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

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

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

underlying flow → U_{geo}, V_{geo}

upper wind stress driven flow → U_{ekman}, V_{ekman}

τ_e= Effective Wind Stress

δ= Ekman depth

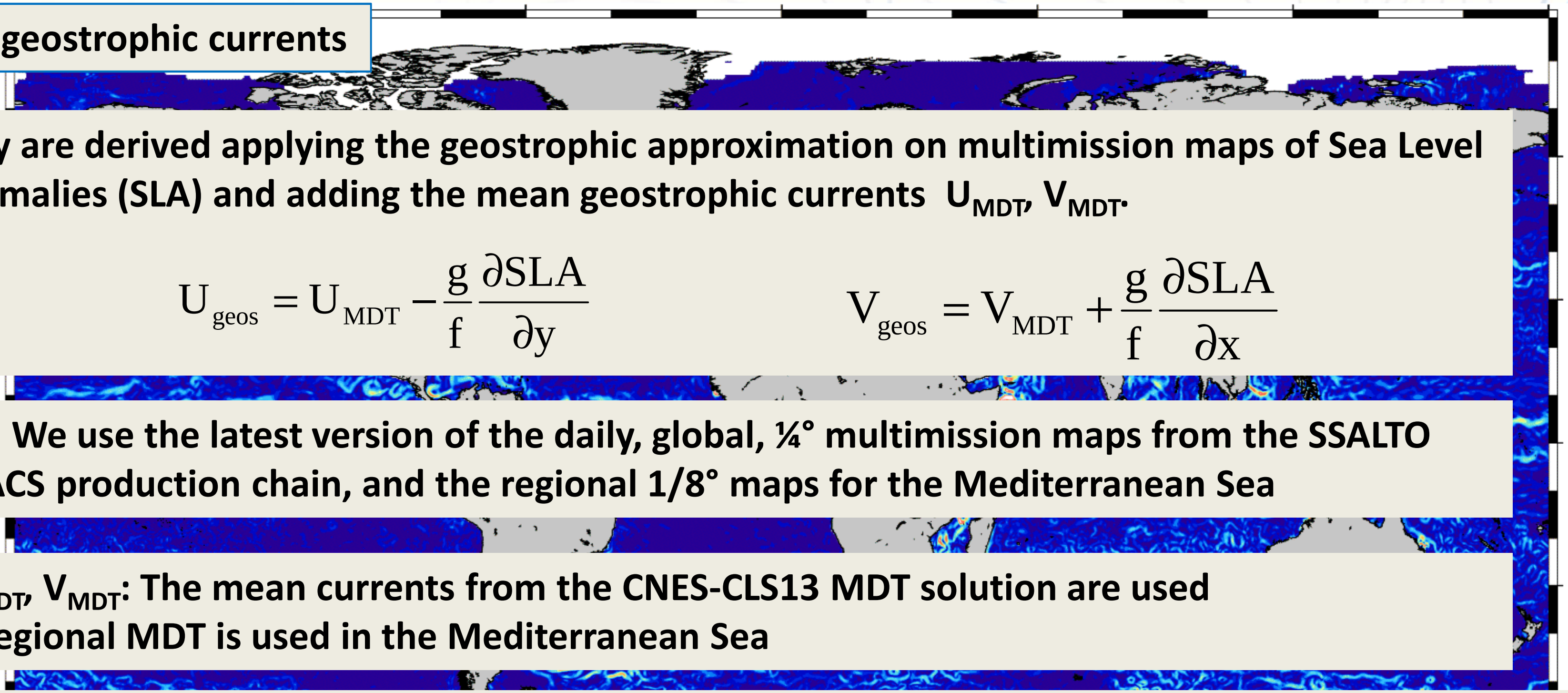
f= planetary vorticity

w=local vorticity

$$2\omega = \partial_x vgeost - \partial_y ugeost$$

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}.

$$U_{geos} = U_{MDT} - \frac{g}{f}\frac{\partial SLA}{\partial y} \qquad V_{geos} = V_{MDT} + \frac{g}{f}\frac{\partial SLA}{\partial x}$$

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:

- **Rio, M-H, S.Mulet, N. Picot (2014): Beyond GOCE for the ocean circulation estimate: Synergetic use of altimetry, gravimetry and in-situ data provides new insight into geostrophic and Ekman currents. Geophysical Res. Letter**
- **Rio, M-H, A. Pascual, P.-M. Poulain, M. Menna, B. Barceló, J. Tintoré (2014) : Computation of a new Mean Dynamic Topography for the Mediterranean Sea from model outputs, altimeter measurements and oceanographic in-situ data. Ocean Sci., 10, 731–744, 2014 www.ocean-sci.net/10/731/2014/ doi:10.5194/os-10-731-2014**

The Geostrophic and Ekman components at a glance

The Ekman Currents

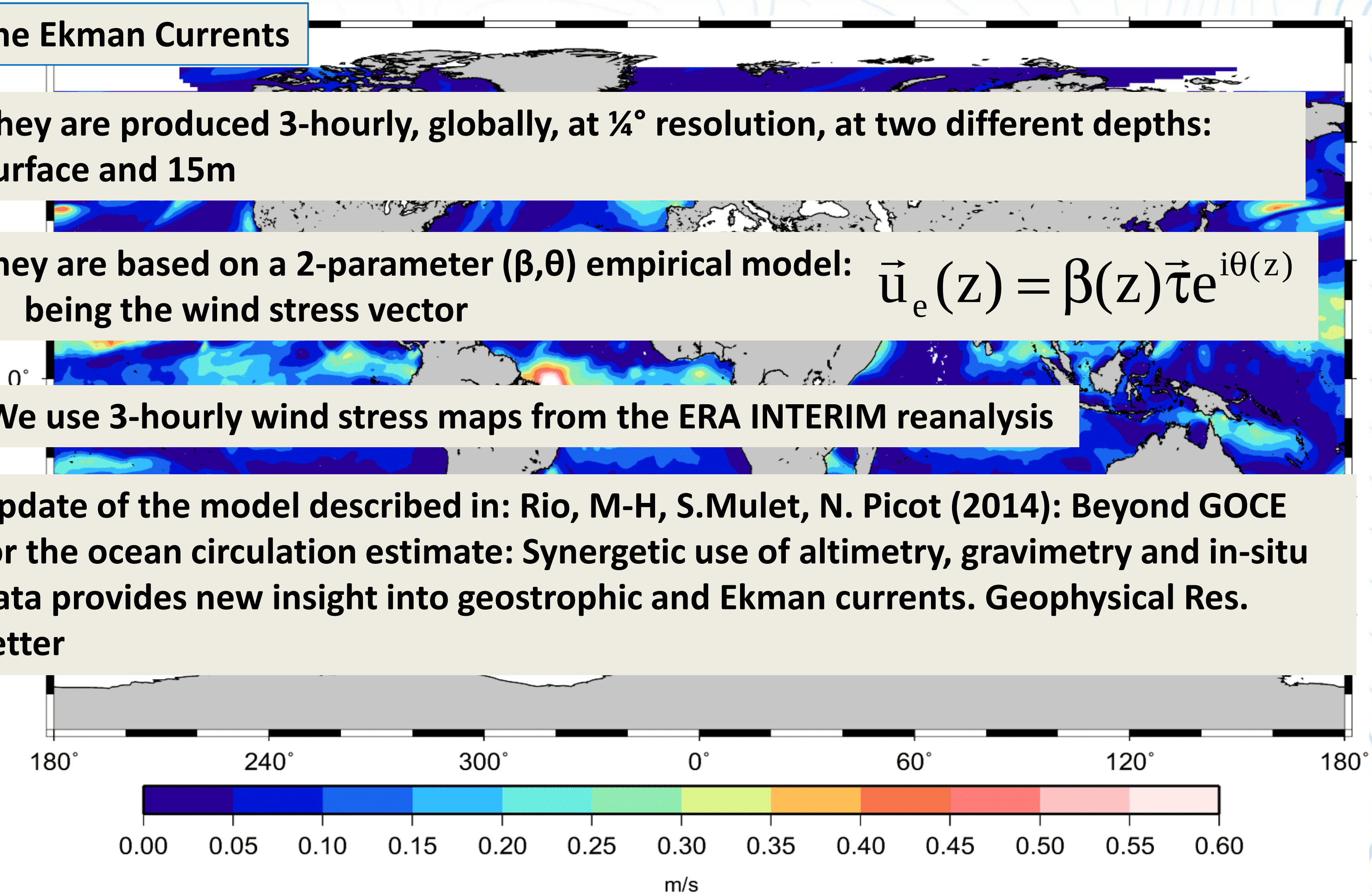
They are produced 3-hourly, globally, at ¼° resolution, at two different depths: surface and 15m

They are based on a 2-parameter (β,θ) empirical model: $\vec{u}_e(z) = \beta(z)\vec{\tau}e^{i\theta(z)}$

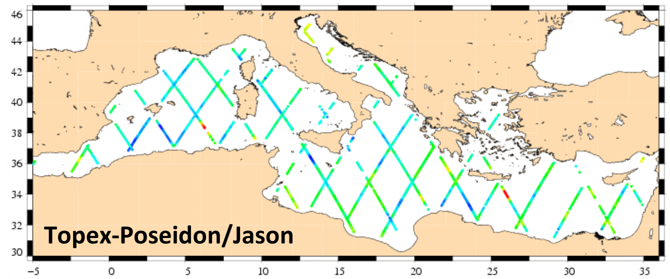
$\vec{\tau}$ being the wind stress vector

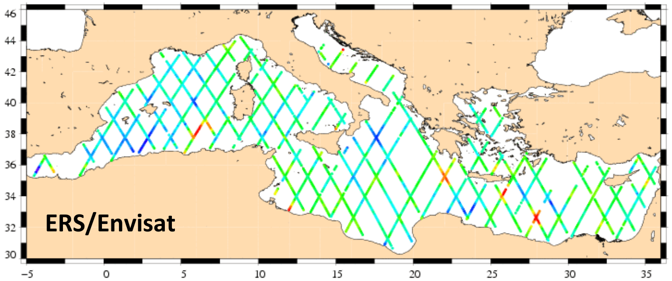
We use 3-hourly wind stress maps from the ERA INTERIM reanalysis

Update of the model described in: Rio, M-H, S.Mulet, N. Picot (2014): Beyond GOCE for the ocean circulation estimate: Synergetic use of altimetry, gravimetry and in-situ data provides new insight into geostrophic and Ekman currents. Geophysical Res. Letter



The altimeter Sea Level Anomaly (SLA) maps



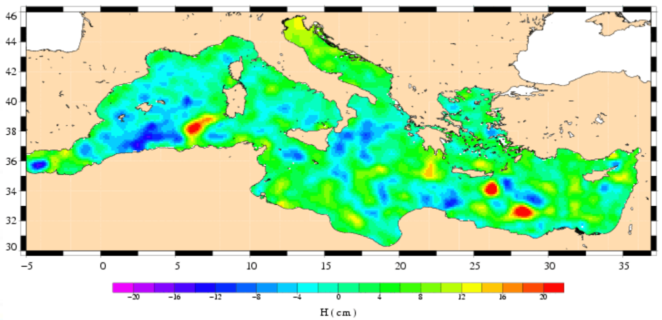


Altimeter Mission characteristics

Orbit inclination	Repetitivity	Equatorial inter-tracks distance
66°	10 days	315 km
98.5°	35 days	80 km

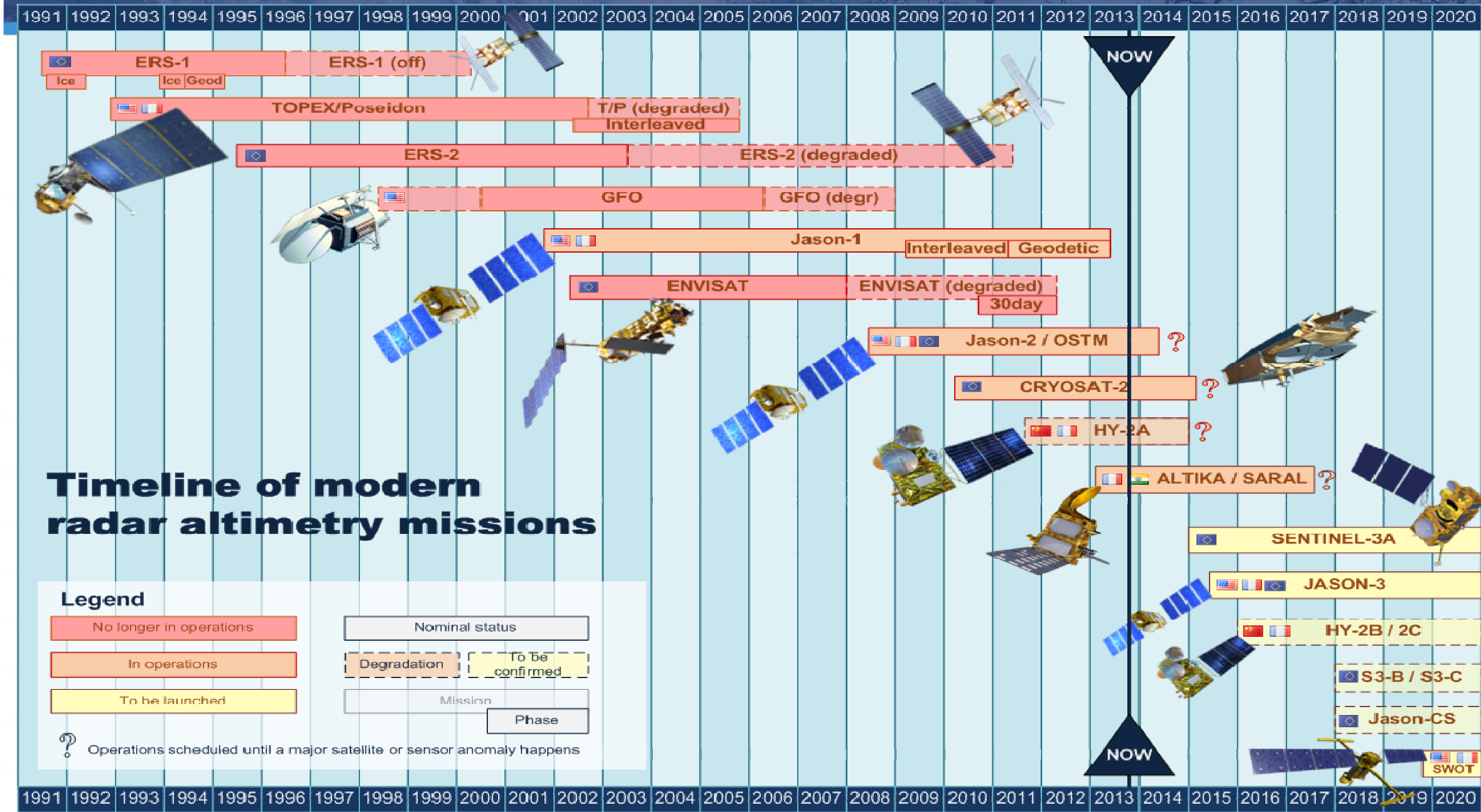
Impact the spatial coverage capability: Spatial coverage limited to 66°N/S for TP/Jason , 82°N/S for ERS/Envisat

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



Spatial resolution achieved for a 10 days temporal resolution

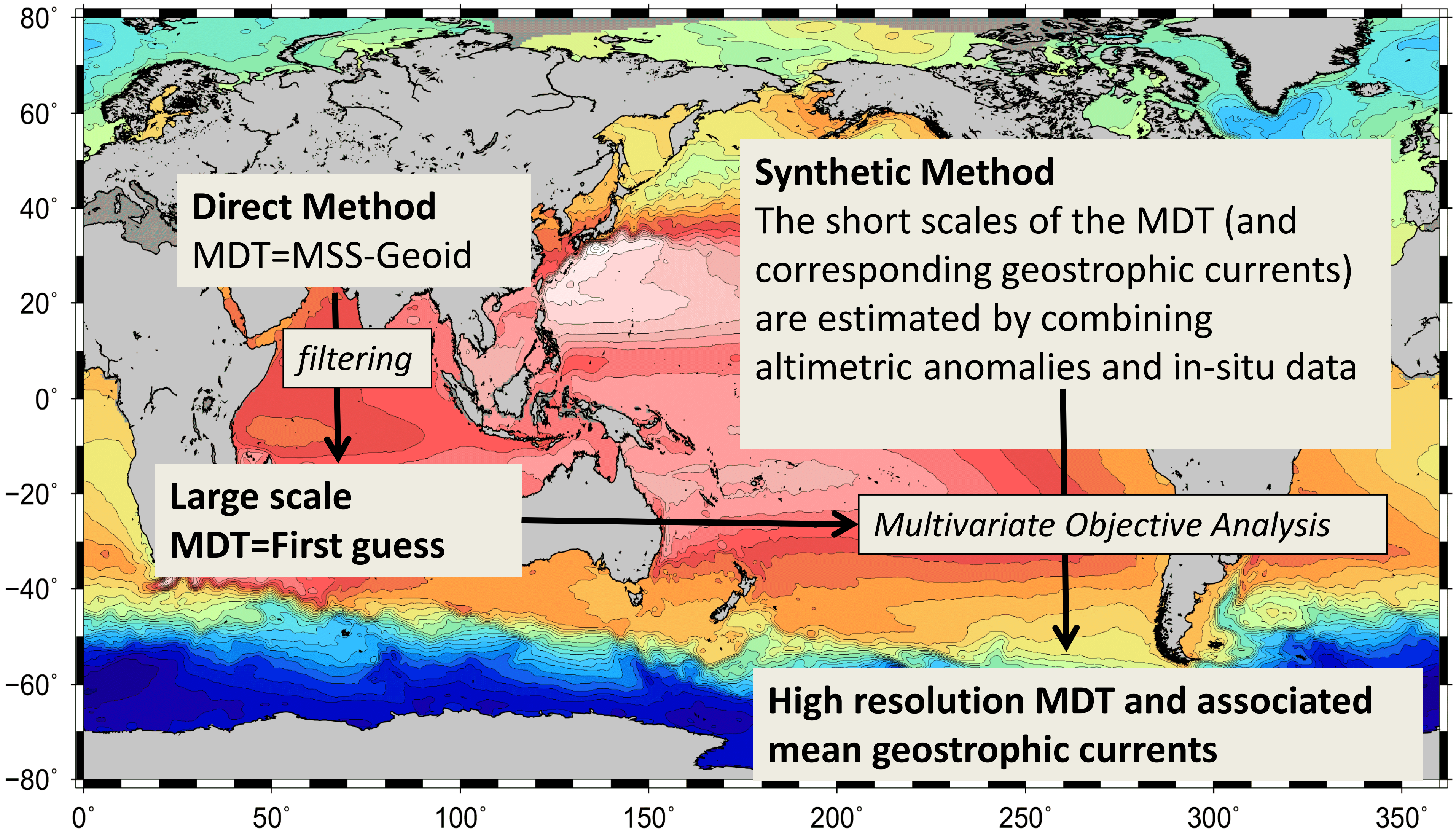
2 satellites 250-300km

4 satellites 100 km

3 satellites 150 km

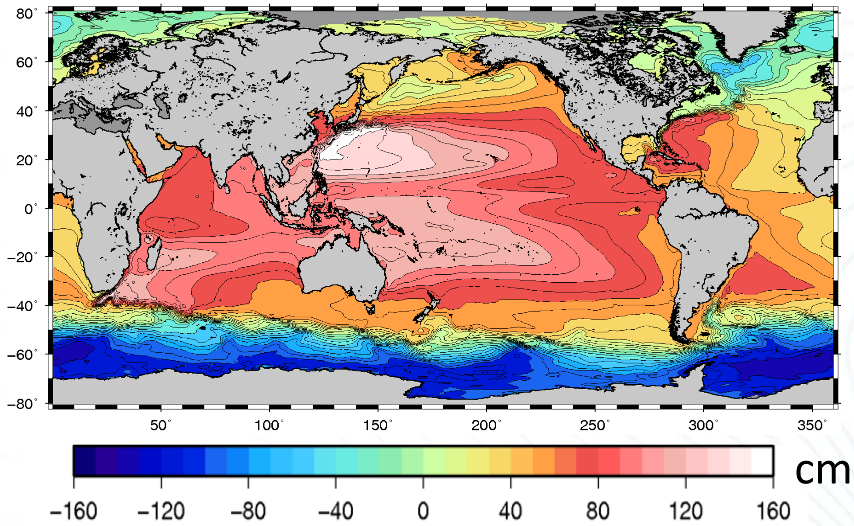
The Mean Dynamic Topography (MDT)

The CNES-CLS13 MDT

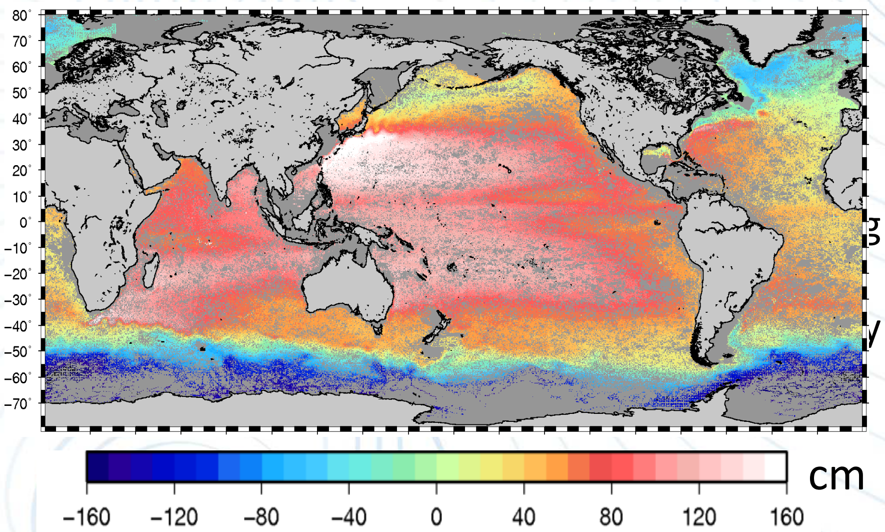


The CNES-CLS13 MDT

First Guess = MSS - Geoid
OPTIMALLY FILTERED

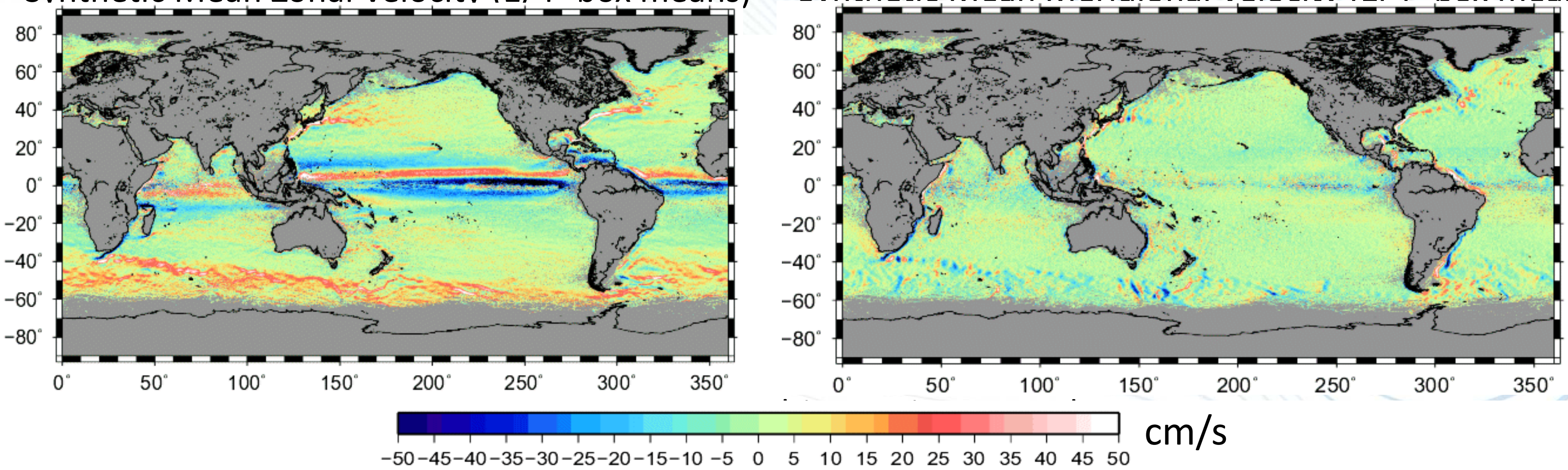


Synthetic Mean Heights (1/4° box means)

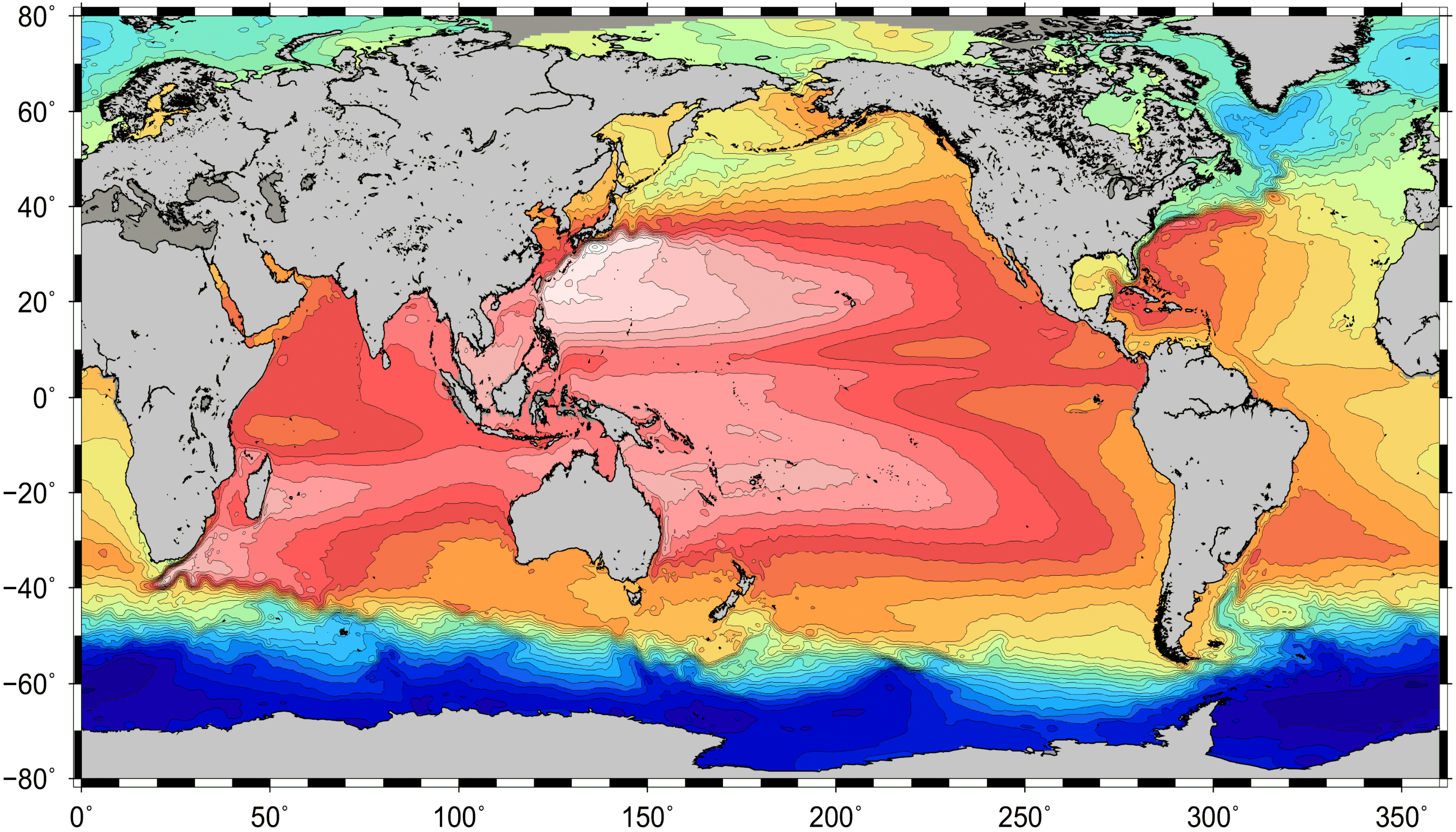


Synthetic Mean Zonal Velocity (1/4° box means)

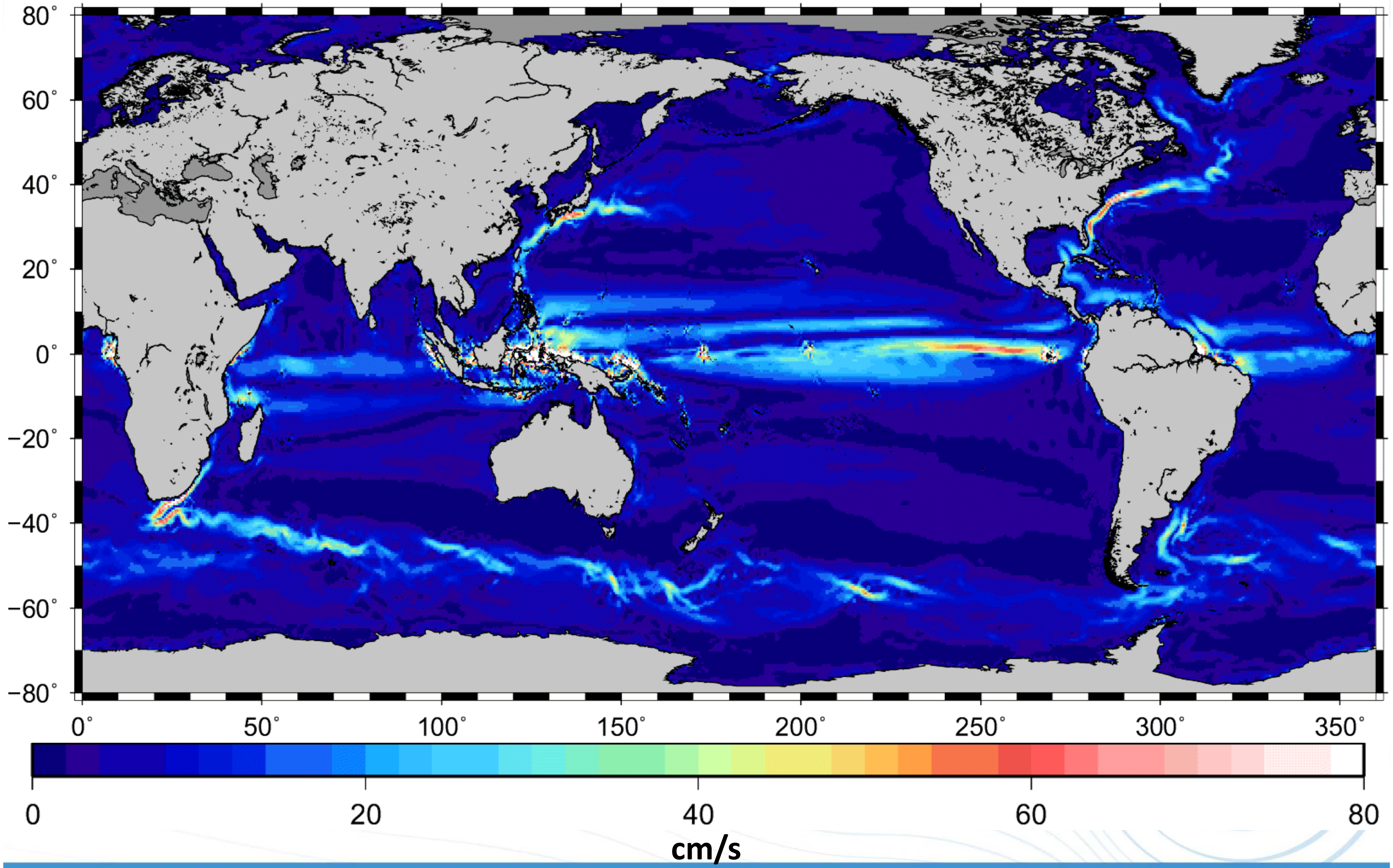
Synthetic Mean Meridional Velocity (1/4° box means)



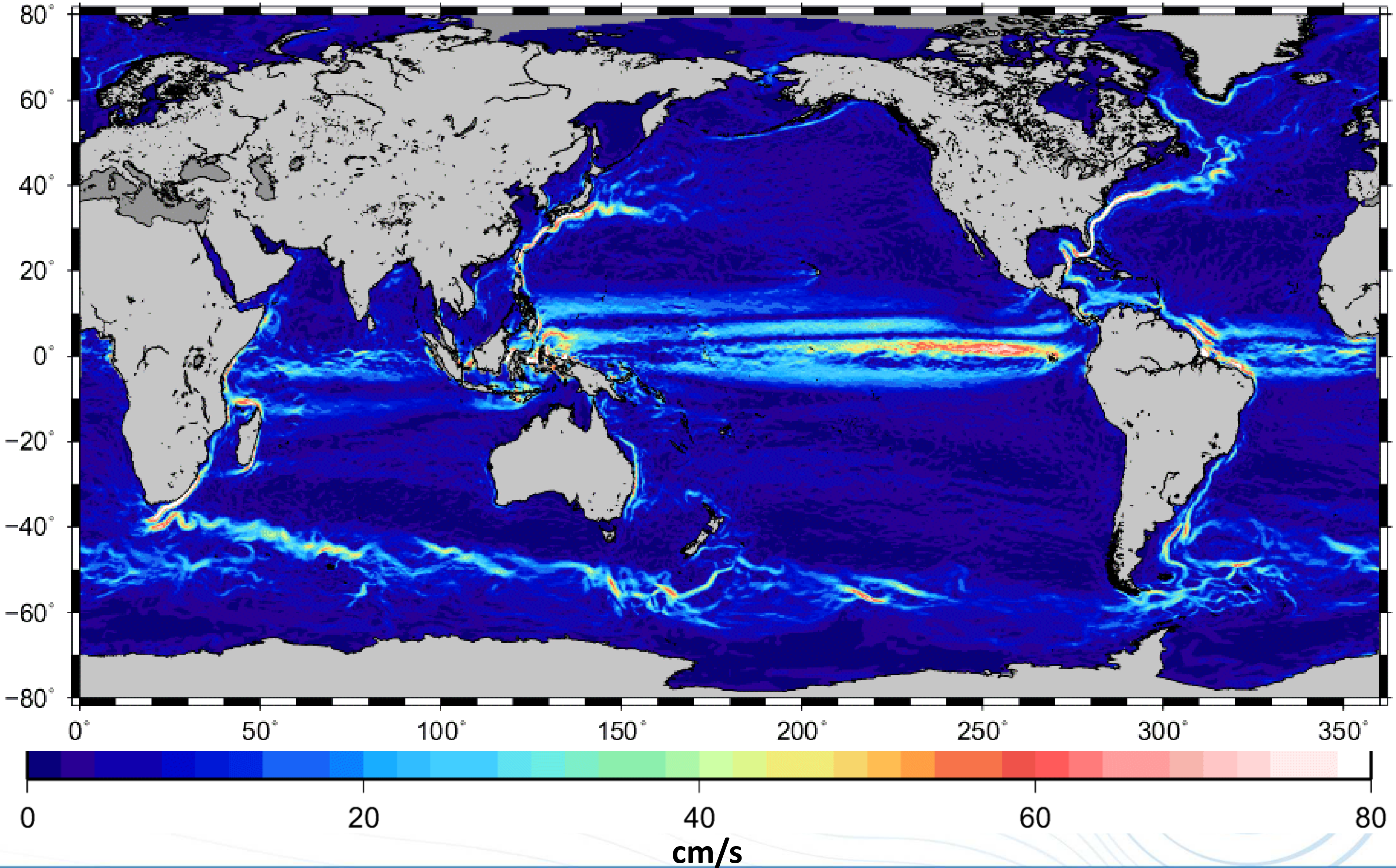
The CNES-CLS13 MDT



The GOCE only MDT (First Guess)

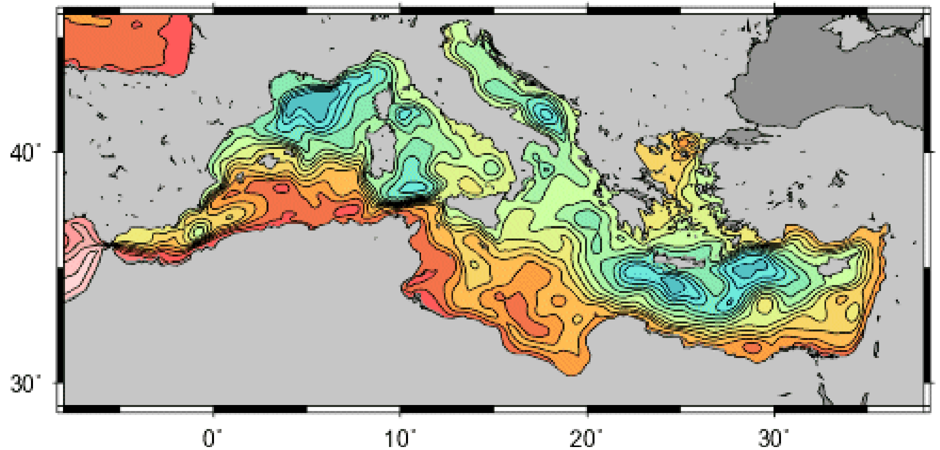


The CNES-CLS13 mean geostrophic currents

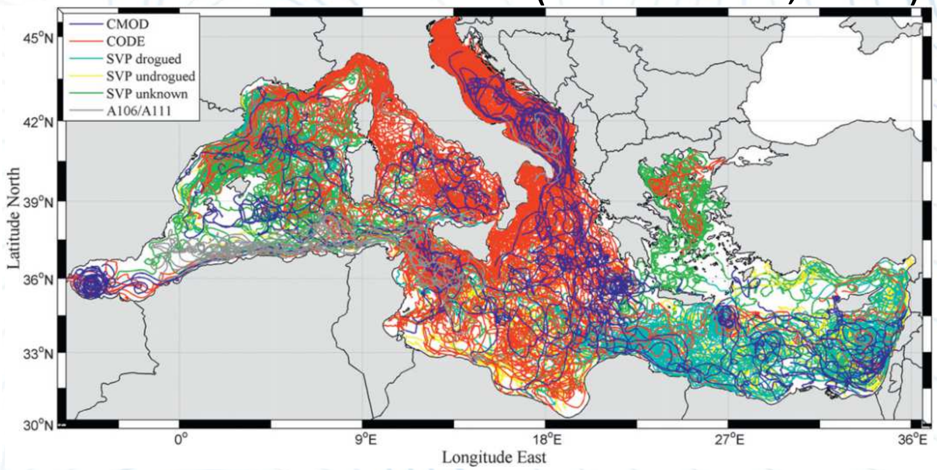


The Mediterranean mean geostrophic currents

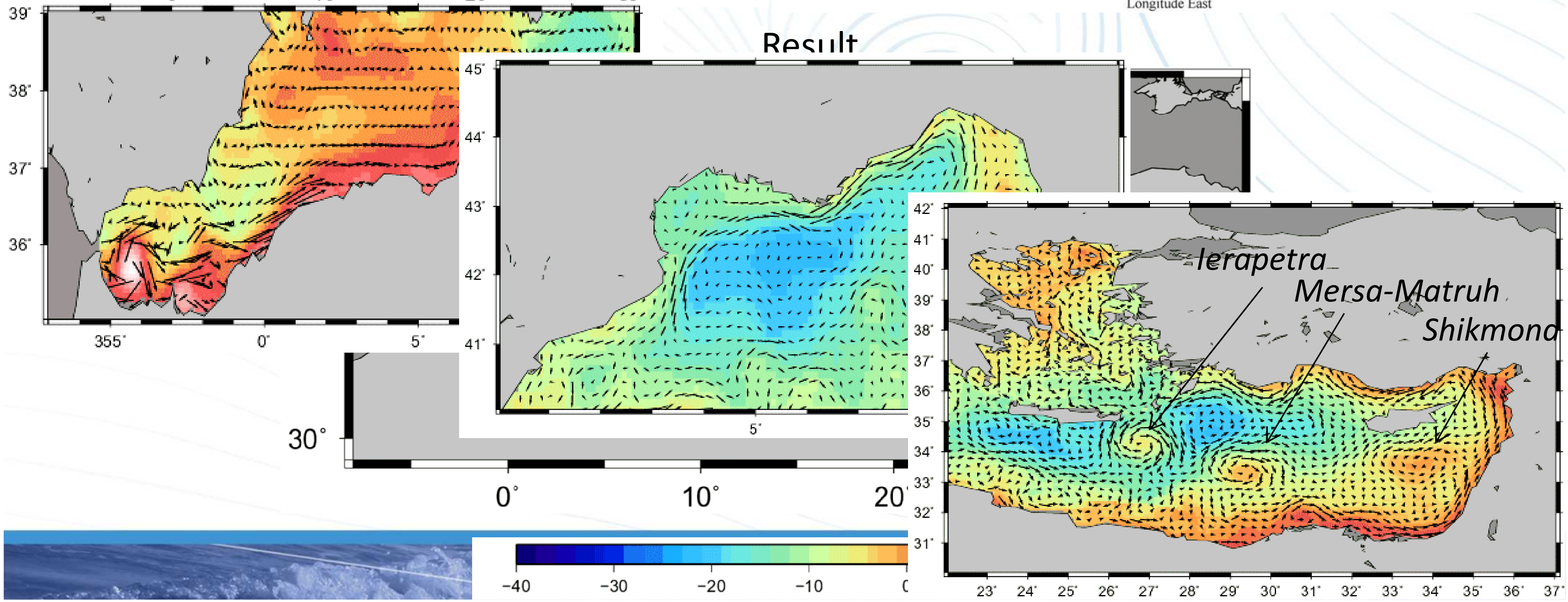
First Guess=MFS model mean



Observations= drifters (Poulain et al, 2012)



Result



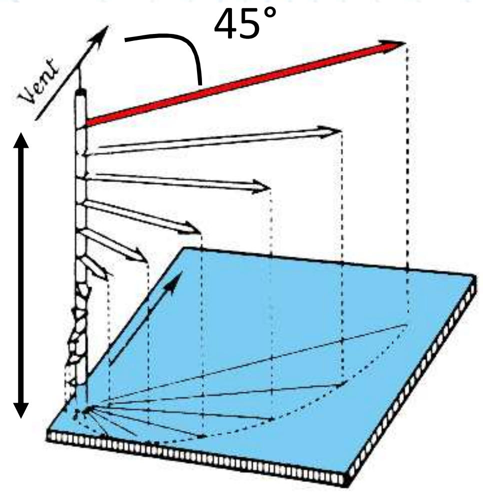
The Ekman currents

Wind-driven Ekman

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

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

β θ



Model

Rio et al, 2014

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

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

Wind stress from ERA INTERIM

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

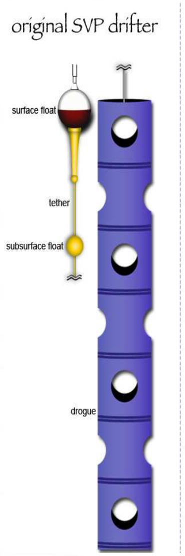
β and θ are estimated through least square fit by month and 4° boxes

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

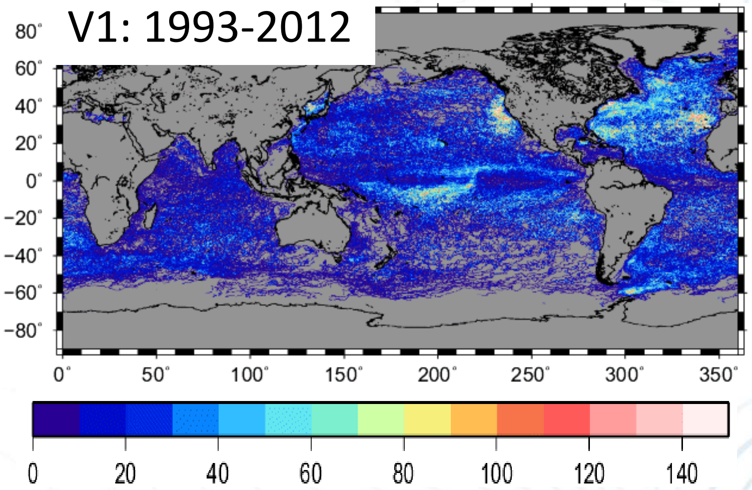
At the surface using the Argo float surface velocity dataset

The Ekman currents

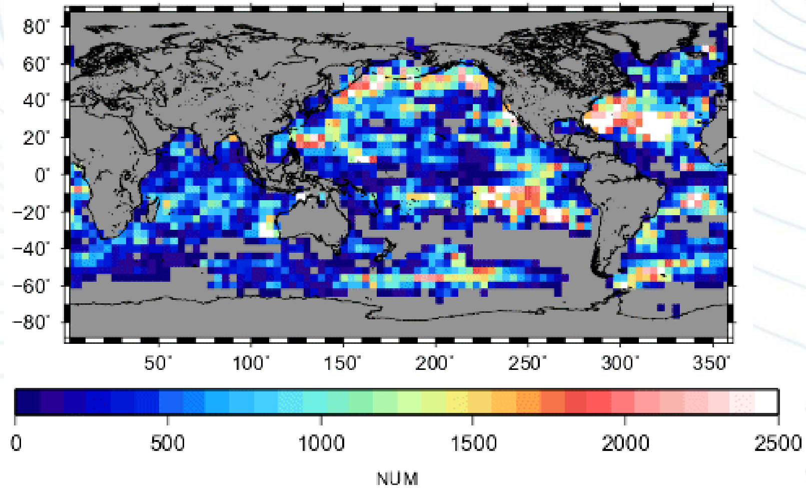
Number of SVP buoy velocities Drogue ATTACHED



V1: 1993-2012

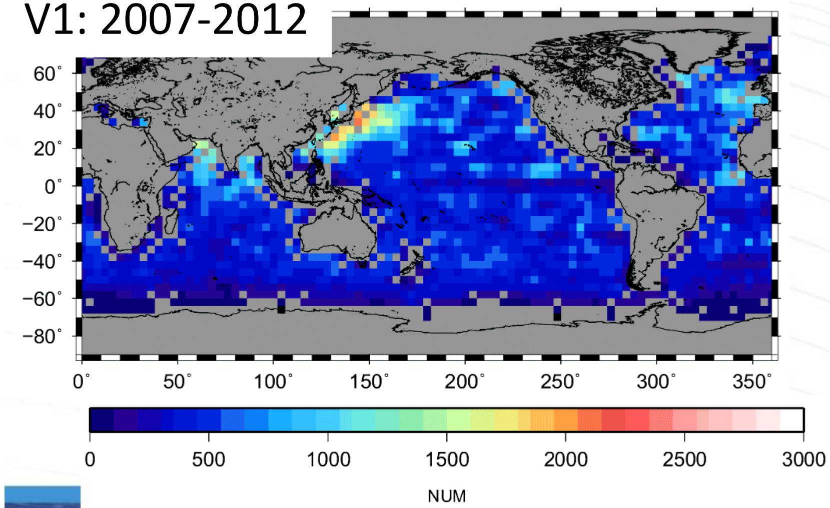


V2: + 2013,2014

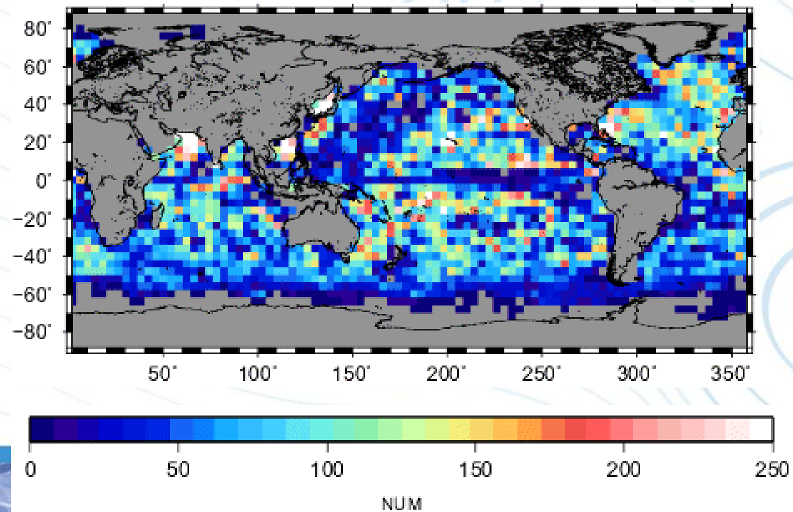


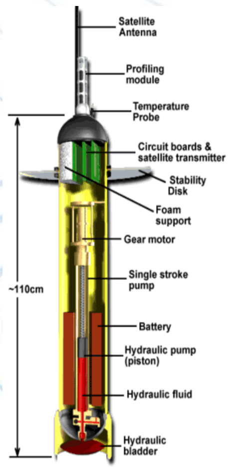
Number of Argo float surface velocities

V1: 2007-2012



V2: +2013,2014

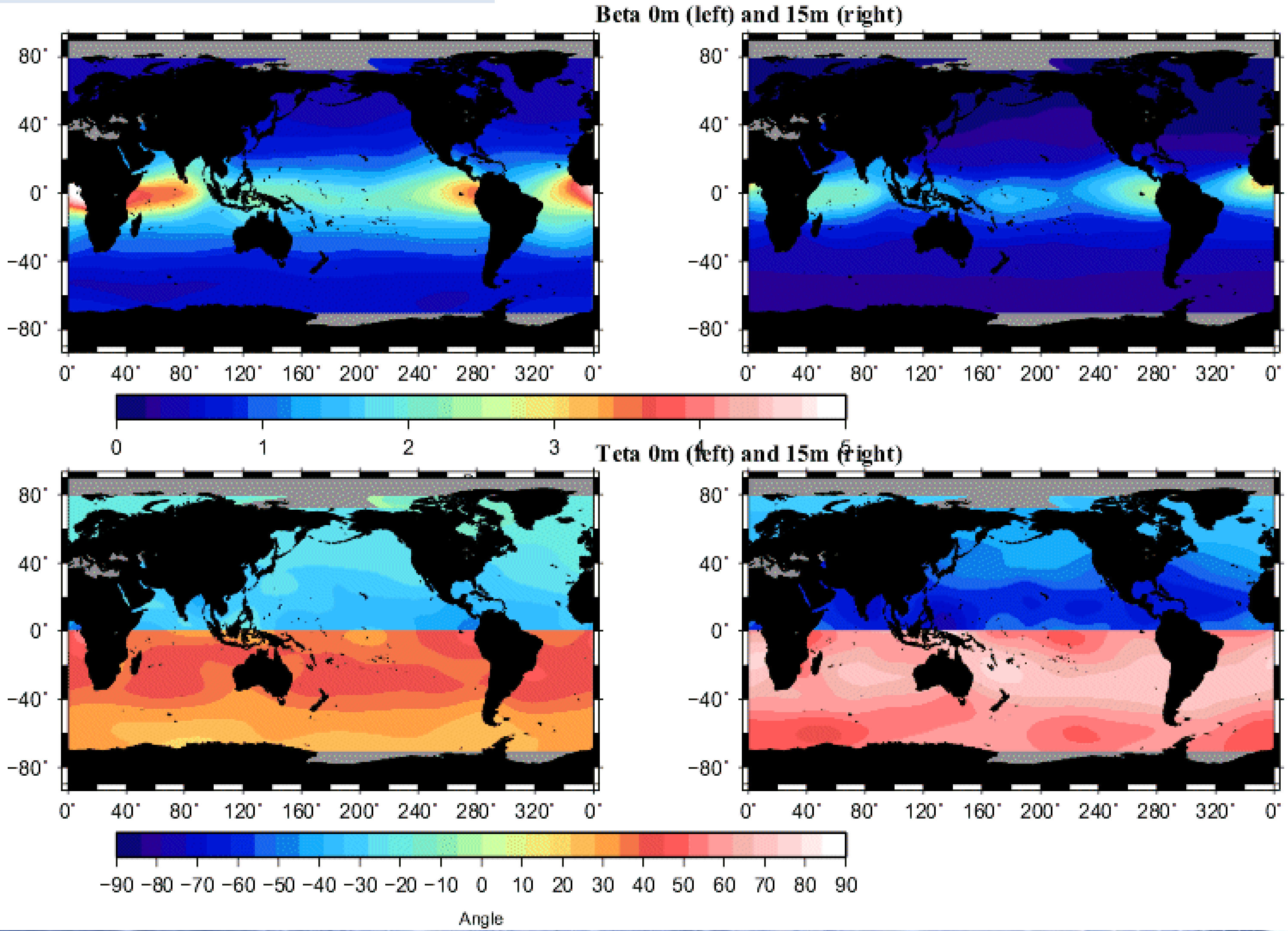




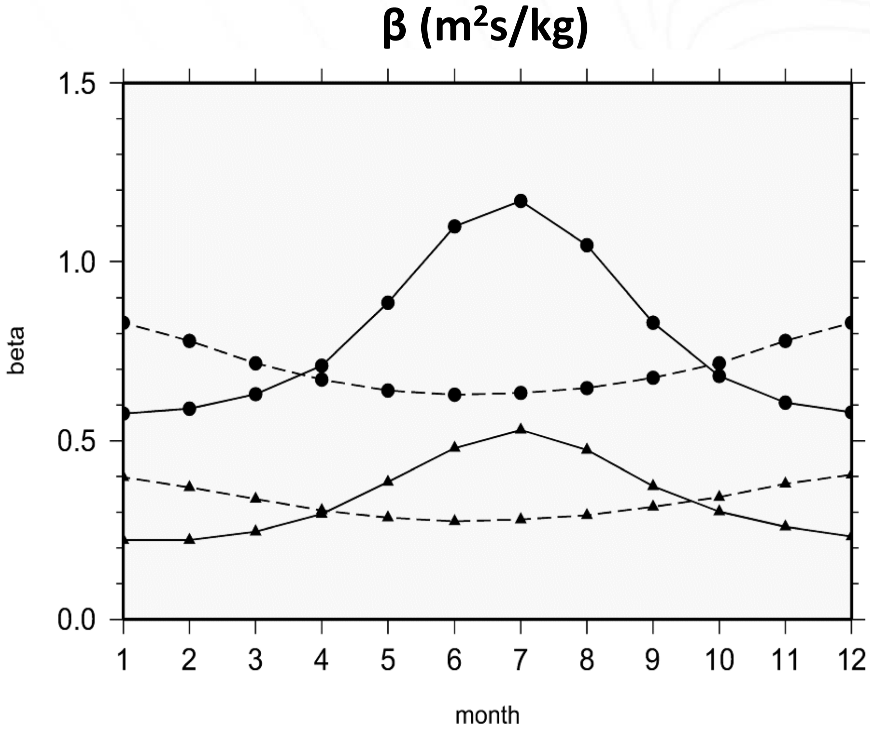
The Ekman currents

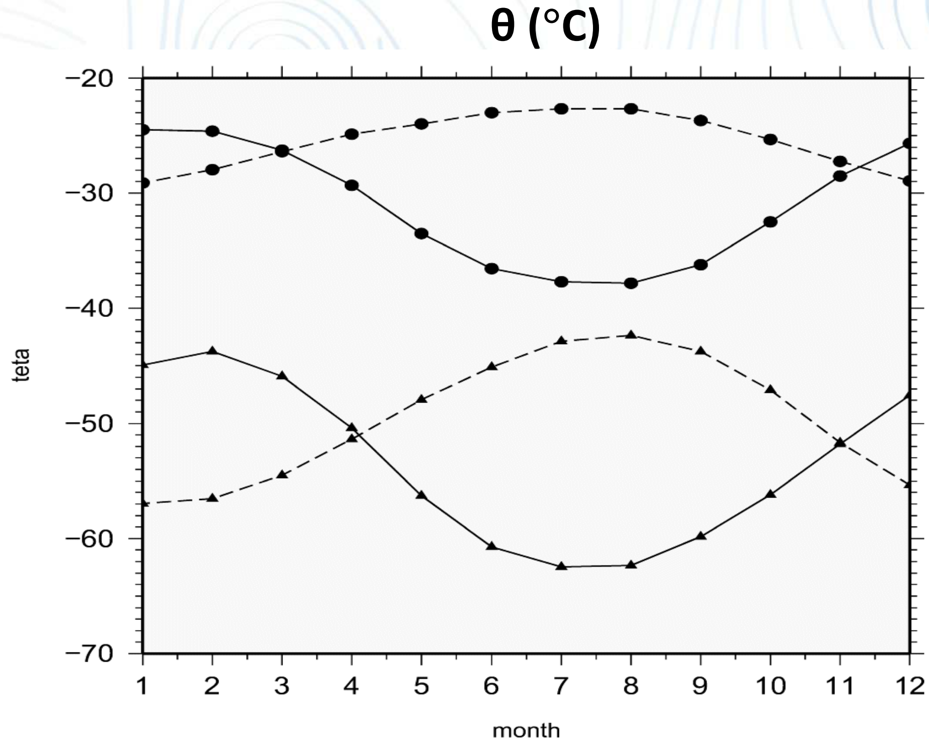
RESULTS: β, θ parameters

JANUARY



The Ekman currents





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

Angle at the surface lower than 45°

- Ekman theory assumes constant vertical viscosity profile. Not true in the real ocean

The Ekman currents: Confidence level

% of variance explained

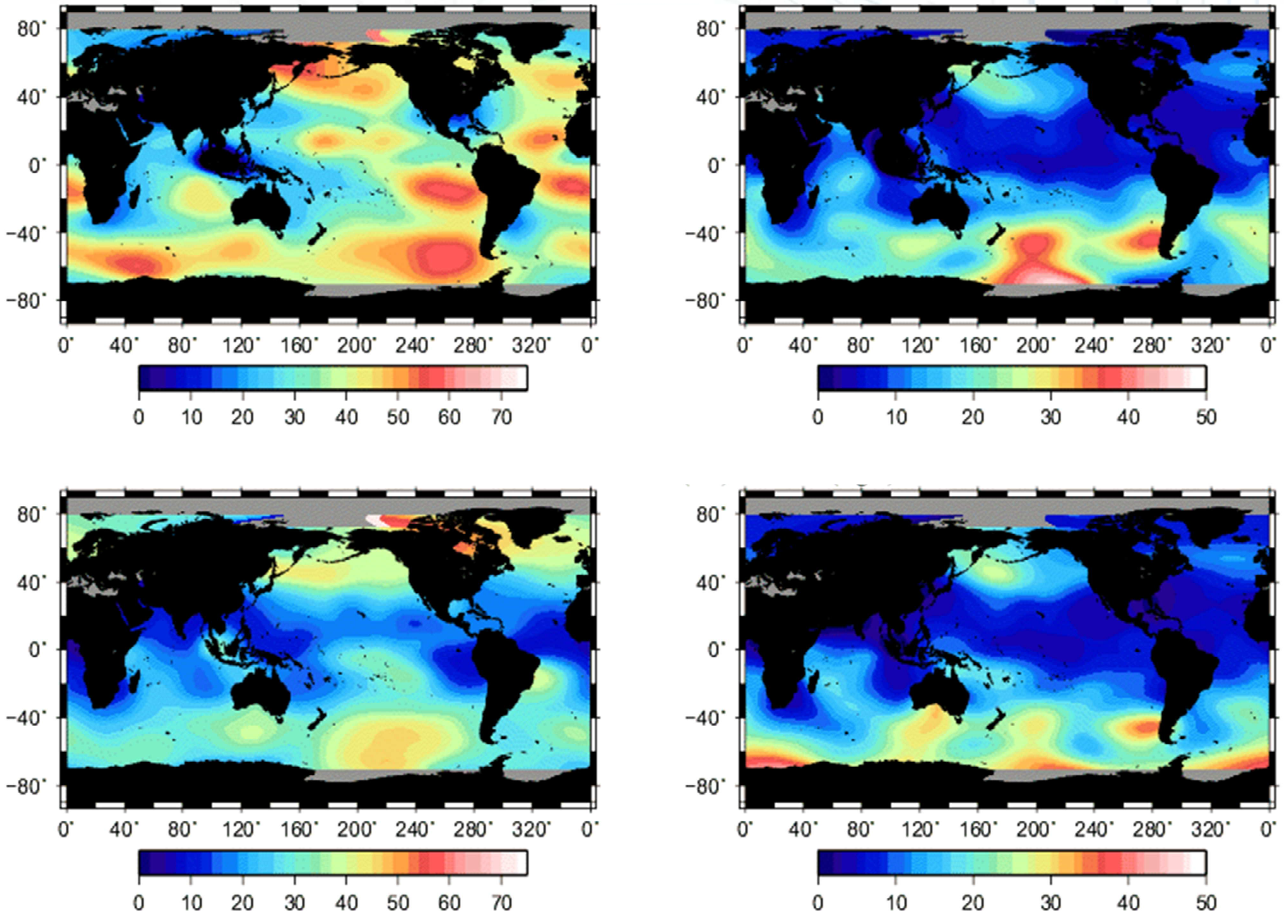
JANUARY

surface model

15m model

U

V



The Ekman currents: Confidence level

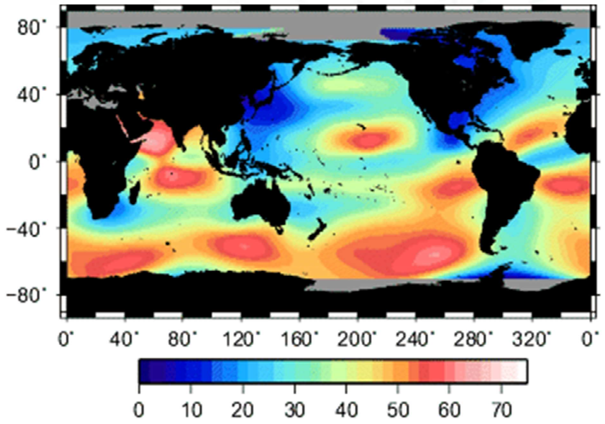
% of variance explained

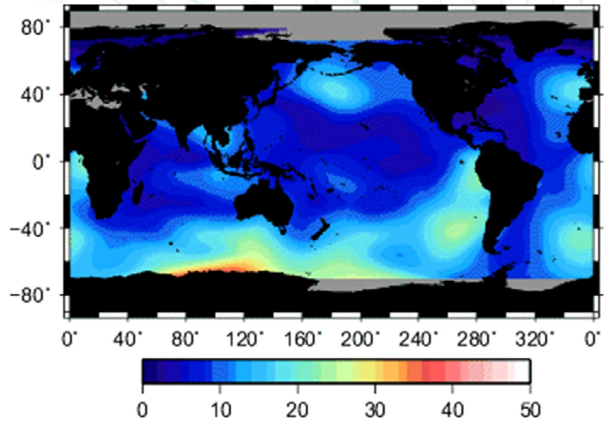
JUNE

surface model

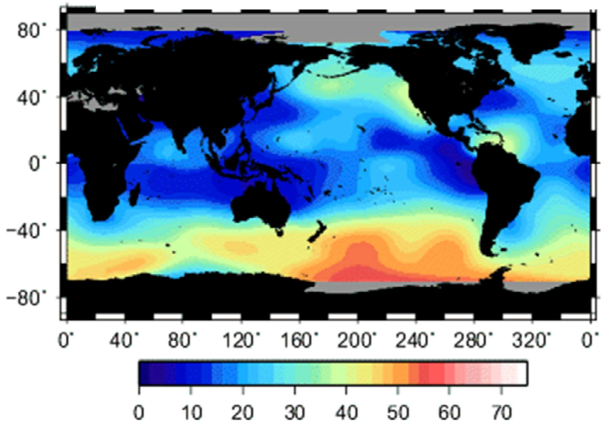
15m model

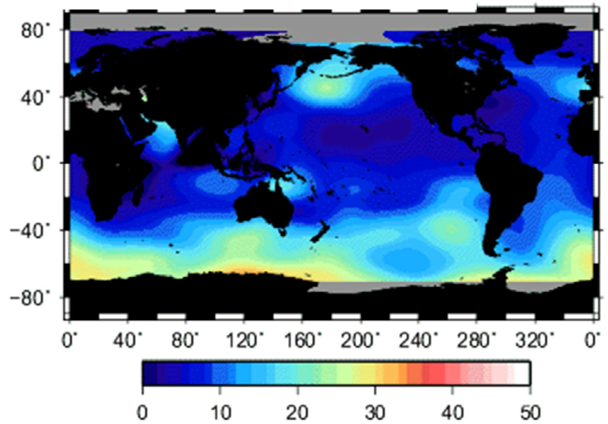
U



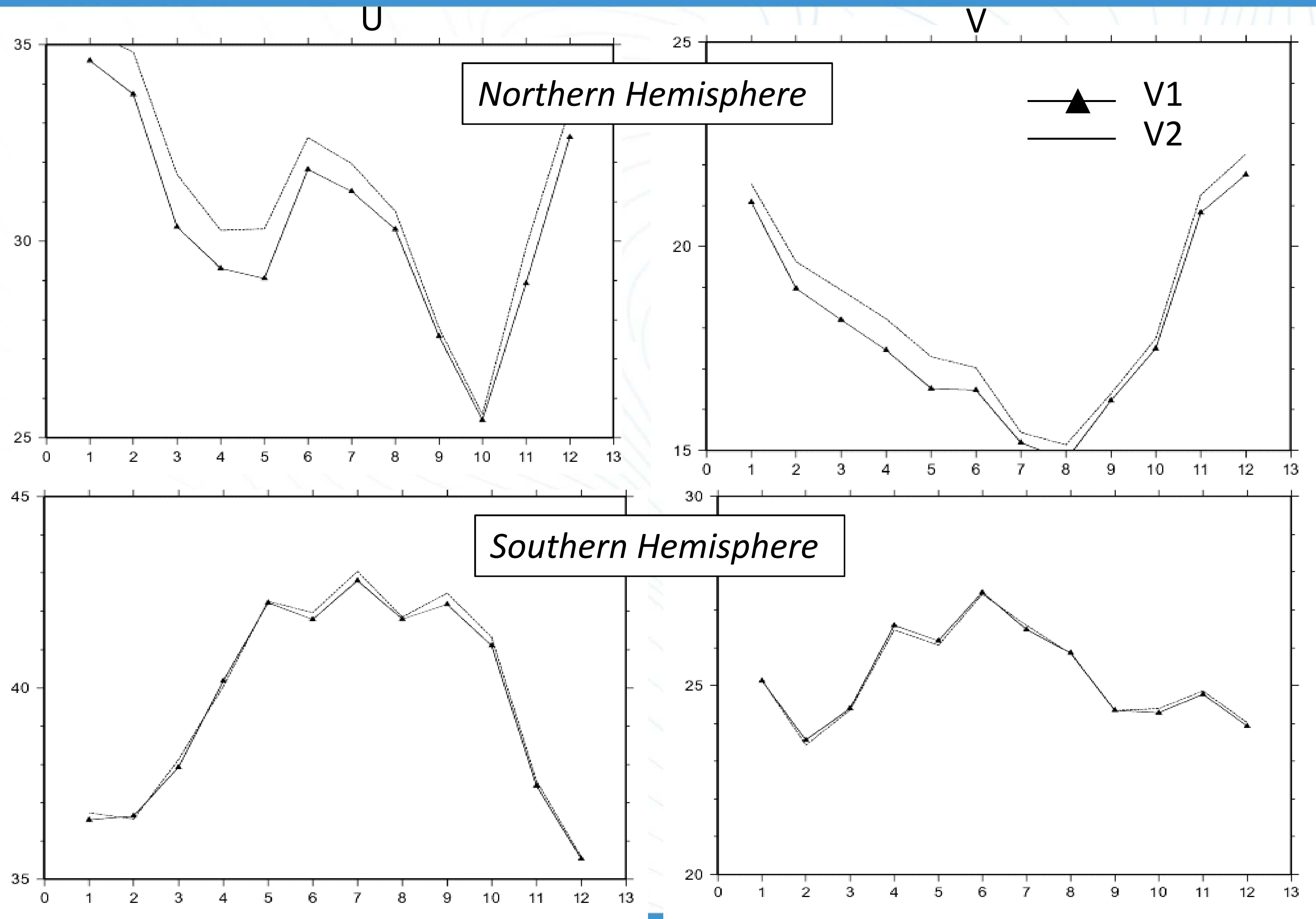


V

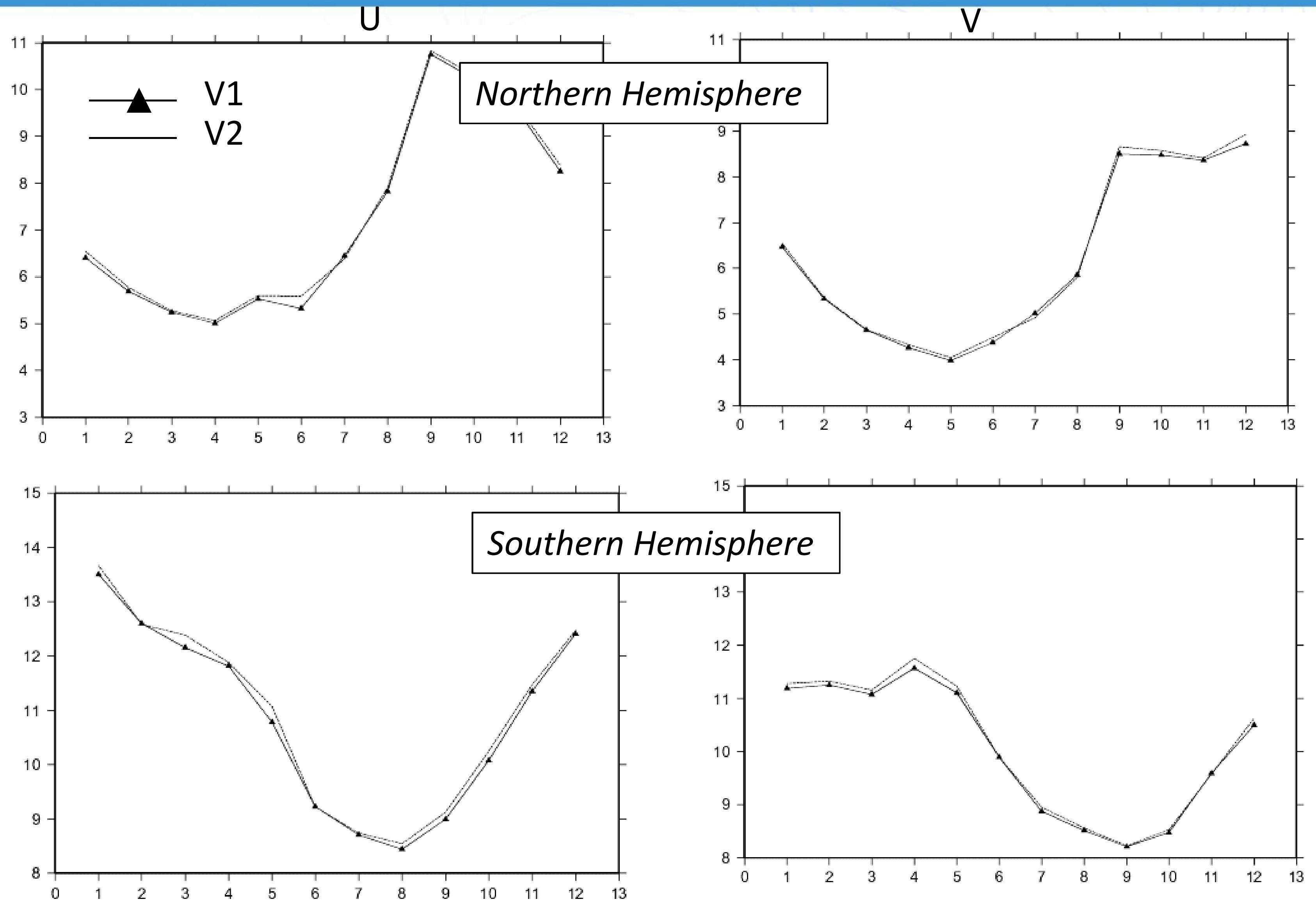




% VAR explained by the Surface model V2 vs V1



% VAR explained by the Surface model V2 vs V1



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

$$DE_{\theta} = \frac{15*180.0}{\pi*(\theta(z=15m)-\theta(z=0m))}$$

Ekman depth based on the rotation of the currents with depth

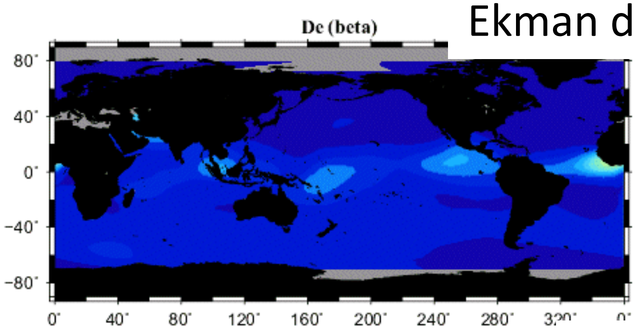
In the Southern Ocean, *Lenn and Chereskin (1999)* found **a rotation depth scale that exceeds the e-folding scale of the speed** by about a factor of 3, resulting in a **current spiral that is compressed relative to predictions from Ekman theory**.
Same order of magnitude has also been noted on the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

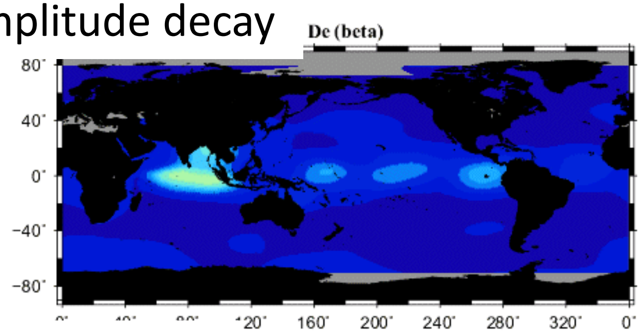
Estimating the Ekman Depth

JANUARY

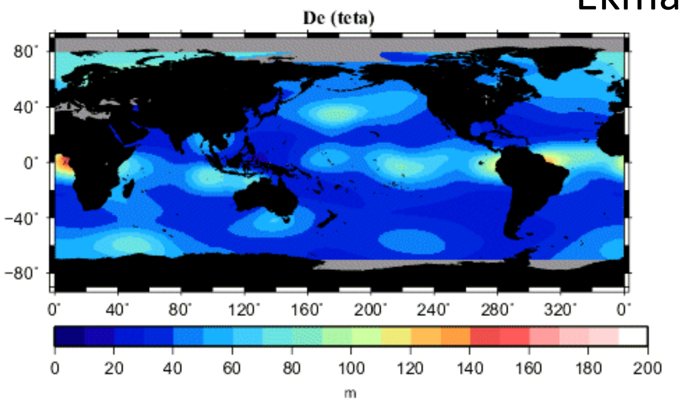
JULY

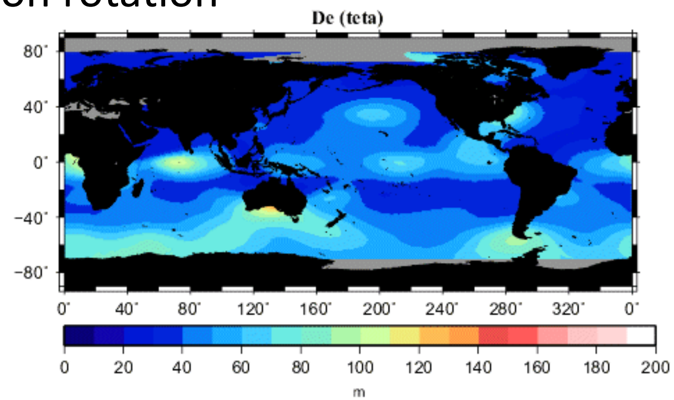
Ekman depth based on amplitude decay





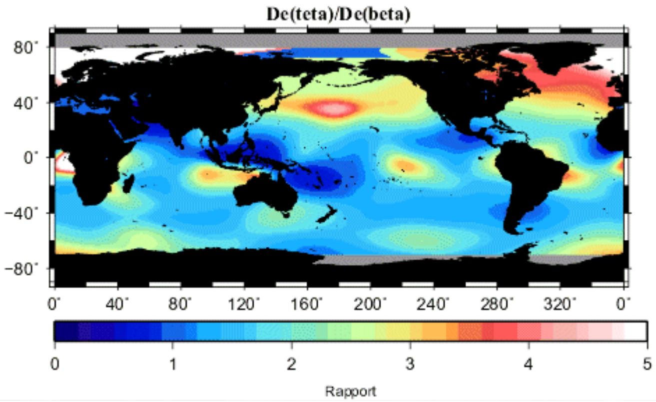
Ekman depth based on rotation

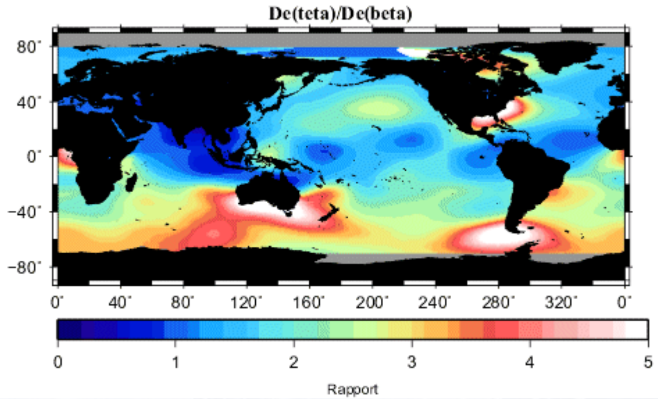




Ratio

more compressed spiral in winter than in summer





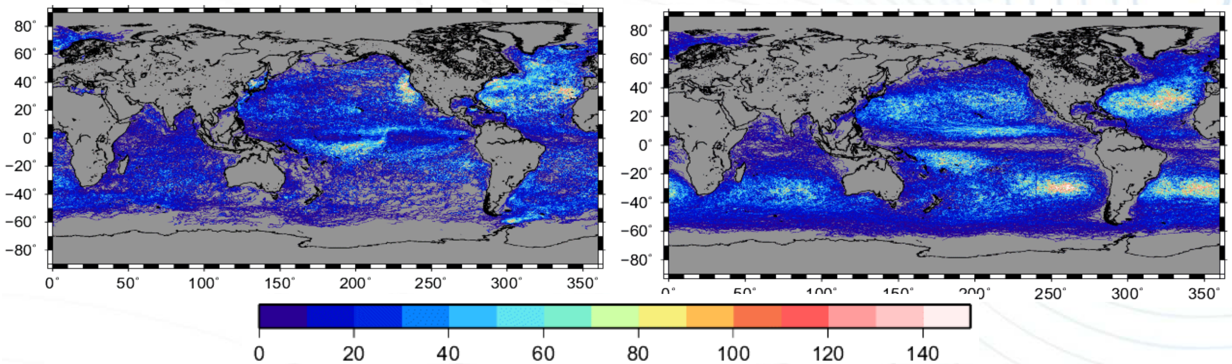
Dataset of drifting buoy velocities available for validation

➢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**.

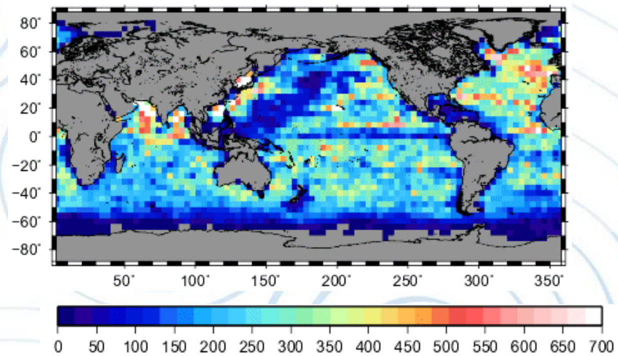
Two distinct files are provided for **drogued and undrogued** SVP-type drifters
Included colocated wind stress, geostorphic currents, Ekman currents, wind slippage (Rio, 2012)

Num buoy velocities Drogue ATTACHED

Num buoy velocities Drogue LOST



Num Surface Argo float velocities



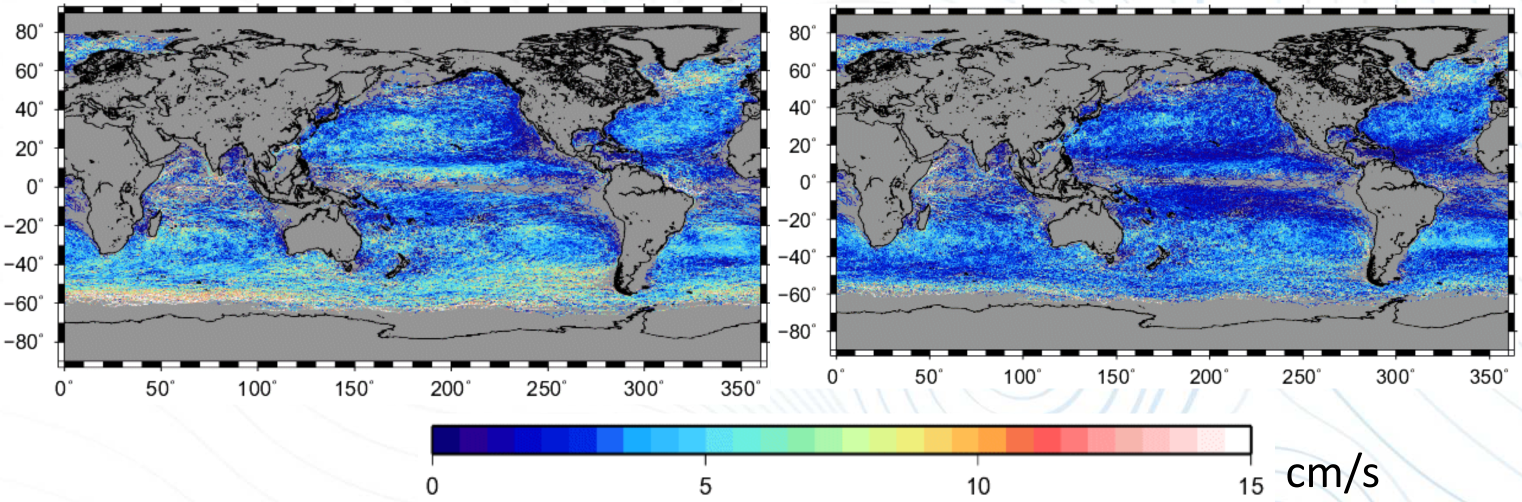
➢Also a dataset of Argo floats derived surface velocities , with collocated fields of wind stress, geostrophic and surface Ekman currents is available, covering **the period 1997-2014**

Wind Slippage Impact on undrogued drifters

Mean wind slippage for undrogued drifters

zonal

meridional

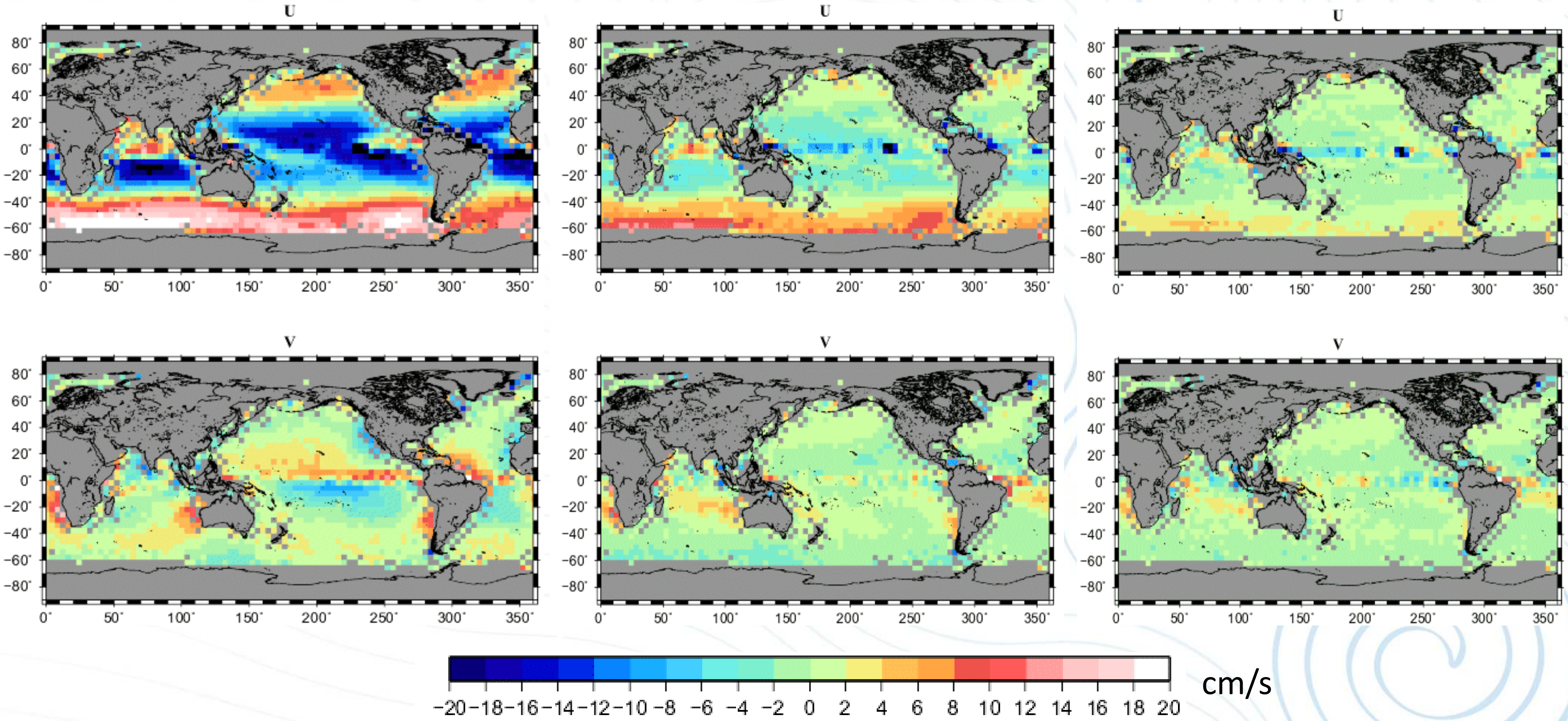


Wind Slippage Impact on undrogued drifters

Buoy velocities-Geost

Buoy velocities-(Geost+Ekman)

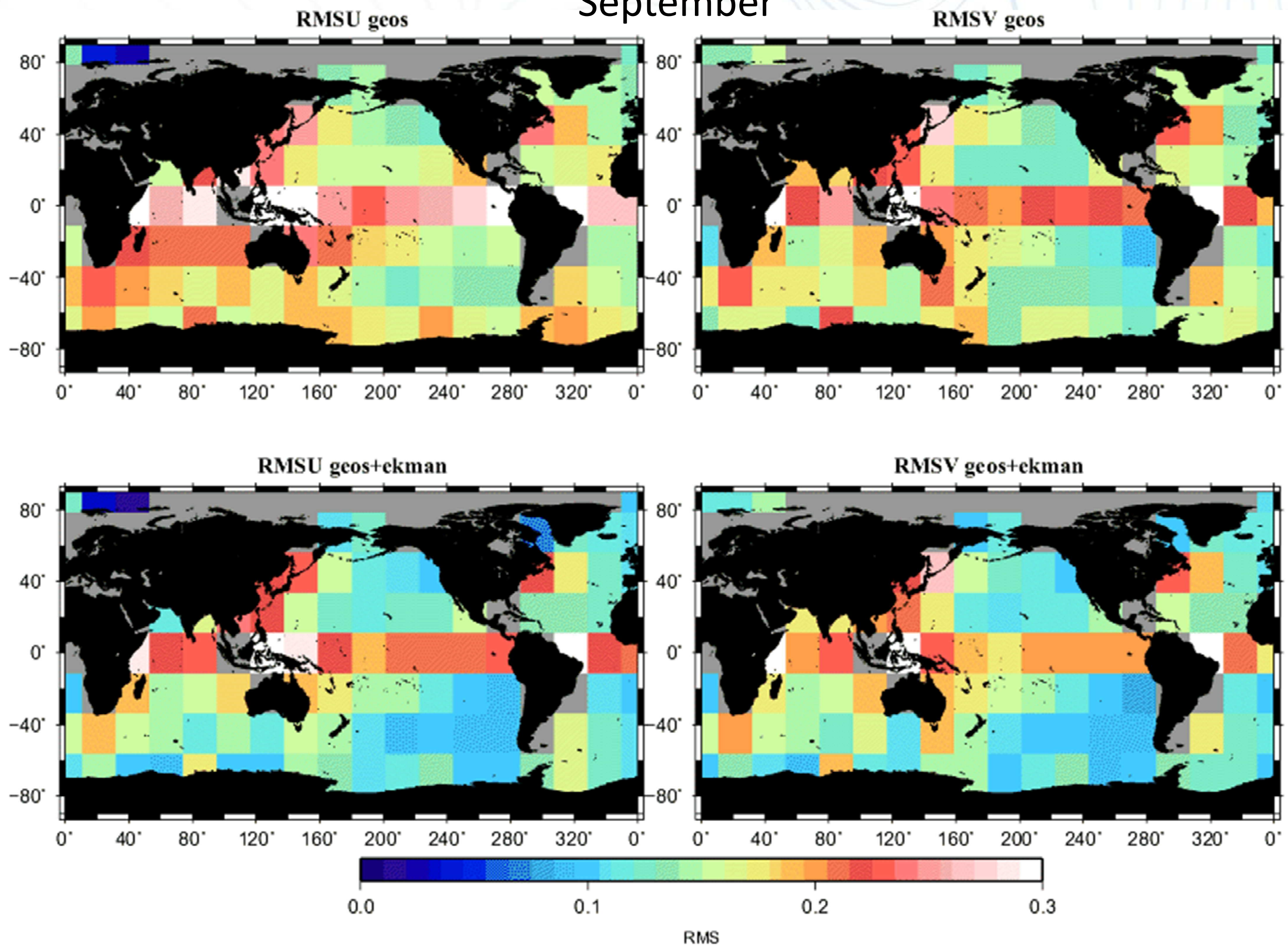
Buoy velocities-Wind slippage-(Geost+Ekman)



GlobCurrent products Error Estimates

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

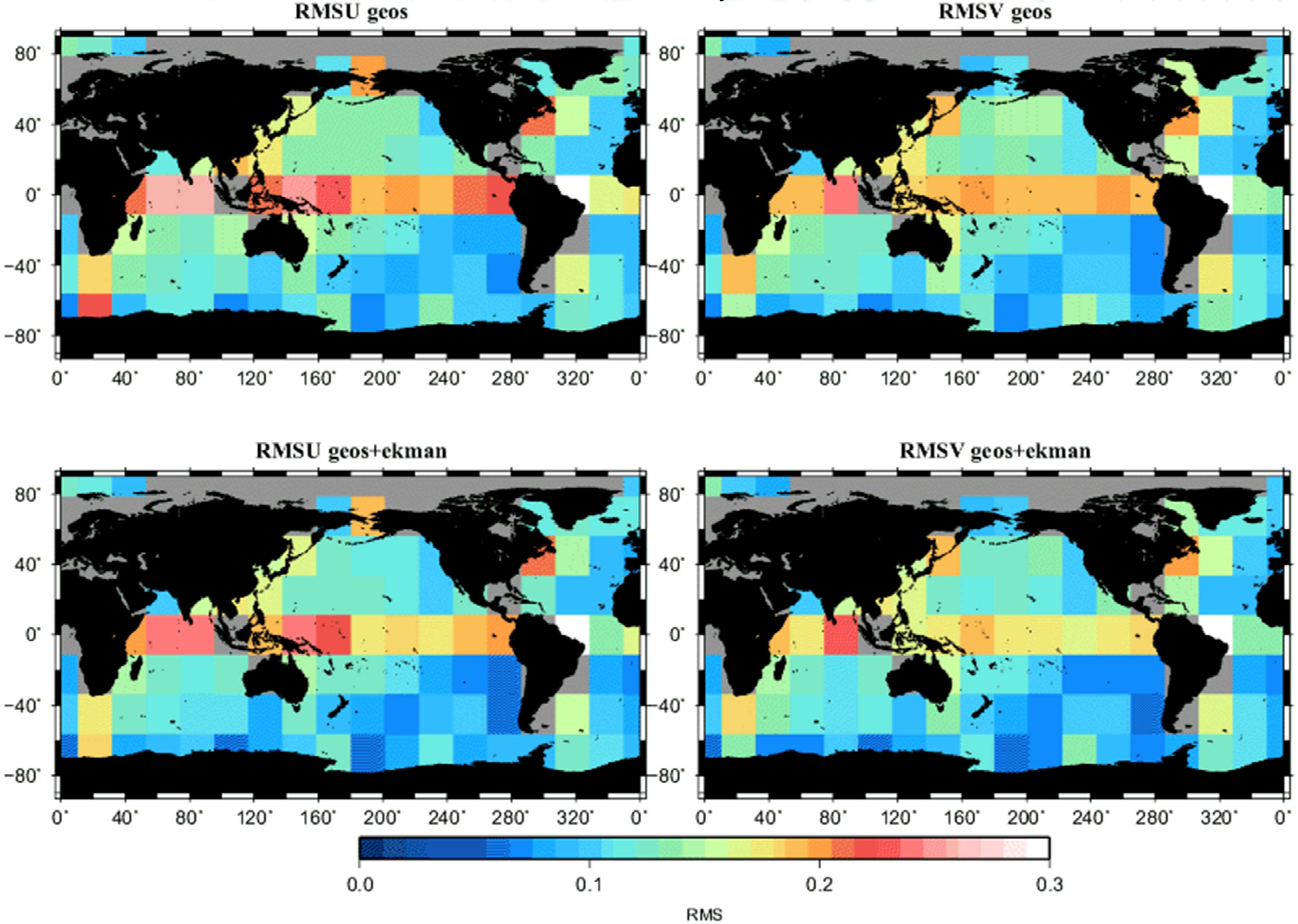
September



GlobCurrent products Error Estimates

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

January



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

see K. Dohan's talk tomorrow!

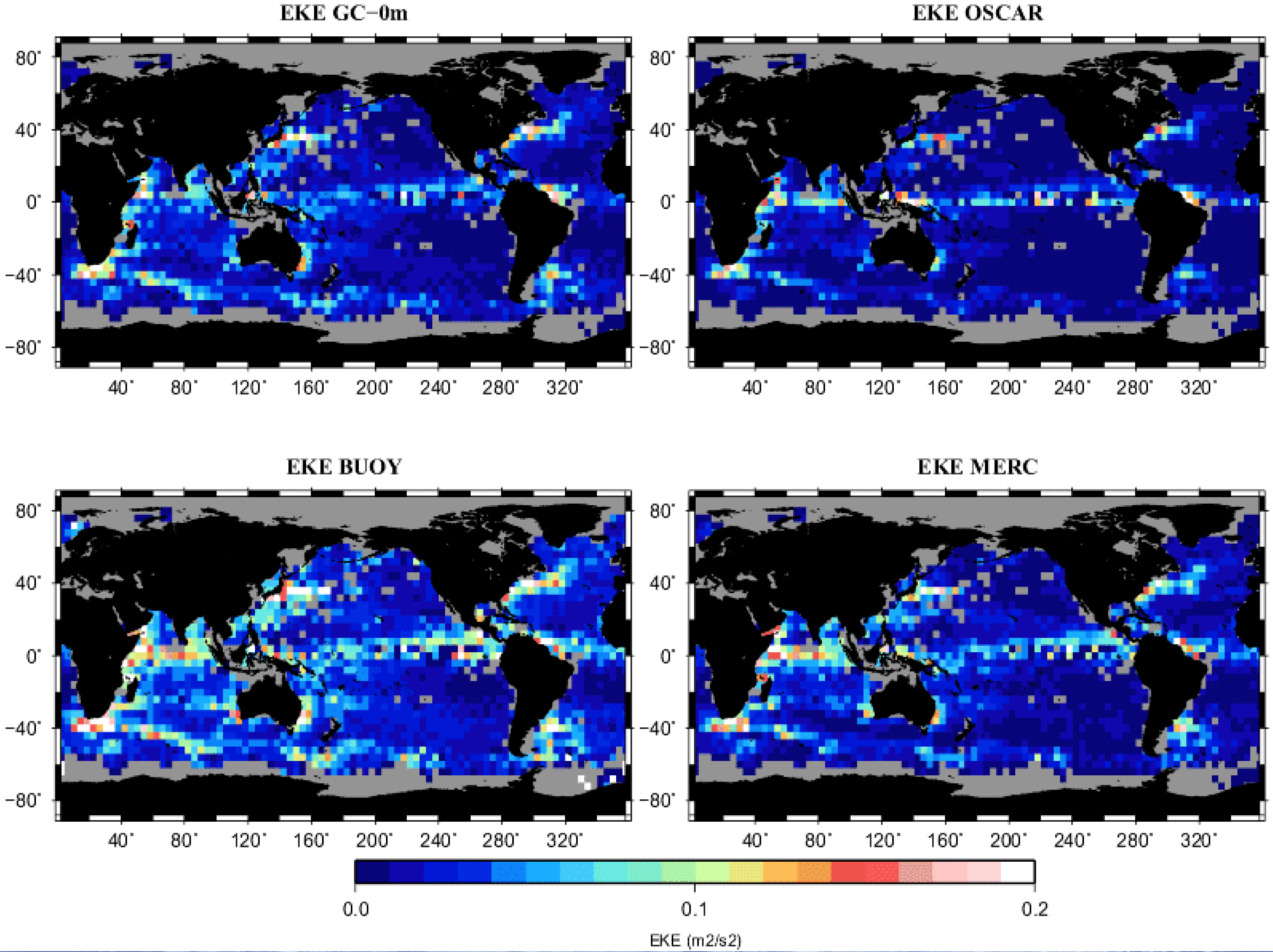
The Mercator-Ocean surface velocities
-first level (0.5m) from the 1/12° operational model (with assimilation)

Comparison to Argo surface velocities for the year 2013

Year 2013: 74973 (72436) velocities*	RMS (cm/s) Bracket: |lat|>3	
	U	V
GC Geostrophic	19.4 (18.5)	17.2 (16.6)
GC Geostrophic + Ekman	**15.9 (14.9)**	**15.5 (14.9)**
OSCAR	19.2 (17.8)	17.6 (16.7)
Mercator (1/12°)	19.3 (19.1)	19.0 (19.0)

***Unfiltered velocities: contain Geos, Ekman, Stokes, inertial oscillations, tidal current…**

Validation of the GlobCurrent 0m currents: Comparison to OSCAR and Mercator currents



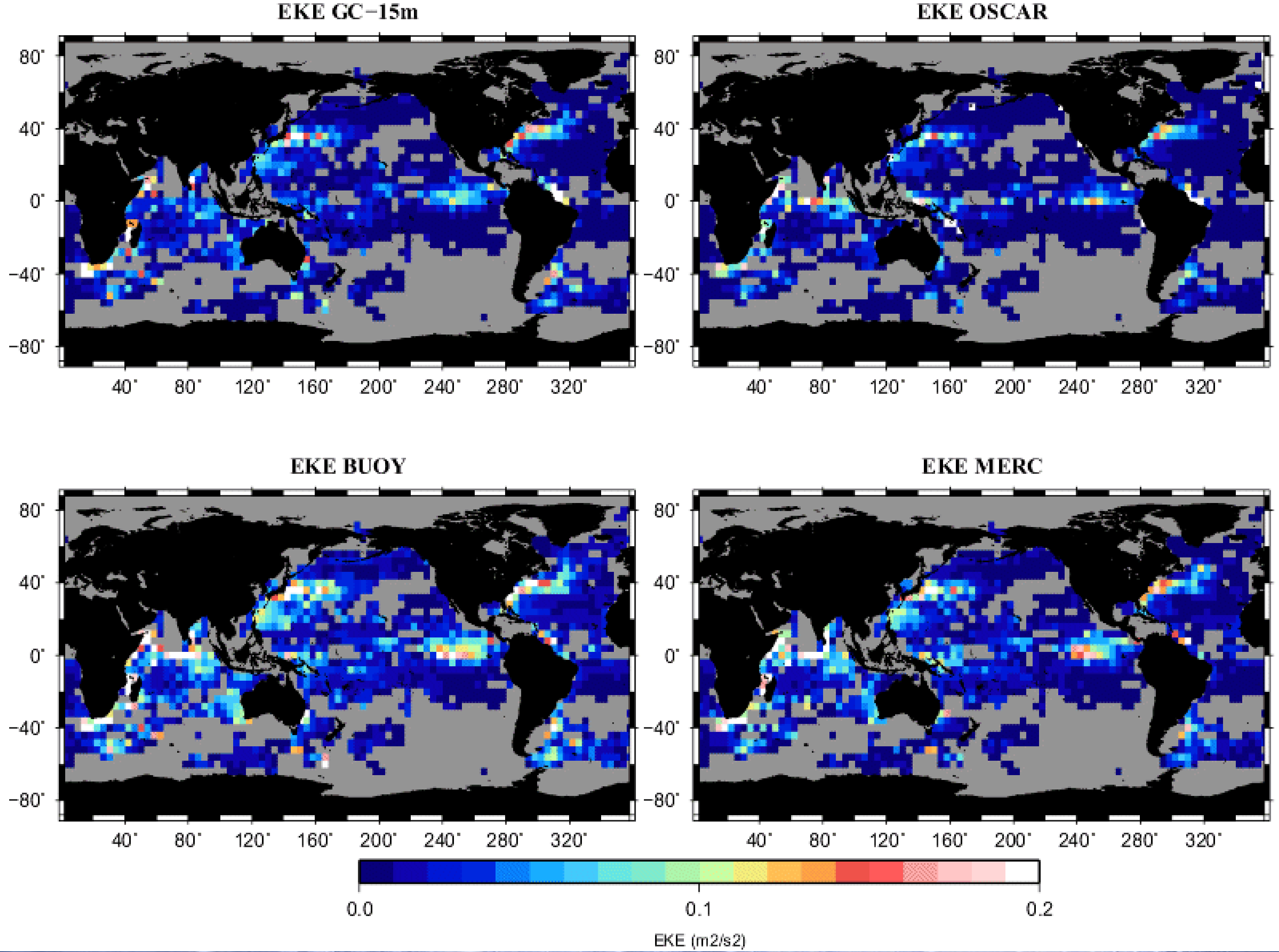
Validation of the GlobCurrent 15m currents: Comparison to OSCAR and Mercator currents

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…**

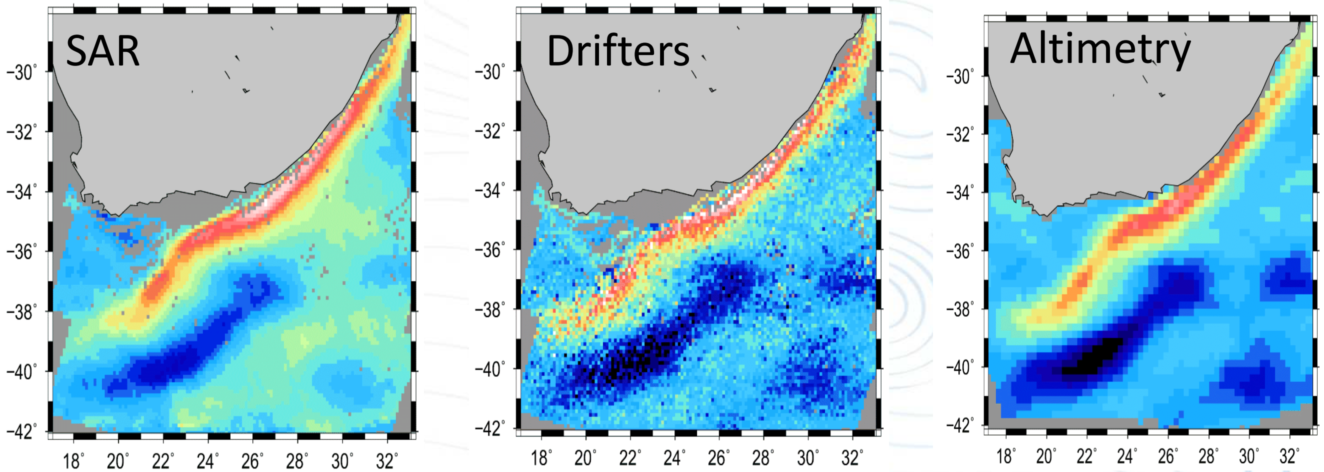
Validation: Comparison to OSCAR and Mercator currents



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

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

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

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

TEST1 $\vec{u}_e = \frac{\beta}{H_{mld}} \vec{\tau} e^{i\theta}$ → Boyer-Montégut climatology

TEST2 $\vec{u}_e = \frac{\beta}{f} \vec{\tau} e^{i\theta}$

TEST3 $\vec{u}_e = \frac{\beta}{f + w} \vec{\tau} e^{i\theta}$

TEST4 $\vec{u}_e = \frac{\beta}{f} \vec{\tau}_e e^{i\theta}$ $\quad \vec{\tau}_e = \rho_a C_D \left| \vec{W} - \vec{U}_g \right| (\vec{W} - \vec{U}_g)$

TEST5: Winds > 4 m/s

TEST6: Removal of Stokes drift from Argo surface velocities

τ_e= Effective Wind Stress

δ= Ekman depth

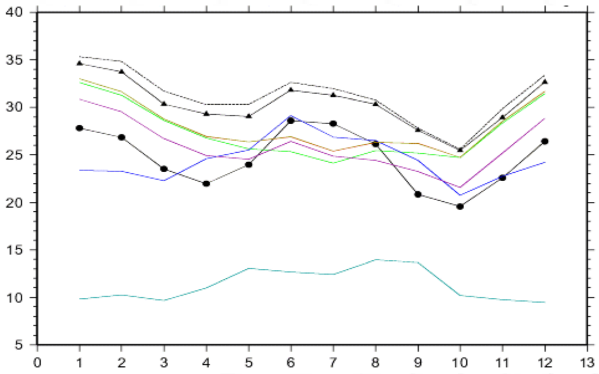
f= planetary vorticity

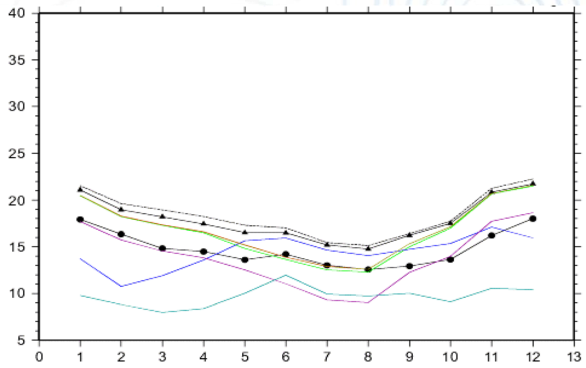
w=local vorticity

$$2\omega = \partial_x vgeost - \partial_y ugeost$$

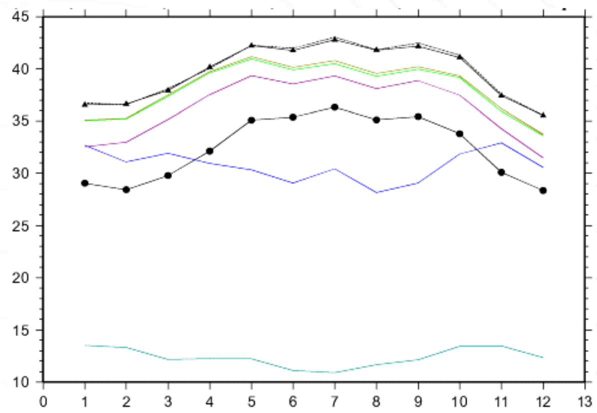
RESULTS: SURFACE MODEL

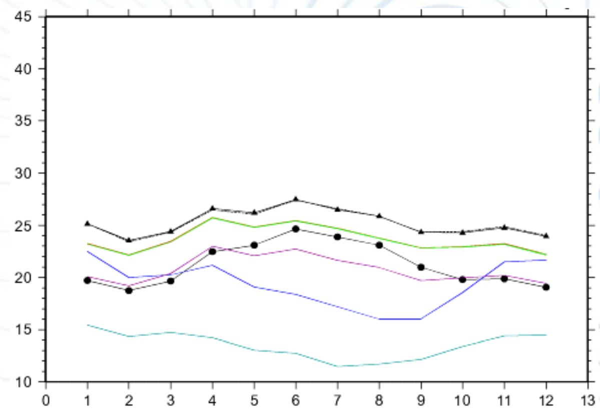
U- Northern Hemisphere V-





U- Southern Hemisphere V-



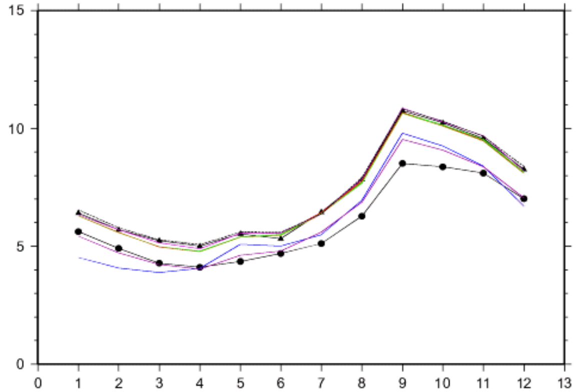


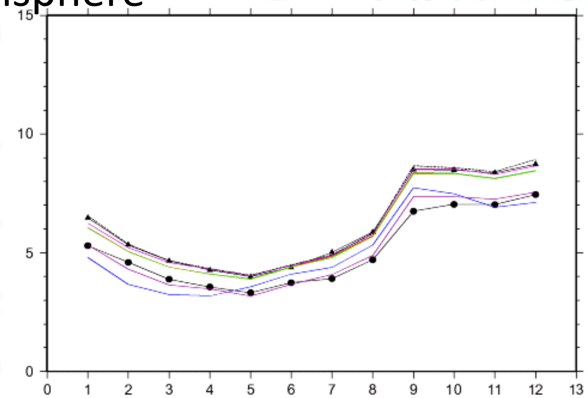
- no impact of introducing the local vorticity w (red vs green)
- negative impact of introducing effective wind stress (green vs purple)
- negative impact of introducing the Mixed Layer Depth in winter / positive in summer (blue vs **black**)
- negative impact of removing Stokes drift (light blue)

Percentage of variance explained by different surface Ekman model formulations (Black circle = f0; Blue line= f0 MLD; Red line= f; Green line=f+w; Purple line=Eff WS; Kaki line=Wind>4m/s; Light blue line=Stokes).

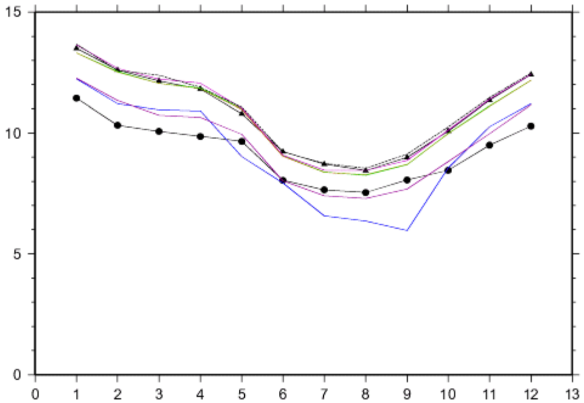
RESULTS: 15m MODEL

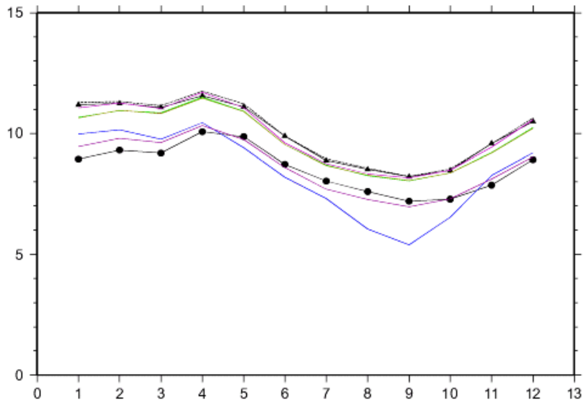
U- Northern Hemisphere V-





U- Southern Hemisphere V-





- 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 = f0; Blue line= f0 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

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

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

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

H_{mld} from the Boyer-Montégut* monthly climatology

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

**De Boyer Montégut, C., G. Madec, A. S. Fischer, A. Lazar, and D. Iudicone (2004), Mixed layer depth over the global ocean: an examination of profile data and a profile-based climatology, J. Geophys. Res., 109, C12003. doi:10.1029/2004JC002378,*

FUTURE IMPROVEMENTS:
INTRODUCING NEW PARAMETERS IN THE EKMAN MODEL

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

a ϵ[0,1]; b ϵ[0,1]; c ϵ[0,1]

	a	b	c	B (10-3)	θ	Criteria		
Surface model						%varu	%varv	Rc
NH	0.2	0.4	0.6	$1.9\ 10^{-2}$	-36	32	19	0.51
SH	0.1	0.4	0.6	$1.3\ 10^{-2}$	33	42	26	0.6
GLOB	**0.2**	**0.4**	**0.6**	$1.9\ 10^{-2}$	+-35	37	22	0.55
15m depth model								
NH	0.3	1	0.9	$6.4\ 10^{-5}$	-57	7.0	6.0	0.25
SH	0.3	0.8	0.9	$4.7\ 10^{-4}$	55	11.	10.	0.32
GLOB	**0.3**	**0.9**	**0.9**	$1.7\ 10^{-4}$	+-56	8.4	7.5	0.28

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).

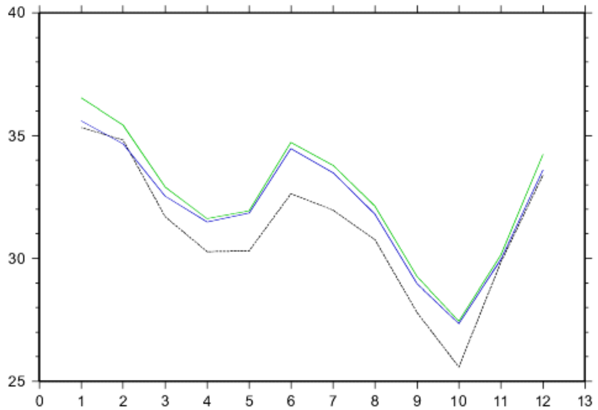
FUTURE IMPROVEMENTS:
INTRODUCING NEW PARAMETERS IN THE EKMAN MODEL

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

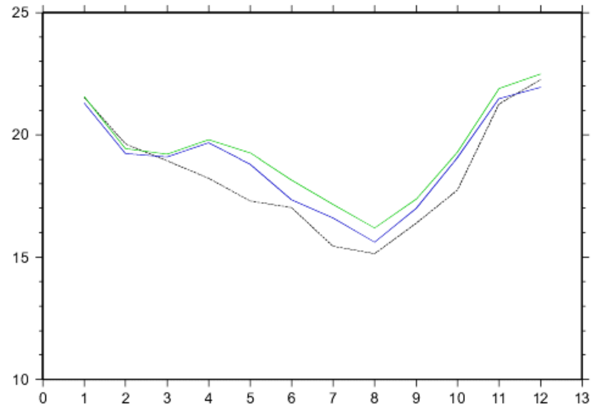
Percentage of variance explained by different 0m depth Ekman model formulations (Black line = New; Blue line= optimized full period; Green line=optimized monthly).

Northern Hemisphere

U-

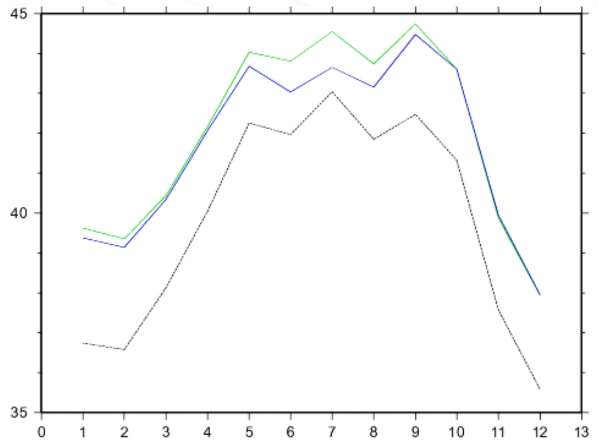


V-

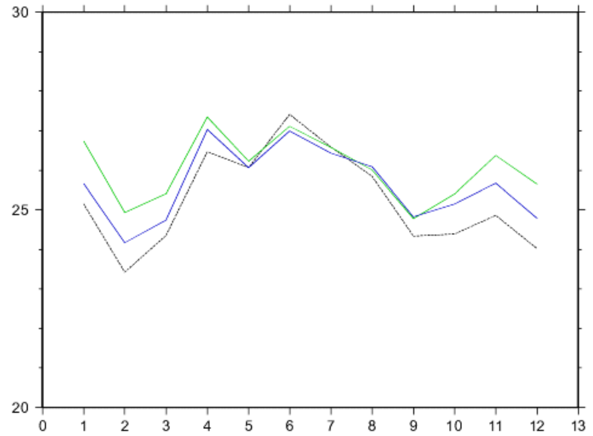


Southern Hemisphere

U-



V-



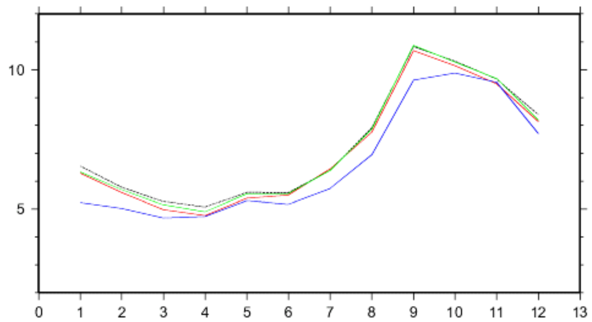
FUTURE IMPROVEMENTS:
INTRODUCING NEW PARAMETERS IN THE EKMAN MODEL

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

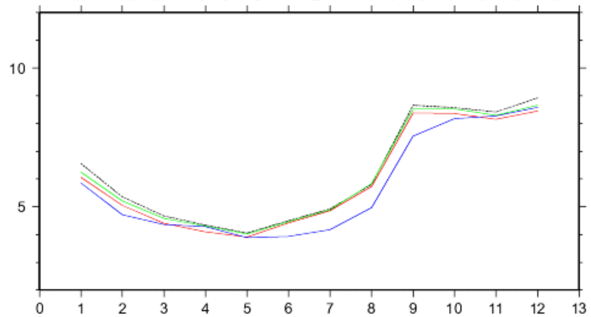
Percentage of variance explained by different 0m depth Ekman model formulations (Black line = New; Blue line= optimized full period; Green line=optimized monthly).

Northern Hemisphere

U-

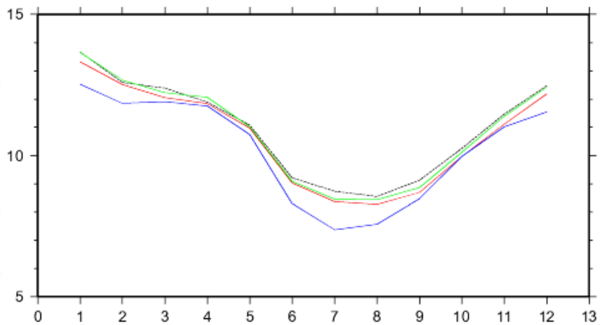


V-

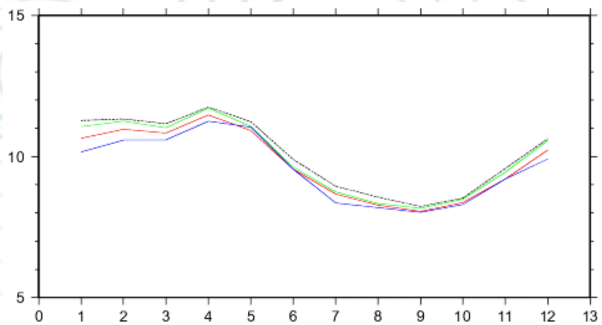


Southern Hemisphere

U-



V-



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

Drifter Type	β	R^2 (%)	N
CODE	0.008exp(-18°i)	10	74498
SVP drogued	0.003exp(-33°i)	2	22805
SVP undrogued	0.01exp(-18°i)	17	39648
SVP unknown	0.006exp(-34°i)	6	63217

Conclusion

➢**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…)

The Oscar velocities

Analytical solution for shear: geostrophic balance, steady Ekman, thermal wind shear (SST horizontal gradient).

$$\underbrace{\mathbf{ifU_0} = -\mathbf{g}\nabla\zeta}_{\text{Geostrophy}} + \underbrace{\frac{1}{\mathbf{H}}\mathbf{q}\left(\frac{\mathbf{H}}{\hbar_e}\right)\tau}_{\text{Ekman}} + \underbrace{\frac{\mathbf{H}/2}{\mathbf{q}\left(\frac{\mathbf{H}}{2\hbar_e}\right)}\nabla\theta}_{\text{Thermal wind}}$$

Surface velocity

$$\mathbf{q}(\xi) = \frac{1}{\tanh(\xi)} = 1 + \frac{\xi^2}{3} - \frac{\xi^4}{45} + \cdots \qquad \nabla = \frac{\partial}{\partial x} + i\frac{\partial}{\partial y}$$

ζ : MADT

τ : wind stress divided by ρ=1025 km.m^{-3}

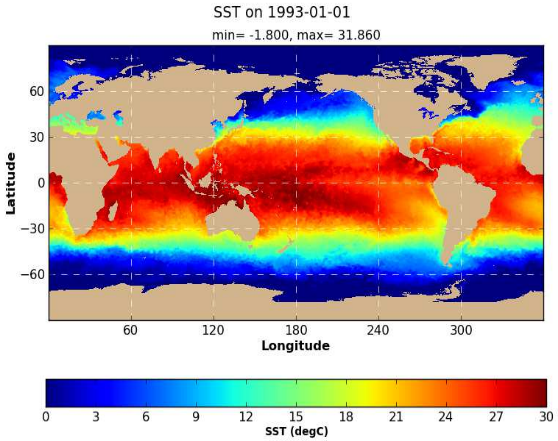
$\hbar_e$: pseudo Ekman depth : $\hbar_e \approx (A/if)^{1/2}$

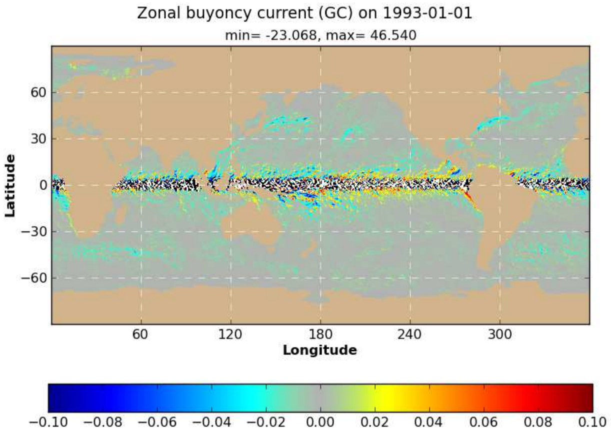
H is the depth where the vertical shear=0 : H=125 m

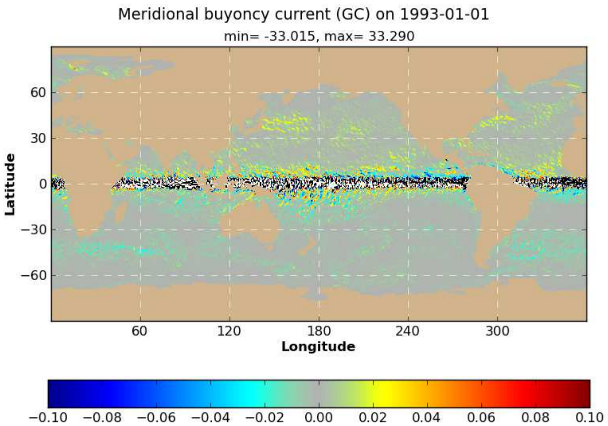
A: horizontal viscosité.

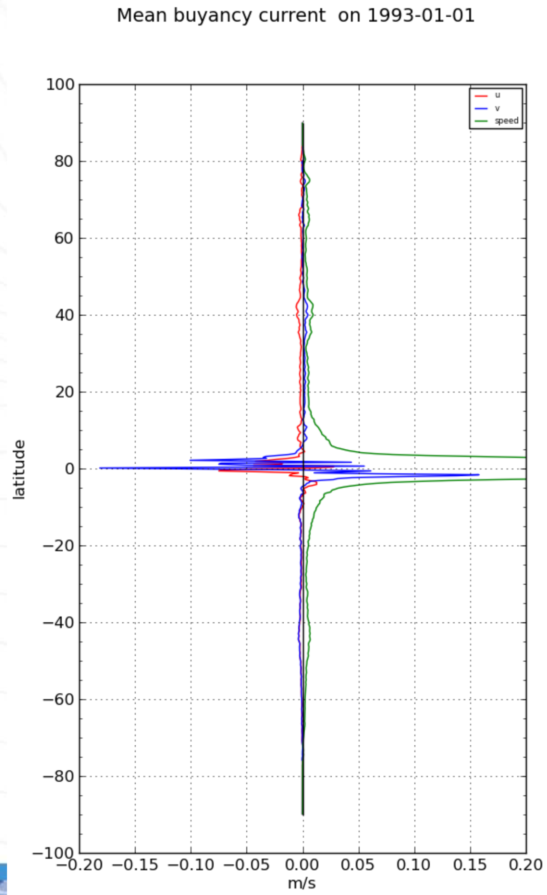
$\nabla\theta = g\chi_T \nabla SST$ With g=9.8 m.s^{-2} , χ_T= 3.10^{-4} K^{-1} thermal expansion coeff, SST is Reynolds SST.

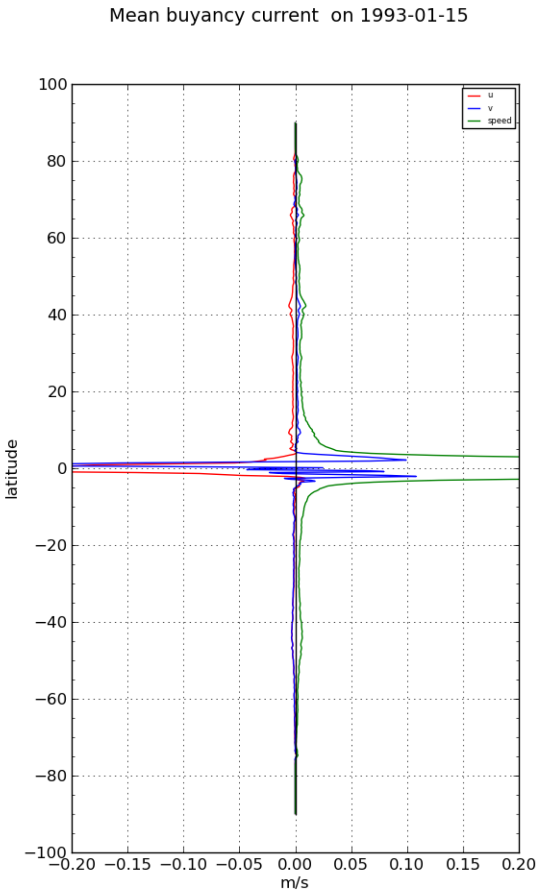
Thermal wind contribution











OSCAR equations

Horizontal viscosity: related to 10m wind W

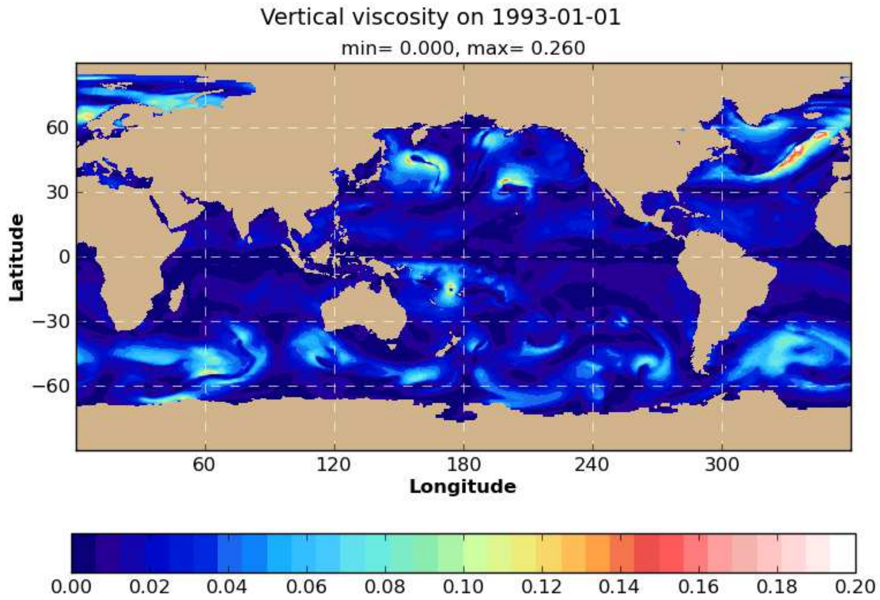
$$A = a\left(\frac{|W|}{W_1}\right)^b$$

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

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

Equatorial area: $a = 8.10^{-5}\ m^2.s^{-1}$; $b = 2.2$

Global: $a = 2.8510^{-4}\ m^2.s^{-1}$ et $b = 2.0$



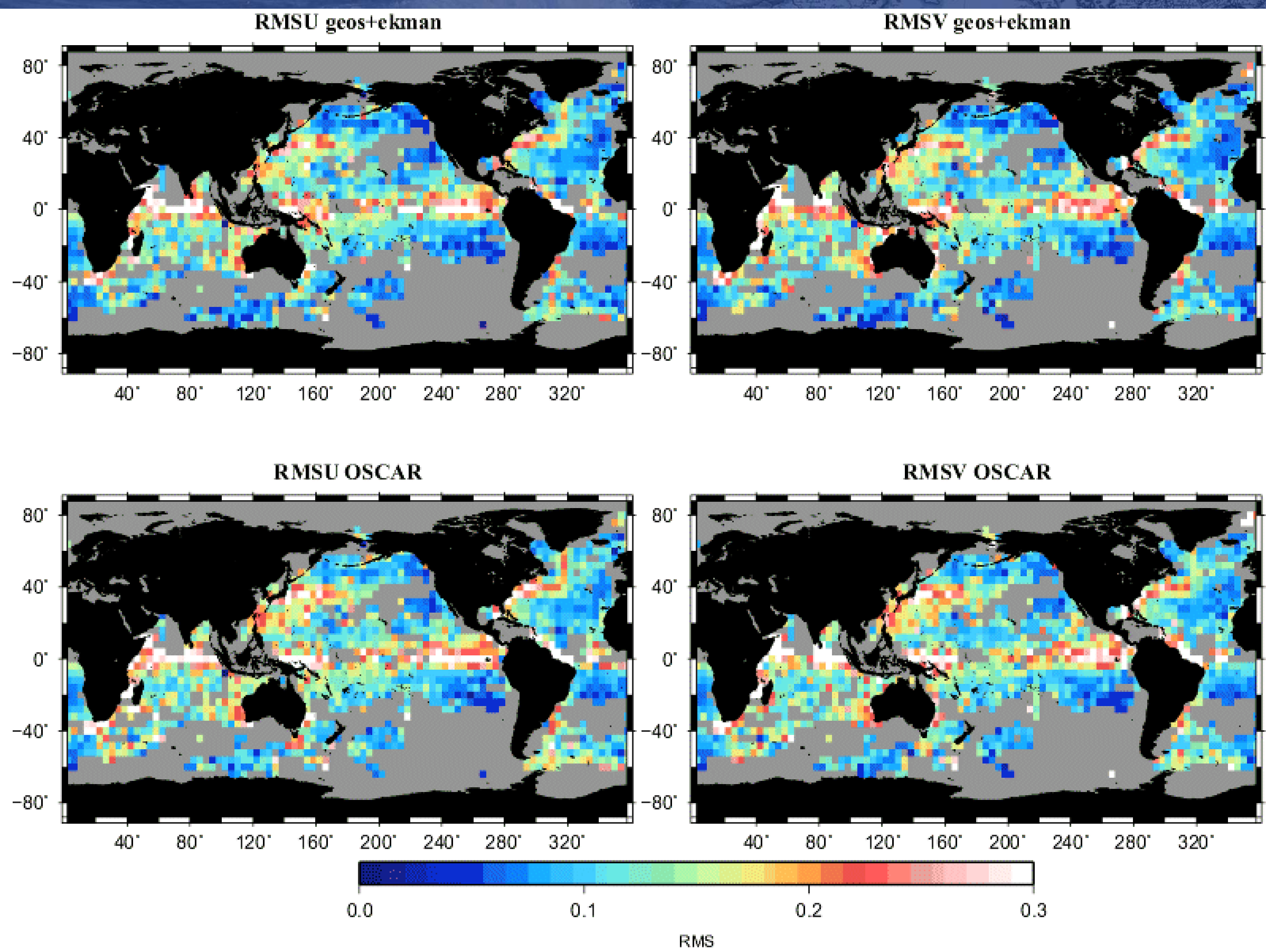
OSCAR equations

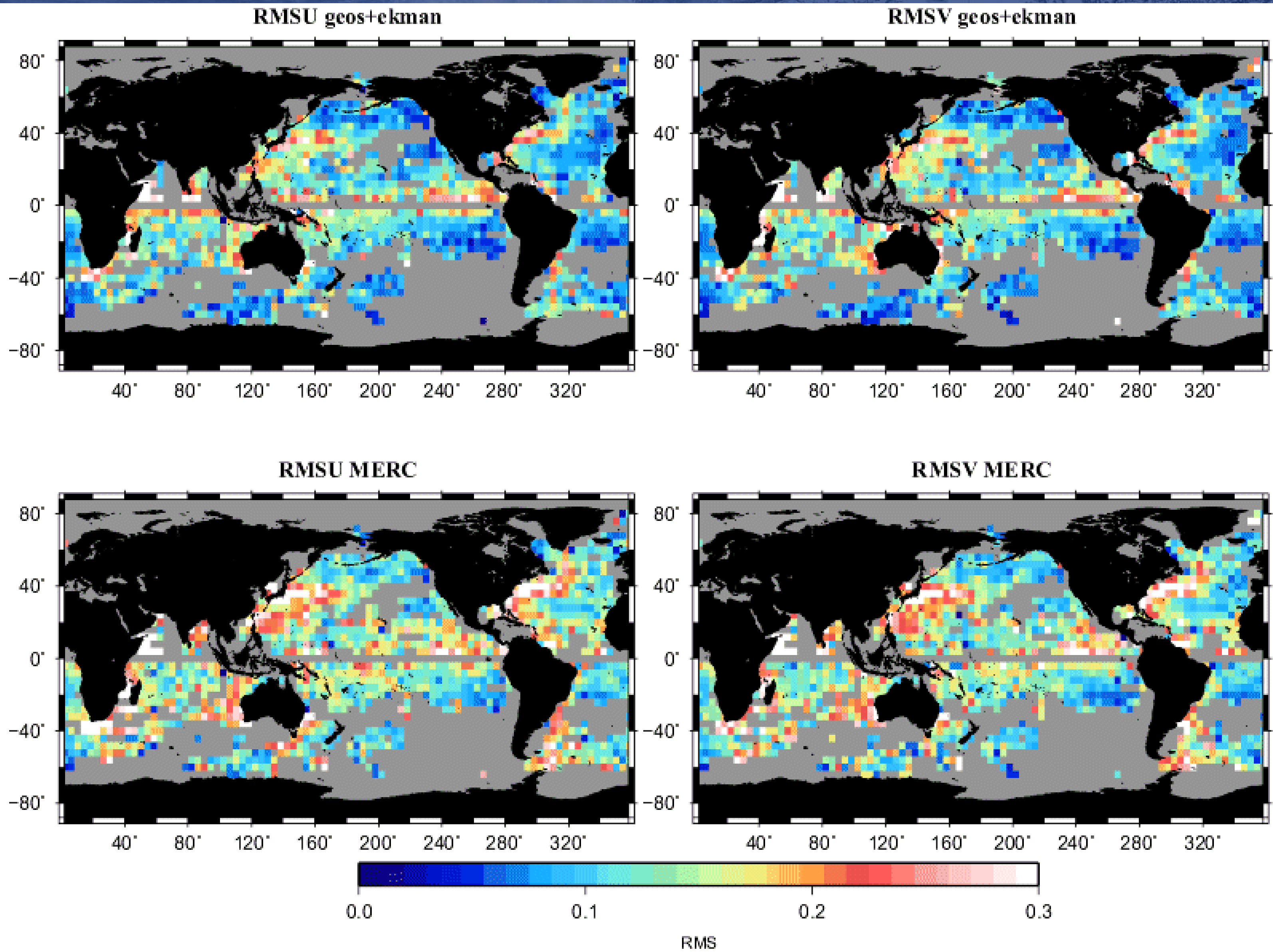
$$\mathbf{U}'(\mathbf{z}) = \underbrace{\frac{\sinh\left(\frac{\mathbf{H}+\mathbf{z}}{\hbar_e}\right)}{\sinh\left(\frac{\mathbf{H}}{\hbar_e}\right)}\frac{\tau}{\mathbf{A}}}_{\mathbf{U}'_\tau} + \underbrace{\frac{2\sinh\left(\frac{\mathbf{H}+\mathbf{z}}{2\hbar_e}\right)\sinh\left(\frac{\mathbf{z}}{2\hbar_e}\right)}{\cosh\left(\frac{\mathbf{H}}{2\hbar_e}\right)}\frac{\hbar_e^2\nabla\theta}{\mathbf{A}}}_{\mathbf{U}'_\theta}$$

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

$$U'(z=-H) = 0$$

Plans for exploiting new products


RMSU geos+ekman
RMSV geos+ekman
RMSU OSCAR
RMSV OSCAR
80˚
40˚
0˚
-40˚
-80˚
40˚
80˚
120˚
160˚
200˚
240˚
280˚
320˚
0.0
0.1
0.2
0.3
RMS


RMSU geos+ekman
RMSV geos+ekman
RMSU MERC
RMSV MERC
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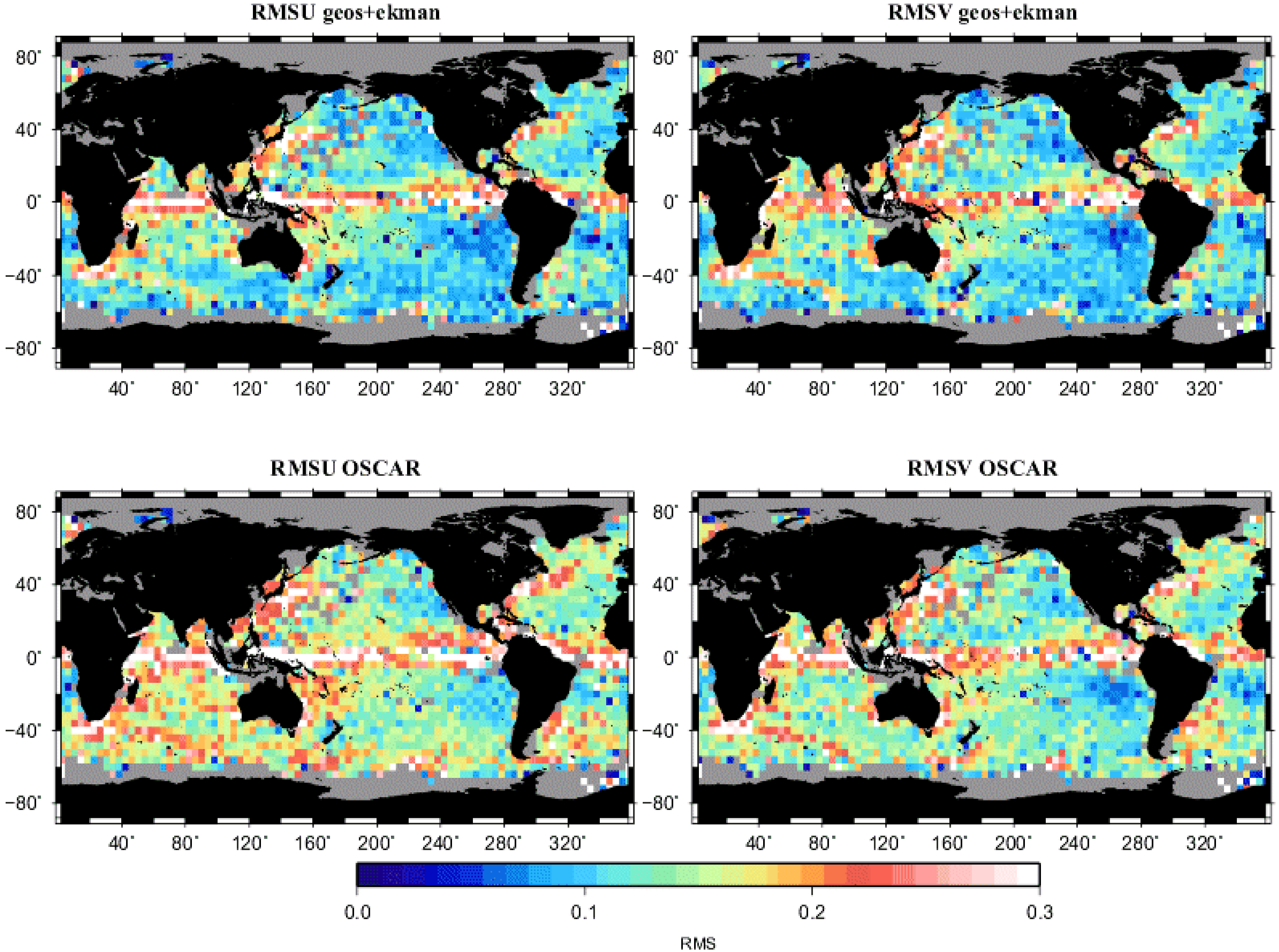
RMS


RMSU geos+ekman
RMSV geos+ekman
RMSU OSCAR
RMSV OSCAR
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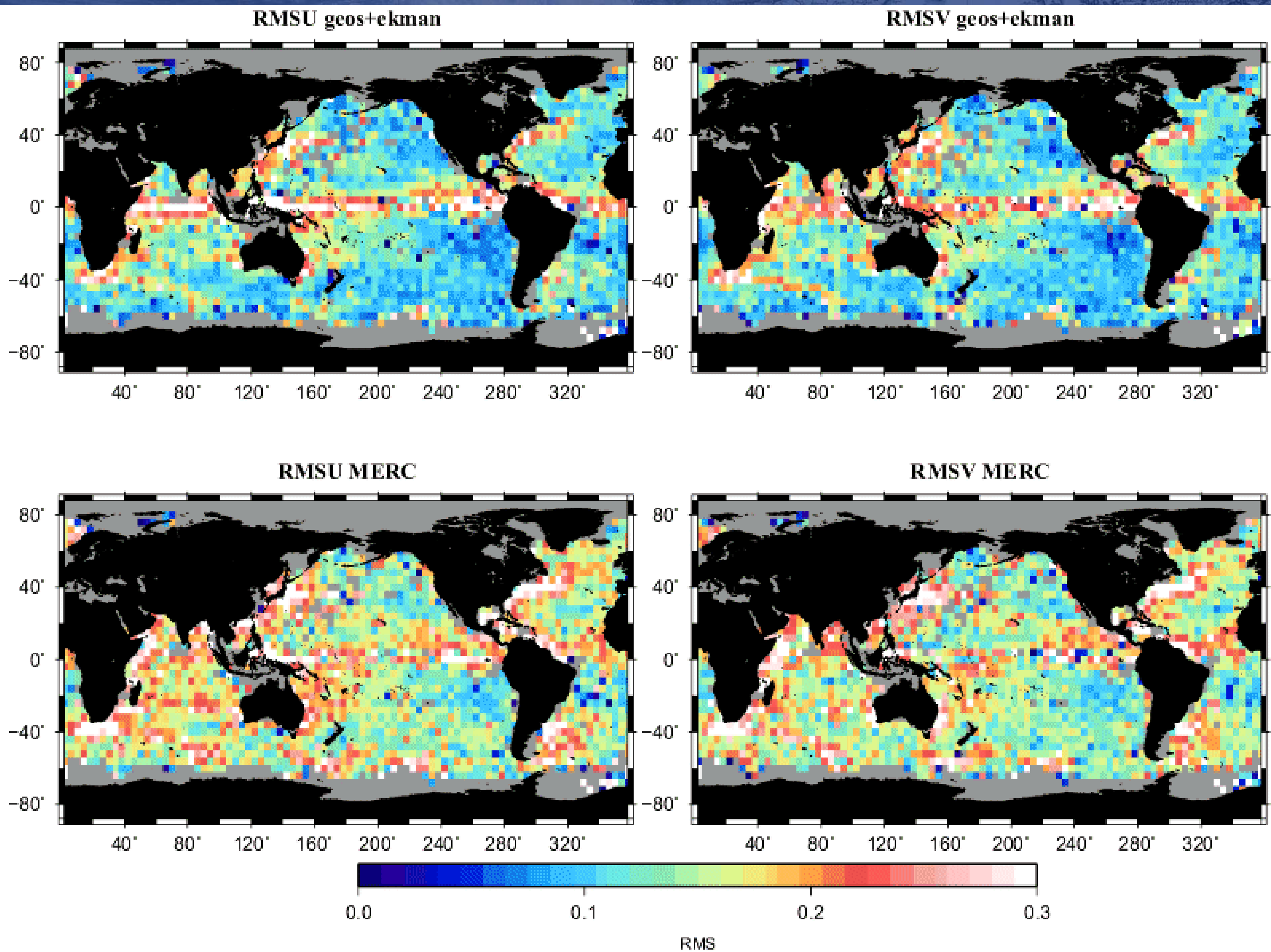

RMSU geos+ekman
RMSV geos+ekman
RMSU MERC
RMSV MERC
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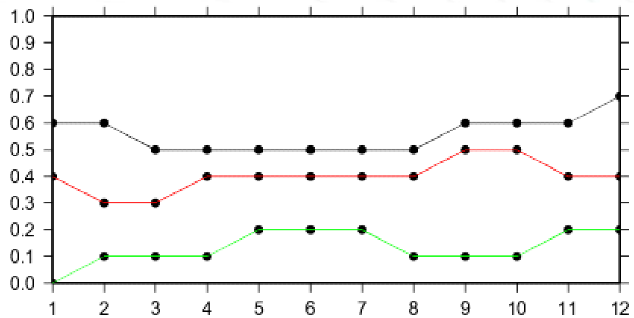
320˚
0.0
0.1
0.2
0.3
RMS

IMPACT OF INTRODUCING NEW PARAMETERS – SURFACE MODEL

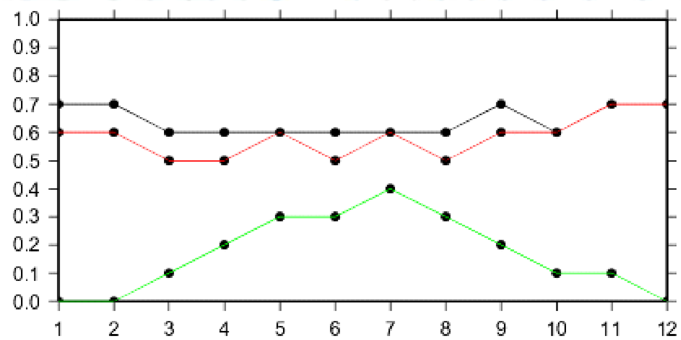
$$\vec{u}_{ek}(z) = \frac{\beta(z)}{H_{mld}^{a}(f+w)^{b}} e^{i\theta(z)} \vec{\tau}^{c}$$

a ϵ[0,1]; b ϵ[0,1]; c ϵ[0,1]

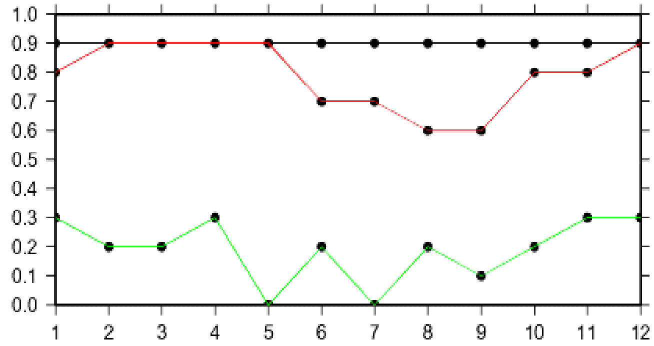
U-NH



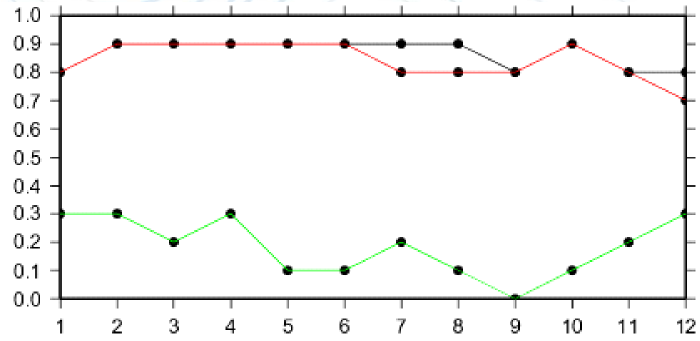
V-NH



U-SH



V-SH



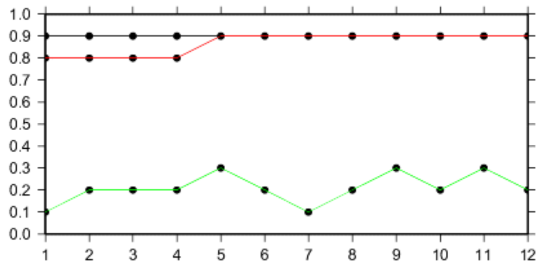
Green: a; Red: b; Black: c

IMPACT OF INTRODUCING NEW PARAMETERS – 15m MODEL

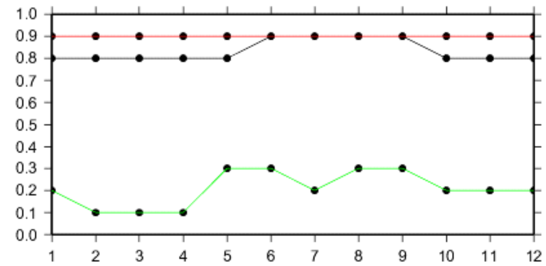
$$\vec{u}_{ek}(z) = \frac{\beta(z)}{H_{mld}^{a}(f+w)^{b}} e^{i\theta(z)} \vec{\tau}^{c}$$

a ϵ[0,1]; b ϵ[0,1]; c ϵ[0,1]

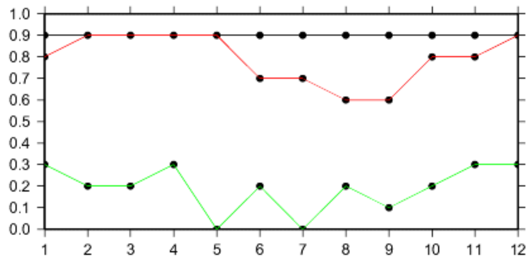
U-NH



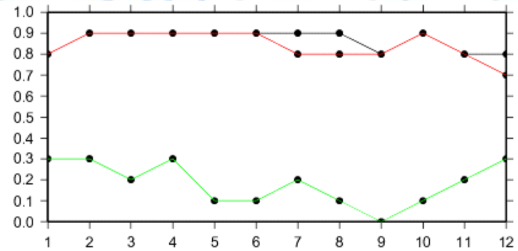
V-NH



U-SH



V-SH



Green: a; Red: b; Black: c