MERCATOR VERT

GREEN MERCATOR

Towards Green Operational Oceanography

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&

The Green Mercator consortium

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PPR associating

- ✓ Mercator-Océan
- ✓ CLS
- ✓ 8 research groups (LSCE, LEGOS, LPO, LEGI, LEMAR, EME, LOCEAN, IIM (SP))
- ✓ 3 years of funding (2012-2014)

connected to major national and international research initiatives

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Motivation:

to provide weekly to seasonal forecasts of ocean biogeochemistry and ecosystem state to the scientific community and to end-users (e.g. fisheries, national environmental agencies, local communities)

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Four main objectives:

O1. to assess the benefits of a physical reanalysis for the off-line forcing of biogeochemical models

O2. to provide the basis for the future addition of assimilation of ocean colour to Mercator-Océan systems

O3. to evaluate of the feasibility of seasonal forecasts of the global ocean biogeochemical state

O4. to demonstrate usefulness of products to end-users

O1. assessment of benefits of a physical ocean reanalysis for the off-line forcing of biogeochemical models

CONFIGURATION of PHYSICAL COMPONENT

NEMO 3.1, ORCA ¼°, 75 vertical layers, LIM2_EVP ice model, atmospheric forcings: ERA-Interim including a large scale correction for downward (shortwave and longwave) radiatice and rainfall fluxes

CONFIGURATION of BIOGEOCHEMICAL COMPONENT

PISCES (NEMO3.5), 1/4° resolution, 2002-2007 (after 3 years of spin-up), offline mode (daily physical forcing), initial conditions: WOA et GLODAP climatologies (+ anthropogenic C), DOC, Fe from 2° model output (3000 years

SIMULATIONS

Period : 1993-2013, start in 1991 from ocean at rest

BIOMER_FREE

no assimilation

BIOMER_GLORYS2v3

assimilation of physical data: T&S profiles (CORA3.3), SST, SLA, sea ice concentration

assimilation system: SAM2/SEEK, IAU

O1. assessment of benefits of a physical ocean reanalysis for the off-line forcing of biogeochemical models

CONFIGURATION of PHYSICAL COMPONENT

Compared to previous project phase:

- ✓ updated model versions & forcing
- ✓ physics & BGC at same resolution (1/4°)
- ✓ increase in forcing frequency (daily)

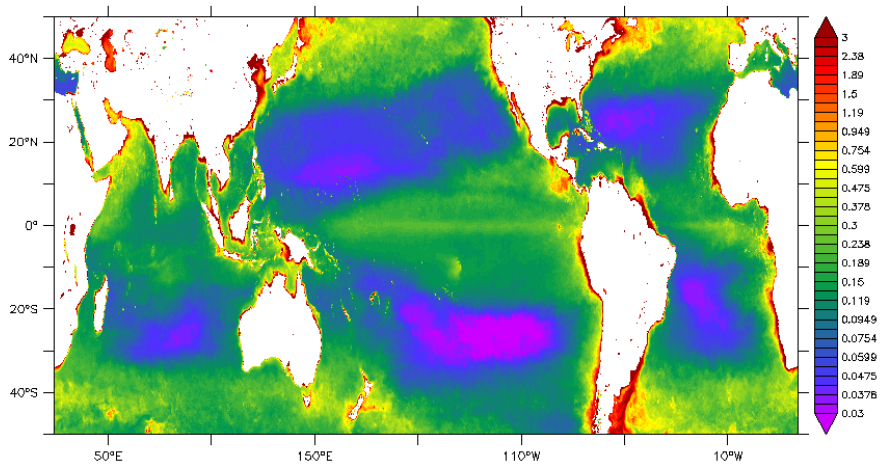
Period : 1993-2013, start in 1991 from ocean at rest

BIOMER_FREE
no assimilation

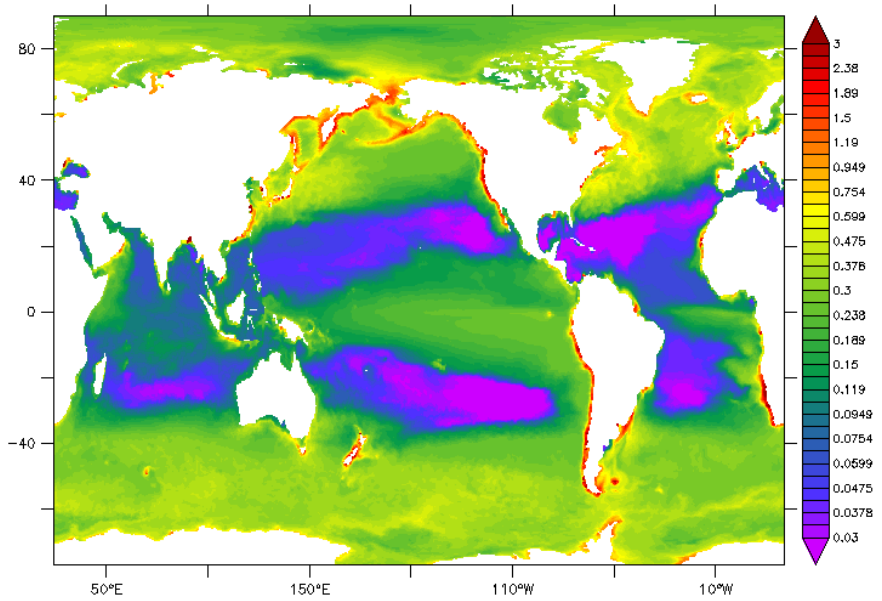
BIOMER_GLORYS2v3
assimilation of physical data: T&S profiles (CORA3.3), SST, SLA, sea ice concentration
assimilation system: SAM2/SEEK, IAU

Year 2011

surface chlorophyll
mg Chl m^{-3}

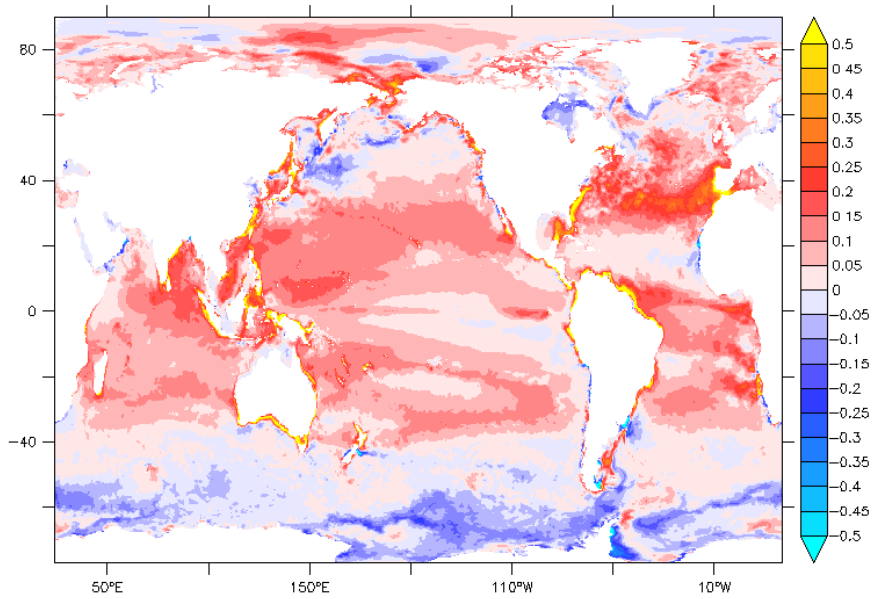


GLOBCOLOUR



BIOMER_FREE

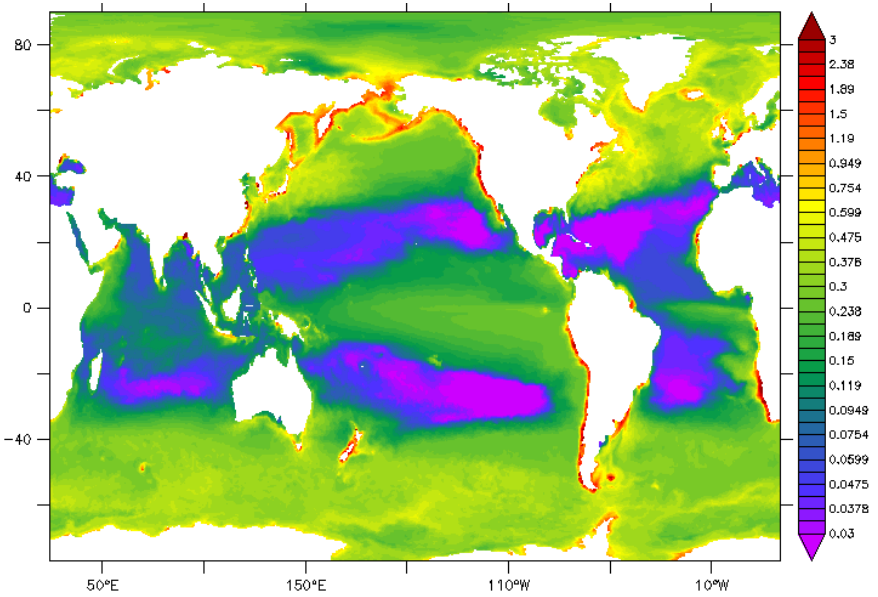
(after 20 years of simulation)



Year 2011

surface chlorophyll
mg Chl m^{-3}

BIOMER_FREE
-
BIOMER_GLORYS2V3



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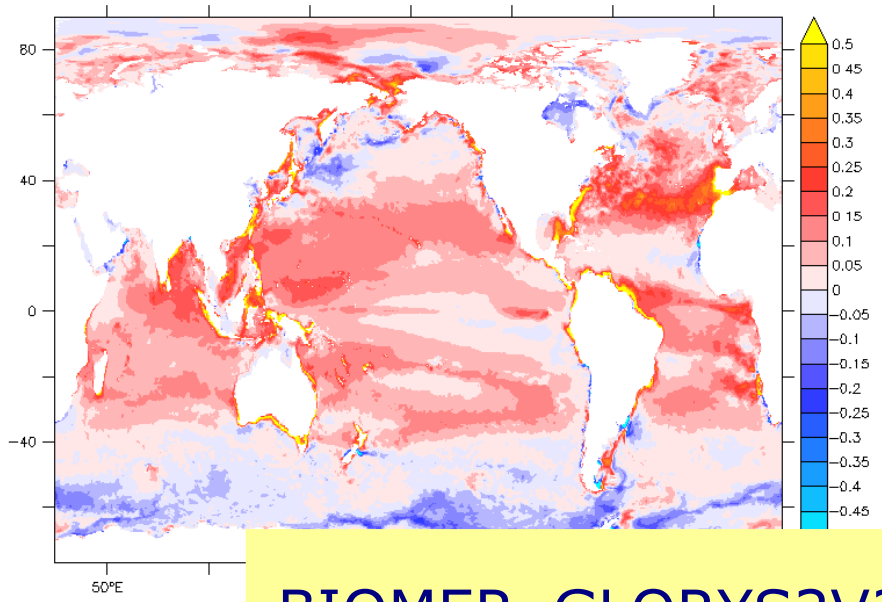


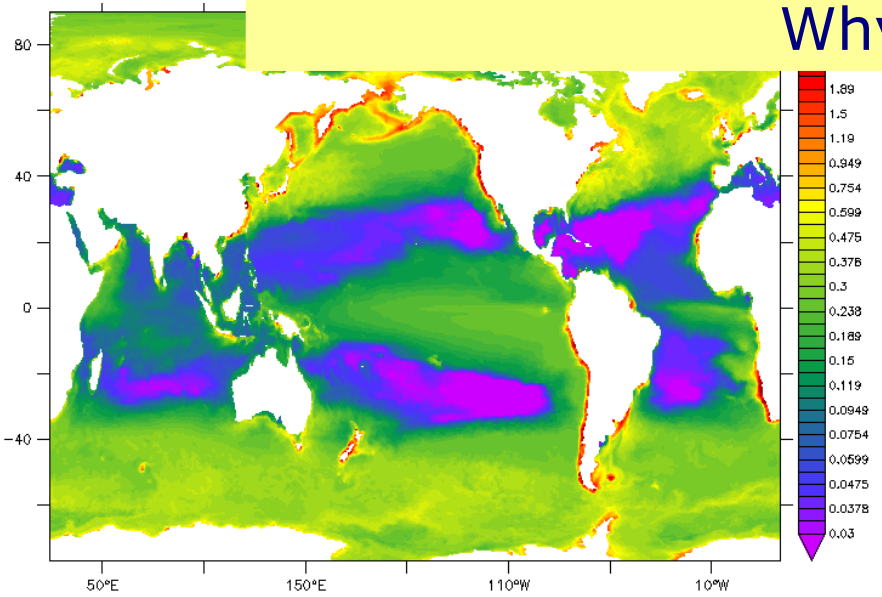
Year 2011

surface chlorophyll
mg Chl m^{-3}

BIOMER_FREE
-
S2V3

BIOMER_GLORYS2V3 is too productive !

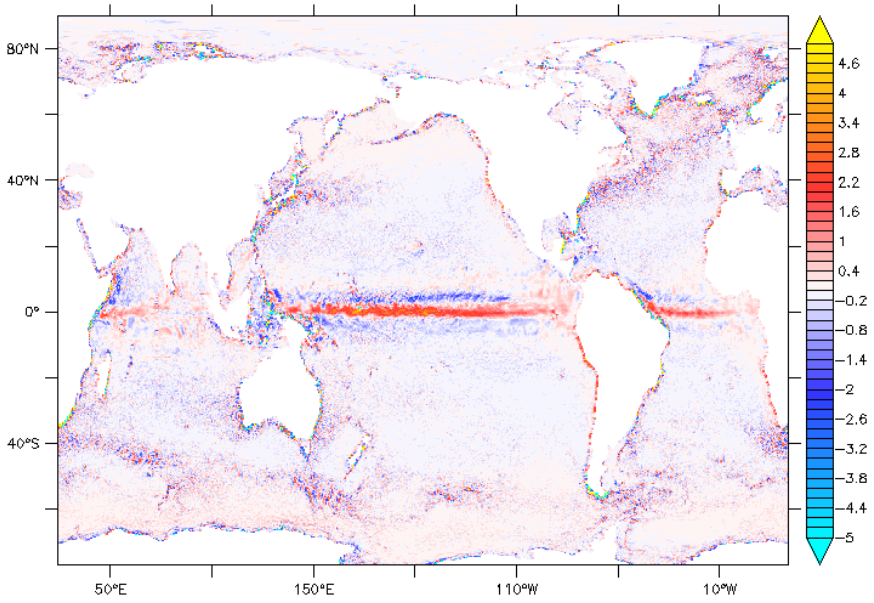
Why ?



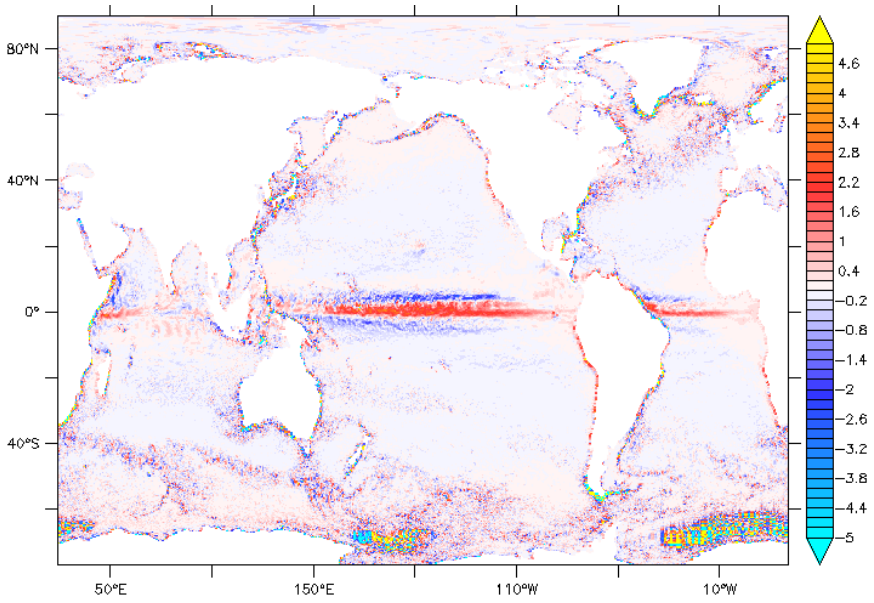
BIOMER_FREE

(after 20 years of simulation)

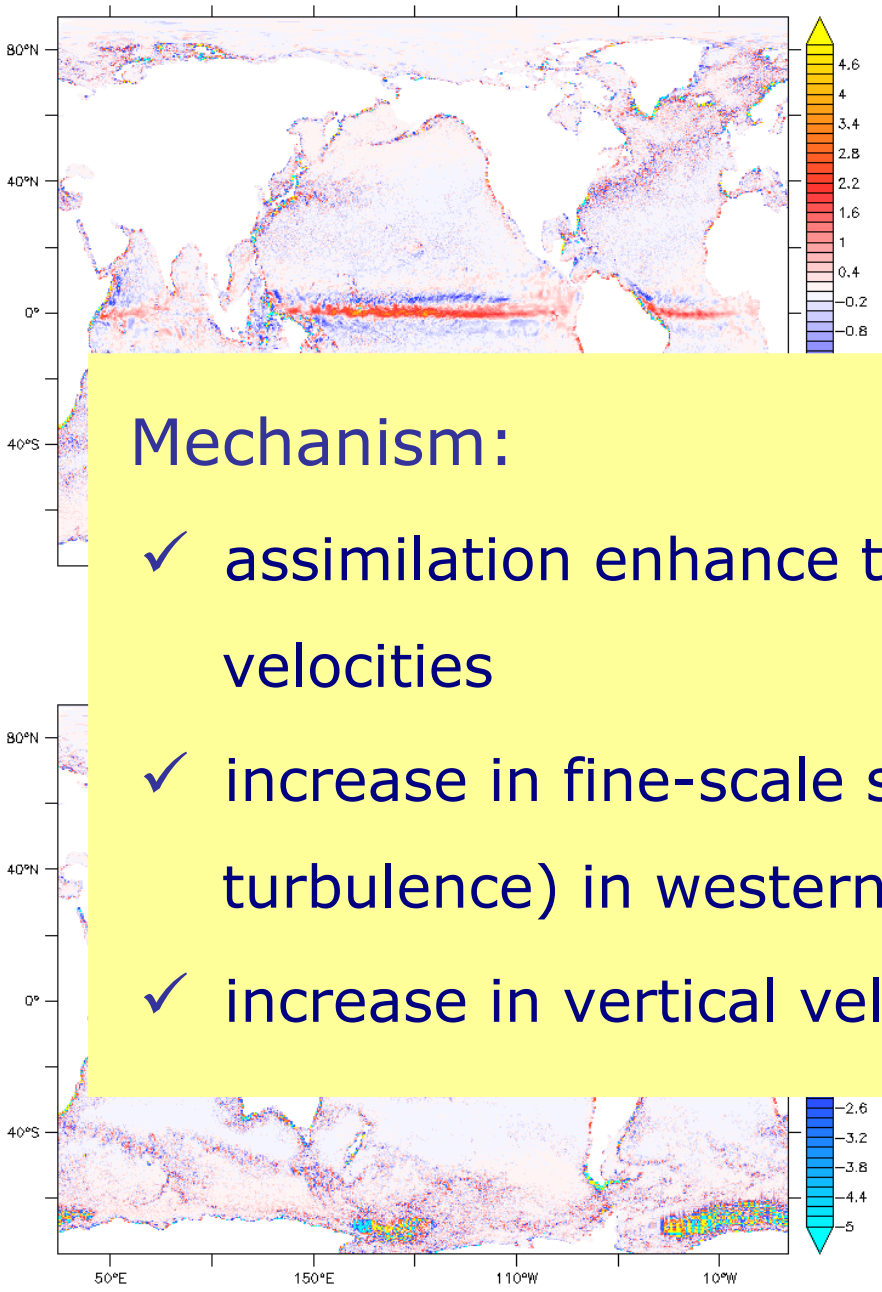
Mean vertical velocities at 50m depth (year 2011)



BIOMER_GLORYS2V3



BIOMER_FREE
(2011



Mean vertical velocities at 50m depth (year 2011)

Mechanism:

- ✓ assimilation enhance the variability of vertical velocities
- ✓ increase in fine-scale structures (mesoscale turbulence) in western boundary currents & ACC
- ✓ increase in vertical velocities along equator

O1. assessment of benefits of a physical ocean reanalysis for the off-line forcing of biogeochemical models

Comparison of results from 2 twin simulations (with and without assimilation of phyiscal data:

- ✓ assimilation enhances mesoscale turbulence
- ✓ assimilation enhances vertical velocities along Equator

⇒ BIOMER_GLORYS2V3 is too productive

tuning of biogeochemical model is not an acceptable solution as it would only compensate the physical bias

O1. assessment of benefits of a physical ocean reanalysis for the off-line forcing of biogeochemical models

Comparison of results from 2 twin simulations (with and without assimilation of phyiscal data:

- ✓ assimilation enhances mesoscale turbulence
- ✓ assimilation enhances vertical velocities along Equator

⇒ BIOMER_GLORYS2V3 is too productive

No progress over the past 3 years ??

Near-real-time products BIOMER4 based on PS3V3:

- ✓ physics and biogeochemistry at 1/4°
- ✓ daily frequency for off-line forcing of BGC
- ✓ tuning of limited number of BGC parameters
- ✓ assimilation of hybrid-MSSH

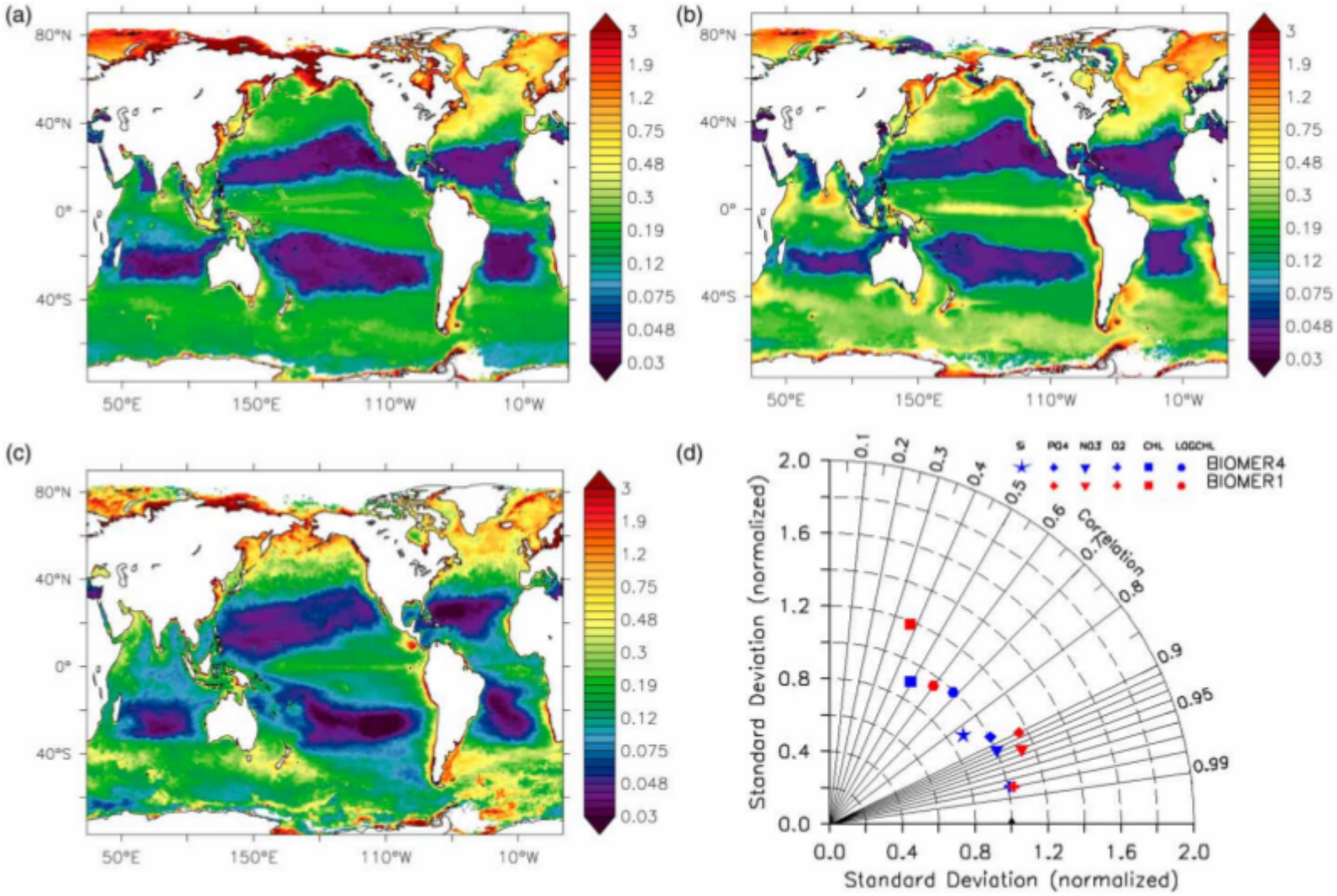


Figure 1. Mean surface chlorophyll-a concentrations (mgChla/m^3) in 2013: (a) BIOMER4 (recent model version); (b) BIOMER1 (previous model version); (c) GlobColour observational product; (d) Taylor diagram of modelled surface concentrations of nutrients (dissolved silica, phosphate, nitrate), oxygen, chlorophyll-a and $\log_{10}$(chlorophyll-a). Standard deviations are normalised with respect to data (WOA2009 and GlobColour).

Gehlen et al. (2015) JOO

Near-real-time products BIOMER4 based on PS3V3:

- ✓ physics and biogeochemistry at 1/4°
- ✓ daily frequency for off-line forcing of BGC
- ✓ tuning of limited number of BGC parameters
- ✓ assimilation of hybrid-MSSH

⇒ quality of BIOMER4 is improved

bias reduction in physical fields allows for a successful tuning of biogeochemical model

O2. production and scientific evaluation of a North Atlantic biogeochemical reanalysis (SeaWIFS period)

=> assess the sensitivity of biogeochemical fields to parameter uncertainty and process parameterization

The probabilistic approach

Given the biogeochemical unresolved complexity, considering a system as deterministic will always be an approximation!!

$\Rightarrow$ **we consider the biogeochemical model as probabilistic**

$\Downarrow$

stochastic parameterizations $\rightarrow$ ensemble simulations

$\Downarrow$

distribution of prior model states

$\Downarrow$

perform EnKF analysis

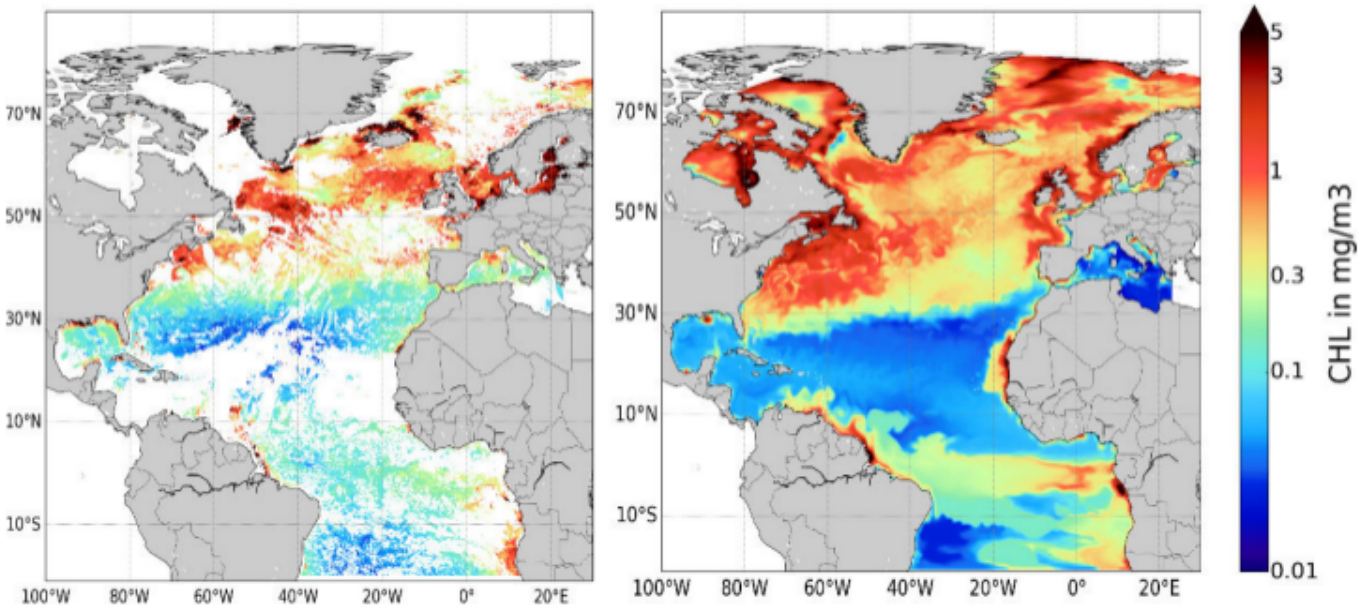
I believe that the ultimate climate models (...) will be stochastic, i.e. random numbers will appear somewhere in the time derivatives.

Edward Lorenz (1975)

SANGOMA

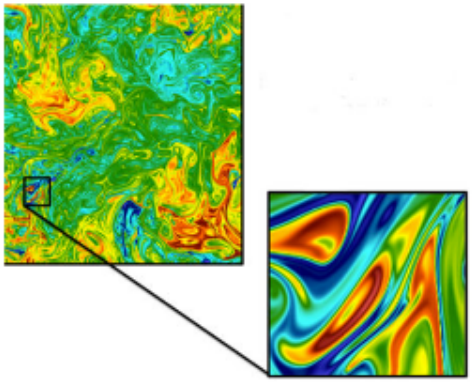
From a PISCES deterministic simulation...

- 1/4° 46 z-levels on-line NATL025-PISCES simulation based on NEMO/OPA code
- Reference PISCES parameterization *[Aumont et al, 2006]*
- Era-Interim forcing fields
- No biological feedback on physics
- No chlorophyll data to limit light penetration



surface chlorophyll for the 15/05/2005, SeaWIFS (left) and the deterministic simulation (right)

...to a probabilistic version: stochastic formulations



Diversity of species

→ 7 parameters are perturbed :

$$\frac{\partial C}{\partial t}|_{bio} = \overbrace{SMS(C,u,p,t)}^{deterministic} \rightarrow \underbrace{SMS(C,u,p',t)}_{stochastic}$$

avec $p' = \exp[\xi(t)]p$ $sd = 30\%$

Unresolved scales (Brankart el al, 2013):

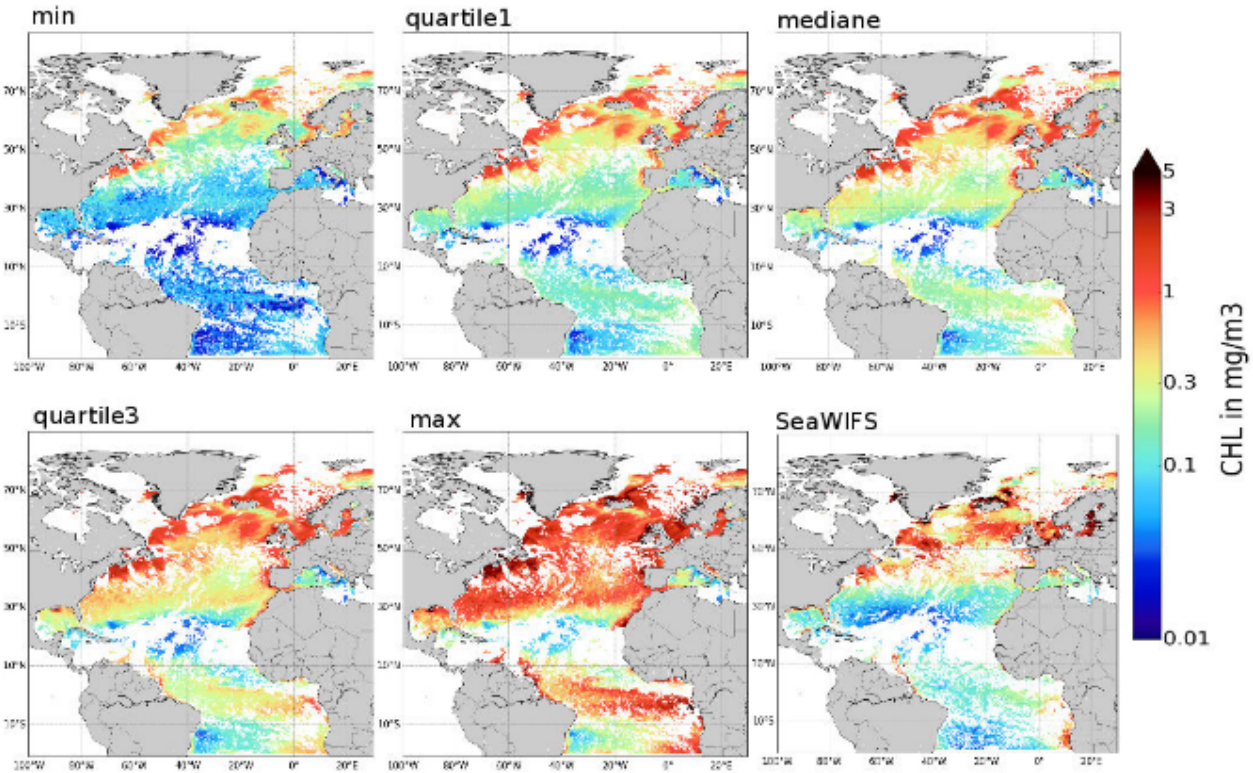
$$SMS(\overline{C}) \neq \overline{SMS(C)} \Rightarrow \frac{\partial C}{\partial t}|_{bio} = \frac{1}{2}\{SMS(\overline{C}+\delta C,u,p,t) + SMS(\overline{C}-\delta C,u,p,t)\}$$

with $\delta C = \xi(t)\overline{C}$ $sd = 20\%$

SANGOMA

Probabilistic response to uncertainties: surface chlorophyll quartile maps

Can the simulated uncertainties explain deviations with observations?

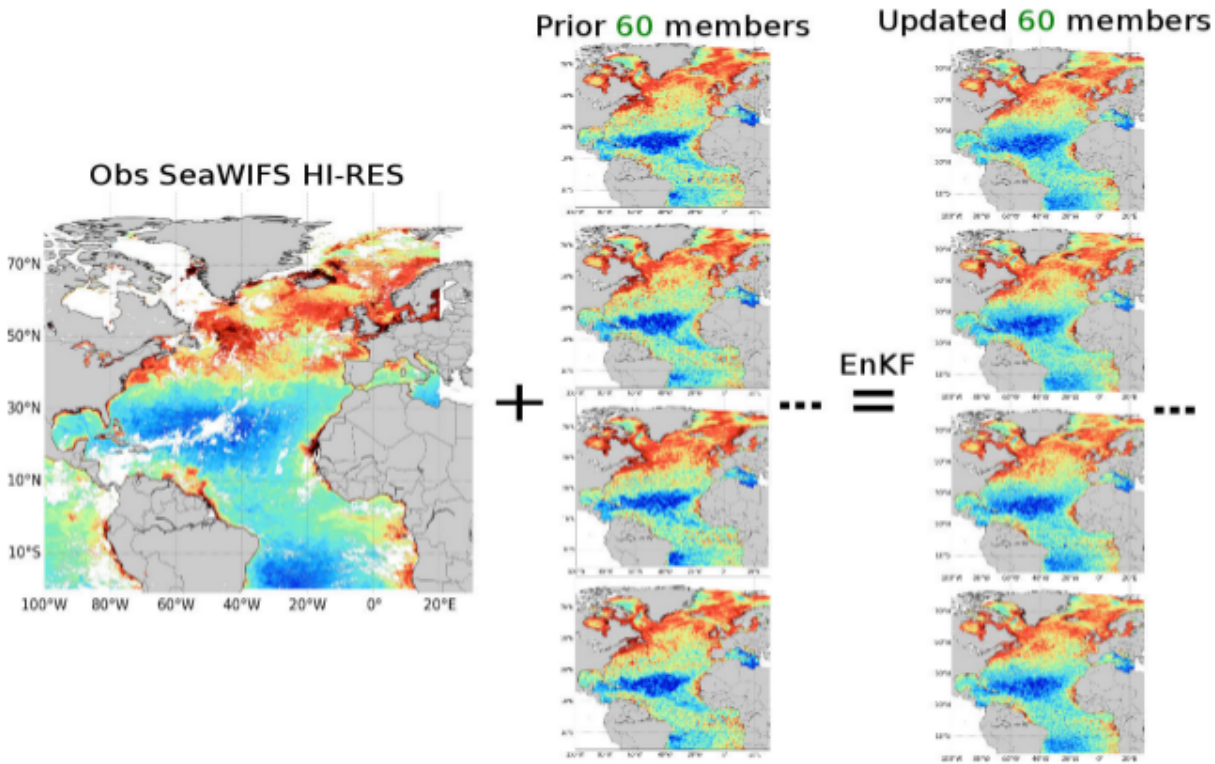


surface chlorophyll described by the ensemble simulation, 15/05/2005

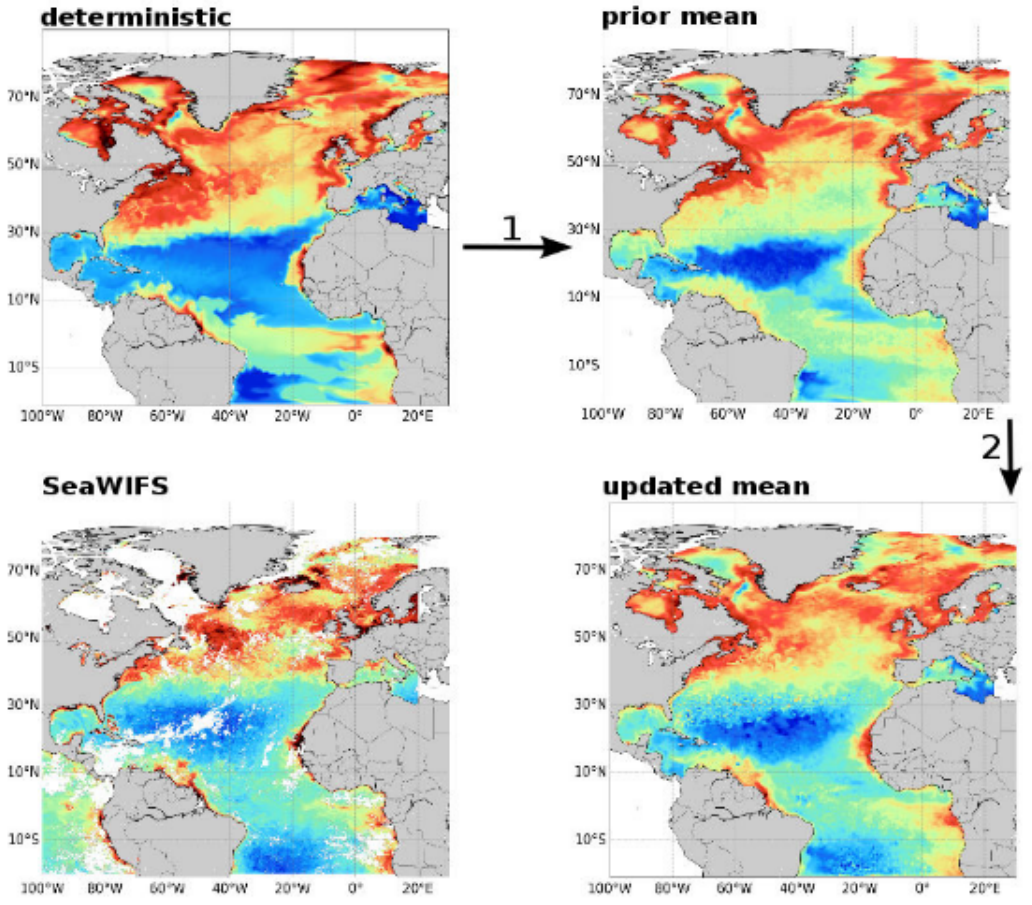
- In most places the envelope of the ensemble seems to include the observations
  → Need a objective comparaison

1 year 3D ensemble kalman filter analysis

- observations are the SeaWIFS data at 4km resolution from the MyOcean OC TAC
- updates are performed at each time step using an **ensemble kalman filter analysis** (EnKF)
- the analysed states **are not** propagated by the model



Conclusion 1



⇒ On a first try, the approach (stochastic parameterizations + EnKF) allows to obtain a much better ocean colour product

Conclusion 2

- The **ensemble of updated states** provides statistical information on the system distribution
- this could still be **improved:**
  - using more sophisticated stochastic parameterizations (physics, non constant sd for perturbations...)
  - using more accurate ocean colour data

- $\Rightarrow$ focus here on probabilistic comparisons with observations
- not shown in this presentation:
  - relevant **impacts** on **non observed variables** (e.g zooplankton, nitrates)
  - deterministic model **vertical information** is not deteriorated

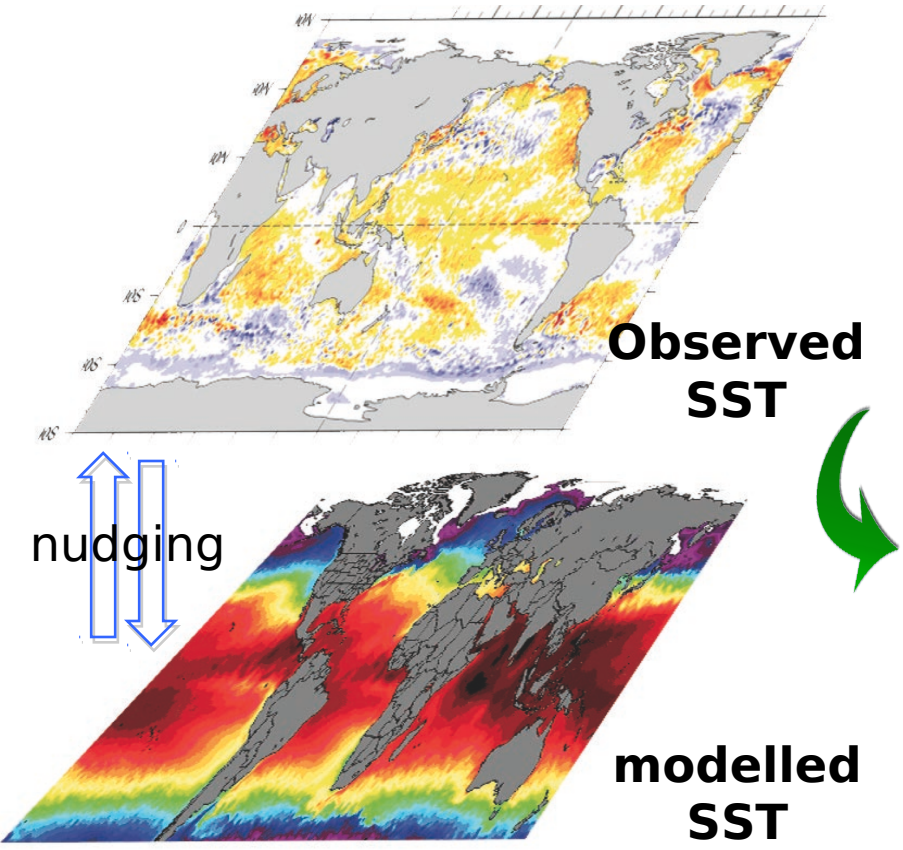
O2. evaluate the feasibility of seasonal to inter-annual forecasts of the global ocean biogeochemical state

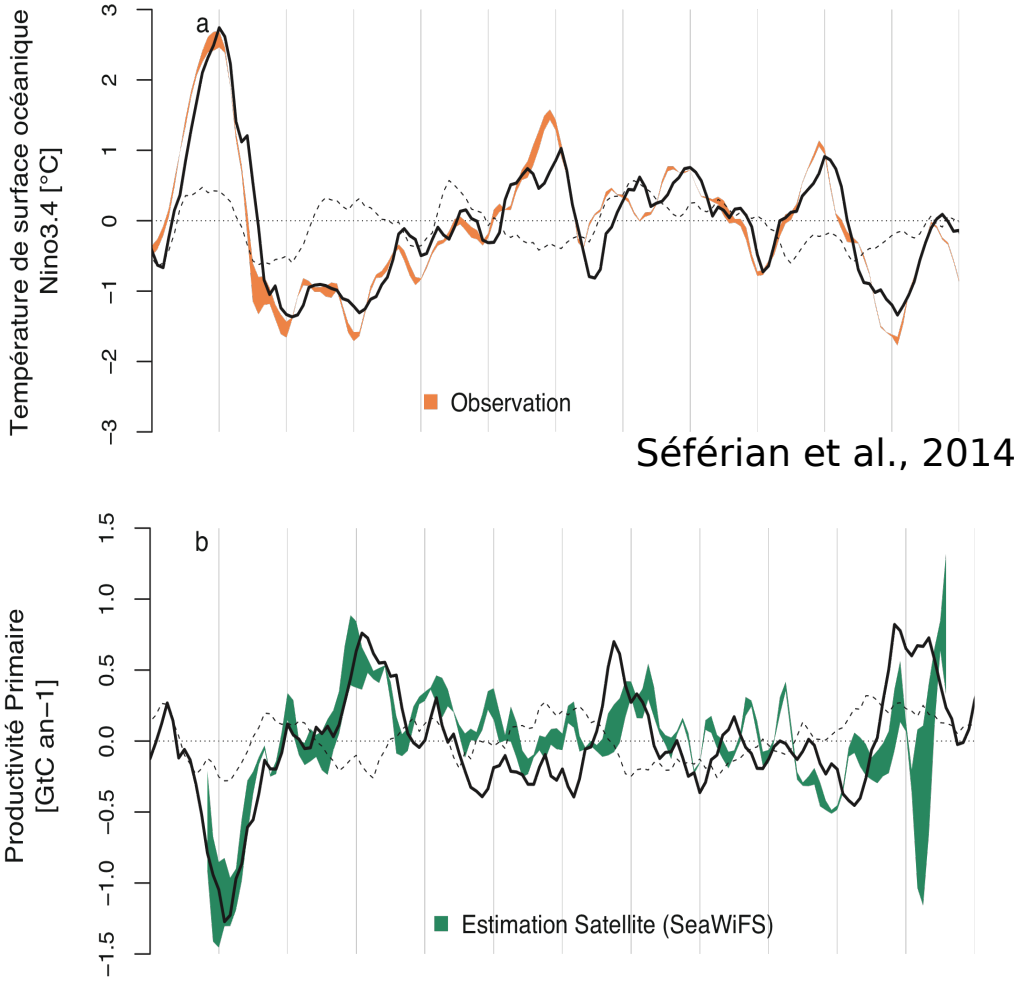
=> decadal scales predictions with IPSL-CM5-LR

Séférian et al., 2014, PNAS

Decadal approach applied to biogeochemistry

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





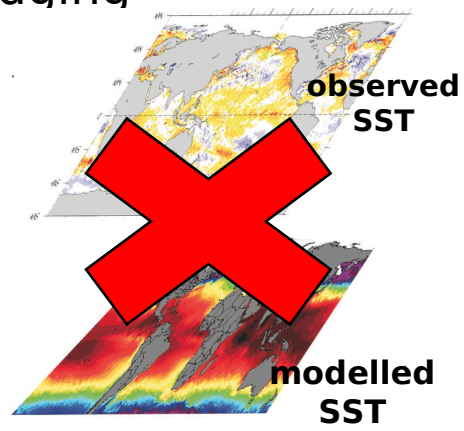
Séférian et al., 2014

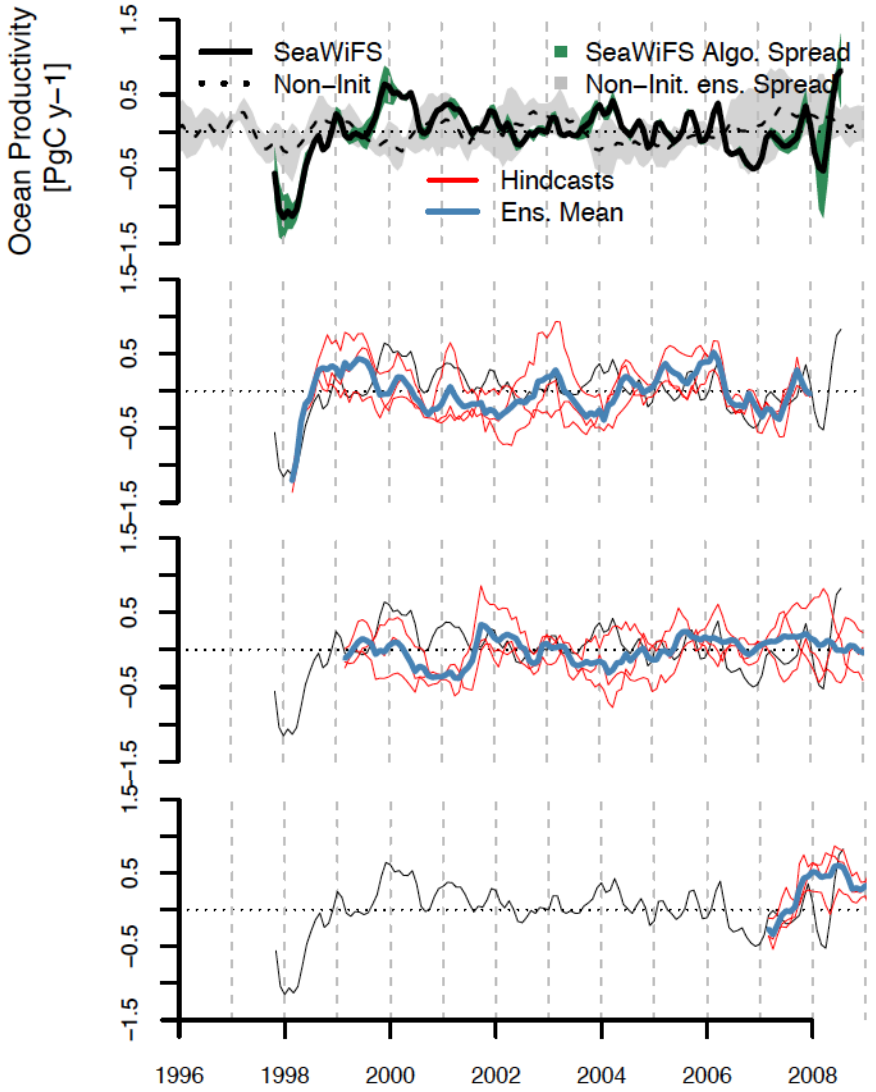
over 60% of observed NPP variability is reproduced by the model

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



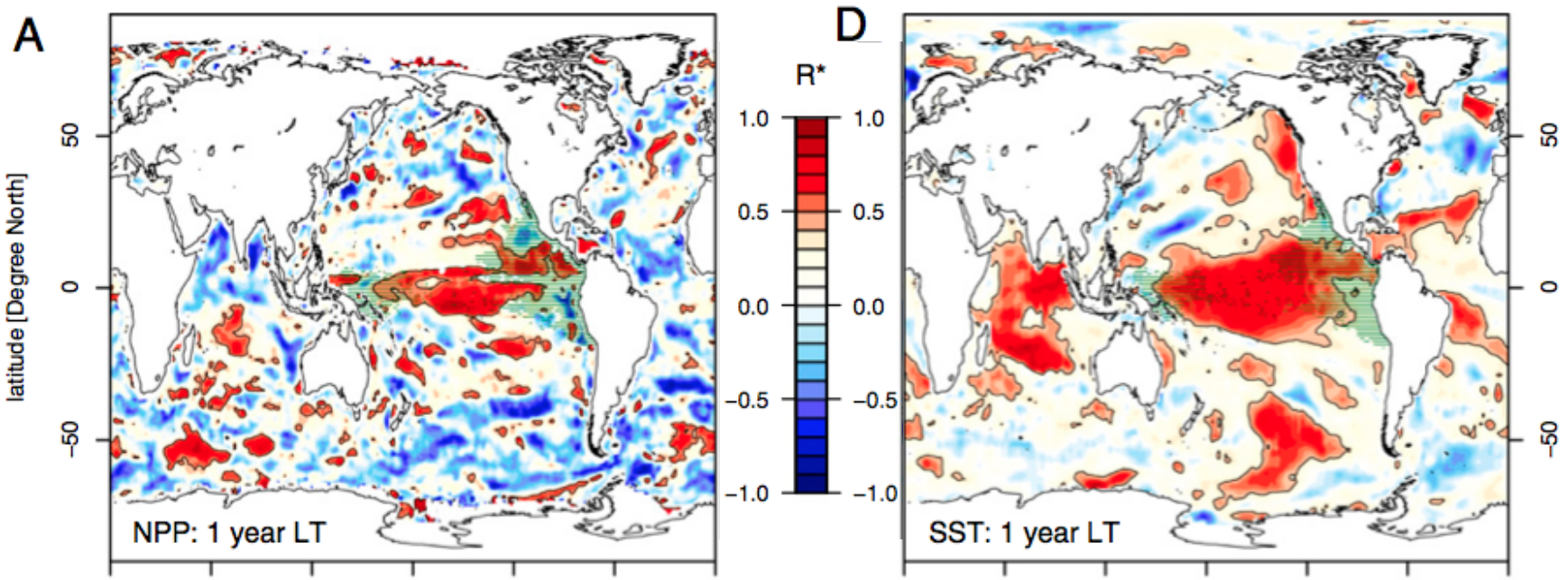


Séférian et al., 2014

Prediction of NPP

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

NPP **SST**

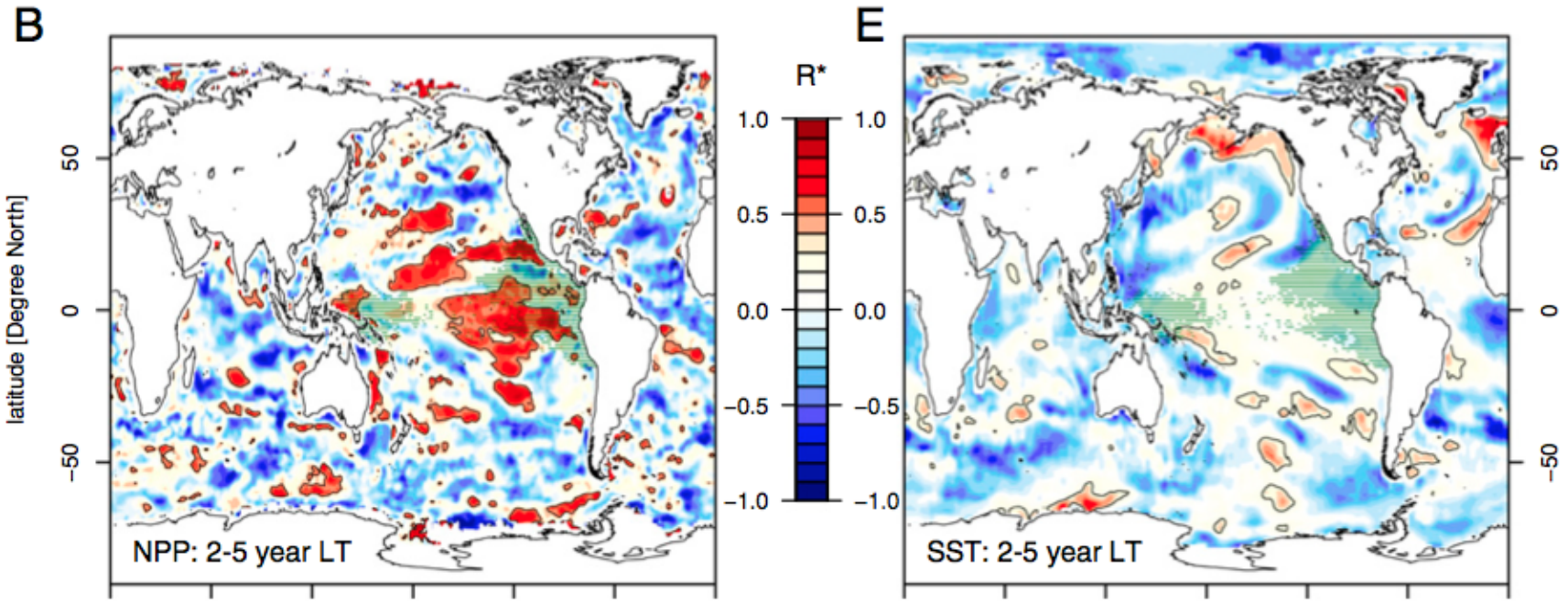


Séférian et al., 2014

Prediction of NPP

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

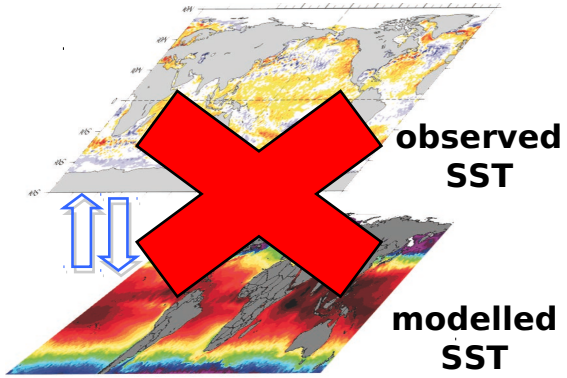
NPP **SST**



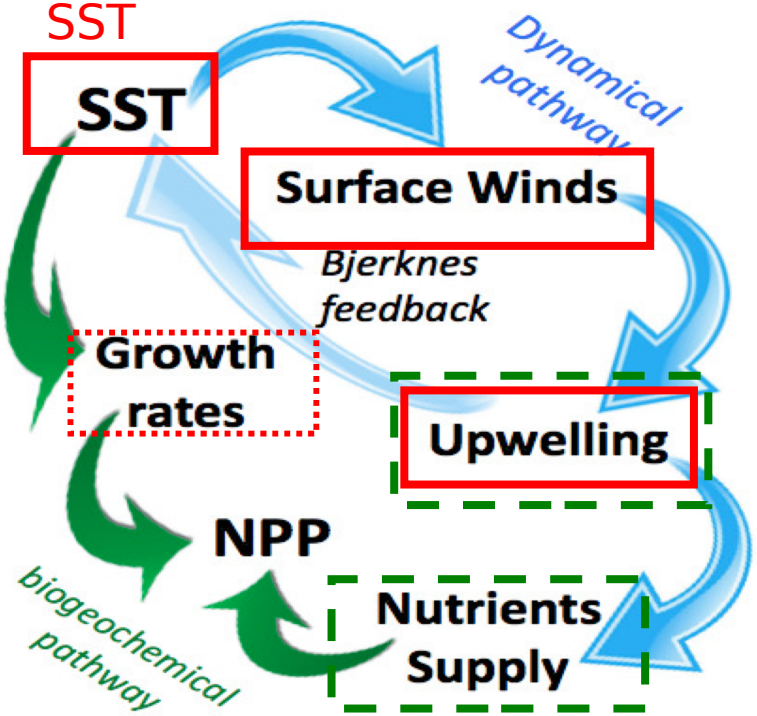
SST is predicted up to 1 year
NPP is predicted from 2 up to 5 years !

Séférian et al., 2014

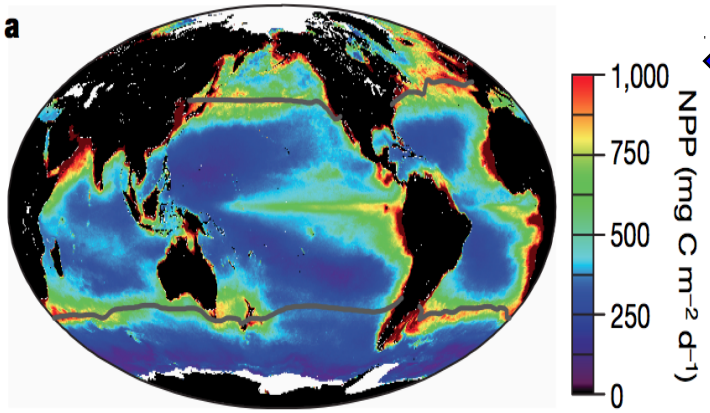
Prediction of NPP: explanation



Fast dynamic adjustment for SST



Slow dynamic adjustment fo BGC



Séférian et al., 2014

O4. demonstrate usefulness of products to end-users

INDESO

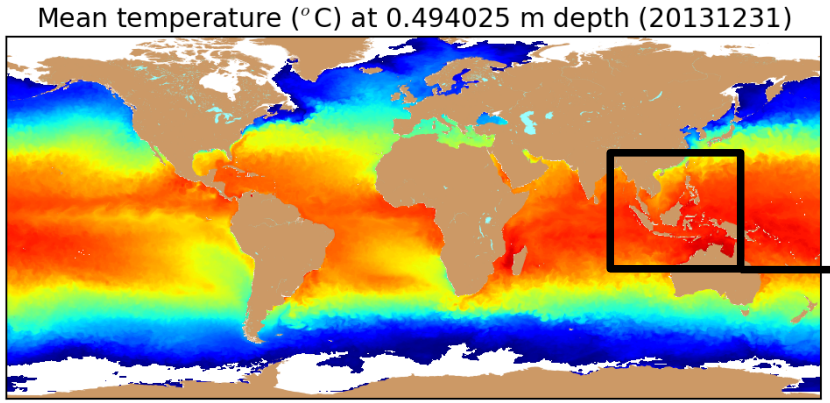
INfrastructure DEvelopment

for Space Oceanography

Objective : monitoring tuna stocks and fisheries

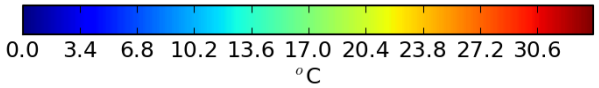
=> Indonesian government implements a chain of operational regional models from physics to fish at 1/12° x day resolution

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

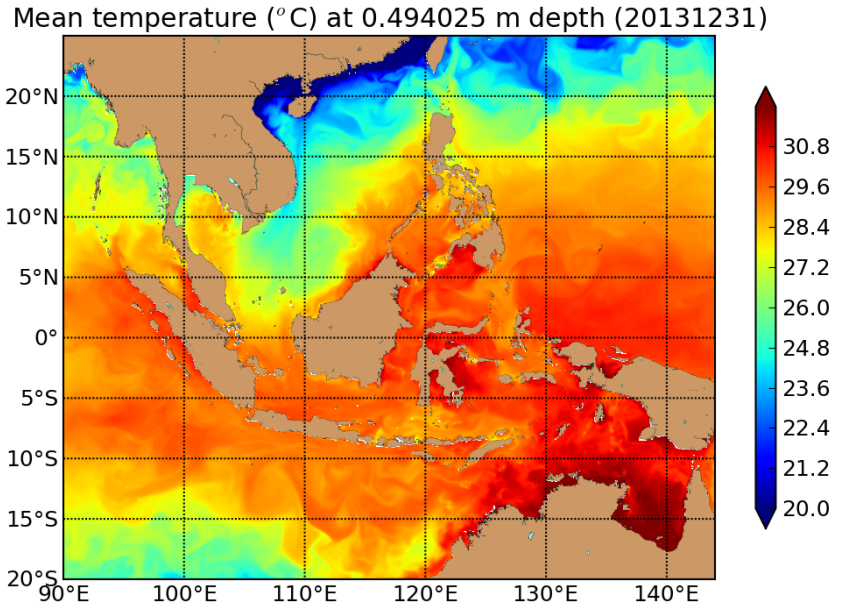


December 31, 2013

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



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

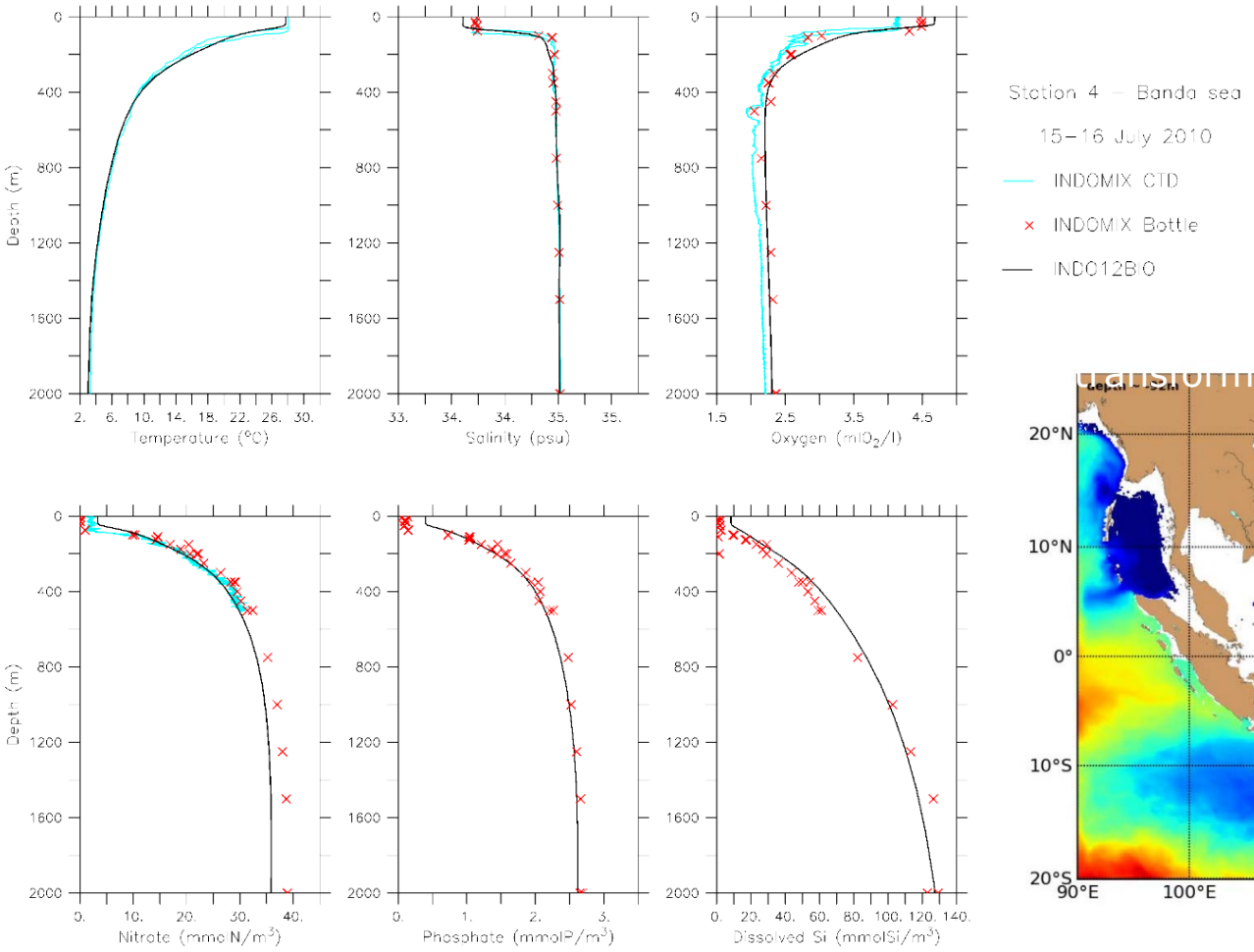


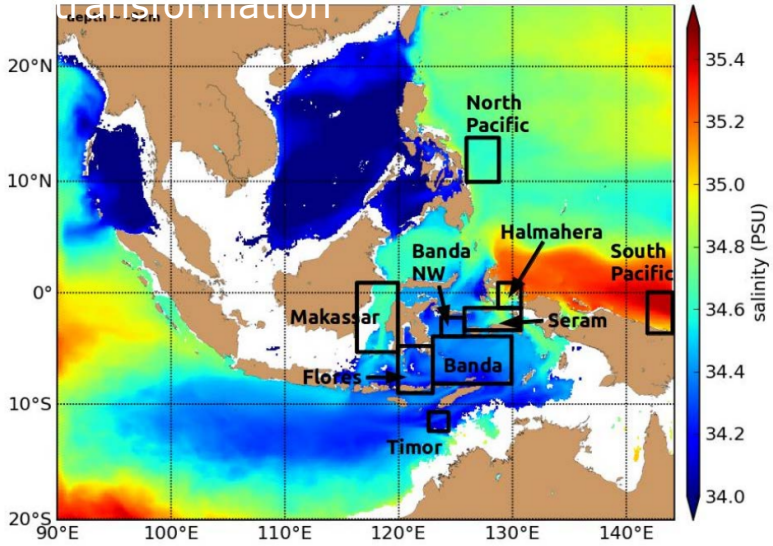
Tranchant et al., in prep

environmental forcings

Vertical profiles of temperature at Station 4 of INDOMIX cruise (Banda Sea; 15 - 16 July 2010), CTD and bottle measurements model output as 2-day averages (co-located in time and space)

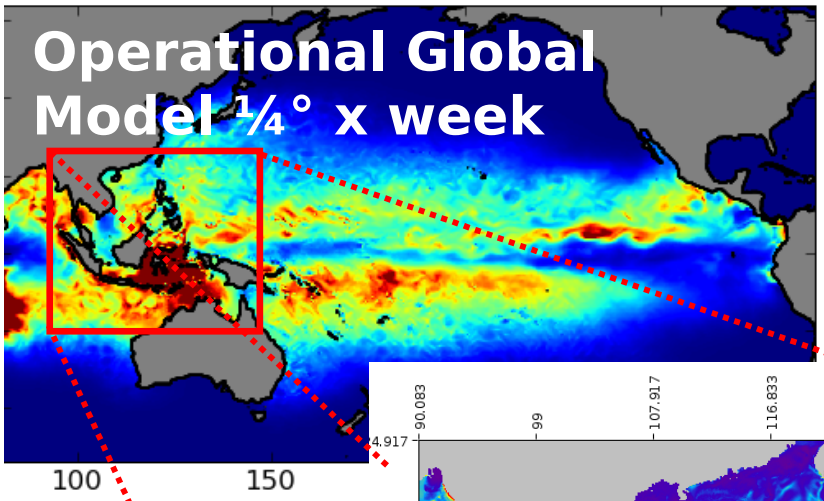
coupled Physical-biogeochemical/ LTL model (NEMO/PISCES)





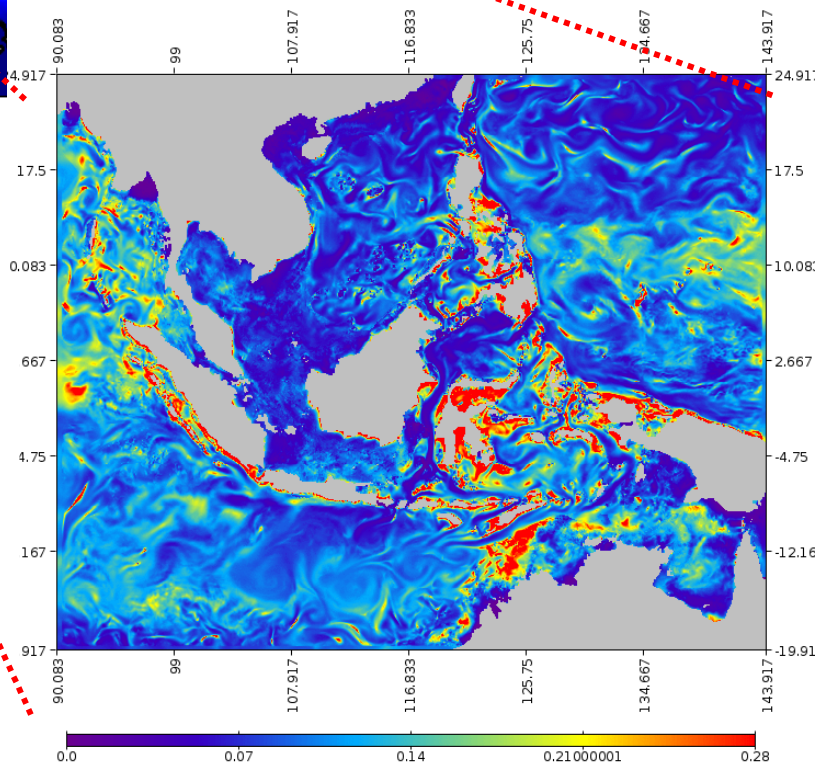
Gutknecht et al., GMDD

Step 3: Regional operational model



Once per week, the chain of production provides 10 day forecast

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

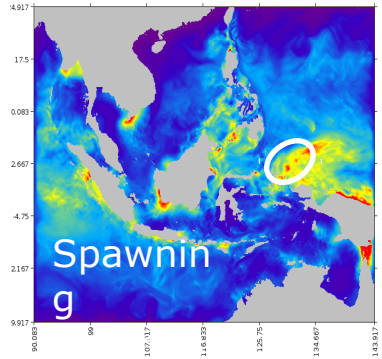


Total skipjack tuna biomass

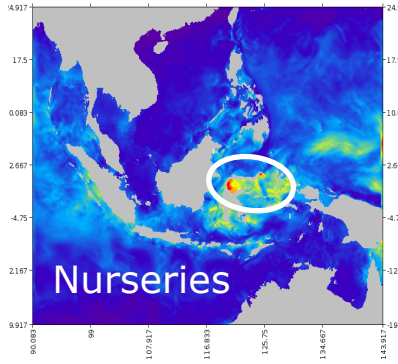
Model configuration

- Zooplankton
- Micronekton
- Skipjack
- Yellowfin
- Bigeye

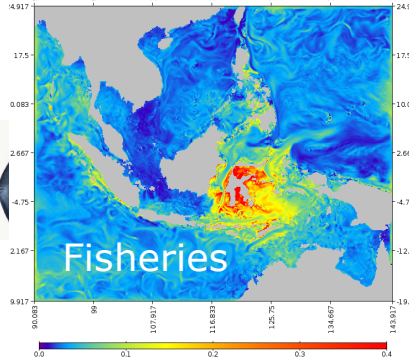
Larvae



juveniles



Adults

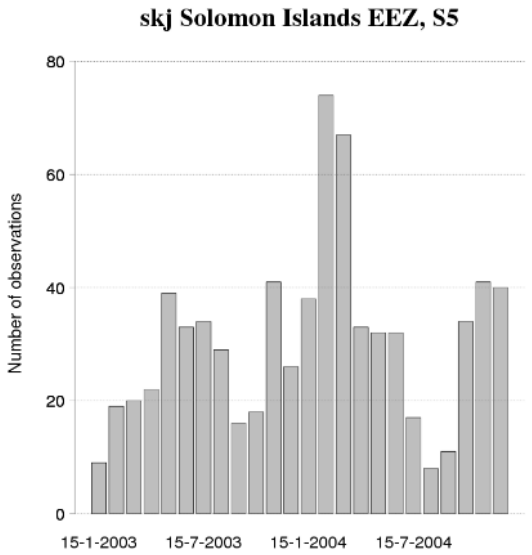


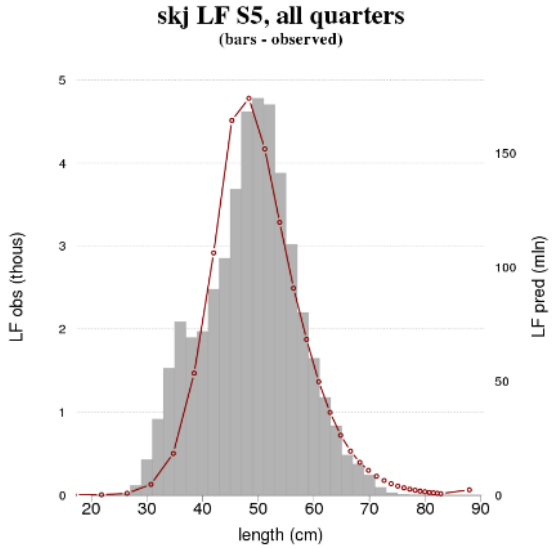
INDESO long-term metrics

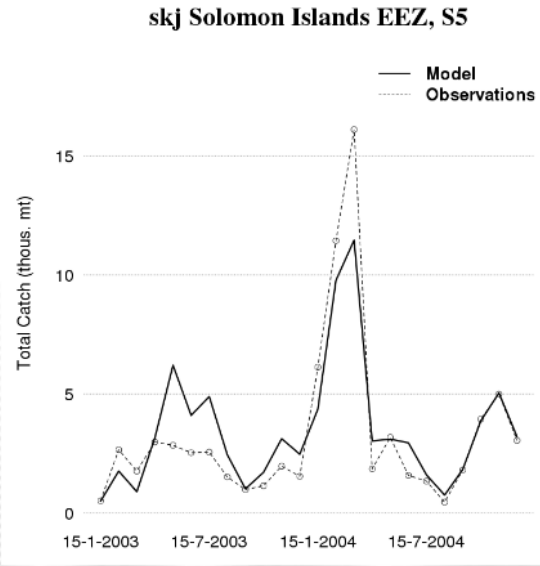
Automatic production of metrics are included in the operational chain of production to monitor the fisheries.

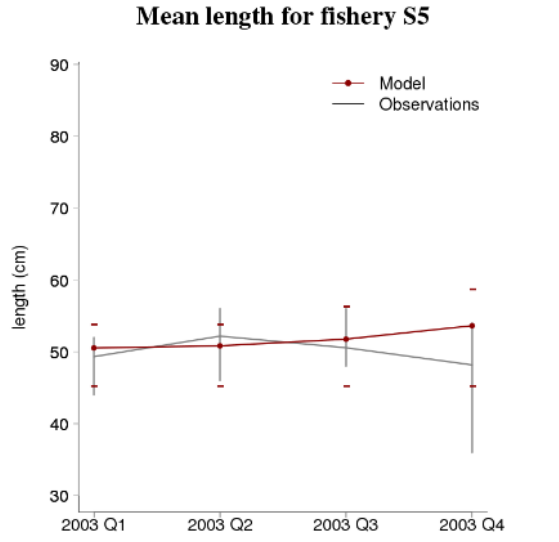
However, for Indonesia there is no data available. The Government is now developing the network.

The Vessel Monitoring System should help to rapidly improve catch and effort data collection.





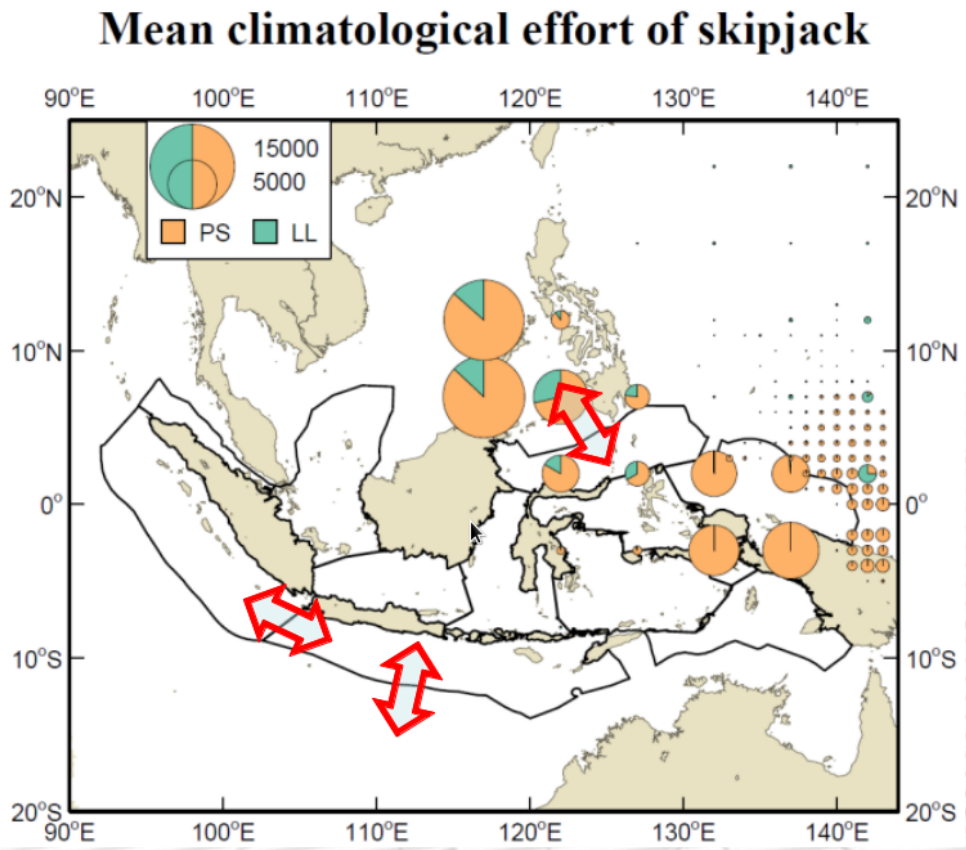




Regional Management of tuna stocks

The Model can be also used to answer key management questions:

- What is the total allowable sustainable catch (TAC) by species in each Fishing Marine Area?
- What is the Maximum fishing effort (fishing licenses) that can be allocated for a given species in each FMA?
- What is the local status of stock?
- How are these estimates above dependent of:
  - i) fishing in other FMA?
  - ii) fishing outside of Indonesia?




Thank you for your attention !