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

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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:
  - 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 \textit{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
**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:
  - A high-resolution 1/15° North Atlantic model, including the Mediterranean sea (PAM).
  - An intermediate resolution free-surface 1/4° Global Ocean model (POG).
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

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
**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)
- 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)

SAM on-line diagnostics

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

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**MERCATOR/PAM configuration**

1/15° North Atlantic and Med Sea

Eddy Kinetic Energy (year 2000)

PAM (free model simulation)  
TOPEX/ERS-2
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

- 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) vs. PAM

MERCATOR ORCA025 configuration

Instantaneous SSH

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

- 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
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Planned improvements
- New MSSH
- Assimilation of SST
- Assimilation in free-surface ORCA 2004
- Physics of error covariances 2004?
- Forecast quality
- Internal consistency 2006?
- ...
Assimilation R&D

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EOF Order Reduction for background error covariance modelling

\[ e^b = S^+ e^r + e^p \]

Multivariate background error (e.g. T, S, U, V ...)

S simplification operator (EOFs)

Reduced-state error

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
...

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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(ψi,T,S)\{x,y,season\}

Current OI upgrade

initial temperature: T on 01-03-2000 near 6m

SAM-1 v1 (univariate) nowcast SST SLA assimilated

SAM-1 v2 (multivariate) + new MSSH
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

Adaptive error estimates with SEEK

- Whiten innovation sequence
- "Simple" adaptive schemes provide 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)
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

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
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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
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