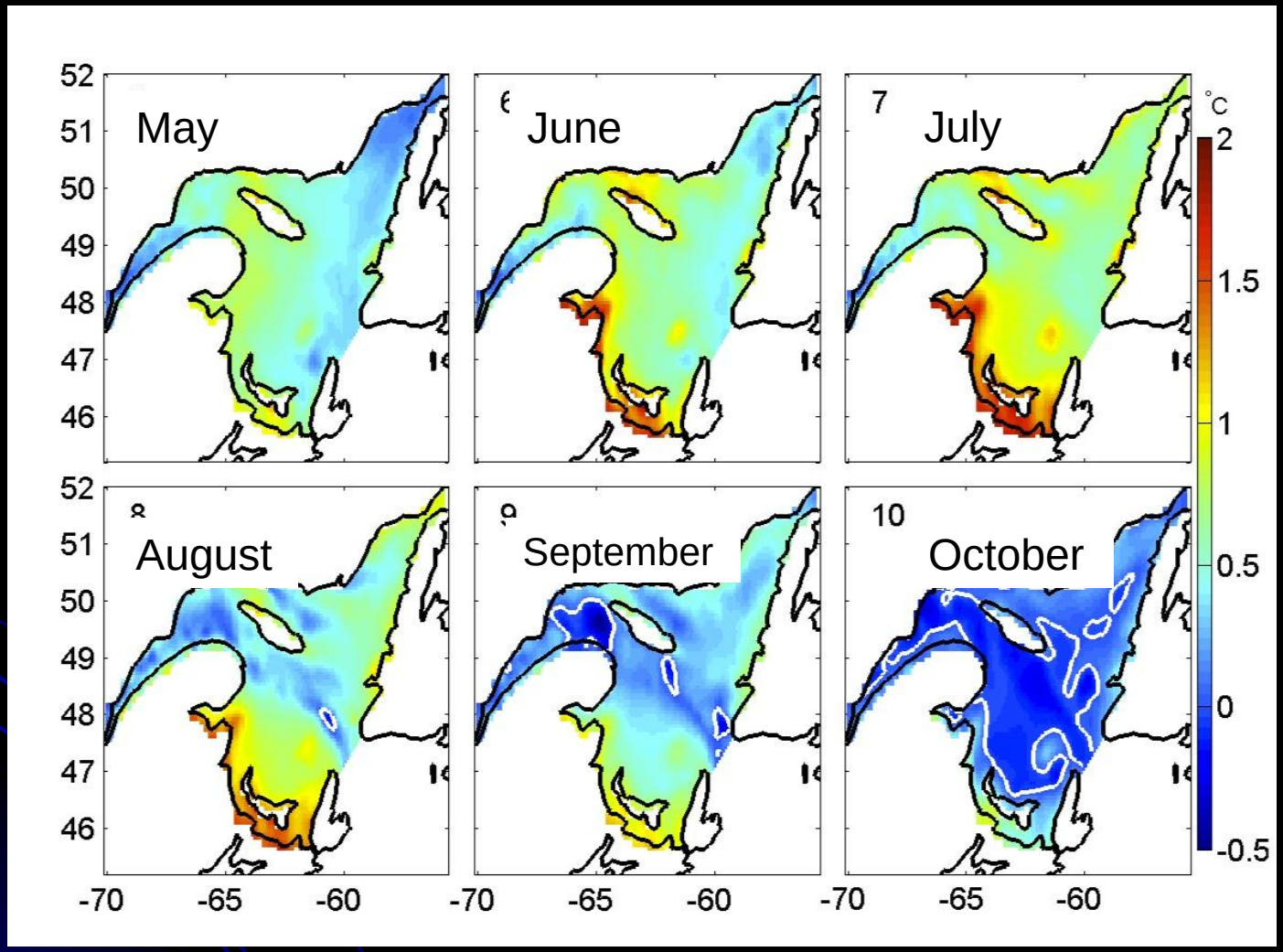
Edwards et al. 2001 (JGR)

Physical-biological Interactions: Evolution of Mixed-layer Biology, Mixed-layer Physics and Air-sea Heat Exchange

Phytoplankton modifies the attenuation of solar radiation in the ocean, therefore the mixed-layer physics. The mixed-layer temperature will modify the heat exchange with air.



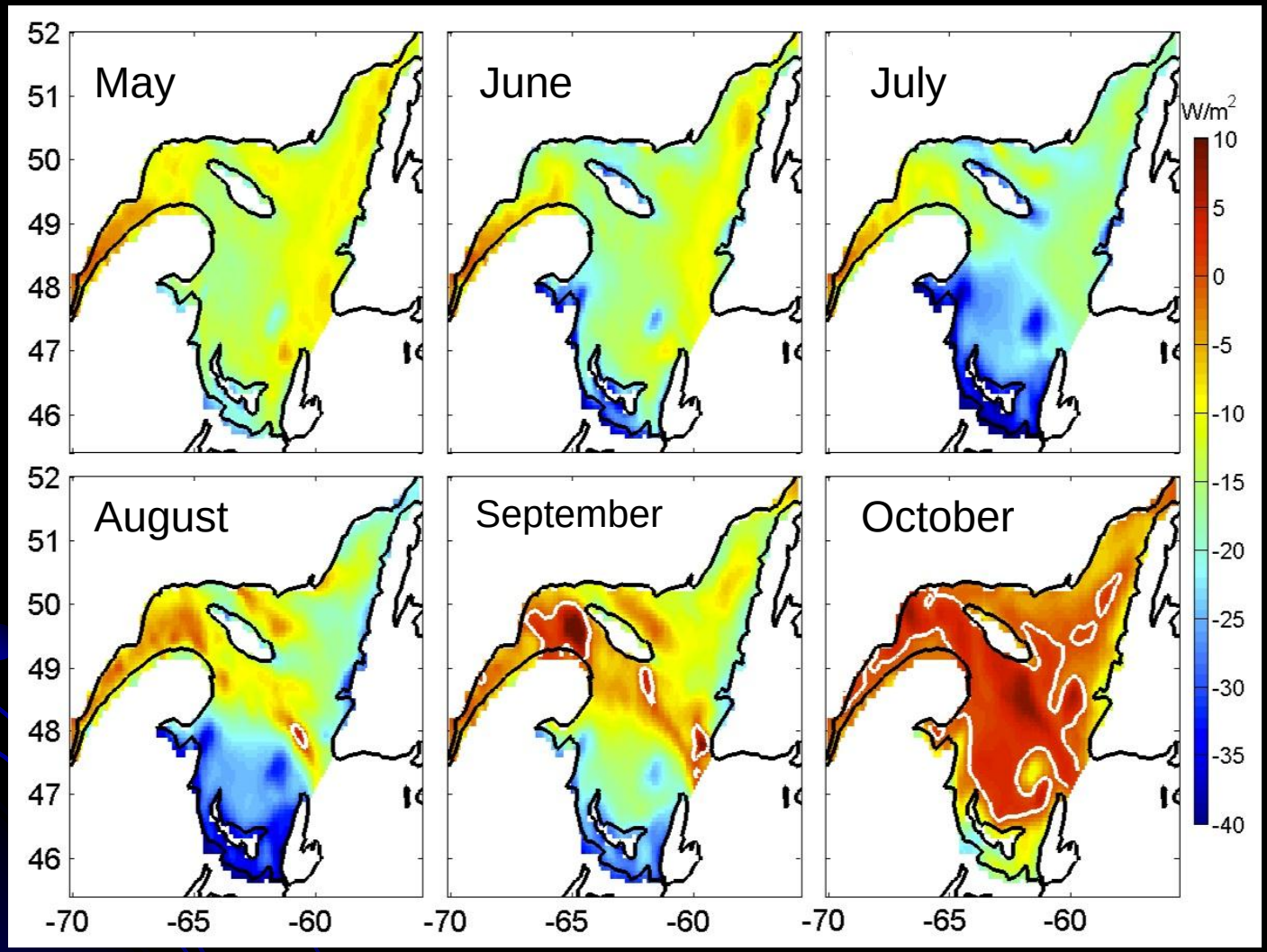
Monthly difference in modelled SST between phytoplankton run and no-phytoplankton runs: Case study for the Gulf of St Laurence



Zhai et al. 2011

Phytoplankton increases SST by up to 2 ° C, SST differences are determined by the light attenuation associated with phytoplankton and the stratification of water column.

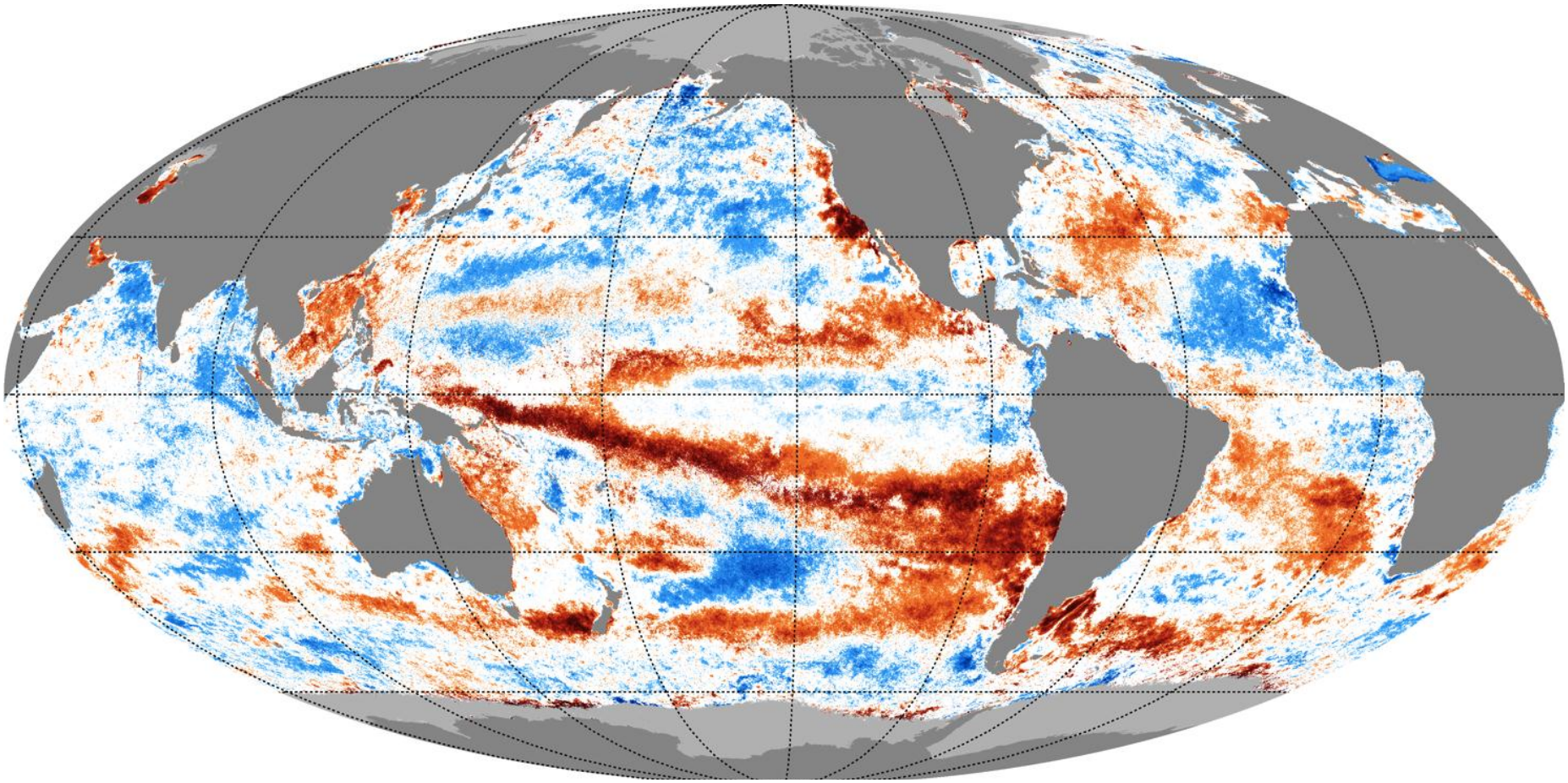
Monthly Difference in Air-Sea Heat Fluxes between Phytoplankton run and No-phytoplankton Run

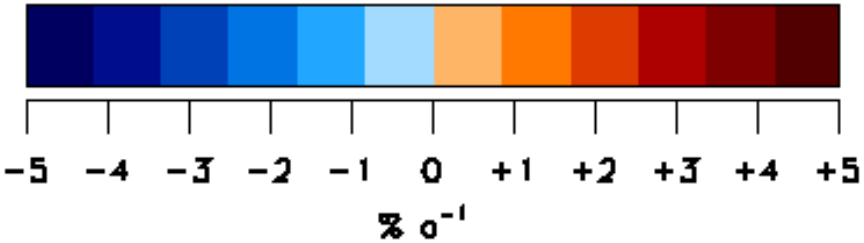


Zhai et al. 2011

The difference in air-sea heat fluxes is between -40 to 15 W/m^2. Spatial variation mirrors the difference of near-surface temperature. Phytoplankton enhances the heat loss from the ocean to the atmosphere through mainly latent and sensible fluxes.

Trend Analysis



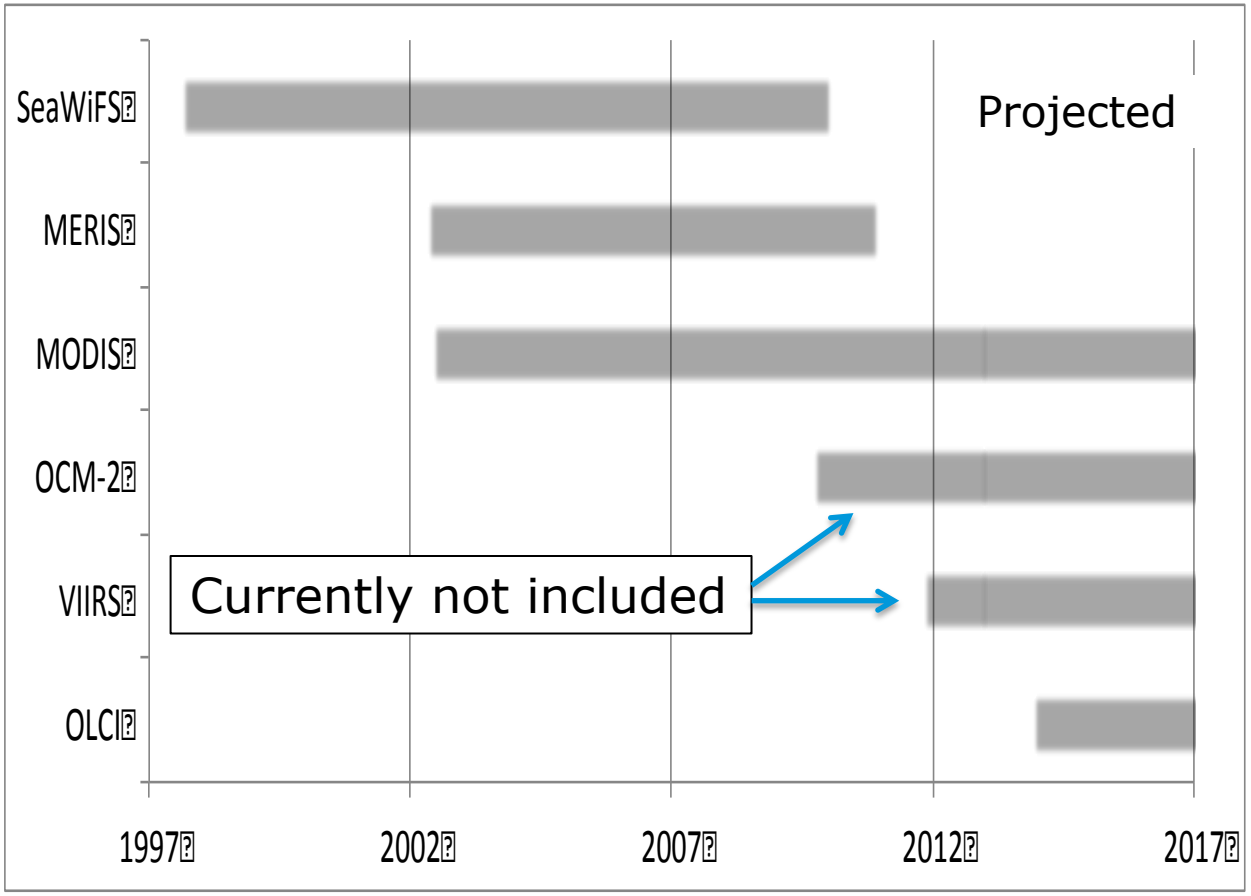


trend [10/1997-09/201

p<0.05

Frédéric Mélin

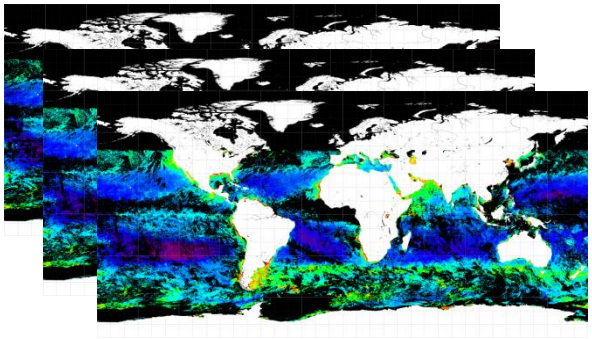
OC-CCI data inputs and time periods



Sensors and Periods

- The period from Feb 2012 until launch of OLCI on Sentinel 3 entirely dependent on MODIS, according to current plan
- Important to add OCM-2 (ISRO) and VIIRS (NASA) to the time series

System Prototype



MERIS

SeaWiFS

MODIS

Atmospheric Correction using best algorithms from round-robin comparison

Merging, Bias Correction

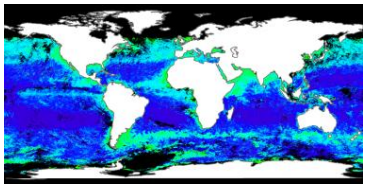
Ocean products using best algorithms from round-robin comparisons

Global In-situ database

Quality Control and Scientific Analysis

Unified multi-sensor Products

Uncertainty characterisation

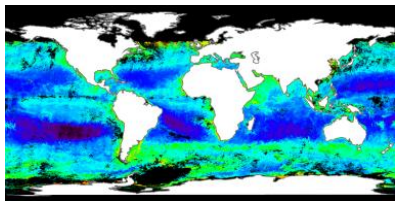


User Community

Modellers

Oceanographic Scientists

Earth Observation Scientists



OC-CCI – Team Structure

Peter Regner, ESA

Shubha Sathyendranath, Science Lead, PML, UK

John Swinton, Project Manager, TPZ Vega, UK

EO Science Team

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F. Mélin, JRC, EU
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P.-Y. Deschamps, HYGEOS, France
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Non-European

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B. Franz, NASA, USA
Z.-P. Lee, BU, USA
T. Hirata, HU, Japan
T. Moore, UNH, USA
M. Wang, NOAA, USA

Climate Research Group

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T. Hirata, HU, Japan
C. Le Quéré, UEA, UK
E. Simon, NERSC, Norway
H. Von Storch, HZG, Germany

System Engineering

M. Boettcher, BC, Germany
N. Formferra, BC, Germany
M. Grant, PML, UK
A. Horseman, PML, UK
J. Swinton, TPZ Vega, UK

Data Availability

Version 1 of data have been released.

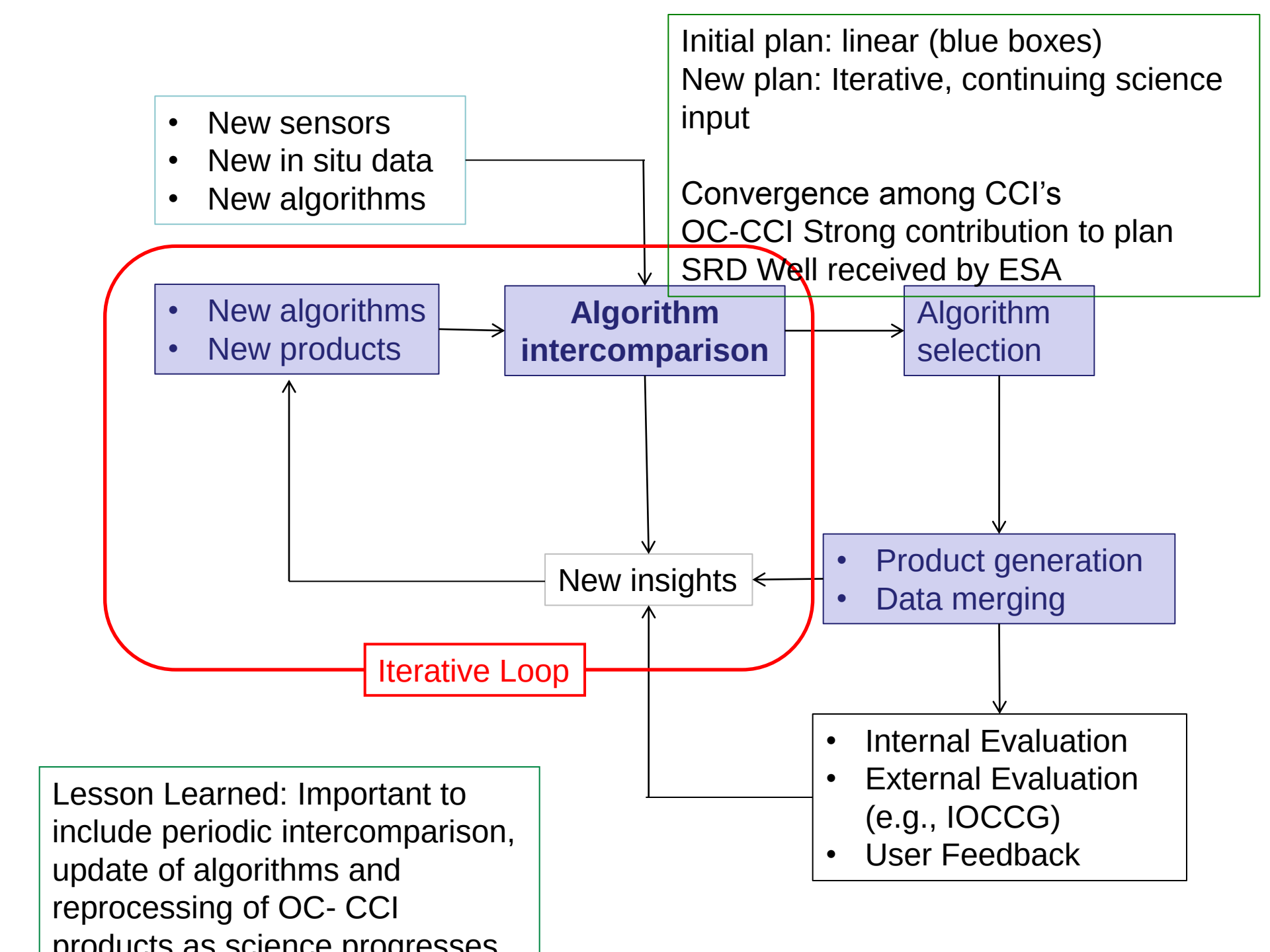
Open and free access.

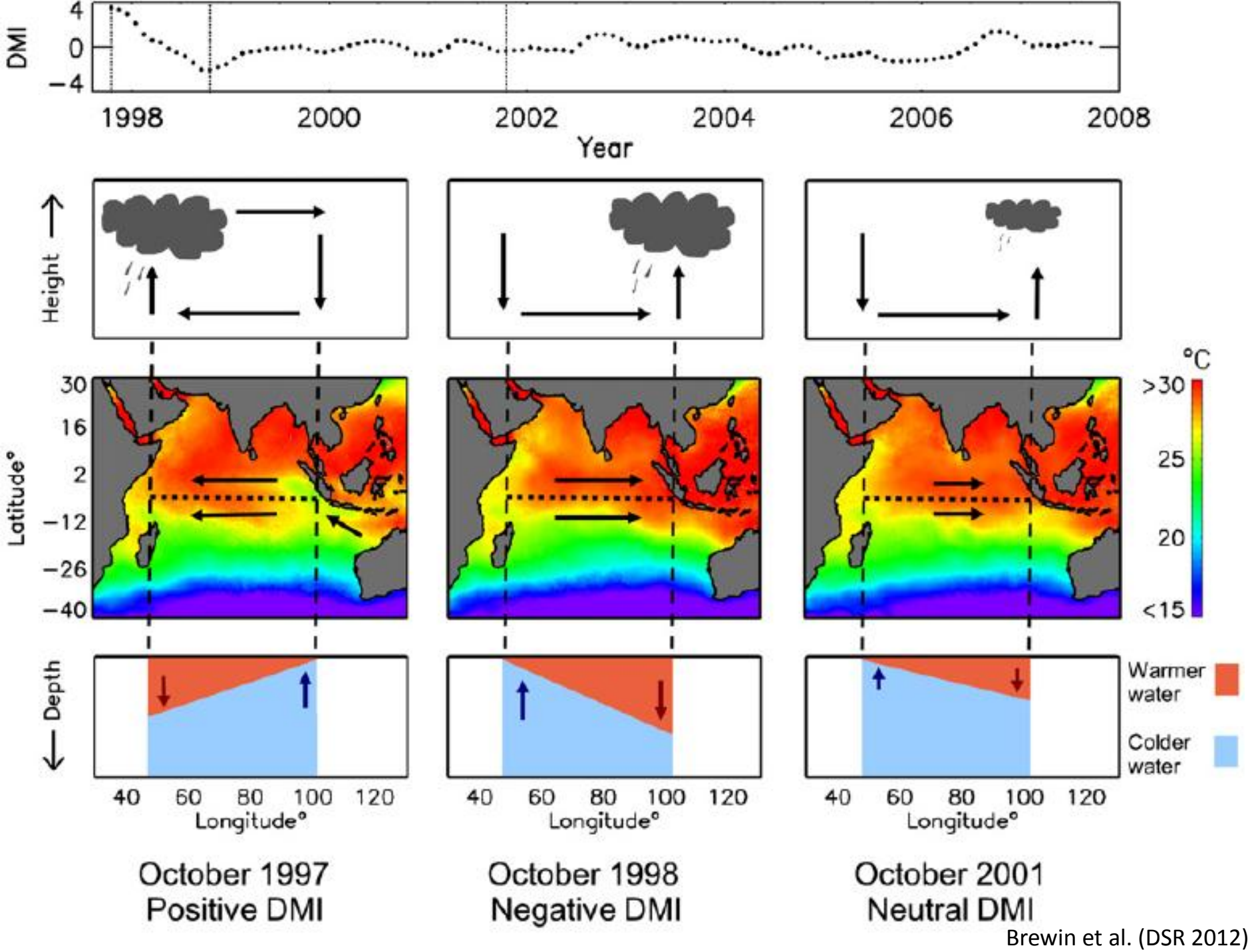
Please visit:

http://www.esa-oceancolour-cci.org/

ECV Product Tables

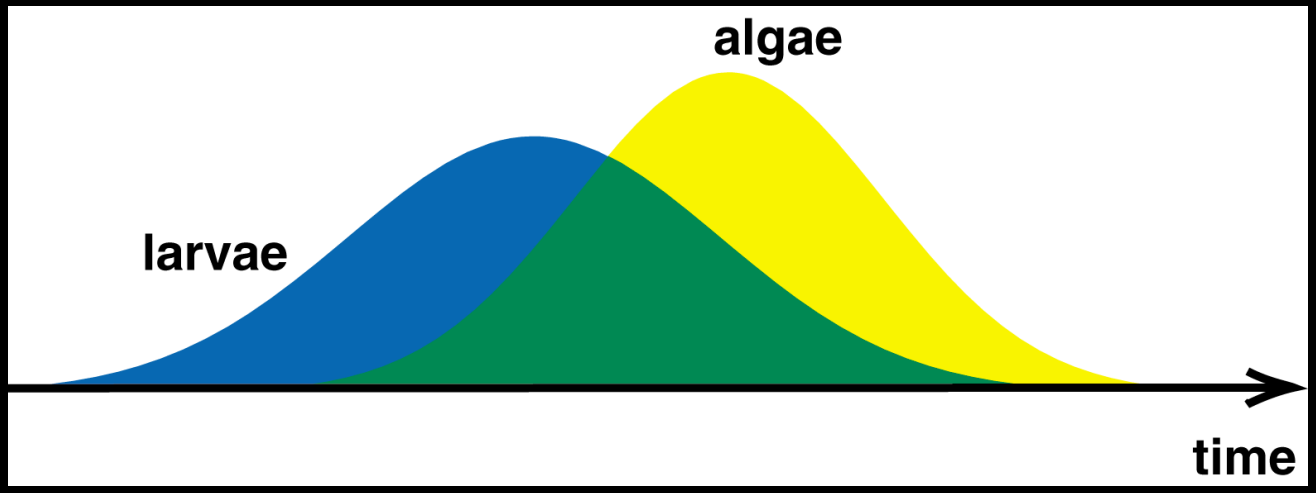
ECV Product Name: Biogeophysical Products							
Parameter	**Sensors**	**Spatial coverage**	**Spatial grid**	**Temporal coverage**	**Temporal resolution**	**Total Data Volume**	**Explanatory Text**
Phytoplankton Chlorophyll-a concentration (Chl-a) [mg m^{-3}] GCOS Climate Variable	MERIS, MODIS, SeaWiFS	Global	4x4km	1997-2012	daily	2 TB	These are level 3 binned, multi-sensor merged, daily composites (primary product, others not listed). Uncertainty layers are also included. This is one of the main OC products.
Water-leaving Radiance at six wavelengths GCOS Climate Variable	MERIS, MODIS, SeaWiFS	Global	4x4km	1997-2012	daily	12 TB	These are level 3 binned, multi-sensor merged, daily composites (primary product, others not listed). Uncertainty layers are also included.
Spectral attenuation coefficient for downwelling irradiance (K_d) [m^{-1}]	MERIS, MODIS, SeaWiFS	Global	4x4km	1997-2012	daily	2 TB	These are level 3 binned, multi-sensor merged, daily composites (primary product, others not listed). Uncertainty layers are also included.
Total absorption (a) and backscattering coefficients (b_b) [m^{-1}] at six wavelengths	MERIS, MODIS, SeaWiFS	Global	4x4km	1997-2012	daily	48 TB	These are level 3 binned, multi-sensor merged, daily composites (primary product, others not listed). Uncertainty layers are also included. This is one of the main OC products.
Coloured dissolved organic matter absorption (a_{CDOM}) [m^{-1}]	MERIS, MODIS, SeaWiFS	Global	4x4km	1997-2012	daily	2TB	These are level 3 binned, multi-sensor merged, daily composites (primary product, others not listed).


Initial plan: linear (blue boxes)
New plan: Iterative, continuing science input
Convergence among CCI's
OC-CCI Strong contribution to plan
SRD Well received by ESA
• New sensors
• New in situ data
• New algorithms
• New algorithms
• New products
Algorithm intercomparison
Algorithm selection
New insights
• Product generation
• Data merging
Iterative Loop
• Internal Evaluation
• External Evaluation (e.g., IOCCG)
• User Feedback
Lesson Learned: Important to include periodic intercomparison, update of algorithms and reprocessing of OC- CCI products as science progresses



Brewin et al. (DSR 2012)

Possible mechanism favouring early bloom of phytoplankton



Where number of haddock larvae and biomass of phytoplankton overlap, larvae have food supply adequate for survival.

Where this is not so, larvae are vulnerable to death by starvation.

Early blooms imply a smaller proportion of the total larvae produced at risk from inadequate food supply.

Cushing (Match-mismatch) Hypothesis