# Impact of non-tidal loading in VLBI analysis

M. Glomsda, M. Bloßfeld, M. Gerstl, Y. Kwak, M. Seitz, D. Angermann, F. Seitz

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

24th Meeting of the European VLBI Group for Geodesy and Astrometry
Gran Canaria, Spain, March 17-19, 2019

# Outline

- Loading effects
- Sources for non-tidal loading displacements
- Impact of non-tidal loading corrections
- Summary

# Outline

- Loading effects
- Sources for non-tidal loading displacements
- Impact of non-tidal loading corrections
- Summary

# Tidal loading effects

- Periodic short term displacements of sites on the Earth‘s crust are, among others, generated by…

  … the gravitational forces of Sun and Moon:
  - solid Earth tide
  - tidal atmospherical loading
  - tidal ocean loading

  … the centrifugal forces of Earth rotation:
  - pole tide
  - ocean pole tide

- For long term reference frames, instantaneous site positions are regularized by subtracting these **tidal loading effects** and other displacements.

# Non-tidal loading effects

- There are other short term site displacements caused by rather local and irregular changes in
  - atmospheric pressure,
  - the mass redistribution of ocean water, or
  - the mass redistribution of land water (hydrology).
- These **non-tidal loading effects** are generally not included in the regularization step and official geodetic analyses.
- Exception: contributions to the International VLBI Service for Geodesy and Astrometry (IVS) should contain non-tidal atmospherical loading corrections.
- Given recent advances in measuring and modelling, is it worthwhile adding non-tidal loading effects in the analysis of VLBI observations?

# Outline

- Loading effects
- Sources for non-tidal loading displacements
- Impact of non-tidal loading corrections
- Summary

# Data providers used for our study

- International Mass Loading Service (IMLS):

  http://massloading.net

  L. Petrov (2015) The International Mass Loading Service, submitted,

  http://arxiv.org/abs/1503.00191.

- Earth System Modelling group at GFZ (ESMGFZ):

  http://esmdata.gfz-potsdam.de:8080

  R. Dill and H. Dobslaw (2013), Numerical simulations of global-scale high-resolution

  hydrological crustal deformations, J. Geophys. Res. Solid earth 118, doi:10.1002/jgrb.50353.

- More data providers can be found at the

  Global Geophysical Fluids Center (GGFC):

  http://loading.u-strasbg.fr/GGFC

# Numerical models used by data providers

| component | IMLS | ESMGFZ |
|---|---|---|
| non-tidal atmospheric surface pressure | MERRA2 (6h resolution) | ECMWF (3h) |
| non-tidal ocean bottom pressure | MPIOM 06 (3h) | MPIOM (3h) |
| land water storage | MERRA2 (3h) | LSDM v2 (24h) |

**MERRA2**: Modern-Era Retrospective Analysis for Research and Applications, version 2, Gelaro et al. (2016)

**MPIOM**: Max-Planck-Institute for Meteorology Ocean Model, Jungclaus et al. (2013)

**ECMWF**: European Centre for Medium-Range Weather Forecasts operational data (http://ecmwf.int)

**LSDM**: Hydrological Land Surface Discharge model, Dill (2008)

# Numerical models used by data providers

| component | IMLS | ESMGFZ |
| --- | --- | --- |
| transforming loads into 3D-displacements | spherical harmonic transform approach | patched Green‘s function approach |

**Farrell (1972), taken from Petrov and Boy (2004):**

vertical displacement: $d_v(\vec{p}, t) = \iint \Delta P(\vec{q}, t)\, G_v(\psi) \cos(\varphi)\, d\lambda\, d\varphi$

horizontal displacement: $d_h(\vec{p}, t) = \iint \vec{n}(\vec{p}, \vec{q})\, \Delta P(\vec{q}, t)\, G_h(\psi) \cos(\varphi)\, d\lambda\, d\varphi$

$\vec{p}$ = site coordinates

$\vec{q}$ = pressure source coordinates

$\Delta P$ = pressure anomaly

$G_{v|h}$ = Green’s functions

$\psi$ = spherical distance of $\vec{p}$ and $\vec{q}$

$\varphi$ = geocentric latitude for $\vec{q}$

$\lambda$ = longitude for $\vec{q}$

$\vec{n}$ = a tangential unit vector

# Numerical models used by data providers

| component | IMLS | ESMGFZ |
| --- | --- | --- |
| transforming loads into 3D-displacements | spherical harmonic transform approach | patched Green‘s function approach |

**Farrell (1972), taken from Petrov and Boy (2004):**

vertical displacement: $d_v(\vec{p}, t) = \iint \Delta P(\vec{q}, t)\, G_v(\psi) \cos(\varphi)\, d\lambda\, d\varphi$

horizontal displacement: $d_h(\vec{p}, t) = \iint \vec{n}(\vec{p}, \vec{q})\, \Delta P(\vec{q}, t)\, G_h(\psi) \cos(\varphi)\, d\lambda\, d\varphi$

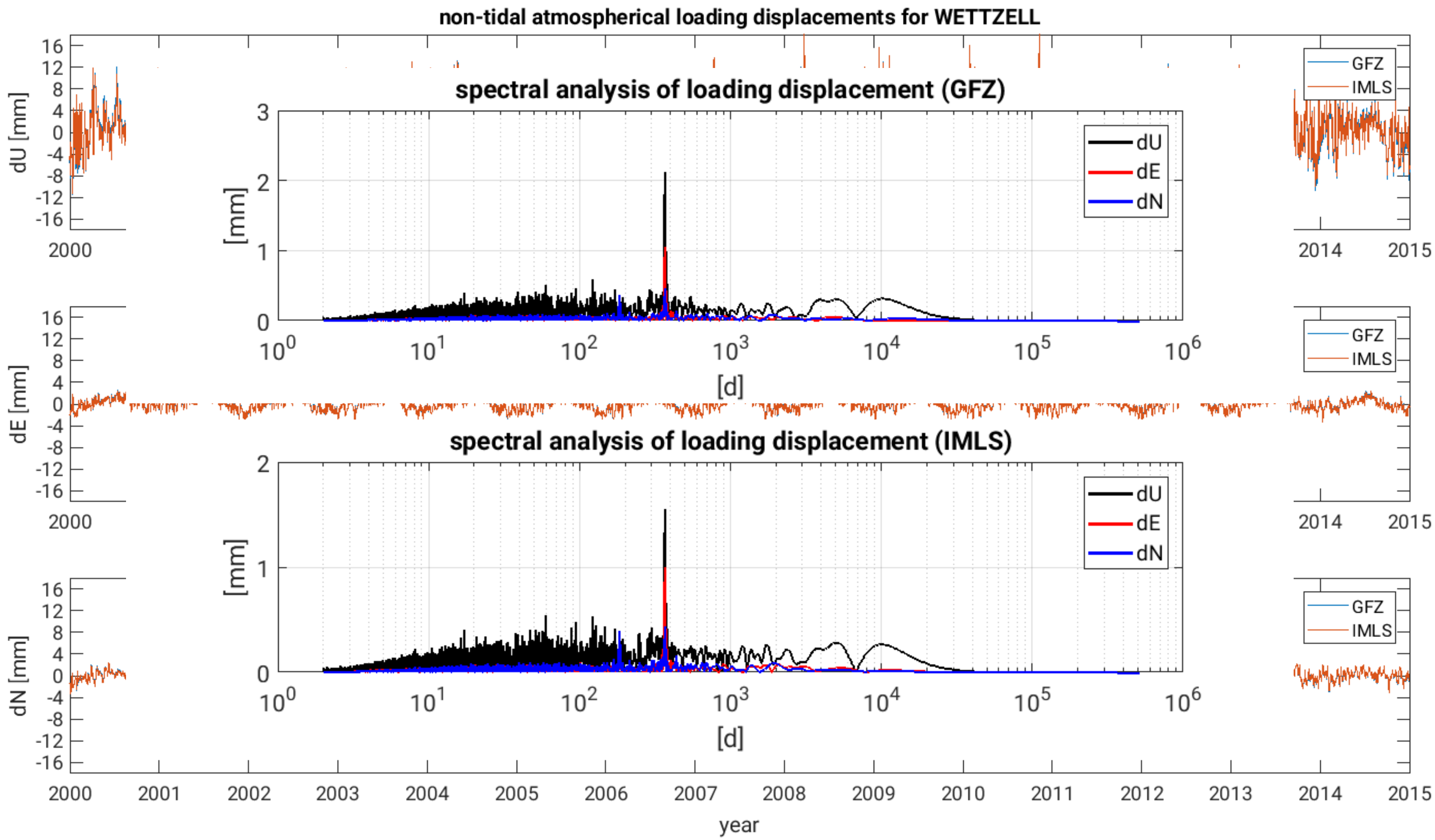
**Petrov (2015):**

“The problem is that this algorithm has complexity $O(d^4)$, where $d$ is the spatial grid size, i.e. it grows very rapidly with an increase of spatial resolu-tion. It becomes impractical to use convolution for loading computation using models with a high spatial resolution. The alternative is to use the spherical harmonic transform approach.“

# Examples of local 3D-displacements

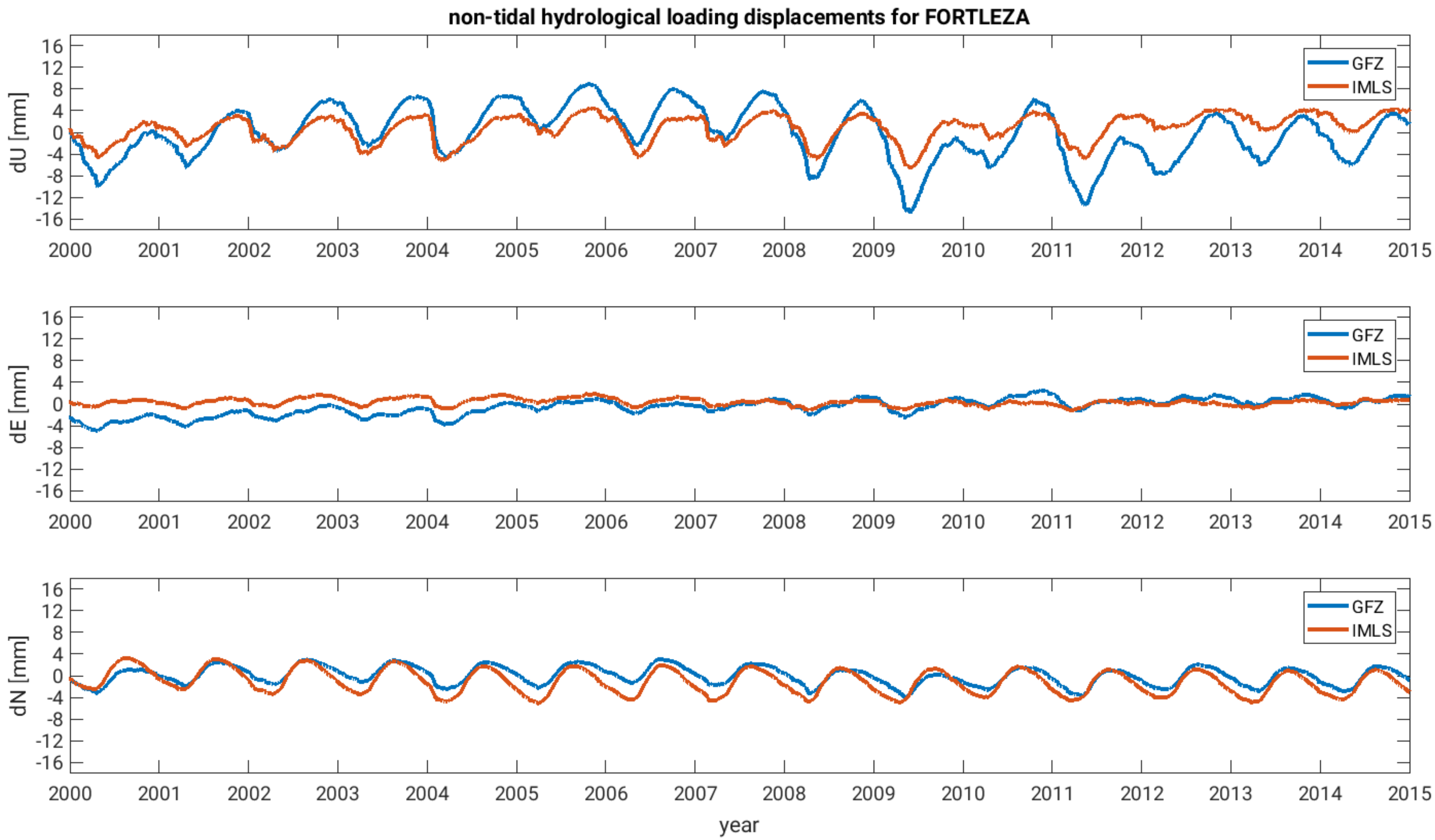

- The vertical displacements have the highest values.
- Both data sets are very close. The same holds for non-tidal ocean loading.

# Examples of local 3D-displacements



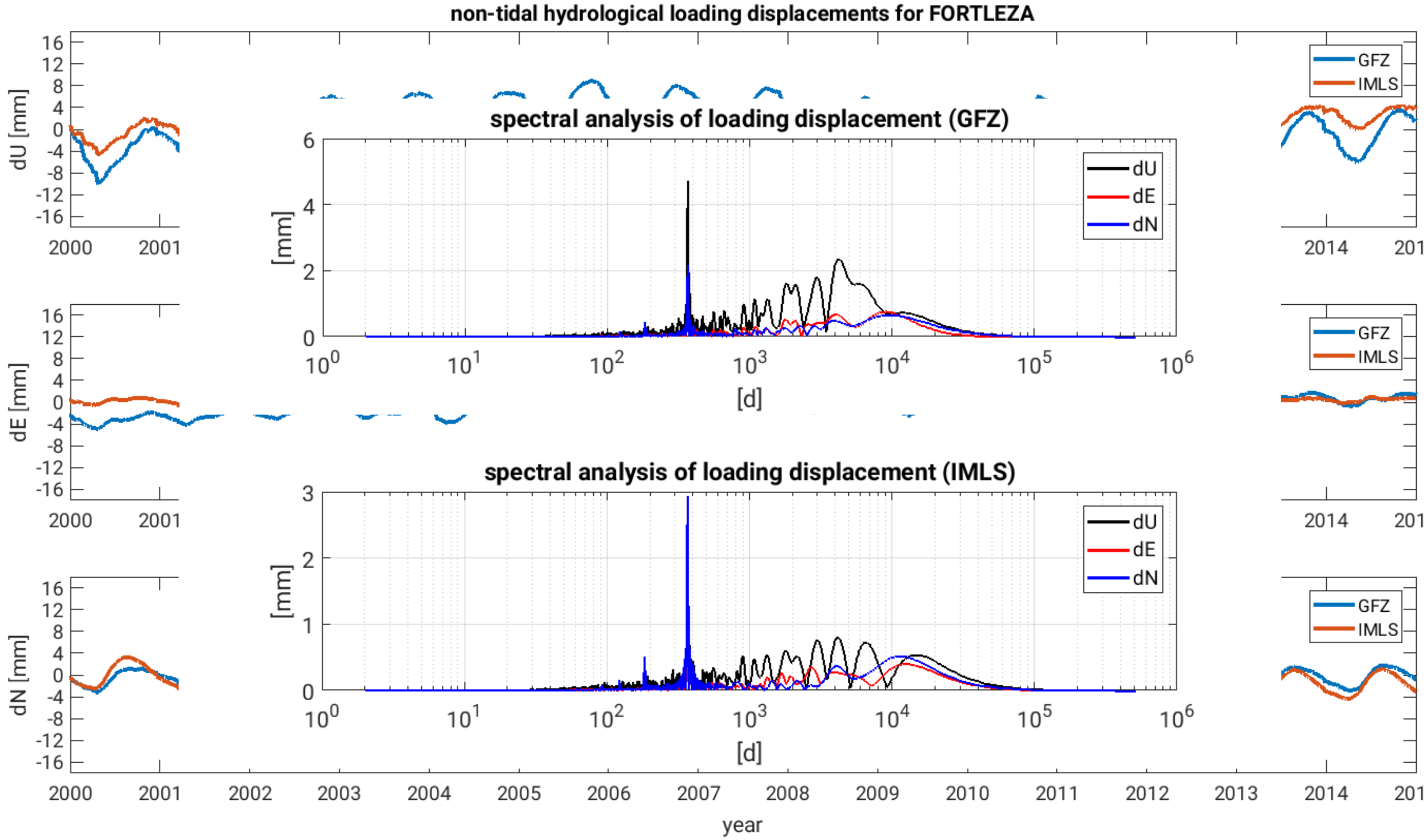

- A spectral analysis of the time series reveals a dominant annual amplitude.

# Examples of local 3D-displacements




- Here, the data sets show higher deviations, presumably due to model differences.
- Hydrological effects are rather long or medium term, hence the series are smoother.

# Examples of local 3D-displacements




- A spectral analysis of the time series again reveals a dominant annual amplitude.

# Outline

- Loading effects
- Sources for non-tidal loading displacements
- Impact of non-tidal loading corrections
- Summary

# Reprocessing setup

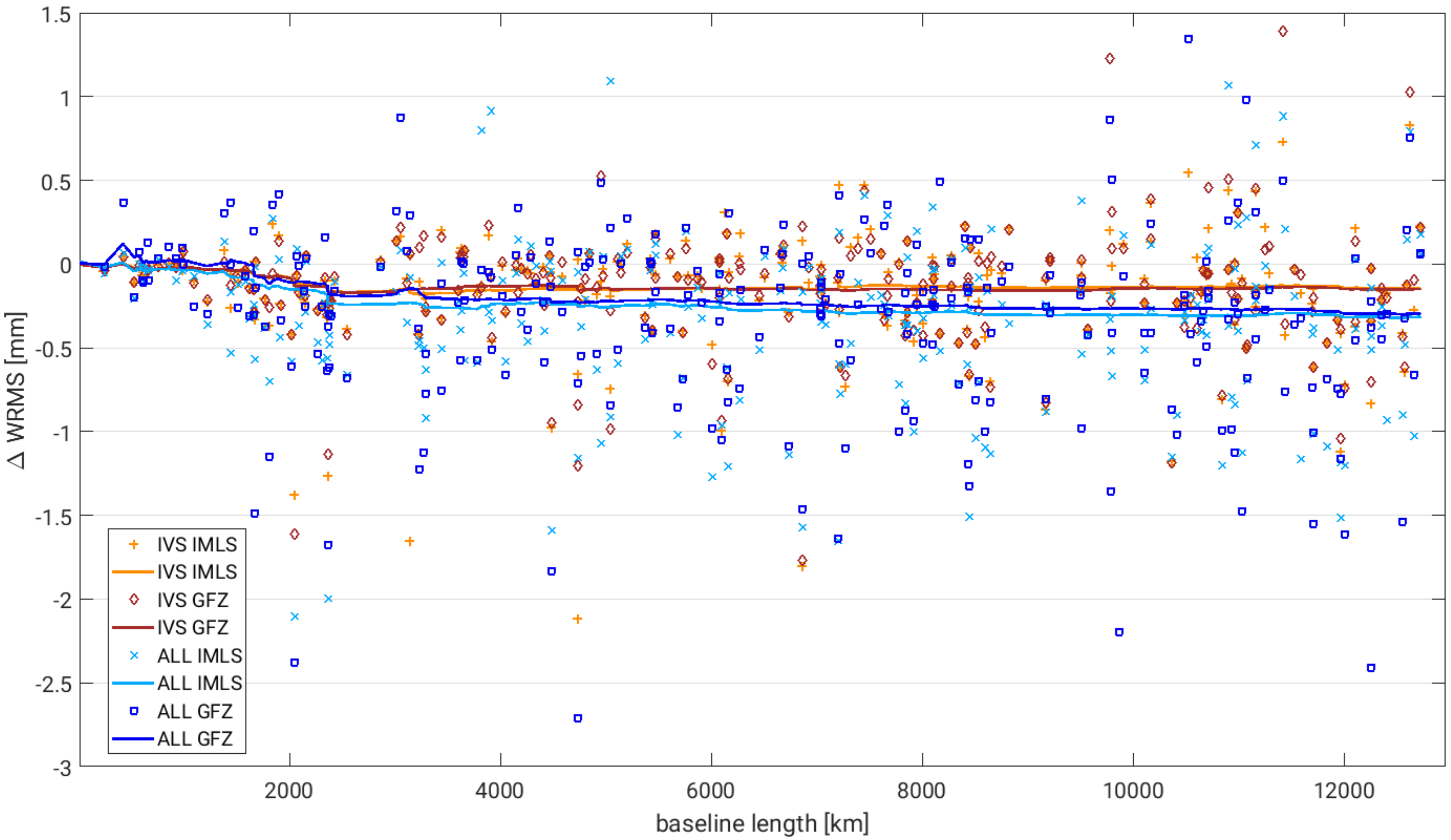
| | |
|---|---|
| software | DOGS-RI (normal equation),<br>DOGS-CS (datum-constraints and solution) |
| session types | mostly 24h sessions (no intensives) |
| time period | 1984 - 2017 |
| estimated parameters | stations positions, source coordinates, EOP<br>(reduced: tropospheric and clock parameters) |
| a-priori values | ITRF2014, ICRF2, IERS 14 C04 |
| tropospheric delay model | Marini / Saastamoinen, VMF1 |
| tidal atmospheric loading | Ray and Ponte (2003) |
| tidal ocean loading | FES2004 |
| solid Earth, pole tide, and<br>ocean pole tide loading | IERS Conventions 2010 |
| precession / nutation | IAU 2006/2000A |
| datum-constraints: stations | NNT, NNR |
| datum-constraints: sources | NNR |

# Reprocessing scenarios

- All scenarios contain tidal loading corrections:

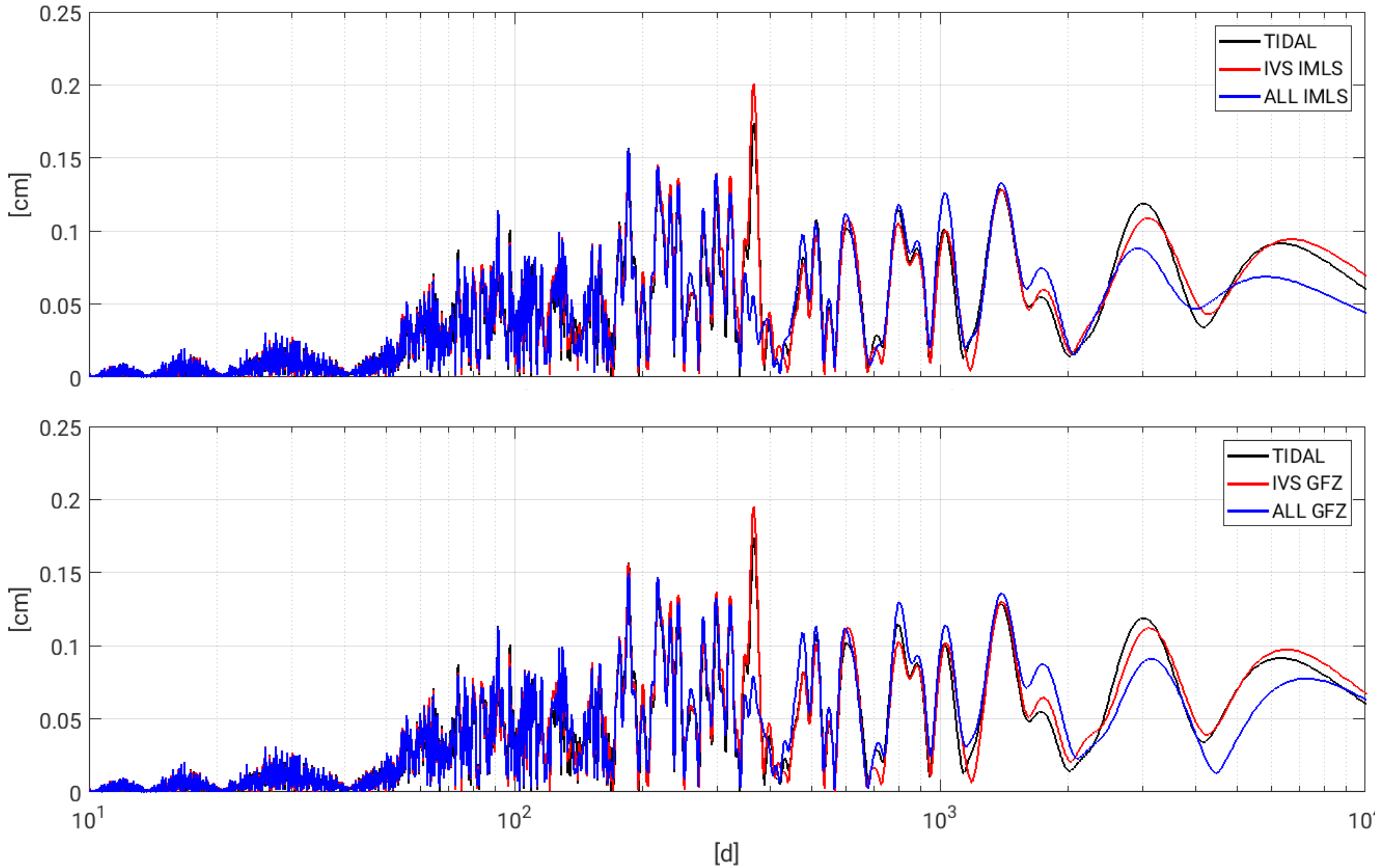
| | |
|---|---|
| **TIDAL** (reference) | no non-tidal loading applied. |
| **IVS IMLS** | non-tidal **atmospherical** loading by IMLS added |
| **IVS GFZ** | non-tidal **atmospherical** loading by ESMGFZ added |
| **ALL IMLS** | non-tidal **atmospherical**, **ocean** and **hydrological** loading by IMLS added |
| **ALL GFZ** | non-tidal **atmospherical**, **ocean** and **hydrological** loading by ESMGFZ added |

# Change in Baseline Length Repeatabilities w. r. t. TIDAL scenario



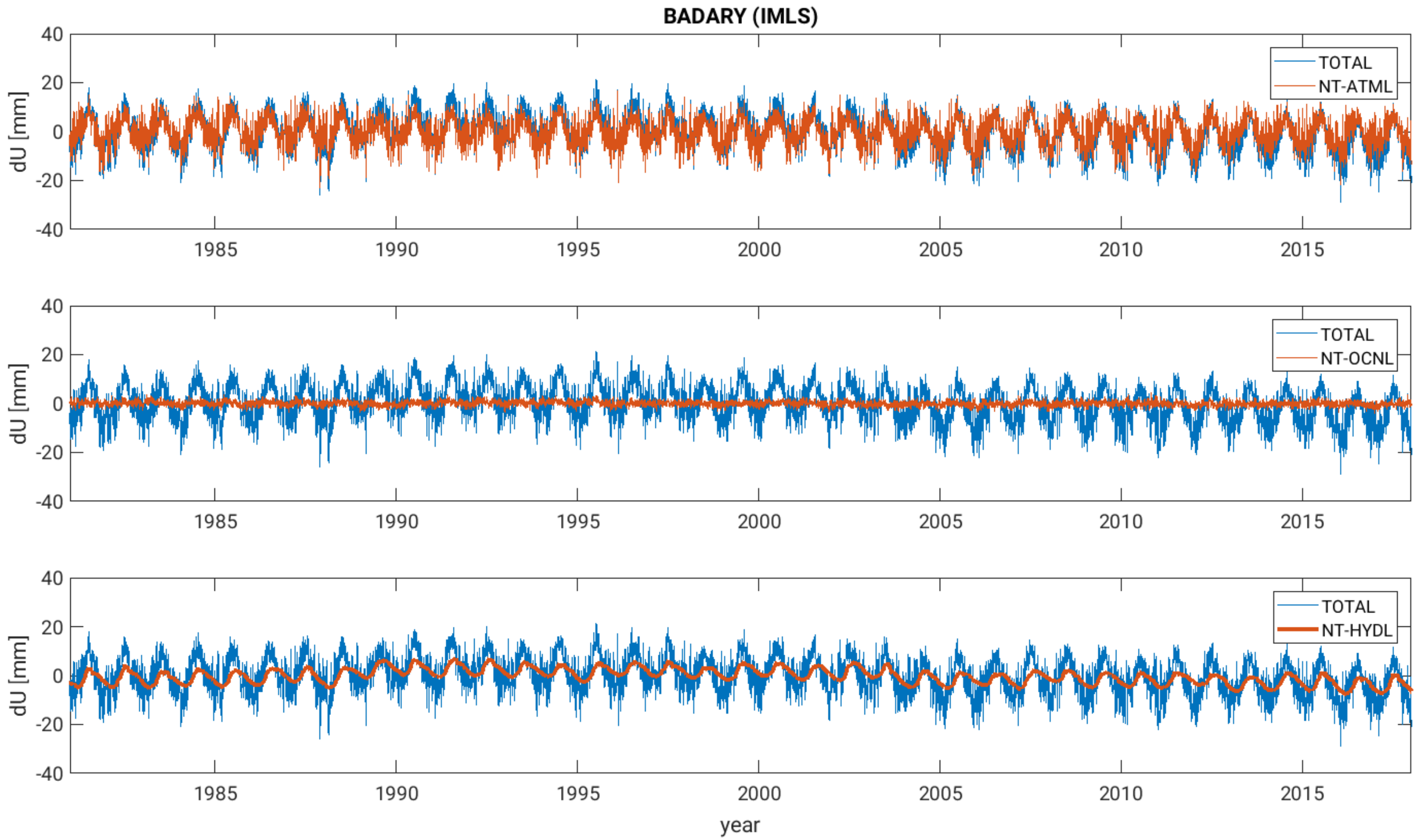

- The BLR improves more by applying all non-tidal loading rather than atmospherical only.

# Frequency analysis of the scale parameter in a Helmert Transformation w. r. t. DTRF2014



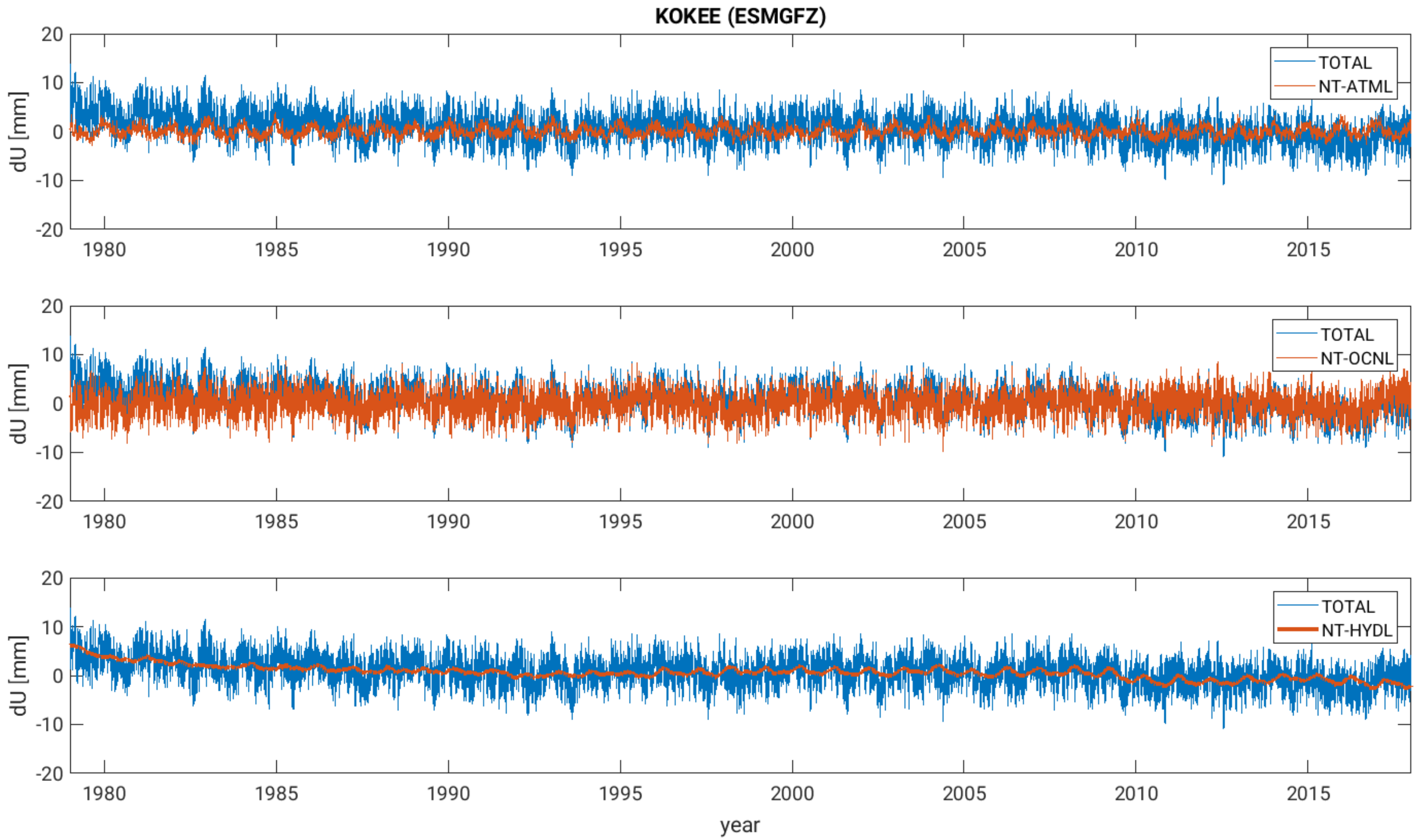

- There is an annual signal, which only disappears when applying all loading types.

# Total vs. individual non-tidal loading displacements



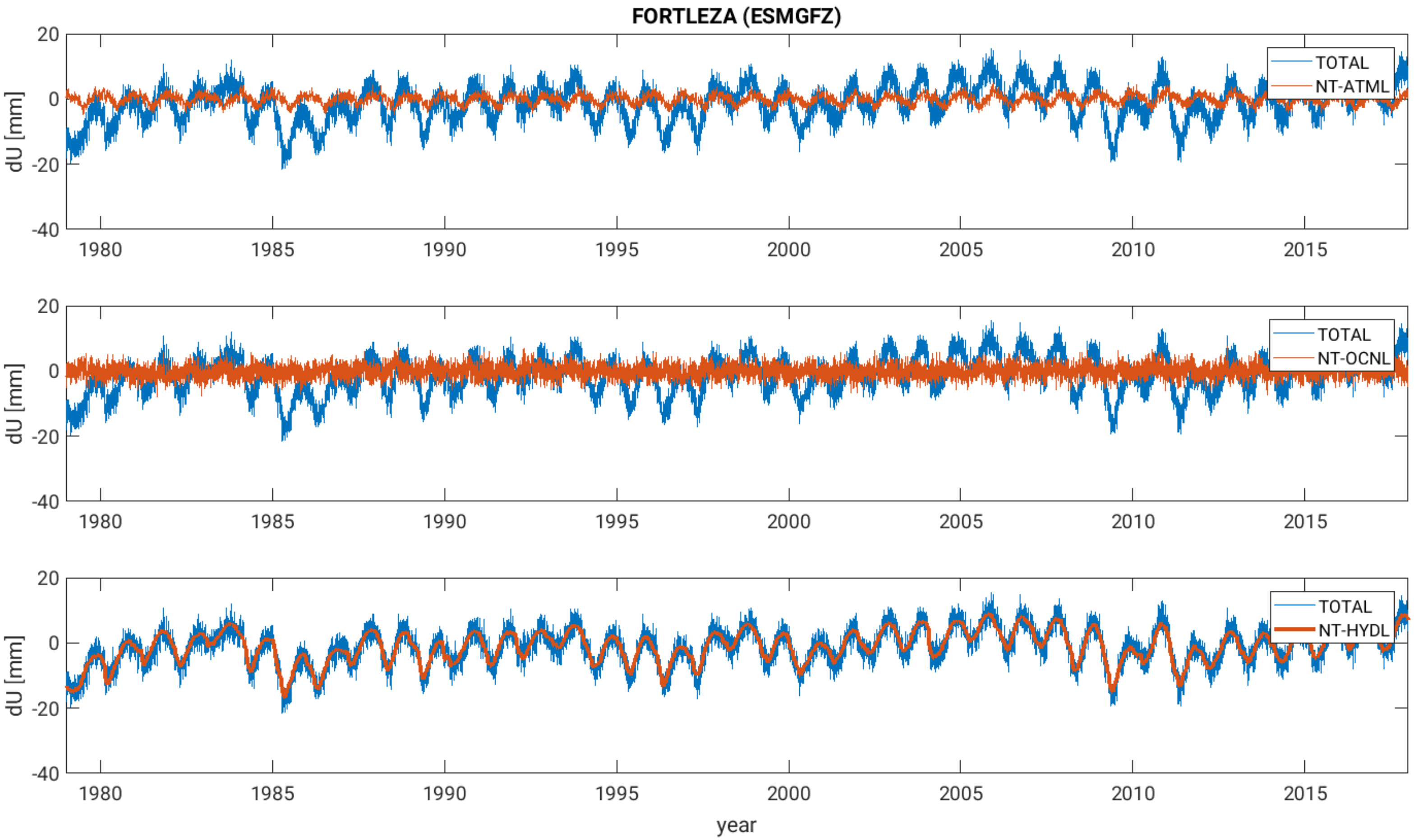

- Inland site: the total loading is driven by atmospherical loading.

# Total vs. individual non-tidal loading displacements



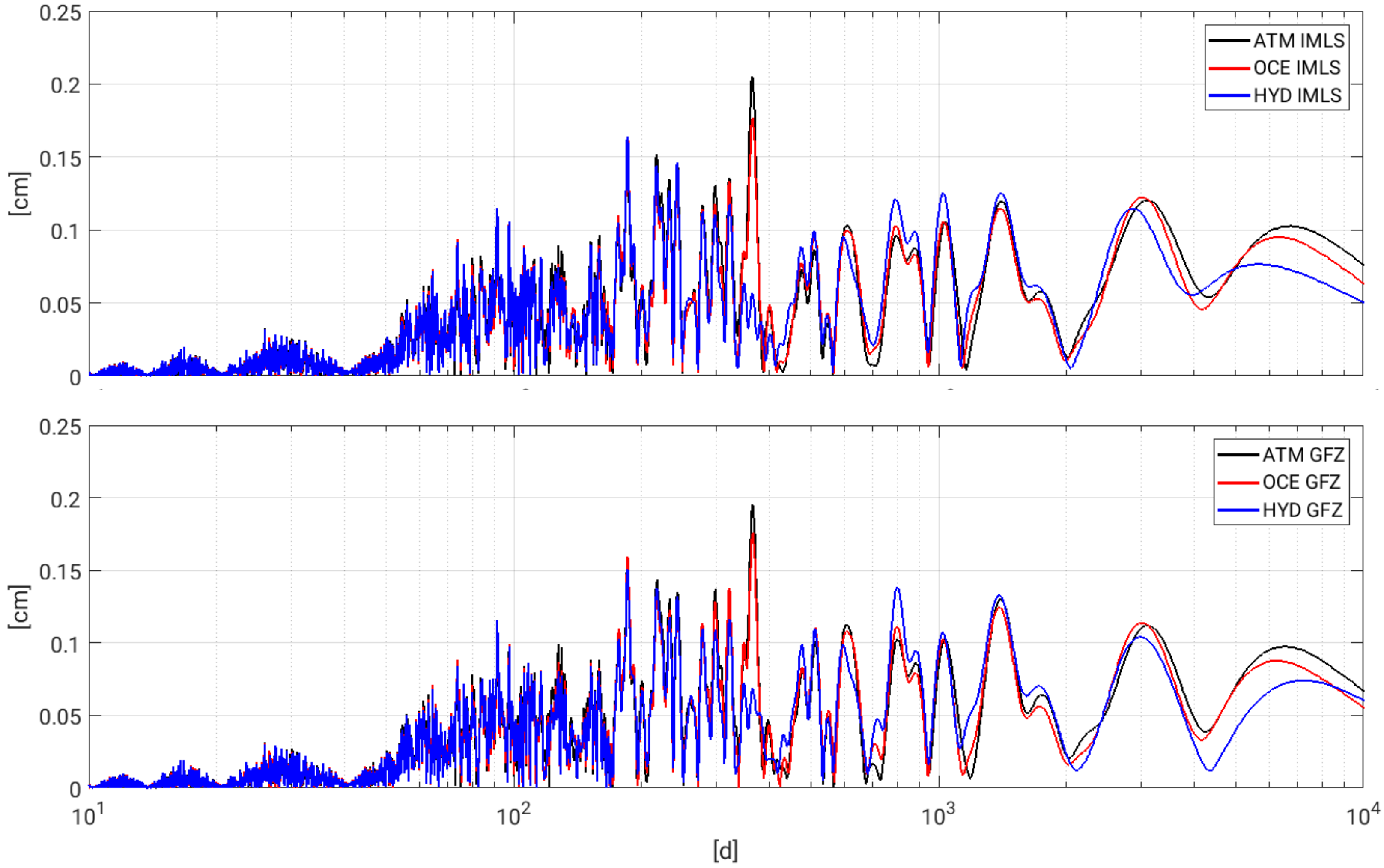

- Site located on an island: the total loading is driven by ocean loading.

# Total vs. individual non-tidal loading displacements



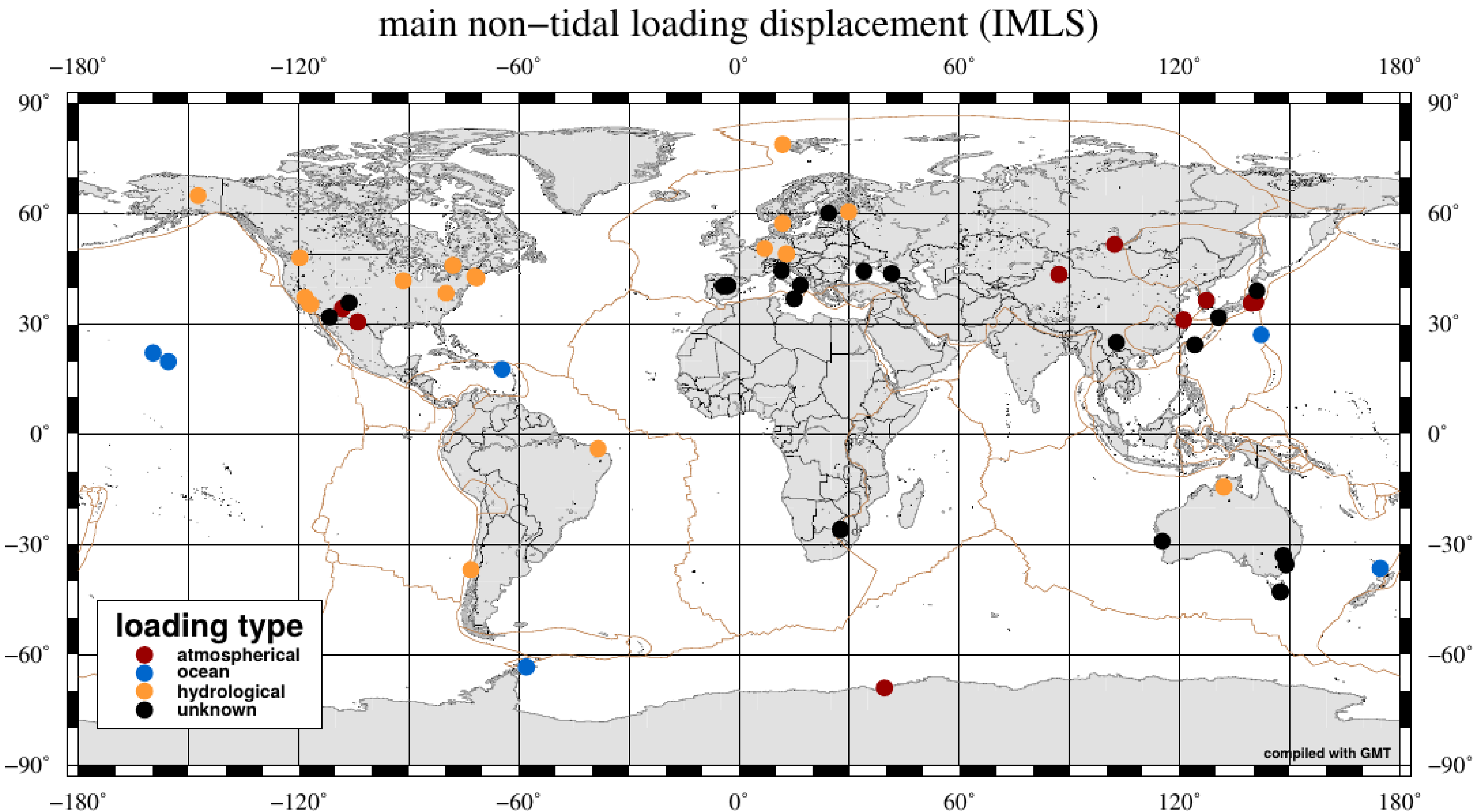

- Coastal site near the equator: the total loading is driven by hydrological loading.

# Frequency analysis of the scale parameter: each non-tidal loading type applied individually

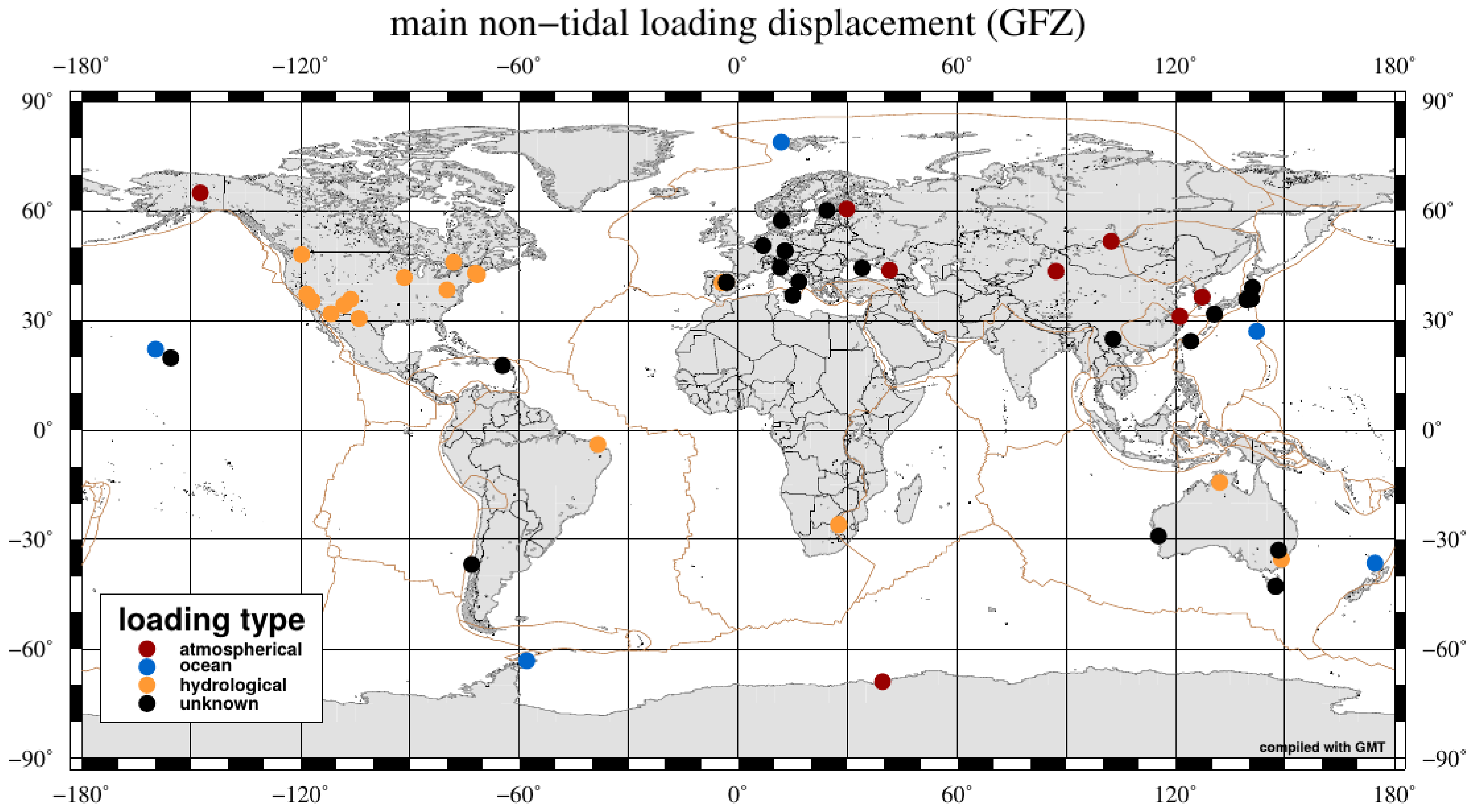



- The annual signal already disappears when applying hydrological loading only!

# Dominating component per site



# Dominating component per site



# Outline

- Loading effects
- Sources for non-tidal loading displacements
- Impact of non-tidal loading corrections
- Summary

# Summary

- For the WRMS of station positions, the impact of applying non-tidal loading displacements at the observation level is small, but in the expected pattern.
- The baseline length repeatabilities generally improve more when correcting for all non-tidal loading effects instead of the atmospherical one only.
- There is no unique dominating loading type: it depends on the location of the station site and the geophysical model used for the pressure anomaly.
- Non-tidal hydrological loading appears to be at least as important as the atmospherical loading, while the ocean loading is mainly relevant for islands.
- In fact, the annual signal in the scale time series of a Helmert transformation w. r. t. a TRF only disappears when applying hydrological loading.
- The exact reason for this still has to be identified.

**Thank you for your attention!**

**Are there any questions?**