Background Models used in Geodetic Data Processing

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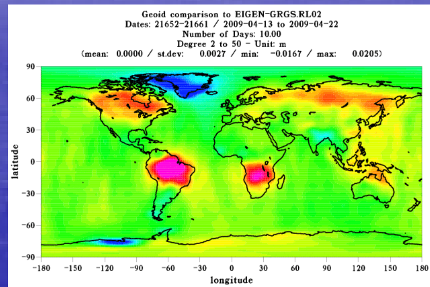
In geodetic data processing, we use empirical time-series of atmosphere, non-tidal oceans and hydrological variations.

Issues: Availability, Accuracy, Continuity, Coherence, Quality, Modeling, Space-Time Scales, Uniformity of standards ...

De-aliasing Products of the CNES/GRGS 10-day solutions Time-Variable Gravity Fields derived from GRACE

R. Biancale, J.-M. Lemoine, G. Balmino, S. Bruinsma, F. Perosanz, J.-C. Marty (CNES/GRGS), S. Loyer, S. Bourgogne (Noveltis), P. Gegout (CNRS/GRGS)
http://bgi.cnes.fr:8110/geoid-variations/README.html

Gravity variations taken into account from background models:



- **Solid Earth tides** (IERS Convention 2003),
- **Ocean tides** (FES-2004, LEGOS, Lyard et al.),
- **Atmospheric** (and associated Solid Earth) ATM3D time-variable gravitational field derived from ECMWF (P. Gegout),
- **Non-Tidal** MOG2D barotropic ocean model (L. Carrère & F. Lyard, 2003), forced by ECMWF fields.

**The time-variable gravity field models therefore only depart from the static gravity field by the un-modeled effects :
hydrology, snow cover, baroclinic oceanic signals and post-glacial rebound.**

The uncertainties of those fields include errors in the measurement data, in the processing, lack of coverage in some instances, and possible remaining errors in the FES, MOG2D and ECMWF models ...

Background Models : Availability

Atmosphere	**Latency**	**Re-analyses**
• ECMWF	2 days	ERA-Interim (1989 -> June 2009)
• NCEP	2 days	NCEP-Reanalysis (latency = 1 day)
Oceans	forced by ECMWF fields	
• OMCT	4 days	forced by ERA-40 and Operational
• MOG2D	3 months	forced by ECMWF Operational
Hydrology	forced by ECMWF fields + in-situ + remote sensing	
• ECMWF	2 days	Operational scheme
• GLDAS	6 months	Assimilation
• WGHM	?	Assimilation

Background Models : Continuity & Coherence

ECMWF Deterministic Atmospheric Model (4DVAR)

Operational Upgrades

Operational Upgrade: November 2000

- Increase in vertical resolution to 60 levels
- Increase in horizontal resolution to T512 (N256, 40 km grid spacing)

Operational Upgrade: February 2006

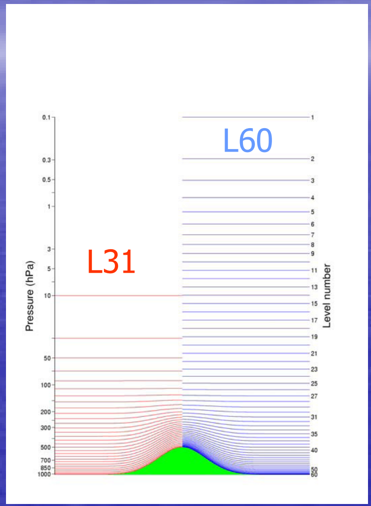
- Increase in vertical resolution to 91 levels
- Increase in horizontal resolution to T799 (N400, 25 km grid spacing)

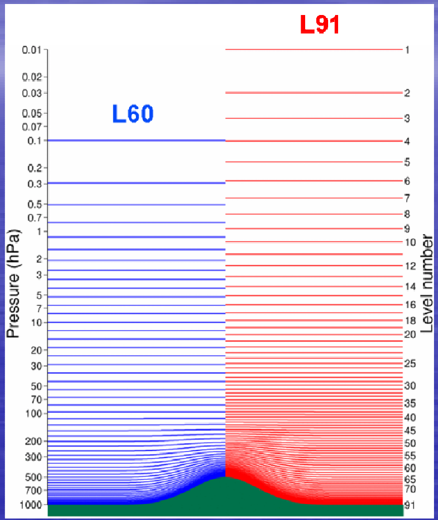
Operational Upgrade: November 2009

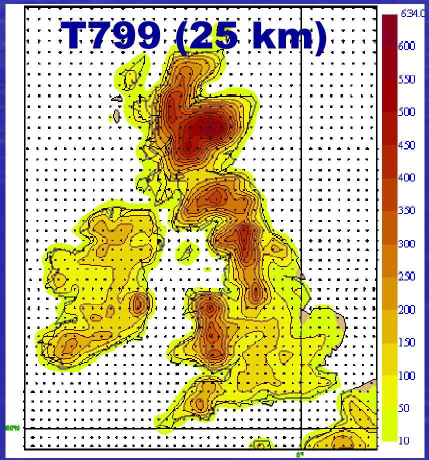
- vertical resolution unchanged 91 levels
- Increase in horizontal resolution to T1279 (N640, 16 km grid spacing)

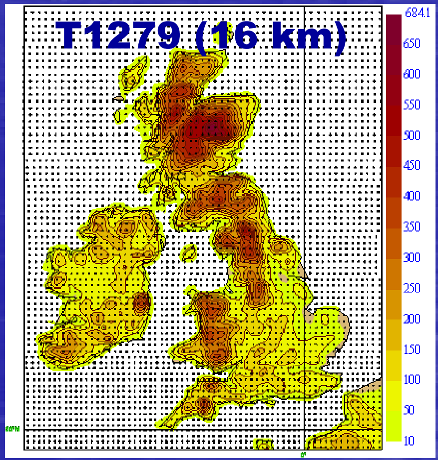
Operational Upgrades : 25 cycles in 10 yrs
http://www.ecmwf.int/products/data/operational_system/evolution/

Re-analyses : More stable but less accurate and delayed availability









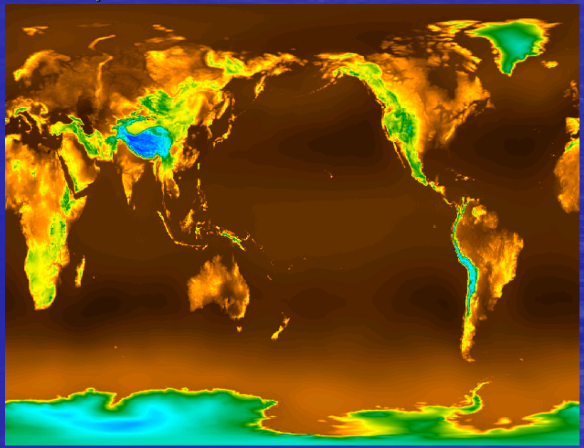
Background Models : Stability
Static and Time-Variable Gravitational Fields

Issue : The recovered Time-Variable Field relies on the realization of the Static Field.

Stability Principle : The static gravity field of the atmosphere and non-tidal oceans is based on the concept of a reference state which generates an invariant potential and which permanently constrains the solid Earth without inducing deformations.

Realization : The stable / reference state is currently realized as the mean over an integer number of years. A 2-year or 3-year mean is assumed to be stable enough. This realization may be biased by model changes.

Mean Equivalent Surface Pressure 2001-2002



Issue : Mass conservation. Mass is not conserved.

Each model include some water inputs/outputs but coherence with other model fluxes is not ensured.

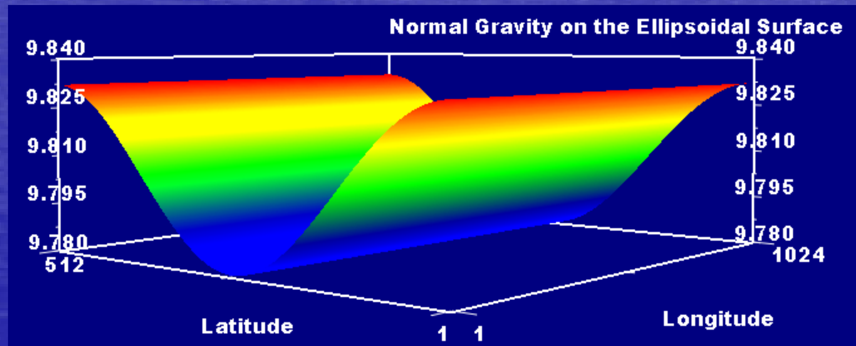
Mass conservation is not always intrinsically built-in and is a posteriori corrected (e.g. in ocean models).

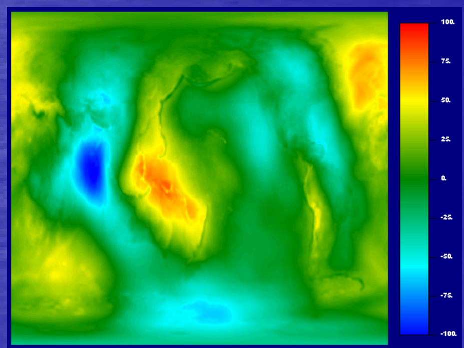
Consequences : Steps. Errors in Trends. Errors in the time-variable atmospheric, oceanic and consequent solid Earth's potentials.

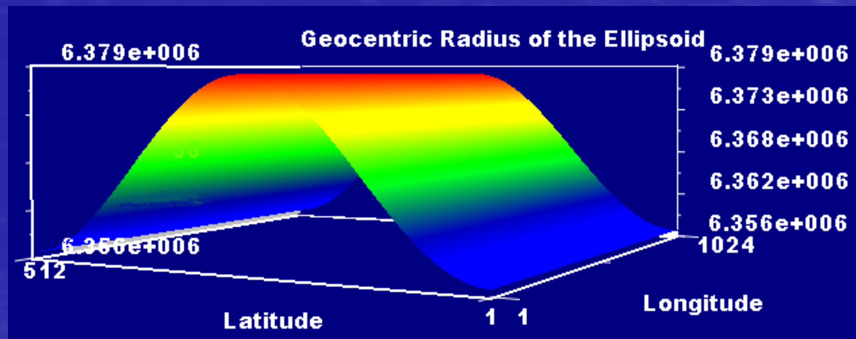
Background Models : Uniformity of Standards

References used to locate masses on and above the ellipsoid

- Normal Gravity on the Ellipsoidal Surface
- Normal Gravity above the Ellipsoid
- WGS 84 Ellipsoid
- WGS 84 EGM96 Geoid's Undulations
- Equivalent density distribution on a reference sphere of radius a







Background Models : 3D Atmosphere Modeling Issues

- Gravitational Potential under the Thin-Layer Approximation

$$\overline{C}_{nm}(t) = (1 + k'_n)\frac{3}{2n+1}\frac{P^s_{nm}(t)}{\overline{\rho}}$$

  - Atmospheric Attraction
  - Earth's Potential : Potential B. C.
  - Earth's Potential : Pressure B. C.

$$\overline{C}_{nm}(t) = V^s_{nm}(t) + k_n V^s_{nm}(t) + \overline{k}_n \frac{P^s_{nm}(t)}{\overline{\rho}}$$

- Gravitational Potential of the 3D Atmosphere

$$\overline{C}_{nm}(t) = V^{up}_{nm}(t) + k_n V^{down}_{nm}(t) + \overline{k}_n \frac{P^s_{nm}(t)}{\overline{\rho}}$$

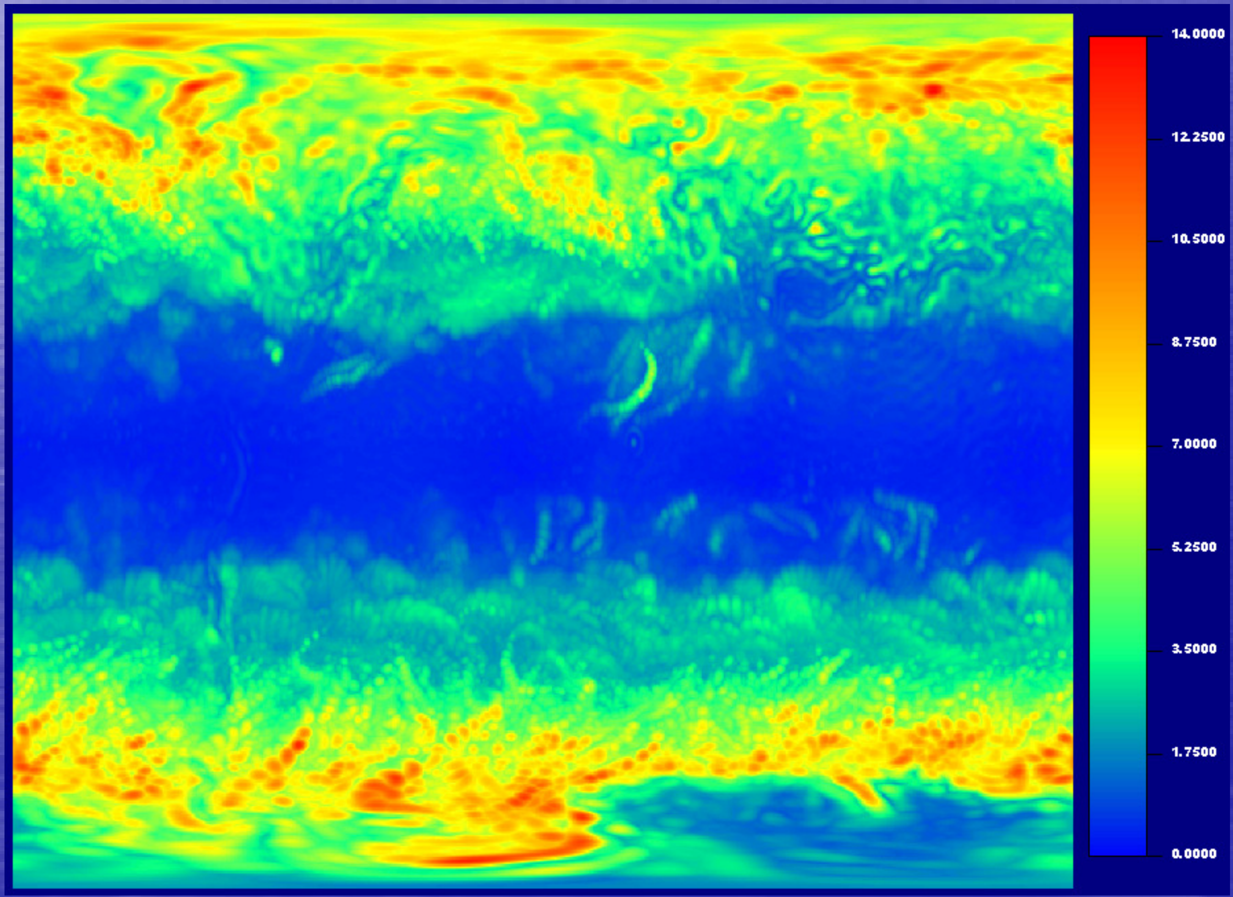
  - Atmospheric Gravitational Potential : upward continuation
  - Atmospheric Gravitational Potential : downward continuation
  - Surface Pressure

$$P_{nm}(t) = \frac{2n+1}{3}\overline{\rho} V_{nm}(t)$$

$$\boxed{\overline{C}_{nm}(t) = \left[P^{up}_{nm}(t) + k_n P^{down}_{nm}(t) + \overline{k}_n P^s_{nm}(t)\right]\frac{3}{(2n+1)\overline{\rho}}}$$

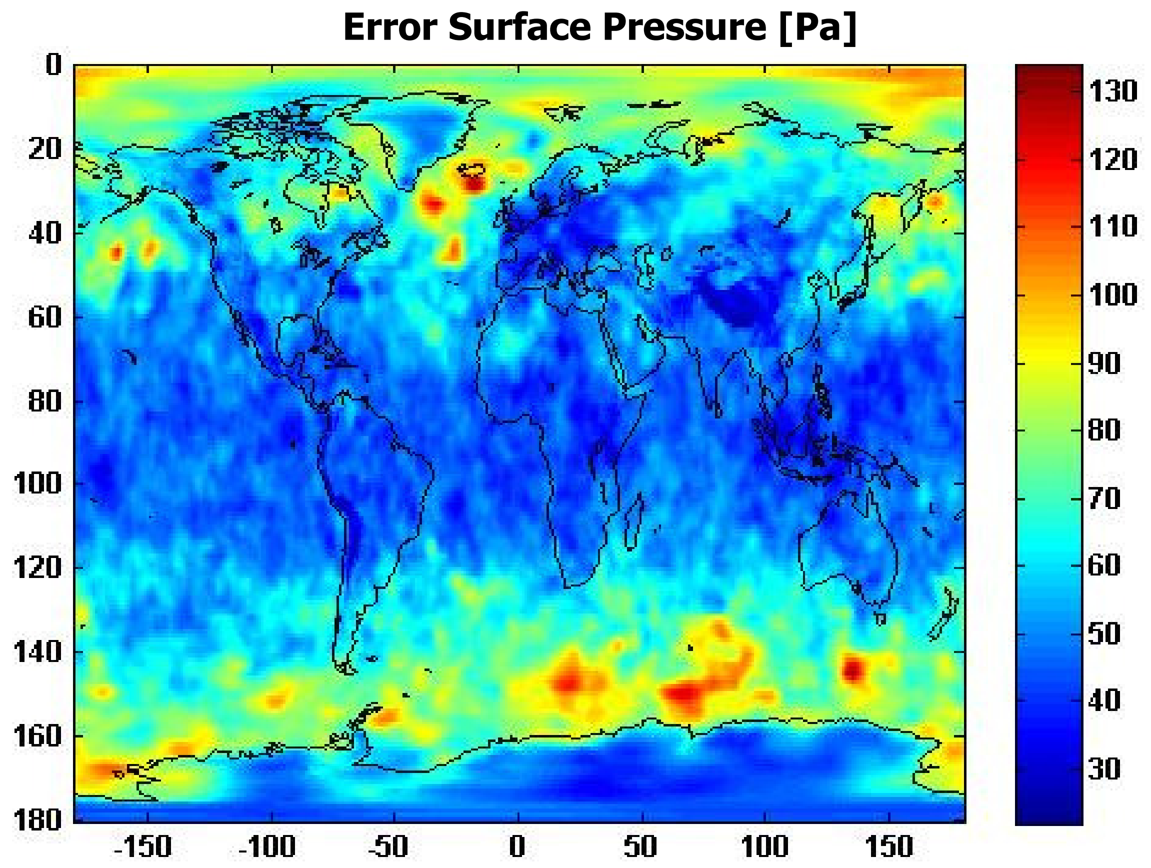
Background Models : Location dependent errors

Maximum Difference over the time span March 2002 – March 2003
between 3D & 2D Models in terms of Water-Equivalent Height (mm)
range from 0 to 14 mm of water-equivalent height



How to improve AOD?

We will no longer regard the input parameters for AOD as error-free!

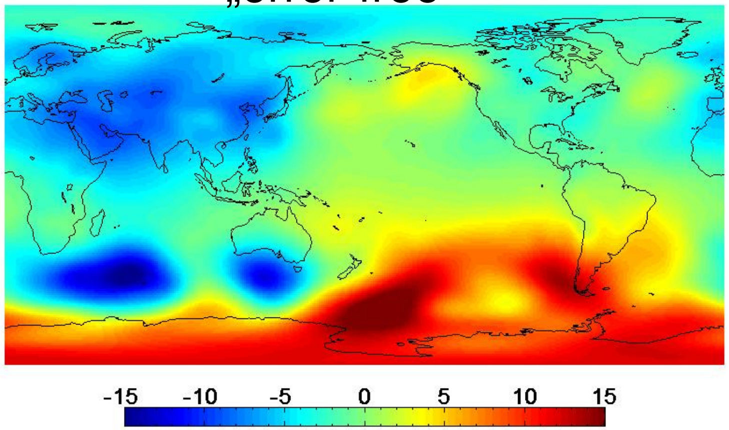


Data from ECMWF, Operational Archive, Errors in Analysis 01. Aug 2007 00h

Gruber, Th.; Zenner, L.; Jäggi, A.: Impact of Atmospheric Uncertainties on GRACE De-Aliasing and Gravity Field Models; Geodesy for Planet Earth - IAG 2009

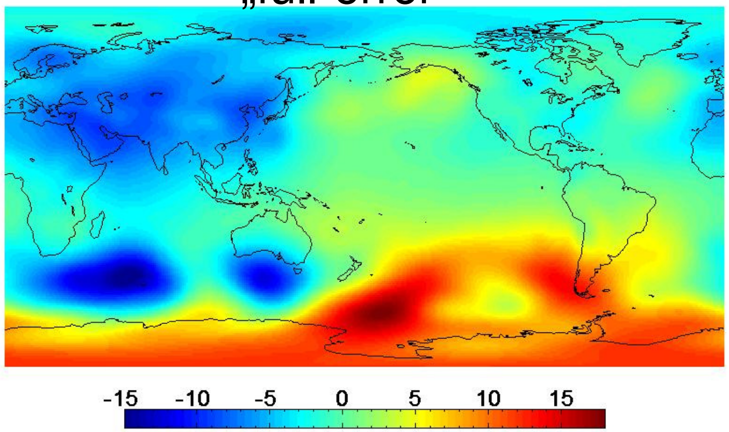
Impact of atmospheric model uncertainties on the geoid

„error-free“

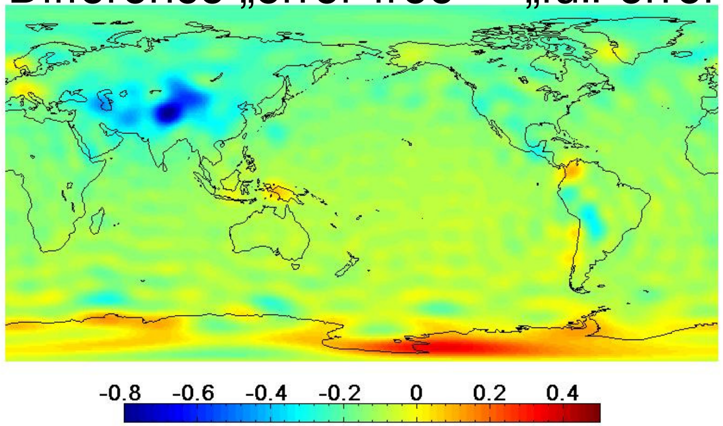


[mm]

„full-error“



Difference „error-free“ – „full-error“

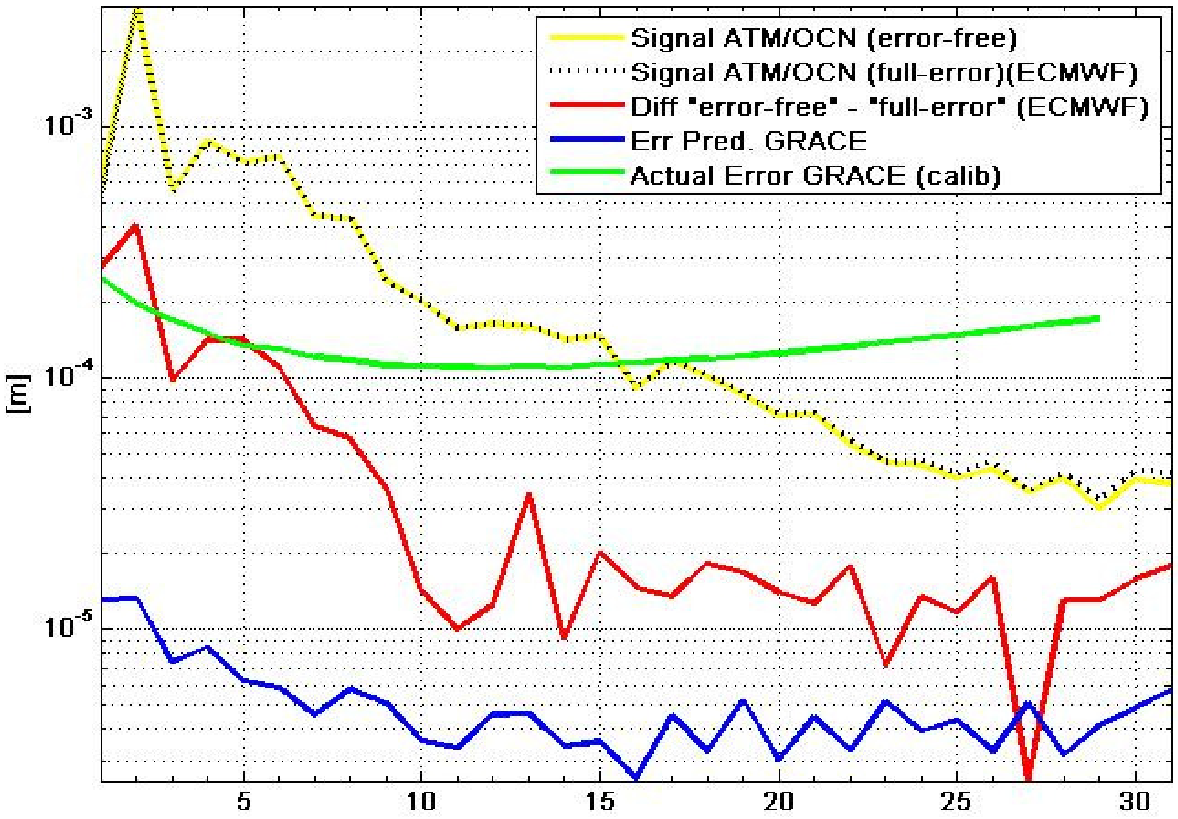


Statistic „error-free“ minus „full-error“

in terms of [mm] geoid height

Mean:	-0.13 mm
Rms:	0.08 mm
Max:	0.35 mm
Min:	-0.84 mm

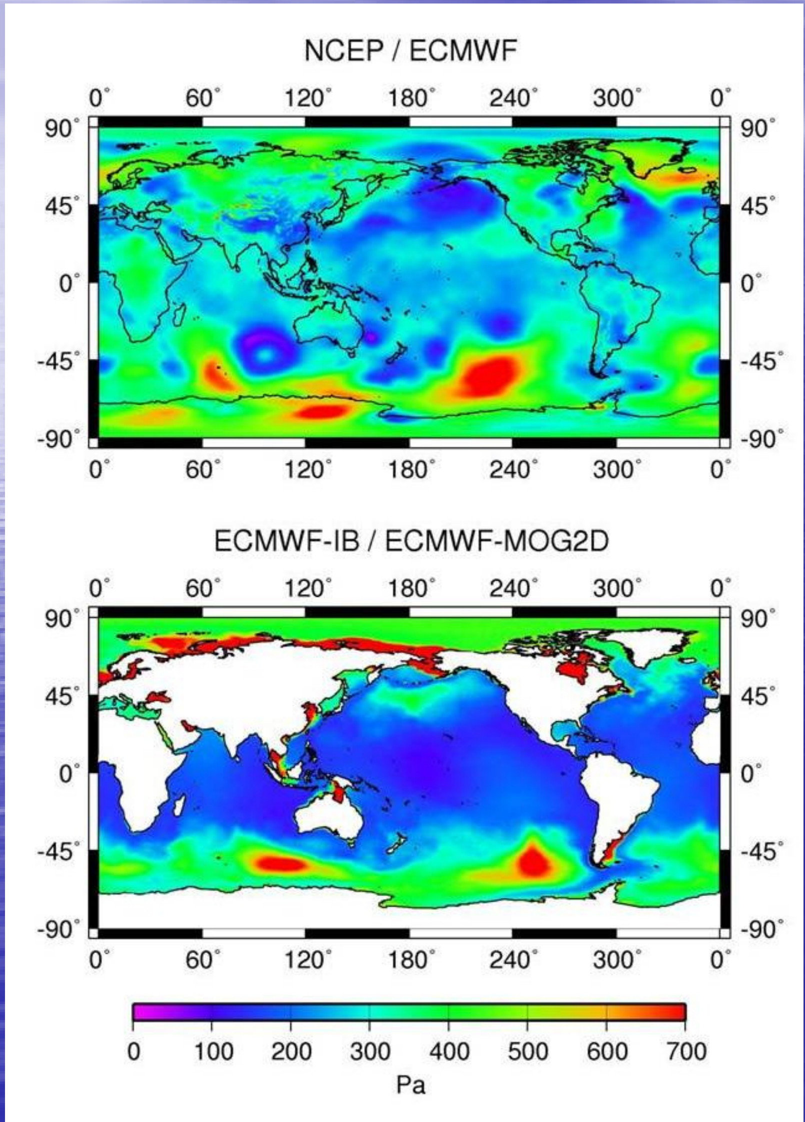
Impact of atmospheric model uncertainties on the De-Aliasing coefficients



degree variances in terms of geoid heights [m]

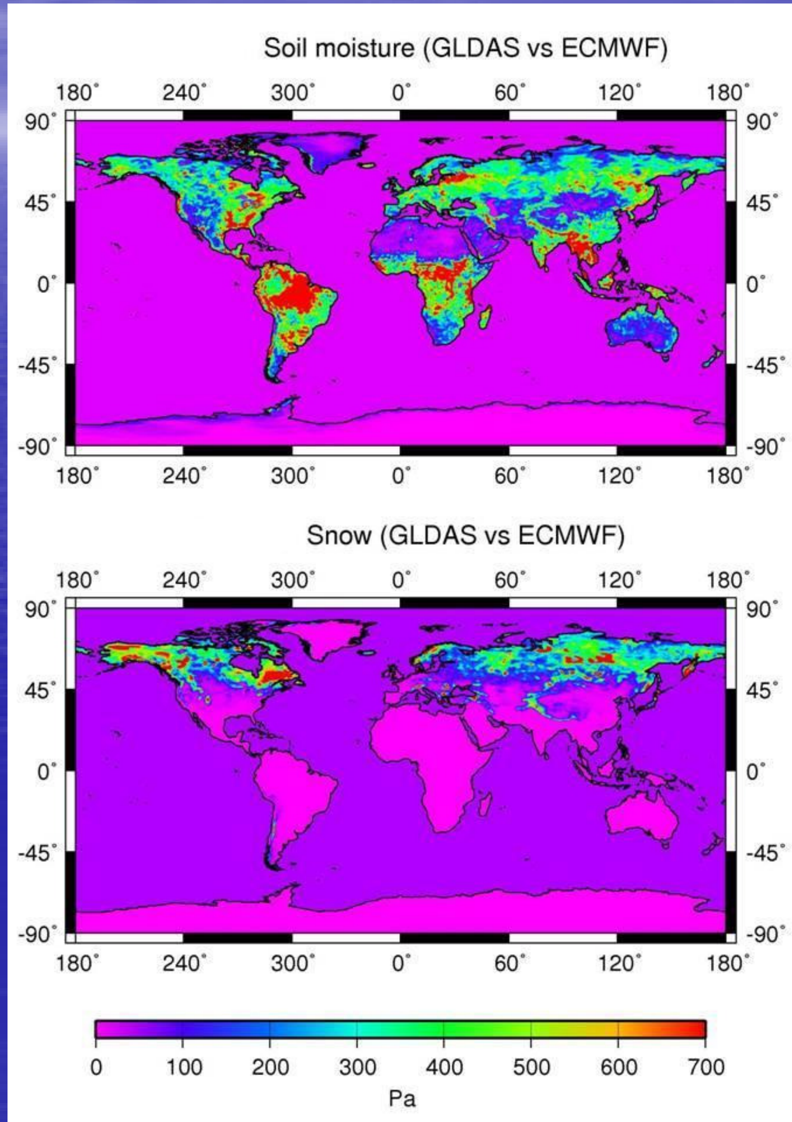
Background Models : Accuracy

RMS_{Global} = 327.8 Pa RMS_{Land} = 352.6 Pa



RMS = 208.4 Pa

RMS in 2002 RMS = 236.9 Pa



RMS = 89.7 Pa

Background Models : Time Discretization Impact on Atmospheric & Oceanic Tides

6-hour sampling of atmospheric and associated non-tidal barometric oceanic tides :
- Have required up to now a specific treatment as mean tides
- Are these daily atmospheric tides linked to solar radiations well represented ?

Time Sampling of Atmospheric Phenomena
- From 6-hour to 3-hour : S1, S2, S3
- From 3-hour to 1-hour :

Hourly sampling should provide a better representation of how these tides change with cloud cover, with seasons, …

Atmospheric Tides, Biancale & Bode, 2003

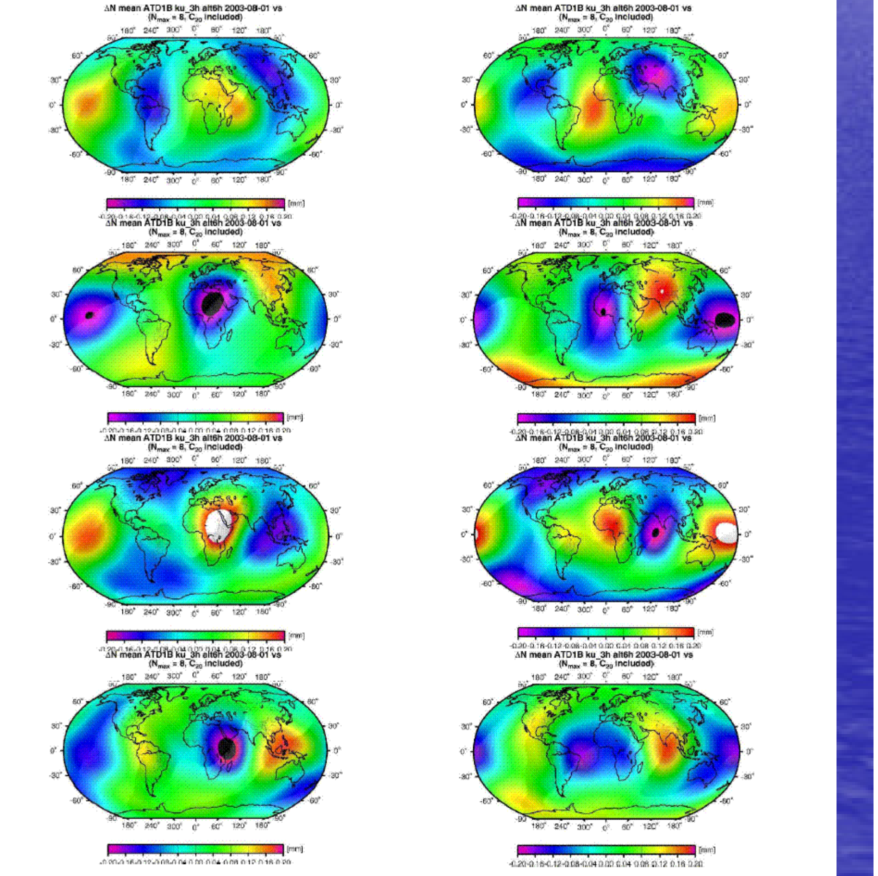


Figure 6.2a : Temporal evolution of the geoid differences derived from the mean atmospheric tide models based on 6h data (1985-2002, model N1) and 3h data (2001-2003, model N3) for August 2, 0h (top left), 3h (top right) up to 21h (bottom right).

Non-Tidal Oceanic Barotropic Response to Atmospheric Forcing and its Time-Variable Gravitational Potential

Current improvements of the MOG2D/T-UGO model (F. Lyard)

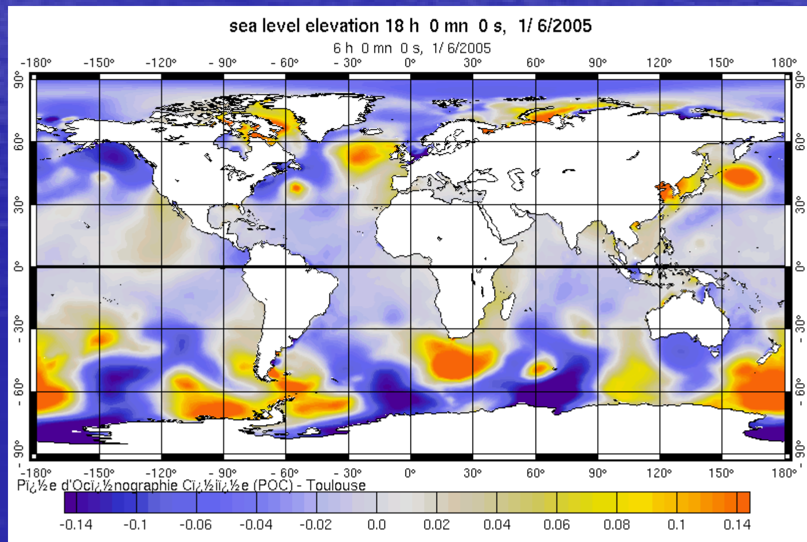
- Horizontal Discretization : Finite Element Grid of FES2004 (instead of FES99)

Increase of grid resolution provide a better definition of bathymetry and improve the dynamical response.

- Time Resolution : 3-hour forcing

Most basins resonances are around 12 hours. Previous 6-hour forcing had its Nyquist frequency at 12 hours !

Increase of the time resolution will improve the dynamic response at frequencies near resonances and oceanic S1, S2, S3 waves.



Background Models used in Geodetic Data Processing : Key Questions and Challenges

Non-Tidal Oceans

Increase the time resolution of the forcing to 1 hour.

Assimilate observations of tide gauges and altimetry in hydrodynamical barotropic models.

Tides

Assimilate altimetric observations in hydrodynamical models at global scale.

Improve model physics in shallow waters.

Study temporal variability of tides at annual and seasonal time scales.

Background Models used in Geodetic Data Processing : Key Questions and Challenges

Availability :

- Build hourly archives of the atmosphere for geodesy applications and Check with meteorologists the modeling of atmospheric tides

Accuracy :

- Improve atmospheric water content by GPS assimilation in GCMs.
- Include statistical information of background models inside inversion.

Aliasing :

- Include hydrology modeling as an a priori of a general inverse problem in order to decrease the impact of aliasing.
- Identify and recognize space-time variable patterns (EOF, SVD, PCA, …) and use these patterns for inversion/stabilization purposes.

Coherence and Stability :

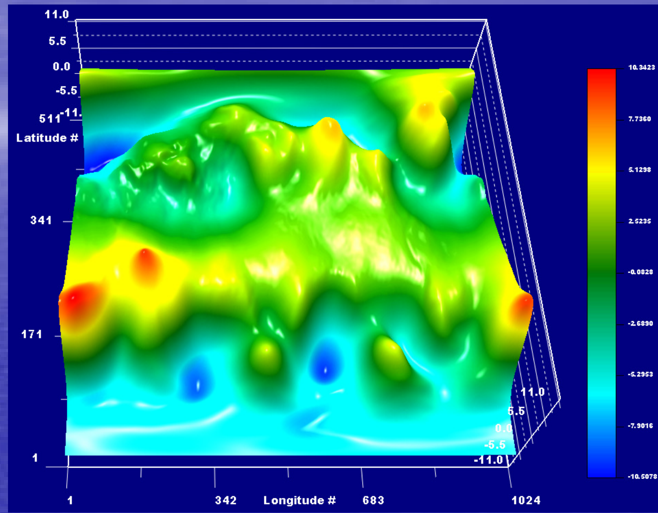
- Define standard trackers of mass budgets/fluxes in each reservoir
- Check coherence between complementary models
- Check impact of model changes if overlaps are available

Modeling and Standards :

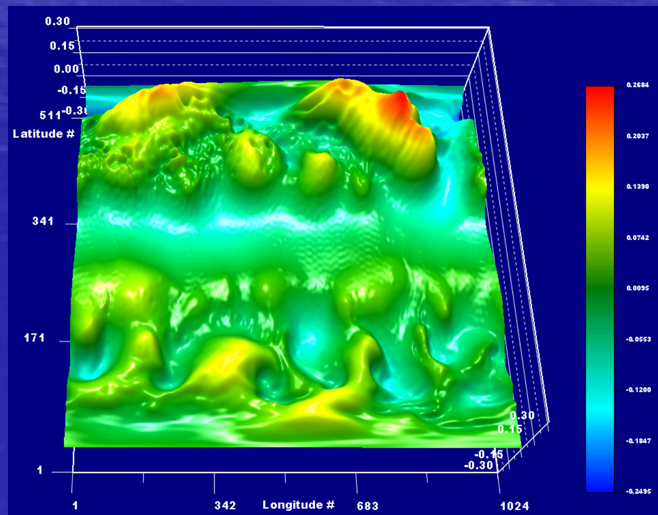
- Investigate the impact of different modeling assumptions (3D, 2D reference)
- Provide a reference definition of the static and time-variable gravity fields coherent with the other standards and reference figures of the Earth.

Background Models : 3D Atmosphere Modeling Issues

- Time-Variable Geopotential of the 3D Atmosphere + Solid Earth
- Geopotential at reference surface (r=a)
- February 15th, 2003
- Geoid Height (mm)
- Range : +/-10 mm

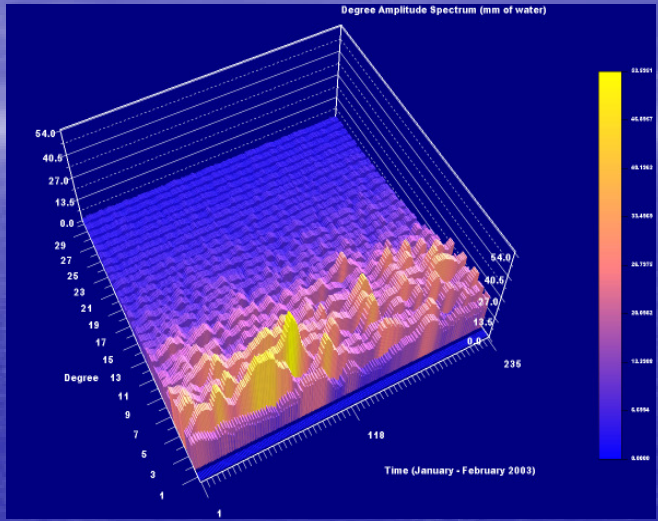


- 3D - 2D : Difference between 3D and 2D Atmospheric Modeling
- Geopotential at reference surface (r=a)
- February 15th, 2003.
- Geoid Height (mm)
- Range : +/- 0.3 mm



Background Models : 3D Atmosphere Modeling Issues

- 3D : Degree Amplitude Spectrum of the Time-Variable Geopotential of the 3D Atmosphere + Solid Earth
- Geopotential at the Earth's surface
- January & February 2003
- Equivalent Water Height (mm)
- Scale : 0 to 50 mm



- 3D – 2D: Degree amplitude spectrum of the difference between 3D and 2D Atmospheric Modeling
- Geopotential at the Earth's surface
- January & February 2003
- Equivalent Water Height (mm)
- Scale : 0 to 1 mm