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Geophysical fluid models for atmosphere, ocean and hydrology and their impact on SLR analysis

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Abstract.
High quality reference frames are very important for a wide range of applications. In order to reach the ambitious GGOS goals with 1 mm accuracy for the terrestrial reference frame, the inclusion of geophysical fluid models in the analysis is necessary. Recent models calculated for this purpose differ, thus comparisons are required. Eleven years of LAGEOS and Etalon data have been analyzed using different loading models for both, i.e., the geometric deformation as well as the gravity effect. We test different model combinations and study the impact on the estimated station coordinates and other parameters, e.g., the geocenter and Earth rotation parameters.

1. Introduction

For a wide range of scientific studies it is important to know the shape of the Earth, the Earth's gravity field, the Earth rotation and their evolution in time. Especially in case of slowly changing phenomena like the sea level rise it is important to have access to high-quality reference frames. Reference frames like the International Terrestrial Reference Frame (ITRF) describe the position of points with coordinates and velocities referring to a reference epoch (Petit & Luzum, 2010). Apart from linear behavior a sum of additional time-dependent variations have to be considered. These additional variations are mostly caused by the oceans, the atmosphere and the hydrology, i.e., the so-called geophysical fluids. Their changes in mass distribution have an impact on the gravity field and – due to the related loading variations – also an impact on the shape of the Earth. It can be distinguished between tidal and non-tidal effects. Sosnica et. al. (2013) investigated the impact of ocean tidal loading and non-tidal atmospheric loading on SLR-derived parameters. The displacement of SLR stations due to non-tidal atmospheric loading was also studied by Bock et. al. (2005). Using models for the atmosphere is also important to reduce the so called "Blue-Sky" effect in SLR (Otsubo et. al. 2004).

This study focuses on the non-tidal models for which special data sets describing the global mass variations in the atmosphere, the ocean and the hydrology are mandatory. We investigated the impact on SLR results by processing long time series with different combinations of models.

2. Loading models

The Global Geophysical Fluid Center (GGFC) of the International Earth Rotation and Reference System Service (IERS) provides several loading models. A compilation of models that are easy to find via the GGFC webpage is given in Table 1. The table distinguishes between geometric and gravity models. It is obvious that there are more models describing the deformation than the gravity. The models differ in the spatial and temporal resolution, the background models that were used for the computation, e.g. ECMWF and NCEP, and the time span they are valid for. Only the GGFC and NASA provide geometry models for all three fluids. Because we are interested in the impact of all fluids the decision was made to use the models from these institutions for our analysis. The variability of the gravity field is modeled by TU Vienna, Strasbourg University and GFZ but no one have a complete set of all fluids available. To handle the gravity variation the GRACE dealiasing products (AOD) which consists of the atmospheric and oceanic gravity part as 6 hourly a set of spherical harmonics from GFZ were used in our analysis (Flechtner, 2013). There are plans to calculate the complete set of models at the GFZ.

For the hydrology and oceanic non-tidal loading grids a preprocessing step is required, because every grid cell includes a long-term trend. This trend is caused by the background models (i.e. ECCO1) which held the ocean volume and not the mass constant (Van Dam, 2002). The trend must be subtracted from the deformation values before introducing them into the analysis.

	Geometry			**Gravity**		
	Atmo.	**Ocean**	**Hydro.**	**Atmo.**	**Ocean**	**Hydro.**
GGFC[1]	X	X	X	-	-	-
NASA[2]	X	X	X	-	-	-
TU Vienna[3]	X	-	-	X	-	-
Uni Strasbourg[4]	X / X	-	X	X	-	X
GFZ[5]	(X)	(X)	(X)	X	X	(X)

Table 1: Compilation of geophysical fluid models available via the GGFC homepage

In order to get an idea of the magnitude of the hydrology-induced loading deformation, the displacement for all SLR stations used in this analysis were computed from GGFC and NASA models. For all stations the displacements in the up component interpolated from the GGFC grids is shown in Figure 1. sorted by latitude. It is easy to see that the Northern stations encounter stronger variations between -8 mm to 8 mm than the others. The differences between the GGFC model values and the values calculated from the NASA grids are illustrated in Figure 1. Both models behave nearly the same for the northern stations where the differences are mostly below 0.5 mm. The southern stations show bigger differences up to 2 mm. The big differences might be caused by different grid resolutions and station positions near the coastline. The general good agreement between GGFC and NASA model at the SLR stations does not reflect the complete Earth where in areas below -60 ° latitude and above 60 ° latitude much bigger differences occure. This differences are especially important when processing GNSS instead of SLR data.

3. Processing and results

In order to test the impact of different loading models an SLR time series for the time span 2001 to the end of 2011 was calculated. Screened normal points from both LAGEOS and both Etalon satellites were used. The processing of weekly solutions was performed with the SLR version of the Bernese GNSS software. This software is used in the daily ILRS analysis at BKG (Noll, 2012). The C04 series and coordinates extracted from the SLRF2008 were selected as apriori values. The gravity model EGM2008 and the GRACE AOD (R5) products were used to describe the static and the variable part of the gravity field, respectively. The models used for the computation of the AOD products are not identical with the models used in the deformation calculation which leads to an inconsistency in the analysis. In addition to the standard parameters

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[1] http://geophy.uni.lu/ggfc-about/products.html

[2] http://lacerta.gsfc.nasa.gov/ (atmosphere + ./aplo_grid_nc/), (ocean + ./oclo/), (hydro + ./hydlo/)

[3] http://ggosatm.hg.tuwien.ac.at/products.html

[4] http://loading.u-strasbg.fr/

[5] http://isdc.gfz-potsdam.de/

like the range bias and station coordinates it was solved for the geocenter coordinates and for the Earth gravity field parameters of degree and order two.

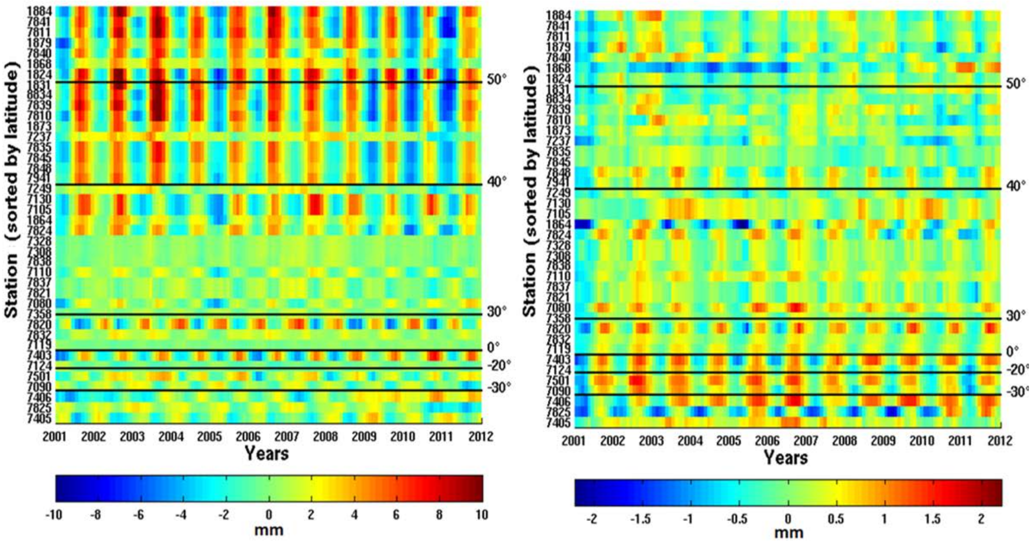

Figure 1: Hydrology height displacement for SLR stations modeled with GGFC grids (left). Differences to values calculated with the NASA grids (right). Stations are sorted by latitude

3.1 Coordinate time series

Analyzing the coordinate time series is one possibility to study the impact of the models. Unfortunately, the series for SLR stations often contains gaps and the sparse network makes model tests complicate. The four week moving average of the height time series for the good performing station 7839 (Graz) is shown in Figure 2. Some seasonal variances included in the blue curve (no models applied) seem to disappear when all geophysical fluids are modeled. The individual model impact on the station height is shown in Figure 3. Graz is an inland station and the impact from the ocean is nearly zero. Amplitudes for the atmosphere and the hydrology have nearly the same size, i.e., up to 5 mm. For stations near the coastline the ocean is more dominant, of course, and can reach variations up to 2 mm for e.g. Yarragadee (Figure 4).

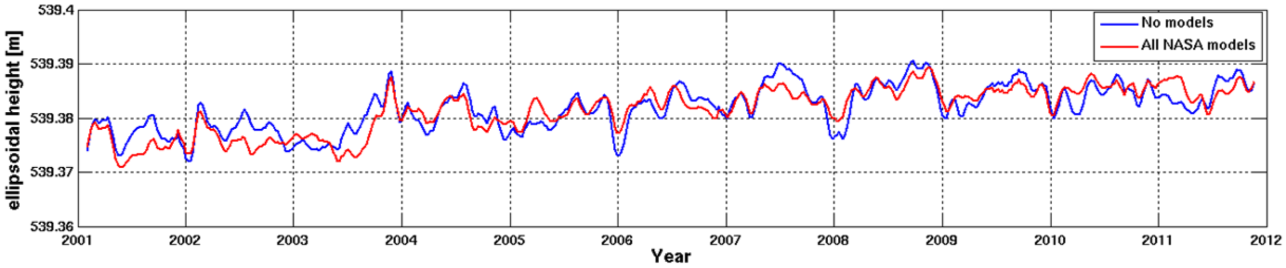

Figure 2: Time series of the height component of station 7839 (Graz). Blue = 4 week moving average of solution without models applied. Red = 4 week moving average of solution with all NASA models applied.

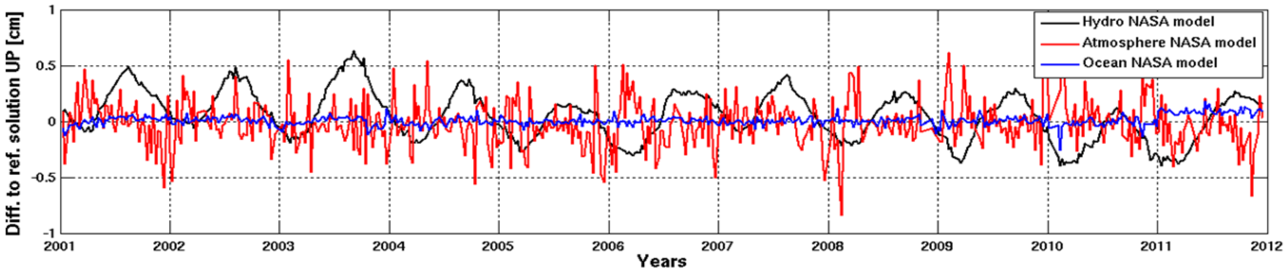

Figure 3: Impact of each fluid model on the height component of station 7839 (Graz). Black = impact of hydrology loading model (NASA). Red = impact of non-tidal atmospheric loading model (NASA). Blue = impact of non-tidal ocean loading model (NASA).

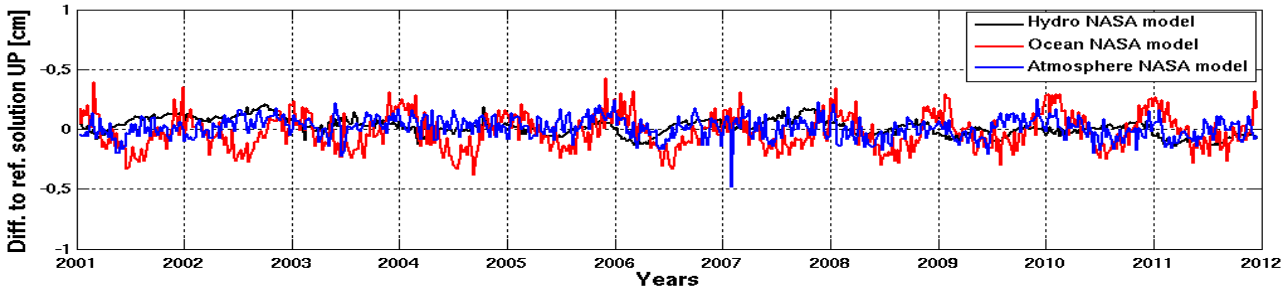

Figure 4: Impact of each fluid model on the height component of station 7090 (Yarragade). Black = impact of hydrology loading model (NASA). Red = impact of non-tidal atmospheric loading model (NASA). Blue = impact of non-tidal ocean loading model (NASA).

3.2 Geocenter coordinates

SLR as other satellite techniques is sensitive to the geocenter. Therefore, the model impact on this parameter is of great interest. In Figure 5 the time series of the z-component is shown as a four week moving average. The blue curve results from the calculation where no models are applied. The red curve represents the solution when all NASA models are used. The seasonal variation visible in the blue curve seems to be reduced when using the geophysical fluid models.

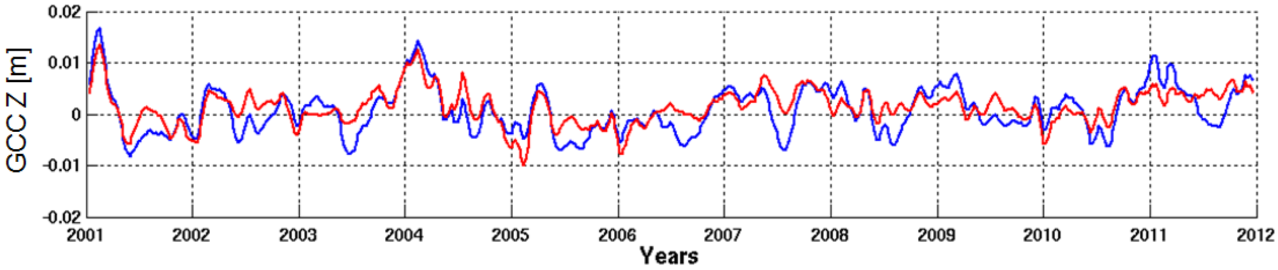

Figure 5: Time series of the geocenter z coordinate. Blue = Solution with no models used (4 week moving average). Red = Solution with all NASA models (4 week moving average).

In contrast to station coordinates, i.e., one week for our SLR solutions, the geocenter time series is given in regular intervals. Thus, it is possible to transform the signal from the spatial domain into the frequency domain using an FFT. The spectrum for the time series of the z-component is shown in Figure 6. The seasonal signal vanishes completely, indicating that this effect can be explained by the sum of all geophysical fluid models. Furthermore, the individual impact of the models is of interest. We processed solutions with different models applied and calculated the difference to a reference solution where no models were used. Figure 7 shows these differences for the z-component. The smoother shape of the hydrology curve originates from the monthly time resolution compared to the 6 hour resp. 12 hour resolution of the atmospheric and the ocean models. The atmosphere has the biggest impact with amplitude of about 4 mm. Hydrology leads to changes with amplitude of approximately 2.5 mm. With 1 mm amplitude the ocean has the smallest impact. For the other components, especially the X component the ocean impact is nearly as big as the impact of the hydrology. This analysis shows that all models are necessary to deal with the seasonal geocenter variations.

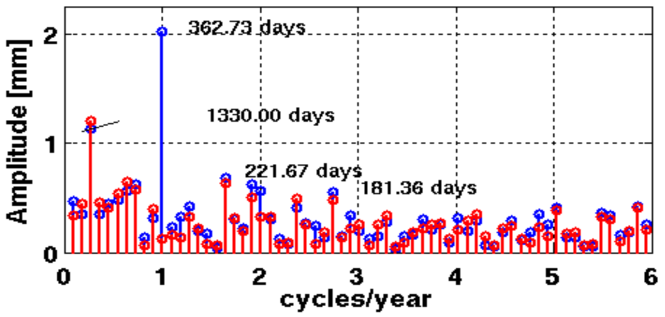

Figure 6: Spectrum of geocenter z-component. Blue: solution without geophysical fluid models. Red = Solution with NASA models for atmosphere, ocean and hydrology

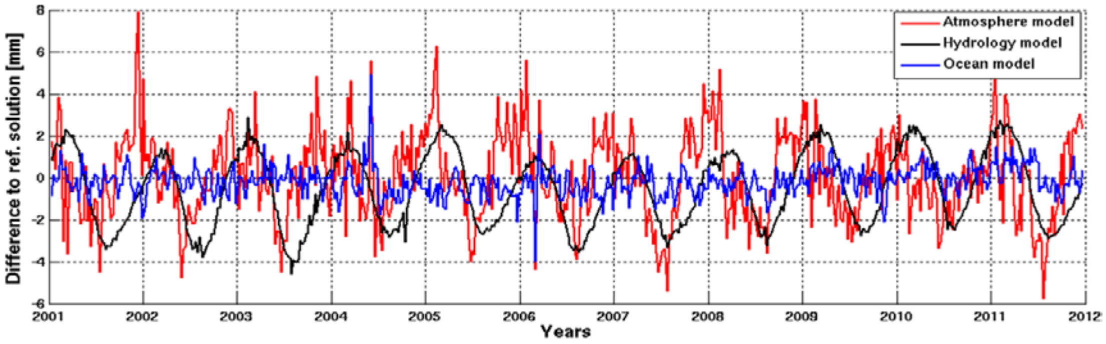

Figure 7: Impact of different fluid models on the z-component of the geocenter.
Red = atmosphere impact. Blue = ocean impact. Black = hydrology impact.

3.3 Earth rotation parameters

The impact of the different geophysical fluid models on the ERPs was also investigated. In Figure 8 the X-Pole differences from individual solutions w.r.t. a reference solution without using geophysical fluid models are presented. It can be seen that the hydrology has the smallest impact, with variations of less than 0.02 mas, on the estimated pole. Using the models for the atmosphere and the ocean leads to changes up to 0.1 mas. Beside this internal test, an external comparison with the IERS 08 C04 series reveals only a small improvement when using the geophysical fluid models.

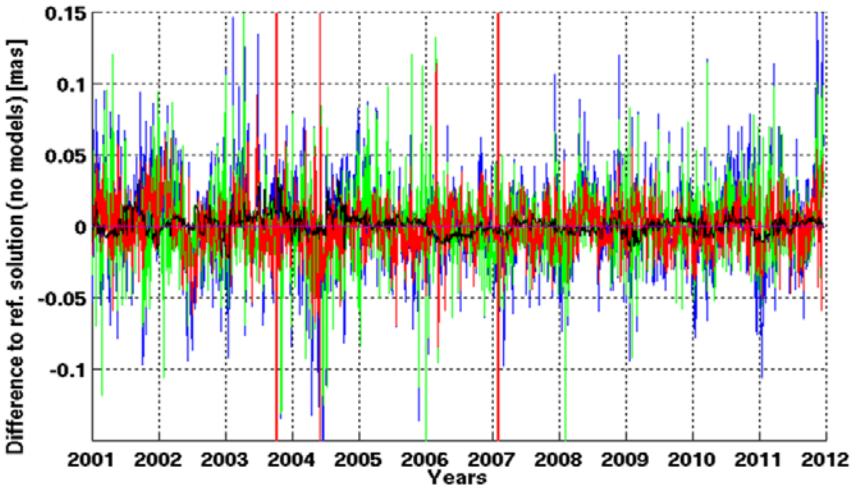

Figure 8: Model impact on X-Pole estimation. Blue = all NASA models. Green = atmosphere model.
Red = ocean model. Black = hydrology model. Lila = ref solution

4. Conclusion

In this work a compilation of geophysical fluid models and results from an eleven year SLR processing were presented. Because of the amount of different models validations are necessary. Because of the sparse network and gaps in some station coordinate time series it is difficult to say which model performs best taking only the station coordinates into account. As additional parameters the geocenter and the Earth rotation parameter provides the opportunity for comparisons. It was shown that the seasonal geocenter variations can be explained by the sum of all three geophysical fluids. The hydrology has a significant impact that is also visible in coordinate time series of well performing stations like Graz. The results indicate that not only the atmospheric loading should be considered in the analysis of the space techniques. Including all models in our processing would lead to a better reference frame quality and a better understanding of the Earth system.

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