Introduction to the 12-year dataset and plans for exploiting new products

M.-H. Rio
Introduction to the 12-year dataset

12 years (2002-2014) of global maps of:

Geostrophic velocities
Ekman velocities at 0m and 15m
Combined Geostrophic+Ekman at 0m and 15m
Stokes drift (from the WaveWatch-III model)

An error estimate is also provided

Temporal resolution:
3-hourly

Spatial resolution:
Native 1/8° resolution for the geostrophic component
Native ¼° for the Ekman component and the combined Geostrophic+Ekman
Reinterpolated on the GlobCurrent 1/10° grid

Global Drifter validation datasets (1993-2014)

Available for download on the GlobCurrent web site http://www.globcurrent.org/ (in a few days...)
Ocean Surface Current (OSC) Definition

Simplified decomposition from GlobCurrent Technical Note #2

\[ U_{osc} = u + \frac{\sqrt{2}}{\rho_0 (f+\omega) \delta} e^{z/\delta} \left[ \tau_e^x \cos \left( \frac{z}{\delta} - \frac{\pi}{4} \right) - \tau_e^y \sin \left( \frac{z}{\delta} - \frac{\pi}{4} \right) \right] \]

\[ V_{osc} = v + \frac{\sqrt{2}}{\rho_0 (f+\omega) \delta} e^{z/\delta} \left[ \tau_e^x \sin \left( \frac{z}{\delta} - \frac{\pi}{4} \right) + \tau_e^y \cos \left( \frac{z}{\delta} - \frac{\pi}{4} \right) \right] \]

\( \tau_e = \text{Effective Wind Stress} \)
\( \delta = \text{Ekman depth} \)
\( f = \text{planetary vorticity} \)
\( w = \text{local vorticity} \)

\[ 2\omega = \partial_x v_{geo} - \partial_y u_{geo} \]
The Geostrophic and Ekman components at a glance

The geostrophic currents

They are derived applying the geostrophic approximation on multimission maps of Sea Level Anomalies (SLA) and adding the mean geostrophic currents $U_{MDT}$, $V_{MDT}$.

\[
U_{\text{geos}} = U_{MDT} - \frac{g}{f} \frac{\partial \text{SLA}}{\partial y}
\]
\[
V_{\text{geos}} = V_{MDT} + \frac{g}{f} \frac{\partial \text{SLA}}{\partial x}
\]

SLA: We use the latest version of the daily, global, ¼° multimission maps from the SSALTO DUACS production chain, and the regional 1/8° maps for the Mediterranean Sea

$U_{MDT}$, $V_{MDT}$: The mean currents from the CNES-CLS13 MDT solution are used

A regional MDT is used in the Mediterranean Sea

Fully described in:
The Geostrophic and Ekman components at a glance

The Ekman Currents

They are produced 3-hourly, globally, at ¼° resolution, at two different depths: surface and 15m.

They are based on a 2-parameter ($\beta, \theta$) empirical model:

\[
\vec{u}_e(z) = \beta(z) \vec{\tau} e^{i \theta(z)}
\]

$\vec{\tau}$ being the wind stress vector.

We use 3-hourly wind stress maps from the ERA INTERIM reanalysis.

The altimeter Sea Level Anomaly (SLA) maps

Altimeter Mission characteristics

<table>
<thead>
<tr>
<th>Orbit inclination</th>
<th>Repetitivity</th>
<th>Equatorial inter-tracks distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>66°</td>
<td>10 days</td>
<td>315 km</td>
</tr>
<tr>
<td>98.5°</td>
<td>35 days</td>
<td>80 km</td>
</tr>
</tbody>
</table>

Impact the spatial coverage capability: Spatial coverage limited to 66°N/S for TP/Jason, 82°N/S for ERS/Envisat

Impact the spatial and temporal resolution capability

Multi-mission merging to obtain gridded maps of altimeter data. Final resolution of gridded products depends on the number of satellites flying at the same moment and their orbit characteristics.
The altimeter Sea Level Anomaly (SLA) maps

Timeline of modern radar altimetry missions

<table>
<thead>
<tr>
<th>Year</th>
<th>Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>ERS-1</td>
</tr>
<tr>
<td>1993</td>
<td>ERS-1 (off)</td>
</tr>
<tr>
<td>1996</td>
<td>TOPEX/Poseidon</td>
</tr>
<tr>
<td>1997</td>
<td>TIP (degraded)</td>
</tr>
<tr>
<td>1998</td>
<td>Interleaved</td>
</tr>
<tr>
<td>2000</td>
<td>ERS-2</td>
</tr>
<tr>
<td>2002</td>
<td>ERS-2 (degraded)</td>
</tr>
<tr>
<td>2005</td>
<td>ENVISAT</td>
</tr>
<tr>
<td>2013</td>
<td>ENVISAT (degraded)</td>
</tr>
<tr>
<td>2013</td>
<td>30-day</td>
</tr>
<tr>
<td>2014</td>
<td>Jason-2 / OSTM</td>
</tr>
<tr>
<td>2016</td>
<td>CRYOSAT-2</td>
</tr>
<tr>
<td>2018</td>
<td>HY-2A</td>
</tr>
<tr>
<td>2018</td>
<td>ALTIKA / SARAL</td>
</tr>
<tr>
<td>2020</td>
<td>SENTINEL-3A</td>
</tr>
<tr>
<td>2022</td>
<td>JASON-3</td>
</tr>
<tr>
<td>2024</td>
<td>HY-2B / 2C</td>
</tr>
<tr>
<td>2026</td>
<td>S3-B / S3-C</td>
</tr>
<tr>
<td>2028</td>
<td>JASON-CS</td>
</tr>
<tr>
<td>2030</td>
<td>SWOT</td>
</tr>
</tbody>
</table>

Spatial resolution achieved for a 10 days temporal resolution:

- 2 satellites: 250-300km
- 4 satellites: 100 km
- 3 satellites: 150 km
The Mean Dynamic Topography (MDT)

The CNES-CLS13 MDT

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

Direct Method
MDT = MSS-Geoid

Synthetic Method
MDT = First guess

filtering

Multivariate Objective Analysis

High resolution MDT and associated mean geostrophic currents
The CNES-CLS13 MDT

First Guess = MSS - Geoid
OPTIMALLY FILTERED

Synthetic Mean Heights (1/4° box means)

- CTD (Cora3.4), ARGO T/S Profiles
- Pref variable 200/400/900/1200/1900
- Period 1993-2012
- Dynamic Heights corrected for the missing barotropic and deep baroclinic contribution
- Temporal variability measured by altimetry (AVISO SLA multimission maps) removed

Synthetic Mean Zonal Velocity (1/4° box means)

- SD-DAC SVP drifters, 15m drogued and undrogued for the Period 1993-2012
- Corrected for Wind slippage in case of drogue loss (applying the Rio (2012) method)
- The Ekman currents are modeled and removed
- A 3-day low pass filter is further applied to remove the residual ageostrophic components of the drifter velocity (tides, inertial currents, Stokes drift)
- The temporal variability measured by altimetry is removed

Synthetic Mean Meridional Velocity (1/4° box means)

- Argo floats surface velocities for the Period 2000-2013
- The Ekman currents are modeled and removed
- The temporal variability measured by altimetry is removed
The CNES-CLS13 MDT
The GOCE only MDT (First Guess)
The CNES-CLS13 mean geostrophic currents
The Mediterranean mean geostrophic currents

First Guess = MFS model mean

Observations = drifters (Poulain et al, 2012)

Result
The Ekman currents

Wind-driven Ekman

\[ u_e = \pm \frac{\sqrt{2}}{\rho(f+w)D_e} \frac{\beta}{\pi} \frac{\pi}{\tau_e \cos(\frac{\pi}{4} + \frac{\pi}{D_e} z)} \]

\[ v_e = \frac{\sqrt{2}}{\rho(f+w)D_e} \frac{\theta}{\pi} \frac{\pi}{\tau_e \sin(\frac{\pi}{4} + \frac{\pi}{D_e} z)} \]

Model

Rio et al, 2014

Altimetric velocities calculated using the GOCE MDT to reference the SLA (no drifter information)

\[ \vec{u}_b - \vec{u}_a = \beta \tau e^{i\theta} \]

Wind stress from ERA INTERIM

\[ \beta \text{ and } \theta \text{ are estimated through least square fit by month and 4° boxes} \]

At 15m depth using SVP Drifting buoys flagged as DROGUED by the SD-DAC

At the surface using the Argo float surface velocity dataset
The Ekman currents

Number of SVP buoy velocities Drogue ATTACHED

V1: 1993-2012

V2: + 2013, 2014

Number of Argo float surface velocities

V1: 2007-2012

V2: +2013, 2014
The Ekman currents

RESULTS: $\beta$, $\theta$ parameters

JANUARY
The Ekman currents

Northern Hemisphere: solid line
Southern Hemisphere: dashed line
Surface: circles
15m depth: triangles

Angle at the surface lower than $45^\circ$
- Ekman theory assumes constant vertical viscosity profile. Not true in the real ocean
The Ekman currents: Confidence level

% of variance explained

JANUARY

surface model

15m model
The Ekman currents: Confidence level

% of variance explained

U

V

JUNE

surface model

15m model
% VAR explained by the Surface model V2 vs V1

Northern Hemisphere

Southern Hemisphere
% VAR explained by the Surface model  V2 vs V1

- **Northern Hemisphere**
  - V1
  - V2

- **Southern Hemisphere**
  - V1
  - V2
Estimating the Ekman Depth

Definition

\[ DE_\beta = -\frac{15}{\ln(\beta(z = 15m)/\beta(z = 0m))} \]

Ekman depth based on amplitude decrease of the currents with depth

\[ DE_\theta = \frac{15 \times 180.0}{\pi \times (\theta(z = 15m) - \theta(z = 0m))} \]

Ekman depth based on the rotation of the currents with depth

In the Southern Ocean, Lenn and Chereskin (1999) found a rotation depth scale that exceeds the e-folding scale of the speed by about a factor of 3, resulting in a current spiral that is compressed relative to predictions from Ekman theory. Same order of magnitude has also been noted on the few occasions where the Ekman balance has been observed in the open ocean, mostly at Northern Hemisphere midlatitudes (Price et al. 1987; Chereskin and Roemmich 1991; Wijffels et al. 1994; Chereskin 1995; Price and Sundermeyer 1999).
Estimating the Ekman Depth

**Ekman depth based on amplitude decay**

**Ekman depth based on rotation**

**Ratio**

more compressed spiral in winter than in summer
The SVP-type drifter validation dataset has been updated for validating the GlobCurrent products. The original data have been downloaded from the Surface Drifter – Data Assembly Center at AOML (http://www.aoml.noaa.gov/phod/dac/dacdata.php). They cover the period January 1993 - December 2014.

Two distinct files are provided for drogued and undrogued SVP-type drifters. Included colocated wind stress, geostrophic currents, Ekman currents, wind slippage (Rio, 2012).

Also a dataset of Argo floats derived surface velocities, with collocated fields of wind stress, geostrophic and surface Ekman currents is available, covering the period 1997-2014.
Mean wind slippage for undrogued drifters

### zonal

### meridional

*cm/s*
Wind Slippage Impact on undrogued drifters

Buoy velocities - Geost

Buoy velocities - (Geost + Ekman)

Buoy velocities - Wind slippage - (Geost + Ekman)

cm/s
GlobCurrent products Error Estimates

Root Mean Square differences between 0m depth Argo floats velocities and the GlobCurrent surface velocities

September

RMSU geos

RMSV geos

RMSU geos+ekman

RMSV geos+ekman

0.0 0.1 0.2 0.3

RMS
GlobCurrent products Error Estimates

Root Mean Square differences between the 15m depth SVP drifter velocities and GlobCurrent 15m velocities

January

[Map showing RMSU and RMSV geos, RMSU and RMSV geos+ekman]
Validation of the GlobCurrent 0m currents: Comparison to OSCAR and Mercator currents

The OSCAR (Ocean Surface Current Analysis Real-Time) NOAA product
- Geostrophic currents based on AVISO data (with the old CNES-CLS09 MDT)
- Ekman current using variable eddy viscosity and NCEP winds
- 5 days mean, 1/3°
- Averaged value over the top 30 m of the solution

The Mercator-Ocean surface velocities
- First level (0.5m) from the 1/12° operational model (with assimilation)

Comparison to Argo surface velocities for the year 2013

<table>
<thead>
<tr>
<th>Year 2013: 74973 (72436) velocities*</th>
<th>RMS (cm/s) Bracket:</th>
<th>lat</th>
<th>&gt;3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>GC Geostrophic</td>
<td>19.4 (18.5)</td>
<td>17.2 (16.6)</td>
<td></td>
</tr>
<tr>
<td>GC Geostrophic + Ekman</td>
<td>15.9 (14.9)</td>
<td>15.5 (14.9)</td>
<td></td>
</tr>
<tr>
<td>OSCAR</td>
<td>19.2 (17.8)</td>
<td>17.6 (16.7)</td>
<td></td>
</tr>
<tr>
<td>Mercator (1/12°)</td>
<td>19.3 (19.1)</td>
<td>19.0 (19.0)</td>
<td></td>
</tr>
</tbody>
</table>

*Unfiltered velocities: contain Geos, Ekman, Stokes, inertial oscillations, tidal current...
Validation of the GlobCurrent 0m currents: Comparison to OSCAR and Mercator currents
Validation of the GlobCurrent 15m currents: Comparison to OSCAR and Mercator currents

Comparison to 15m depth SVP velocities for the year 2013

| Year 2013: 525818 (510319) velocities * | RMS (cm/s) Bracket: |lat|>3 |
|------------------------------------------|---------------------|-----|
|                                          | U                   | V   |
| GC Geostrophic                           | 14.5 (13.6)         | 14.3 (13.6) |
| GC Geostrophic + Ekman                   | 13.5 (12.5)         | 13.6 (12.9) |
| OSCAR                                    | 28.3 (13.4)         | 14.1 (13.2) |
| Mercator (1/12°)                         | 16.9 (16.4)         | 16.2 (16.0) |

*Unfiltered velocities: contain Geos, Ekman, Stokes, inertial oscillations, tidal current...
Validation: Comparison to OSCAR and Mercator currents
Future improvements

✓ Cyclo-geostrophy contribution -> talk from P. Penven tomorrow morning
✓ Dynamical interpolation of altimeter maps of SLA -> talk from C. Ubelmann tomorrow afternoon
✓ Improved regional Mean Dynamic Topography / mean geostrophic velocities using high resolution SAR Doppler velocity information – ongoing work

Mean of ENVISAT ASAR Ascending path radial velocities (2009-2011)

✓ Improved Ekman current calculation – ongoing work
FUTURE IMPROVEMENTS: INTRODUCING NEW PARAMETERS IN THE EKMAN MODEL

\[ U_{osc} = u + \frac{\sqrt{2}}{\rho_0 (f+\omega) \delta} e^{z/\delta} \left[ \tau_s^x \cos\left(\frac{z}{\delta} - \frac{\pi}{4}\right) - \tau_s^y \sin\left(\frac{z}{\delta} - \frac{\pi}{4}\right) \right] \]

\[ V_{osc} = v + \frac{\sqrt{2}}{\rho_0 (f+\omega) \delta} e^{z/\delta} \left[ \tau_s^x \sin\left(\frac{z}{\delta} - \frac{\pi}{4}\right) + \tau_s^y \cos\left(\frac{z}{\delta} - \frac{\pi}{4}\right) \right] \]

\[ \tilde{u}_e = \beta \tilde{\tau} e^{i\theta} \]

**TEST1** \[ \tilde{u}_e = \frac{\beta}{H_{mld}} \tilde{\tau} e^{i\theta} \] Boyer-Montégut climatology

**TEST2** \[ \tilde{u}_e = \frac{\beta}{f} \tilde{\tau} e^{i\theta} \]

**TEST3** \[ \tilde{u}_e = \frac{\beta}{f+w} \tilde{\tau} e^{i\theta} \]

**TEST4** \[ \tilde{u}_e = \frac{\beta}{f} \tilde{\tau} e^{i\theta} \]

\[ \tilde{\tau}_e = \rho_0 C_D \left| \tilde{W} - \tilde{U}_g \right| (\tilde{W} - \tilde{U}_g) \]

**TEST5**: Winds > 4 m/s

**TEST6**: Removal of Stokes drift from Argo surface velocities

\[ \tau_e = \text{Effective Wind Stress} \]
\[ \delta = \text{Ekman depth} \]
\[ f = \text{planetary vorticity} \]
\[ w = \text{local vorticity} \]
\[ 2\omega = \partial_x v_{geo} - \partial_y u_{geo} \]
RESULTS: SURFACE MODEL

- Northern Hemisphere
  - U-: No impact of introducing the local vorticity \( w \) (red vs green)
  - V-: Negative impact of introducing effective wind stress (green vs purple)
  - Negative impact of introducing the Mixed Layer Depth in winter / positive in summer (blue vs black)
  - Negative impact of removing Stokes drift (light blue)

- Southern Hemisphere
  - U-: No impact of introducing the local vorticity \( w \) (red vs green)
  - V-: Negative impact of introducing effective wind stress (green vs purple)
  - Negative impact of introducing the Mixed Layer Depth in winter / positive in summer (blue vs black)
  - Negative impact of removing Stokes drift (light blue)

Percentage of variance explained by different surface Ekman model formulations (Black circle = \( f_0 \);
Blue line = \( f_0 \) MLD; Red line = \( f \); Green line = \( f+w \); Purple line = Eff WS; Kaki line = Wind > 4m/s; Light blue line = Stokes).
RESULTS: 15m MODEL

- no impact of introducing the local vorticity \( w \) (red vs green)
- negative impact of introducing effective wind stress (green vs purple)
- negative impact of introducing the Mixed Layer Depth in winter / positive in summer (blue vs black)

Percentage of variance explained by different surface Ekman model formulations (Black circle = \( f_0 \); Blue line= \( f_0 \) MLD; Red line= \( f \); Green line=\( f+w \); Purple line=Eff WS; Kaki line=Wind>4m/s)
FUTURE IMPROVEMENTS: INTRODUCING NEW PARAMETERS IN THE EKMAN MODEL

\[
U_{osc} = u + \frac{\sqrt{2}}{\rho_0 (f + \omega) \delta} e^{z/\delta} \left[ \tau_x^e \cos\left(\frac{z}{\delta} - \frac{\pi}{4}\right) - \tau_y^e \sin\left(\frac{z}{\delta} - \frac{\pi}{4}\right) \right]
\]

\[
V_{osc} = v + \frac{\sqrt{2}}{\rho_0 (f + \omega) \delta} e^{z/\delta} \left[ \tau_x^e \sin\left(\frac{z}{\delta} - \frac{\pi}{4}\right) + \tau_y^e \cos\left(\frac{z}{\delta} - \frac{\pi}{4}\right) \right]
\]

\[
\tilde{u}_{ek}(z) = \frac{\beta(z)}{H_{mld}^a (f + w)^b} e^{i \theta(z) c}
\]

(a, b, c) maximizing the % of variance explained by the model?

**FUTURE IMPROVEMENTS:**  
INTRODUCING NEW PARAMETERS IN THE EKMAN MODEL

\[
\tilde{u}_{\text{ek}}(z) = \frac{\beta(z)}{H_{\text{mld}}^a (f + w)^b} e^{i\theta(z)z^c} \quad a \in [0,1]; \ b \in [0,1]; \ c \in [0,1]
\]

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>B (10^-3)</th>
<th>(\theta)</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Surface model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>NH</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>1.9 10^{-2}</td>
<td>-36</td>
<td>32 19 0.51</td>
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<tr>
<td>SH</td>
<td>0.1</td>
<td>0.4</td>
<td>0.6</td>
<td>1.3 10^{-2}</td>
<td>33</td>
<td>42 26 0.6</td>
</tr>
<tr>
<td>GLOB</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>1.9 10^{-2}</td>
<td>+35</td>
<td>37 22 0.55</td>
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<tr>
<td><strong>15m depth model</strong></td>
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<tr>
<td>NH</td>
<td>0.3</td>
<td>1</td>
<td>0.9</td>
<td>6.4 10^{-5}</td>
<td>-57</td>
<td>7.0 6.0 0.25</td>
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<tr>
<td>SH</td>
<td>0.3</td>
<td>0.8</td>
<td>0.9</td>
<td>4.7 10^{-4}</td>
<td>55</td>
<td>11 10 0.32</td>
</tr>
<tr>
<td>GLOB</td>
<td>0.3</td>
<td>0.9</td>
<td>0.9</td>
<td>1.7 10^{-4}</td>
<td>-56</td>
<td>8.4 7.5 0.28</td>
</tr>
</tbody>
</table>

Ralph and Niiler (1999) worked on 1503 15m drogued drifters deployed in the tropical Pacific between March 1987 and December 1994. They found for optimal model (for the speed only) the triplet (a=0.23, b=0.58, c=1.16).
FUTURE IMPROVEMENTS: INTRODUCING NEW PARAMETERS IN THE EKMAN MODEL

\[
\tilde{u}_{ek}(z) = \frac{\beta(z)}{H_{mld}^{0.2}(f + w)^{0.4}} e^{i\theta(z)} \tau^{0.6}
\]

Percentage of variance explained by different 0m depth Ekman model formulations (Black line = New; Blue line= optimized full period; Green line=optimized monthly).

U- Northern Hemisphere  V-

U- Southern Hemisphere  V-
FUTURE IMPROVEMENTS: INTRODUCING NEW PARAMETERS IN THE EKMAN MODEL

\[ \bar{u}_{ek}(z) = \frac{\beta(z)}{H_{mld}^{0.3} (f + w)^{0.9}} e^{i\theta(z)\tau^{0.9}} \]

Percentage of variance explained by different 0m depth Ekman model formulations (Black line = New; Blue line = optimized full period; Green line = optimized monthly).

U- Northern Hemisphere

V- Southern Hemisphere

Percentage of variance explained by different 0m depth Ekman model formulations (Black line = New; Blue line = optimized full period; Green line = optimized monthly).
Future Improvements: Ekman in the Mediterranean Sea

Personal communication from M. Menna and P.-M. Poulain
Work from the JPO 2002 paper has been updated

Winds: NCDC blended daily 0.25° grids
Different drifters in the Med Sea for the period 2002-2014

<table>
<thead>
<tr>
<th>Drifter Type</th>
<th>$\beta$</th>
<th>$R^2$ (%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODE</td>
<td>$0.008\exp(-18^\circ i)$</td>
<td>10</td>
<td>74498</td>
</tr>
<tr>
<td>SVP drogued</td>
<td>$0.003\exp(-33^\circ i)$</td>
<td>2</td>
<td>22805</td>
</tr>
<tr>
<td>SVP undrogued</td>
<td>$0.01\exp(-18^\circ i)$</td>
<td>17</td>
<td>39648</td>
</tr>
<tr>
<td>SVP unknown</td>
<td>$0.006\exp(-34^\circ i)$</td>
<td>6</td>
<td>63217</td>
</tr>
</tbody>
</table>
12 years (2002-2014) of global maps of:

- Geostrophic velocities
- Ekman velocities at 0m and 15m
- Combined Geostrophic+Ekman at 0m and 15m
- Stokes drift (from the WaveWatch-III model)

**Temporal resolution:**
3-hourly

**Spatial resolution:**
Native 1/8° resolution for the geostrophic component
Native ¼° for the Ekman component and the combined Geostrophic+Ekman
Reinterpolated on the GlobCurrent 1/10° grid

- Global Drifter validation datasets (1993-2014)

Available for download on the GlobCurrent web site [http://www.globcurrent.org/](http://www.globcurrent.org/) (in a few days...)

An error estimate is also provided
Analytical solution for shear: geostrophic balance, steady Ekman, thermal wind shear (SST horizontal gradient).

\[ \zeta : \text{MADT} \]
\[ \tau : \text{wind stress divided by } \rho = 1025 \text{ km.m}^{-3} \]
\[ \delta_e : \text{pseudo Ekman depth} : \delta_e \approx (A/\nu f)^{1/2} \]
\[ H \text{ is the depth where the vertical shear}=0 : H=125 \text{ m} \]
\[ A : \text{horizontal viscosité.} \]
\[ \nabla \theta = g \chi_T \nabla S \text{ with } g=9.8 \text{ m.s}^{-2}, \chi_T = 3.10^{-4} \text{ K}^{-1} \text{ thermal expansion coeff}, \text{SST is Reynolds SST.} \]
Thermal wind contribution

SST on 1993-01-01

Zonal buoyancy current (GC) on 1993-01-01

Meridional buoyancy current (GC) on 1993-01-01

Mean buoyancy current on 1993-01-01

Mean buoyancy current on 1993-01-15
Horizontal viscosity: related to 10m wind $W$

$$A = a \left( \frac{|W|}{W_1} \right)^b$$

if $|W| \geq 1 \text{ m.s}^{-1}$: $W_1 = 1 \text{ m.s}^{-1}$
if $|W| < 1 \text{ m.s}^{-1}$: $A = a$

Equatorial area: $a = 8.1 \times 10^{-5} \text{ m}^2.\text{s}^{-1}$; $b = 2.2$
Global: $a = 2.85 \times 10^{-4} \text{ m}^2.\text{s}^{-1}$ et $b = 2.0$
OSCAR equations

\[ U'(z) = \frac{\sinh \left( \frac{H + z}{h_e} \right) \tau}{\sinh \left( \frac{H}{h_e} \right) u'_{\tau}} + \frac{2 \sinh \left( \frac{H + z}{2h_e} \right) \sinh \left( \frac{z}{2h_e} \right) h_e^2 \nabla \theta}{\cosh \left( \frac{H}{2h_e} \right) u'_{\theta}} \]

\[ U'(z = 0) = \frac{\tau}{A} \]

\[ U'(z = -H) = 0 \]
Plans for exploiting new products
\[ \tilde{u}_{ek}(z) = \frac{\beta(z)}{H^a_{mld}(f + w)^b} e^{i\theta(z)} \tau^c \]

\[ a \in [0,1]; \quad b \in [0,1]; \quad c \in [0,1] \]

U-NH

V-NH

U-SH

V-SH

Green: a; Red: b; Black: c
IMPACT OF INTRODUCING NEW PARAMETERS – 15m MODEL

\[ \tilde{u}_{ek}(z) = \frac{\beta(z)}{H_{mld}^a (f + w)^b} e^{i\tau(z)} \tau^c \]

\( a \in [0,1]; \ b \in [0,1]; \ c \in [0,1] \)

Green: \( a \); Red: \( b \); Black: \( c \)