A New Mean Dynamic Topography Computed Over the Global Ocean from GRACE Data Altimetry and In-situ Measurements

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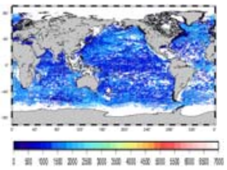
A **new Mean Dynamic Topography** has been computed for the global ocean using a similar method as described in Rio and Hernandez (2003), Rio et al. (2005).

Compared to the previous RIO05 field, the main improvements are:
- ✓The use of the recent EIGEN-GRGS.RL02.MEAN-FIELD based on **$4^{1/2}$ years of GRACE** data
- ✓The use of an **updated dataset of drifting buoy velocities (1993-2008) and dynamic heights (1993-2007)**
- ✓The use of an **improved Ekman model** to extract the geostrophic component of the buoy velocities
- ✓The use of an improved processing method of the dynamic heights allowing to **make use of T/S profiles to different reference depths.**
- ✓ Estimation was done on a **$\frac{1}{4}$° resolution grid** (instead of $\frac{1}{2}$° for RIO05).

Updated dataset of synthetic mean heights

Reference depths of the different profiles used

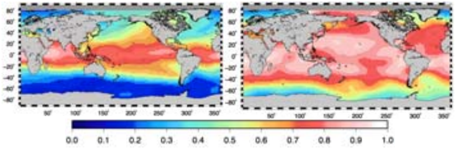


- ➢T/S profiles from CTD and ARGO floats from 1993 to 2007 are used
- ➢Dynamic heights relative to different reference depths (Pref) are computed: h_{dyn}/Pref
- ➢Altimetric SLA $h'_a(t,x,y)$ are interpolated at the profile position
- ➢The steric component of the sea level variability is computed for the different reference depths and removed

$$h'dyn_{/Pref}(x,y) = \alpha(p_{ref},x,y) * h'_a(t,x,y)$$

$$\overline{h}dyn_{synth/Pref}(x,y) = hdyn_{/Pref}(t,x,y) - h'dyn_{/Pref}(x,y)$$

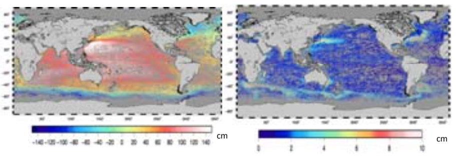
α(400m,x,y) α(1900m,x,y)



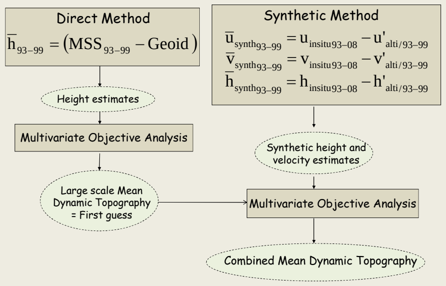
- ➢An estimate of the MDT at the reference depth is estimated from the GRACE first guess – climatology/Pref and added.

$$\overline{h}_{synth}(x,y) = \overline{h}dyn_{synth/Pref}(x,y) + \left[\overline{h}(x,y) - \overline{h}dyn_{/Pref}(x,y)\right]$$

Synthetic MDT estimates in $\frac{1}{4}$° boxes **Associated errors**



Method



Direct Method

$$\overline{h}_{93-99} = \left(MSS_{93-99} - Geoid\right)$$

Height estimates

Multivariate Objective Analysis

Large scale Mean Dynamic Topography = First guess

Synthetic Method

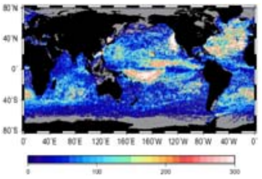
$$\overline{u}_{synth93-99} = u_{insitu93-08} - u'_{alti/93-99}$$
$$\overline{v}_{synth93-99} = v_{insitu93-08} - v'_{alti/93-99}$$
$$\overline{h}_{synth93-99} = h_{insitu93-08} - h'_{alti/93-99}$$

Synthetic height and velocity estimates

Multivariate Objective Analysis

Combined Mean Dynamic Topography

Updated dataset of synthetic mean velocities



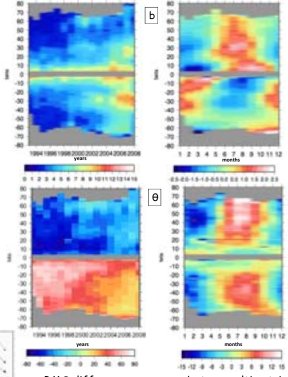
- ➢15m-drogued drifting buoy velocities from 1993 to 2008
- ➢Ekman currents have been modelled and subtracted
- ➢Further 3-days low pass filtering has been applied to remove inertial and tidal currents
- ➢Altimetric velocity anomalies have been interpolated along the buoy trajectory and removed

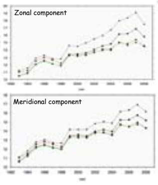
New Ekman model

V_{buoy}-V_{alti} filtered between 30h and 20 days

$$\vec{u}_{ek} = \frac{b}{\sqrt{f}} e^{i\theta} \vec{\tau}$$

3-hourly ERA-INTERIM wind stress

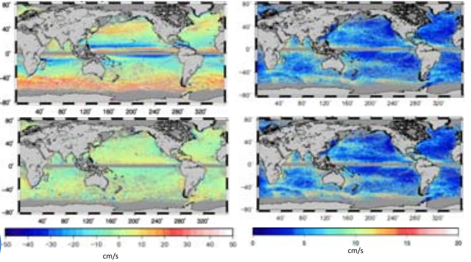




RMS differences per year between altimetric geostrophic velocities and drifting buoy velocities corrected from the Ekman component using various Ekman models:

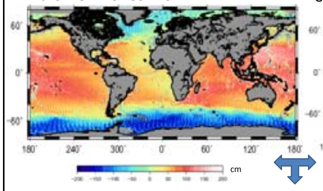
- - - - Drifting buoy velocities standard deviation
- ─── Ekman model fitted for the 1993-1999 period
- ─── Ekman model fitted for the 2000-2008 period
- ─── New yearly Ekman model

Synthetic Velocity estimates in $\frac{1}{4}$° boxes **Associated errors**

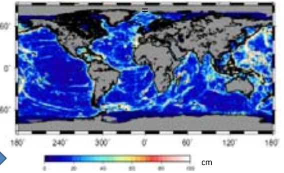


Updated large scale MDT first guess from GRACE data

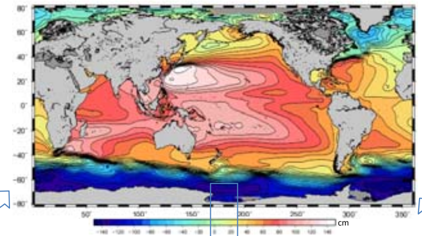
Difference between the CLS01 MSS and the EIGEN-GRGS.RL02.MEAN-FIELD



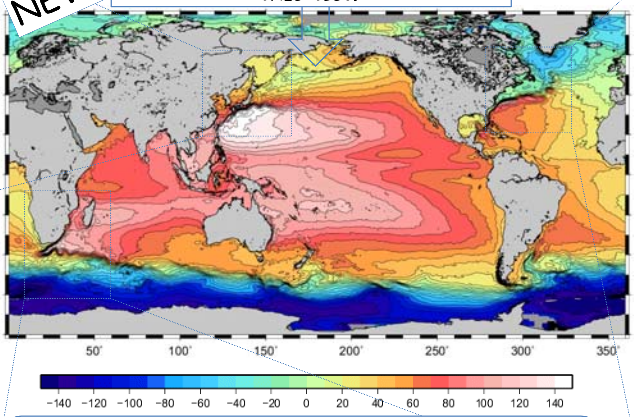
Observation error = Standard deviation of the differences between the (CLS01 MSS -EIGEN-GRGS.RL02.MEAN-FIELD) and the GLORYS1V1 MDT



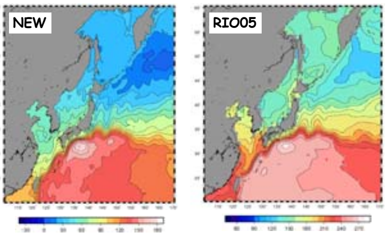
Large scale MDT estimate from GRACE = First Guess



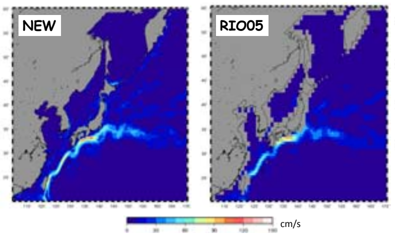
NEW Global, high resolution Mean Dynamic Topography CNES-CLS09



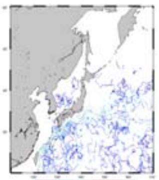
The Kuroshio current



Mean geostrophic current velocity module

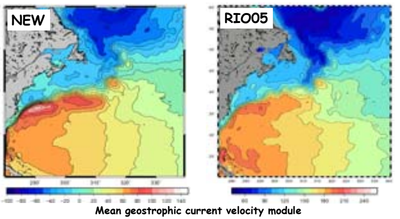


Comparison to independent synthetic velocity estimates (2009)

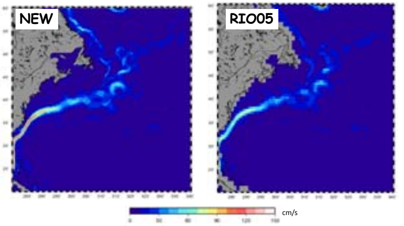


	CNES-CLS09	RIO05	MAX05	GLORYS	DNSC08	First Guess
DIFF RMSU	15.5	16.0	16.4	15.9	16.3	17.2
DIFF RMSV	15.8	16.5	16.8	16.3	16.8	18.2
Au	0.65	0.61	0.58	0.62	0.62	0.55
Av	0.58	0.54	0.52	0.56	0.55	0.46
Rc	0.82	0.80	0.79	0.80	0.79	0.76
σU	21.8	20.8	20.0	21.0	21.4	19.3
σV	18.9	18.1	17.6	18.7	18.6	16.8
σUobs	28.2					
σVobs	25.7					

The Gulfstream current

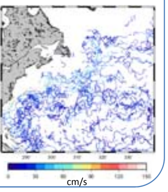


Mean geostrophic current velocity module

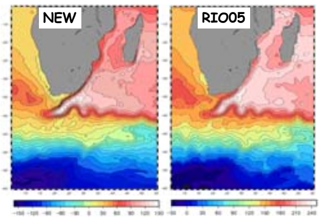


Comparison to independent synthetic velocity estimates (2009)

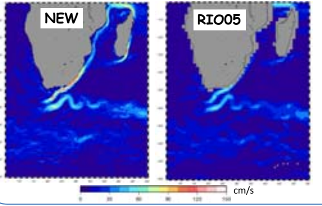
	CNES-CLS09	RIO05	MAX05	GLORYS	DNSC08	First Guess
DIFF RMSU	14.2	14.2	14.4	14.1	14.2	14.9
DIFF RMSV	13.0	13.1	13.4	13.3	13.4	13.8
Au	0.56	0.52	0.50	0.53	0.53	0.49
Av	0.55	0.53	0.51	0.53	0.53	0.49
Rc	0.76	0.76	0.75	0.76	0.75	0.73
σU	16.1	14.8	14.3	15.0	15.4	14.5
σV	14.3	13.8	13.6	14.1	14.2	13.6
σUobs	22.1					
σVobs	19.7					



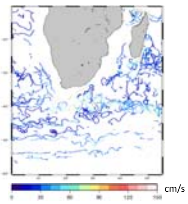
The Aghulas current



Mean geostrophic current velocity module



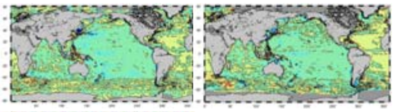
Comparison to independent synthetic velocity estimates (2009)



	CNES-CLS09	RIO05	MAX05	GLORYS	DNSC08	First Guess
DIFF RMSU	17.0	17.3	17.4	17.4	17.2	18.0
DIFF RMSV	15.8	15.9	15.9	15.8	16.6	17.0
Au	0.61	0.57	0.56	0.58	0.59	0.55
Av	0.61	0.60	0.60	0.61	0.58	0.56
Rc	0.83	0.83	0.83	0.83	0.82	0.81
σU	22.1	20.9	20.6	21.5	21.7	20.6
σV	20.6	20.1	20.1	20.4	20.2	19.7
σUobs	30.6					
σVobs	27.7					

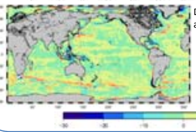
Solving for the RIO05 large scale bias issue

The RIO05 MDT was built using as first guess a merging between a large-scale GRACE-based MDT and (at low latitudes) the Levitus climatology relative to 1500m. This introduced a large-scale bias between the pacific-indian oceans and the atlantic ocean.
As a consequence the same bias is found in the GLORYS1V1 MDT, based on the MERCATOR system that assimilates the RIO05 MDT.



Difference between the RIO05 MDT and a large-scale (400km) GRACE-based MDT

Difference between the GLORYS1V1 MDT and a large-scale (400km) GRACE-based MDT



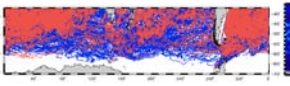
Difference between the NEW CNES-CLS09 MDT and a large-scale (400km) GRACE-based MDT

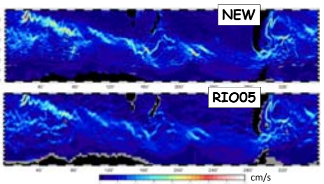
In the NEW MDT, this large-scale bias is no more present. This should have a positive impact on ocean forecasting systems assimilating altimetric data.

Refinement of the Antarctic Circumpolar Current

Red: drifting buoy velocities available from 1993 to 2002

Blu: drifting buoy velocities available from 2003 to 2008





Validation of the new CNES-CLS09 MDT

The new MDT solution was compared to independent synthetic estimates of the mean velocities computed from drifting buoy data available in 2009 as well as to a number of other existing MDT:
-The previous RIO05 MDT from (Rio et al, 2005)
-The Max05 MDT from (Maximenko et al, 2005) based on GRACE data and drifting buoy measurements.
-The DNSC08 MDT (Andersen et al, 2009) based on the DNSC08 MSS and the EGM08 geoid model.
-The GLORYS MDT, computed from a reanalysis of the MERCATOR system (global $\frac{1}{4}$°)

The main results from this validation study are:
- ✓The **intensity** of all major currents has been **significantly increased** (by 50 to 100% locally).
- ✓Currents are **better defined along the coasts.**
- ✓Higher spatial sampling of in-situ data allows for a **significant refinement of the Antarctic Circumpolar Current**
- ✓Comparison to independent synthetic velocity estimates shows a **decrease of the RMS differences** (DIFF RMSU and DIFF RMSV) and an **increase of the vector correlation (Rc)** compared to the use of the previous RIO05 solution and other global MDT fields based on models, in-situ data and/or gravity data.
- ✓**Regression slopes** (Au and Av) between the mean velocities and the synthetic mean velocities **are getting closer to 1**, still being lower than 1 though (the observed mean velocities are more intense). Standard deviation of the mean velocities from the new MDT are getting closer (though also still smaller) to the observed standard deviation. Higher resolution of both the MDT and the altimetric SLA is needed to further improve the estimation of ocean currents at all spatial scales. Further improvements will be obtained in the future with the use of GOCE data.

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