Data assimilation methods based on the Kalman Filter

Operational implementations in oceanography

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LEGI — LABORATOIRE DES ECOULEMENTS GEOPHYSIQUES ET INDUSTRIELS: L. Berline, J.M. Brankart, G. Broquet, V. Carmillet, Y. Ourmières, J. Verron

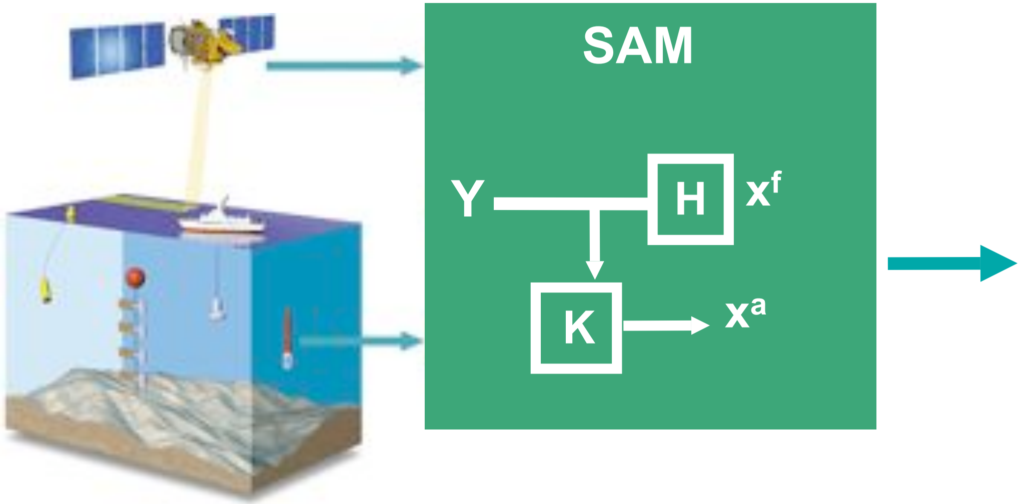
MERCATOR OPERATIONAL OCEANOGRAPHY: P. Bahurel, M. Drevillon, E. Rémy, N. Ferry, L. Parent, C.E. Testut, B. Tranchant

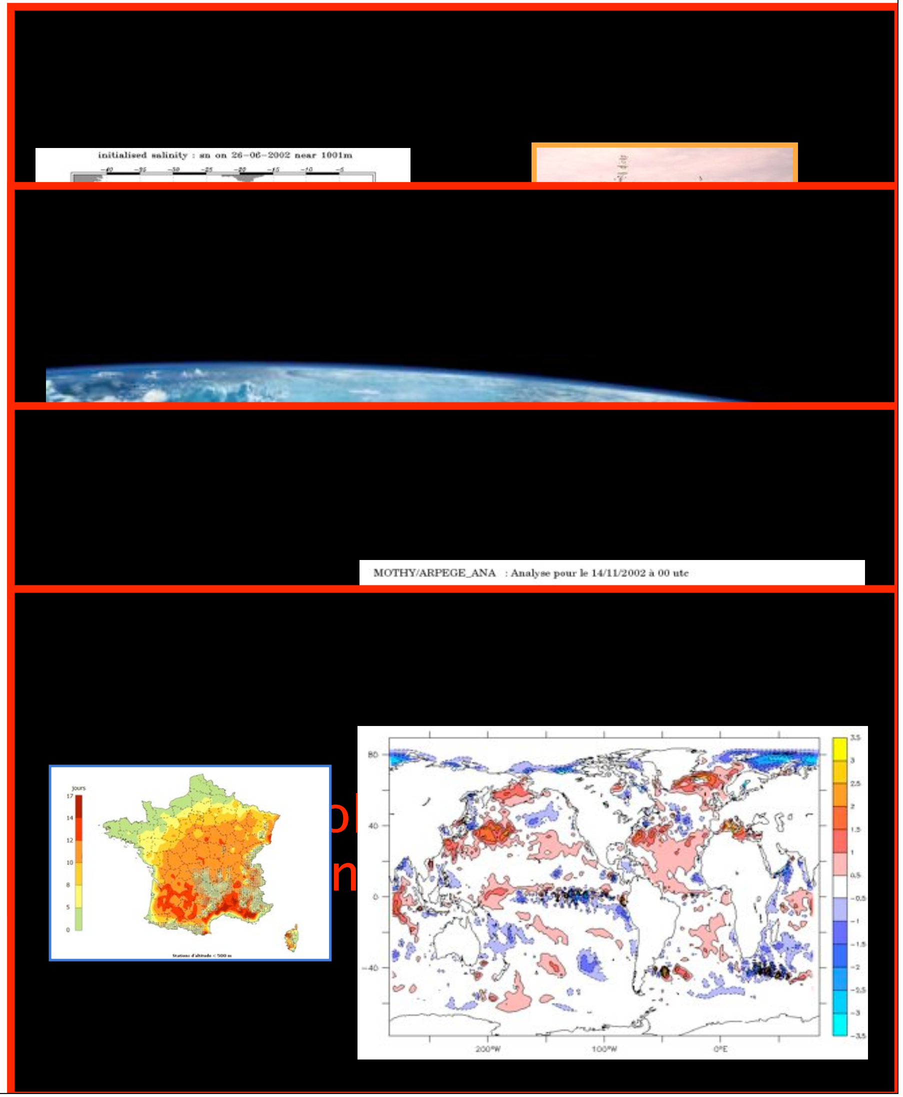
NERSC: L. Bertino, G. Evensen

MFS Toward Environmental Predictions: N. Pinardi, S. Dobricic

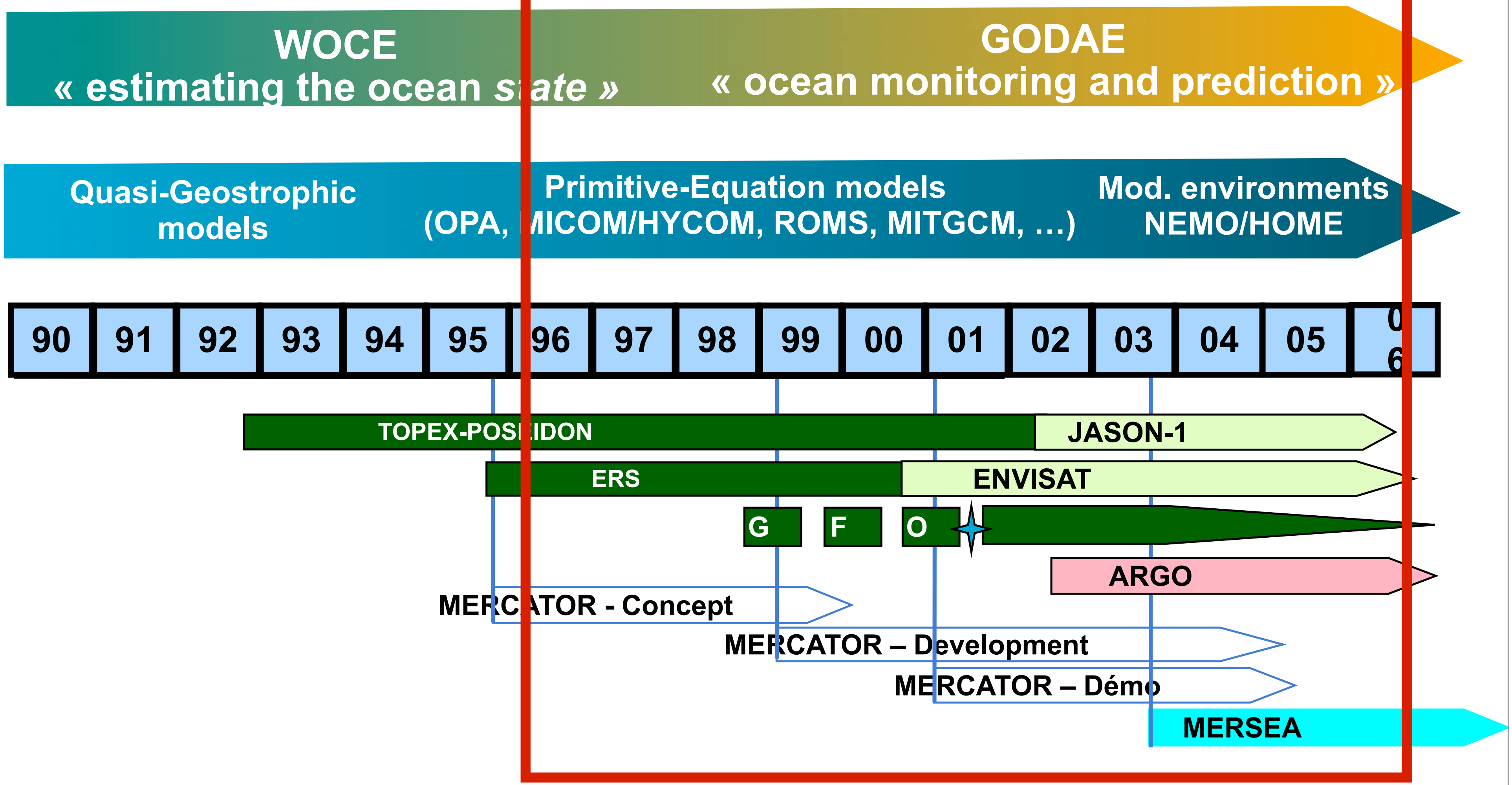
MERSEA — CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE — cnes CENTRE NATIONAL D'ETUDES SPATIALES — Ifremer — SHOM — esa

Operational Oceanography: the backbone for <u>regular</u> and <u>routine provision of data and information</u> for the Ocean

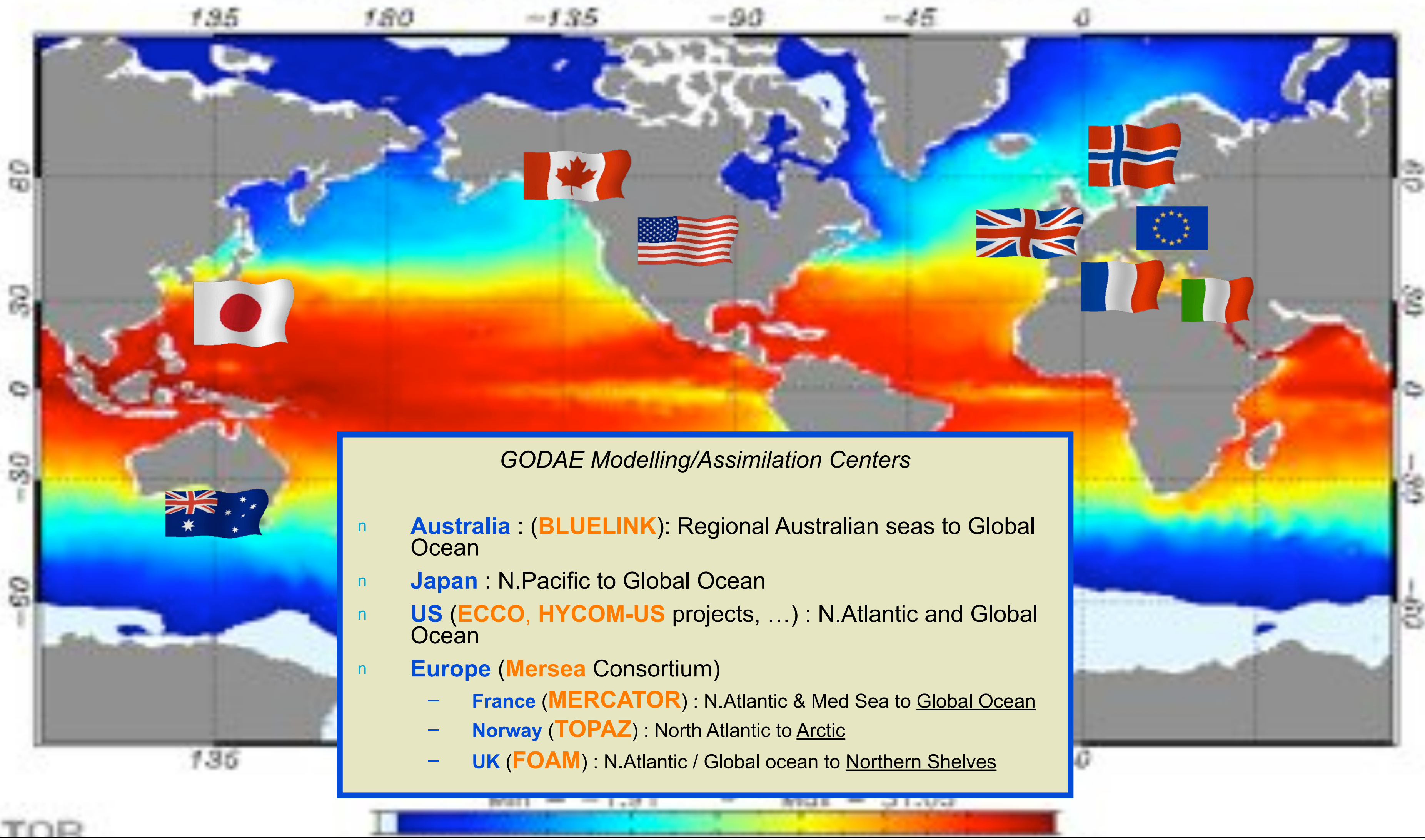




Operational Oceanography: the first steps



GODAE
Global Ocean Data Assimilation Experiment



GODAE Modelling/Assimilation Centers

- **Australia** : (**BLUELINK**): Regional Australian seas to Global Ocean
- **Japan** : N.Pacific to Global Ocean
- **US** (**ECCO**, **HYCOM-US** projects, …) : N.Atlantic and Global Ocean
- **Europe** (**Mersea** Consortium)
  - **France** (**MERCATOR**) : N.Atlantic & Med Sea to Global Ocean
  - **Norway** (**TOPAZ**) : North Atlantic to Arctic
  - **UK** (**FOAM**) : N.Atlantic / Global ocean to Northern Shelves

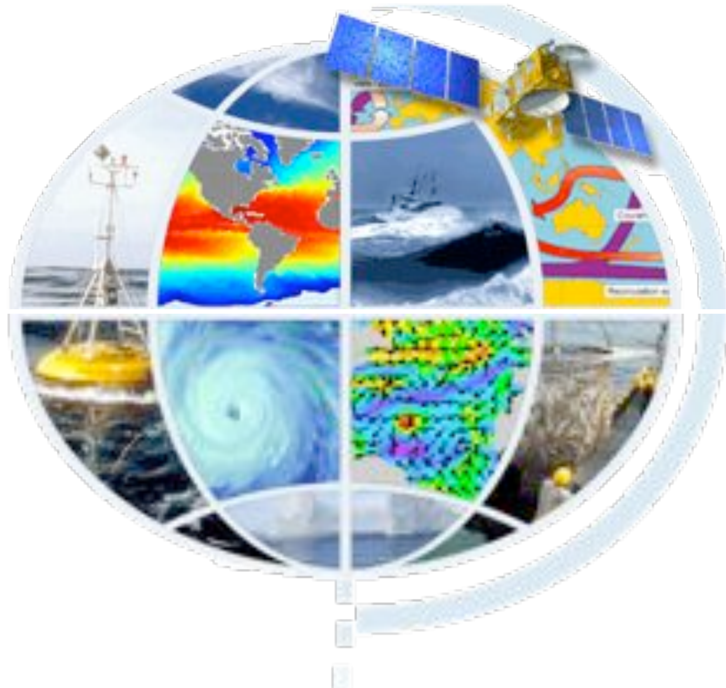
MERSEA

MARINE ENVIRONMENT AND SECURITY FOR THE EUROPEAN AREA

Ocean and Marine Applications for GMES

Objective: *development of a European system of systems for operational monitoring and forecasting of the ocean physics, biogeochemistry, and ecosystems, on global and regional scales*

Funded by E.U. (FP6) 2004-2008



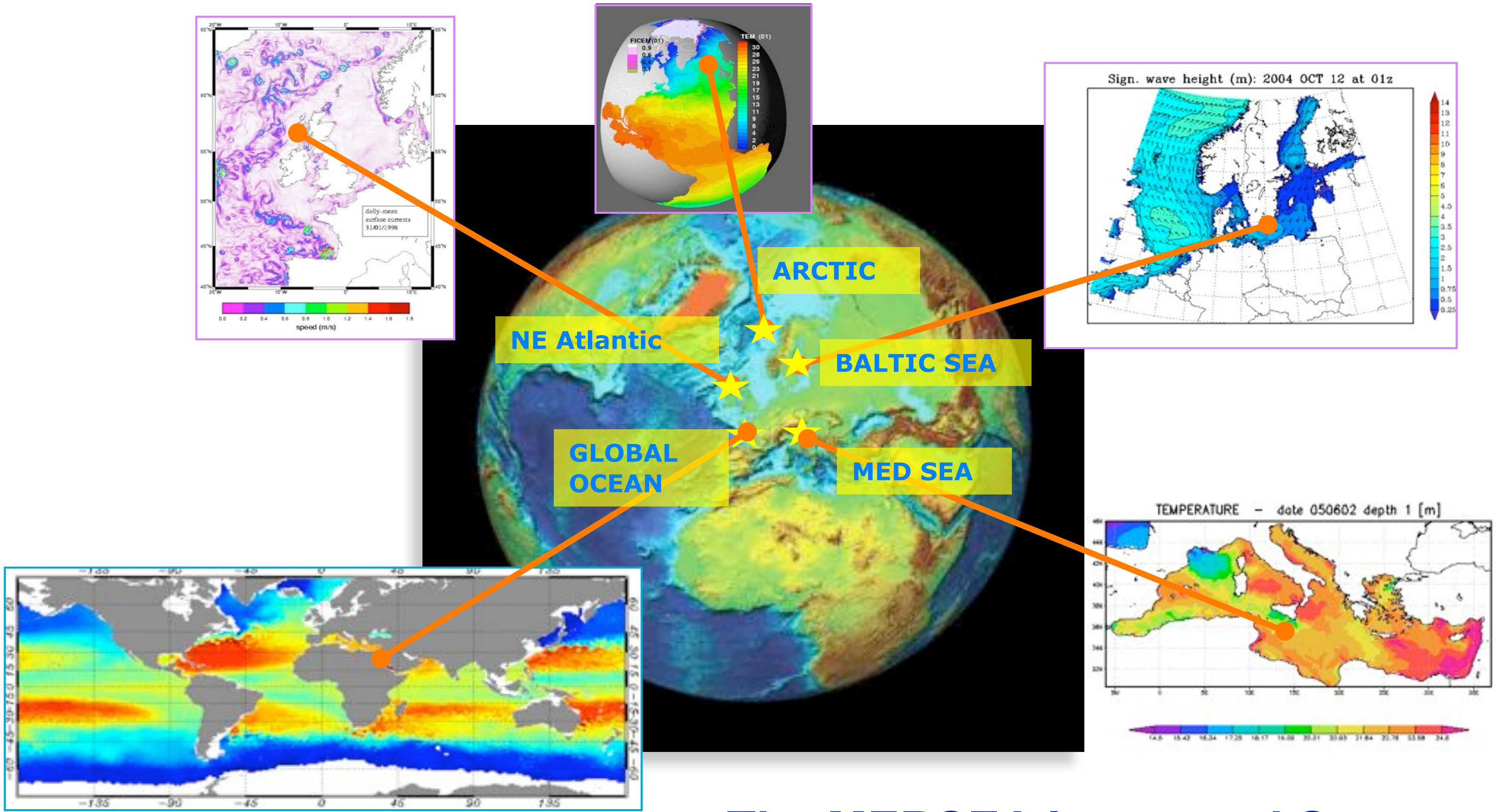
Mersea Executive Committee (**Y. Desaubies**, P. Bahurel, M. Bell, E. Buch, J. Johannessen, P.-Y. Le Traon, G. Manzella N. Pinardi, S. Pouliquen, R. Rayner, H. Roquet, U. Send, J.Verron)

and many partners ….

MERSEA

MARINE ENVIRONMENT AND SECURITY FOR THE EUROPEAN AREA

Ocean and Marine Applications for GMES



The MERSEA Integrated System

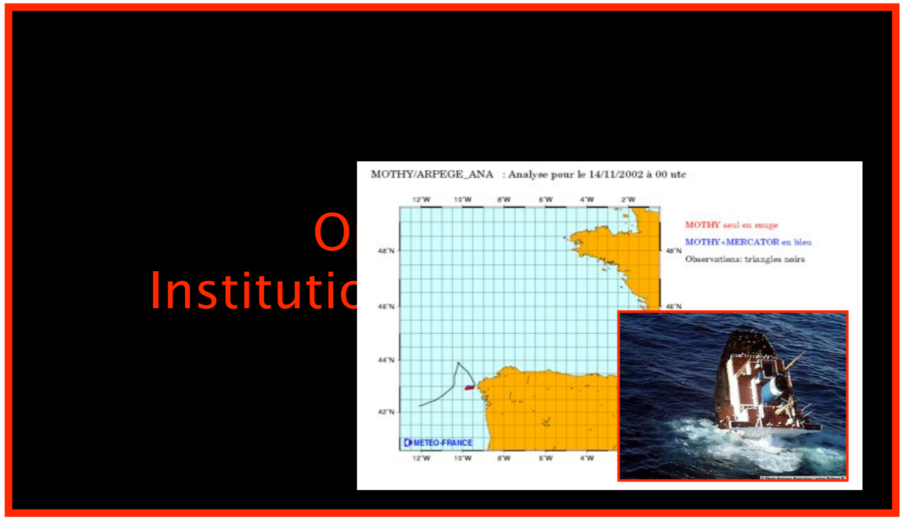
OUTLINE of this talk

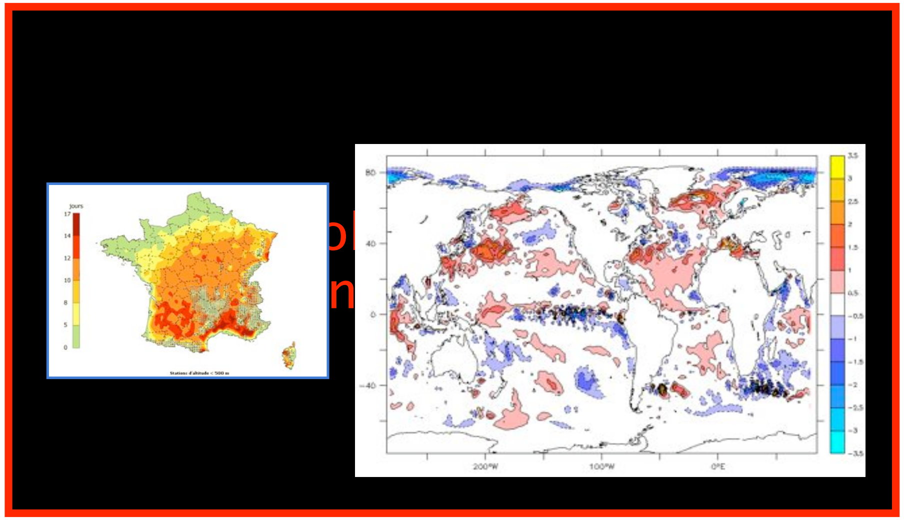
- The MERCATOR Ocean Prediction System
  - Objectives and components
  - SAM: a hierarchy of Assimilation Schemes
  - Applications

- Assimilation Challenges for MERSEA
  - Assimilating observations at the air/sea interface
  - New perspectives for SMOS-type measurements
  - Integration of marine ecosystem models

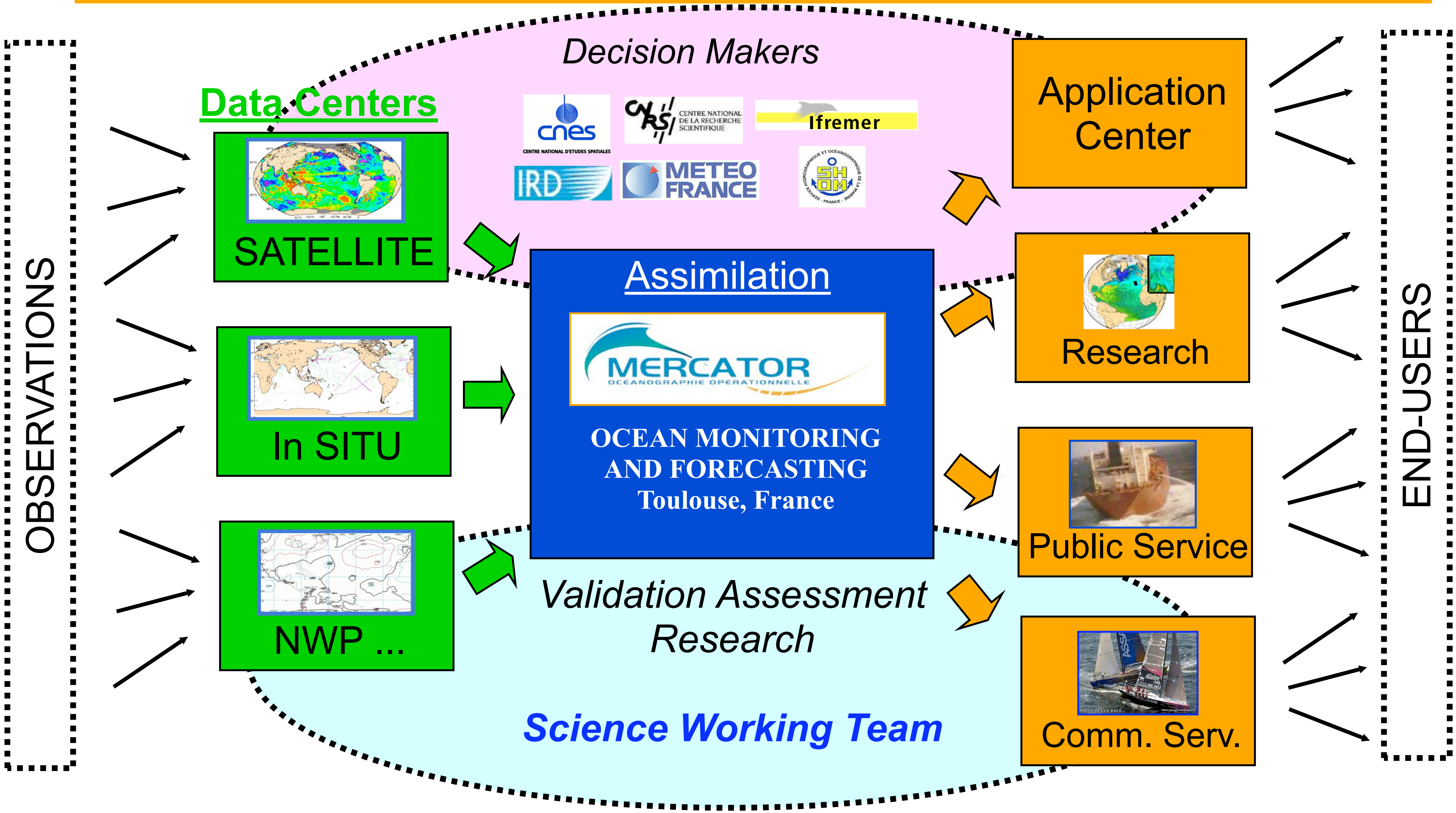
MERCATOR
a new player in oceanography since 1995

- **Joint initiative of French agencies for Global/Regional Operational Ocean Monitoring and Forecasting**
- **Providing real-time Ocean Services since 2001, to a wide variety of users**
- **Participating to the E.U MERSEA integrated project**
- **Next objective: the Fast Track Marine Service for GMES (*Global Monitoring for Environment and Security*)**

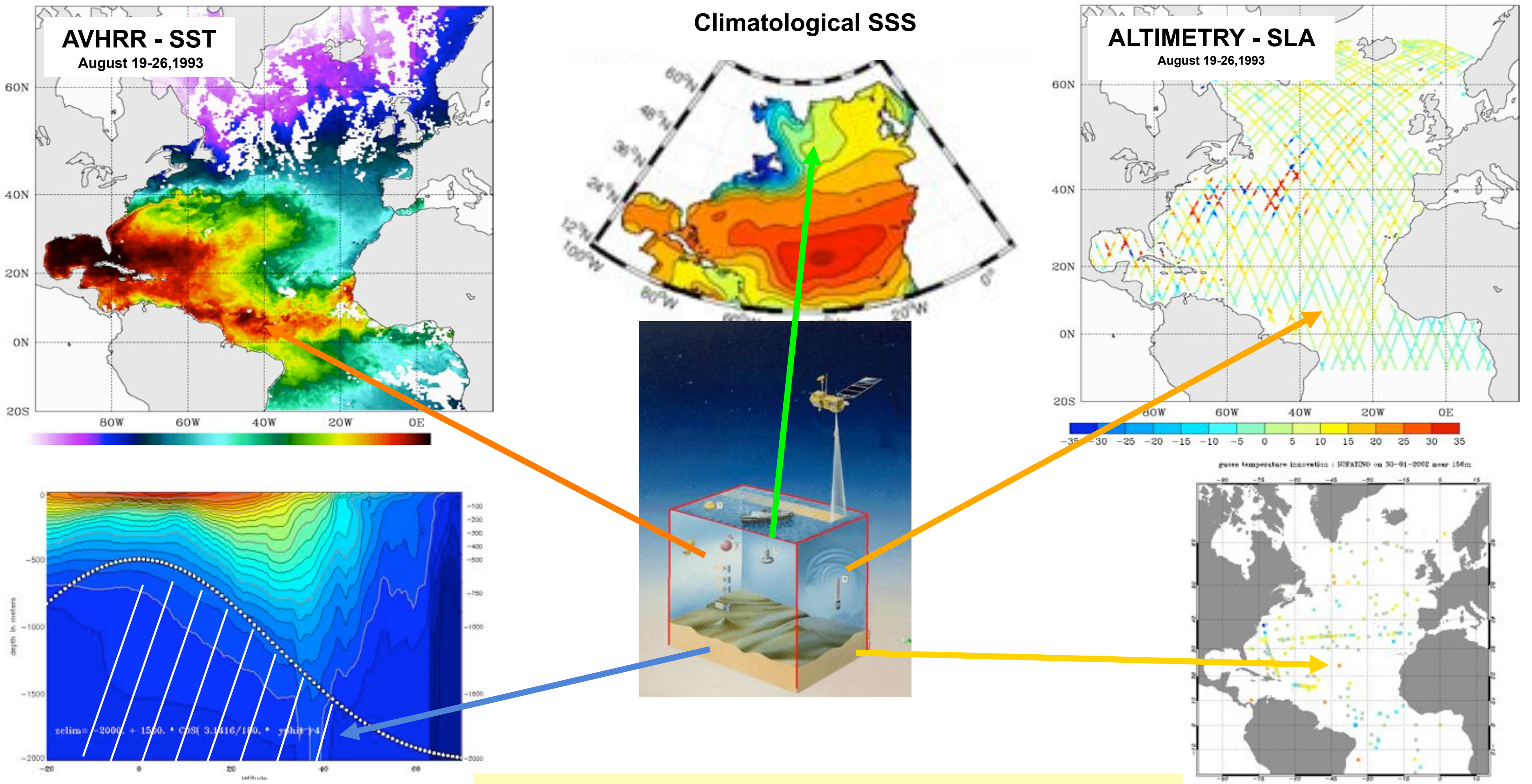




From observations to end-users



Ocean data assimilated in operational systems



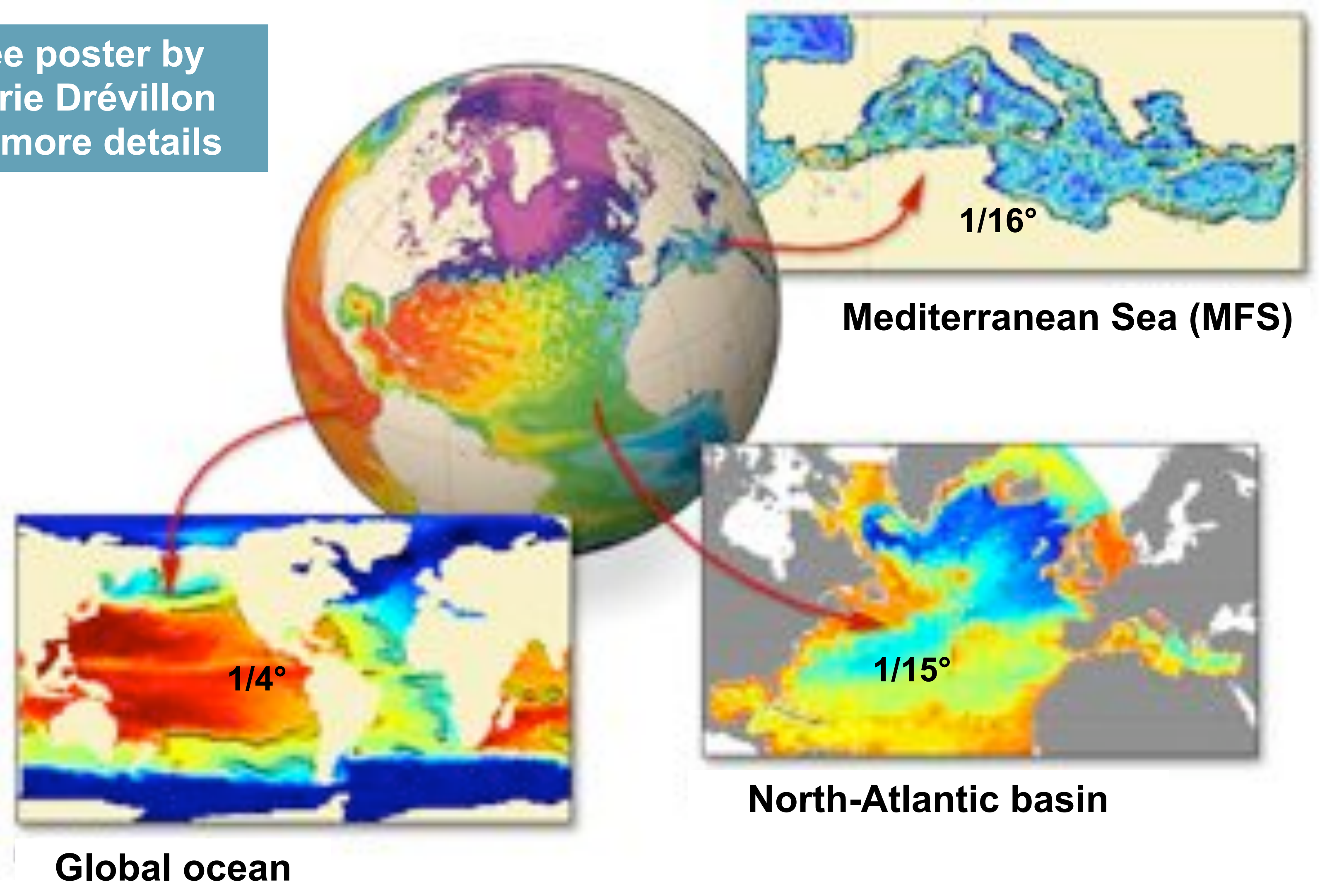
T/S climatological fields

in situ (e.g. ARGO floats)

A scientific challenge:
combining surface with sub-surface data

Ocean domains

See poster by Marie Drévillon for more details



The MERCATOR global ¼° model developed in liaison with a science project (CLIPPER)

Barnier *et al.*, 2006: Impact of partial steps and momentum advection schemes in a global ocean circulation model at eddy-permitting resolution, *Ocean Dynamics, in press (online first).*

The Mercator Assimilation System (SAM)

from research to real-time operations

Brasseur *et al*., 2006: Data assimilation for marine monitoring and prediction : the MERCATOR operational assimilation systems and the MERSEA developments, *QJRMS, in press.*

Research	**1993 (OI)**
R&D	**1997**
Integration	**1999**
Operational	**2001**

SAM-1

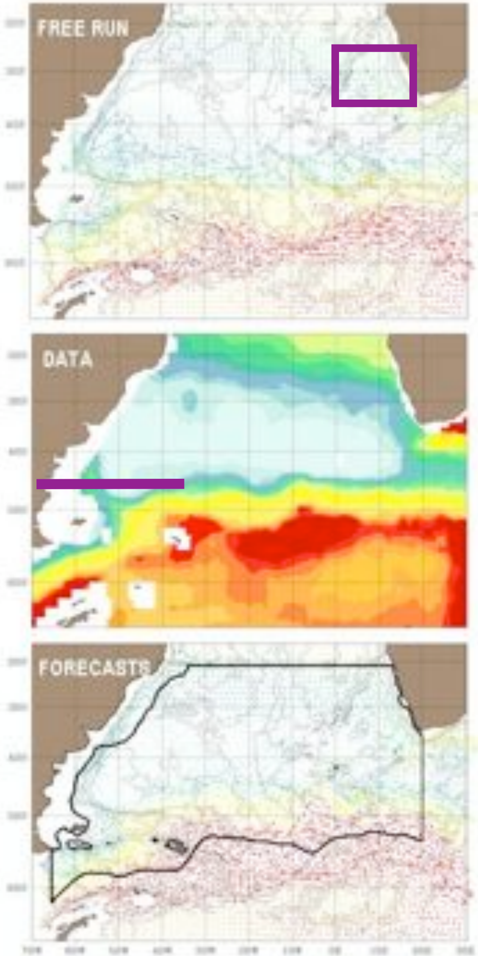
Incremental implementation strategy

The SAM-2 scheme (derived from SEEK) for mesoscale data assimilation in MERCATOR

Free run

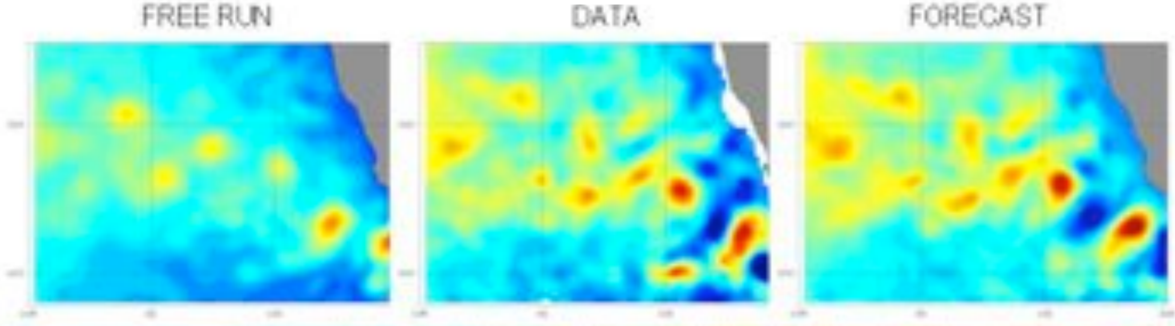
S_{clim}

Forecast

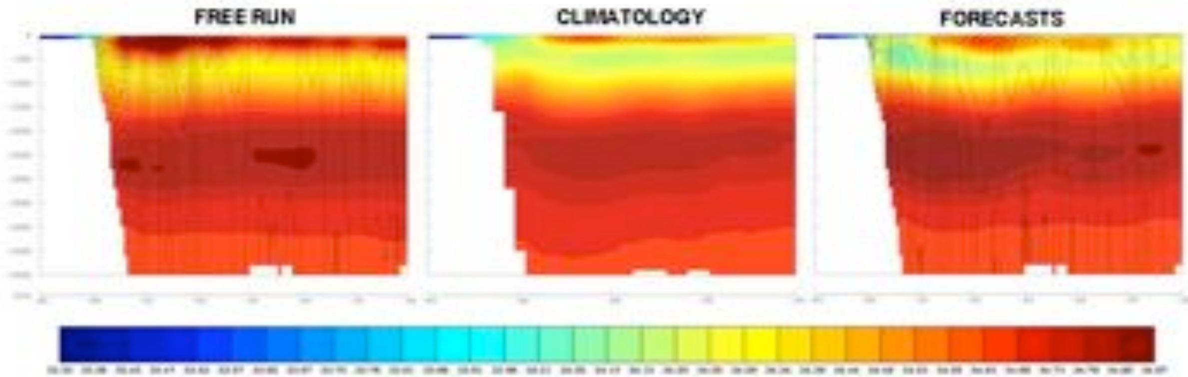


Circulation at 872 m

Agulhas Rings – June 25, 1995



Confluence – mean salinity at 45S

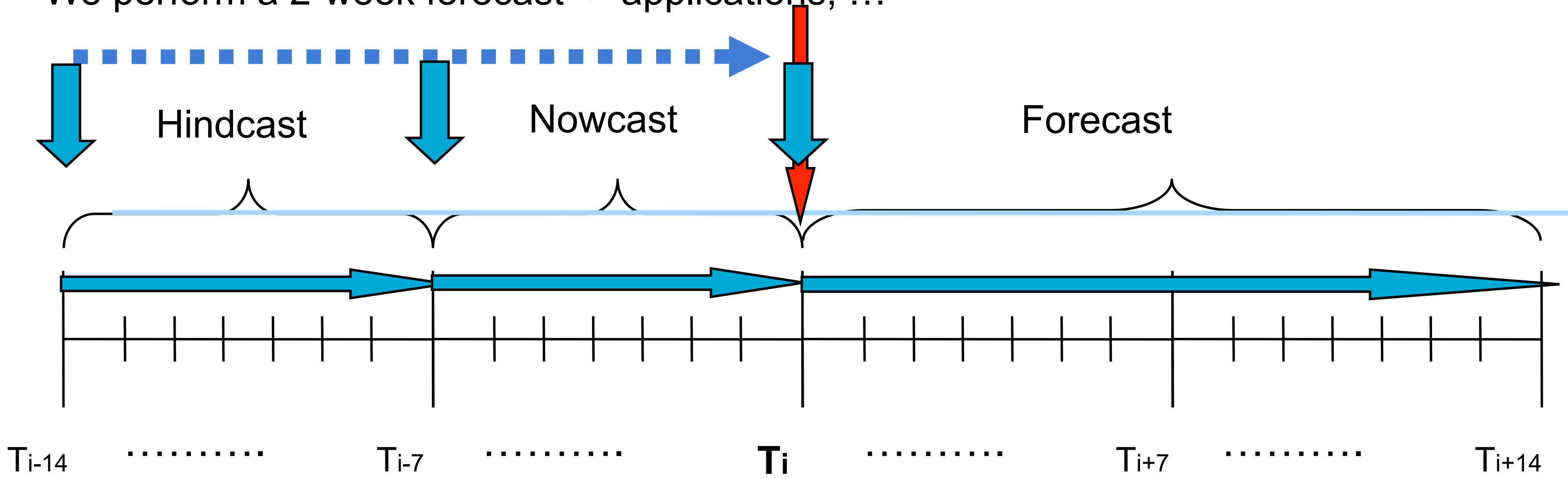


<u>**South Atlantic hindcast**</u> (Penduff *et al.*, 2002)

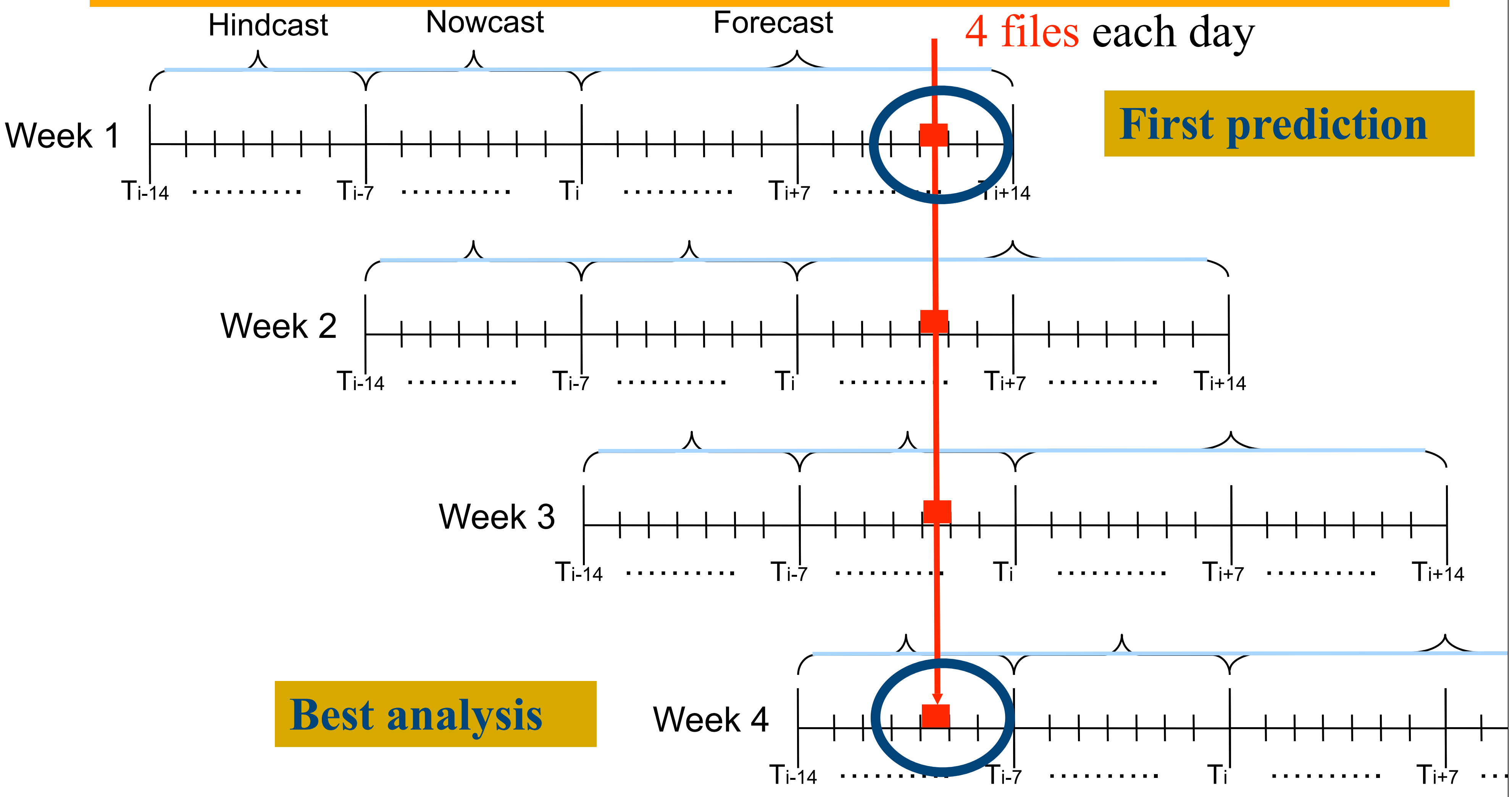
- **OPA model 1/3°, 1993-1996, 6h ECMWF**
- **Assimilation of SLA (T/P, ERS), SST (AVHRR)**

Real-time assimilation cycle: how does it work ?

- Every week on Tuesday night / Wednesday morning:
  - Most recent data are collected from data centres (SSALTO/DUACS & CORIOLIS)
  - Forcing fields are downloaded (ECMWF)
  - We go 2 weeks back in time and perform a run from T_{i-14} to T_i
    - Hindcast: forecast the past, perform analysis at T_{i-7}:
      - best MERCATOR estimate from T_{i-14} to T_{i-7}
    - Nowcast: forecast the present, perform analysis at T_i:
      - Temporary results (not all the obs available), will be updated next week
  - We perform a 2-week forecast -> applications, …

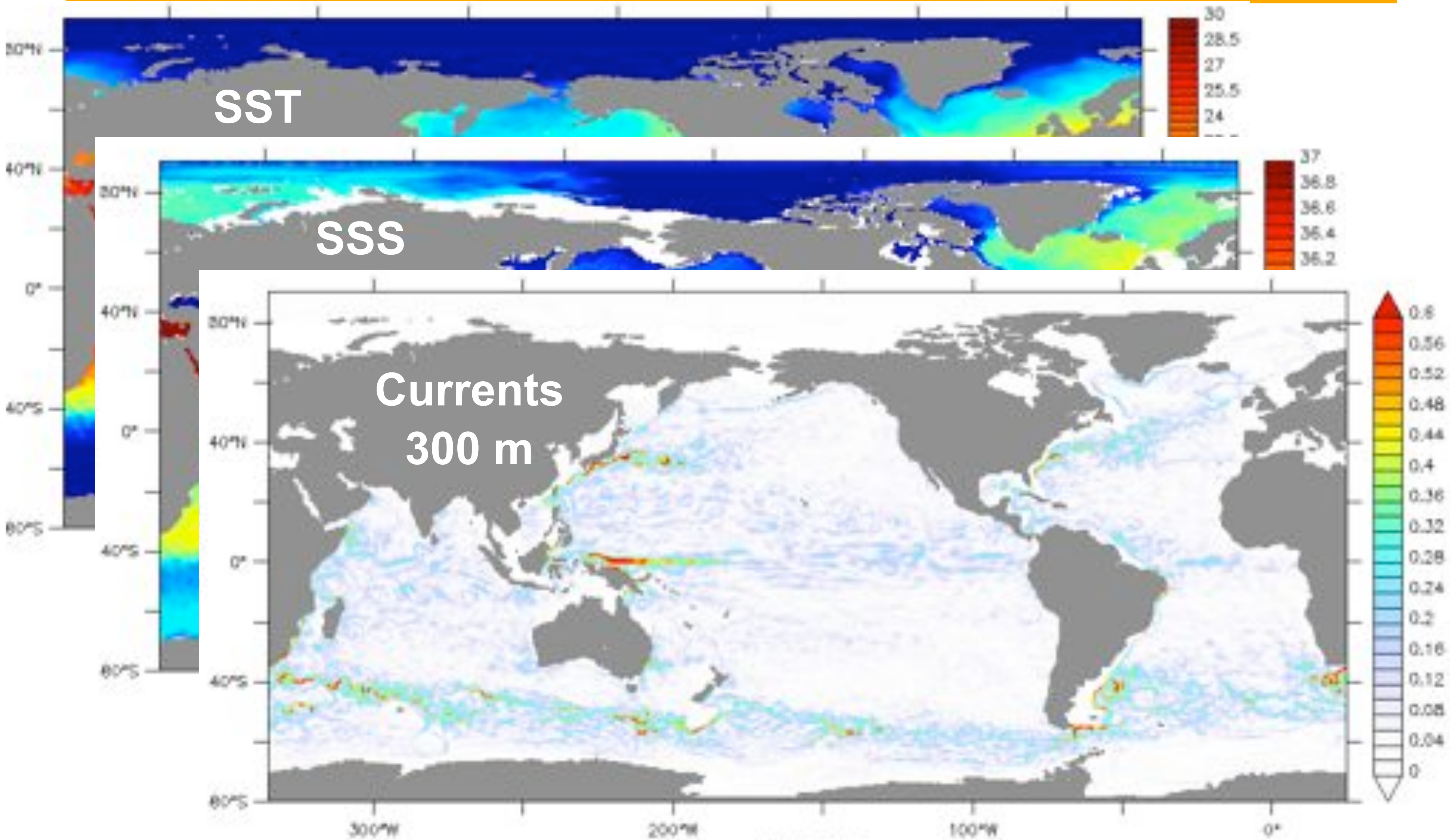


Files created by MERCATOR: full fields - daily



14-day forecast, valid August 1st, 2006

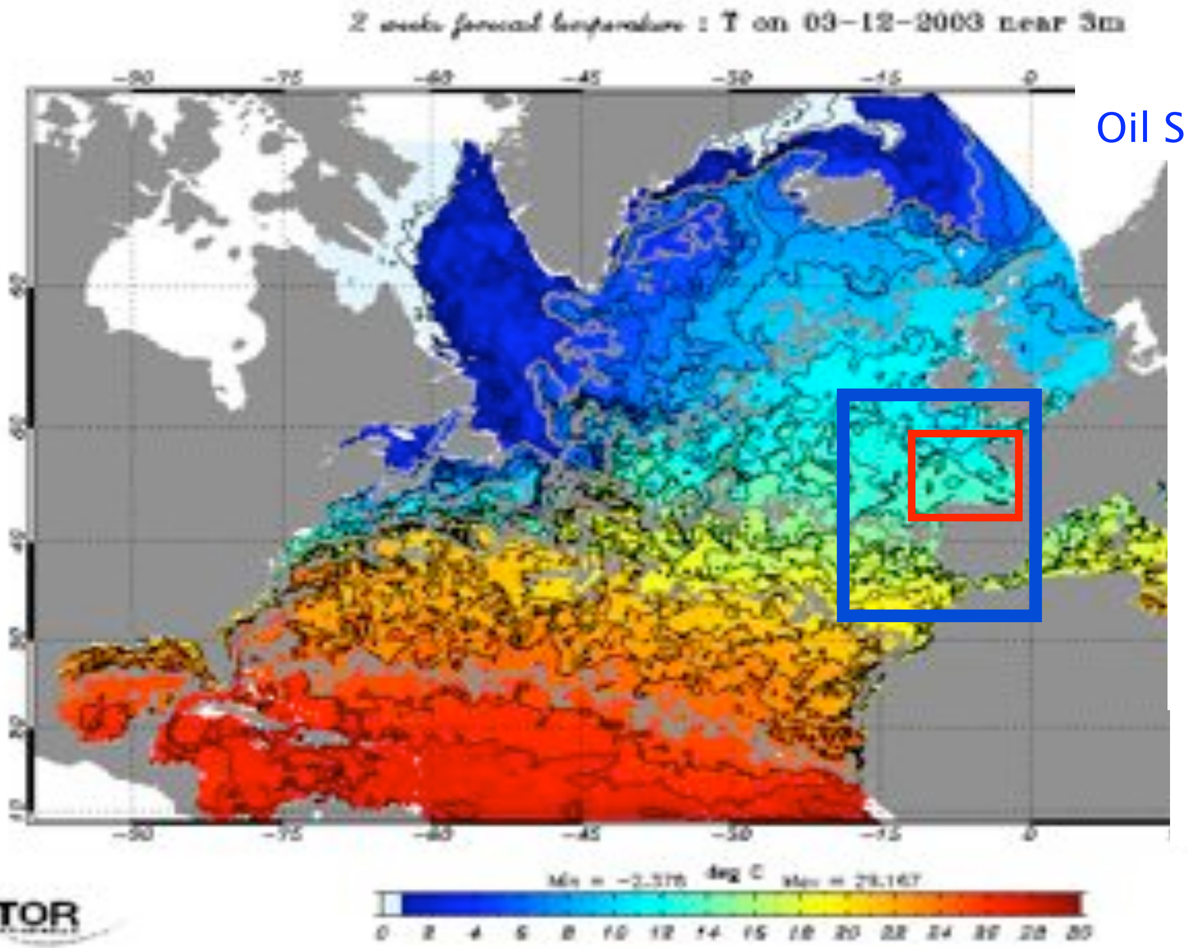
Global ocean at 1/4° resolution



Oceanic bulletin web page: http://www.mercator-ocean.fr/

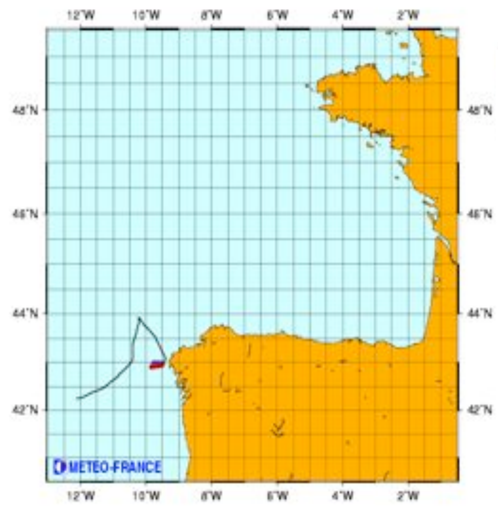
… operations against Oil Pollution

(serving Météo-France, …)



Oil spill model alone

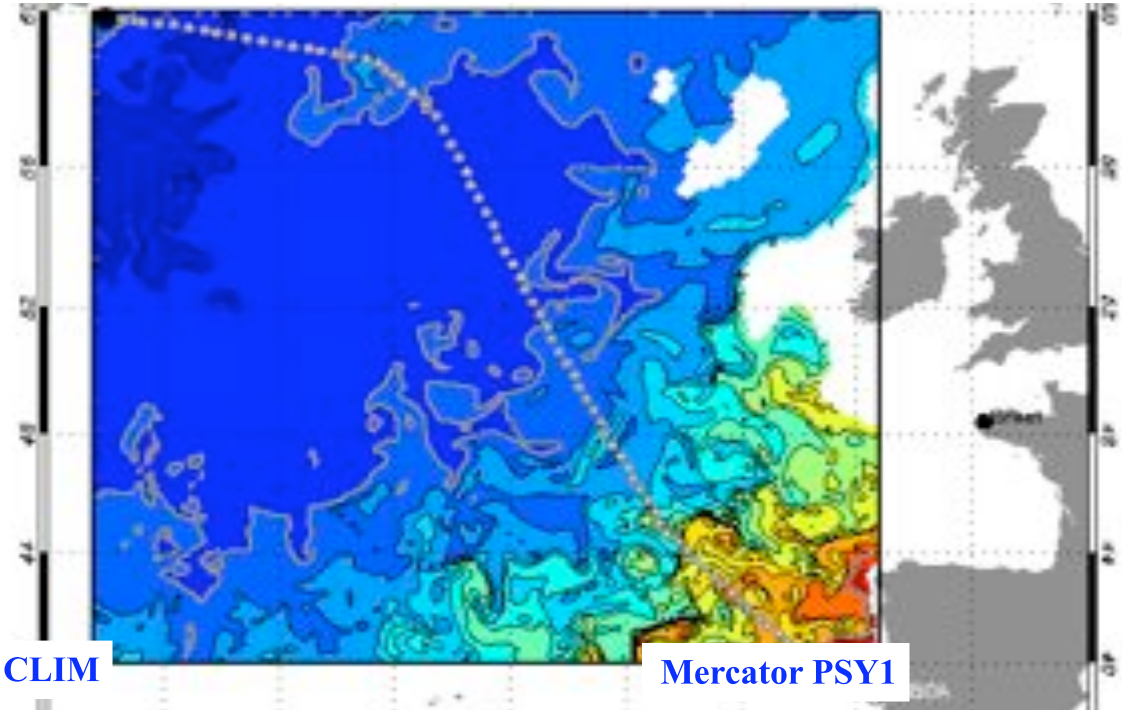
Oil Spill model, forced by Mercator



Météo-France Oil Drift Forecast

(courtesy of P.Daniel)

… supporting field campaigns

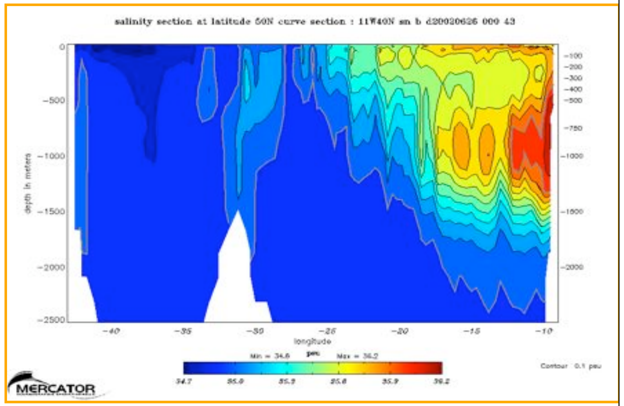


June 2002

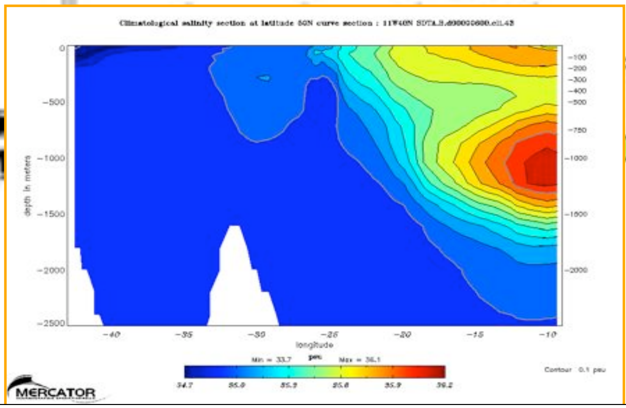
Scientific Cruise (OVIDE)

Salinity Field

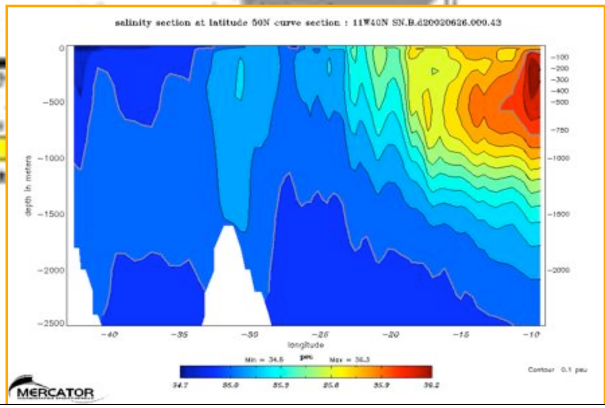
Mercator PSY2



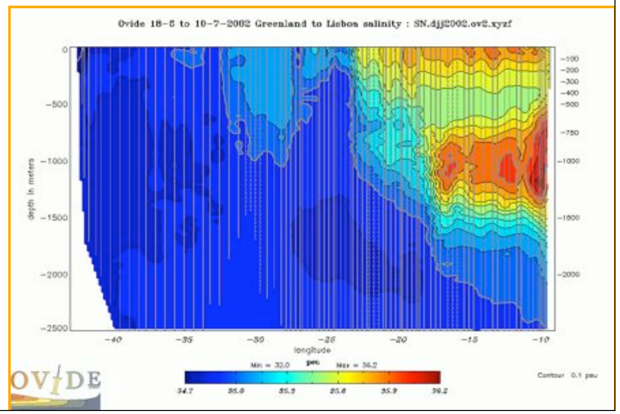
CLIM



Mercator PSY1

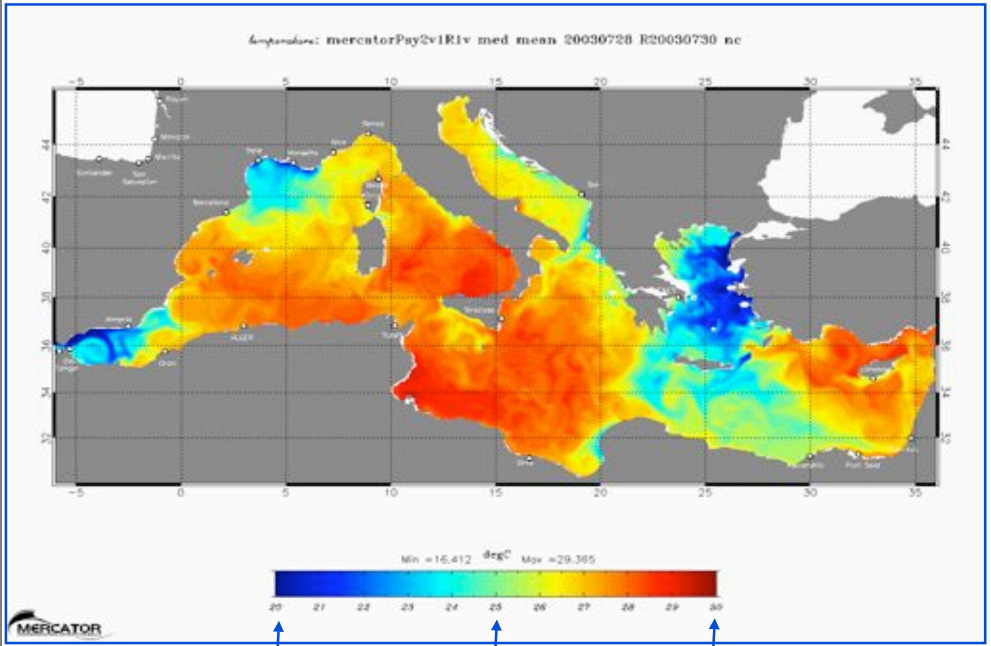


CTD



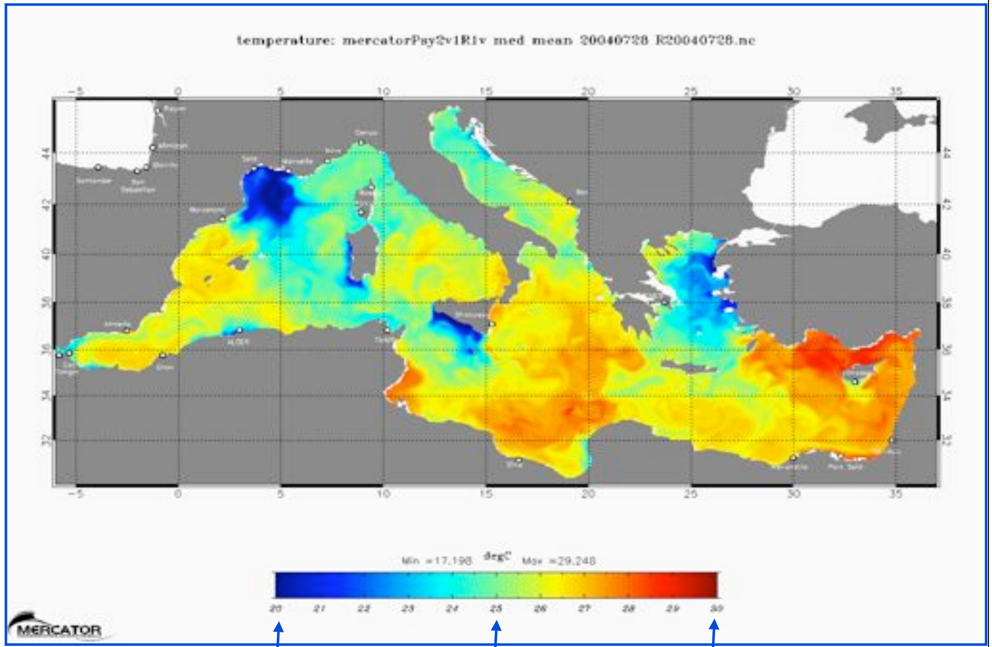
… monitoring « ocean climate » and looking back to extreme events

- hot weather event during summer 2003



20° 25° 30°

Mercator SST
(reanalysis PSY2)
28 July 2003

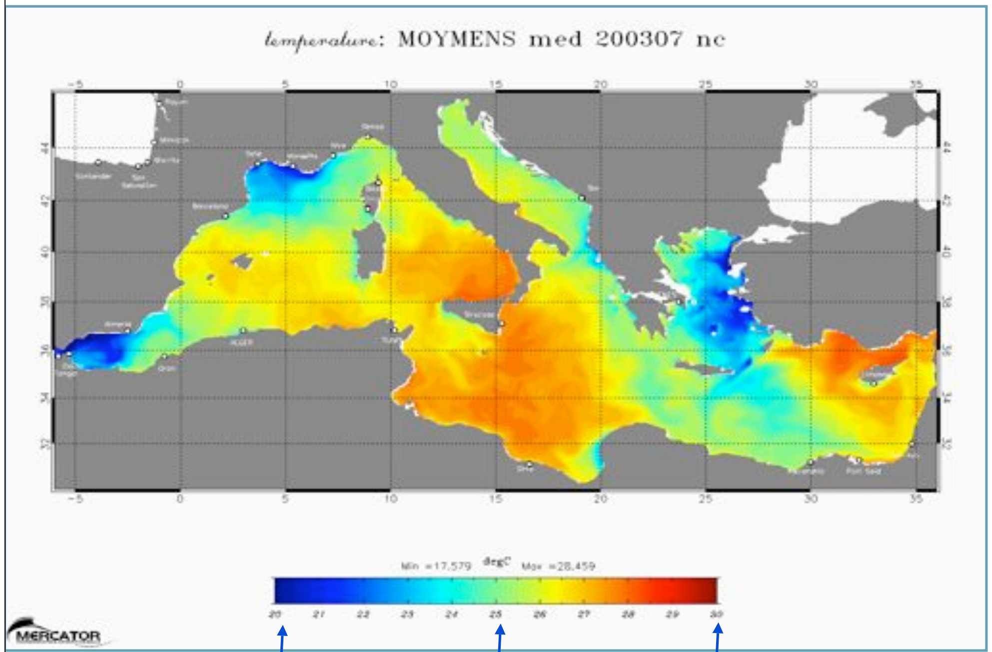


20° 25° 30°

Mercator SST
(real time PSY2)
28 July 2004

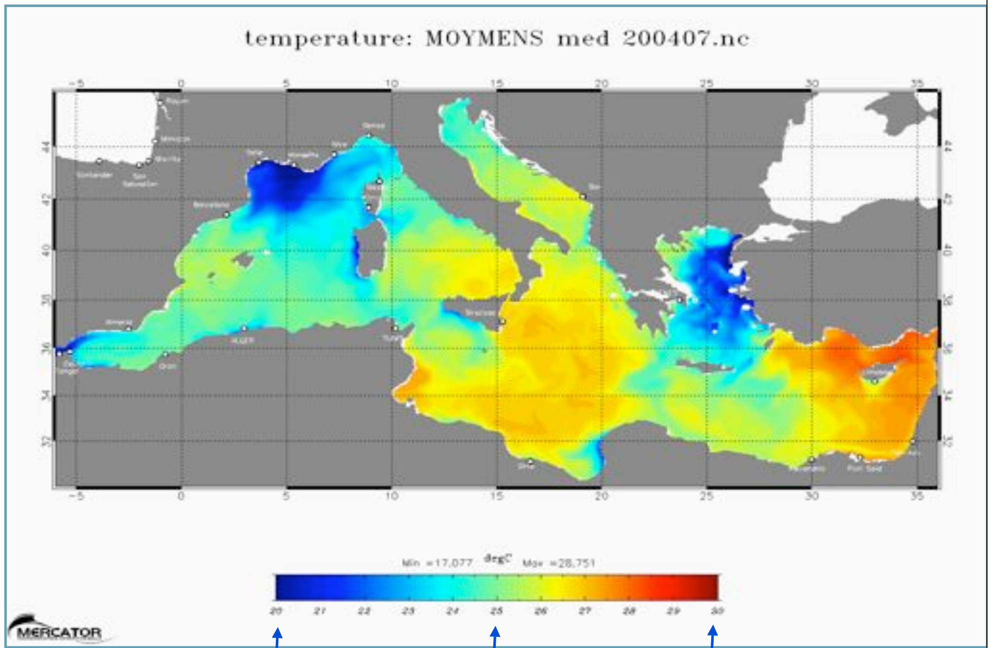
… monitoring « ocean climate » and looking back to extreme events

- hot weather event during summer 2003



20° 25° 30°

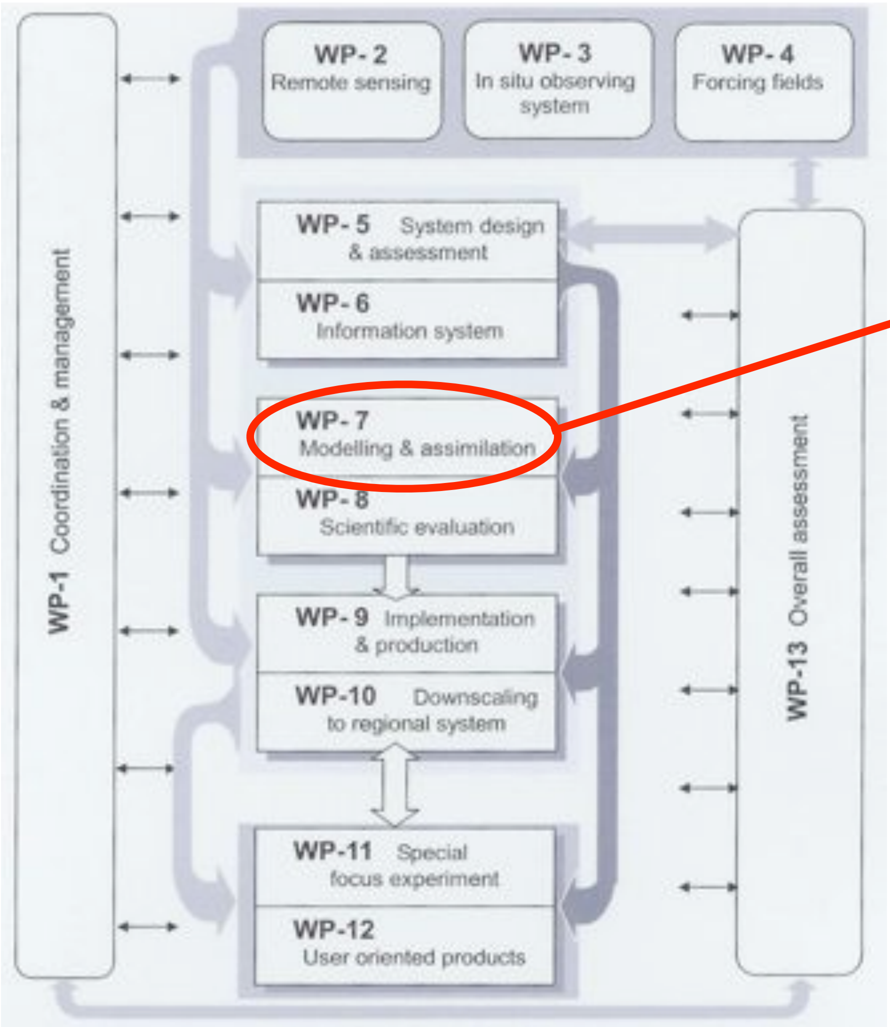
Mercator Mean SST
(reanalysis PSY2)
July 2003



20° 25° 30°

Mercator Mean SST
(real time PSY2)
July 2004

MERSEA R&D in Data Assimilation



DA objectives

- to improve our capacity to assimilate data from different sources (satellite altimetry, SST, SSS, in situ profiles, sea-ice param., ocean colour, …) in ocean circulation models;
- to develop the prototype of a coupled physical biological assimilative system, with the objective to demonstrate the capacity to routinely estimate and forecast biogeochemical variables.

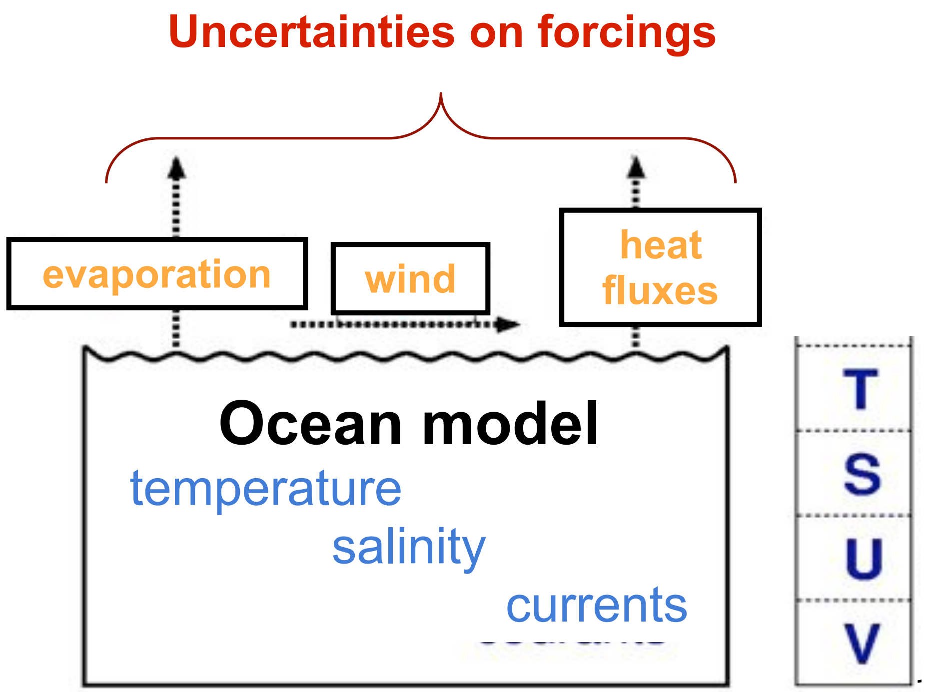
Participants

- NERSC, Norway (L. Bertino)
- AWI, Germany (J. Schröter)
- UU, The Netherlands (P.J. van Leeuwen)
- CNRS, France (J. Verron)

OUTLINE of this talk

- The MERCATOR Ocean Prediction System
  - Objectives and components
  - SAM: a hierarchy of Assimilation Schemes
  - Applications
- **Assimilation Challenges for MERSEA**
  - **Assimilating observations at the air/sea interface**
  - **New perspectives for SMOS-type measurements**
  - **Integration of marine ecosystem models**

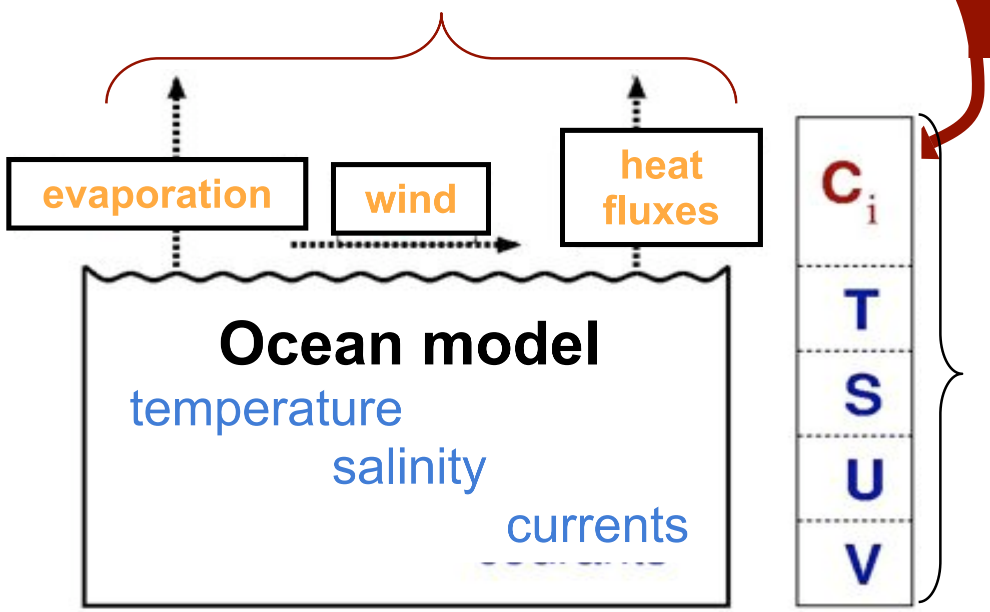
« Augmented » state vector estimation
(Skachko *et al.*, 2006)



« Augmented » state vector estimation
Skachko *et al.*, 2006

Uncertainties on forcings

Surface observations
(SST, SSS, wind, ice, …)



exchange coef., atmospheric state …

« Augmented » state vector

tested using twin experiments

(Skachko *et al.*, 2006)

Expected benefits:

q **Reduction of uncertainties on oceanic forcings (parameterizations)**

q **Improved control of mixed layer properties**

« Augmented » state vector estimation including « bulk » coefficients (Skachko *et al.*, 2006)

Assimilation of simulated data (0-200 m) in global OPA 2°x2°

T
S
U
V

C_i
T
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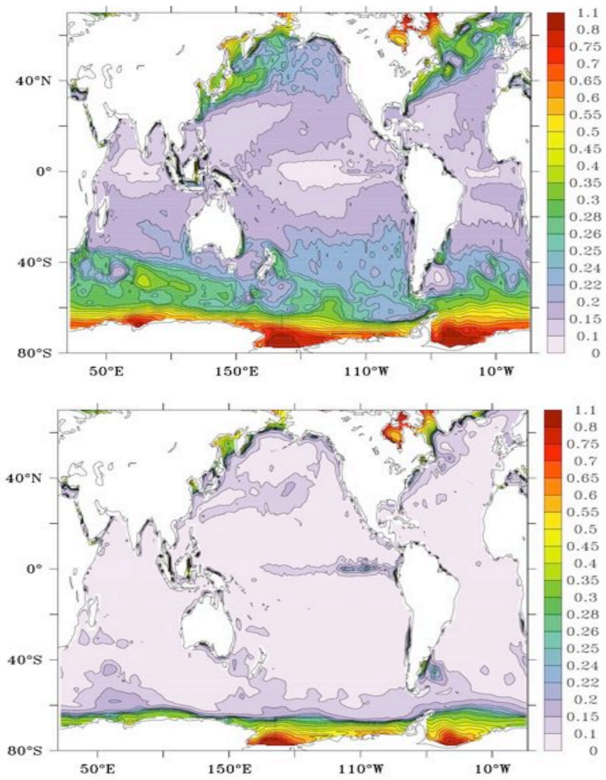
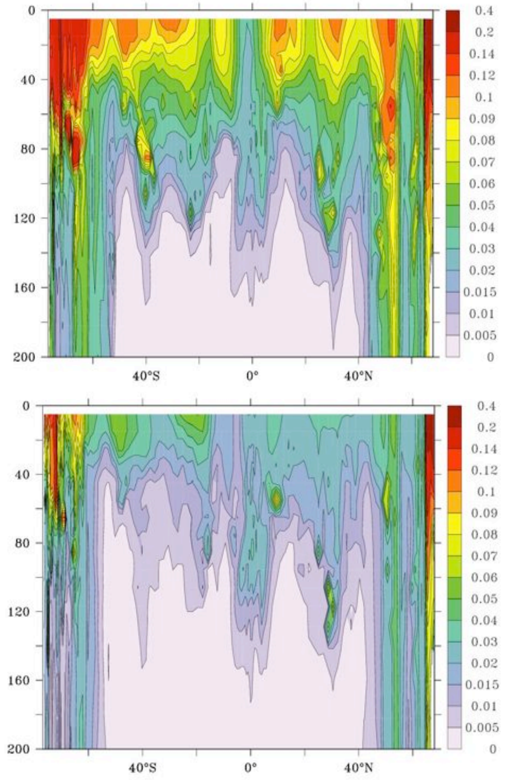
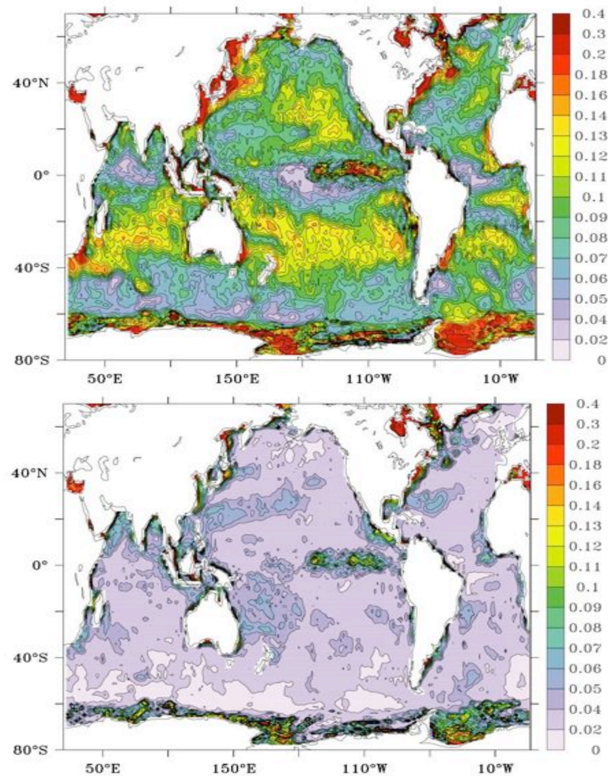


RMS error on latent heat flux coef (x 10³)

$$Q_{lat} = \tilde{n}_{air} L_w C_E W max(\mathbf{0}, q_{srf} - q_{air})$$



RMS error on temperature

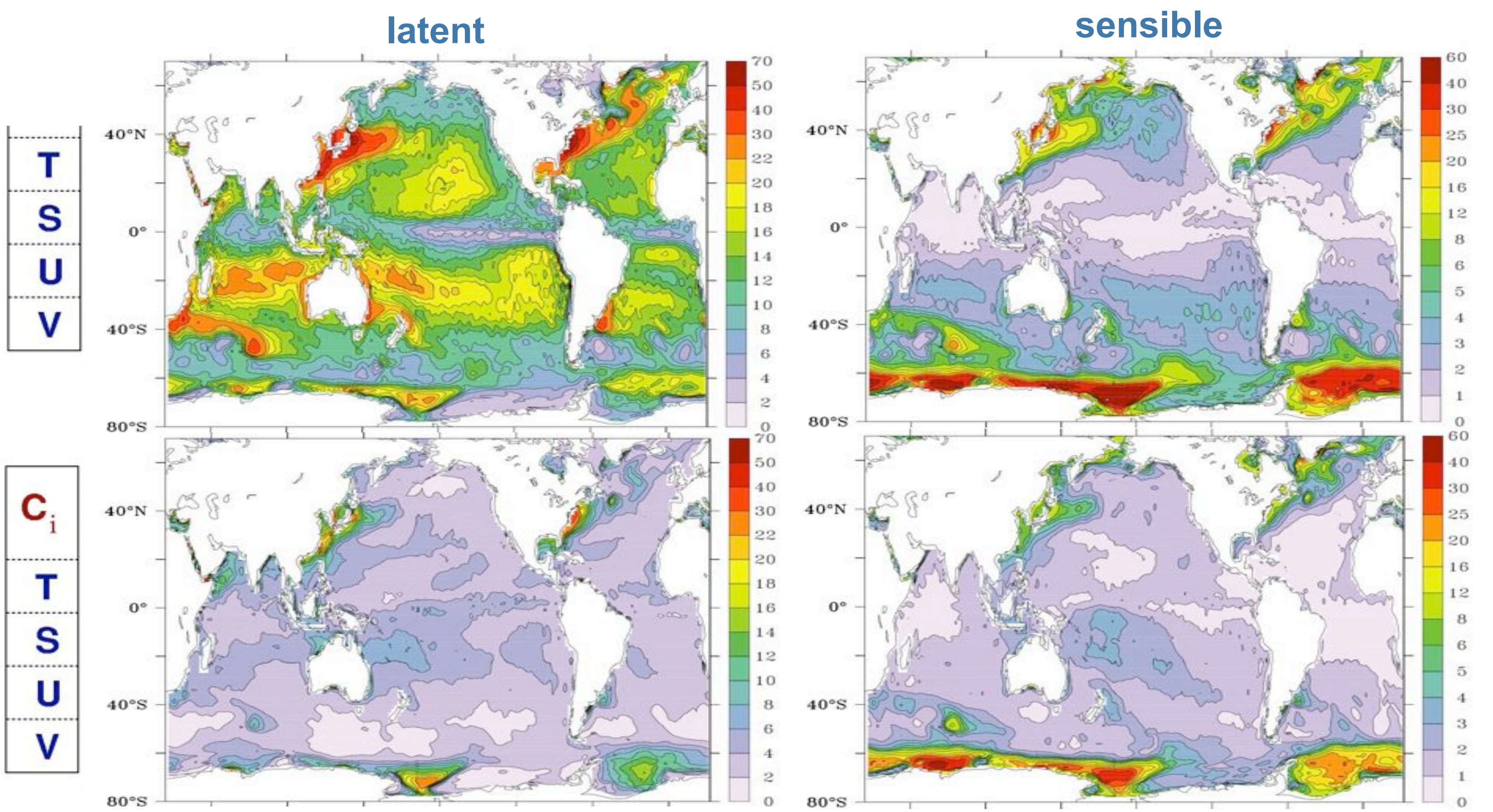


RMS error on SST

« Augmented » state vector estimation including « bulk » coefficients (Skachko *et al.*, 2006)

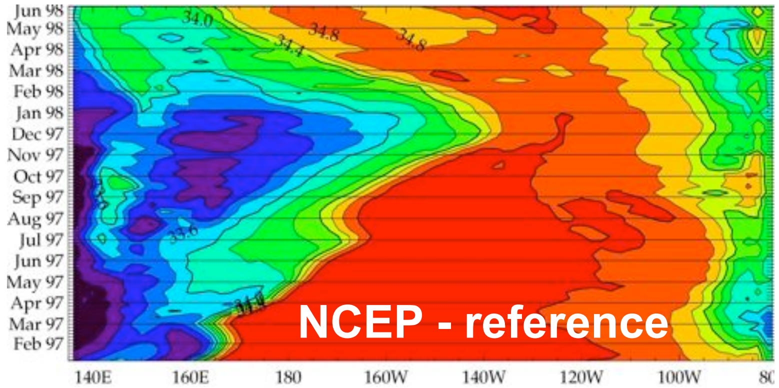
Assimilation of simulated data (0-200 m) in global OPA 2°x2°

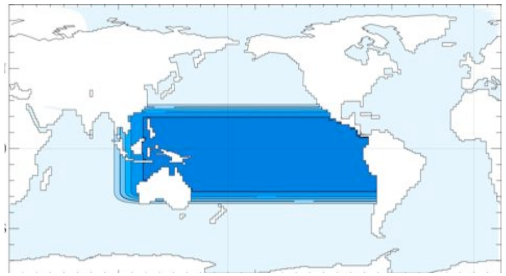
RMS error on heat flux (computed *a posteriori,* in W/m2)



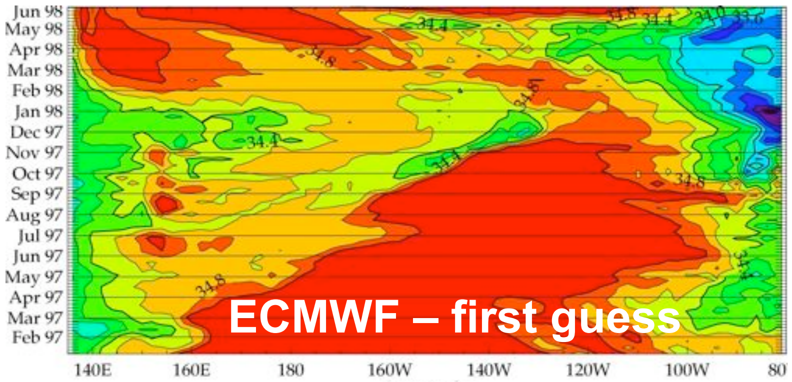
q **Generic approach: to be generalised to other observations at O/A interfaces**

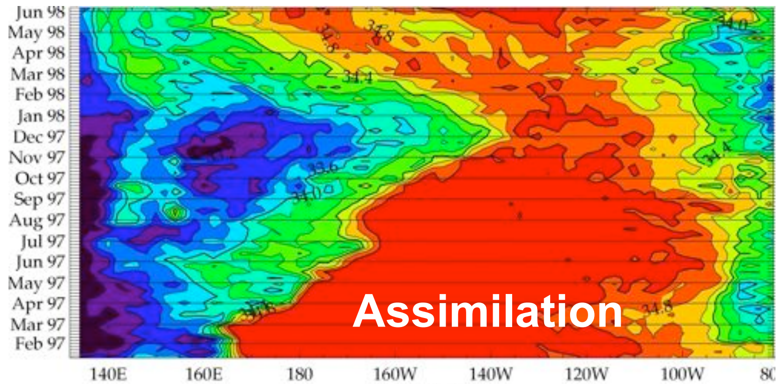
Towards Sea-Surface Salinity Data Assimilation with SMOS (2007) (Durand *et al*., 2003)





Migration de la Fresh Pool – El Ninõ



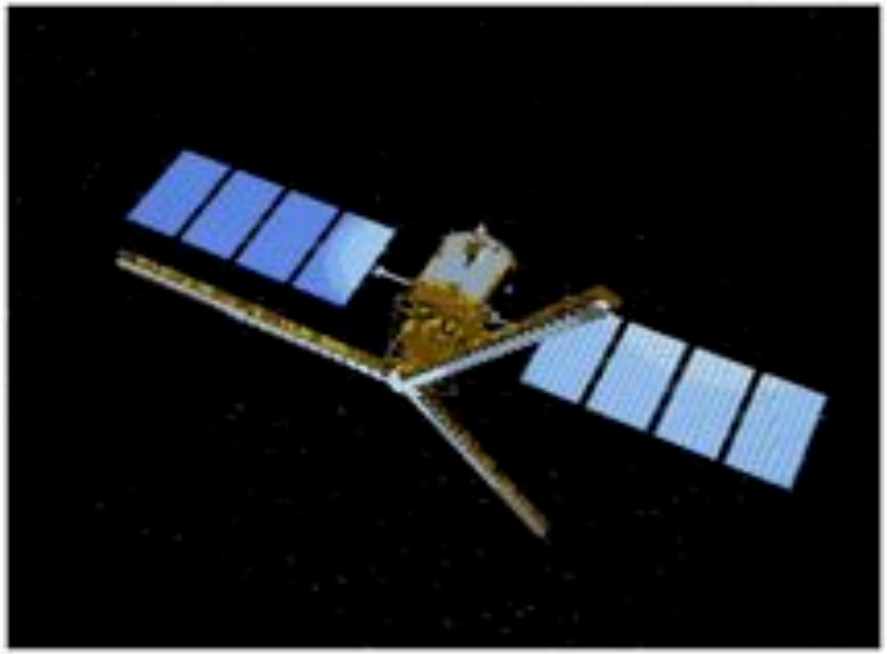


32.8 33.6 34.4 35.2 (psu)

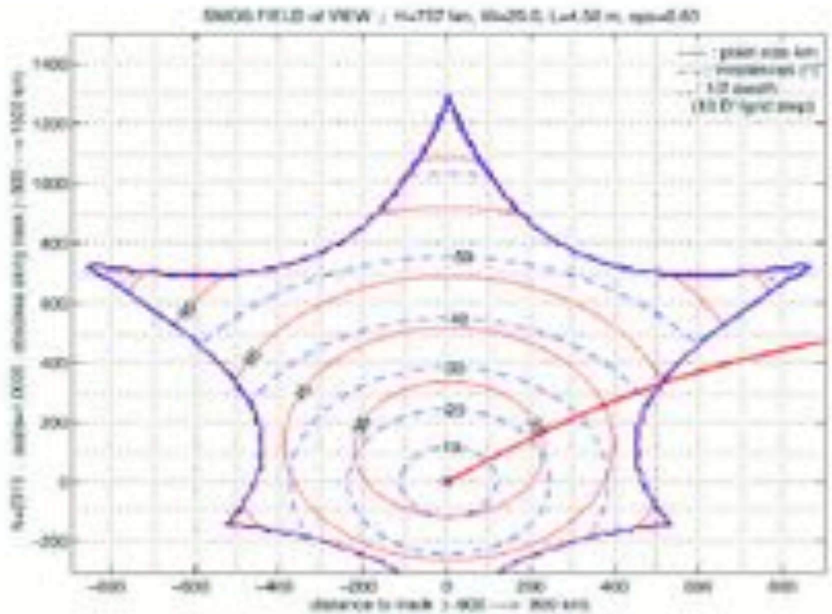
- **In the Tropical Pacific, SSS is potentially useful to**
  (i) compensate errors arising from ocean/atmosphere interactions (E-P)
  (ii) better understand / forecast (?) seasonal climate variability.

The ESA SMOS Mission
(**S**oil **M**oisture and **O**cean **S**alinity, 2007)

- **The MIRAS sensor:** an L-band Y-shape interferometric radiometer (1.4 GHz)



(a) Artist view of SMOS



(b) Field of view (FOV)

- **The measurements**: for a given pixel in FOV (sizes from ~35km to ~80km), a series of reconstructed L-band **brightness temperature** is measured at several incidence angles (0-60°) and polarization

(*Courtesy N. Reul, Ifremer*)

Ocean Surface Salinity: measurement principle of SMOS

- For electromagnetic frequencies < 20 GHz, the dielectric constant ε of sea water follows :

$$\epsilon(T,S,f) = \underbrace{\epsilon_\infty(T,S) + \frac{\epsilon_o(T,S) - \epsilon_\infty(T,S)}{1 - j2\pi f \tau(T,S)}}_{relaxation} + \underbrace{j\frac{\sigma_i(T,S)}{2\pi\epsilon'_o f}}_{conductivite}$$

where $\epsilon_\infty,\ \epsilon_o,\ \tau_{sw}$ et σ_i are polynomial functions of sea surface salinity S (SSS) and Sea Surface Temperature T. Maximum sensitivity to S occurs for low values of *f* (=1.4 GHz)

- The brightness temperature T_B of the sea surface measured by a radiometer at frequency *f*, incidence angle θ_i, azimuth Φ_i and polarization *p* is given by:

$$T_B(\theta_i,\phi_i,f,p) = T \cdot e(\theta_i,\phi_i,f,p,\epsilon(T,S,f),\vec{U},X)$$

where *e* is surface emissivity and $\vec{U}$ is the wind speed vector

(*Courtesy N. Reul, Ifremer*)

SSS assimilation impact studies using SAM-2

Tranchant *et al.*, 2006

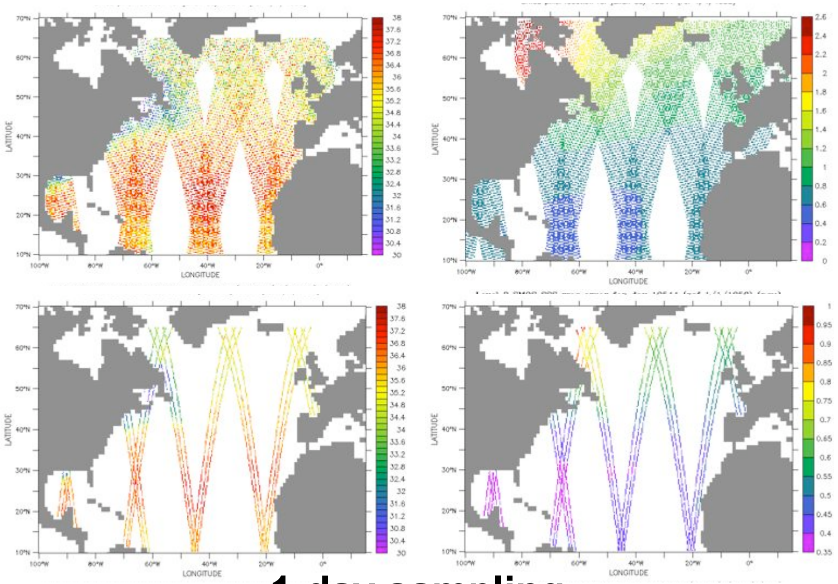
$$T_B(\theta_i, \phi_i, f, p) = T \cdot e(\theta_i, \phi_i, f, p, \epsilon(T, S, f), \vec{U}, X)$$

ð 2 different approaches:

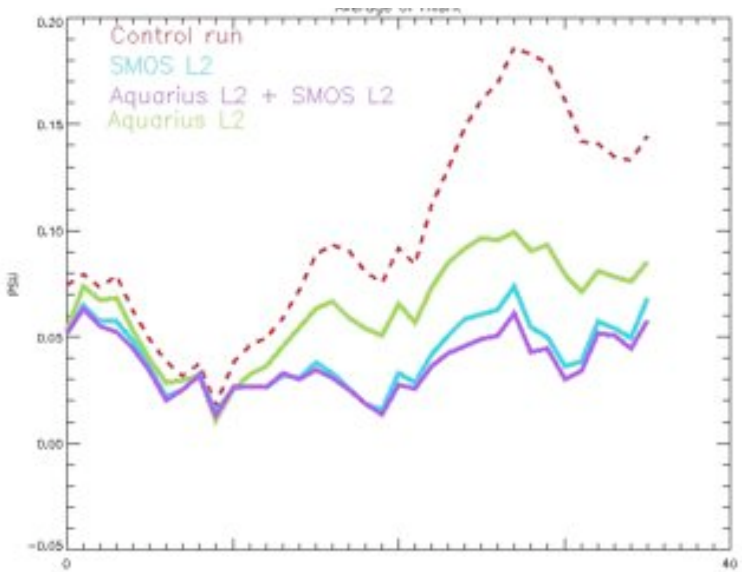
Ø **Invert T_b measurements into SSS data (using, e.g. look-up tables), and then assimilate SSS in the PE model.**

SMOS

AQUARIUS



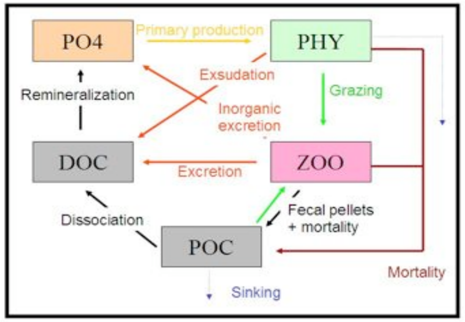
1-day sampling



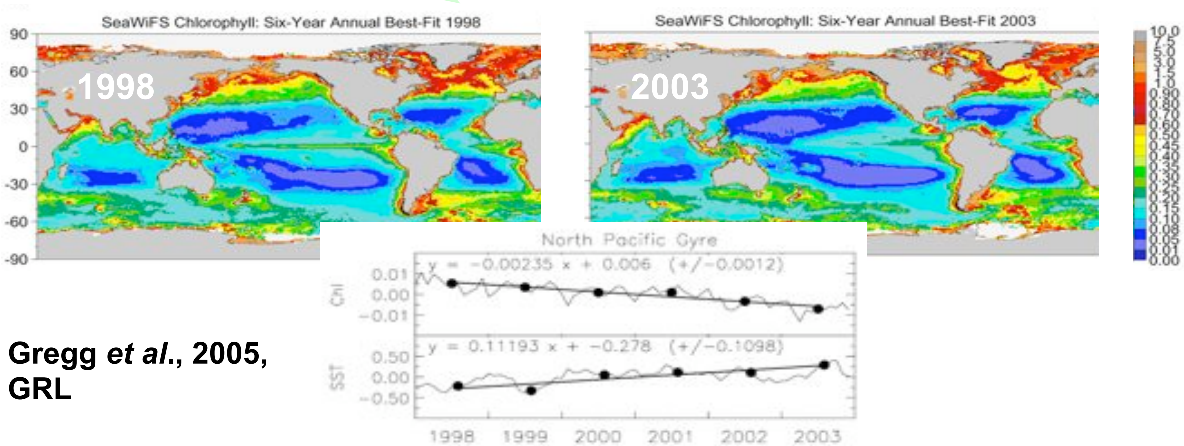
Mean error (t)

Response of marine ecosystems to ocean climate variability ?

NPDZ - LOBSTER - PISCES - ?



ASSIMILATION



Gregg *et al.*, 2005, GRL

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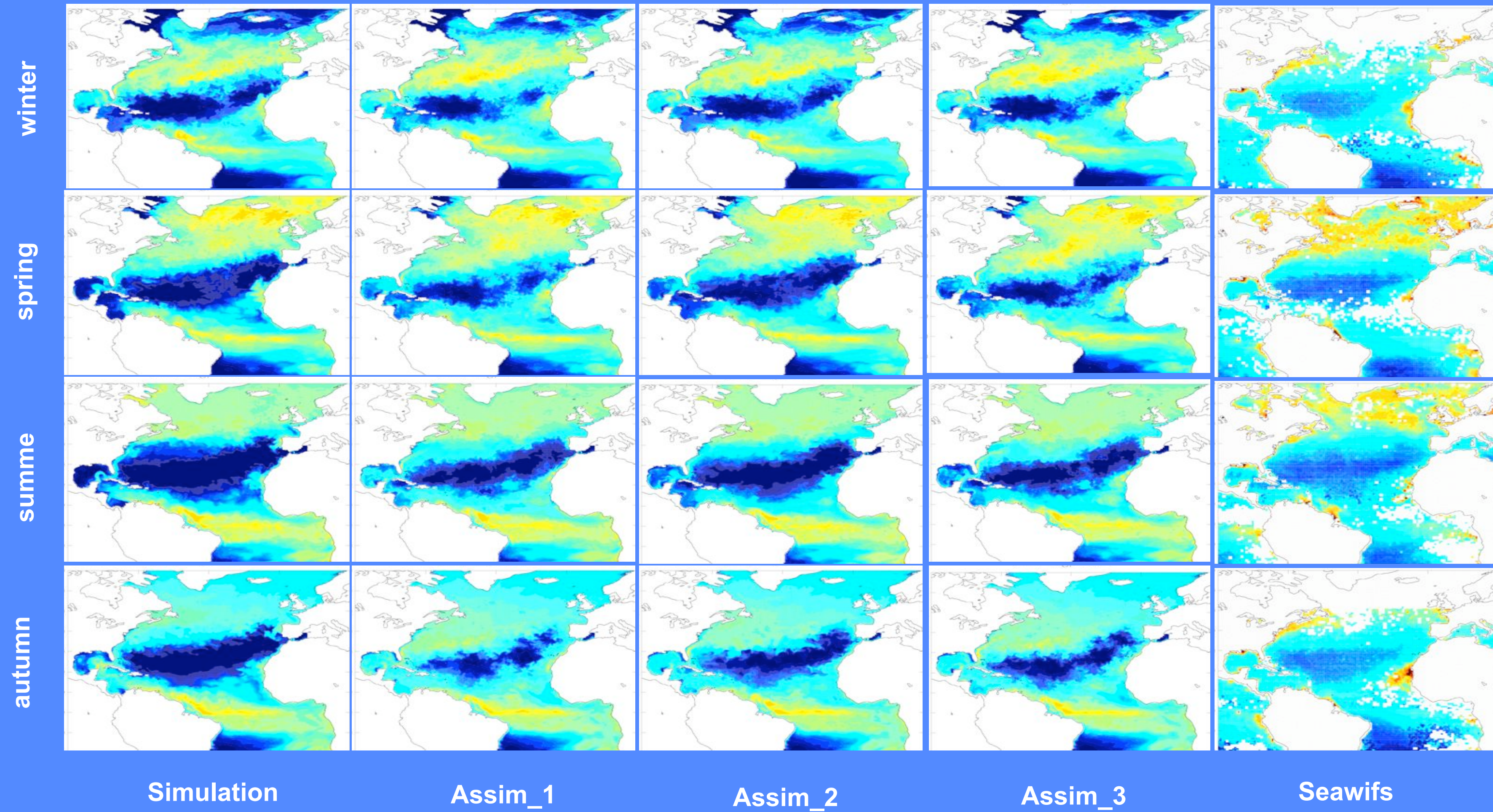
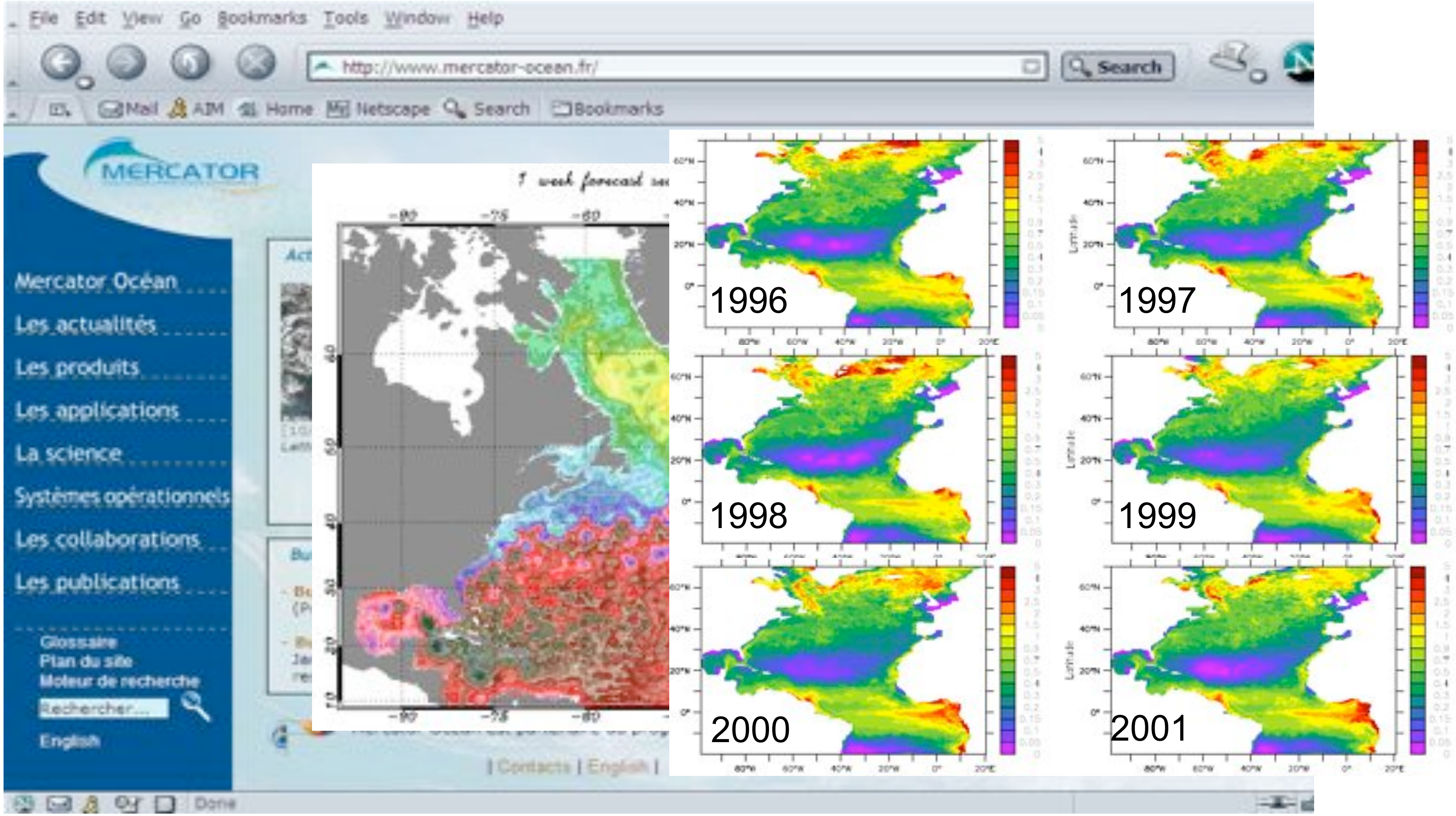
LABORATOIRE DES ECOULEMENTS GEOPHYSIQUES ET INDUSTRIELS

Assimilation of SLA+SST data in coupled models

Surface Chlorophyll_a (mg .m^{-3}) **– seasonal average** (Berline *et al.*, 2006)

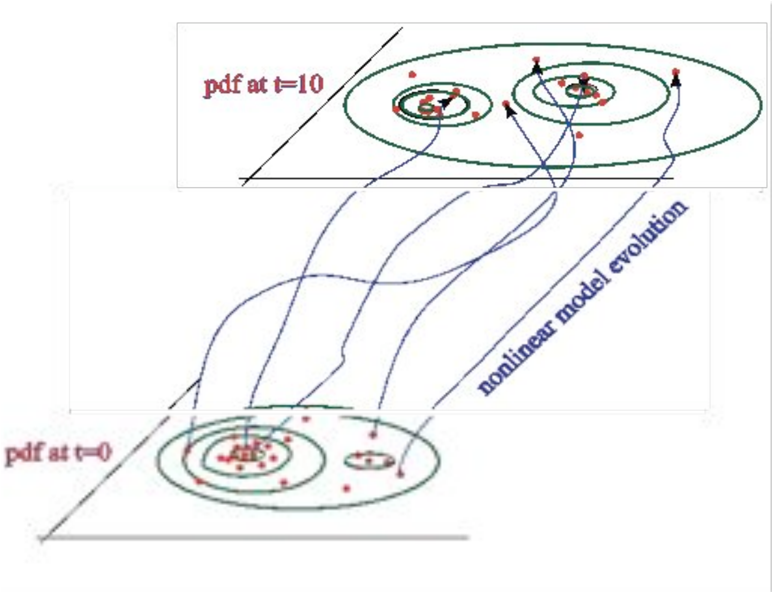


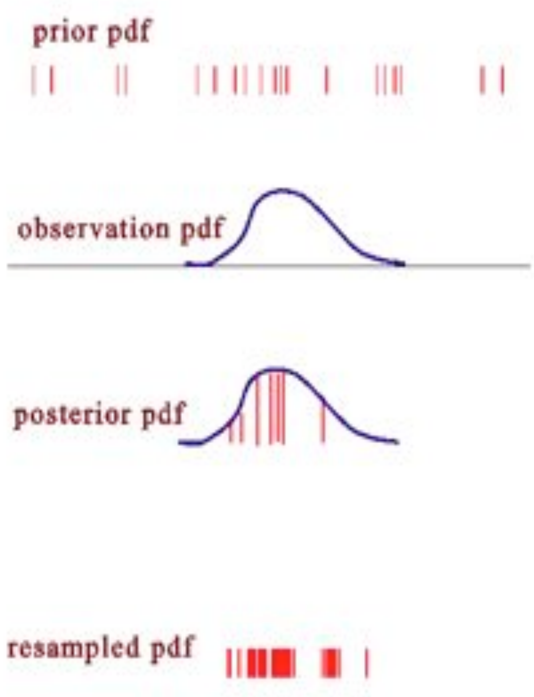
A MERSEA demonstration: the BIONUTS/Mercator project



Development of advanced sequential filters: towards non-linear filtering

- Traditional data-assimilation based on linearizations (Kalman Filter, 4D-VAR)
- Models become strongly nonlinear (physics/bio-chemistry, higher resolution)
- Need for nonlinear data-assimilation

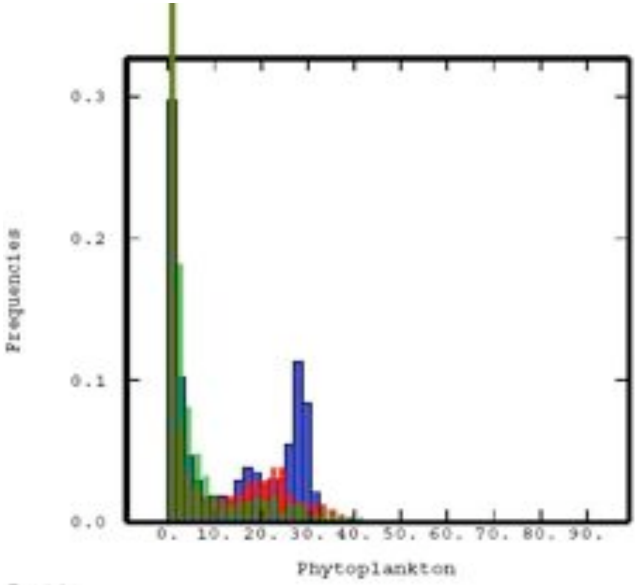




→ new « resampling » strategies (SIR, EnKF)

Development of the EnKF: anamorphosis

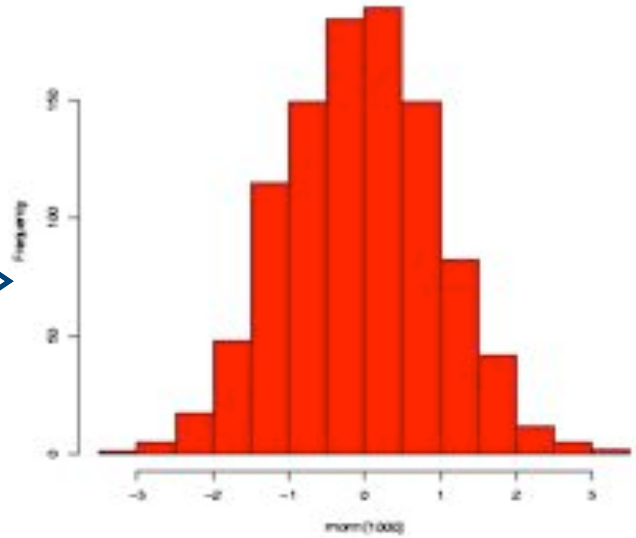
Model variable: *P*



Example: phytoplankton
in situ concentrations

$$S = \varphi(P)$$

Statistical variable: *S*



Improves EnKF with 1D ecosystem model [Bertino et al. *ISR 2003]*

Illustration

Idealised case: 1-D ecological model

- Spring bloom model, yearly cycles in the ocean
- *Evans & Parslow (1985), Eknes & Evensen (2002)*

Characteristics

- *Sensitive to initial conditions*
- *Non-linear dynamics*

Nutrients

Phytoplankton

time-depths plots

Herbivores

Anamorphosis: a logarithmic transform

Original

histograms

asymmetric

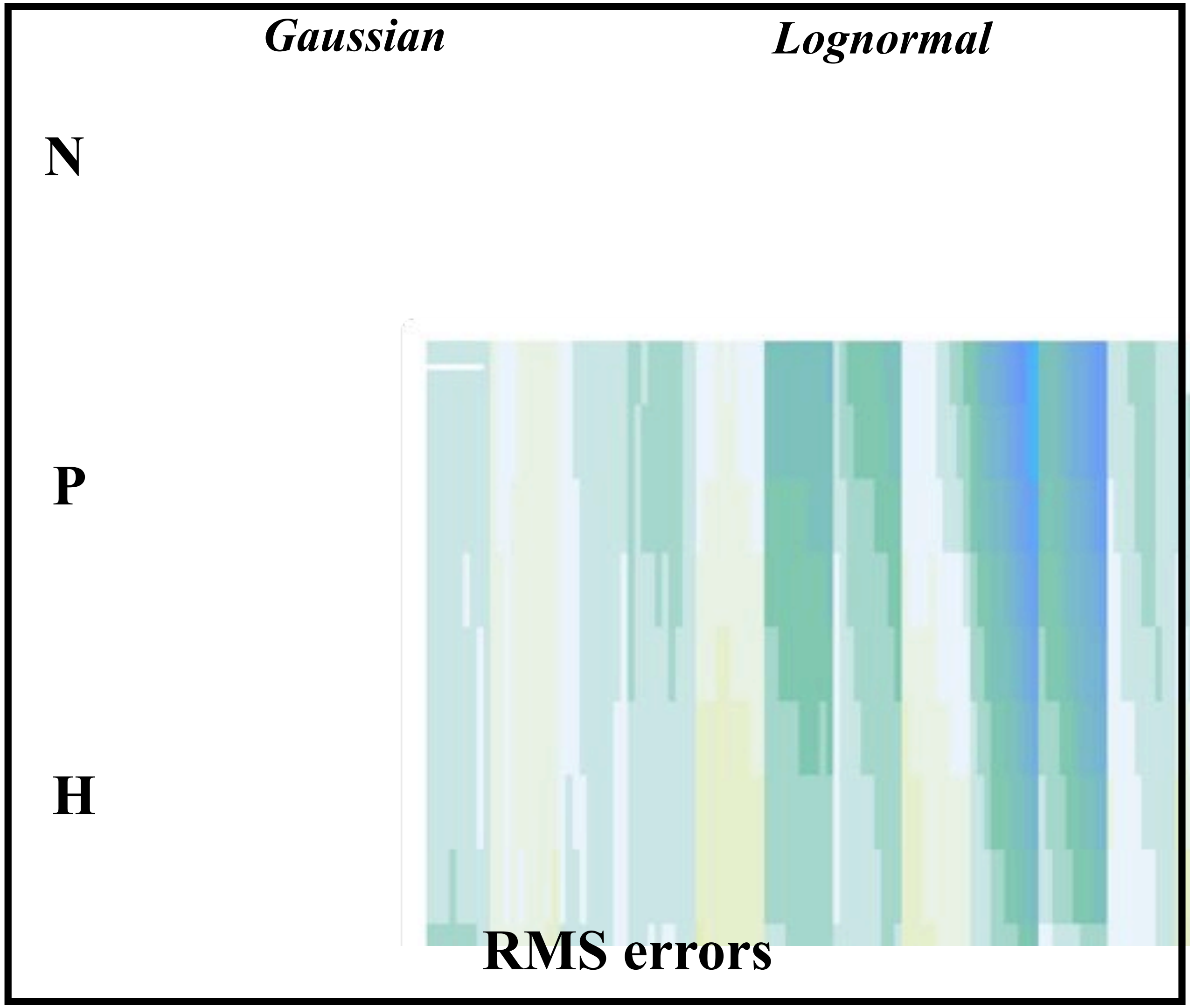
N P H

Histograms of logarithms

less asymmetric

Arbitrary choice, possible refinements (polynomial fit)

EnKF assimilation results
(Bertino et al., 2003)



- Gaussian assumption
  - Truncated H < 0
  - Low H values overestimated
  - "False starts"
- Lognormal assumption
  - Only positive values
  - Errors dependent on values

Concluding remarks

- **Operational Oceanography is on good tracks**; the progress should continue after GODAE

- **Satellite altimetry is absolutely vital** for ocean forecasting systems. The expected gap in altimetric missions (post-Envisat, post Jason-1) will not be filled in by alternative observing systems (in space or *in situ*).

- Efforts should be undertaken (at institutional level) to make sure that the ocean **research and operational communities** are **working together** in the best possible way (GMES will not solve everything !)


THAT CONCLUDES MY TWO-HOUR PRESENTATION. ANY QUESTIONS?
www.dilbert.com
DID YOU INTEND THE PRESENTATION TO BE INCOMPREHENSIBLE, OR DO YOU HAVE SOME SORT OF RARE "POWERPOINT" DISABILITY?
ARE THERE ANY QUESTIONS ABOUT THE CONTENT?
THERE WAS CONTENT?

Thank you !