New global Mean Dynamic Topography from a GOCE geoid model, altimeter measurements and oceanographic in-situ data

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INTRODUCTION

- The Mean Dynamic Topography (MDT) is a key reference surface for the optimal exploitation of altimeter data.

- It is the missing component that allows to estimate the ocean absolute dynamic topography (ADT) and the corresponding absolute geostrophic surface currents from the altimeter Sea Level Anomalies (SLA): \( ADT = MDT + SLA \)

- It may be written as the difference between an altimeter Mean Sea Surface (MSS=mean sea level above a reference ellipsoid) and a geoid height relative to the same reference ellipsoid. \( MDT = MSS - Geoid \)

- However, due to the spectral differences of both surfaces (the MSS is known at few kilometer; present satellite-only geoid models resolve, with centimetric accuracy, geoid scales of 200-300 km (GRACE) to 100km (GOCE)) spatial filtering is needed.

- MDT information at shortest scales may be brought by combination to oceanographic in-situ information as ARGO floats and drifting buoys velocities (Rio et al, 2004; 2005;2007;2011).
INTRODUCTION

Direct Method
MDT=MSS-Geoid

Synthetic Method
The short scales of the MDT (and corresponding geostrophic currents) are estimated by combining altimetric anomalies and in-situ data

Large scale
MDT=First guess

Multivariate Objective Analysis

High resolution MDT

- At CLS/CNES, continuous improvements of the MDT have been achieved in the past 10 years using this approach: RIO03 MDT, RIO05 MDT, CNES-CLS09 MDT, all of them distributed via the AVISO web portal
- Objective of this talk is to present the next version: the CNES-CLS13 MDT
# INTRODUCTION

## Comparison of MSS and CMDT CNES-CLS09 with CMDT CNES-CLS13

<table>
<thead>
<tr>
<th>MSS used for first guess computation</th>
<th>MSS CNES-CLS01</th>
<th>MSS CNES-CLS11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geoid model used for First Guess computation:</td>
<td>EIGEN-GRGS.RL02.MEAN based on 4 1/2 years of GRACE data</td>
<td>EGM-DIR-R4 based on 7 years of GRACE data and 2 years of reprocessed GOCE data</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Filtering used for First Guess computation:</th>
<th>Optimal filter (~400 km)</th>
<th>Optimal filter ~125km</th>
</tr>
</thead>
</table>

<table>
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<tr>
<th>Buoy velocities dataset</th>
<th>15m drogued SVP drifters Period 1993-2008</th>
<th>SD-DAC SVP drifters, with or without the drogue - Period 1993-2012 Corrected for Wind slippage in case of drogue loss</th>
</tr>
</thead>
</table>

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<tr>
<th>Ekman model</th>
<th>Parameters fitted over the 1993-2008 period, by latitude, year, and month (3 months moving window)</th>
<th>Parameters fitted over the 1993-2012 period, by longitude, latitude and month (3 months moving window) Computation of an Ekman model at 0m and at 15m depth</th>
</tr>
</thead>
</table>

|----------|-------------------------|--------------------------------------|

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Global, ¼° (no Mediterranean)</th>
<th>Global 1/4° (including the Mediterranean Sea)</th>
</tr>
</thead>
</table>

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Computation of the MDT first guess

$$\text{MDT} = \text{MSS CNES-CLS11} - \text{EGM-DIR-R4}$$

RAW \quad \text{DIFFERENCE}

1- Observation error
2- Variance of the estimated signal
3- Correlation radius

Objective analysis

$$\sum_{i=1}^{N} \alpha_i \text{MDT}_i$$

OPTIMALLY FILTERED \sim 125 \text{ km resolution}
Use of in-situ oceanic measurements to improve the MDT at scales < 100 km

At each position \( r \) and time \( t \) for which an oceanographic in-situ measurement is available: dynamic height \( h(r,t) \) or surface velocity \( u(r,t), v(r,t) \):

1- the altimetric height/velocity anomaly is interpolated to the position/date of the in-situ data.

2- the in-situ data is processed to match the physical content of the altimetric measurement (corrected from ekman current; add of barotropic contribution…).

3- the altimetric anomaly is subtracted from the in-situ height/velocity

\[
\bar{h}_{93-99} = h_{\text{insitu}} - h'_{93-99} \quad \bar{u}_{93-99} = u_{\text{insitu}} - u'_{93-99} \quad \bar{v}_{93-99} = v_{\text{insitu}} - v'_{93-99}
\]
Final set of synthetic mean velocities

Dataset used for the CNES-CLS09 MDT computation
Final set of mean heights from the CORA3.4 T/S profiles

Dataset used for the CNES-CLS09 MDT computation

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The CNES-CLS13 MDT

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The GOCE only MDT (First Guess)
VALIDATION:
COMPARISON TO INDEPENDENT SURFACE VELOCITIES

RMS differences between the ARGO floats surface velocities (YoMaHa) and altimeter derived velocities (expressed in % of Argo floats velocity variance)

Comparison to other existing MDT solutions

<table>
<thead>
<tr>
<th></th>
<th>MDT CNES-CLS13</th>
<th>MDT CNES-CLS09 (First Guess)</th>
<th>MDT GLORYS2V1</th>
<th>MDT MAX08</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS U</td>
<td>44.6</td>
<td>46.1</td>
<td>46.7</td>
<td>47.0</td>
</tr>
<tr>
<td>RMS V</td>
<td>52.4</td>
<td>53.2</td>
<td>55.0</td>
<td>55.8</td>
</tr>
</tbody>
</table>
VALIDATION: Expected impact on altimeter data assimilation in the Mercator-Ocean system

Difference between the MDT currently used at Mercator-Ocean for SLA assimilation and the CNES-CLS13 MDT

SLA innovation computed during the latest Mercator-Ocean reanalysis run (GLORYS2V3)

→ Similarities between the two plots mean that the use of the CNES-CLS13 MDT will lead to improvements of the altimeter SLA assimilation into the Mercator-Ocean forecasting system
CONCLUSIONS

- A new global MDT is currently being computed at CLS/CNES
- Compared to the previous solution (CNES-CLS09 MDT) the major improvements come from
  - the use of one of the most recent satellite-only geoid model based on GRACE and GOCE data (EGM-DIR-R4)
  - The use of updated in-situ datasets
    - The CORA3.4 T/S database for the computation of the ocean dynamic heights
    - An updated dataset of drifting buoy velocities covering the period 1993-2012 including
      - Drogued SVP drifters corrected for the 15m Ekman current
      - Undrogued SVP drifter corrected for both the surface Ekman currents and direct wind slippage
- First validation results show:
  - An expected improvement of SLA assimilation into the Meractor-Ocean forecasting system by using the new MDT CNES-CLS13 solution
  - Improved quantitative comparison to independent in-situ data (surface velocity measurements from ARGO floats)
The CNES-CLS13 MDT will be publically available in November 2013

Also, further, extensive validation will be carried out

Specific work in the Arctic Ocean (new MSS or new method to compute directly ADT)

The MDT CNES-CLS13 will be used as reference surface for the generation of the next delayed-time altimeter ADT (Absolute Dynamic Topography) products that will be distributed through AVISO early 2014, based on the reprocessing of the entire altimeter data serie.
20 years of absolute surface currents from MDT+SLA

For further information, don’t hesitate to contact us! smulet@cls.fr mrlo@cls.fr
Observations: ADT Along Track
15 August – 25 September 2007

ADT Mapping

Objective analysis

\[ \sum_{i=1}^{i=N} \alpha_i \ ADT_i \]

1- along track interpolation of the geoid (GOCE_R3)
2- ADT = SSH\textsuperscript{ENVISAT} – Geoid
3- filter at 125 km of resolution

1- Observation error
2- Variance of the estimated signal
3- Correlation radius:
   Time \rightarrow 15 days
   Space \rightarrow 125 km of resolution
Classical versus direct method

- Beaufort gyre: +40 cm, contracted
- Gradient across the basin: 100 cm
Computation of the MDT first guess

Bruinsma et al., 2013, GRL
Drifting buoy data processing: Modelling Ekman currents

Ekman theory

\[ u_e = \pm \frac{\pi \sqrt{2}}{\rho f D_e} e^{\frac{\pi}{2} z} * \tau * \cos\left(\frac{\pi}{4} + \frac{\pi}{D_e} z\right) \]

\[ v_e = \frac{\pi \sqrt{2}}{\rho f D_e} e^{\frac{\pi}{2} z} * \tau * \sin\left(\frac{\pi}{4} + \frac{\pi}{D_e} z\right) \]

Model

Rio and Hernandez, 2003

\[ \vec{u}_{buoy} - \vec{u}_{alti} = \beta \tau e^{i\theta} \]

Wind stress from ERA INTERIM

Band pass filtered 30 hours - 20 days

\( \beta \) and \( \theta \) are estimated through least square fit

Dataset used for the CNES-CLS09 MDT computation: SVP Drifting buoys flagged as DROGUED by the SD-DAC for the period 1993-2008
Drifting buoy data processing: Modelling Ekman currents

\[ \beta \text{ and } \theta \text{ computed over the global ocean by year} \]

Strong dependency of \( \beta \) and \( \theta \) parameters with time

- Increase with time of parameter \( \beta \)
- Decrease with time of \(|\theta|\)

Direction of Ekman currents closer to wind direction

This was due to a failure in the SVP buoy drogue loss detection system:
Undetected undrogued drifter, directly advected by the wind in addition to surface currents, pollute the dataset

Rio et al, 2011

Drifting buoy data processing:
Modelling Ekman currents at 15m depth

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Rio et al, 2011
Drifting buoy data processing: Modelling Ekman currents at 15m depth
Drifting buoy dataset: Number of drogued versus undrogued data

Content of the updated SD-DAC SVP drifter dataset

Num buoy velocities Drogue ATTACHED

Num buoy velocities Drogue LOST

STRONG interest of using undroged buoy velocities to improve data coverage
However, undrogued buoys are advected by
- surface Ekman currents, not 15m Ekman currents!
- the direct action of wind (wind slippage)

These 2 effects must be modeled and removed

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Drifting buoy data processing: Modelling Ekman currents at the surface

Use of the surface velocities derived from the ARGO floats (YOMAHA database covering the period 2000-2013)

Number of ARGO buoy velocities
Drifting buoy data processing: Modelling Ekman currents at the surface
Drifting buoy data processing: Modelling Ekman currents at the surface

![Beta (m^2 s/kg)](chart1)

![Theta (Degree)](chart2)

- **UNDROGUED SVP drifters**
- **DROGUED SVP drifters OLD**
- **DROGUED SVP drifters UPDATED**

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Drifting buoy data processing: Modelling Ekman currents at the surface

Beta (m²/s/kg)

![Graph showing Beta vs year]

Theta (Degree)

![Graph showing Theta vs year]

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Drifting buoy data processing: Modelling Ekman currents at the surface

OSTST, Boulder 2013
Drifting buoy data processing:
Modelling Ekman currents at the surface

15m JUNE surface

β

θ

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Drifting buoy data processing: Wind slippage correction

Method from Rio et al, 2012, JAOT

Correlation between the drifter velocity and the wind

Mean wind slippage of 0.6% is found and applied on undrogued buoy velocities
Comparison between drifting buoy velocities and altimeter velocities (derived from SLA+First Guess MDT)

Drogued SVP buoys
Corrected for 15m Ekman currents

Undrogued SVP buoys
Corrected for 15m Ekman currents

Undrogued SVP buoys
Corrected for surface Ekman currents

Mean zonal differences

Root Mean Square zonal differences
Comparison between drifting buoy velocities and altimeter velocities (derived from SLA+First Guess MDT)

- Drogued SVP buoys
  - Corrected for 15m Ekman currents

- Undrogued SVP buoys
  - Corrected for 15m Ekman currents
  - Corrected for surface Ekman currents and wind slippage

**Mean zonal differences**

- cm/s

**Root Mean Square zonal differences**

- cm/s

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Comparison between drifting buoy velocities and altimeter velocities (derived from SLA+First Guess MDT)

Drogued SVP buoys
Corrected for 15m Ekman currents

Undrogued SVP buoys
Corrected for surface Ekman currents and wind slippage

Mean zonal differences

Root Mean Square zonal differences

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Comparison between drifting buoy velocities and altimeter velocities (derived from SLA+First Guess MDT)

Drogued SVP buoys
Corrected for 15m Ekman currents

Argo floats
Corrected for surface Ekman currents

Undrogued SVP buoys
Corrected for surface Ekman currents and wind slippage

Mean zonal differences

Root Mean Square zonal differences

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VALIDATION: COMPARISON TO INDEPENDENT SURFACE VELOCITIES

RMS differences between the ARGO floats surface velocities and altimeter derived velocities (expressed in % of Argo floats velocity variance)

1-Consistency check of using only drogued SVP drifters (‘DROG ATTACHED’) versus only undrogued SVP drifters (‘DROG LOST’) versus both drogued+undrogued SVP drifters (‘DROGUE ALL’)

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<tr>
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<th>MDT DROGUE LOST</th>
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<tr>
<td>RMS U</td>
<td>45.2</td>
<td>~</td>
</tr>
<tr>
<td>RMS V</td>
<td>53.4</td>
<td>~</td>
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[Map showing MDT differences with 1cm RMS]
VALIDATION: COMPARISON TO INDEPENDENT SURFACE VELOCITIES

RMS differences between the ARGO floats surface velocities and altimeter derived velocities (expressed in % of Argo floats velocity variance)

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<td>&lt; 45.2</td>
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Computation of the MDT first guess

Geostrophic velocity speed from the 100km Gaussian filtered MDT

Geostrophic velocity speed from the Optimally filtered MDT

Geostrophic velocity speed from the 200km Gaussian filtered MDT

OSTST, Boulder 2013
Computation of the MDT first guess

Geostrophic velocity speed from the 100km Gaussian filtered MDT

Geostrophic velocity speed from the Optimally filtered MDT

Geostrophic velocity speed from the 200km Gaussian filtered MDT

OSTST, Boulder 2013
Computation of the MDT first guess

$$\text{MDT} = \text{MSS CNES-CLS11} - \text{EGM-DIR-R4} \quad \text{OPTIMALLY FILTERED}$$