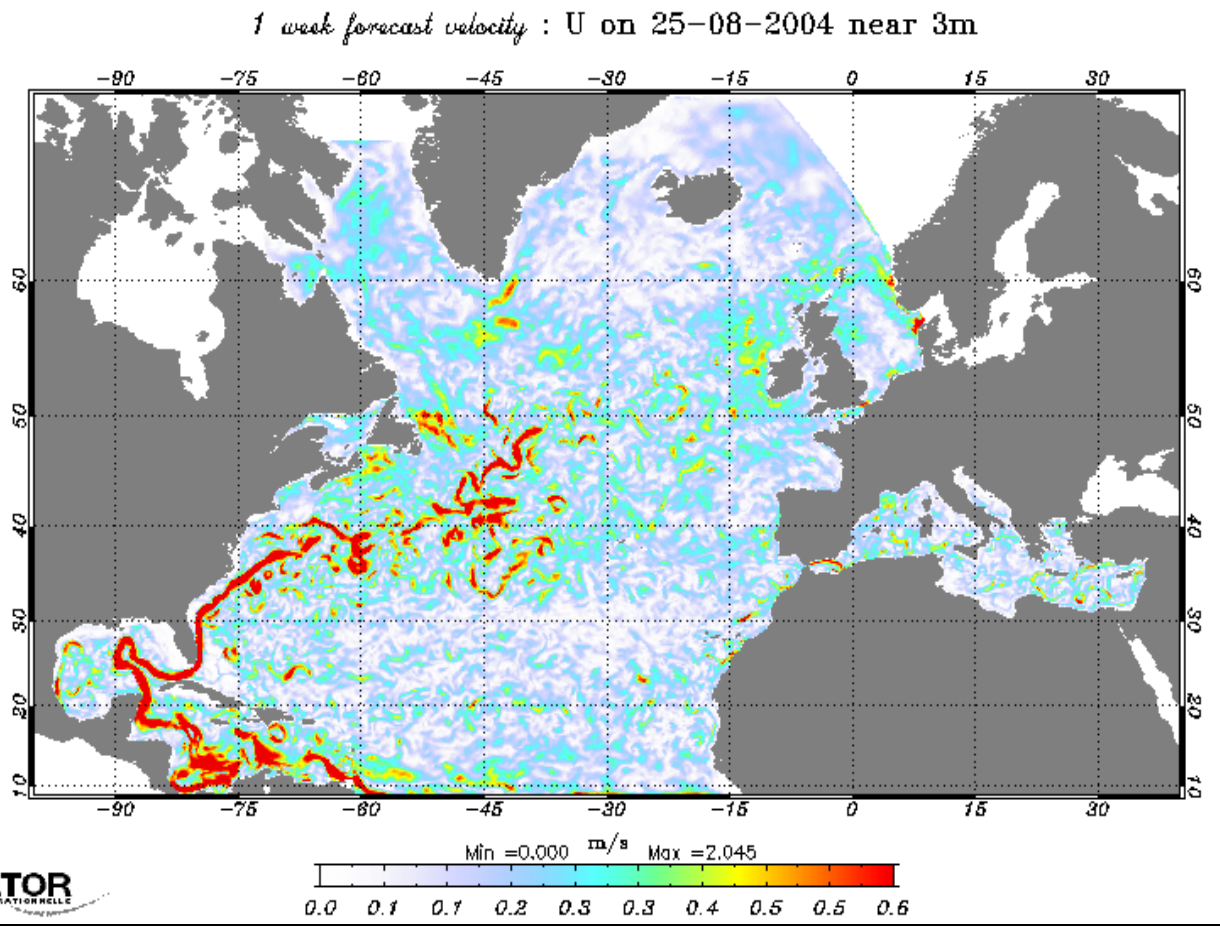
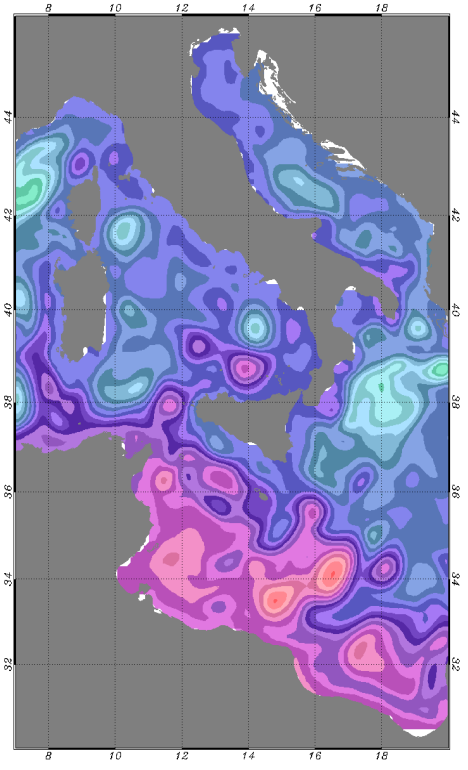
7-day ocean forecast – North Atlantic

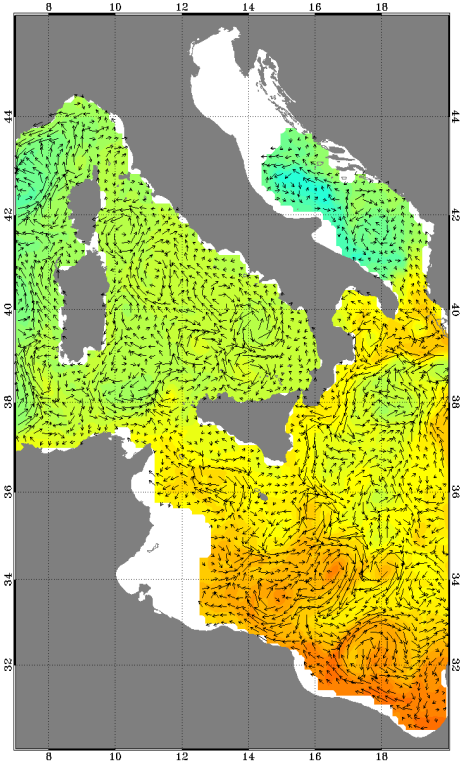


7-day forecast – Mediterranean

1 week forecast sea surface height : SSH on 25-08-2004



1 week forecast potential temperature : T on 25-08-2004 near 103m



Oceanic bulletin web page: http://www.mercator.com.fr

MERCATOR products

PSY1 Oceanic bulletins on 21 march 2001

The MERCATOR ocean bulletin includes a range of maps and other information about the underlying variables of the ocean, such as sea level anomalies, ocean currents, temperature and salinity, which describe the ocean in all its dimensions. Information that gives us a closer insight into current and forecast ocean conditions from the sea surface to the sea floor, at regional or basin scale.

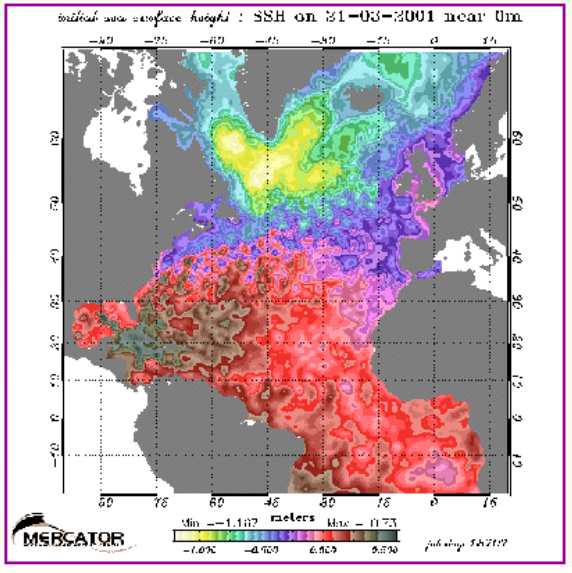
Whole domain plots

Zooms

Sections

Vertical profiles
time series

North atlantic
Sea level anomaly on 21 march 2001 (T0)



All results:

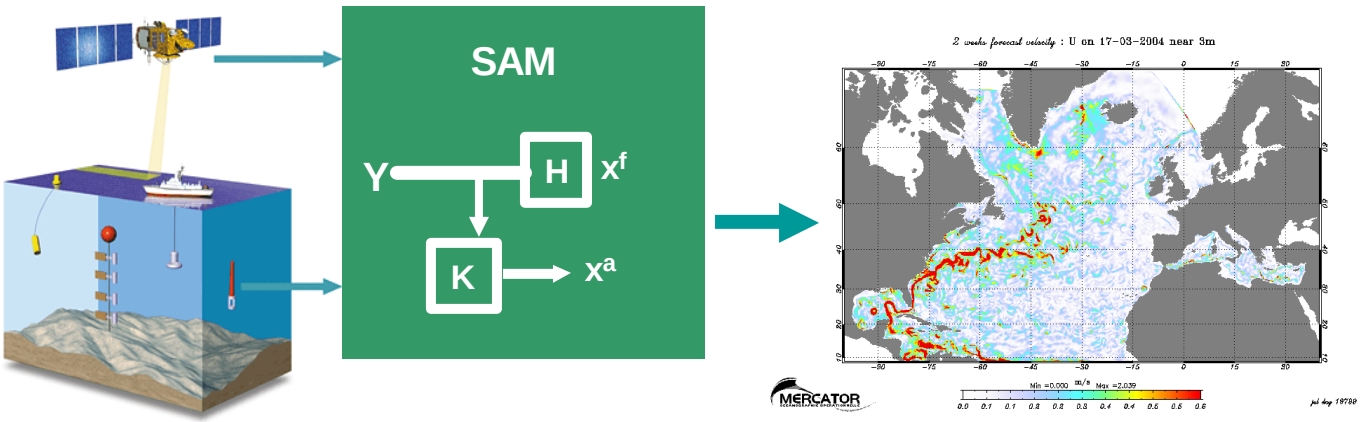
> Geographic areas

- North Atlantic
- Zonal mappings
- Sections
- Moorings

784 graphic files are put on the web every week

The Mercator Assimilation System (SAM)

from research to real-time operations



The MERCATOR R&D Assimilation Team

Pierre BRASSEUR, *Pierre DE MEY*

Nicolas FERRY, Elisabeth REMY, Charles-Emmanuel TESTUT, Benoît TRANCHANT

+ input from M. Benkiran, E. Dombrowsky, H. Etienne, E. Greiner

OUTLINE

- State-of-the-art
- Advanced issues
- **The MERCATOR Ocean Prediction System**
  1. **Objectives**
  2. **Operational systems**
  3. **Assimilation systems**
  4. **Validation procedures**
  5. **Global prototype**
  6. **North Atlantic prototypes**

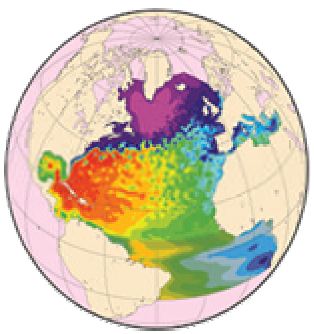
- An initiative of the French ocean science community
- Sponsored by CNES, CNRS, Ifremer, SHOM, IRD, Météo-France
- GIP (public interest group) status during 2002-2006
- One of the European participants to GODAE
  (Global Ocean Data Assimilation Experiment)

1. Objectives

- ***Retrospective analyses,*** near-real time ***nowcasts*** and medium-range ***forecasts*** of the mesoscale currents and T/S properties of the **basin/global ocean** at eddy-resolving resolution (1/4° to 1/15°)

  - ***Initial oceanic conditions*** of coupled ocean/atmosphere models for **seasonal and climate** forecasting systems.

  - ***Boundary conditions*** for **regional** focus experiments at sub-mesoscale resolution (~ 1/60°)



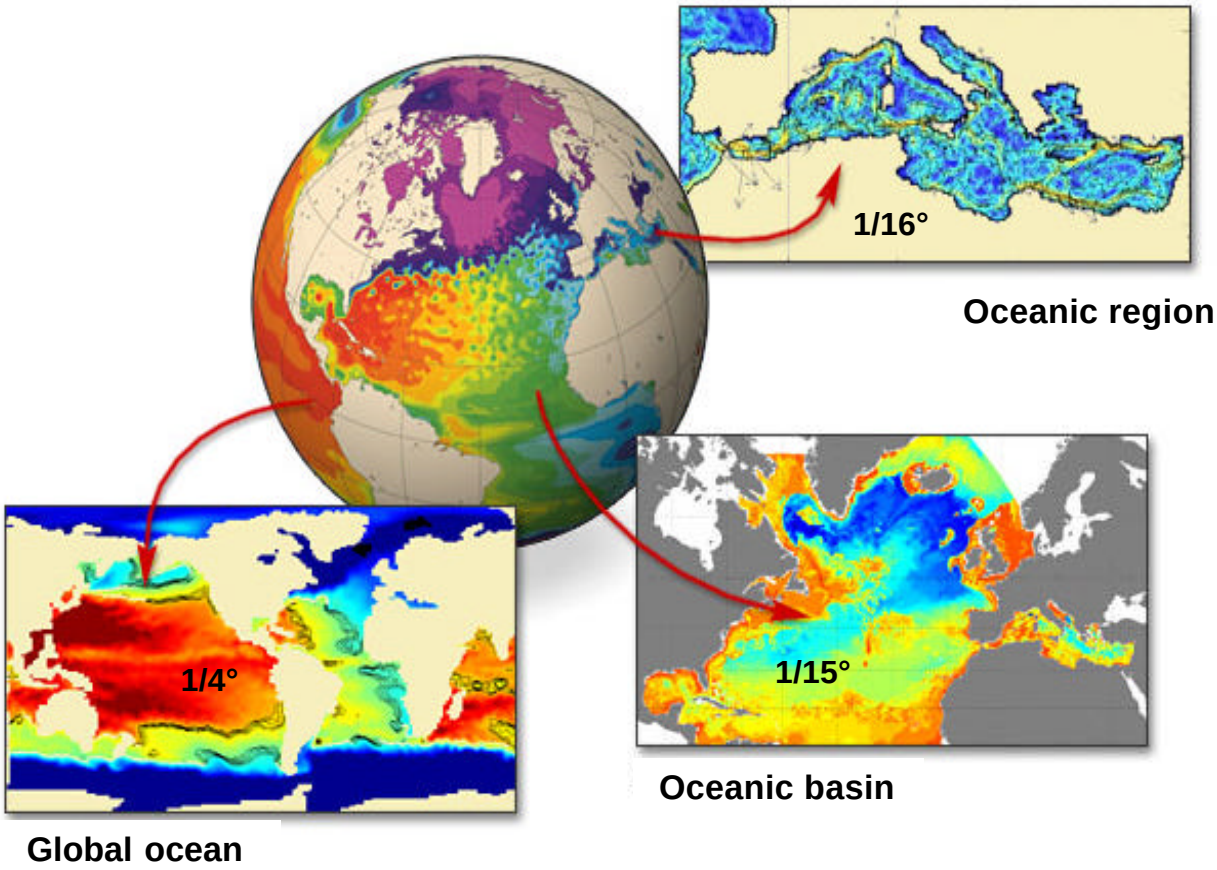
→ **Wide spectrum of ocean/marine processes**

at different time/space scales

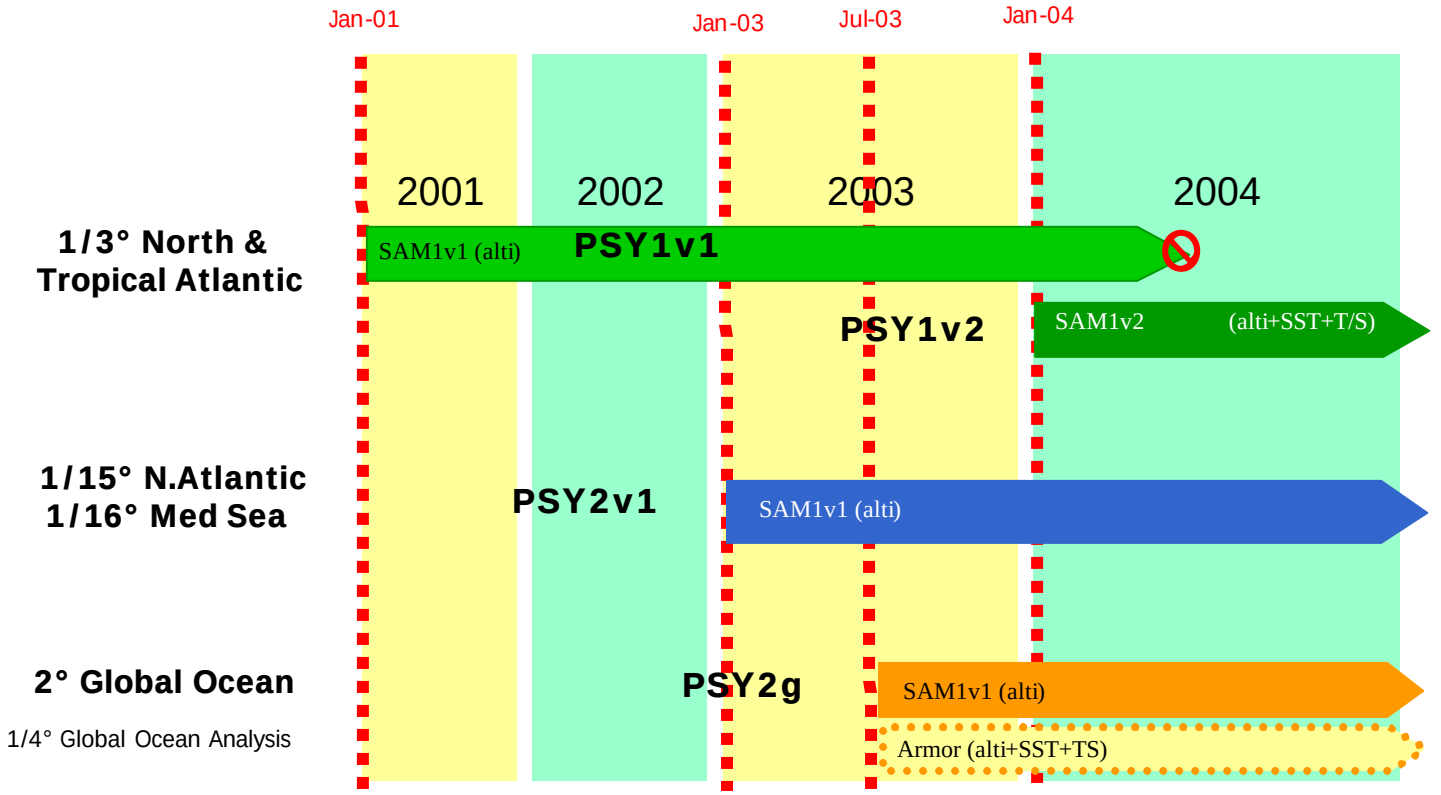
→ **Hierarchy of interacting Mercator prototypes**

→ **Range of complementary systems of assimilation**

MERCATOR domains



2. Operational systems



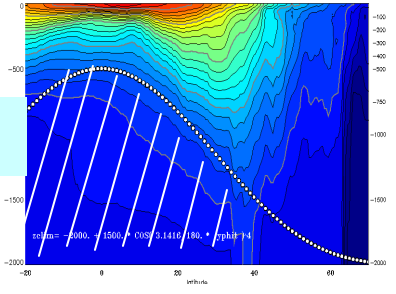
Assimilated data

- Altimetry : JASON, ENVISAT, GFO
- SSS Climatology(Reynaud)
- SST at the analysis day (Reynolds)

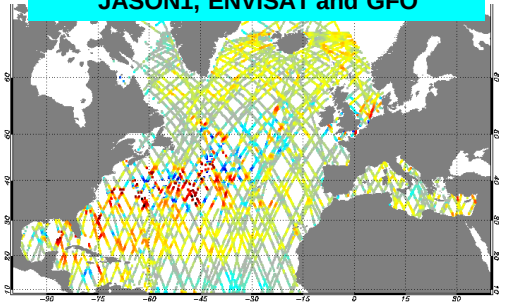
- Temperature et Salinity profiles
  - XBT : Temperature
  - CTD : Temperature and Salinity
  - BATHY : Temperature
  - TESAC : Temperature and Salinity

- Temperature and Salinity Climatology in the deep ocean

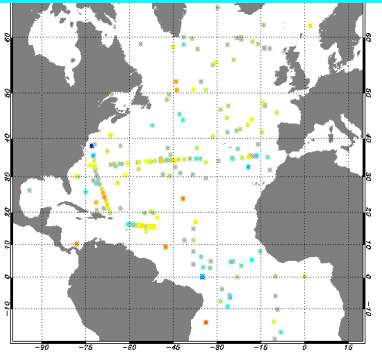
Meridional section of Temp. climatology.



Typical SLA coverage for a week with JASON1, ENVISAT and GFO

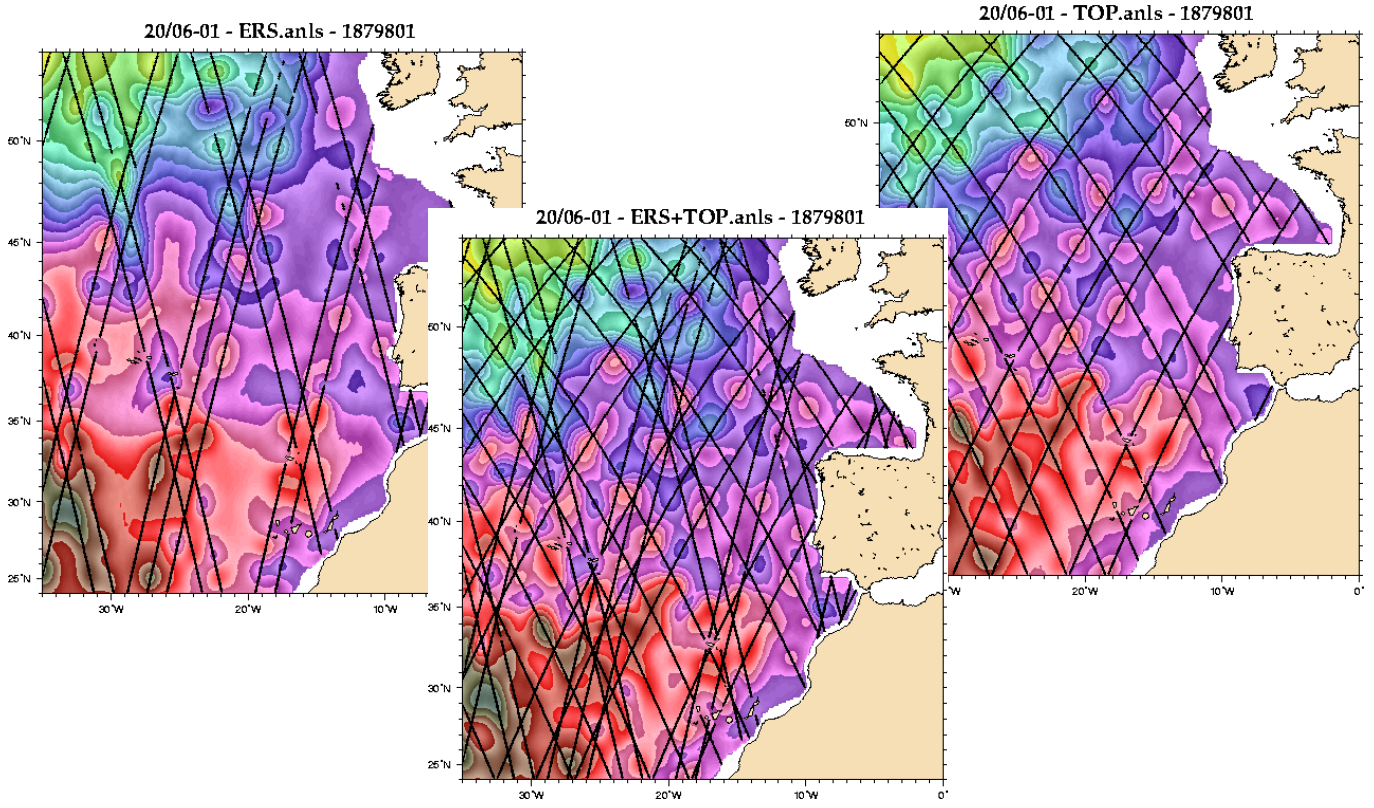


Typical weekly coverage for in situ data with temperature profiles



Altimeter data processed on June, 20 2001

- One week of Near Real Time altimeter data



3. MERCATOR Assimilation Systems

❑ Incremental implementation strategy

	OI	Kalman filters	3D/4D-VAR
Research	1993 (SOFA)	1998 (SEEK)	1999 (OPAVAR)
R&D	1997	2002	2004
DEV	1999	2005	2008 ?
OP	2001	2007 ?	?
	SAM-1	SAM-2	SAM-3

3D state estimation : SAM-1 and SAM-2

- **Optimal interpolation : SAM-1**
  1. SOFA + Cooper/Haines mode (open ocean attractor): 2D statistical estimation + vertical adjustement : **SAM-1v1**
  2. SOFA + multivariate 1D vertical EOFs (from model or data variability): 2D +1D statistical estimation : **SAM-1v2**
- **Reduced-order Kalman filter : SAM-2**
  1. SOFA + EOFs 3D (multivariate model variability): inversion in observation space : **SAM-2v0**
  2. SEEK + EOFs 3D (multivariate model variability): inversion in error sub-space: **SAM-2v1**

➔ ***Local inverse 3D estimates, « FGAT » approximation***

SAM-1 and SOFA3 assimilation library

Developed as part of the MFSPP European R&D project *(De Mey and Benkiran, 2001)*

Algorithm

- OI-based
- Reduced-order modelling of guess errors using local multivariate EOFs
- Local inverse
- Binary tree search algorithm
- Line-of-sight algorithm (islands and peninsulae)

- The **f77** library is free (GNU LGPL)
- Growing users group
- Extensive online and offline diagnostics (forecast, persistence, verification data, biases, trends, regional breakdown, etc.)

Known limitations

- Surface layer
- Shallow areas (coasts, shelf)
- Assimilation of velocities
- No error propagation

MERCATOR System	*On-line*	*Description*
AM-1 version 1	Jan-2001	♦ SOFA3/**f90** + PALM ♦ Altimetry only ♦ "weighted" LL method
SAM-1 version 2	Jan-2004	♦ SOFA3/**f90** + PALM ♦ Altimetry + profiles ♦ Multivariate EOFs

SAM 1 / SAM 2

$$\mathbf{x}^a = \mathbf{x}^f + \mathbf{K}\mathbf{d} \quad \text{with} \quad \mathbf{d} = \mathbf{y}^o - \mathbf{y}^f = \mathbf{y}^o - \mathbf{H}(\mathbf{x}_f) \quad \text{and} \quad \mathbf{K} = \mathbf{P}^f \mathbf{H}^T \left(\mathbf{H}\mathbf{P}^f \mathbf{H}^T + \mathbf{R}\right)^{-1}$$

$\mathbf{K}_r$ reduced gain defined by $\mathbf{K} = \mathbf{S}^T \mathbf{K}_r$

SAM-1 (SOFA)

$$\mathbf{K}_r = \mathbf{B}_r^f \mathbf{H}_r^T \left(\mathbf{H}_r \mathbf{B}_r^f \mathbf{H}_r^T + \mathbf{R}_r\right)^{-1}$$

with $\mathbf{B}_r^f = \mathbf{D}^{1/2}\mathbf{C}\mathbf{D}^{1/2}$ and $\mathbf{H}_r = \mathbf{H}\mathbf{S}^T$

Inversion in observation space, with **S** (simplification operator) acting on the vertical

→ 1D modes (EOFs)

SAM-2 (SEEK)

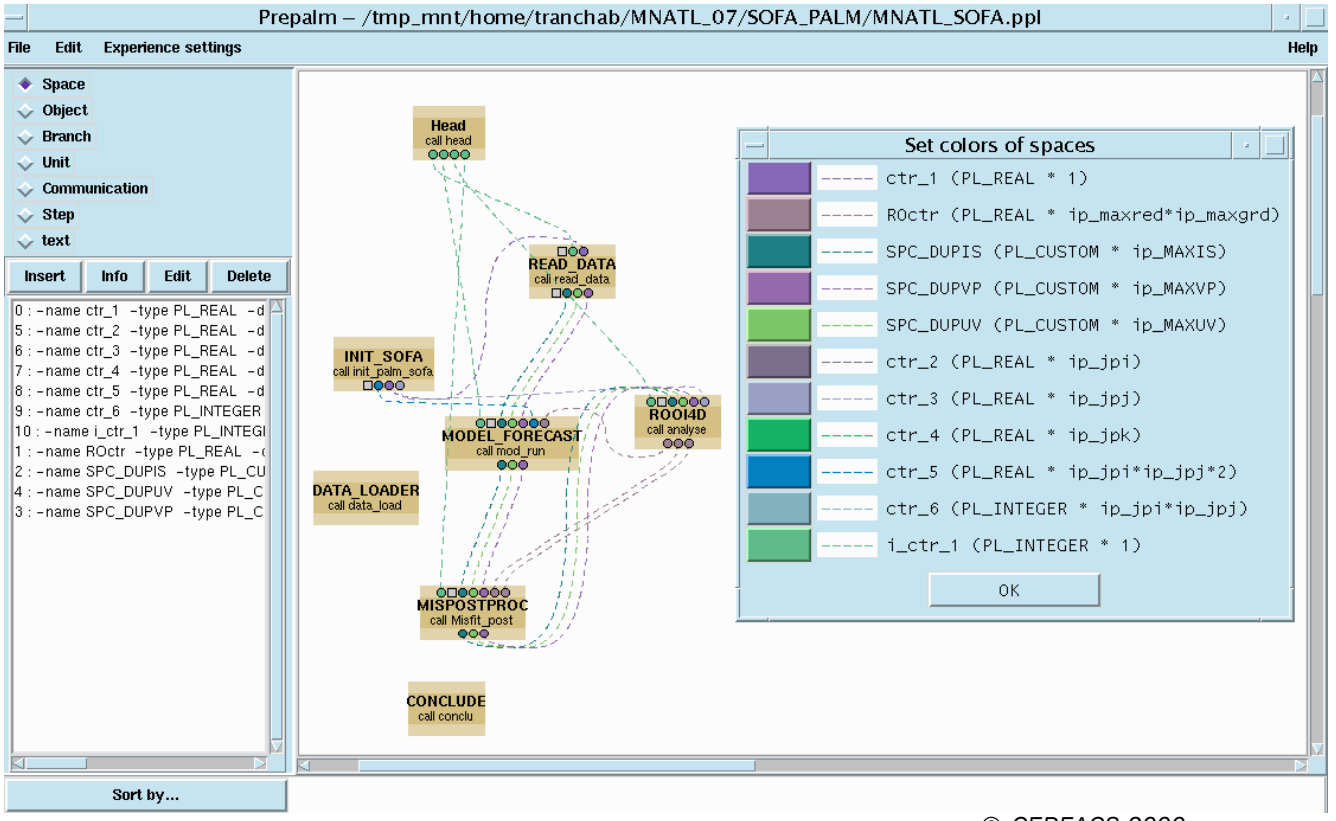
$$\mathbf{K}_r = \mathbf{B}^{1/2}\left[\mathbf{I} + \left(\mathbf{H}\mathbf{S}^T\mathbf{B}^{1/2}\right)^T \mathbf{R}^{-1}\left(\mathbf{H}\mathbf{S}^T\mathbf{B}^{1/2}\right)\right]^{-1}\left(\mathbf{H}\mathbf{S}^T\mathbf{B}^{1/2}\right)^T \mathbf{R}$$

with $\mathbf{P}^f = \mathbf{S}^T\mathbf{B}\mathbf{S}$

Inversion in the modal space with **S** (simplification operator) acting on the 3D space

→ 3D modes (EOFs)

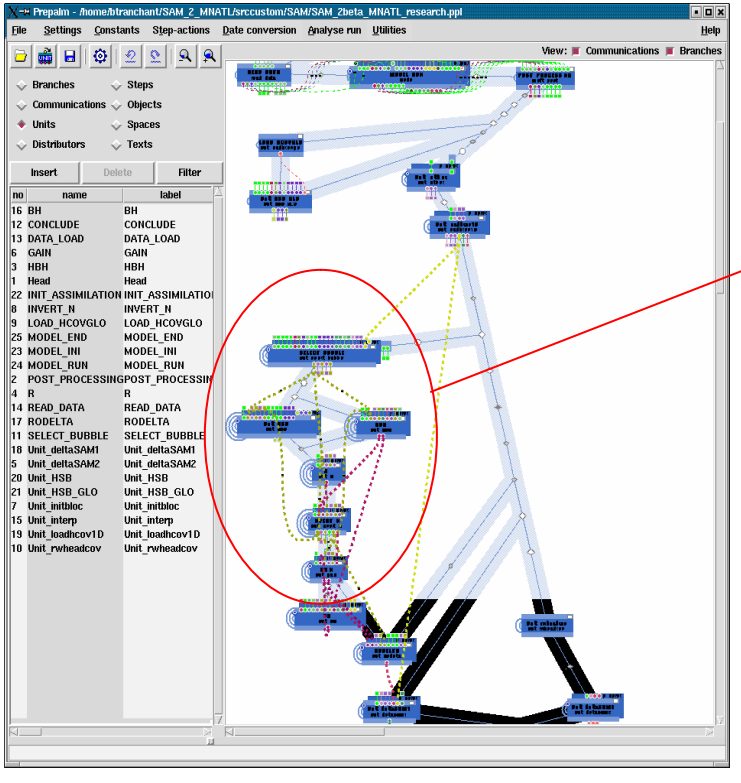
Modular development and parallel solution with PALM

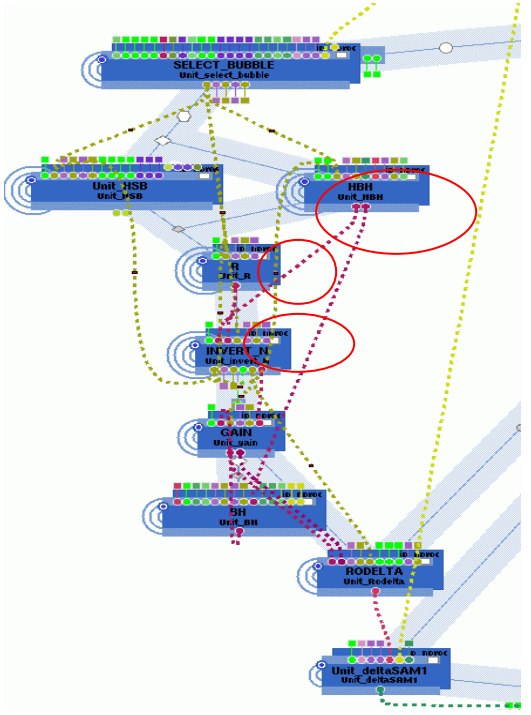


Graphical PALM interface
example: SAM1-v2

- **PALM Coupler**: modular tool for coupling and running various data assimilation schemes

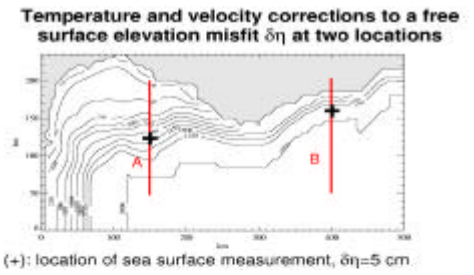
$$\mathbf{K_r} = \mathbf{B_r}^{f}\mathbf{H_r}^{T}\left(\mathbf{H_r}\mathbf{B_r}^{f}\mathbf{H_r}^{T} + \mathbf{R_r}\right)^{-1}$$

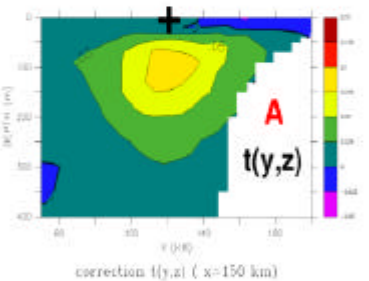


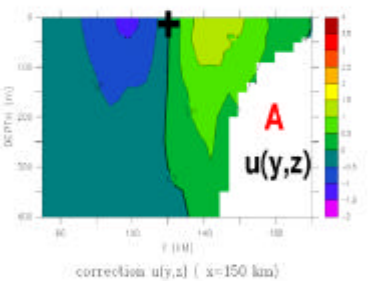


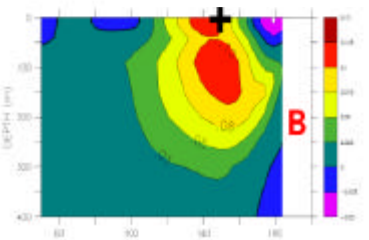
SAM-2 : scientific motivation (I)

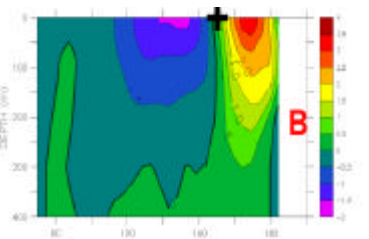
- **Multivariate error modes in 3D space (EOFs of model variability)**
  - Covariance structures consistent with the model dynamics;
  - Useful in regions with strong topographic control.







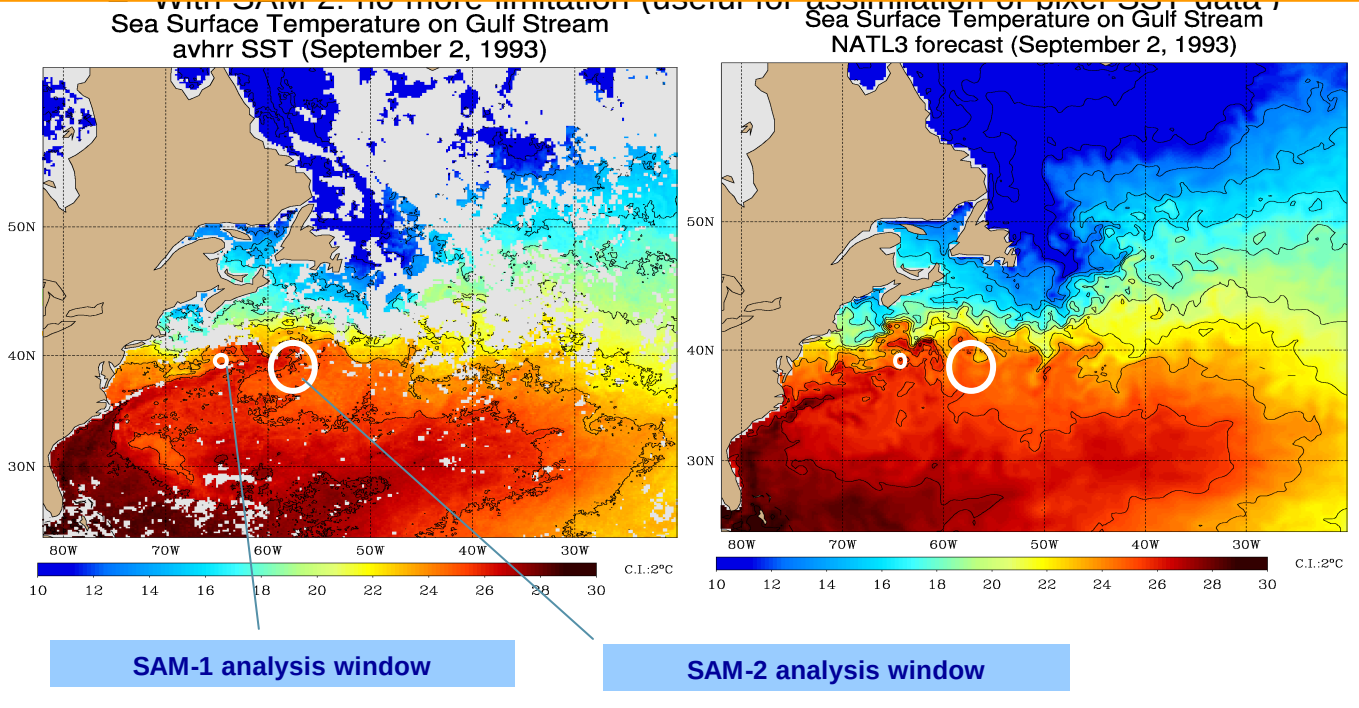




Green functions of SSH variable in a free-surface coastal model
(*Echevin et al., JPO, 2000)*

SAM-2 : scientific motivation (II)

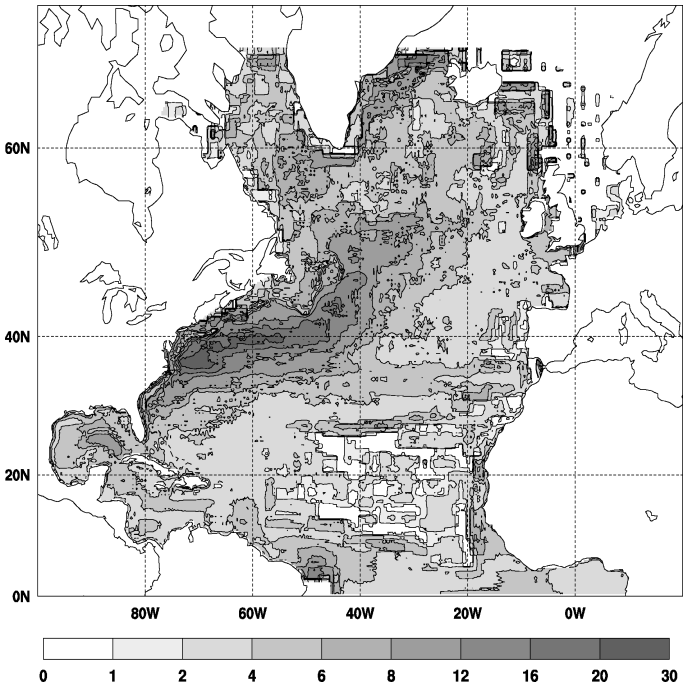
- **Analysis kernel inversion in reduced space (not observation space)**
  - With SAM-1: limitation to ~ 400 data in each influence bubble
  - With SAM-2: no more limitation (useful for assimilation of pixel SST data)



SAM-2 : scientific motivation (III)

- **Analysis/forecast error estimation**
  - Adaptatives approaches for on-line tuning of statistical parameterization

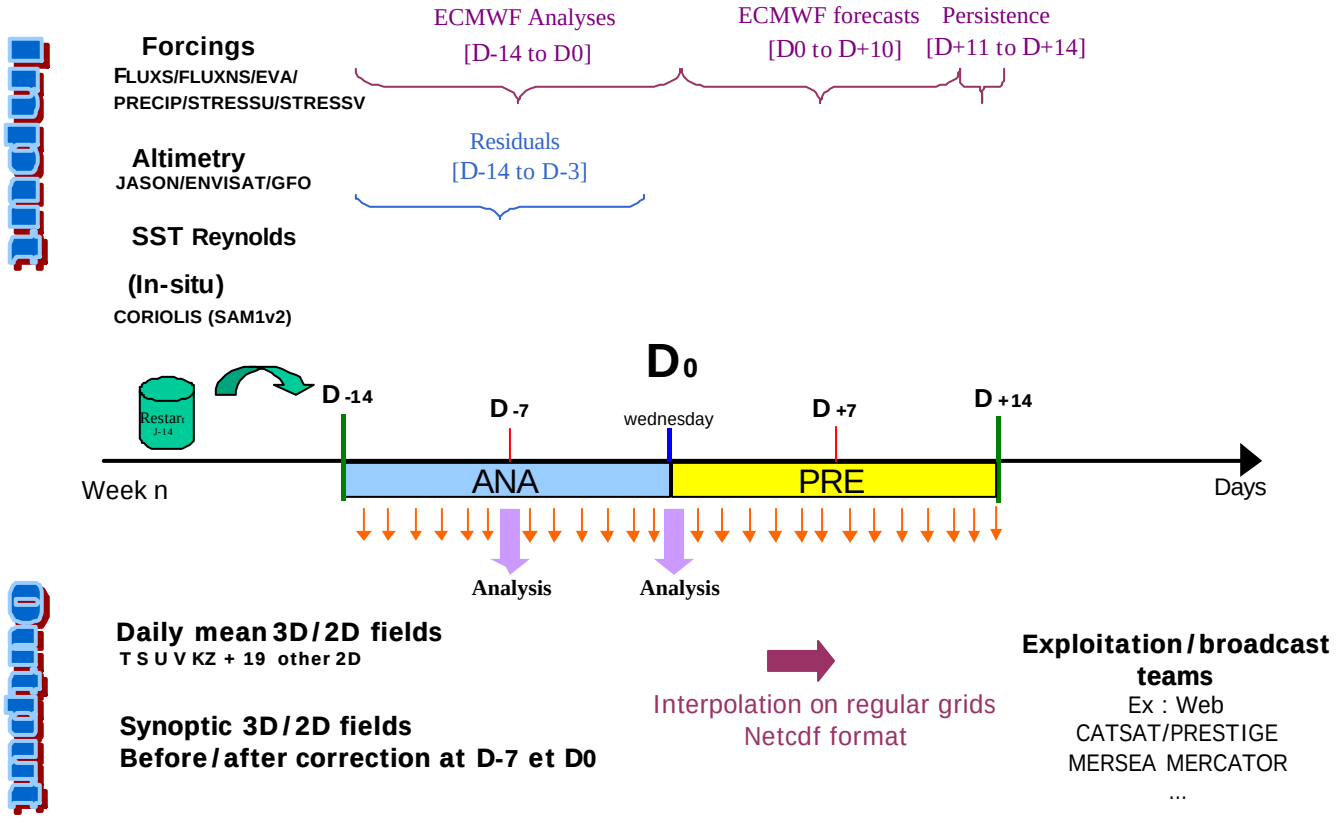
Adaptive estimation of the forecast error std (Testut *et al*., 2003)



Towards 4D state estimation : SAM-3

- **Motivation:** global, low-resolution estimates of temperature/salinity properties (at seasonal scale, with focus on the upper layers), which will be used
  - as a first guess to higher resolution (eddy-resolving) ocean forecasting;
  - as oceanic initial conditions for coupled o/a seasonal forecasting
- **Approach: variational assimilation (Weaver et al., 2003)**
  1. 3D-VAR estimator (SAM-3v0), useful to develop and validate the suite of operators ($\mathbf{H}$, $\mathbf{P}_0$, …)
  2. 4D-VAR estimator (SAM-3v1), with multivariate space-time interpolation capability, adapted to « fast » dynamics (equatorial waves) and well suited to the production of low-resolution global analyses.
- **First R&D prototype in project:**
  - Based on global 2°x2° ocean model (ORCA2)
  - Development of multivariate assimilation of altimetric, SST and *in situ* profiles

Weekly operational process



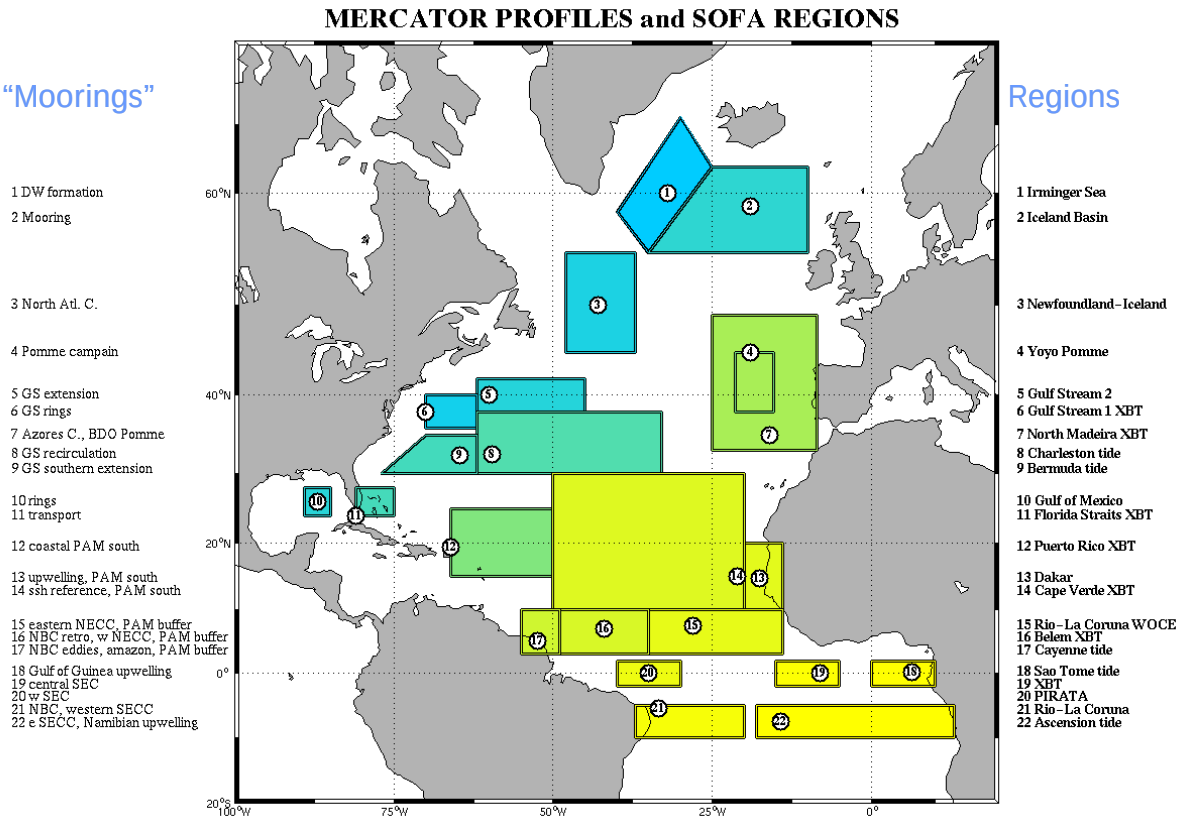
4. Validation procedures

- **On-line weekly technical validation**
  - analyze on-line diagnostics, look at standard graphics
  - non-expert validation
  - done every week before **www** and **ftp** dissemination

- **Off-line short-loop scientific validation**
  - uses low-rate diagnostics
  - done by an expert every month
  - synthesis published every 3 month: MERCATOR Newsletter

- **Off-line long-loop scientific validation**
  - done by the MERCATOR Science Working Team (annual AO)
  - “topic oriented” studies
  - coordinated by the project (3 Project Scientists)

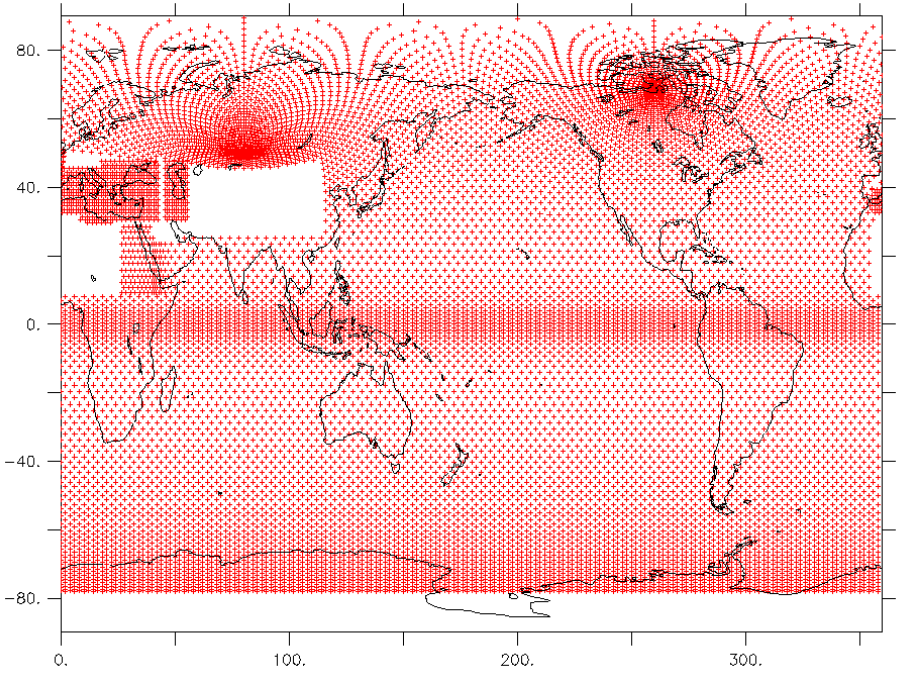
Regionalized assimilation diagnostics



5. Global prototype

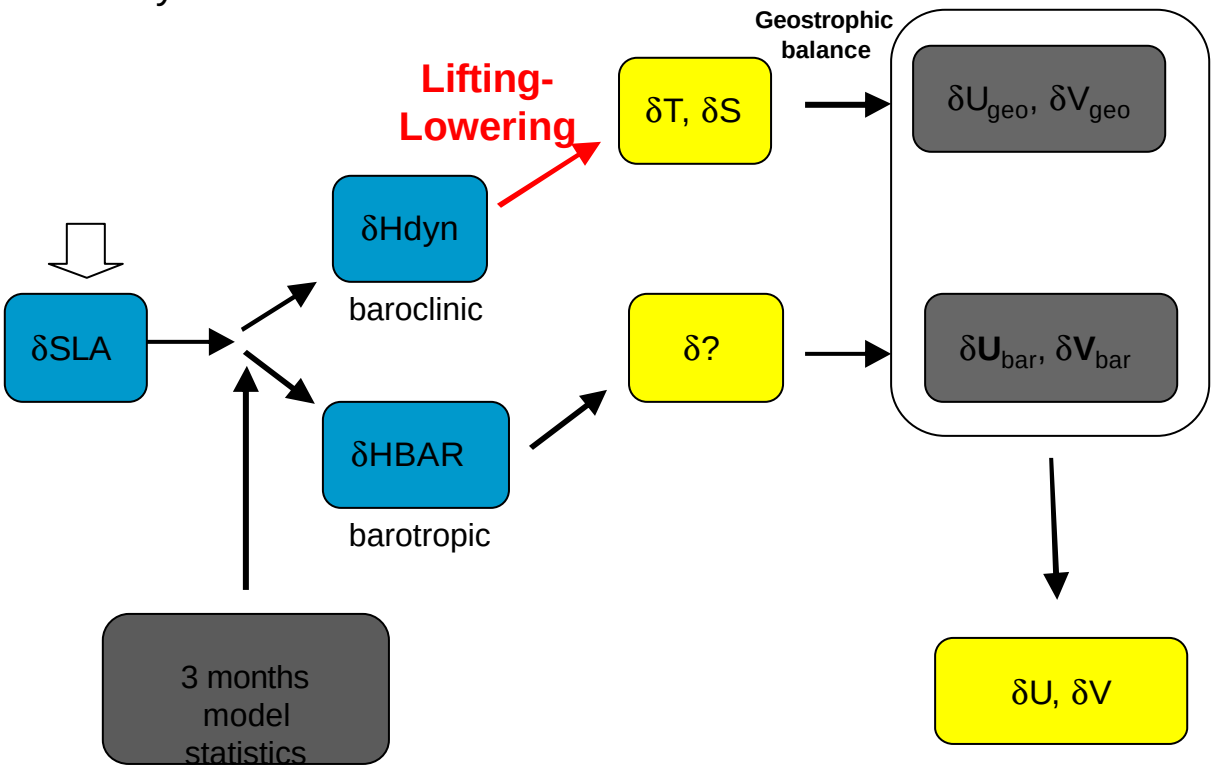
Assimilation SLA using SAM1-v1 : univariate system

- PSY2-G: 2° Global ocean



5. Global prototype
SAM-1, version 1

Schematically:

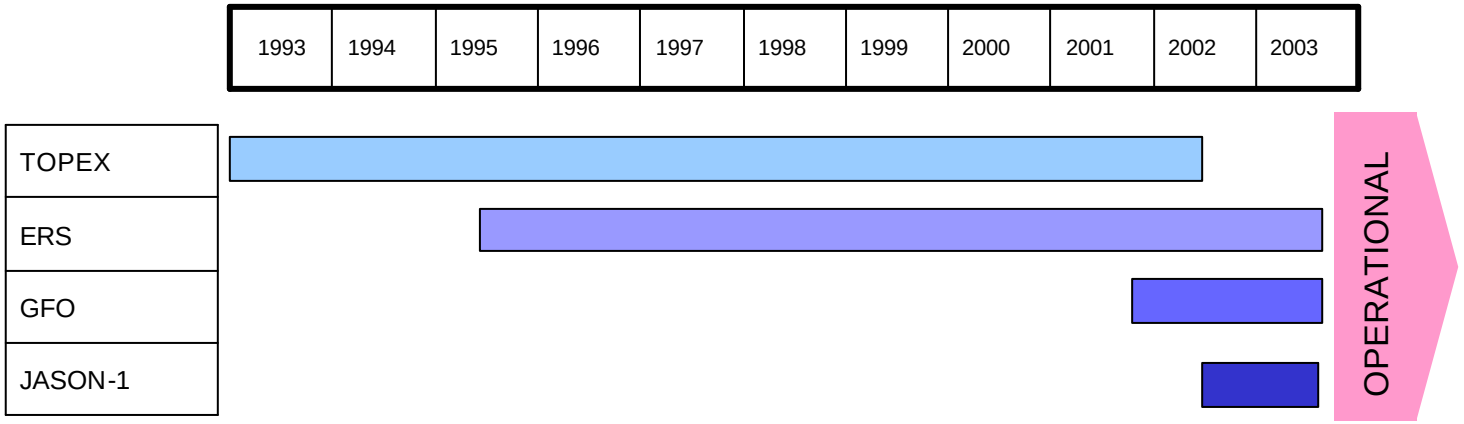


PSY2-G : 1993-2002 reanalysis

1 year spin-up (1992) followed by 11 years of **weekly** assimilation of all SLA observations available :

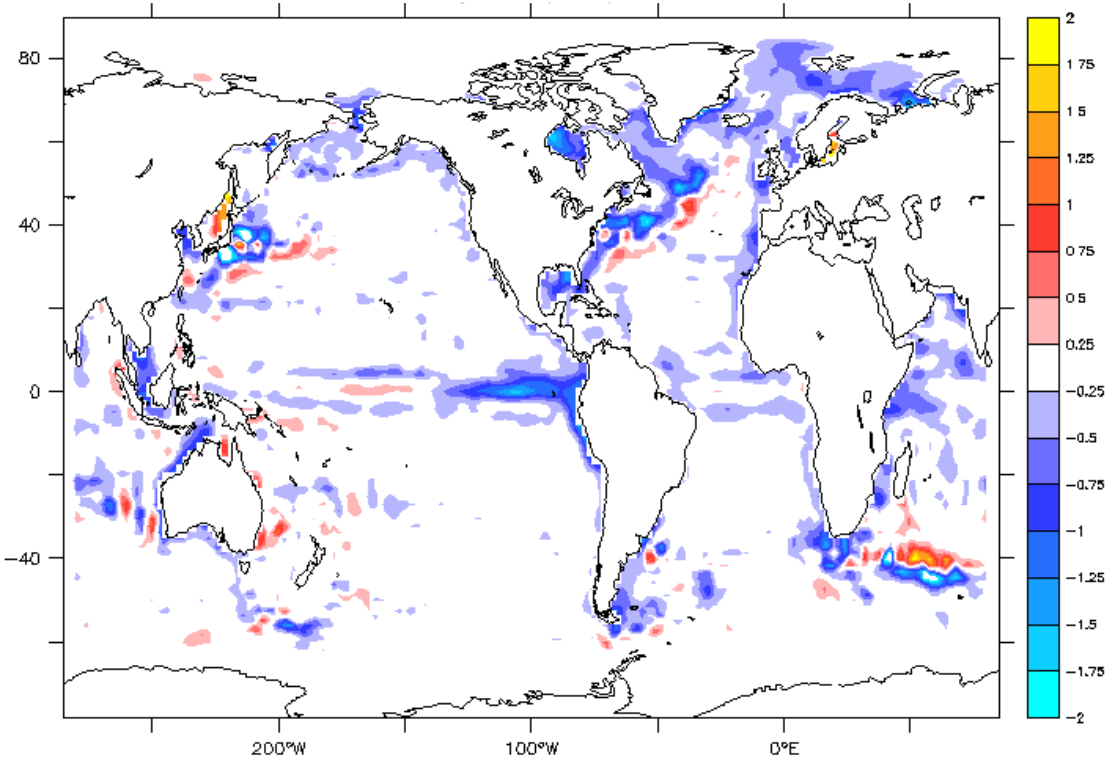
→ assessment of the system's performance

→ generation of 10 years of oceanic initial fields for operational climate prediction at Météo France



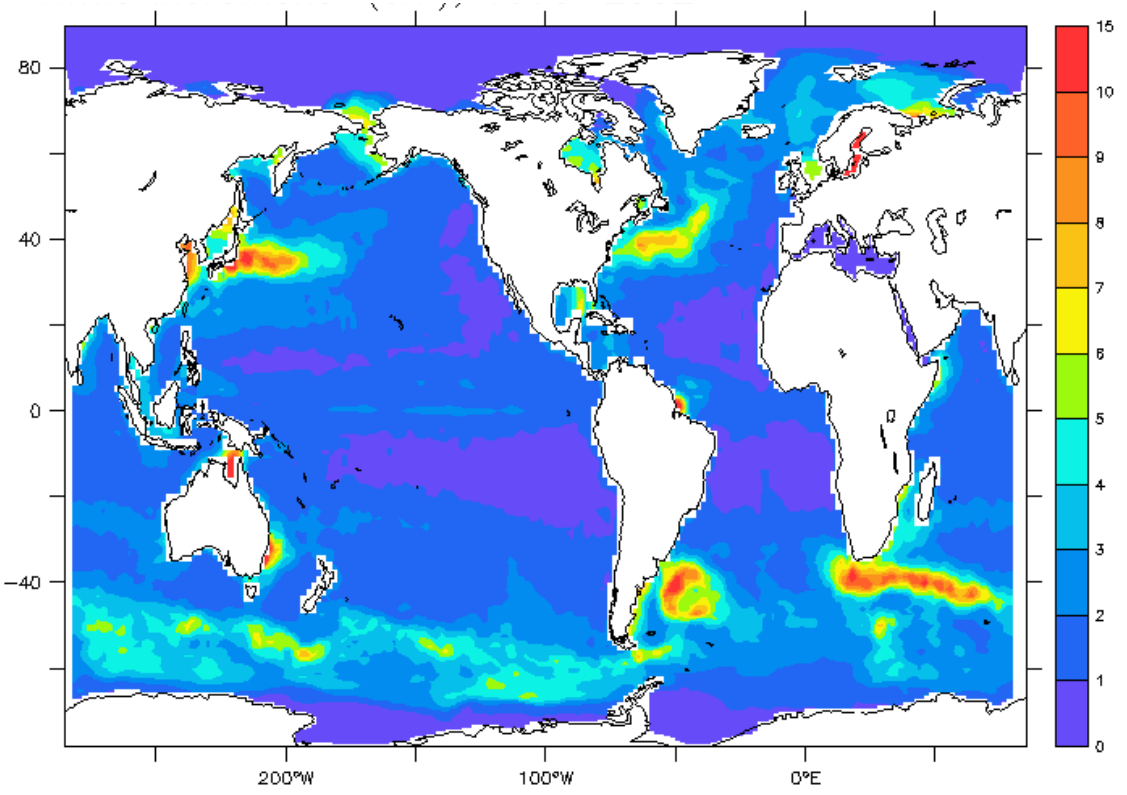
PSY2-G assessment (I)

Average **baroclinic** SLA increment, 1993-2002, (cm)

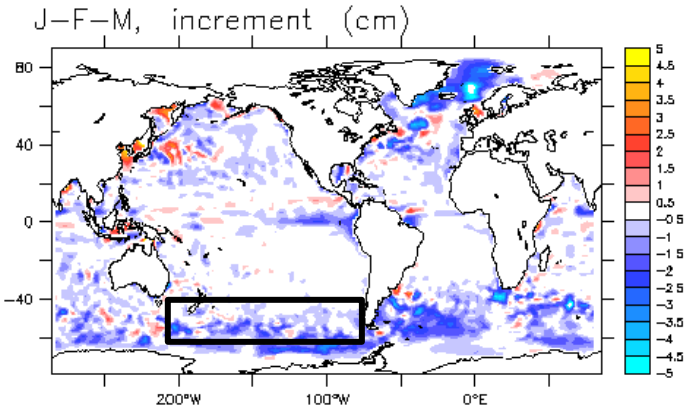


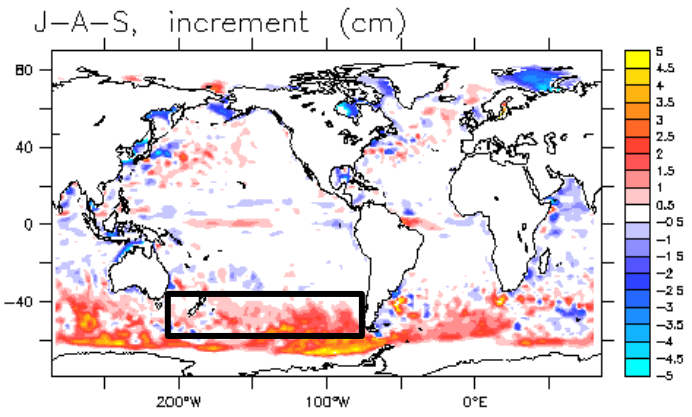
PSY2-G assessment (II)

Variability: std. dev. of SLA increment for 1993-2002, (cm)

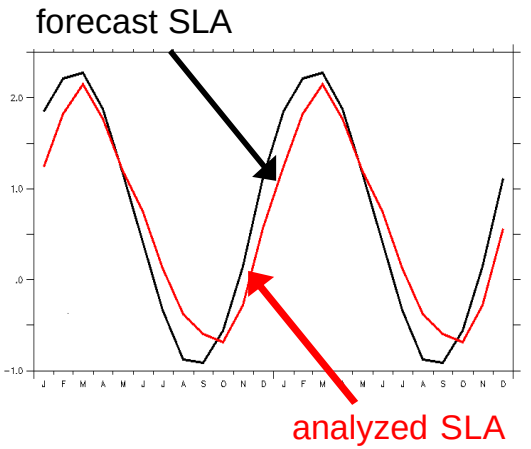


PSY2-G assessment (III)



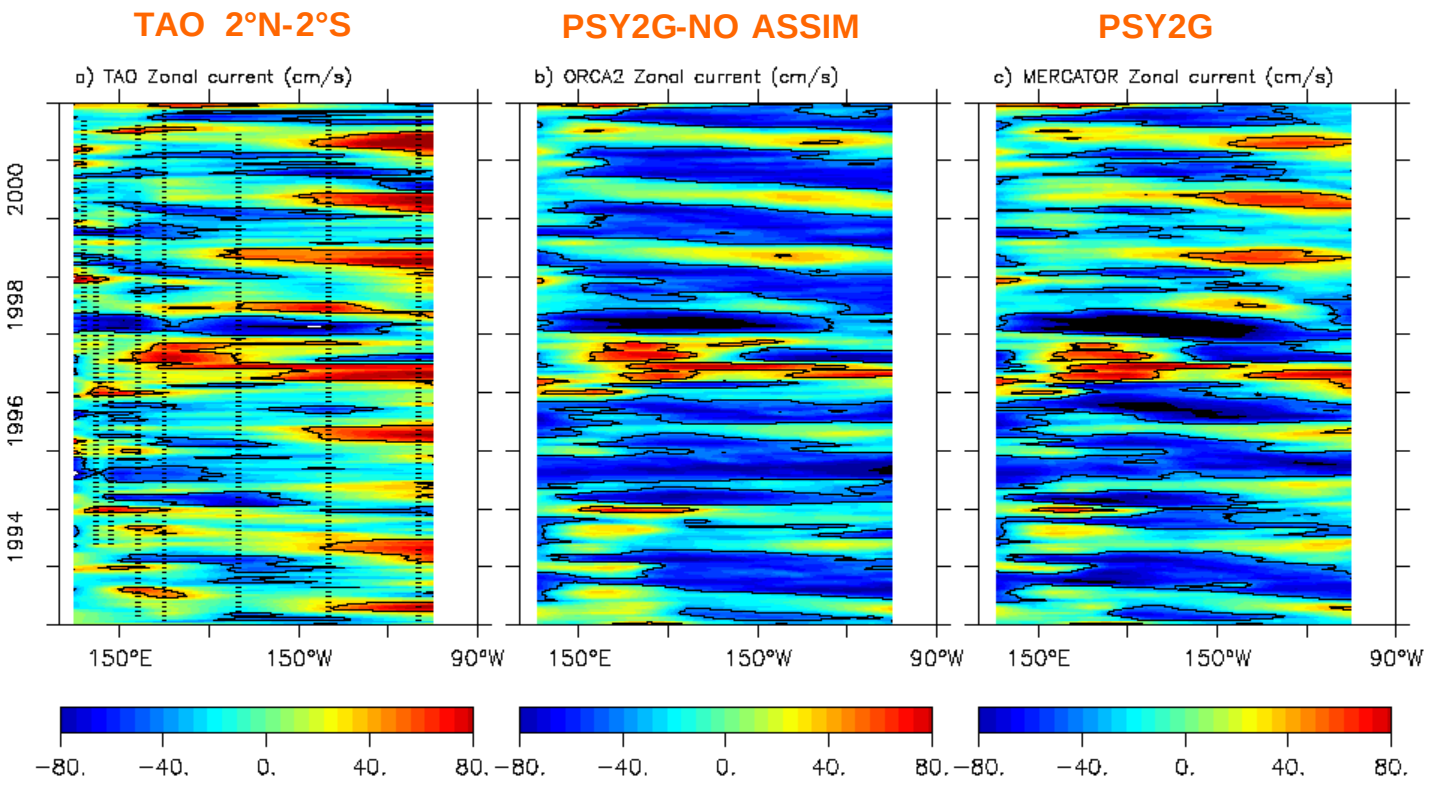


- Mean seasonal SLA increment



PSY2-G assessment (IV)

- Zonal velocity in the equatorial Pacific (Maes *et al*., 2004)

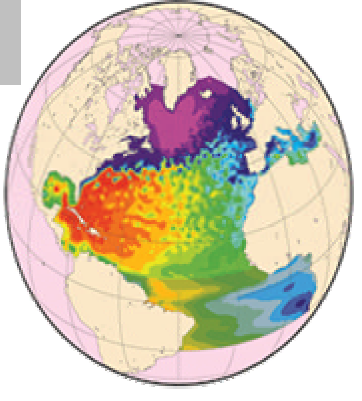


6. North Atlantic prototypes

Univariate system

Assimilation SLA using the Cooper & Haines method

- PSY1V1: 1/3° North Atlantic 20°S-70°N
- PSY2V1: 1/15° North Atlantic 9°N-70°N +Med



Multivariate system

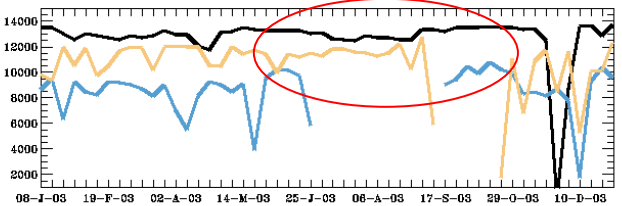
- PSY1V2: 1/3° North Atlantic 20°S-70°N

Assimilation **SLA and in situ** data with EOFs (1D)

2003 assimilation diagnostics

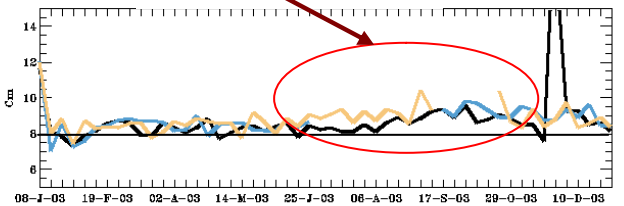
Data number impact

Data number

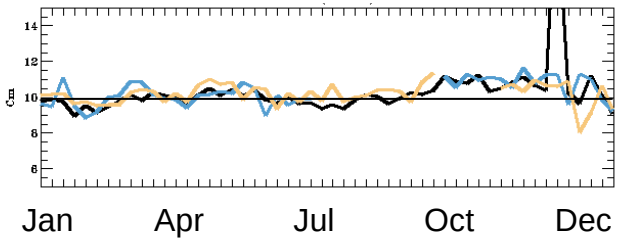


Rms (Misfit)

8cm

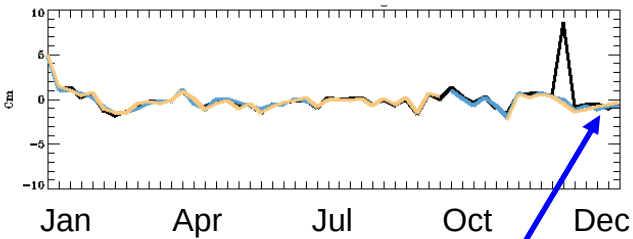


Rms (Data)



10cm

Mean (Misfit)



0.

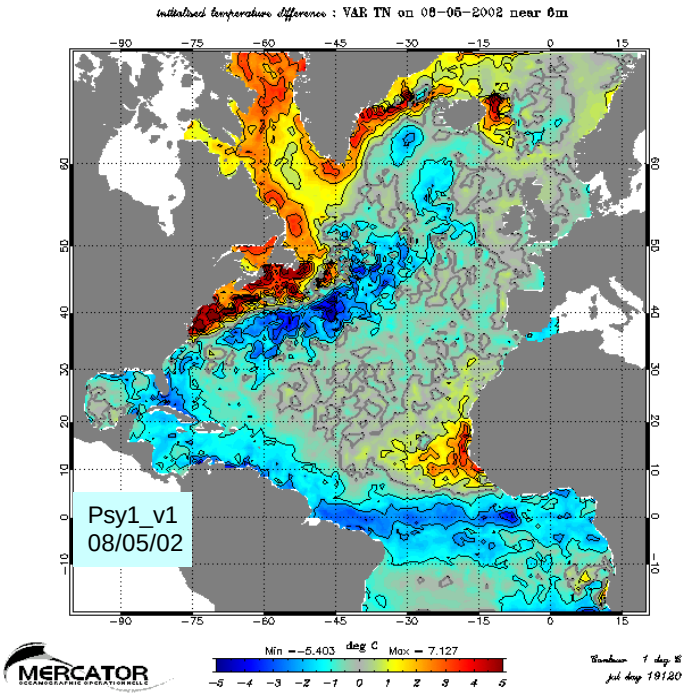
Black : Jason1
Blue : Ers2 (Envisat)
Orange : Gfo

No bias

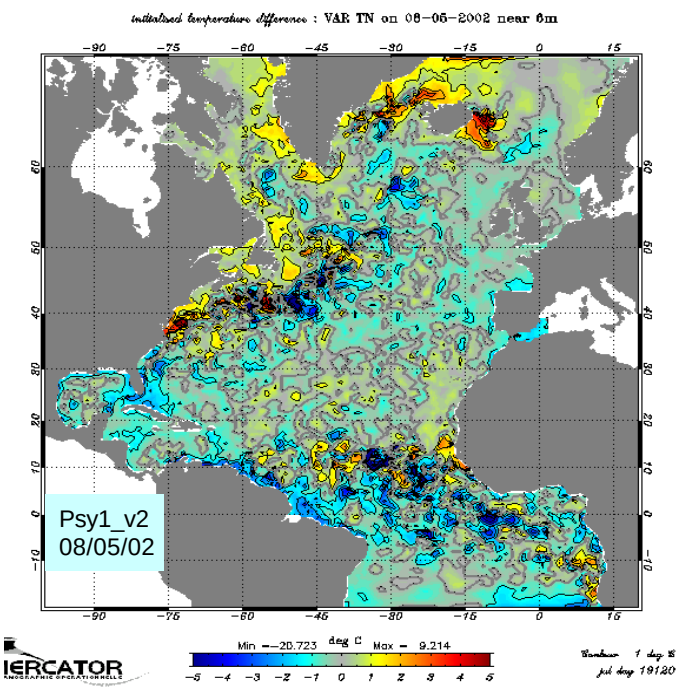
Sea Surface Temperature

SST(model forecast) – SST (Reynolds)

Univariate scheme



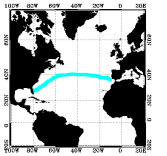
Multivariate scheme



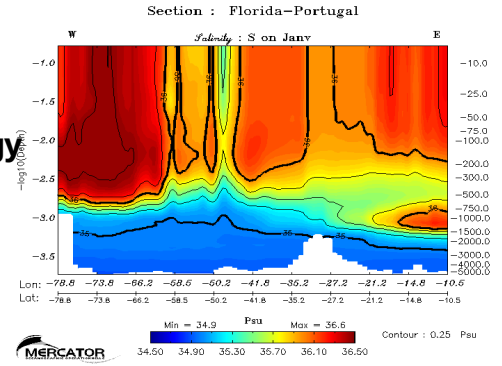
With *in-situ* data assimilated and improved correlation statistics

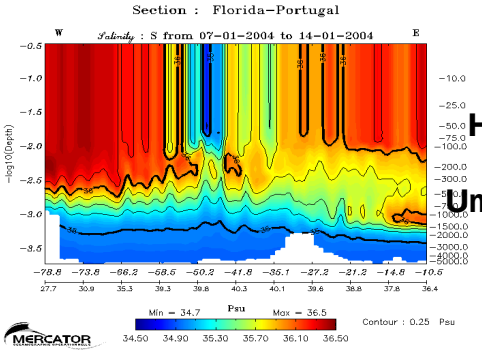
High Resolution / Univariate *versus* Middle Resolution / Multivariate

Salinity section Florida-Portugal



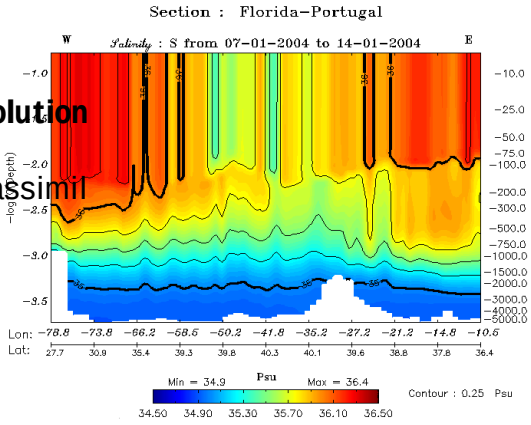
Climatology

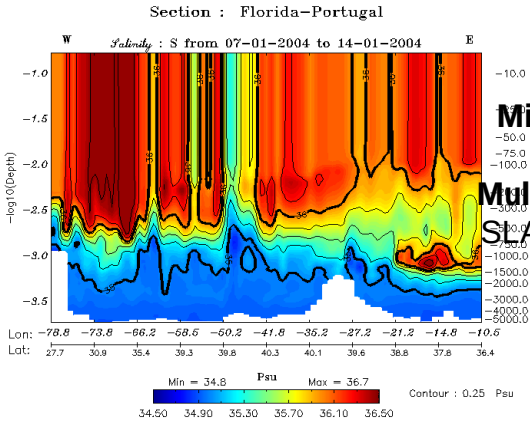




High Resolution
1/15°
Univariate assimil
SLA

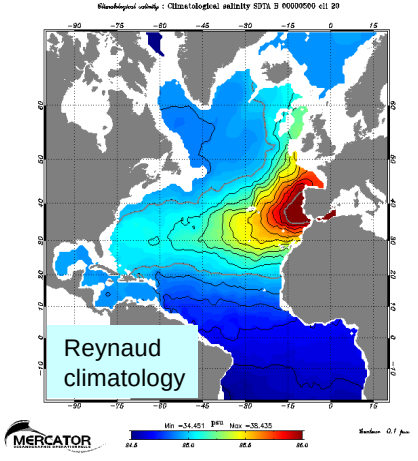
Middle Resolution
1/3°
Univariate assimil
SLA

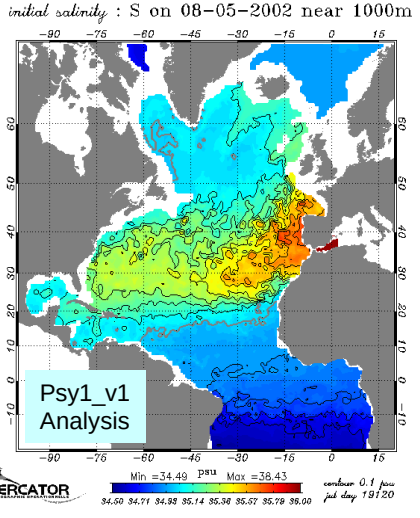


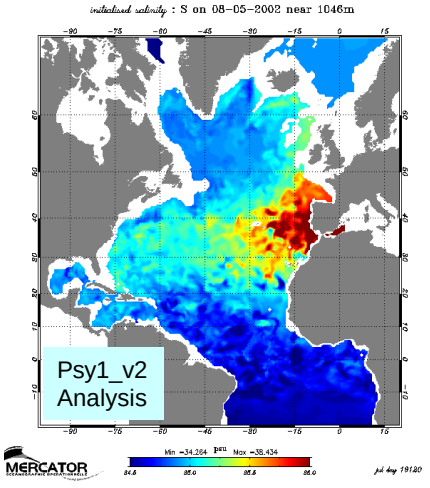


Middle Resolution
1/3°
Multivariate assimil
SLA + SST + T/S(z)

Salinity at 1000 m depth



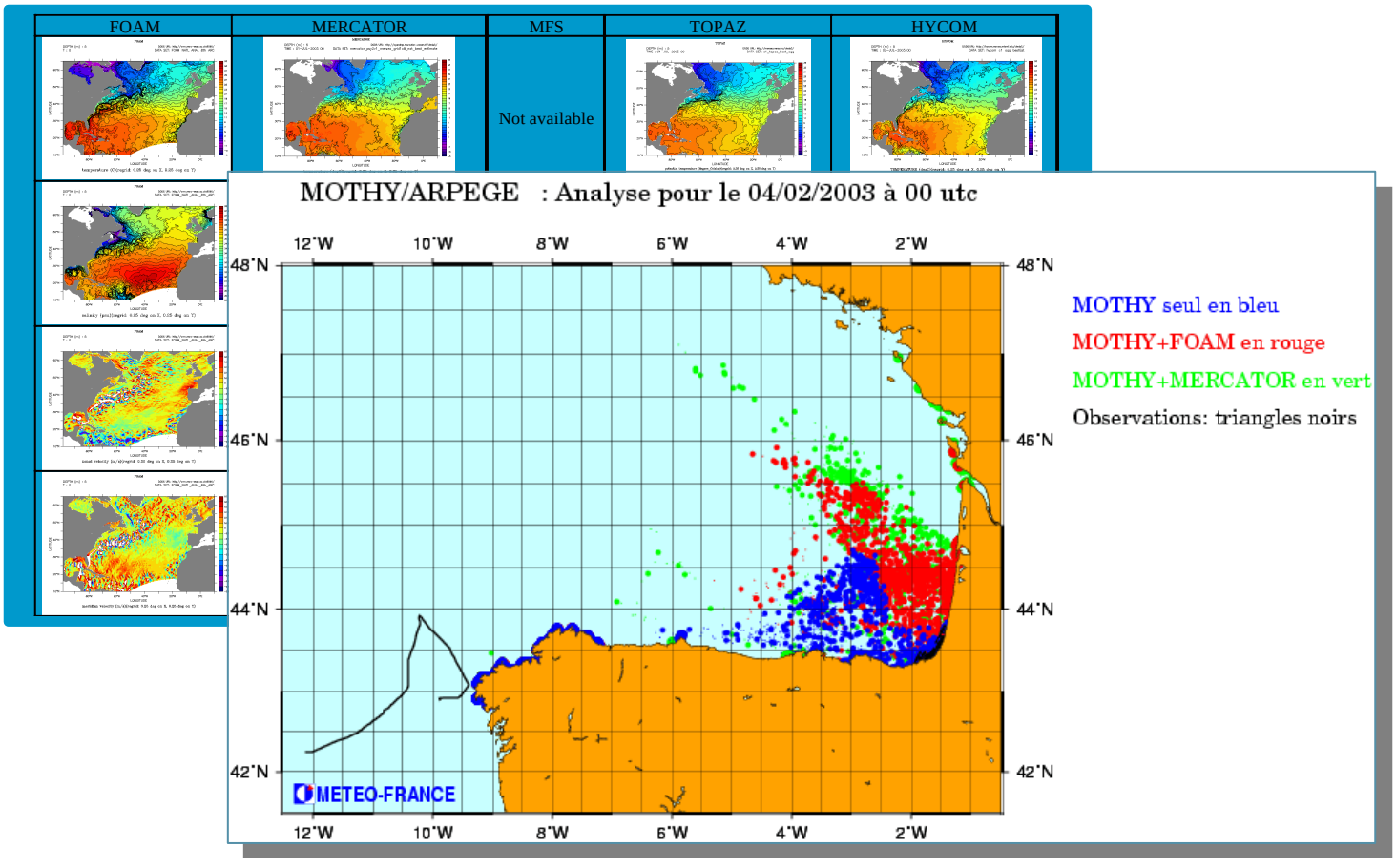




Univariate/monodata analysis

Multivariate/ multidata analysis

Intercomparisons



Oceanic bulletin web page: http://www.mercator.com.fr

MERCATOR products

PSY1 Oceanic bulletins on 21 march 2001

The MERCATOR ocean bulletin includes a range of maps and other information about the underlying variables of the ocean, such as sea level anomalies, ocean currents, temperature and salinity, which describe the ocean in all its dimensions. Information that gives us a closer insight into current and forecast ocean conditions from the sea surface to the sea floor, at regional or basin scale.

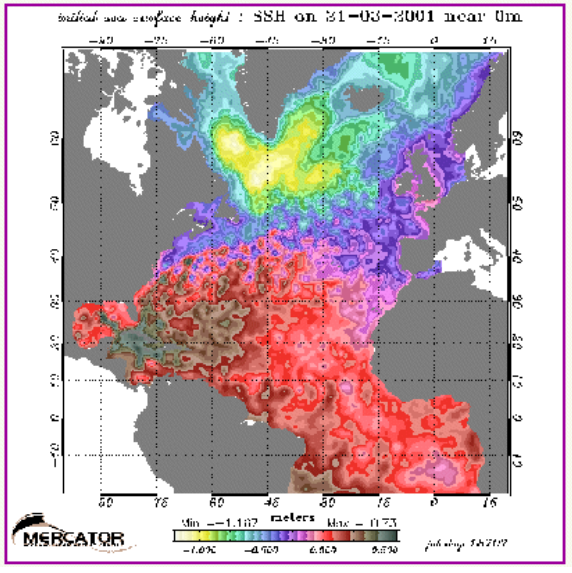
Whole domain plots

Zooms

Sections

Vertical profiles
time series

North atlantic
Sea level anomaly on 21 march 2001 (T0)



All results:

> Geographic areas

- North Atlantic
- Zonal mappings
- Sections
- Moorings

784 graphic files are put on the web every week