MEsoSCale dynamical Analysis through combined model, satellite and in situ data

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MESCLA project
• Scientific motivation & background
• Main objectives and tasks
• First year results
• Conclusions and future work
Vertical exchanges are key factors to understand mesoscale processes and their impact at both regional and global scales

Mesoscale vertical displacements influence biology:

- upward transport of nutrients can lead to enhanced algal biomass in the photic zone...
- downward motions transport the biomass produced at the surface to deeper layers where it is remineralized, releasing once again nutrients into the dissolved phase...

Mesoscale has a primary role in the global heat, freshwater, carbon, and nutrient budgets

- impact on global climate system
- net effect under debate (e.g. role of mesoscale on ACC dynamical balance)

From: Lévy, et al.(JMR2001)
Space and time resolutions are key factors to correctly estimate mesoscale vertical exchanges and their impact on climate and biology

Vertical velocities cannot be directly measured
→ indirect estimates from models or observations (through Omega equation)

MODELLING APPROACH
→ climate models still have low resolution (computational limitations): effects of mesoscale on property diffusion/transport need to be parameterized (e.g. through Eddy diffusivity)
→ data assimilation in higher resolution numerical models → accurate but significantly influenced by specific model configurations (e.g. forcing, parameterization of smaller scale processes), costly from numerical point of view

OBSERVATIONAL APPROACH
→ simplified dynamics (quasi-geostrophy) → requires 3D density and geostrophic velocity estimates
→ High resolution synthetic 3D re-analyses obtained combining satellite data, historical in situ dataset, taking advantage of variables covariance

Observational approaches can help to better understand the vertical exchanges associated with mesoscale processes, analyse their impact on ocean circulation and ecosystem and eventually help to define new parameterizations of mixing for climate models (far beyond MESCLA...)
MESCLA project is focused on the estimation and analysis of the vertical exchanges associated with mesoscale dynamics and of their interannual variability, concentrating on selected test areas (North-Atl., Gulf Stream).

MESCLA tasks:

• **diagnosis/comparison of vertical velocity fields**
  estimated from:
  → numerical model analyses (MyOcean MERCATOR)
  → Omega equation and synthetic 3D fields (MyO ARMOR-3D/Surcouf3D products)

• **improvement of the synthetic 3D fields**
  → ingest high resolution SST L4 products in ARMOR-3D
  → development of multivariate horizontal interpolation techniques to obtain high resolution Sea Surface Salinity from in situ data (and altimeter Absolute Dynamic Topography)
  → test of new methodologies to **retrieve vertical profiles** from surface data
    (several methods available: multivariate EOF reconstruction, Gravest Empirical Modes, Self Organizing Maps, etc. → only mEOF-R will be tested)

• **analysis of the interannual variability**
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• **analysis of the interannual variability**
Ingestion of HR SST L4 product in Armor3D

**MyOcean Armor3D/Surcouf3D: 3-step method based on observations and statistical method** (poster by Sandrine Mulet et al. yesterday)

Step1: Vertical projection of satellite Sea Level+Sea Surface Temperature using a **multiple linear regression** method
Step2: Combination of synthetic fields and in-situ T/S profiles using an optimal interpolation method
Step3: Compute geostrophic velocities using surface ADT as reference (**Surcouf3D**)

• Armor3D-V0 → 1/3° resolution, uses Reynolds OI 1° SST
• Armor3D-V1 → 1/3° resolution, uses Reynolds AVHRR-AMSR 1/4° SST (real-time and reanalysis)

• Several global L4 SST products exists (**MyOcean**, GHRSSST):
  How do they compare?
  What is the impact on Armor3D?
Ingestion of HR SST L4 product in Armor3D

Impact of higher resolution on ARMOR3D/MESCLA (1/3°, 1/4°, 1/10°, 1/20°)

Results
Development of a high resolution Sea Surface Salinity (SSS) L4 product

→ HR SSS ingestion in ARMOR3D/MESCLA planned during year 2
→ HR SSS needed by new 3D reconstruction methods (to be tested in year 2)
→ new product potentially useful in combination with SMOS data

Hypothesis:
high correlation between sea surface temperature (SST) and sea surface salinity (SSS) variations can be expected (in the open ocean) at scales significantly smaller than the ones dominating atmospheric variability

Proposed technique:
optimal interpolation (Bretherton-like) algorithm that includes satellite (spatially high-pass filtered) SST differences in the covariance estimation

\[ x_{analysis} = x_{background} + C(R + C)^{-1}(y_{obs.} - x_{background}) \]

\[ C(\Delta r, \Delta t, \Delta SST) = e^{-\left(\frac{\Delta t}{\tau}\right)^2} e^{-\left(\frac{\Delta r}{L}\right)^2} e^{-\left(\frac{\Delta SST_{filtered}}{T}\right)^2} \]

Covariance function parameters (i.e. spatial (L), temporal (t) and thermal (T) decorrelation scales and spatial filtering) determined empirically minimizing errors vs independent surface observations
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Same test performed on simulated observations taking MERCATOR model output as ‘true’ SSS field (not shown)
Test datasets

**in situ SSS**

Red dots (input) 30 days window, centered on interpolation day → MyOcean INSITU-TAC PF, CTD and XCTD, referenced to 5 m depth

Blue dots (validation) (only for interpolation day)
GOSUD and LEGOS TSG data
Test datasets

**in situ SSS**
- **Red dots (input)** 30 days window, centered on interpolation day → MyOcean INSITU-TAC PF, CTD and XCTD, referenced to 5 m depth
- **Blue dots (validation)** (only for interpolation day)
  - GOSUD and LEGOS TSG data

**Background SSS (1/2°)**
- MyOcean CORIOLIS SSS objectively analyzed maps
Test datasets

**in situ SSS**
- Red dots (input) 30 days window, centered on interpolation day → MyOcean INSITU TAC PF, CTD, and XCTD, referenced to 5 m

**Blue dots (validation)** (only for interpolation day) GOSUD and LEGOS TSG data

**ODYSSEA L4 SST (1/10°)**
Empirical determination of OI parameters:

RMSE (black contour) and MBE (red) vs validation data (expressed as % with respect to CORIOLIS – SSS L4 errors), as a function of the spatial and thermal decorrelation scales. High-pass filtered SST (<1000 km)
“Best” configuration and quantitative validation

- Lowest errors:
  - RMSE $\sim 0.11$ psu $\sim 70\%$ of CORIOLIS error
  - MBE $\sim 0.01$ psu $\sim 30\%$ of CORIOLIS error

- $L = 400$ km $\tau = 6$ days $T = 2.75 \degree C$
- Signal-to-noise $= 0.01$
- High-pass filter: signals $< 1000$ Km

RMSE (black contour) and MBE (red) vs validation data (expressed as % with respect to CORIOLIS–SSS L4 errors)
Qualitative results:

MESCLA high resolution SSS field and derived SSS gradient reveal more realistic and smaller scale structures than those visible in CORIOLIS-SSS product. MERCATOR 1/12° displays even smaller scales...
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MESCLA high resolution SSS field and derived SSS gradient reveal more realistic and smaller scale structures than those visible in CORIOLIS-SSS product. MERCATOR 1/12° displays even smaller scales.
Development of a high resolution Absolute Dynamic Topography (ADT) L4 product

- Same technique as for SSS
- Now working on tuning/validation vs independent observations (i.e. using a reduced number of sensors)
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Vertical velocity estimate: Omega equation

Q-vector formulation of the OMEGA equation

\[ \nabla^2 (N^2 w) + f^2 \frac{\partial^2 w}{\partial z^2} = 2 \nabla \cdot \vec{Q} \]

\[ \vec{Q} = \left[ f \left( \frac{\partial V}{\partial x} \frac{\partial U}{\partial z} + \frac{\partial V}{\partial y} \frac{\partial U}{\partial z} \right) - f \left( \frac{\partial U}{\partial x} \frac{\partial U}{\partial z} + \frac{\partial U}{\partial y} \frac{\partial V}{\partial z} \right) \right] \]

\[ w \rightarrow \text{Vertical velocity} \]
\[ U, V \rightarrow \text{Horizontal geostrophic velocities} \]

Omega eq. model adapted to different output

\rightarrow \text{re-interpolation on regular grid}
\rightarrow \text{geostrophic computations (sensitivity to reference level)}

Tests performed on:

Model analyses (MERCATOR)

- PSY3V2R2: 1/4° resolution, 50 vertical levels
- PSY2V3R1: 1/12° resolution, 50 vertical levels

Synthetic 3D fields

- ARMOR3D–V0 (1/3°)
- ARMOR3D–V1 (1/3°)(improved SST resolution)
Application of the Omega equation to MERCATOR model analyses

Results

**SST**

**PSY2V3R1 1/12°**

**PSY3V2R2 1/4°**

**ADT**

**w-model**

**w-Omega**
Results

Application of the Omega equation to MERCATOR model analyses

**PSY2V3R1 1/12°**

- SST

**PSY3V2R2 1/4°**

- ADT

- w-model

- w-Omega

• at 1/12°, w-Omega gives accurate results

• at 1/4°, lower/smorer values both with primitive equation solution and omega estimates
Application of the Omega equation to 3D synthetic fields, comparison to model output

Results

ARMOR-3D V1
PSY3V2R2 1/4°

SST

Reynolds 1°

ADT

AVISO 1/3°

w-model

w-Omega

qgw – Depth = 100 m

1/4°
Application of the Omega equation to 3D synthetic fields, comparison to model output

Results

ARMOR-3D V1

PSY3V2R2 1/4°

SST

Reynolds 1°

ADT

AVIS0 1/3°

w-model

w-Omega

Synthetic estimates lower by a factor ~2÷3
Application of the Omega equation to 3D synthetic fields ingesting HR SST

Results

- ARMOR-3D V1
  - SST
  - ADT
  - w-model
  - w-Omega

- ARMOR/MESCLA V1
  - SST
  - ADT
  - AVISO 1/3°
  - Reynolds 1°
  - Reynolds 1/4°
  - AVISO 1/3°

Reynolds 1°
Reynolds 1/4°
AVISO 1/3°
AVISO 1/3°

AVISO - Depth = 100 m

qgw - Depth = 100 m
Results

Application of the Omega equation to 3D synthetic fields ingesting HR SST

ARMOR-3D V1

ARMOR/MESCLA V1

SST

Reynolds 1°

Reynolds 1/4°

ADT

synthetic estimates obtained with higher resolution SST improved with respect to original ARMOR3D

w-model

w-Omega
Results

Omega identify vertical velocity patterns associated with frontal quasi-geostrophic dynamics

TSsynthetic_ReynoldsHR_Surcouf3D

w-Omega (1/4°) + DH overimposed

dh - Depth = 100 m

m/day
Omega identify vertical velocity patterns associated with frontal quasi-geostrophic dynamics

**Results**

**TSsynthetic_ReynoldsHR_Surcouf3D**

\( w - \text{Omega} \left( \frac{1}{4}^\circ \right) + \text{DH overimposed} - \text{zoom} \)
First year results and future work:

• w-Omega gives accurate results at 1/12° compared to primitive equation w, lower accuracy at 1/4°

• W-Omega obtained from ARMOR3D underestimated at 1/4°

• Ingestion of higher resolution SST in ARMOR3D leads to improved w results

• Method for high resolution (1/10°) SSS (and ADT) multivariate interpolation gives promising results → 1/10° ARMOR3D/MESCLA 3D fields soon available

• Test of multivariate 3D extrapolation just started (using combinations of SSH, SST, SSS as input)... → 1/10° Synthetic MESCLA 3D fields soon available

• Vertical velocity interannual variability will be estimated from reanalyses (plans to compare with ocean colour data)
Conclusions and future work

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More details on poster XY609 [EGU2011-11326](#)

**Pascual et al.** Vertical motion analysis through combined model, satellite and in situ data.

Preliminary results of the MESCLA project

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Thanks!