Atmospheric refractivity gradients from VLBI compared to those from GNSS, DORIS, WVR, and NWM

Robert Heinkelmann, Zhiguo Deng, Galina Dick, Tobias Nilsson,
Benedikt Soja, Florian Zus, Jens Wickert, Harald Schuh

Credits: Dr. M. Ramatschi, GFZ

CONT14 – 15 days of continuous VLBI

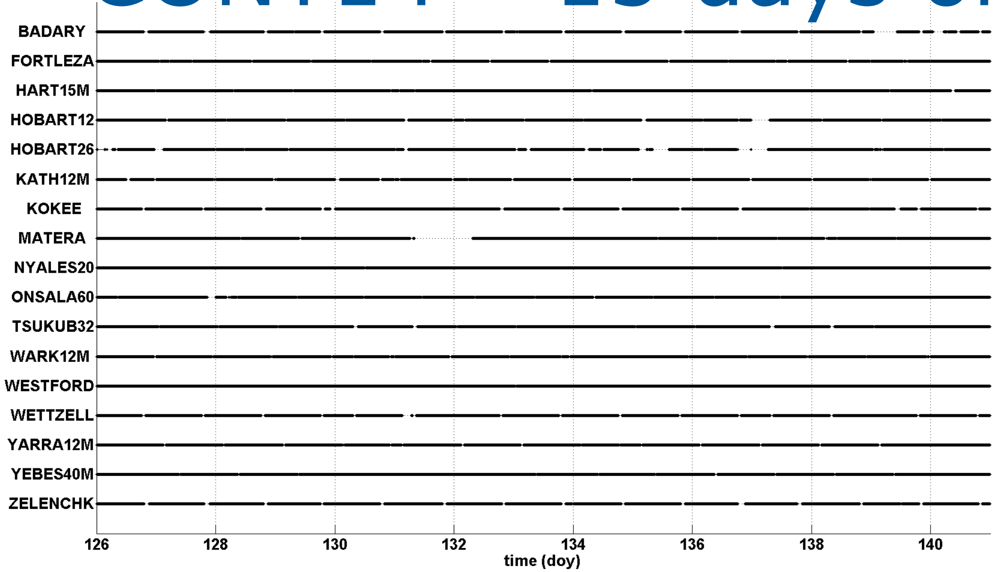
- 17 stations at 16 sites, good geographical distribution
- 2 antennas at Hobart, Australia: HOBART12, HOBART26

CONT14 – 15 days of continuous VLBI

During CONT14 …

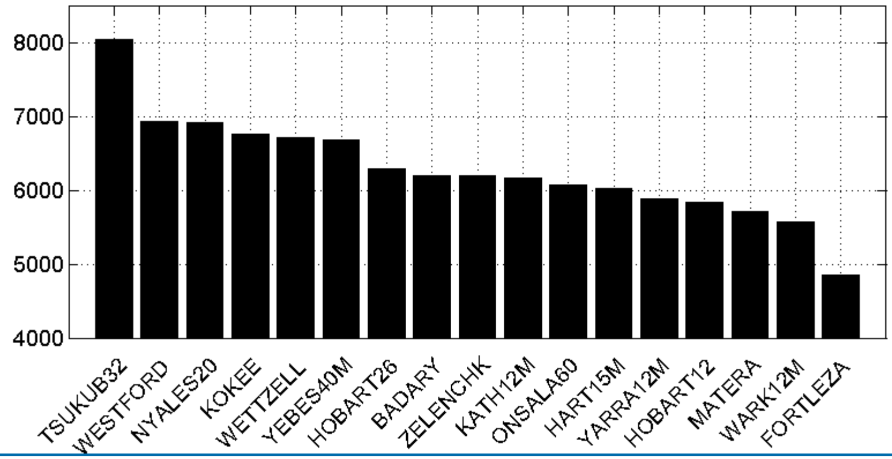
- BADARY and ZELENCHK have observed daily Russian intensive sessions ruu891 – ruu905 (duration: 90 min, start: 18:00 UT – 19:20 UT, end: 19:30 UT – 21:00 UT)
- WETTZELL together with KOKEE or TSUKUB32 have observed daily IVS intensive sessions (duration: 60 – 90 min, 07:00 UT – 09:00 UT or 18:30 UT – 20:30 UT)
- At Hobart several strong wind events occurred that led to down times of several hours at both telescopes
- At several stations occurred hardware problems and some stations didn't observe for unknown reason for several hours
- At Katherine and Warkworth there were extended system checks (KATH12M 1h and WARK12M 2h)

CONT14 – 15 days of continuous VLBI



← distribution of scans

scans per station →



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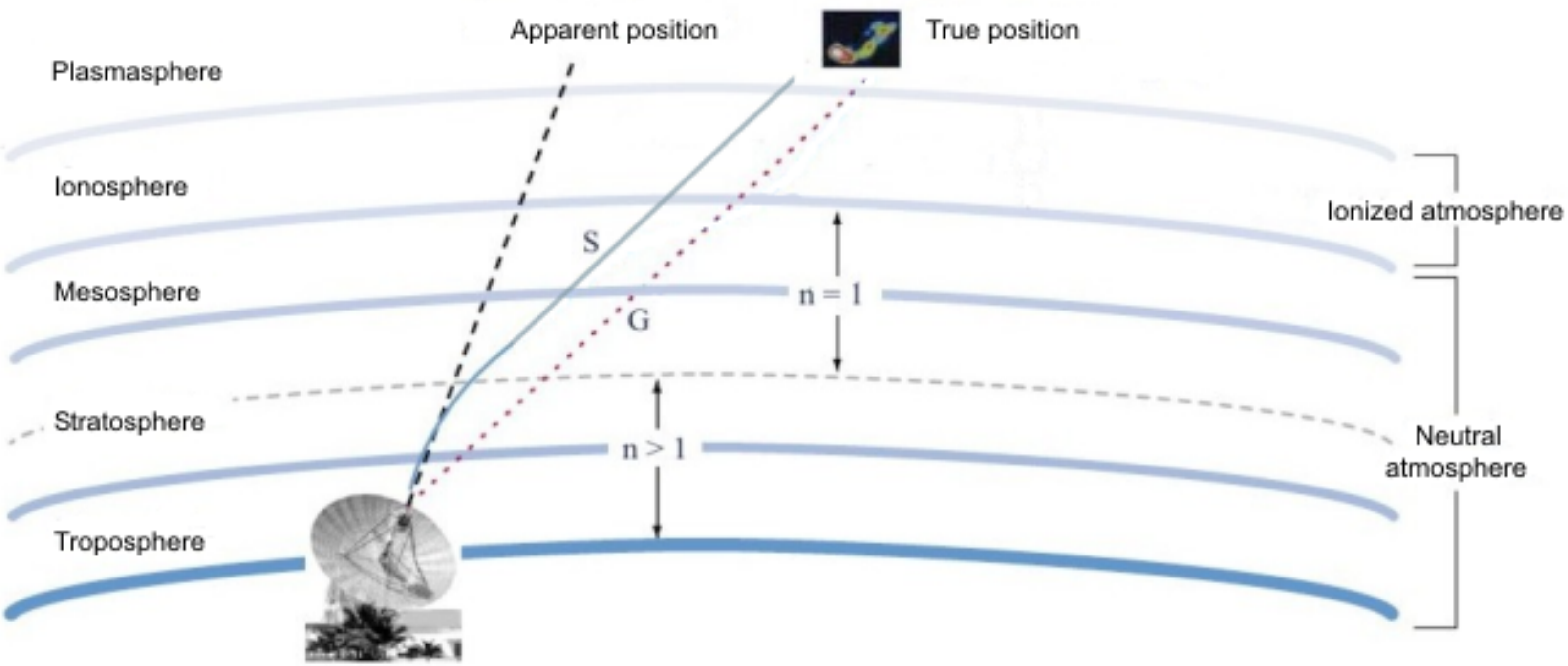
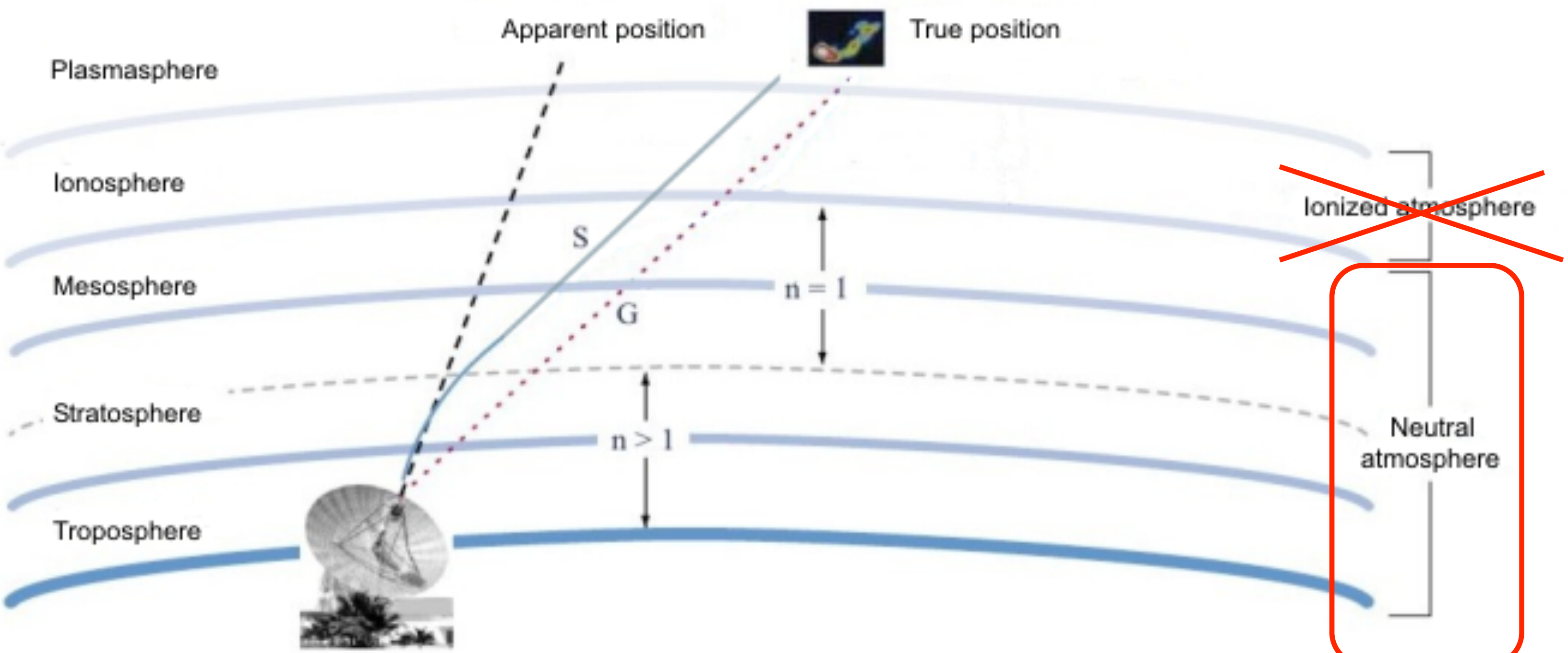
Non-dispersive delay model, short review



Non-dispersive delay model, short review



$$\tau_{tot} = m_h(e)\tau_{apr}(t_{obs}) + m_w(e)\tau_{est}\left(t_{par1}\right) + \\ + \tau_{grad}\left(a, e, t_{par2}\right)$$

Non-dispersive delay model, short review

$$\tau_{tot} = m_h(e)\tau_{apr}(t_{obs}) + m_w(e)\tau_{est}(t_{par1}) + \\ + \tau_{grad}(a, e, t_{par2})$$

$m_{h,w}$: Mapping functions, such as: VMF1, GMF, NMF, …
e: Elevation angle
a: Azimuth angle
t_{obs}: Given time of observation
t_{par}: Defined time of parameter

Non-dispersive delay model, short review

$$\tau_{tot} = m_h(e)\tau_{apr}(t_{obs}) + m_w(e)\tau_{est}(t_{par1}) + \\ + \boxed{\tau_{grad}(a, e, t_{par2})}$$

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$$\boxed{\tau_{grad} = m_g(e)(G_N \cos a + G_E \sin a)}$$

Non-dispersive delay model, short review

$$\tau_{grad} = m_g(e)(G_N \cos a + G_E \sin a)$$

m_g:	Gradient mapping function
e:	Elevation angle
a:	Azimuth angle
G_N:	Gradient in north-south direction
G_E:	Gradient in east-west direction

Non-dispersive delay model, short review

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$m_g(e) = m_{h,w} \cot e$ (MacMillan, 1995)
$m_g(e) = 1/(\sin e \tan e + 0.0032)$ (Chen & Herring, 1992)

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$$m_g(e) = 1/(\sin e \tan e + 0.0032)$$ (Chen & Herring, 1992)

recommended by IERS

Gradient parameterization

$$\boxed{\tau_{grad} = m_g(e)(G_N \cos a + G_E \sin a)}$$

$$G_N = G_{N,tot} = G_{N,apr} + G_{N,est}$$
$$G_E = G_{E,tot} = G_{E,apr} + G_{E,est}$$

$G_{N,E,apr}$: A priori gradients from empirical models

Gradient parameterization

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$$G_E = G_{E,tot} = G_{E,apr} + G_{E,est}$$

$G_{N,E,apr}$: A priori gradients from empirical models,
e.g.: APG (Böhm et al., 2013)
or DAO (MacMillan & Ma, 1997)

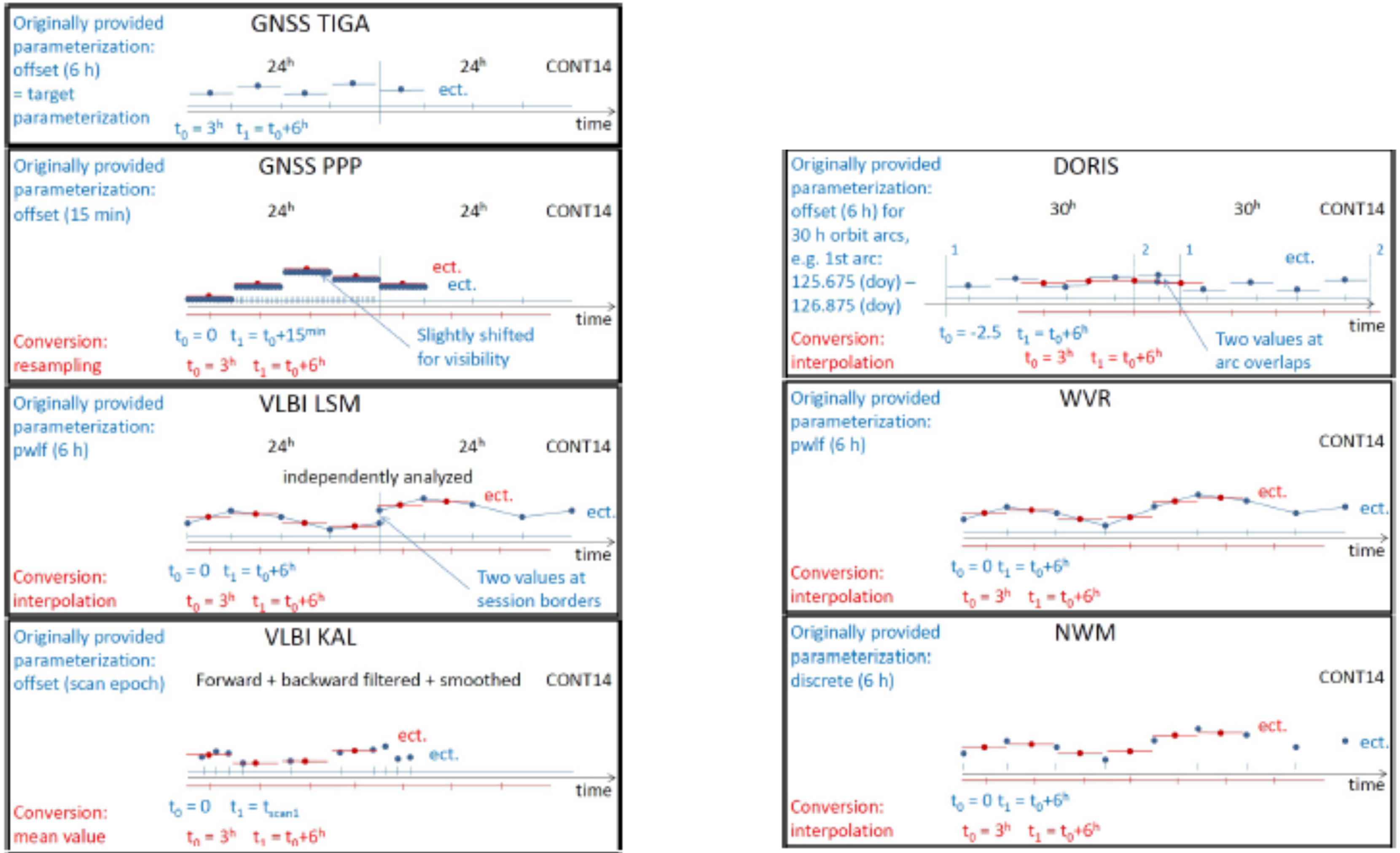
Important, if the gradients are absolutely constrained!
(E.g. for VLBI data prior to about 1990)
This is not the case here!

Gradient comparison during CONT14

- VLBI least squares method solution (Heinkelmann, GFZ)
- VLBI Kalman filter solution (Soja, GFZ)
- GPS network solution, TIGA reprocessing (Deng, GFZ)
- GPS PPP solution, operational GFZ product (Dick, Wickert, GFZ)
- DORIS highly resolved (6 h) solution (Willis, IGN)
- Water vapor radiometer „Konrad“ (Nilsson, GFZ)
- NCEP
  - GFS 0.5 deg
  - GFS 1.0 deg
- ECMWF IFS

(Zus, GFZ)

Gradient parameterization



GNSS intra-technique comparison

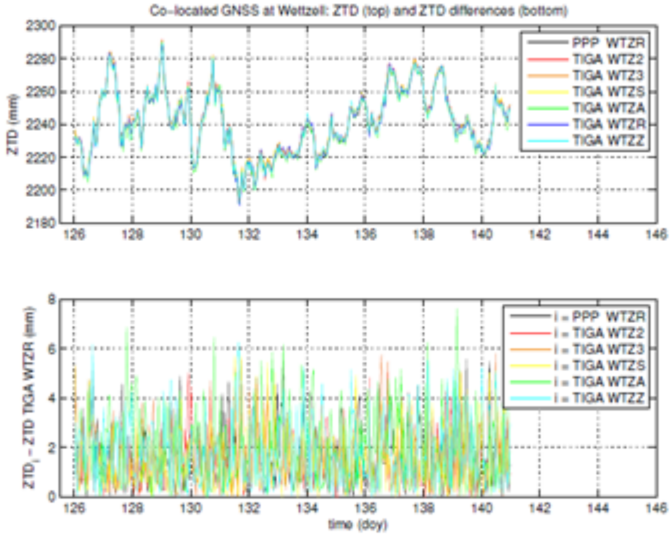
credits: Geodetic Observatory Wettzell
(http://www.fs.wettzell.de/)

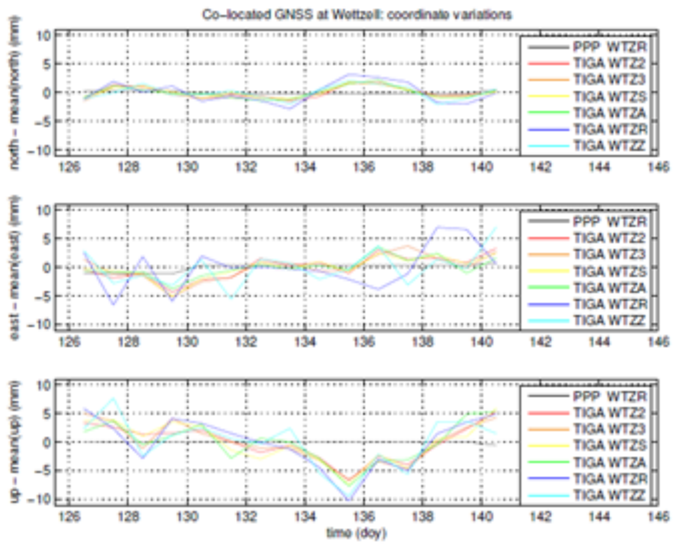
Bundesamt für Kartographie und Geodäsie

FESG

IGS name	antenna	dome	receiver
WTZ2*	LEIAR25.R3*	LEIT*	LEICA GR25
WTZ3*	LEIAR25.R3*	LEIT*	JAVAD TRE_G3TH DELTA
WTZS*	LEIAR25.R3*	LEIT*	SEPT POLAR X2
WTZA	ASH700936C_M	SNOW	ASHTECH Z-XII3T
WTZR	LEIAR25.R3	LEIT	LEICA GR25
WTZZ	LEIAR25.R3	LEIT	JAVAD TRE_G3TH DELTA

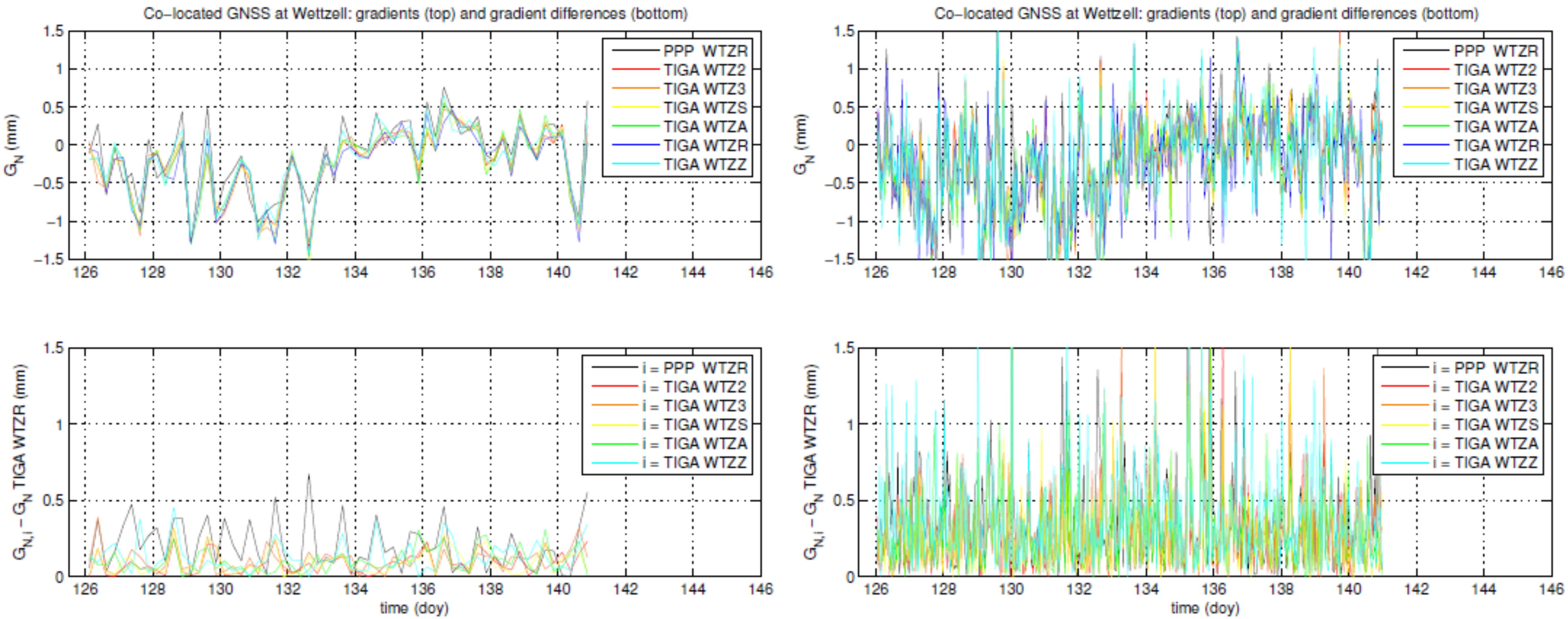
<u>ZTD</u> ρ ≈ 1, SNR ≈ 500,
stdv (TIGA) ≈ 2 mm
stdv (TIGA vs. PPP) ≈ 4.6 mm





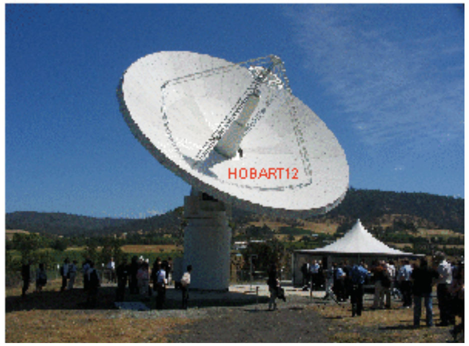
GNSS intra-technique comparison

6 h **resolution** **1 h**



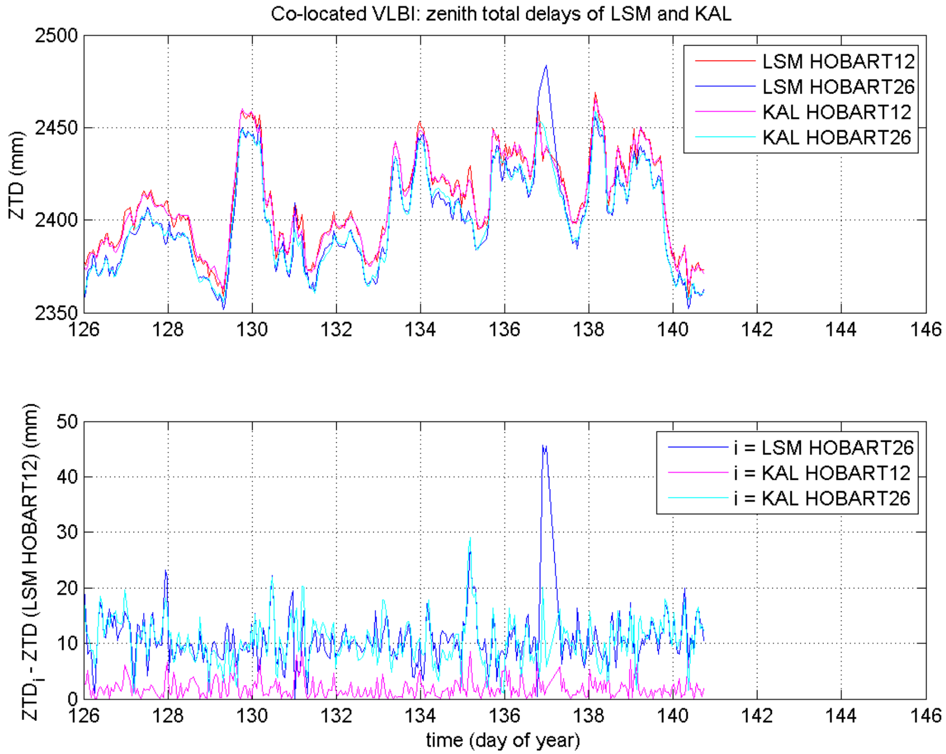
G_N	6 h	1 h
Corr. coef.	0.9	0.75
stdv (TIGA)	0.15 mm	0.40 mm
stdv (TIGA vs. PPP)	0.20 mm	0.45 mm

VLBI intra-technique comparison



credits: University of Tasmania, Australia (UTAS, http://www.utas.edu.au/)

UNIVERSITY of TASMANIA



Height difference HOBART26 – HOBART12 = 24.1 m (WGS84)

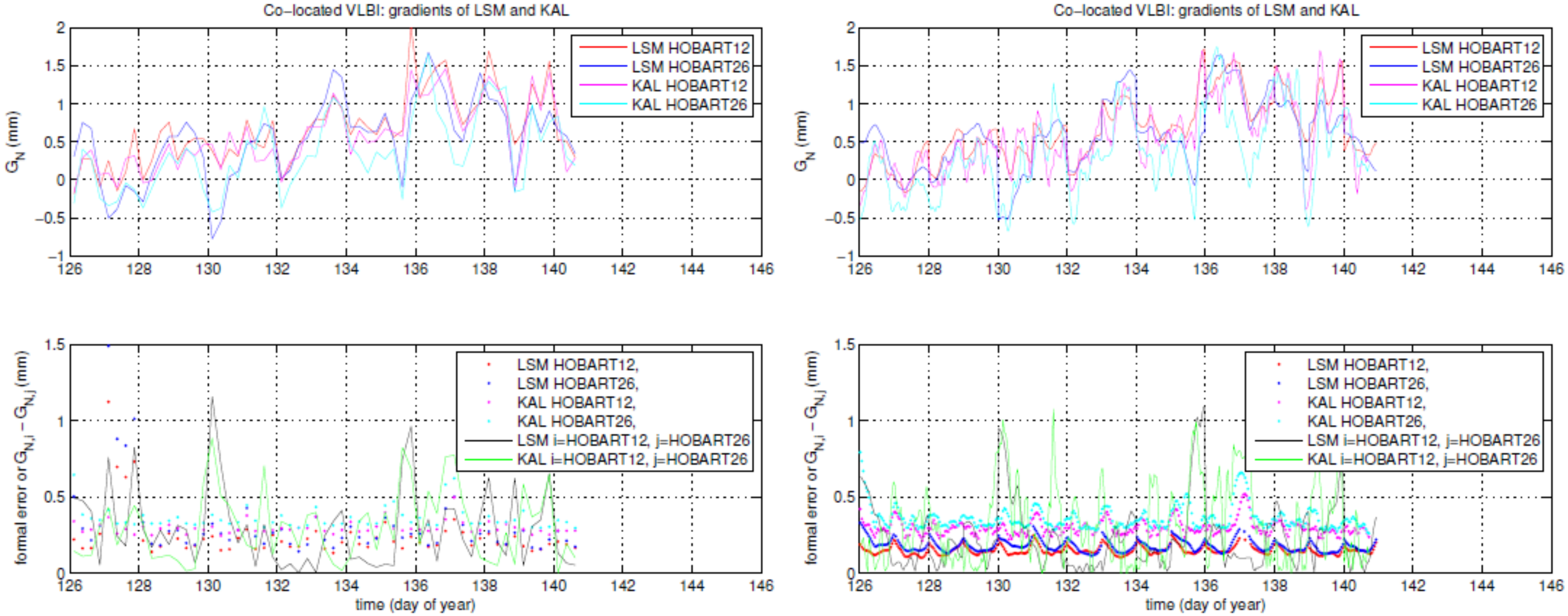
ZTD difference HOBART26 – HOBART12 = 9.75 mm (LSM) 9.96 mm (KAL)

HOBART12 vs. → HOBART26

ZTD	LSM	KAL
Corr. coef.	0.97	0.99
stdv	6.86 mm	3.85 mm

VLBI intra-technique comparison

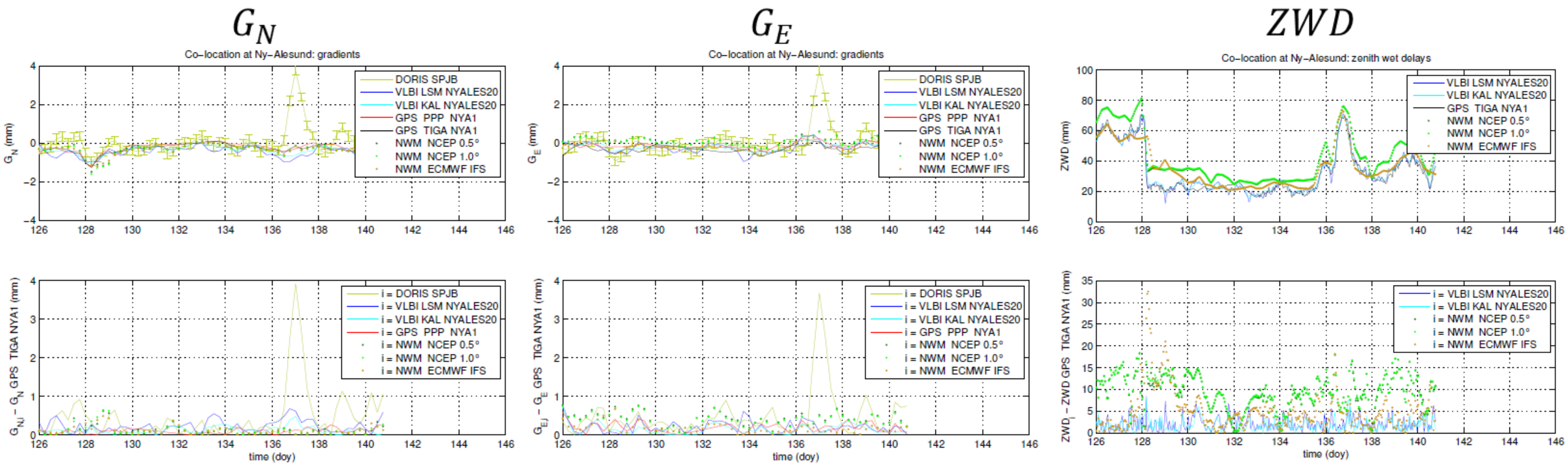
6 h resolution 1 h



HOBART12 vs. → HOBART26

G_N	LSM	KAL
Corr. coef.	0.73 | 0.75	0.78 | 0.76
stdv	0.37 | 0.31 mm	0.32 | 0.35 mm

Multi-technique comparison with DORIS

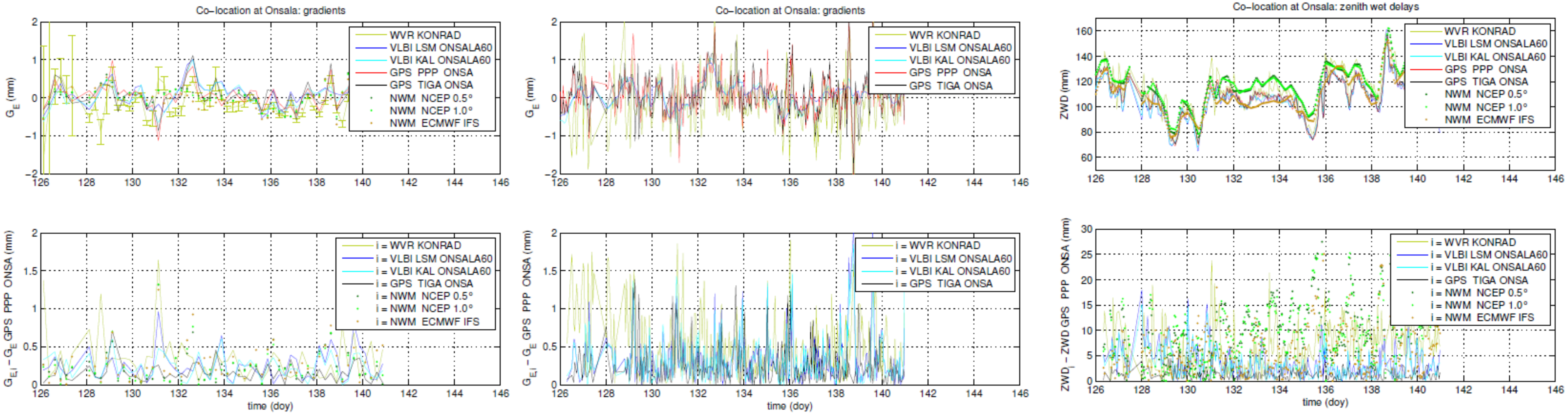


credits: LAREG
(http://recherche.ign.fr/labos/lareg/)

Solution	difference of mean values (mm)			correlation coefficient			standard deviation (mm)		
	G_N	G_E	ZWD	G_N	G_E	ZWD	G_N	G_E	ZWD
DORIS SPJB*	0.10	0.01	n.a.	0.39	0.01	n.a.	0.35	0.37	n.a.
GPS NYA2**	-0.03	-0.08	1.89	0.79	0.83	0.99	0.28	0.13	2.08
VLBI LSM	-0.22	-0.10	0.51	0.46	0.63	0.99	0.29	0.21	2.53
VLBI KAL	-0.13	-0.06	0.79	0.73	0.73	0.99	0.20	0.14	2.10
NCEP 0.5°	-0.09	0.23	9.45	0.75	0.59	0.97	0.21	0.21	3.90
NCEP 1.0°	-0.11	0.21	9.59	0.74	0.60	0.97	0.22	0.18	3.92
ECMWF IFS	-0.10	-0.07	3.44	0.74	0.54	0.92	0.20	0.19	5.92

Multi-technique comparison with WVR

G_E **6 h** **resolution** **1 h** G_E ZWD

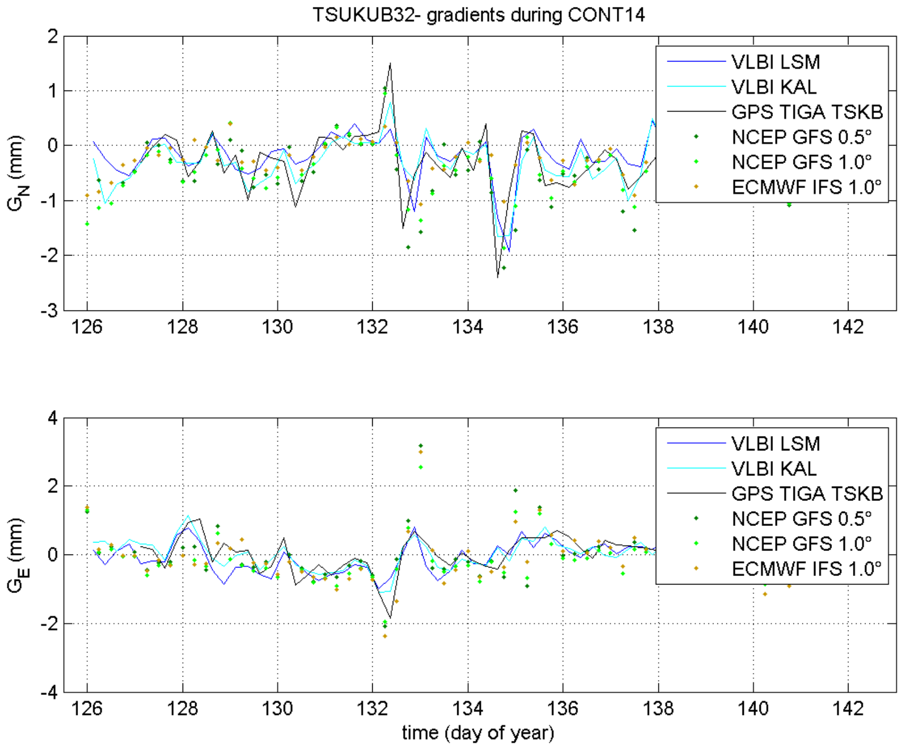


credits: Dr. T. Nilsson, GFZ

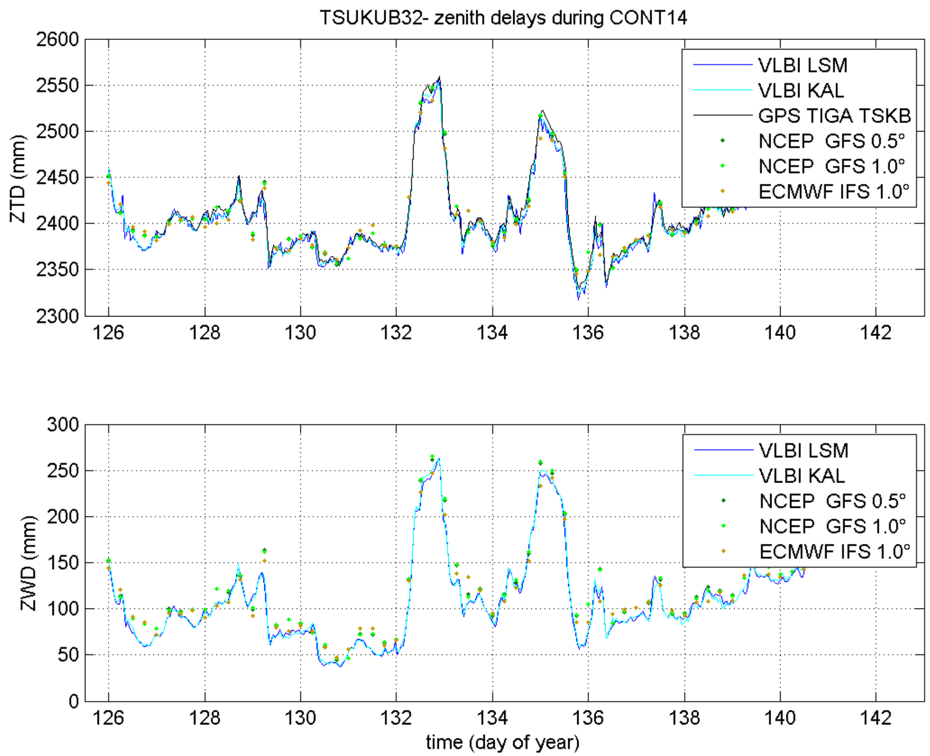
Solution	difference of mean values (mm)			correlation coefficient			standard deviation (mm)		
	G_N	G_E	ZWD	G_N	G_E	ZWD	G_N	G_E	ZWD
WVR KONRAD	0.10	-0.21	5.36	0.71	0.46	0.96	0.31	0.40	5.36
	0.12	-0.26	5.65	0.57	0.61	0.96	0.55	0.57	5.26
GPS ONSA*	0.01	-0.02	-0.20	0.85	0.83	0.99	0.19	0.20	1.74
	0.02	-0.01	-0.01	0.73	0.74	0.99	0.37	0.37	1.74
VLBI LSM	-0.08	0.01	-2.57	0.62	0.58	0.97	0.29	0.31	3.57
ONSALA60	-0.12	-0.01	-2.16	0.48	0.42	0.97	0.44	0.48	3.46

Multi-technique comparison with NWM

G_N, G_E resolution 6 h



ZTD, ZWD



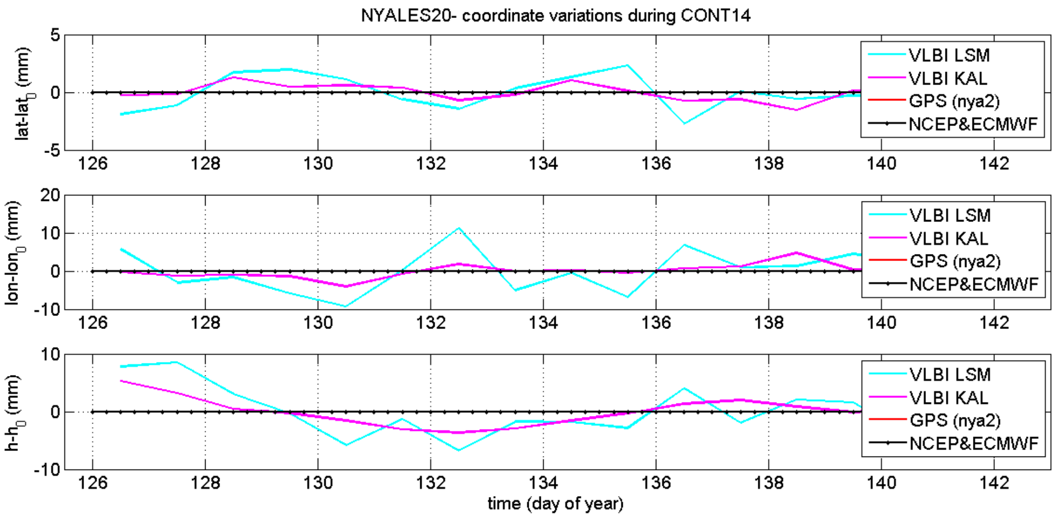
- If the atmospheric conditions change too rapidly, the gradients from space geodetic techniques do not catch the changes. This is most probably due to the relative constraints of gradient parameters that prohibit extreme variations.

Comparison of LSM and KAL VLBI solutions

- The Kalman filter solution (KAL) provides remarkably better results than the least squares solution (LSM)
  better := closer to GNSS results
  - $\rho(G_N)$ 12.5% higher (average of 16 sites)
  - $\rho(G_E)$ 14.9% higher (average of 16 sites)
  - stdv(ZTD) 36.8% smaller (average of 16 sites)

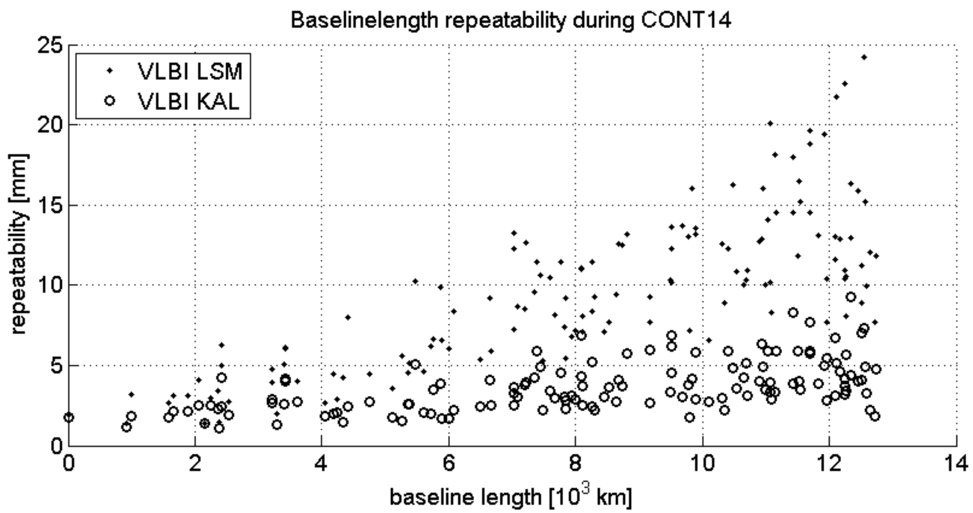
- Reasons for the better agreement with GNSS:
  - Station-based noise tuning (→ talk by B. Soja et al.)
  - Forward, backward and smoothing is applied
  - The continuity of analysis over the session borders does not play a role (GNSS TIGA solution is also based on 24h datasets)

Comparison of LSM and KAL VLBI solutions



← Sub-daily coordinate variations at NYALES20

Baseline lengths → repeatability



Conclusions

- For observationally dense sessions such as CONT14 atmospheric gradients can be estimated with 1 h or 30 min resolution, in the LSM case this improves the results, in the KAL case it slightly worsens the results
- The gradients do not show systematics depending on the height, also the decorrelation with horizontal station coordinates seems to be sufficient
- The gradient signal is very small and so the SNR is very small. A significant fraction is due to other azimuthal effects that are system-dependent
- The current level of agreement of gradients determined from different techniques (apart from DORIS) is not very good, only good. Gradients as a common parameter for inter-technique combination could be tested
- The combined parameter estimation, e.g. gradients at co-located VLBI telescopes seems to be very promising (→ poster by Nilsson et al.)
- Since Kalman filter has shown to provide superior quality, the classical LSM approach with its parametric models could be replaced

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Thank you for your attention.

heinkelmann@gfz-potsdam.de