Applying Kalman filtering to investigate tropospheric effects in VLBI analysis

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1 Introduction

- Troposphere: one of the most important error sources for space geodetic techniques
- Currently not possible to model water vapor sufficiently, therefore ZWD estimated in VLBI analysis
- Usually least squares method (LSM) with piece-wise linear functions used
- This work: Kalman filter (KF, e.g. Herring et al., 1990)
- Advantages: real time capability, state based approach

Kalman filter

- Implemented into VieVS@GFZ
- Possibility to estimate the same parameters as LSM
- ZWD modeled as random walk process
- KF processing strategy: forward + backward + smoothing

VLBI data

- CONT campaigns between 2002 and 2014

2 ZWD noise characterization

- ZWD time series of all CONT campaigns and all stations
- Allan standard deviation (ASD): ZWD like random walk (***Fig. 1***)
- Power spectral densities (PSD) from ASD: ***Fig. 2***
- PSD changes over time: ***Fig. 3***

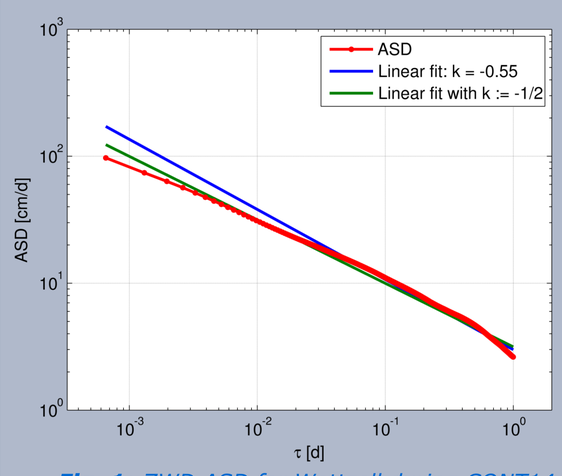

***Fig. 1**: ZWD ASD for Wettzell during CONT14*

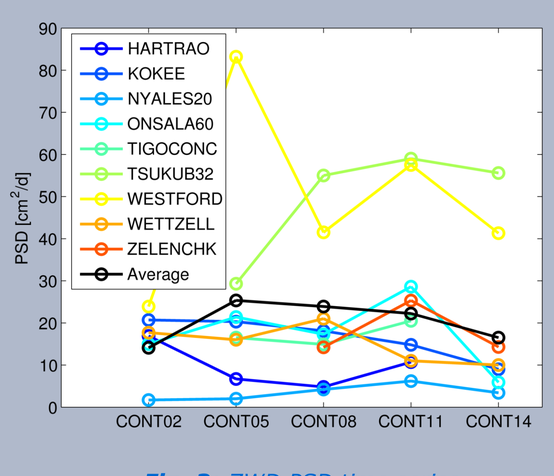

***Fig. 3**: ZWD PSD time series*

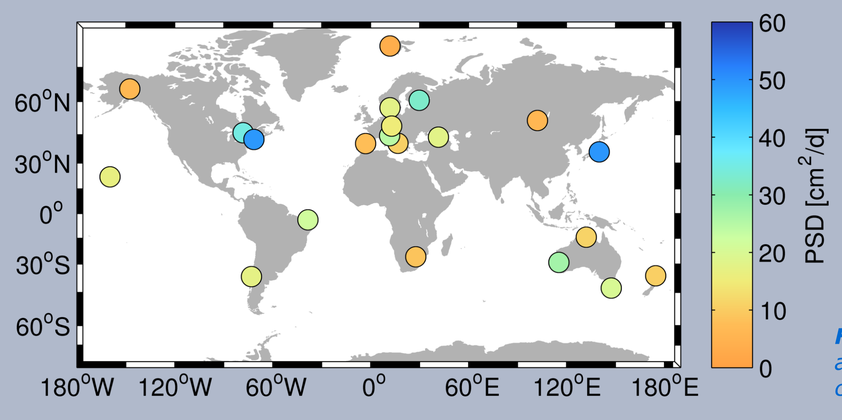

***Fig. 2**: ZWD PSD map averaged over all CONT campaigns*

3 Effects on station coordinates

- Baseline length (***Fig. 4***) and station coordinate repeatabilities (***Figs. 5 & 6***)
- Three different solutions:
  #1 KF solution with station based ZWD PSD (see ***Fig. 2***)
  #2 KF solution with average ZWD PSD
  #3 LSM solution (ZWD@20 min)
- Best result with solution #1: 2-3% improvement vs. #2, 3-7% vs. #3

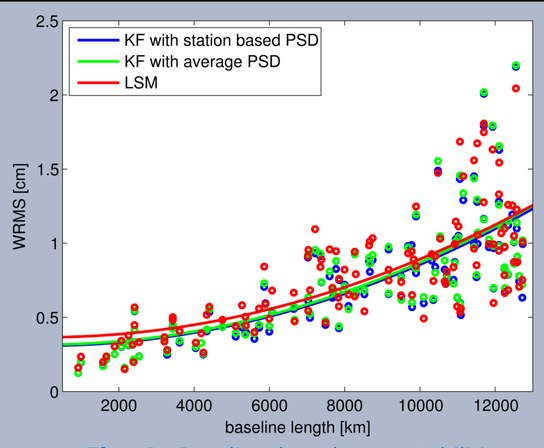

***Fig. 4**: Baseline length repeatabilities for CONT14*

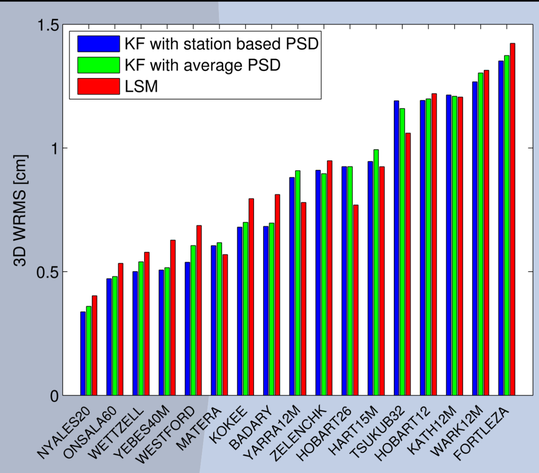

***Fig. 5**: 3D position repeatabilities for CONT14*

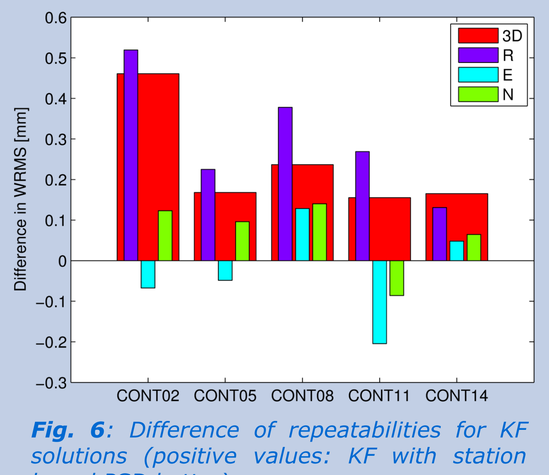

***Fig. 6**: Difference of repeatabilities for KF solutions (positive values: KF with station based PSD better)*

Conclusions

- Average **ZWD noise decreases** during the last CONT campaigns
- **KF performs better than LSM** in terms of baseline length and station position repeatabilities (improvement of 3-7%) & compared to ZWD from external datasets (>10%).
- **Station dependent ZWD noise improves** repeatabilities by 2-3%; strongest impact in height component

4 Comparison of ZWD

- Water vapor radiometer (WVR) ZWD every 6-51 sec available for Onsala (CONT11 - ***Fig. 7*** & CONT14) and Tsukuba (CONT11)
- GPS ZWD every 5 min available for Onsala & Wettzell (***Fig. 8***) during CONT14
- Linearly interpolated VLBI solutions to GPS/WVR epochs to compute differences (averaged over all stations: ***Tab. 1***)
- KF shows smaller standard deviations w.r.t. WVR (11%) and GPS (13%) compared to LSM

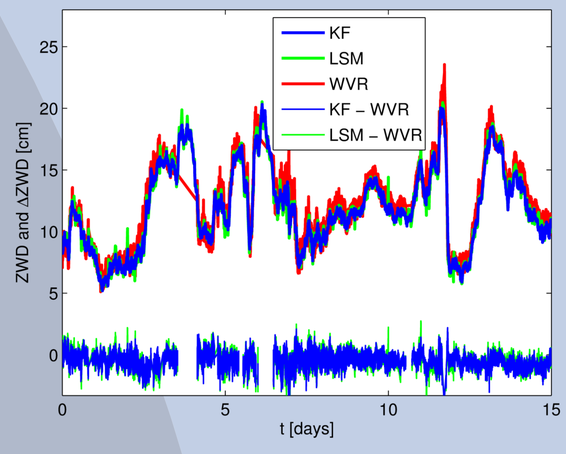

***Fig. 7**: ZWD from VLBI (KF & LSM) and WVR for Onsala during CONT11*

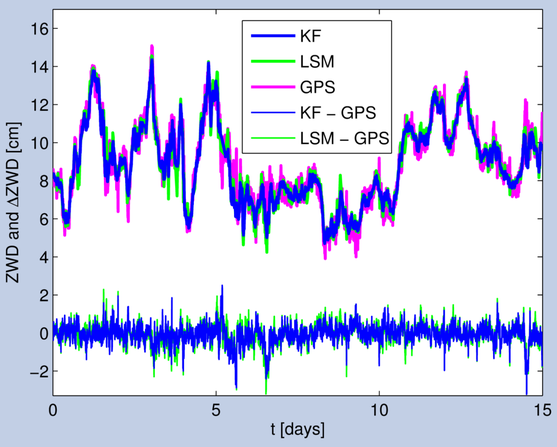

***Fig. 8**: ZWD from VLBI (KF & LSM) and GPS for Wettzell during CONT14*

***Tab. 1**: Statistics for the ZWD differences, averaged over all stations*

	Bias [cm]	RMS [cm]	STD [cm]
KF – WVR	-1.11	1.33	0.65
LSM – WVR	-1.13	1.39	0.72
KF – GPS	-0.10	0.48	0.47
LSM – GPS	-0.09	0.53	0.53

Reference:
Herring, T.A., Davis, J.L., Shapiro, I.I.: Geodesy by radio interferometry: The application of Kalman Filtering to the analysis of very long baseline interferometry data. Journal of Geophysical Research: Solid Earth 95(B8), 12561–12581 (1990). doi:10.1029/JB095iB08p12561
Soja, B., Nilsson, T., Karbon, M., Zus, F., Dick, G., Deng, Z., Wickert, J., Heinkelmann, R., Schuh, H.: Tropospheric delay determination by Kalman filtering VLBI data. Earth, Planets and Space (2015, submitted).

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).