Review of OSSE/OSE performed at Mercator-Ocean

Eric Dombrowsky, Fabrice Hernandez, Mounir Benkiran, Eric Greiner, Sylvie Giraud, Didier Jourdan and Stephanie Vrac
A few words about OSE and OSSE methodologies

Focus on two impact studies done at Mercator Océan
- **OSSE**: potential impact of surface velocities derived from SAR and/or optical flow methods applied to SST and/or ocean color on an eddy permitting system (1/3°)
- **OSE**: Impact of altimeter data (1, 2, 3, 4 satellites) on an eddy resolving forecasting system (0(1/15°))
OSE/OSSE, a well defined methodology to assess the impact existing and future measurements

From R. Atlas 97

OSE/OSSSE characteristics

- **OSE » Observing System Experiment**
  - Use **real data**, withdraw or keep components of the observation system in parallel assimilation run and measure the impact
  - The **truth is unknown**, need for an external assessment protocol (for exemple use of independant observations)
  - Allow to assess the **relative impact of existing** observing systems on analysis and forecast produced by a given assimilative system

- **OSSE » Observing System Simulation Experiment**
  - Use **simulated data** instead of real data
  - **Truth is** simulated, and assumed to be **known** (identical/fraternal twin experiments)
  - Allow to assess the **potential impact of future** observing systems
  - **Results depend on the experimental protocol**, and the confidence one may have in quality of the observations simulation. Results have to be consolidated afterwards with real data
Impact studies done with Mercator systems

- 2003: Impact of MSSH (Davidson et al.)
  - OSE
  - 1/3° North and Tropical Atlantic, ROOI (alt only)
- 2005: Impact of Pirata (Hernandez et al.)
  - OSE
  - 1/3° North and Tropical Atlantic, ROOI (multi data)
- 2005: Impact of SMOS and AQUARIUS (Tranchant et al.)
  - Mix of OSE/OSSE (fraternal twin)
  - ¼° North and Tropical Atlantic, SEEK
- 2006: Impact of altimeter data, ARGO, etc… (Benkiran et al.)
  - OSE
  - 1/3° North and Tropical Atlantic, ROOI (multi data)
- 2006: Impact of surface velocities derived from SAR (Giraud et al.)
  - OSSE (fraternal twin)
  - 1/3° North and Tropical Atlantic, ROOI (multi data)
- 2007 (ongoing): Impact of altimeter data (Benkiran et al.)
  - OSE
  - 5-7 km North Atlantic and Mediterranean, ROOI (multi data)
Impact studies done with Mercator systems shown here

- 2003: Impact of MSSH (Davidson et al.)
  - OSE
  - 1/3° North and Tropical Atlantic, ROOI (alt only)
- 2005: Impact of Pirata (Hernandez et al.)
  - OSE
  - 1/3° North and Tropical Atlantic, ROOI (multi data)
- 2005: Impact of SMOS and AQUARIUS (Tranchant et al.)
  - Mix of OSE/OSSE (with real data except simulated SSS from fraternal twin)
  - 1/4° North and Tropical Atlantic, SEEK
- 2006: Impact of altimeter data, ARGO, etc… (Benkiran et al.)
  - OSE
  - 1/3° North and Tropical Atlantic, ROOI (multi data)
- 2006: Impact of surface velocities derived from SAR (Giraud et al.)
  - OSSE (fraternal twin)
  - 1/3° North and Tropical Atlantic, ROOI (multi data)
- 2007 (ongoing): Impact of altimeter data (Benkiran et al.)
  - OSE
  - 5-7 km North Atlantic and Mediterranean, ROOI (multi data)
Probability of having 2 (red) or 3 (blue) altimeters delivering data

From G. Dibarboure 2007

OSSE to evaluate the potential impact of surface velocities derived from SAR or optical flow methods on MERCATOR 1/3° North and Tropical Atlantic system

Eric Greiner, Mounir Benkiran, Sylvie Giraud St Albin and Stéphanie Vrac

Work done by CLS, BOOST technology and Mercator-Océan under contract with SHOM
Objectives and experimental protocol

Objective:
- Assess the potential impact of surface velocities that could be deduced from SAR (radial velocities) and/or velocities obtained by the “optical flow” (OF) method from SST and/or ocean color.
- Evaluate how this could complement the altimeter data observing system in the case of degradation in the coming years (or even be an alternative to it in the case of total loss).

Experimental protocol OSSE:
- Simulate observations: altimeter, in situ profiles, SST, SAR and OF velocities from a realistic high resolution forced model simulation: North Atlantic 1/12°
- Implement the assimilation of velocities in the Mercator system
- Run several simulation runs with different instrument combinations
- Use an eddy permitting system to do that (North and Tropical Atlantic 1/3°)
- Assess overall performances of the products

**Upgrade of the assimilation system**

**SAM1v2: ROOI using multivariate 1D vertical EOF**

**SAM1V2 kernel**

**Modal Space (Reduced Space)**

**ROOI Analysis**

**1D EOFs acting on the vertical**

**Control Space**

**δHbar**

**δT(k)**

**δS(k)**

**Model initialisation**

**Barotropic**

δψ → δU_{bar}, δV_{bar}

**Baroclinic**

δT, δS → δU_{geo}, δV_{geo}

δη → δU, δV

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Upgrade of the assimilation system

SAM1v3: ROOI using multivariate 1D vertical EOF

SAM1V2 kernel

Control Space

Barotropic

Modal Space (Reduced Space)

1D EOFs acting on the vertical

ROOI Analysis

Model initialisation

Baroclinic

Simulation of the “true ocean”: Conventional data

- Use a multi year 1/12° North and Tropical Atlantic, + Mediterranean sea simulation
  - NEMO, ORCA1/12°, 50 levels, free surface (implicit), bulk formulae, ECMWF forcing, partial cells, prognostic ice, …
  - An evaluation of the “nature run” has been performed

- Observations simulated for the year 2004:
  - Actual coverage
  - Along-track SLA:
    - Jason 1, Envisat and Gfo
  - CORIOLIS in situ profiles:
    - CTD : T+S
    - PF : T+S
    - TESAC : T+S
    - MO : T+S
    - BATHY : T only
    - XBT : T only
  - SST (RTG_SST)

- Add typical noise to observations
- Apply real processing to simu. alti. data
  - remove along track long wavelength signals

Simulation of the “true ocean”: non conventional data

Specifications provided by BOOST technology

- SAR data (Envisat)
  - Radial velocity 400km offshore
  - Repeat time = 3 days
  - Instrumental noise = 30 cm/s
    - + test with 10 cm/s
  - 10-20 km spatial resolution

- Optical flow data
  - Weekly U and V
  - Cloud + Ice mask
  - wind threshold (2 cm/s)
  - Instrumental noise = 30 cm/s
    - + test with 10 cm/s

Zonal velocity better observed than meridian
### Fraternal twin experiments done

<table>
<thead>
<tr>
<th></th>
<th>Coriolis</th>
<th>Jason</th>
<th>Envisat</th>
<th>Gfo</th>
<th>SST</th>
<th>radial U (SAR)</th>
<th>Weekly U, V (OF)</th>
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<td>Simulated</td>
<td>Simulated</td>
<td>Simulated</td>
<td>Simulated Err=30cm/s</td>
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<tr>
<td><strong>RUN03 No alti +SAR</strong></td>
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<td>Simulated Err=10cm/s</td>
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<tr>
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<td></td>
</tr>
<tr>
<td><strong>RUN05 One alti +SAR</strong></td>
<td>Simulated</td>
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<td>Simulated</td>
<td>Simulated</td>
<td>Simulated Err=30cm/s</td>
<td></td>
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<tr>
<td><strong>RUN06 No alti, +SAR+OF</strong></td>
<td>Simulated</td>
<td></td>
<td></td>
<td>Simulated</td>
<td>Simulated</td>
<td>Simulated Err=30cm/s</td>
<td>Simulated Err=30cm/s</td>
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<tr>
<td><strong>RUN07 No alti, +SAR+OF</strong></td>
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<td>Simulated Err=30cm/s</td>
<td>Simulated Err=10cm/s</td>
</tr>
</tbody>
</table>

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**Eric Dombrowsky - 25 Octobre 2007**
Results: SLA assimilation diags

• Black plain line
  - RUN01/CONTROL (conventional obs)
• Blue plain line:
  - RUN02 (+ SAR) (superimposed to black line)
• Green plain line:
  - RUN03 (no alti, +SAR 10 cm/s)
• Orange plain line:
  - RUN04 (no alti, +SAR 30 cm/s)
• Blue dotted line:
  - RUN05 (One alti only, +SAR 30 cm/s)
• Black dotted line:
  - RUN06 (no alti, +SAR+OF 30 cm/s)

- SAR has almost no additional impact when altimetry is assimilated
- SAR and OF are not sufficient to compensate altimeters
- Assimilating SAR + OF with 30cm/s errors performs like assimilating SAR with 10cm/s errors

Little impact on analysis increments at the surface due to obs errors
Impact of OF in addition to altimetry
RUN06 and RUN07

Little impact on analysis increments at the surface due to obs errors
Good agreement in tropical region between innovation and increment
  Velocities derived from OF method seem to be well adapted to tropical dynamics

Conclusions of this OSSE

- SAR derived surface velocities have marginal impact on performances of Mercator 1/3° North and Tropical Atlantic system when altimeter data are assimilated (3 altimeters)
- Error on velocity estimated should not exceed 7cm/s if we want them to have an impact comparable to other data
- In the case of loss of altimeter capacity, SAR derived velocity would not enable to compensate the loss
  - Too local, and too noisy
  - Corrections made upstream (“coastal” gulf stream) degrades the situation in the open ocean after advection
  - No control over large parts of the ocean
- Assimilation of optical flow velocities has positive impact

*Future work will include use of real data (OSE)*

OSE to measure the impact of altimeter data on MERCATOR 5-7km resolution system in the North Atlantic and Mediterranean

M. Benkiran, E. Greiner, Eric Dombrowsky and D. Jourdan

Work done by Mercator Océan and CLS under contract with SHOM
Objectives and experimental protocol

Objective:
- Assess the impact of the probable altimeter coverage degradation on products delivered to the French Navy using Mercator Océan forecasting systems

Experimental protocol OSE:
- Run several hindcast runs starting from an operational restart file with 0, 1, 2, 3, and 4 altimeters (baseline 3 satellites, operational setup)
- Use high resolution system to do that (Natl+Med 5-7 km resolution)
- Assess overall performances of Mercator system products
- For a selected set of dates, simulate forecasts, apply Navy post processing, and measure the impact on the service delivery to the Navy
The system used: 1) eddy resolving model configuration

- OPA OGCM, ECMWF surface forcing (fluxes)
- 5 to 7 km rotated grid in the Atlantic, 1/16° in the Med
- 43 levels in both basins (19 at Gibraltar Strait)
The system used: 2) multivariate multidata OI assimilation system

multivariate multidata optimal interpolation

Statistical representation of the forecast error = 2D analytical (horiz.) + EOFs 1D (vert.)
✓ Altimetry along track SLA (+ MSSH from Rio et al.)
✓ RTG SST
✓ T/S vertical profiles

Analysis

Increments
Components on each mode

Modal Space (Reduced Space)

EOFS 1D on the vertical (seasonal)

Initialisation

\( \delta \psi \)
\( \delta U_{\text{bar}}, \delta V_{\text{bar}} \)

\( \delta T, \delta S \)

\( \delta U_{\text{geo}}, \delta V_{\text{geo}} \)

\( \delta U, \delta V \)

The system used: 3) GoDAE validation and assessment protocols

147 Class2 moorings, 4h

85 Class2 sections, daily

46 class3 transport sections, daily

6-month period selected: 
Sept 22\textsuperscript{nd} 2004 to March 23\textsuperscript{rd} 2005

Number SLA obs per week over the domain

Number of T/S valid profiles per week over the domain(2003-2006)

Number of valid SLA data per satellite for the period

Jason1

Envisat

Geosat Follow-On

Topex/Poseidon

Overall performances in temperature and salinity for the baseline: innovation statistics

Number of profiles

RMS diff

RMS diff

0°C                  +2.5°C

0° C                  +2.5° C

0 Psu +0.5 Psu

0                        400

-3° C                  +3° C

-0.5Psu              +0.5Psu

0 Psu                  +0.5 Psu
# The experiments

<table>
<thead>
<tr>
<th></th>
<th>Coriolis</th>
<th>JASON</th>
<th>ENVISAT</th>
<th>GFO</th>
<th>TOPEX</th>
<th>SST</th>
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<tbody>
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<td>x</td>
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<td>verif</td>
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<td>x</td>
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<td>RTG</td>
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<tr>
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<td>RTG</td>
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<tr>
<td>without altimeters EXP3</td>
<td>x</td>
<td>verif</td>
<td>verif</td>
<td>verif</td>
<td>verif</td>
<td>RTG</td>
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<td>Jason+Envisat+GFO+T/P EXP4</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>RTG</td>
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<tr>
<td>Progressive loss EXP5</td>
<td>x</td>
<td>First 4.5 month</td>
<td>First 3 month</td>
<td>First 1.5 month</td>
<td>verif</td>
<td>RTG</td>
</tr>
</tbody>
</table>

*Eric Dombrowsky - 25 Octobre 2007*
OSE: Impact of multi-mission altimeters on North Atlantic + Mediterranean 5-7 km Mercator forecasting system

- OSE in 2004 (6 month)

Shown here diags from innovation: forecast – obs (not yet assimilated)

\[
\frac{\text{RMS(EXPi-obs)} - \text{RMS(EXP0-obs)}}{\text{RMS(obs)}}
\]

> 0 means degradation in %
0 is the baseline (3 sats)
< 0 means improvement in %

**EXP0**: Jason + Envisat + GFO
**EXP1**: Jason + Envisat
**EXP2**: Jason
**EXP3**: No alt
**EXP4**: Jason + Envisat + GFO + T/P

All EXP: In situ T/S + RTG SST

**Mercator forecasting system**

**RMS(obs)**

**M. Benkiran 2007**

Impact of a fourth altimeter in the Gulf of Mexico 1-week forecast

In Situ T/S, RTG SST
Jason
+ Envisat
+ GFO

In Situ T/S, RTG SST
Jason
+ Envisat
+ GFO
+ TOPEX/POSEIDON

M. Benkiran 2007
Standard deviation of forecast SST
Vs RTG SST

Jason Envisat GFO

Jason only

SST and SLA correlation

Jason+Envisat+GFO versus Jason+Envisat

Conclusions for this OSE

- High resolution systems see the impact of multi satellite missions
  - Even a fourth altimeter has impact
    - Where energy is low (Northeastern Atlantic)
    - Where signals are fast (Tropics)
    - Everywhere if we look locally and carefully (example gulf of Mexico)
- One single altimeter enables to get and keep some predictive skill, while there is no skill for mesoscale without altimeters

This is an ongoing work, further conclusions to follow, especially for the impact on Navy products
General conclusions

- Operational oceanography assimilation systems are unique tools to perform observing systems impact studies
  - They are designed to reproduce the real ocean
  - Their performances is generally well documented
  - The impact on applications can be assessed
- Running OSE is “simple” if the system has a hindcast capacity
  - Observations and forcing already in house
  - Operational chain and tools can be used
  - Evaluation protocol can be derived from the operational one
  - But need computer (and manpower) resources: several additional years of integration, CPU, storage, expertise...
- Running OSSE is more complex and demanding
  - Need to simulate data: better to involve the observation agencies and expert groups
  - System has to be adapted if new kind of data has to be assimilated

- Evaluation protocol is an important issue and GoDAE or Post GoDAE could be a good framework to work together on that