Do we need to consider dispersive troposphere delays for current and next generation space-geodetic instruments?

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Refractivity

Current model used for micro-wave techniques in space geodesy

$$N = N_0(P,T,RH) + N'(P,T,RH,f) + i \cdot N''(P,T,RH,f)$$

Frequency dependent complex contribution which is neglected for micro-wave techniques.
Real part $\longrightarrow$ delay
Imaginary part $\longrightarrow$ damping

Question: *Can we really neglect the dispersive part for current and upcoming space geodetic techniques ?*

Liebe93 Model (dispersive terms only)

$$N(f) = N_D(f) + N_V(f)$$

(Note: these are all complex functions!)

Dry-Air Module

$$N_D(f) = N_n(f) + \sum_k S_k(f) F_k(f)$$

$N_n(f)$ non-resonant term of the 0_2 spectrum

$S_k(f)$ line strength of the k-th 0_2 line

$F_k(f)$ Van Vleck-Weisskopf function

44 oxygen lines

Water Vapor Module

$$N_V(f) = N_c(f) + \sum_l S_l(f) F_l(f)$$

$N_c(f)$ H_2O continuum spectrum

$S_l(f)$ line strength of the l-th H_2O line

$F_l(f)$ Van Vleck-Weisskopf function

34 H_2O lines

Liebe93 model has been adopted in the ITU-R recommendation P.676-8*:*
“ … valid for the frequency range between 1 – 1,000 GHz … “

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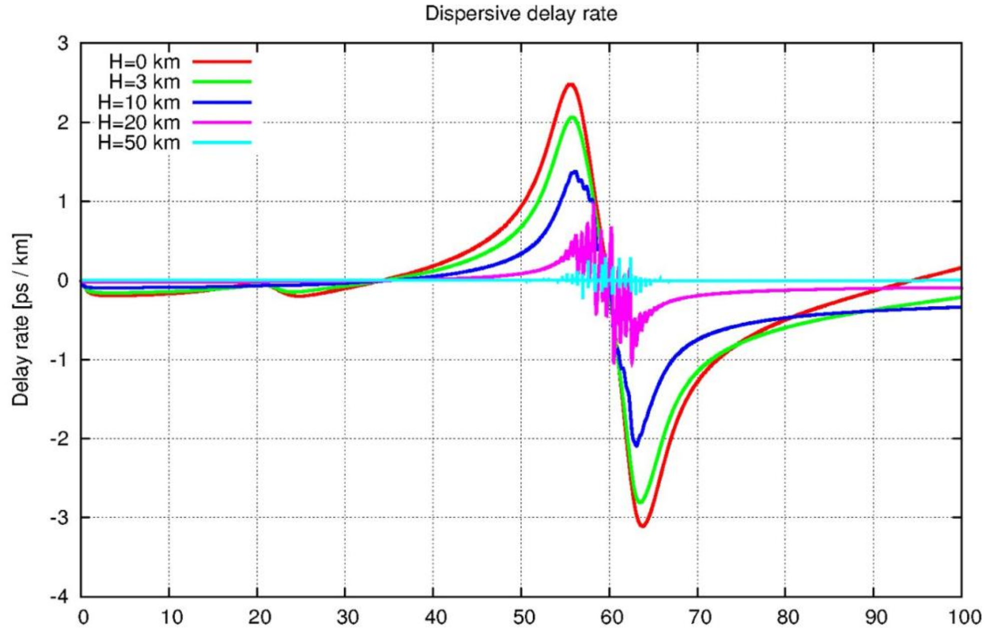
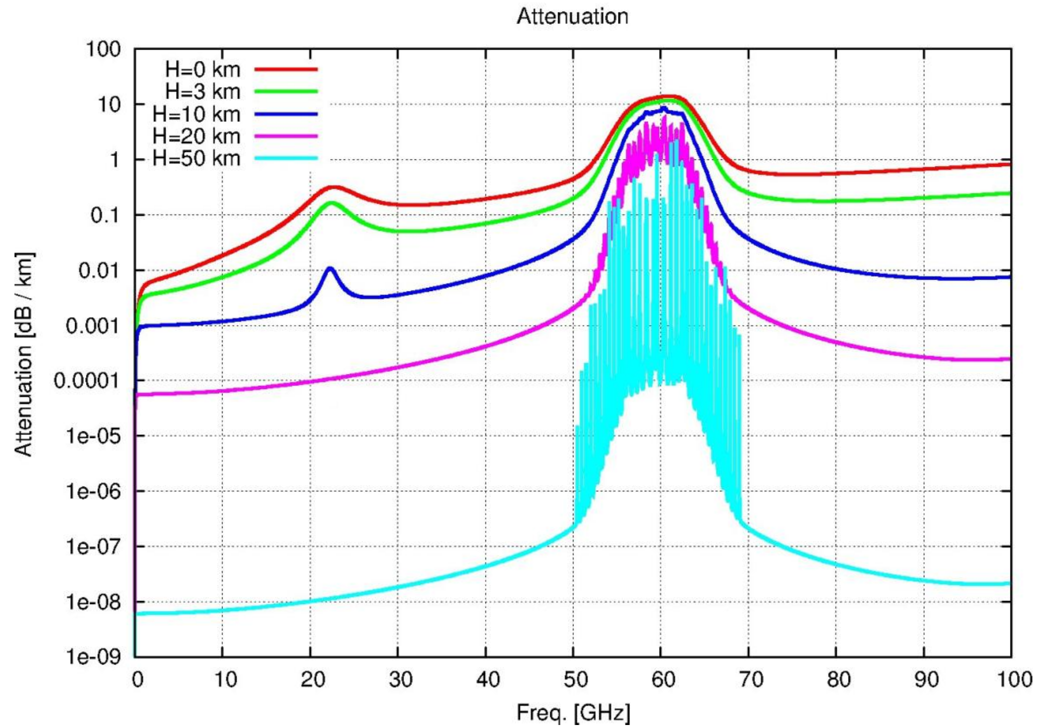
Simulations:

- P and T from US standard atmosphere
- RH = 50 for H < 13 km
- RH = 0 for H > 13 km



- Space geodetic micro-wave techniques are not operating close to the O_2 lines
- However, there are significant slopes of the real part (delay) which need to be studied for dual-frequency techniques!



KARAT-λ

- Modified version of our ray-tracer KARAT (Hobiger et al., JGR, 2008)
- Carries out ray-tracing in long-double precision
- Computes complex refractivity values for a given frequency based on data from a numerical weather model (P, T, RH)
- Very time consuming calculations
- Requires large CPU memory (> 8 GB)
- Benefit: allows to derive signal attenuation by integrating over the imaginary part of the refractivity index $\rightarrow$ tool for radio-communication (link budget, signal fading, etc…)

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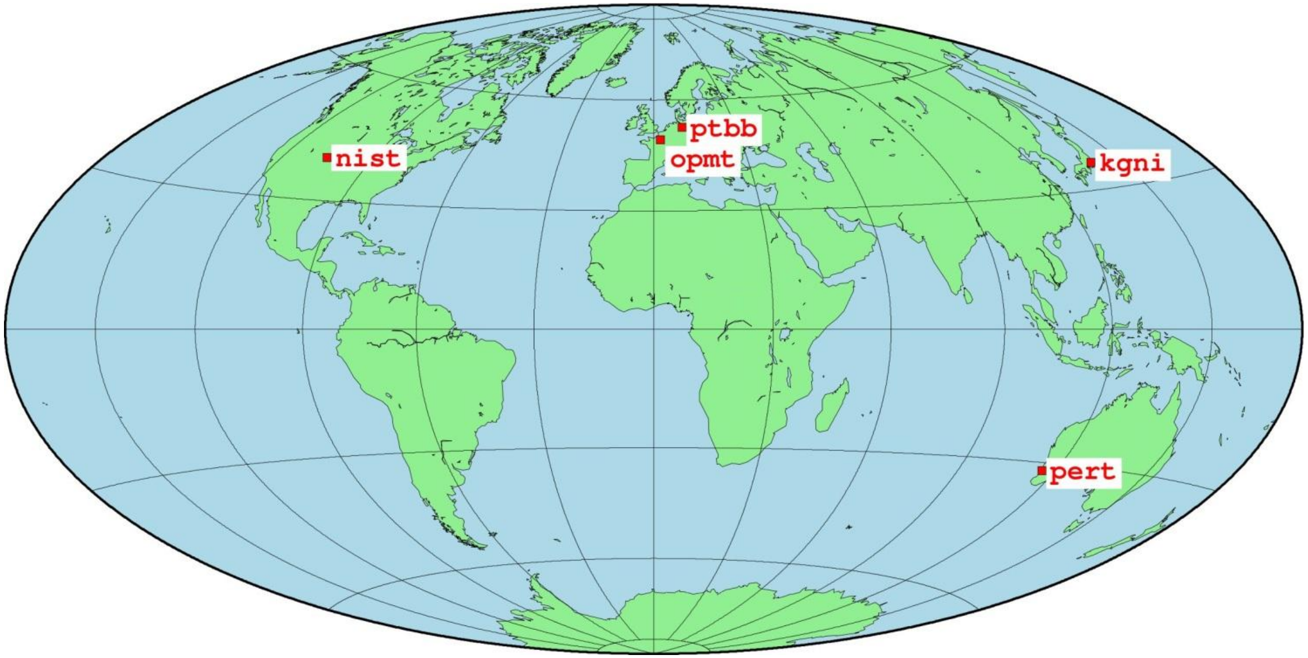
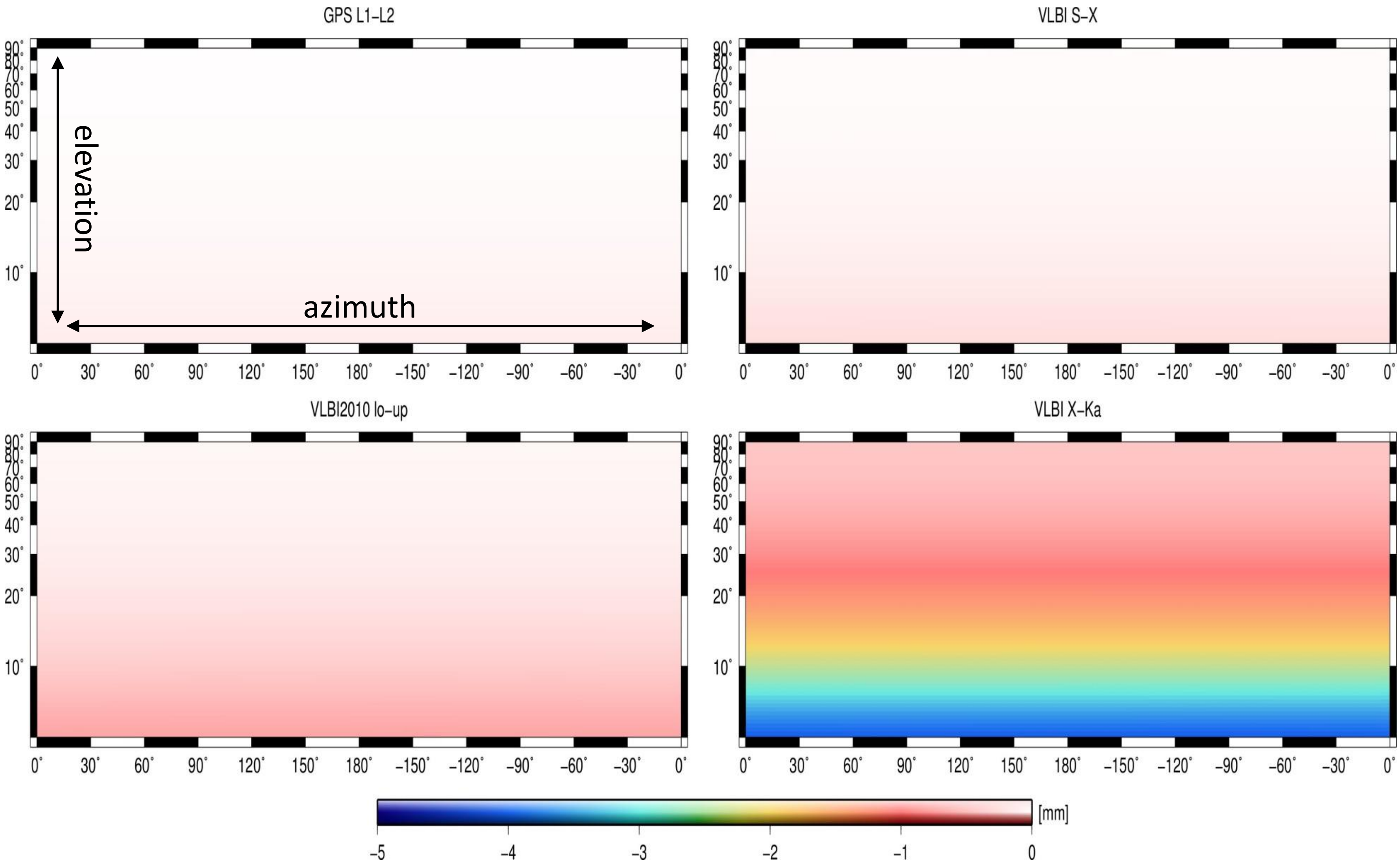
Simulations

- 5 Stations

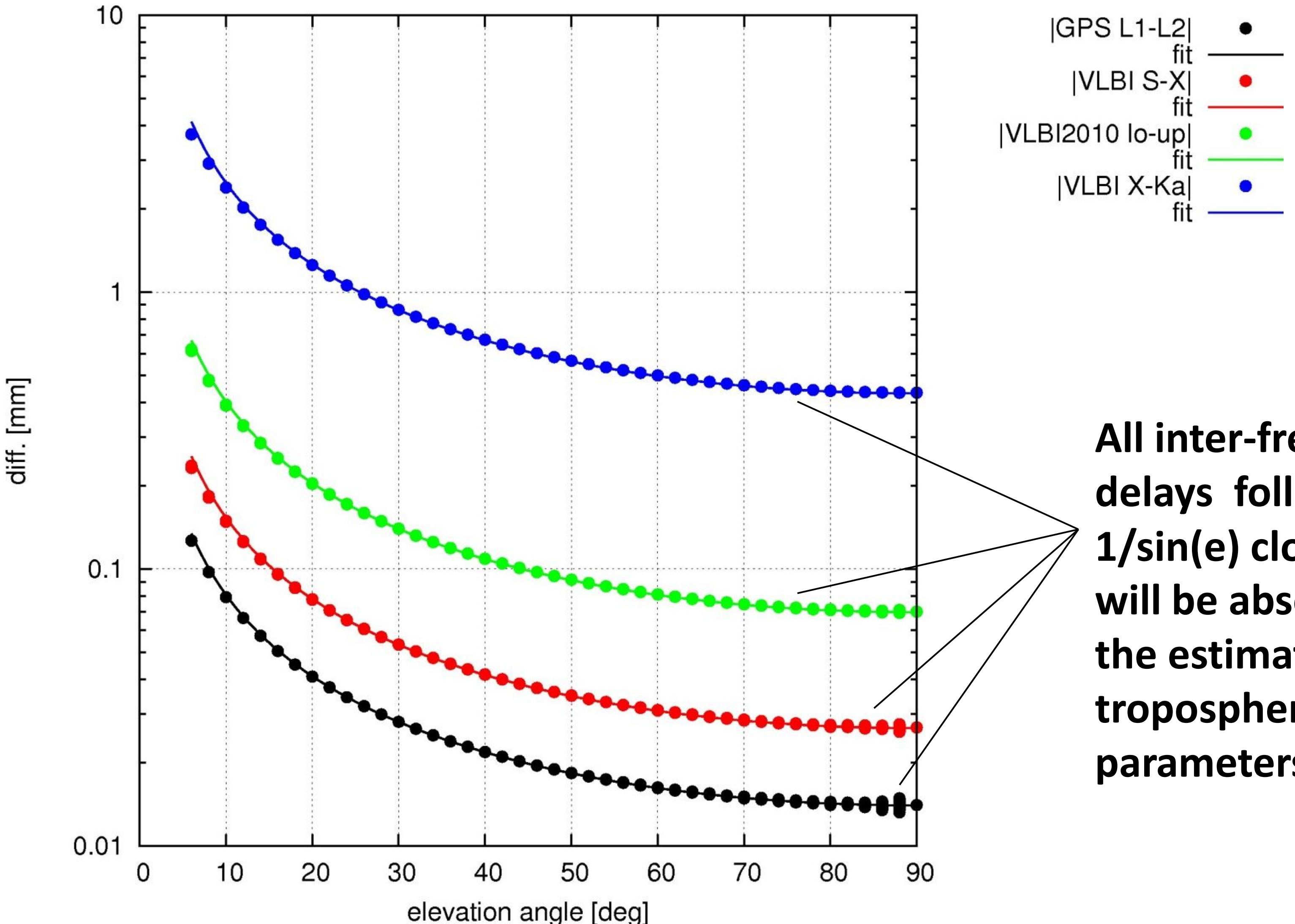


- ECMWF data (0.2 x 0.2 deg) between Aug. 1st and Aug. 7th, 2011
- Every day at 0 UT, delays in all azimuth directions and for elevation angles between 6 and 90 degree
- Space geodetic techniques considered
  - GPS-L1, GPS-L2
  - VLBI-S (2.3 GHz), VLBI-X (8.4 GHz)
  - VLBI2010-lowest band (2.5 GHz), VLBI2010-highest band (11.7 GHz)
  - VLBI-X (8.4 GHz), VLBI-Ka (32 GHz)

Results (Koganei, Japan, Aug. 1st, 2011, 0 UT)



Elevation dependency (Koganei, Aug. 1st, 2011, 0 UT)



All inter-frequency delays follow 1/sin(e) closely → will be absorbed by the estimated troposphere parameters !

Effect on geodetic parameter estimation

- Assume 4 unknowns position (N,E,U) + ZWD
- Utilize ray-traced dispersive troposphere total delays and form the ionosphere-free linear combination

$$\tau = \frac{f_1^2}{f_1^2 - f_2^2}\tau_1 - \frac{f_2^2}{f_1^2 - f_2^2}\tau_2$$

- Mapping function: GMF
- ZHD: Saastamoinen model, based on T and P at the station as obtained from numerical weather model
- Computing the differences w.r.t. the GPS L1/L2 position and ZWD estimates

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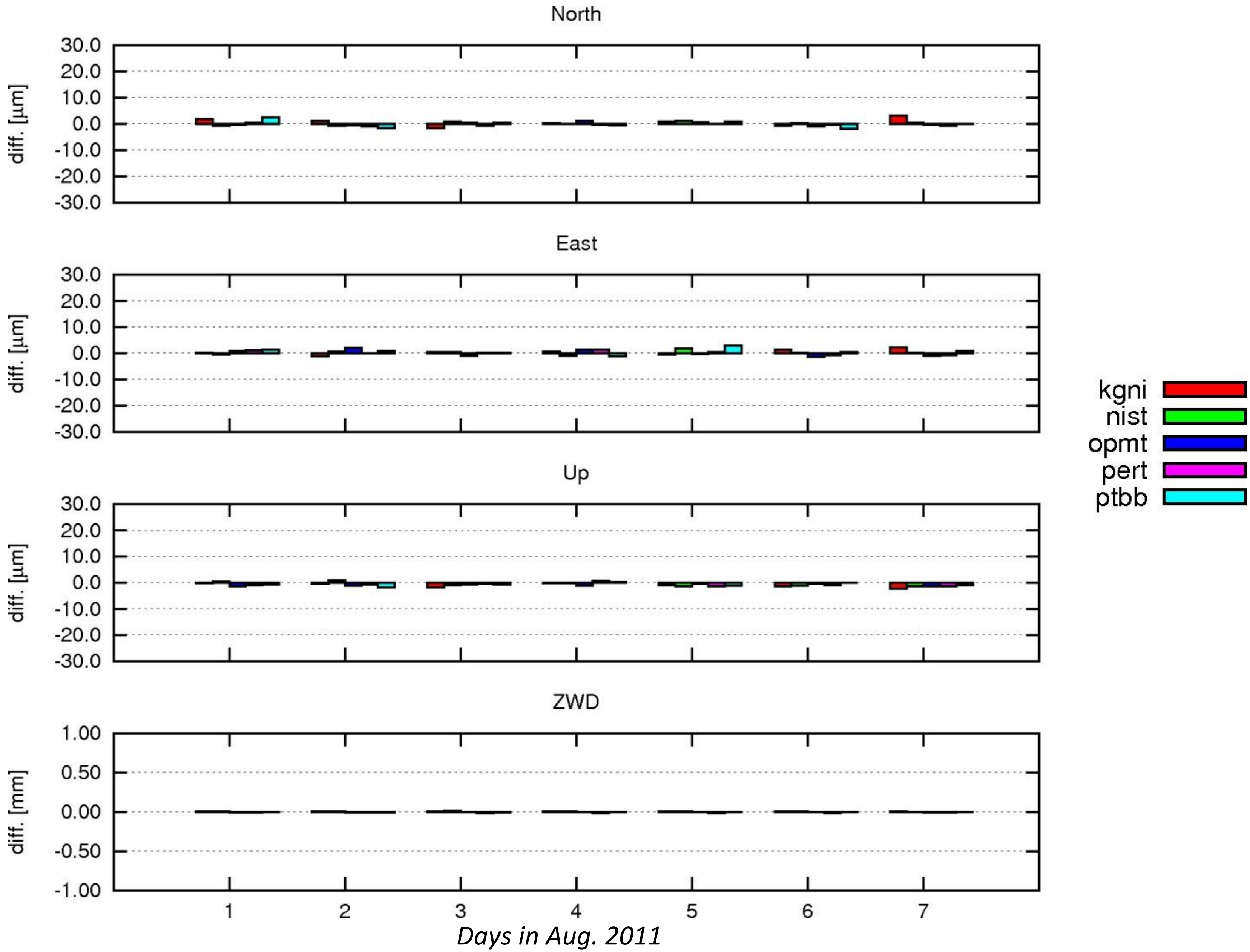
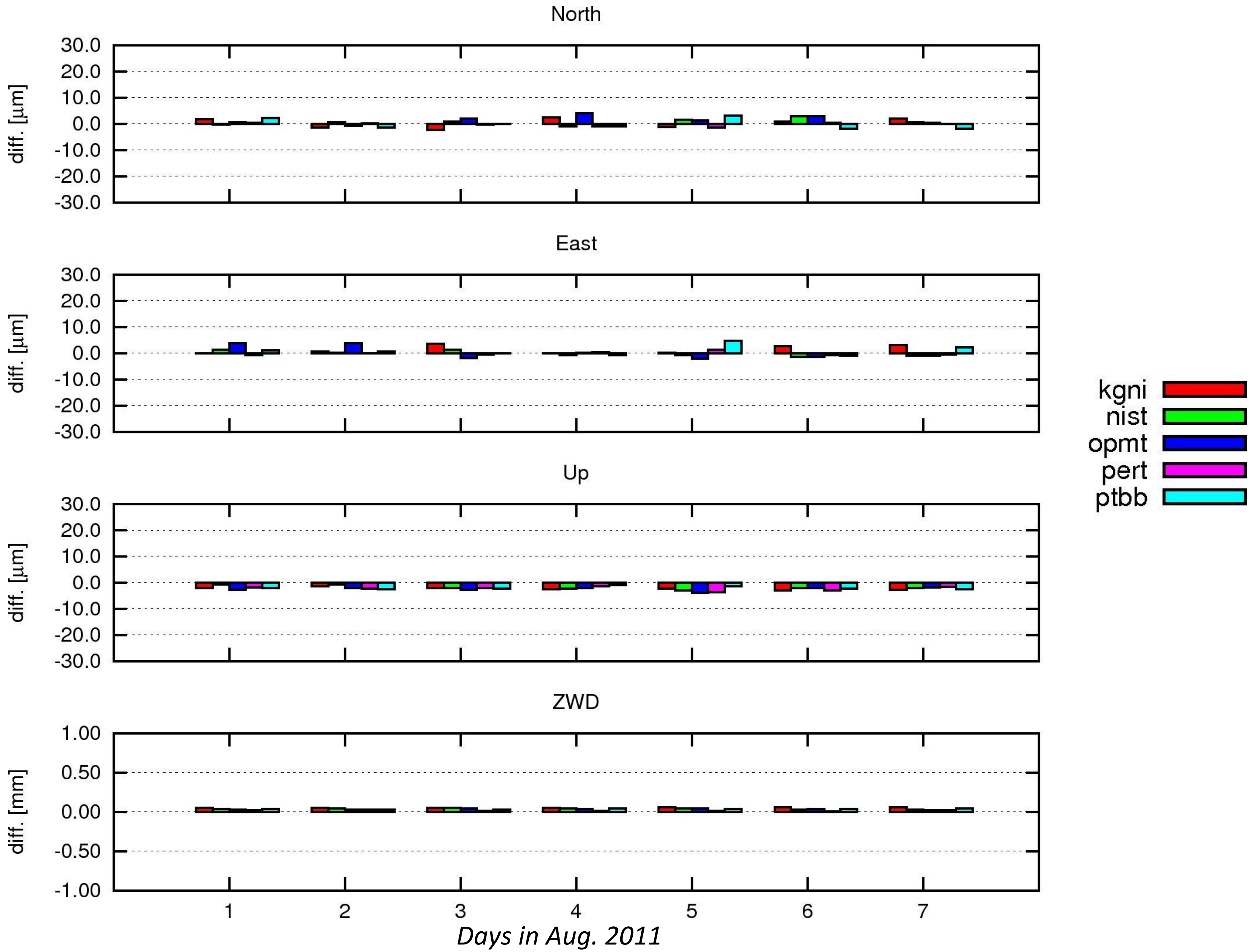
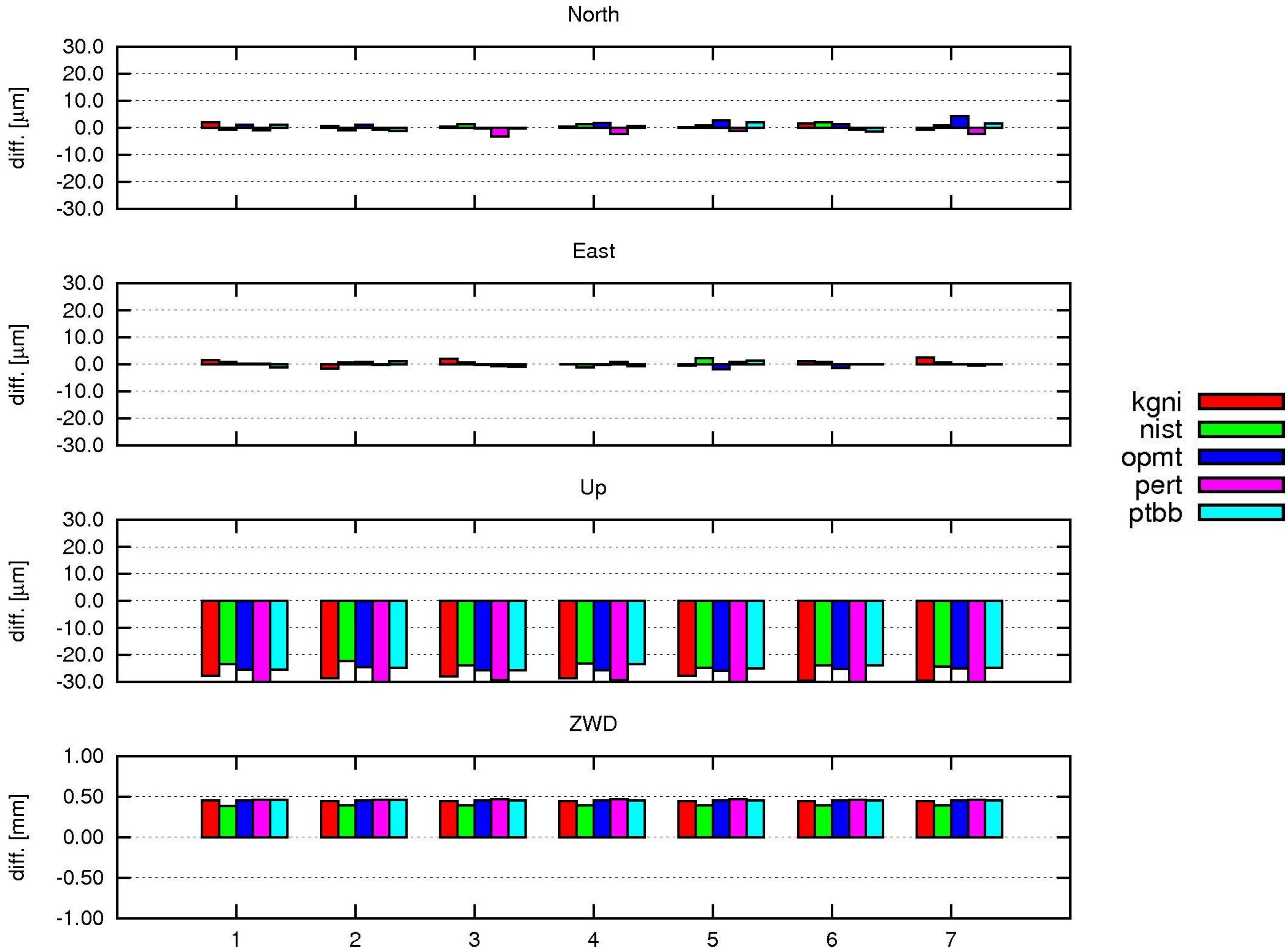
VLBI S/X w.r.t. GPS L1/L2



VLBI2010 w.r.t. GPS L1/L2



VLBI X/Ka w.r.t. GPS L1/L2



Days in Aug. 2011

Conclusions

- For current and upcoming space geodetic techniques dispersive troposphere delays
  - reach several mm at very low elevation angles, but are absorbed into the troposphere parameters.
  - have no significant impact on geodetic target parameters
  - bias troposphere parameters by less than 0.1 mm (except X/Ka VLBI)
  - Only VLBI in X/Ka mode should be treated with care when combining troposphere parameters in the (far) future

Thank you very much for your attention.

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