GFZ

Helmholtz Centre POTSDAM

Poster-EGU2015-970

Contact information

HELMHOLTZ CENTRE POTSDAM

GFZ GERMAN RESEARCH CENTRE FOR GEOSCIENCES

VLBI TRF determination via Kalman filtering

Benedikt Soja[1], M. Karbon[1], T. Nilsson[1], S. Glaser[1,2], K. Balidakis[1], R. Heinkelmann[1], H. Schuh[1,2]

[1]GFZ German Research Centre for Geosciences, Potsdam, Germany
[2]Technische Universität Berlin, Berlin, Germany
Contact: bsoja@gfz-potsdam.de

Introduction

The determination of station positions is one of the primary tasks for space geodetic techniques. Station coordinate offsets are conventionally determined w.r.t. a linear coordinate model after removing elastic displacement effects caused by mass redistributions within the Earth system. In this work, we have investigated the possibility of applying Kalman filtering for station position determination. Firstly, we studied to what extent subdaily crustal motion can be detected in VLBI station coordinates. Next, we fed the station coordinates into another Kalman filter, estimating a global terrestrial reference frame (TRF). As TRFs are usually based on a linear model, we first created a linear TRF for comparison with ITRF2008 and a TRF based on the same VLBI data, but estimated in a least squares adjustment. Finally, we adapted the stochastic model in the Kalman filter to allow for non-linear motion, e.g. induced by earthquakes and post-seismic relaxation.

Kalman filters

We have implemented a Kalman filter into the VLBI software VieVS@GFZ, which is able to estimate station and radio source coordinates, Earth orientation parameters, as well as clock and tropospheric parameters. Additionally, we have developed a filter to process the estimated station coordinates in order to create a TRF-like product. In post-processing mode, both filters are run forwards and backwards, and a smoothing operation is applied afterwards.

VLBI data

For our study of subdaily and non-linear station coordinate variations, we considered the **CONT14** campaign, coordinated by the IVS (Schuh & Behrend, 2012). It features continuous observations over 15 days by 17 radio telescopes and is one of the highest quality VLBI data sets available. The **TRF** solution is based on a much extended data set, featuring 143 stations and **4241 VLBI sessions** between 1980 and 2013. In all of these sessions, more than three radio telescopes participated, spanning a polyhedron with a volume of more than 10^{15} m^3, ensuring a suitable geometry.

Subdaily station motions

Station coordinates are estimated for every observation epoch and modeled as random walk processes, the noise of which is defined by the power spectral density (PSD) of the driving white noise processes. For the estimation of station coordinates during CONT14, different levels of noise were tested (***Fig. 1***). Additionally, daily coordinates derived by a classical least squares adjustment (LSM) are depicted. ***Tab. 1*** displays the RMS of the subdaily variations using the same noise for all stations. The variations might be due to un- or mismodeled geophysical effects, correlations with other parameters like the troposphere, or due to the network geometry. As a test, it was investigated whether the Kalman filter is capable of recovering the signals in the station positions when not accounting for solid earth or ocean tide displacements (***Fig. 2 & 3***). The WRMS of the difference between the estimated coordinates and the models are 1.8 cm (YEBES40M/solid earth) and 1.6 cm (WARK12M/ocean). Computing the RMS of the displacement time series according to the models results in 10.8 cm and 1.9 cm, respectively.

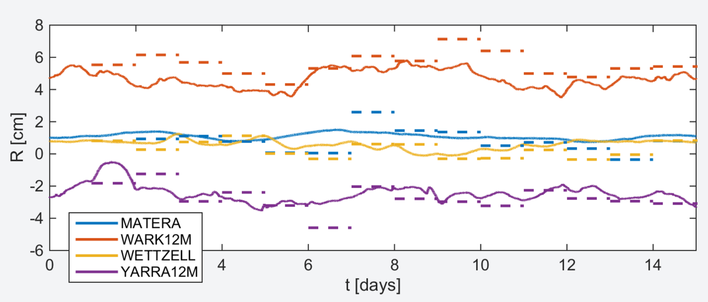
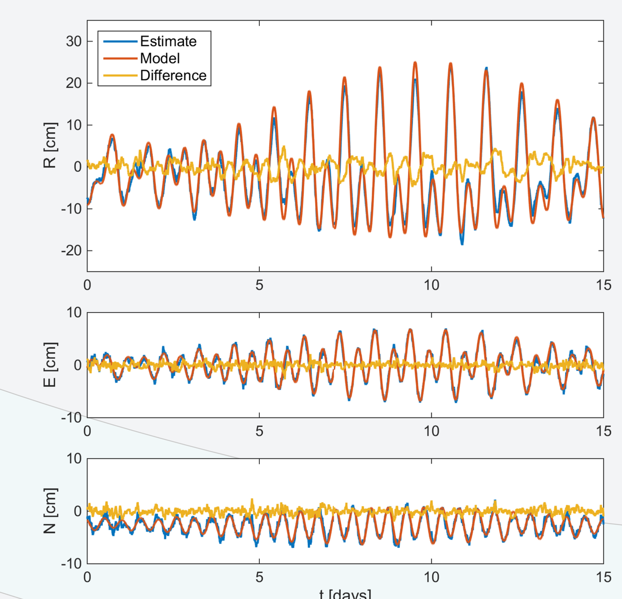


Fig. 1: *Radial component of station coordinates during CONT14. Datum stations MATERA and WETTZELL: PSD of 0.1 cm²/d, non-datum stations WARK12M and YARRA12M: 1 cm²/d. Solid line: Kalman filter, dashed line: LSM.*

Station	RMS (mm)	Station	RMS (mm)
BADARY	2.7	ONSALA60	1.8
FORTLEZA	4.1	TSUKUB32	3.9
HART15M	3.4	WARK12M	2.2
HOBART12	5.6	WESTFORD	1.3
HOBART26	1.7	WETTZELL	3.0
KATH12M	4.4	YARRA12M	2.7
KOKEE	1.9	YEBES40M	3.5
MATERA	2.0	ZELENCHK	2.9
NYALES20	1.7		

Tab. 1: *RMS in radial component of station coordinates during CONT14 after subtracting a mean offset. PSD of 0.1 cm²/d for all stations.*



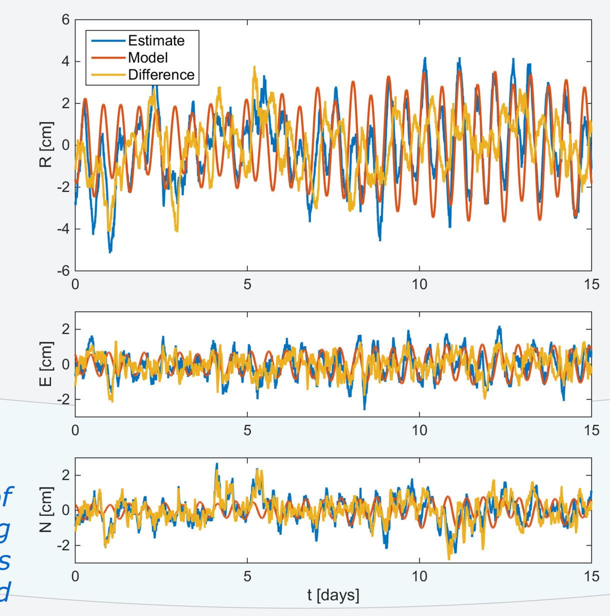


Fig. 2 & 3: *Local station coordinates of YEBES40M (top) and WARK12M (right) during CONT14, without accounting for solid earth tides (top) and ocean tides (right). PSD of 100 cm²/d and 30 cm²/d, respectively.*

Conclusions

- **Subdaily station motions** investigated using a Kalman filter for VLBI analysis; solid earth and ocean tidal displacement effects recovered if not corrected a priori (WRMS of a few centimeters)
- **Good agreement of the linear Kalman filter TRF** with ITRF2008 and a VTRF based on least squares
- Capability of the Kalman filter TRF to **capture non-linear signals** demonstrated
- Large differences between linear and non-linear TRF in **seismically active regions** (e.g., U.S. west coast and Japan), stations with sparse VLBI data (e.g., OHIGGINS) or short observation history (e.g., AuScope)

References:
Altamimi et al.: ITRF2008: an improved solution of the international terrestrial reference frame. J Geod. 85(8), 457-473 (2011). doi:10.1007/s00190-011-0444-4
Schuh, H., Behrend, D.: VLBI: A fascinating technique for geodesy and astrometry. J. Geodyn. 61, 68–80, (2012). doi:10.1016/j.jog.2012.07.007

Acknowledgements:
The authors would like to thank the IVS for observing, correlating and providing the VLBI data used in this work. Benedikt Soja works under project VLBI-ART (P 24187-N21), funded by the Austrian Science Fund (FWF).

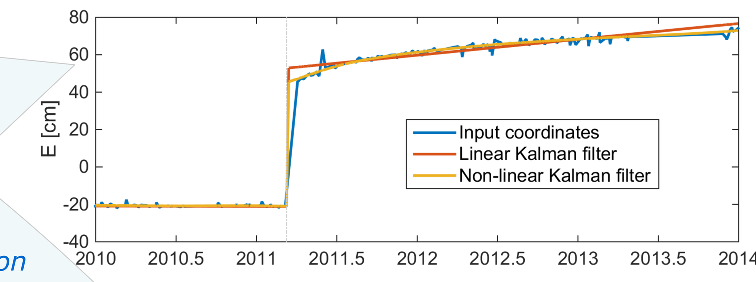


Fig. 5: *East local coordinates for station TSUKUB32 (Japan) from Kalman filter solutions with and without noise. Tōhoku 2011 earthquake: magnitude of 9.0 (M_w).*

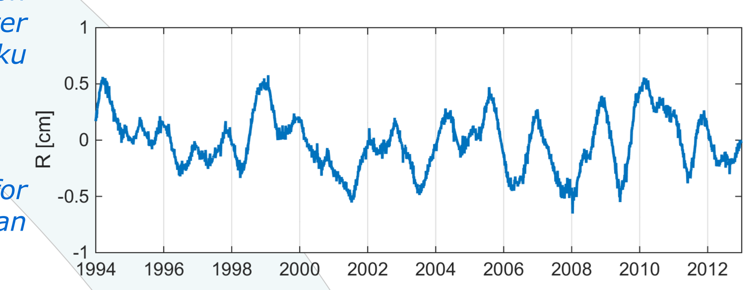


Fig. 6: *Difference in the radial component for station KOKEE (Hawaii) between Kalman filter solutions with and without noise.*

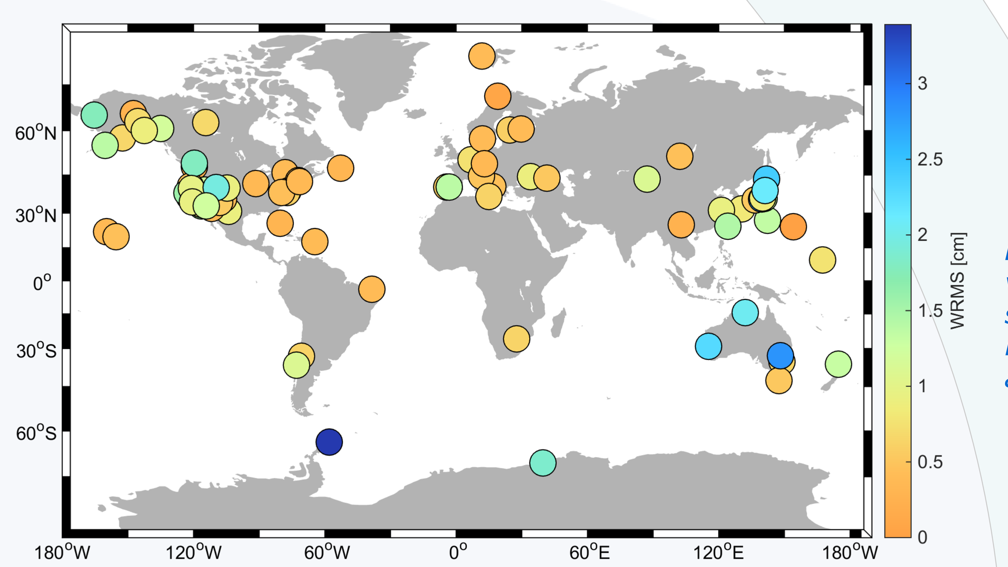
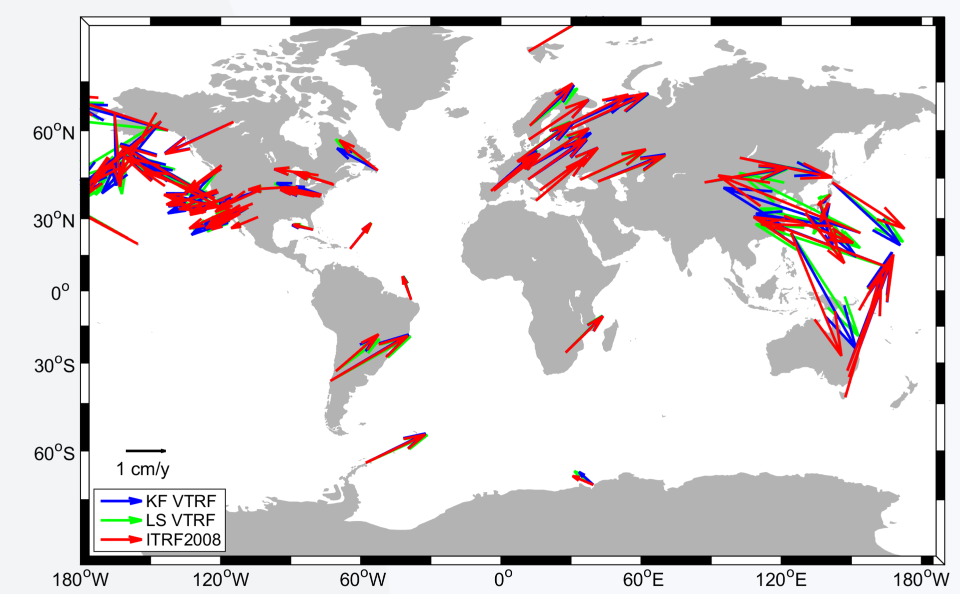


Fig. 7: *Color-coded WRMS values of the 3D difference in station coordinates from Kalman filter solutions with and without noise.*

Non-linear Kalman filter TRF

Next, the process noise was increased to 10^{-10} cm²/d³, allowing the filter to follow non-linear station motions, such as post-seismic motions (***Fig. 5***) or geophysical signals (***Fig. 6***). The WRMS of the difference between the linear and non-linear Kalman filter solutions is shown in ***Fig. 7***.



w.r.t. ITRF2008	Tx (mm)	Ty (mm)	Tz (mm)	D (ppb)	Rx (µas)	Ry (µas)	Rz (µas)
Offset 2005	0.0 ± 0.3	-0.2 ± 0.3	1.4 ± 0.3	-0.5 ± 0.05	-9 ± 14	8 ± 11	11 ± 11
Velocity (/y)	-0.00 ± 0.05	-0.07 ± 0.05	-0.03 ± 0.05	-0.01 ± 0.01	0.8 ± 2.1	0.8 ± 1.8	4.1 ± 1.7

w.r.t. LS VTRF	Tx (mm)	Ty (mm)	Tz (mm)	D (ppb)	Rx (µas)	Ry (µas)	Rz (µas)
Offset 2005	0.4 ± 0.3	-0.8 ± 0.3	0.9 ± 0.3	0.06 ± 0.04	7 ± 12	-14 ± 9	15 ± 10
Velocity (/y)	0.2 ± 0.06	-0.1 ± 0.06	-0.03 ± 0.06	-0.01 ± 0.01	-0.9 ± 2.5	-1.6 ± 2.1	4.0 ± 2.1

Tab. 2 & 3: *Helmert transformation parameters between the linear Kalman filter VTRF and ITRF2008 (top), and the least squares VTRF (bottom), based on the ten datum stations of the LS VTRF.*

Fig. 4: *Horizontal velocities from TRF solutions by Kalman filtering and least squares adjusting VLBI data, in comparison to those of ITRF2008. Only segments included in all three catalogues are shown.*

TRF from linear Kalman filtering

Initially, session-wise coordinates were calculated using VieVS@GFZ, imposing NNT+NNR conditions w.r.t. ITRF2008 (Altamimi et al., 2011) for all 108 stations with valid ITRF2008 coordinates. These values were fed into a Kalman filter designed for TRF creation. Here, the coordinates are modeled as an integrated random walk process. If the PSD of the driving white noise is set to zero, the Kalman filter produces linear coordinate time series, comparable to conventional TRF products. Additionally, a TRF was created by solving the normal equations from the same VLBI sessions in a least squares adjustment („global solution"). The datum was realized by applying NNT+NNR w.r.t. ITRF2008 for 10 selected stations. In both, Kalman filter and least squares solutions, the same configuration of breaks, fixed velocities, etc., was used. ***Fig. 4*** illustrates the horizontal velocities of both solutions, compared to ITRF2008. The transformation parameters are given in ***Tab. 2 & 3***.

www.gfz-potsdam.de

HELMHOLTZ ASSOCIATION