CONVENTIONS FOR MODELING AND PARAMETERIZATION: 2ND ITERATION OF GGOS-D

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Motivation

The major goal of the GGOS-D project is the rigorous and consistent combination of the space-geodetic techniques Global Positioning System (GPS), Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Altimetry and observations of Low Earth Orbiters (LEOs). As the contributions of these different techniques are computed with different software packages, a number of common standards have to be fulfilled to generate a consistent set of products. This is essential in order to avoid misinterpretations due to differences in modeling. In addition, as the contributions of the different techniques will be combined on the normal equation level, the parameterization of the estimated parameters has to be identical. The standards of the first iteration (*Steigenberger et al.*, 2006) have been reviewed, updated and implemented in altogether seven different software packages used within this project.

Parameterization

The combination covers the parameters station (GPS, SLR, VLBI) and quasar coordinates (VLBI), troposphere zenith delays and gradients (GPS, VLBI), Earth rotation (GPS, SLR, VLBI), nutation (GPS, VLBI) and the lower harmonics of the Earth's gravity field (Altimetry, GPS, SLR, LEO, SLR). In the terrestrial reference frame solution the station coordinates are represented by an offset and a drift (velocity) parameter. The station coordinates of the daily/weekly solutions, the quasar coordinates (celestial reference frame solution) and the lower harmonics of the Earth's gravity field are represented by offsets per parameter interval. For the other parameters, a continuous piece-wise linear function is used. This kind of parameterization has the advantage that there are no discontinuities at the interval boundaries. The usual parameter intervals as well as further details on the parameterization are given in Table 1.

Station coordinates	Constant daily/weekly offsets
Quasar coordinates	Constant offsets
Earth rotation parameters	*Standard solution:* continuous piece-wise linear function with a parameter interval of 24 hours. *Subdaily solution:* continuous piece-wise linear function with a parameter interval of 1 hour.
Nutation parameters	Nutation parameters are estimated as corrections with respect to the a priori model IAU2000A and represented by a continuous piece-wise linear function with a parameter interval of 24 hours.
Troposphere parameters	The wet part of the troposphere zenith delay is represented by a continuous piece-wise linear function with a parameter interval of 1 hour for VLBI and 2 hours for GPS. Troposphere gradients are modeled according to *MacMillan* (1995) and represented by a continuous piece-wise linear function with a parameter interval of 24 hours. Wet VMF1 mapping function (*Boehm et al.*, 2006) for the troposphere zenith delay and the troposphere gradients.
Lower harmonics of the Earth's gravity field	Spherical harmonic expansion: - LEOs: up to degree and order 10 - GPS/SLR: up to degree and order 2 + selected sensitive coefficients

TABLE 1: Parameterization and parameter spacing used for the 2nd iteration of GGOS-D. Changes w.r.t. the first iteration are given in red.

Improved Troposphere Modeling

The Niell mapping function (NMF, *Niell*, 1996) used for the first GGOS-D iteration is an empiric mapping function that has several deficiencies:

- the seasonal behavior of the southern and the northern hemisphere is the same except for a phase difference of 180°
- the equatorial region from 15°S to 15°N is described by the 15°N latitude profile
- the polar regions with latitudes larger than 75° are described by the 75°N latitude profile.

More recent mapping functions are based on data of numerical weather models which provide the best available description of the atmospheric state. The Vienna mapping function 1 (VMF1, *Boehm et al.*, 2006) is derived from a rigorous raytracing through pressure layers of the ECMWF numerical weather model.

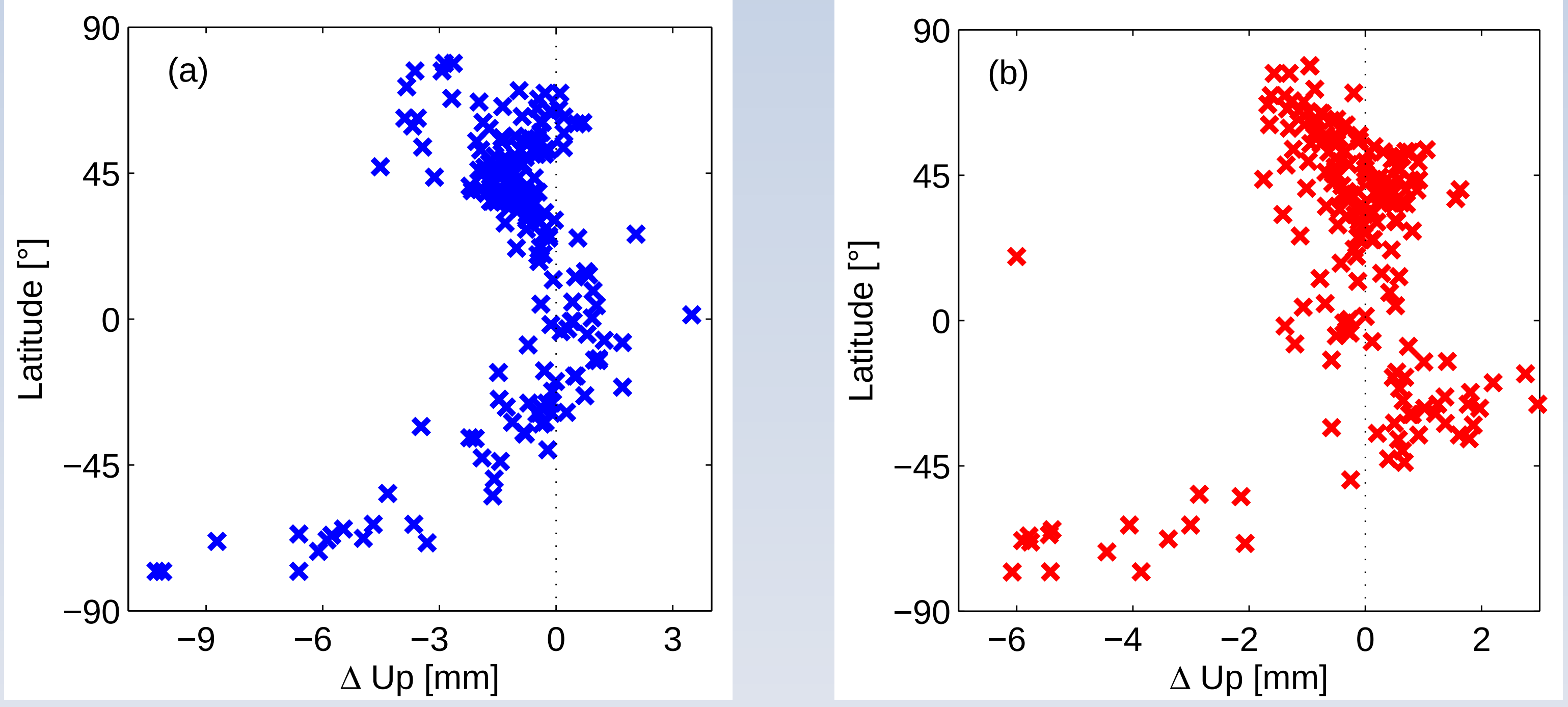

FIGURE 1: Mean station height differences induced by different troposphere modeling: (a) mapping functions NMF and VMF1; (b) constant a priori hydrostatic troposphere zenith delay and 6-hourly ECMWF data.

Figure 1 (a) shows the mean station height differences due to the different mapping functions NMF and VMF1 computed from 11 years of GPS data. A clear latitude-dependent systematic pattern due to the deficiencies of the NMF can be seen. In particular the coordinate differences of up to almost 1 cm in Antarctica are striking. But also in the northern hemisphere there is a slightly latitude-dependent pattern visible.

The station height differences induced by different modeling of the a priori hydrostatic troposphere zenith delay of the first GGOS-D iteration (constant values per station based on a standard atmosphere) and the second GGOS-D iteration (6-hourly ECMWF data) are shown in Figure 1 (b). Like for the different mapping functions, the largest differences (more than 5 mm in the station height) occur in Antarctica due to the deficiencies of the standard atmosphere in that region.

In addition, the behavior of the time series changes. Figure 2 shows the station height differences between GPS solutions applying the troposphere modeling of the two GGOS-D iterations described above for a station in Antarctica. A clear annual signal with a peak-to-peak amplitude of up to 2 cm can be seen. This artificial signal is introduced by the deficiencies of the troposphere modeling applied in the first iteration.

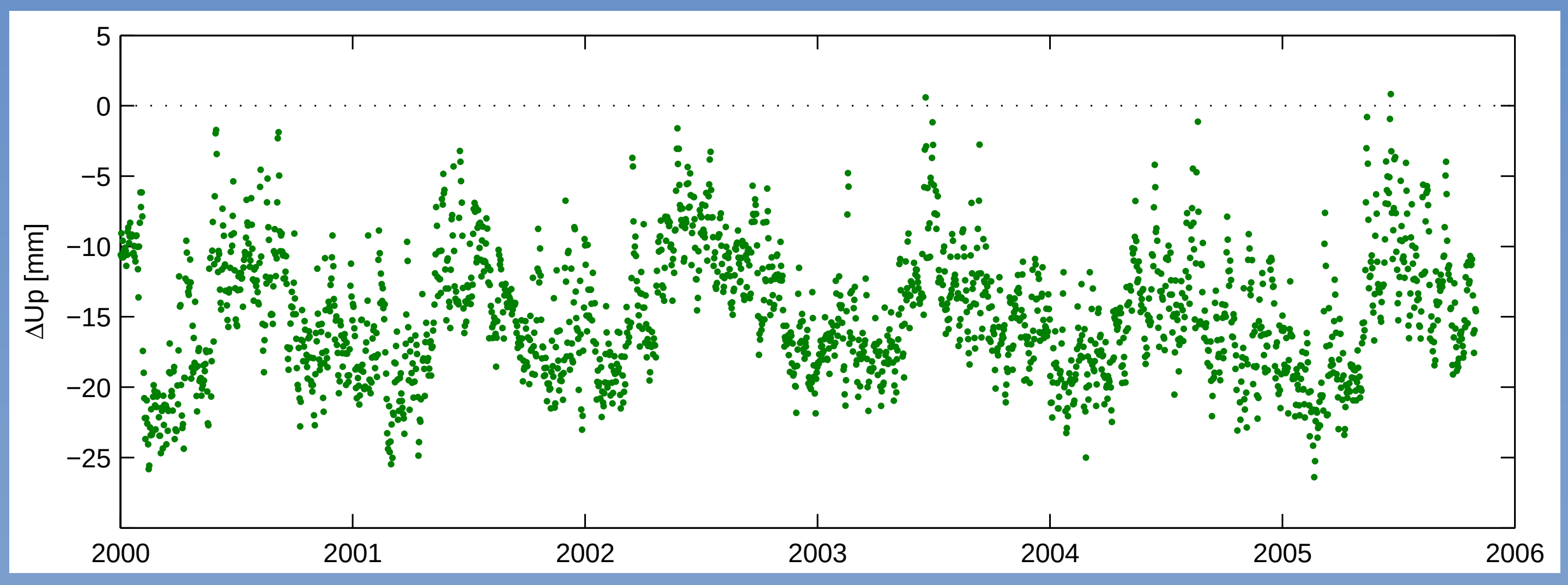

FIGURE 2: Time series of station height differences for Casey (Antarctica) due to different troposphere modeling of both GGOS-D iterations.

Modeling

The standards are based on the recommendations of the IERS 2003 conventions (McCarthy and Petit, 2004) and the standards (or future standards) of the international services International GNSS Service (IGS), International Laser Ranging Service (ILRS) and International VLBI Service for Geodesy and Astrometry (IVS). The changes w.r.t. the first iteration (*Steigenberger et al.*, 2006) are given in red in Table 2.

Station coordinates/Sea surface heights	
Solid Earth tides	IERS Conventions 2003
Permanent tide	Not considered for coordinates
Ocean tides	FES2004, *Letellier* (2004)
Pole tides	Linear trend for mean pole offsets: IERS Conventions 2003
Ocean loading	FES2004 including the CoM correction for the motion of the Earth due to the ocean tides[a]
Atmospheric loading	Not applied
Earth Orientation Parameters	
A priori information	Daily values of the C04 05 series[b] (x-pole, y-pole, UT1)
Interpolation polar motion	linear interpolation between daily values of x-pole and y-pole
Interpolation UT1	1) reduction of UT1 to UT1R 2) linear interpolation between daily values of UT1R 3) conversion of UT1R to UT1
Subdaily ERP model	IERS2003, *McCarthy and Petit* (2004)
Nutation	IAU2000A (without free core nutation), *Mathews et al.* (2002)
Lower harmonics of the Earth's gravity field	
A priori model	EIGEN-GL04S1 including temporal variations of C_{20}, C_{30}, C_{40}
Troposphere modeling	
Radio Techniques	
Hydrostatic delay	Computed from 6-hourly ECMWF grids[c]
Mapping function for hydr. delay	Hydrostatic VMF1, *Boehm et al.* (2006)
Wet delay	No a priori model, wet delay estimated (see Table 1)
Gradients	Zero a priori values
SLR	
Troposphere model	*Mendes and Pavlis* (2004)
Technique-specific effects GPS	
Phase center model	igs05_1421.atx[d], *Schmid et al.* (2007)
Radome calibrations	igs05_1421.atx
Antenna height	igs.snx[e] + IGSMAIL/IGSSTATION[f]
Hor. antenna offsets	Applied
2nd and 3rd order iono. corr.	Applied according to *Fritsche et al.* (2005)
Technique-specific effects SLR	
CoM corrections (reflector offsets)	ILRS conform[g]
Range bias	For selected stations, ILRS conform
Arc length	7 days
Technique-specific effects VLBI	
Thermal deformations	Applied, IVS conform (*Nothnagel et al.*, 1995; *Skurikhina*, 2001), mean value of the temperature recordings during the VLBI sessions used as station-specific reference temperature
Gravitational sag	Not applied

[a] `http://www.oso.chalmers.se/~loading/`
[b] `http://hpiers.obspm.fr/iers/eop/eopc04_05/eopc04.62-now`
[c] `http://mars.hg.tuwien.ac.at/~ecmwf1/GRID/`
[d] `ftp://igscb.jpl.nasa.gov/igscb/station/general/`
[e] `ftp://igscb.jpl.nasa.gov/igscb/station/general/`
[f] `http://igscb.jpl.nasa.gov/mail/mailindex.html`
[g] `http://ilrs.gsfc.nasa.gov/satellite_missions/center_of_mass/index.html`

TABLE 2: Common standards for the 2nd iteration of GGOS-D. Changes w.r.t. the first iteration are given in red.

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