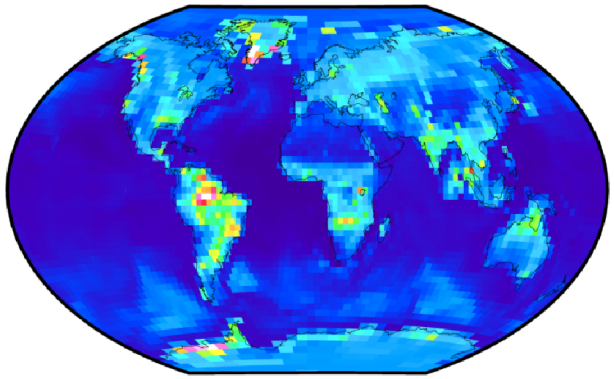
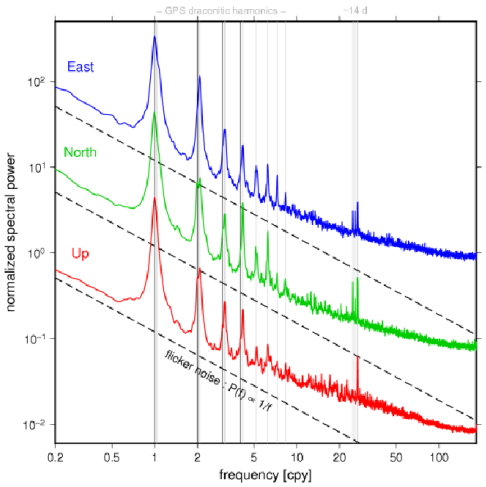
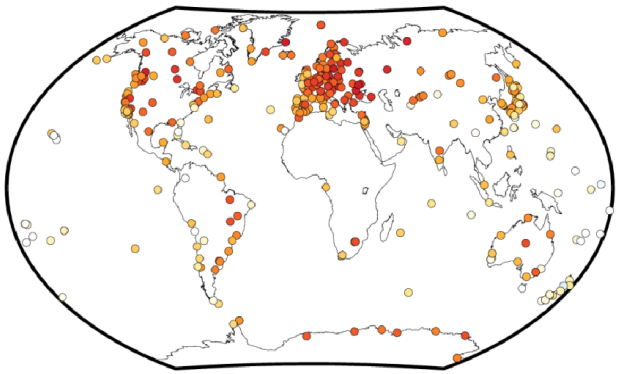
Aperiodic surface mass transport observed in GRACE and GNSS time series

Paul Rebischung, Kristel Chanard, Laurent Métivier, Zuheir Altamimi

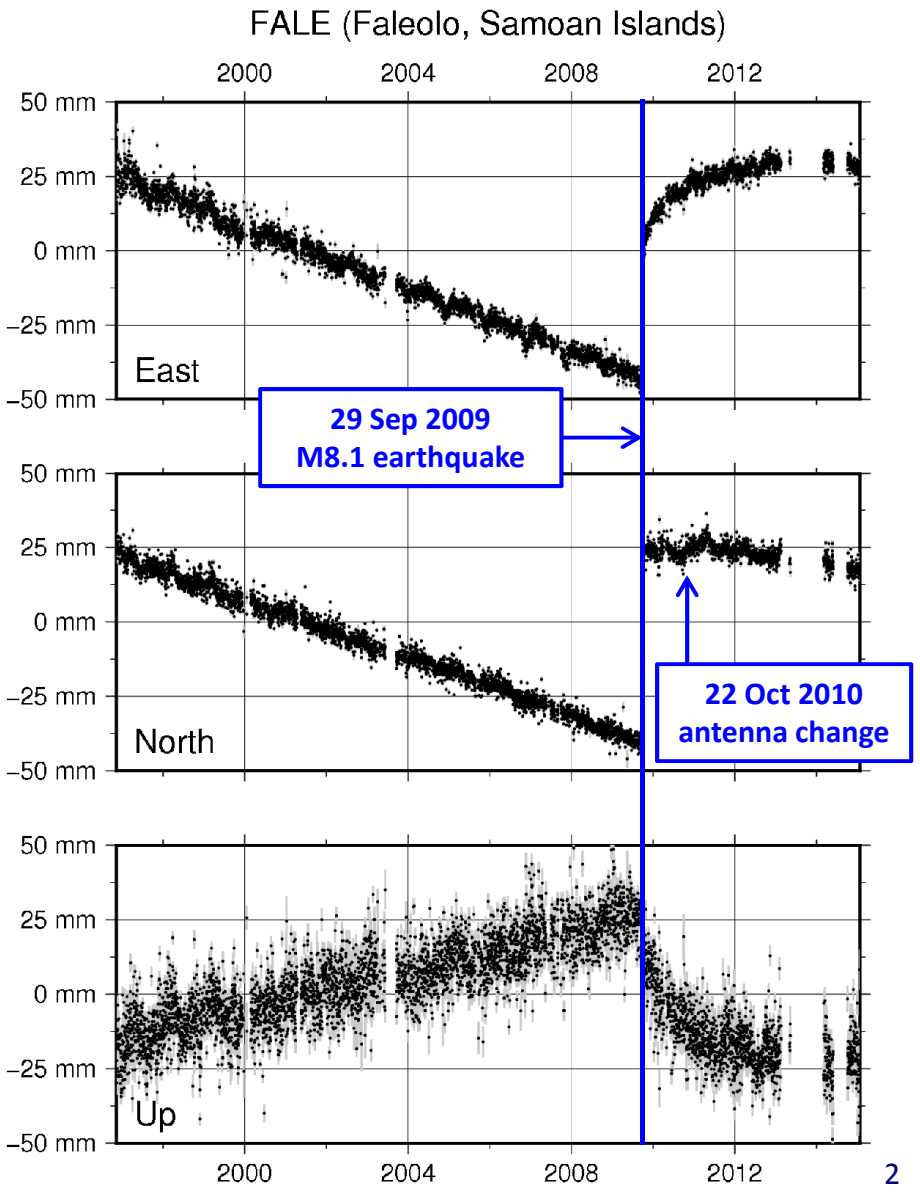






Anatomy of GNSS station position time series

- **Linear trend:**
  - Tectonic motions
  - Post-glacial rebound
  - …
- **Discontinuities:**
  - Co-seismic displacements
  - Equipment changes
  - …
- **Transient events**
  - Post-seismic displacements
  - (Visco-)elastic rebound due to current ice melting
  - …



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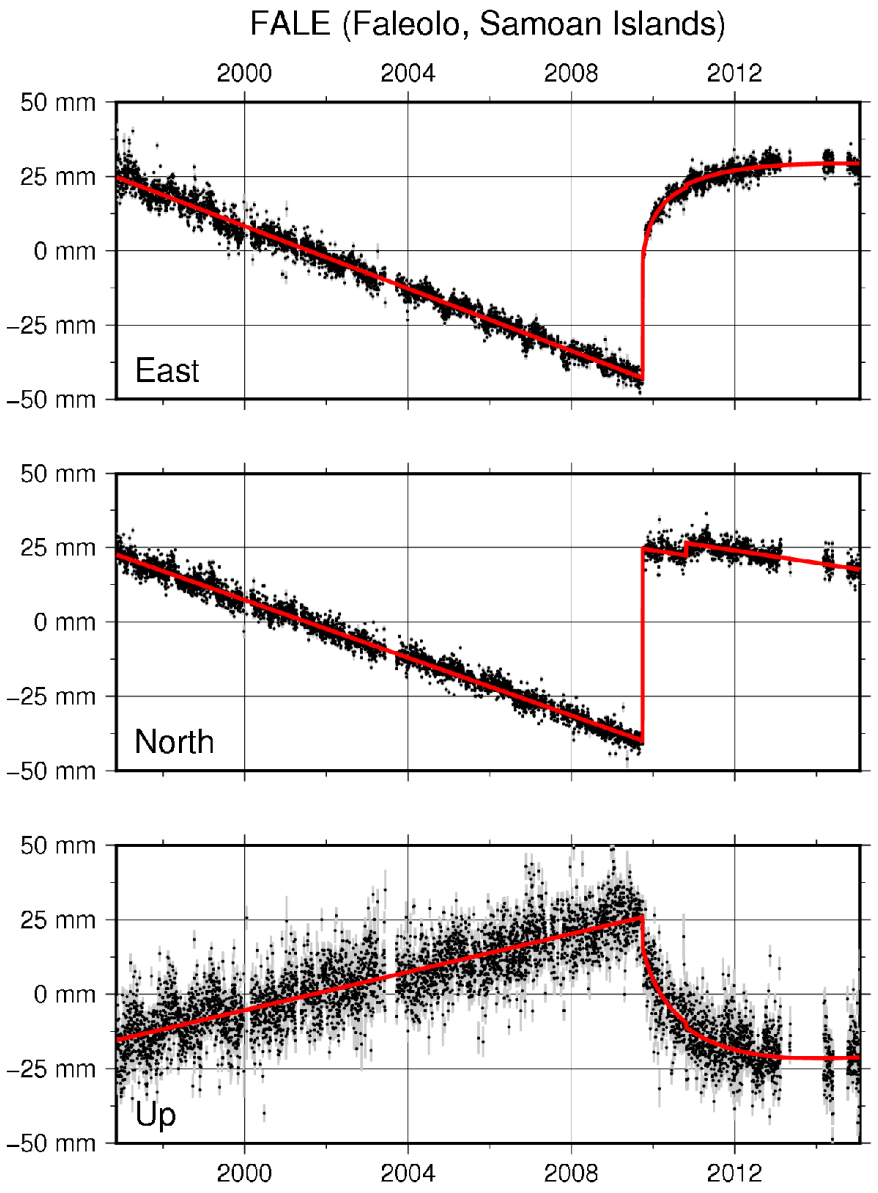
— ITRF2014 kinematic model



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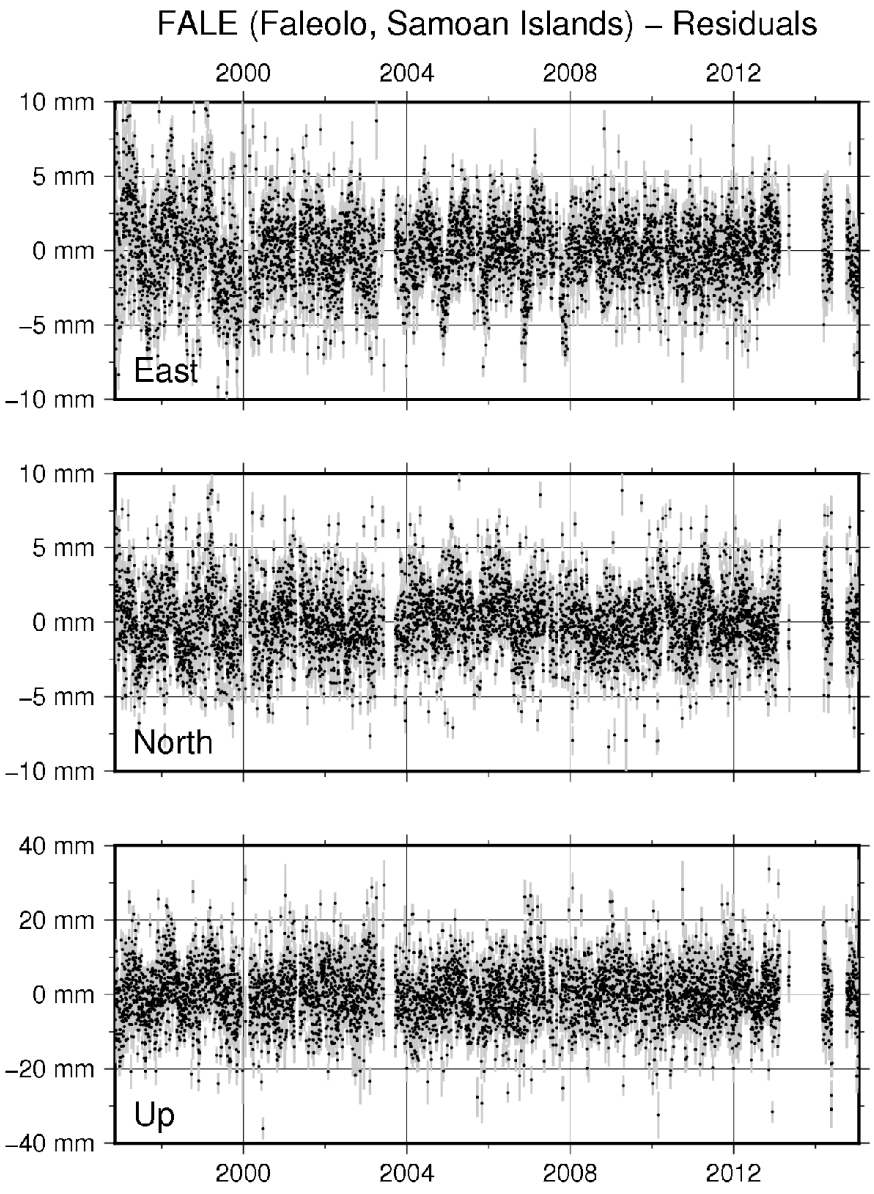

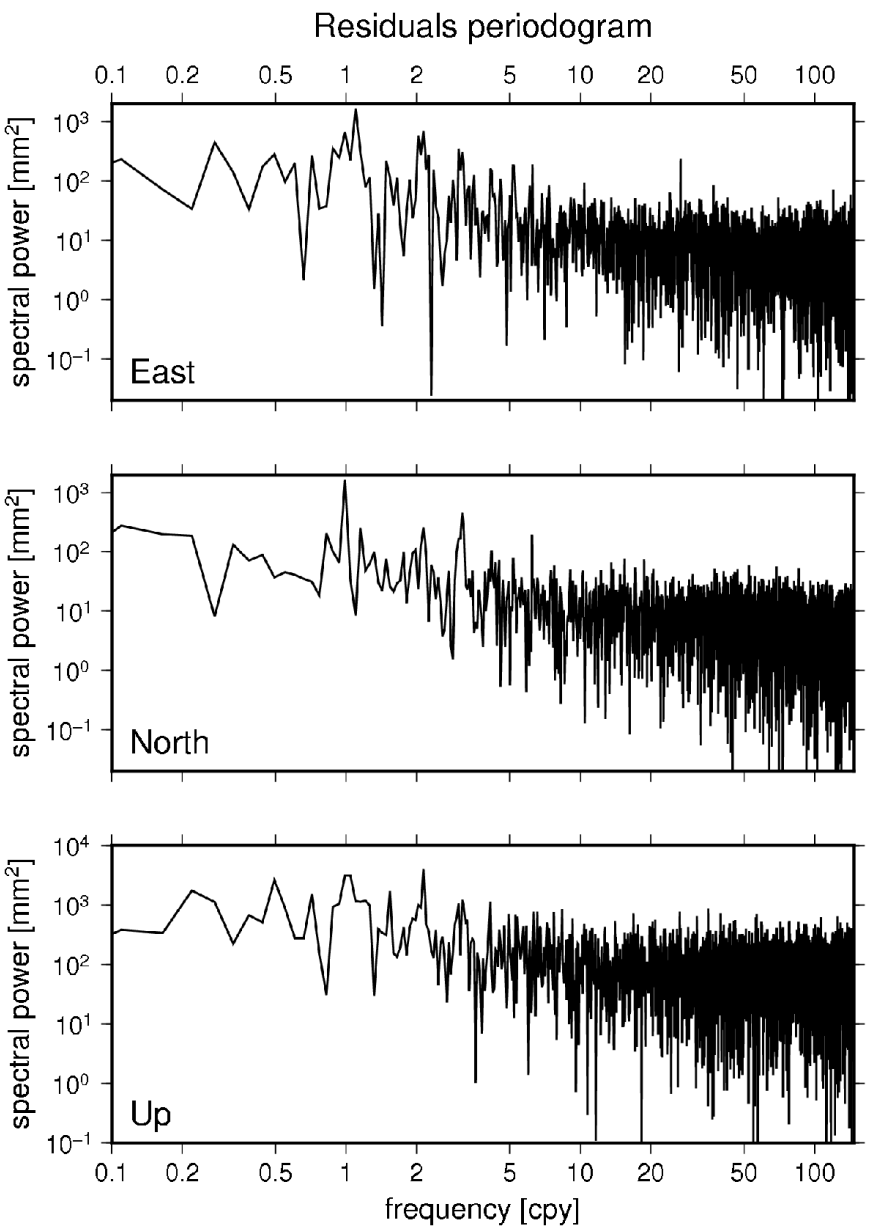

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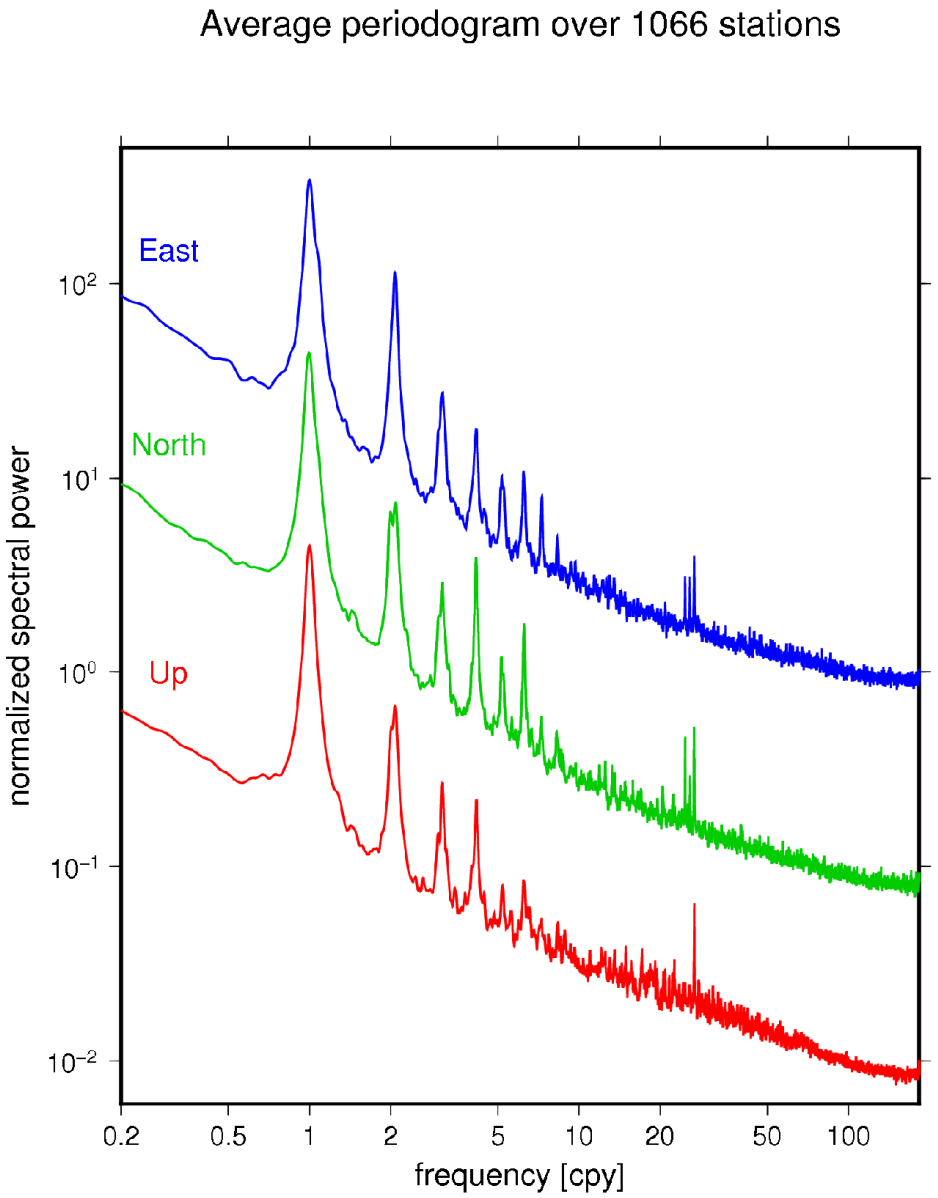
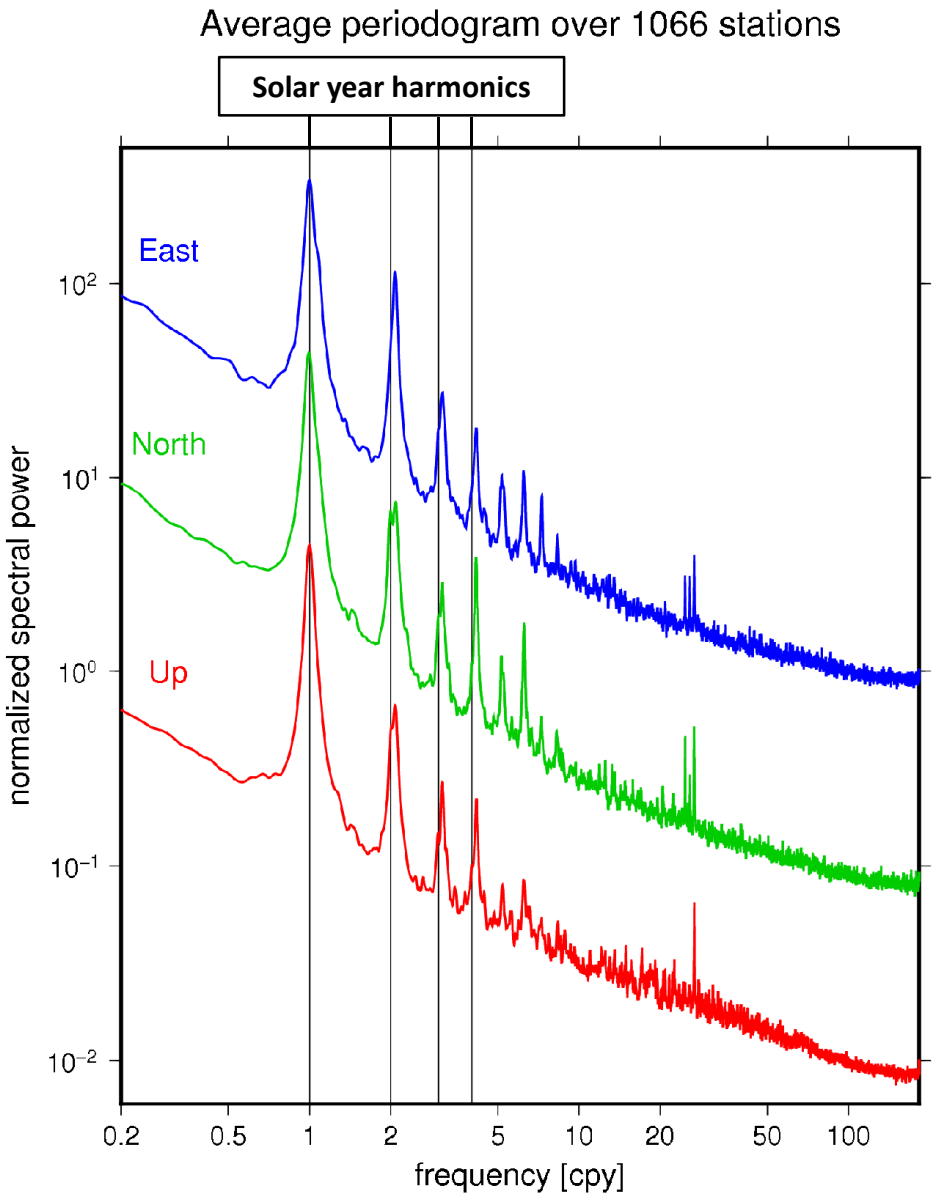


Anatomy of GNSS station position time series

- **Seasonal signals:**
  - **Loading deformation**
  - **Thermal deformation of the ground and the monuments**
  - **…**



Anatomy of GNSS station position time series

- **Seasonal signals:**
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  - Thermal deformation of the ground and the monuments
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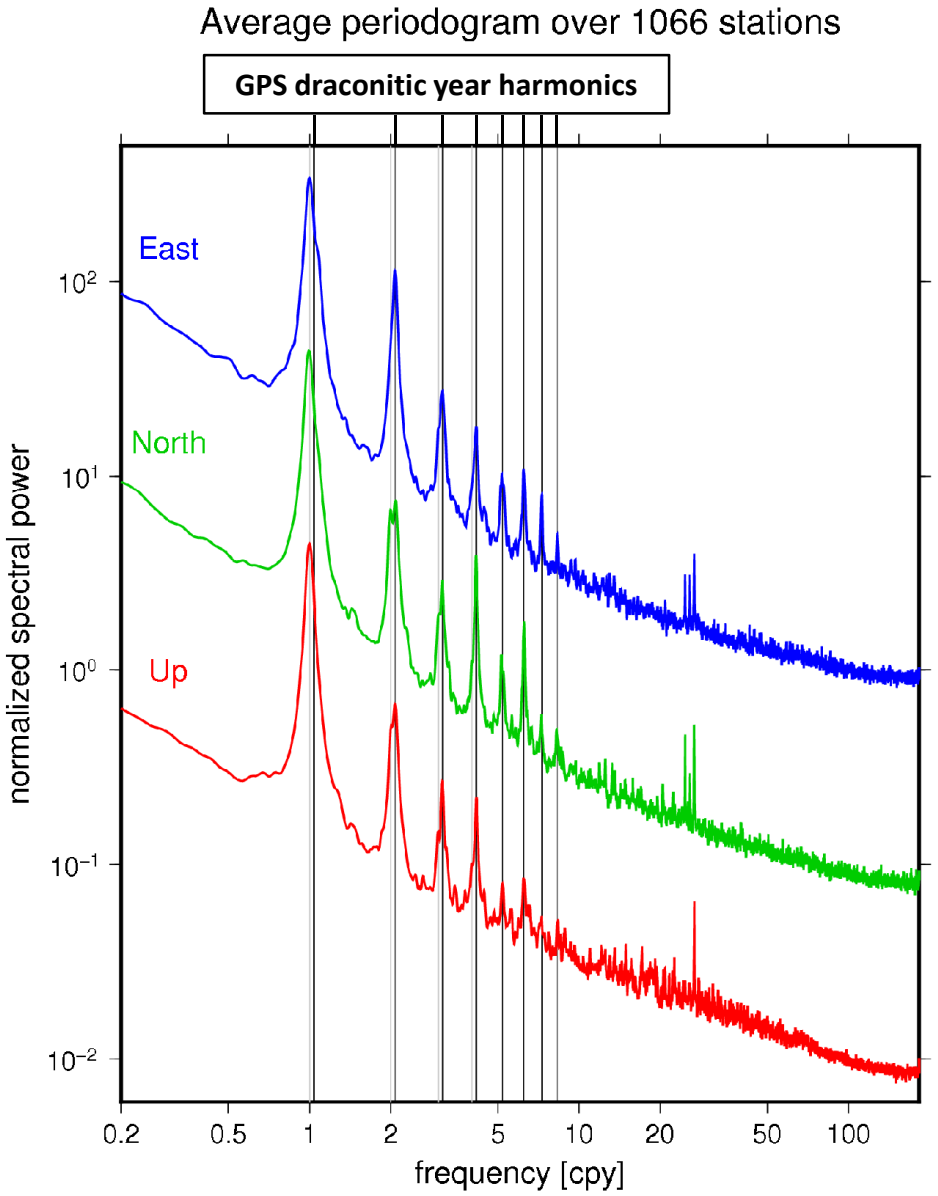
- **Draconitic signals:**
  - Orbit modelling errors
  - Multipath
  - …



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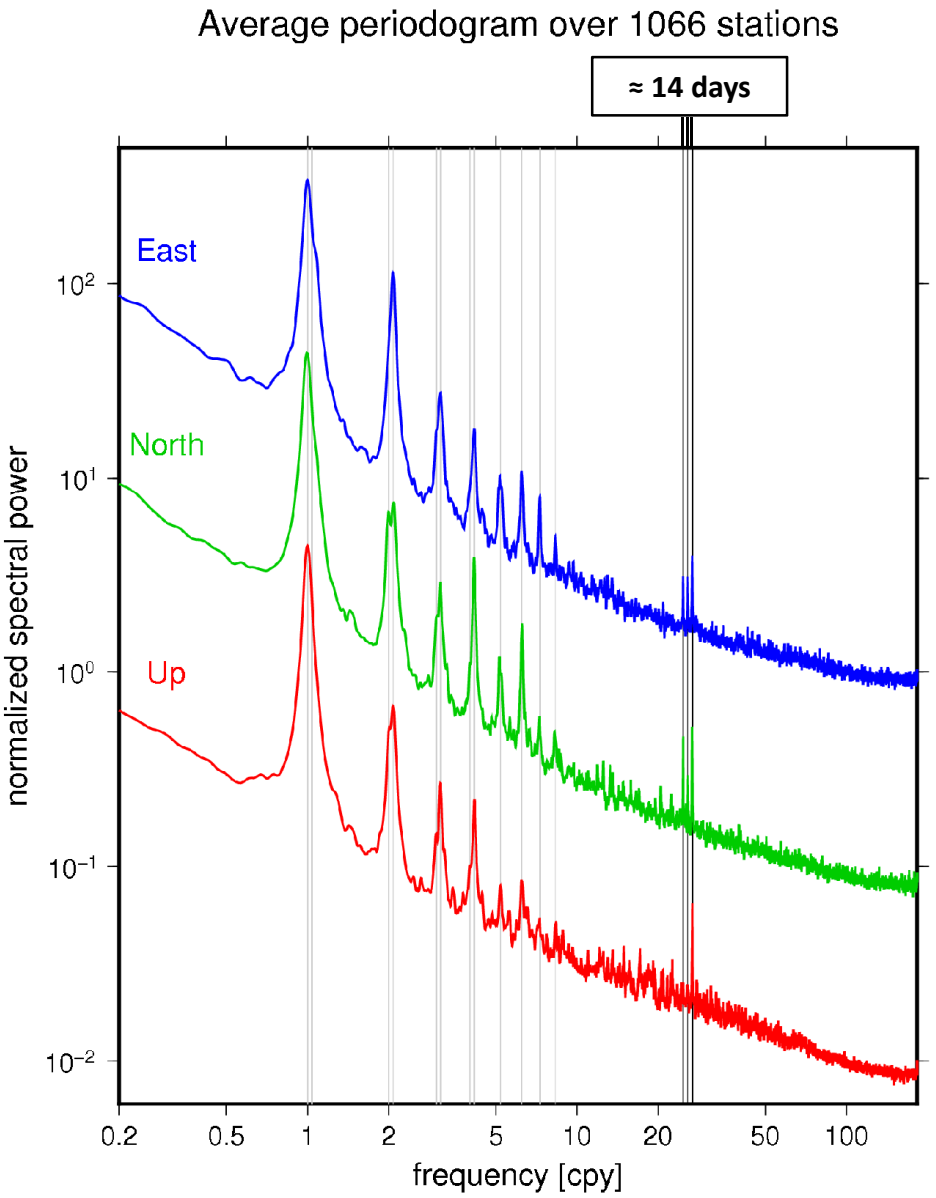
  - Tide modelling errors



Anatomy of GNSS station position time series

- **Seasonal signals:**
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  - Thermal deformation of the ground and the monuments
  - …
- **Draconitic signals:**
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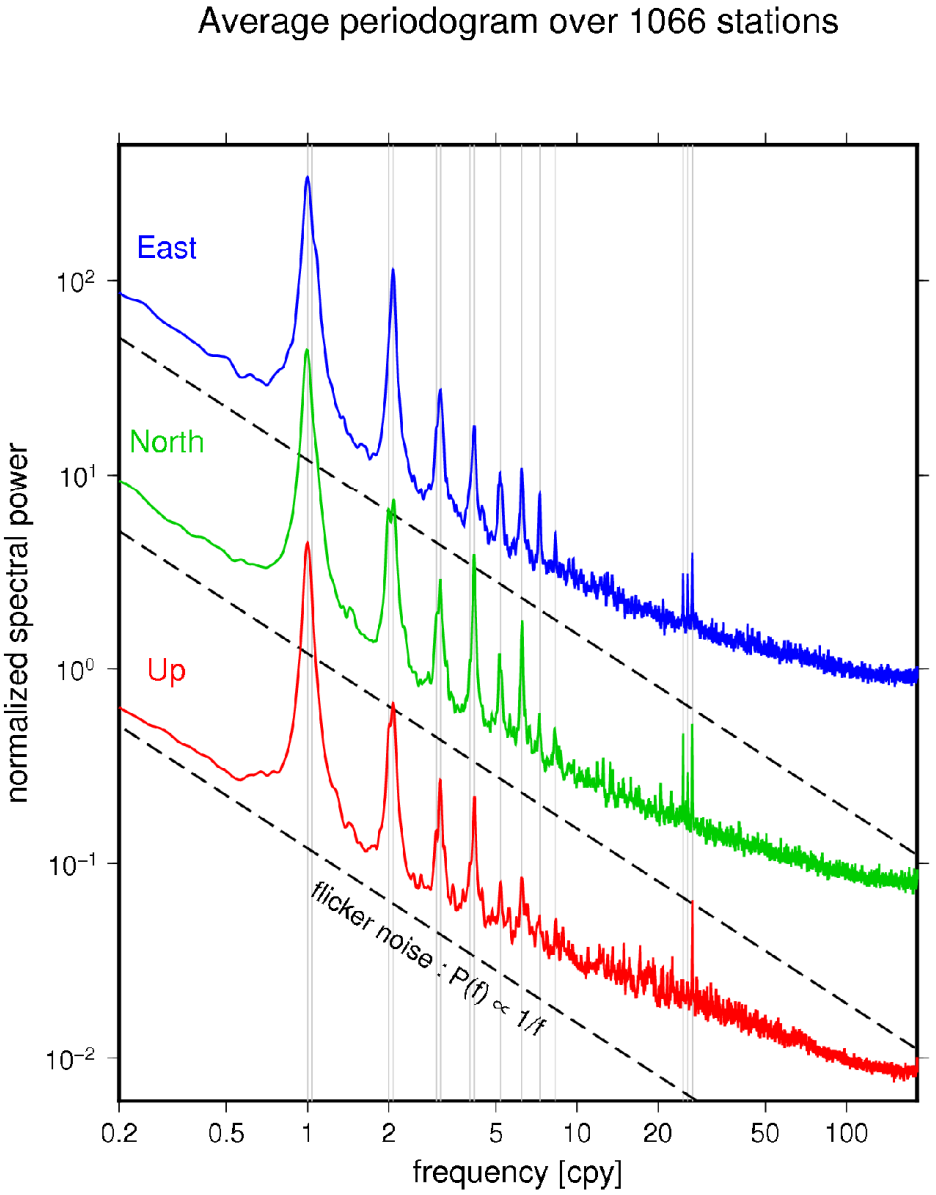
  - …
- **Fortnightly signals:**
  - Tide modelling errors
- **Background noise:**
  - Flicker noise
  - Some white noise at high frequencies

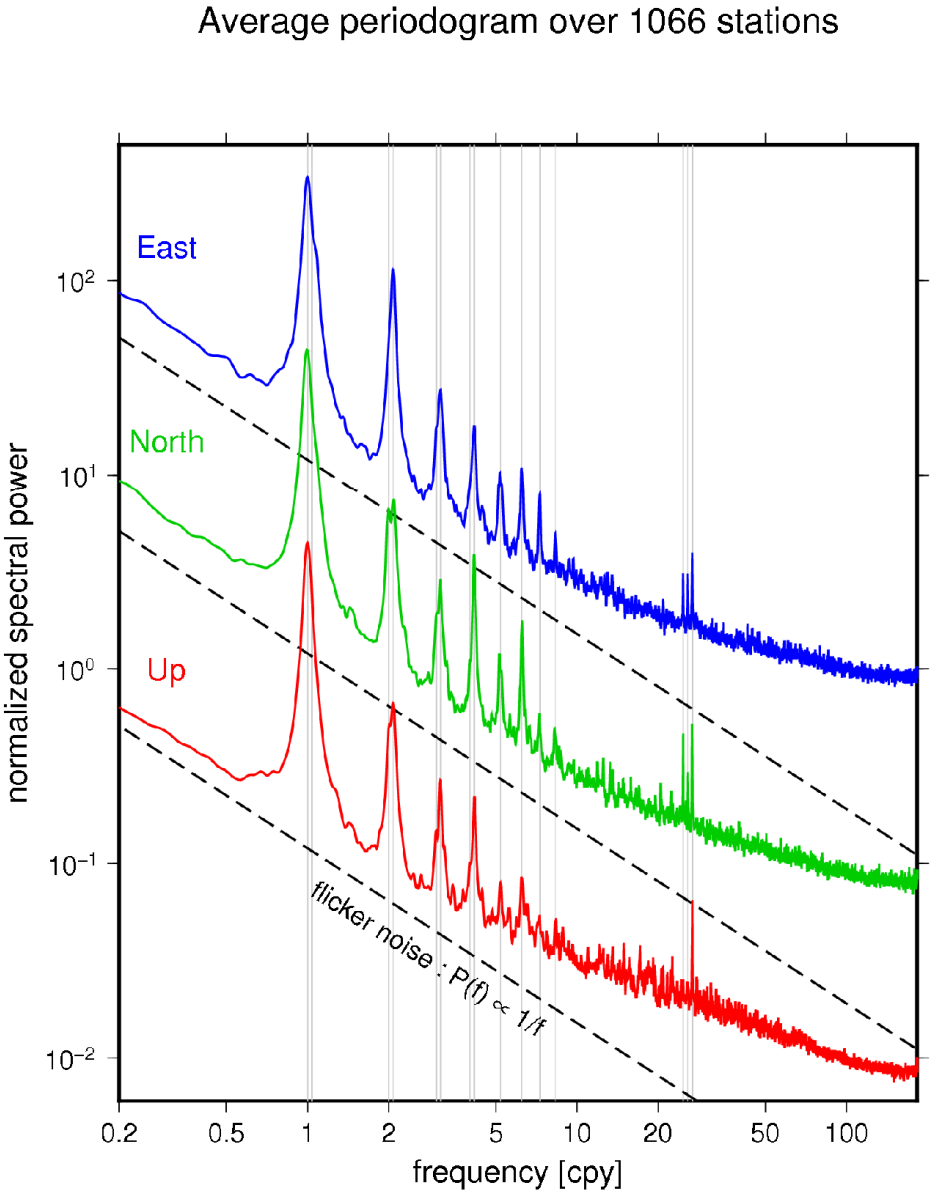


Anatomy of GNSS station position time series

- **Flicker noise:**
  - Identified ≈20 years ago
  - Has since then remained the preferred model for time-correlated noise in GNSS time series
  - Needs to be taken into account when interpreting GNSS time series to avoid, e.g., underestimating trend errors by factors 5 – 10

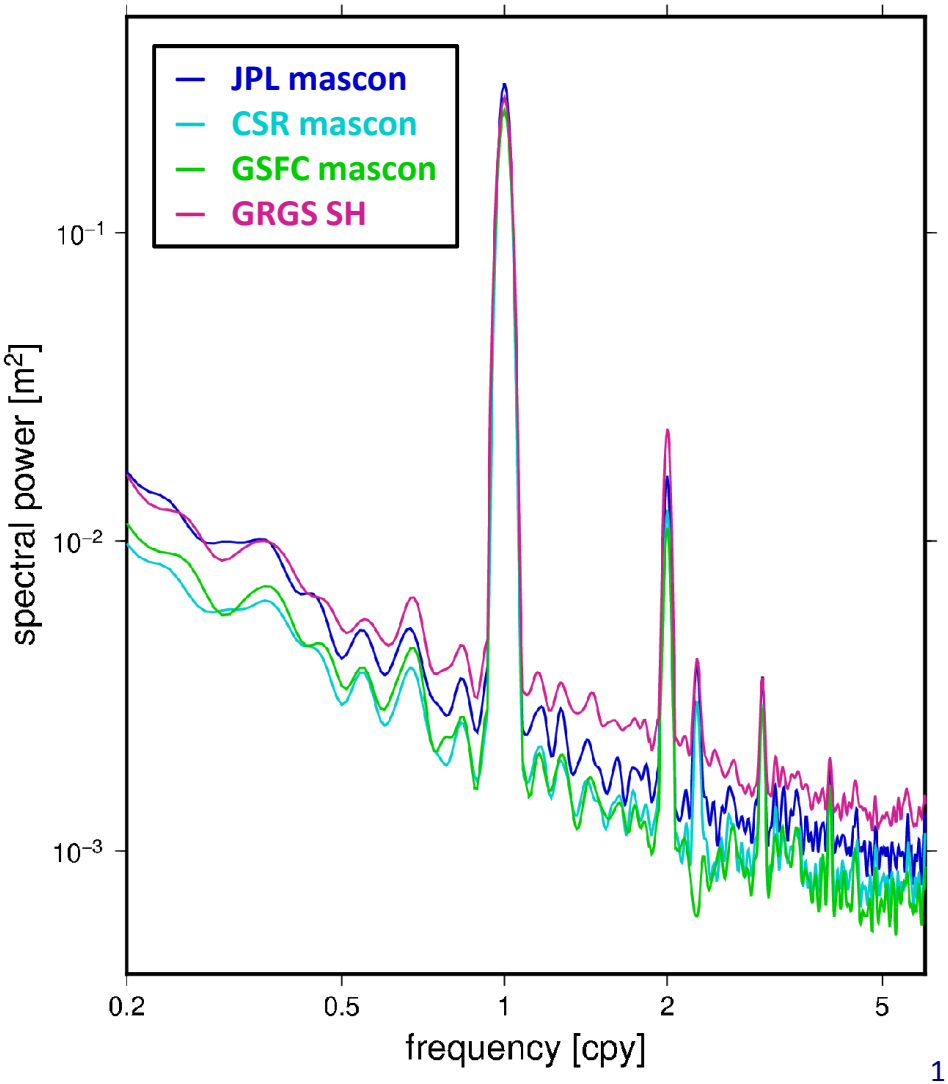
- **Where does it come from?**
  - Different origins proposed, including geophysical effects and technique/modelling errors
  - But none actually identified that could explain the level of observed flicker noise

  → The origins of flicker noise in GNSS time series remain unclear.



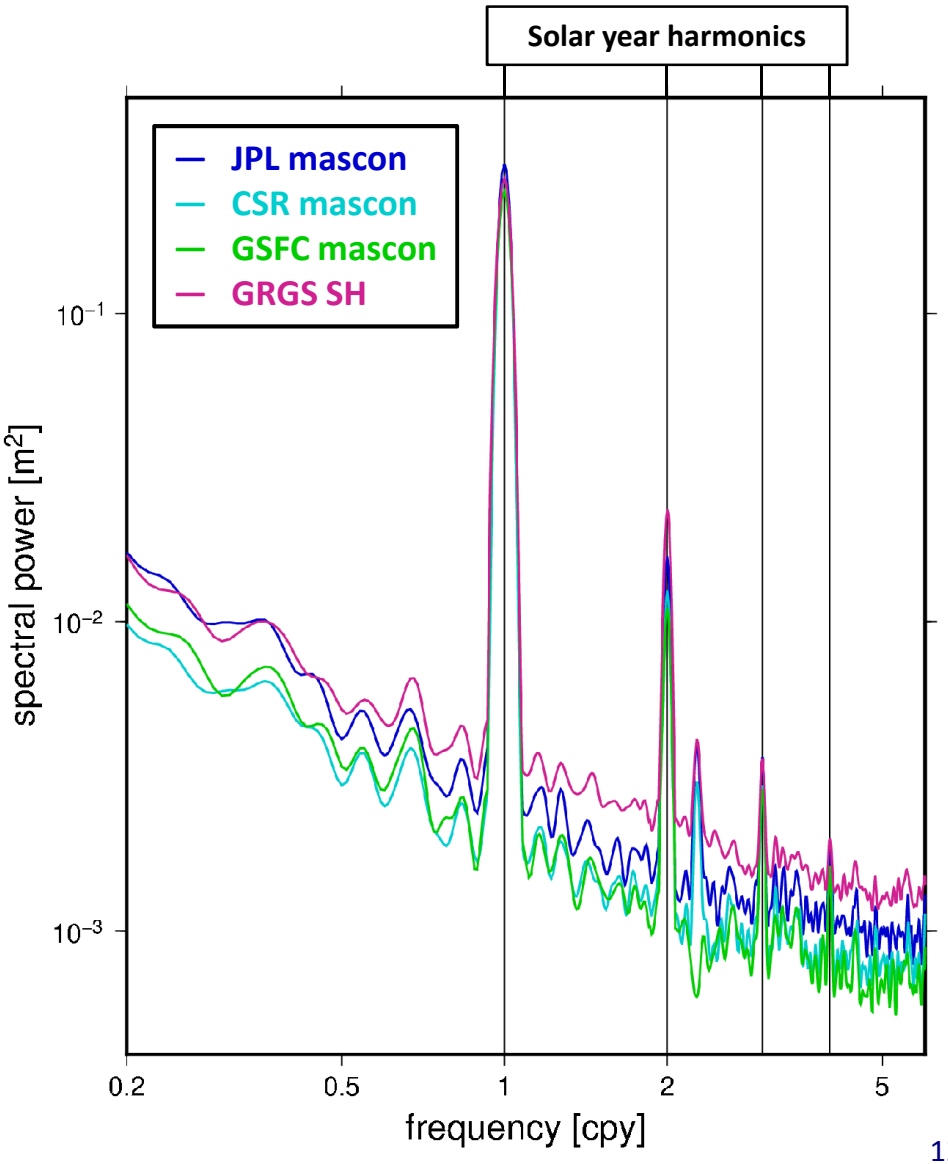
What about GRACE-derived EWH time series?

- **Use monthly regularized GRACE solutions:**
  - JPL-RL05 mascon solution
  - CSR-RL05 mascon solution
  - GSFC-v02.4 mascon solution
  - GRGS-RL04 spherical harmonics solution
- **Restore atmospheric and oceanic dealiasing products**
- **Compute average periodogram of EWH time series over the Earth's surface**
  - accouting for periodic gaps in EWH time series



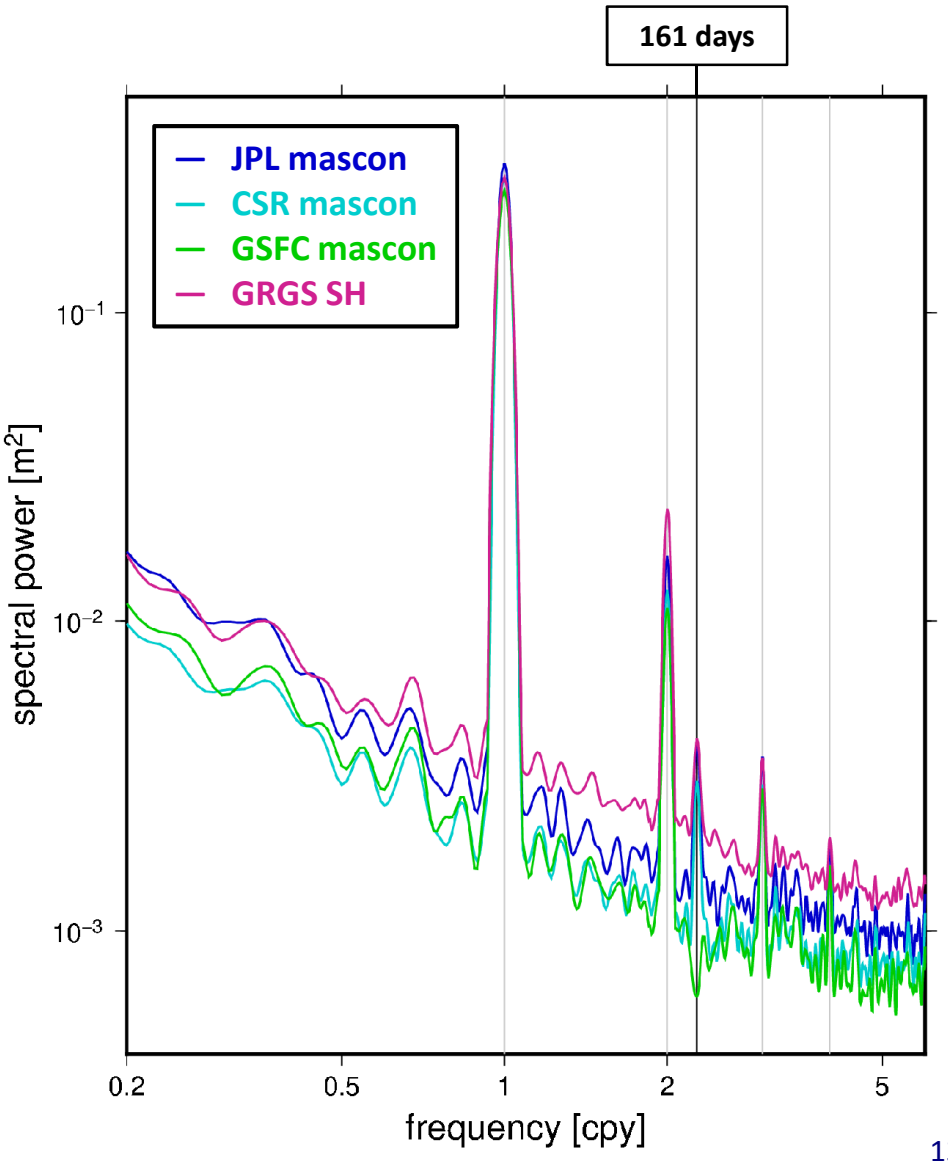
What about GRACE-derived EWH time series?

- **Seasonal signals:**
  - **Seasonal surface mass transport**



What about GRACE-derived EWH time series?

- **Seasonal signals:**
  - Seasonal surface mass transport
- **161-day signal:**
  - Aliasing of S_2 tide model errors
  - Absent from GSFC mascon solution (?)

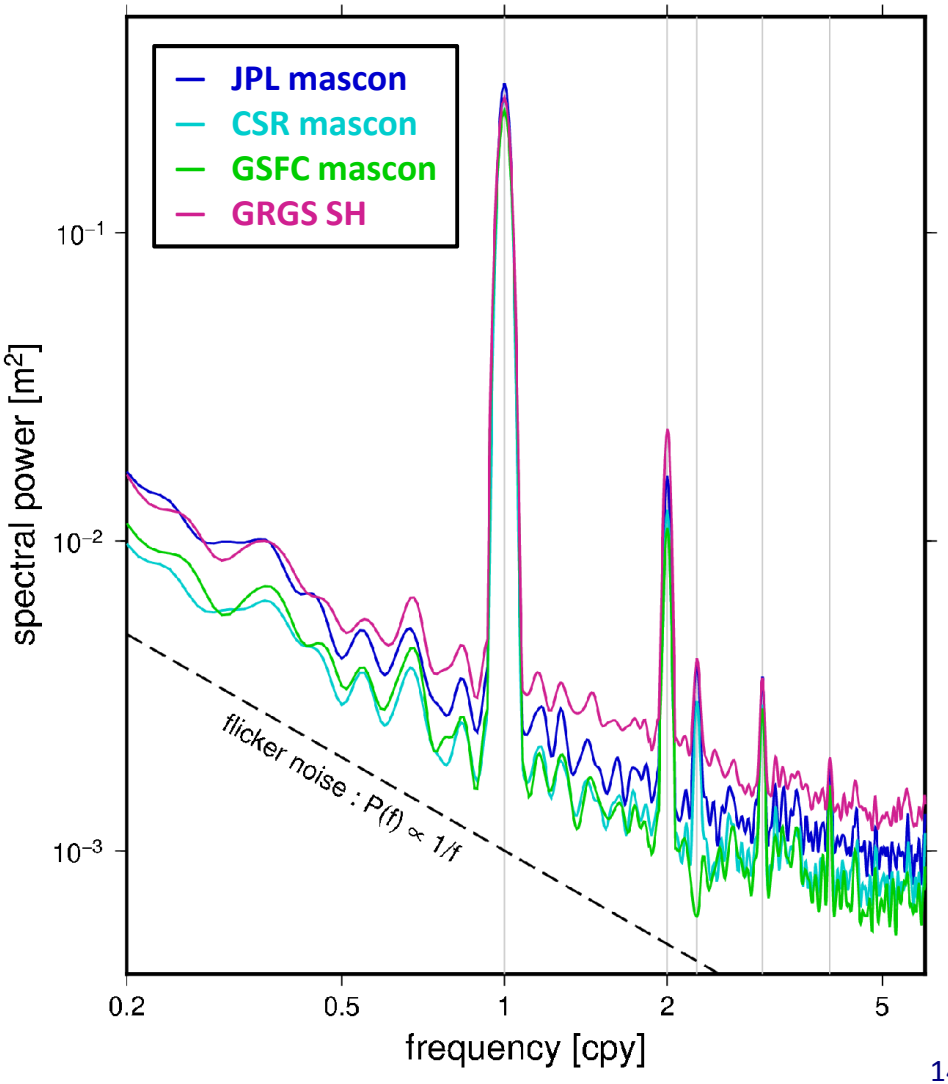


What about GRACE-derived EWH time series?

- **Seasonal signals:**
  - Seasonal surface mass transport
- **161-day signal:**
  - Aliasing of S_2 tide model errors
  - Absent from GSFC mascon solution
- **Average background noise:**
  - Flicker noise
  - Possibly some white noise at highest frequencies

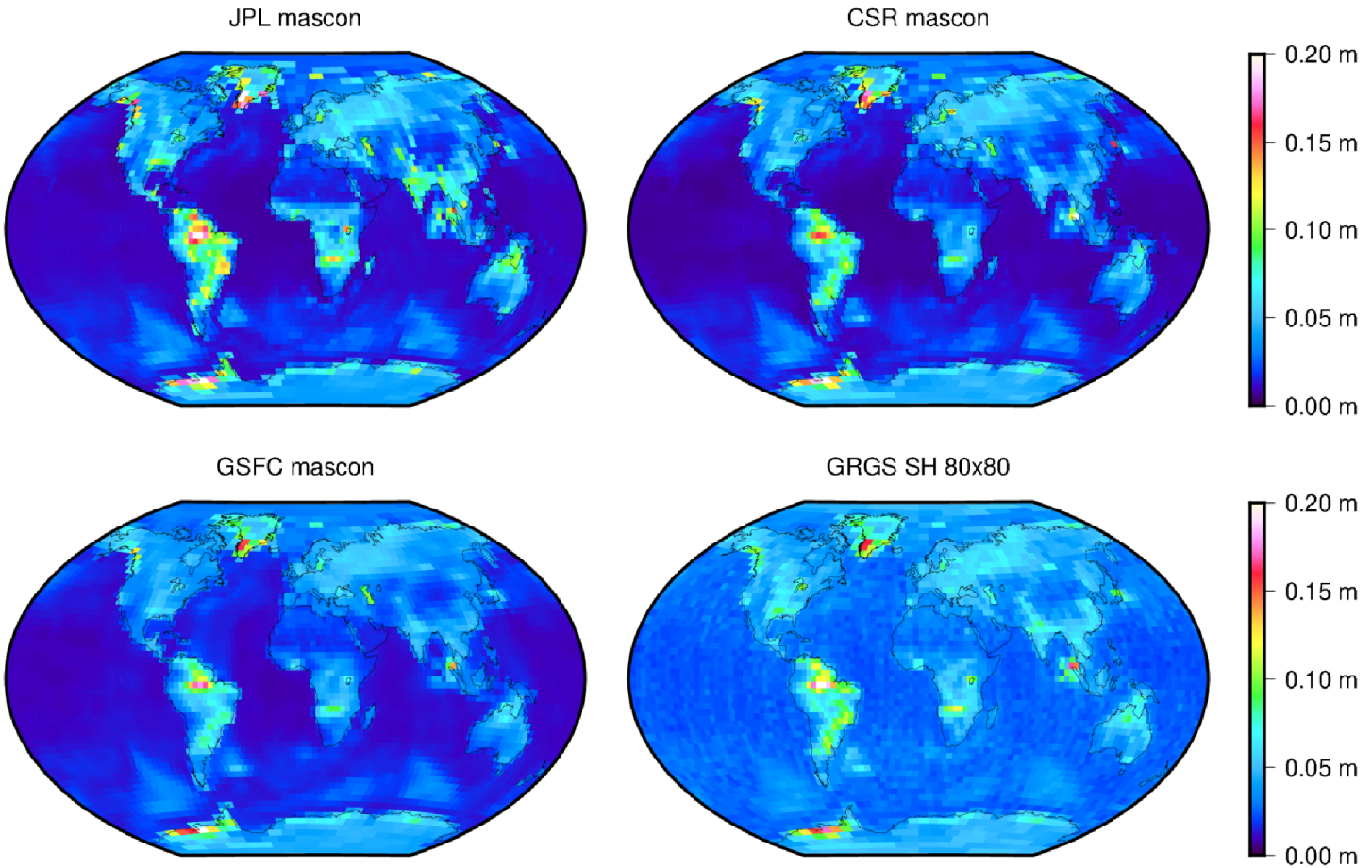
? → Errors in GRACE solutions?

? → Real, aperiodic surface mass transport signal?



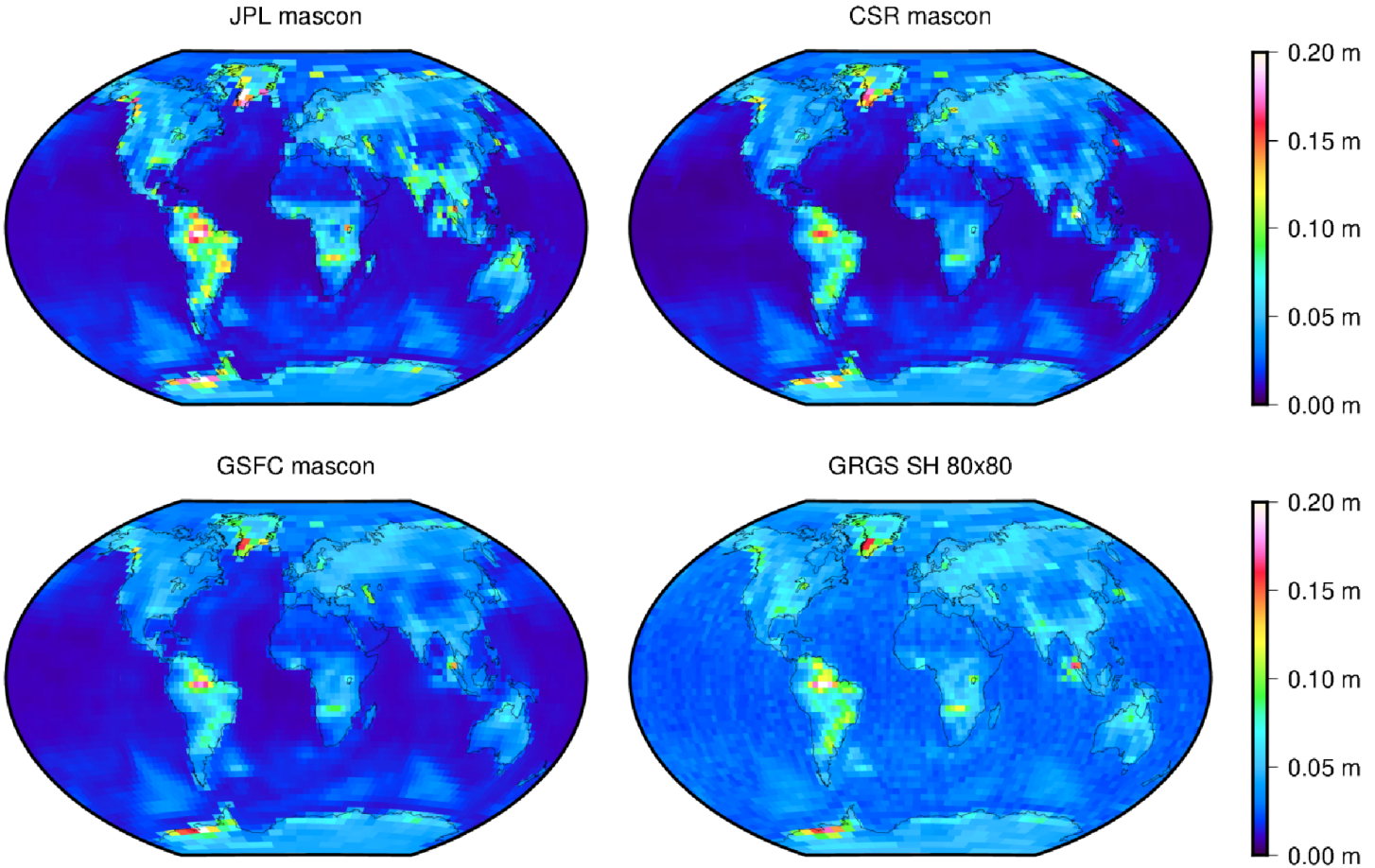
Distribution of « noise » in GRACE EWH time series

- **Processing:**
  - Average all solutions over JPL mascons for comparability
  - Remove trend and periodic signals from EWH time series
  - Plot RMS of residual EWH variations (i.e., amplitude of background noise)

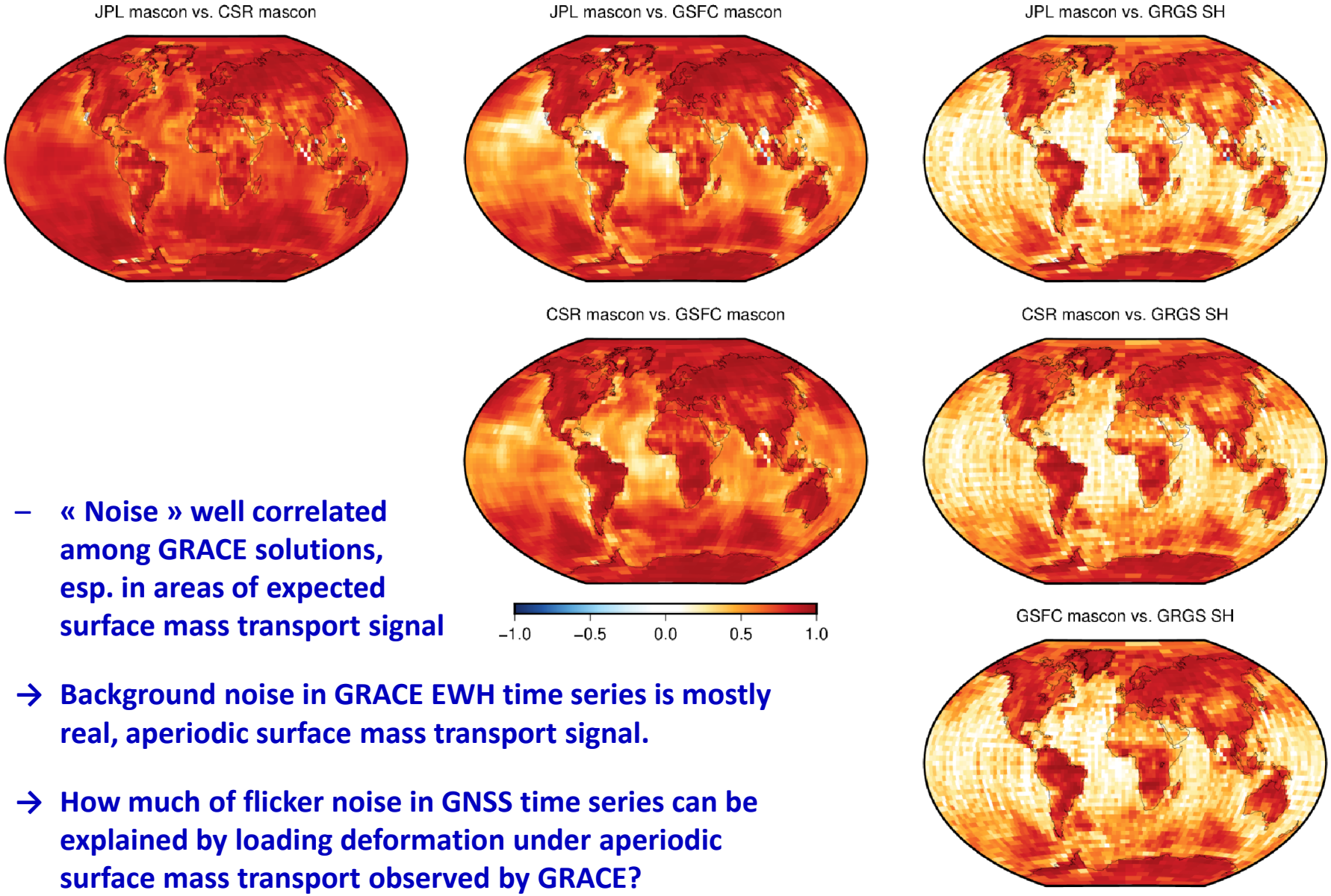


Distribution of « noise » in GRACE EWH time series

- **Observations:**
  - **Distribution of « noise » follows distribution of expected surface mass transport signal**
  - **Mascon solutions « cleaner » than GRGS SH solution**
  - **GSFC regularization > CSR regularization > JPL regularization**



Correlation of « noise » between GRACE solutions



– « Noise » well correlated among GRACE solutions, esp. in areas of expected surface mass transport signal

→ Background noise in GRACE EWH time series is mostly real, aperiodic surface mass transport signal.

→ How much of flicker noise in GNSS time series can be explained by loading deformation under aperiodic surface mass transport observed by GRACE?

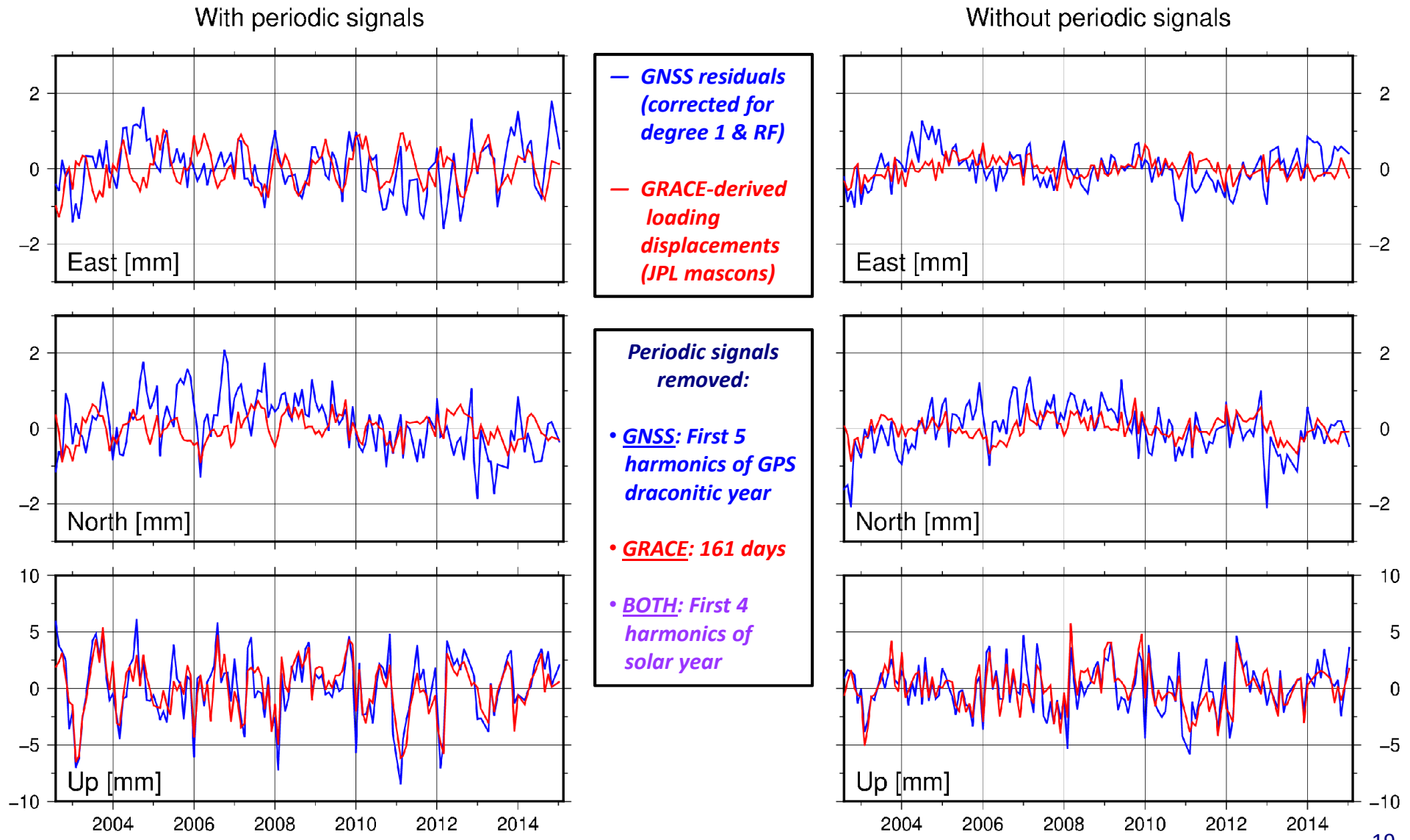
GNSS vs. GRACE: data & processing

- **GNSS:**
  - Residuals from an ITRF2014-like long-term stacking of the daily IGS repro2 solutions
  - Residuals averaged over monthly intervals
  - Estimated annual and semi-annual signals restored

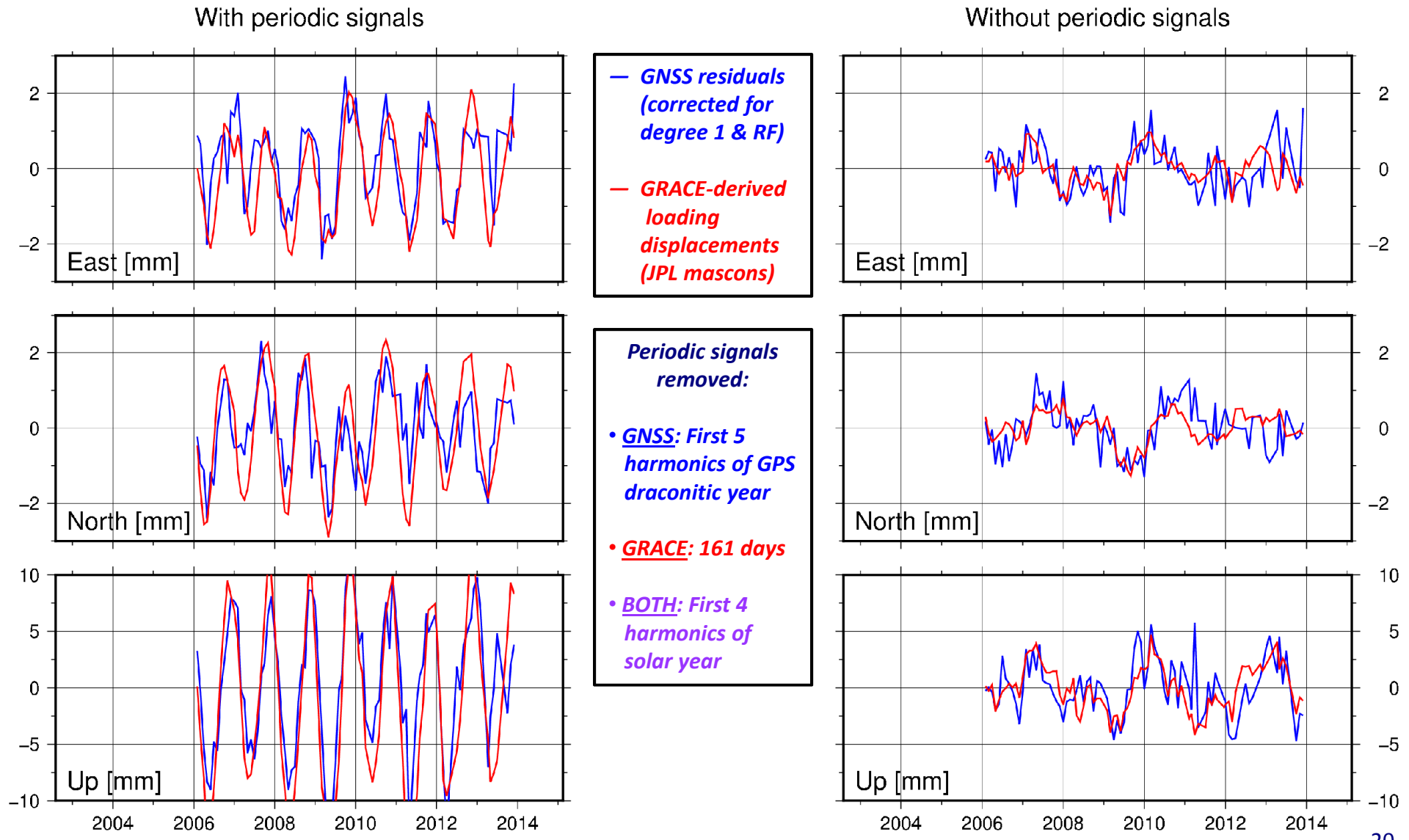
- **GRACE:**
  - Monthly JPL-RL05 mascon and GRGS-RL04 SH solutions
  - Co- and post-seismic effects removed
  - Atmospheric and oceanic dealiasing products restored
  - Degree-1 removed
  - Converted into loading displacements at GNSS stations using PREM-based elastic load Love numbers / Green's functions

- **Degree 1 & Reference Frame:**
  - Every month, form the difference between GNSS and GRACE deformation fields
  - Estimate {translation + rotation + degree 1 deformation field} from the GNSS – GRACE differences
  - Remove {translation + rotation + degree 1 deformation field} from GNSS displacements

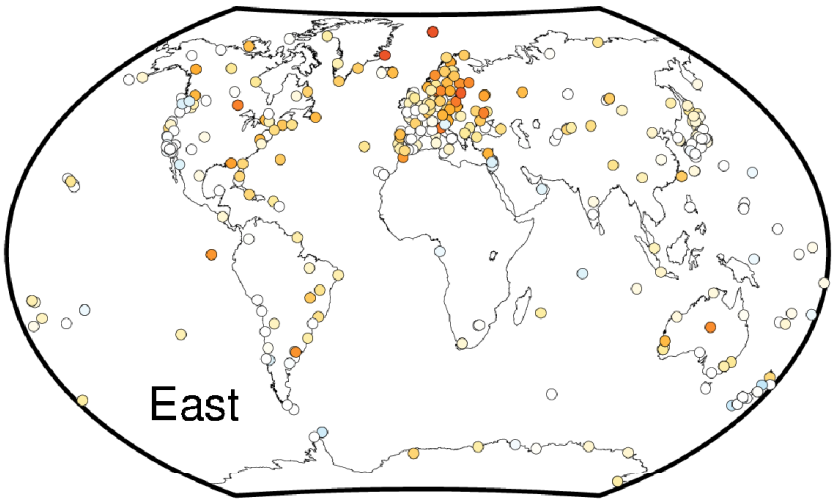
Time series example: BOR1 (Borowiec, Poland)

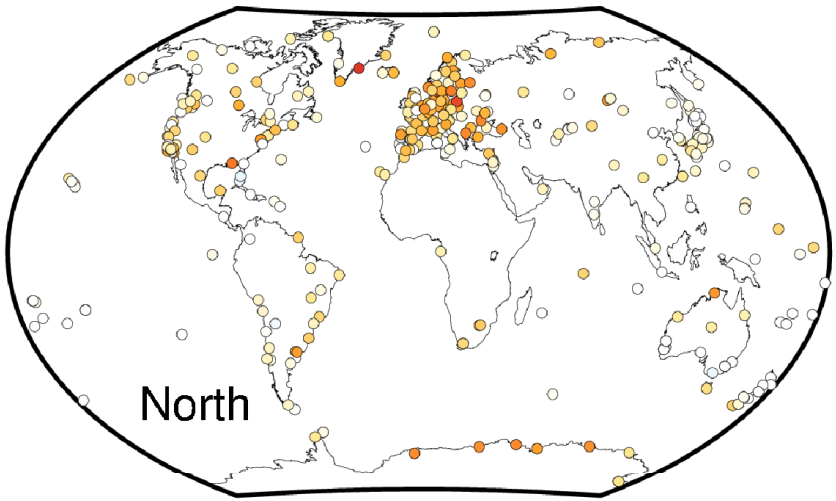


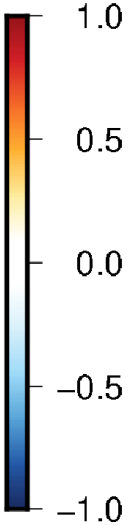
Time series example: MAPA (Macapa, Brazil)

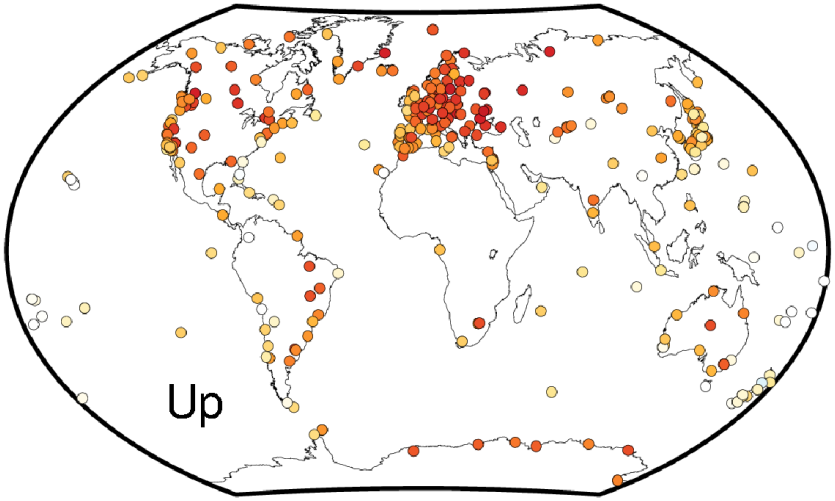


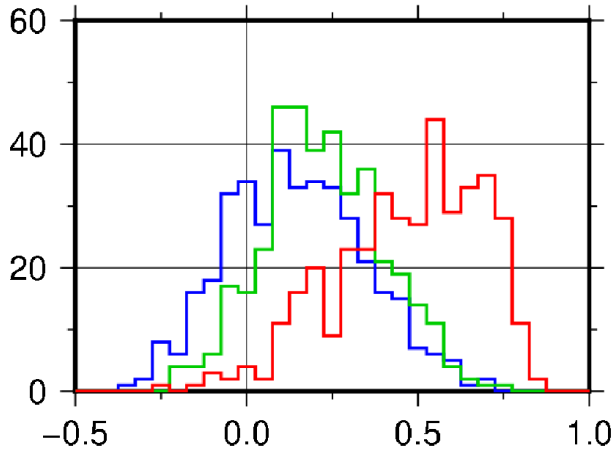
GNSS / GRACE(JPL) noise correlation











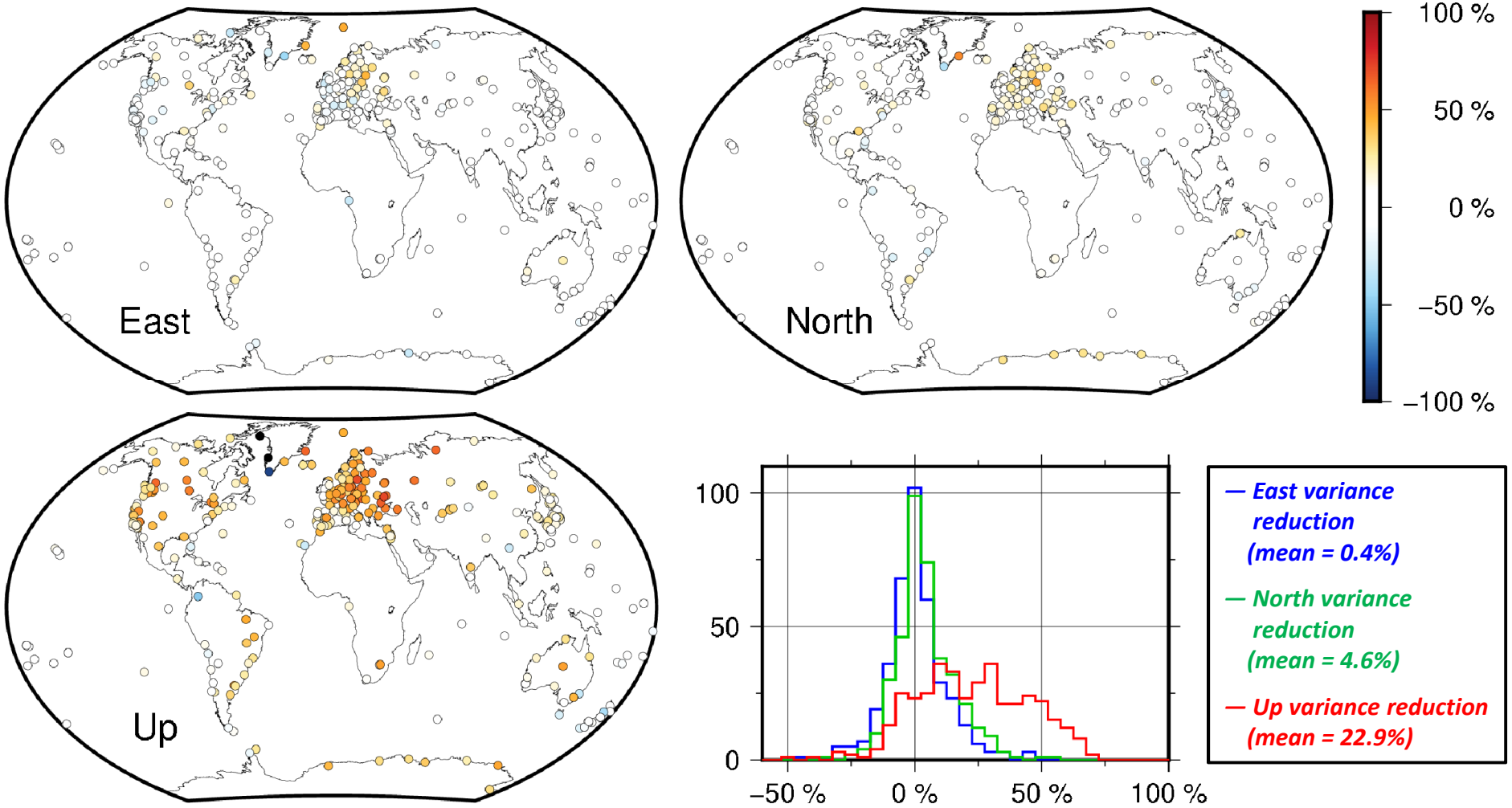
— *East correlation (mean = 0.15)*

— *North correlation (mean = 0.22)*

— *Up correlation (mean = 0.48)*

Correlation coefficients between GNSS residual time series (corrected for degree 1 and RF effects) and GRACE-derived loading deformation time series, after having removed periodic signals from both

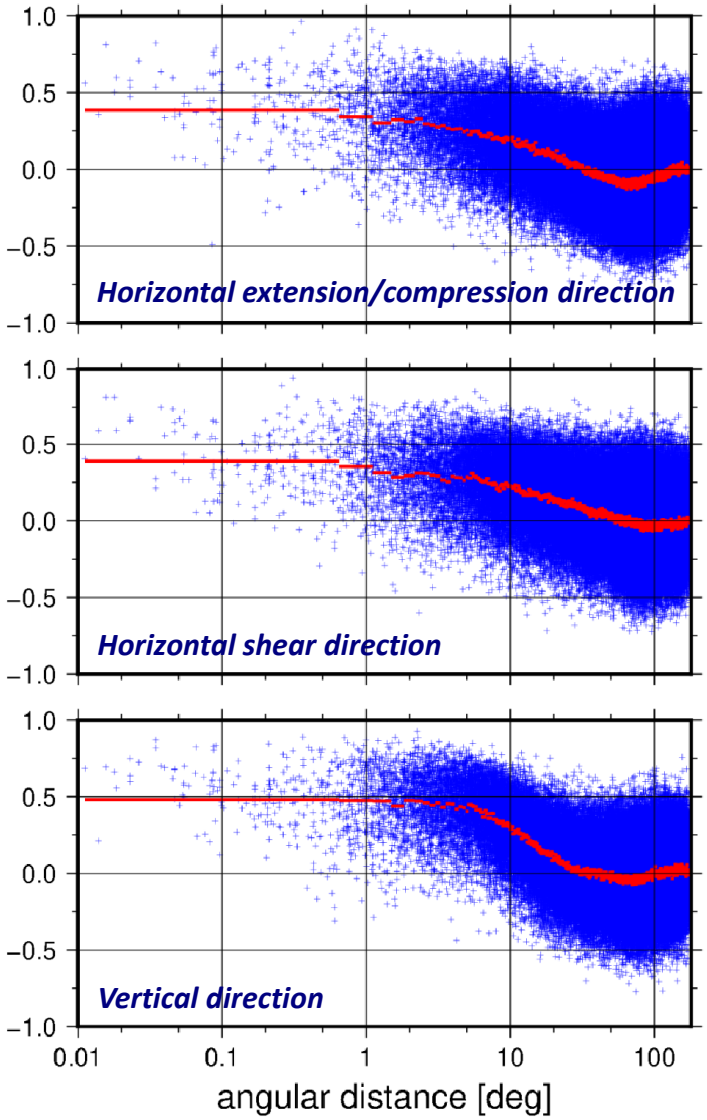
Relative variance reduction of GNSS noise



Relative variance reduction between background noise in "raw" GNSS residual time series and background noise in GNSS residual time series corrected from GRACE(JPL)-derived loading displacements

Spatial correlation of GNSS noise

Without GRACE corrections



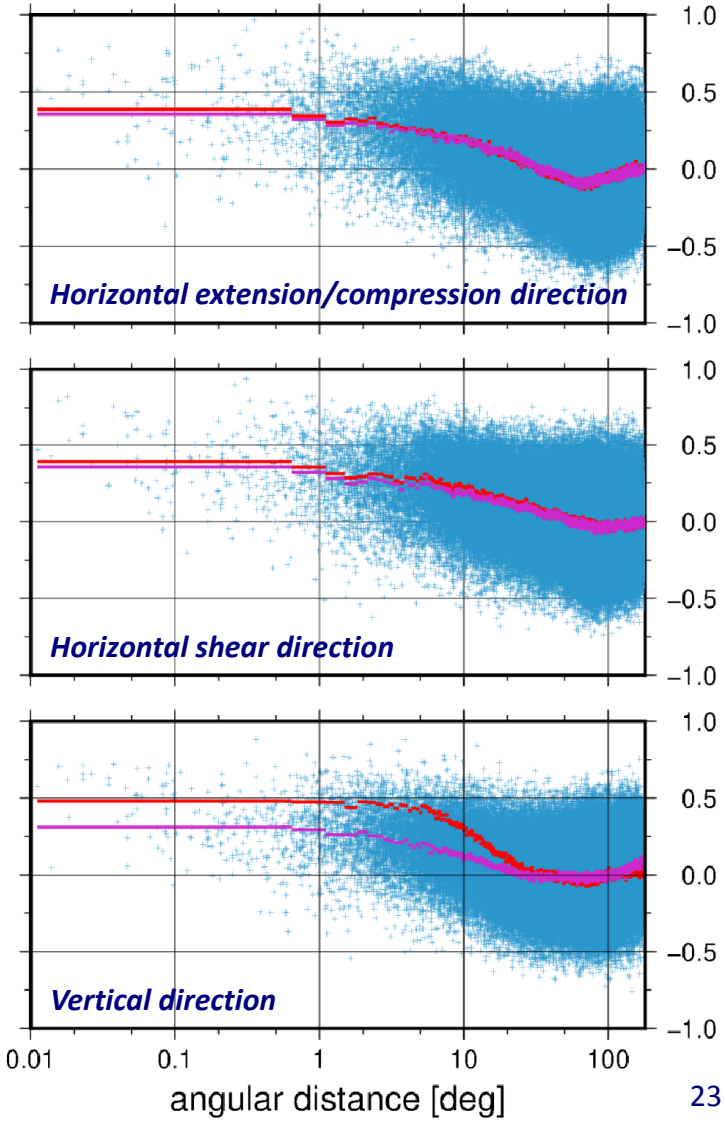
+ *Correlation of background noise between pairs of GNSS time series*

— *Average correlation per class of distance*

+ *Correlation of background noise between pairs of GNSS time series corrected from GRACE(JPL)-derived loading displacements*

— *Average correlation per class of distance*

With GRACE corrections



Summary & Conclusions

- **Background noise in regularized GRACE solutions:**
  - has flicker behavior in average,
  - follows geographical distribution of expected surface mass transport signal,
  - is highly correlated between different GRACE solutions,
  - → is mostly real, aperiodic surface mass transport signal.

- **Loading deformation under aperiodic surface mass transport observed by GRACE:**
  - shows significant correlations with background noise in GNSS time series,
  - explains >20% of GNSS background noise in vertical / a few % in horizontal,
  - contributes to spatial correlation of GNSS background noise in vertical.

- **Remaining (non-loading) GNSS background noise:**
  - is still partially spatially correlated,
  - → must result from both spatially correlated and spatially uncorrelated processes, which remain to be identified.
  - Similar situation as for non-loading seasonal variations in GNSS time series