LAC SUT REPORT: STANDARD AND ALTERNATIVE NETWORK SOLUTIONS

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Introduction

- LAC SUT: Department of Theoretical Geodesy, Faculty of Civil Engineering, Slovak University of Technology in Bratislava (SUT)
- Main research activities of the department: local and regional geodynamics, geodetic GPS applications, geoid determination, geographical information systems
- Participation of SUT in EPN: Operation of GPS permanent station Modra-Piesok (MOPI) since 1996, EPN LAC from September 2002

LAC SUT : main features

- First weekly solution included into EPN combination: week 1182
- Analysed network in September 2002: 25 stations distributed over the whole European continent, status in September 2003: 32 stations
- Main purpose of the network geometry: regular station distribution all over the continent enabling geodynamics monitoring and investigations
- Analysing tools: BERNESE GPS software, version 4.2, Linux operating system, BPE + own scripts
- Standard processing following the guidelines for EPN analysis centres: daily solutions, weekly combination, troposphere zenith delays with weekly coordinates fixed.

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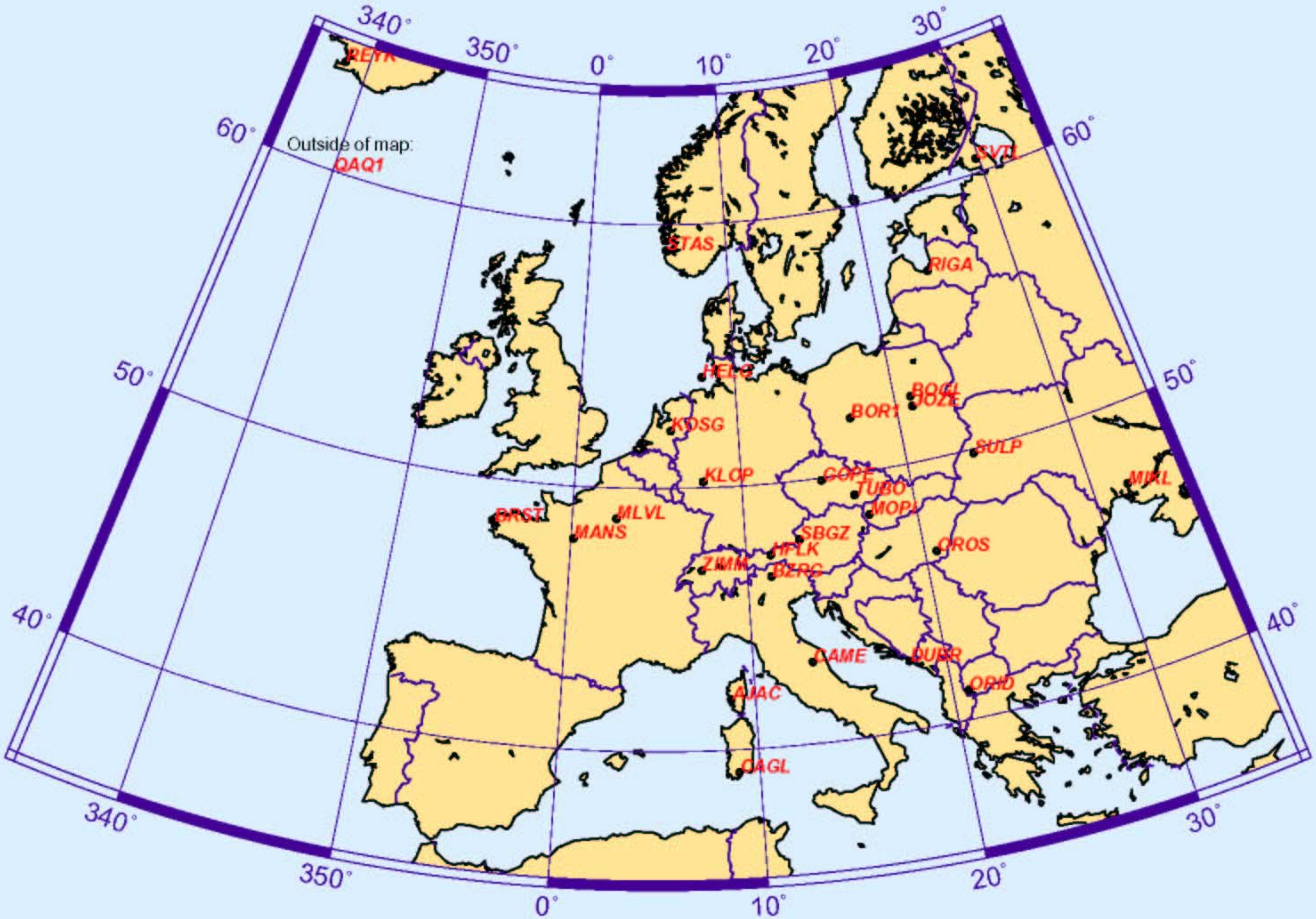
EPN subnetwork processed at SUT Bratislava

(status Jan. 2003)



Basic information from one-year network processing at LAC SUT

- Baselines are in range from 40 to 1550 km, average baseline is 500 km. All the baselines are solved without significant problems
- Reference site ZIMM: very stable without any interruptions and without local variations or jumps up to week 1230. Reference site from 1231: BOR1
- Problematic sites with frequent interruptions or breaking of observations: SBGZ, HFLK, SVTL, ORID, DUBR, BRST, REYK, QAQ1
- Sites with larger scatter and specific behaviour: QAQ1, REYK, CAME, DUBR, ORID, MIKL, MOPI
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Additional and alternative solutions at LAC SUT

- Network processing in 4-hour separate intervals - “sub-daily” resolution: only coordinate estimations, ambiguities and troposphere zenith delays taken from 24-hour solutions.
- Ionosphere models from 24 h intervals, coordinates and troposphere fixed from weekly and daily solutions.
- Estimation of station troposphere gradients simultaneously with troposphere zenith delays, coordinates are fixed from weekly solutions.

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Time series from sub-daily network solutions in 4-hour observing intervals

- **Main goals: daily coordinate variations, detailed investigation of jumps in the coordinate time series, tidal phenomena in station positions.**
- **Two approaches are applied:**
  - Spectral analysis of individual station series (*n*, *e*, and *up* components), problems with observation gaps and series discontinuities.
  - Least squares estimates of amplitudes and phases of harmonics with known frequencies.
- **Data processing: high-frequency filtration, jumps identification and exclusion, outliers detection, interpolation of sub-daily coordinates, spectral analysis and LS estimates for dominating terms.**

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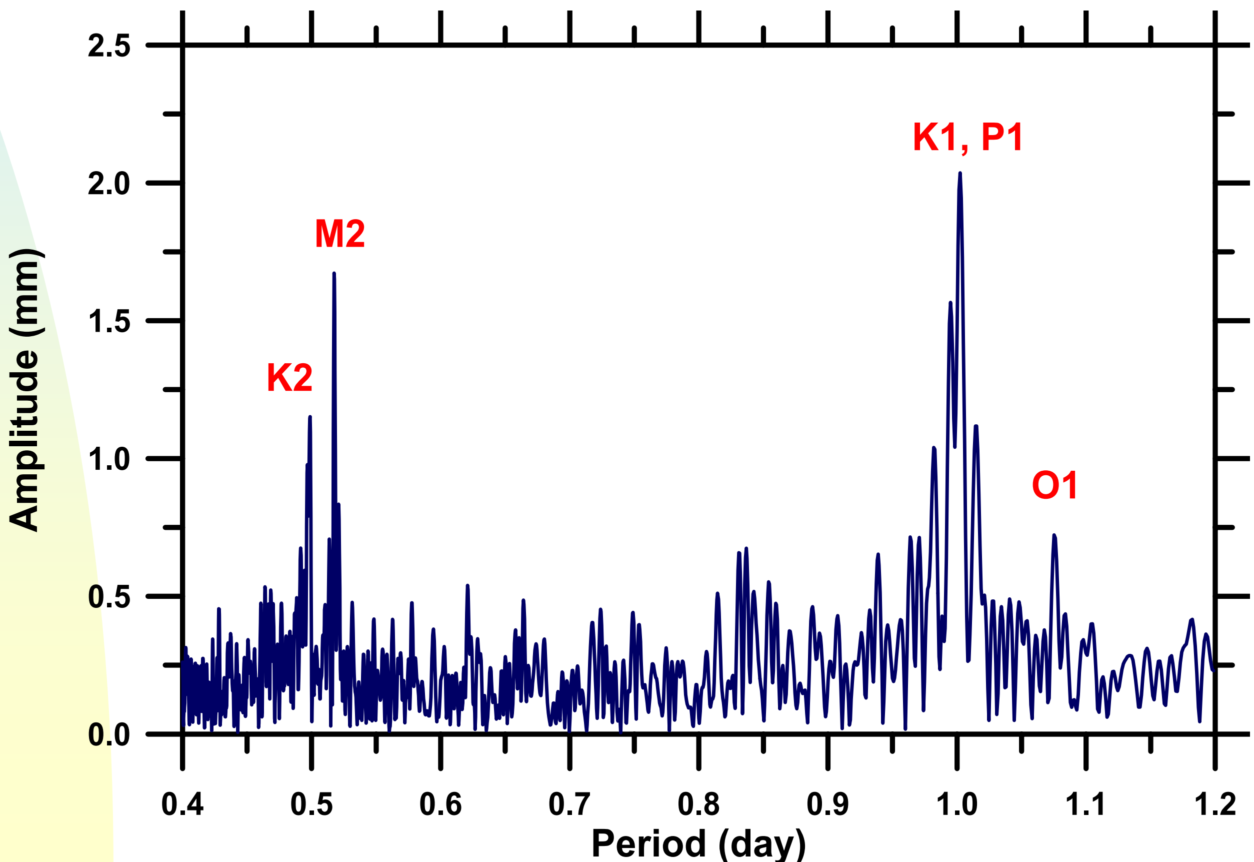
Example of variations in the band 0.4 - 1.2 day
Station BRST - *n* component

- data from 0.5 year series
- ocean loading effects included in processing
- all the effects are relative to reference point ZIMM



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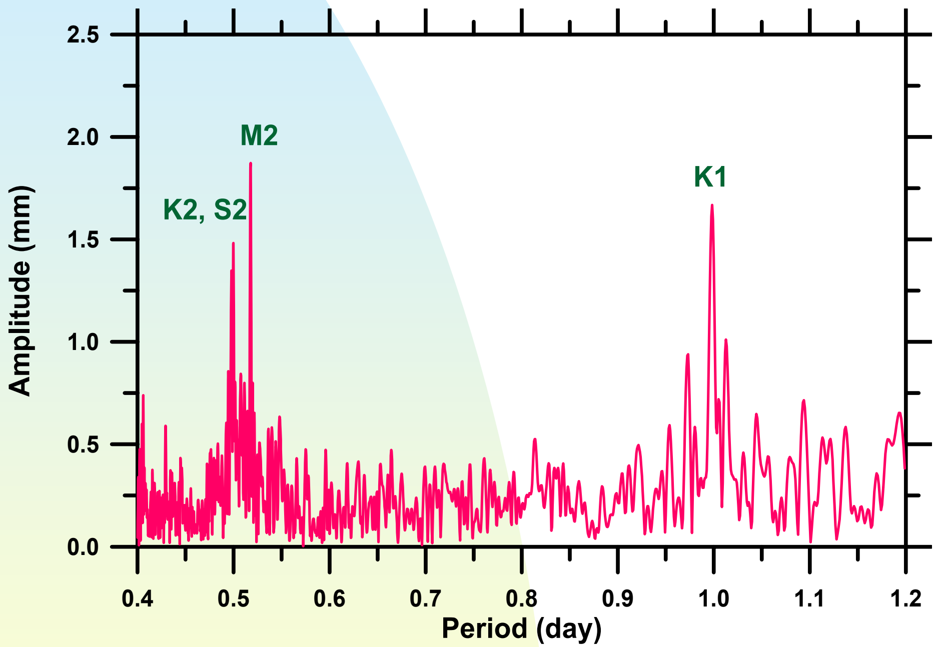
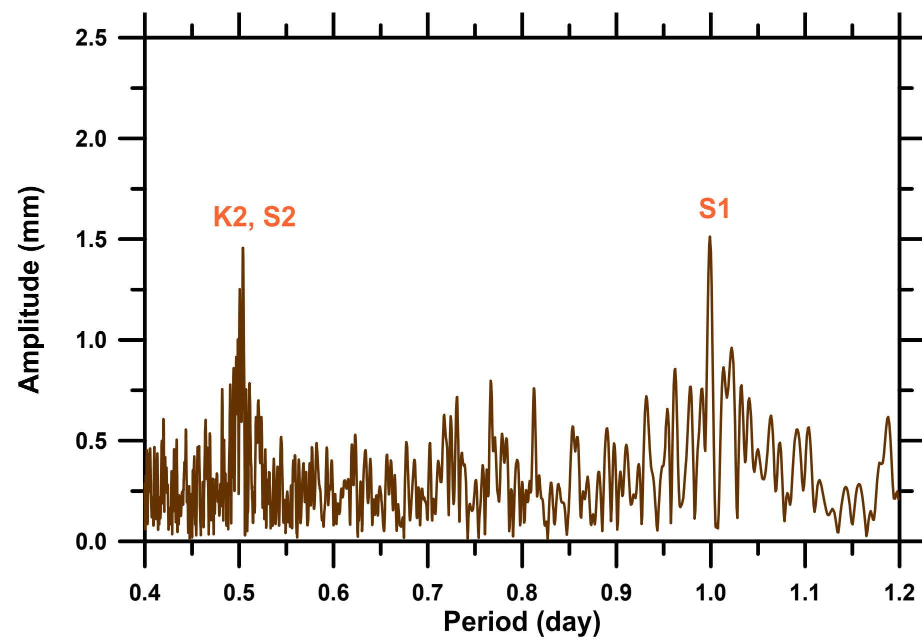
Example of variations in the band 0.4 - 1.2 day
Station BRST - *e* and *up* components

Direction E-W



Ellipsoidal height



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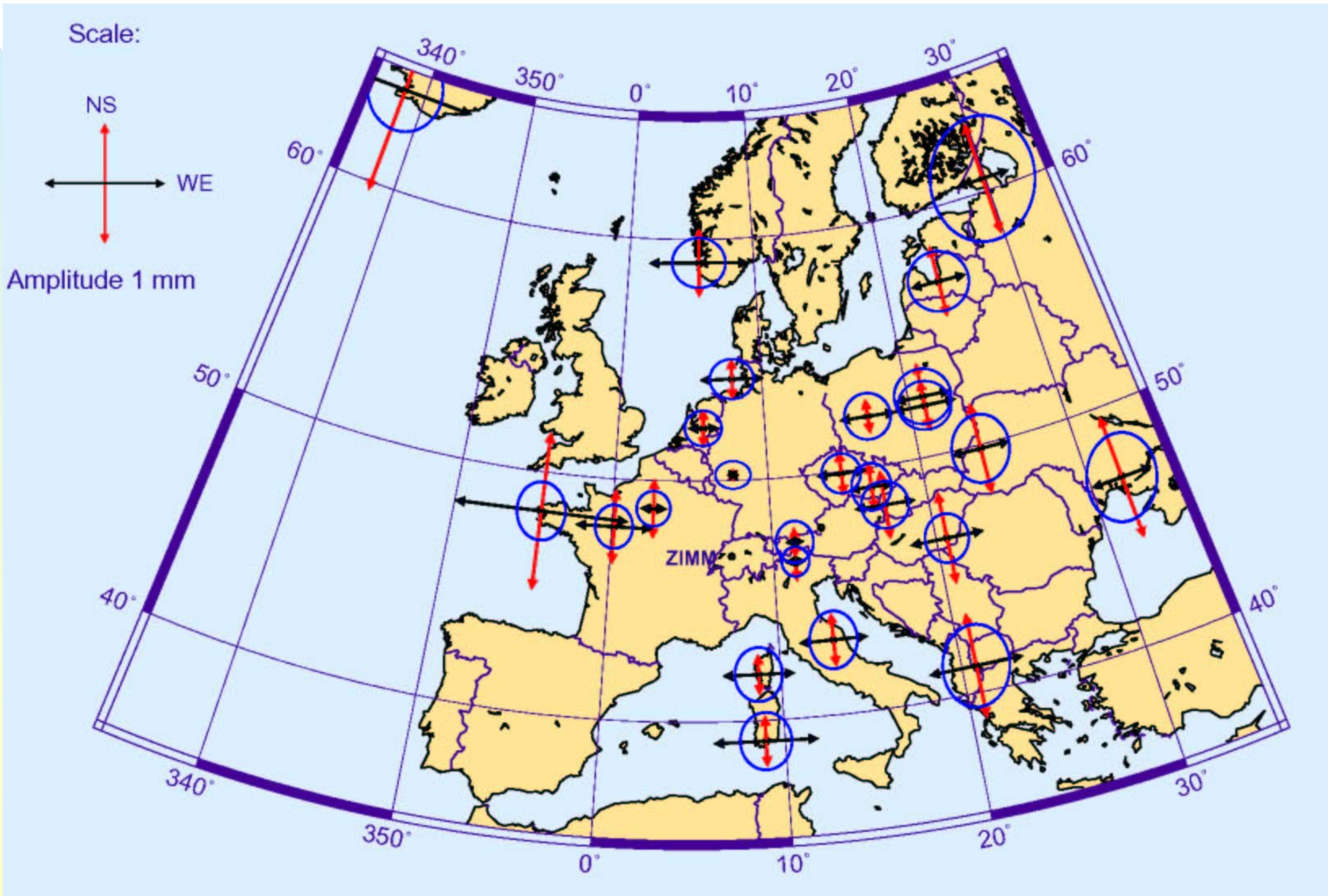
Amplitudes of horizontal components variations with period M2 (the ocean loading effect was included in network processing)



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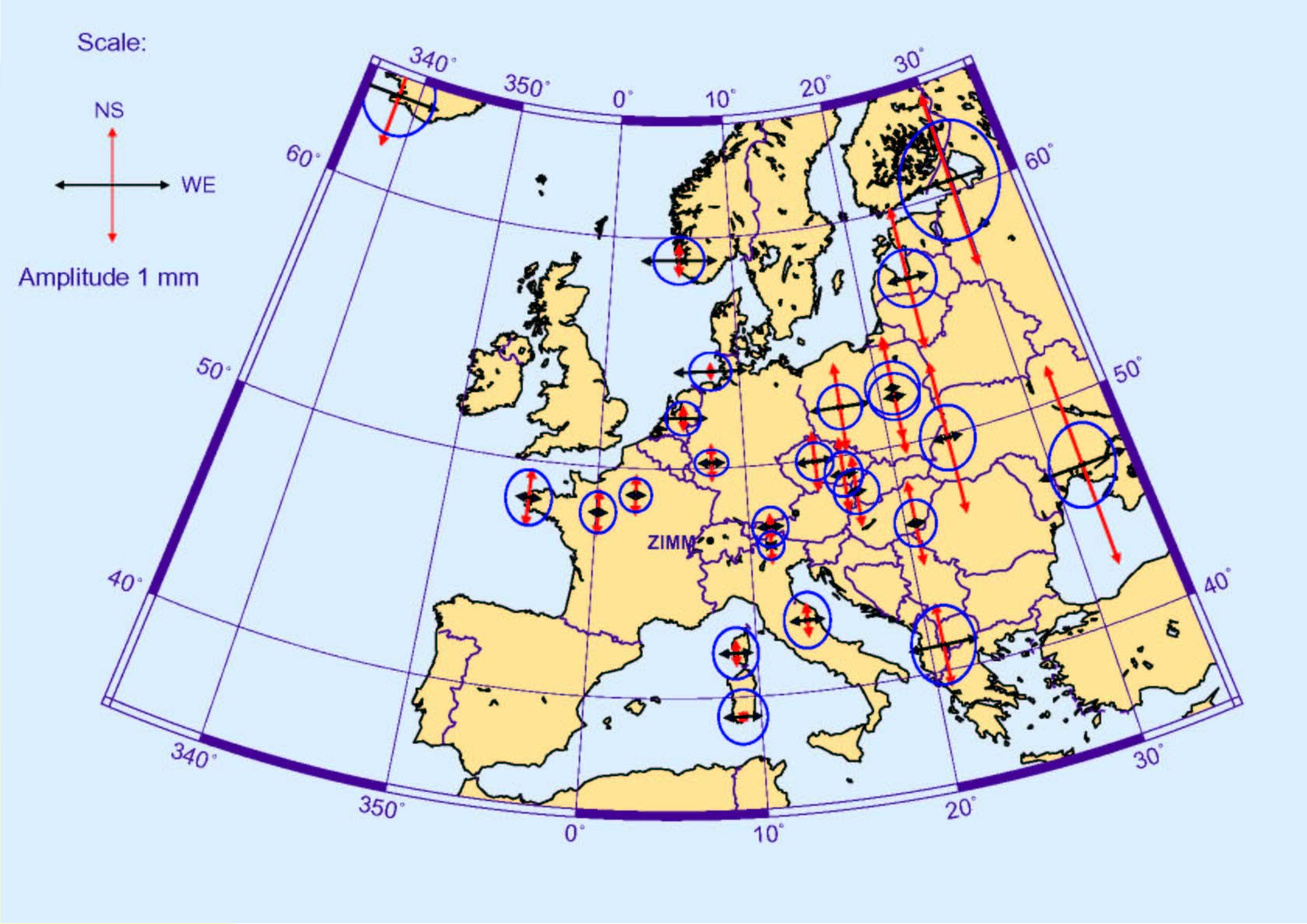
Amplitudes of horizontal components variations with period O1 (the ocean loading effect was included in network processing)



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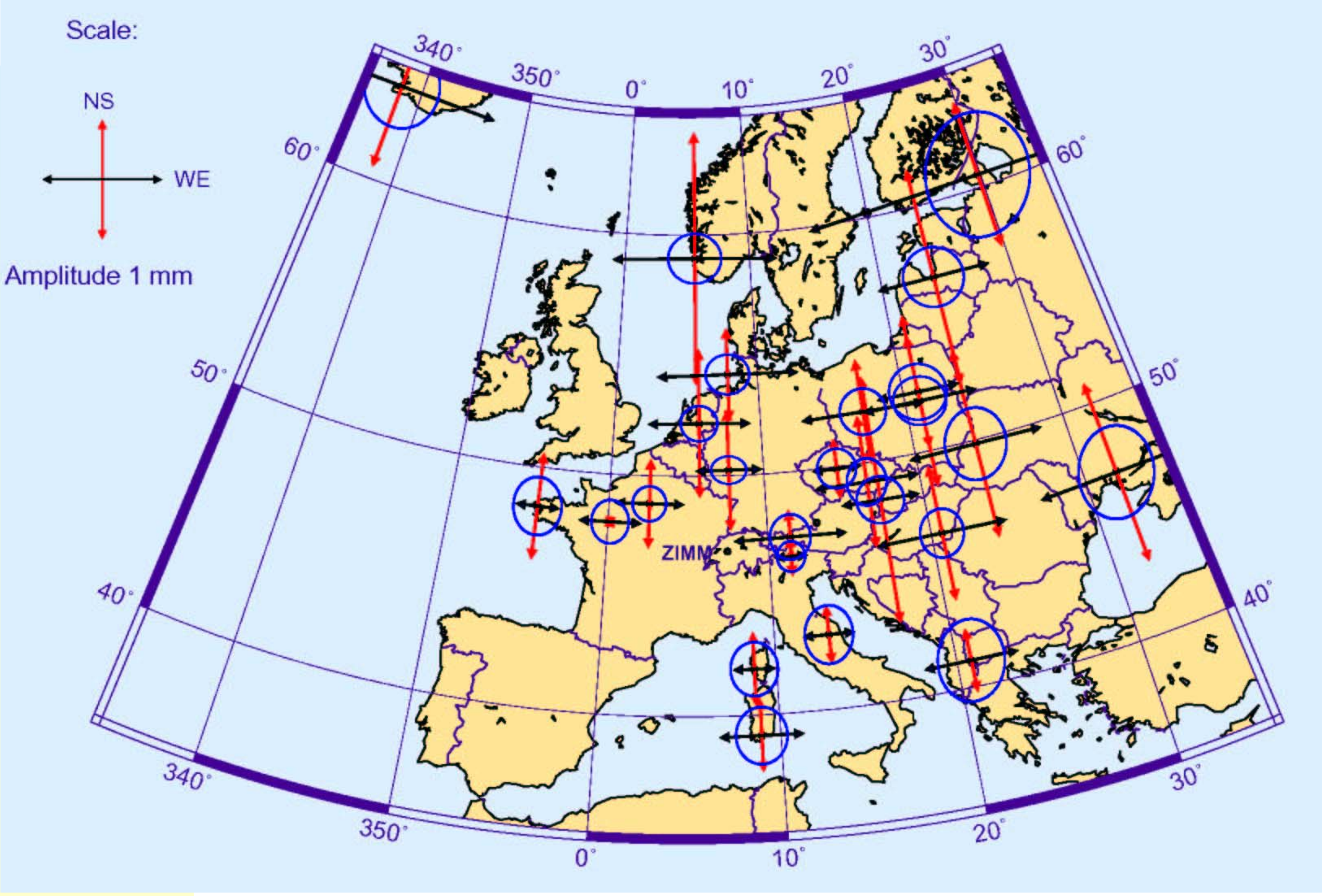
Amplitudes of horizontal components variations with period K2

(Probably residual effect of GPS orbit modelling. Orbiting period of GPS satellite = period of K2)



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Conclusions from analysis of sub-daily station coordinate variations

- In all the analysed series dominate in the high frequency spectra the terms with diurnal and semidiurnal frequencies.
- All the significant terms could be associated with main tidal frequencies M2, K2, S2, O1, P1, K1, S1
- The applied processing strategies allow for identification of periodic variations at sub-millimetre level.
- The observed amplitudes of horizontal *n* and *e* components are in general at the same level (or larger) than of the *up* component

Conclusions from analysis of sub-daily station coordinate variations (cont.)

- Observed M2 and O1 waves could be associated with deficiencies in solid Earth, and mainly of ocean loading tidal modelling
- The K2 and K1 residual effects in the series are probably associated with modelling of GPS satellite orbits
- variations with S2 and S1 frequencies reflect mainly the thermal and atmospheric effects at the observing sites

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Further development: complex effective model for least squares estimates from whole network solutions

$$\begin{bmatrix} \mathbf{N}_1 \\ \mathbf{N}_2 \\ \vdots \\ \mathbf{N}_n \end{bmatrix} = \begin{bmatrix} \mathbf{I} & \mathbf{T}_1 & \mathbf{H}_1 & \mathbf{S}_1 \\ \mathbf{I} & \mathbf{T}_2 & \mathbf{H}_2 & \mathbf{S}_2 \\ \vdots & \vdots & \vdots & \vdots \\ \mathbf{I} & \mathbf{T}_n & \mathbf{H}_n & \mathbf{S}_n \end{bmatrix} \begin{bmatrix} \mathbf{x} \\ \mathbf{v} \\ \mathbf{a} \\ \mathbf{w} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{bmatrix}$$

$i = 1, 2 \ldots, n$

n number of analysed solutions $\approx 10^4$

$\mathbf{N}_i$ coordinates from network solution in epoch t_i (results from sub-daily processing)

$\mathbf{T}_i = \mathrm{diag}(t_i - t_0)$

$\mathbf{H}_i$ matrix of coefficients of harmonic terms – seasonal and tidal - diag($\mathbf{h}$)
$\mathbf{h} = \{\sin[\pi(t_i - t_0)/P_j], \cos[4\pi(t_i - t_0)/P_j] \ \ldots\}$

$\mathbf{S}_i$ matrix of coefficients defining biases, pulses and jumps with known time resolution

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Parameters:

x coordinates in epoch t_0

v velocities

a amplitudes of seasonal and tidal periodic variations

w sudden coordinate changes

Covariance matrix of estimated coordinates N

$$\Sigma_{\mathbf{N}} = \begin{bmatrix} \Sigma_{\mathbf{N}1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \Sigma_{\mathbf{N}2} & & \mathbf{0} \\ \vdots & & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \Sigma_{\mathbf{N}n} \end{bmatrix}$$

The model enables statistically rigorous estimates of periodic phenomena taking the covariance matrices of observed coordinates into account

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Global daily ionosphere models

- Latitude band covered: from 30 to 75 degrees
- Spherical harmonics representations with degree and order 5 (36 terms).
- Applications:
  - processing of data from single frequency GPS receivers,
  - precise short baseline determination for special purposes separately on L1 and L2,
  - utilisation of GPS based ionosphere models in various fields of geophysics.

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Estimation of troposphere gradients (azimuthal asymmetry in tropospheric delay)

Tropospheric zenith delay:

$$\Delta\rho(t) = \Delta\rho_{apriori} f(z) + \Delta\rho_h(t) f(z) + \Delta\rho(t)_n \frac{\partial f}{\partial z}\cos(A) + \Delta\rho(t)_e \frac{\partial f}{\partial z}\sin(A)$$

$f(z)$	mapping function
$\Delta\rho_h$	zenith delay parameter
$\Delta\rho_n$	gradient parameter in north-south direction
$\Delta\rho_e$	gradient parameter in east-west direction

- **Troposphere gradients are estimated for 24 and 6 hour intervals**
- **RMS of $\Delta\rho$ estimates are usually less than 0.3 mm**

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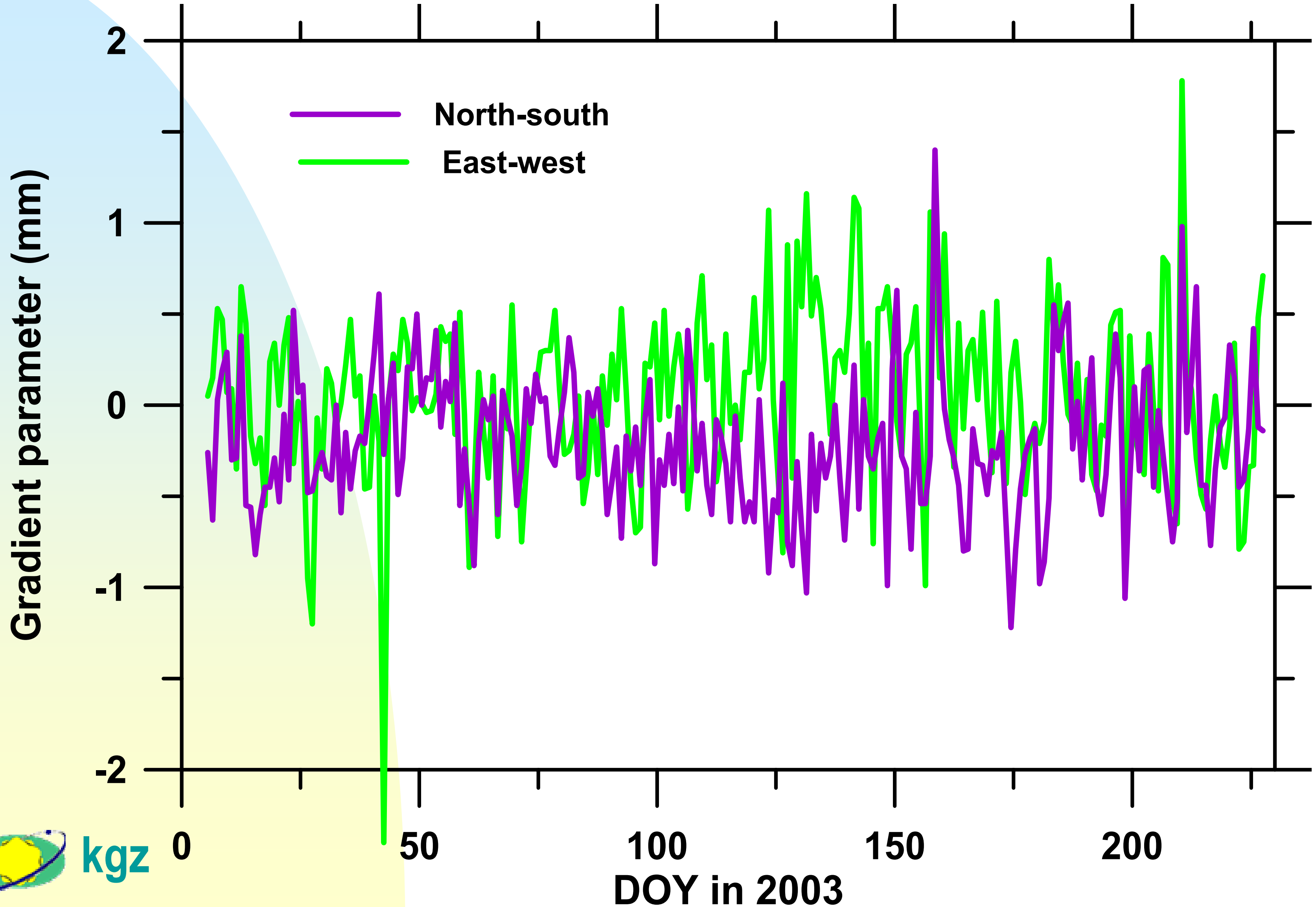
Example of troposphere gradient time series: station BOR1 , 24-hour intervals



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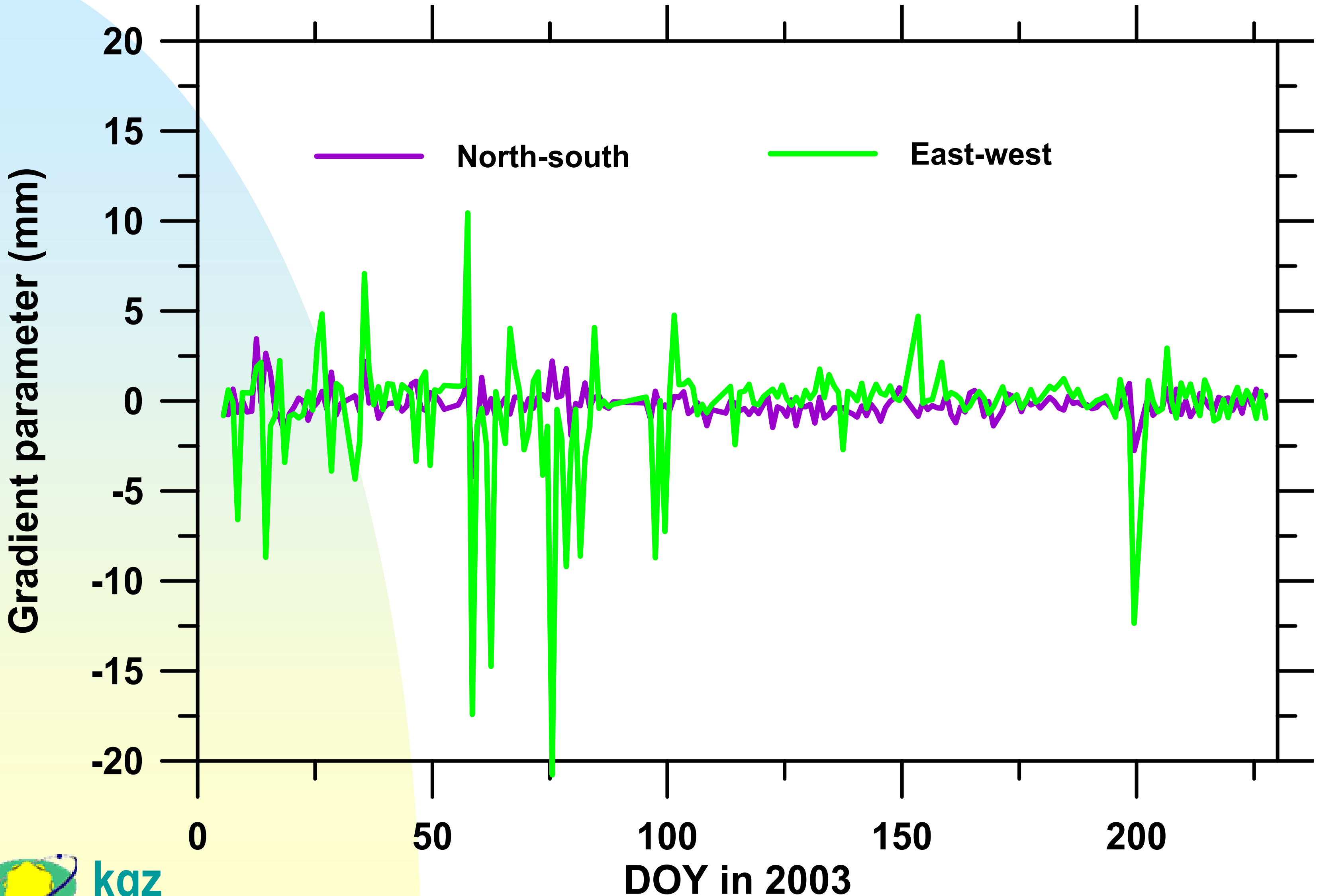
Example of troposphere gradient time series: station DUBR , 24-hour intervals



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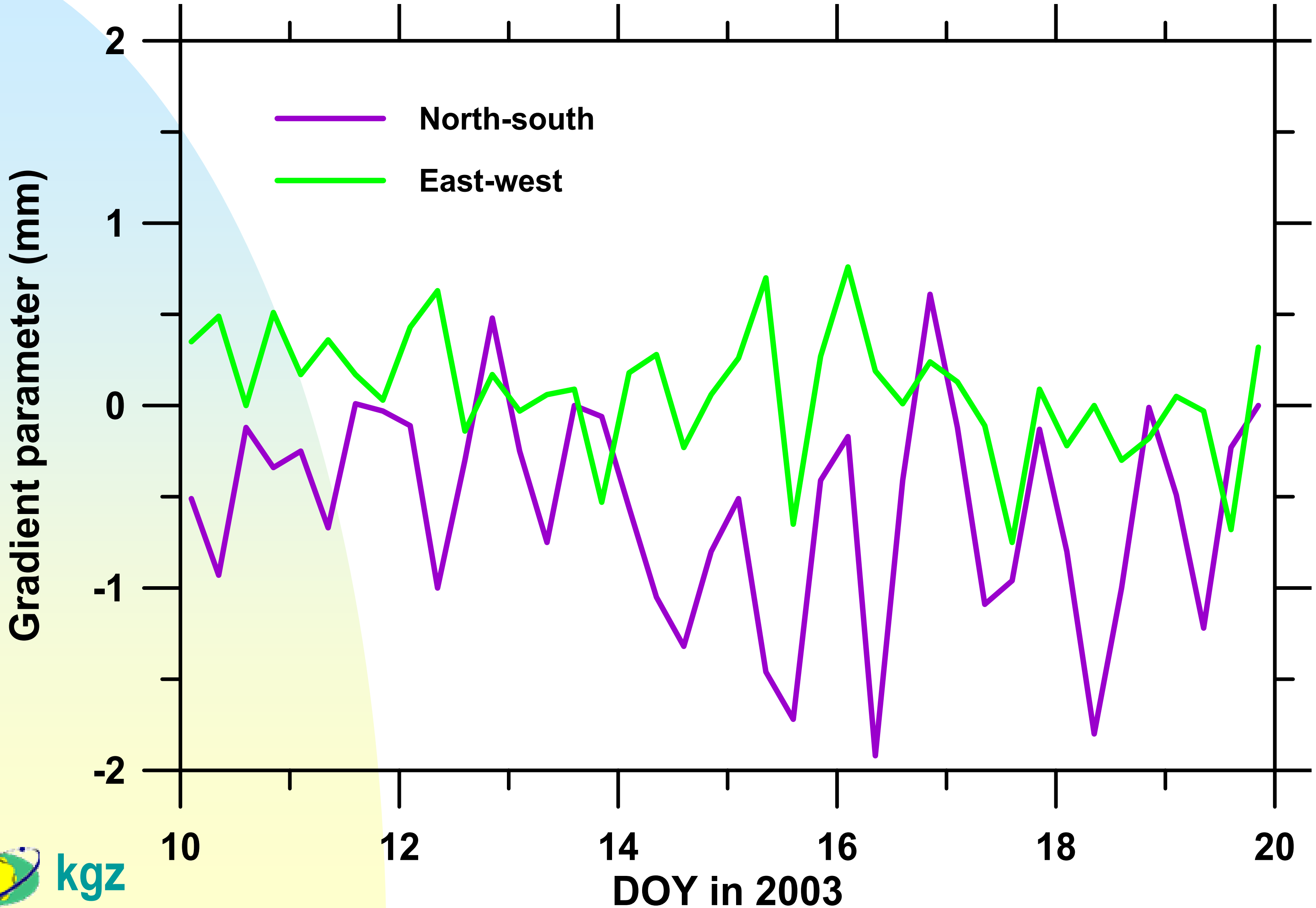
Example of troposphere gradient time series: station ZIMM , 6-hour intervals



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Conclusions to troposphere gradients

- The majority of estimated troposphere gradients exceed the one-sigma interval.
- The typical amplitudes of 24-hour gradients are about 0.5 mm, individual values reach about 2 mm.
- Some stations (DUBR, ORID) show one order larger troposphere gradients.
- A significant diurnal variation is observed in 6-hour gradients estimates .
- Open question: are the observed gradients at some stations real mapping of troposphere behaviour or an artefact of processing and estimation procedure?

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