7-day ocean forecast – North Atlantic

1 week forecast velocity: U on 25-08-2004 near 3m
7-day forecast – Mediterranean

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

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
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

- Oceanic region
- Global ocean
- Oceanic basin

MERCATOR operational oceanography
2. Operational systems
Assimilated data

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

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

- Temperature and Salinity Climatology in the deep ocean

Typical weekly coverage for in situ data with temperature profiles

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

Meridional section of Temp. climatology.
Altimeter data processed on June, 20 2001

- One week of Near Real Time altimeter data
### 3. MERCATOR Assimilation Systems

- **Incremental implementation strategy**

<table>
<thead>
<tr>
<th></th>
<th>OI</th>
<th>Kalman filters</th>
<th>3D/4D-VAR</th>
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<tbody>
<tr>
<td><strong>Research</strong></td>
<td>1993 (SOFA)</td>
<td>1998 (SEEK)</td>
<td>1999 (OPAVAR)</td>
</tr>
<tr>
<td><strong>R&amp;D</strong></td>
<td>1997</td>
<td>2002</td>
<td>2004</td>
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<td><strong>DEV</strong></td>
<td>1999</td>
<td>2005</td>
<td>2008 ?</td>
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<tr>
<td><strong>OP</strong></td>
<td>2001</td>
<td>2007 ?</td>
<td>?</td>
</tr>
</tbody>
</table>

- **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 adjustment: **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 £77 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

<table>
<thead>
<tr>
<th>MERCATOR System</th>
<th>On-line</th>
<th>Description</th>
</tr>
</thead>
</table>
| AM-1 version 1  | Jan-2001| ♦ SOFA3/£90 + PALM  
♦ Altimetry only  
♦ "weighted" LL method |
| AM-1 version 2  | Jan-2004| ♦ SOFA3/£90 + PALM  
♦ Altimetry + profiles  
♦ Multivariate EOFs |
\[ x^a = x^f + Kd \quad \text{with} \quad d = y^o - y^f = y^o - H(x_r) \quad \text{and} \quad K = P^f H^T (H P^f H^T + R)^{-1} \]

\[ K_r \quad \text{reduced gain defined by} \quad K = S^T K_r \]

**SAM-1 (SOFA)**

\[ K_r = B_r f H_r^T (H_r B_r f H_r^T + R_r)^{-1} \]

with \( B_r f = D^{1/2} C D^{1/2} \) and \( H_r = H S^T \)

**SAM-2 (SEEK)**

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

with \( P^f = S^T B S \)

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

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

\[ \rightarrow \text{1D modes (EOFs)} \quad \rightarrow \text{3D modes (EOFs)} \]
Modular development and parallel solution with PALM

© CERFACS 2000
PALM Coupler: modular tool for coupling and running various data assimilation schemes

\[ K_r = B_r^T H_r^T \left( H_r B_r^T H_r^T + R_r \right)^{-1} \]
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)

Sea Surface Temperature on Gulf Stream

- AVHRR SST (September 2, 1993)
- NATL3 forecast (September 2, 1993)

SAM-1 analysis window
SAM-2 analysis window
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 \( (H, P_0, \ldots) \)
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

Forcings
- FLUXS/FLUXNS/EVA/PECIP/STRESSU/STRESSV
- Residuals: [D-14 to D-3]
- Altimetry: JASON/ENVISAT/GFO
- SST Reynolds: (In-situ) CORIOLIS (SAM1v2)

ECMWF Analyses: [D-14 to D0]
ECMWF forecasts: [D0 to D+10]
Persistence: [D+11 to D+14]

Exploitation/broadcast teams:
- Ex: Web
- CATSAT/PRESTIGE
- MERSEA MERCATOR

Daily mean 3D/2D fields:
- T S U V KZ + 19 other 2D

Synoptic 3D/2D fields:
- Before/after correction at D-7 et D0

Interpolation on regular grids: Netcdf format
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

MERCATOR PROFILES and SOFA REGIONS

“Moorings”

1. TEP formation
2. Moorings
3. North Atl. C.
4. Pemba channel
5. OS extension
6. OS rings
7. Azores C., EBC Pemba
8. OS assimilation
9. OS northern extension
10. rings
11. Channel
12. western PAM south
13. spreading, PAM north
14. north channel, PAM north
15. south channel, PAM north
16. Gulf of Guinea spreading
17. central ESC
18. NAO ESC
19. NAO assimilation ESC
20. Asian ESC

Regions

1. Labrador Sea
2. St. George Basin
3. Newfoundland–Iceland
4. Westerm Atlantic
5. Gulf Stream 2
6. Gulf Stream 1, NBT
7. North Mozambique NBT
8. Charleston NBT
9. Barreda NBT
10. Gulf of Mexico
11. Florida Straits NBT
12. Puerto Rico NBT
13. U.S.
14. Cape Verde NBT
15. Bisc–La Guaira WOCE
16. Eastern NBT
17. Canary NBT
18. San Tomas NBT
19. NWA
20. BRET A
22. Atlantic NBT

Moorings Regions
Assimilation SLA using SAM1-v1: univariate system
- PSY2-G: 2° Global ocean
5. Global prototype
SAM-1, version 1

Schematically:

δSLA

δHdyn
baroclinic

δHBAR
barotropic

δT, δS

δT, δS

δUgeo, δVgeo

δUbar, δVbar

δU, δV

3 months model statistics
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 : 1993-2002 reanalysis**
Average **baroclinic** SLA increment, 1993-2002, (cm)
Variability: std. dev. of SLA increment for 1993-2002, (cm)
PSY2-G assessment (III)

- Mean seasonal SLA increment

- Forecast SLA

- Analyzed SLA
PSY2-G assessment (IV)

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

**TAO 2°N-2°S**
- TAO Zonal current (cm/s)

**PSY2G-NO ASSIM**
- ORCA2 Zonal current (cm/s)

**PSY2G**
- MERCATOR Zonal current (cm/s)
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 (Data)

Rms (Misfit)

Mean (Misfit)

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

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

Middle Resolution
1/3°
Univariate assimil
SLA

Middle Resolution
1/3°
Multivariate assimil
SLA + SST + T/S(z)
Salinity at 1000 m depth

Reynaud climatology

Psy1_v1 Analysis

Univariate/monodata analysis

Psy1_v2 Analysis

Multivariate/multidata analysis
## Intercomparisons

<table>
<thead>
<tr>
<th>FOAM</th>
<th>MERCATOR</th>
<th>MFS</th>
<th>TOPAZ</th>
<th>HYCOM</th>
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<tr>
<td><img src="image1" alt="FOAM Image" /></td>
<td><img src="image2" alt="MERCATOR Image" /></td>
<td><img src="image3" alt="MFS Image" /></td>
<td><img src="image4" alt="TOPAZ Image" /></td>
<td><img src="image5" alt="HYCOM Image" /></td>
</tr>
</tbody>
</table>

**MOTHY/ARPEGE** : Analyse pour le 04/02/2003 à 00 utc

- **MOTHY seul en bleu**
- **MOTHY+FOAM en rouge**
- **MOTHY+MERCATOR en vert**

Observations: triangles noirs

![Map Image](image6)

MERCATOR products

Whole domain plots

PSY1 Oceanic bulletin 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.

North Atlantic
Sea level anomaly on 21 March 2001 (T0)

All results:
> Geographic areas
  > North Atlantic
  > Zonal maps
    > Sections
    > Margins

Vertical profiles

784 graphic files are put on the web every week

Time series

Zooms

Sections