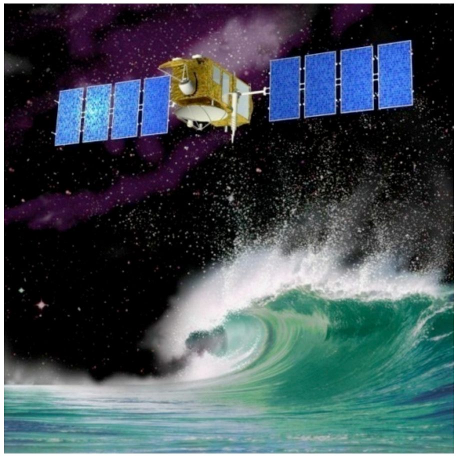
Absolute Dynamic Topography from Altimetry: Status and prospects in the upcoming GOCE era

M.-H. Rio



With material from: Nikolaï Maximenko, Peter Niiler, Chris Hughes, Martin Saraceno, Lee Fu, A. Hunegnaw, Femke Vossepoel, P. Schaeffer, N. Pavlis, Per Knudsen, Ole Andersen, E. Jeansou, P. De Mey, P. Legrand.

OSTST - Seattle - June 22-24, 2009

Absolute Dynamic Topography from Altimetry: Status and prospects in the upcoming GOCE era

1990 : *in Douglas, B. and R. Cheney, JGR*

GEOSAT: Beginning a new era in Satellite oceanography

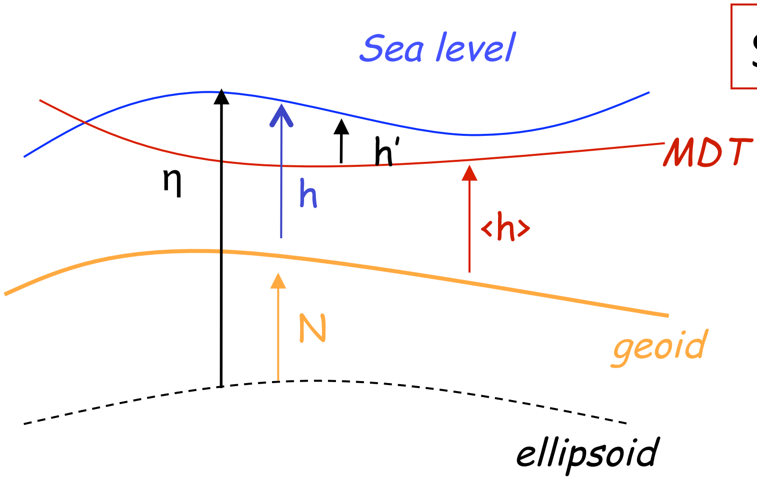
"We are seeing the extension of satellite altimetry to determination of absolute dynamic height to scales of many thousands of kilometers"

20 years of improvements

2009 (March, 17th) :

Successful launch of GOCE satellite, whose objective is to measure the geoid height at 100km resolution with 1-2 cm accuracy

Absolute Dynamic Topography from Altimetry: Status and prospects in the upcoming GOCE era



Some very simple equations

$$h = \eta - N$$

$$h = h_P' + MDT_P$$

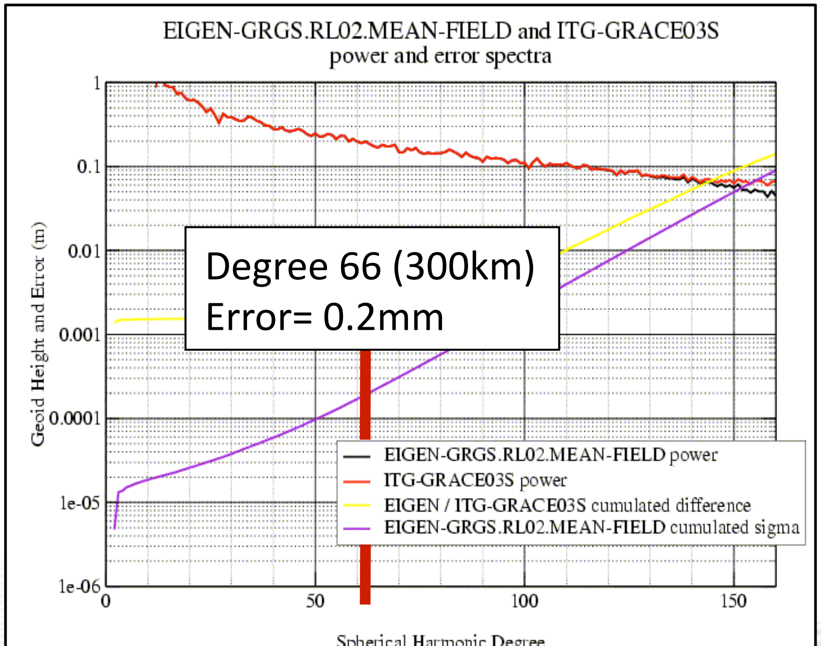
$$MDT_P = MSS_P - N$$

- ❑ 20 years of geoid improvement and its impact for the large scale MDT determination using the direct method $MDT_P = MSS_P - N$ (+filtering)
- ❑ Different methods used to enhance the resolution of the geoid and the MDT
- ❑ Scientific advances allowed by recent MDT determination improvement
- ❑ Benefits and limits of GOCE for oceanographic applications

20 years of geoid improvements

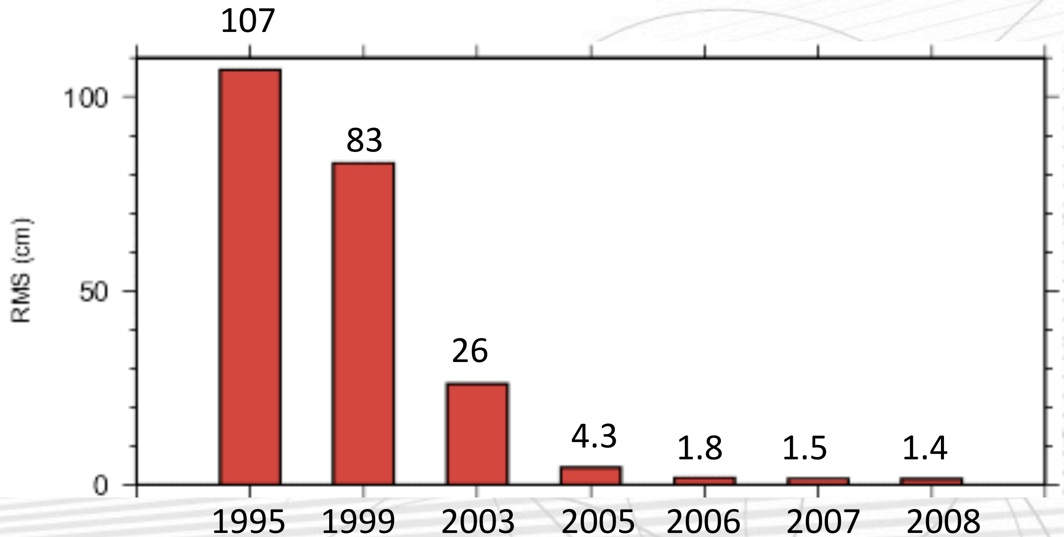
Satellite-only solutions

Model	GRIM4S4	GRIM5S1	CHAMP3S	GGM02S EIGEN3S	EIGEN4S	ITG-GRACE03S	GGM03S EIGEN5S	EIGEN-GRGS.RL02
Year	1995	1999	2003	2005	2006	2007	2008	2009
HS	70	99	140	150	150	180	150-180	160
Data	Geodetic satellites	Geodetic satellites	33 months CHAMP	2 years GRACE	3 years GRACE	$4^{1/2}$ years GRACE	4 years GRACE	$4^{1/2}$ years GRACE

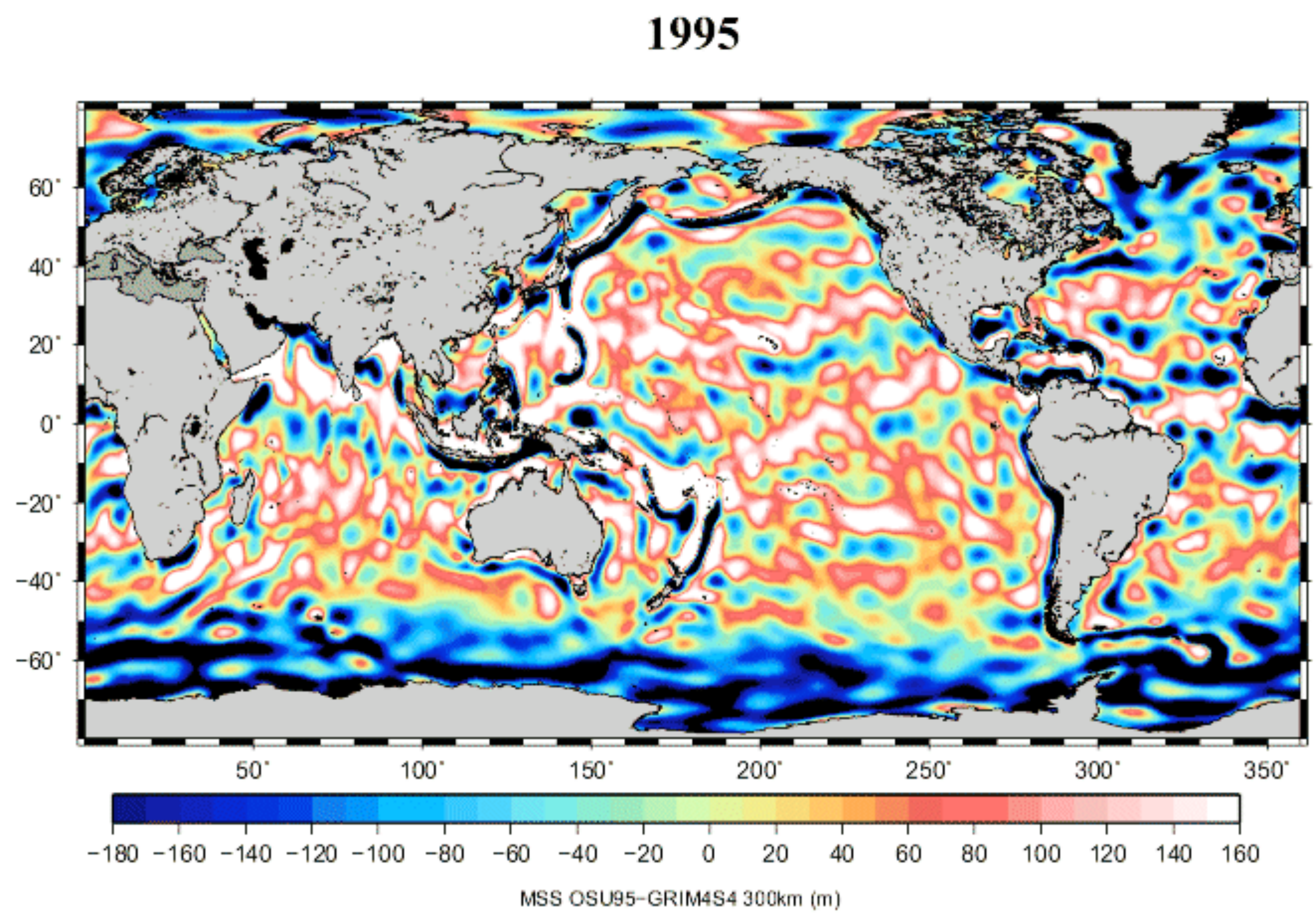


From Jean-Michel Lemoine

RMS differences (in cm) between geoid models and EIGEN-GRGS.RL02 filtered at 300km (on oceans)

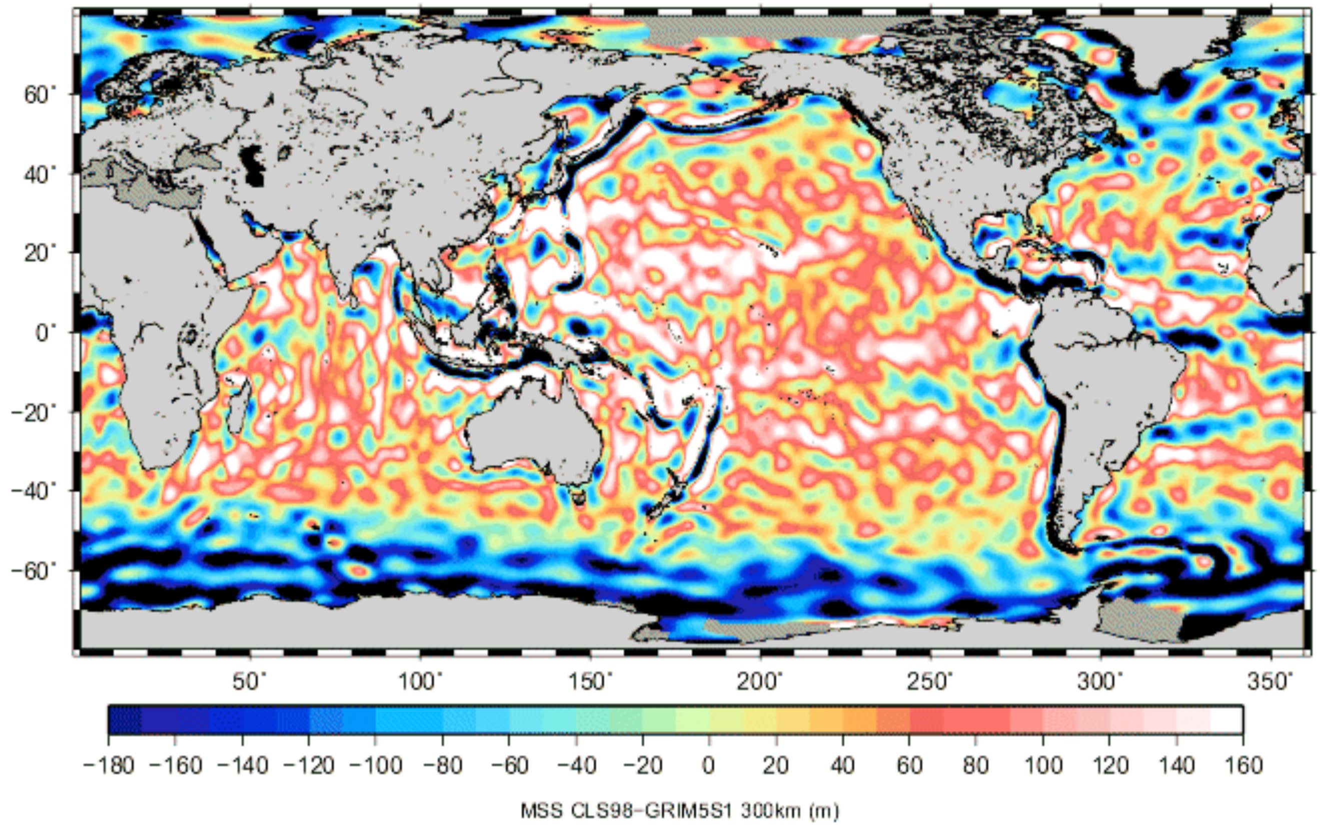


20 years of geoid improvements: Impact on MDT determination



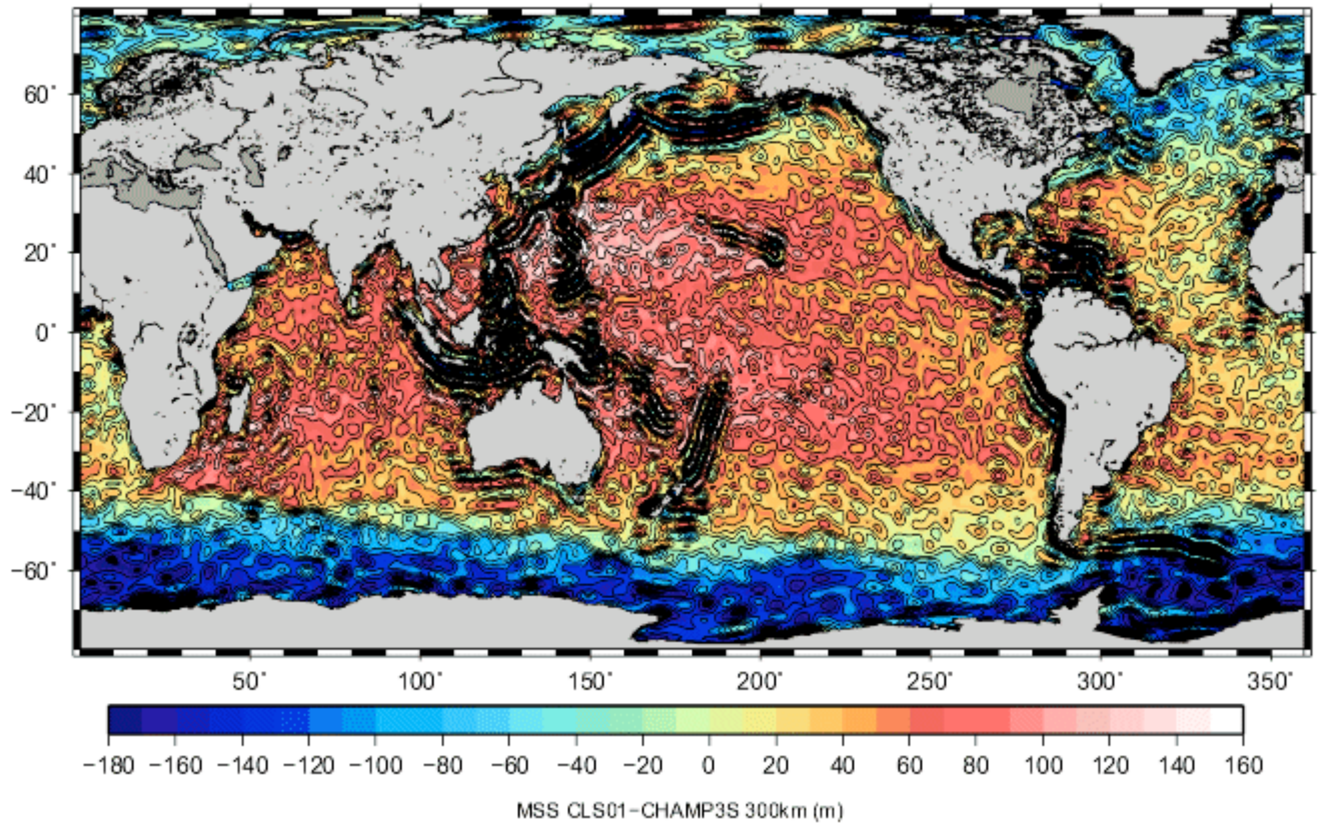
20 years of geoid improvements: Impact on MDT determination

1999



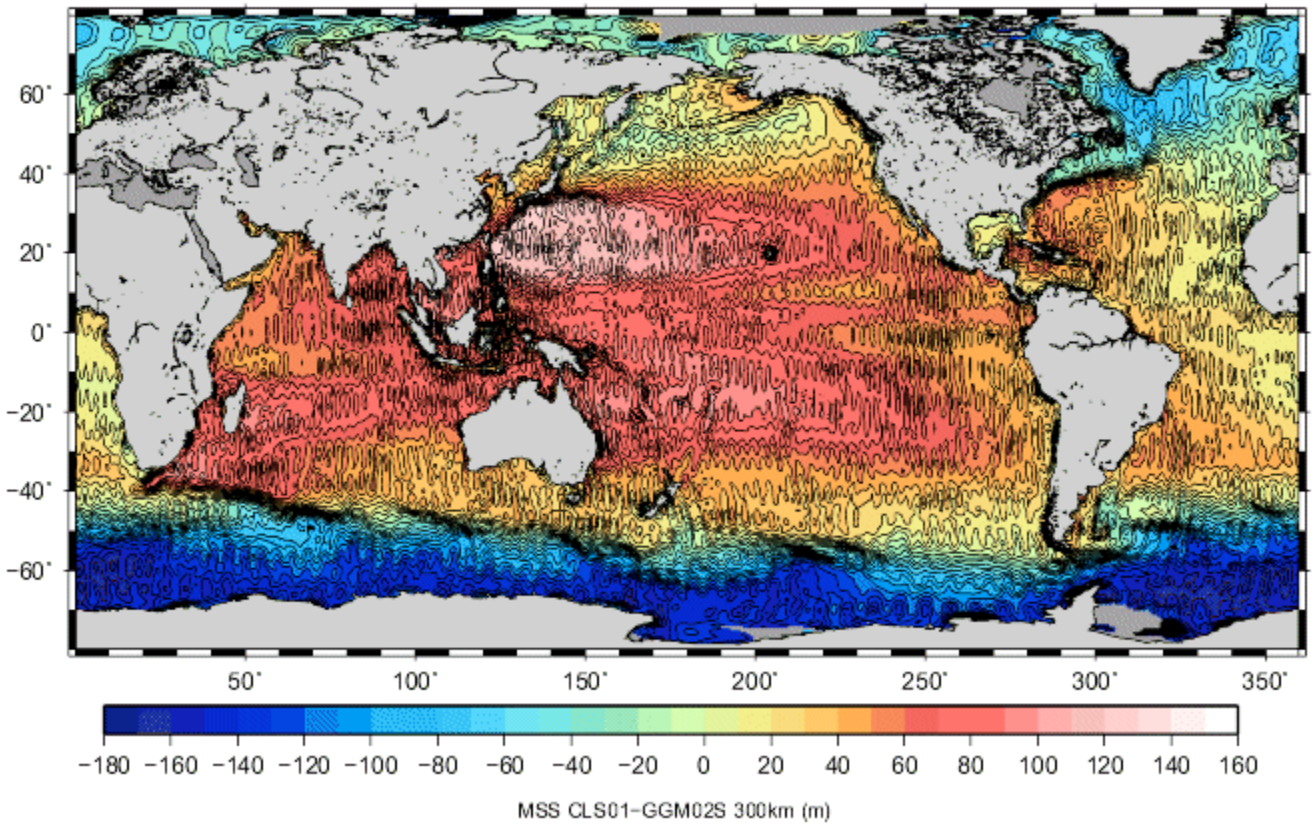
20 years of geoid improvements: Impact on MDT determination

2003



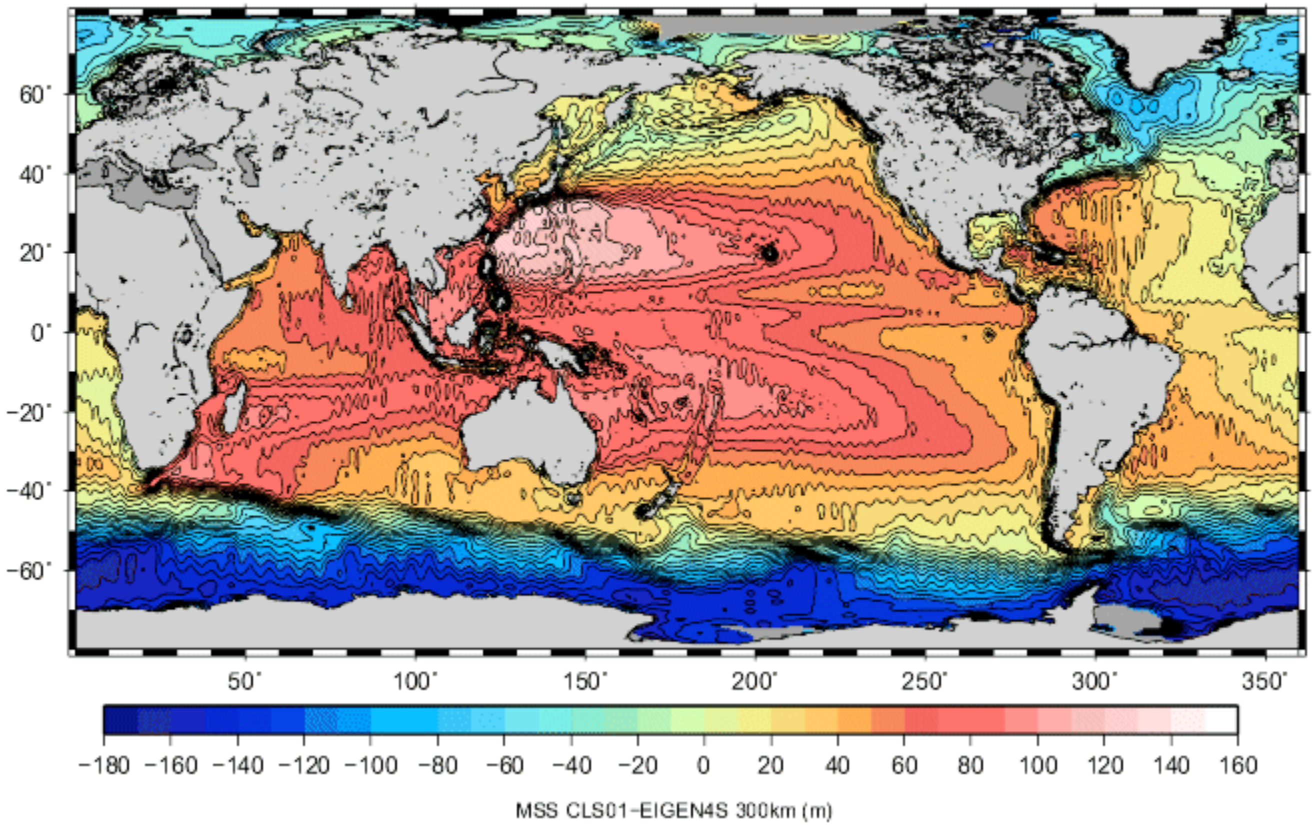
20 years of geoid improvements: Impact on MDT determination

2005



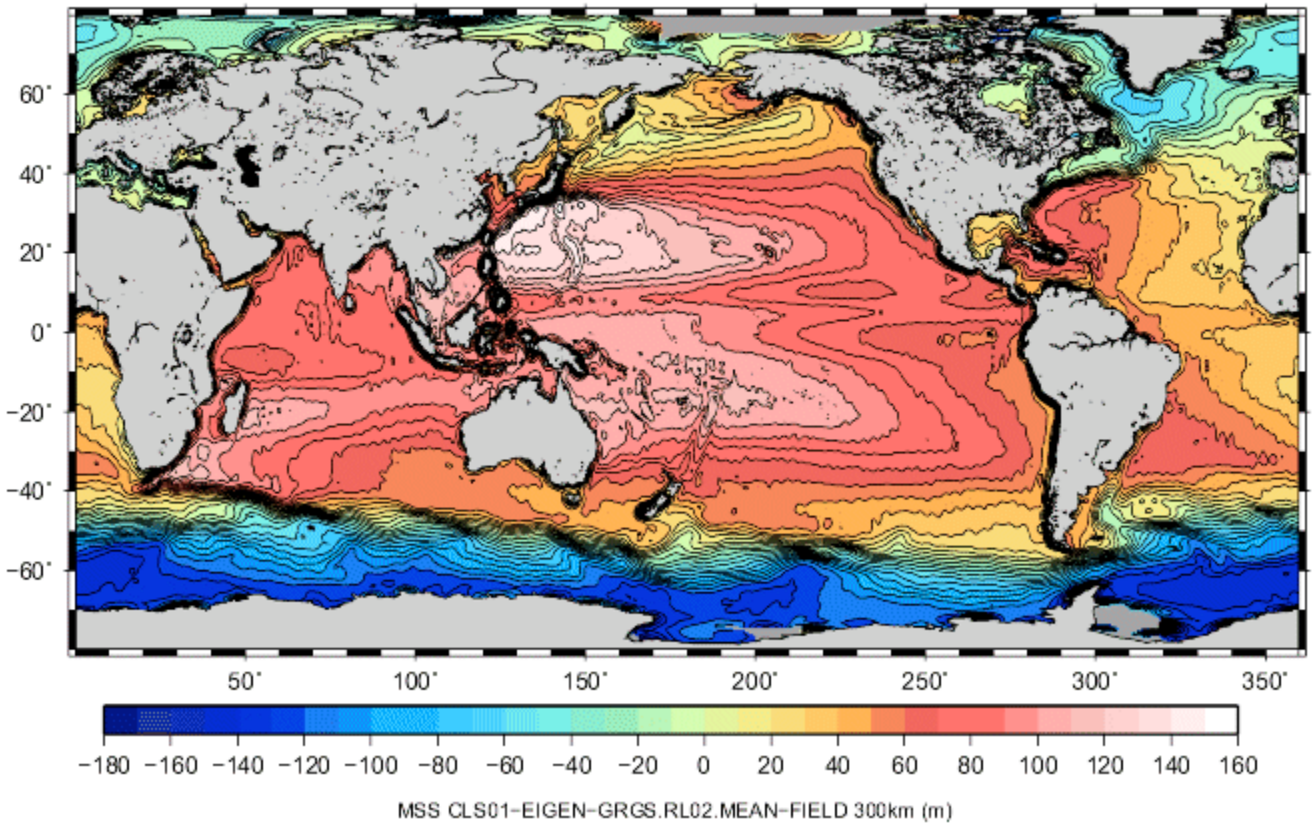
20 years of geoid improvements: Impact on MDT determination

2006



20 years of geoid improvements: Impact on MDT determination

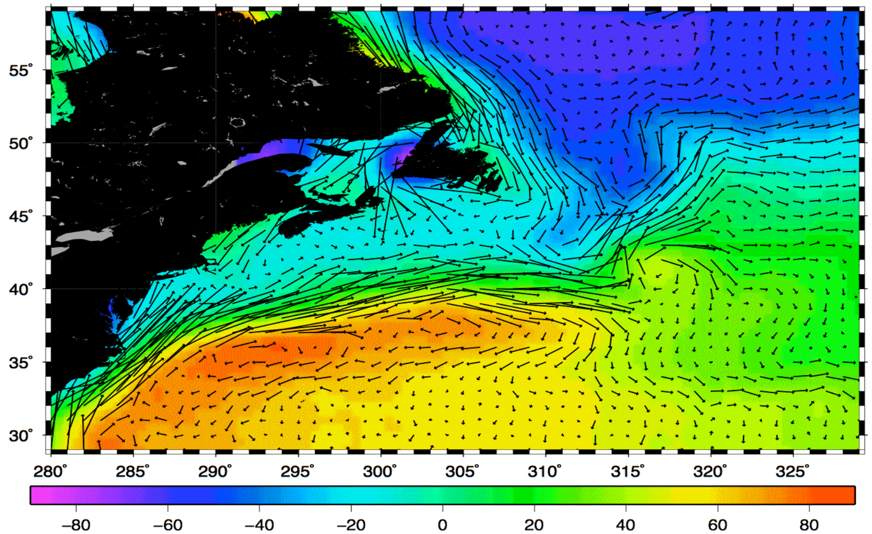
2009



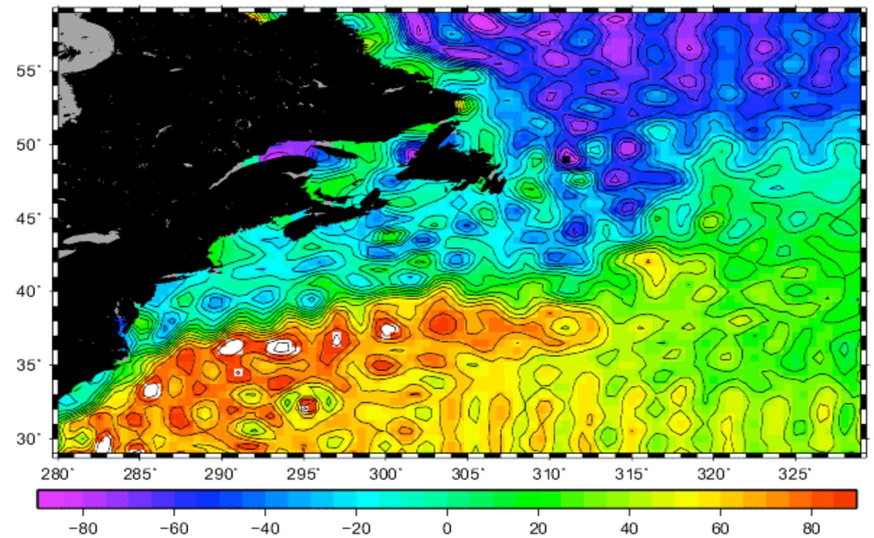
20 years of geoid improvements: Impact on MDT determination

2009

SMO CLS01-EIGEN-GRGS 300 km



SMO CLS01-EIGEN-GRGS 133 km



300 km: best trade-off between resolution and accuracy for MDT computation based on most recent satellite-only GRACE models

☒ 20 years of geoid improvement and its impact for the MDT determination using the direct method $MDT_P=MSS_P$-Geoid

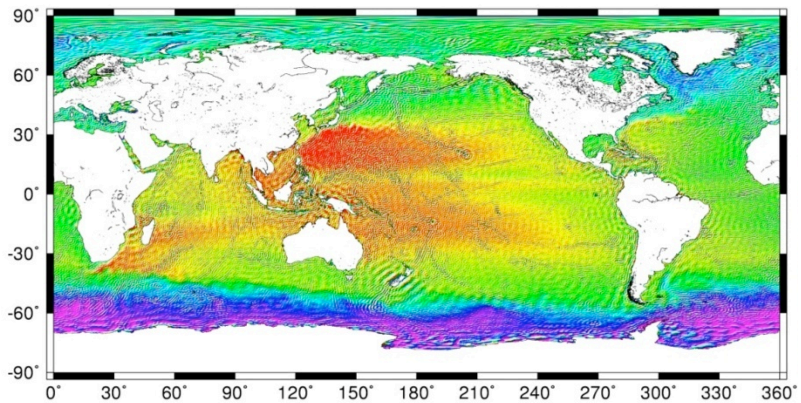
- ❑ **Different methods used to enhance the resolution of the geoid and the MDT**
- ❑ Scientific advances allowed by recent MDT determination improvement
- ❑ Benefits and limits of GOCE for oceanographic applications

Improving the MDT at short scales

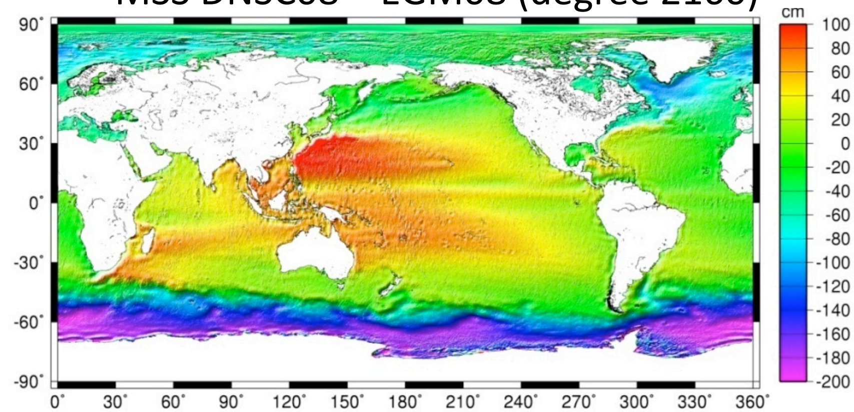
by improving the geoid

Using altimetry-derived gravity anomalies and/or in-situ gravimetric data

MSS DNSC08 – EIGEN4C (degree 360)

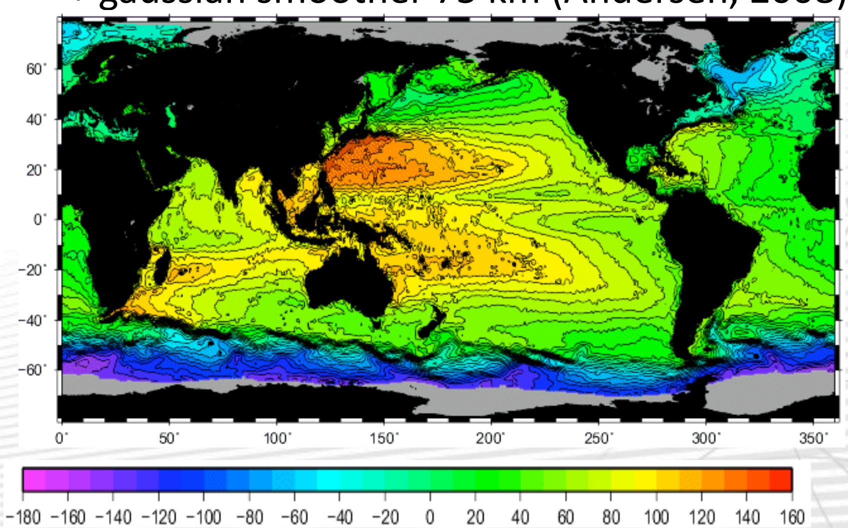


MSS DNSC08 – EGM08 (degree 2160)



Pavlis et al, 2008

+ gaussian smoother 75 km (Andersen, 2008)

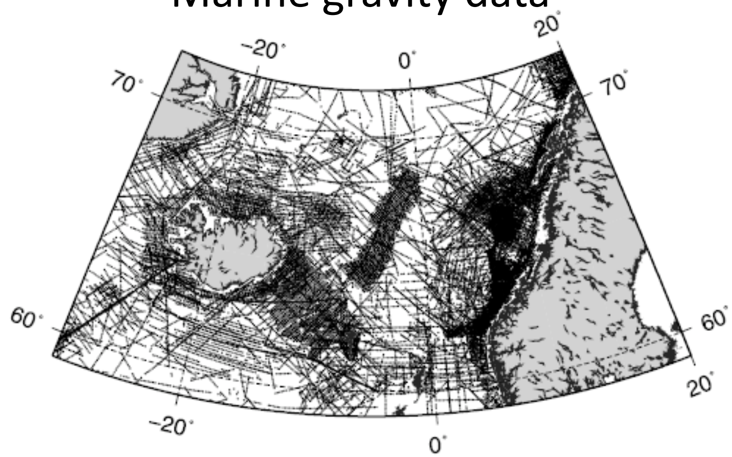


DNSC08 MDT

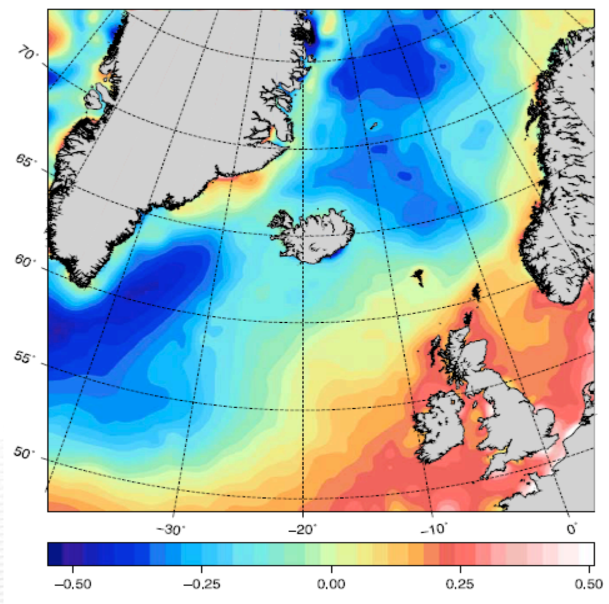
Improving the MDT at short scales

by improving the geoid

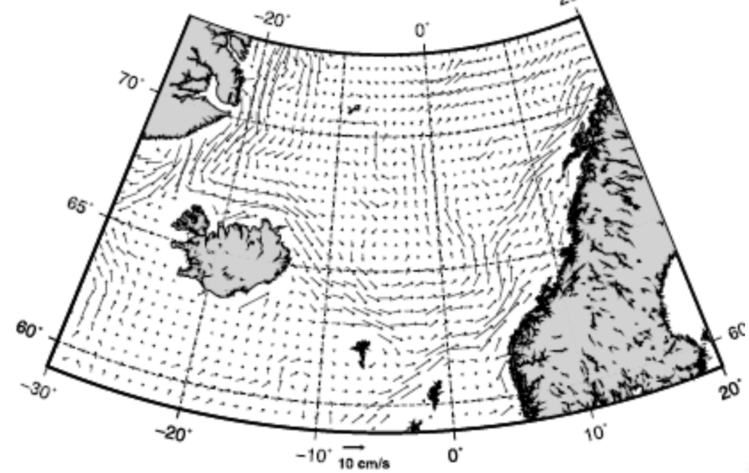
Marine gravity data



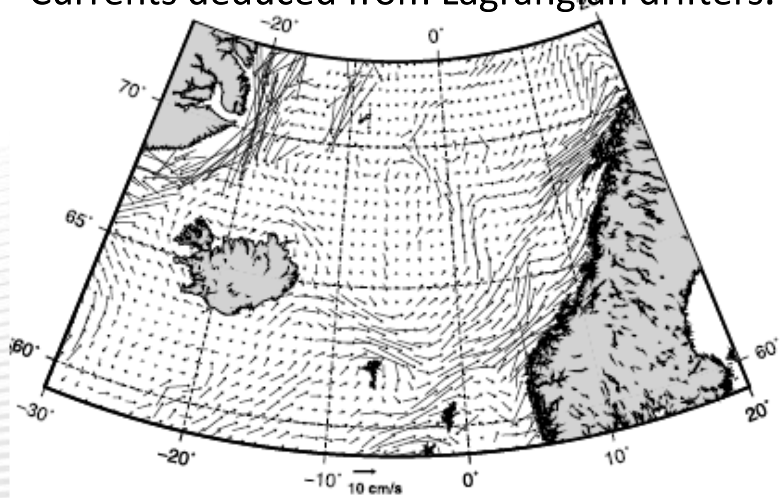
ICM MDT 25 km



The geostrophic currents as deduced from the ICM CMDT



Currents deduced from Lagrangian drifters.



Hunegnaw et al, 2009, JGR

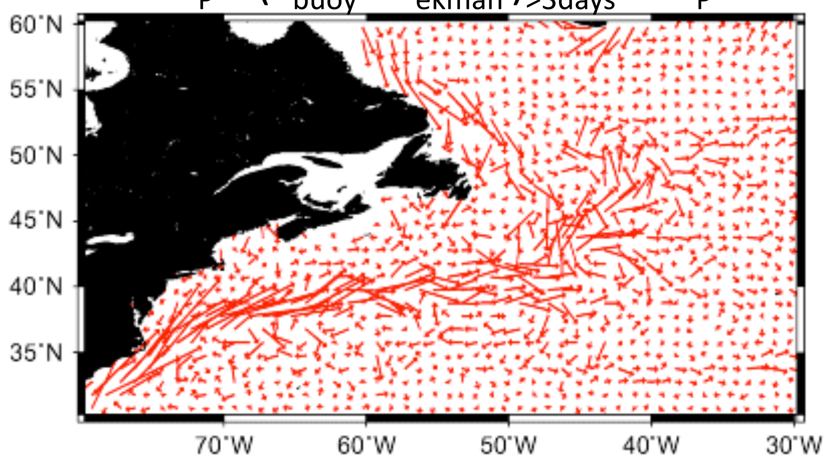
Improving the MDT at short scales

By combining GRACE-based MDT to synthetic height and velocity estimates

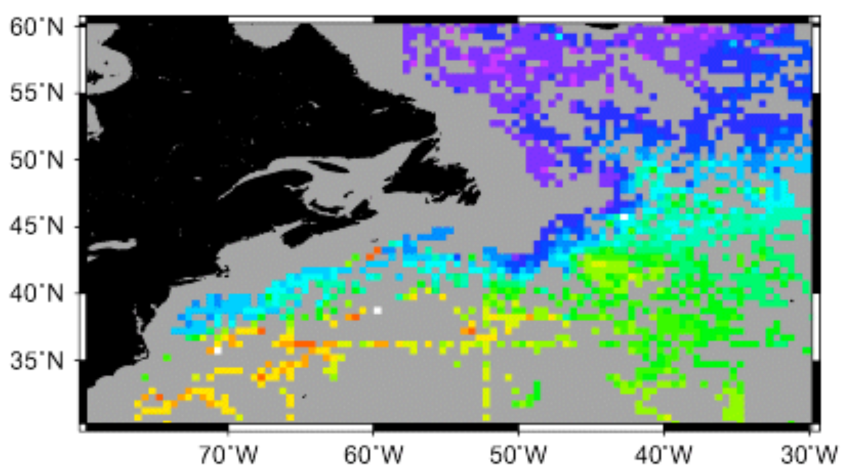
CLS
COLLECTE LOCALISATION SATELLITES

Synthetic velocities

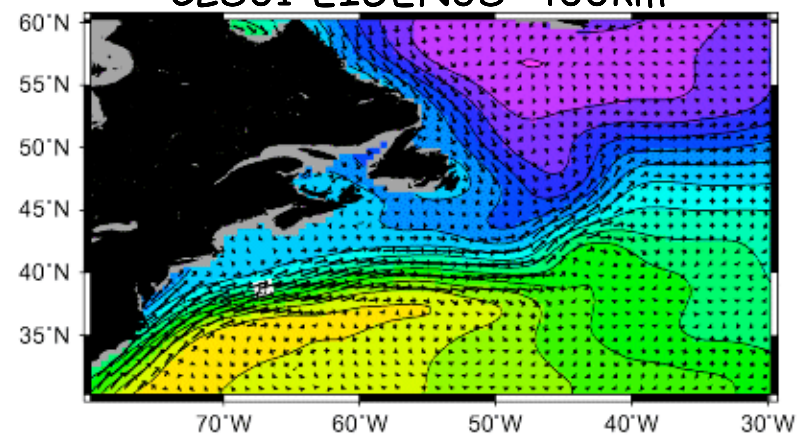
$$\langle u \rangle_P = (u_{buoy} - u_{ekman})_{>3days} - u'a_P$$
$$\langle v \rangle_P = (v_{buoy} - v_{ekman})_{>3days} - v'a_P$$



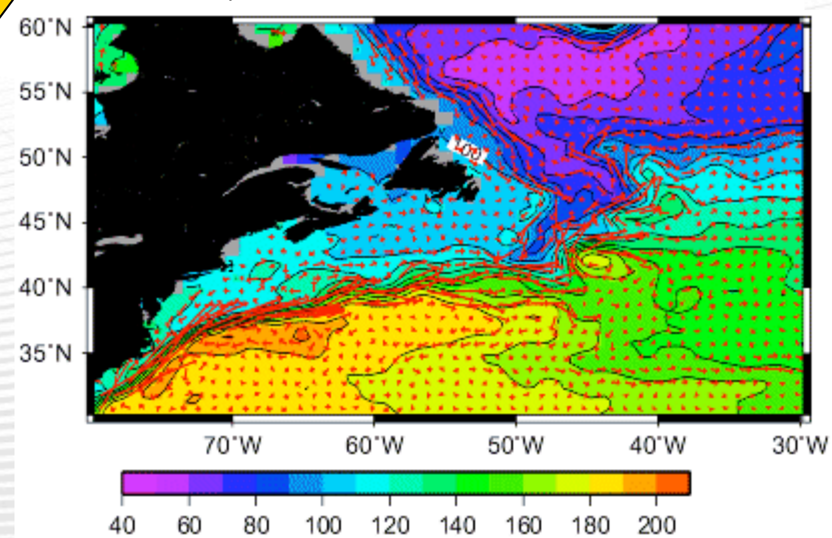
+ Synthetic heights $\langle h \rangle_P = h - h'a$



First guess based on MSS CLS01-EIGEN3S 400km



Combined MDT RIO05

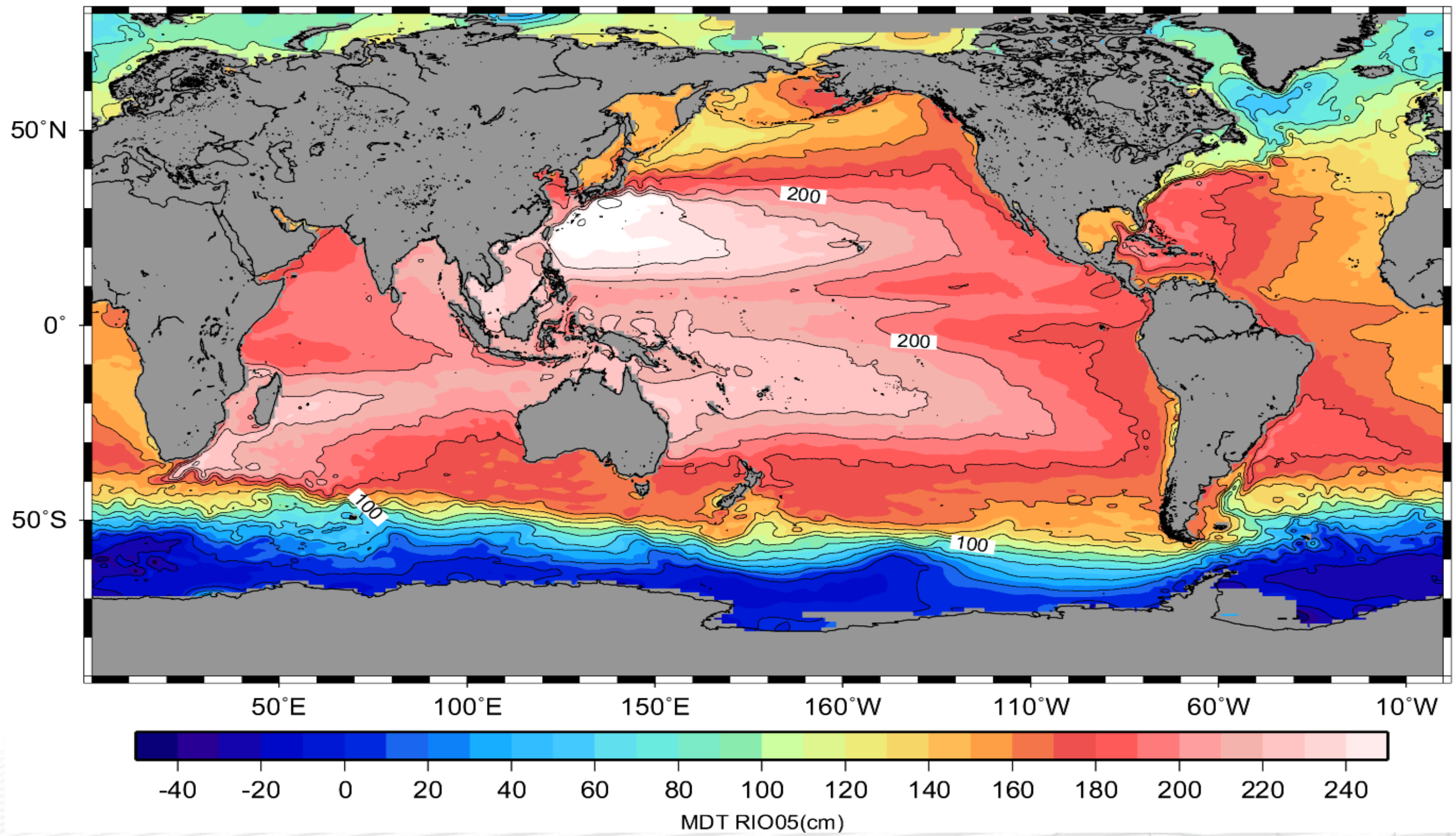


Rio et al, 2005

Improving the MDT at short scales

By combining GRACE-based MDT to synthetic height and velocity estimates

First guess based on EIGEN-GRACE03S 400 km
In-situ data: Drifting buoys and T,S profiles over the 1993-2002 period
Global Estimation on a ½° grid



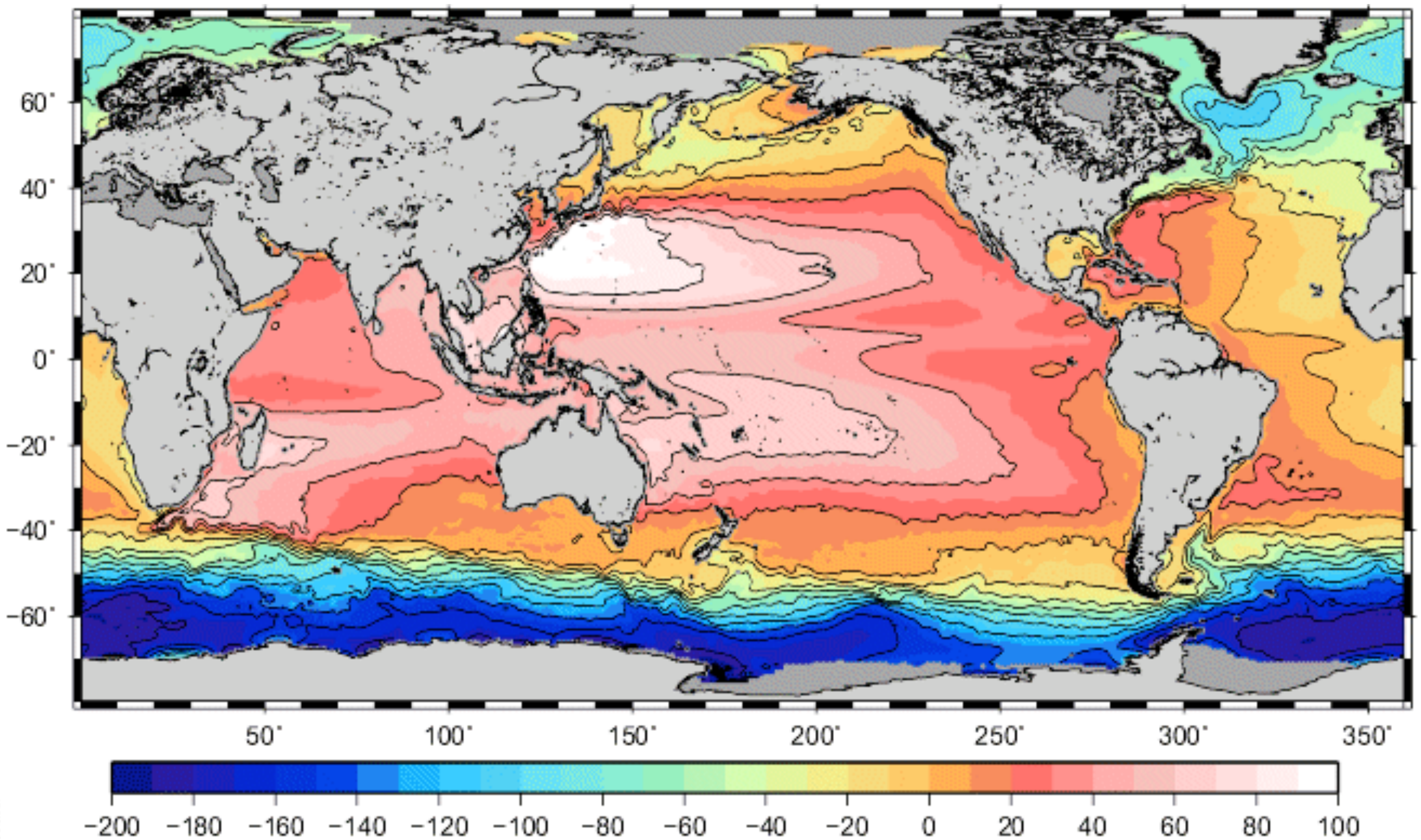
Rio et al, 2005

Is currently being updated in the framework of the SLOOP project

Improving the MDT at short scales

By combining GRACE-based MDT to synthetic height and velocity estimates

Based on GGM01 geoid model and drifting buoy data

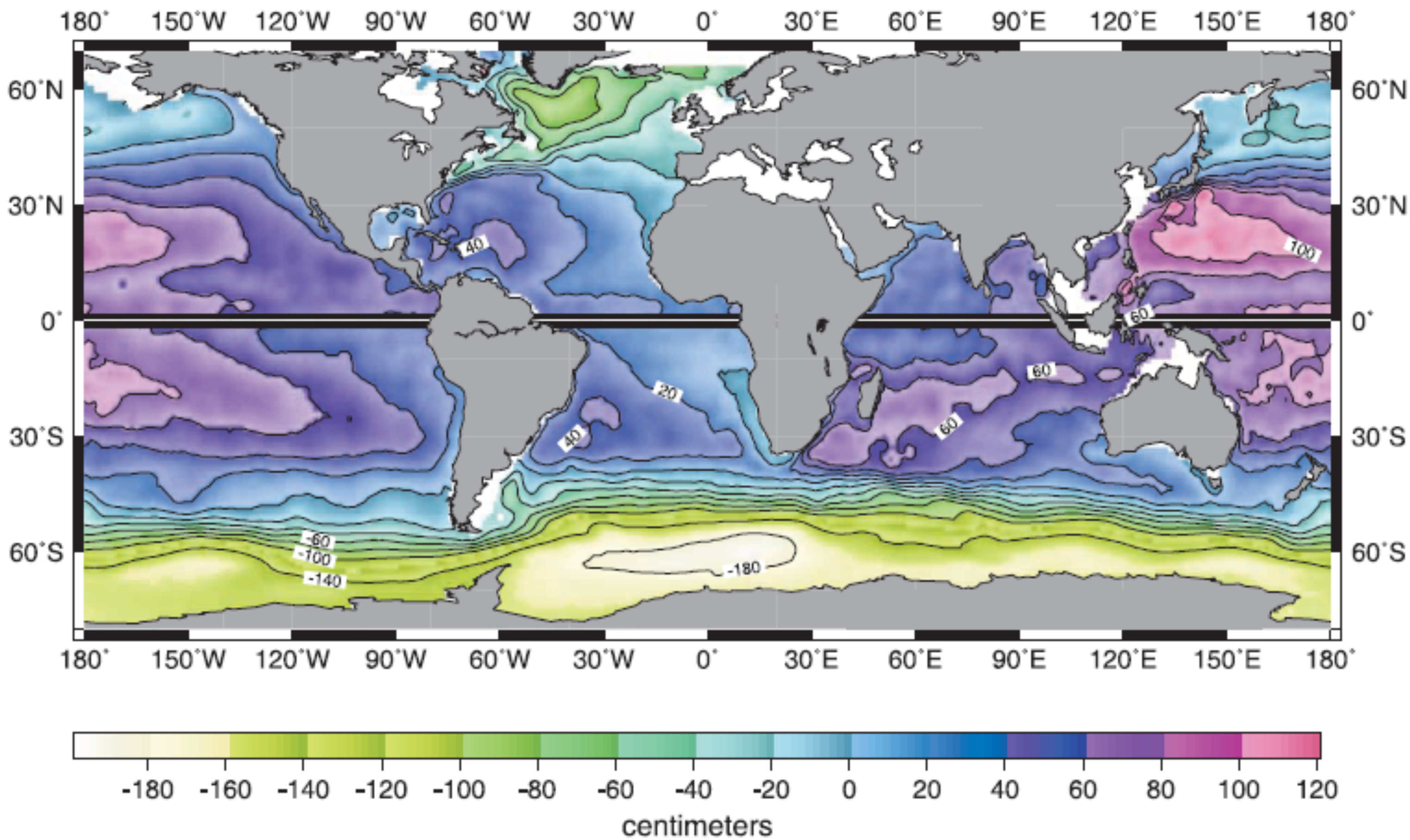


Maximenko and Niiler, 2005

Improving the MDT at short scales

By inverse modelling

MDT consistent with a number of observational and dynamical constraints



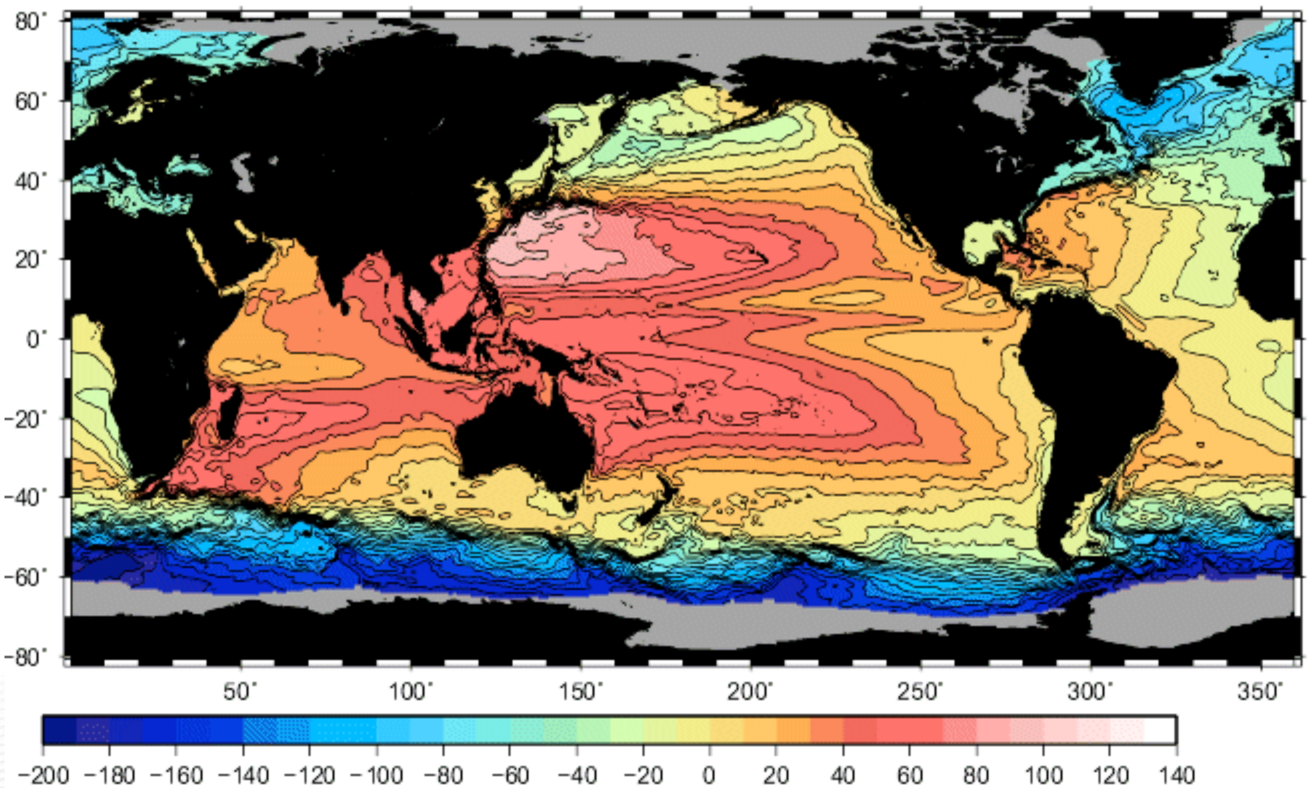
Legrand et al, GRL 2003

Improving the MDT at short scales

by data assimilation into OGCM

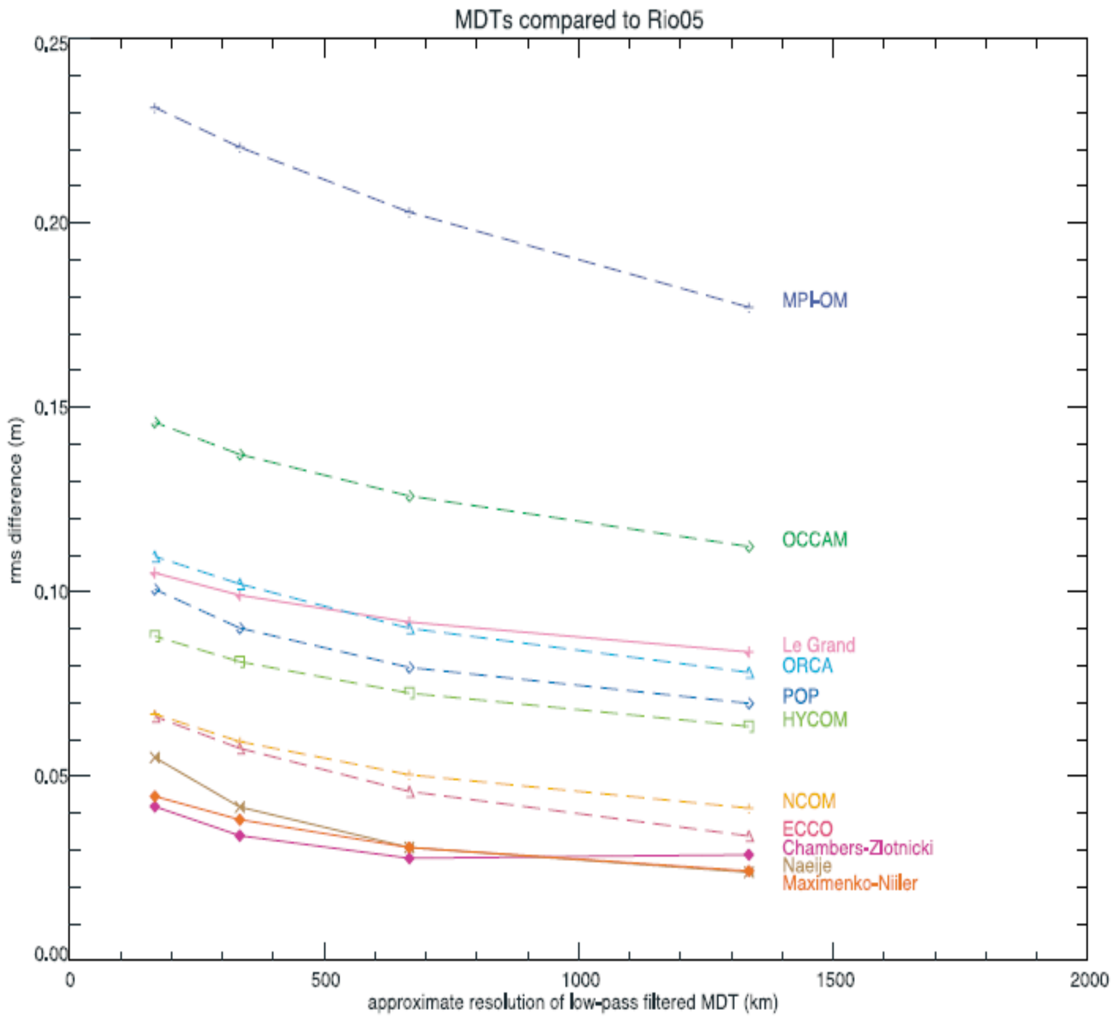
Synthesis of all available information through data assimilation into Ocean General Circulation Models

MDT from recent MERCATOR reanalysis (GLORYS1V1)



From N. Ferry

Accuracy of existing MDT



1 At 167 km resolution Observation-based estimates

4.2 cm <RMS<10.5 cm

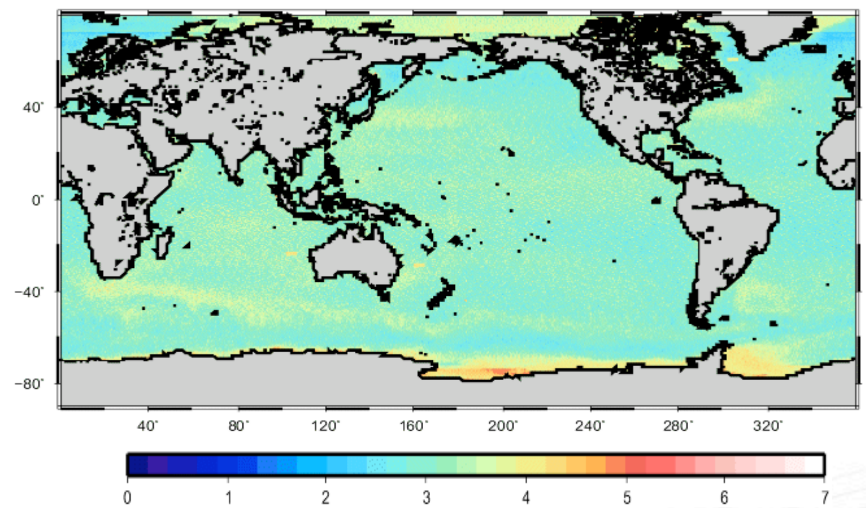
2 RMS reduction at large scale smaller than expected.

Reduction of MSS errors at large scale needed

Vossepoel, 2007 (JGR)

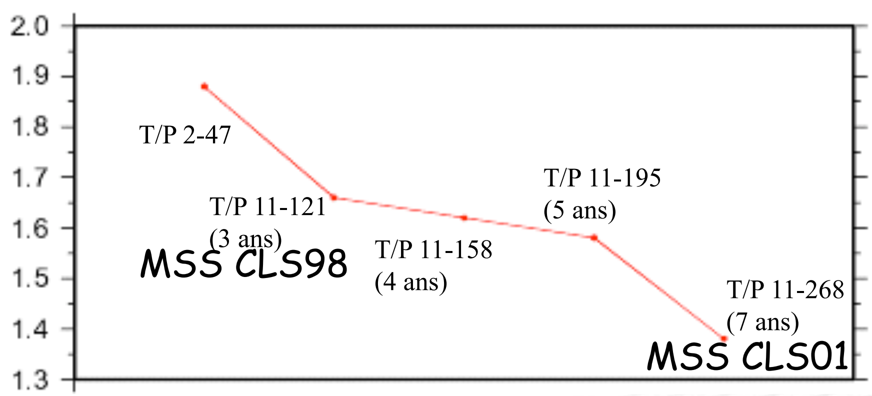
The Mean Sea Surface

MSS DNSC08 error field



Global and local MSS now available on 1’ grids (1.5km)

Most recent MSS: DNSC08 based on T/P, T/P TDM, ERS1 ERM+GM, ERS2 ERM, ENVISAT, GeosatGM, GFO and Icesat



European coasts (SHOM+GUT project)

(cm)	RMS Cross over differences (GUT)	RMS Cross over differences (CLS01)
T/P (reference)	0.4	0.9
TPn	1.0	/
GFO	1.0	/
ERS-2	1.1	1.6
E1-GM	5.9	~8.0

✓MSS error level based on cross over differences

⇩

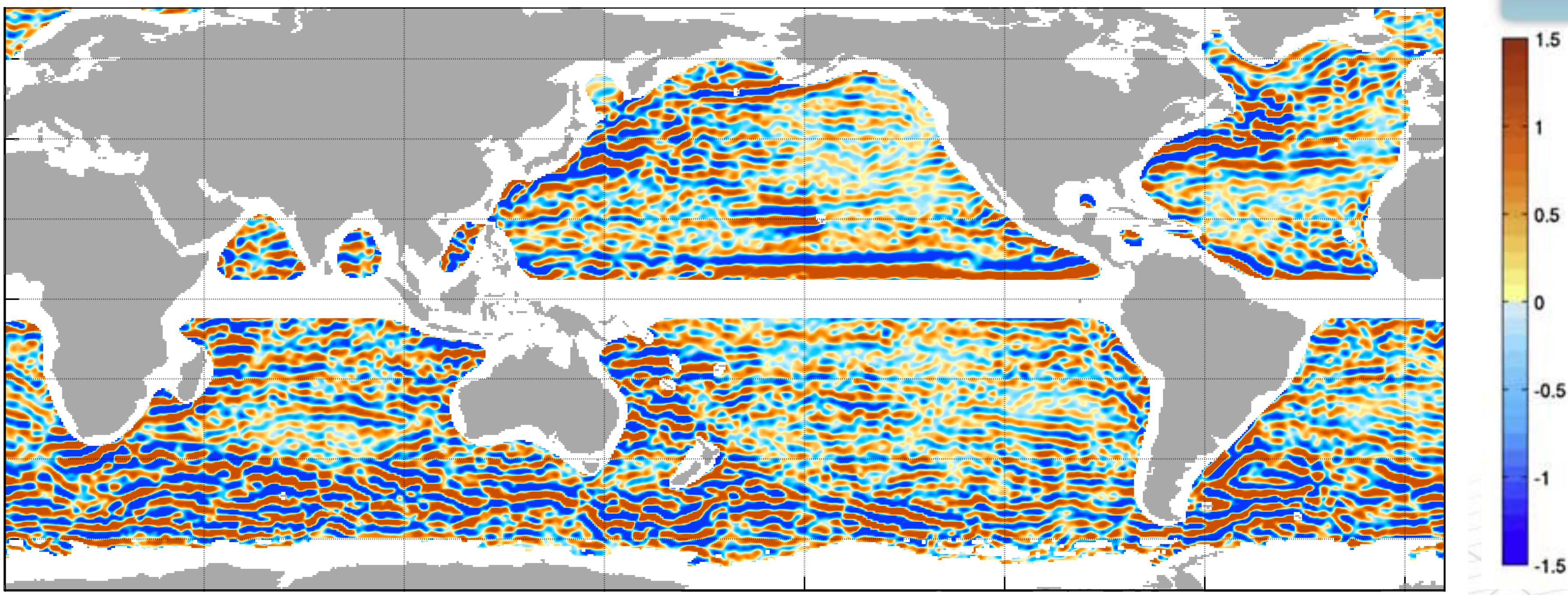
Not absolute but relative accuracy

✓Need for better assesment of altimetric error variances and covariances

- ☒ 20 years of geoid improvement and its impact for the MDT determination using the direct method $MDT_P = MSS_P$-Geoid
- ☒ Different methods used to enhance the resolution of the geoid and the MDT
- ❑ **Scientific advances allowed by recent MDT determination improvement**
- ❑ Benefits and limits of GOCE for oceanographic applications

Scientific advances based on recent MDTs

Striations in the mean dynamic ocean topography

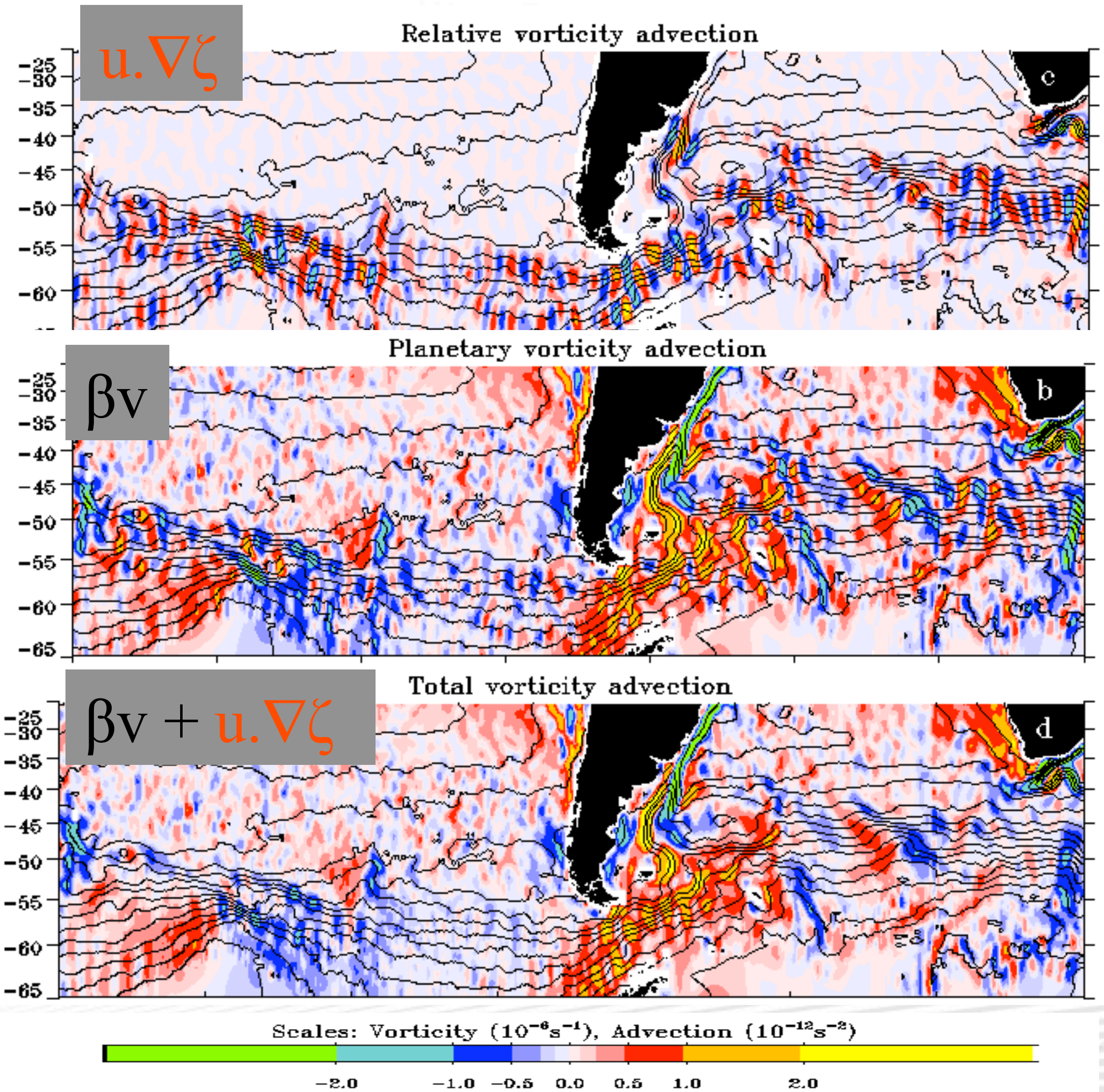


1993-2002 mean zonal surface geostrophic velocity calculated from the MDOT of Maximenko and Niiler [2005] high-pass filtered with a two-dimensional Hanning filter of 4° half-width.

Maximenko et al., GRL, 2008

Scientific advances based on recent MDTs

Non linear surface vorticity balance in the ACC



$$\beta v + u.\nabla\zeta = w_z$$

At wavelengths > 300-500km relative and planetary advection compensate

Total vorticity advection clearly related to features in the bottom topography

Non linear terms in the vorticity balance well resolved because of the **strong mean flow in** the ACC

In weaker flow, **higher resolution is needed + error covariance estimates**, in order to better quantify errors in this kind of analysis

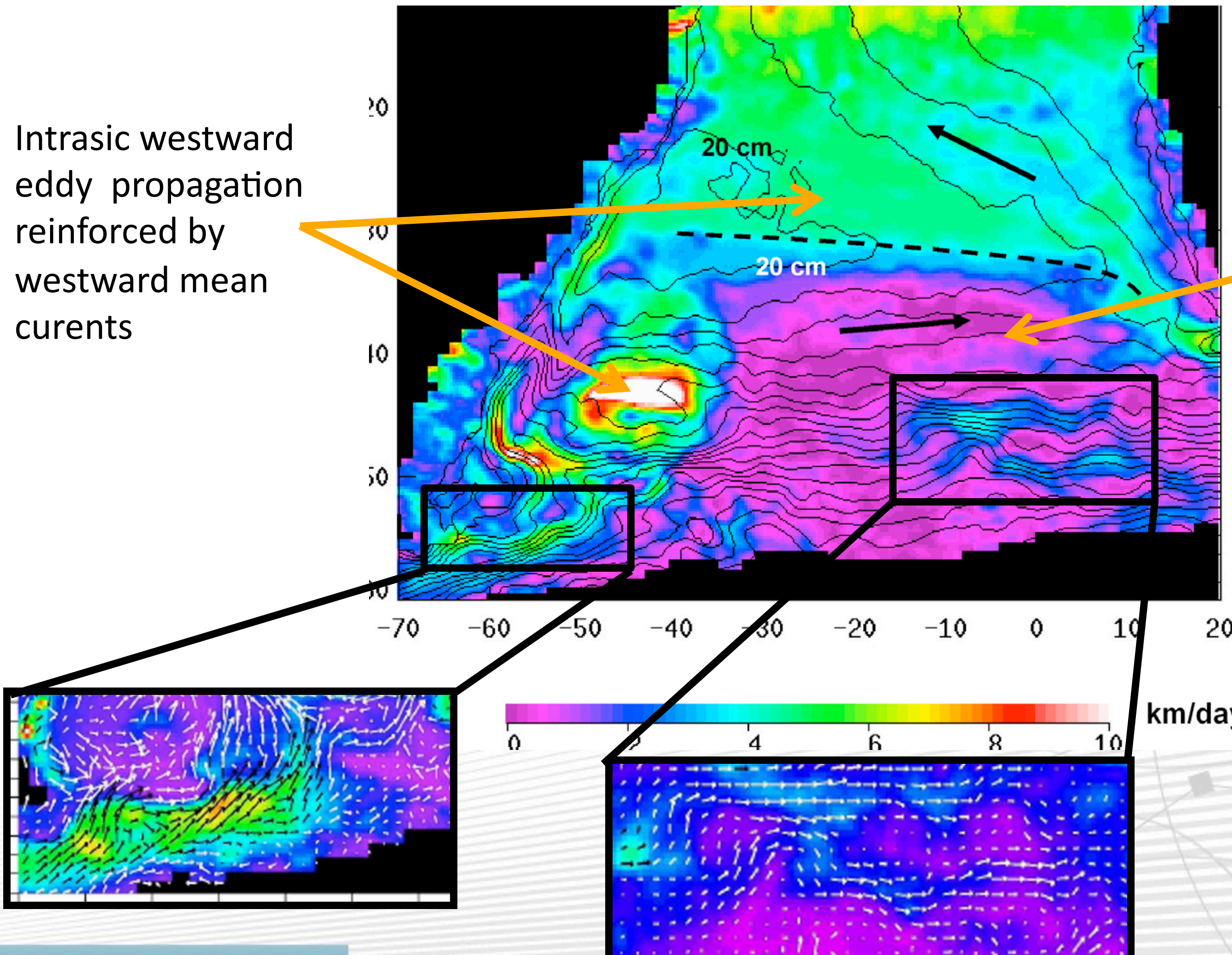
C. W. Hughes, JGR, 2005

COLLECTE LOCALISATION SATELLITES

Scientific advances based on recent MDTs

Investigating eddy-mean flow interactions

Intrasic westward eddy propagation reinforced by westward mean curents



Intrasic westward eddy propagation compensated by eastward mean curents…

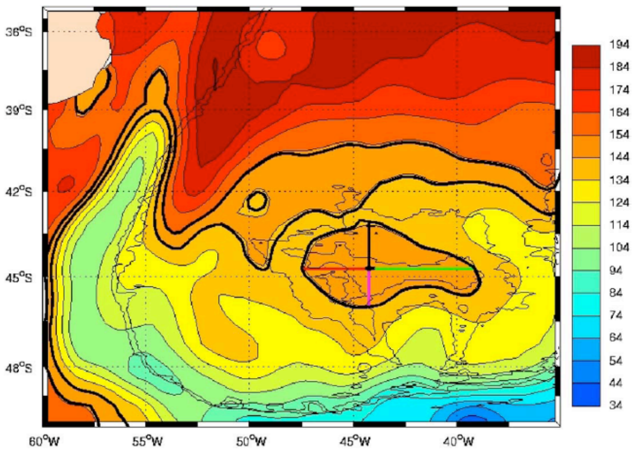
… leading locally to eastward propagating eddies

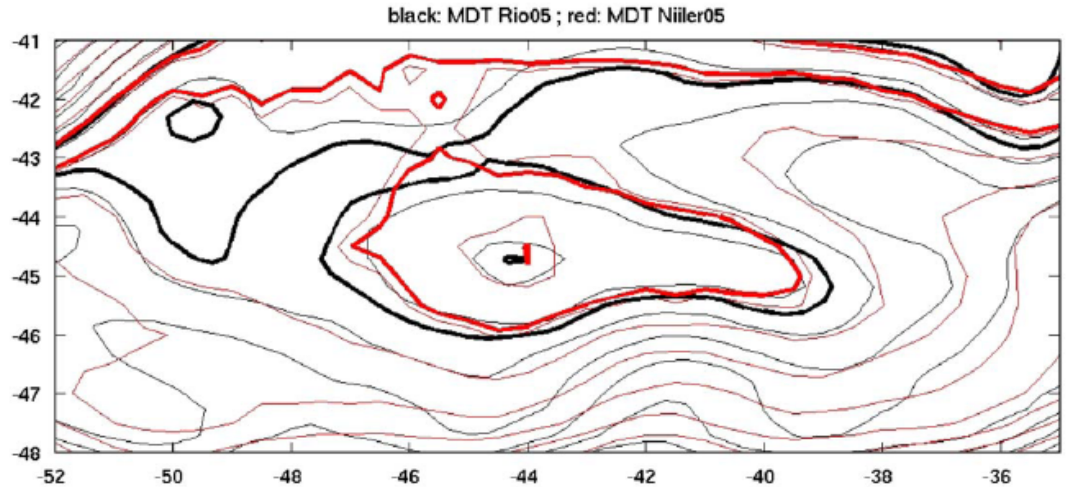
(Fu, GRL, 2006)

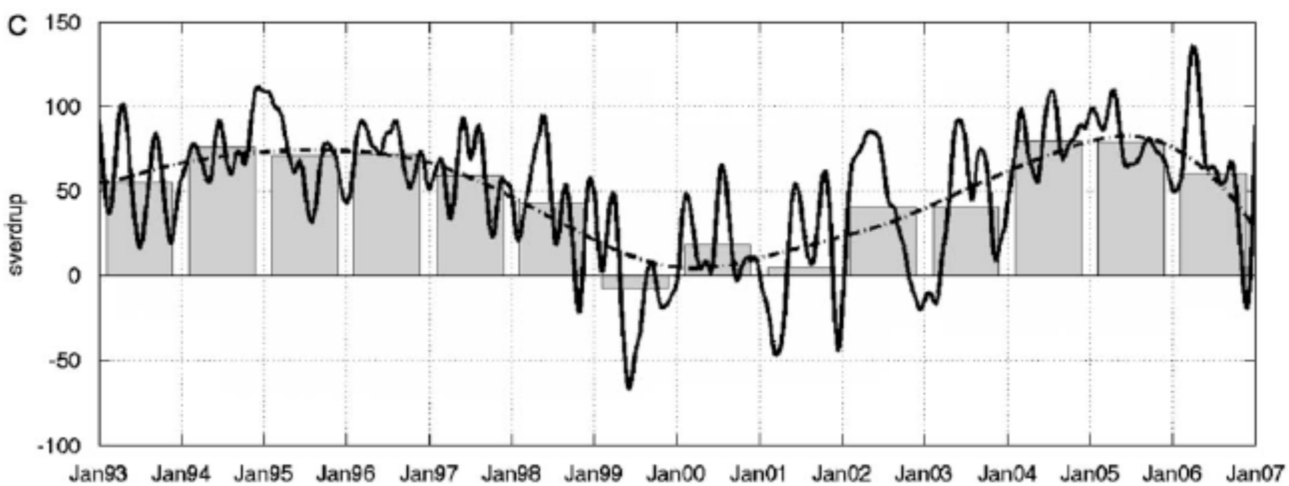
Scientific advances based on recent MDTs

Improving transport computation in the Zapiola anticyconic flow

Barotropic assumption is made → T=V*H







Mean Transport 1993-2007:
50Sv (Rio05 MDT)
40 Sv (Niiler05 MDT)

20% uncertainty

77.5Sv (Volkov and Fu, 2008 over 1993-2006)

Saraceno et al, DSR 2009

Scientific advances based on recent MDTs

Using altimetric surface velocities as reference for hydrographic data based velocity computation

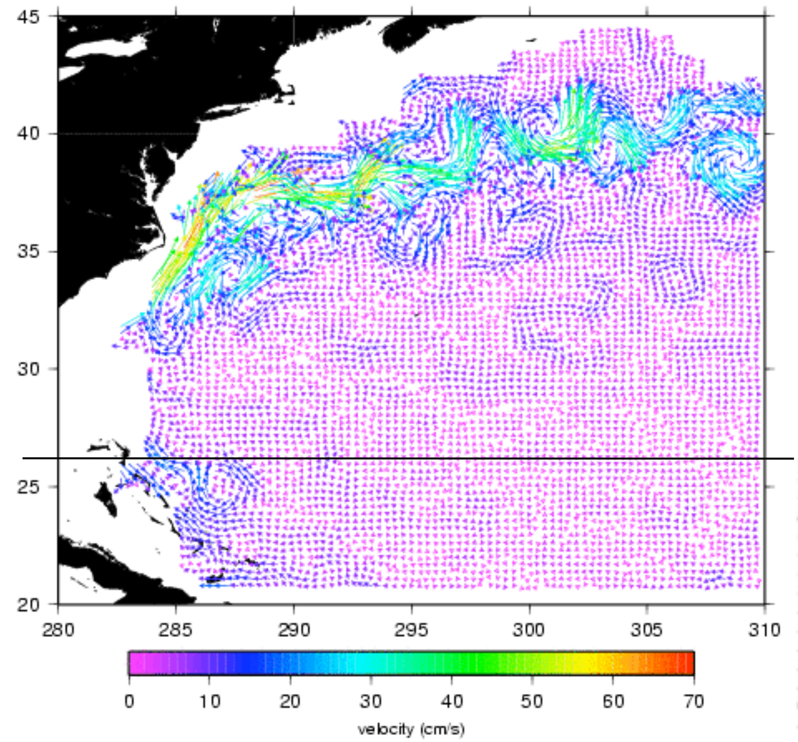
$$u(z = z_i) = u(z = 0) + \frac{g}{\rho f}\int_{z=0}^{z_i} \frac{\partial}{\partial y}\rho'(z)dz$$

$$v(z = z_i) = v(z = 0) - \frac{g}{\rho f}\int_{z=0}^{z_i} \frac{\partial}{\partial x}\rho'(z)dz$$

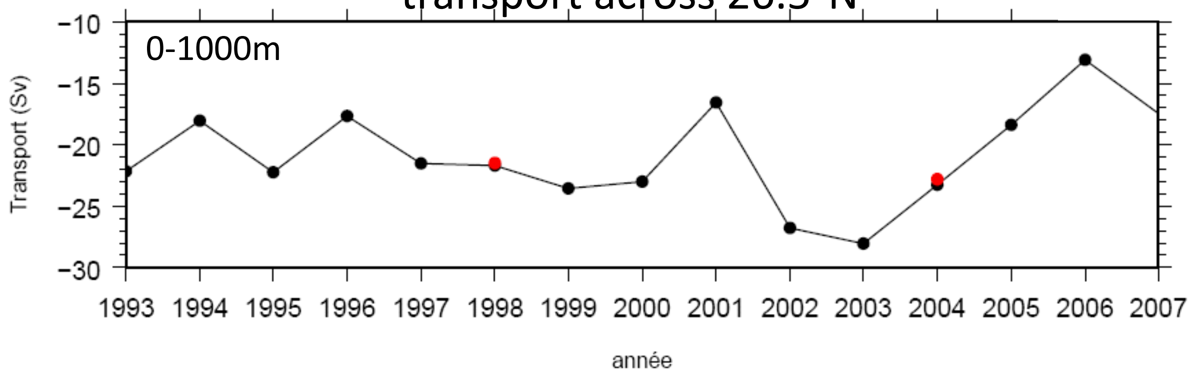
MDT+SLA

From ARMOR3D T,S gridded products

1994 mean at 500m



Depth integrated geostrophic meridional transport across 26.5°N



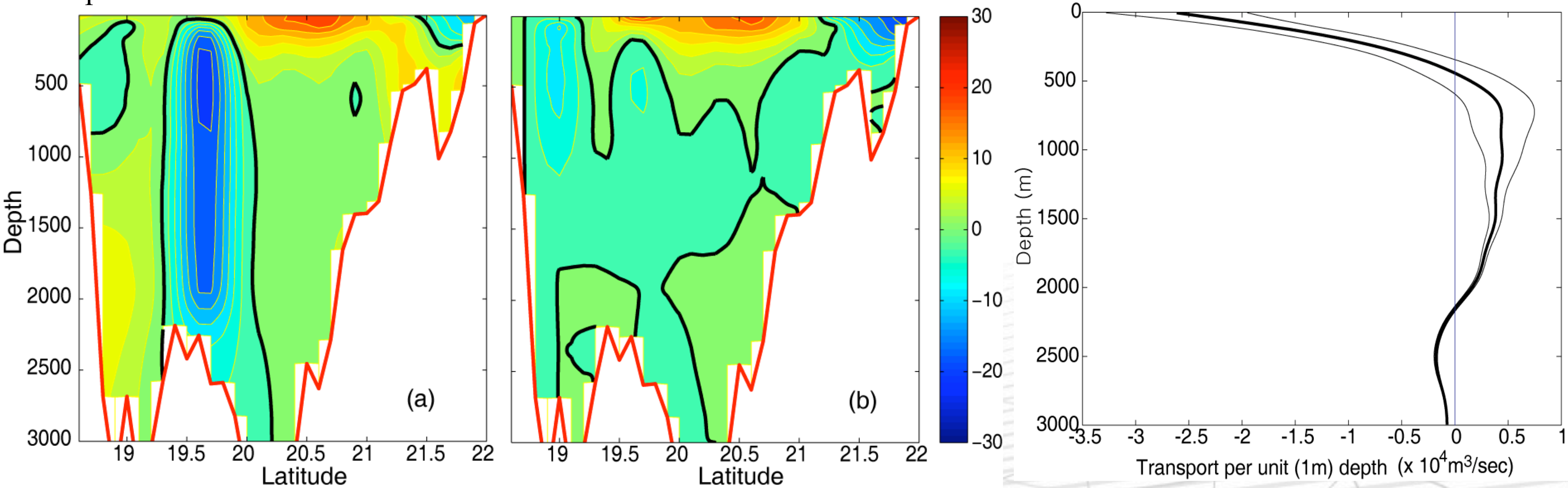
● Bryden et al,2005

Scientific advances based on recent MDTs

South China Sea water influx calculation based on Maximenko-Niiler MDT and a continuation of the 'good' hydrographic data based geostrophic pressure gradient continuation to the bottom. In contrast to all publications to date, the net geostrophic transport during the northeast Monsoon is most likely zero

Referencing CTD data by the monthly Sea Level Anomaly plus Maximenko et al MDT

Zonal geostrophic velocity from CTD



Total transport across the Luzon Strait is 0.2 ± 3.6 Sv.

From P. Niiler

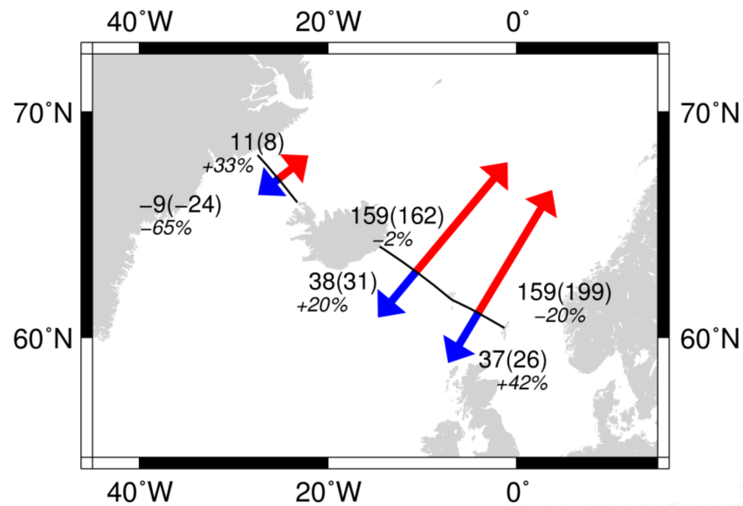
GOCE impact studies

The GOCINA project - RESULTS

Geoid and Ocean Circulation In the North Atlantic

- Improved heat transport

Section		Observed	FOAM	FOAM-C
Iceland-Greenland	N	**22**	**11**	8
	S		9	24
Faroe-Iceland	N	**134**	**159**	162
	S		38	31
Faroe-Shetland	N	**156**	**159**	199
	S		37	26



- Improved volume transport in all three systems

Section		Observed	Simulated					
			FOAM	FOAM-C	**TOPAZ**	TOPAZ-C	**MERCATOR**	MERCATOR-C
All sections	N				**10.7**	10.9	**8.72**	8.81
	S	7.9	11.2	13.4	9.4	9.7	9.66	10.92

- Changes in flow of 10-20 % were found
- Changes in heat transport of about 30 % were found
- Increased agreement versus observations

GOCE impact studies

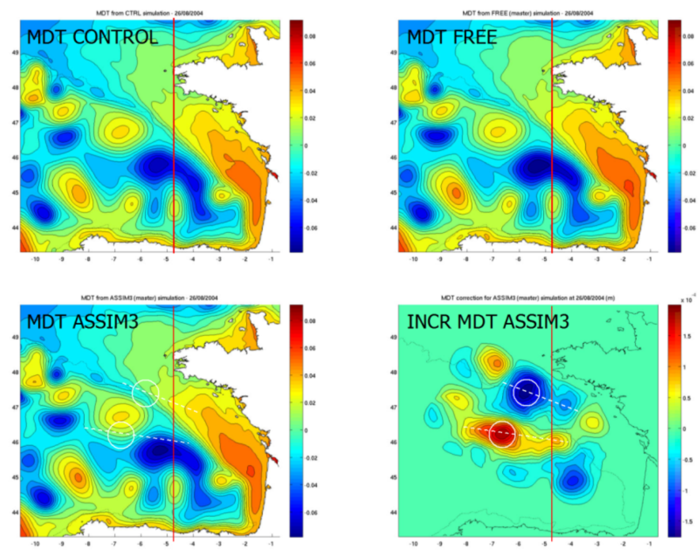
GOCEAN - Gravity Improvement of Continental Slope and Shelf Ocean Circulation Modelling

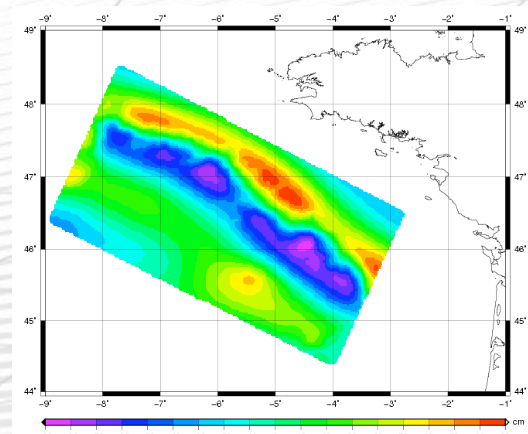
- Direct assimilation experiments of simulated altimetry and GOCE data were conducted in an eddy-resolving, 3D numerical ocean model to look at the impact of simulated GOCE data onto the topographically-steered flow at the shelf break.

- Small but clearly positive effect of GOCE on topographically-steered current evidenced, on top of altimetry

- However the small slope current signal (at the limit of the ability of GOCE to detect) coupled with large geoid omission errors over the slope makes the detection of the slope current difficult without an additional information

- Need for higher resolution geoid for altimetry assimilation in coastal areas





From E. Jeansou and P. De Mey

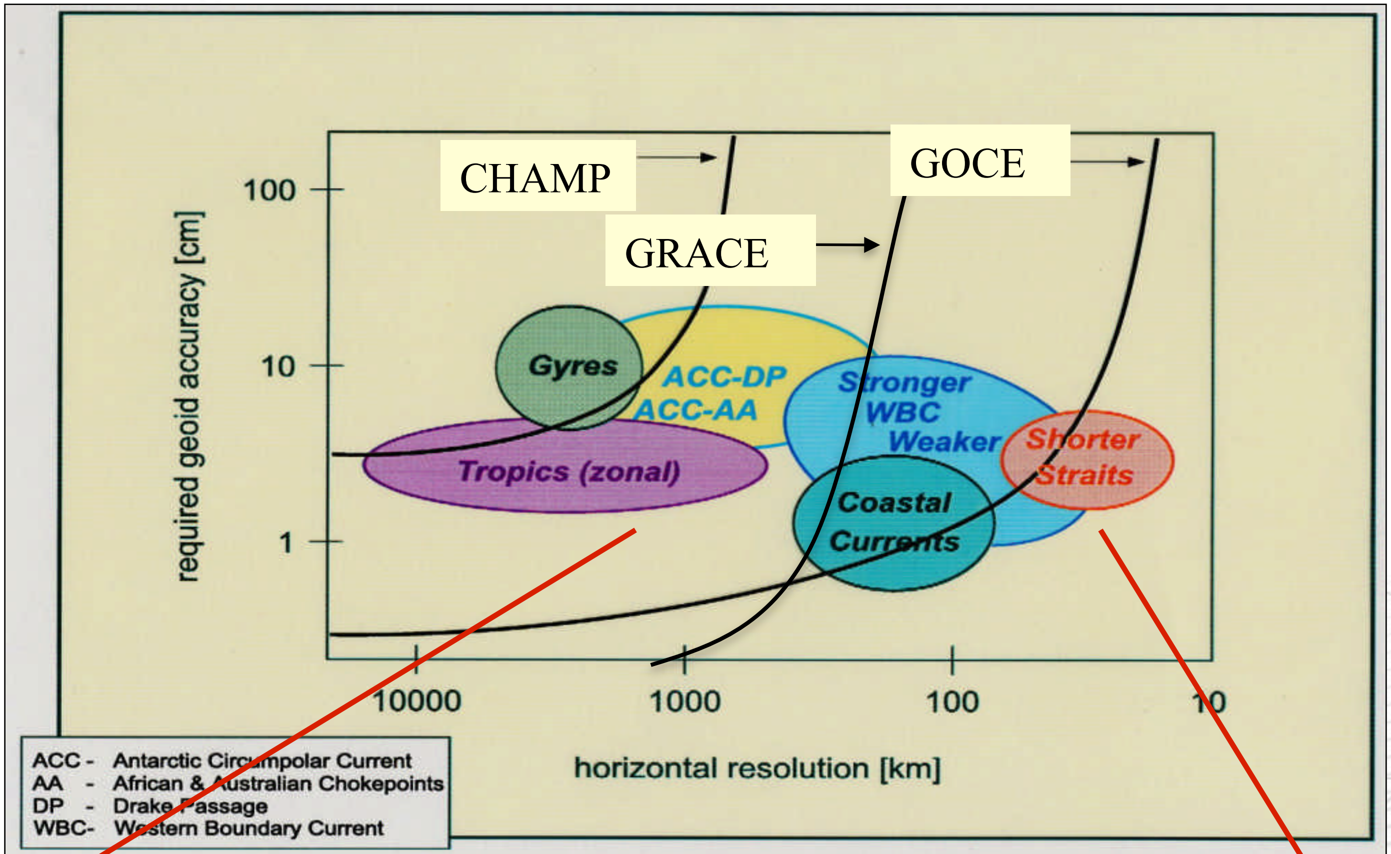
☒ 20 years of geoid improvement and its impact for the MDT determination using the direct method $MDT_P = MSS_P - Geoid$

☒ Different methods used to enhance the resolution of the geoid and the MDT

☒ Scientific advances allowed by recent MDT determination improvement

❑ **Benefits and limits of GOCE for oceanographic applications**

GOCE, the beginning of a new era?



Toward $h = \eta - N$?

Need for higher resolution geoids…

GOCE, the beginning of a new era?

1- for global, gridded multi-missions products

Spatial resolution depends on across-track distances

2 satellites (Ex. TP+ERS)	250-300km	T>10 days
3 satellites (present)	200km	
SWOT + 2 satellites (2016)	100 km	

Along-track
$\eta(L>100km) - N_{GOCE}$

Optimal mapping

Maps of absolute dynamic topography
(T>10jours, L>100km)

no need for orbit repetitivity

Feasability still to be demonstrated

BUT

Thanks to GOCE, this is the first time in altimetry history that we can start thinking about it!

2- along-track(/swath) products

Classic altimeters

Spatial resolution: Present 1Hz (7 km), 20 Hz (350m coastal applications)

Wide-swath altimeters (SWOT – 2016)

Spatial resolution: 1km

~~$h=\eta-N$~~ $h=\eta-<\eta>+MDT$

Need for high resolution MDT

Combination to in-situ gravimetric data and/or in-situ oceanographic data

Need for high resolution mean profiles (repetitive orbits) or high resolution MSS (non-repetitive orbit)

CONCLUSIONS

Where we are now

- MDT > 300km based on altimetric MSS and satellite-only geoid models

  Geoid known with millimetric error

  MSS error often considered negligeable
- MDT < 300km

  Global combined MDT at 50-100km resolution (where sampled by in-situ data)
  Accuracy difficult to assess – better than 10cm – highly inhomogeneous
- High number of studies showing the benefit of high resolution MDT for ocean analysis

What will be achieved with GOCE

- Geoid will be known at 100 km resolution and centimetric accuarcy+ error covariance
- MDT at 50-100 km resolution with centimetric accuracy and homogeneous error field?

  ↳ Present MSS resolution is enough but better assesment of MSS error is needed
- Start investigating MDT scales shorter than 50-100km
- Further and significative improvements will be made in interpretating the altimetric signal, in computing transports, in assimilating altimetry into OGCM
- Global mapping of ocean dynamic topography at scales > 100 km ⟹ h=SSH-Geoid?

GOCE… the limits

❑ Upcoming context
- Increasing need for high resolution altimetric mission (SWOT)
- Non repetitive orbit missions (ENVISAT,Cryosat,
- Coastal altimetry application developments

❑ Optimal exploitation of along-track data for model assimilation, coastal studies, sub-mesoscale studies will require the estimation of Geoid, MSS and MDT at resolutions higher than 100 km