Comparison of VLBI TRF solutions based on Kalman filtering and recent ITRS realizations

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EGU General Assembly #EGU16

GFZ Helmholtz Centre Potsdam

April 19th, 2016

HELMHOLTZ ASSOCIATION

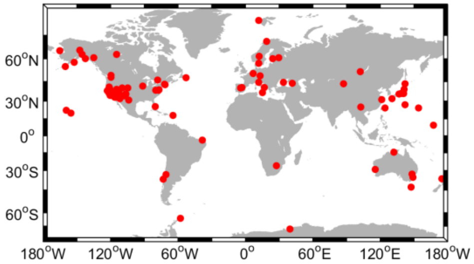
Kalman filter for TRF determination

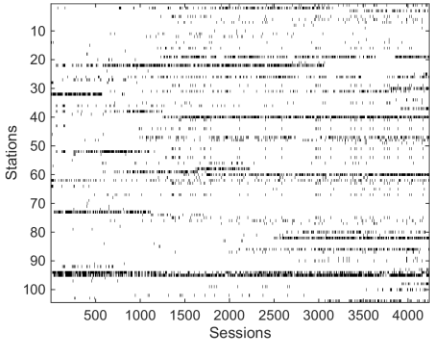
- Time series representation → capture short-term variations
- Short-term stability by restrictive stochastic model
- Predictions by extrapolating the functional model
- TRF easy to update & real-time capable

- Kalman filter software for multi-technique TRFs (KALREF) developed at NASA JPL
  - Wu et al. (JGR, 2015)
  - JTRF2014
- Software at GFZ: VLBI only – focus on different modeling approaches
  - Soja et al. (JoG, submitted)

Input VLBI data

- 4239 IVS VLBI sessions between 1980 and 2013
  - 4 or more telescopes participating
  - Spanning a polyhedron with a volume of more than 10^{15} m^3
- 104 stations out of 143 stations considered
  - Regular observations over more than 1 year
- Session-wise station coordinates XYZ
  - NNT+NNR w.r.t. ITRF2008 for all stations with ITRF2008 coordinates





Kalman filter setup

- Kalman filter & smoother
- States updated for every VLBI session (usually every 1-4 d)
- Breaks in position and/or velocity
  - Earthquakes, equipment changes
- Output:
  - Filtered and smoothed XYZ time series
  - Average values: XYZ at reference epoch, velocities, annual signals
- Datum by 12 parameter transformation (scale not changed)
  - Average coordinates & velocities w.r.t. ITRF2008 for selected datum stations

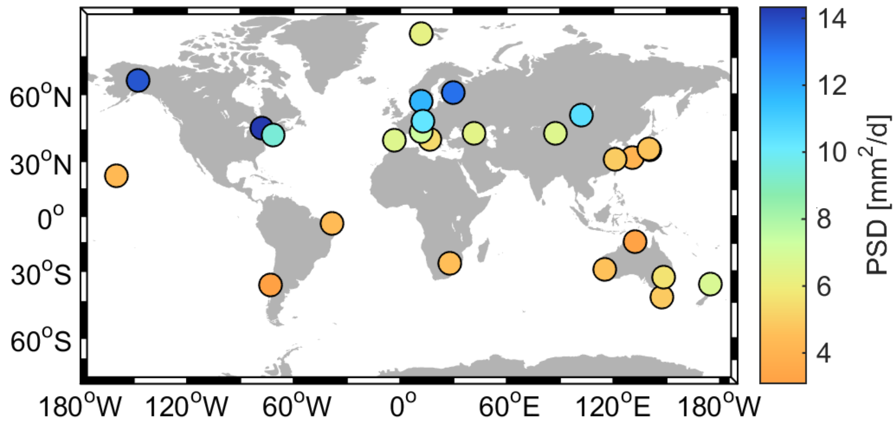
$$\tilde{x}_k = F_k x_{k-1}$$

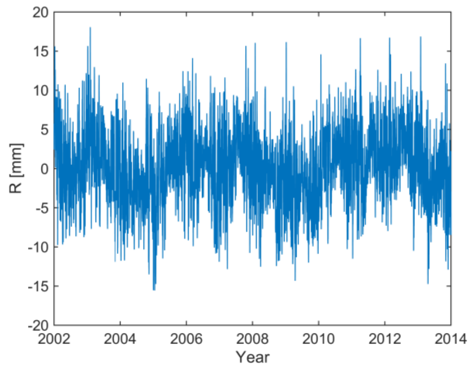
$$\tilde{P}_k = F_k P_{k-1} {F_k}^T + Q_k$$

$$F_k = \begin{bmatrix} 1 & dt & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 2\cos\left(2\pi \frac{dt}{T}\right) & -1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Process noise of station coordinates

- Assumption: irregular station coordinate variations due to unmodeled NTAL, NTOL & CWSL displacements
- Time series of NTAL, NTOL & CWSL
  - Downloaded from massloading.net (Petrov, 2015), resolution 6 h
  - Sum of displacements calculated; trend & annual signal removed
- Assuming random walk (RW) processes → computation of power spectral densities (PSDs) of driving white noise

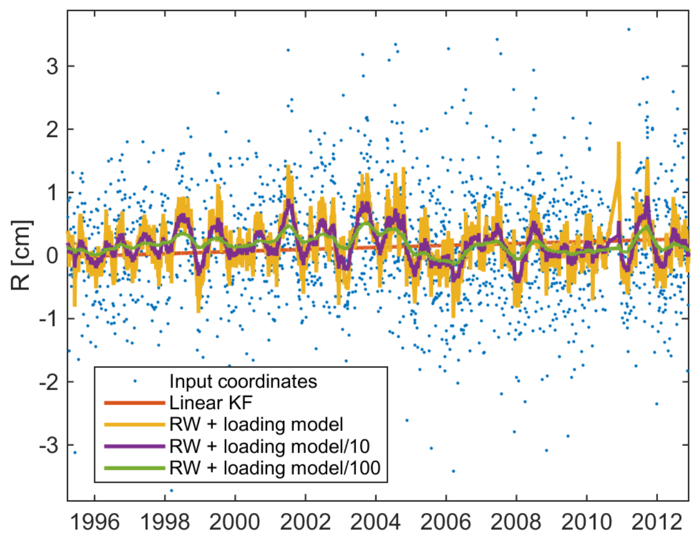




ALGOPARK

Station coordinate time series

- Solutions with different functional and stochastic models
  - Linear, linear+annual, RW, RW+annual, integrated RW
- RW solutions: applying noise model from loading displacements
  - Scaled by factor 1, 1/10, 1/100



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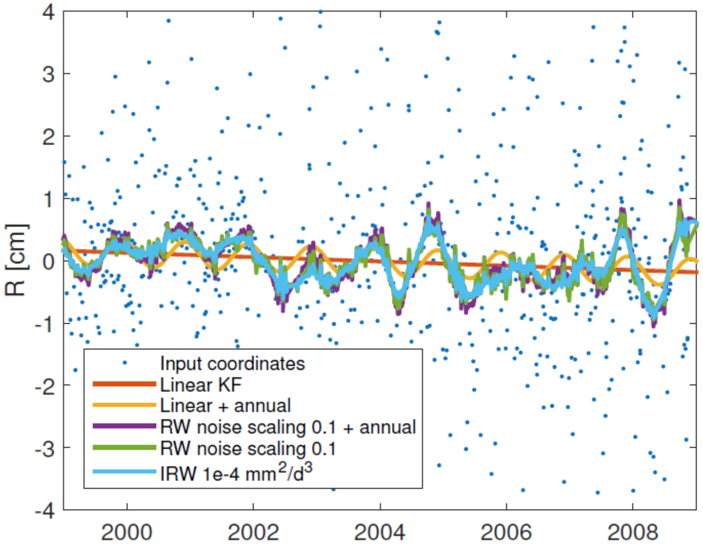
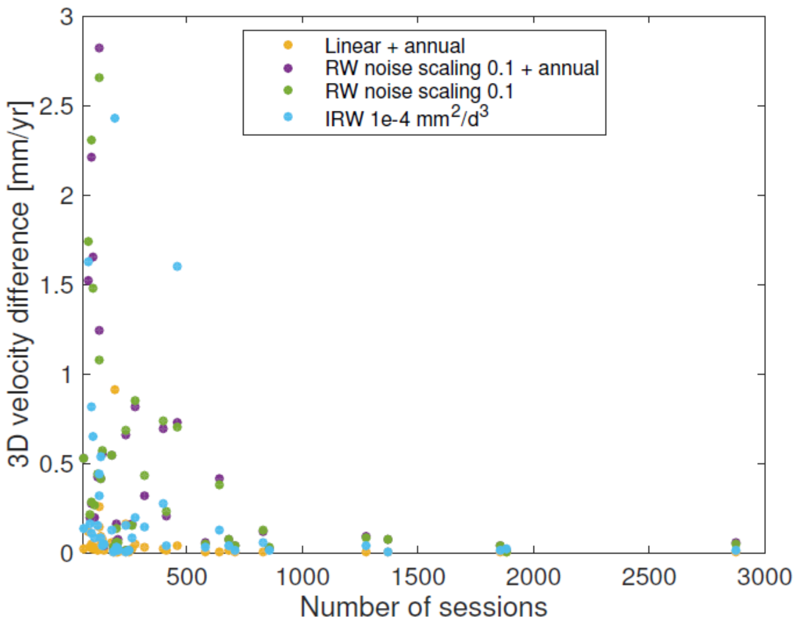


FORTLEZA

Velocity comparison of TRF solutions

- RMS values of the velocity differences of Kalman filter TRF solutions w.r.t. the linear Kalman filter TRF solution
- 74 stations
  - with observation history > 3 years
  - without breaks
- 22 stations
  - out of the 74 stations
  - participated in more than 200 sessions

RMS [mm/yr]	74 stations				22 stations (> 200 obs.)			
	R	E	N	3D	R	E	N	3D
Linear + annual	1.65	0.64	0.52	1.85	0.03	0.01	0.01	0.04
RW noise scaling 0.1 + annual	3.52	0.88	2.61	4.47	0.30	0.12	0.09	0.34
RW noise scaling 0.1	1.26	0.56	1.48	2.02	0.31	0.13	0.10	0.35
IRW 10^{-4} mm^2/day^3	1.26	0.39	0.61	1.45	0.28	0.09	0.19	0.35



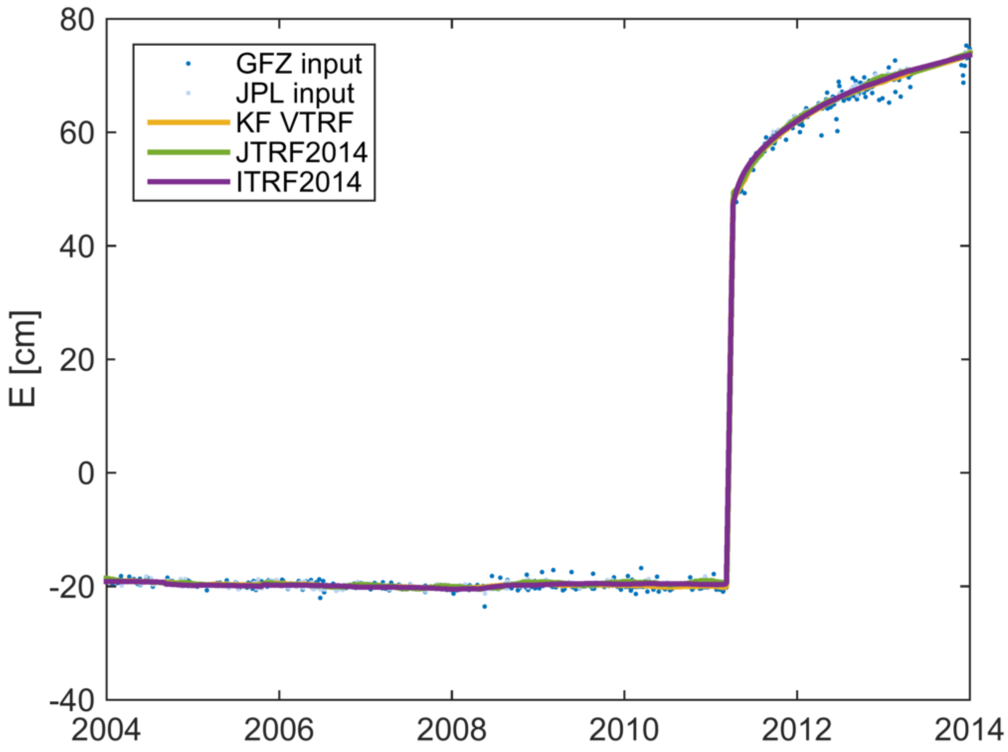
0.3 mm/yr effect

ITRF2014 & JTRF2014

- Based on GNSS, VLBI, SLR & DORIS SINEX files
- Combination at the parameter level
  - VLBI normal equations inverted before combination
- Datum: SLR origin, ITRF2008 orientation, VLBI+SLR scale
- ITRF2014: least squares estimation
  - Linear + post-seismic + annual + semi-annual
- JTRF2014: Kalman filter & smoother
  - Linear + annual + semi-annual
  - Process noise for non-linear & non-harmonic signals
  - Weekly time steps

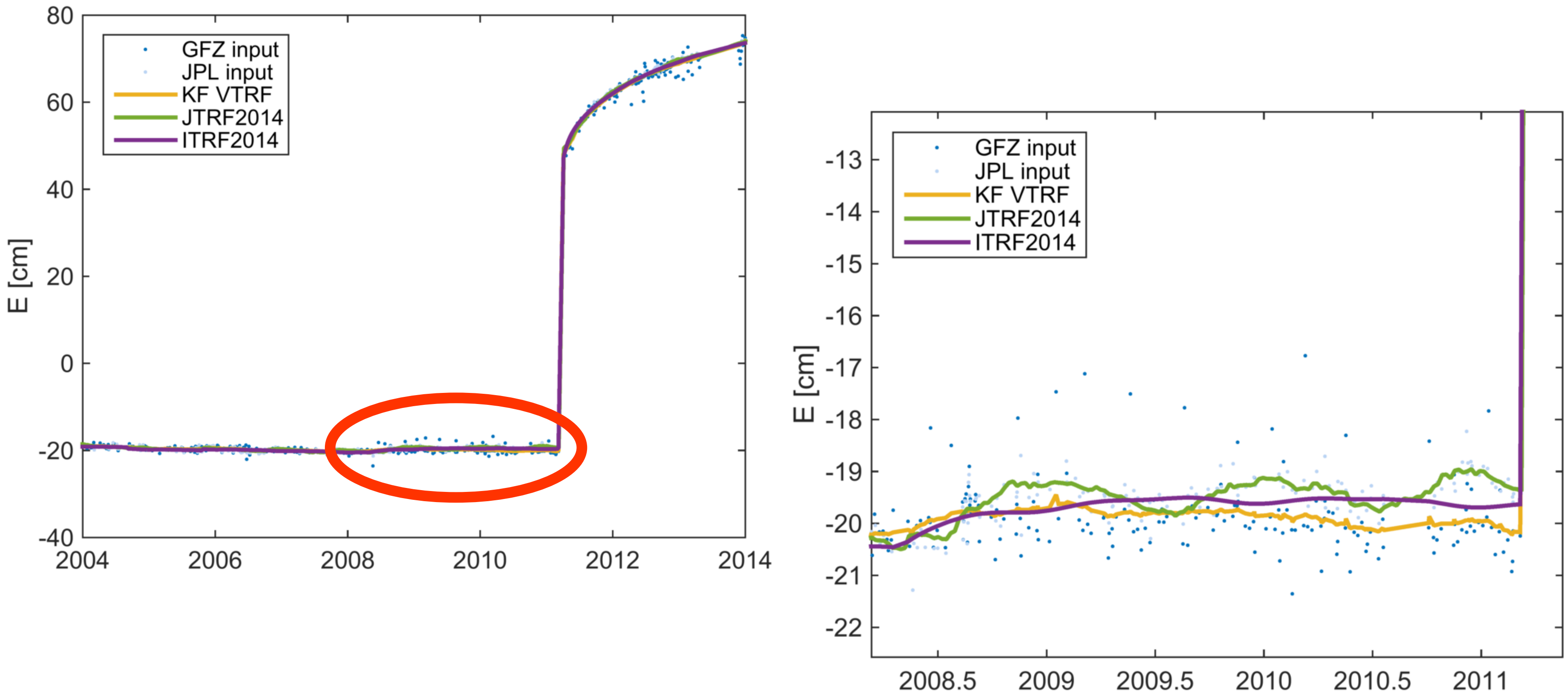
Comparison KF VTRF vs. JTRF/ITRF

- TSUKUB32: east component



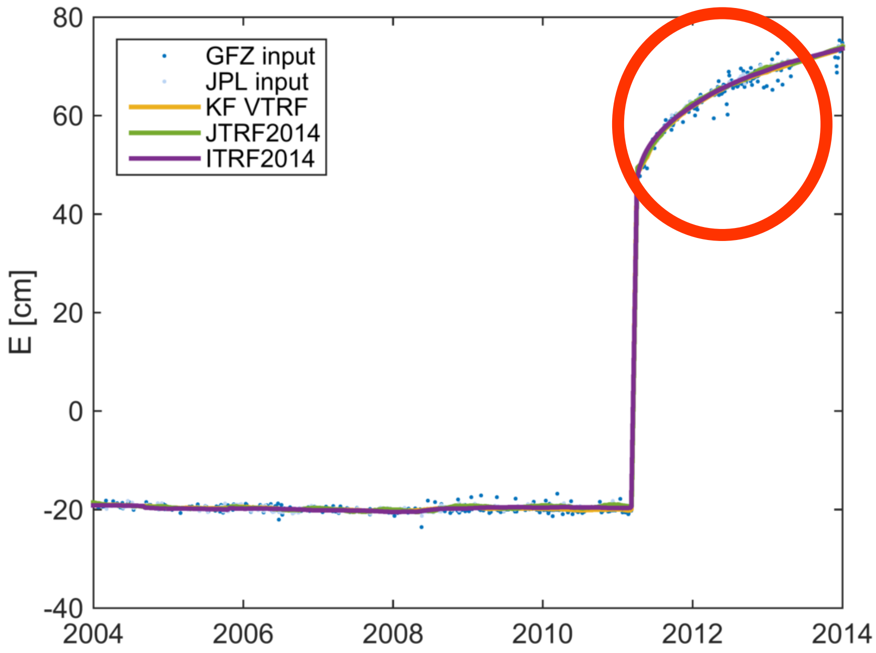
Comparison KF VTRF vs. JTRF/ITRF

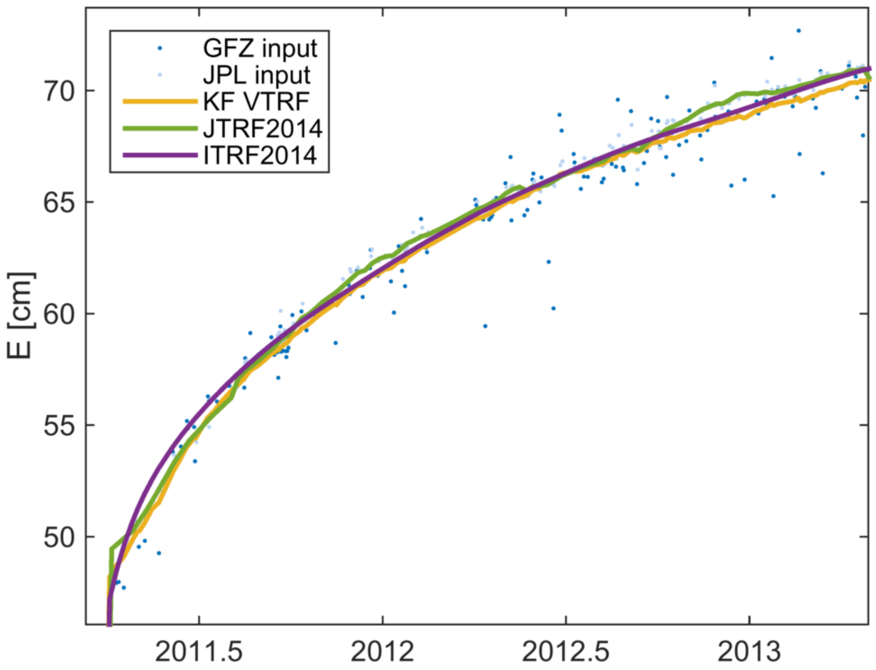
- TSUKUB32: east component – before Tōhoku earthquake



Comparison KF VTRF vs. JTRF/ITRF

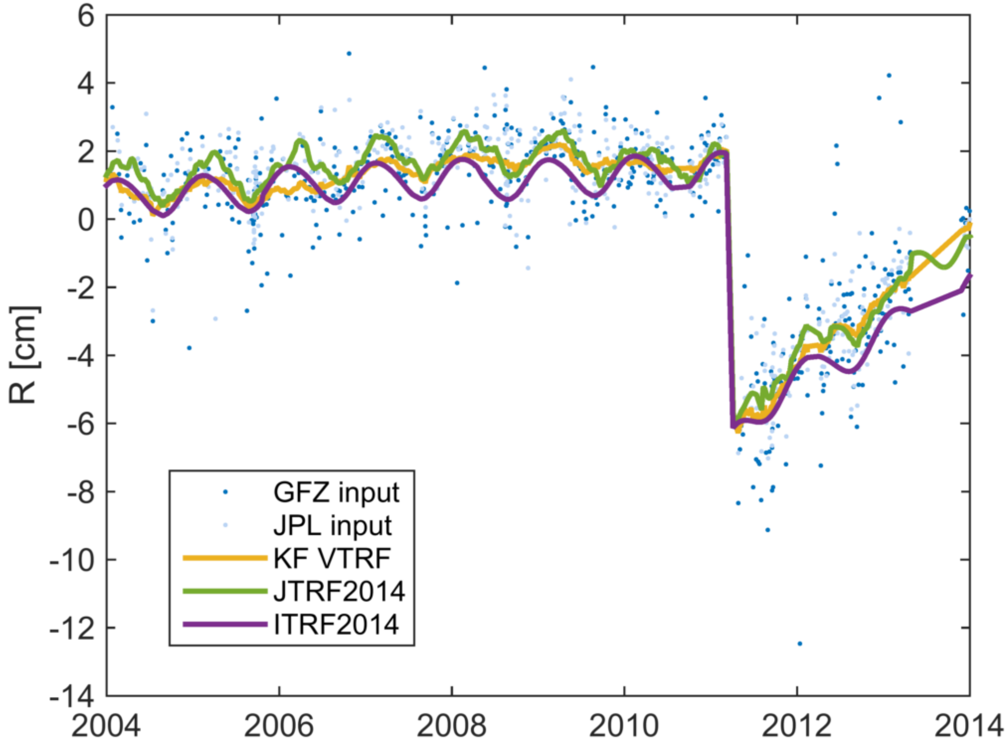
- TSUKUB32: east component – after Tōhoku earthquake





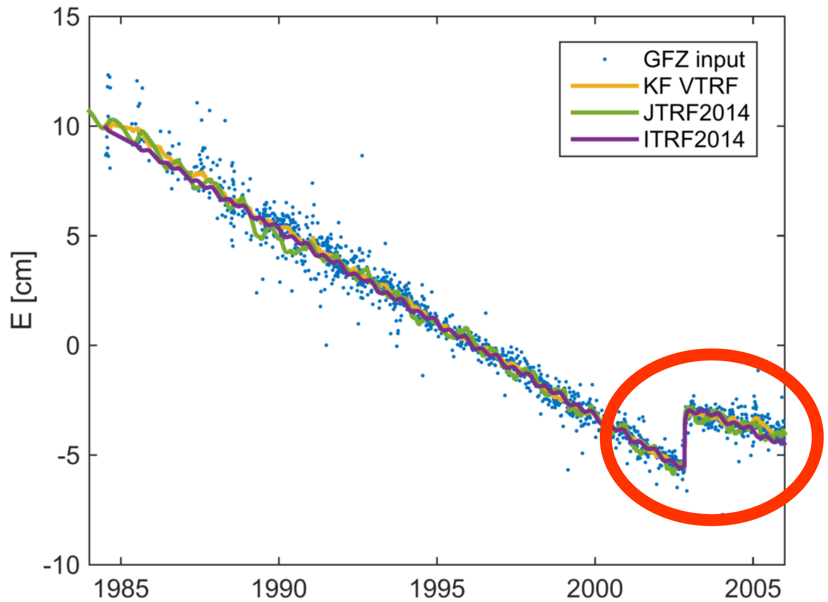
Comparison KF VTRF vs. JTRF/ITRF

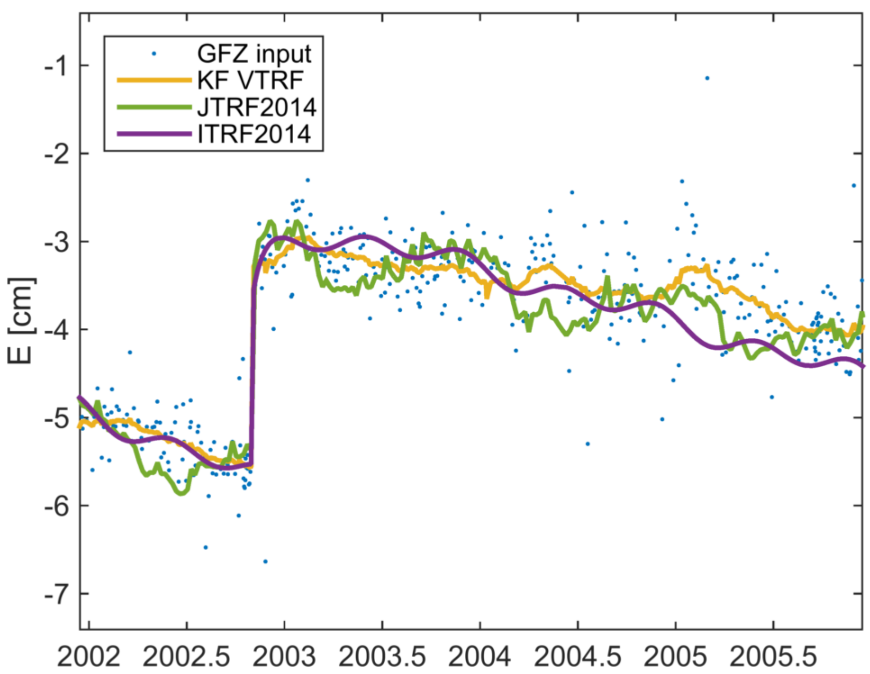
- TSUKUB32: height component



Comparison KF VTRF vs. JTRF/ITRF

- GILCREEK: east component





Recapitulation

- **Kalman filtering** successfully used to create **VLBI TRFs**
  - Time series representation – recovery of non-linear signals
- **Stochastic model** station-dependent and time-variable
  - Noise from unmodeled elastic displacements
- **Effect on velocities** when using process noise: > 0.3 mm/yr
- **Comparison** to ITRF2014 and JTRF2014
  - Promising agreement of post-seismic signals
  - Differences in seasonal signals
  - Investigations to be extended… (e.g., including DTRF2014)

References

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Thanks for your attention!

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Acknowledgements
VLBI data: IVS
TRF data: IGN & JPL
Loading data: IMLS
Project funding: FWF (VLBI-ART – P 24187-N21)