Atmosphere loading in VLBI analysis

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Outline

- VLBI analysis

- Comparison of 3 APL models (tidal + non-tidal part):
  - Vienna-APL (Pressure Level – ECMWF)
  - GSFC (Surface Pressure – NCEP)
  - van Dam (Surface Pressure – NCEP)

- Reference pressure

VLBI analysis

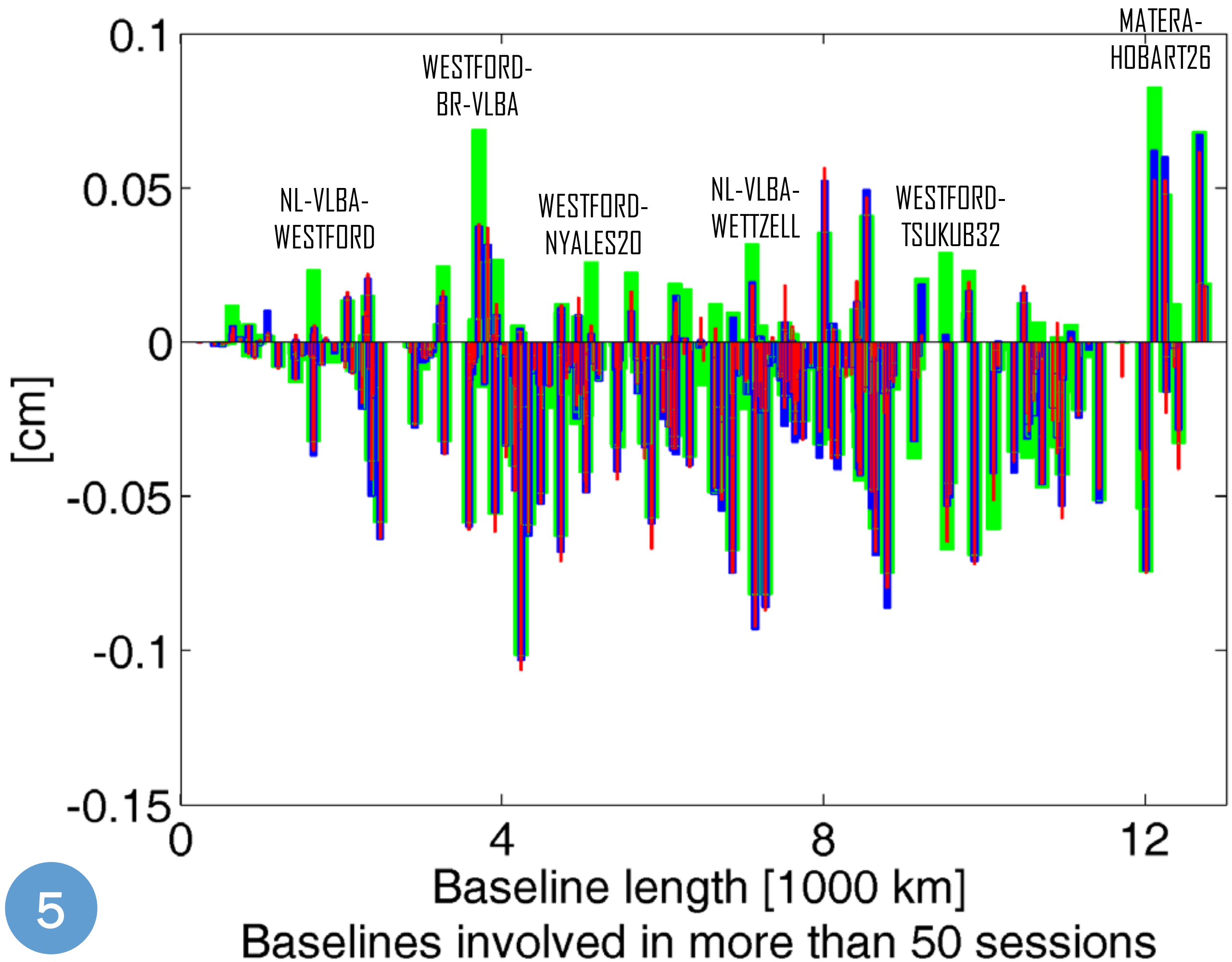
- VLBI data (1990.0 – 2010.0), 2787 sessions
- processed with VieVS

Availability of corrections

- Vienna-APL (Wijaya et al., 2011)
  - analysis with delay of 1 day
  - forecast data for real-time applications
  - http://ggosatm.hg.tuwien.ac.at/loading.html
- GSFC (Petrov and Boy, 2004)
  - analysis with delay of 3 days
  - http://gemini.gsfc.nasa.gov/aplo
- van Dam (van Dam and Ray, 2010)
  - on request
  - http://geophy.uni.lu/ggfc_atmosphere/NCEP-loading.html
- atmospheric tidal model
  - S1/S2 tides derived from the Ray and Ponte (2003) model, (van Dam and Ray, 2010)

Standard deviation of baseline length repeatability

- w.r.t. solution without applying APL corrections

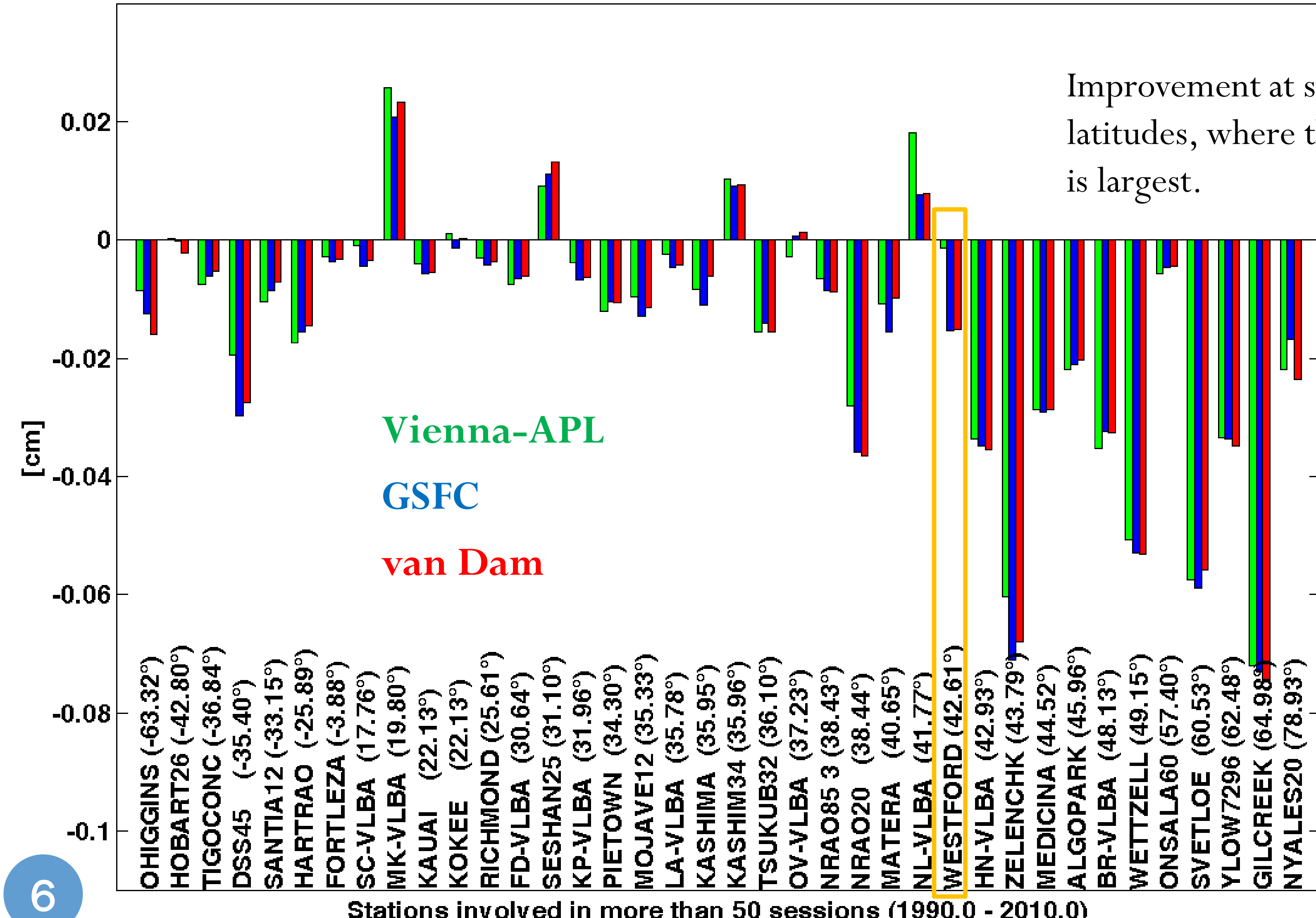


- after applying of the APL model (tidal + non-tidal part), there is improvement of the baseline length repeatability at
  - 72 % (Vienna-APL)
  - 75 % (GSFC)
  - 75 % (van Dam)

  of the baselines

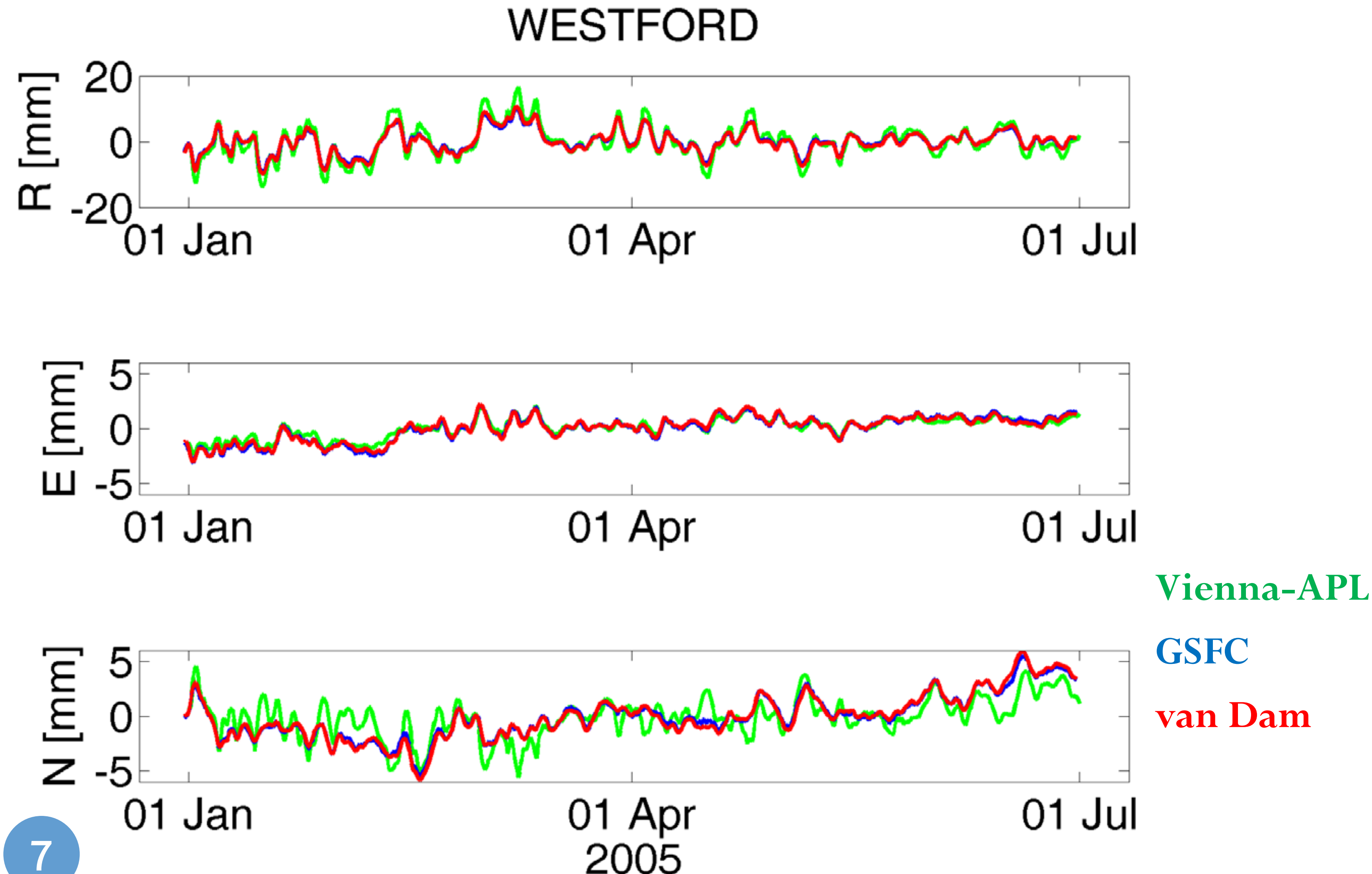
Standard deviation of height time series

- w.r.t. solution without applying APL corrections



Improvement at stations at mid-latitudes, where the APL effect is largest.

Modelled APL corrections



Comparison of APL series from van Dam

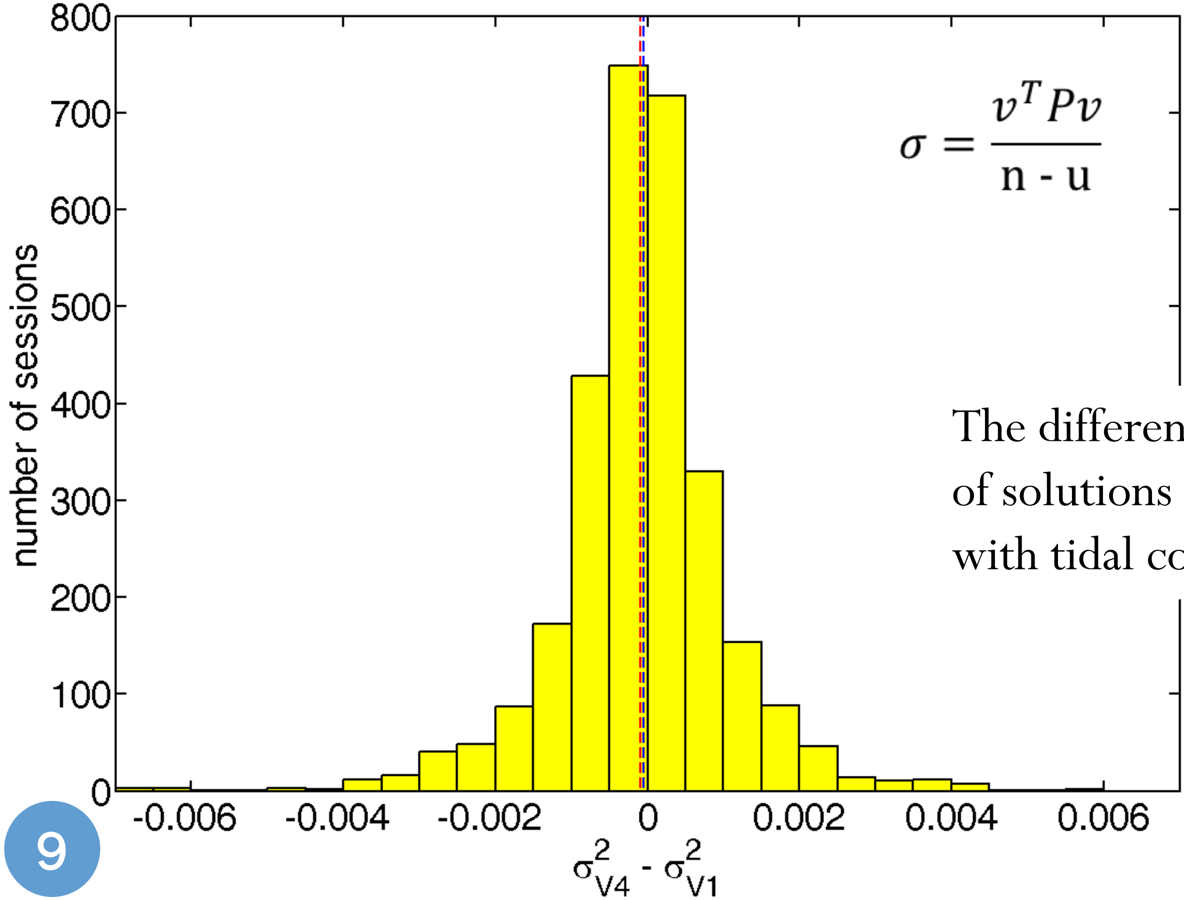
Solution	[1]	[2]	[3]	[4]	[5]	[6]
tidal part (S1/S2)	✗	✓	✗	✓	✓	✓
non-tidal part	✗	✓	✓	✗	✓	✓
		applied as one model			non-tidal part applied at **stacking level**	non-tidal part applied at **observation level**

Comparison of Solution [4] with [1]

[tides only] – [no APL corrections]

- Histogram of $\sigma^2_{[4]} - \sigma^2_{[1]}$

mean($\sigma^2_{[4]} - \sigma^2_{[1]}$) = -0.000 095
median($\sigma^2_{[4]} - \sigma^2_{[1]}$) = -0.000 045



$$\sigma = \frac{v^T P v}{n - u}$$

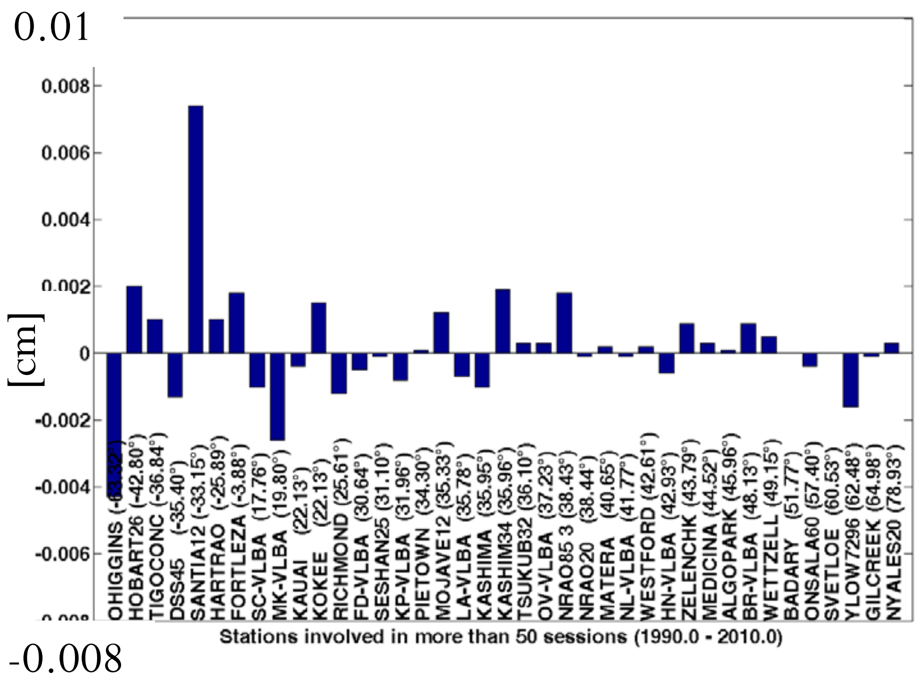
n – number of observations
u – number of estimated parameters

The difference between the a posteriori sigma of solutions without APL corrections and with tidal corrections is very small.

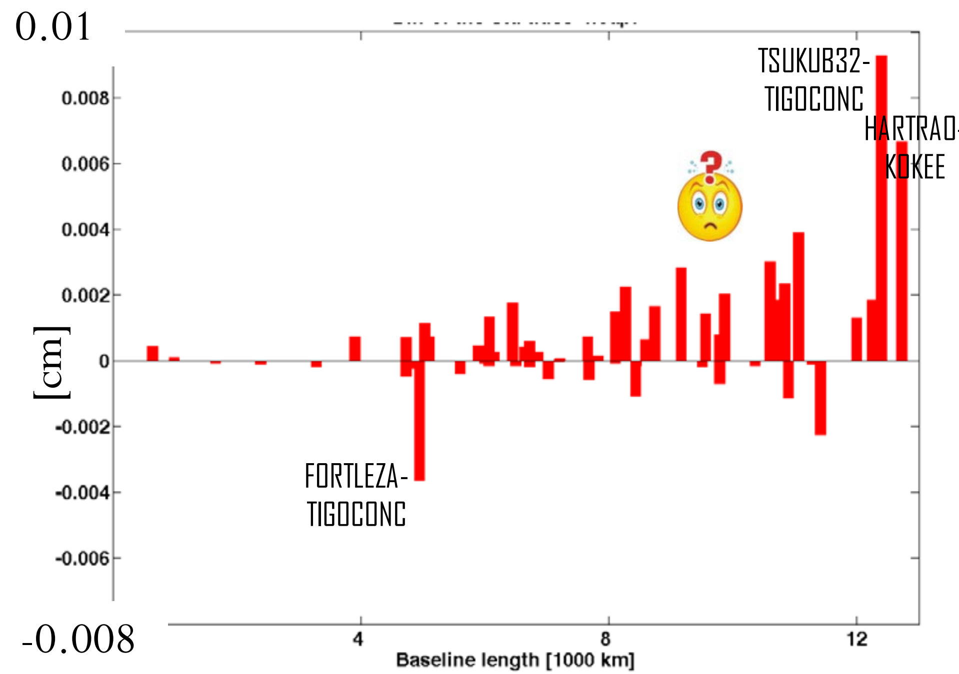
Comparison of Solution [4] with [1]

[tides only] – [no APL corrections]

Difference of standard deviation of height time series



Difference of baseline length repeatability

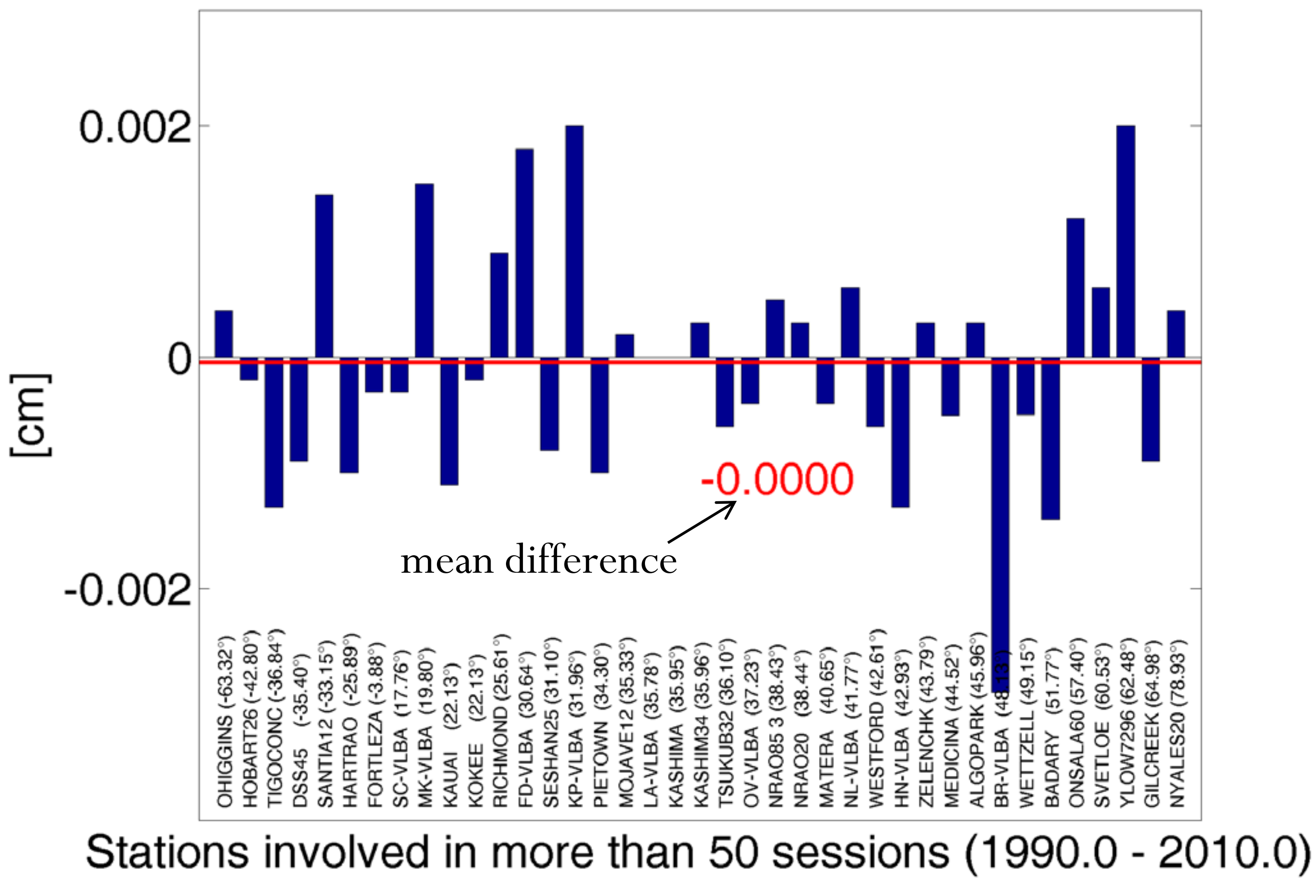


For solution [4 – tides only] we get a slight degradation in terms of baseline length repeatability w.r.t. solution [1 – no APL corrections].

Comparison of Solution [5] with [6]

corrections at [**stacking level**] – [**observation level**]

Difference of standard deviation of height time series

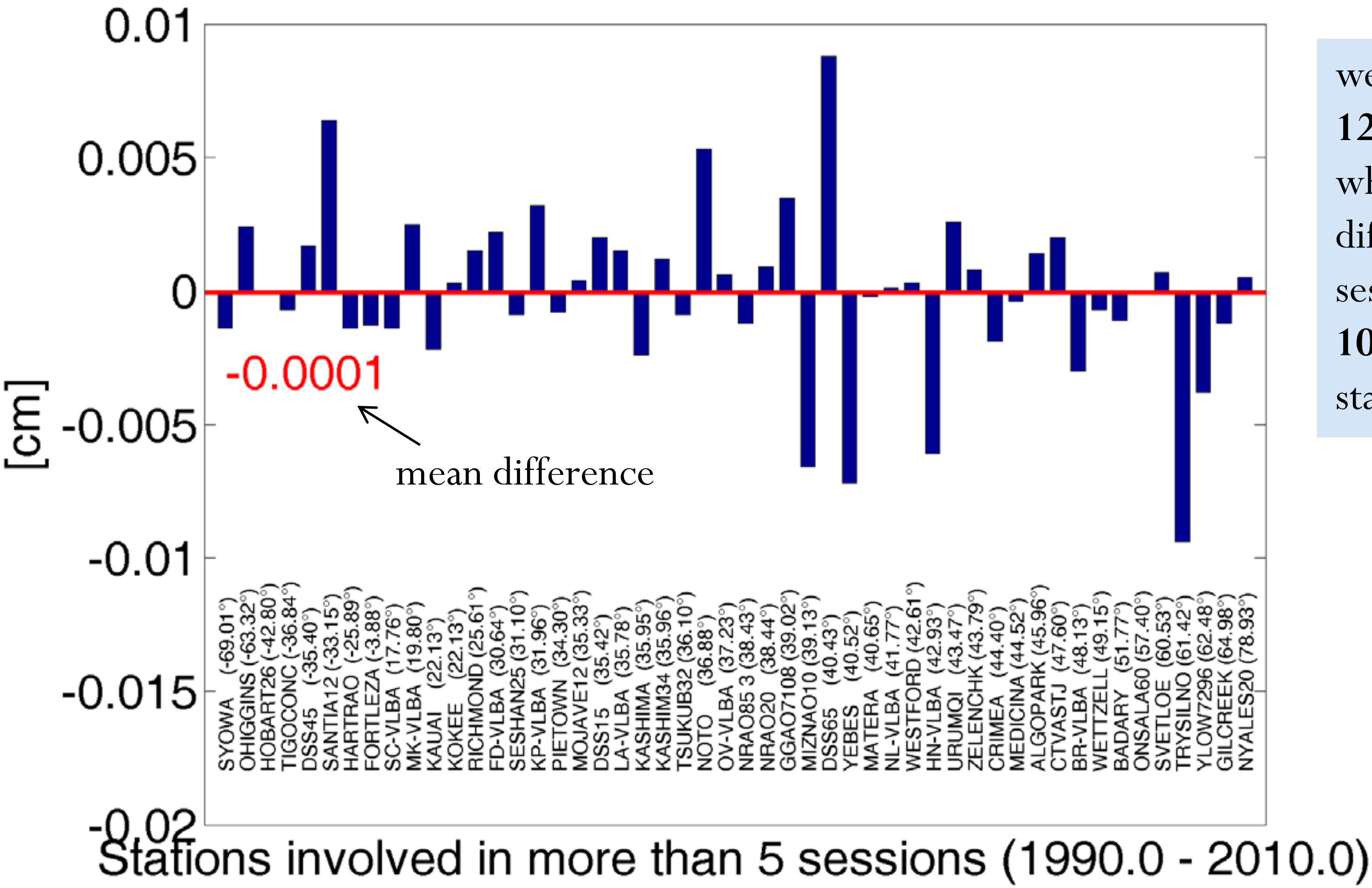


The standard deviation of height time series is **better at 49% of the stations** in solution **[observation level]** compared to [stacking level]

Comparison of Solution [5] with [6]

corrections at [**stacking level**] – [**observation level**]

Difference of standard deviation of height time series



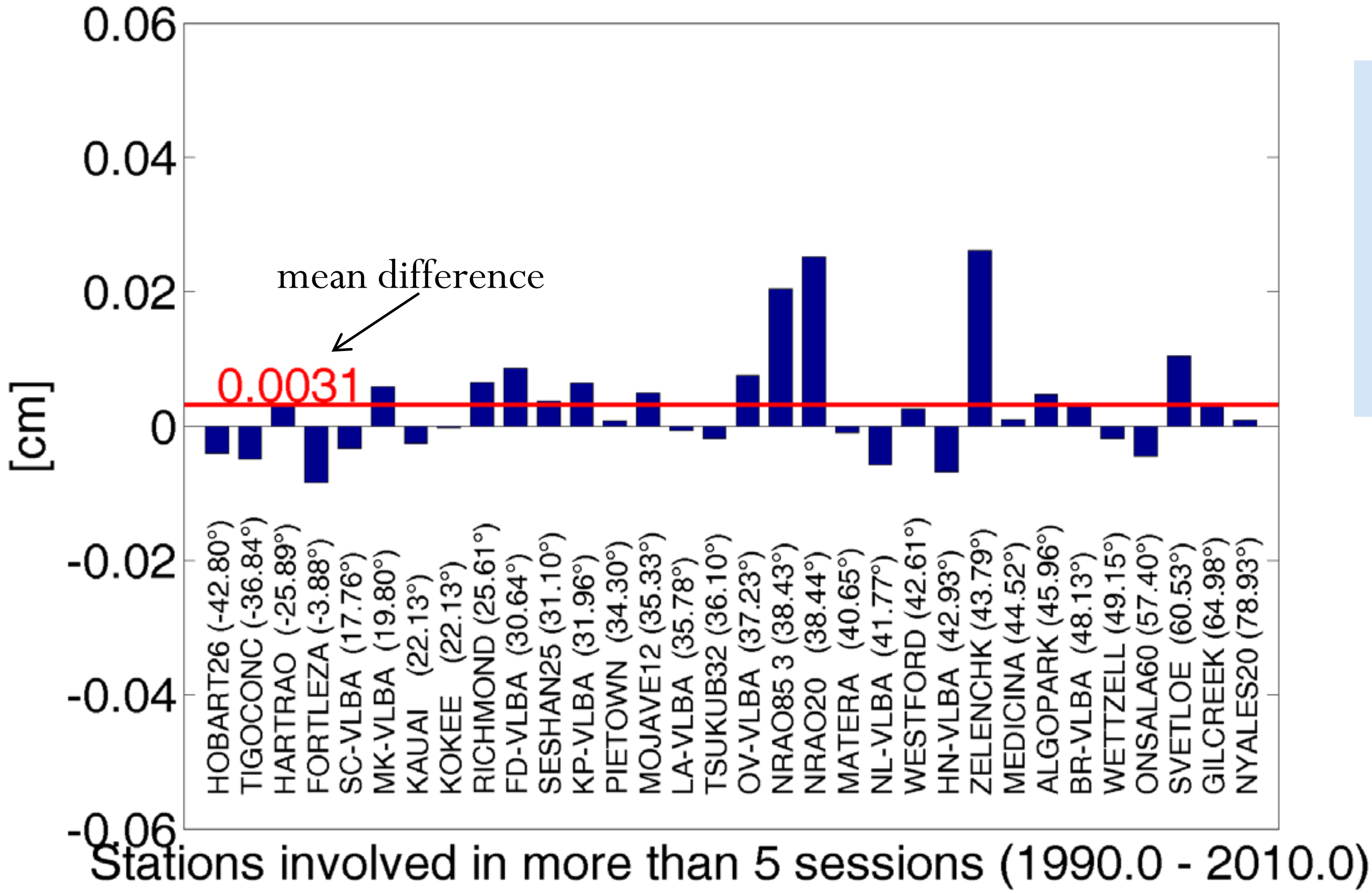
we analysed only **1200 sessions** where a pressure difference during a session is more than **10 hPa** at at least one station

The standard deviation of height time series is **better at 52% of the stations** in solution **[observation level]** compared to [stacking level]

Comparison of Solution [5] with [6]

corrections at [**stacking level**] – [**observation level**]

Difference of standard deviation of height time series

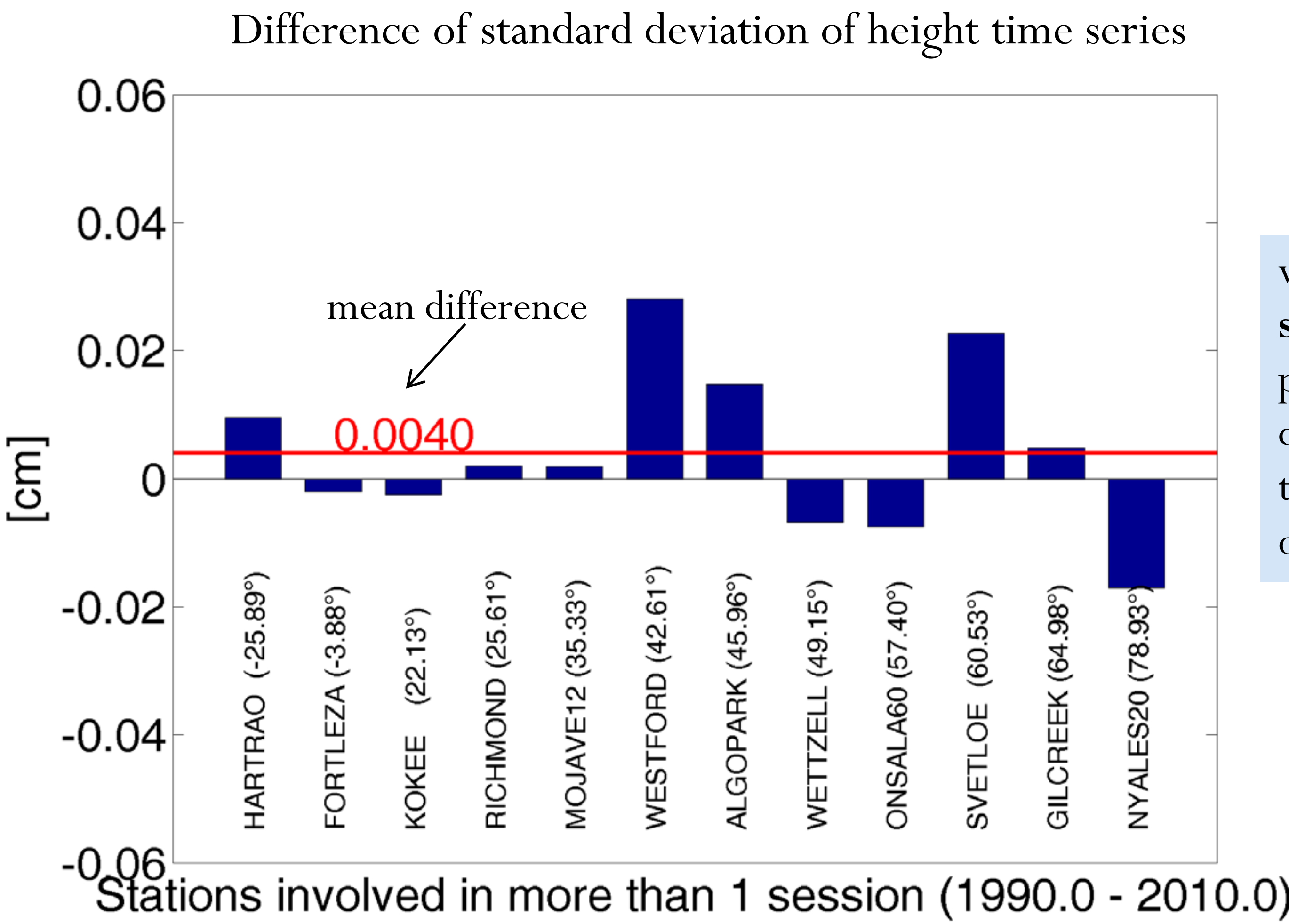


we analysed only **157 sessions** where a pressure difference during a session is more than **20 hPa** at at least one station

The standard deviation of height time series is **better at 59% of the stations** in solution **[observation level]** compared to [stacking level]

Comparison of Solution [5] with [6]

corrections at [**stacking level**] – [**observation level**]



we analysed only **13 sessions** where a pressure difference during a session is more than **30 hPa** at at least one station

The standard deviation of height time series is **better at 58% of the stations** in solution **[observation level]** compared to [stacking level]

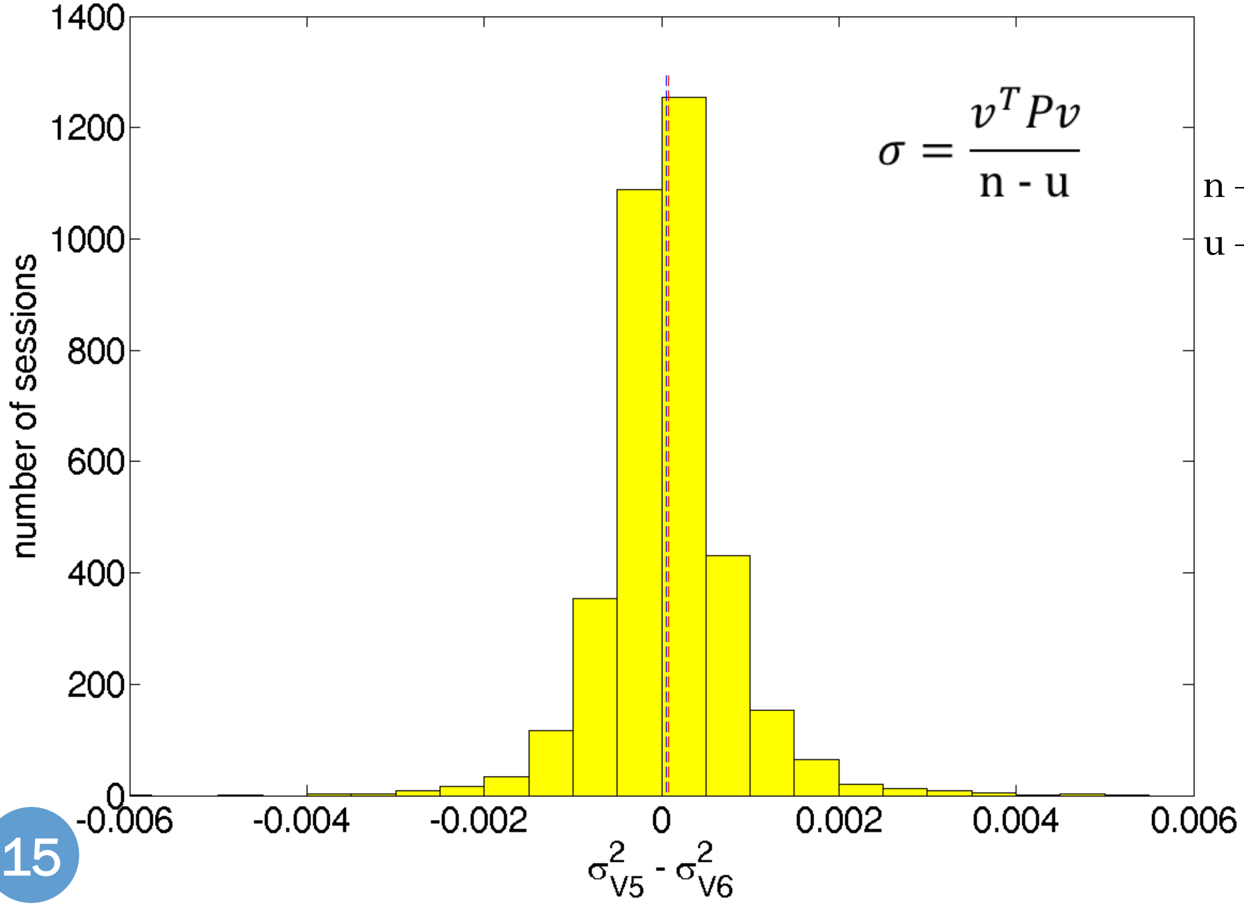
Comparison of Solution [5] with [6]

corrections at [**stacking level**] – [**observation level**]

- Histogram of $\sigma^2_{[5]} - \sigma^2_{[6]}$

mean($\sigma^2_{[5]} - \sigma^2_{[6]}$) = 0.000 074

median($\sigma^2_{[5]} - \sigma^2_{[6]}$) = 0.000 050



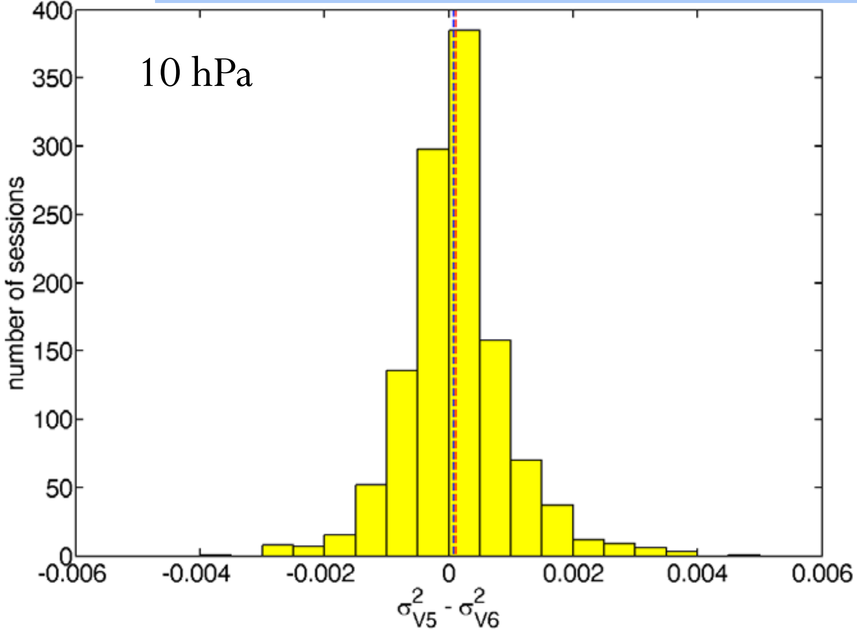
$$\sigma = \frac{v^T P v}{\text{n - u}}$$

n – number of observations

u – number of estimated parameters

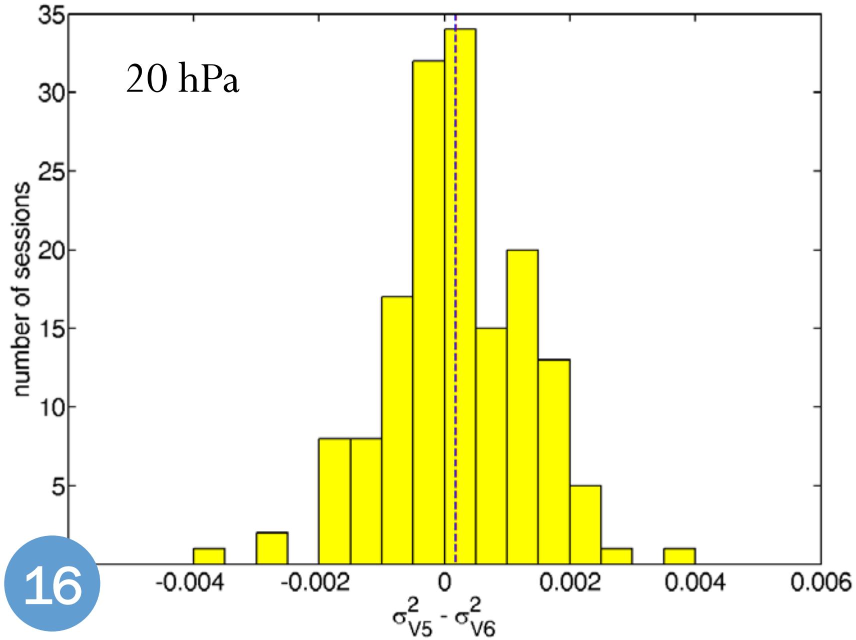
Comparison of Solution [5] with [6]

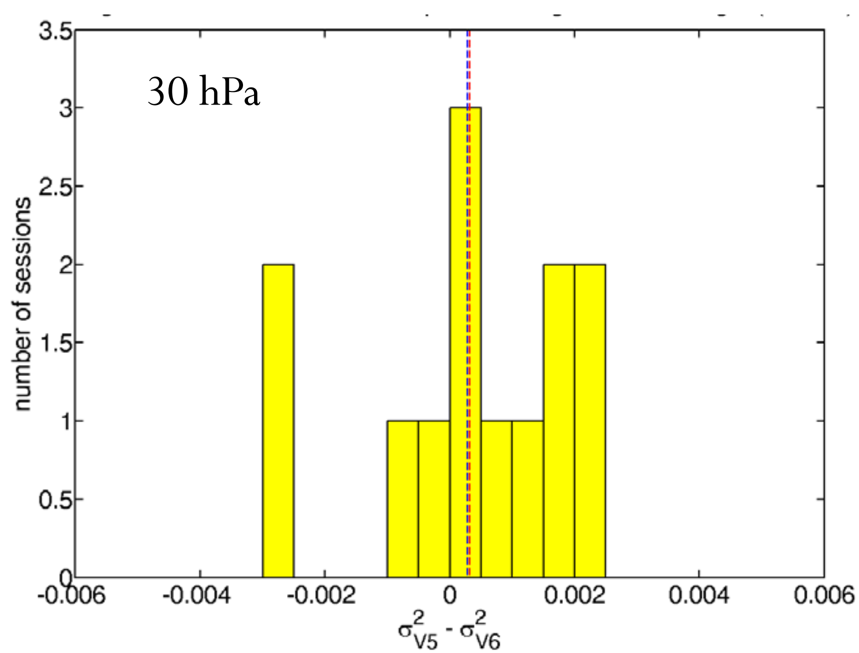
corrections at [**stacking level**] – [**observation level**]



	mean ($\sigma^2_{[5]} - \sigma^2_{[6]}$)	median ($\sigma^2_{[5]} - \sigma^2_{[6]}$)
all ses.	0.000 074	0.000 050
10 hPa	0.000 116	0.000 075
20 hPa	0.000 187	0.000 179
30 hPa	0.000 326	0.000 282

In terms of a posteriori sigma of unit weight the **solution [observation level] performs better** than solution [stacking level].





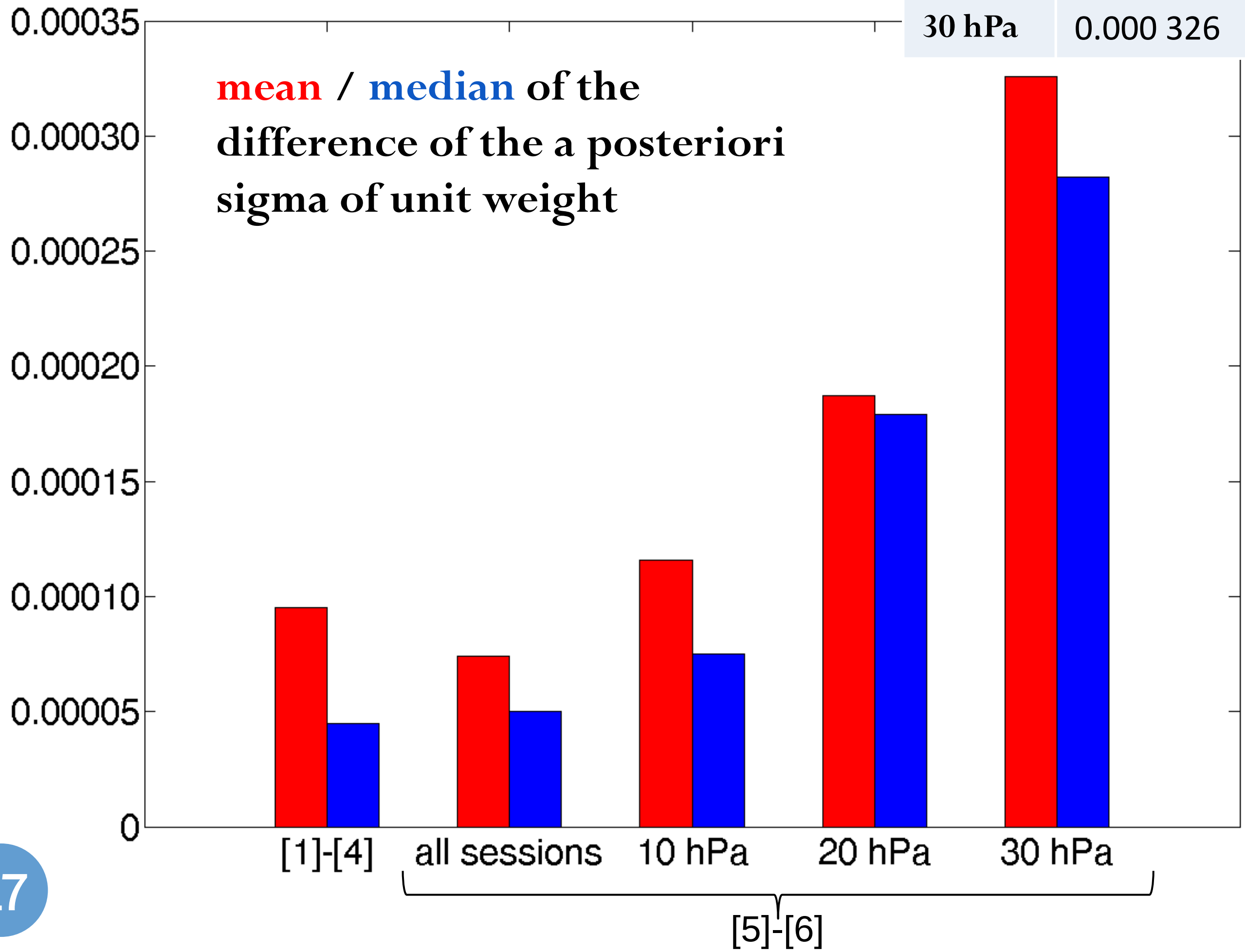
A posteriori sigma of unit weight

[no APL] – [tides only]

	mean ($\sigma^2_{[1]} - \sigma^2_{[4]}$)	median ($\sigma^2_{[1]} - \sigma^2_{[4]}$)
all ses.	0.000 095	0.000 0450

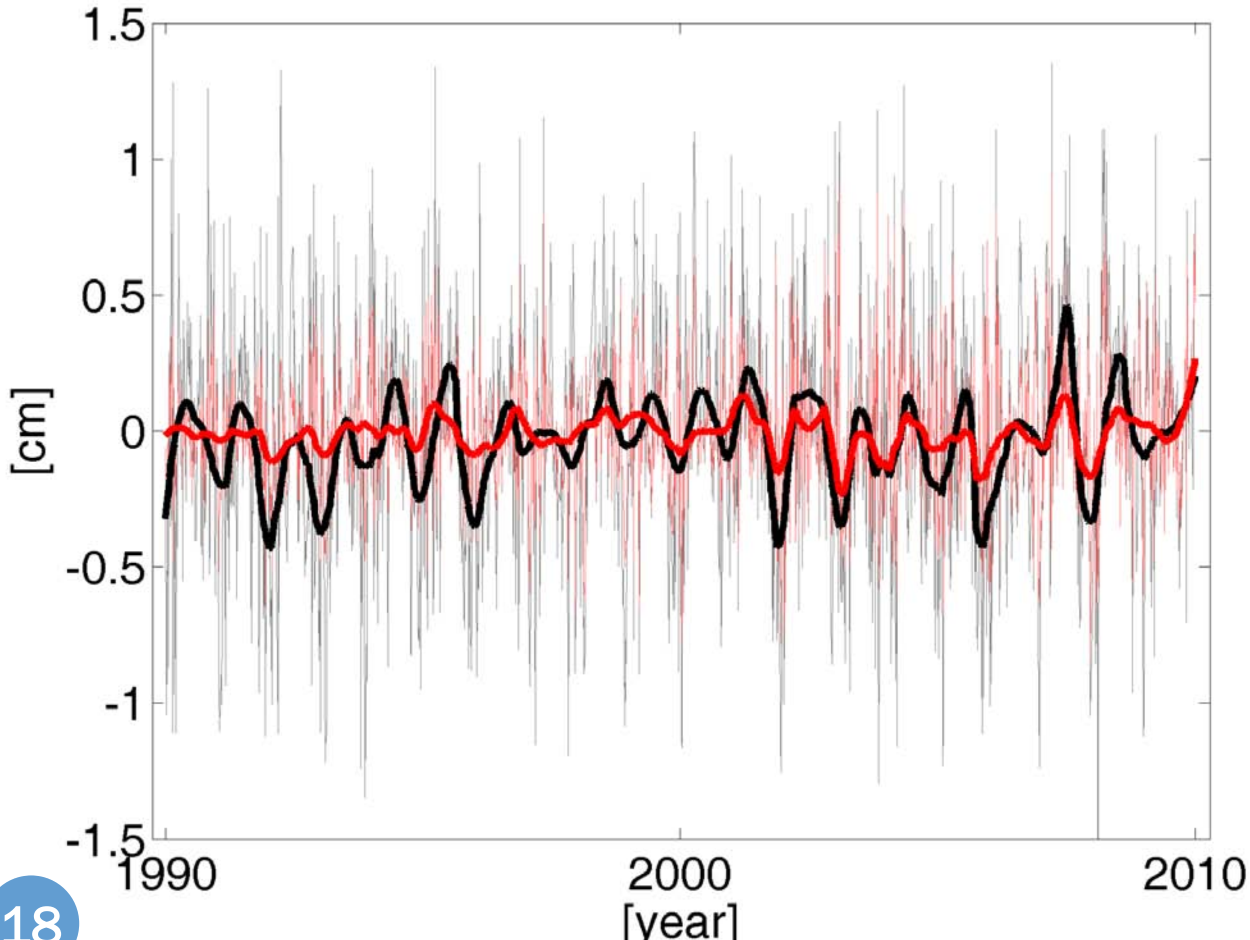
[stacking level] – [observation level]

	mean ($\sigma^2_{[5]} - \sigma^2_{[6]}$)	median ($\sigma^2_{[5]} - \sigma^2_{[6]}$)
all ses.	0.000 074	0.000 050
10 hPa	0.000 116	0.000 075
20 hPa	0.000 187	0.000 179
30 hPa	0.000 326	0.000 282



Height time series

- difference of the height time series (no APL – solution [2]) of station Wettzell compared to the values from APL model
- NNT/NNR condition absorbs part of the unmodelled effect



black: model values

red: difference between height estimates (no APL – solution [2])

smoothed over 90 days

similar study was published by Böhm et al. (2009)

Conclusions

- tidal effects are very small
- difference between corrections at observation level and stacking level visible in sessions with high pressure variability
- if APL neglected $\longrightarrow$ partly absorbed by NNT/NNR

Recommendations

- in VLBI APL corrections should be applied at observation level, in particular to "save" sessions
- for combination and investigation of geophysical signals daily mean values of applied APL models will be provided (and can be added back a posteriori)

Reference Pressure

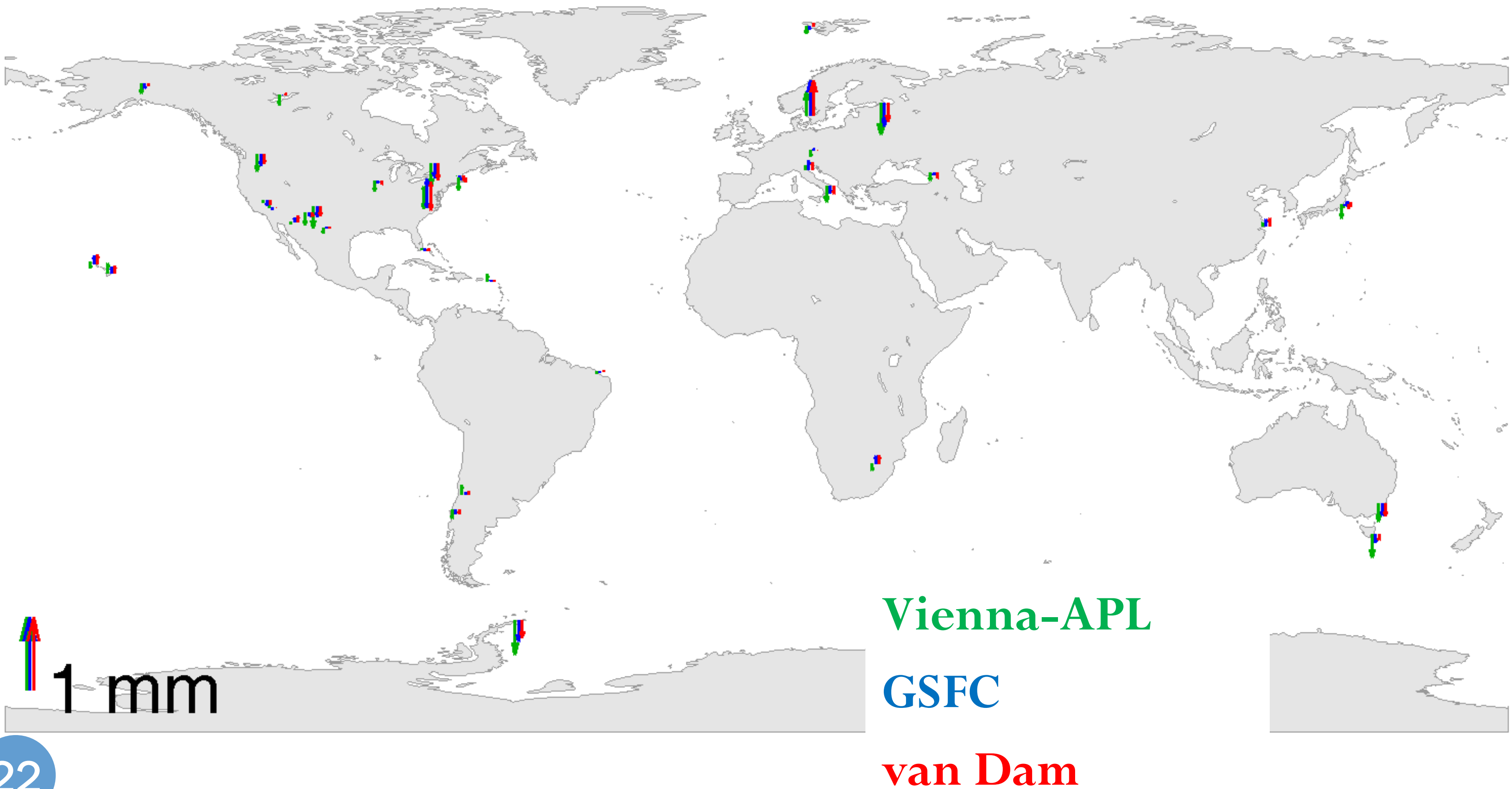
- Reference pressure is important for the following calculations:
  - Atmospheric pressure loading (Petrov & Boy, 2004)
  - Atmospheric gravity (Flechtner, 1997)
  - Reference frames (Plag et al., 2007)
  - Total atmospheric mass (Gruber, 2004)
  - The center of atmospheric mass (Chen et al., 1999)
  - Seasonal variations in the atmosphere (Hoinka, 1998)
  - …. etc

Recommendation for the definition of reference pressure

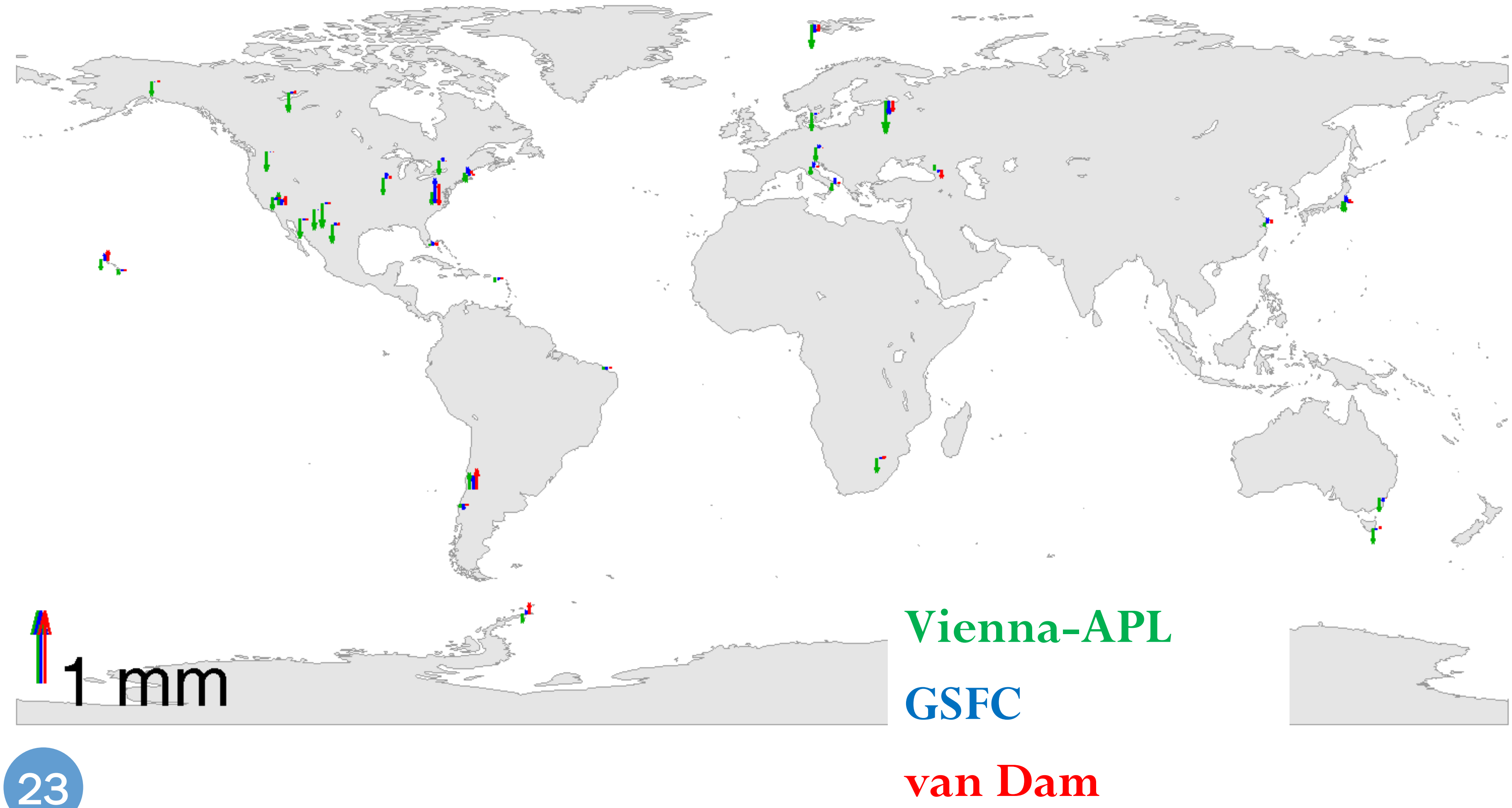
- A reference pressure field should be accompanied by information about its corresponding height
- The model for the reference pressure should be as simple as possible but accurate
- The same reference pressure should be unambiguously determinable now and any time in the future
- The reference pressure should cause no (or only small) biases of previous results
- Surface topography model should be clearly defined (orography model or real topography ?, sea level height or ellipsoidal height?)

Mean height estimates

- solution without applying APL correction – with APL model
- effect of reference pressure



Mean height corrections (from model)



Requirements for ref. pressure to obtain 1mm of station bias

- **Atmospheric pressure loading correction (unit in mm)**

$$APL = r\left(P - P_{ref}\right) \approx 0.5\left(P - P_{ref}\right)$$

$$\sigma_{P_{ref}} = 2 \text{ hPa} \qquad \sigma_{H_{ref}} = 20 \text{ m}$$

In order to obtain the 1-mm level of station bias:

- The reference pressure P_{ref} has to be known with an error of 2 hPa

- The corresponding height H_{ref} has to be known with an error of 20 m

For other purposes, the requirements are different

Methods for the definition of reference pressure

- Empirical pressure model
  - Berg model (Berg, 1948)
  - Global Pressure and Temperature (GPT) model (Böhm et al., 2007)
- Pressure data from Numerical Weather Models (NWM)
  - Global average of the surface pressure data
  - Reduced reference pressure at the 5’ x 5’ topographic height (Plag et al., 2007)
  - Global Reference Pressure (GRP)

Global Reference Pressure (GRP)

Basic principle

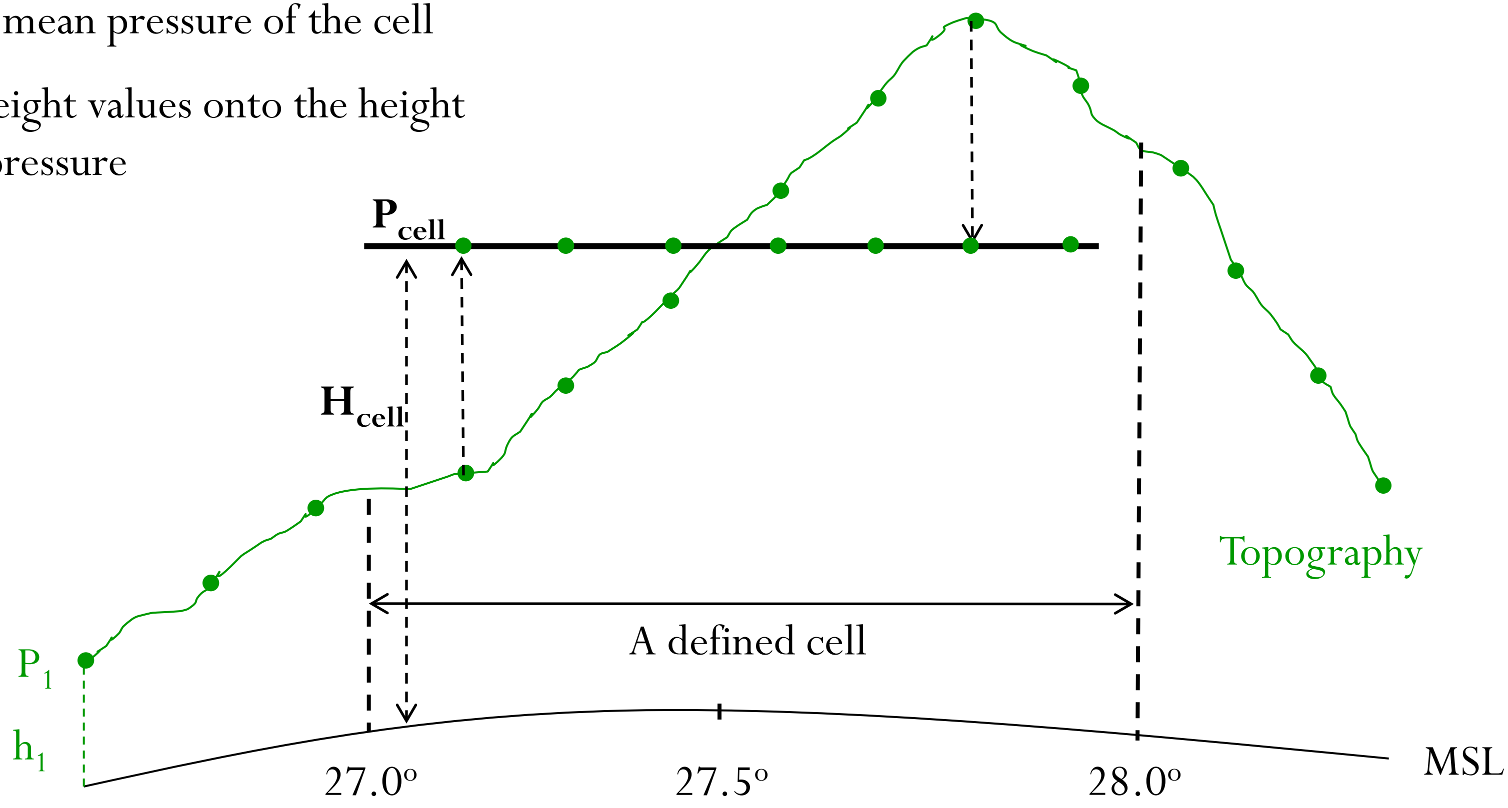
- **Reduction to the mean height of a defined cell (block-mean)**

a. Interpolate in pressure levels to ETOPO5

b. Define a cell with standard size (0.5° x 0.5°, **1.0° x 1.0°**, 2.5° x 2.5°)

c. Calculate the mean pressure of the cell

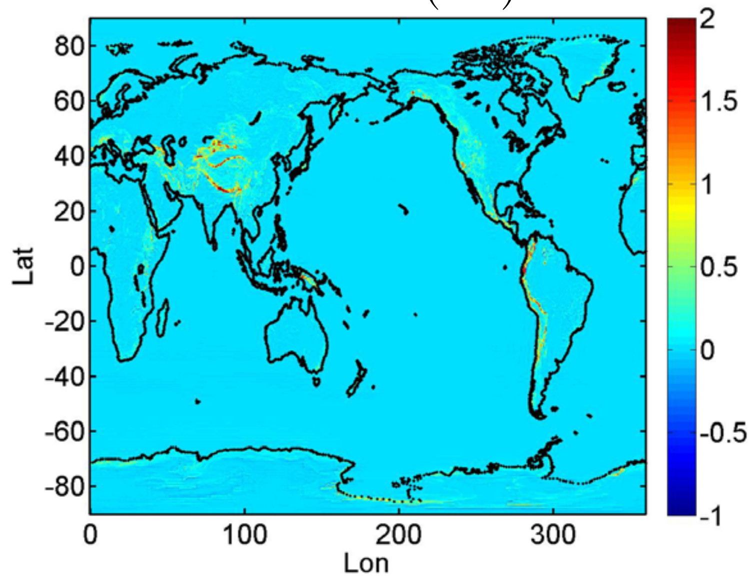
d. Project the height values onto the height of the mean pressure



Global Reference Pressure (GRP)
Summary

GRP model:

- is based on the ECMWF 40 re-analysis (ERA-40) data (monthly means)
- uses block-mean value
- provides a reference pressure value at any point
- is suitable for various applications



GRP memo, GRP data and MATLAB/Fortran codes can be found at

http://ggosatm.hg.tuwien.ac.at/LOADING/REFPRES/

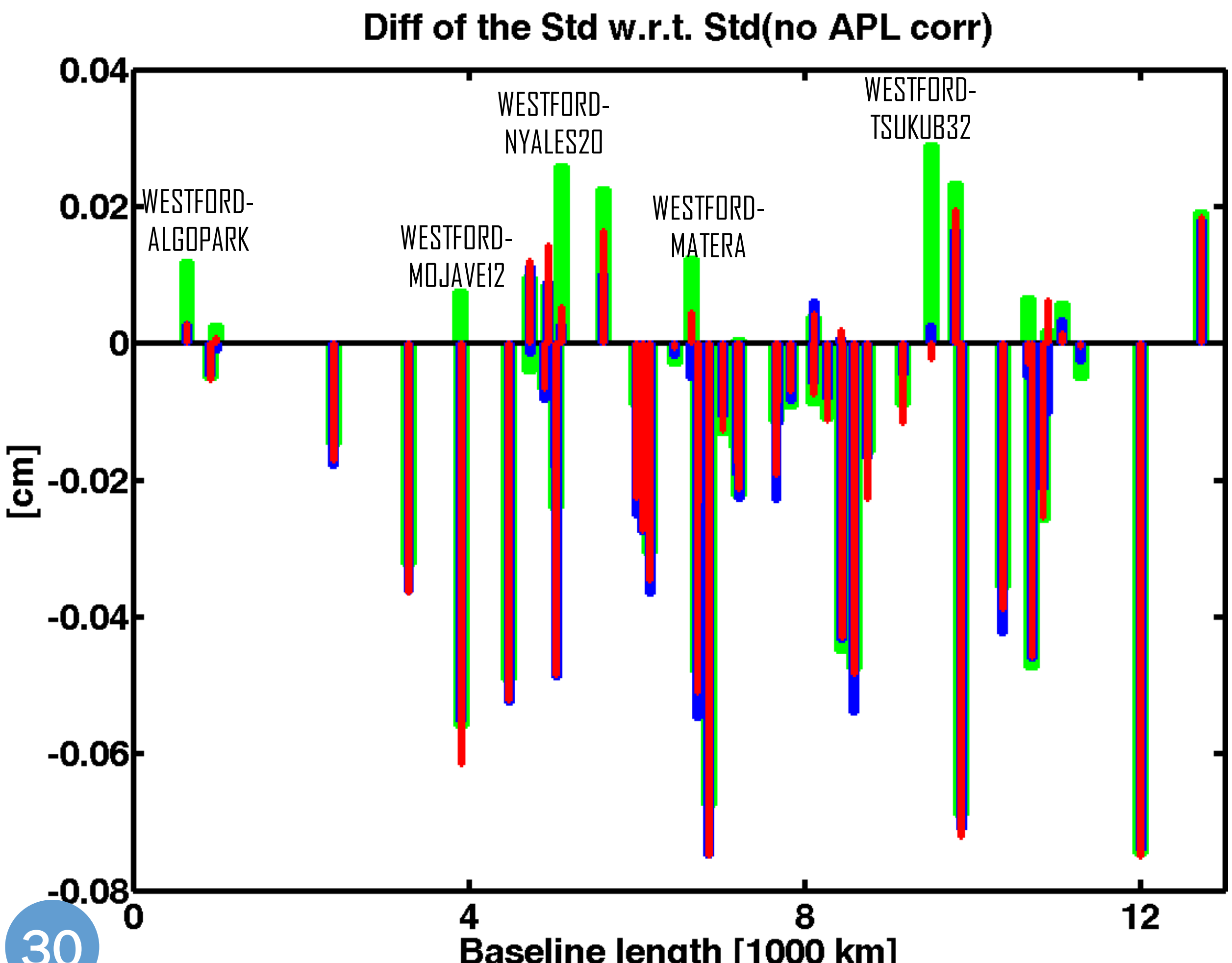
Wijaya et al. (2011). ***Determination of atmospheric pressure loading corrections based on a new concept of reference pressure.*** **In prep. for JGR.**

Thank you for your attention!

Backup slides

Standard deviation of baseline length repeatability

- w.r.t. solution without applying APL corrections



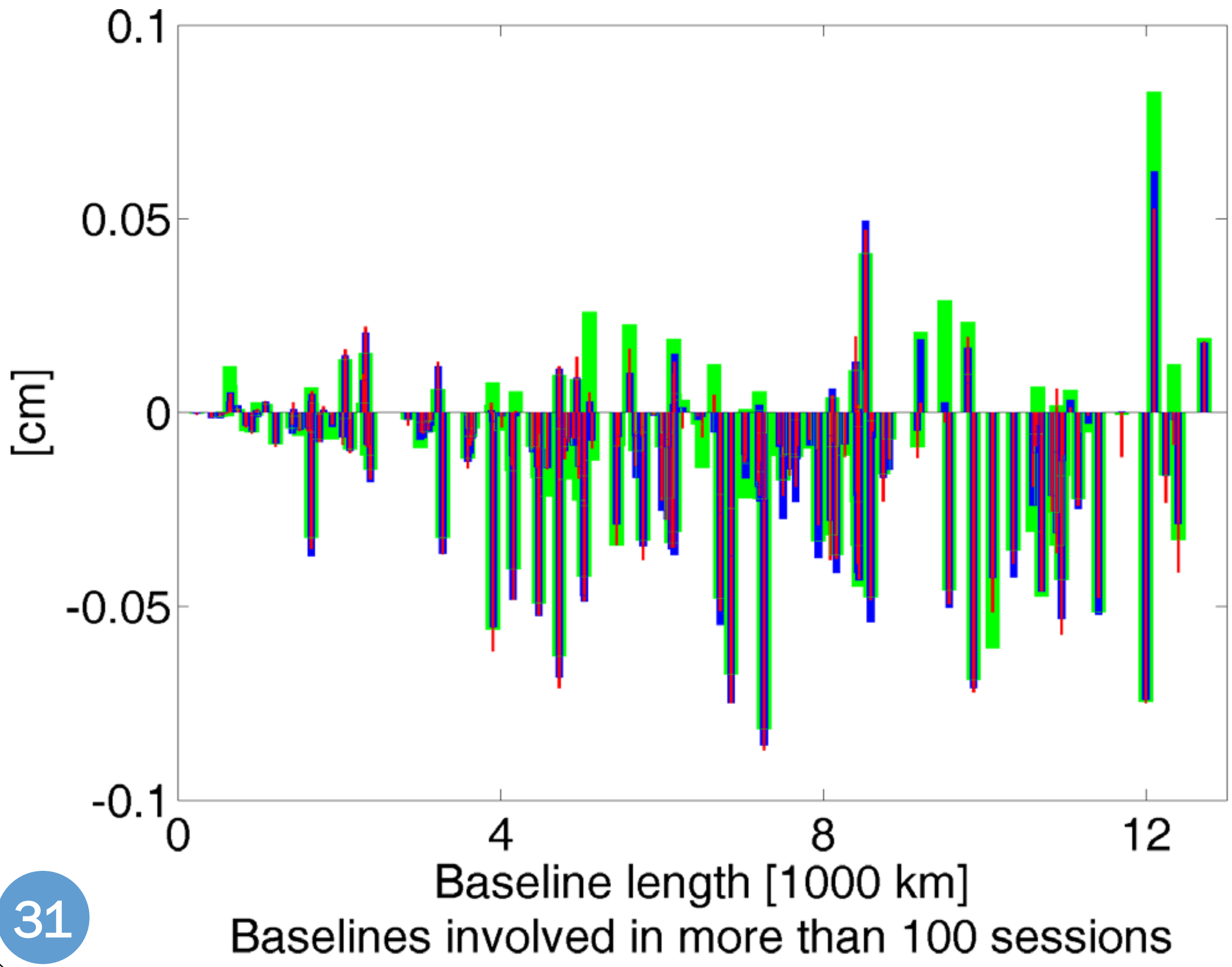
- after applying of the APL model (tidal + non-tidal part), there is improvement of the baseline length repeatability at
  - 67.9 % (Vienna-APL)
  - 77.4 % (GSFC)
  - 71.7 % (van Dam)

  of the baselines

Baselines involved in more than 200 sessions.

Standard deviation of baseline length repeatability

- w.r.t. solution without applying APL corrections



- after applying of the APL model (tidal + non-tidal part), there is improvement of the baseline length repeatability at
  - **74 % (Vienna-APL)**
  - **77 % (GSFC)**
  - **77 % (van Dam)**

of the baselines

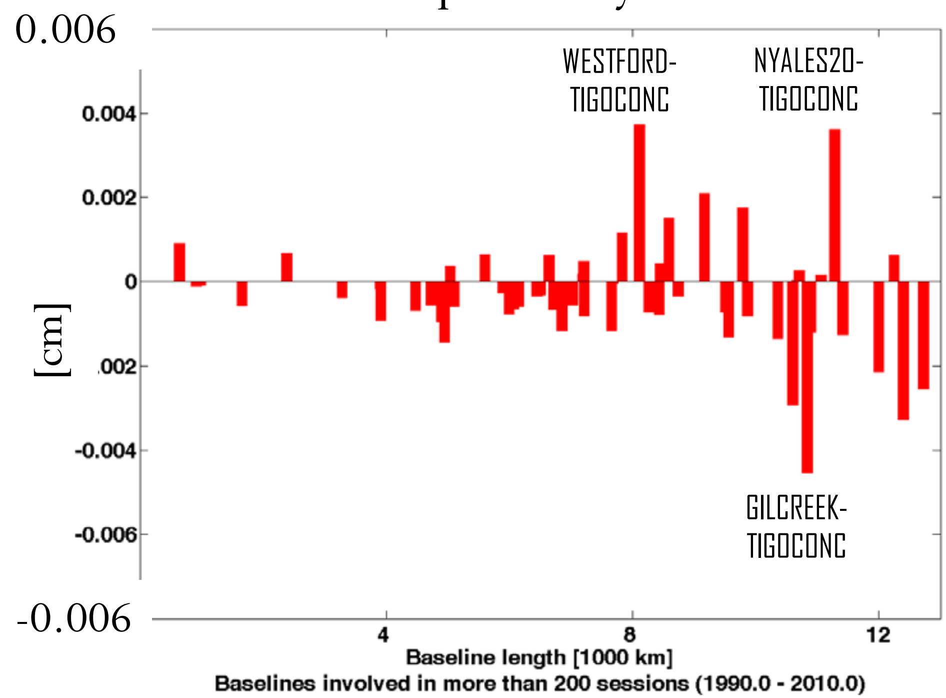
Comparison of Solution [5] with [6]

corrections at **[stacking level] – [observation level]**

all sessions

The baseline length repeatability is **better at 33% of the baselines** in solution **[observation level]** compared to solution [stacking level]

Difference of baseline length repeatability



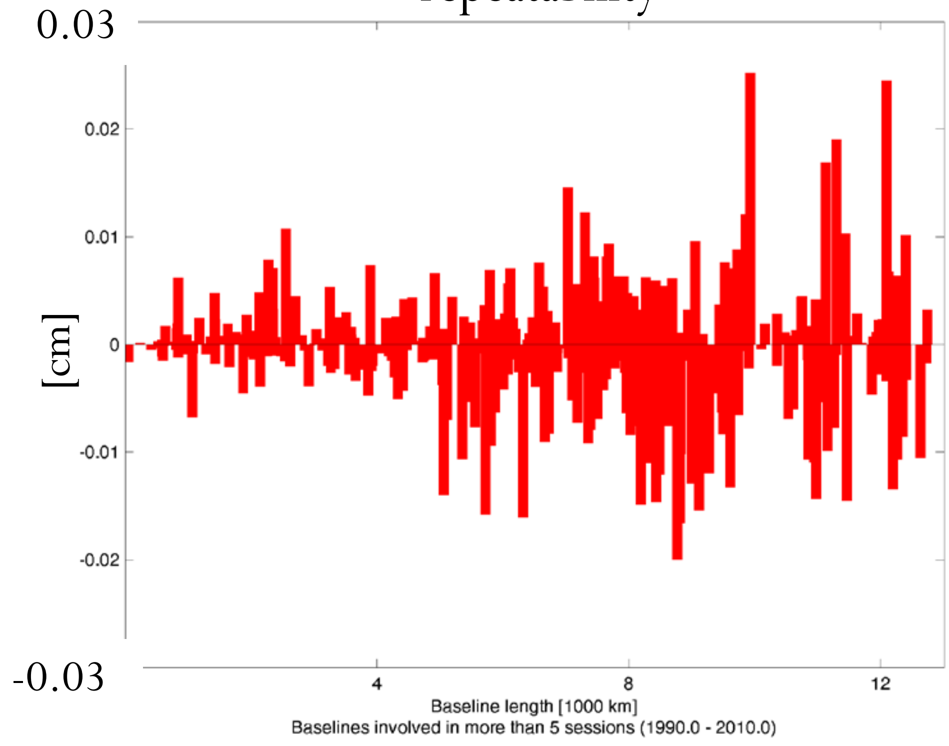
Comparison of Solution [5] with [6]

corrections at [**stacking level] – [observation level]**

10 hPa

The baseline length repeatability is **better at 46% of the baselines** in solution **[observation level]** compared to solution [stacking level]

Difference of baseline length repeatability



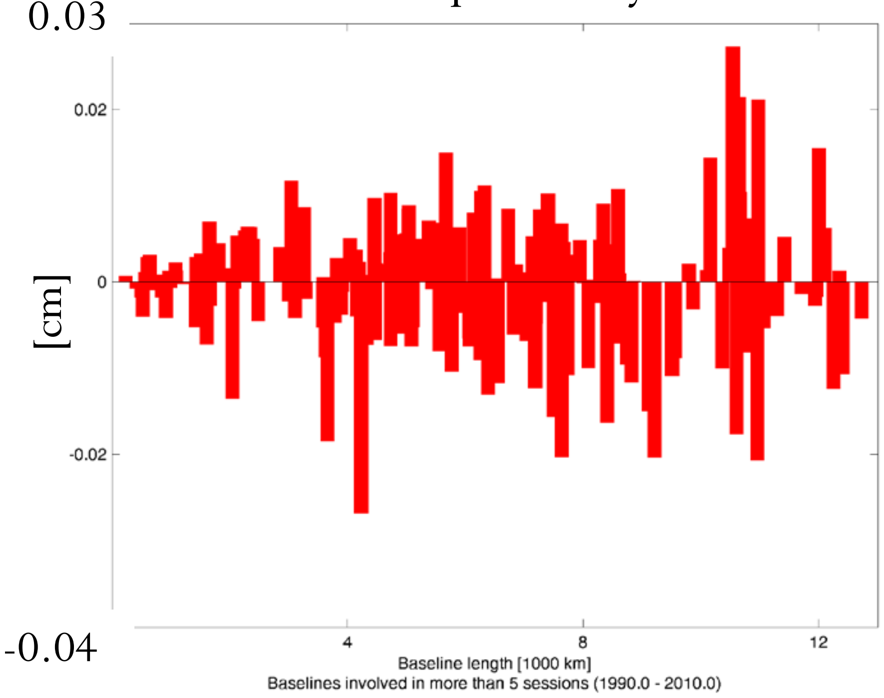
Comparison of Solution [5] with [6]

corrections at [**stacking level**] – [**observation level**]

20 hPa

The baseline length repeatability is **better at 51% of the baselines** in solution **[observation level]** compared to solution [stacking level]

Difference of baseline length repeatability

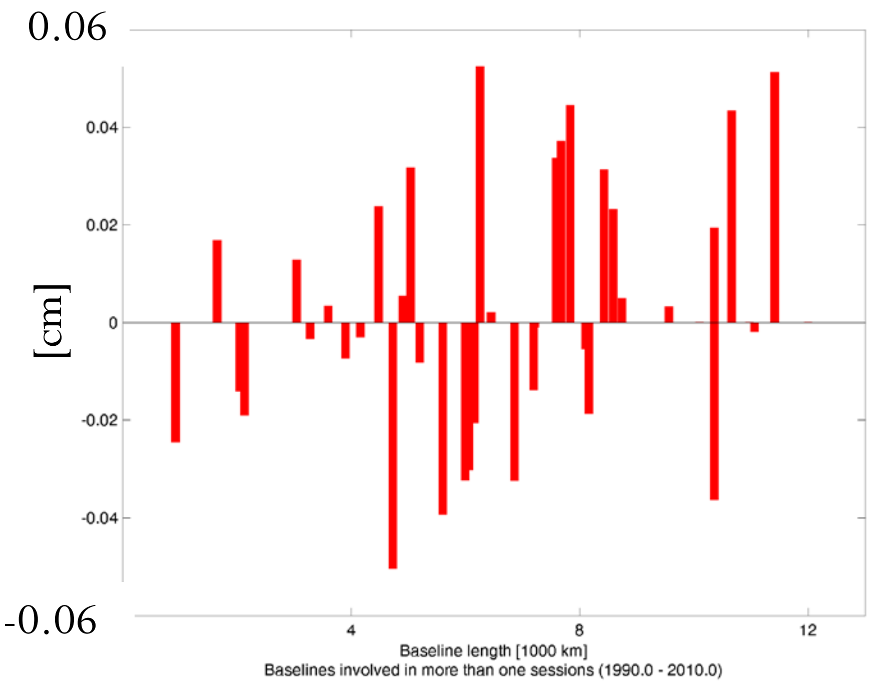


Comparison of Solution [5] with [6]

corrections at [**stacking level**] – [**observation level**]

30 hPa

Difference of baseline length repeatability



The baseline length repeatability is **better at 49% of the baselines** in solution **[observation level]** compared to solution [stacking level]