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Kalman filter terrestrial reference frame solutions based on time-variable process noise

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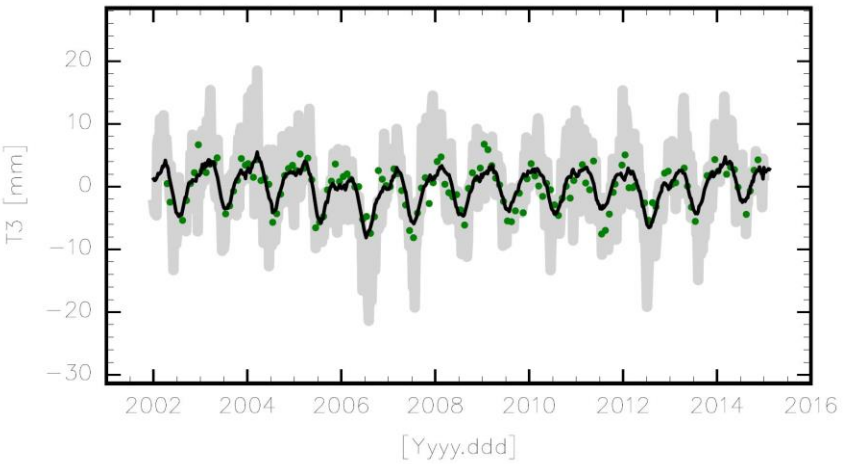
Background

- **Kalman filtering** has become an established technique for the determination of terrestrial reference frames (TRF)
  - Example: JTRF2014 [Abbondanza et al., submitted]
- Time series realization → capture short-term variations
- Predictions by extrapolating the functional model

- **Process noise** controls temporal variability of station coordinates
- So far, process noise assumed to be station-dependent, but *constant over time*

JTRF2014 geocenter [Abbondanza et al., submitted]



Goals

1. Derive process noise model with temporal variability
   - Monthly station-dependent process noise model

2. Study impact of this process noise model on TRF solutions
   - Here: VLBI TRF (VTRF)

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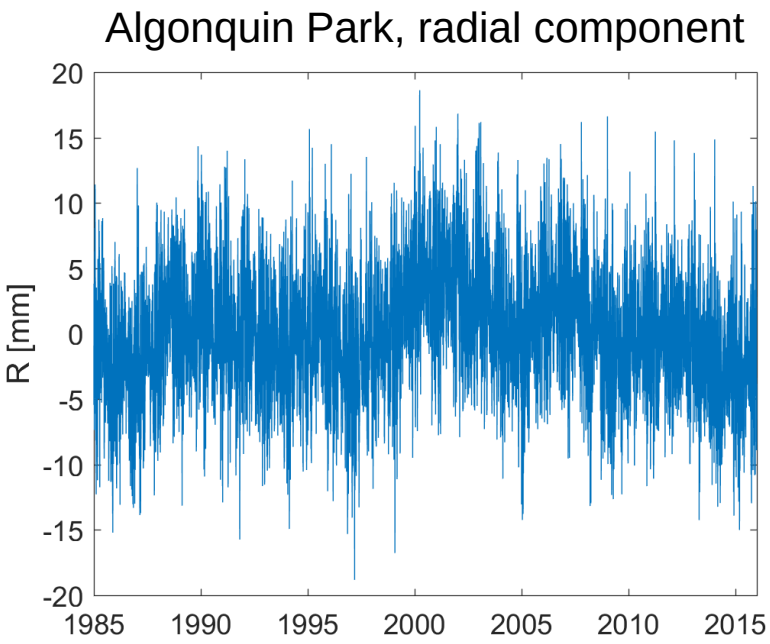
Process noise model

- Assumption: irregular station coordinate variations due to unmodeled non-tidal (NT) loading displacements
  - Atmosphere (NTAL), oceans (NTOL) & hydrology (HYDL)
- Time series of NTAL, NTOL & HYDL between 1985 – 2015
  - GFZ Potsdam loading models
    - Dill & Dobslaw, 2013
  - Temporal resolution 1 day
  - Sum of displacements calculated
  - Trend and seasonal signal removed (part of TRF coordinate model)

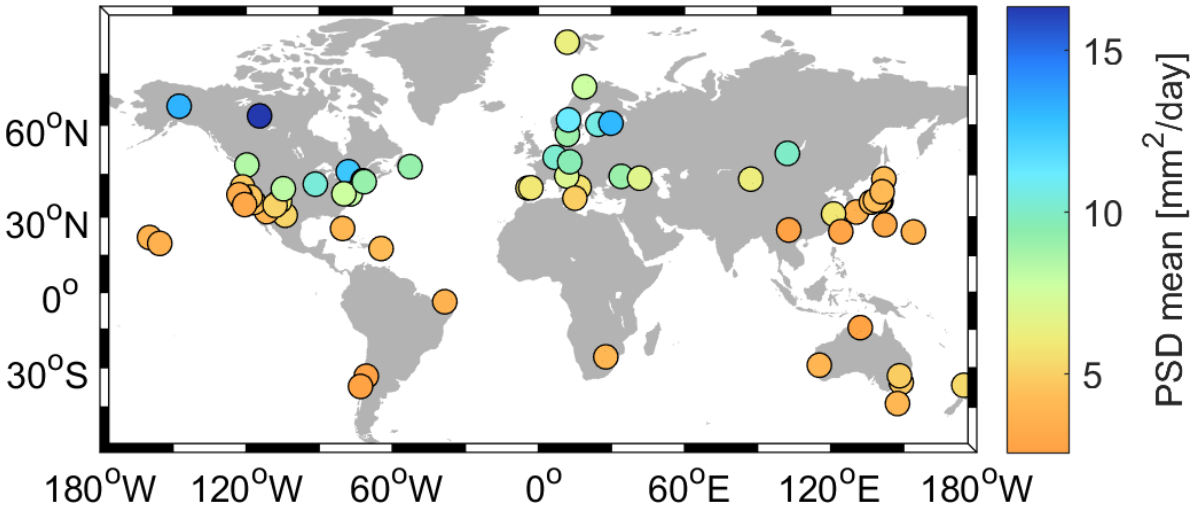


Constant process noise model

- Allan standard deviation (ADEV) for noise characterization
- Assuming random walk (RW) processes → computation of power spectral densities (PSD) of driving white noise

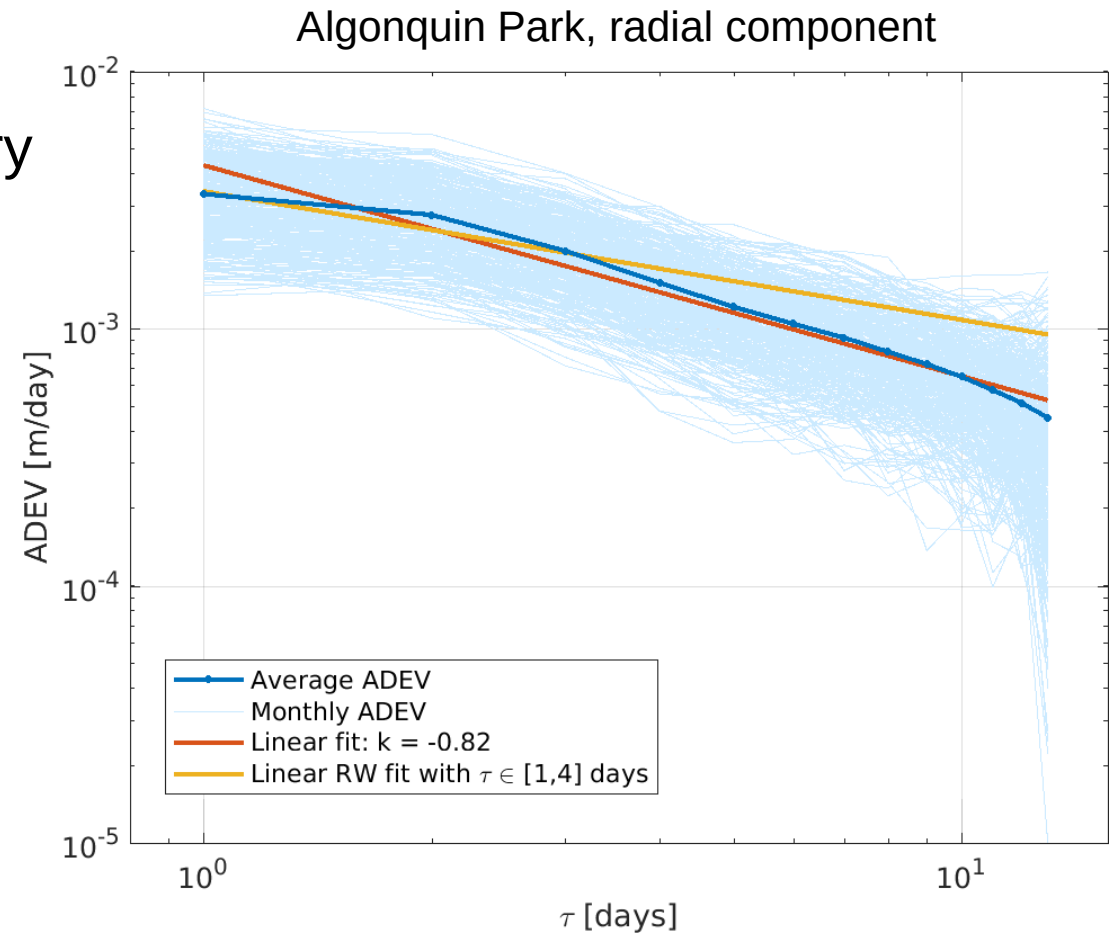
[Soja et al., 2016]

Constant process noise model (radial):



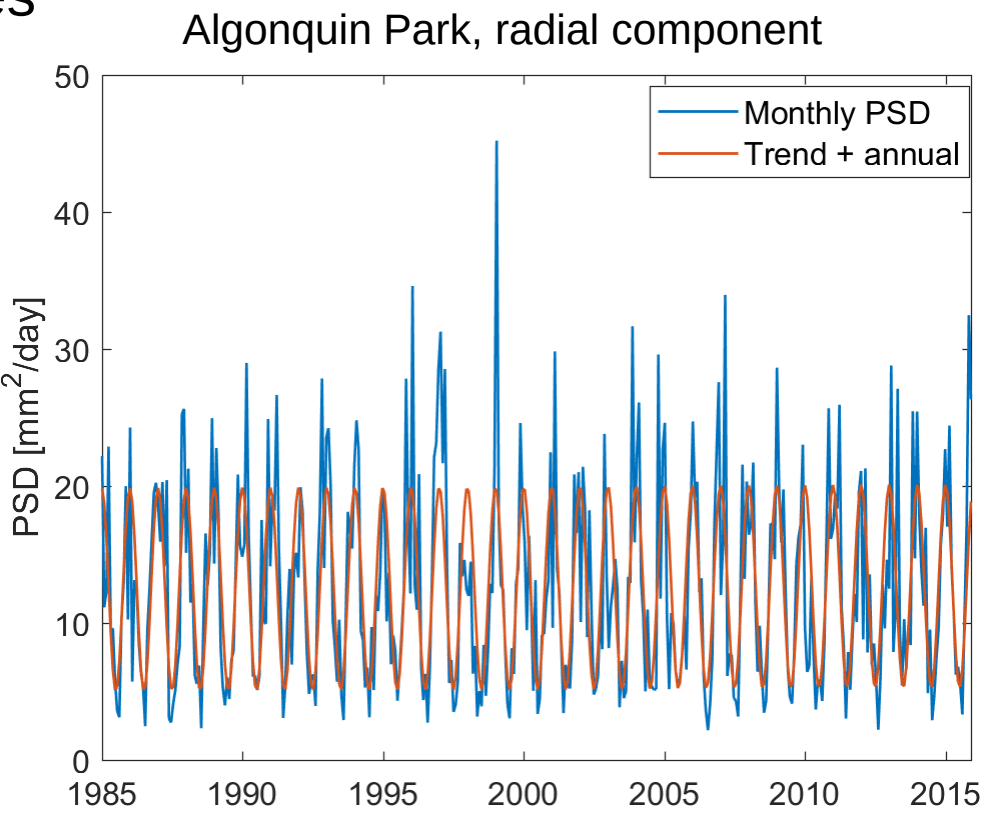
Monthly process noise model

- Split loading time series into monthly chunks
- Compute ADEV for every station and month



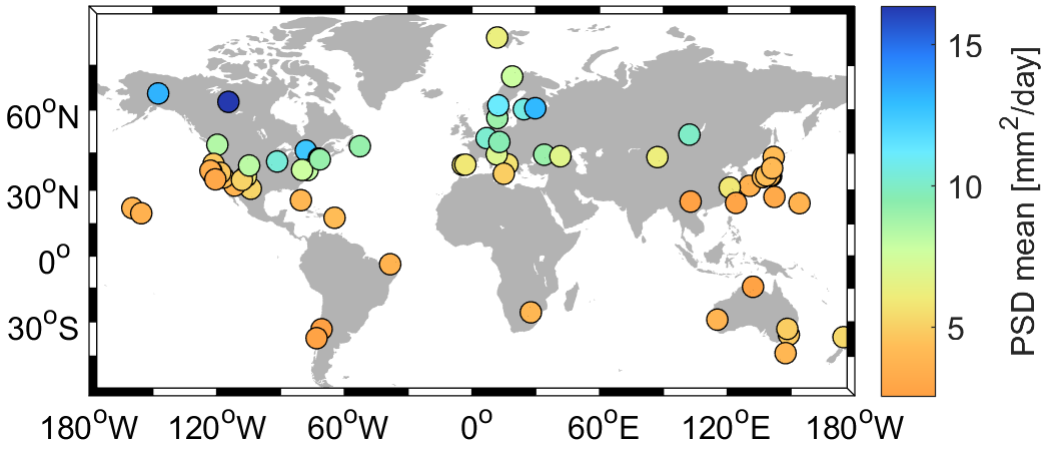
Monthly process noise model

- Estimate monthly PSD values for every station
- Fit trend and annual signal (not used in TRF computation)

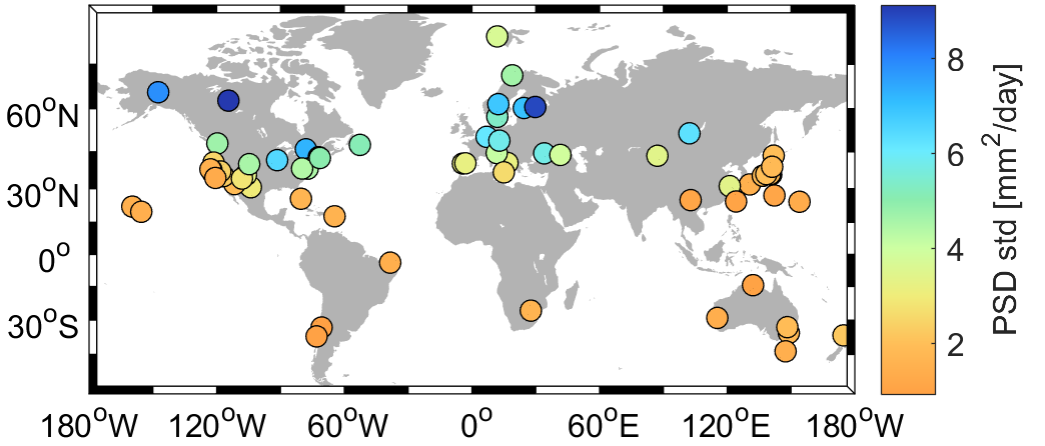


Mean and std. dev. of PSD time series

- **Mean** PSD larger for high latitudes (NTAL)
- Differences in PSD between individual stations: factor 4

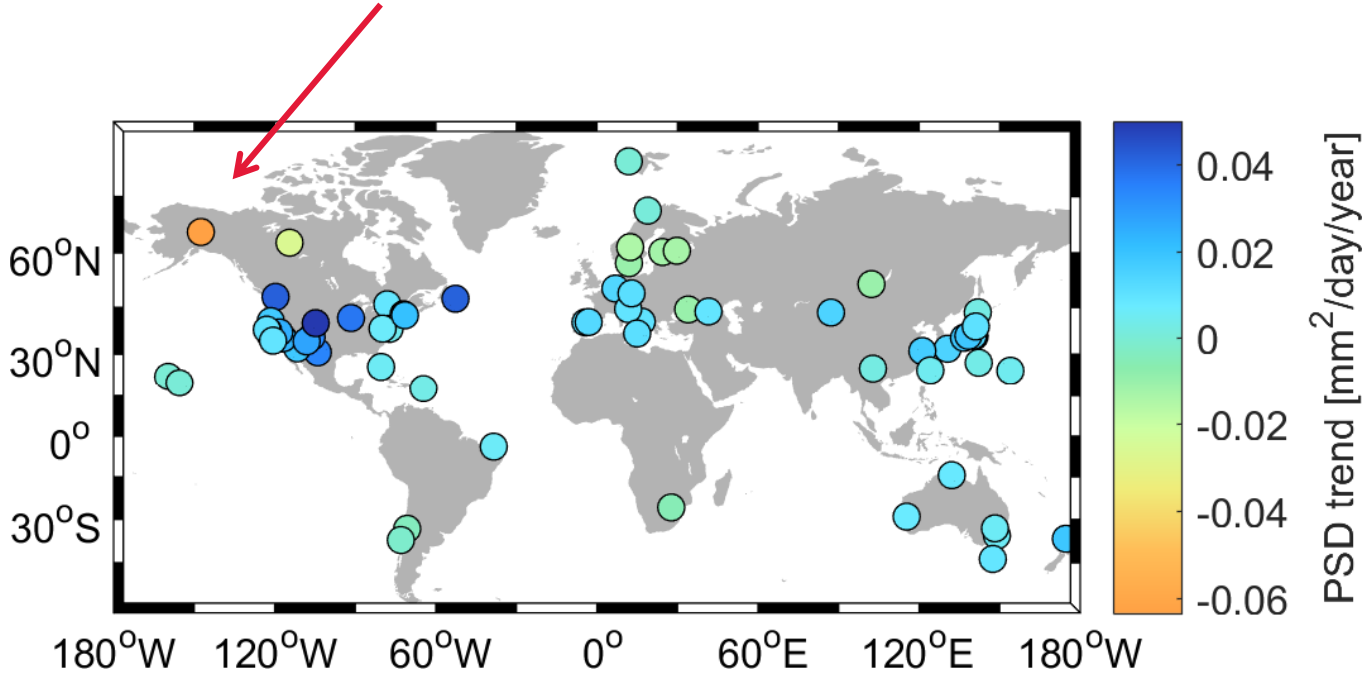


- **Standard deviation** of monthly PSD shows same pattern as mean PSD



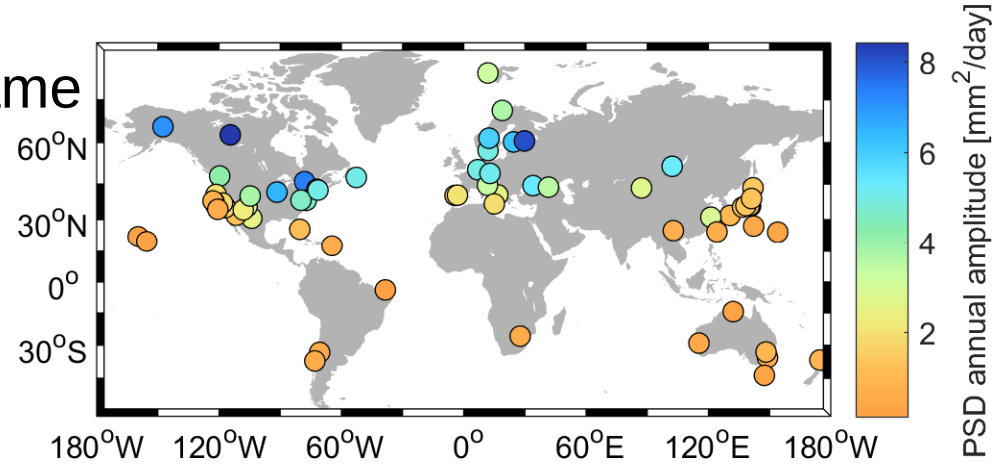
Trends in PSD time series

- On average: noise slightly increases over time
  - 0.01 mm^2/day/year (5% change in noise over 31 years)
- Largest change: Gilmore Creek (10% reduction over 31 years)

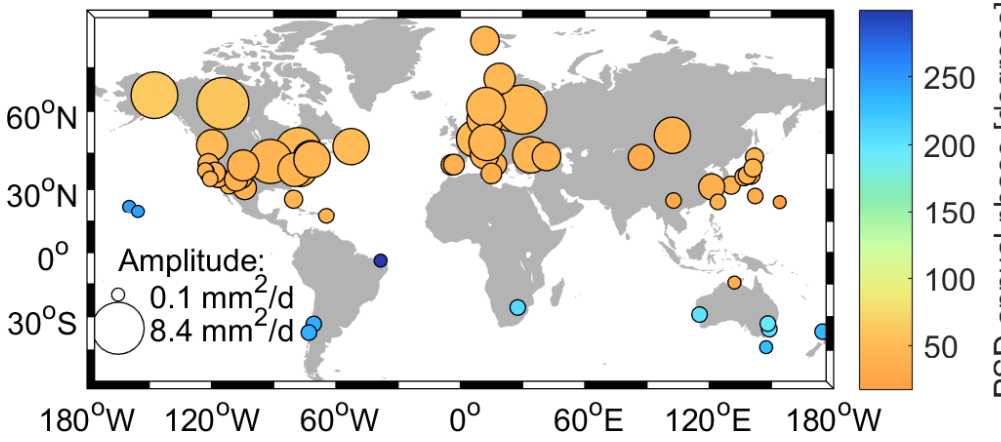


Annual signals in PSD time series

- **Amplitude** pattern is the same as for mean and std. dev.
- Annual signals much more important than trend: on average 37% of average offset



- **Phase** is in line with seasons on different hemispheres



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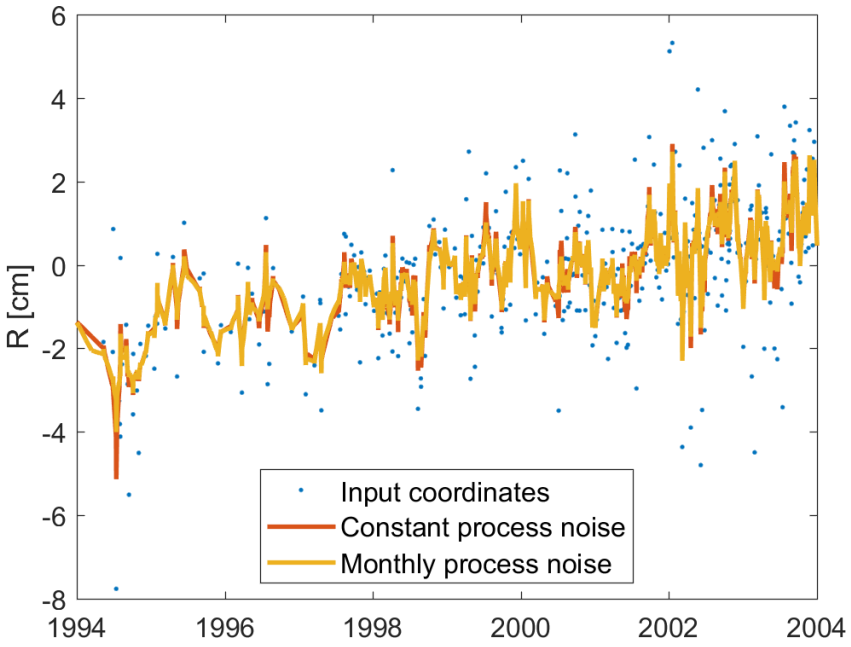
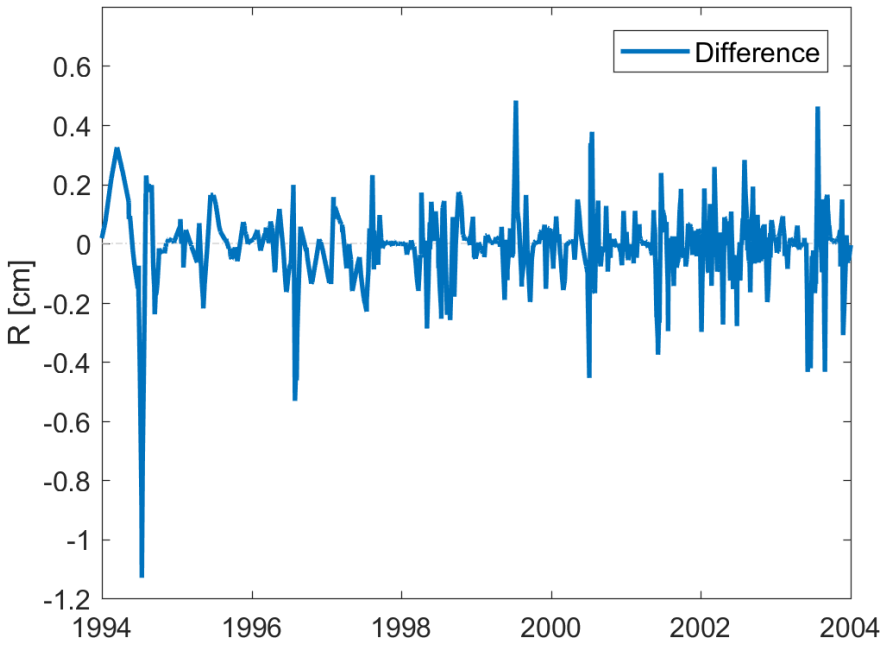
VLBI TRF solutions

- Kalman filter & smoother
- Coordinate model: linear (offset + velocity) & annual
- States updated for every VLBI session (usually every 1-4 days)
- Input data: 1985 – end of 2015
  - 3992 IVS VLBI sessions
  - 84 stations
  - Single session analysis with least-squares module of VieVS@GFZ, adhering to IERS Conventions 2010
- Output: filtered and smoothed time series of station coordinates and their covariances

TRF solutions for Algonquin Park

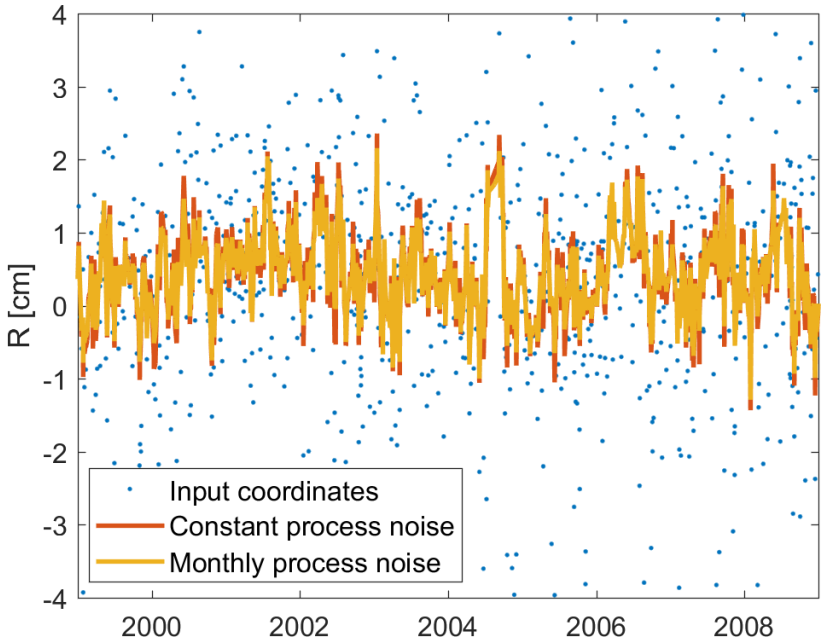
- Comparison between TRFs based on constant and monthly process noise
- Algonquin Park: difference 0.1 mm on average, max. 1 cm

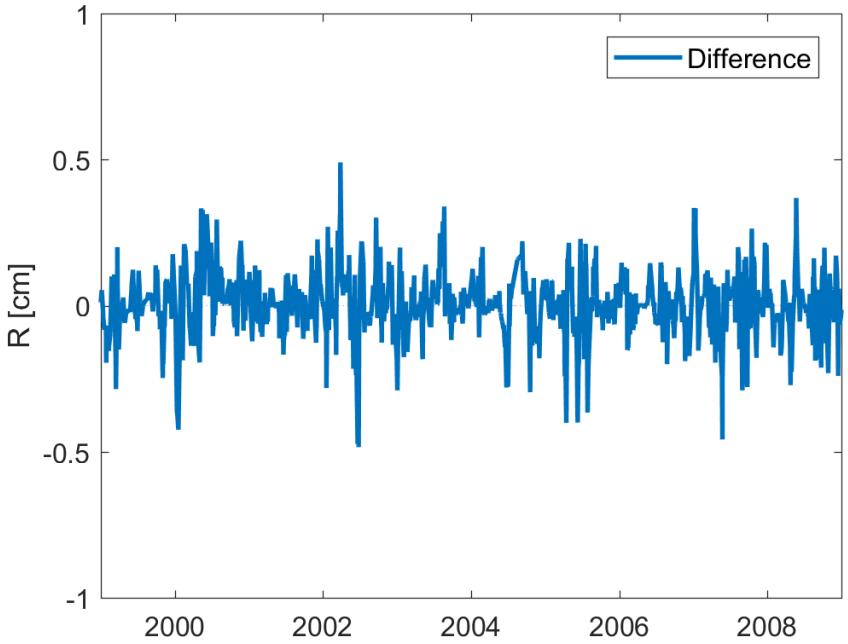




TRF solutions for Kokee Park

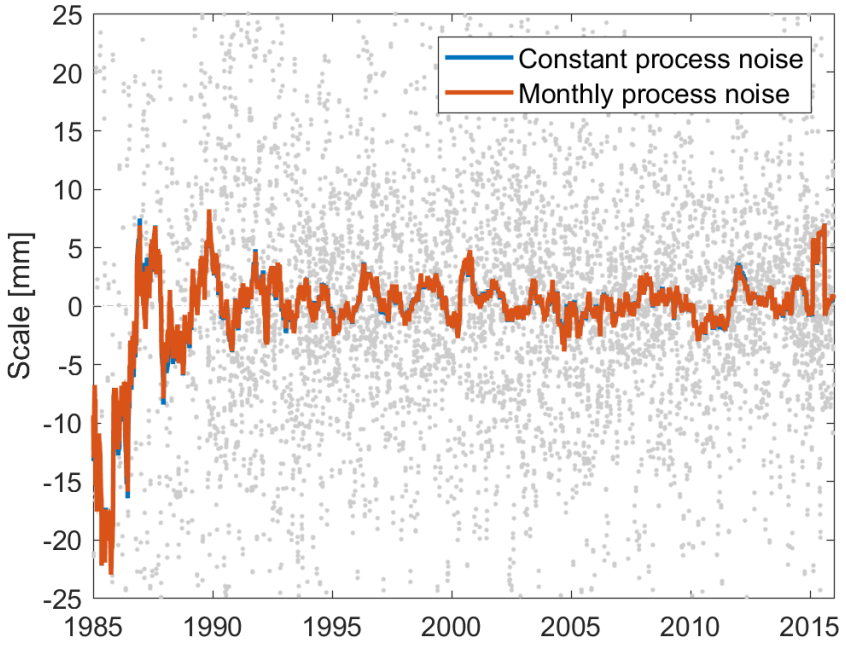
- Comparison between TRFs based on constant and monthly process noise
- Kokee Park: difference 0.1 mm on average, max. 5 mm

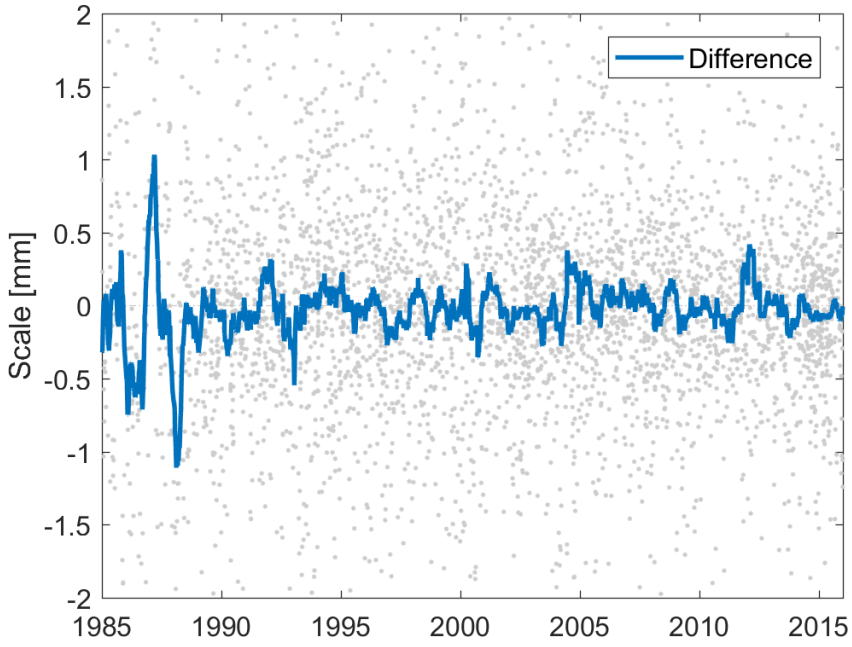




Network scale

- Scale from Helmert transformation between TRF coordinates and input coordinates
- Difference: 0.02 mm on average, 9 mm maximum





Grey dots: scale per session, colored lines: 180-day moving average

Network scale

Scale [mm]	WMEAN	WRMS
Constant PSD	0.10	9.26
Monthly PSD	0.12	9.27
Difference	**0.02**	**0.01**

- WRMS of residuals of Helmert transformation
  - Average over all stations

WRMS [mm]	R	E	N	3D
Constant PSD	4.19	2.31	2.60	5.85
Monthly PSD	4.21	2.32	2.64	5.88
Difference	**0.03**	**0.01**	**0.01**	**0.03**

Conclusions

- **Kalman filter TRF** solution with **monthly process noise** model based on loading displacements
- Time series of process noise values:
  - Noise, noise variability & annual amplitudes larger in higher latitudes (NTAL dominated)
  - On average, noise slightly increases over time
  - Seasonal signals much larger than trend
- TRF coordinates differ by **up to 1 cm** between solutions with monthly and constant process noise models
- **Average effect** on TRF coordinates at the **level of 0.01 mm**

Thanks for your attention!

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Loading models: GFZ Potsdam

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References

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