What are the challenges and opportunities for using ocean colour data for ecological forecasting?

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anthropogenic climate change

synoptic variability

natural climate variability
seasonal, inter-annual to
decadal modes

time

days to weeks
- harmful algae
- jelly fish
- OA events
- coastal hypoxia
- larval drift

...

seasons to decades
- marine productivity
- biomasses
- fish stocks

...

centennial
projections

Meehl et al. (2009), BAMS

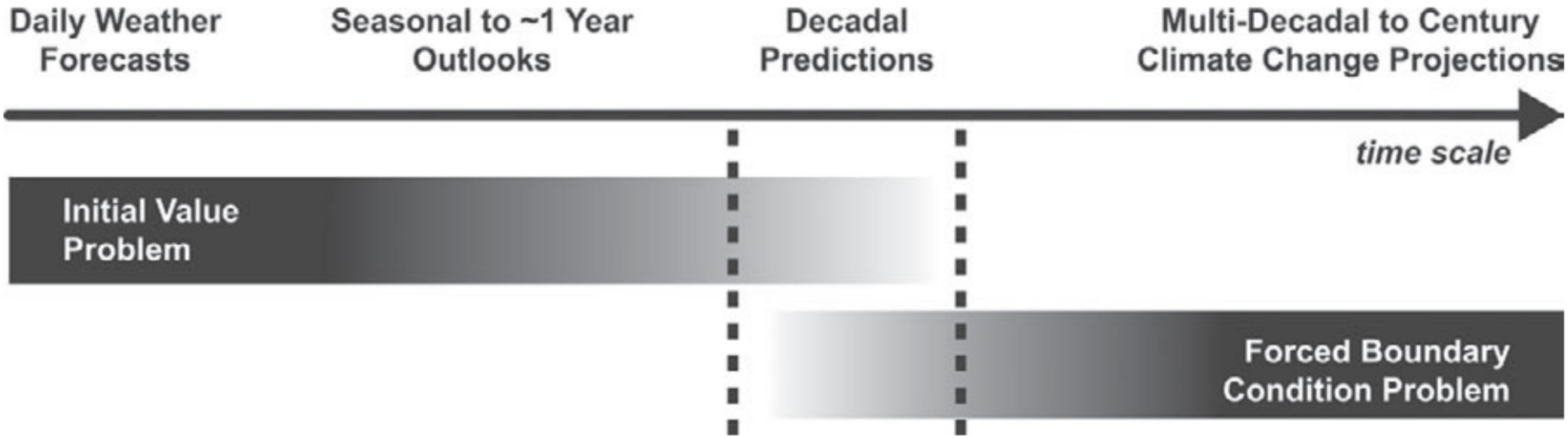
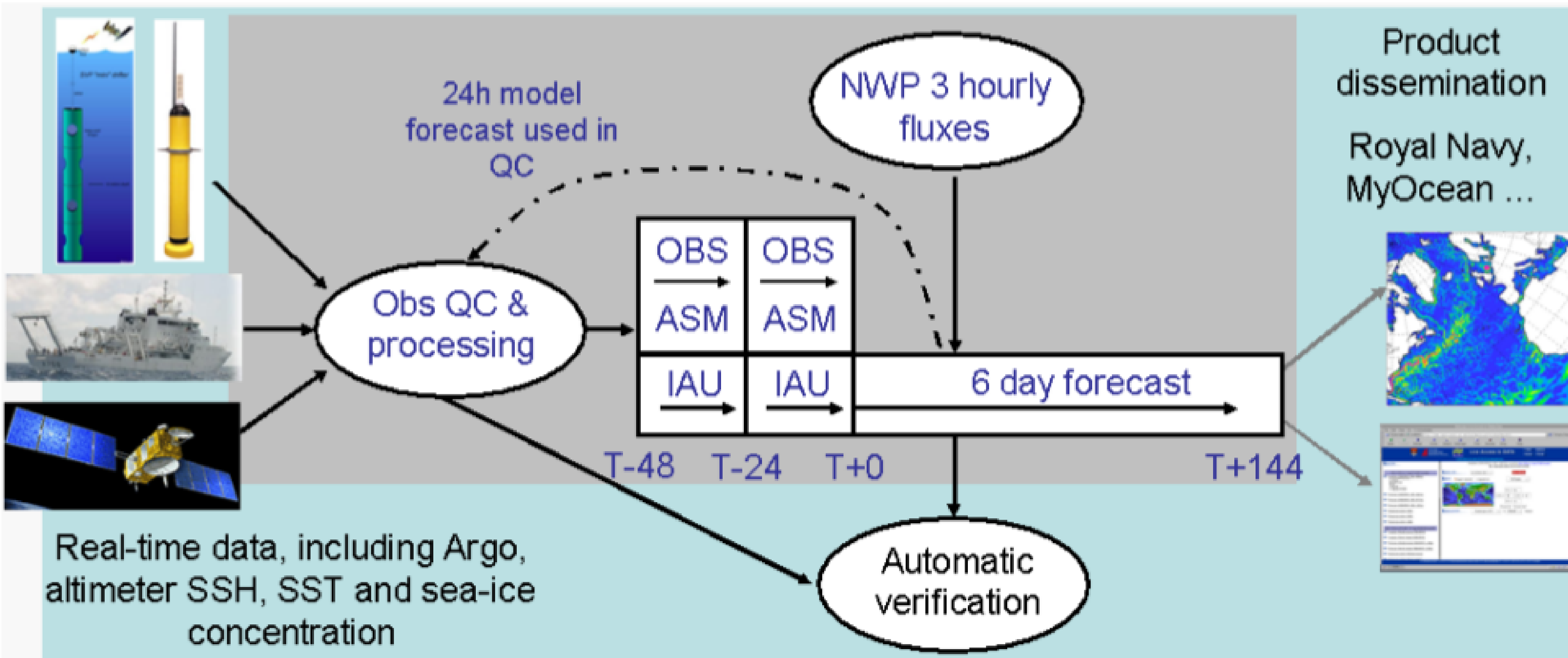


FIG. 2. Schematic illustrating progression from initial value problems with daily weather forecasts at one end, and multidecadal to century projections as a forced boundary condition problem at the other, with seasonal and decadal prediction in between.

Forecasting ocean 'weather' = initialization problem

Example of forecasting system

Schematic of an operational FOAM run



based on NEMO (v3.2)

Forecasting ocean 'weather' = initialization problem

Need of “integrated systems”

- data streams: physical/**biogeochemical**
- data assimilation to constrain ocean physics and biogeochemistry
- coupled biogeochemical ocean general circulation model

Forecasting ocean 'weather' = initialization problem

Need of “integrated systems”

- data streams: physical/**biogeochemical**

  need for :

  – NRT high quality data streams

  – delayed delivery of consistent time series for reanalysis

Main characteristics of selected GODAE/GOV forecasting systems

System	Ocean model	Biogeo-chemical model	Configuration	Data assimilation scheme		Assimilated data		System status
				PHYS[(1)]	BGC[(2)]	PHYS	BGC	
FOAM-HadOCC	NEMO3.2-CICE	HadOCC	global, 1/4°cos(lat) resolution, 75 vertical layers	3D-Var	analysis correction + multi-variate balancing	satellite SLA, SST, sea ice, in situ SST, T/S profiles	chlorophyll-a or pCO_2	pre-operational (BGC) operational (PHYS)
FOAM-ERSEM	NEMO3.2	ERSEM	Atlantic Margin, 7km resolution, 32 hybrid vertical layers	analysis correction	no	SST	no	operational
TOPAZ-NORWECOM	HYCOM	NORWECOM	North Atlantic and Arctic (Bering Strait), 50 km resolution 28 vertical layers	DEnKF	DEnKF & Gaussian ana-morphosis	satellite SLA, SST, sea ice	chlorophyll-a	pre-operational
TOPAZ-NORWECOM	HYCOM	NORWECOM	same but 12 km resolution	DEnKF	no	satellite SLA, SST, sea ice, in situ T/S profiles	no	operational
MERCATOR-OCEAN/ BIOMER	NEMO 3.1	PISCES (NEMO3.2) off-line coupled[(3)]	global, 1/4°cos(lat) resolution, 50 vertical layers	SAM2V1	no	satellite SST, SSH, in situ T/S profiles	no	operational
MFS	NEMO3.4 +waves+ atm.press ure	BFM (OPATM) off-line coupled[(3)]	Mediterranean Sea (1/16°), 72 vertical layers	3D-Var	3D-VAR	Satellite SSH, in situ T/S profiles	chlorophyll-a	operational
CANOPA-GSBM	OPA9-LIM2	GSBM	East-Canadian shelf (1/12°), 46 vertical layers	no	no	no	no	non-assimilative hindcast

[(1)]PHYS = physics; [(2)]BGC = biogeochemistry; [(3)] biogeochemical model coupled off-line (run sequential) to physical model;

Gehlen et al., 2015, JOO

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biogeochemical/ecological forecasting

=

a young, but rapidly evolving field

Gehlen et al., 2015, JOO

Ocean colour products for

⇒ applications in operational oceanography :

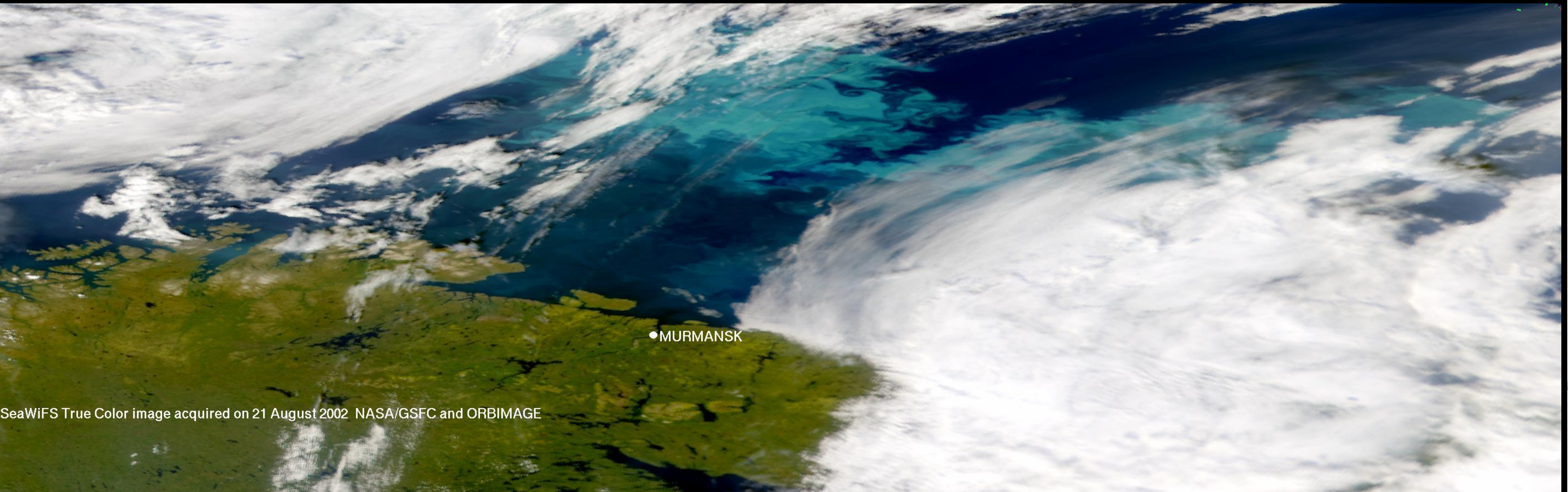
model guidance / data assimilation

management of living marine ressources

⇒ applications in biogeochemical research :

model evaluation

process studies



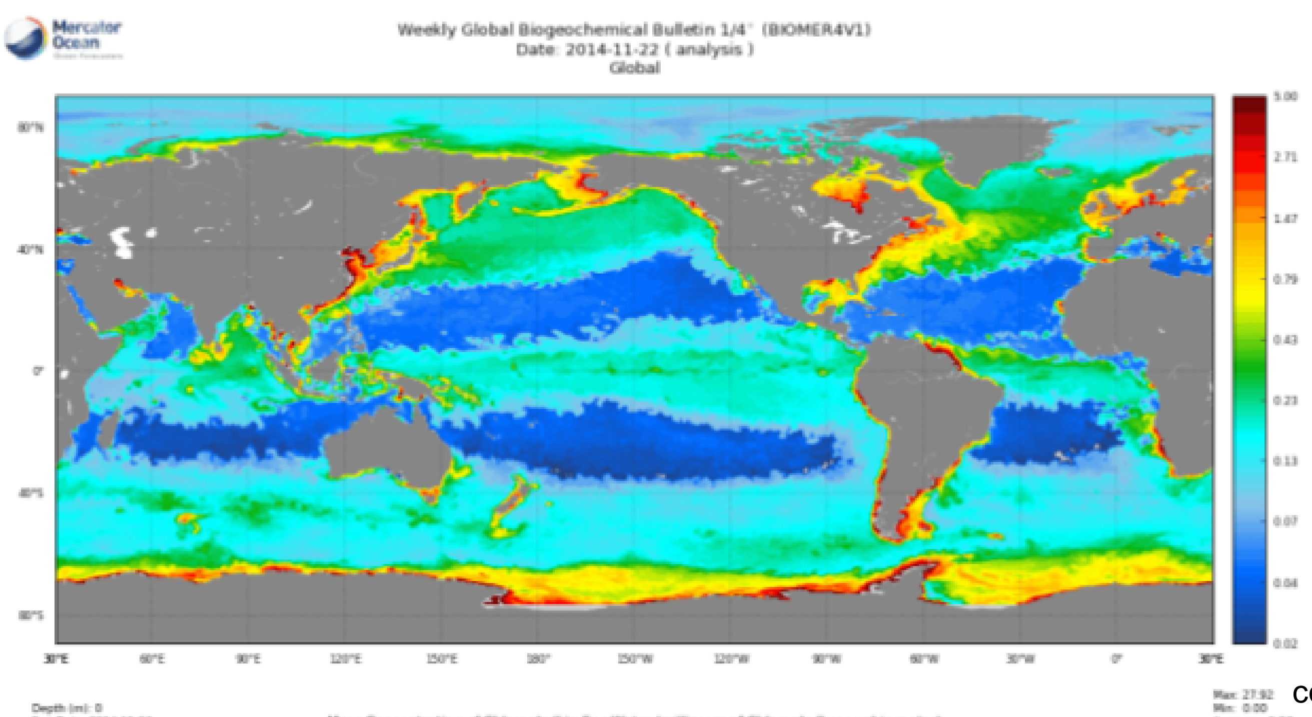
Current operational monitoring capabilities for the « green » ocean at Mercator-Océan

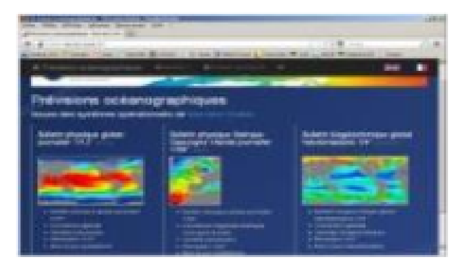
- **Context**: transition towards **Copernicus Marine Service** (delegated to Mercator-Ocean for a start April 2015)

- **Objective**: to provide reanalyses, analyses and real-time forecasts (global + regional) of
(i) the physical ocean state (T/S, currents, mixed layer ...) at high spatial effective resolution (~ 10 to 50 km) ;
(ii) the biogeochemical state (nutrients, phytoplankton, chlorophyll …) at best possible resolution.

- **Current capability**:
  (i) *Physics*: global physical ocean at 1/12° (target 1/36° in 2020+); european seas 1/36° (daily updates)
  (ii) *Biology*: global biological state at 1/4° (weekly updates) + regional focus IBI (target 1/12 ° in 2020)

- **Data needs** to reach 2020+ target (in addition to SST, SLA and in situ T/S data already assimilated into physical components): **eddy-resolving ocean color maps** in European seas, daily updates, for assimilation.





contact: Pierre.Brasseur@legi.grenoble-inp.fr

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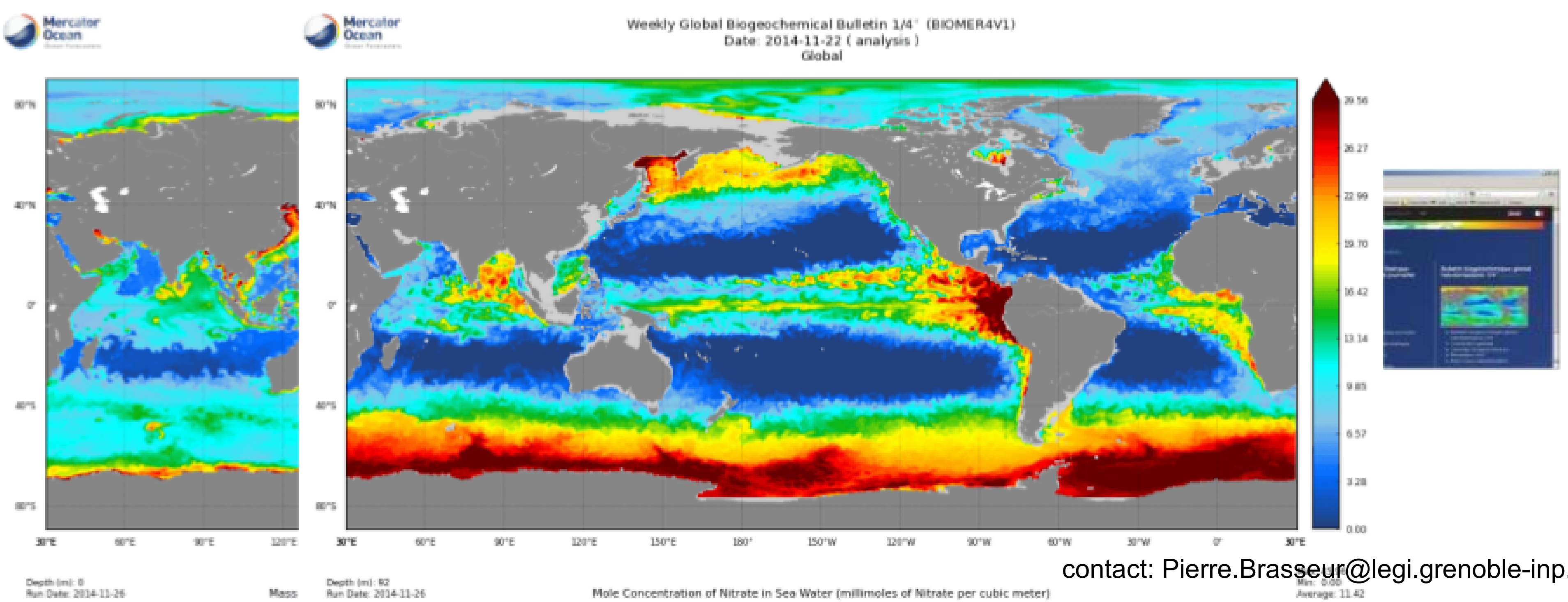

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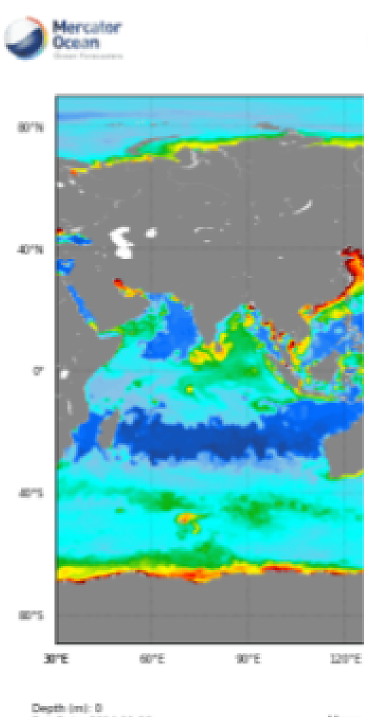

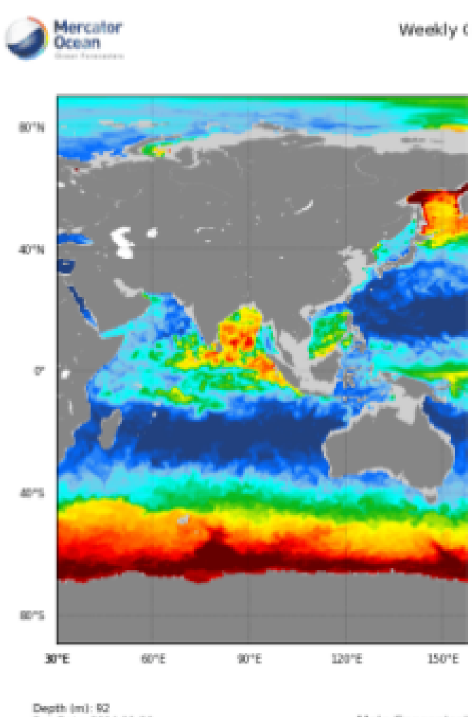

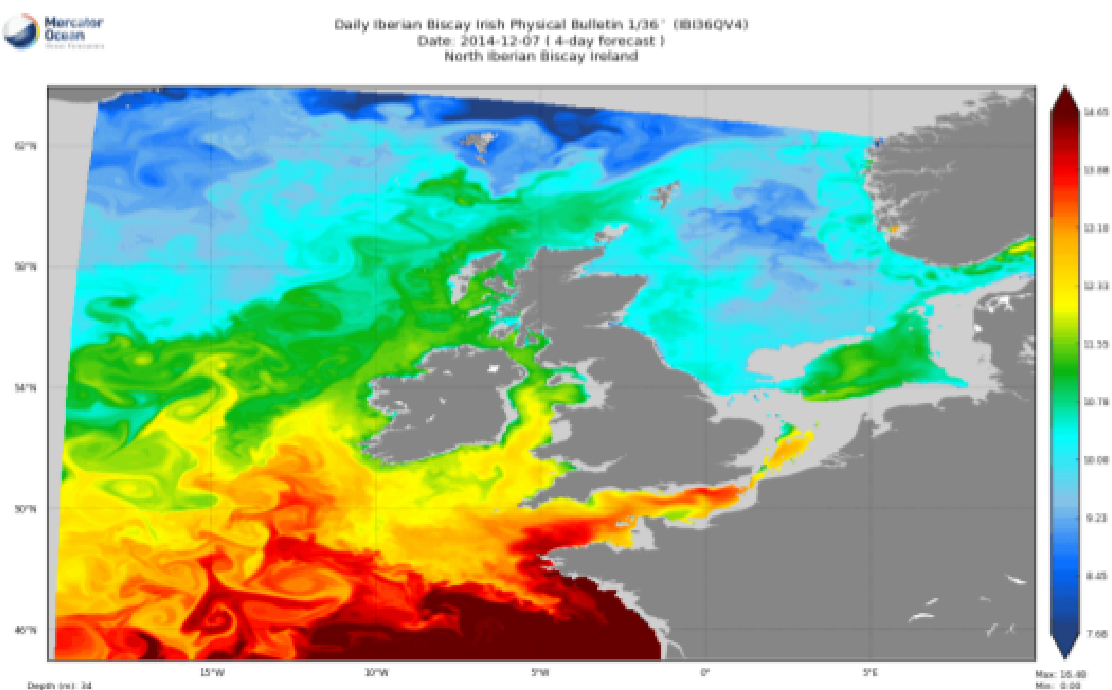

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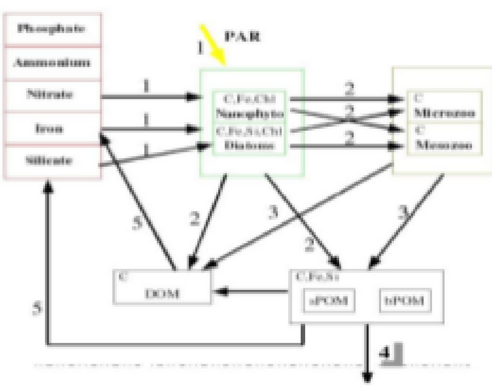
Assimilation of ocean colour data product into coupled physical-biological models

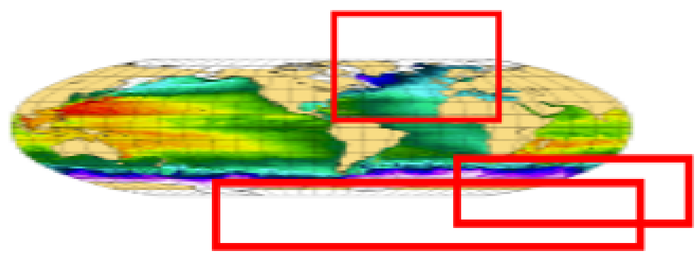
Current limitations in ocean colour products (e.g. weekly - monthly composites):

- Insufficient spatial resolution and repetitivity for assimilation into eddy-resolving models
- Inadaptation of assimilation schemes for incorporation of biogeochemistry

Required evolutions:

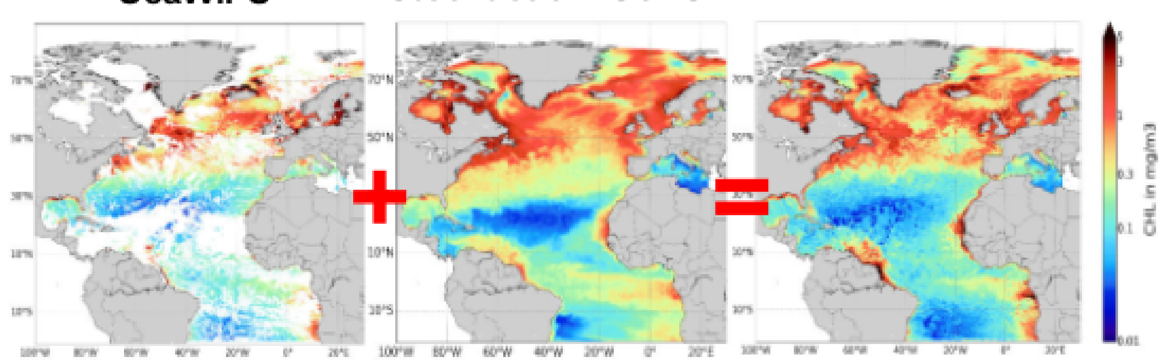
- Assimilation schemes to be prepared to future OC products (e.g. from geostationary orbits)
- Methods for synergistic use of HRES satellite observations (colour, SST, SWOT altimetry)
- Extension to the coastal domain





Mercator-Océan: ORCA025 + PISCES including physical data assimilation (SST, SLA, in situ T/S)

SeaWiFS + Stochastic PISCES = Weekly analysis



Source: F. Garnier, P. Brasseur, CNRS-LGGE, Grenoble

contact: Pierre.Brasseur@legi.grenoble-inp.fr

Ocean colour products for

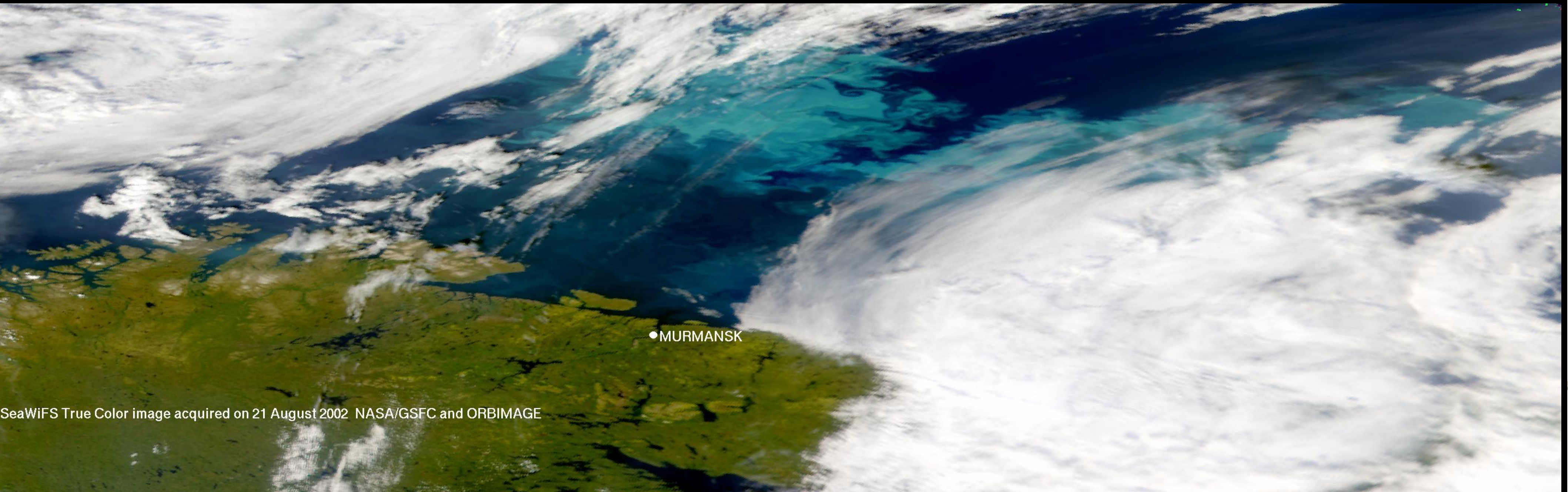
⇒ applications in operational oceanography:

Indonesian Sea operational « ecological » forecasting system

INDESO

INfrastructure DEvelopment

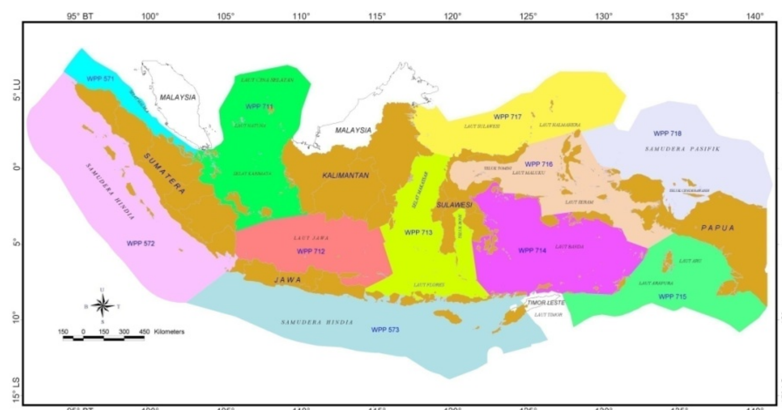
for Space Oceanography



INDESO

INfrastructure DEvelopment for Space Oceanography

- Indonesia has the 6th largest EEZ in the world and fisheries generates US$ 3.1 billions revenue and direct employment to 4 millions people (in 2004, source FAO)
- Vessel Monitoring System deployed in 2004; next steps are:
  - Eradicate illegal fishing (IUU)
  - Support sustainable management of stocks
  - Support sustainable development of aquaculture
  - Support coastal environmental protection



Integrated model suite

- Numerical models suite:

  ocean physics

  lower trophic levels

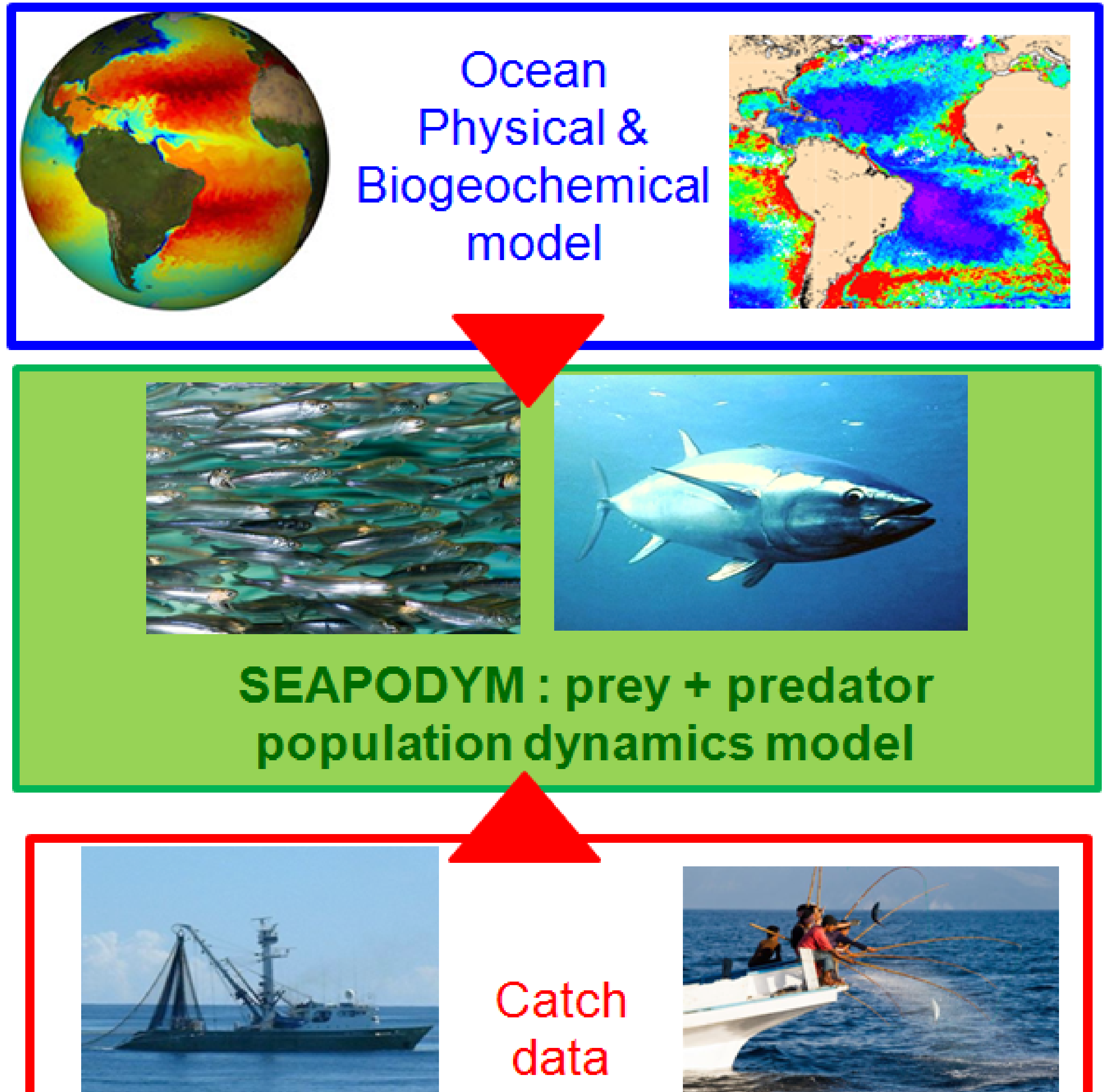
  & biogeochemistry

  prey fields

  predator populations
- Fed by satellite

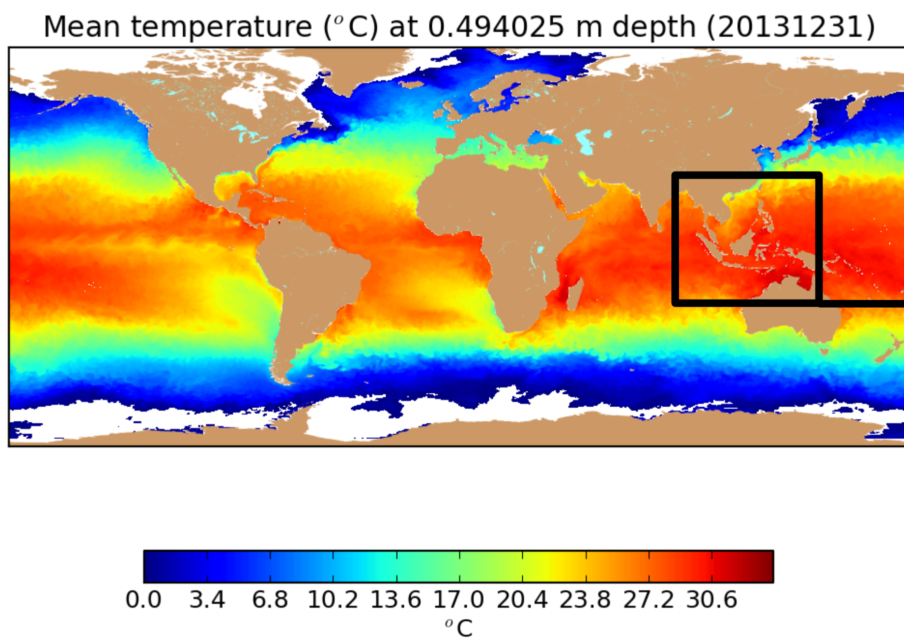
  & in-situ observations
- Generation of forecasts

  & analysis

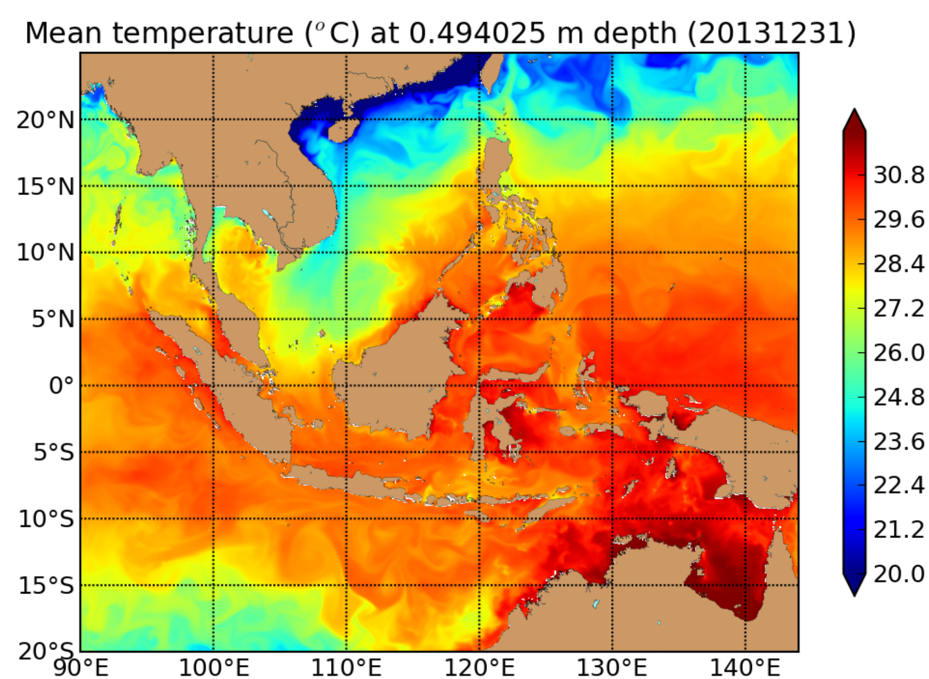


=> fish stock management

operational global model ¼°
weekly forecast (MERCATOR OCEAN)
(assim. of physical data)

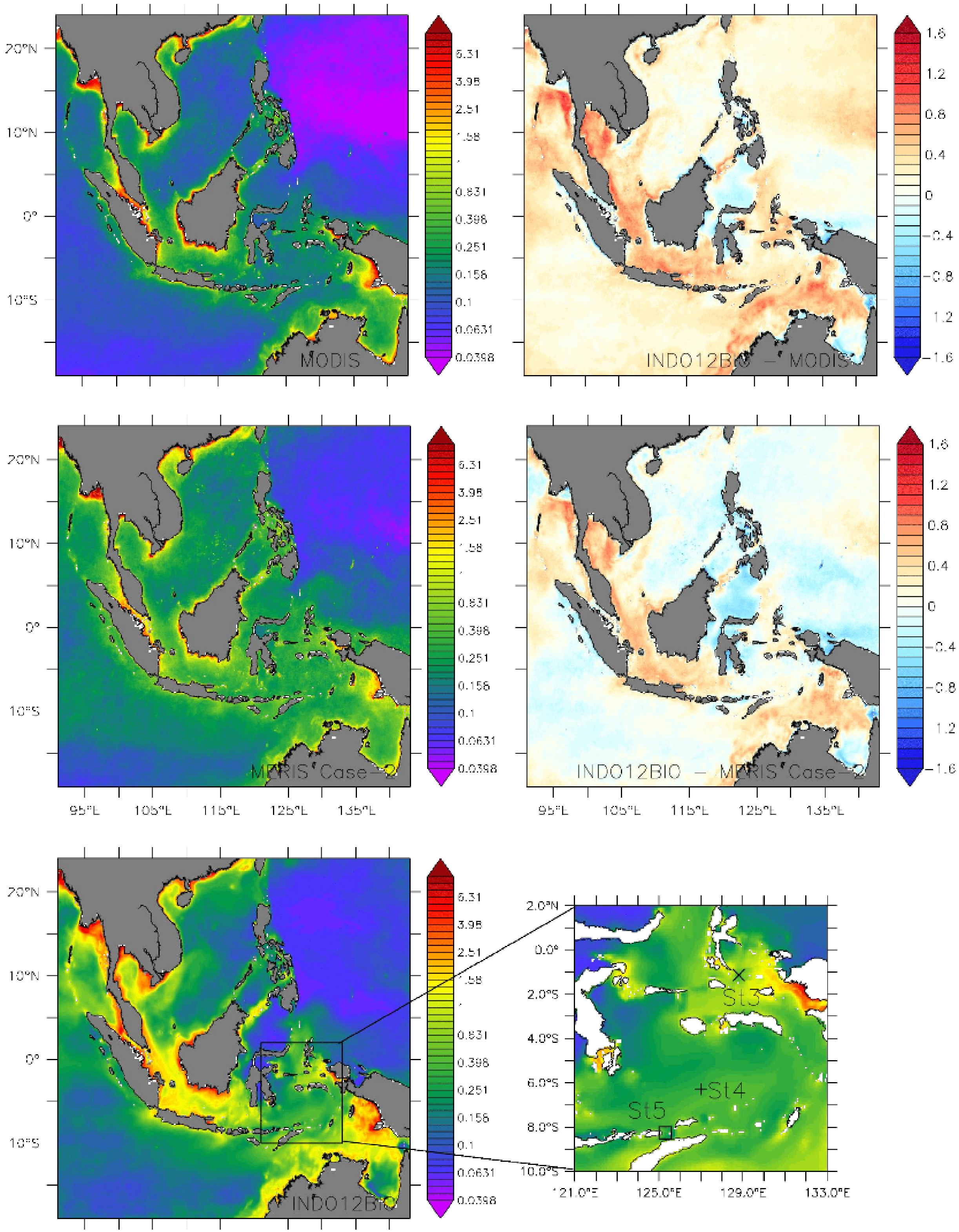


December 31, 2013



Regional model
1/12° x 1day with Open Boundaries Conditions provided from global model

Tranchant et al., in prep

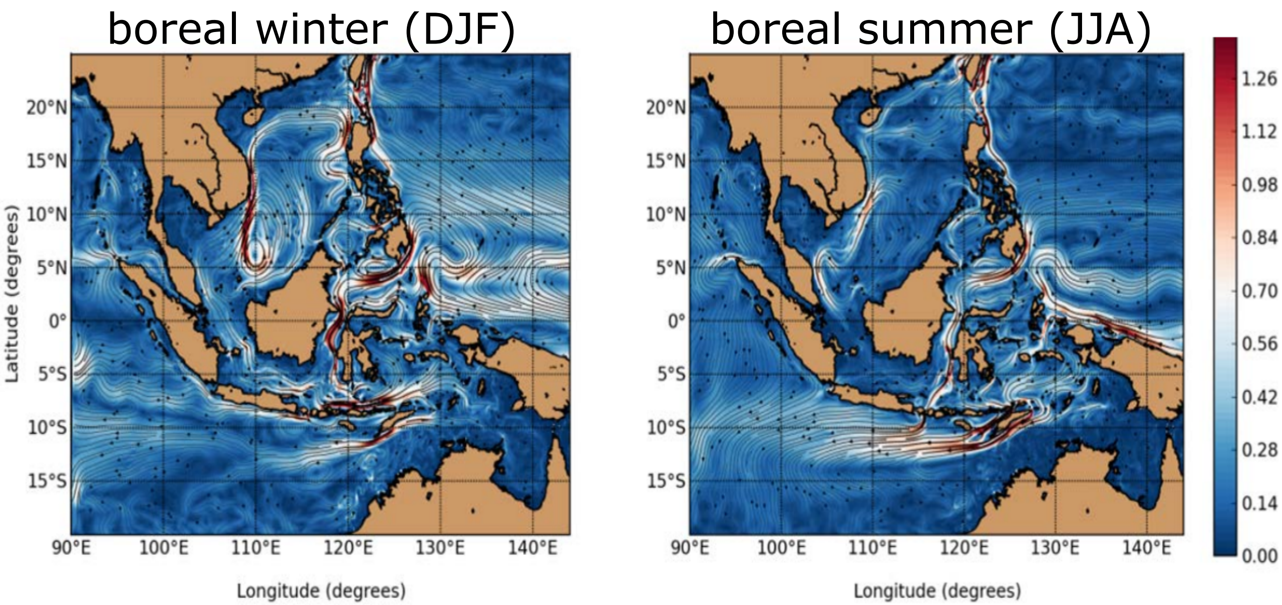


coupled Physical-biogeochemical/ LTL model (NEMO/PISCES)

annual mean surface chlorophyll-a (mg Chl m^{-3}) for year 2011

Gutknecht et al., 2015, GMDD

environmental forcings



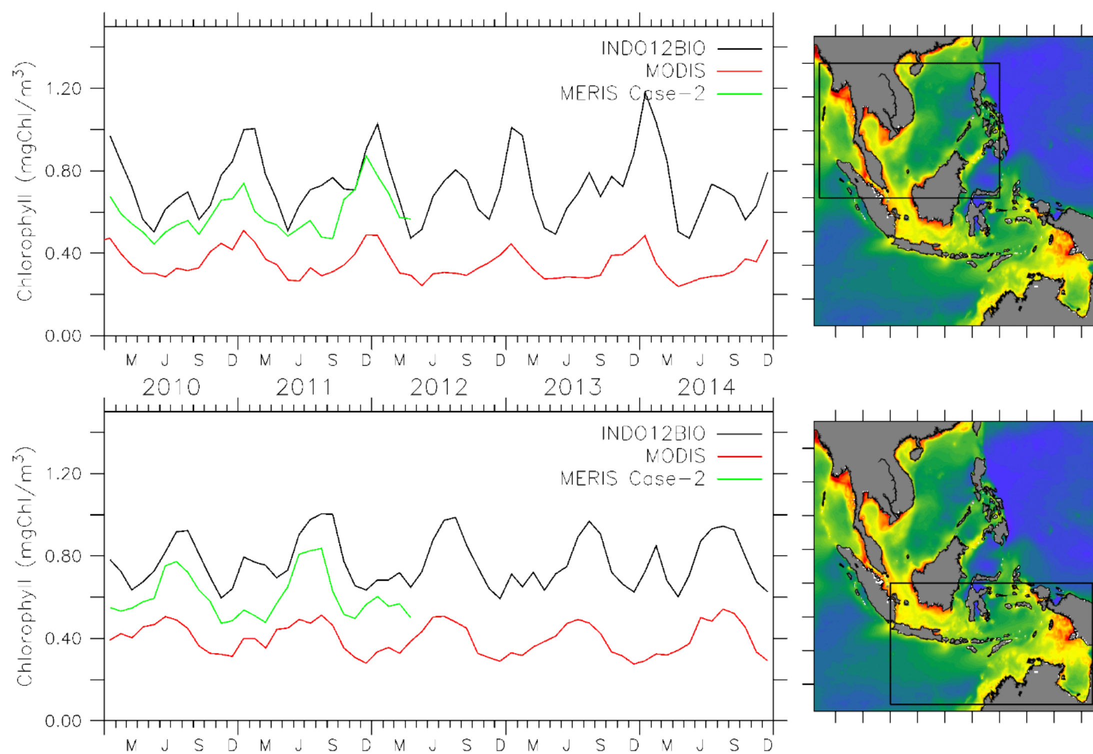
Tranchant et al., 2015, GMDD

coupled Physical-biogeochemical/ LTL model (NEMO/PISCES)

Mean Circulation at surface (16 m depth) during 2008-2013 period

PISCES biogeochemical model (Aumont et al., 2015, GMDD)

NPP, oxygen, euphotic depth as forcings for M&HTL model (SEAPODYM)



Gutknecht et al.,2015, GMDD

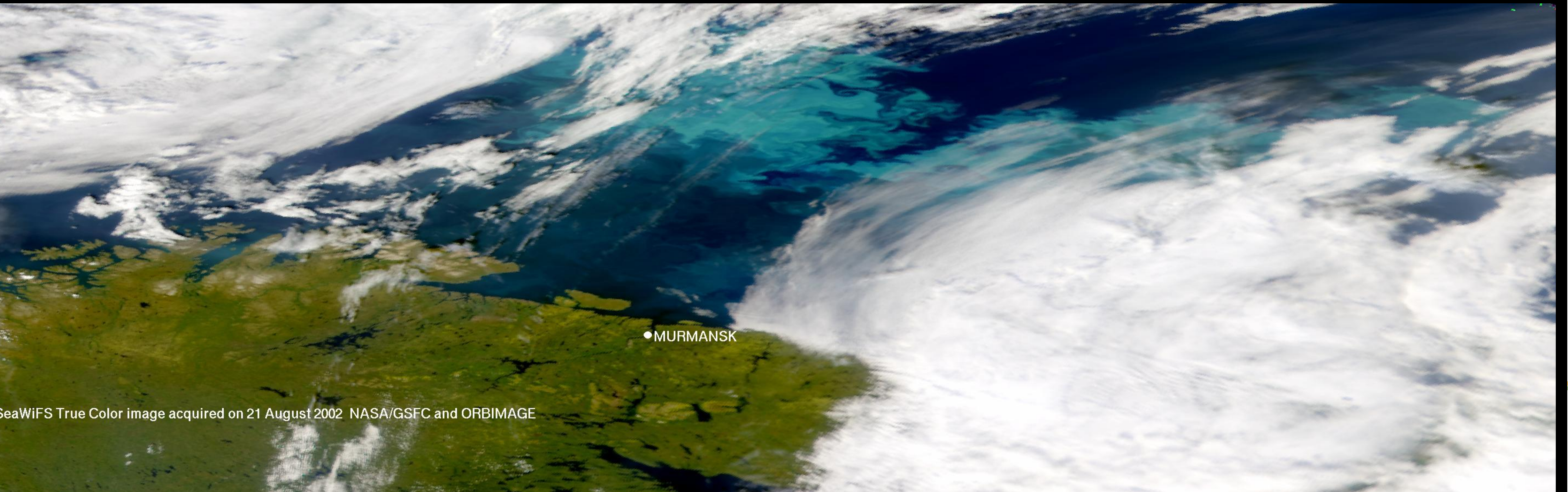
Ocean colour products for

⇒ applications in operational oceanography :

management of living marine ressources

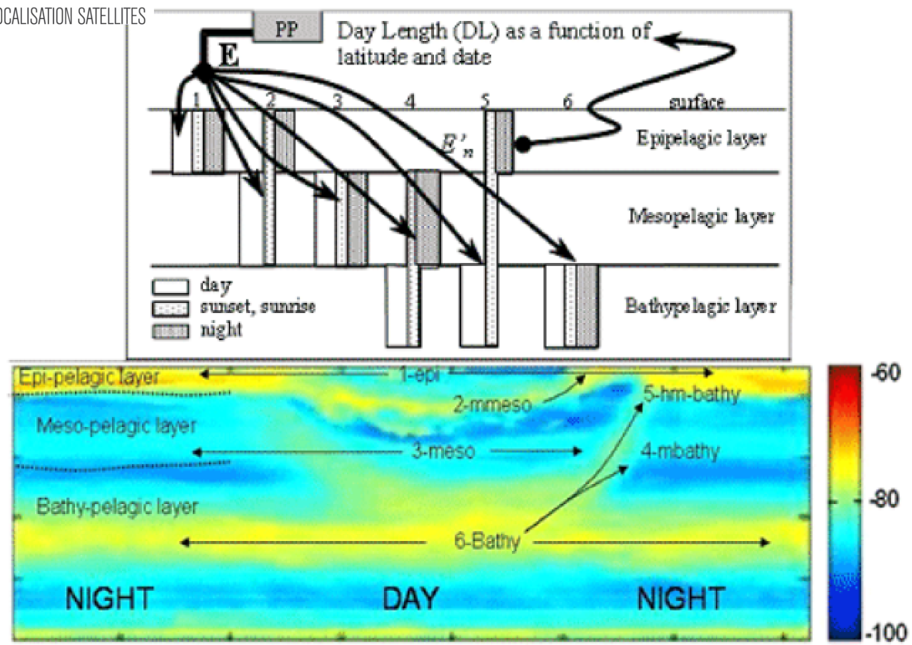
Predicting of Bluefin Tuna

Feeding Habitat



Prey model
(Lehodey et al., 2010)

Feeding habitat prediction : ex. Bluefin tuna



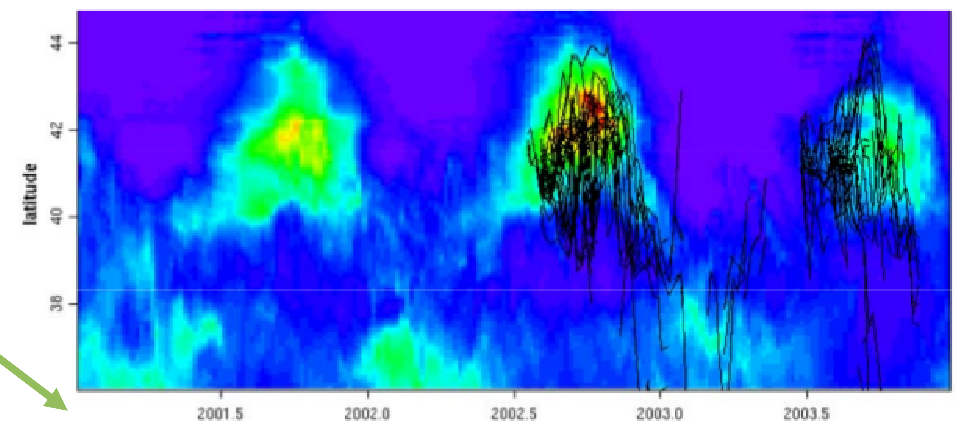
Input :

+ physical variables from ocean re-analysis (GLORYS1V1, Mercator Ocean)

+ **NPP seawifs**

Bluefin tuna
Feeding habitat model

Top : geographical box 36°N-45°N; 70°W-56°W, bluefin tracks on model predicted feeding habitat.
Bottom : predicted Bluefin tuna habitat centred on 16 Oct 2002 ; zoom Gulf of Lyon with juveniles bluefin tuna schools (circles) identified the same week (Royer et al., 2004).



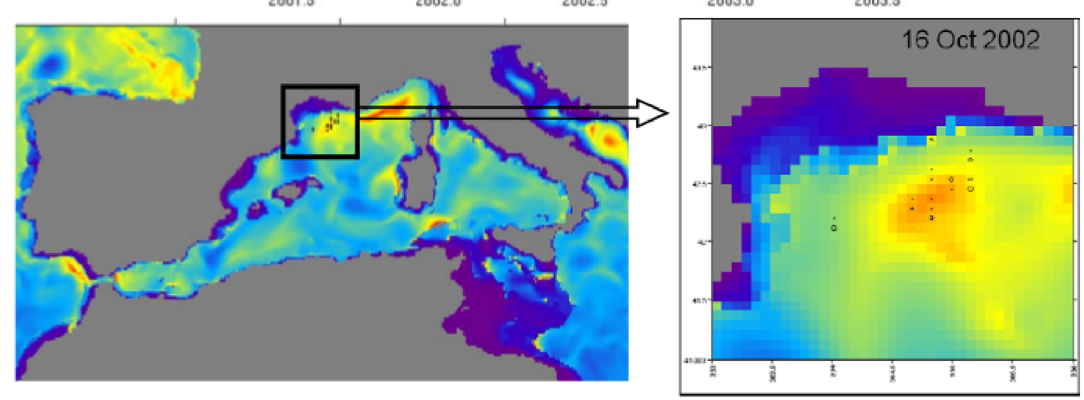


Figure 3

Lehodey 2009, Mercator Ocean Newsletter, 35

Use of ocean colour products : ecological forecasting

- re-analyses
- realtime and forecasts

Requirements :

- continuous observational records for re-analyses
- high resolution for realtime and forecasts

Problems :

- undersamplig of key regions (cloud cover)
- coherence between spatial/temporal scales of physical and biogeochemical fields
- from open ocean to shelf seas: changes in optical properties of ocean waters, needed corrections

Ocean colour products for

⇒ applications in operational oceanography :

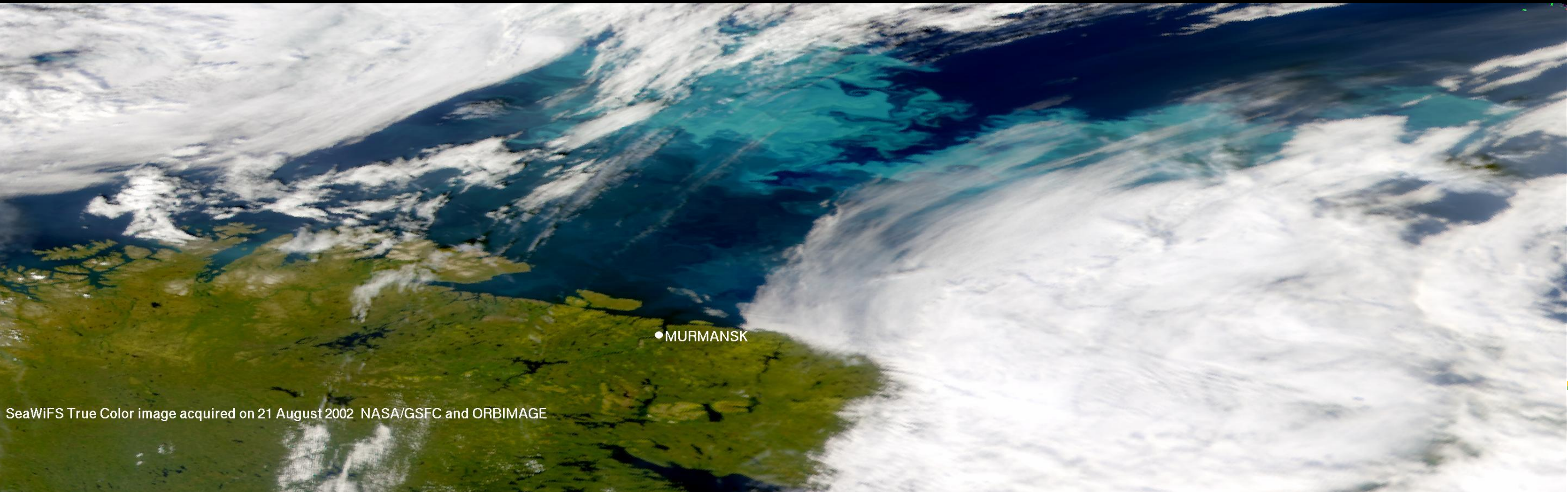
model guidance / data assimilation

management of living marine ressources

⇒ applications in biogeochemical & climate research :

model evaluation

process studies



Use of ocean colour products : model evaluation & skill assessments

- model mean state
- variability : seasonal, inter-annual to decadal

Requirements :

- continuous observational records

  Q: to what extent are merged products suitable for study of variability and trend?

Problems (shared with OO applications):

- undersamplig of key regions (cloud cover)
- from open ocean to shelf seas: changes in optical properties of ocean waters, needed corrections

Use of ocean colour products : process studies

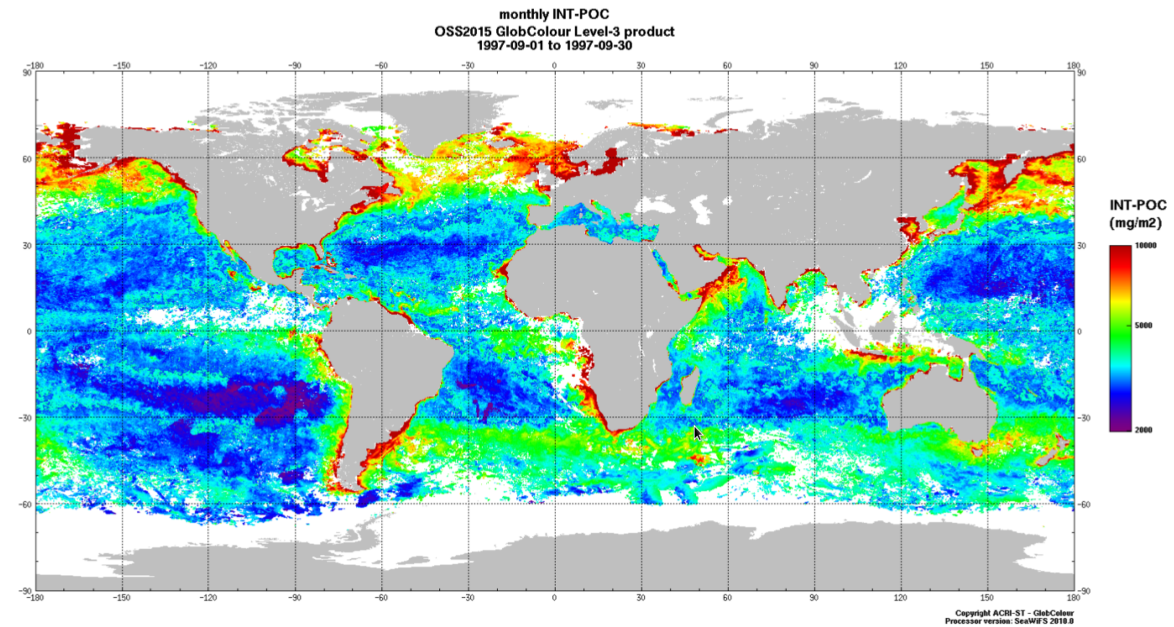
- detection of trends in response to climate change
- ecosystem dynamics : from NPP to export production
- 'diversity' of surface ocean ecosystem : PFTs

Requirements:

- continuous observational records
- further development and improvement of downstream products: e.g. algorithms for PFT identification
  suspended particle and size spectra
  chlorophyll to C ratio

Problems:

- undersamplig of key regions (cloud cover)
- open ocean to shelf seas: changes in optical properties
- poorly constraint uncertainty

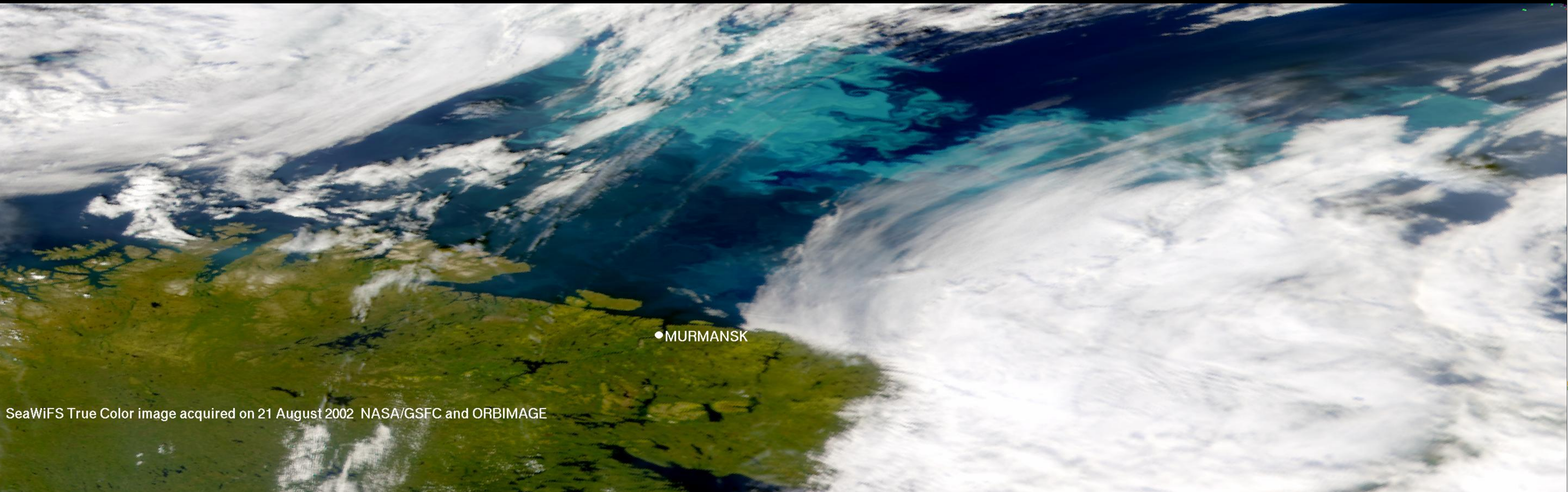


Ocean colour products for

⇒ applications in biogeochemical & climate research :

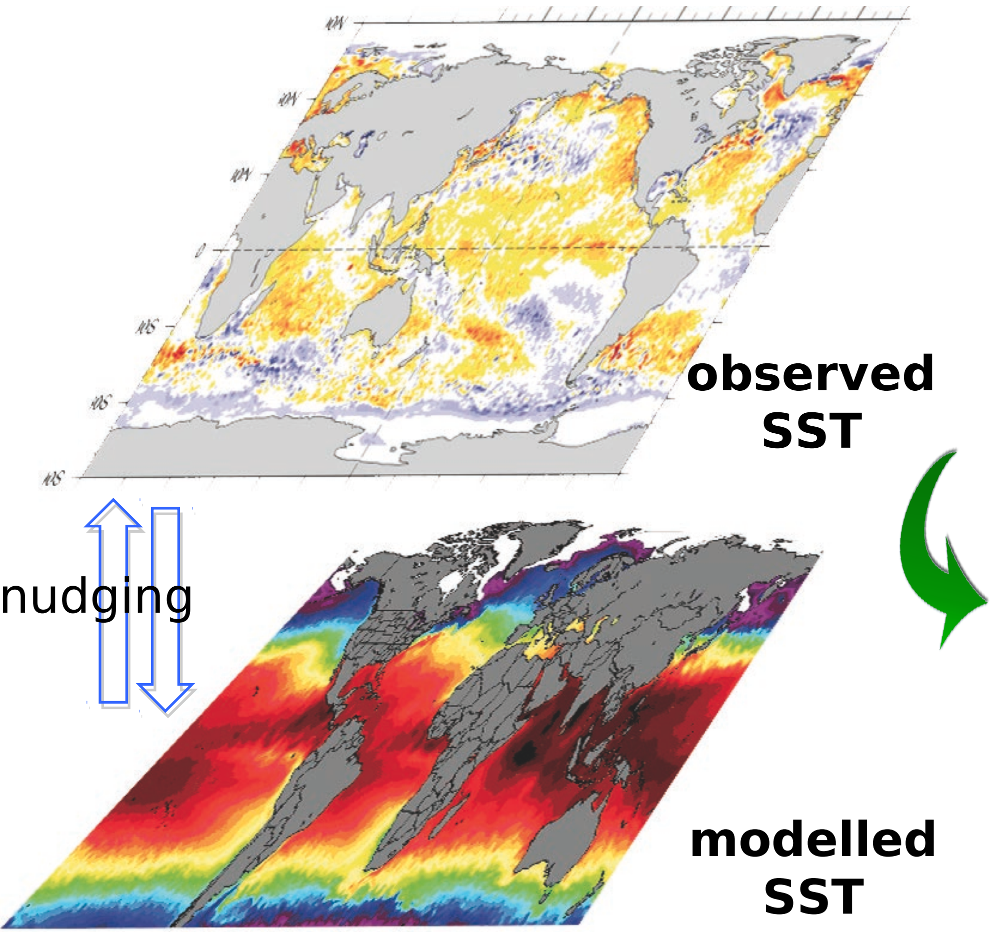
decadal scale predictions of biogeochemistry

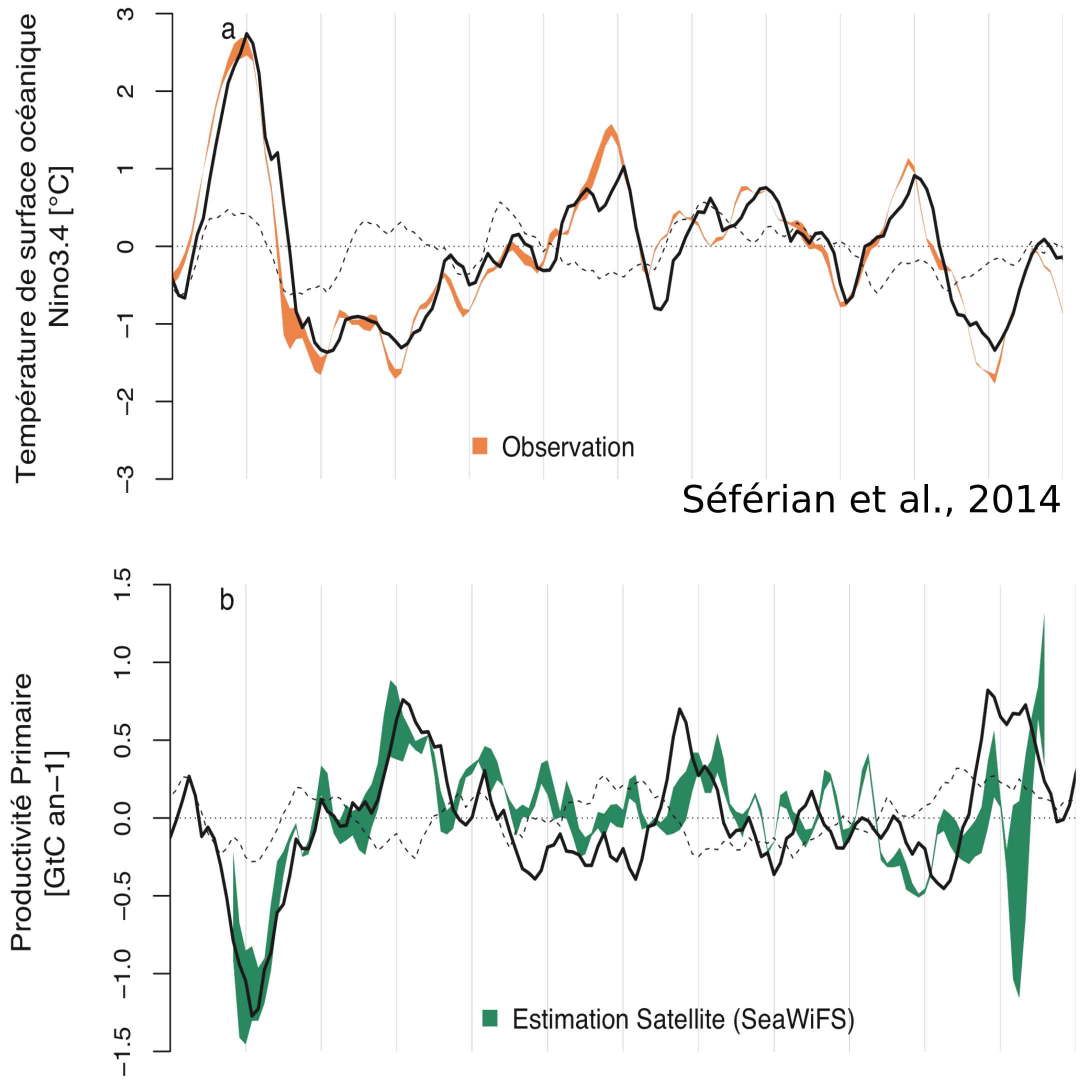
Decadal Prediction of NPP across the Equatorial Pacific



Decadal approach applied to biogeochemistry

Initialization: guiding the model along the trajectory of observed natural variability



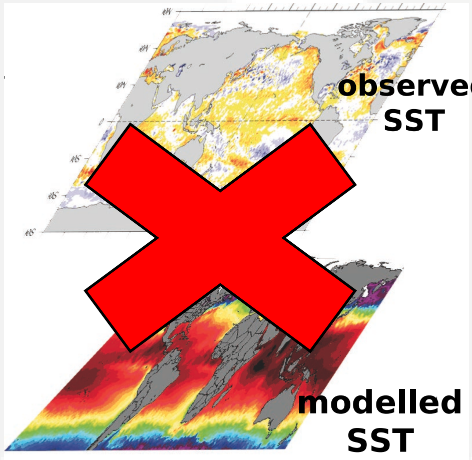


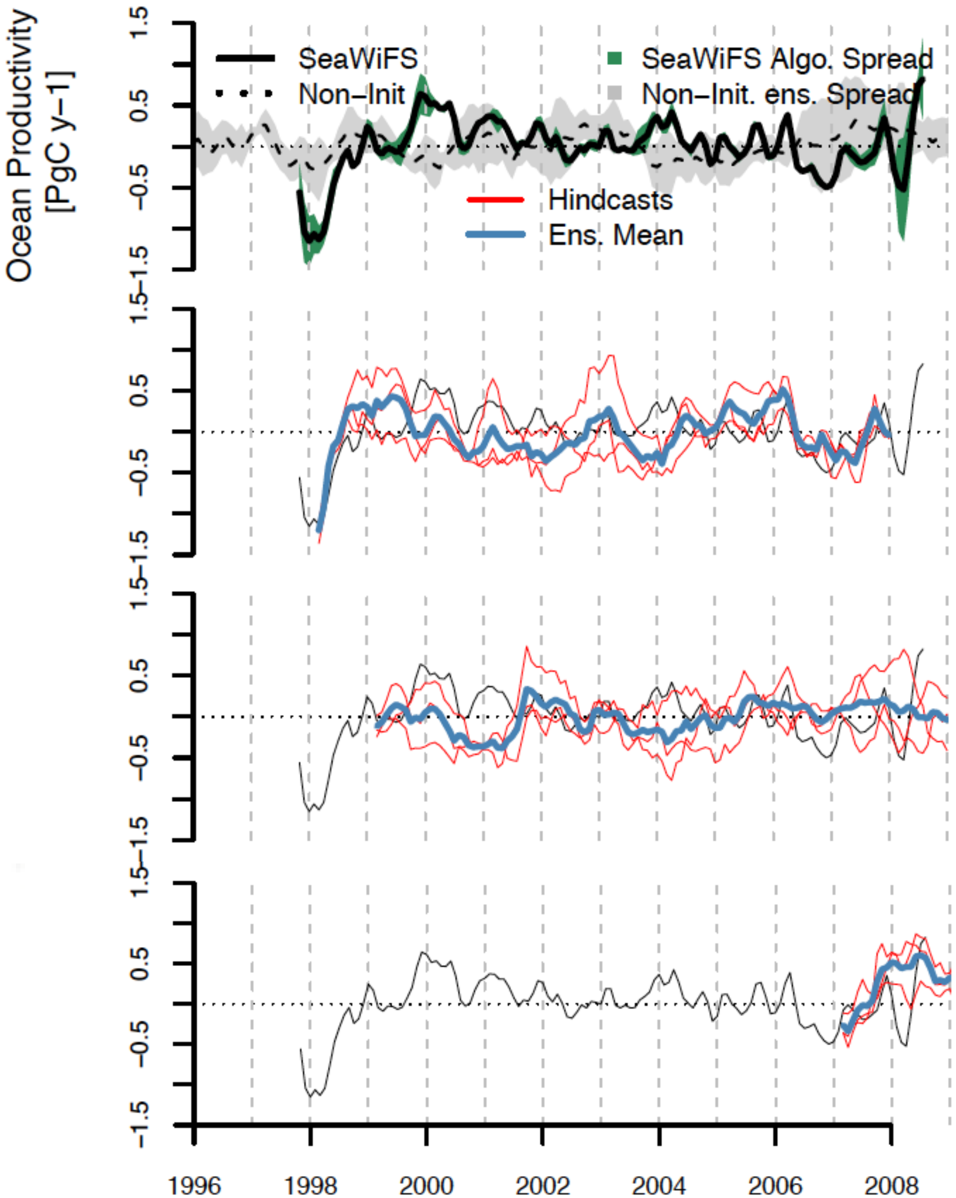
over 60% of observed NPP variability is reproduced by the model

Prediction of NPP

Retrospective forecasting period:
1997 to 2012.
Observations:
-SeaWiFS: 1997-2008
-MODIS : 2002-2012

Prediction :
- each year
- ensemble of 3 members
- for 10 years
- no nudging



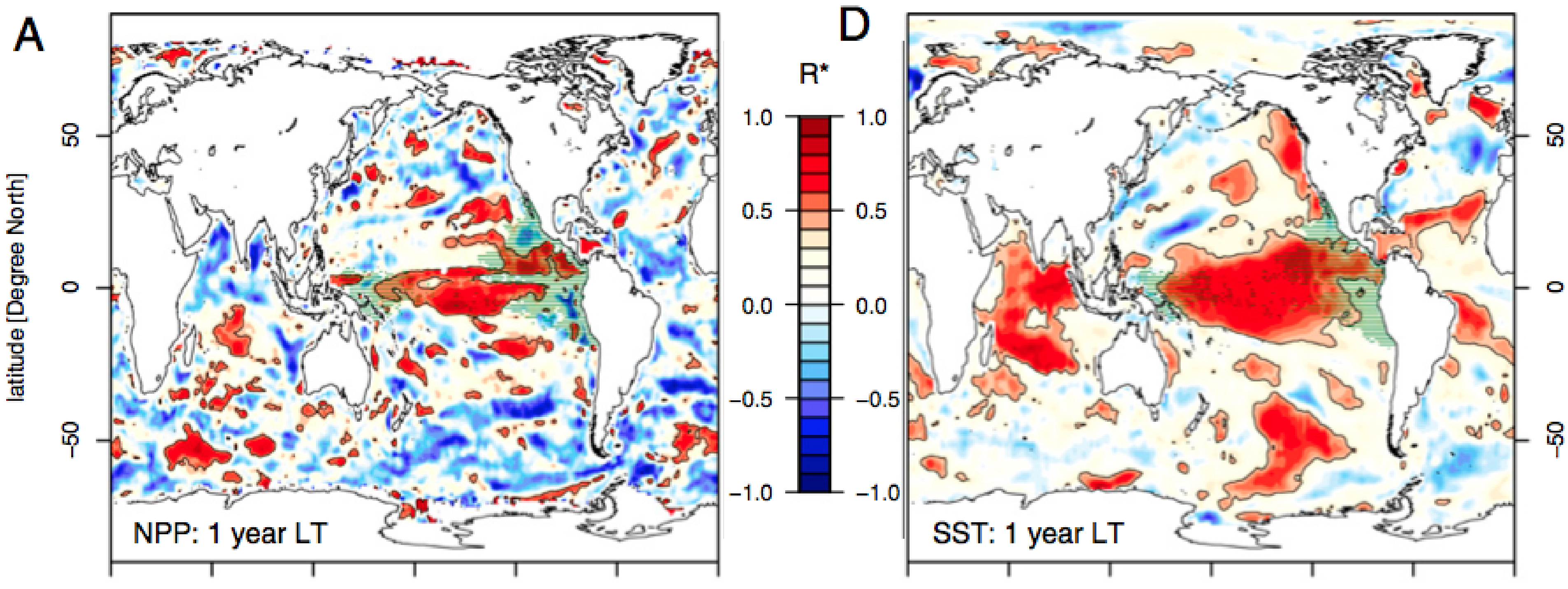


Séférian et al., 2014

Prediction of NPP

<u>1-year predictability</u> (from correlation)

NPP **SST**

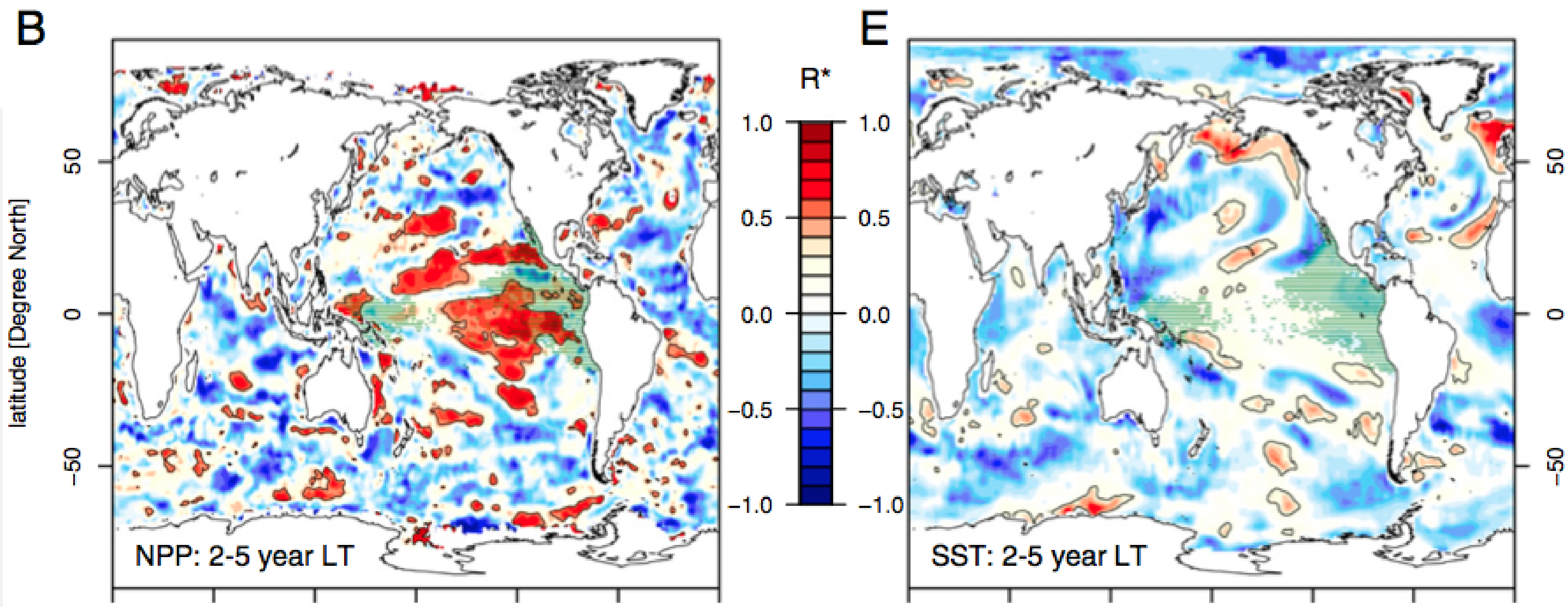


Séférian et al., 2014

Prediction of NPP

<u>2 to 5 year predictability</u> (from correlation)

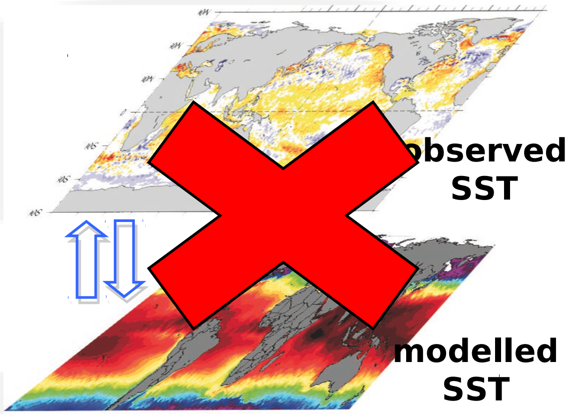
NPP **SST**



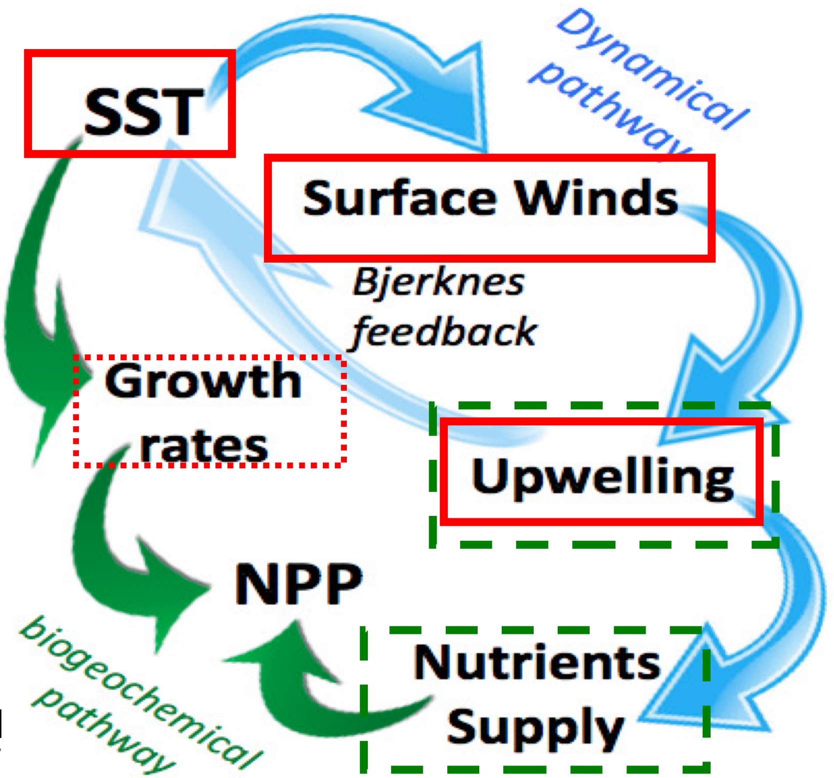
SST is predicted up to 1 year
NPP is predicted from 2 up to 5 years !

Séférian et al., 2014

Prediction of NPP: explanation

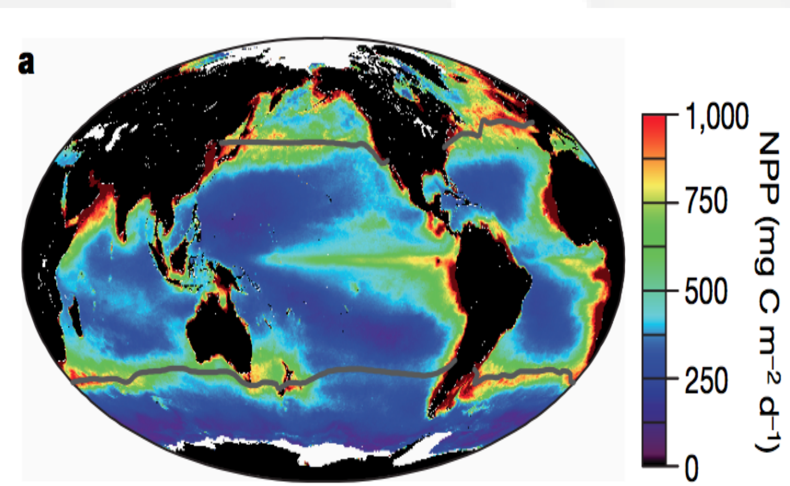


Fast dynamic adjustment for SST



Slow dynamic adjustment fo BGC

Primary production



Séférian et al., 2014

Summary

Requirements: - a modeller's wish list -

- continuity in space and time of observational records
- matching of spatial (eddy resolving) and temporal (high frequency) resolution: model – ocean colour products
- information uncertainty associated to specific products
- continuous development of algorithms suitable for shelf seas and coastal ocean
- continuous development and improvement of downstream products for ecosystem studies