Analysis of atmospheric data products for the reduction of satellite gravity measurements

O. Engels(1,2), E. Forootan (1), J. Kusche (1)
(1) Institute of Geodesy and Geoinformation (IGG), Astronomical, Physical and Mathematical Geodesy Group, University of Bonn, Germany
(2) Department of Geoscience & Remote Sensing, Delft University of Technology, The Netherlands

Abstract

In order to reveal long-term and seasonal hydrological and oceanographic signals, a careful reduction of high-frequency atmospheric mass redistributions from the observations of satellite gravimetry missions is essential. Yet, in the light of the next generation of gravity missions, any approximations used for this reduction may pose a limitation for exploiting the full accuracy of time-variable gravity solutions. This study explores the possible physical, geometrical and numerical improvements of the 3-dimensional (3D) integration approach to eliminate the high-frequency atmospheric effects from satellite gravimetry observations using atmospheric models. New is that we apply an improved 3D integration approach (ITG-3D-Method) to compute new sets of atmospheric de-aliasing products, based on data obtained from the Integrated Forecast System (IFS) of the European Center for Medium Range Weather Forecast (ECMWF) and the ERA-Interim reanalysis, covering the period of 2001 to 2009.

Processing Steps

1. From atmospheric parameter to de-aliasing product

ECMWF Reduced Gaussian Grid
↪ equiangular 0.5 x 0.5 Grid
↓
Blockmean Values
(smoothing the inputs)
↓
Radial Integration
↓
Spherical Harmonics
↓
Geoid Heights

2. Radial integration

Methods for calculating $I_n(\theta,\lambda)$		
2D	Spherical Earth	$\frac{P_s(\theta,\lambda)}{g}$
	Realistic Earth	$\left(\frac{R(\theta)+\xi(\theta,\lambda)+z(\theta,\lambda)}{a}\right)^{n+2}\frac{Ps(\theta,\lambda)}{g(\theta,z)}$
3D	Spherical Earth	$\int_0^{Ps}\left(\frac{a}{a-\Phi^g_{k+1/2}}+\frac{\xi(\theta,\lambda)}{a}\right)^{n+4}\frac{dP(\theta,\lambda)}{g}$
	GRACE-AOD1B	$\int_0^{Ps}\left(\frac{a}{a-\Phi^g_{k+1/2}\frac{g}{g(\theta)}}+\frac{\xi(\theta,\lambda)}{a}\right)^{n+4}\frac{dP(\theta,\lambda)}{g}$
	ITG-3D	$\int_0^{Ps}\left(\frac{R(\theta)+z_{k+1/2}+\xi(\theta,\lambda)}{a}\right)^{n+2}\frac{dP(\theta,\lambda)}{g(\theta,z_{k+1/2})}$

3. Scheme of ITG-3D method

INPUT: ECMWF: P_s Φ_s T H $a_{k+1/2}$ $b_{k+1/2}$
constant: g_{45} a R_{dry} f m
and ξ from ITGGrace2010s

1. $$P_{k+1/2} = a_{k+1/2} + b_{k+1/2}P_s$$

2. $$T_v = T\,(1+0.608H)$$

3. $$\Phi^g_{k+1/2} = \Phi^g_s + \frac{1}{g_{45}}\sum_{j=k+1}^{k_{max}} R_{dry}(T_v)_j \ln\frac{P_{j+1/2}}{P_{j-1/2}}$$
(transformation according to the OFCM, 1997)

4. $$z_{k+1/2} = \frac{R(\theta)\Phi^g_{k+1/2}}{\frac{g(\theta)R(\theta)}{g_{45}}-\Phi^g_{k+1/2}} \text{ with}$$
$$g(\theta) = \gamma_e\left(1+f_2\cos^2\theta+f_4\cos^4\theta\right);\; f_2(f,m), f_4(f,m)$$
(more realistic relationship between geo-potential heights and orthometric heights)

5. $$g(\theta,z_{k+1/2}) = g(\theta)\left[1-\frac{2}{a}\left(1+f+m-2f\cos^2(\theta)\right)z_{k+1/2}+\frac{3}{a^2}z^2_{k+1/2}\right]$$
(second-order expansion of the latitude- and altitude-dependent gravity accelerations)

OUTPUT: $$I_n = \int_0^{P_s}\left(\frac{R(\theta)+z_{k+1/2}+\xi}{a}\right)^{n+2}\frac{dP}{g(\theta,z_{k+1/2})}$$
(physically and geometrically improved radial integral)

4. Numerical improvements

➢Refining the vertical resolution, by considering 5 sub-intervals between each model level, for better estimation of the radial integration.

➢Improving the computation of the desired atmospheric de-aliasing spherical harmonics by using the Gauss-Legendre-Quadrature method (GLQ) in

$$\left.\begin{matrix}C_{nm}(t)\\ S_{nm}(t)\end{matrix}\right\} = \frac{(1+k_n')a^2}{(2n+1)M}\iint_\sigma \Delta I_n(\theta,\lambda,t)\cdot P_{nm}(\cos\theta)\left\{\begin{matrix}\cos m\lambda\\ \sin m\lambda\end{matrix}\right\}d\sigma$$

Results

Refining the vertical resolution:

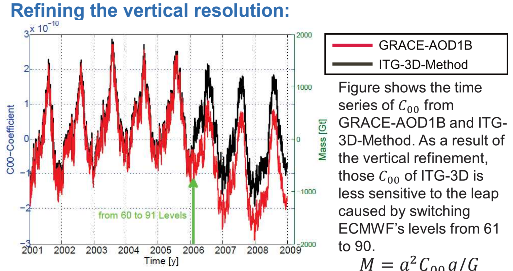
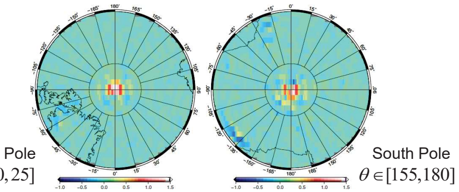


Figure shows the time series of C_{00} from GRACE-AOD1B and ITG-3D-Method. As a result of the vertical refinement, those C_{00} of ITG-3D is less sensitive to the leap caused by switching ECMWF's levels from 61 to 90.

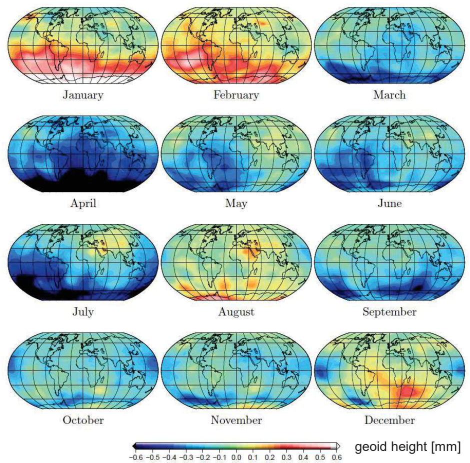
$$M = a^2 C_{00} g/G$$

Gauss-Legendre-Quadrature:



The differences between the error percentage of an ordinary 2D integration and the error percentage of GLQ for synthesizing a pressure field on 1.January 2001 at 00:00. Replacing the ordinary integration by GLQ considerably improves the estimations of the zonal coefficients.

IFS versus ERA-Interim (for 2001):

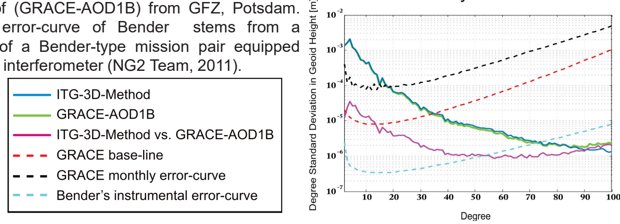


➢impact of input parameters on the computation of atmospheric de-aliasing products

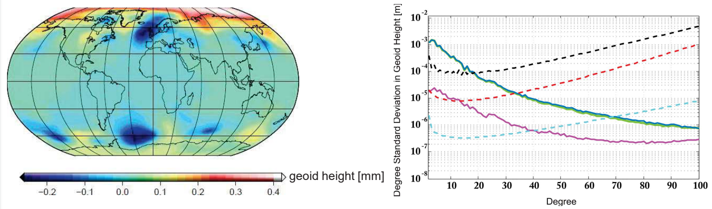
ITG-3D-Method versus GRACE-AOD1B:

Figures compare the results of the suggested improved method (ITG-3D-Method) to the current approach of (GRACE-AOD1B) from GFZ, Potsdam. Note: the error-curve of Bender stems from a simulation of a Bender-type mission pair equipped with a laser interferometer (NG2 Team, 2011).

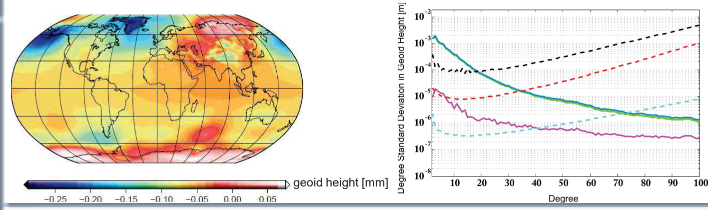
Difference of 6-hourly anomalies, on 1. January 2001 at 00:00



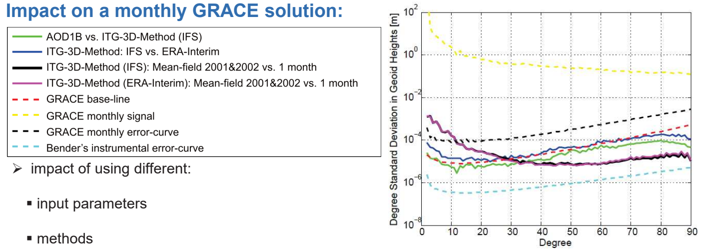
Difference of daily anomalies, average of 1. January 2001



Difference of monthly anomalies, average of January 2001



Impact on a monthly GRACE solution:



➢ impact of using different:
- input parameters
- methods
- mean-fields

within computing atmospheric de-aliasing products

GRACE monthly solution on January 2009 (a product of the Institute of Geodesy and Geoinformation (IGG), Bonn University).

Conclusions and outlook

Our numerical investigations show that the suggested ITG-3D-Method, which involves a more realistic parameterization of the Earth within a numerically and physically improved 3D integration approach, performs better than previous methods for computing atmospheric de-aliasing products suited to future missions.

A large difference was also found between the derived de-aliasing products from ERA-Interim and IFS data sets suggesting that, apart from an improved computation approach, the precision of atmospheric data itself represents an issue which needs more investigations.

References

Engels, O (2011). Analyse von atmosphärischen Datenprodukten zur Reduktion von Satelliten-Schweremessungen. Master thesis, Bonn University, Germany.
Flechtner, F. (2007). AOD1B Product Description Document for Product Releases 01 to 04. Technical Report, Geoforschungszentrum, Potsdam.
Boy, JP., and B. F. Chao (2005). Precise evaluation of atmospheric loading effects on Earths time-variable gravity field. Journal of Geophysical Research, 110(B08412). doi: 10.1029/2002JB002333.

Institute of Geodesy and Geoinformation
Department of Astronomical, Physical and Mathematical Geodesy
University of Bonn, Germany

Contact:
Olga Engels
oengels@uni-bonn.de
Ehsan Forootan
forootan@geod.uni-bonn.de