The MERCATOR approach to real-time ocean data assimilation and forecasting

Pierre de Mey, Christian le Provost and the MERCATOR Project Team

MERCATOR, Toulouse, France
http://www.mercator.com.fr

This talk

- Objectives and organisation of the MERCATOR project
- The current on-line configuration
- Next configurations
- Some upper-ocean issues
- Assimilation R&D
- Some applications

MERCATOR OCEAN

- MERCATOR is the main French contribution to **GODAE** (Global Ocean Data Assimilation Experiment)
- MERCATOR is sponsored by **six major French agencies** involved in **oceanography** and **climate** :

cnes CNRS IRD Ifremer METEO FRANCE SHOM

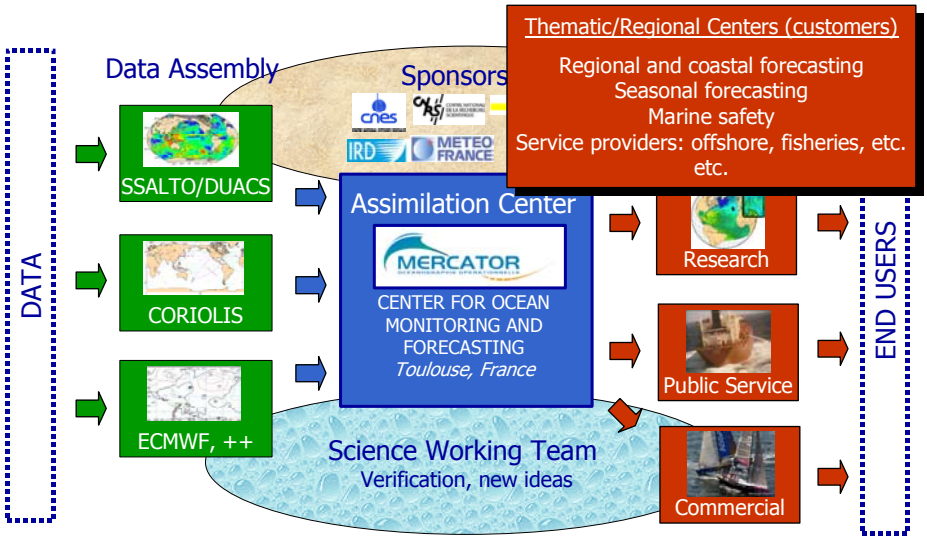
with a focal role given to their subsidiaries CERFACS and CLS.

- January 2001: First Bulletin (analysis and 2-week ocean forecast over N. Atlantic)
- April 2002: the **MERCATOR OCEAN** Public Interest Group is created

Objectives

- **Simulate the global ocean** with a range of primitive-equation, high-resolution models which assimilates satellite and *in situ* data to provide hindcasts and near-real time nowcasts and forecasts of the global ocean circulation
- **Run operationally** (i.e. routine and near-real-time) to meet the needs of (i) public+research, (ii) national (military and civilian), and (iii) commercial users

General Working Structure

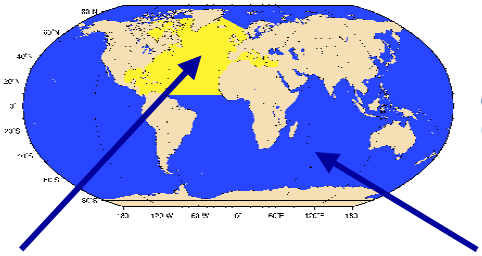


De Mey et al., ECMWF Workshop, Reading, UK, Nov. 13-15, 2002

Model configurations with assimilation

- In a first phase from January 2001 to December 2002, MERCATOR is running a first North Atlantic prototype (PSY1) with 1/3° horizontal resolution and assimilation of altimetry only
- Starting in 2003, and throughout the GODAE time frame, two model configurations will be running :

Assimilation Data: NRT ALT, SST, profiles



Common boundary @ 9N in Atlantic

a high-resolution 1/15° **North Atlantic** model, including the **Mediterranean** sea (PAM)

an intermediate resolution free-surface 1/4° **Global Ocean** model (POG)

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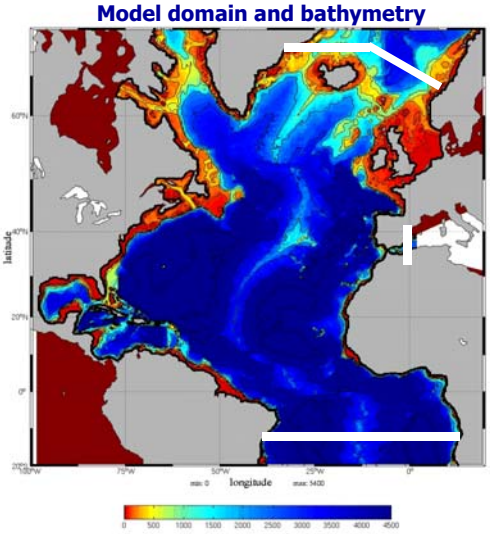
1/3° North Atlantic model configuration

- Primitive-equation, rigid-lid model (OPA 8.1, *Madec et al., 1998*)
- 43 vertical levels (5600 m)
- Three buffer zones relaxed towards monthly climatology (*Reynaud et al., 1998*)
- Lateral physics : horizontal biharmonic operator for tracers and momentum
- Vertical physics : turbulent closure TKE scheme (*Blanke et Delecluse, JPO, 1993*)
- Surface forcings : daily ECMWF 6-hour winds+fluxes interpolated by OASIS coupler, SST feedback term to *Reynolds and Smith (1994)*, SSS relaxation to *Reynaud et al.* seasonal climatology
- Climatological river runoff
- Diagnostic ice cover

Model domain and bathymetry



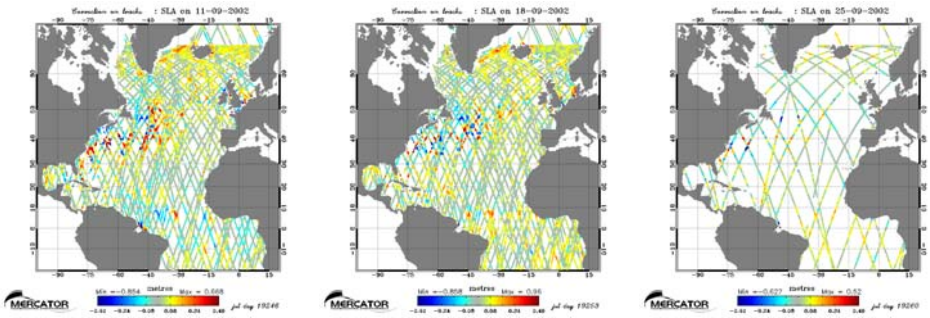
1/3° routine North Atlantic Forecasting

- **North and Tropical Atlantic Ocean data assimilation**

  - Atlantic ocean [20°S-70°N] ; OPA model, 1/3° resolution, 43 levels

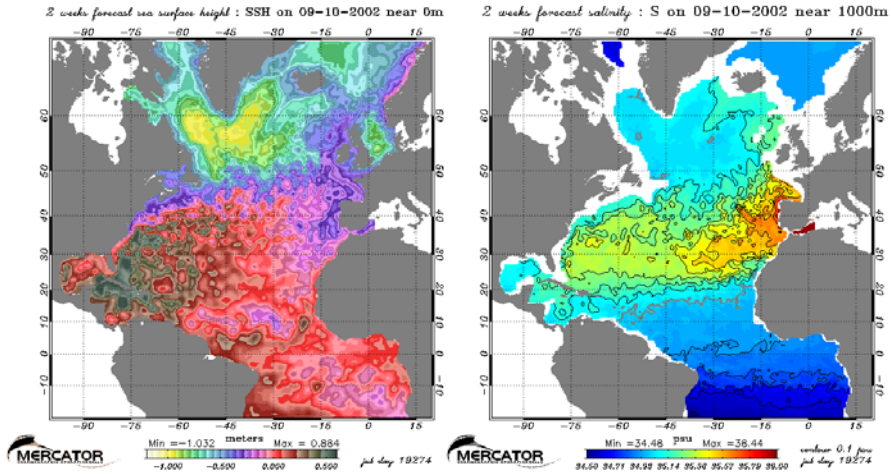
  - Assimilation of T-P/JASON, ERS/ENVISAT along-track altimeter data using the SAM-1 data assimilation system (Reduced Order Optimal Interpolation on a base of vertical EOFs)

- **Weekly routine:** 3-week hindcast/nowcast, 2-week forecast (use ECMWF forecast to day 10 then persist)



3-weekly innovation as of Sept. 26, 2002

1/3° routine North Atlantic Forecasting
http://www.mercator.com.fr



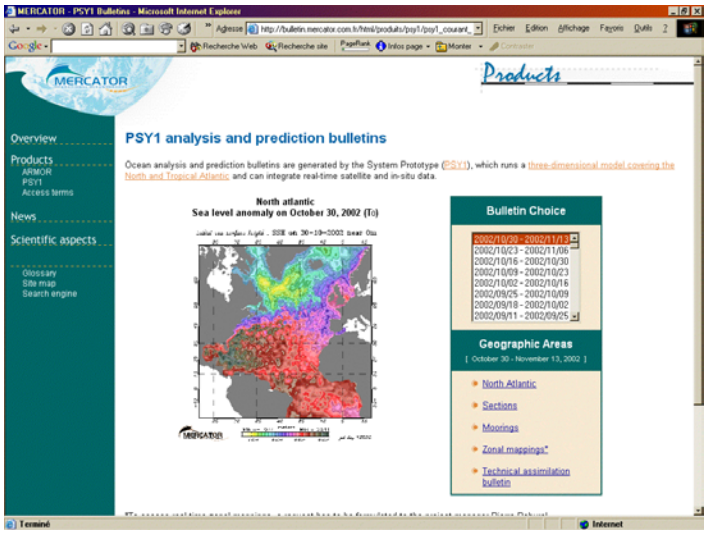
7-day forecast SSH
October 9, 2002

7-day forecast 1000m salinity
October 9, 2002

Weekly MERCATOR OCEAN Bulletin
http://www.mercator.com.fr

Weekly Bulletin

- 4D description of the ocean: T, S, u, v, transport, SSH, MLD, etc.
- Real-time (nowcast,1-week, 2-week forecasts) and on a hindcast mode (RA)
- Routine intercomparison of input data (ARMOR)
- Freely available on www.mercator.com.fr
- LAS project (GODAE)



Quality checks

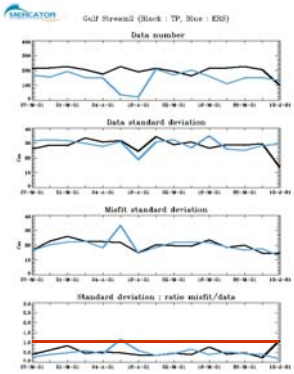
Validation mostly occurs through internal or external comparison

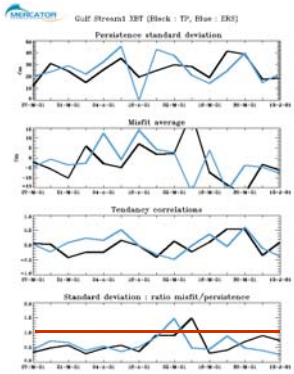
- between the System outputs and unassimilated observations (cruises, cross-validation)
- between the System outputs and another System
  - INTERCAST In Atlantic (with FOAM, UK Met. Office)
  - MEDCAST (in prep) in the Med Sea (with MFS)
- between the System's outputs at various ranges (hindcasts, nowcast, forecasts)

Quarterly MERCATOR Newsletter
(on web site)
Quality check of the active configuration
Scientific hot topics
Intercomparison with data

SAM on-line diagnostics

- Routinely calculated for all observations, whether assimilated or verification
- Mostly innovation statistics
- Available on web site





ALT: TP ERS

Next configurations

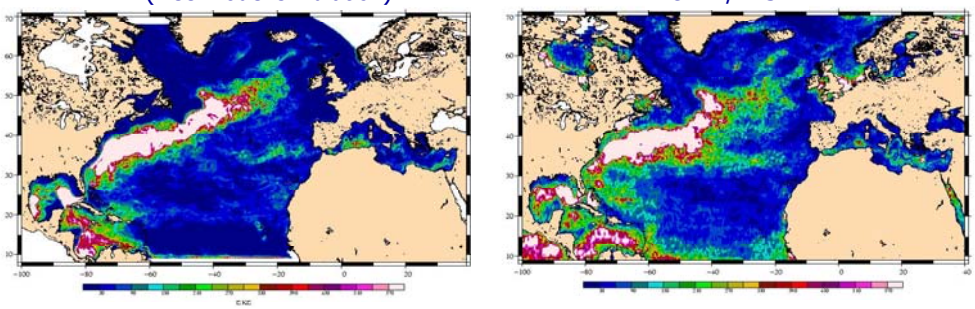
- PSY2: PAM (North Atlantic + Mediterranean), high resolution
  - On-line end 2002
    - Benchmark for advection schemes, partial steps, open boundaries
  - Also ORCA2 global with ALT assimilation within 2003
    - benchmark for free-surface assimilation, bulk formulae (heat, freshwater) with ice
- PSY1 ver.2: 1/3° North/Tropical Atlantic with multivariate assimilation of ALT, profiles, SST
  - On-line in 2003
    - Benchmark for consistent SST assimilation and forcings, next assimilation schemes
- PSY3: PAM and POG (1/4° global)
  - 2004
  - Switch to SEEK during period
  - Plus possible global ORCA2 R&D config with variational assimilation

MERCATOR *De Mey et al., ECMWF Workshop, Reading, UK, Nov. 13-15, 2002*

MERCATOR/PAM configuration
1/15° North Atlantic and Med Sea

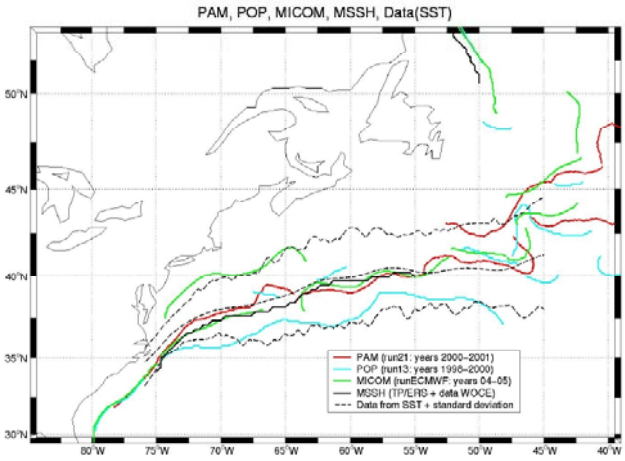
Eddy Kinetic Energy (year 2000)

PAM (free model simulation) TOPEX/ERS-2



MERCATOR *De Mey et al., ECMWF Workshop, Reading, UK, Nov. 13-15, 2002*

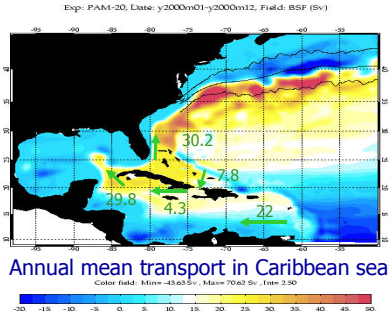
The Gulf Stream Pathway



Locus of max. gradient of mean SSH

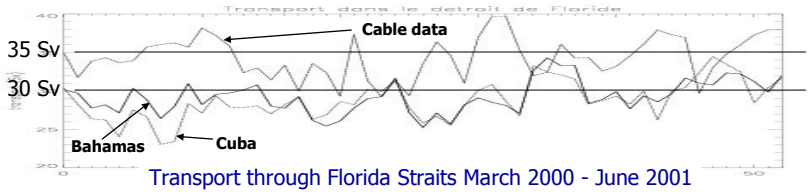
Brémond and Le Provost (2002); MSSH : Rio (CLS), POP : Smith et al. (1999)

Circulation in the Caribbean Sea



Annual mean transport in Caribbean sea

- Tuning of SST and SSS relaxation parameters provides improved meridional circulation
- Circulation around islands in agreement with observations and other simulations
- Realistic generation of eddies in Gulf of Mexico

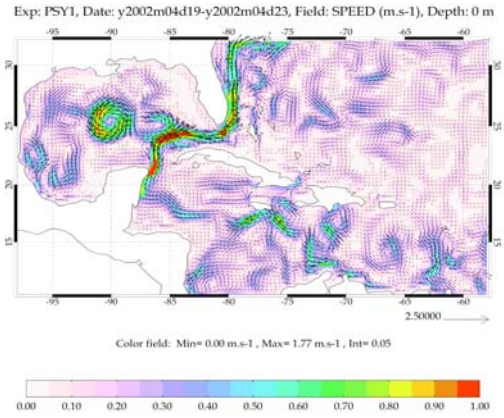


Transport through Florida Straits March 2000 - June 2001

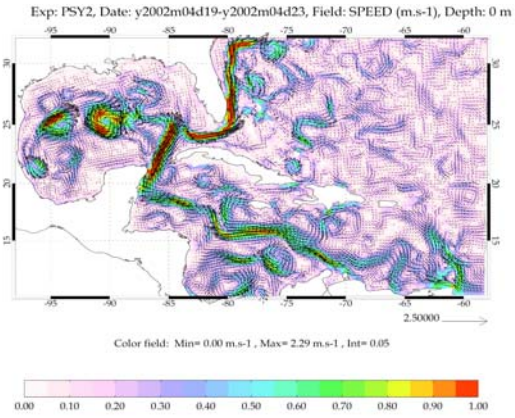
e.g. Larsen (1985), Flosadottir et al. (1997)

Current 1/3° configuration vs. PAM

1/3° (current operational system)



PAM



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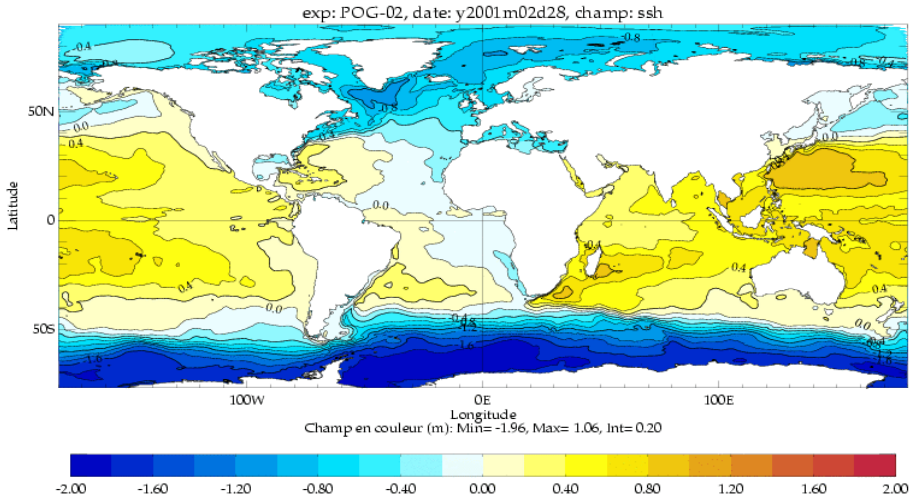
MERCATOR ORCA025 configuration
1/4° Global

Instantaneous SSH



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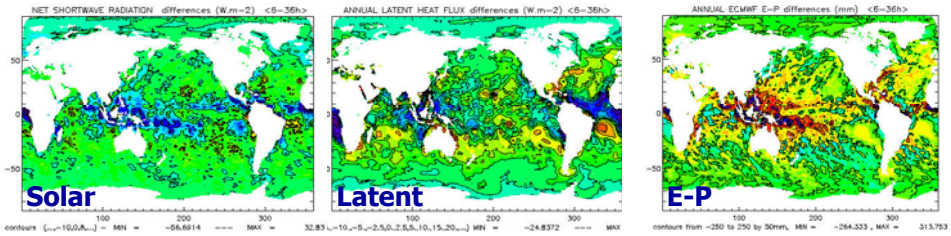
Some upper-ocean issues

- Tests on forcings
  - e.g. 6-hour vs. 36-hour ranges, SST/SSS relaxation coefficient
- Free surface
  - Global configurations mostly
  - Some tests with tides
- Bulk formulae and ice
  - Global configurations mostly
- Surface layer error growth and SST assimilation
  - Still in R&D
  - Coherence with bulk formulation sought

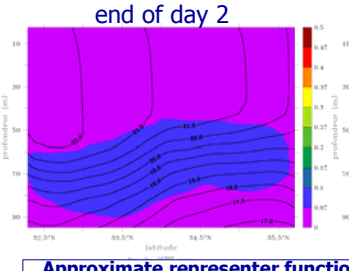
6-hour vs. 36-hour fluxes



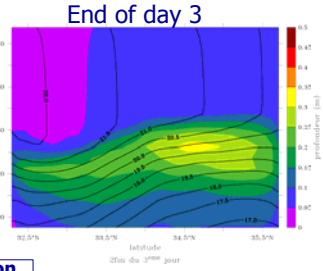
- Objective: select "best" range to force PAM spin-up in 1998-99
- Study differences of annual averages <6-36> between Mar-98 and Feb-99
- 6-hour solar fluxes slightly stronger (2%) in mid-latitudes, about 4% lower in Tropics; 6-hour latent exchanges about 4% stronger in Tropics
  - 36-hour forecast would correct for part of the heating excess in mid-latitudes, but would enhance the bias identified in equatorial net heat flux (*Perez et al., 2001*)
- Precipitations spin-down can be scaled
- Better 6-hour winds (scatterometer assimilation)
- 6-hour fluxes finally used

Surface layer error growth

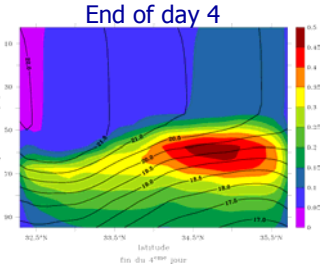
Ensemble variance of T end of day 2



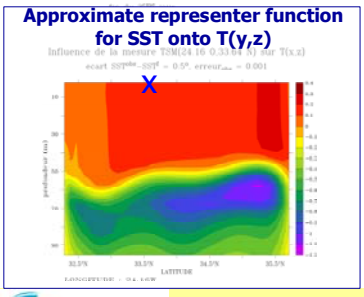
End of day 3



End of day 4



Approximate representer function for SST onto T(y,z)



- Section across Azores Current/Front system
- Monte-Carlo method, O(100) members with synoptic-scale flux perturbations (Andreu-Burillo et al., 2002)
  - Analyze mixed layer T error growth attributable to flux errors, calibrate background error variances
  - Analyze potential influence of SST measurements on subsurface variables

CNRM,LEGOS -- I Andreu-Burillo, P De Mey, G Caniaux

Assimilation R&D

3D tools

- **SAM-1 ver.1 :** ROOI – univariate analysis (ALT) — **since 2001**
- **SAM-1 ver.2 :** ROOI – multivariate analysis (ALT, profiles, SST) — **end 2002**
- Routine maintenance and improvement of OI scheme…
- **SAM-2 :** adaptive SEEKFL – multi. analysis (ALT, profiles, SST) — **early 2004**

4D tools

- **SAM-Va :** global 3D-var / Tropical 4D-var –
  - multivariate analysis (profiles) — **2004**
  - multivariate analysis (ALT, profiles, SST) — **2004?**
- **SAM-3 :** global 4D-PSAS — **2006?**

Additional resources

- **PALM:** Modular integration tool
- **GMMC:** The MERCATOR Science Working Team

De Mey et al., ECMWF Workshop, Reading, UK, Nov. 13-15, 2002

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Planned improvements

New MSSH
Assimilation of SST
Assimilation in free-surface ORCA
Physics of error covariances
Forecast quality
Internal consistency
…

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EOF Order Reduction for background error covariance modelling

$$\mathbf{e}^b = \mathbf{S}^+\mathbf{e}^r + \mathbf{e}^p$$

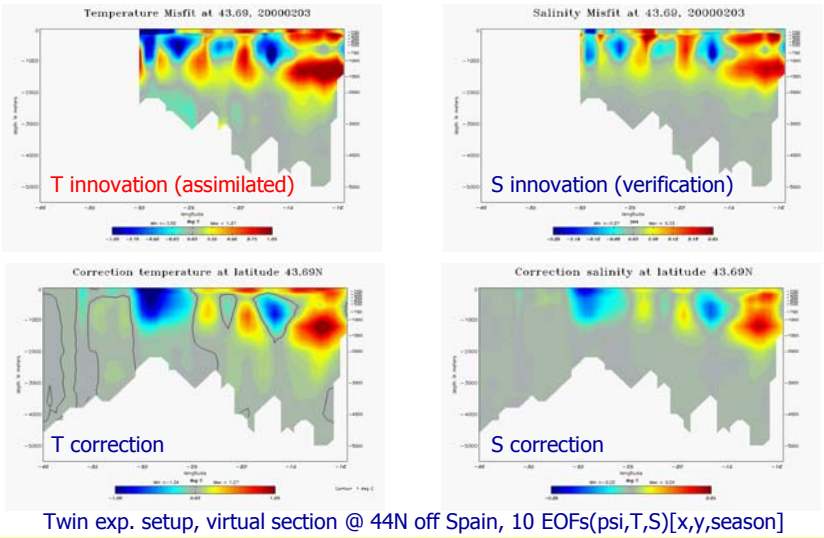
- $\mathbf{e}^b$: Multivariate background error (e.g. T, S, U, V ...)
- $\mathbf{S}$: simplification operator (EOFs)
- $\mathbf{e}^r$: Reduced-state error
- $\mathbf{e}^p$: Residual projection error

Advantages

- Efficiency (reduce d.o.f)
- Introduce statistical+physical relationships in error formulation
- Block-diagonal form of covariances

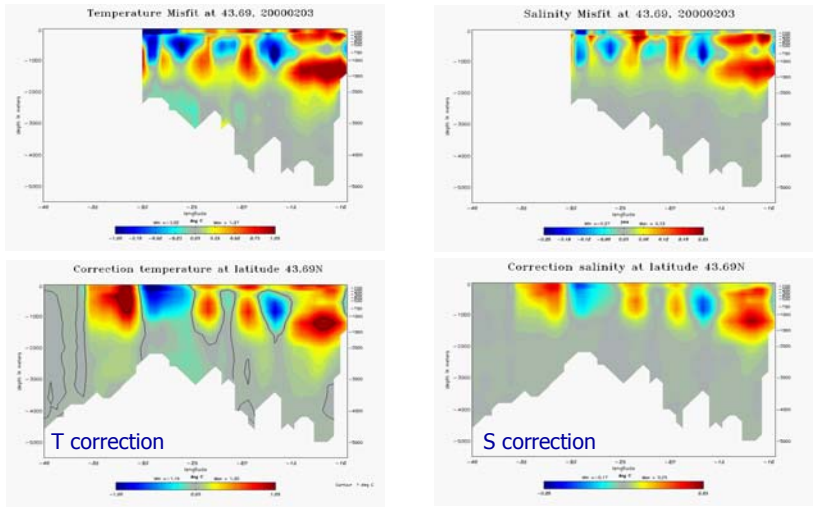
e.g. Fischer and Latif, 1995
Rienecker and Adamec, 1995
De Mey and Benkiran, 2002
Faucher et al., 2002
…

Assimilation of T only with SAM-1: multivariate correction



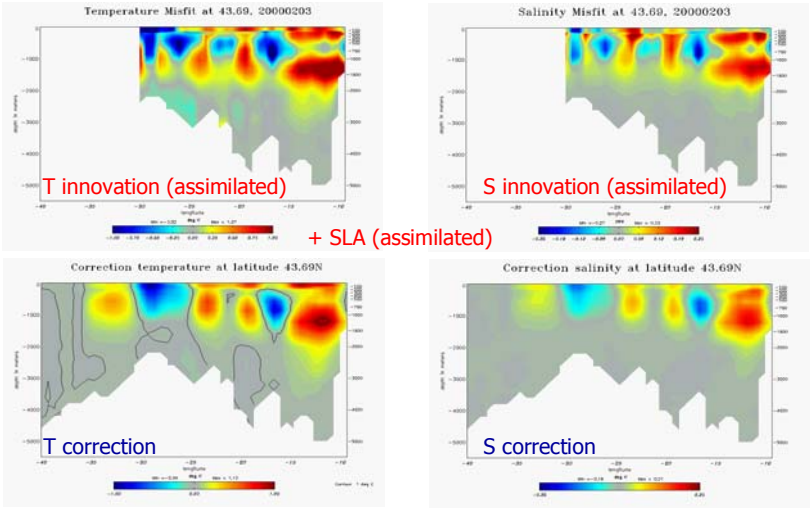
Twin exp. setup, virtual section @ 44N off Spain, 10 EOFs(psi,T,S)[x,y,season]

Assimilation of T and S with SAM-1: multivariate correction



Twin exp. setup, virtual section @ 44N off Spain, 10 EOFs(psi,T,S)[x,y,season]

Assimilation of SLA, T and S with SAM-1: multivariate correction



Twin exp. setup, virtual section @ 44N off Spain, 10 EOFs(psi,T,S)[x,y,season]

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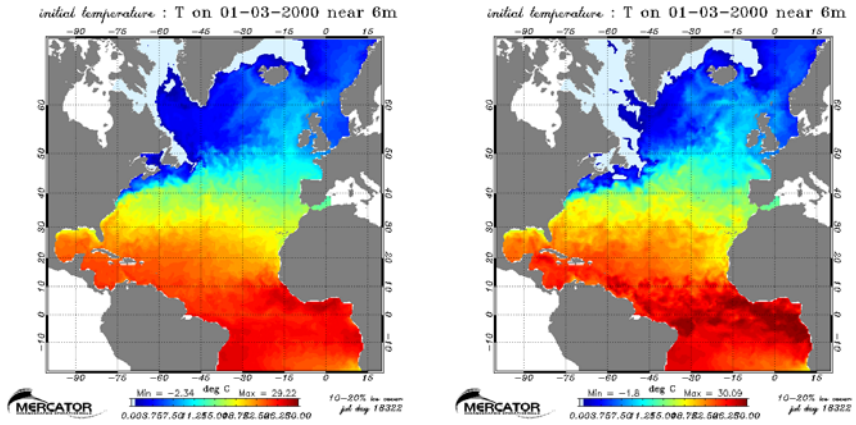
Current OI upgrade



SAM-1 v1 (univariate) nowcast SST SLA assimilated **SAM-1 v2 (multivariate)** + **new MSSH**

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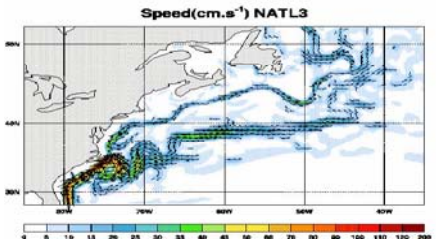
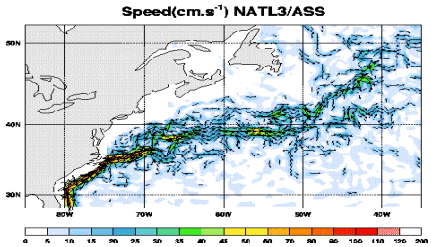
First tests of SEEK-FL

- A prototype SAM-2 assimilation system is being developed based on the fixed/local version of the SEEK filter with a simple adaptive scheme to set the guess error *(Testut, 2000)*
- A series of hindcast experiments have been performed in the 1/3° MERCATOR model configuration assimilating SST and SLA in 1992-93



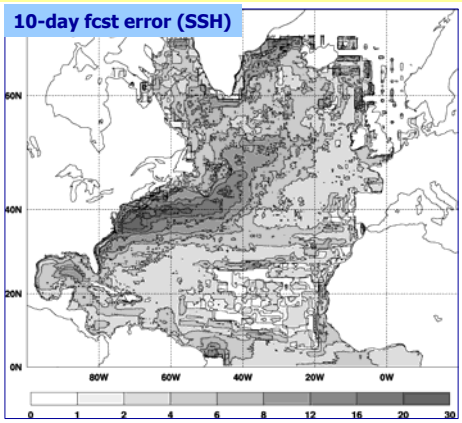
Free model simulation

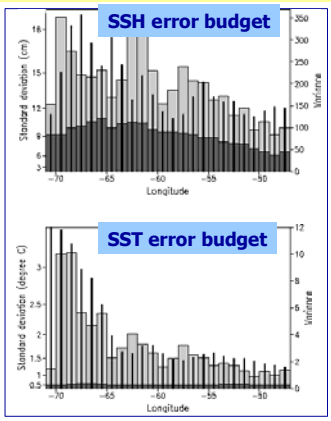


Assimilation of SLA and SST

LEGI –Testut

Adaptive error estimates with SEEK





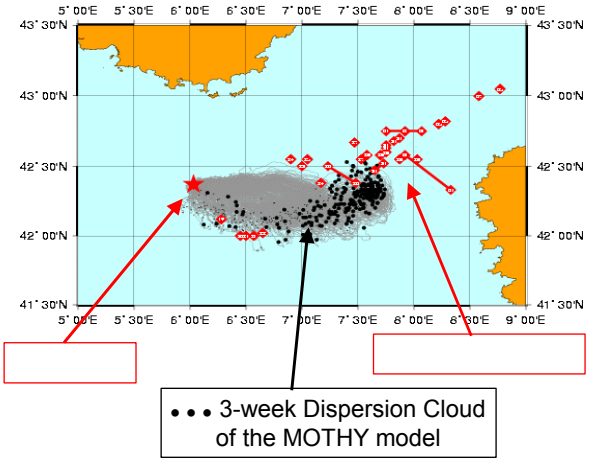
- Whiten innovation sequence
- "Simple" adaptive schemes provides forecast error estimates which are consistent with the observational errors and innovation statistics
  - E.g. Brasseur et al. (1999) with SEEK filter
- Adaptive Filter and ROAF: Hoang et al. (1997)

LEGI -- Brasseur, Brankart
MERCATOR -- B Tranchant, P De Mey

Some applications

- Cruise design: POSEIDON cruise 284
- Cruise design: POMME cruise
- Underwater acoustics
- Oil drift monitoring: the Lyria tanker accident

Oil Drift Monitoring: the Lyria Tanker Accident

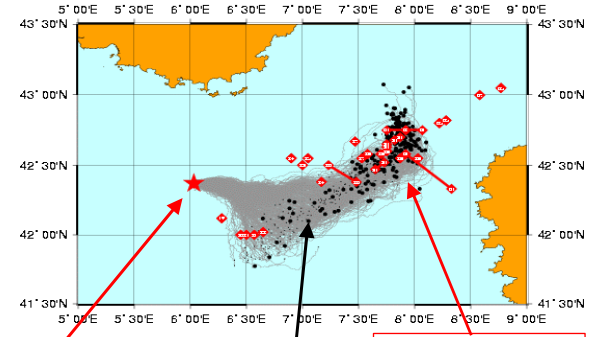


August 18, 1993, off Toulon:
Lyria tanker accident
2800 tons of oil released

METEO FRANCE

- Results from F.Marty, P.Daniel, and P.Josse
- Modelling and Hindcasting Lyria Oil Patch with MOTHY and Lagrangian analysis
- MERCATOR provided 3D ocean analyses from the PAM 1/16° model in Mediterranean

Oil Drift Monitoring: the Lyria Tanker Accident



★ Accident

♦ Oil Observations

• • • 3-week Dispersion Cloud of the MOTHY model forced with monthly mean currents from MERCATOR

August 18, 1993, off Toulon: Lyria tanker accident 2800 tons of oil released

METEO FRANCE

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MERCATOR

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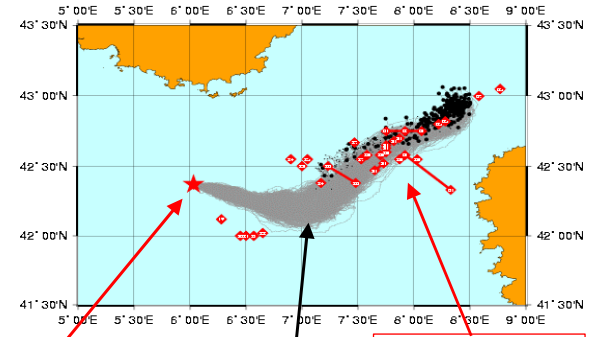
Oil Drift Monitoring: the Lyria Tanker Accident



• • • 3-week Dispersion Cloud of the MOTHY model forced with MERCATOR currents + T/P & ERS2 altimetry

August 18, 1993, off Toulon: Lyria tanker accident 2800 tons of oil released

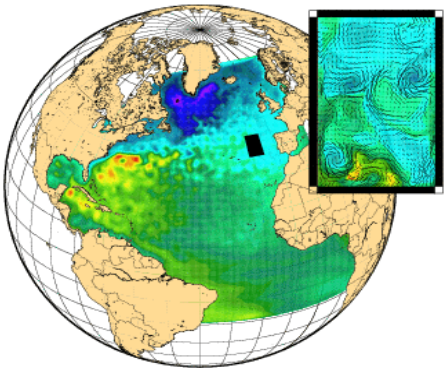
METEO FRANCE

- Results from F.Marty, P.Daniel, and P.Josse
- Modelling and Hindcasting Lyria Oil Patch with MOTHY and Lagrangian analysis
- MERCATOR provided 3D ocean analyses from the PAM 1/16° model in Mediterranean

MERCATOR

De Mey et al., ECMWF Workshop, Reading, UK, Nov. 13-15, 2002

POMME array design and verification

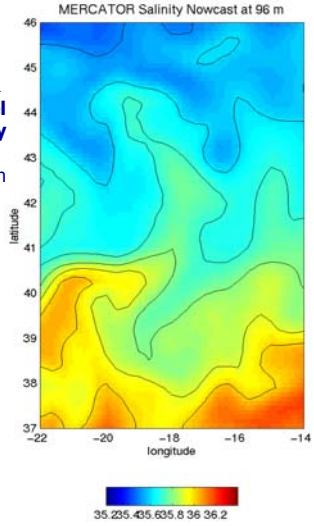


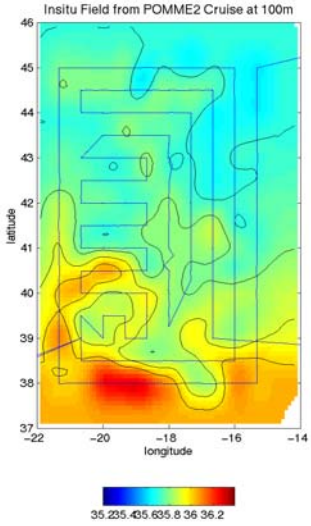
- The POMME experiment was carried out in 2000 and 2001 (5 cruises) by the POMME group headed by *Gilles Reverdin* and *Laurent Memery* at **LODyC**, Paris
- POMME aims at understanding the subduction mechanisms of mode waters in the Eastern-North Atlantic, and how it affects biological production and carbon export
- MERCATOR provided
  - 3D analysis and forecasts of T, S and currents
  - boundary conditions for a 1/20° regional model

De Mey et al., ECMWF Workshop, Reading, UK, Nov. 13-15, 2002

POMME array design and verification

MERCATOR 1/3° model 100m salinity with T/P and ERS-2 Assimilation



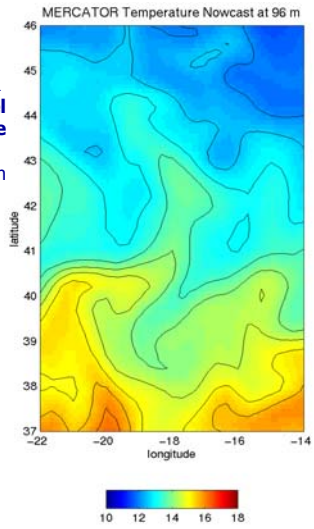


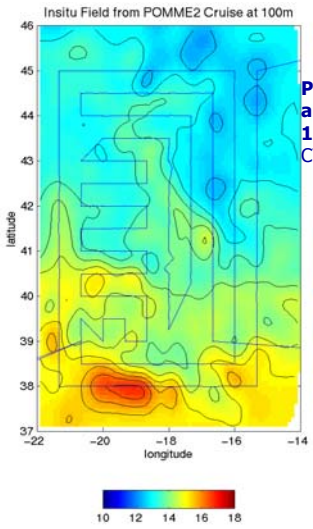
POMME analysis 100m salinity CTD data

De Mey et al., ECMWF Workshop, Reading, UK, Nov. 13-15, 2002

POMME array design and verification

MERCATOR
1/3° model
100m temperature
with T/P and ERS-2
Assimilation





POMME
analysis
100m temperature
CTD/XBT data

De Mey et al., ECMWF Workshop, Reading, UK, Nov. 13-15, 2002