Non-tidal atmospheric loading corrections in global reference frame computations - A case study using SLR -

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Motivation I

- DFG Research Unit "Reference Systems" (FOR 1503)

  FOR 1503 comprises a joint project of DGFI and BKG which investigates non-linear station motions based on an extended parameterization (sine-/cosine-terms with periods of 0.5/1yr) and on **different geophysical fluid models**.

	Deformation			Gravity		
	Atmo.	Ocean	Hydro.	Atmo.	Ocean	Hydro.
GGFC	X	X	X	-	-	-
NASA	X	X	X	-	-	-
TU Vienna	X	-	-	X	-	-
Uni Strasburg	X / X	-	X	X	-	X
GFZ	(X)	(X)	(X)	X	X	(X)

- In this presentation, the non-tidal atmospheric loading (NT-ATML) **site displacement model of NASA** and **gravitational perturbation model of GFZ** will be investigated.

Motivation II

Furthermore,

- Unified Analysis Workshop 2011 → ILRS Pilot Project 2012

  Call for space geodetic solutions corrected for ***non-tidal atmospheric loading (site displacement and gravitational perturbation)*** *at the* ***observation level****.*

- ITRF2013 Call for Participation (CfP)

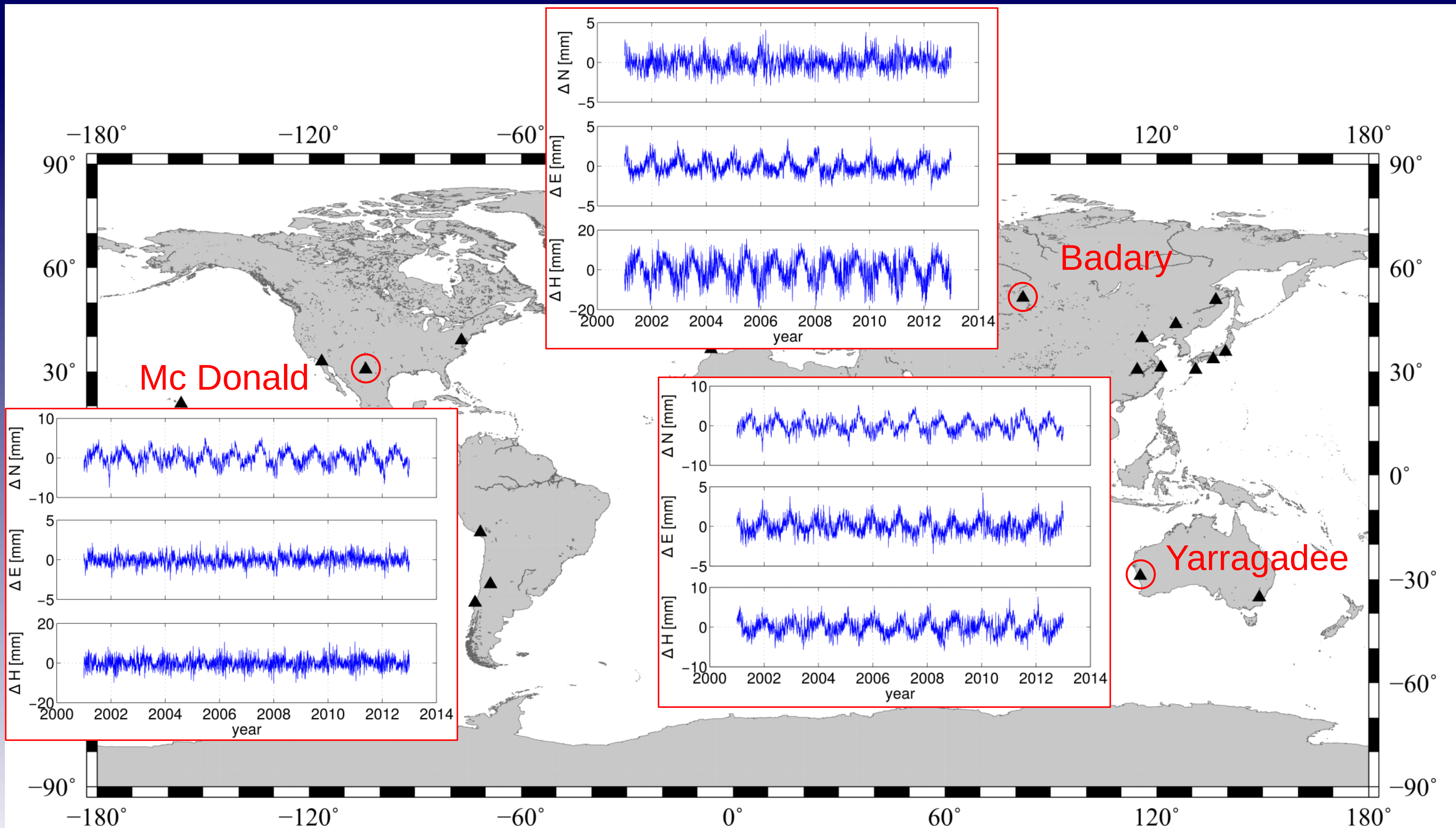
  "… the ***individual TC solutions will be corrected for non-tidal atmospheric loading during the ITRF computation****, using a unique loading model provided by the IERS Global Geophysical Fluid Center (GGFC)."*

  This correction will be applied at the ***normal equation / parameter level****.*

→ What is the impact of the NT-ATML corrections on geodetic parameters?

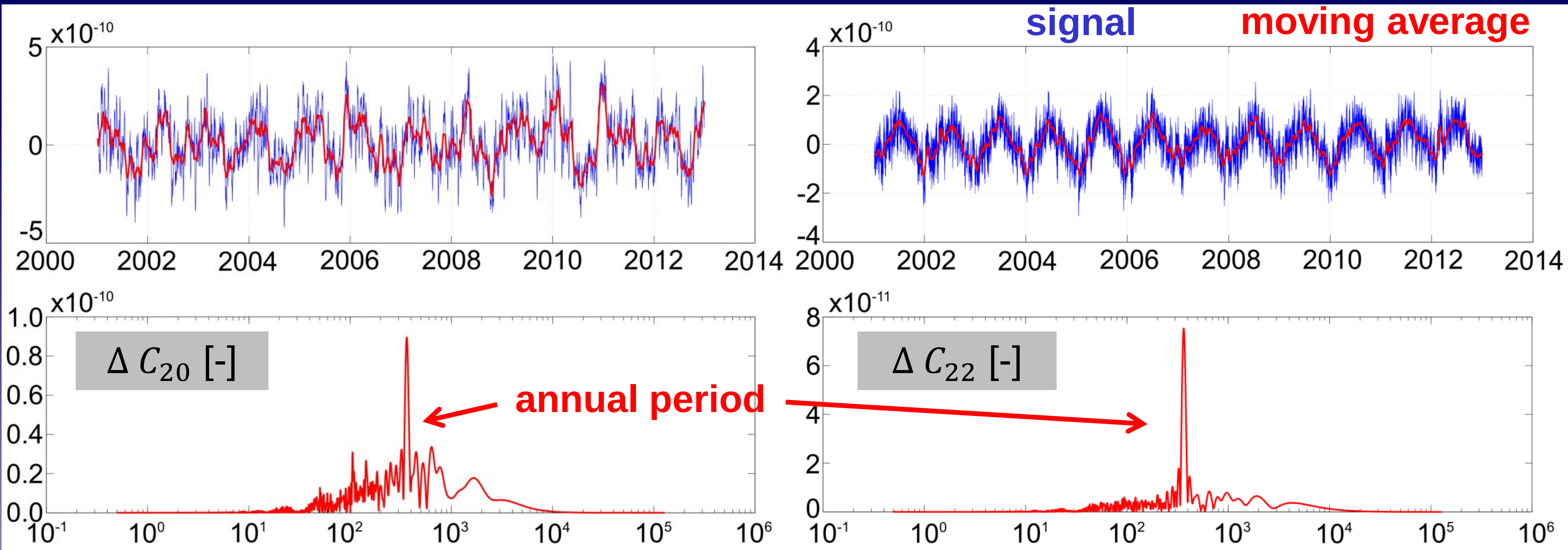
→ Does the application at different levels cause any inconsistencies?

Site displacements due to NT-ATML



The NT-ATML corrections of more than 50% of the SLR stations have an annual amplitude larger than 2 mm in the height component.

Gravitational perturbation due to NT-ATML



- NT-ATML corrections comprise annual periods with significant amplitudes
- These corrections are only important for geodetic space techniques which observe LEOs/MEOs such as SLR, DORIS (altitude of GNSS satellites is too high)

coefficient	C_{20}	C_{21}	S_{21}	C_{22}	S_{22}
ampl. (1 yr)	8.95E-11	5.29E-11	1.22E-10	7.54E-11	4.07E-11

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Global reference frame solutions

In order to quantify impact of NT-ATML on global reference frames and EOP, **three test solutions** using SLR data are computed:

- conventional TRF; **no NT-ATML corrections applied**
- TRF + **NT-ATML corrections applied a posteriori** (only site displacements at normal equation / parameter level)
  - **site displacements are a mean of all displacements during a week**
  - consequently only displacements at observation epochs should be used (for ITRF2013 processing, this information is not available)
- TRF + **NT-ATML corrections applied at observation level** (site displacements + gravitational perturbations → complete effect)
  - **corrections are applied at observation epochs**

SLR blue sky effect

Solution setup

The computed global TRFs …

- ❑ contain observations to LAGEOS 1/2 and Etalon 1/2 (weighted by iterative VCE),
- ❑ are computed for a time interval between 2001.0 and 2013.0,
- ❑ contain station coordinates, velocities (60 stations → 360 parameters),
- ❑ contain daily EOP values (terrestrial pole coordinates; 13128 parameters),
- ❑ have an orientation realized through an NNR condition w.r.t. a selected subnet of the SLRF2008 (updated),
- ❑ contain reduced orbit parameters and station-dependent biases.

NT-ATML corrections at normal equation level

NT-ATML corrections $\boldsymbol{\delta\hat{x}}$ computed from NASA model

SLR-only normal equations

$$\tilde{\hat{\boldsymbol{x}}} = \hat{\boldsymbol{x}} + \boldsymbol{\delta x}$$

$$\tilde{\boldsymbol{x}}_0 + \Delta\tilde{\hat{\boldsymbol{x}}} = \boldsymbol{x}_0 + \Delta\hat{\boldsymbol{x}} + \boldsymbol{\delta x}$$

Keeping the a priori values ($\tilde{\boldsymbol{x}}_0 = \boldsymbol{x}_0$) yields

$$\Delta\tilde{\hat{\boldsymbol{x}}} = \Delta\hat{\boldsymbol{x}} + \boldsymbol{\delta x}$$

$$\Delta\tilde{\hat{\boldsymbol{x}}} = \boldsymbol{N}^{-1}(\boldsymbol{y} + \boldsymbol{N}\boldsymbol{\delta x}) = \boldsymbol{N}^{-1}\tilde{\boldsymbol{y}}.$$

$$\tilde{\boldsymbol{N}} = \boldsymbol{N},$$

$$\tilde{\boldsymbol{y}} = \boldsymbol{y} + \boldsymbol{N}\boldsymbol{\delta x},$$

$$\tilde{\boldsymbol{l}}^T\tilde{\boldsymbol{P}}_{ll}\tilde{\boldsymbol{l}} = \boldsymbol{l}^T\boldsymbol{P}_{ll}\boldsymbol{l} + \boldsymbol{\delta x}^T(2\boldsymbol{y} + \boldsymbol{N}\boldsymbol{\delta x}),$$

$$\tilde{\boldsymbol{x}}_0 = \boldsymbol{x}_0.$$

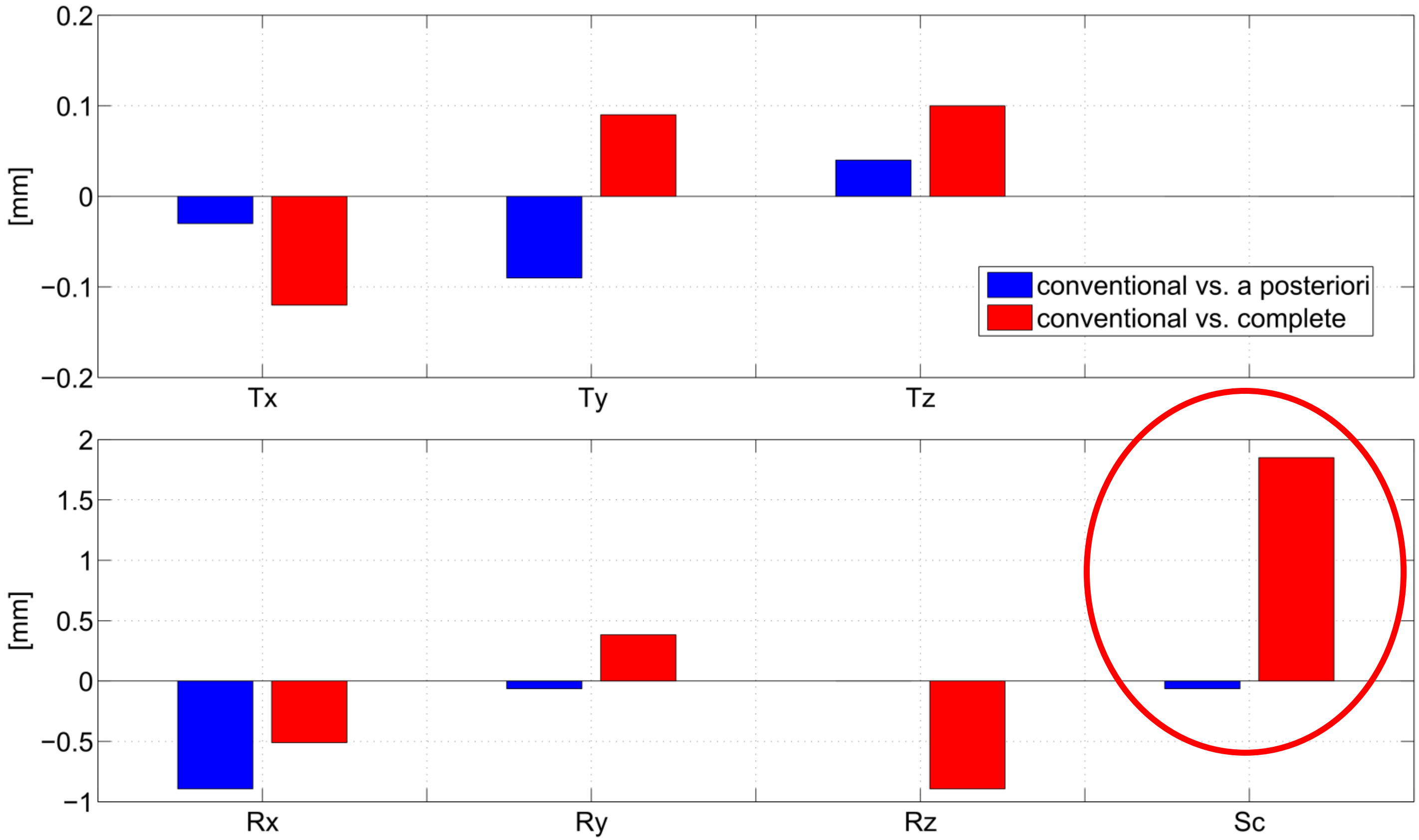
SLR-only normal equations corrected a posteriori for NT-ATML

Accumulation ...

Introduction of station velocities …

Realization of geodetic datum …

Impact on geodetic datum of global TRFs



- Translations are very small (< 0.20 mm), rotations are smaller than 1.0 mm
- Different treatment of NT-ATML corrections cause scale difference of ca. 1.8 mm (this might be caused by gravitational perturbation and blue sky effect)
- Rates are nearly zero for all parameters

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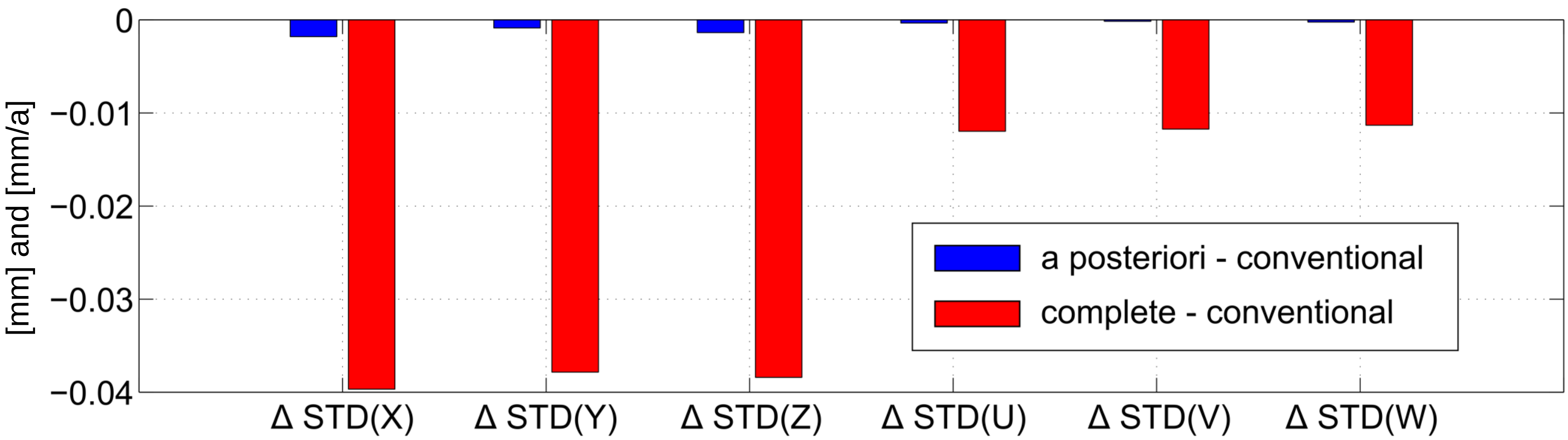
Impact on internal accuracy of TRFs

	$l^T P l$	$\hat{v}^T P \hat{v}$
conventional TRF	5.16656E+06	3.09233E+06
a posteriori corr. TRF	5.17203E+06	3.09861E+06
complete corr. TRF	5.12014E+06	2.98952E+06



- $l^T P_{ll} l$ and $\hat{v}^T P_{ll} \hat{v}$ are dominated by the EOP (13128 EOP vs. 360 station parameters)
- differences in the coordinate / velocity STDs are very small (<0.05 mm)

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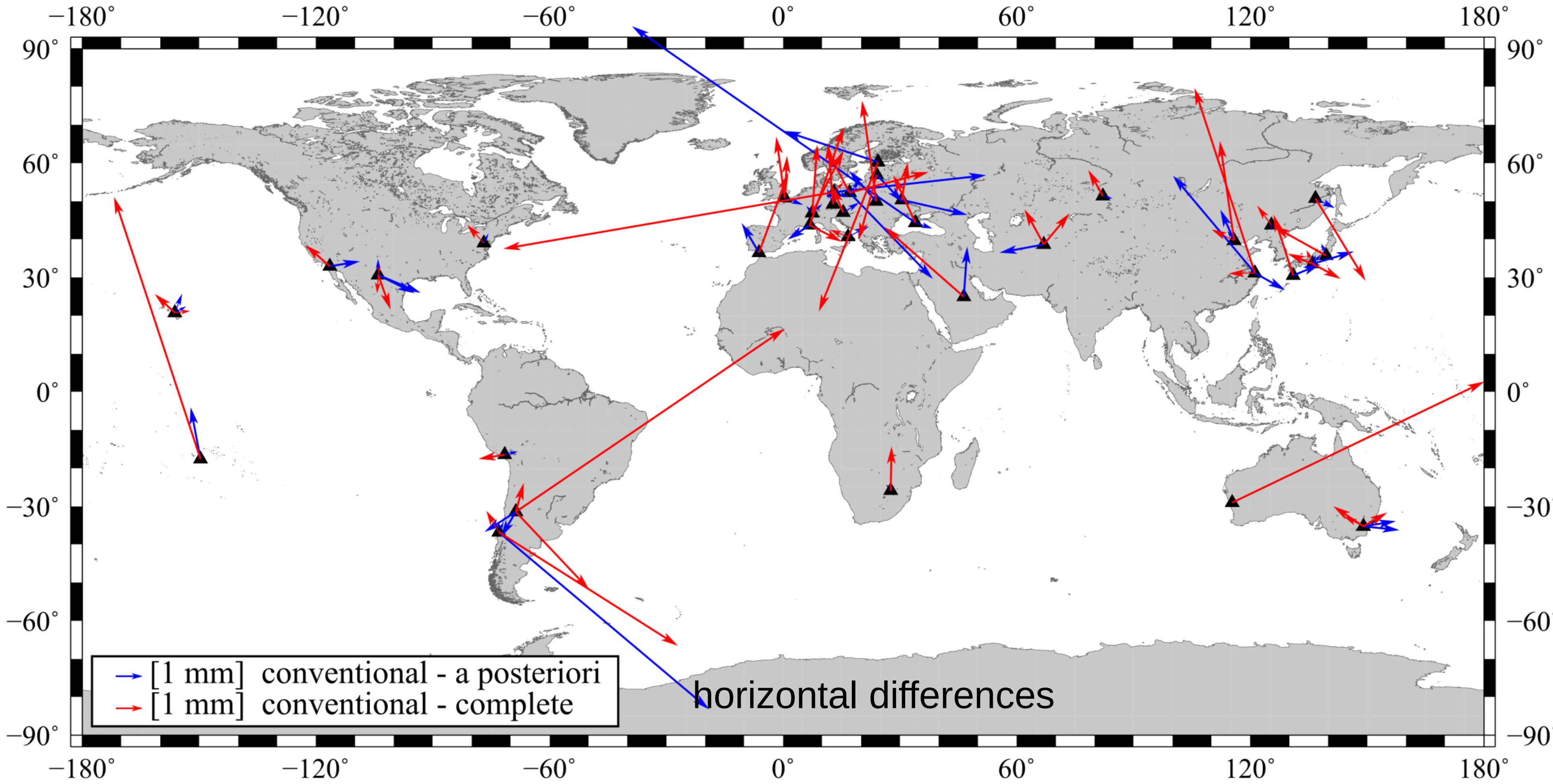
Impact on station coordinates / velocities I



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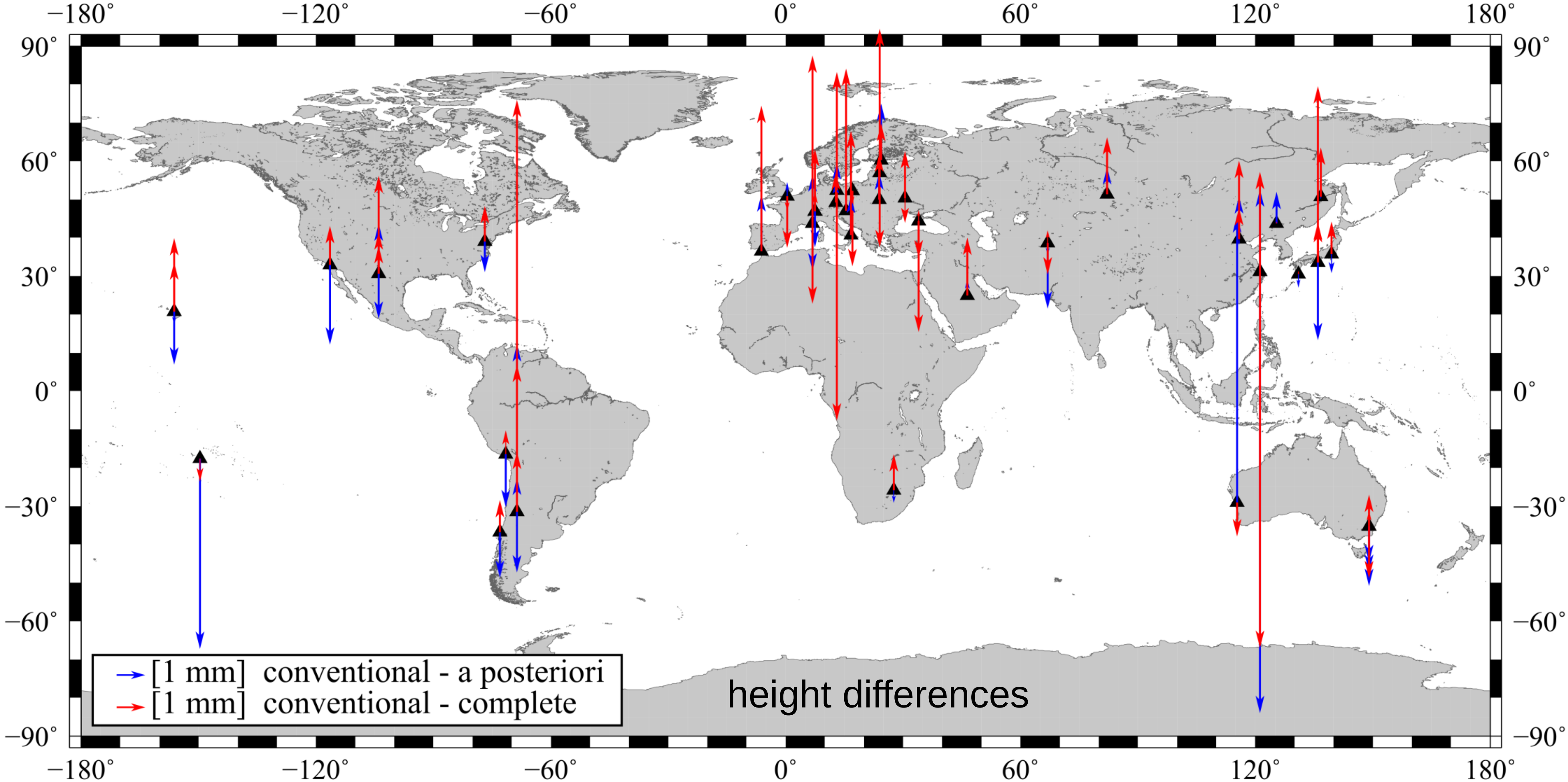
Impact on station coordinates / velocities II



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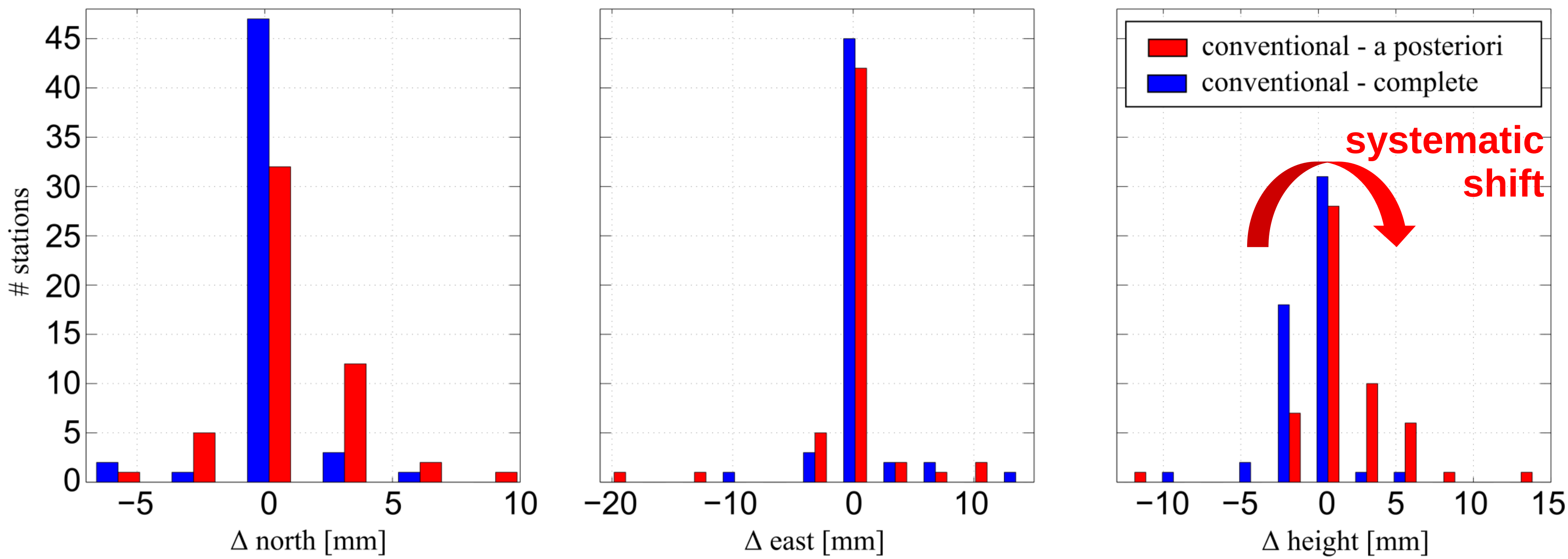
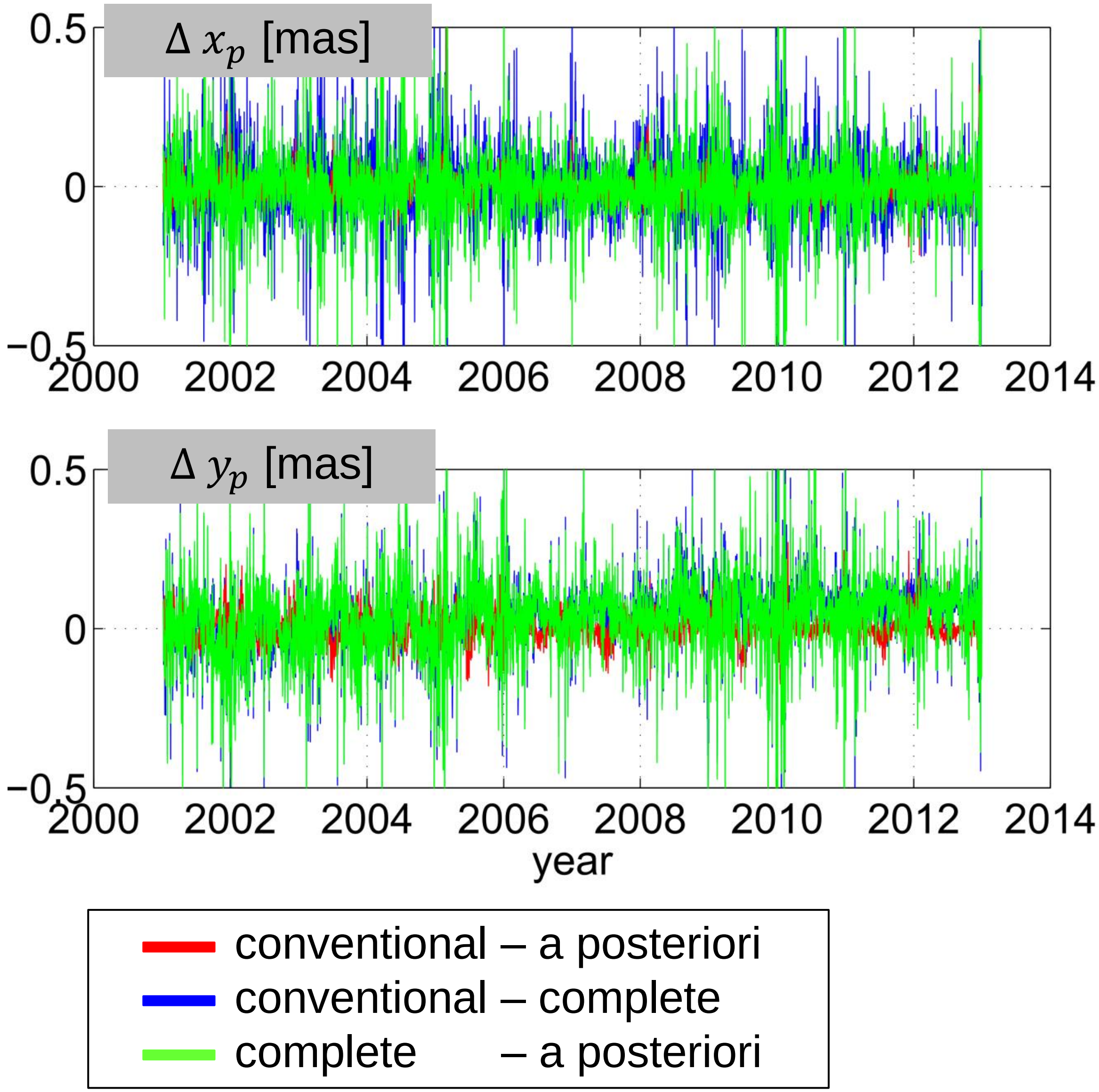
Impact on station coordinates / velocities III



- ❑ horizontal coordinate differences show no systematic change between a posteriori and complete correction
- ❑ height differences show a **systematic shift into positive domain in the southern and northern hemisphere**

  → **scale factor!**

Impact on terrestrial pole coordinates I



- Δx_p time series agree well w.r.t. each other
- Δy_p time series of a posteriori and complete corrected TRF show small systematic drift w.r.t conventional TRF
- Improvement of STDs:

Δ STD(x_p)	Δ STD(y_p)
0.18 μs	3.4 μs
0.17 μs	3.4 μs

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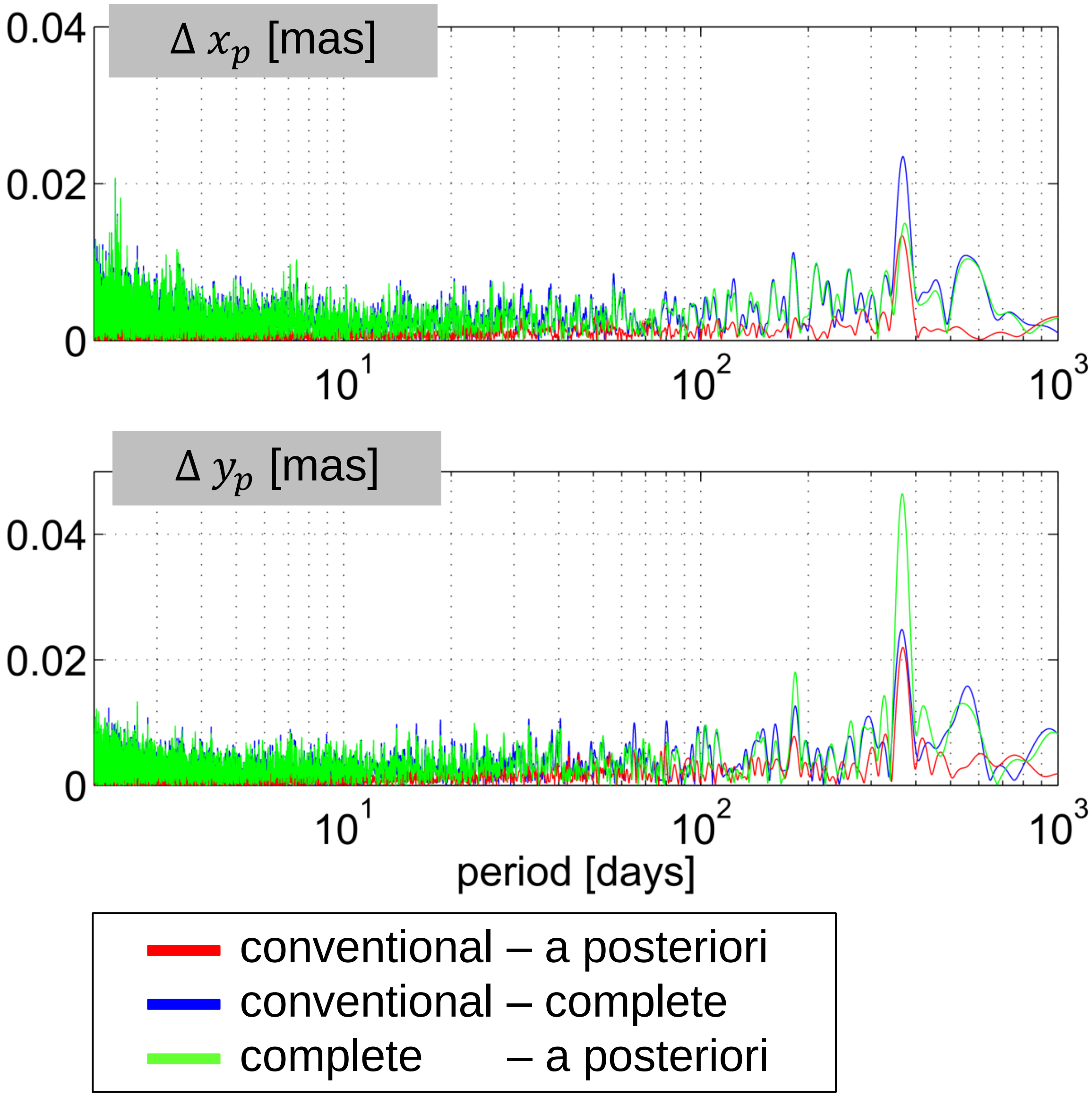
Impact on terrestrial pole coordinates II



- Application of NT-ATML corrections at different levels cause differences in polar motion with clear seasonal variations
- Δx_p

amplitude [mas]	phase [deg]
0.014 ± 0.001	93.6 ± 3.3
0.023 ± 0.004	63.9 ± 3.0
0.015 ± 0.004	32.5 ± 3.2

- Δy_p

amplitude [mas]	phase [deg]
0.023 ± 0.001	102.3 ± 2.7
0.027 ± 0.003	270.3 ± 5.6
0.047 ± 0.002	96.8 ± 3.5

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Summary

The application of the **gravitational perturbation is only necessary for LEOs/MEOs** (→ correction only important for DORIS and SLR)

The different applications of NT-ATML corrections
→ at observation equation level (**site displacement + gravitational perturbation at observation epoch**) and
→ at normal equation / parameter level (**only weekly mean site displacement**) cause

- a **difference of ca. 1.8 mm in the scale** between the a posteriori corrected TRF and the complete corrected TRF (SLR blue sky effect)

- an **small improvement in the stochastic model** (improved STDs) if the complete correction is applied at the observation equation level

- **systematic differences with annual period in the terrestrial pole coordinates** (different amplitudes in x_p, y_p and a phase shift of ca. 180 degree in y_p)

Outlook

Future investigations:

- Separation of **SLR blue sky effect**, **effect due to gravitational perturbation** and **effect of the application at different levels**
- Evaluation of other model combinations (currently NASA and GFZ have been used)
- Investigation of the hydrological and oceanic non-tidal loading (site displacement and gravitational perturbation)
- Application of non-tidal corrections to DORIS

For ITRF2013 computation:

- GGFC NT-ATML model will be used for ITRF2013 computation
- Further investigation of NT-ATML effect on station coordinates/velocities
- Investigation if combined pole coordinates are affected

Thank you very much for your attention!

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