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Comparison of tropospheric delay estimation using VLBI CONT14 data and WVR for the Onsala station

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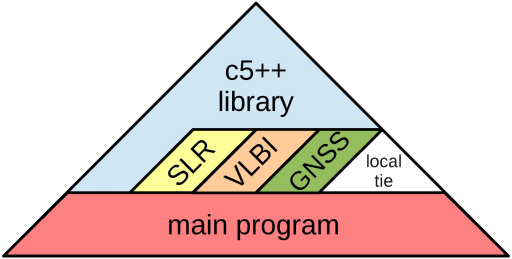
Outline

- Space-geodetic analysis with c5++
- Kalman filter basics and implementation in c5++
- Motivation for comparison of VLBI and WVR derived tropospheric parameters
- Comparison setup between VLBI and WVR
- Results
- Conclusions

Space-geodetic data analysis in c5++

- Fully controllable with external scripts & suitable for an automated analysis.
- Supports **S**olution (Software/Solution) **IN**dependent **EX**change (SINEX) format.



Hobiger & Otsubo (2014)

Kalman filter in c5++

Probabilistic concept of the filter

The purpose of any Bayesian filter is to compute the posterior distribution, $p(x_k|y_{1:k})$, at every timestep k, where x_k denotes a vector of parameters and $y_{1:k}$ the observations from the start of the estimation window.

Kalman filter in c5++

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On condition that the parameters are markovian, i.e., $p(x_k|x_{1:k-1}) = p(x_k|x_{k-1})$ and that all the distributions can be approximated as Gaussian, a closed form solution can be obtained which is the well-known Kalman filter equations.

Kalman filter in c5++

Implementation features

A square-root formulation of the filter has been developed which supports analysis of VLBI, GNSS and combination of them on the observation level.

Modelled stochastic processes are random walk, integrated random walk and Gauss-Markov.

Forward and backward runs are available to give averaged results. Outliers are detected using the mahalanobis distance.

Optimized implementation with advantages in computation time over LSQ, e.g., a continuous 15-day run is intractable in tha latter case on an ordinary work laptop.

Motivation for comparison of VLBI and WVR derived tropospheric parameters

	VLBI	WVR
Parameters	Continuous	Independent
Time Resolution	Epoch-wise	15 min[1]
Sampling rate	Moderate[2](2-4 min)	High (30 s)
Wet delay	Nuisance parameter	Primary observable

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[1] Time-averaged solution

[2] Particular for CONT14

Comparison Setup between VLBI and WVR

	VLBI	WVR
Method	Kalman filter in c5++	LSQ
Time period	6-20 May 2014	6-20 May 2014
Estimation model	IERS Conventions 2010, total delay	Four-Parameter Model, wet delay
Parameter setup	Random walk	every 15 min
ZWD	$\Phi = 8$ cm^2/day	
Gradients	$\Phi = 0.02$ cm^2/day	
Elevation cutoff ($^\circ$)	5	20

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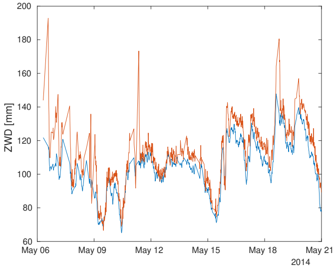
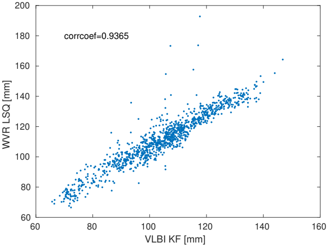
Results
Zenith Wet Delay Determination



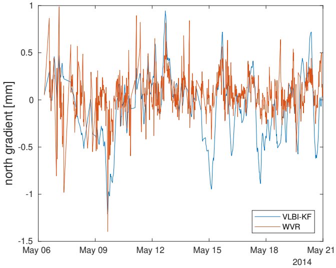
Estimated ZWD from VLBI and WVR



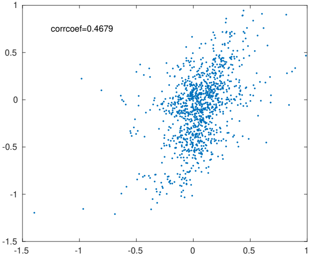
Correlation between estimated ZWD from VLBI and WVR during the CONT14 session (correlation coefficient is 0.9365).

Results

Tropospheric Gradients Determination



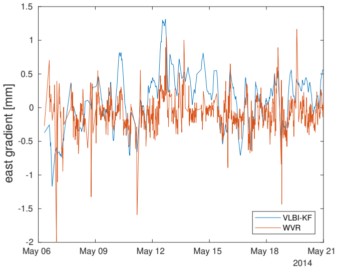
Estimated north gradient from VLBI and WVR



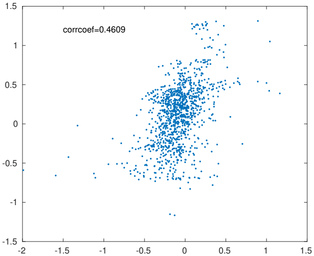
Correlation between estimated north gradient from VLBI and WVR during the CONT14 session (correlation coefficient is 0.4679).

Results

Tropospheric Gradients Determination-cont'd



Estimated east gradient from VLBI and WVR



Correlation between estimated east gradient from VLBI and WVR during the CONT14 session (correlation coefficient is 0.4609).

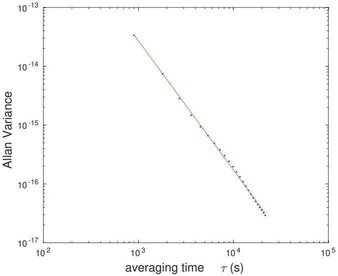
Results

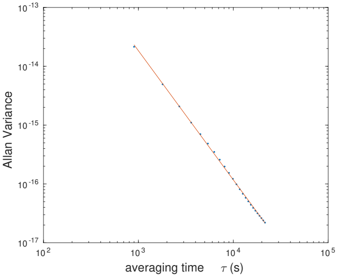
Tropospheric Gradients Determination-cont'd

	North gradient	East gradient
Averaging time	Correlation coefficient	
15 min	0.4679	0.4609
30 min	0.5262	0.5152
1 hr	0.5366	0.5120
2 hr	0.5689	0.5522
6 hr	0.5832	0.5777

Results

Allan Variance on WVR data for gradients

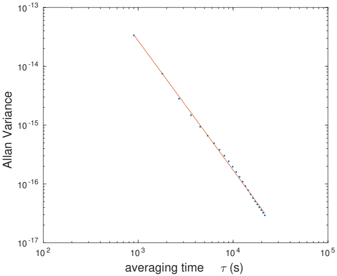


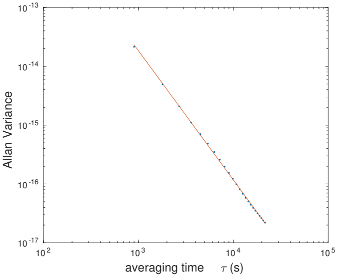


The analysis was performed for $\tau_0 = 15$ min, using the overlapping M-sample variance estimator and slopes of both components are equal to 2.1.
Gradients do not follow a random walk behavior, but are not pure white noise either.

Results

Allan Variance on WVR data for gradients





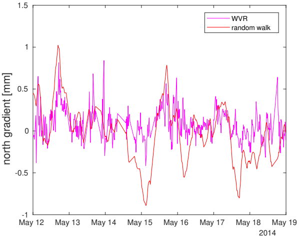
A Gauss-Markov model is examined

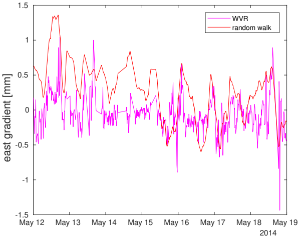
$$x_k = e^{\left(-\frac{\Delta t}{T_c}\right)} x_{k-1} + w_n$$

for $T_c = 1800$ s and $\Phi = 0.4$ cm^2/day

Results

Case study: Gauss-Markov model on gradients





Results

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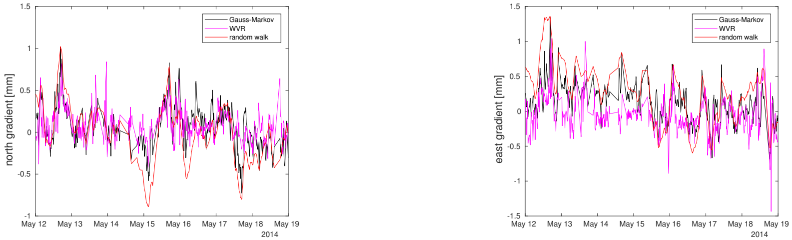

Stochastic Model	North gradient	East gradient
	rms [mm]	
random walk	0.3226	0.4726
Gauss-Markov	0.2225	0.3099

Conclusions

- The Kalman filter implementation on c5++ was presented and initial results show a clear performance advantage over LSQ in computational cost for multiple day runs.
- A comparison of tropospheric parameters between VLBI CONT14 data and WVR at the Onsala site show good agreement for zenith wet delay between them.
- Allan Variance on the gradients shows that they are more contaminated by noise, i.e., local gradients are short-lived and dissipate quickly. This suggests a Gauss-Markov process as a more proper stochastic model for them.
- A case study confirmed this with a reduction of about 30% for both north and east component.

Conclusions

- The implications of further tuning on gradients are to be explored when it comes to baseline repeatabilities.
- Frequency of observations of the legacy VLBI network is probably a limiting factor on the short time-scale resolution of gradients.
- An analysis using VGOS era data can provide further insight into that.

Thank you for your attention!

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