Consistency of diurnal and semidiurnal variations estimated from GPS with ocean tide loading displacements evaluated at some EPN sites

J. Hefty, Department of Theoretical Geodesy
Slovak University of Technology, Bratislava

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Motivation

- The space techniques, like VLBI, SLR and GPS are capable to measure harmonic site displacement with millimeter accuracy if the long term observations are appropriately analyzed.
- Ocean tide loading effects cause in Europe site position variations with amplitudes from sub-milimeter level to several centimeters.
- The amplitudes of loading effects at various sites differ due to their distance from ocean, however they are not negligible also in the inland of Europe.
- The several ocean tide models recently available lead to differences in loading effects reaching few millimeters.
- The aim of this presentation is to evaluate the potential of GPS for contribution to verification of ocean tidal loading models.

Content

- Ocean tidal loading effects at ~30 sites analyzed at LAC SUT Bratislava
- Two separate intervals 2004.0 – 2006.8 and 2006.8 – 2008.3 were analyzed. They are differing in dependence of the processing strategy adopted.
- Spectral analysis of unmodeled effects with diurnal and sub-diurnal frequencies
- Phasor diagrams of observed variations and the modeled tidal ocean loading based on least squares adjustment.
- Regional distribution of unmodeled phenomena with tidal diurnal and semidiurnal frequencies

Analyzed sites – LAC SUT subnetwork

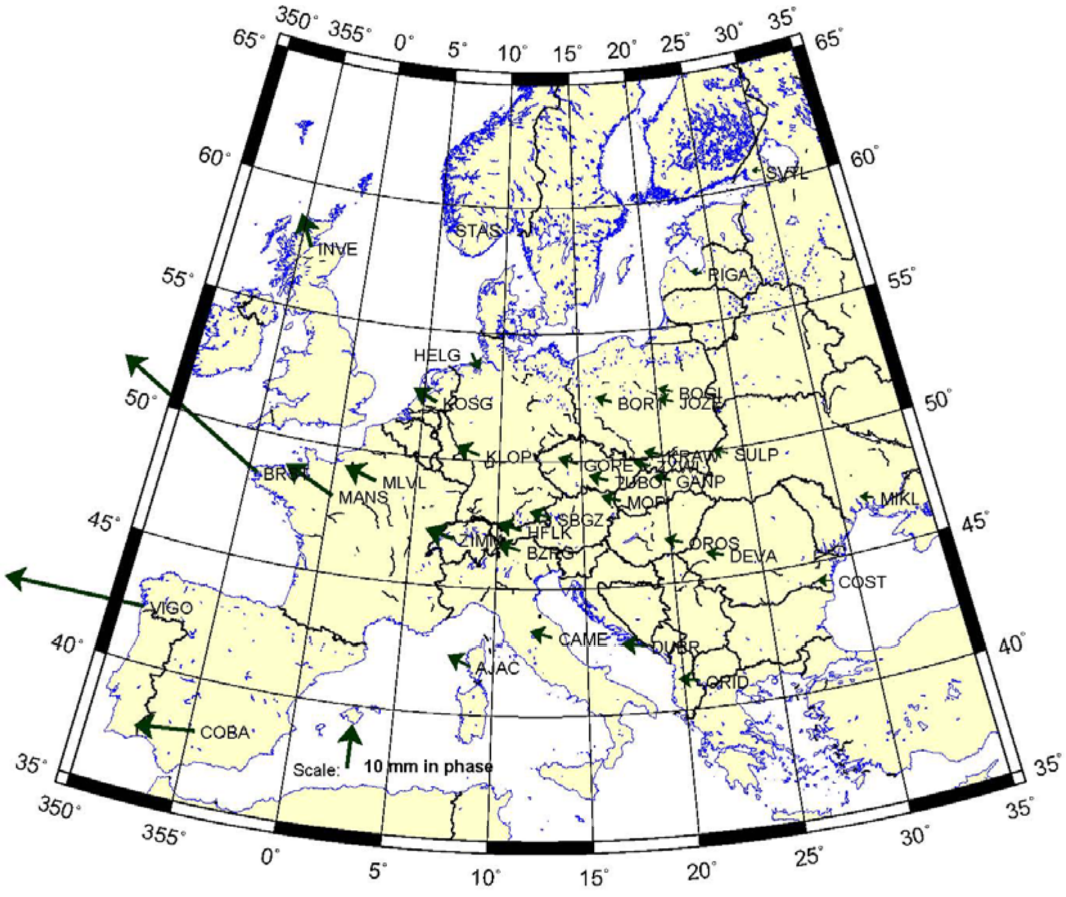
- Status in May 2008 – 42 sites spread out over the whole continent
- The continual observations from 2004.0 to 2008.3 are available at ~ 30 sites
- Till 2006.8 the BV42 and ITRF2000 used, after 2006.8 the BV50 and ITRF2005

Solid earth tides and ocean loading modeling

- Solid earth tides are modeled consistently with IERS Conventions, 2003. The “step 1” and “step 2” corrections are implemented.
- For the site displacements due to ocean loading are recently available about 15 various ocean tidal models.
- These models account for 11 tidal terms – semidiurnal M2, S2, N2, K2, diurnal K1, O1, P1, Q1 fortnightly Mf, monthly Mm and semiannual Ssa.
- The largest amplitude differences among the models are up to 5 mm, generally being at the one millimeter level.
- In this presentation four recently applied tidal loading models will be examined, namely GOT00.2, FES2004, CSR4.0 and TPXO.7.1.

Modeled ocean tide loading displacements – FES2004

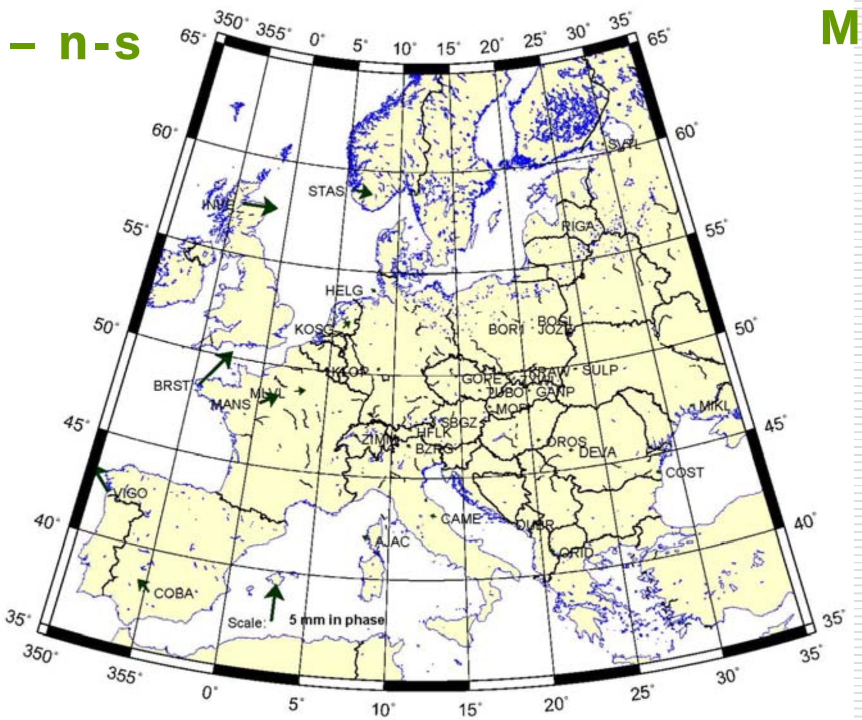
- M2 – the semidiurnal wave with 0. 5175 day periodicity
- M2 up component – the ocean loading effect with the largest amplitude
- The amplitude is from 3 mm in inland to 40 mm in the regions close to Atlantic
- The in phase variations are represented in n-s direction, the out of phase constituent is in e-w direction



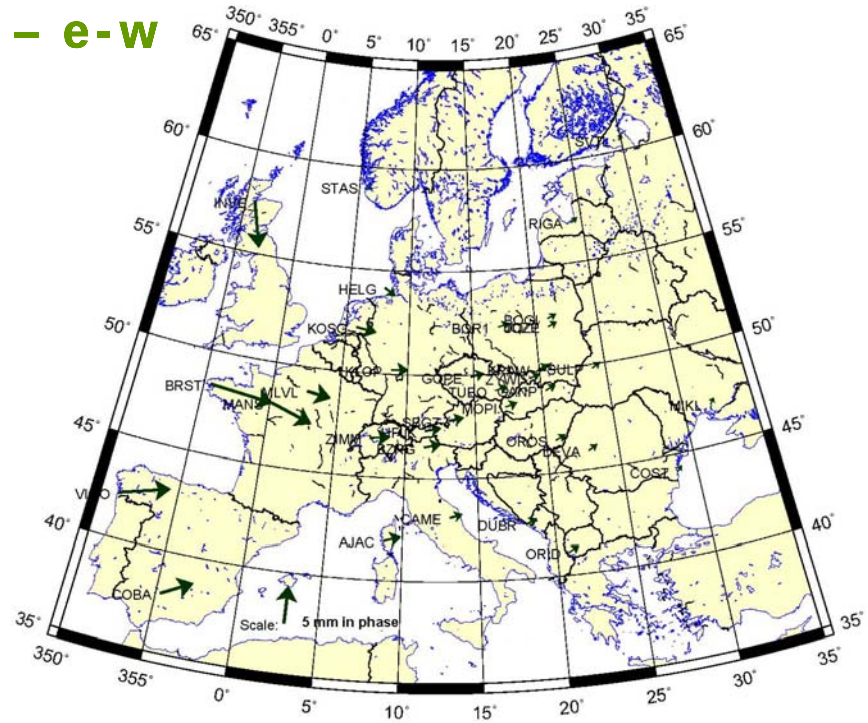
Modeled ocean tide loading displacements – FES2004

- M2 variations in n-s and e-w components
- The predicted amplitudes in the sites analyzed are from zero to 8 mm

M2 – n-s



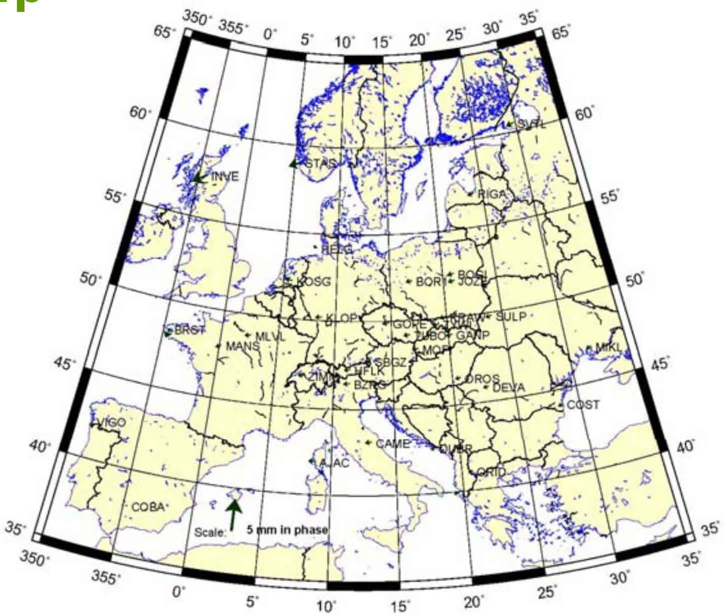
M2 – e-w



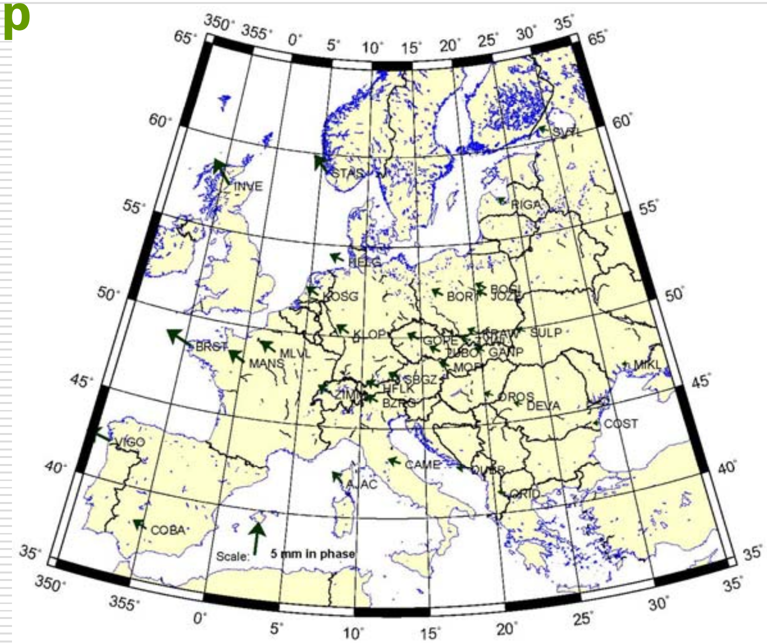
Modeled ocean tide loading displacements – FES2004

- Predicted vertical displacements with periods of O1 tide (1.078 day) and K1 tide (0.997 day)
- Maximum amplitudes are 3 mm (O1) and 7 mm (K1)

O1 – up



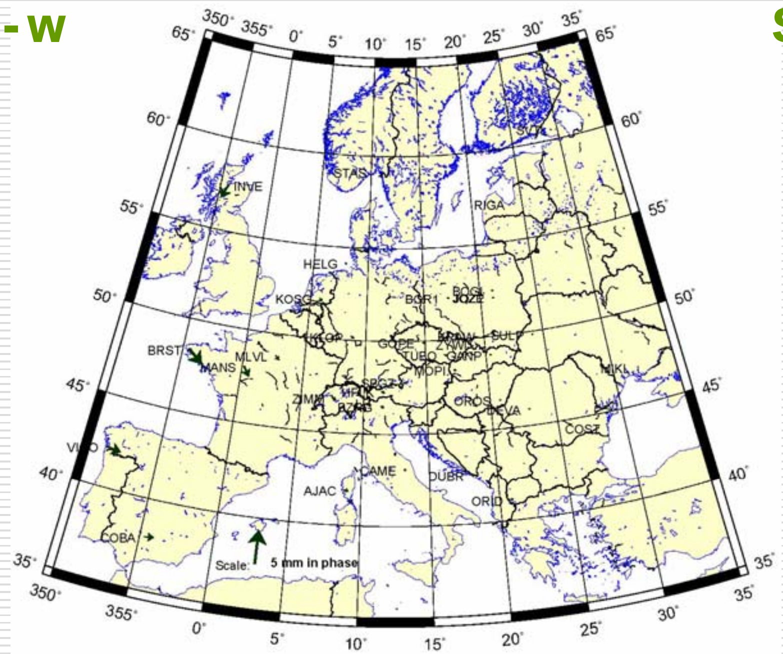
K1 – up



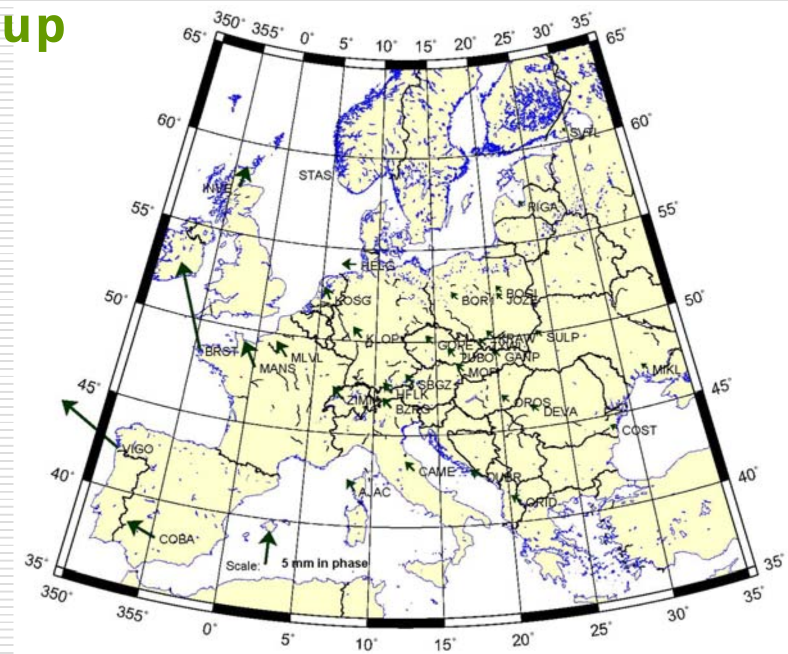
Modeled ocean tide loading displacements – FES2004

- S2 tide (period 0.5000 day) – e-w component (max. amplitude 2 mm) and up component (max. amplitude 13 mm)

S2 – e-w



S2 – up

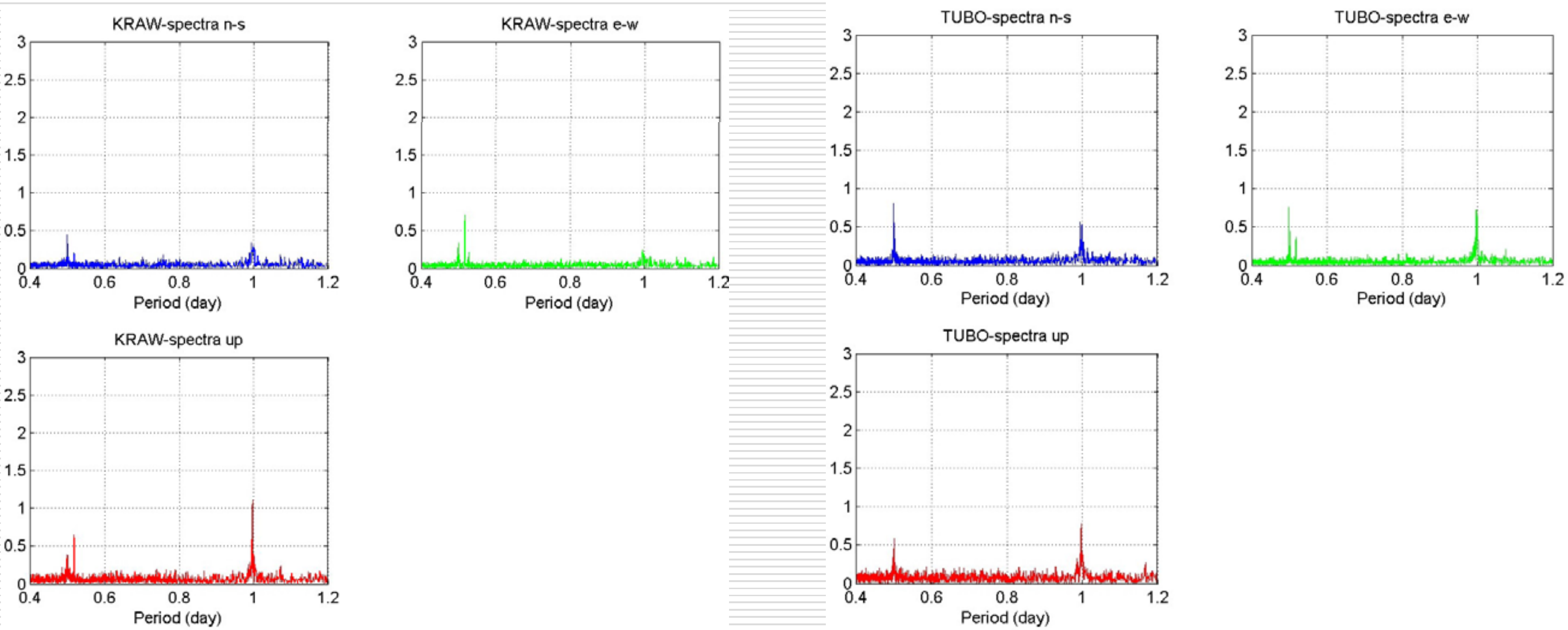


Main features of the GPS data analysis

- Site coordinates are estimated from separate 4-hour intervals (6 values per day)
- Ambiguities are taken from daily solutions (one batch in 0-24 h)
- Handling with the troposphere zenith delays in 4-hour batches:
  - in solutions till 2006.8 hourly ZTD are taken from 24 h solutions,
  - in solutions after 2006.8 are ZTD estimated simultaneously with coordinates.
- Generating of station coordinate series with subdiurnal resolution: Firstly, the reference coordinate series based on set of ~20 stable stations is evaluated. Next, the residual variations of individual stations are obtained by reduction of the reference series.
- Two step analysis of time series:
  - Spectral analysis of n-s, e-w and up components
  - Least square estimates of amplitudes of terms with main tidal frequencies.

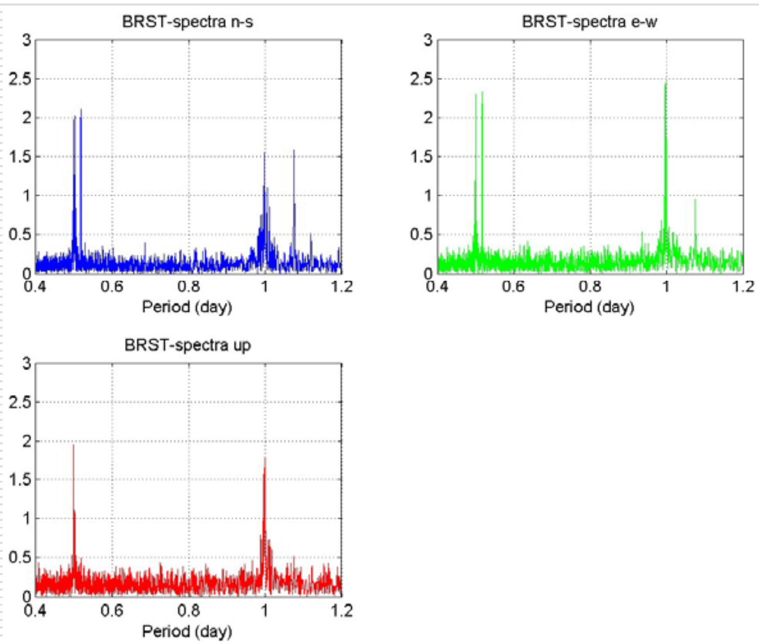
Examples of spectral analysis of n-e, e-w and up coordinates time series (based on observations from interval 2004.0 – 2006.8, reduced for GOT00.2) – inland stations

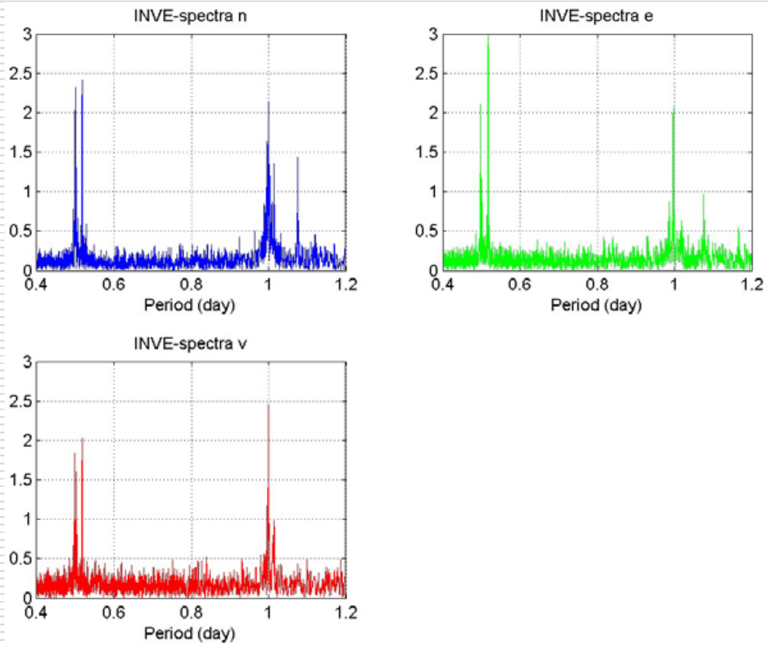
- The spectral peaks are concentrated around 0.5 and 1.0 periods. Amplitudes are up to 1 mm.
- Dominating terms are with tidal periods S1, K1, S2, M2 and K2



Examples of spectral analysis of n-e, e-w and up coordinates time series (based on observations from interval 2004.0 – 2006.8, reduced for GOT00.2) – stations close to coast

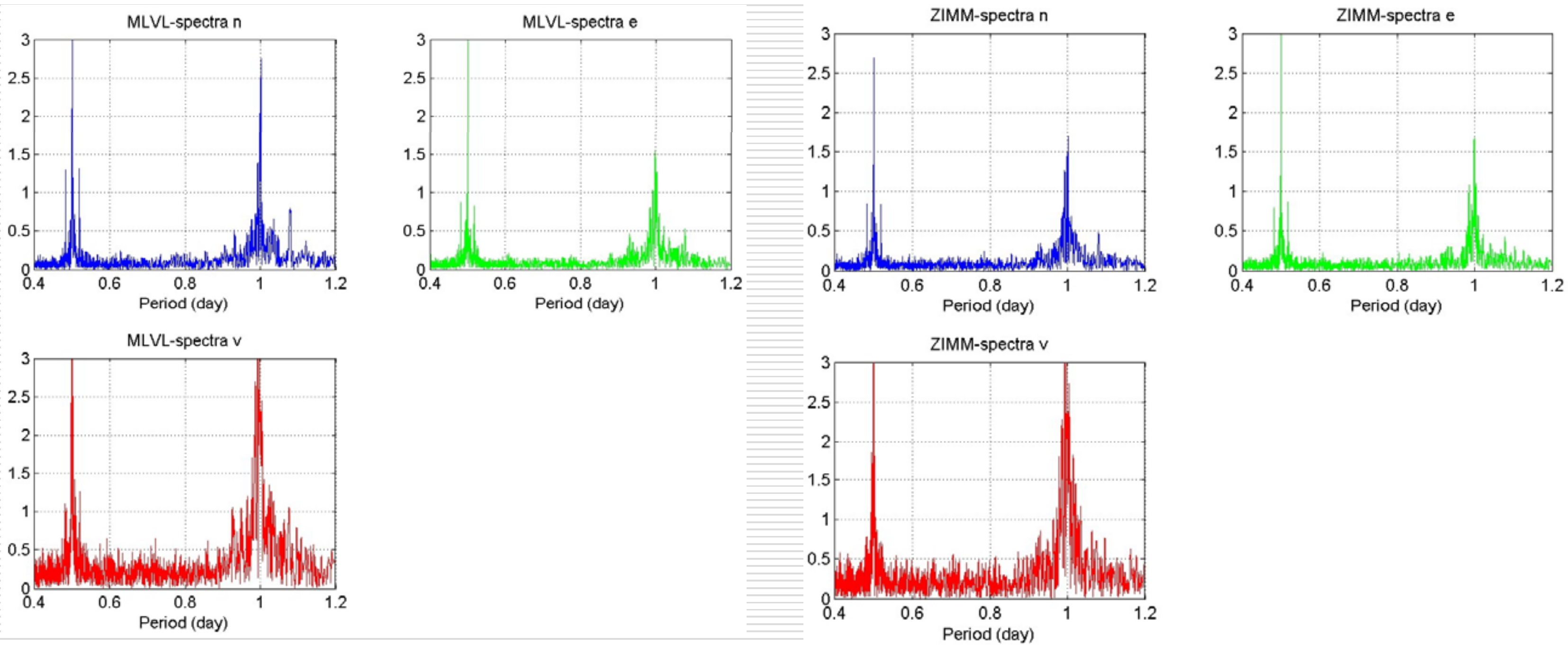
- Dominating terms are M2, S1, K1, O1, S2 and K2
- Their amplitudes vary from 1 to 3 mm. Amplitudes of the horizontal components are relatively larger than amplitudes for the up components





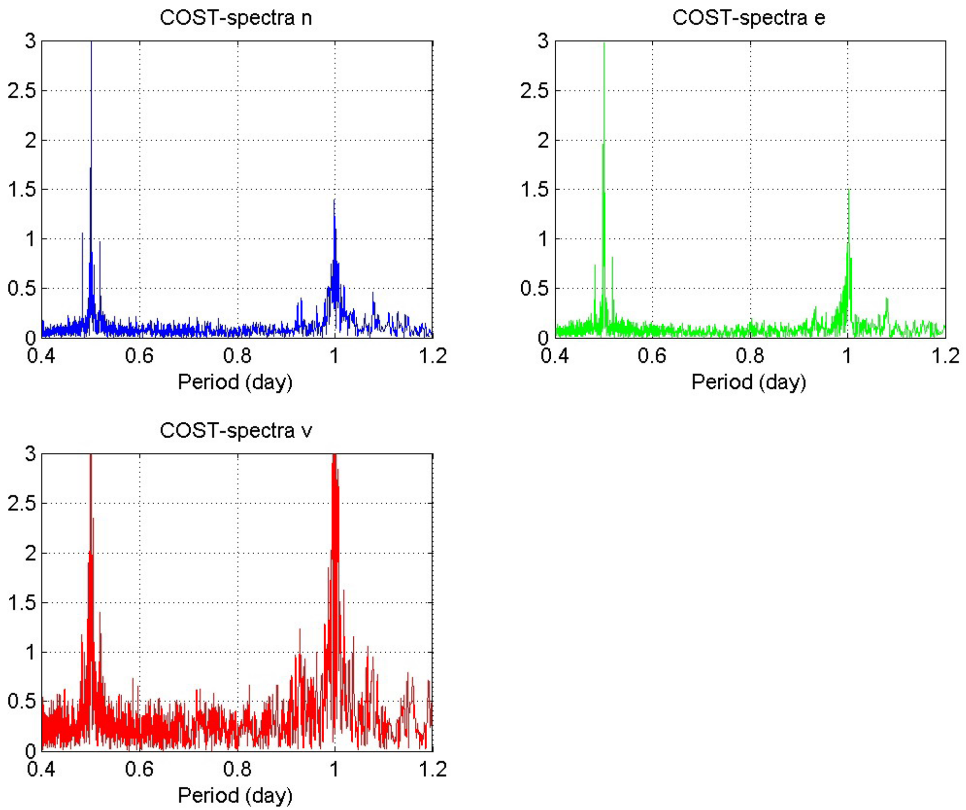
Examples of spectral analysis of n-e, e-w and up coordinates time series (based on observations from interval 2006.8 – 2008.3, reduced for FES2004)

- Dominating terms are spread out around S1 and S2 frequencies (1.000 and 0.500 days) with amplitudes up to 3-6 mm



Examples of spectral analysis of n-e, e-w and up coordinates time series (based on observations from interval 2006.8 – 2008.3, reduced for FES2004)

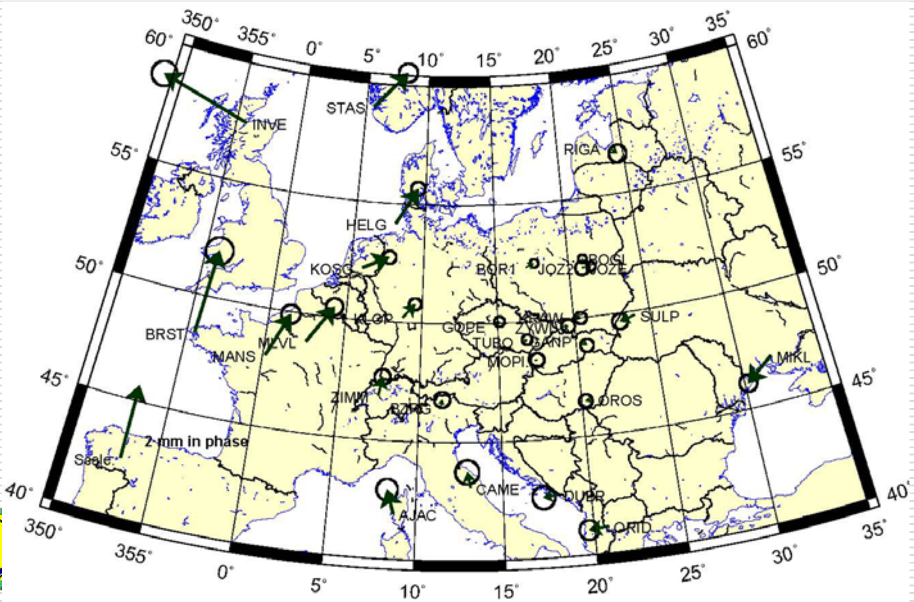
- In the spectra besides S1 and S2 the other tidal terms – M2, O1, K2 and K1 are not clearly distinguishable
- Probable reason: simultaneous estimate of coordinates and ZTD is not appropriate for the separation of strictly diurnal and semidiurnal variations (S1 and S2) from other tidal terms.
- The outputs from 2006.8-2008.3 will be not used in this presentation.



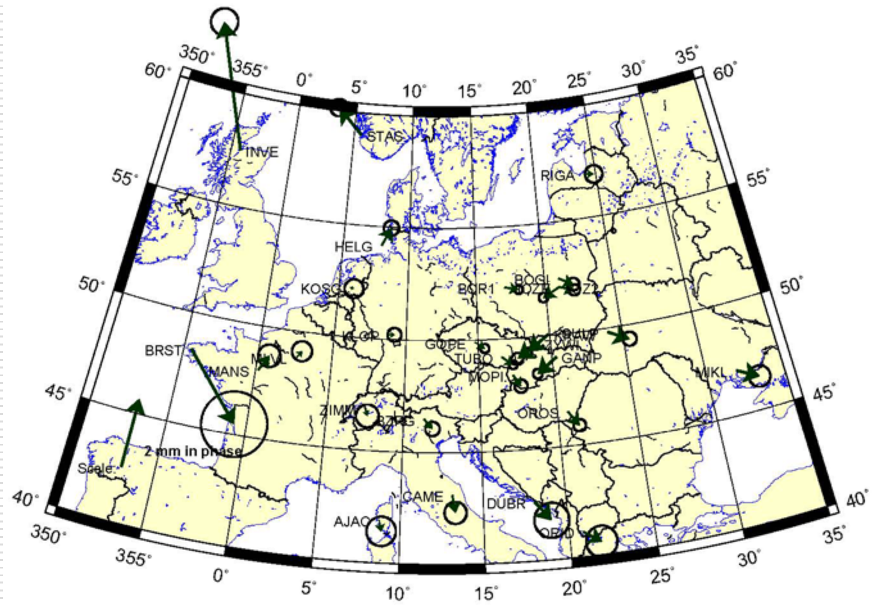
Regional distribution of observed residual horizontal variations with M2 period (reference GOT00.2 ocean loading model)

- Vectors represent the observed deficiencies in tidal modeling with the 95% error ellipses. These variations can be considered as the discrepancies with applied ocean loading model.
- In general, the largest amplitudes are for sites close to coast

M2 – n-s



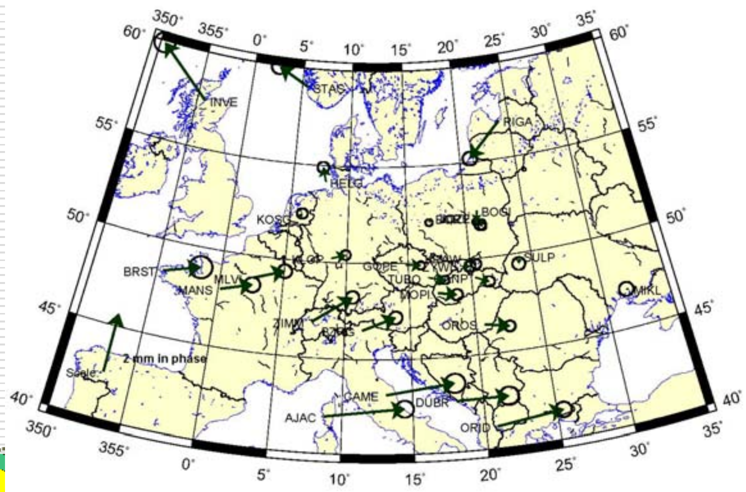
M2 – e-w



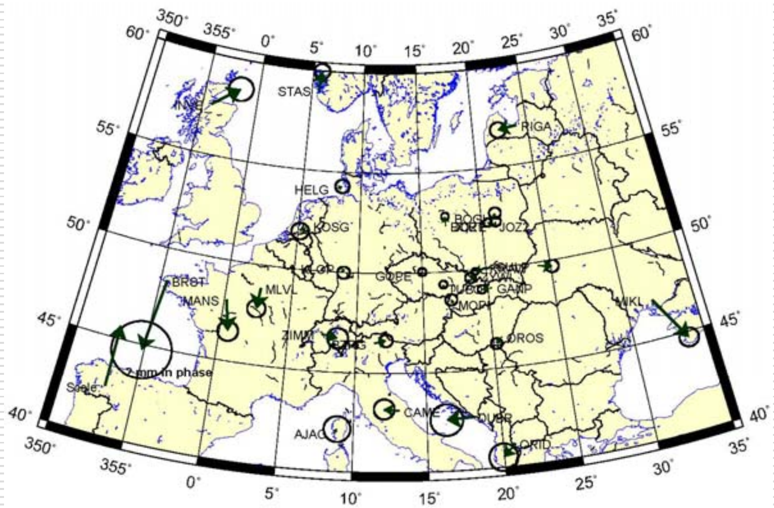
Regional distribution of observed residual horizontal variations with S2 period (reference GOT00.2 ocean loading model)

- Vectors represent the observed deficiencies in tidal modeling with the 95% error ellipses. It is on the further investigations if these variations can be considered as the discrepancies with applied ocean loading model as the period of S2 is exactly 0.500 day.

S2 – n-s



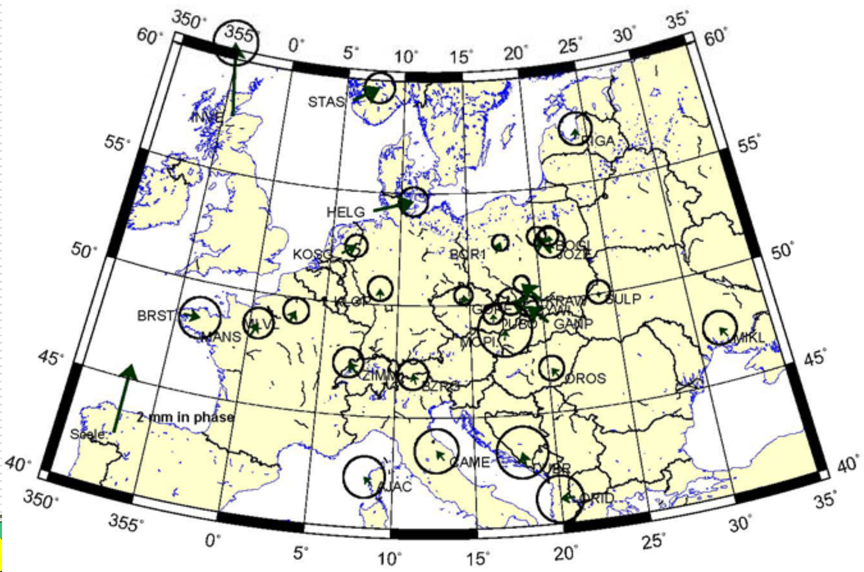
S2 – e-w



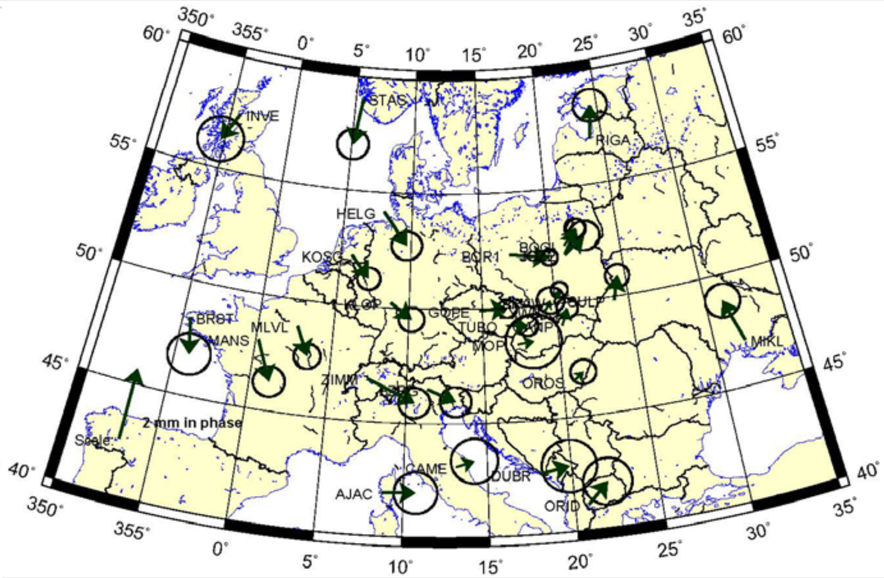
Regional distribution of observed residual vertical variations with M2 and S2 periods (reference GOT00.2 ocean loading model)

- The M2 and S2 residual up variations are of the same order
- Residual vertical M2 and S2 variations are of the same magnitude or even smaller than the M2 and S2 horizontal constituents

M2 – up



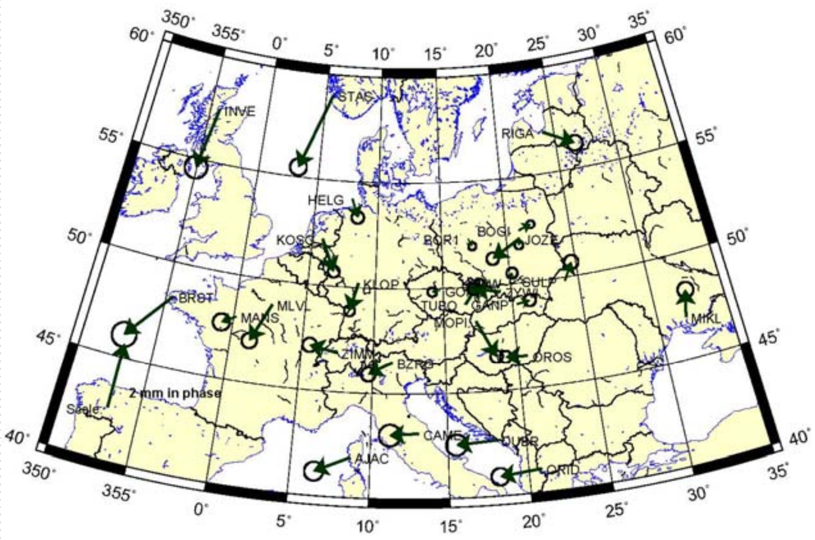
S2 – up



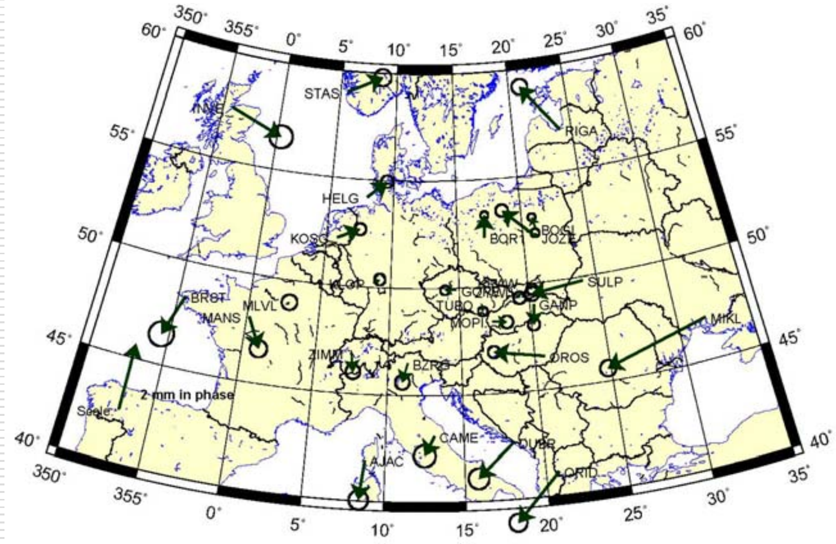
Regional distribution of observed residual n-s variations with K2 and K1 periods (reference GOT00.2 ocean loading model)

- The K2 (0.4986 day) and K1 (0.9973 day) variations are associated with GPS satellites orbiting and repeating of satellite constellation as well as with multipath effects.
- The K1 and K1 residual variations are very probably not the consequence of ocean loading mismodeling.

K2 – n-s

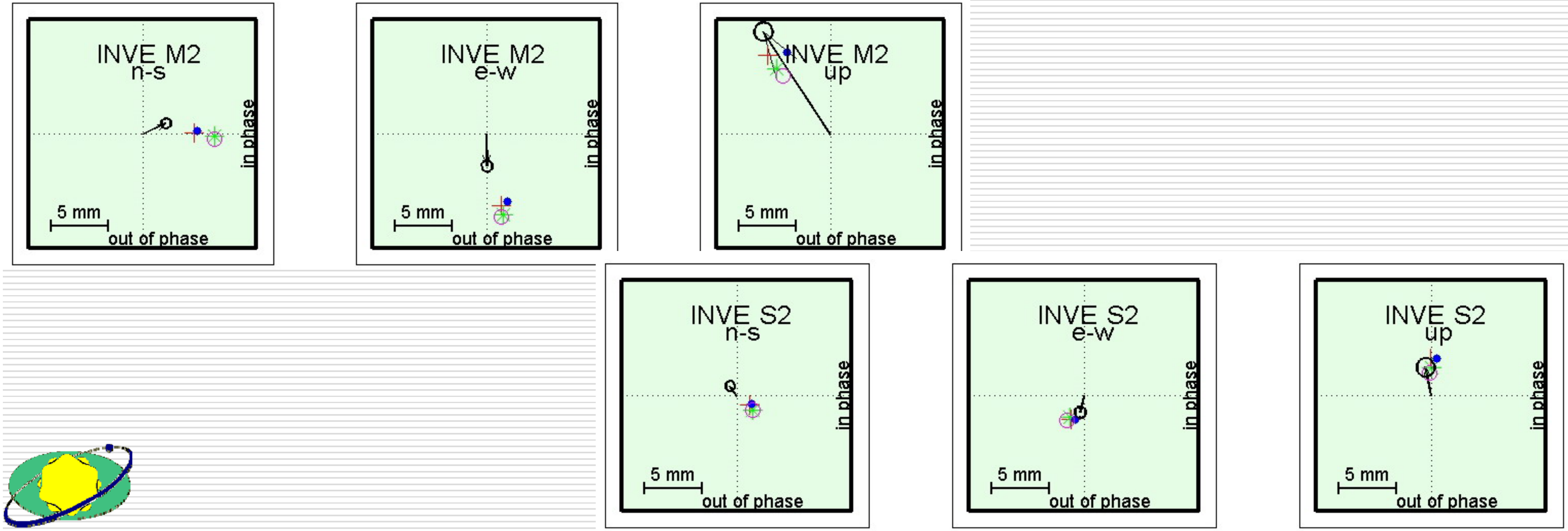


K1 – n-s



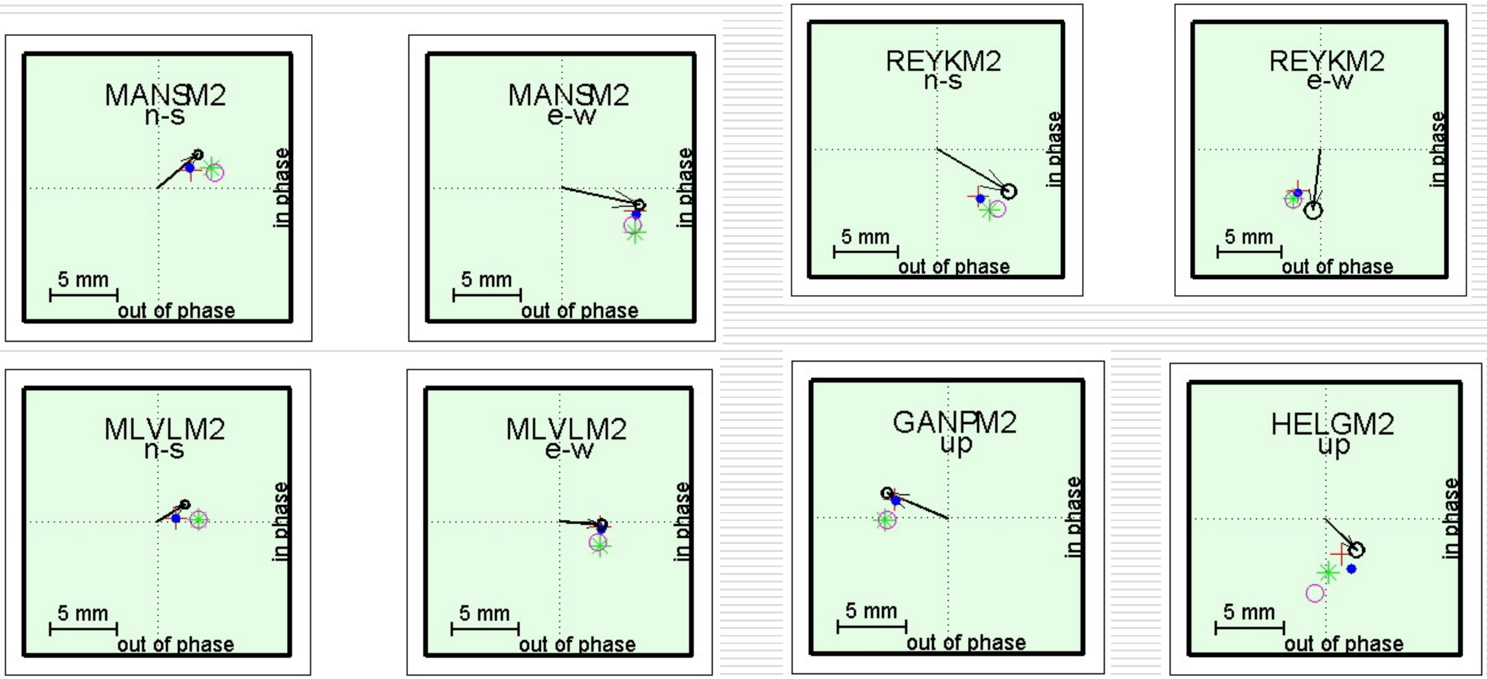
Phasor diagrams of observed and modeled ocean tidal loading displacements. Examples: station INVE, M2 and S2 tidal waves

- The tidal models: + FES2004, . GOT00.2, o CSR4.0 and * TPXO.7.1
- Arrows with 95% confidence ellipse – the GPS estimates
- Inconsistencies among observations and models in range 2-3 mm detected for INVE M2 (all constituents) and S2 (n-s)



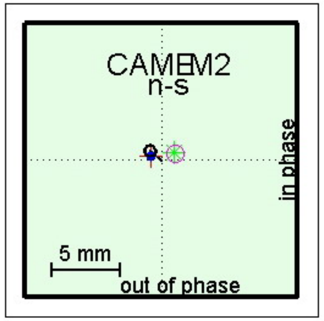
Phasor diagrams of observed and modeled ocean tidal loading displacements. Examples: stations MANS, MLVL, REYK, GANP, HELG - M2 tidal wave

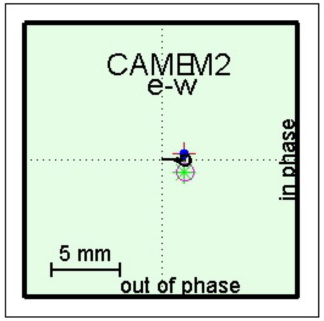
- The tidal models: + FES2004, . GOT00.2, **o** CSR4.0 and * TPXO.7.1
- Situations where the inconsistencies with the M2 models are observed, however the + FES2004 model values are close to the observed values; discrepancies are less than 2 mm.

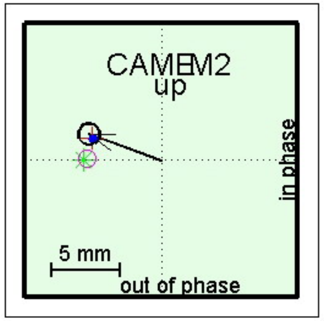


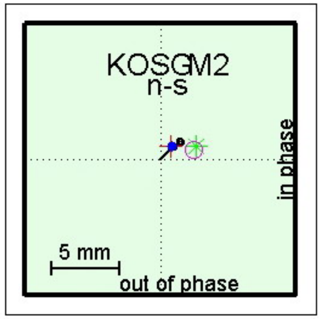
Phasor diagrams of observed and modeled ocean tidal loading displacements. Examples: stations CAME and KOSG - M2 tidal wave

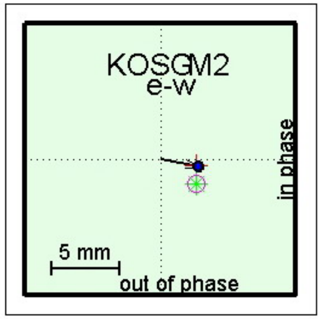
- Situations where the consistency with the M2 model + FES2004 is observed, discrepancies are about 1 mm or less.
- The preference of FES2004 is proved

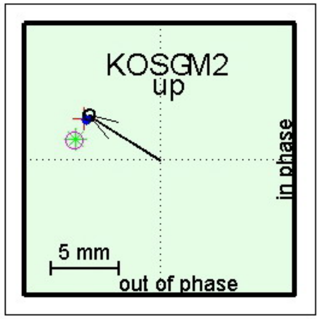












Conclusions

- The GPS coordinate time series with subdiurnal resolution allow to recognize the shortage of recent ocean tide loading models for some of the tidal constituents.
- The most reliable results were obtained for the M2 tidal wave, where discrepancies with GOT2000 model up to 3 mm were observed; this concerns the stations close to coast. Detected differences with model are larger for horizontal constituents than for the up components.
- For the S2 wave discrepancies with model at 1-2 mm level are detected, however their relation to ocean tide modeling has to be proved.
- The K1 and K2 tidal waves are not suitable for tidal model validation.