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

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COLLECTE LOCALISATION SATELLITES

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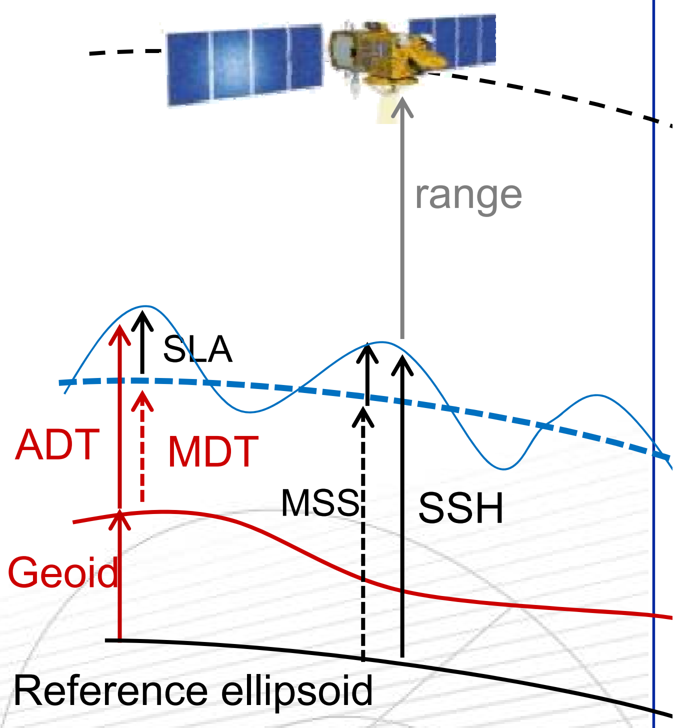
INTRODUCTION

❑ 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 ellispoid) 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

filtering

Large scale
MDT=First guess

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

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

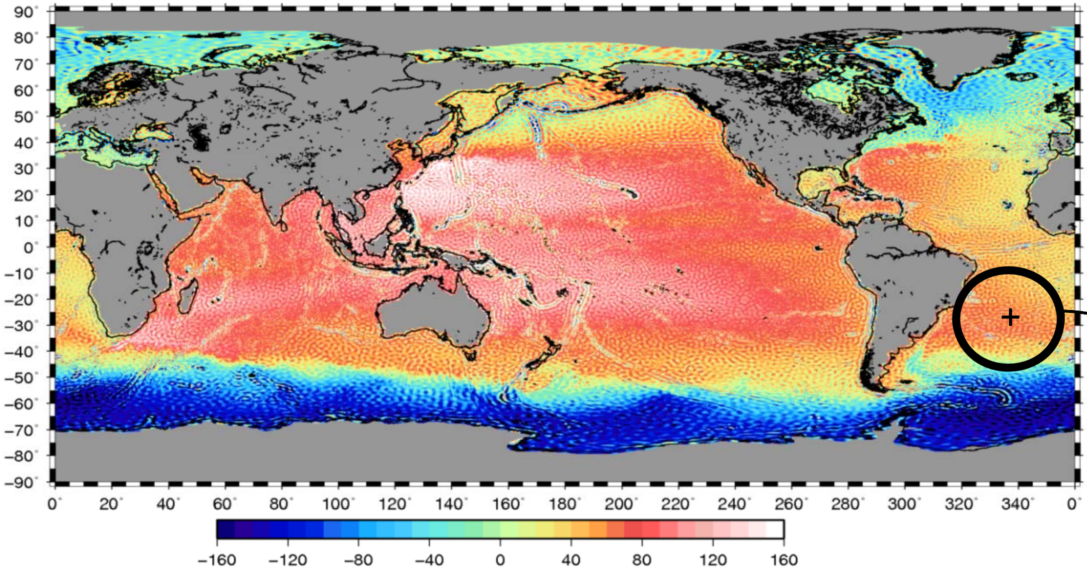
INTRODUCTION

CMDT CNES-CLS09 ⟶ CMDT CNES-CLS13

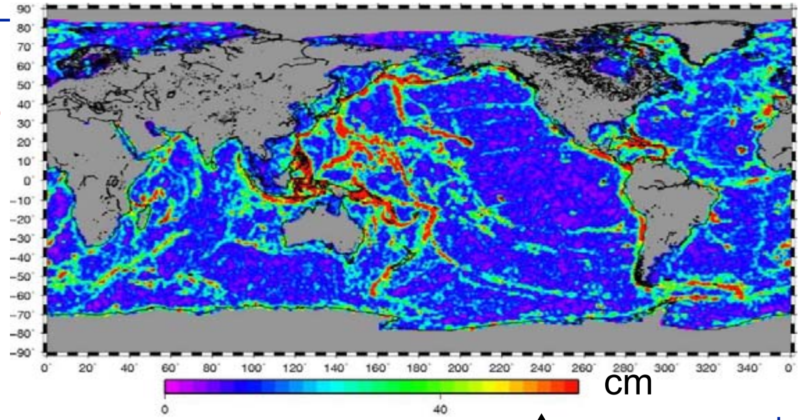
	CMDT CNES-CLS09	CMDT CNES-CLS13
MSS used for first guess computation Geoid model used for First Guess computation:	MSS CNES-CLS01 EIGEN-GRGS.RL02.MEAN based on $4^{1/2}$ years of GRACE data	MSS CNES-CLS11 EGM-DIR-R4 based on 7 years of GRACE data and 2 years of reprocessed GOCE data
Filtering used for First Guess computation:	Optimal filter (~400 km)	Optimal filter ~125km
Buoy velocities dataset	15m drogued SVP drifters Period 1993-2008	SD-DAC SVP drifters, with or without the drogue - Period 1993-2012 Corrected for Wind slippage in case of drogue loss
Ekman model	Parameters fitted over the 1993-2008 period, by latitude, year, and month (3 months moving window)	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
T/S data	CTD, ARGO Period 1993-2008	CTD, ARGO (CORA3.4) Period 1993-2012
Resolution	Global, ¼° (no Mediterranean)	Global 1/4° (including the Mediterranean Sea)

Computation of the MDT first guess

MDT=MSS CNES-CLS11 – EGM-DIR-R4



RAW DIFFERENCE



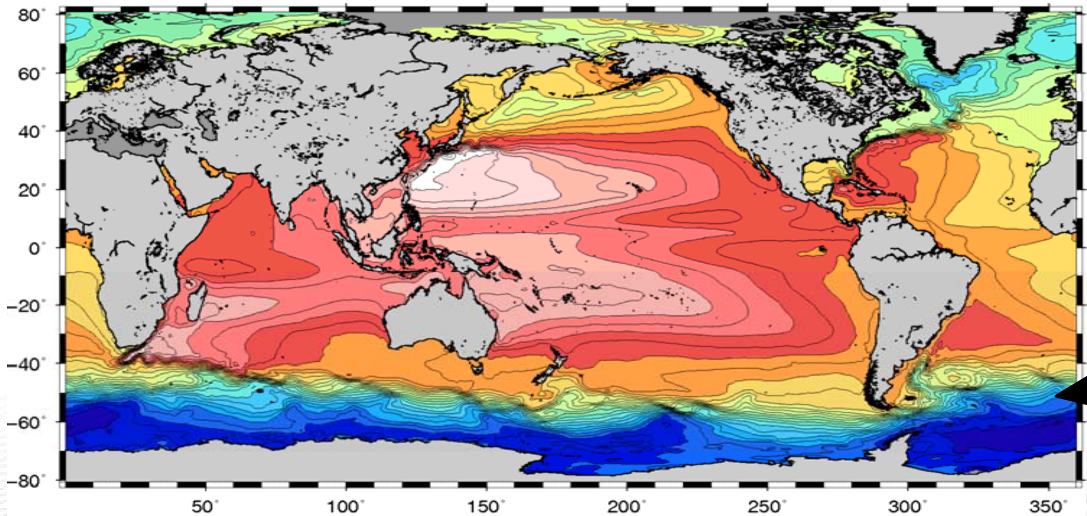
1- Observation error

Objective analysis

$$\sum_{i=1}^{i=N} \alpha_i \, MDT_i$$

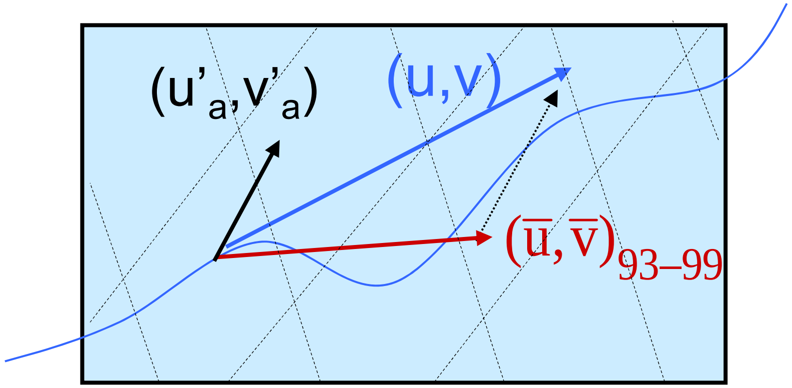
2- Variance of the estimated signal

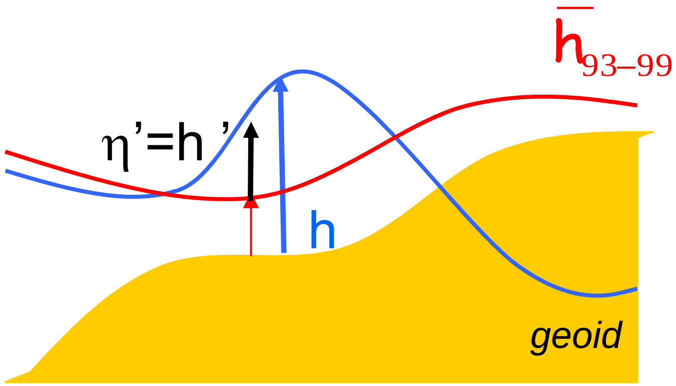
3- Correlation radius



OPTIMALLY FILTERED ~125 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) :

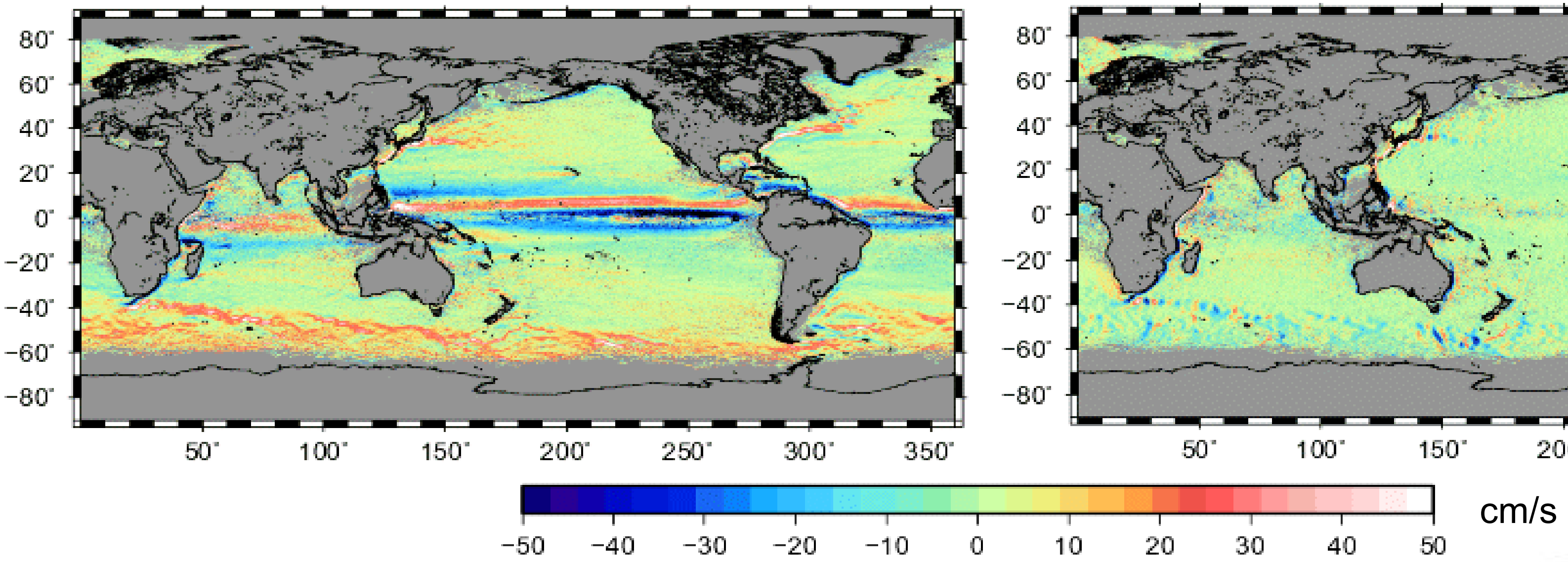
1- the altimetric height/velocity anomaly is interpolated to the position/date of the in-situ data.

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

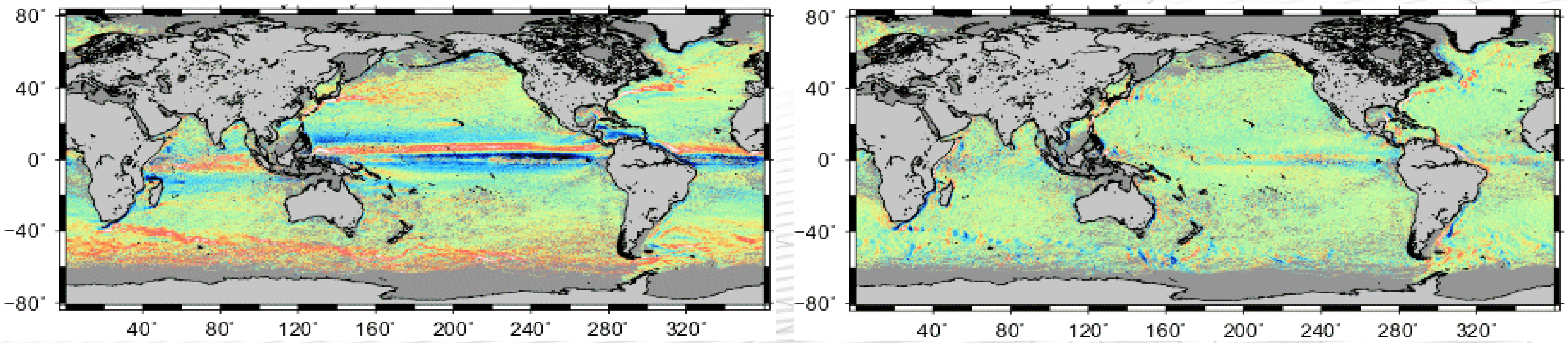
3- the altimetric anomaly is subtracted from the in-situ height/velocity

$$\overline{h}_{93-99} = h_{insitu} - h'_{93-99} \qquad \overline{u}_{93-99} = u_{insitu} - u'_{93-99} \qquad \overline{v}_{93-99} = v_{insitu} - v'_{93-99}$$

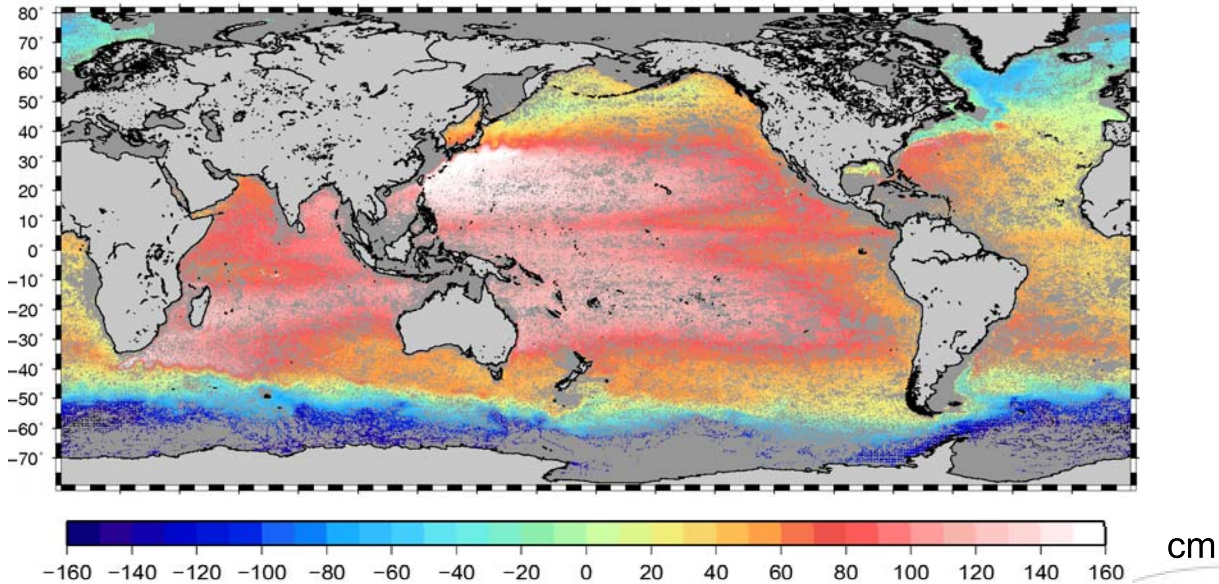
Final set of synthetic mean velocities



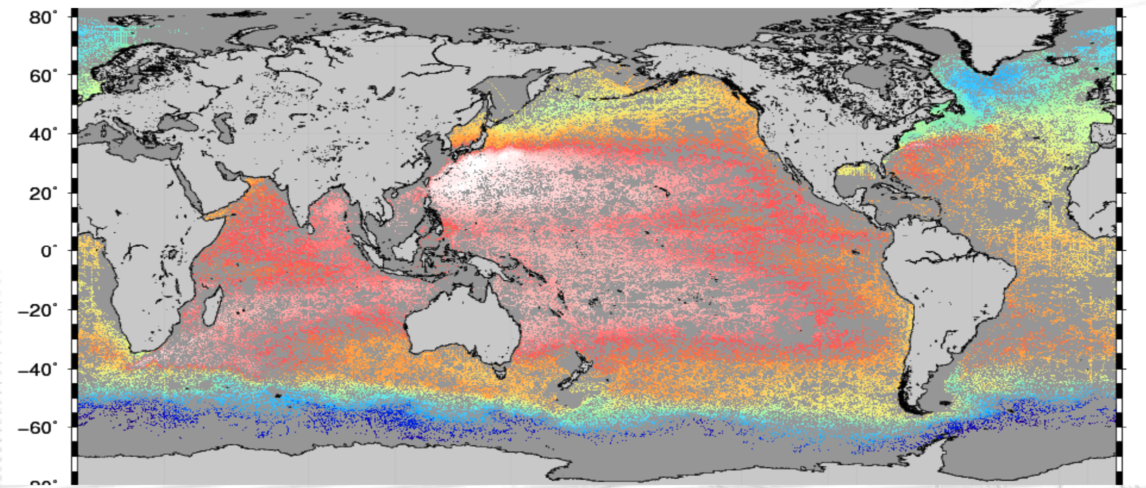
Dataset used for the CNES-CLS09 MDT computation



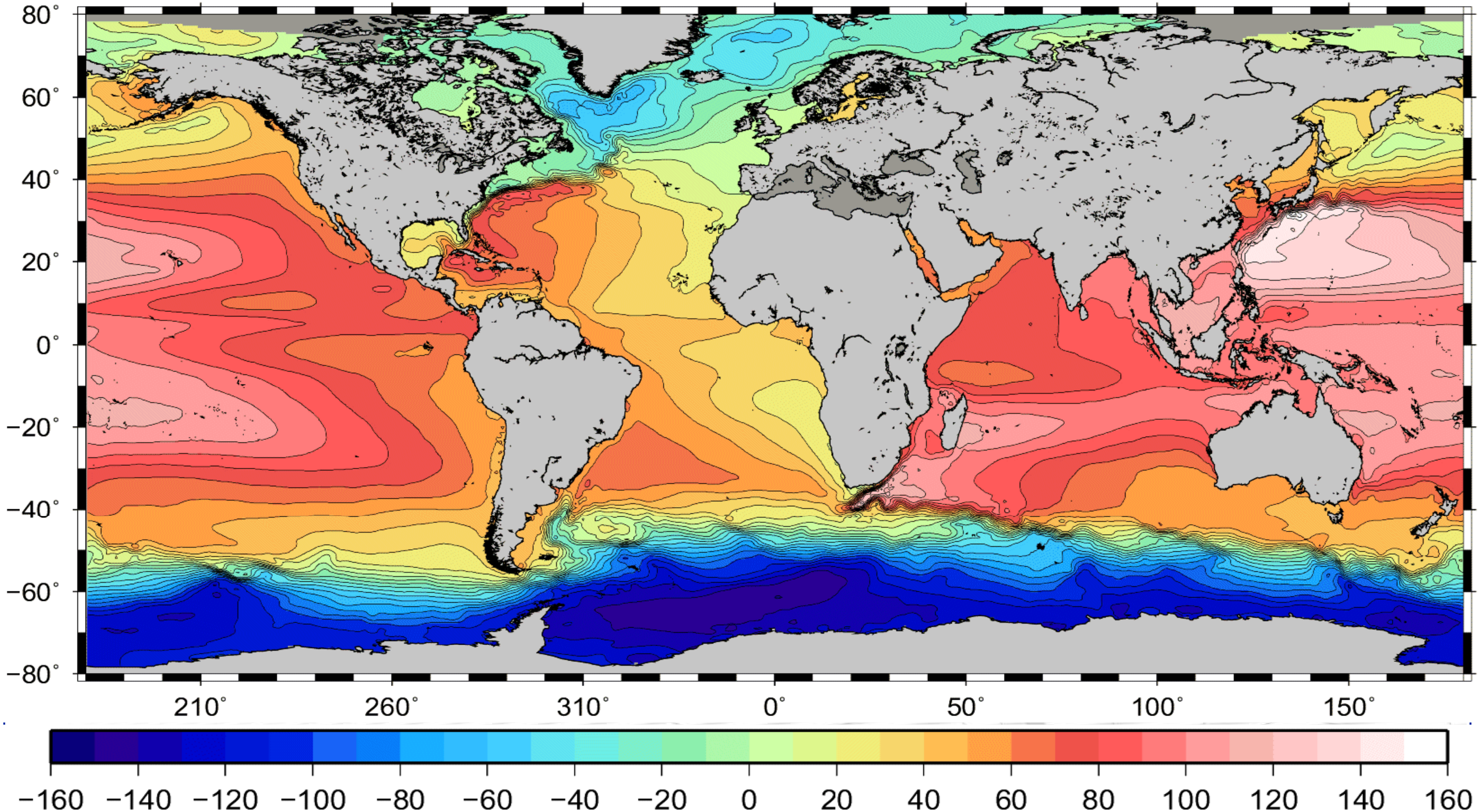
Final set of mean heights from the CORA3.4 T/S profiles



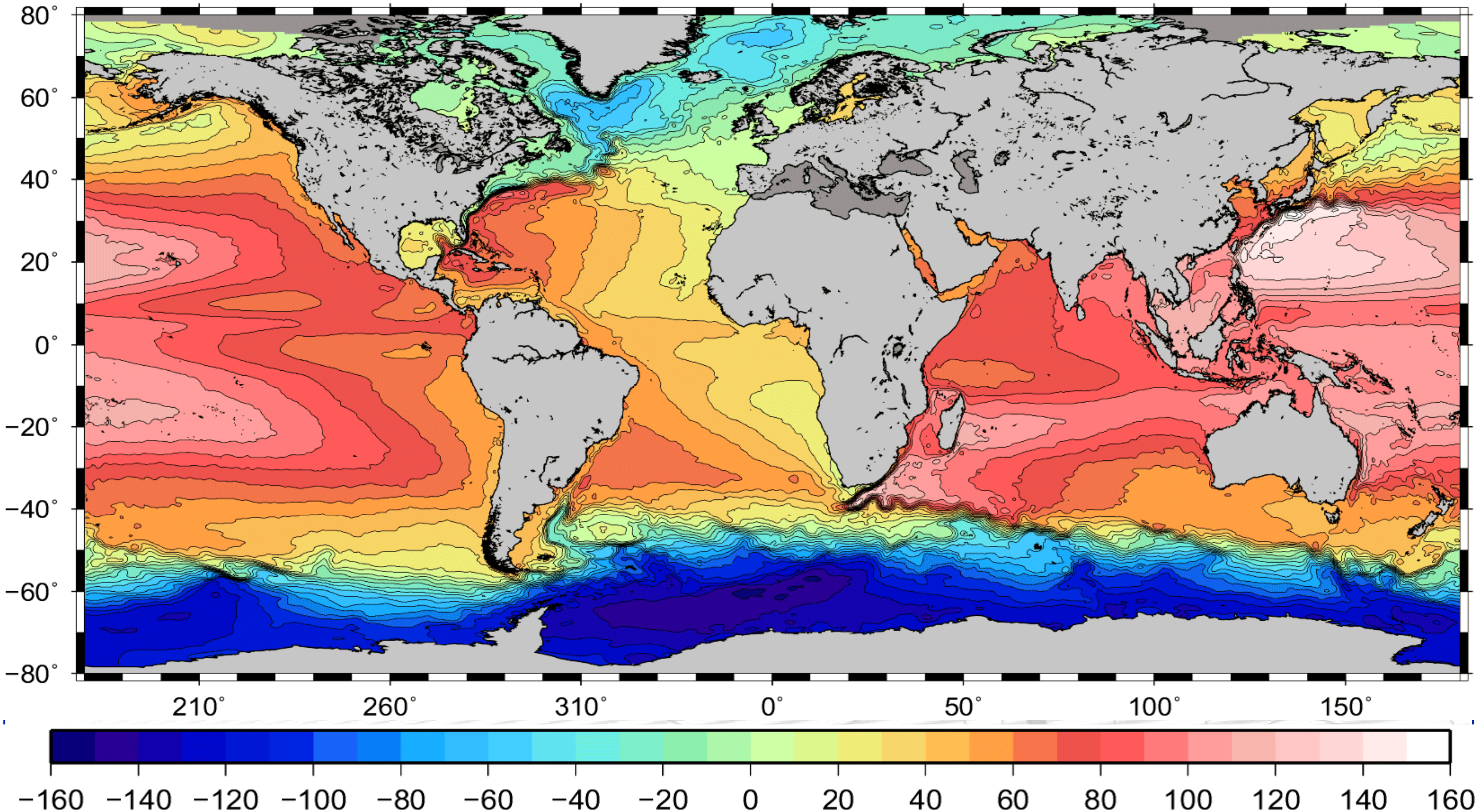
Dataset used for the CNES-CLS09 MDT computation



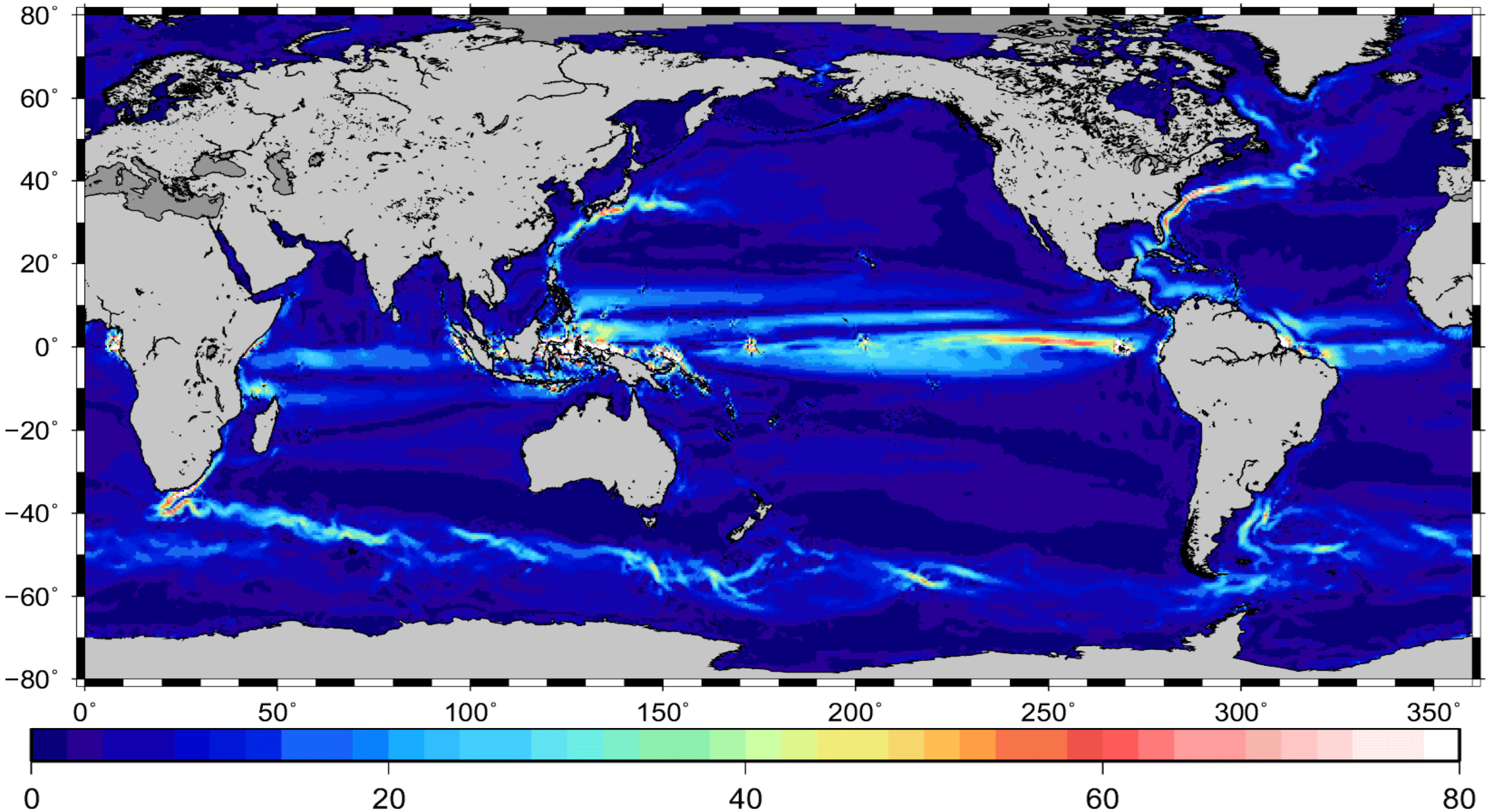
The GOCE only MDT (First Guess)



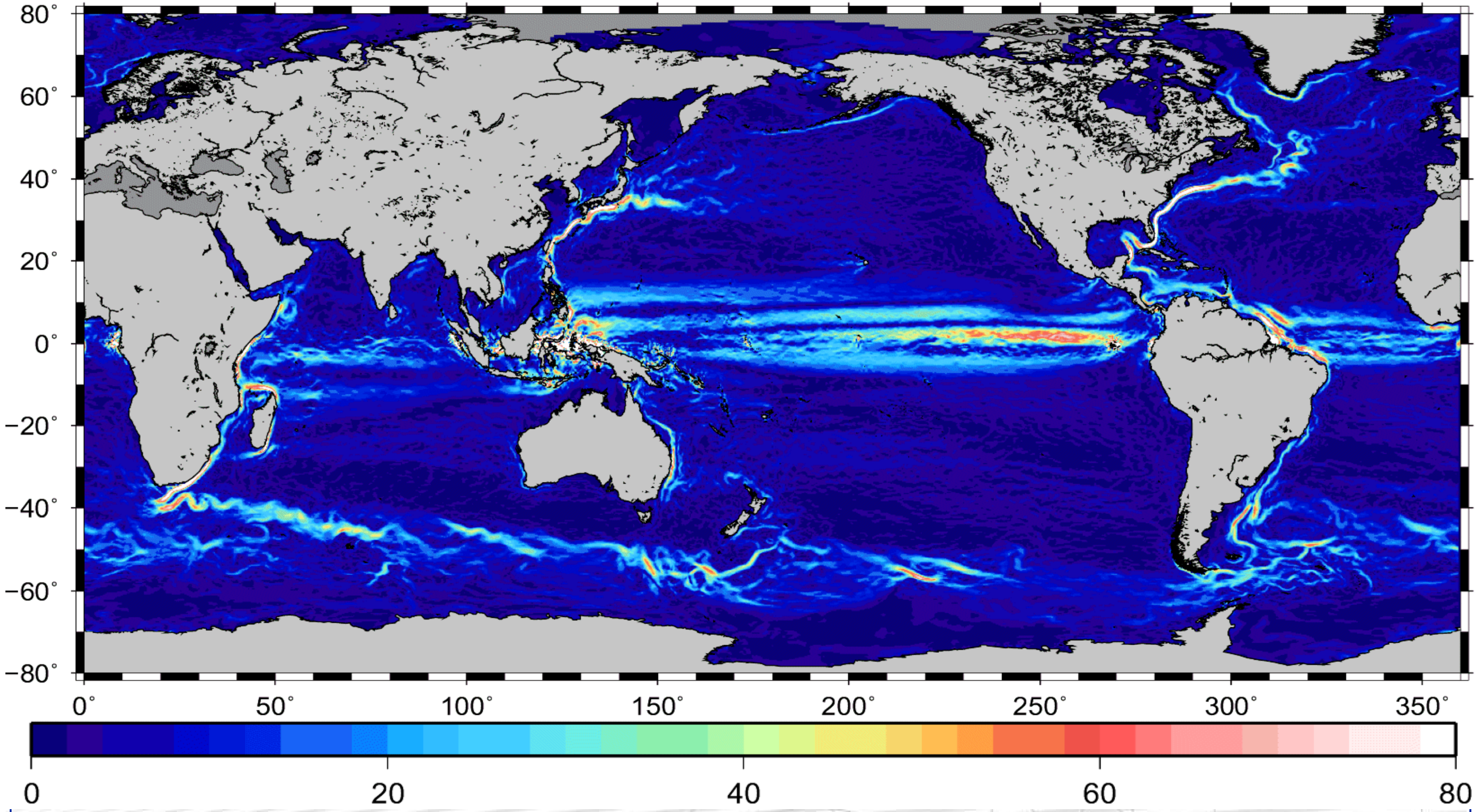
The CNES-CLS13 MDT



The GOCE only MDT (First Guess)



The CNES-CLS13 MDT



VALIDATION:
COMPARISON TO INDEPENDENT SURFACE VELOCITIES

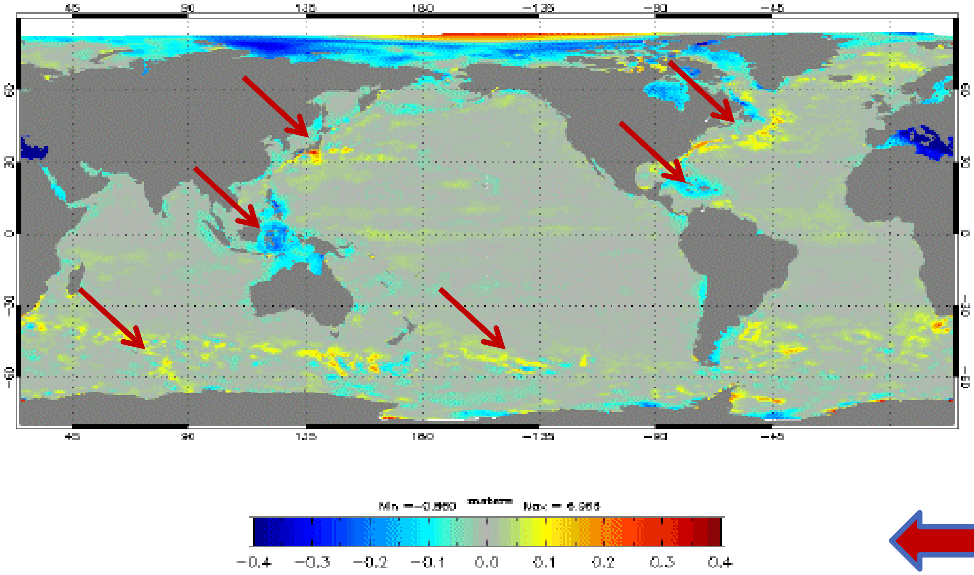
RMS differences between the ARGO floats surface velocities (YoMaHa) and altimeter derived velocities (expressed in % of Argo floats velocity variance)

Comparison to other existing MDT solutions

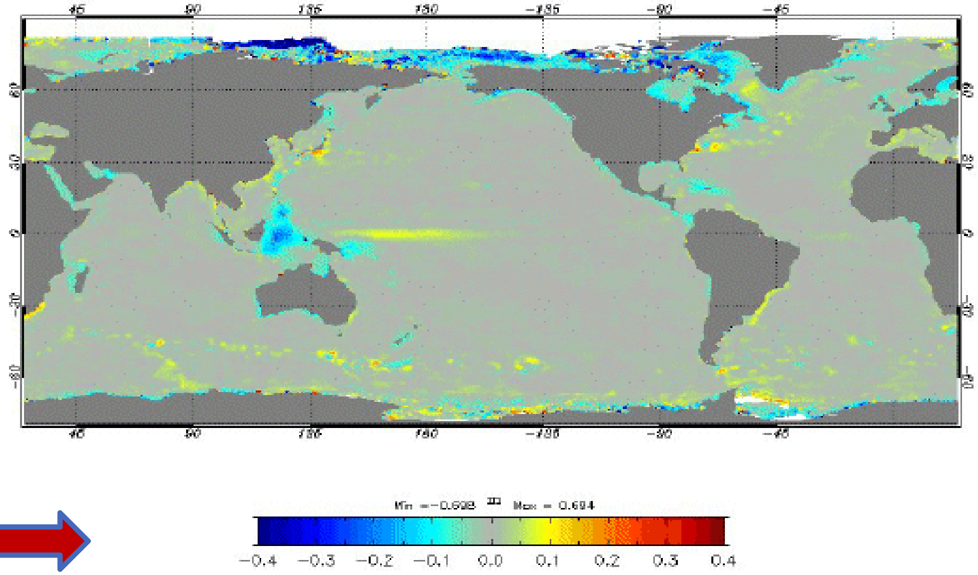
	MDT CNES-CLS13	MDT CNES-CLS09	MDT GOCE (First Guess)	MDT GLORYS2V1	MDT MAX08
RMS U	44.6	46.1	46.7	47.0	46.3
RMS V	52.4	53.2	55.0	55.8	54.0

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

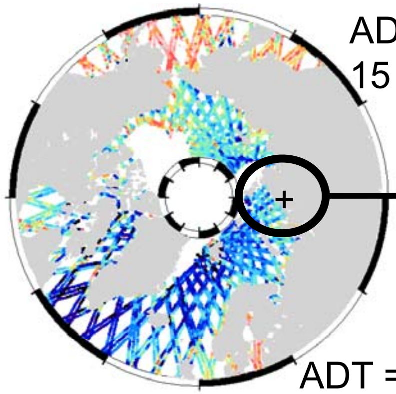
- ❑ A new global MDT is currently being computed at CLS/CNES
- ❑ Compared to the previous solution (CNES-CLS09 MDT) the major improvements come from
  - ➢ the use of one of the most recent satellite-only geoid model based on GRACE and GOCE data (EGM-DIR-R4)
  - ➢The use of updated in-situ datasets
    - ➢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)

PERSPECTIVES

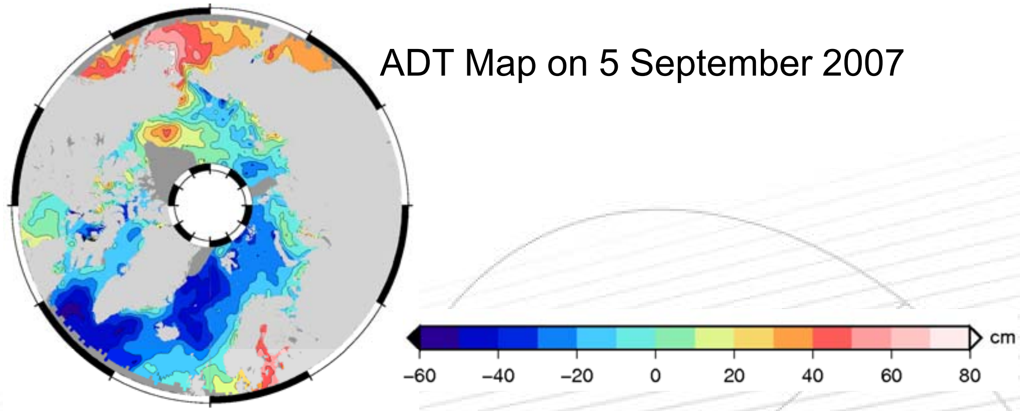
- ❑ The CNES-CLS13 MDT will be publically available in November 2013
- ❑ Also, further, extensive validation will be carried out
- ❑ Specific work in the Arctic Ocean (new MSS or new method to compute directly ADT)



ADT Along Track
15 Aug – 25 Sept 2007

$$\sum_{i=1}^{i=N} \alpha_i \; ADT_i \longrightarrow$$

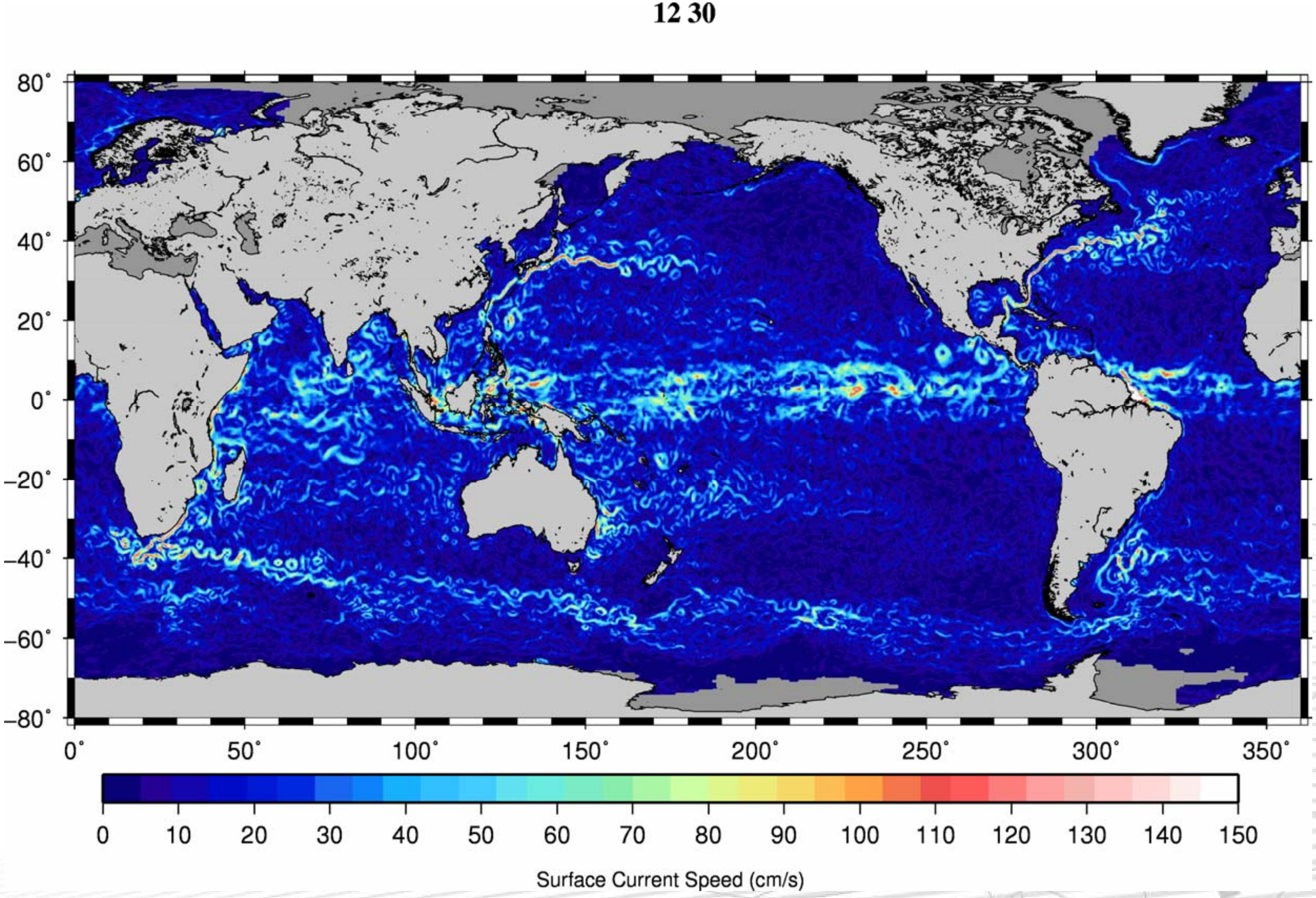
ADT = $SSH_{ENVISAT}$ – EGM-DIR-R4



ADT Map on 5 September 2007

❑ 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.

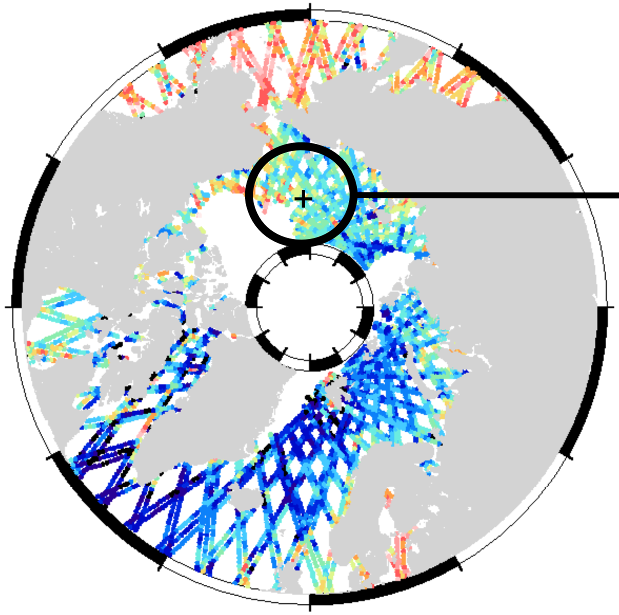
❑ 20 years of absolute surface currents from MDT+SLA



❑ For further information, don't hesitate to contact us! **smulet@cls.fr** **mrio@cls.fr**

ADT Mapping

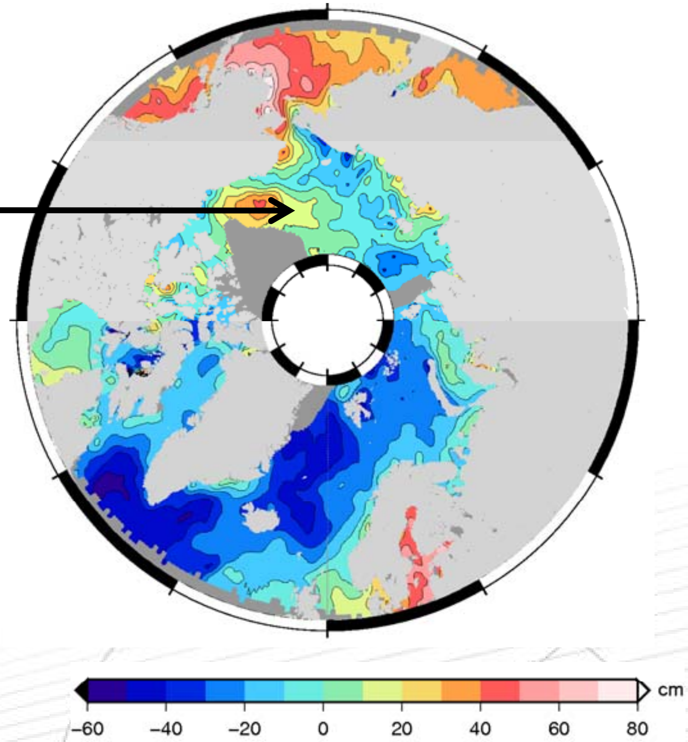
Observations : ADT Along Track
15 August – 25 September 2007



$$\sum_{i=1}^{i=N} \alpha_i \; ADT_i$$

Objective analysis

ADT Map on 5 September 2007



1- along track interpolation of the geoid (GOCE_R3)

2- ADT = $SSH_{ENVISAT}$ – Geoid

3- filter at 125 km of resolution

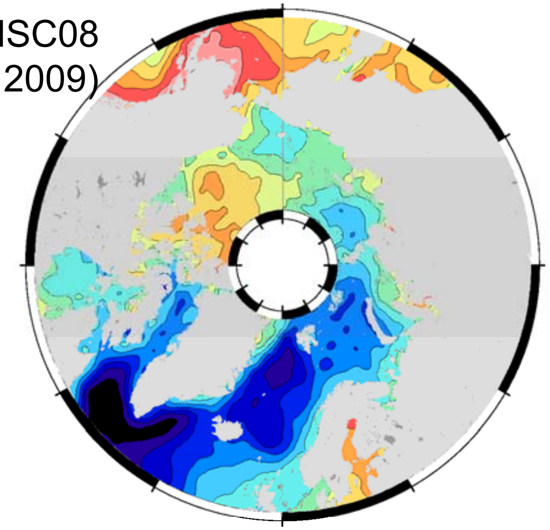
1- Observation error

2- Variance of the estimated signal

3- Correlation radius :
Time → 15 days
Space →125 km of resolution

Classical *versus* direct method

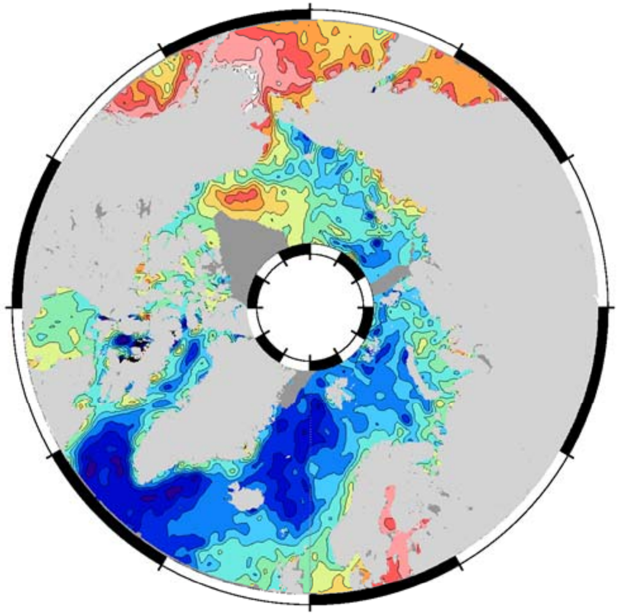
MDT DNSC08
(Andersen et al., 2009)



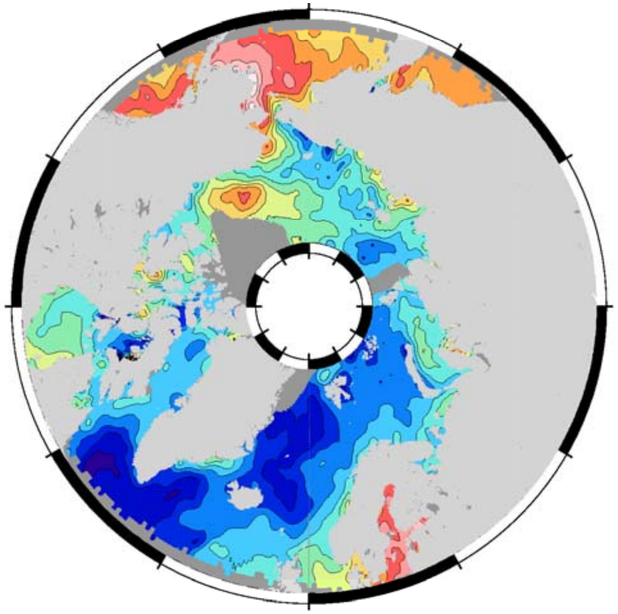
→ Beaufort gyre : +40 cm, contracted

→ Gradient across the bassin : 100 cm

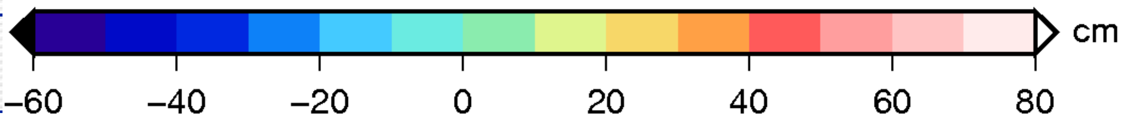
Classical method :
$[\text{MDT DNSC08 + SLA}]_{125km}$



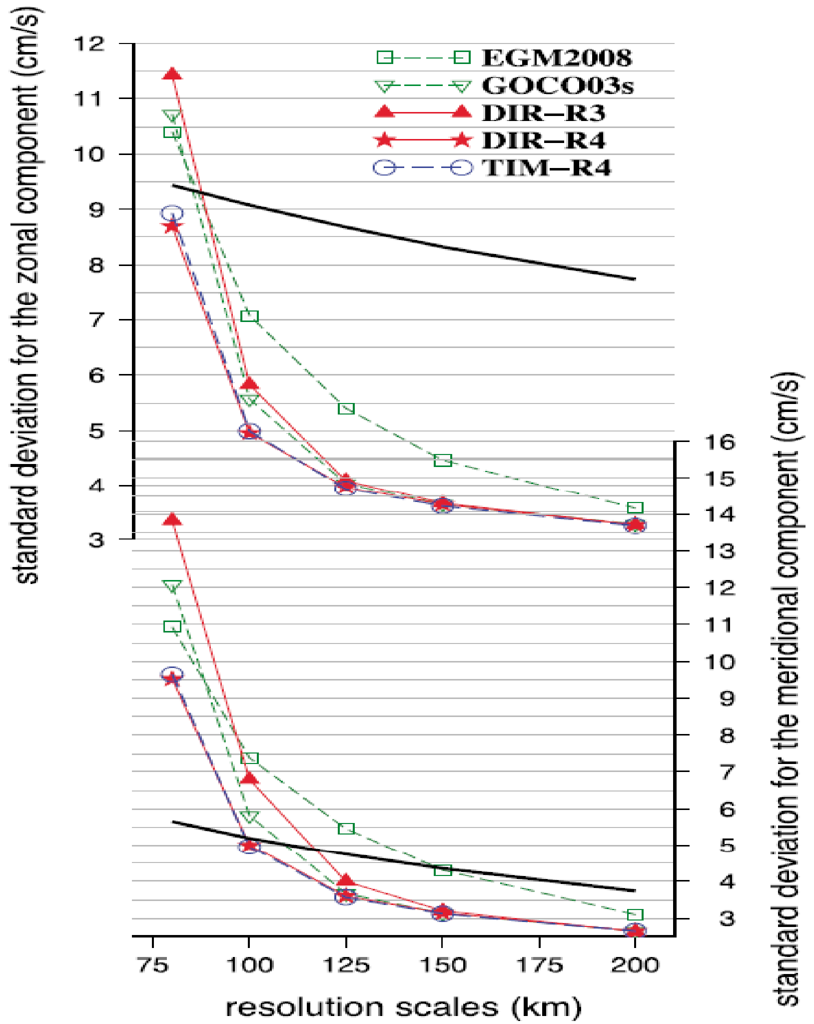
Direct method :
$[\text{SSH – GOCE\_R3}]_{125km}$



5 September 2007



Computation of the MDT first guess



Bruinsma et al, 2013, GRL

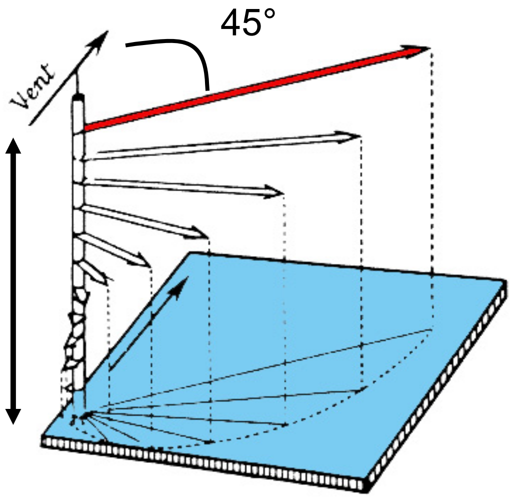
Drifting buoy data processing: Modelling Ekman currents

Ekman theory

$$u_e = \pm \underbrace{\frac{\pi\sqrt{2}}{\rho f D_e} e^{\frac{\pi}{D_e} z}}_{\beta} * \tau * \underbrace{\cos\left(\frac{\pi}{4} + \frac{\pi}{D_e} z\right)}_{\theta}$$

$$v_e = \underbrace{\frac{\pi\sqrt{2}}{\rho f D_e} e^{\frac{\pi}{D_e} z}}_{\beta} * \tau * \underbrace{\sin\left(\frac{\pi}{4} + \frac{\pi}{D_e} z\right)}_{\theta}$$

β θ



Model

Rio and Hernandez, 2003

$$\vec{u}_e = \beta \vec{\tau} e^{i\theta}$$

$\vec{u}_{buoy} - \vec{u}_{alti}$

Wind stress from ERA INTERIM

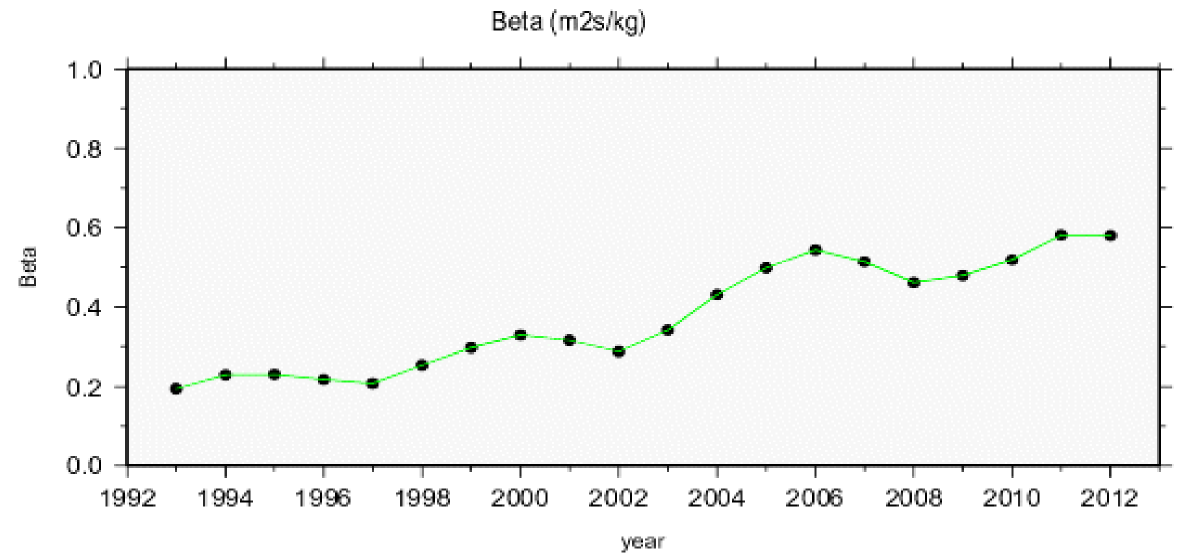
Band pass filtered 30 hours - 20 days

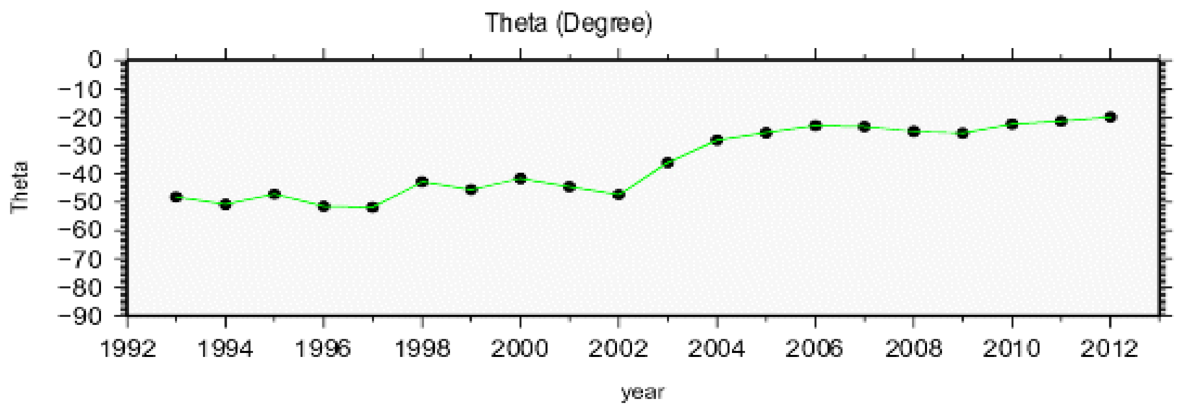
β and θ are estimated through least square fit

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

β and θ computed over the global ocean by year





Strong dependency of β and θ parameters with time

✓ Increase with time of parameter β

✓ Decrease with time of |θ| Direction of Ekman currents closer to wind direction

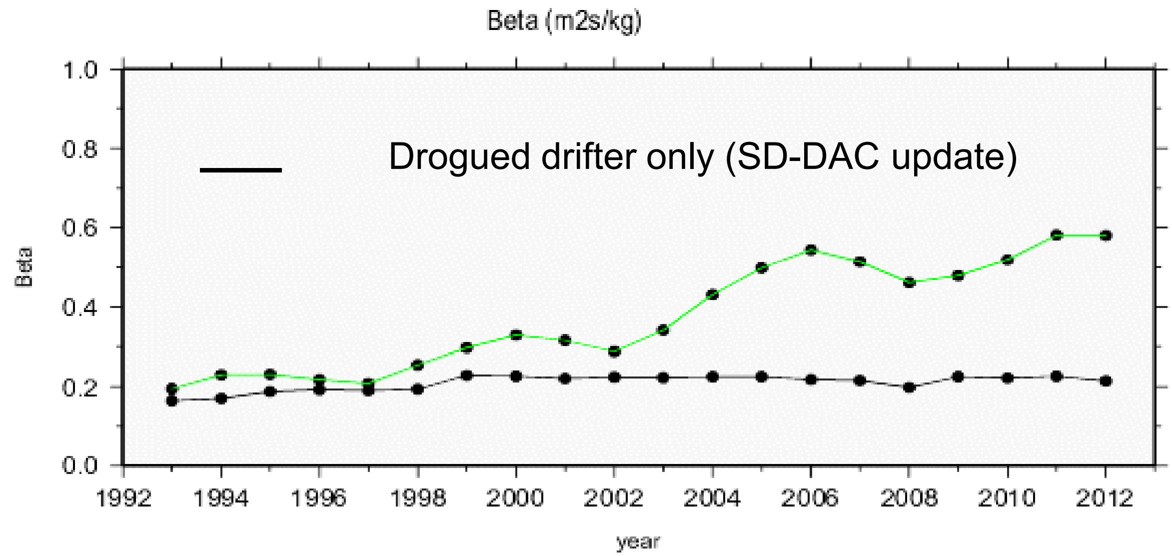
Rio et al, 2011

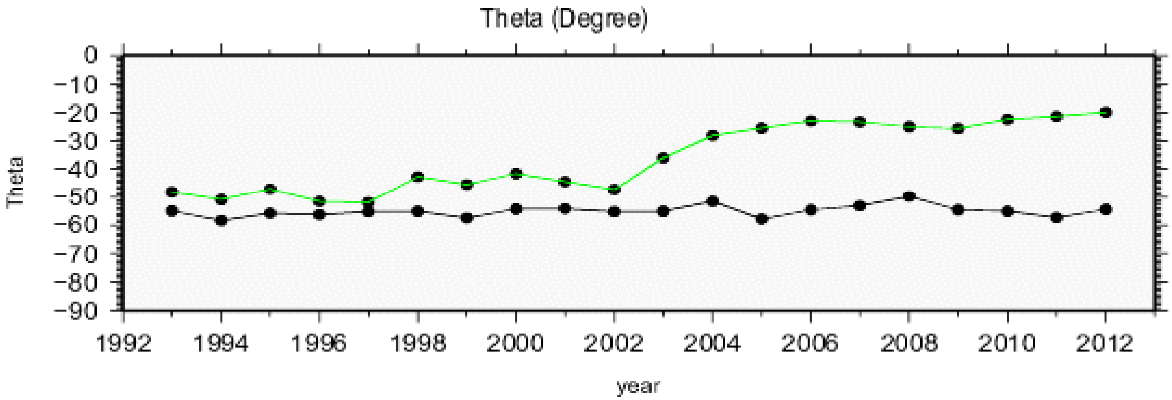
This was due to a failure in the SVP buoy drogue loss detection system: Undetected undrogued drifter, directly advected by the wind in addition to surface currents, pollute the dataset

Grodsky et al, 2011; Rio et al, 2012, Lumpkin et al, 2012

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

β and θ computed over the global ocean by year





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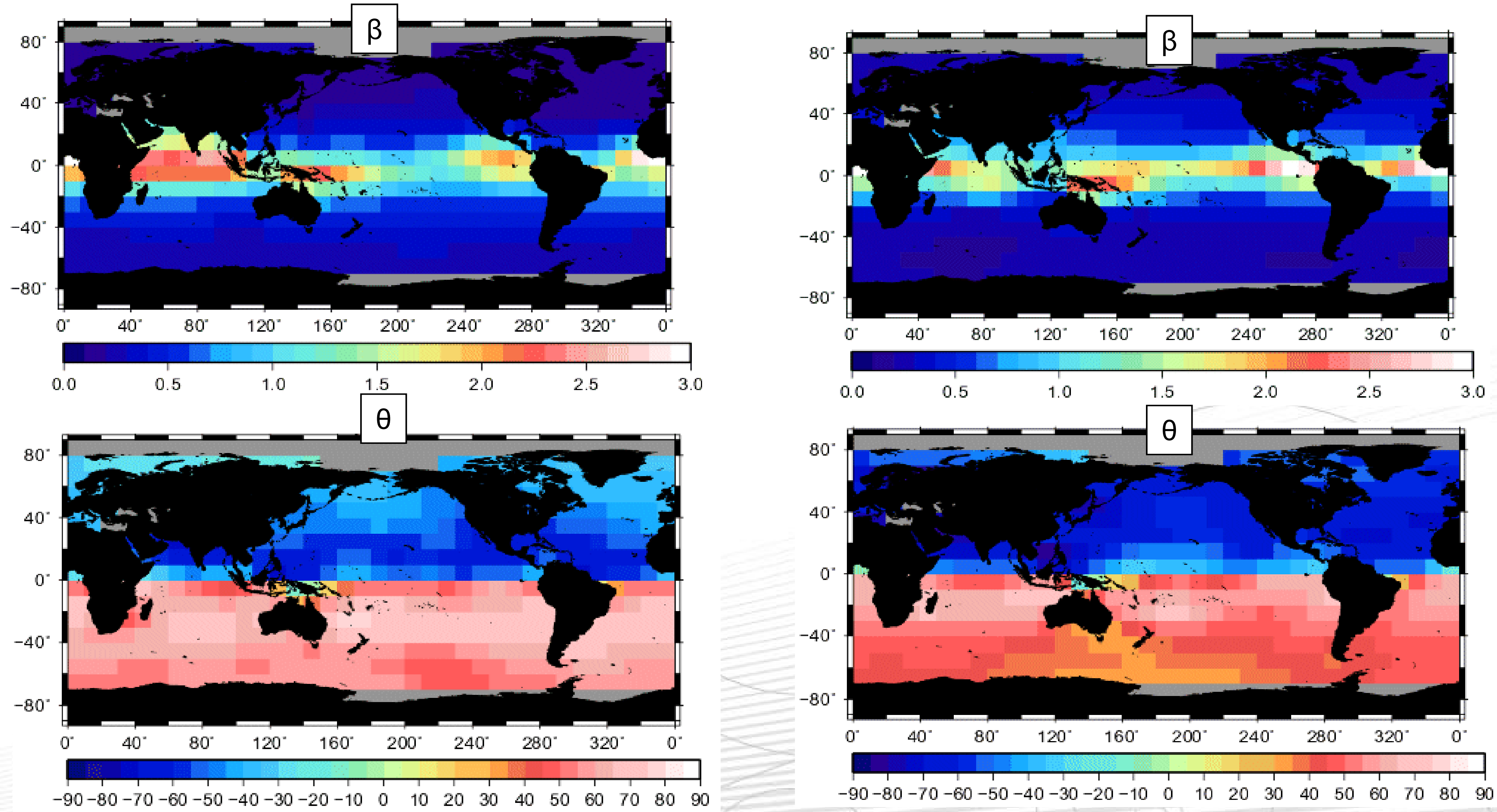
Drifting buoy data processing: Modelling Ekman currents at 15m depth

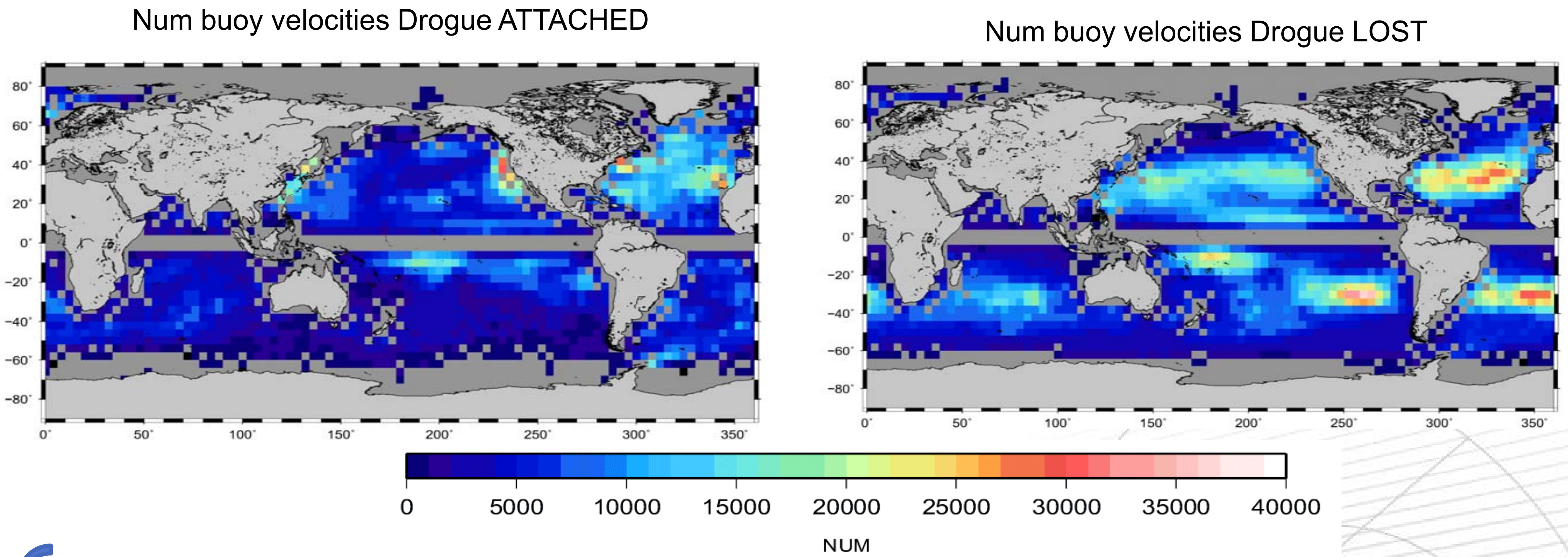
JANUARY

JUNE



Drifting buoy dataset:
Number of drogued versus undrogued data

Content of the updated SD-DAC SVP drifter dataset



STRONG interest of using undrogued buoy velocities to improve data coverage

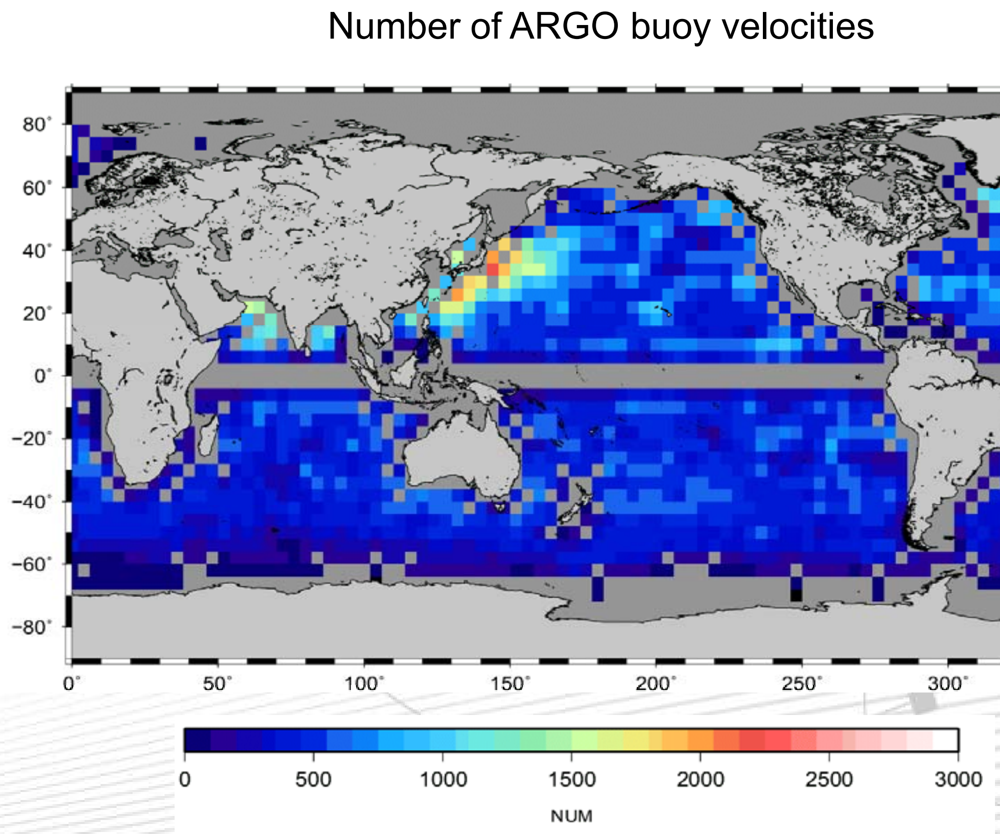
However, undrogued buoys are advected by

- **surface** Ekman currents, not **15m** Ekman currents!
- **the direct action of wind (wind slippage)**

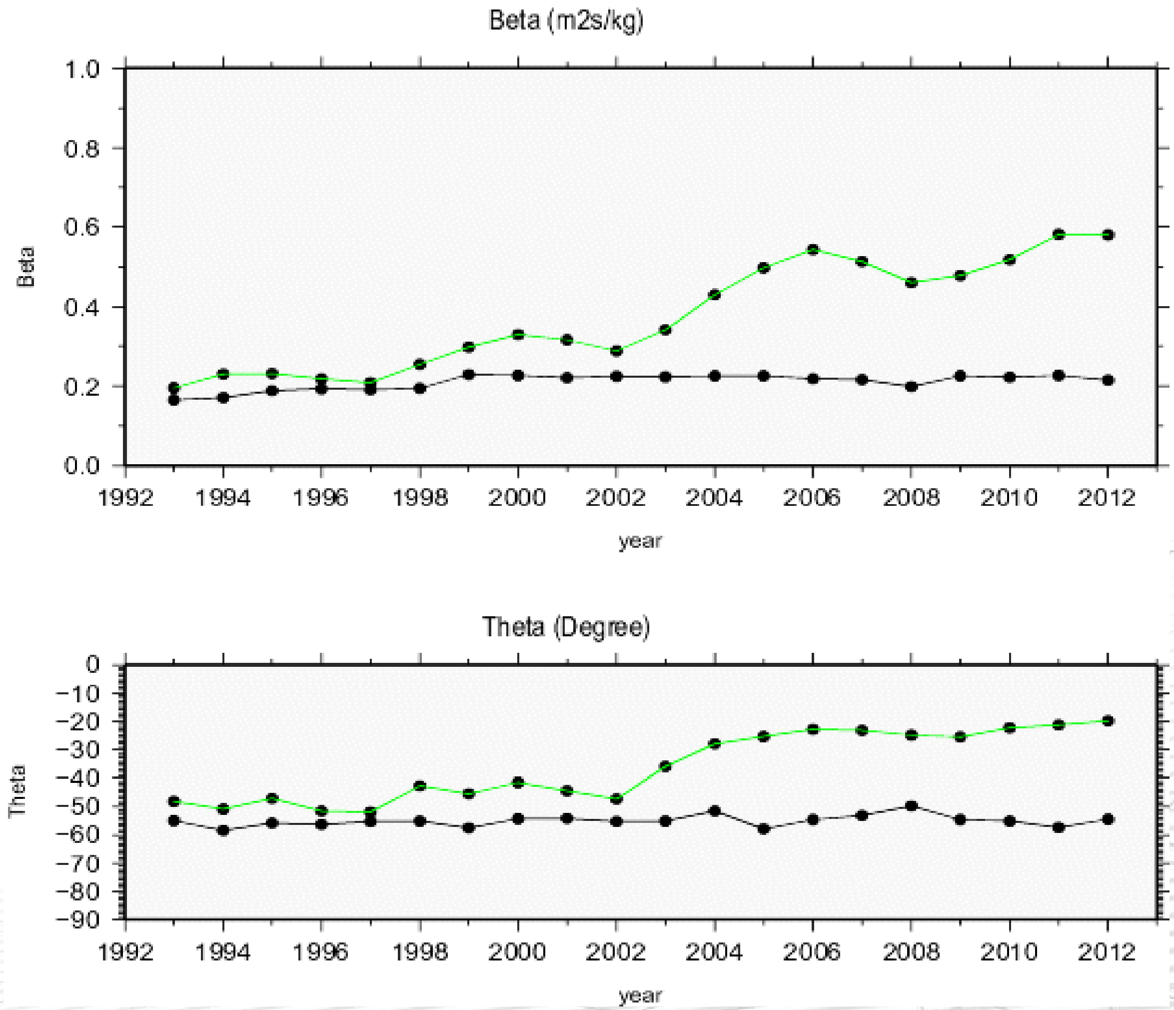
These 2 effects must be modeled and removed

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



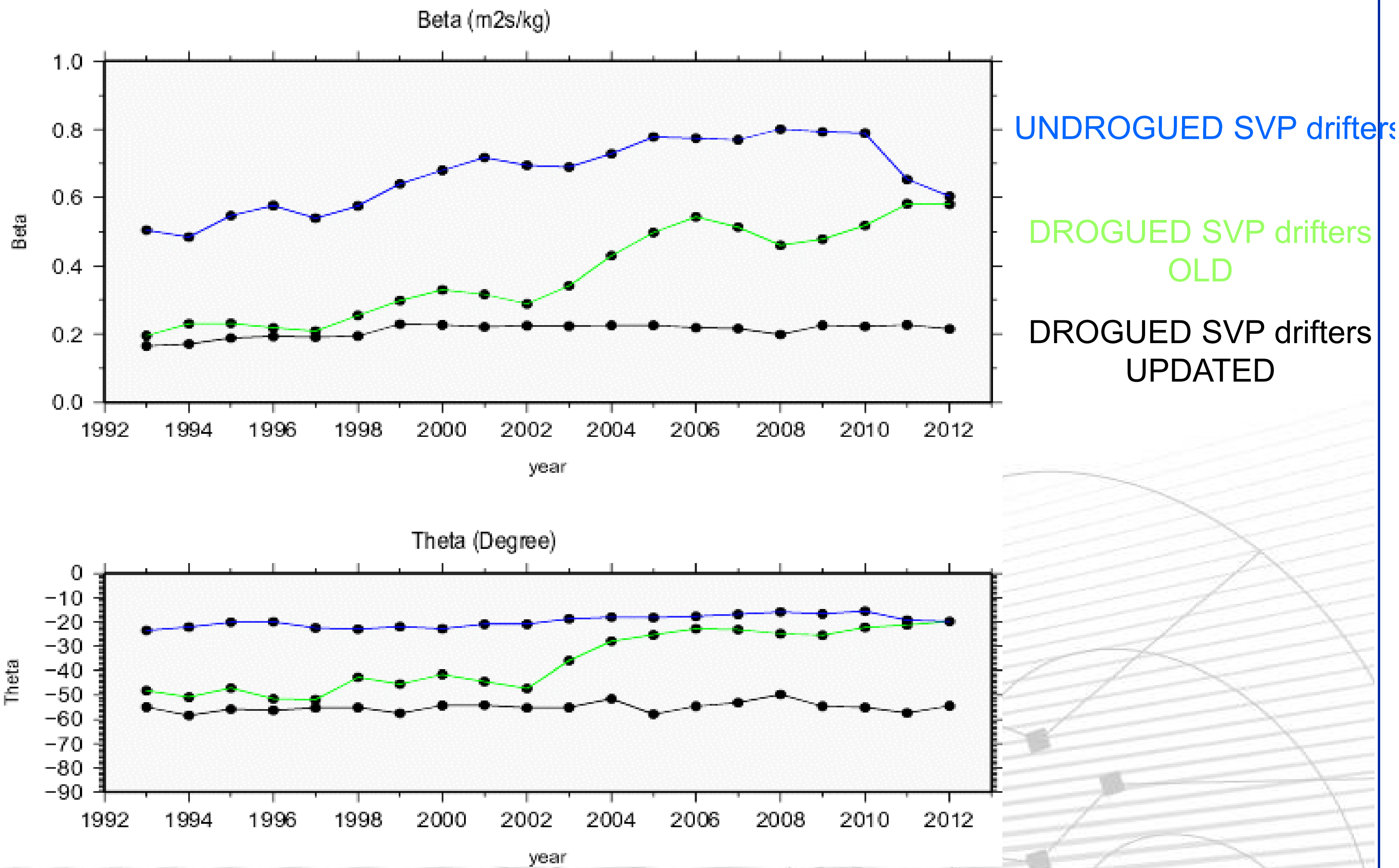
Drifting buoy data processing: Modelling Ekman currents at the surface



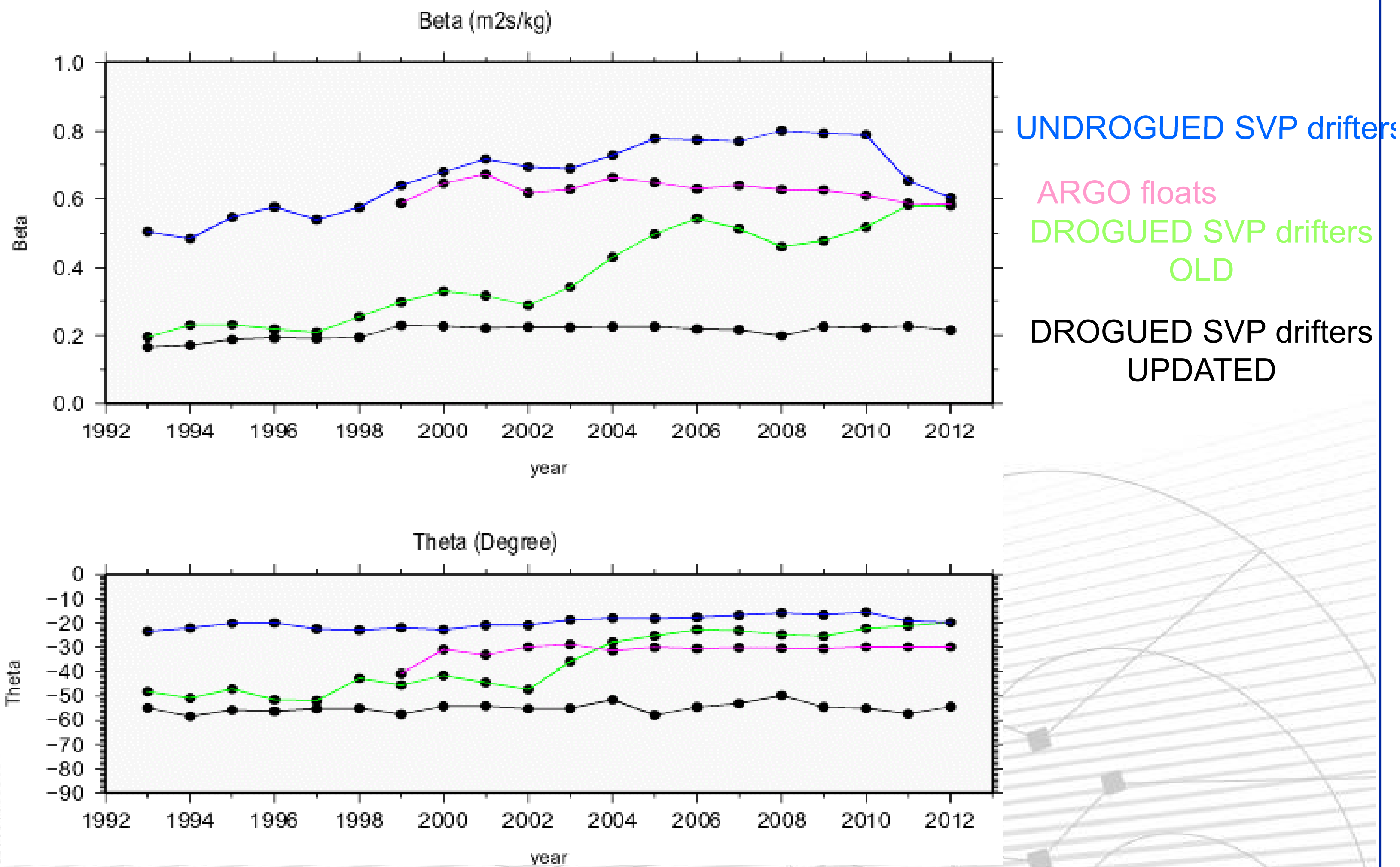
DROGUED SVP drifters OLD

DROGUED SVP drifters UPDATED

Drifting buoy data processing: Modelling Ekman currents at the surface

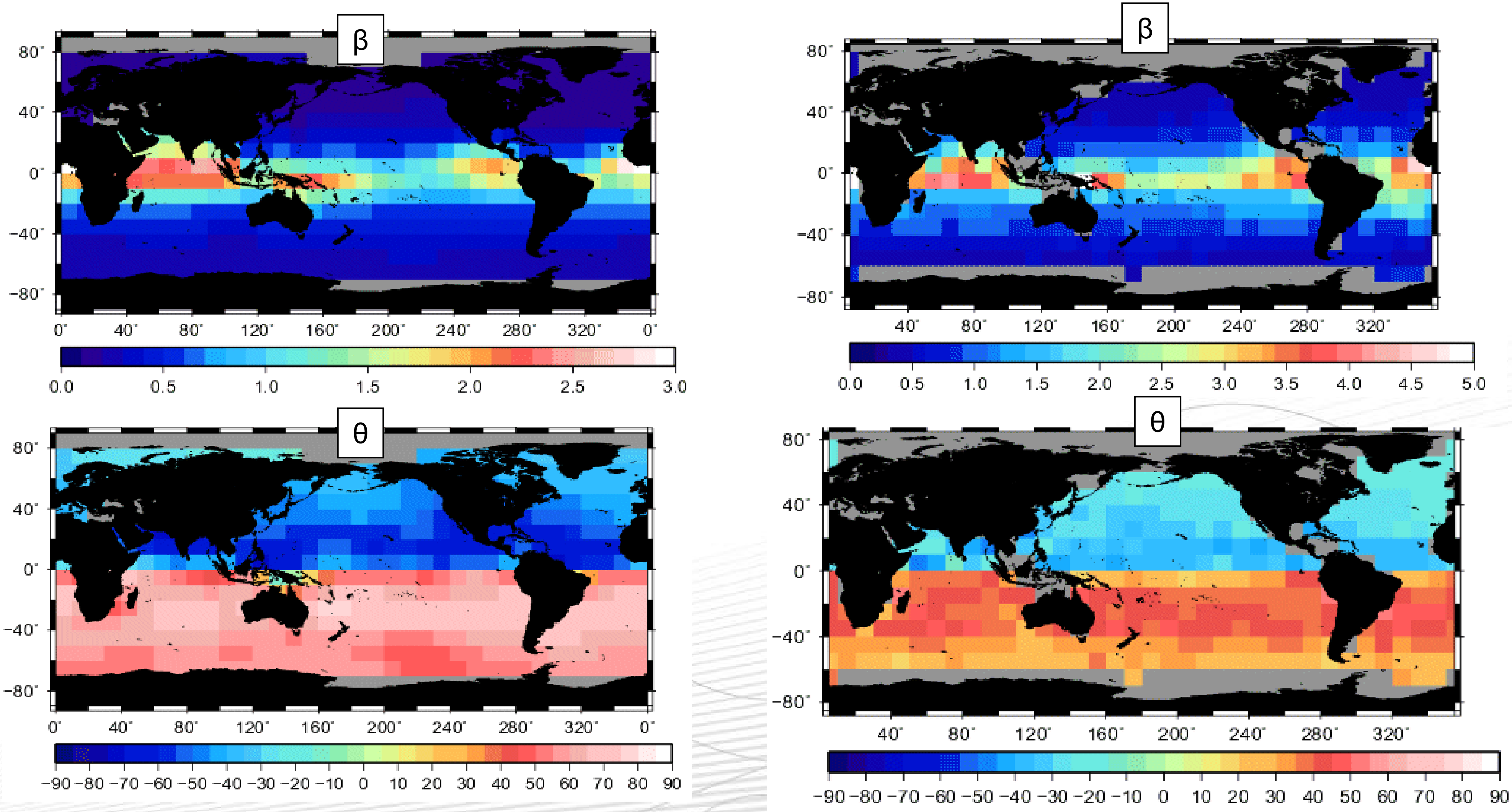


Drifting buoy data processing: Modelling Ekman currents at the surface



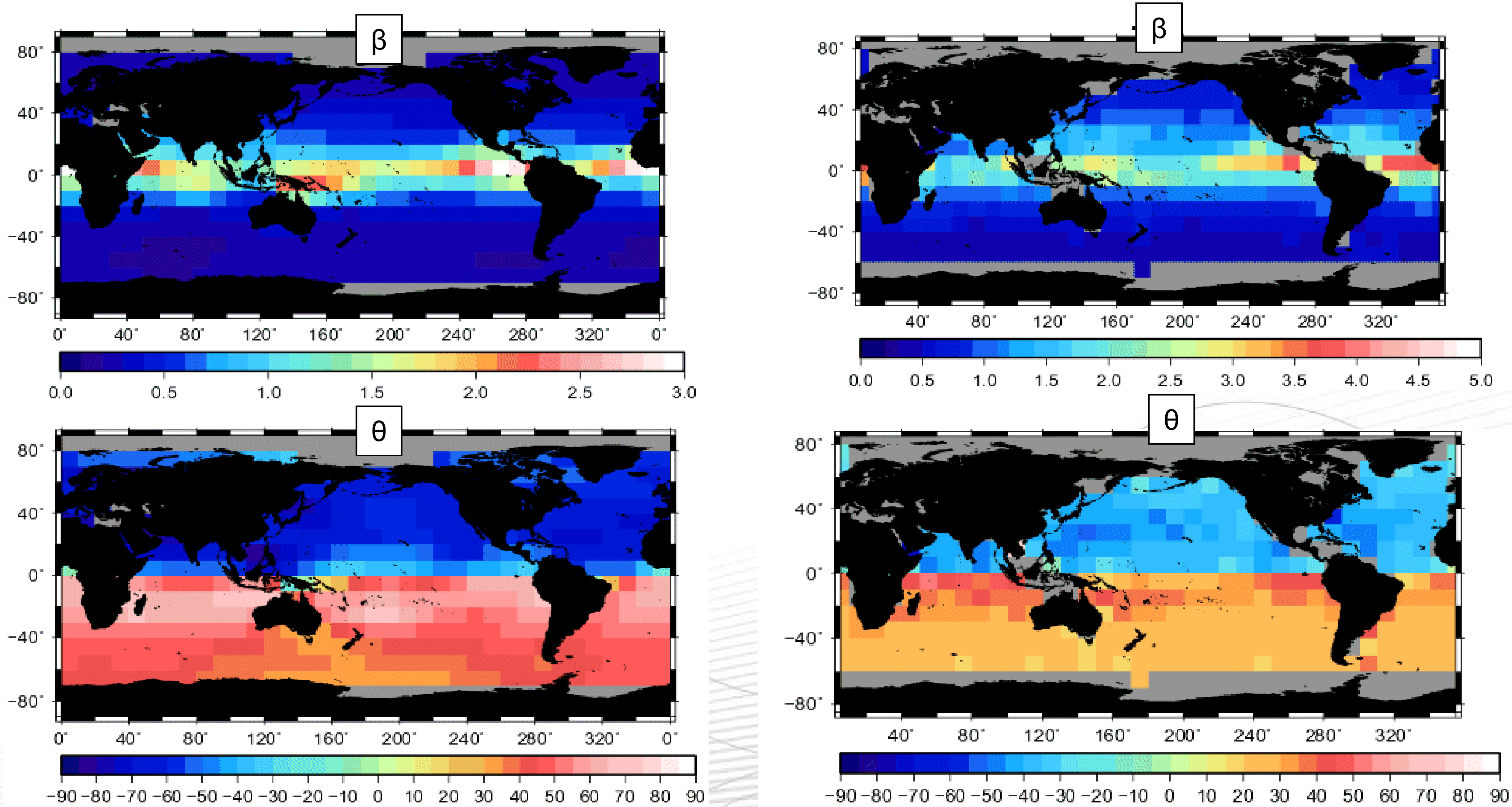
Drifting buoy data processing:
Modelling Ekman currents at the surface

15m JANUARY surface



Drifting buoy data processing:
Modelling Ekman currents at the surface

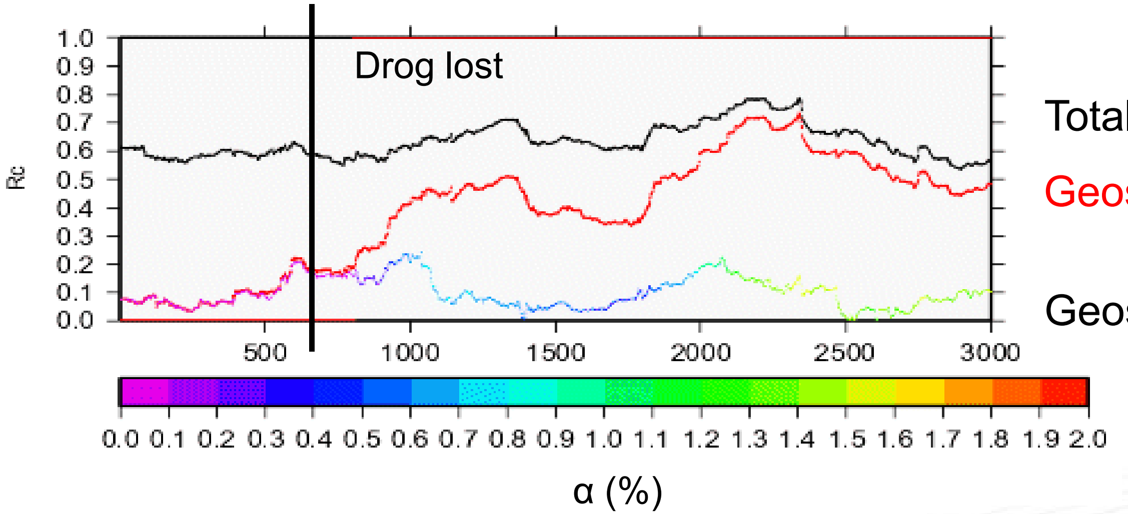
15m JUNE surface



Drifting buoy data processing: Wind slippage correction

Method from *Rio et al, 2012, JAOT*

Correlation between the drifter velocity and the wind



Total drifter velocity vs wind

Geostrophic drifter velocity vs wind

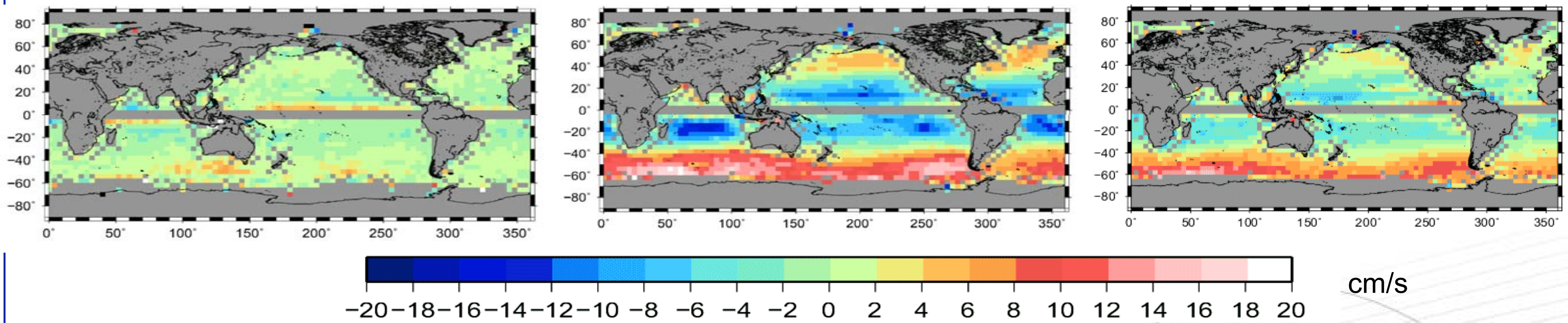
Geostrophic drifter velocity minus α Wind vs Wind

Mean wind slippage of 0.6% is found and applied on undrogued buoy velocities

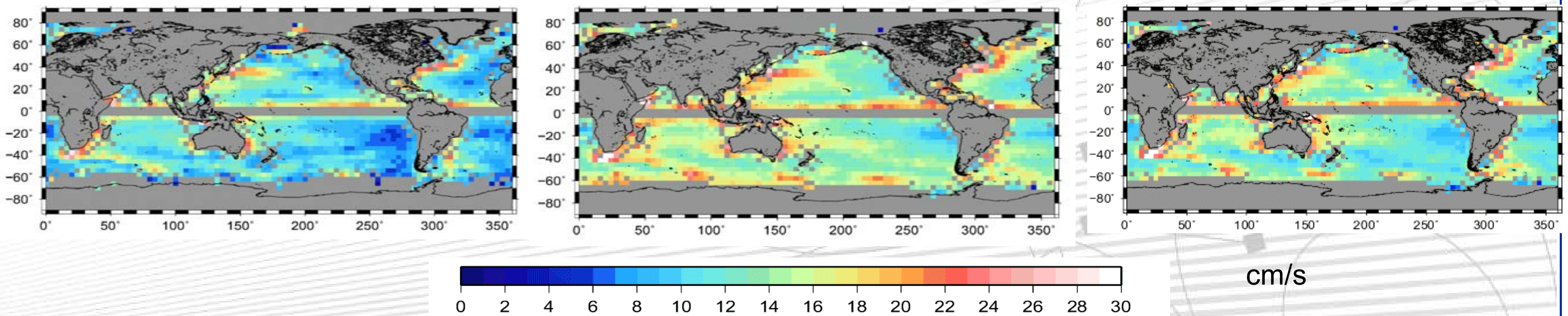
Comparison between drifting buoy velocities and altimeter velocities (derived from SLA+First Guess MDT)

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



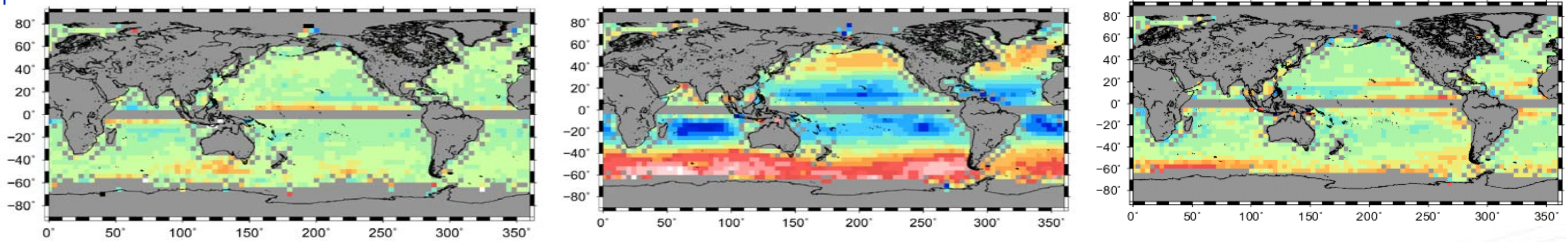
Comparison between drifting buoy velocities and altimeter velocities (derived from SLA+First Guess MDT)

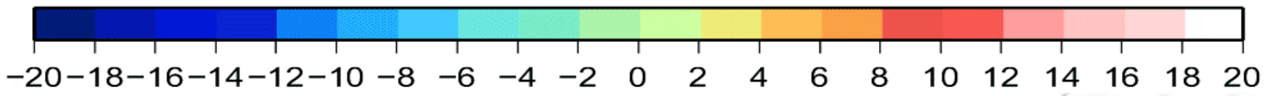
Drogued SVP buoys
Corrected for 15m Ekman currents

Undrogued SVP buoys
Corrected for 15m Ekman currents

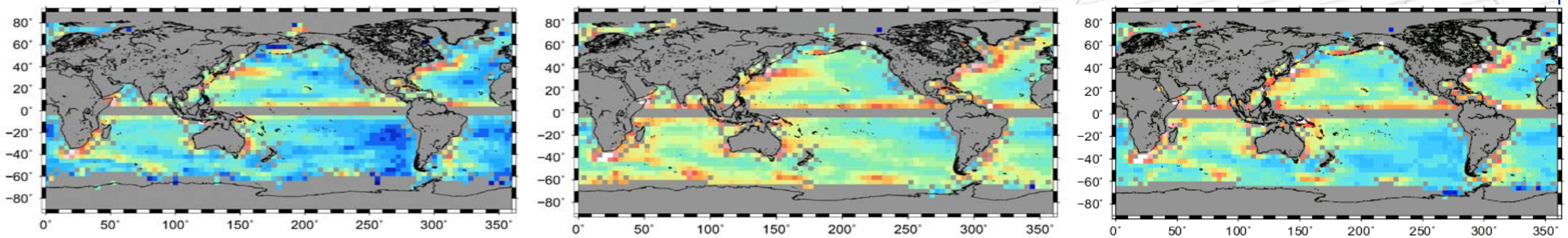
Undrogued SVP buoys
Corrected for surface Ekman currents and wind slippage

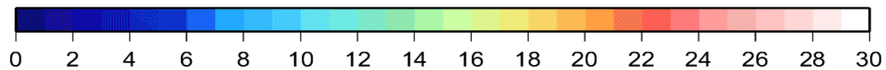
Mean zonal differences





Root Mean Square zonal differences



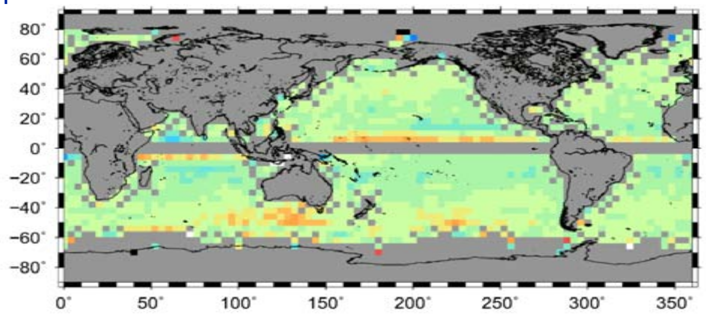


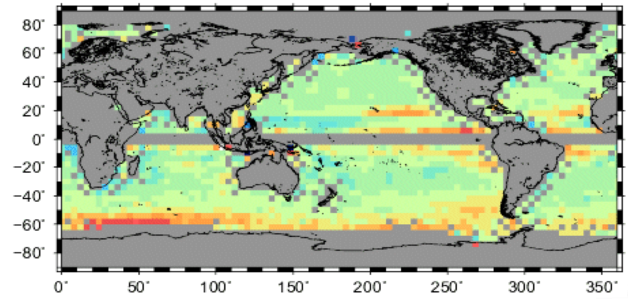
Comparison between drifting buoy velocities and altimeter velocities (derived from SLA+First Guess MDT)

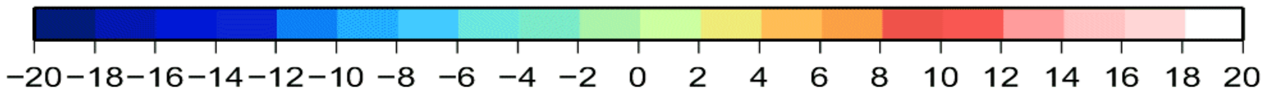
Drogued SVP buoys
Corrected for 15m Ekman currents

Undrogued SVP buoys
Corrected for surface Ekman currents and wind slippage

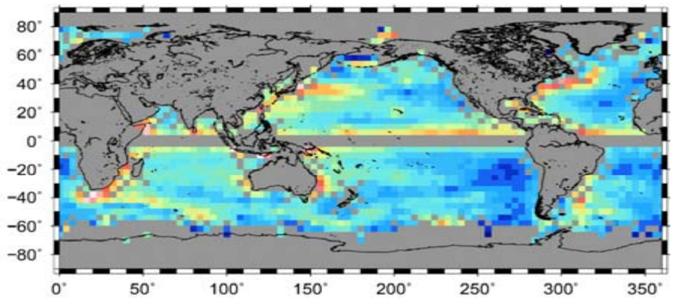
Mean zonal differences

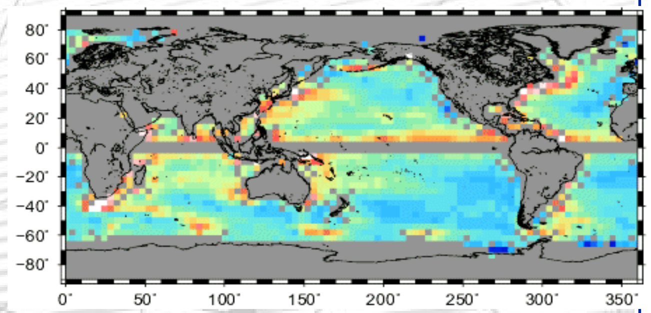


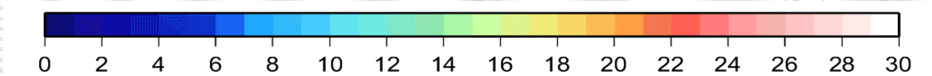




Root Mean Square zonal differences







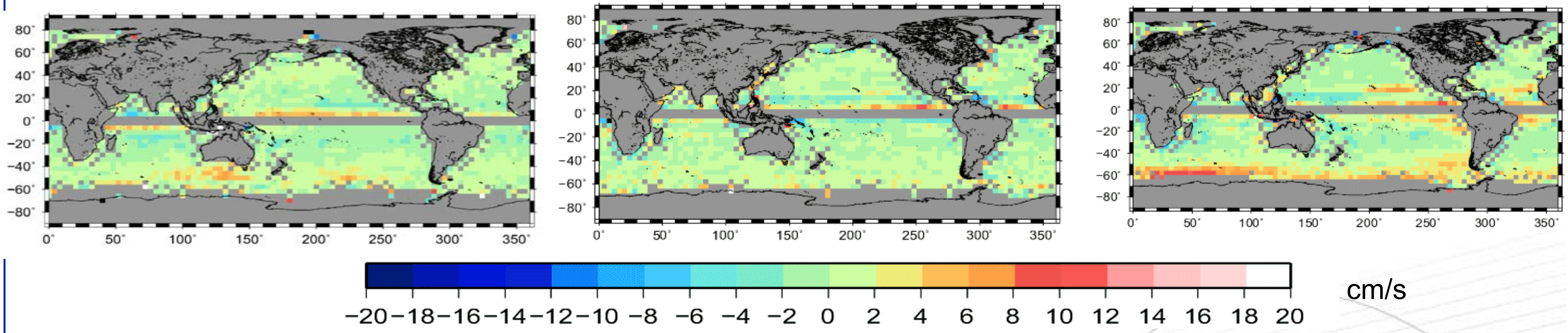
Comparison between drifting buoy velocities and altimeter velocities (derived from SLA+First Guess MDT)

Drogued SVP buoys
Corrected for 15m Ekman currents

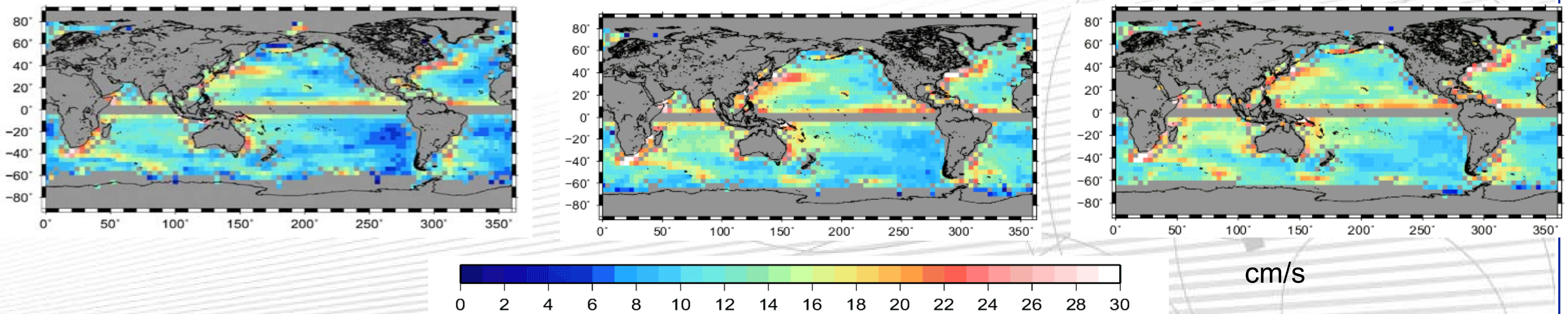
Argo floats
Corrected for surface Ekman currents

Undrogued SVP buoys
Corrected for surface Ekman currents and wind slippage

Mean zonal differences



Root Mean Square zonal differences



VALIDATION:
COMPARISON TO INDEPENDENT SURFACE VELOCITIES

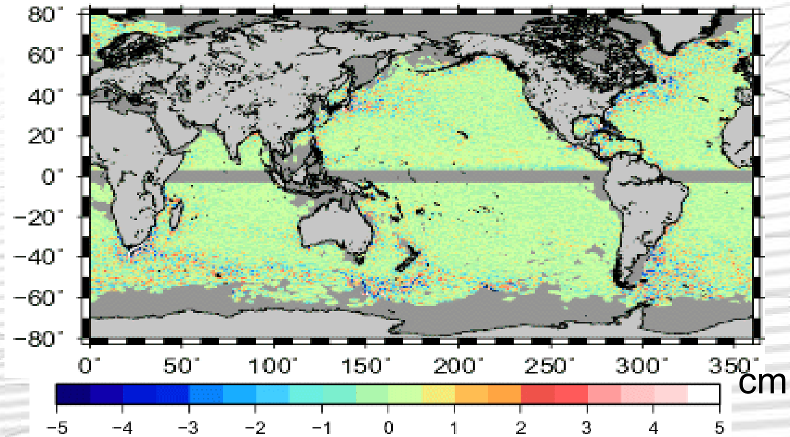
RMS differences between the ARGO floats surface velocities and altimeter derived velocities (expressed in % of Argo floats velocity variance)

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')

		MDT DROGUE ATTACHED		MDT DROGUE LOST
RMS U		45.2	~	45.0
RMS V		53.4	~	53.2

MDT DROGUE ATTACHED – MDT DROGUE LOST

MDT differences
1cm RMS



VALIDATION:
COMPARISON TO INDEPENDENT SURFACE VELOCITIES

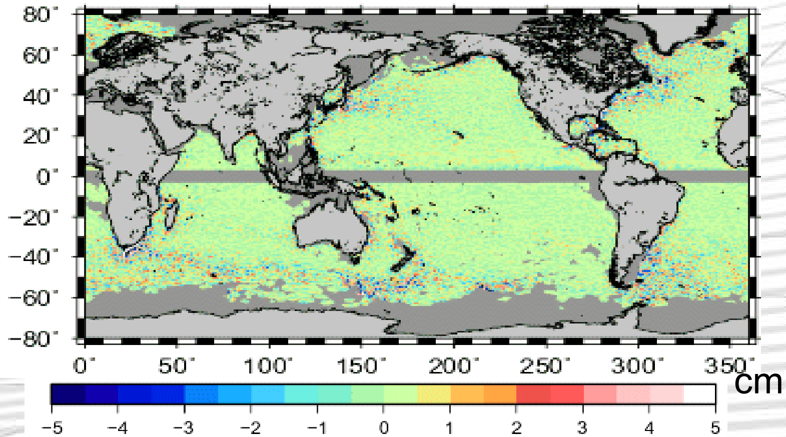
RMS differences between the ARGO floats surface velocities and altimeter derived velocities (expressed in % of Argo floats velocity variance)

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')

	MDT CNES-CLS13 DROGUE ALL	MDT DROGUE ATTACHED	MDT DROGUE LOST
RMS U	44.6 <	45.2 ~	45.0
RMS V	52.4 <	53.4 ~	53.2

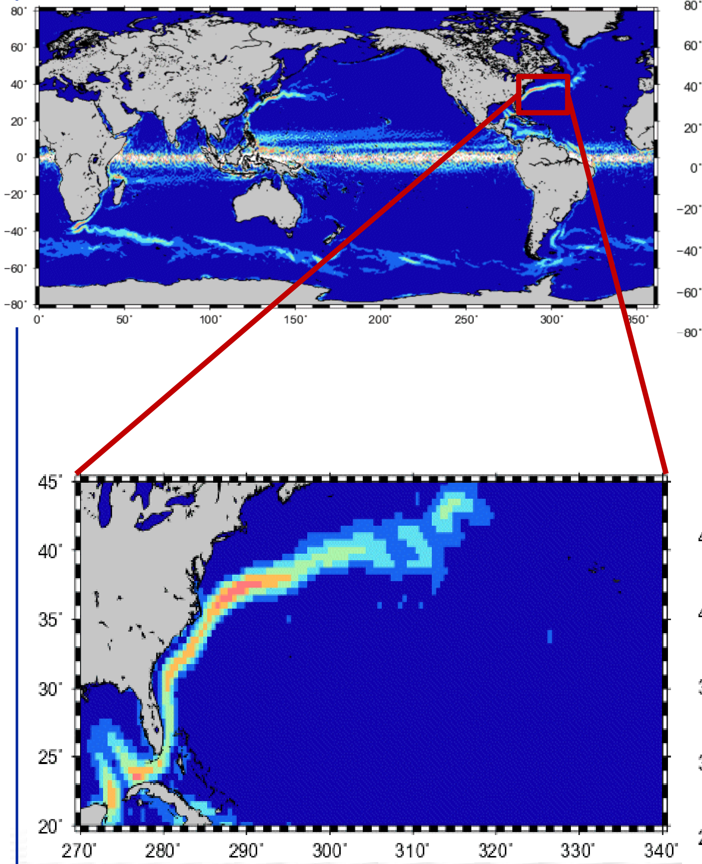
MDT differences
1cm RMS

MDT DROGUE ATTACHED – MDT DROGUE LOST

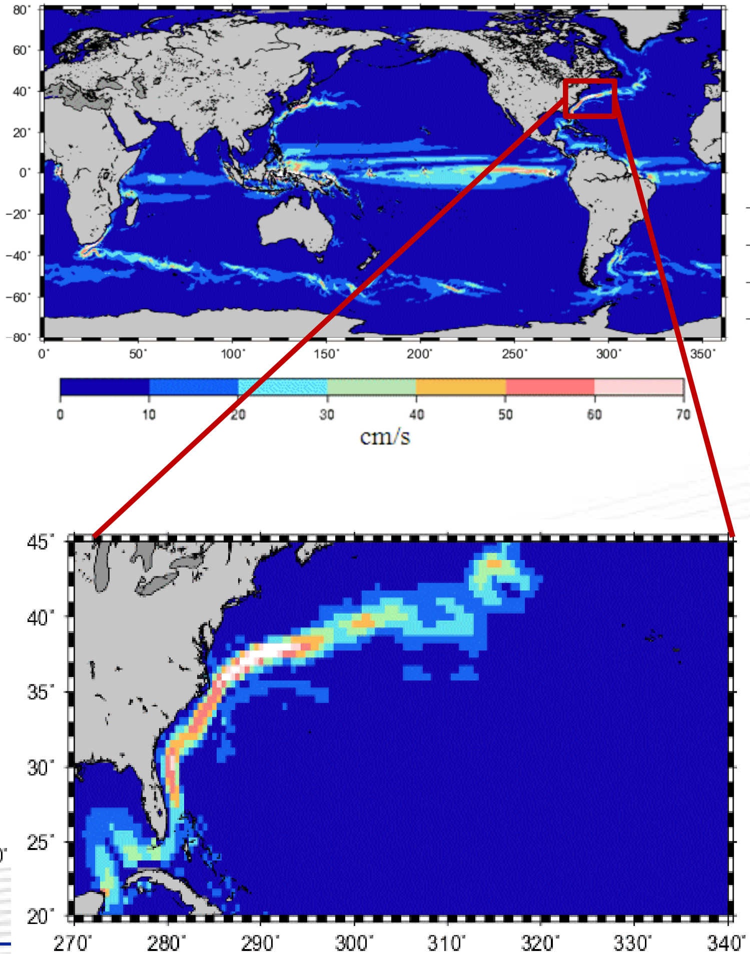


Computation of the MDT first guess

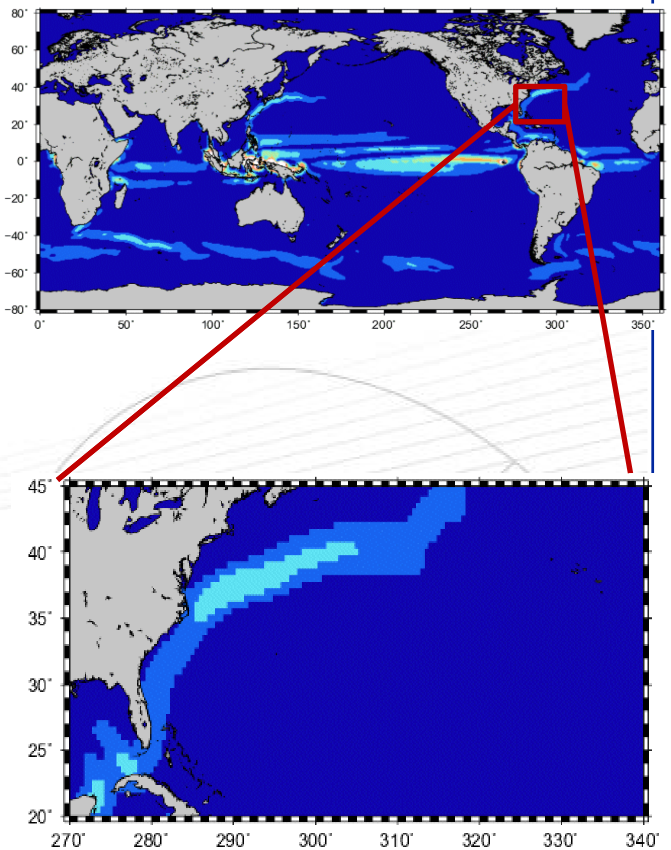
Geostrophic velocity speed from the 100km Gaussian filtered MDT



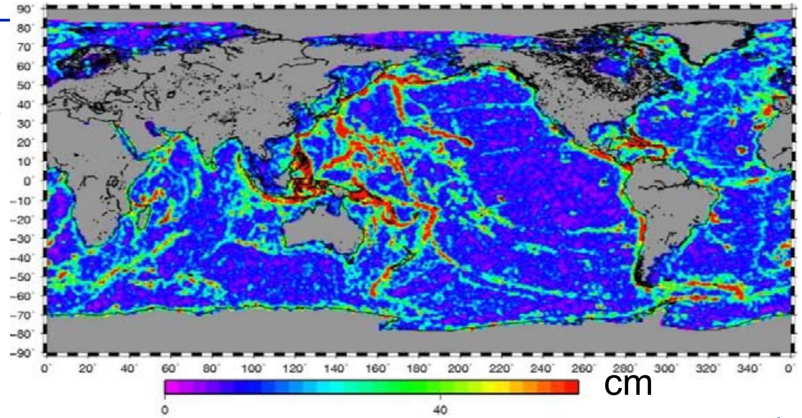
Geostrophic velocity speed from the Optimally filtered MDT

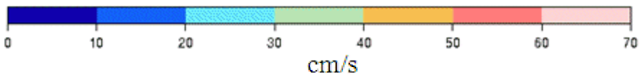


Geostrophic velocity speed from the 200km Gaussian filtered MDT



Computation of the MDT first guess

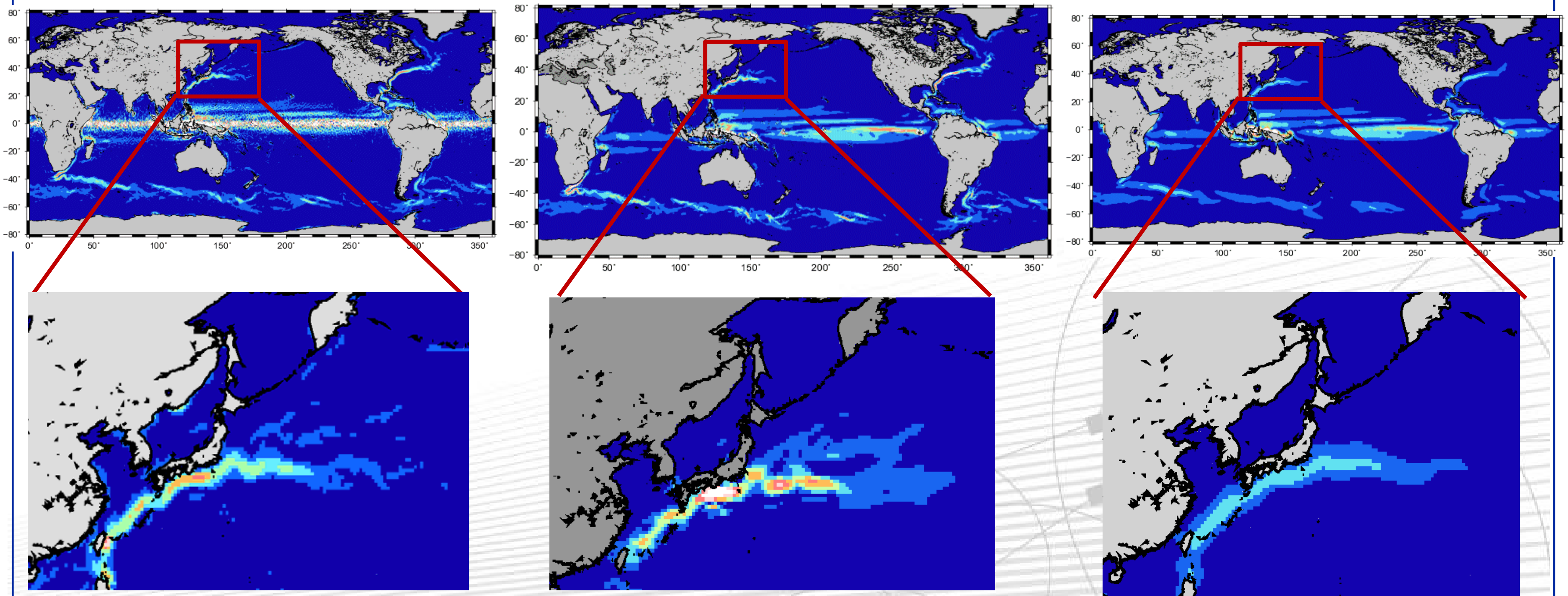




Geostrophic velocity speed from the **100km** Gaussian filtered MDT

Geostrophic velocity speed from the **Optimally filtered** MDT

Geostrophic velocity speed from the **200km** Gaussian filtered MDT



Computation of the MDT first guess