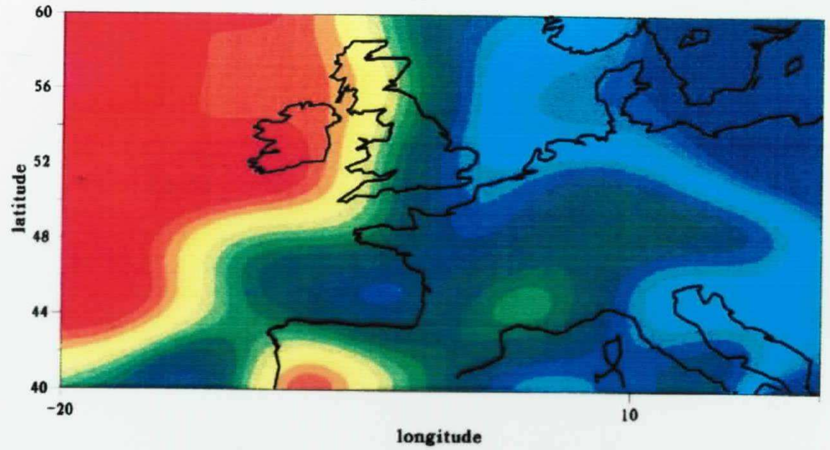
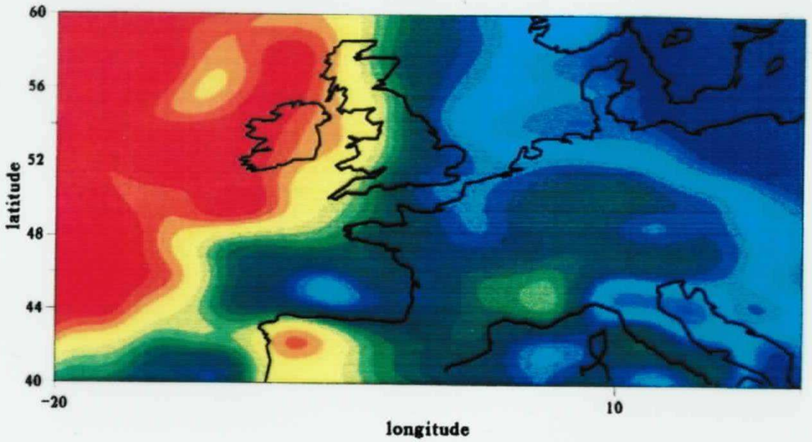
Utilisation des données de gravimétrie pour la glaciologie

Jean-Michel Lemoine
Service de Géodésie Spatiale
CNES

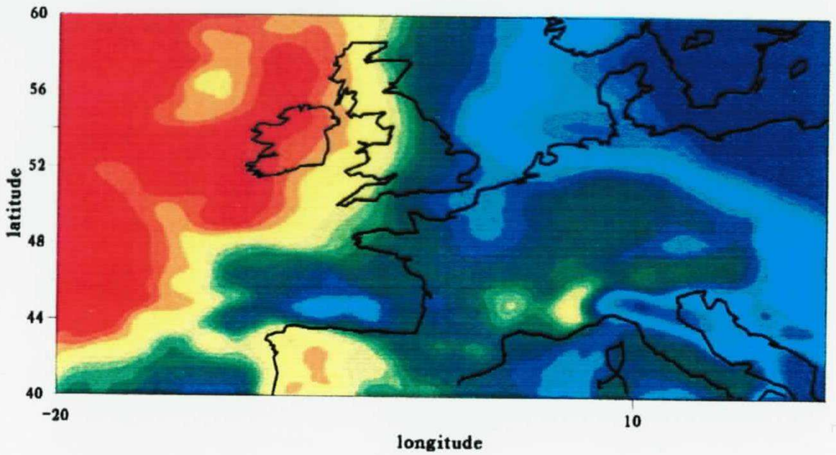
L'oeil "gravitationnel" des nouvelles missions



CHAMP

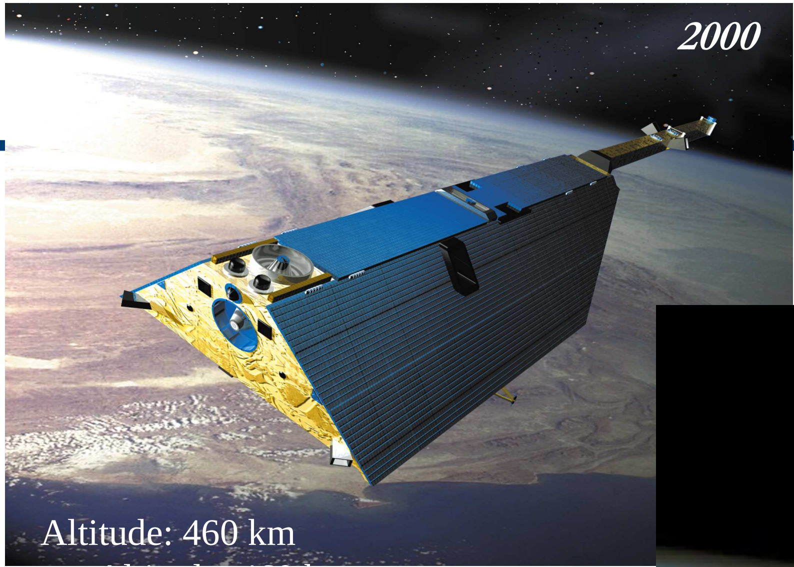


GRACE



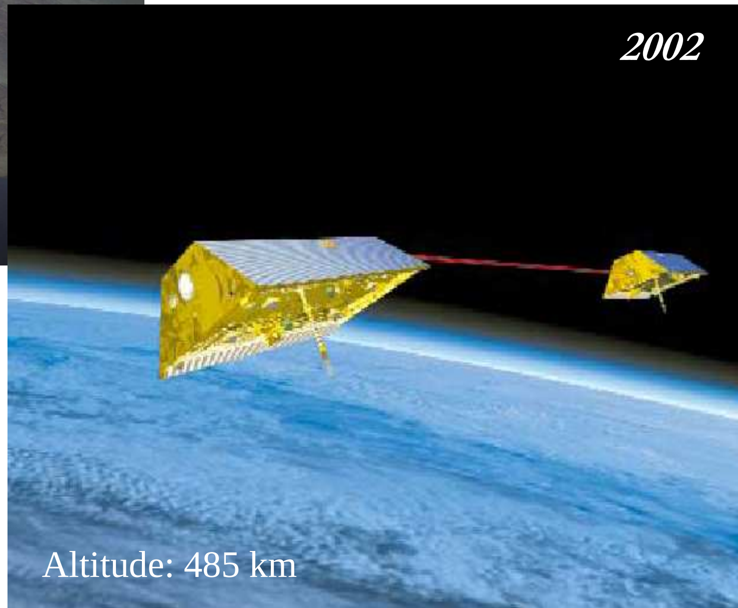
GOCE

CHAMP



précision géoïde: ***10 cm à 400 km***

GRACE

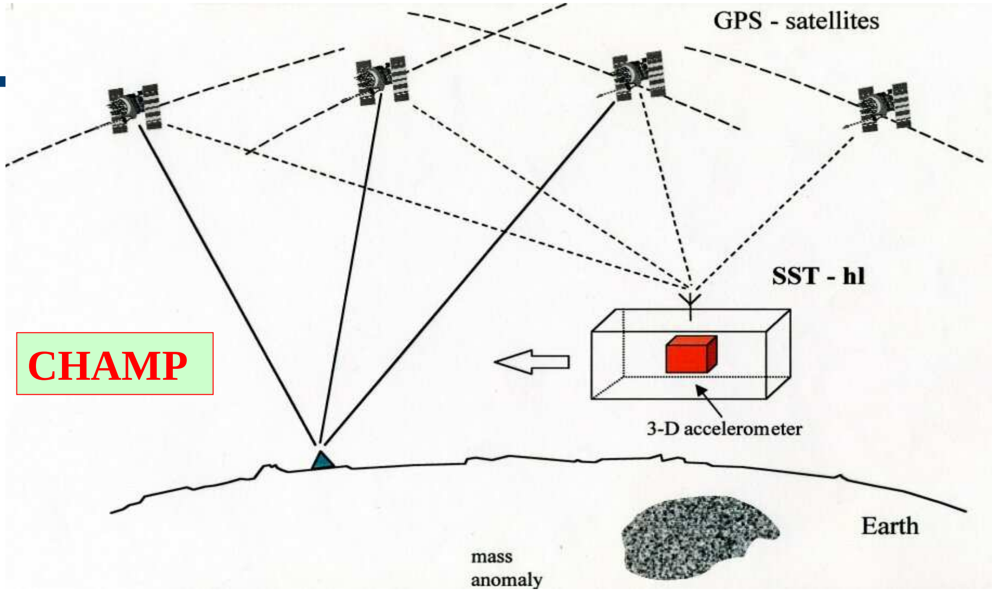


1 mm à 400 km

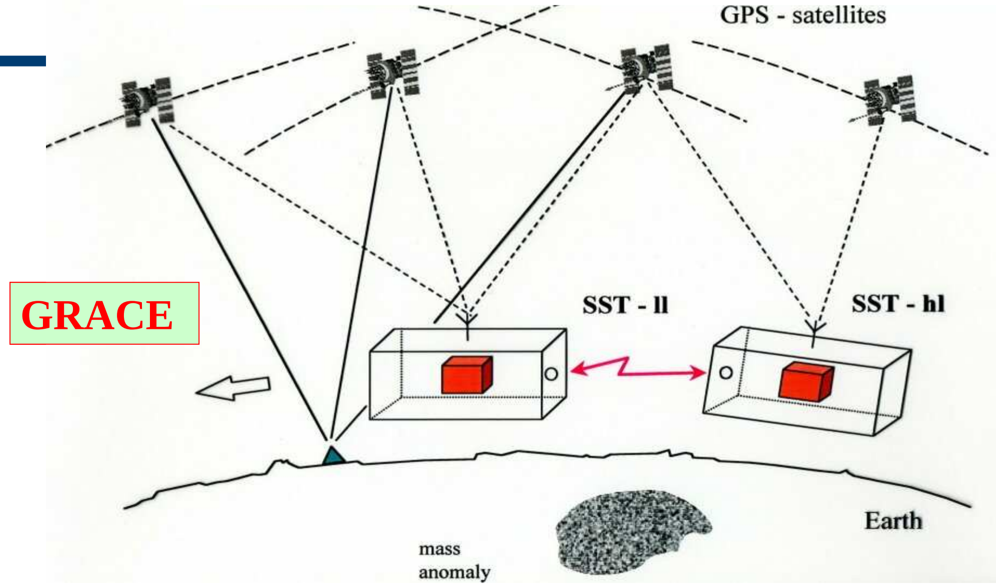
GOCE

haute résolution 1 cm à 100 km

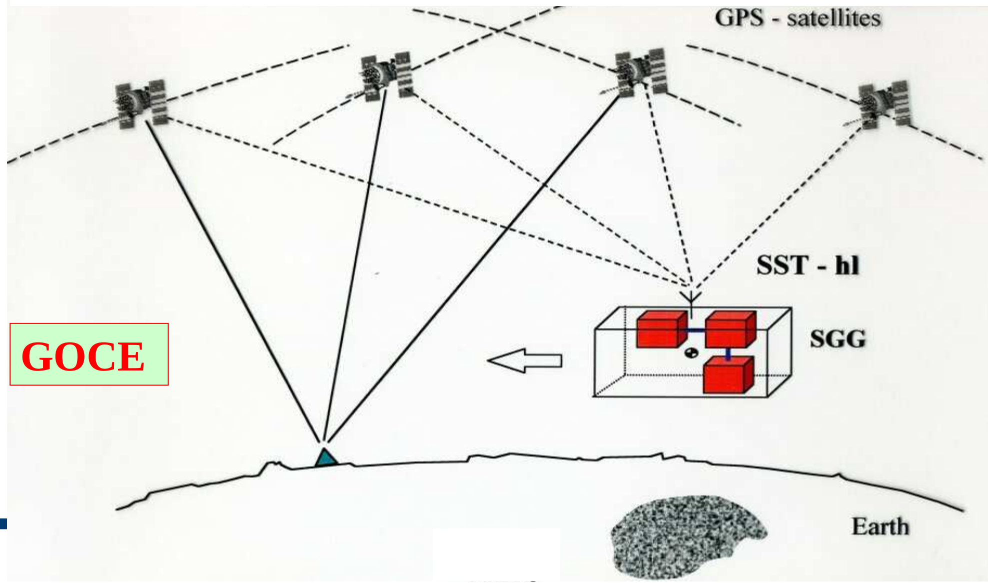
Poursuite de satellite bas par satellite(s) haut(s)
= SST-hl *(Satellite to Satellite Tracking- high low)*



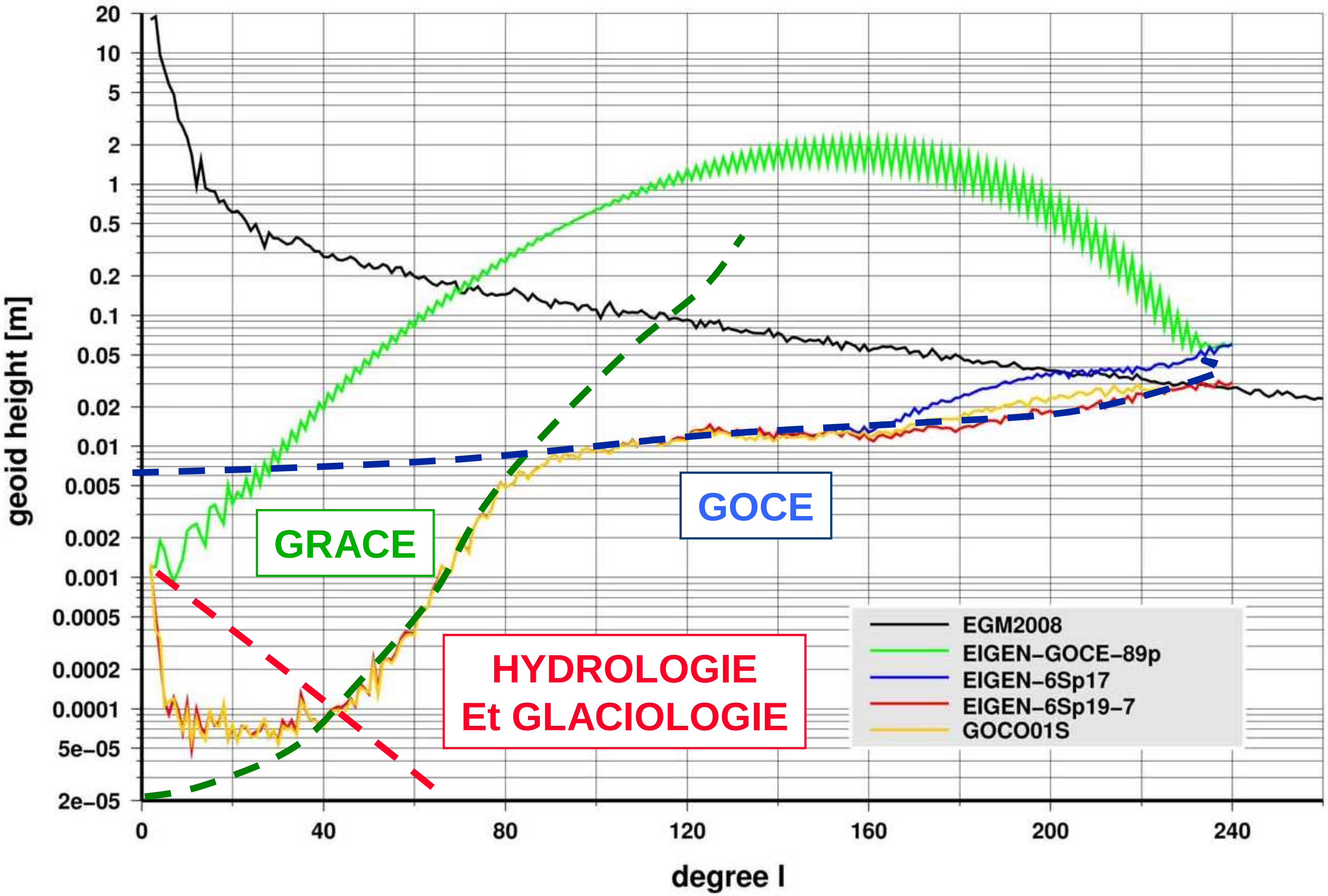
Poursuite de satellite bas par un autre satellite bas
= SST-ll *(Satellite to Satellite Tracking- low low)*



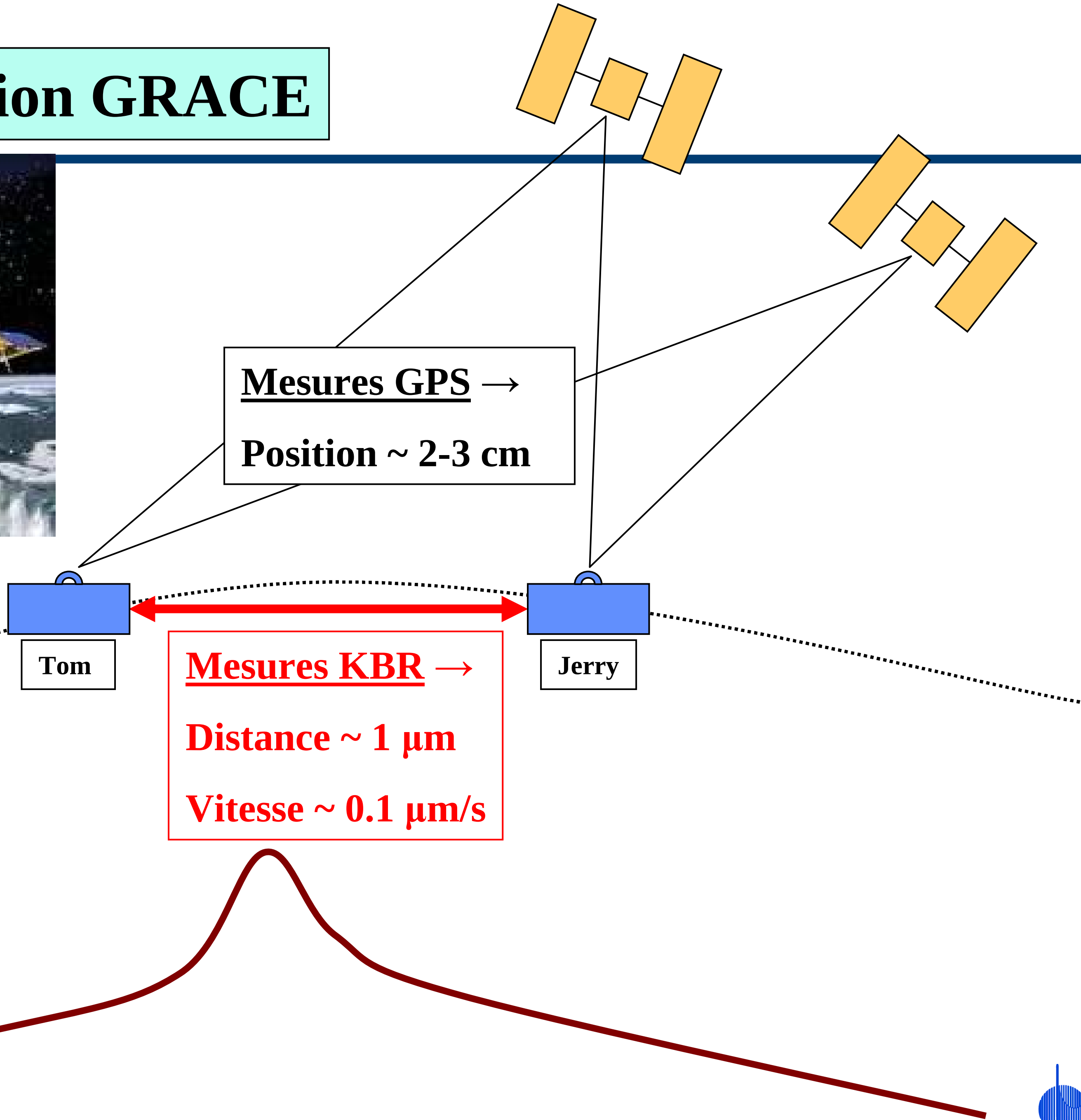
Gradiométrie (mesure des gradients de gravité) : SGG *(sat. grav. grad.)*
combinée avec SST-hl



Domaines d'excellence des missions GRACE et GOCE



Principe de la mission GRACE

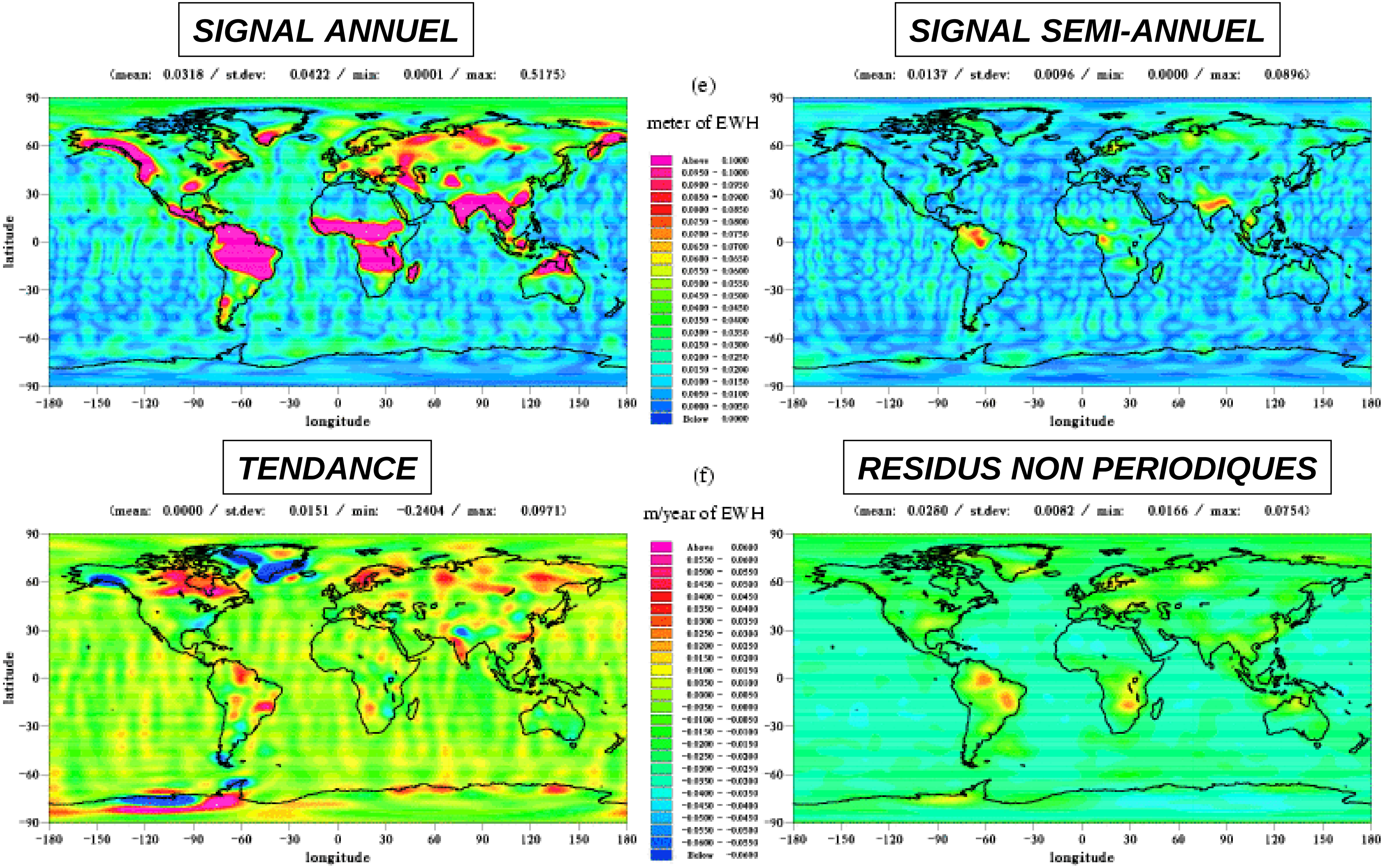


APRES 10 ANS EN ORBITE,

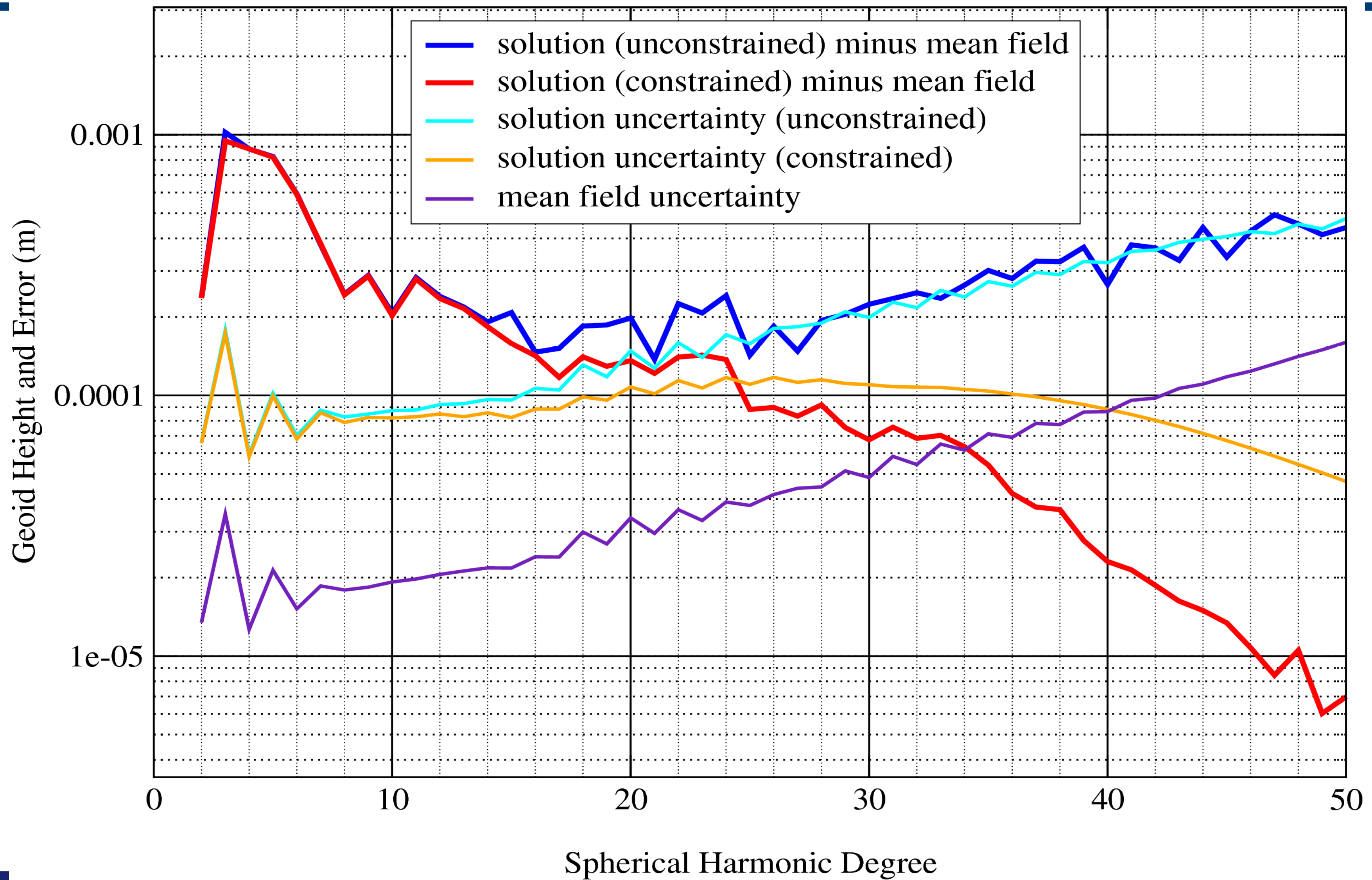
RESULTATS ACTUELS DE LA MISSION GRACE

Planisphère

Vue polaire


SIGNAL ANNUEL
(mean: 0.0318 / st.dev: 0.0422 / min: 0.0001 / max: 0.5175)
SIGNAL SEMI-ANNUEL
(mean: 0.0137 / st.dev: 0.0096 / min: 0.0000 / max: 0.0896)
(e)
meter of EWH
TENDANCE
(mean: 0.0000 / st.dev: 0.0151 / min: -0.2404 / max: 0.0971)
RESIDUS NON PERIODIQUES
(mean: 0.0260 / st.dev: 0.0082 / min: 0.0166 / max: 0.0754)
(f)
m/year of EWH
latitude
longitude

FREE vs. CONSTRAINED solutions



Stratégies de gestion de l'instabilité des solutions

GFZ, CSR, JPL :

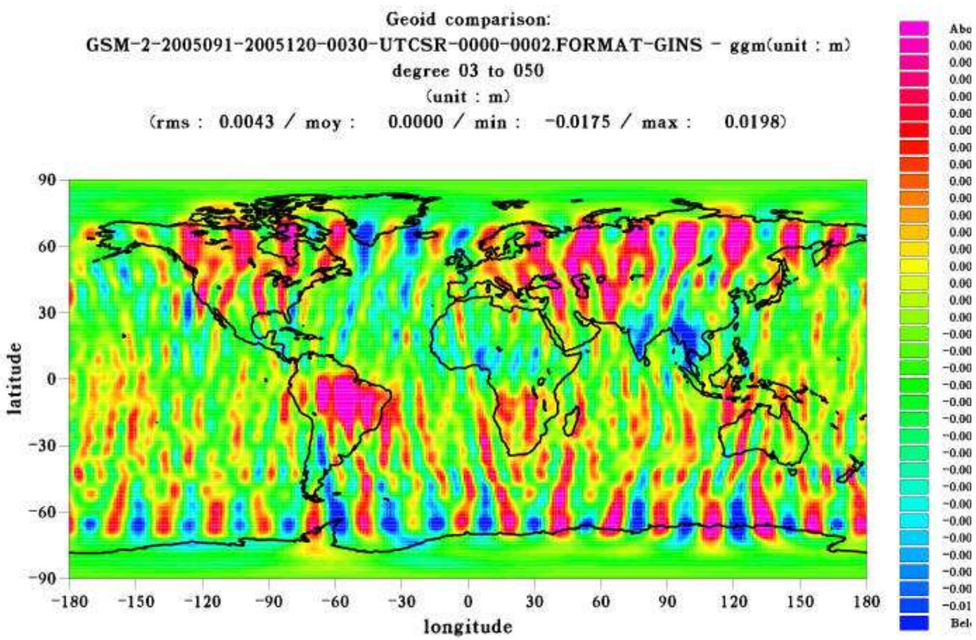
- Résolution sans contrainte jusqu'au degré ~90
- Application d'un traitement spécifique aux striations verticales
- Et/ou application d'un filtre gaussien à 300 / 400 / 500 km

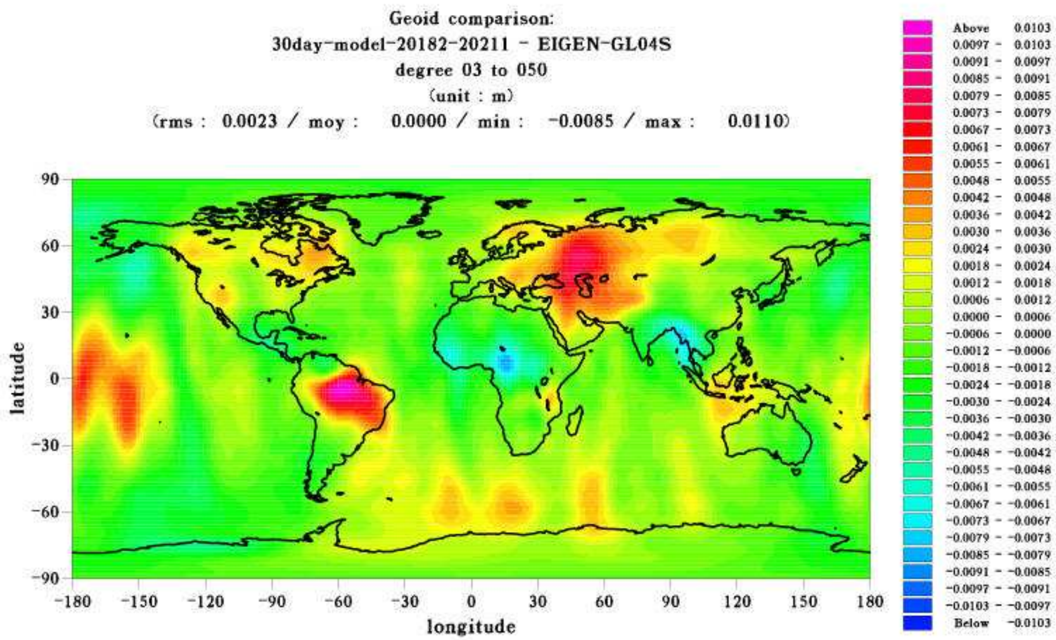
GRGS :

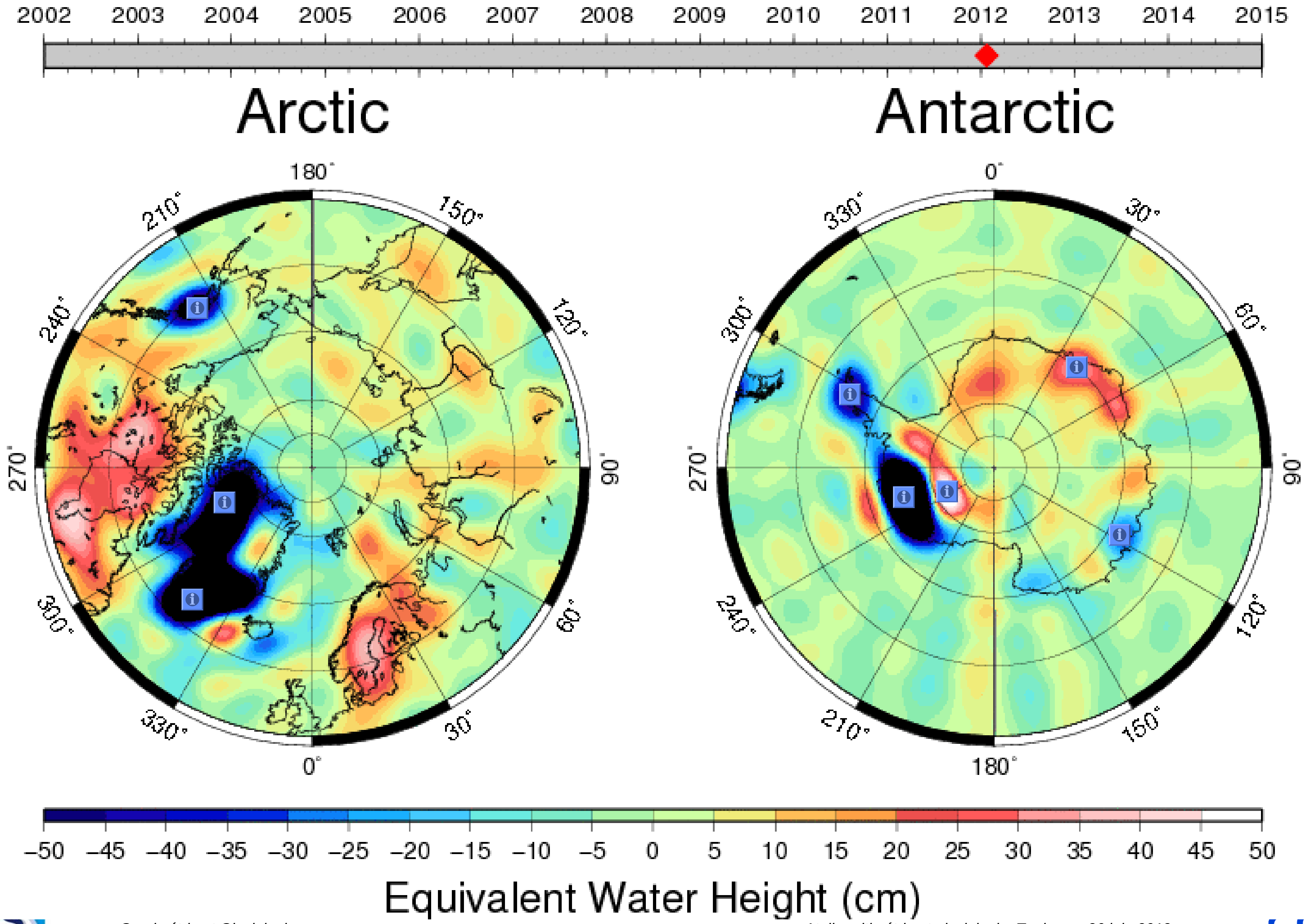
- Solution au degré 50 stabilisée par une contrainte vers le champ moyen (et pas de filtrage ultérieur)

Autres groupes (GSFC, G. Ramillien et F. Frappart au GRGS) :

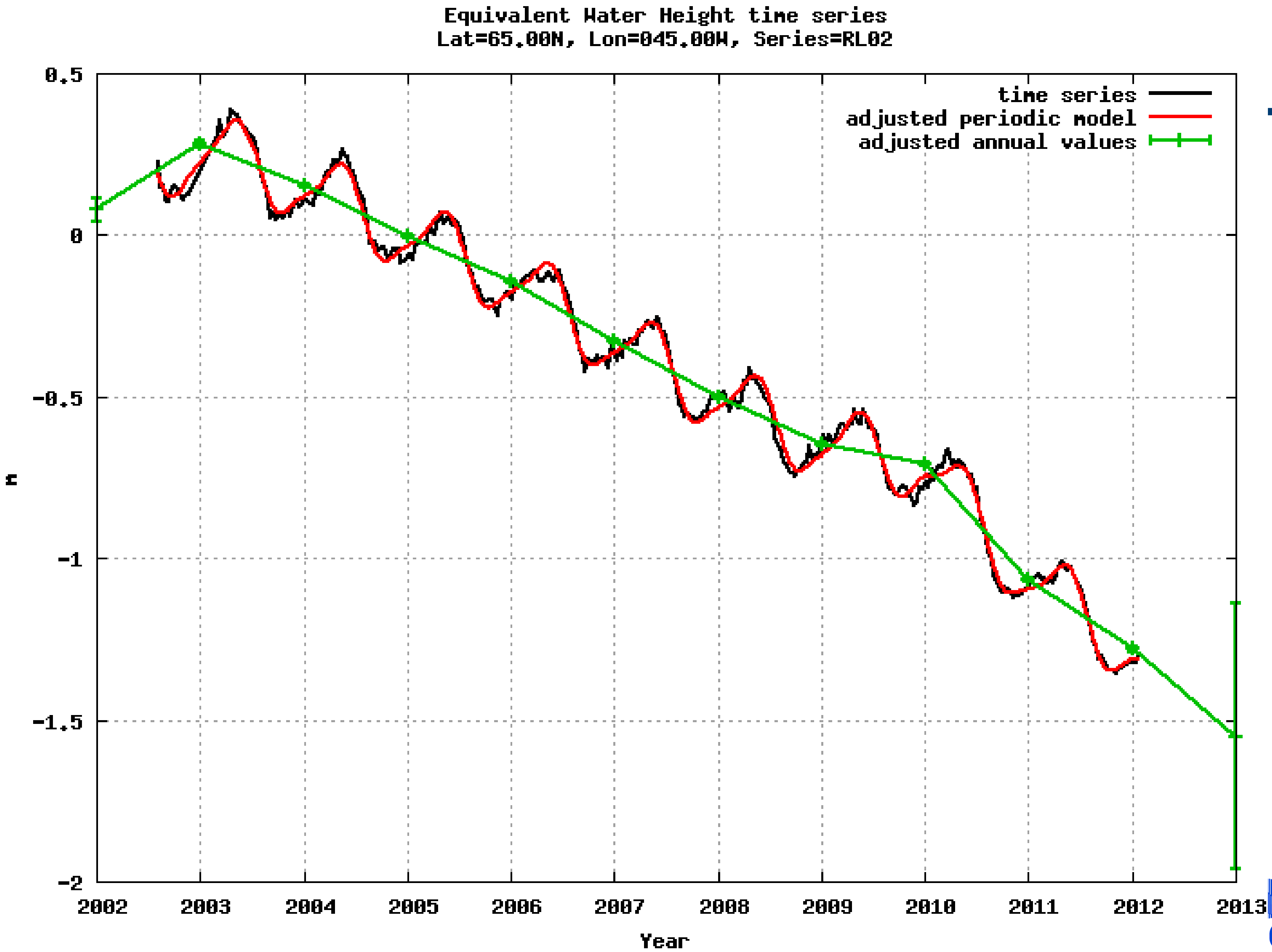
- Calcul de densités surfaciques (mascons) à partir de la méthode de l'intégrale de l'énergie





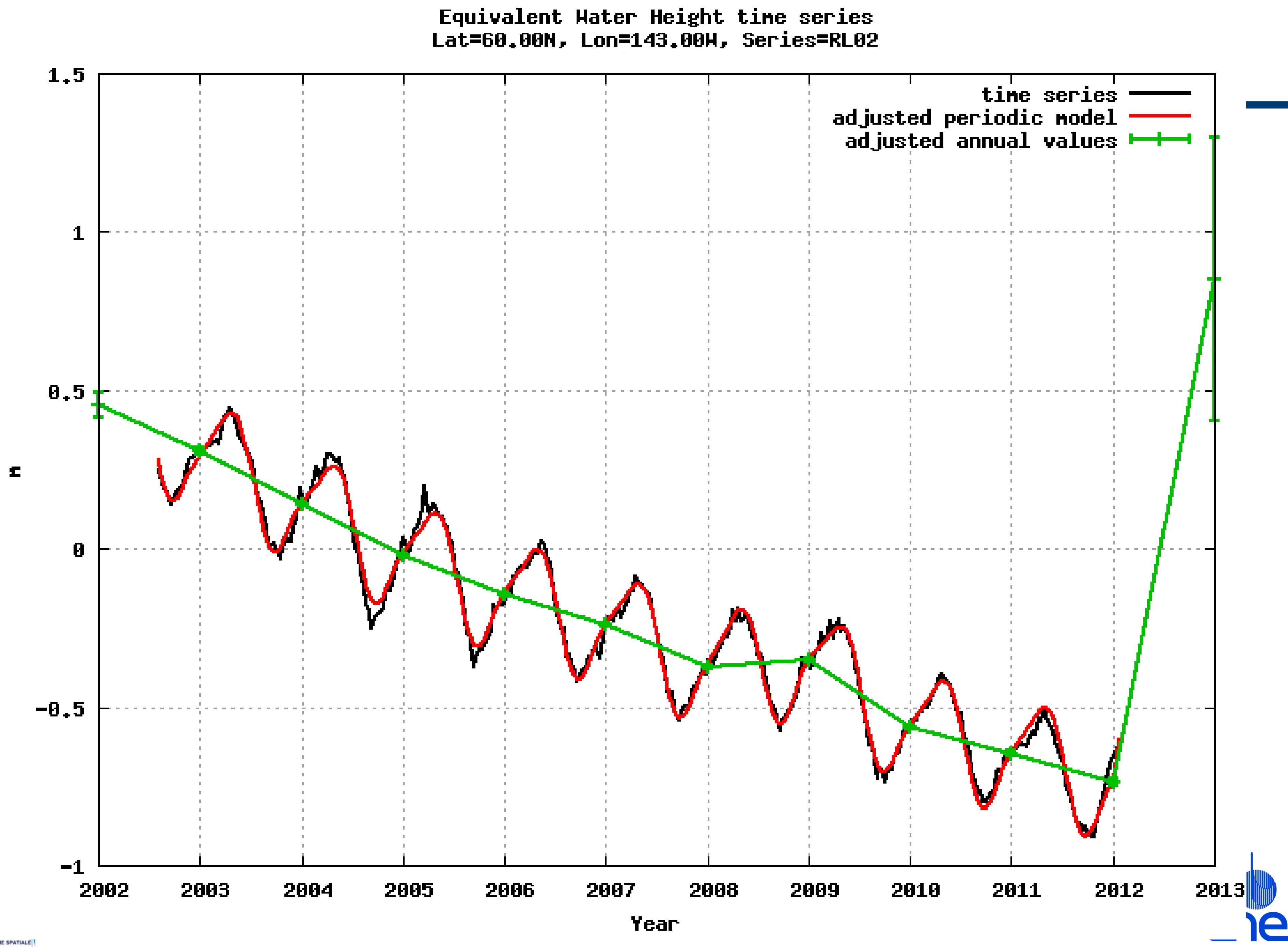


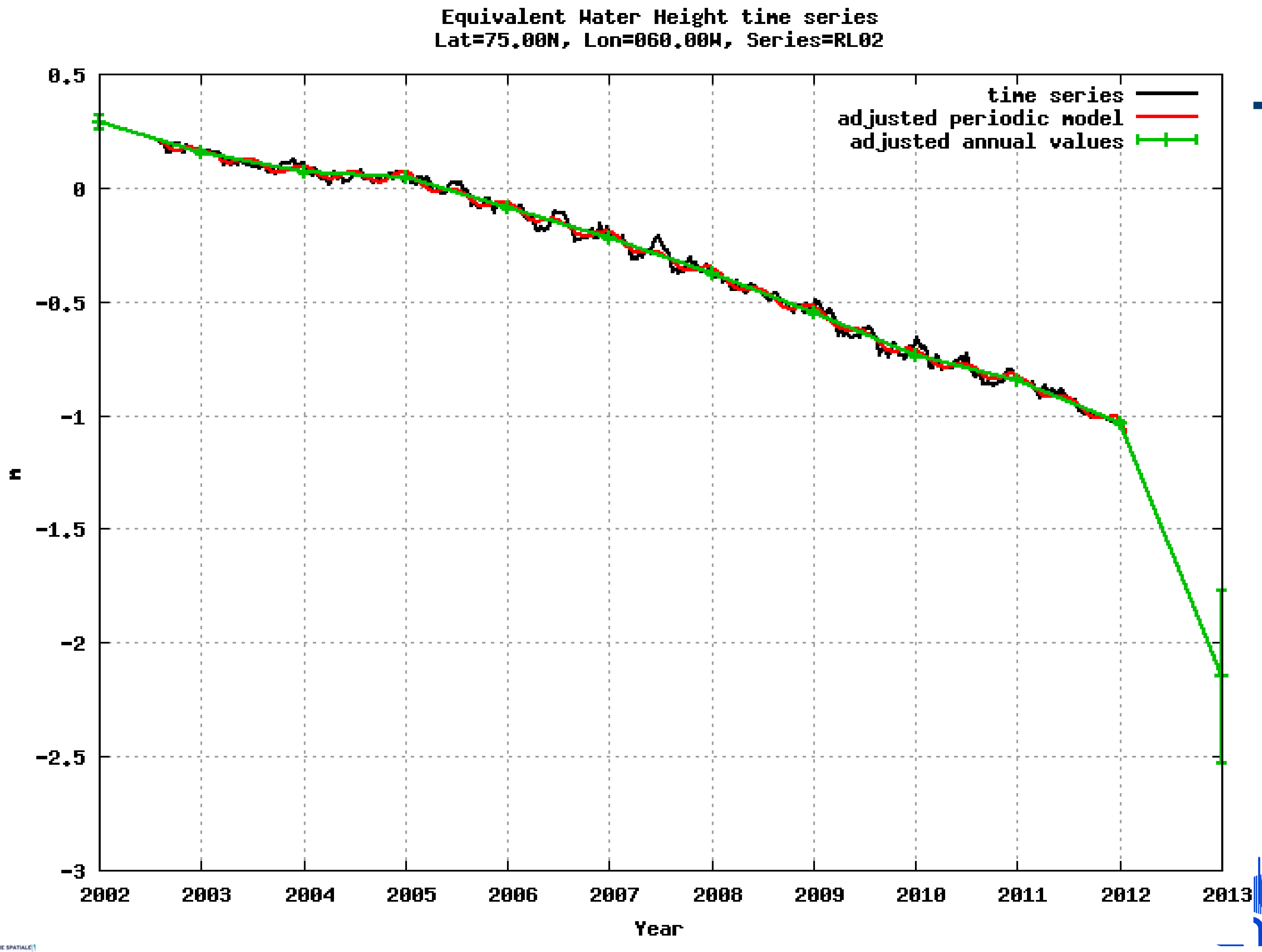
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Arctic
Antarctic
180°
150°
120°
90°
60°
30°
0°
330°
300°
270°
240°
210°
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
−50 −45 −40 −35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35 40 45 50
Equivalent Water Height (cm)


Equivalent Water Height time series
Lat=65.00N, Lon=045.00W, Series=RL02
time series
adjusted periodic model
adjusted annual values
0.5
0
-0.5
-1
-1.5
-2
m
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

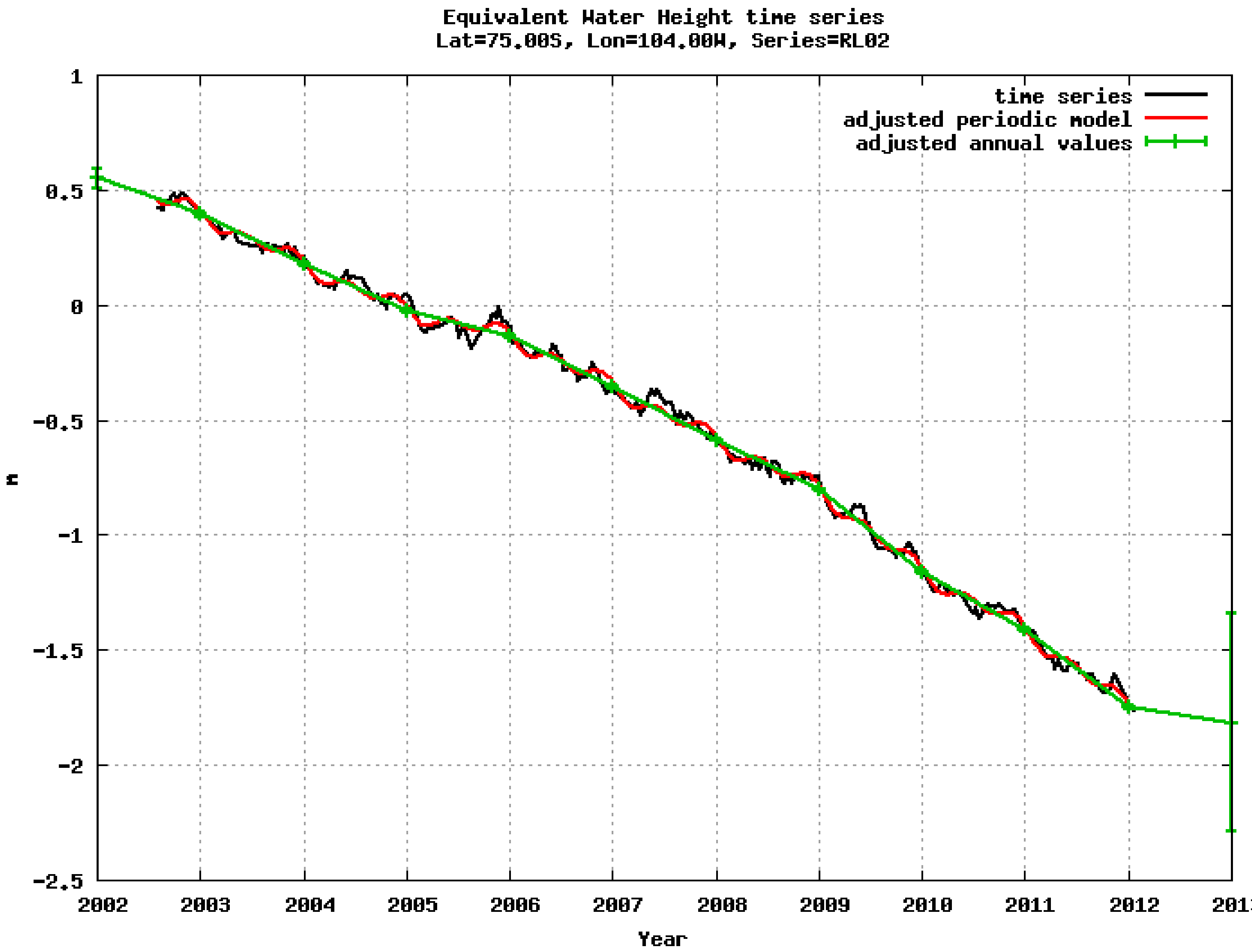
GR

es

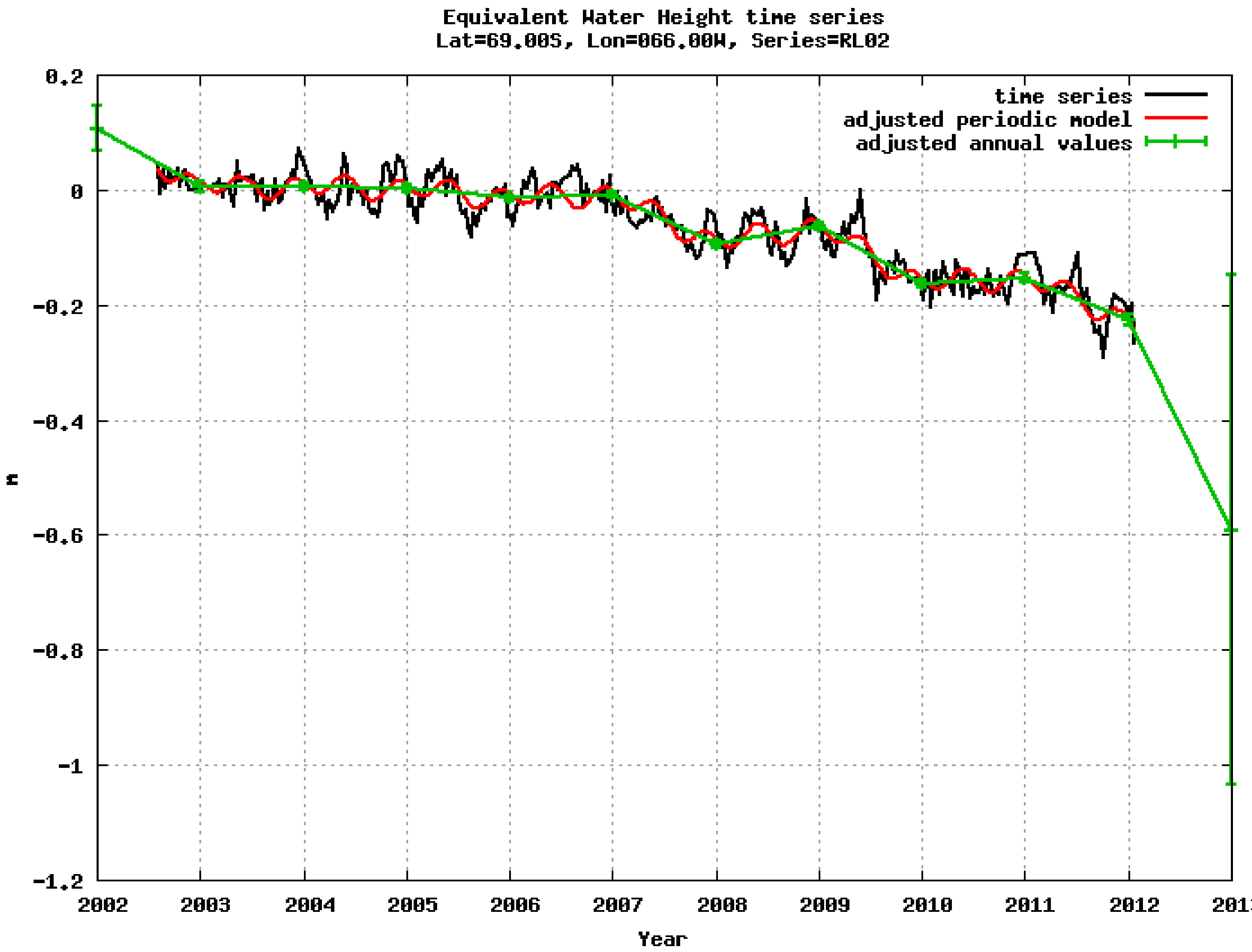

Equivalent Water Height time series
Lat=60.00N, Lon=143.00W, Series=RL02
time series
adjusted periodic model
adjusted annual values
1.5
1
0.5
0
-0.5
-1
m
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

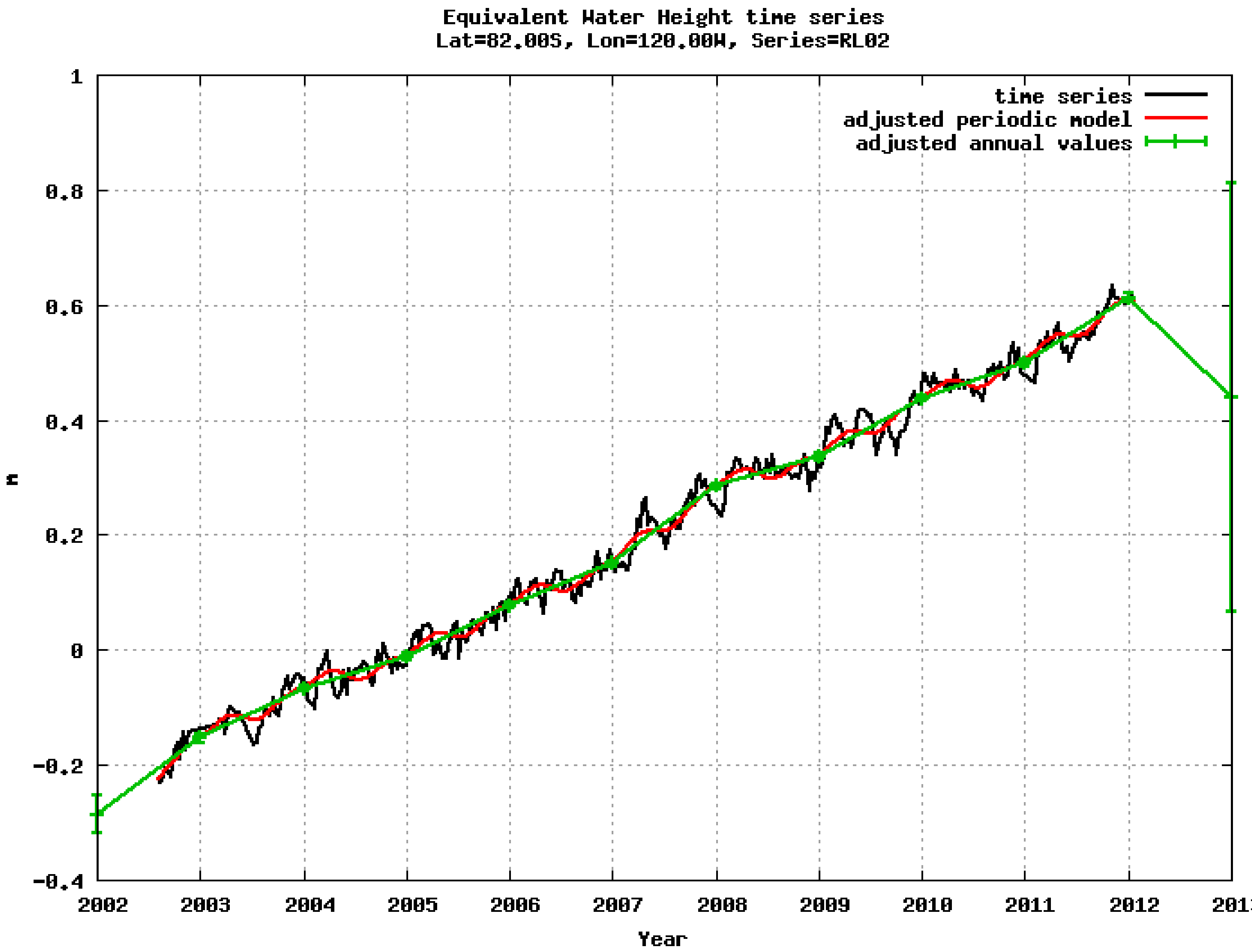


Equivalent Water Height time series
Lat=75.00N, Lon=060.00W, Series=RL02
time series
adjusted periodic model
adjusted annual values
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
m
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

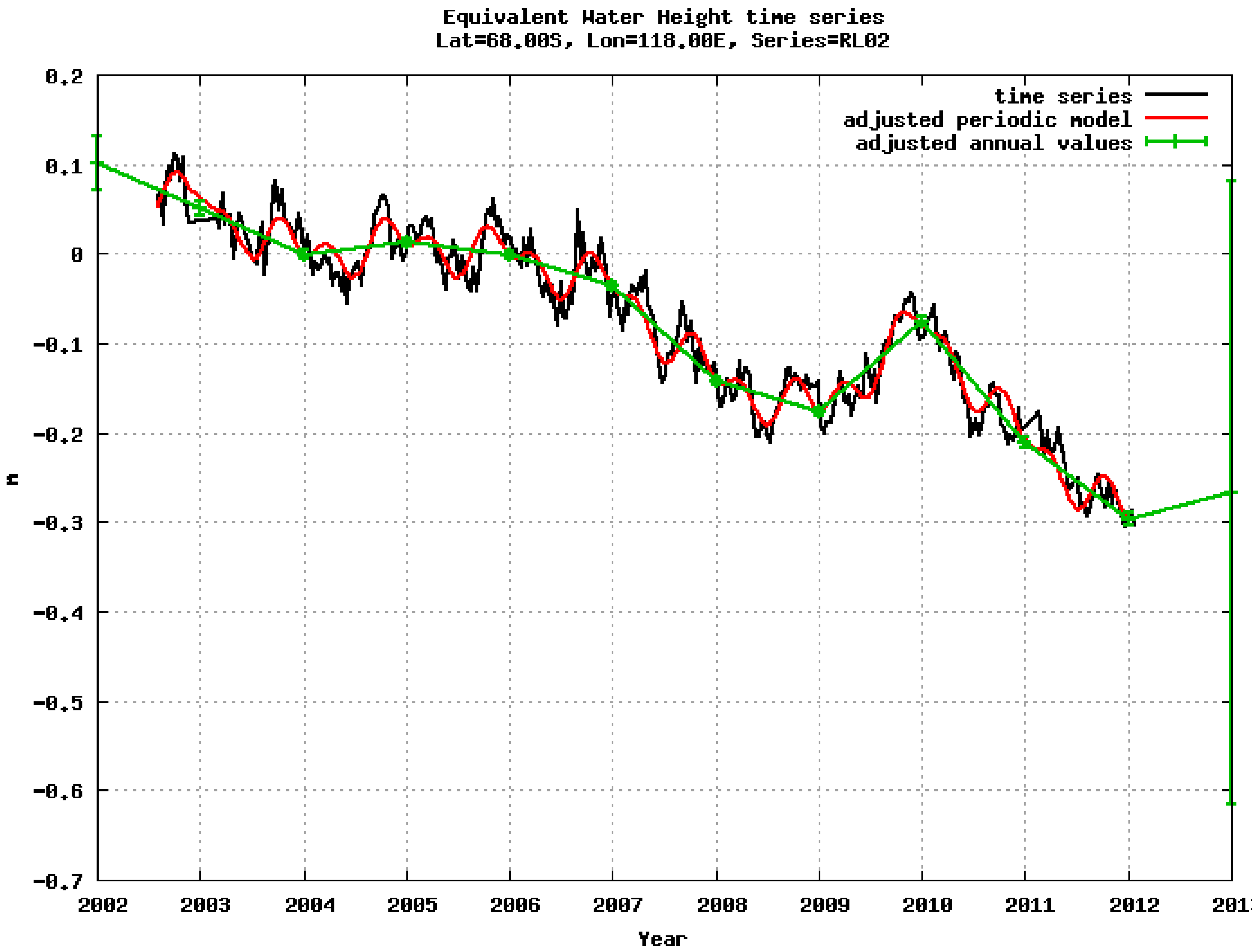


Equivalent Water Height time series
Lat=75.00S, Lon=104.00W, Series=RL02
time series
adjusted periodic model
adjusted annual values
m
Year
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

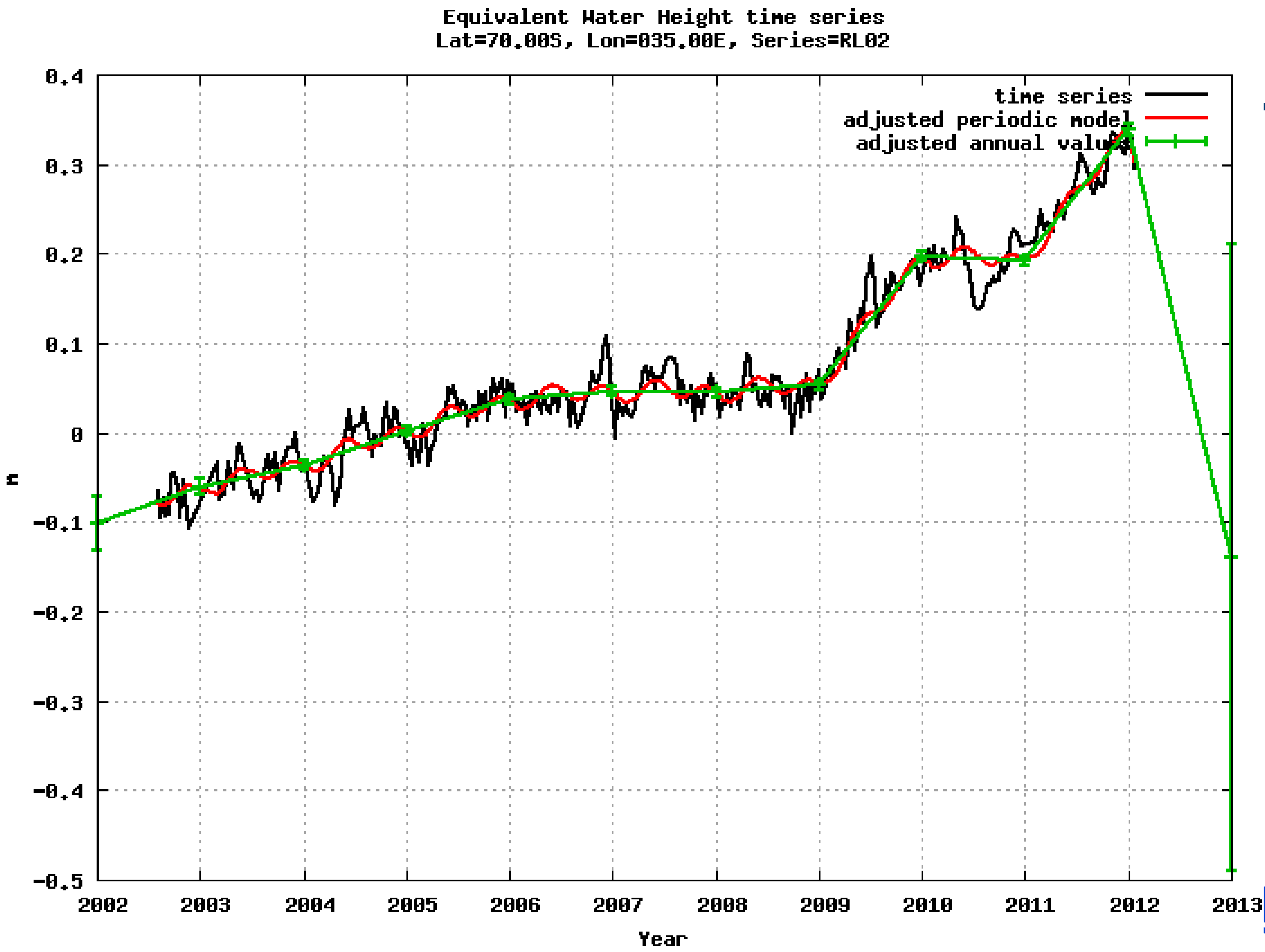

Equivalent Water Height time series
Lat=69.00S, Lon=066.00W, Series=RL02
time series
adjusted periodic model
adjusted annual values
m
Year
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013



Equivalent Water Height time series
Lat=82.00S, Lon=120.00W, Series=RL02
time series
adjusted periodic model
adjusted annual values
m
Year
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

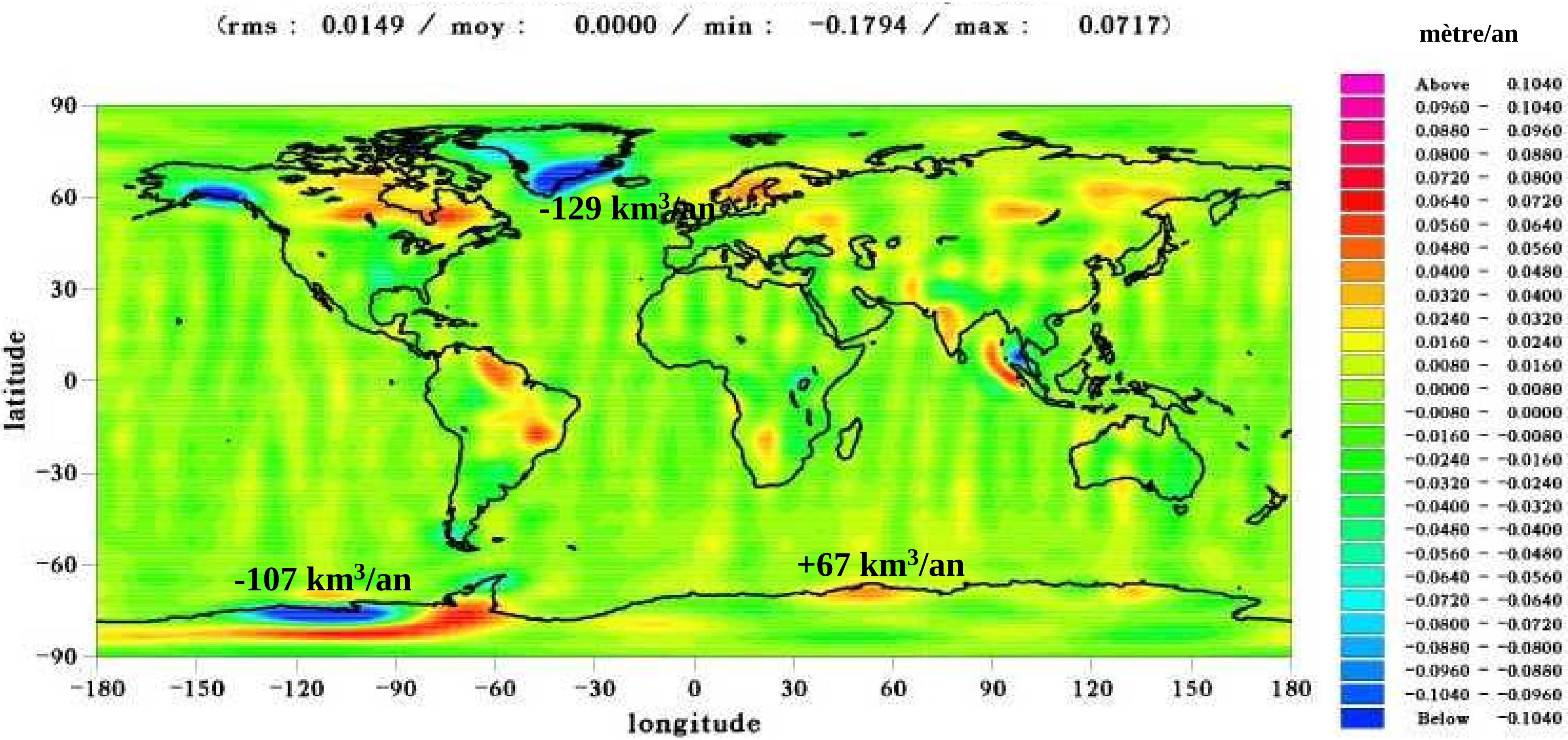


Equivalent Water Height time series
Lat=68.00S, Lon=118.00E, Series=RL02
time series
adjusted periodic model
adjusted annual values
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
m
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

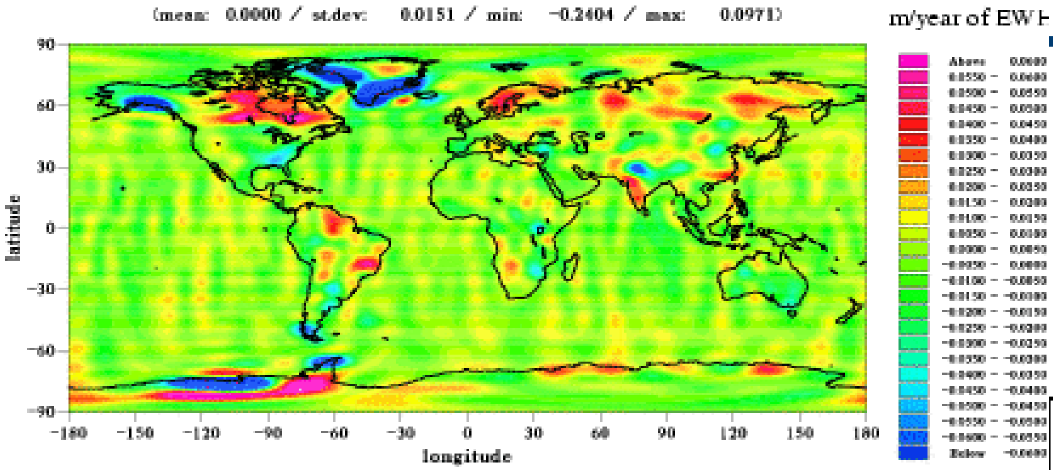


Equivalent Water Height time series
Lat=70.00S, Lon=035.00E, Series=RL02
time series
adjusted periodic model
adjusted annual values
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
m
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

Tendance linéaire des variations massiques (exprimée en hauteur d'eau)

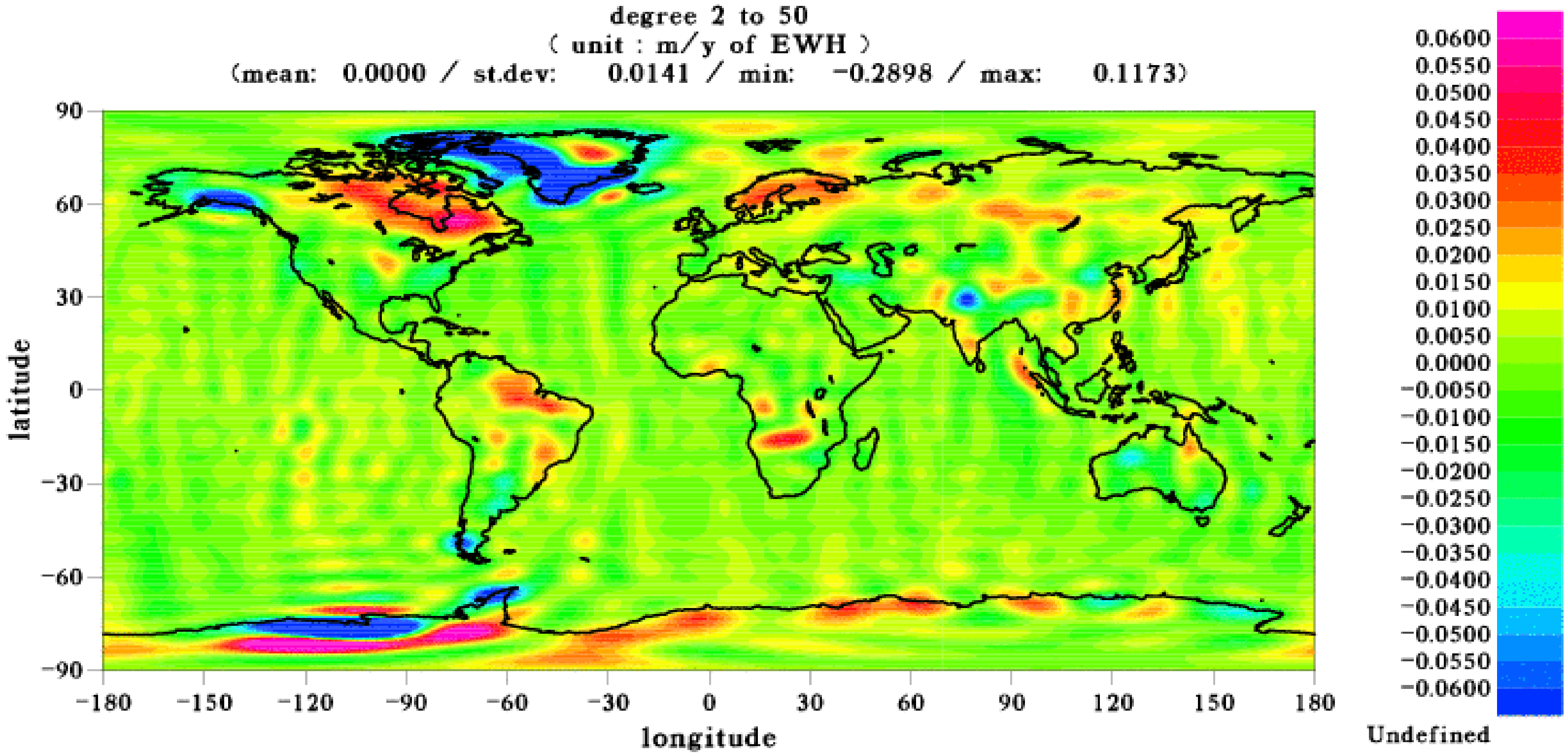


Inter-annual variations of the mass balance of the Antarctica and Greenland ice sheets from GRACE , G. Ramillien (LEGOS) & al., 2006



2003-2007

2003-2010



Défis actuels et futurs pour l'utilisation de GRACE en glaciologie

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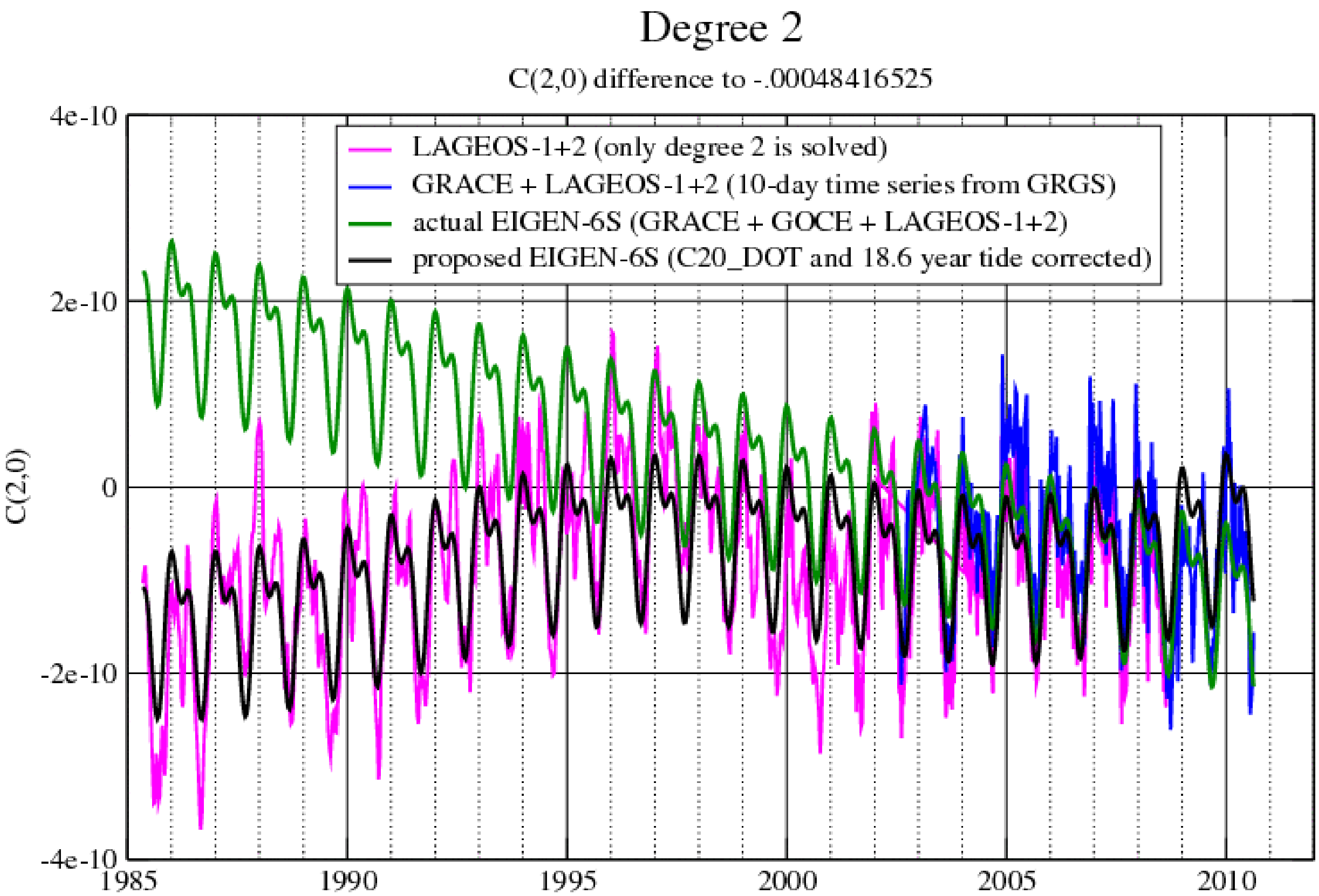
→),



GRG

nes

Défis actuels et futurs pour l'utilisation de GRACE en glaciologie

→ **Incertitude des champs de pression atmosphérique au dessus des calottes polaires**

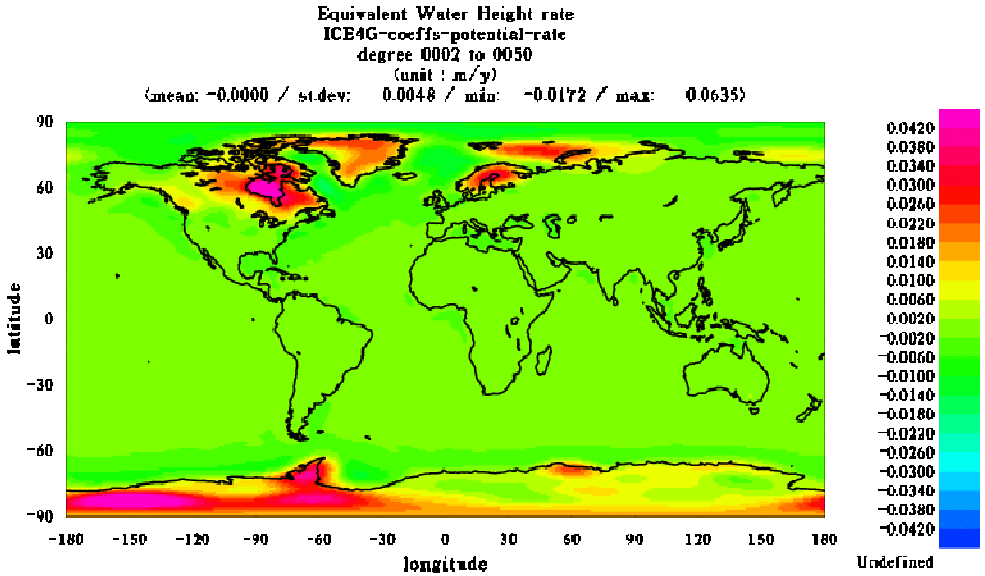
→ Ne semble pas critique pour l'instant

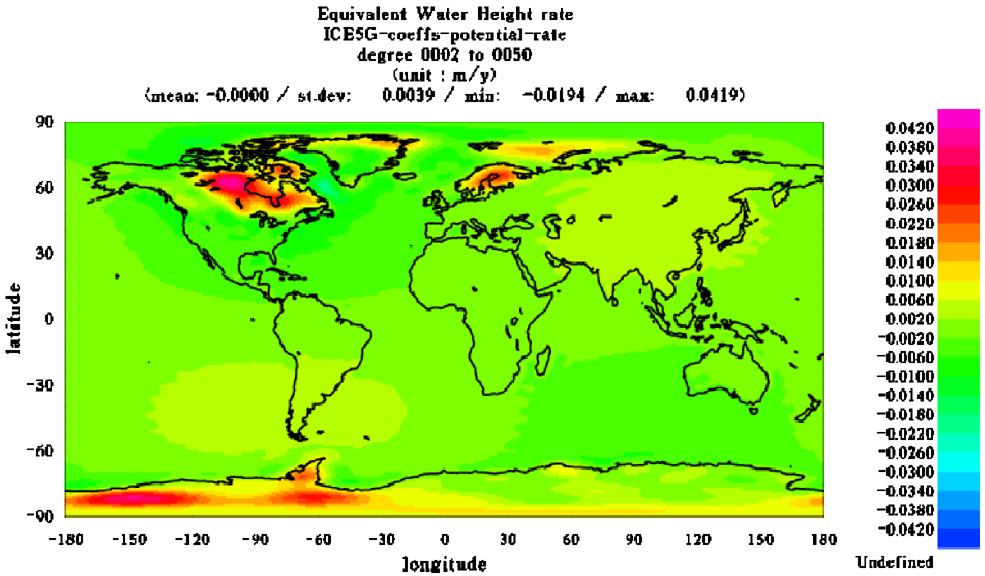
→ **Difficulté de la comparaison altimétrie-gravimétrie**

→ La gravimétrie est une mesure intégrée sur toute la colonne de matière

→ L'altimétrie est une mesure de surface, affectée des phénomènes de compaction

→ L'altimétrie ne peut pas s'approcher des côtes, où le signal est fort, alors que la gravimétrie, du





Introduction to GRACE solutions / Modèles variables GRACE / LAGEOS / GRACE - GRACE - Mozilla Firefox

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grgs.obs-mip.fr/grace/variable-models-grace-lageos/introduction-GRACE-solutions

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GRACE / LAGEOS

Modèles variables GRACE / LAGEOS | Modèles statiques EIGEN | Recherche

GRACE > Modèles variables GRACE / LAGEOS > Introduction to GRACE solutions

MODÈLES VARIABLES GRACE / LAGEOS
- Présentation
- Introduction to GRACE solutions
- GRACE solutions release 01
- GRACE solutions release 02
- Formats
- Static field
- Interactive Tools

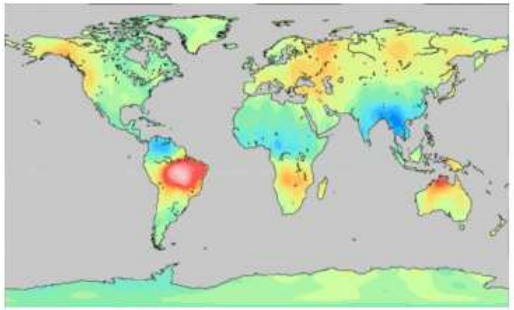
MODÈLES STATIQUES EIGEN

Introduction to GRACE solutions

News | Introduction | Summary

9 years of gravity variations from GRACE and LAGEOS data from CNES/GRGS

R Biancale, J-M Lemoine, G Balmino, S Bruinsma, F Perosanz, J-C Marty (CNES/GRGS, Toulouse, France), S Loyer, S Bourgogne (Noveltis, Toulouse, France), P Gégout (EOST, Strasbourg, France)



Contacts

Richard.Biancale@cnes.fr
Jean-Michel.Lemoine@cnes.fr

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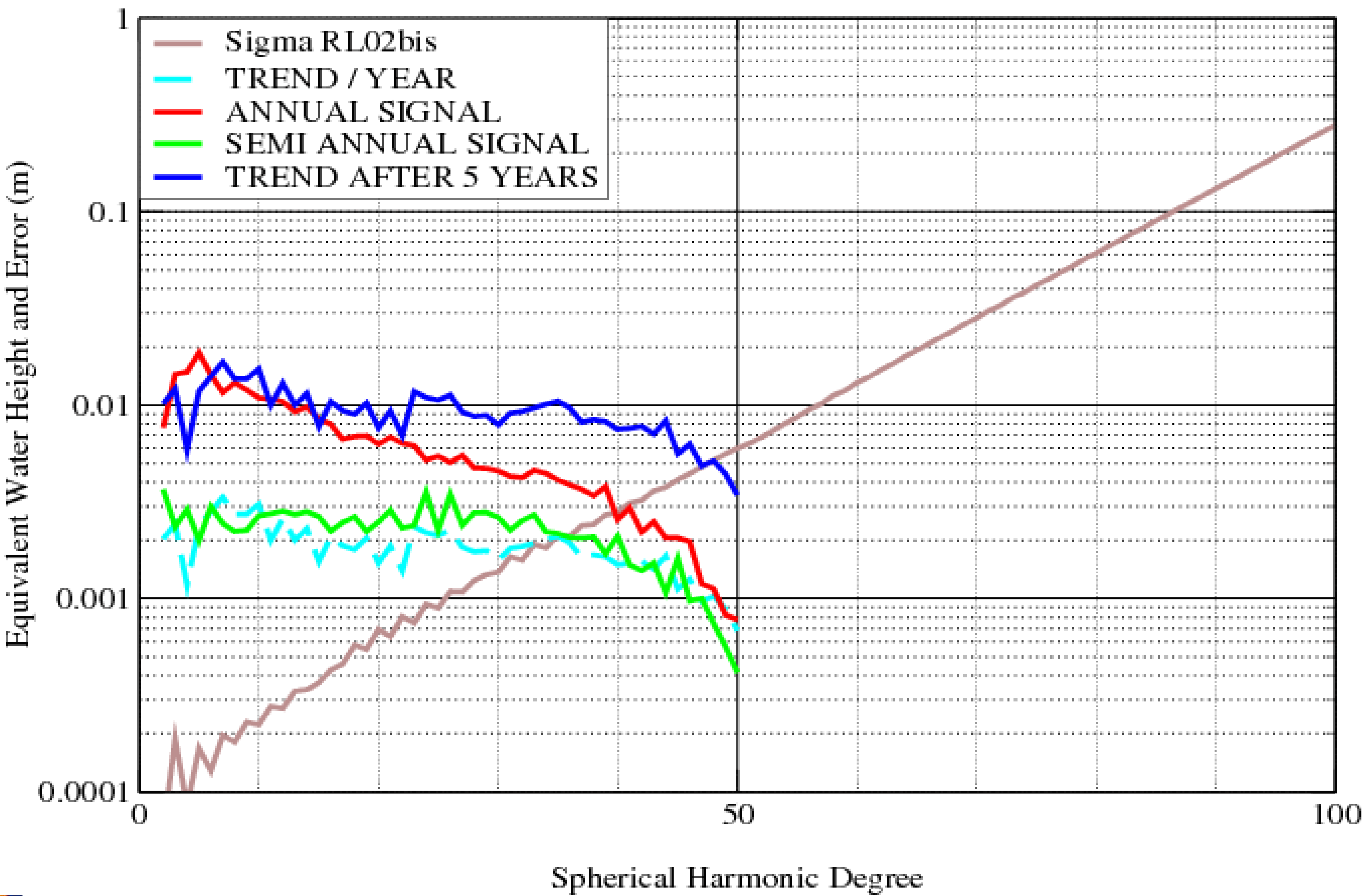
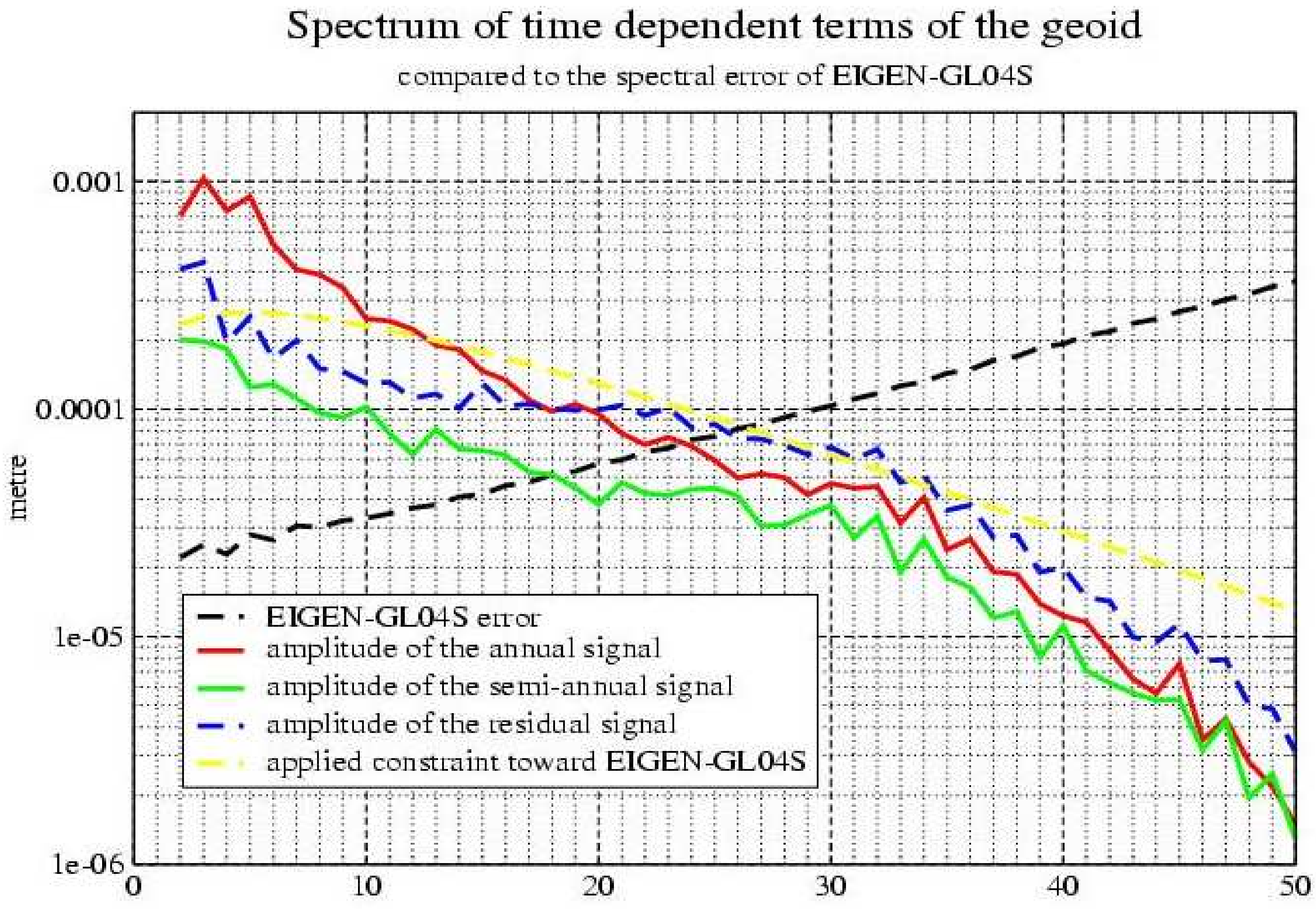
Fin

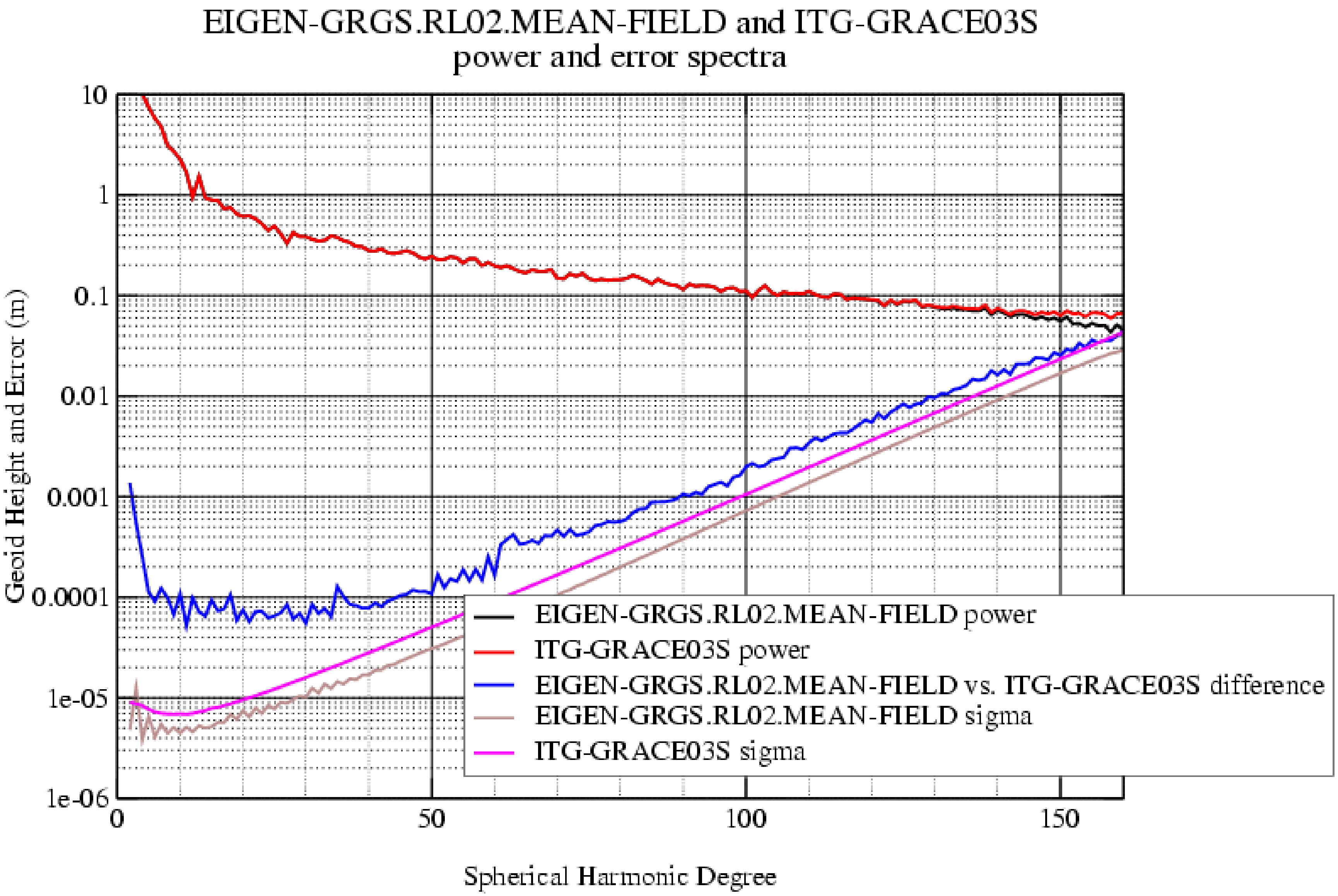
Relative amplitude between hydrology signal and gravity field error



Geoid spectrum per degree



Wavelength :	4000 km	2000 km	1333 km	1000 km	800 km
Resolution :	2000 km	1000 km	666 km	500 km	400 km


EIGEN-GRGS.RL02.MEAN-FIELD and ITG-GRACE03S
power and error spectra
Geoid Height and Error (m)
10
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
0
50
100
150
Spherical Harmonic Degree
EIGEN-GRGS.RL02.MEAN-FIELD power
ITG-GRACE03S power
EIGEN-GRGS.RL02.MEAN-FIELD vs. ITG-GRACE03S difference
EIGEN-GRGS.RL02.MEAN-FIELD sigma
ITG-GRACE03S sigma

Simulation GOCE

sur 60 jours

altitude: 250 km

inclinaison: 96,5 degrés

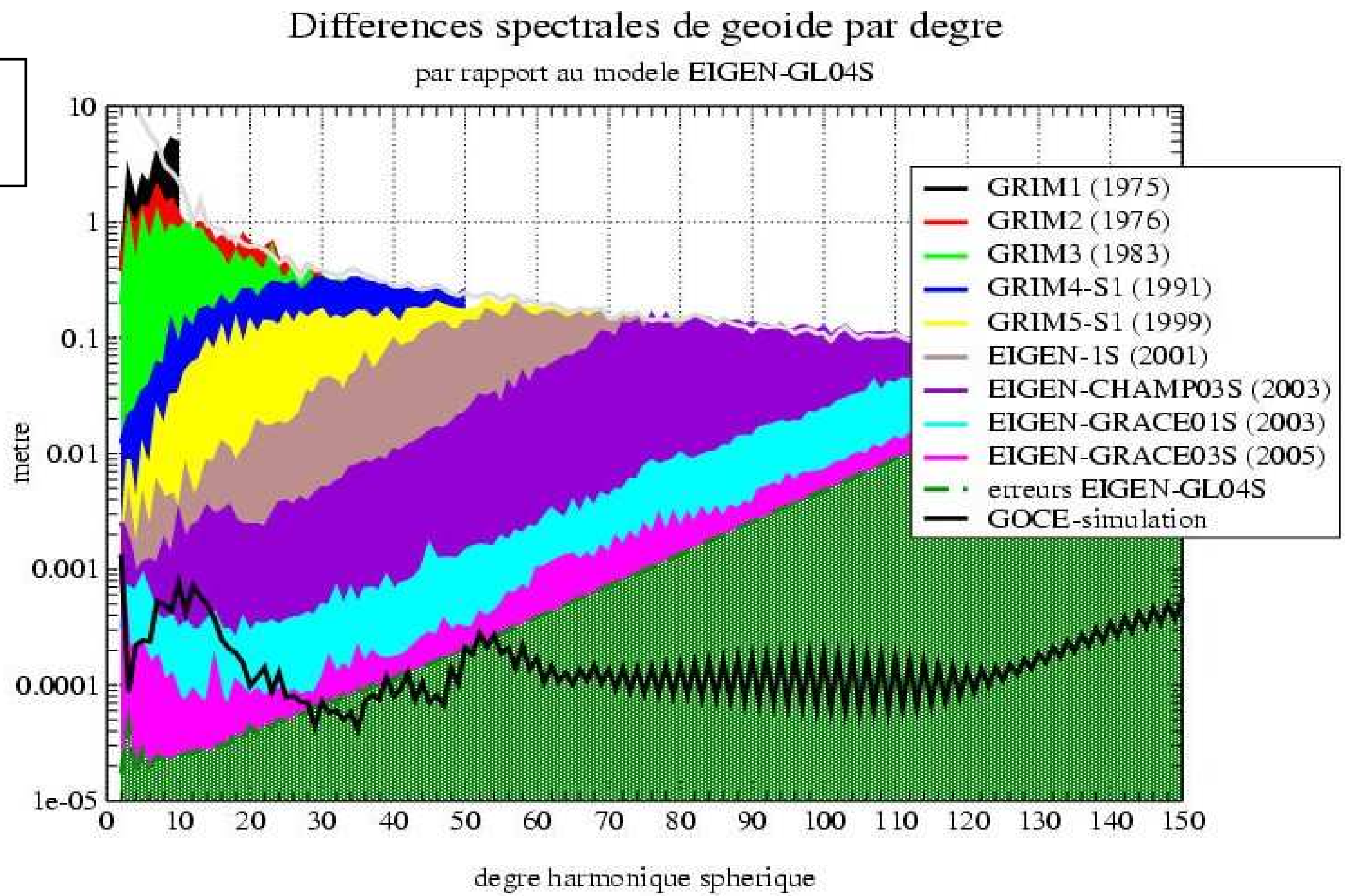
excentricité: 0,001

Données

SST / 10s (dérivées partielles jusqu'au degré 120), bruit blanc: 15mm rms

SGG / 4s (filtré à la période de coupure de 220 s, dérivées partielles jusqu'au degré 240)

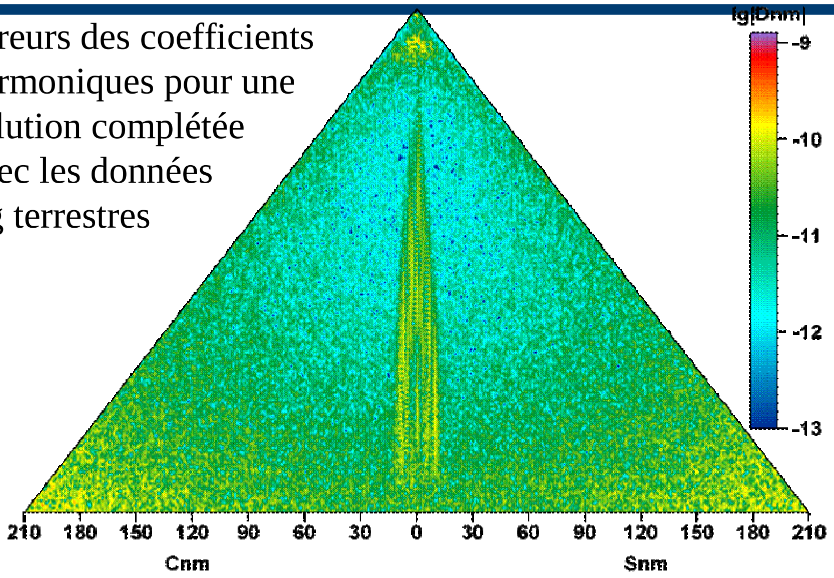
Spectre géoïde

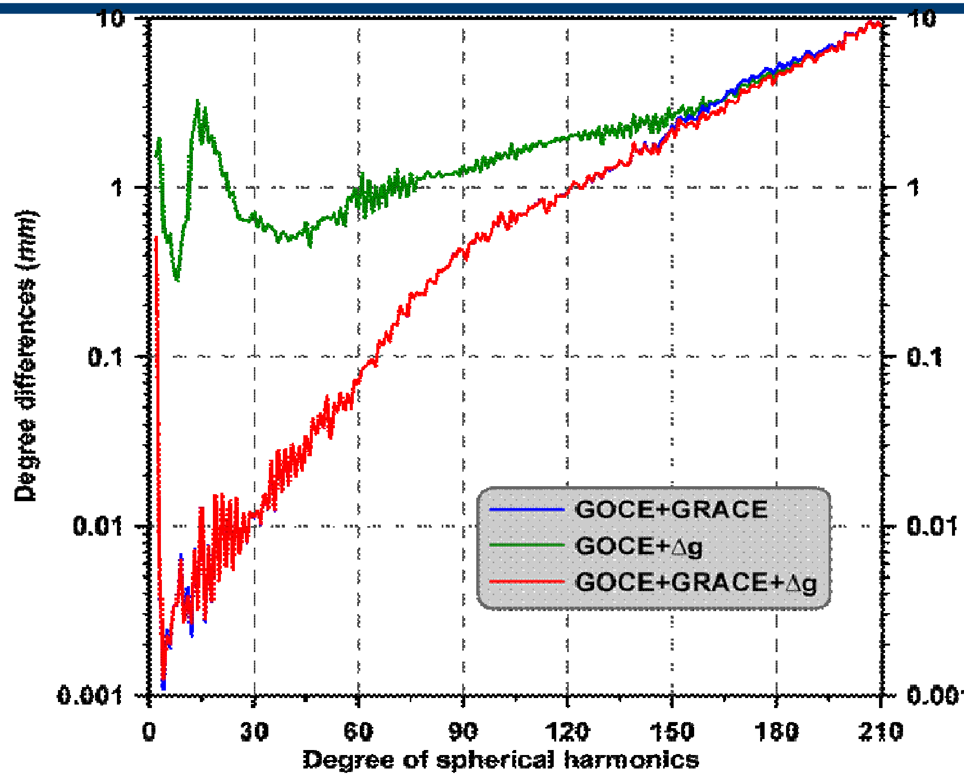


Combinaison avec Δg et GRACE

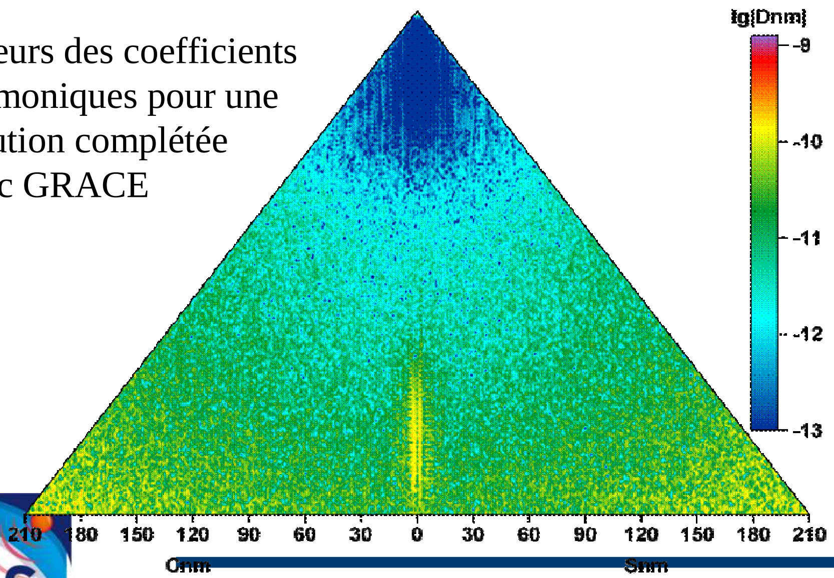
Spectres des solutions GOCE combinées

Erreurs des coefficients harmoniques pour une solution complétée avec les données Δg terrestres

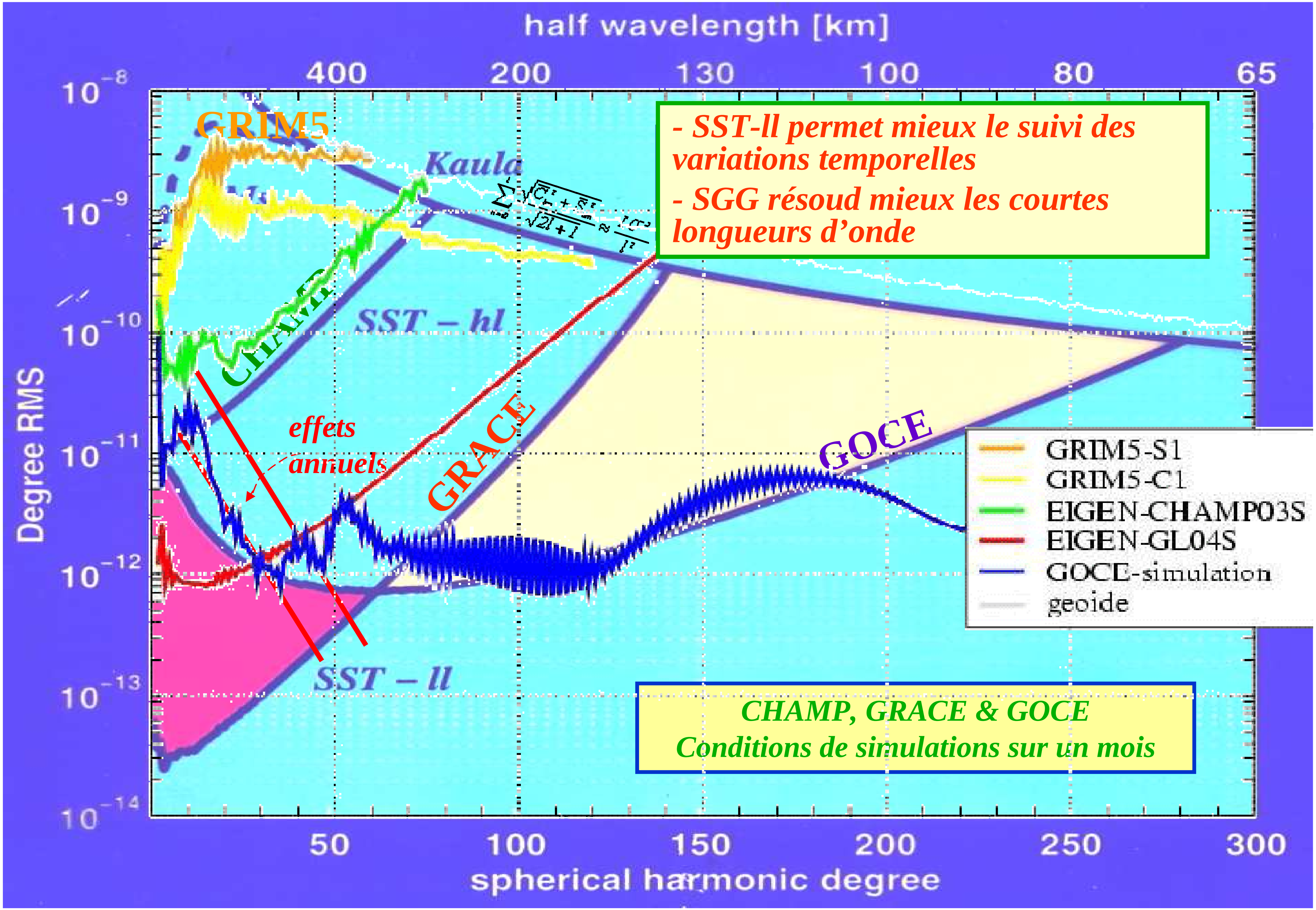




Erreurs des coefficients harmoniques pour une solution complétée avec GRACE

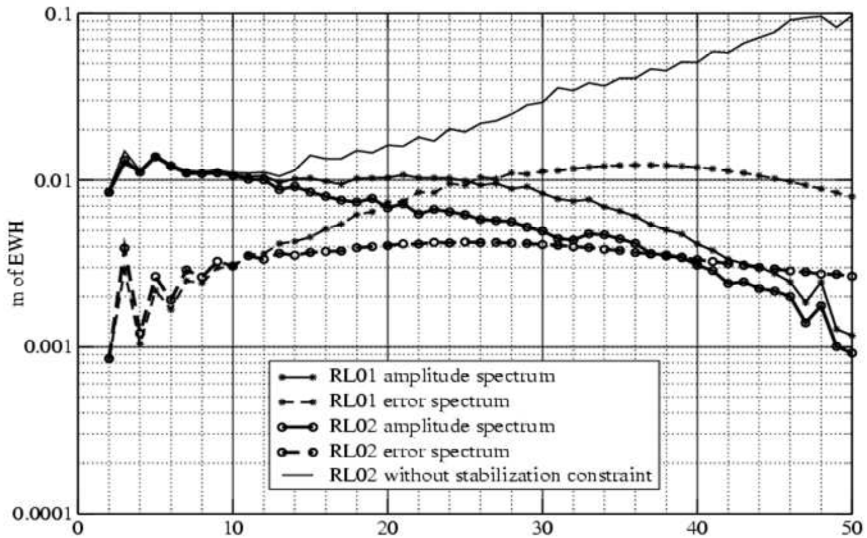


	Whole globe			$-83.5° \leq \varphi \leq +83.5°$
	GOCE+GRACE	**GOCE+Dg**	**GOCE+GRACE+Dg**	**(all cases)**
Max. (cm)	127	144	47	22
R.m.s. (cm)	9	8	5	4

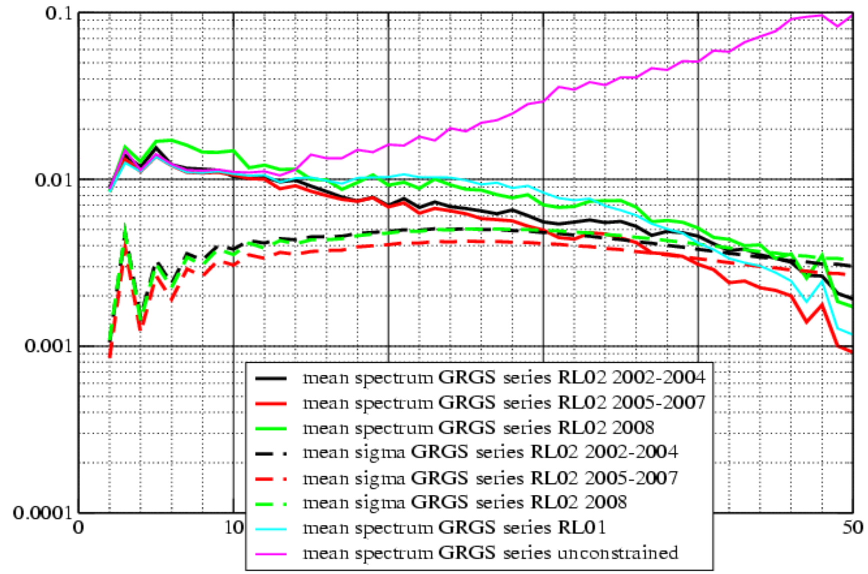

half wavelength [km]
400
200
130
100
80
65
Degree RMS
spherical harmonic degree
50
100
150
200
250
300
GRIM5
Kaula
CHAMP
SST – hl
GRACE
GOCE
SST – ll
effets annuels
- SST-ll permet mieux le suivi des variations temporelles
- SGG résoud mieux les courtes longueurs d'onde
GRIM5-S1
GRIM5-C1
EIGEN-CHAMP03S
EIGEN-GL04S
GOCE-simulation
geoide
CHAMP, GRACE & GOCE
Conditions de simulations sur un mois

« RL02 version of CNES/GRGS consists of information up to degree and order 50 truly different from RL01 version which only provides true information up to degree and order 30 ? »

The figure to the right displays the spectral power (by comparison to a static reference field) and the spectral error of the two GRGS releases RL01 and RL02 and of an unconstrained solution, in terms of equivalent water heights (EWH). It is an average of all the spectra over the entire set of solutions. The static reference field is EIGEN-GL04S/C in the case of RL01 and EIGEN-GRGS.RL02.MEAN-FIELD in the case of RL02. A few remarks:
- It is clear from the unconstrained_RL02 spectrum that some sort of stabilization of the solution is necessary, from spherical harmonic degree 10.
- The comparison between RL01 and RL02 spectra shows that there is more power in RL01 than in RL02 between degrees 10 and 40, but the error curve for RL01 is also much higher. The power of RL01 is almost flat, at ~1 cm EWH, until degree 30, then the stabilization acts sharply between degree 30 and 50, whereas the stabilization is much more smoothly distributed between degree 10 and 50 for RL02. The question is: is this difference of power made up of signal (lacking in RL02…) or of error (removed from RL01…) ? We do not have a definitive answer to that question, except for the fact that the stabilization in RL02 has been much more finely adjusted to the actual uncertainty of the unconstrained coefficients (it is now degree- and order-dependant) than it was for RL01 where it was only degree-dependant.

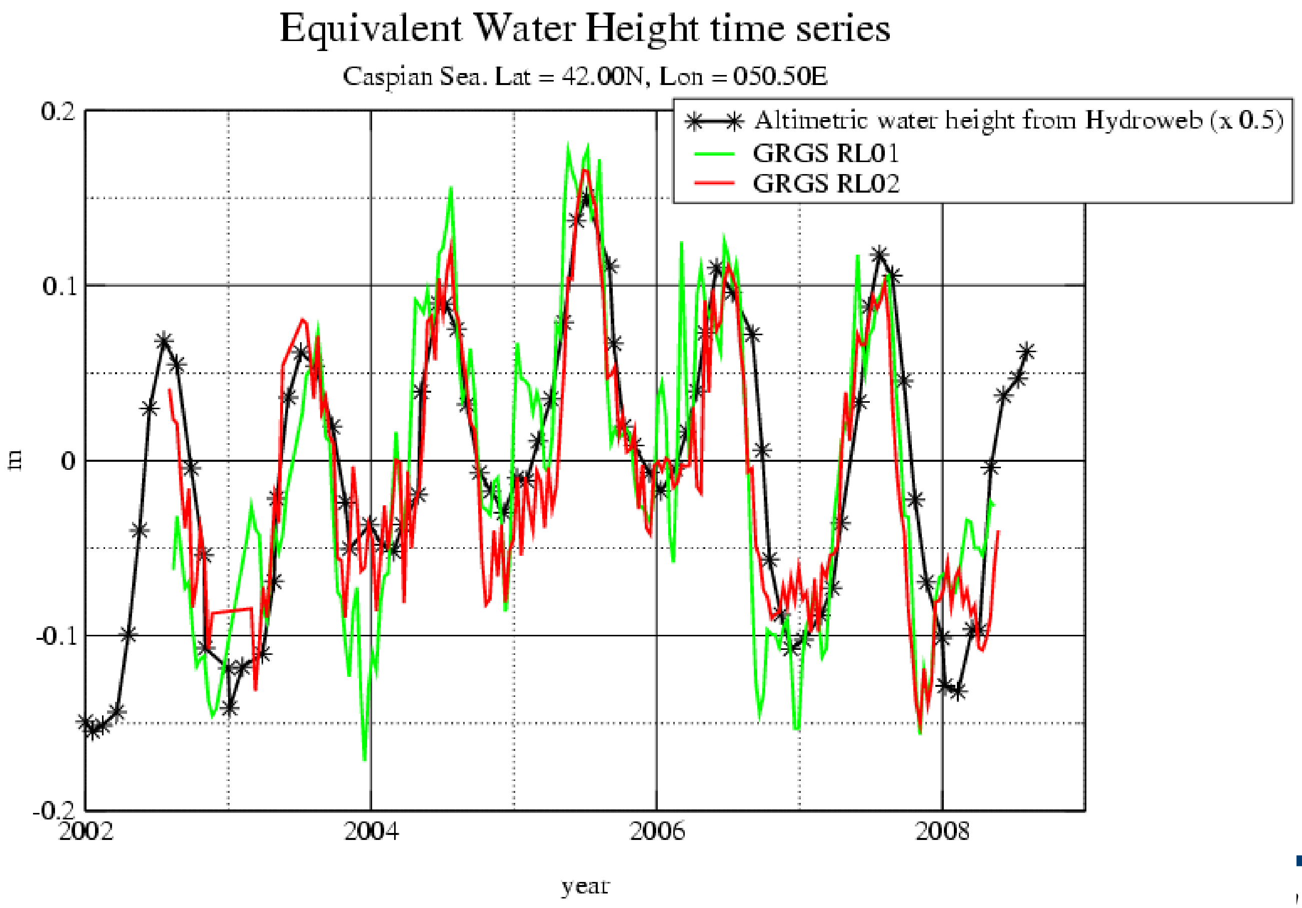


When looking closely at the results, by splitting the whole era in three periods, 2002-2004, 2005-2007 and 2008, the situation is more subtle: the central period 2005-2007 is the one that has the best agreement with the mean field and therefore the lowest spectrum of difference with EIGEN-GRGS.RL02.MEAN-FIELD; whereas the "side" periods 2002-2004 and 2008, because of the drifts of the Earth gravity field, have a higher difference to the mean field and, in the case of 2008, almost as much power as RL01…
We tend to think that we have mostly reduced noise with RL02 in the bandwidth 10-40 with respect to RL01, but it is difficult to prove !
One way to look at that is to plot the two time series RL01 and RL02 in an area where an independent and trustworthy data set is available; and then try to evaluate by comparison to this independent data set whether RL02 is missing signal amplitude or whether RL01 is polluted by noise.
We have tried to do this exercise over the Caspian Sea, where an independent data set is available in the shape of satellite altimetry sea height anomalies...



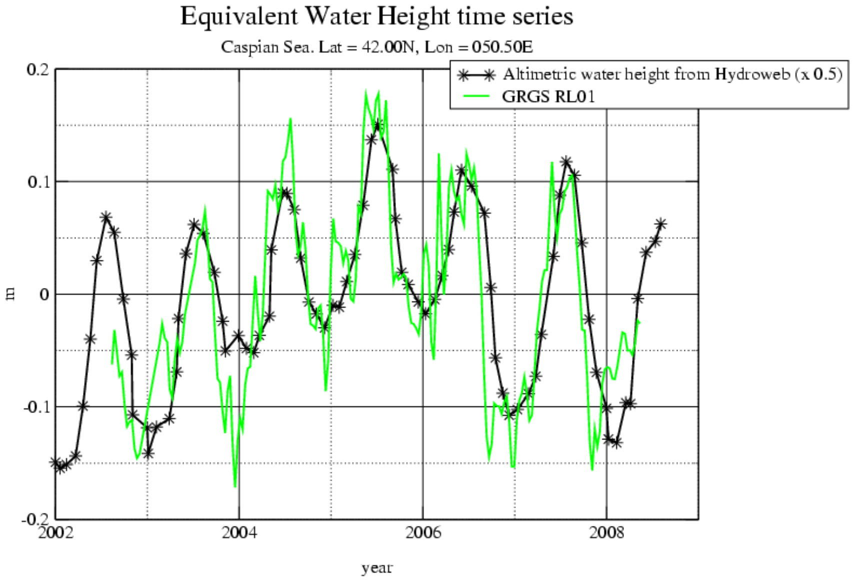
« RL02 version of CNES/GRGS consists of information up to degree and order 50 truly different from RL01 version which only provides true information up to degree and order 30 ? »

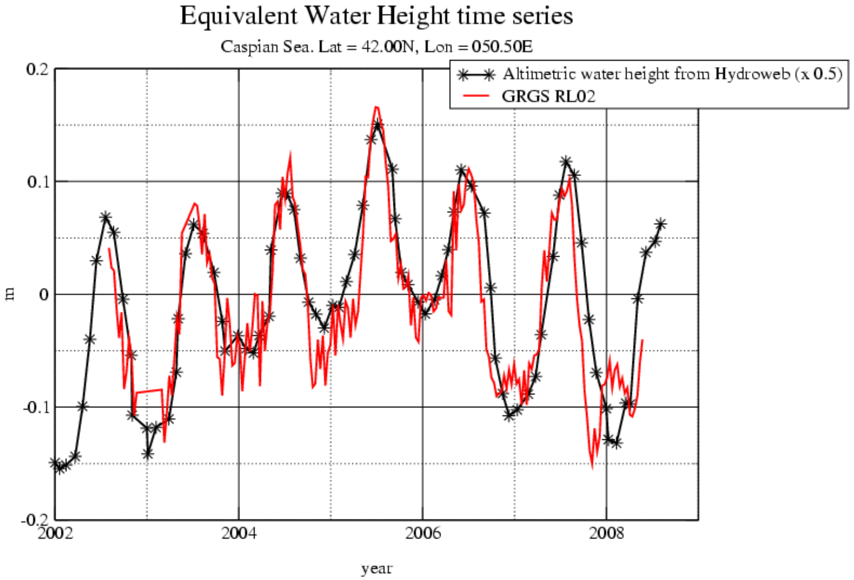
The satellite altimetry anomalies were obtained from Hydroweb (http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/Stat)ionsVirtuelles/Caspian.html) and are based on the data of Jason-1, GFO, Envisat and Topex/Poseidon satellite missions. Over the Caspian Sea, the altimetric series is very precise. The results are given on a monthly basis. There is no temporal filtering applied to this data.
The figure below shows that the RL02 series (red) matches better the altimetry signal (black) than the RL01 series (green). There does not seem to be any lack of power in the RL02 series and there is clearly less noise than in RL01, although the RL02 series is only based on 10-day data batches, while RL01 is based on three consecutive 10-day batches, technique which brings some temporal smoothing.

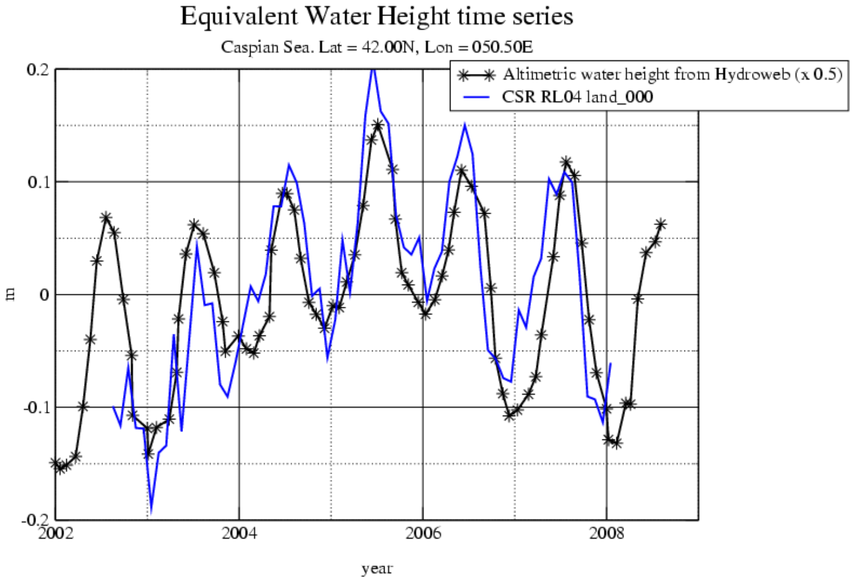


« CNES/GRGS solutions do not require scaling and why ? »

Difficult again to answer this question. The comparison to altimetry can bring some hints.
In these three figures are plotted the comparison of RL01, RL02 and CSR RL04 (CSR RL04 being destriped and not spatially smoothed, i.e. the so-called “000 km radius smoothing”) with the altimetric signal over the Caspian Sea. We note the overall good agreement of the three series with altimetry, in particular RL02 (10-day series) and CSR RL04 (monthly series). There does not seem to be any noticeable scale difference between RL02 and CSR RL04.
However, for the agreement to be good, one has to scale the altimetry signal by a factor 0.5 !!! Does this mean that the GRACE time series have an amplitude problem and that they ought to be scaled by some factor ? This is not for sure for two reasons:
1- There might be some steric effect (increase of volume due to the heating of the water) in the altimetric time series. Since the maximum of the water height is in the middle of the summer and the minimum in the middle of the winter, any steric effect would be in phase with the gravimetric signal and therefore artificially increase the amplitude of the altimetric signal. So the steric effect which ought to be taken into account and corrected for before making the comparison.



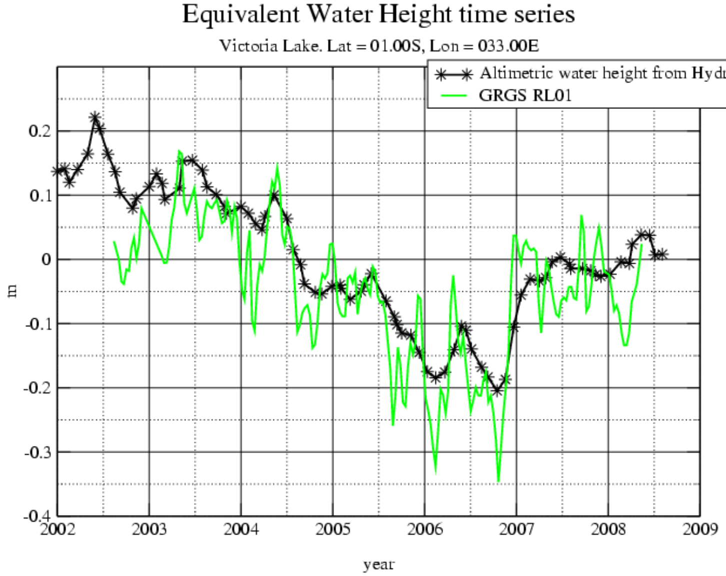


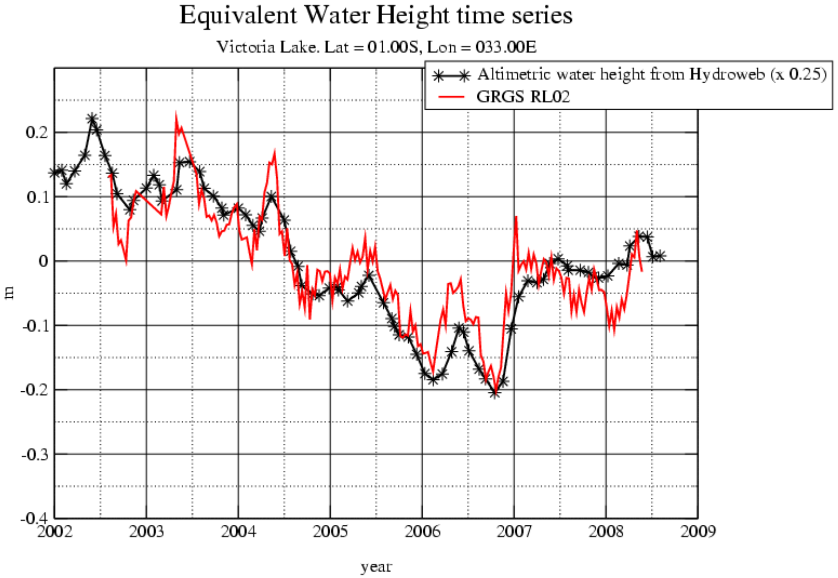


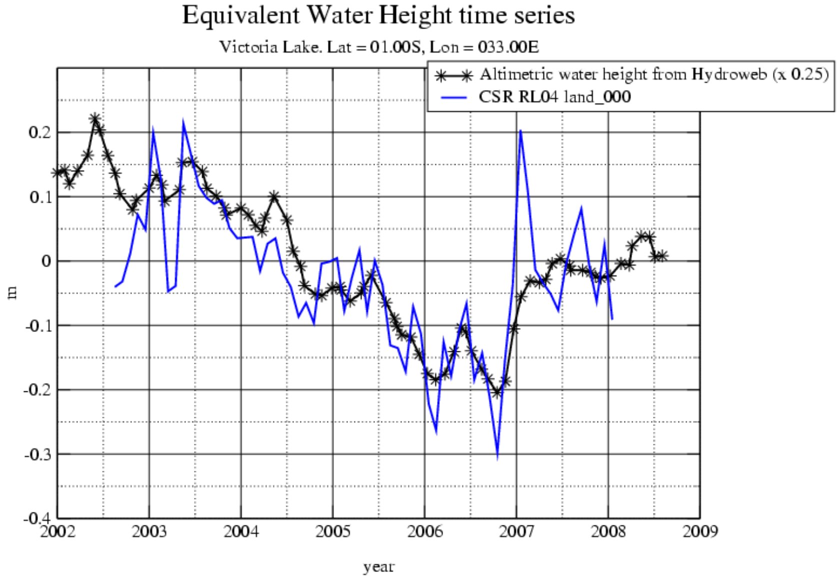
« CNES/GRGS solutions do not require scaling and why ? »

2- The size of the Caspian Sea (maximum width 400 km) is exactly the minimum reachable with spherical harmonic degree 50 (dg 50 ⇔ minimum wavelength 7.2° / 800 km at the Earth's surface ⇔ resolution 3.6° / 400 km ; dg 30 ⇔ minimum wavelength 12° / 1333 km at the Earth's surface ⇔ resolution 6° / 666 km). If one admits that all the water variability is stored in the Caspian Sea (and not in the soil surrounding it) and that the "gravitational footprint" of the GRACE mission is somewhat broader than the best resolution that we are trying to reach (400 km), then we would have an explanation of the difference of amplitude between the altimetric and GRACE signal i.e. GRACE does not downscale the signal, but rather spreads it over a wider area than the one over which it actually occurs.

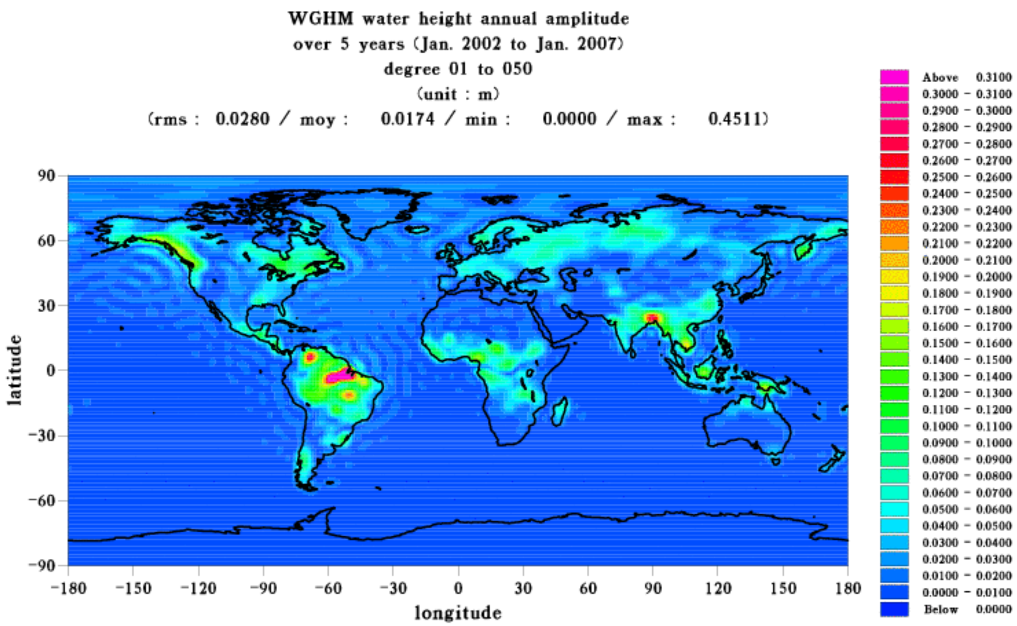
This second point might also be the explanation when one considers an even smaller body of water, Lake Victoria (∅ 200 km). In this case the scaling factor to be applied to altimetry in order to make it coincide with gravimetry is around 0.25, close to the surface ratio between a ∅ 200 and a ∅ 400 cap.

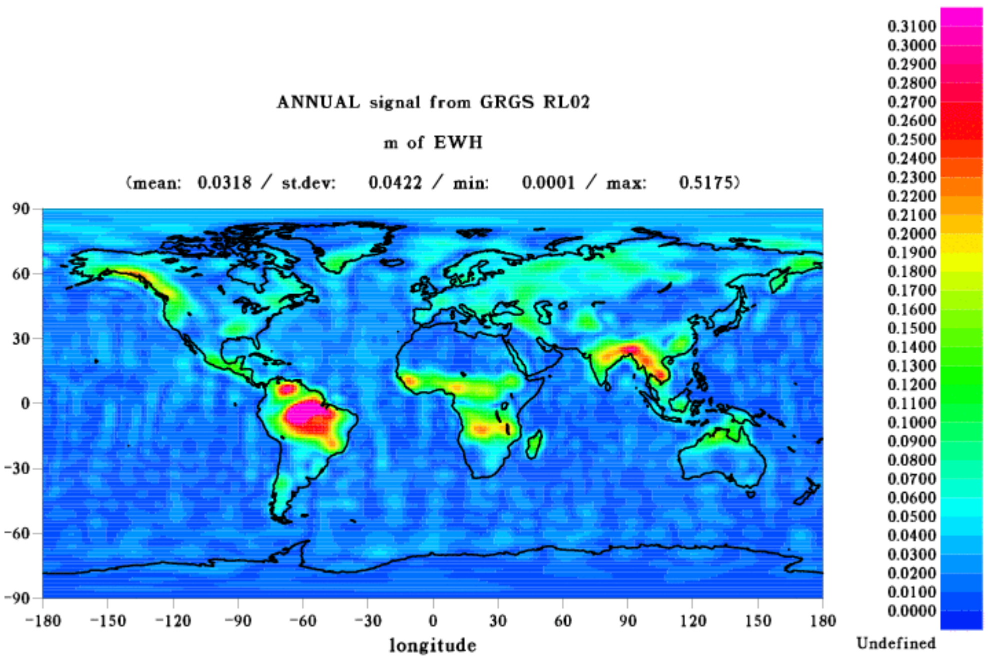




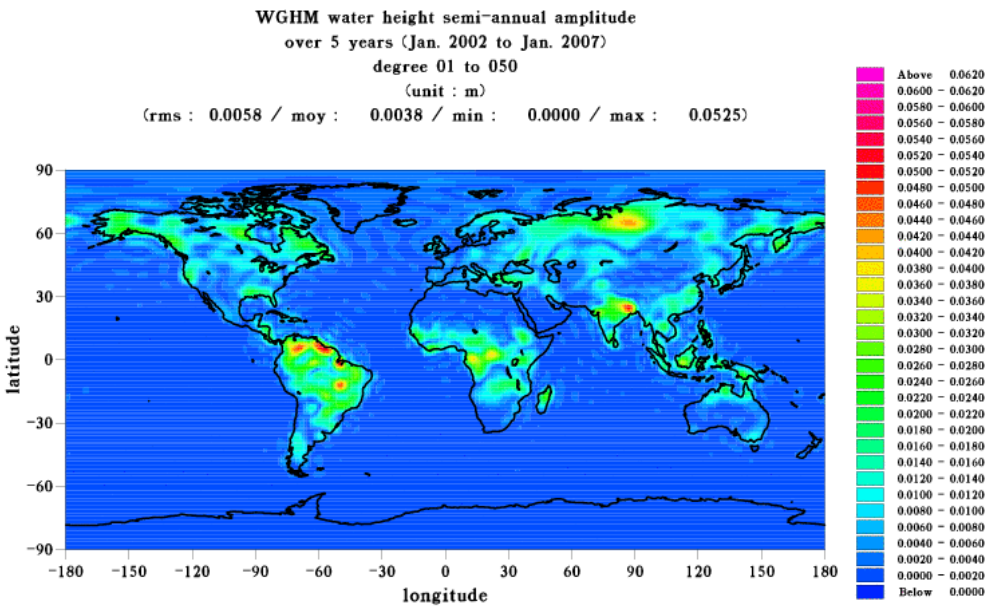


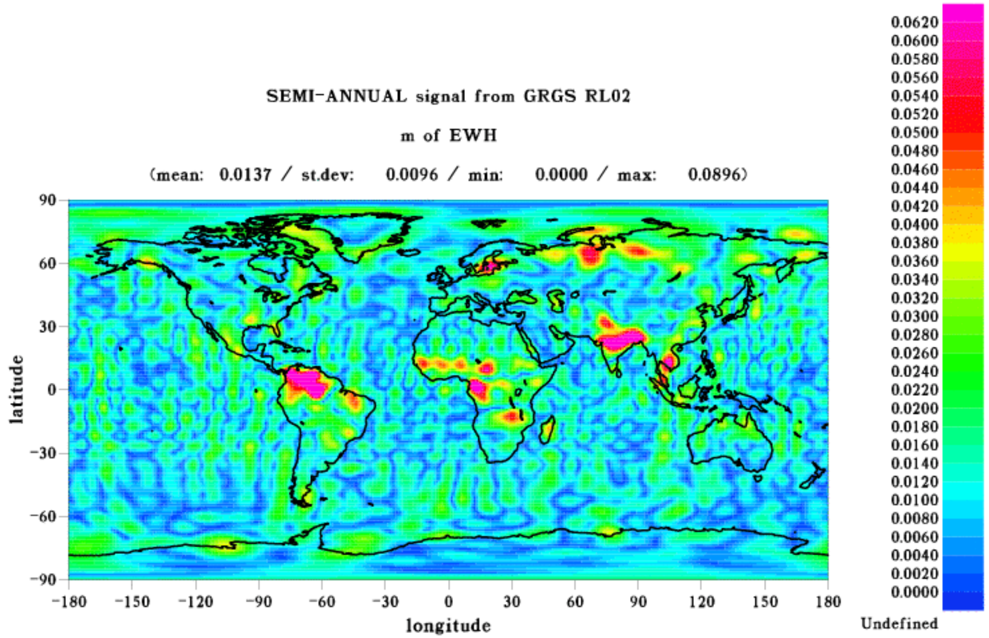
Signal annuel



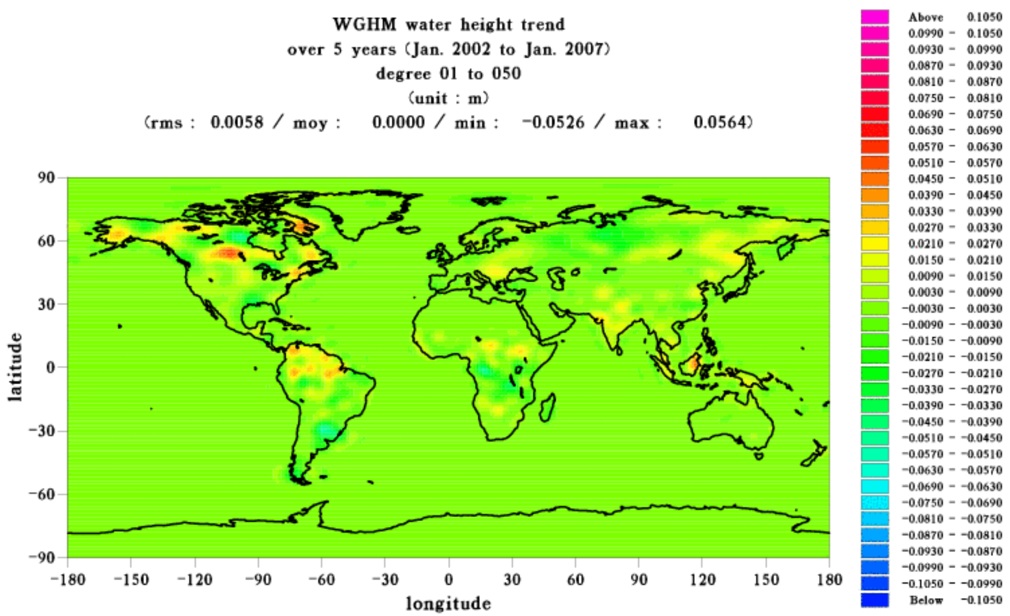


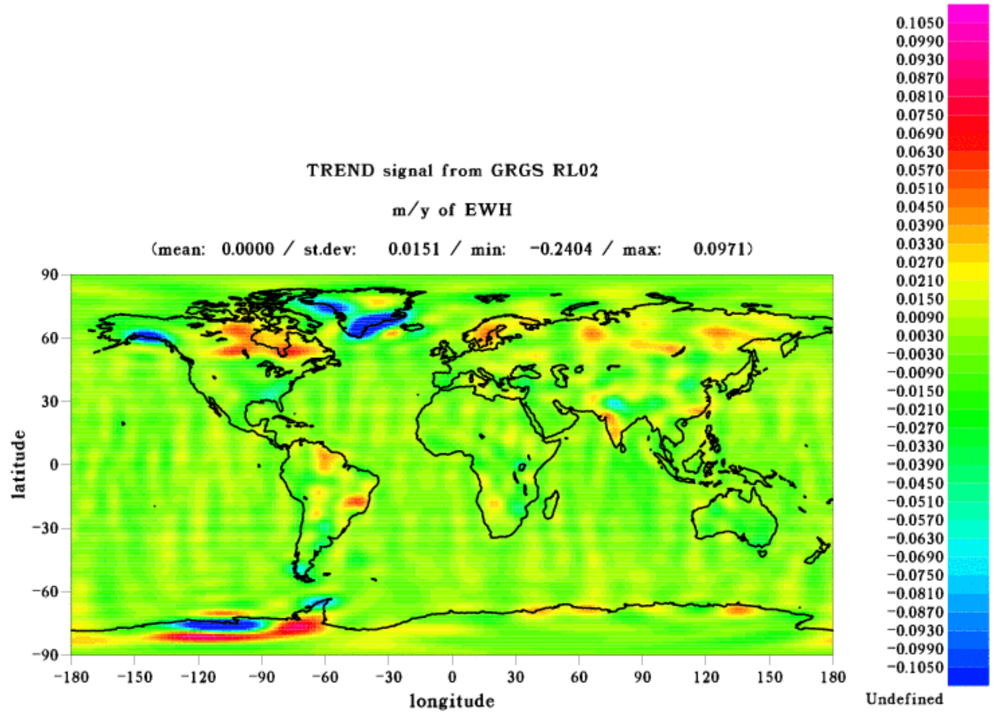
Signal semi-annuel



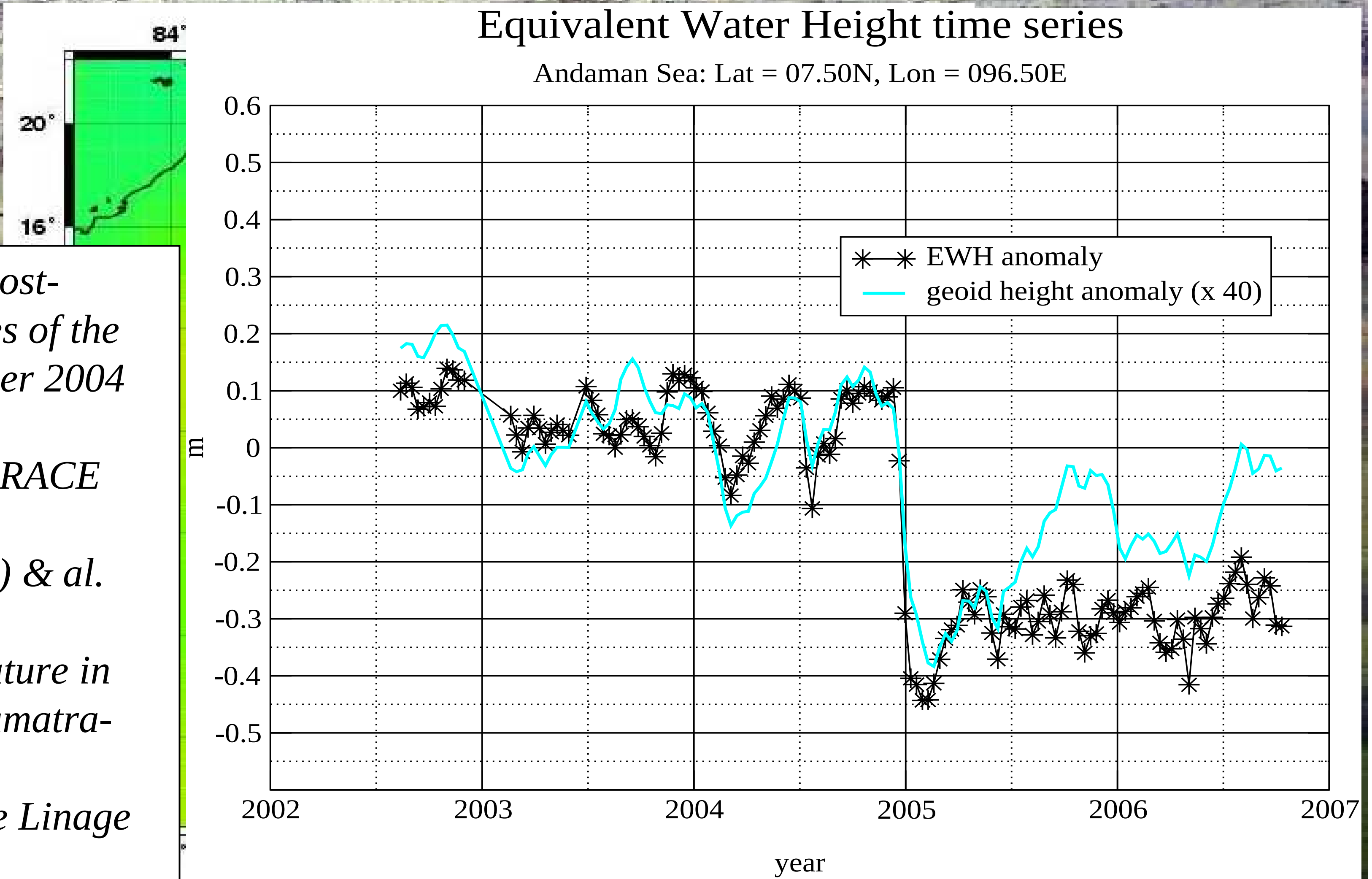


Tendance annuelle





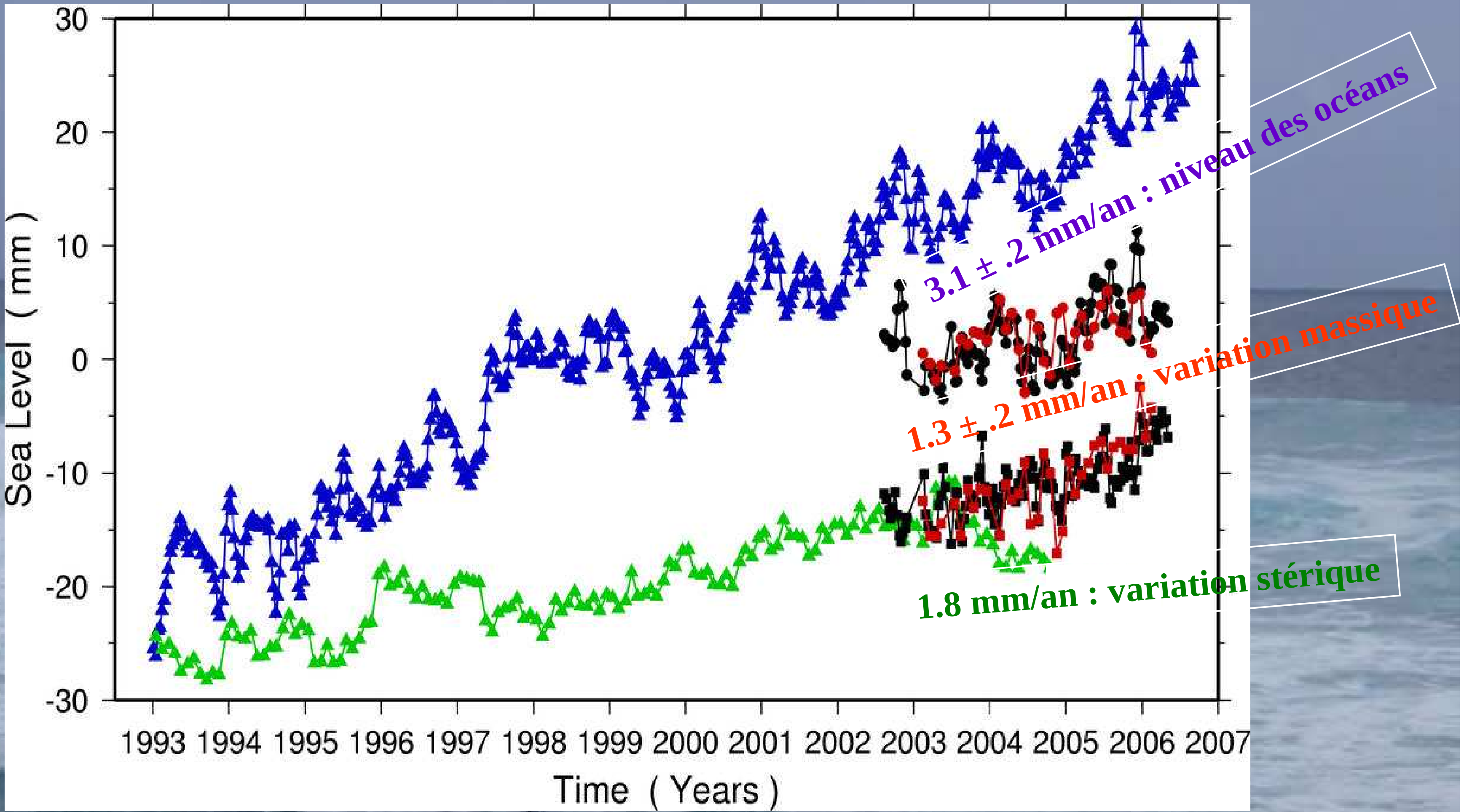
Détection par GRACE de l’événement sismique de Sumatra du 26 décembre 2004



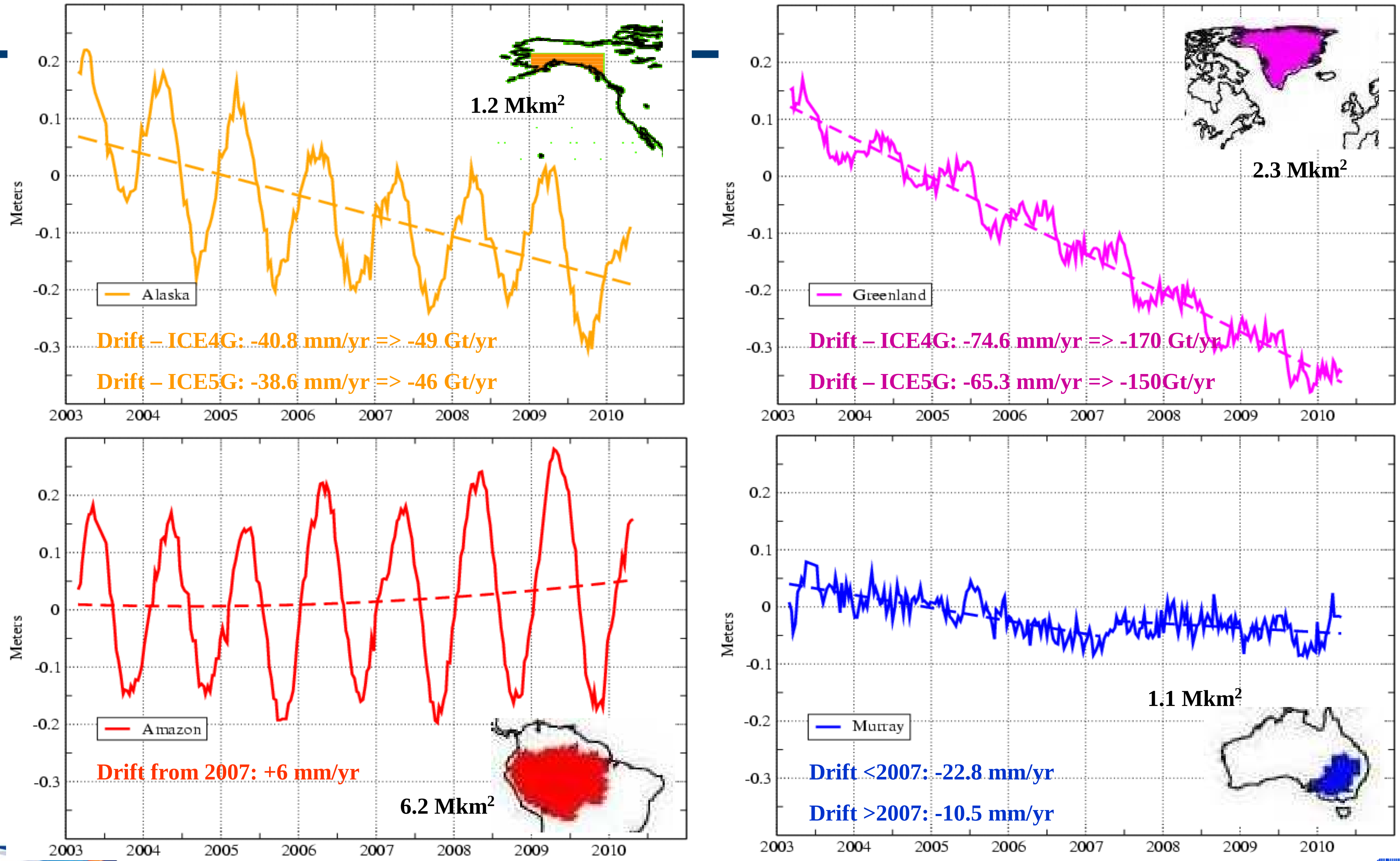
Co-seismis and post-seismic signatures of the Sumatra December 2004 and March 2005 earthquakes in GRACE satellite gravity,
I. Panet (LAREG) & al.

The gravity signature in GRACE of the Sumatra-Andaman 2004 earthquake, C. de Linage & al., 2006

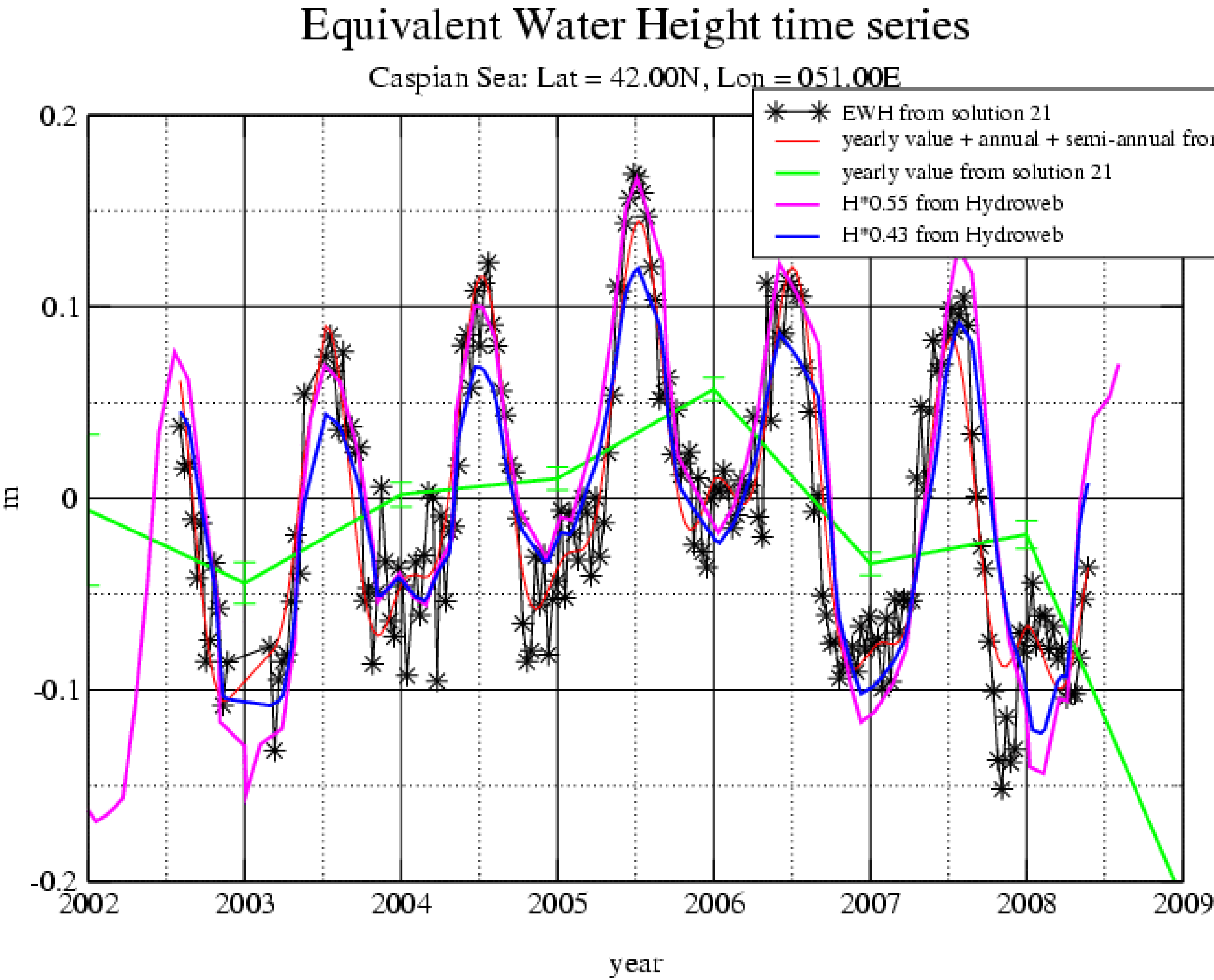
Variations du niveau moyen des océans détectées par les missions GRACE et Jason



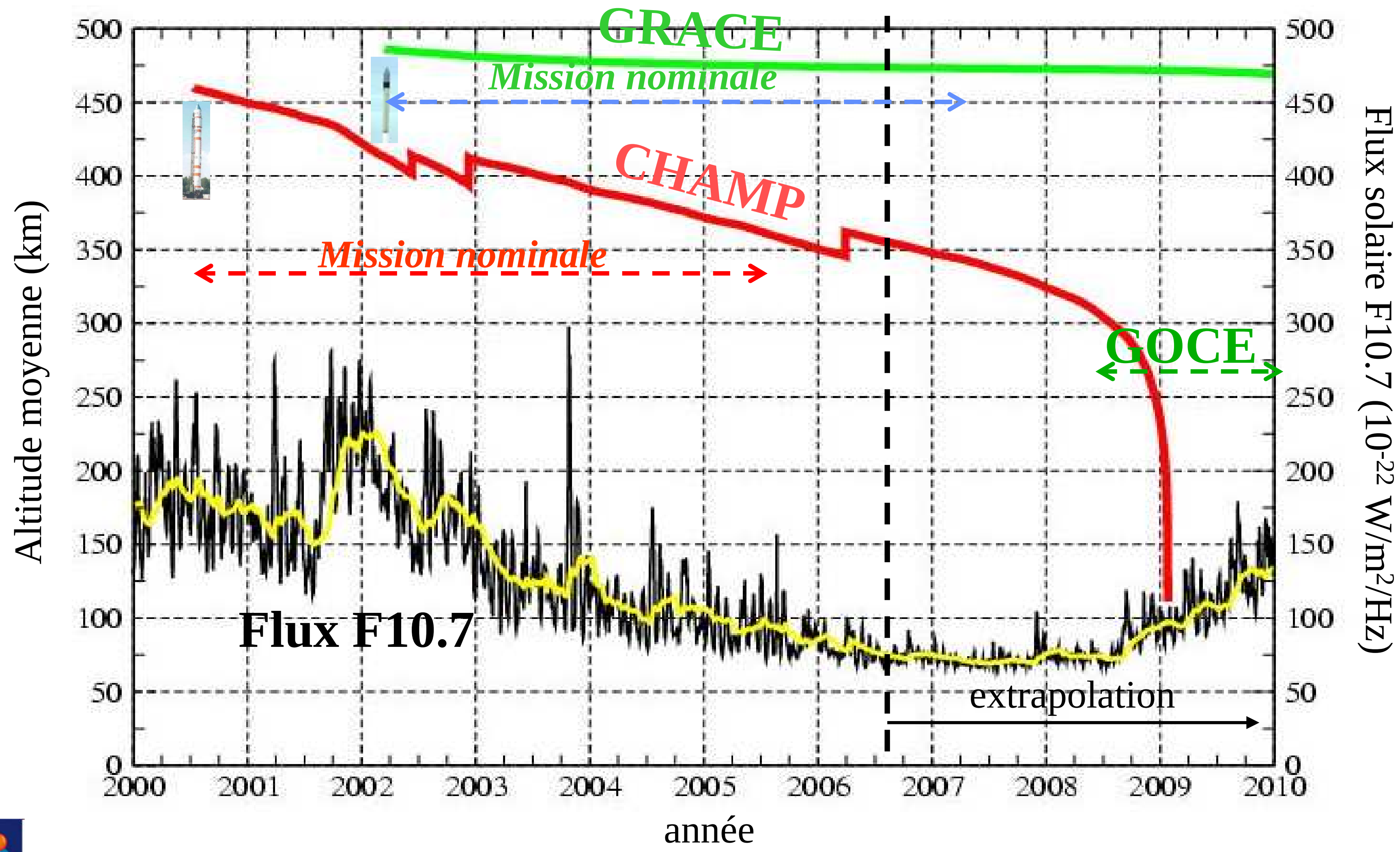
Estimation of steric sea level variations from combined GRACE and Jason-1 data, A. Lombard (LEGOS) & al., 2006


1.2 Mkm²
Alaska
Drift – ICE4G: -40.8 mm/yr => -49 Gt/yr
Drift – ICE5G: -38.6 mm/yr => -46 Gt/yr
2.3 Mkm²
Greenland
Drift – ICE4G: -74.6 mm/yr => -170 Gt/yr
Drift – ICE5G: -65.3 mm/yr => -150Gt/yr
Amazon
Drift from 2007: +6 mm/yr
6.2 Mkm²
1.1 Mkm²
Murray
Drift <2007: -22.8 mm/yr
Drift >2007: -10.5 mm/yr
Meters
2003 2004 2005 2006 2007 2008 2009 2010

Comparaison à l'hydrologie : Mer caspienne

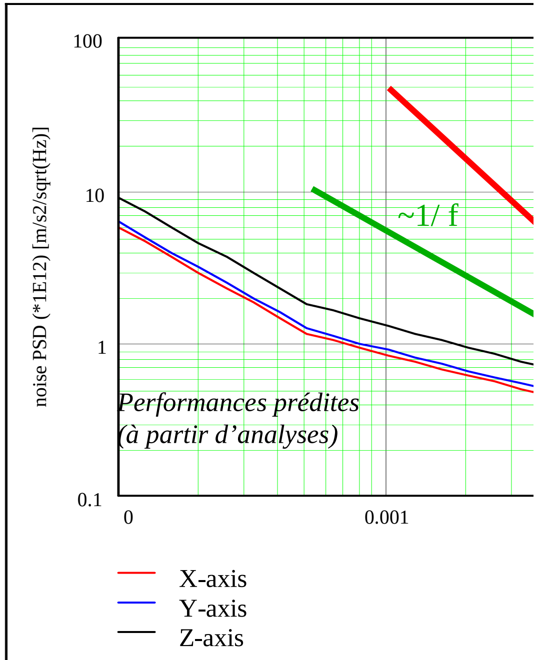


Evolution des orbites de CHAMP/GRACE/GOCE

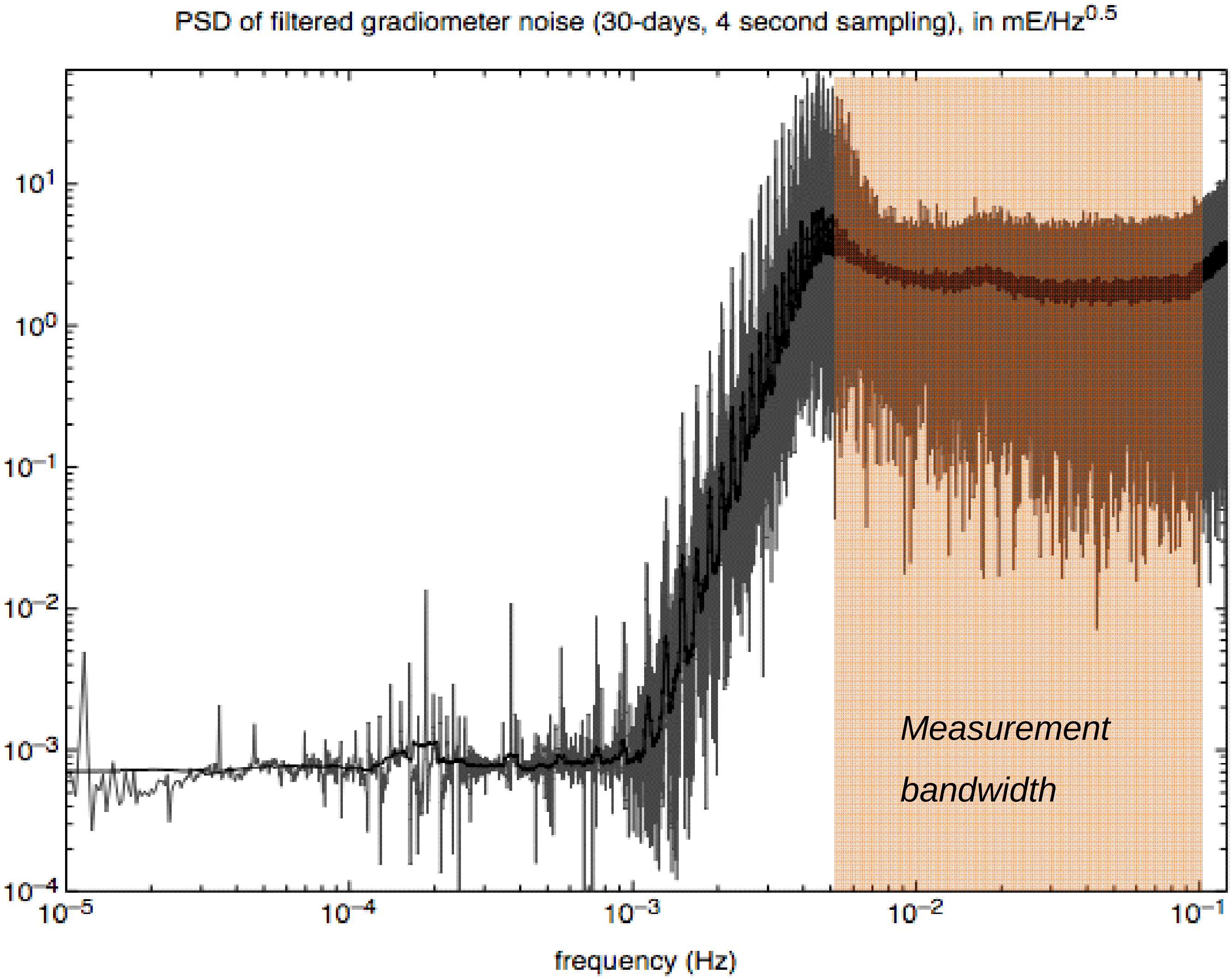


Simulation – Bruit du gradiomètre

PSD of the noise (applied to the diagonal elements of the gradient tensor)



Single accelerometer noise PSD [m s^{-2} Hz$^{-1/2}$]



Par application d'un filtre de moyenne glissante autorégressif à la période de coupure de 220s