GRACE Kinematic Orbit Determination: the Role of Clocks

E. Orliac, A. Jäggi, H. Bock, and R. Dach

Astronomical Institute of University of Bern (AIUB)
Bern, Switzerland

contact: etienne.orliac@aiub.unibe.ch

2013 Joint UFFC, EFTF, and PFM Symposium
21–25 July 2013
Prague, Czech Republic

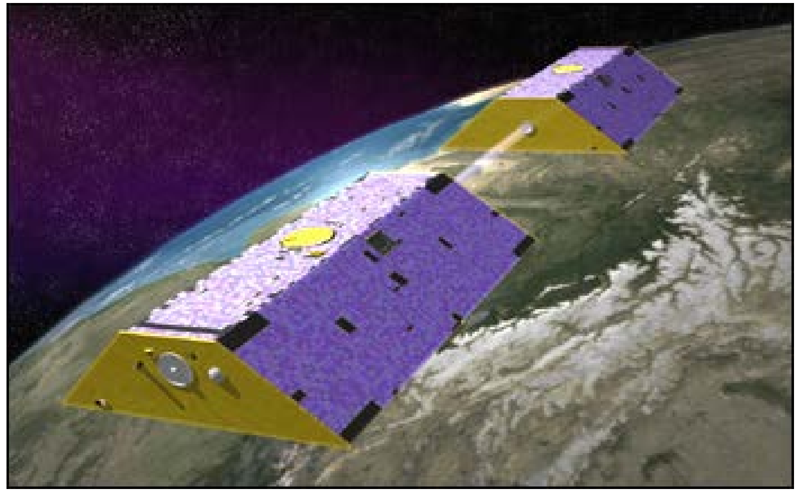
Presentation Outline

- The GRACE Mission: overview
- Kinematic Precise Point Positioning (PPP)
- GPS satellite clock corrections computation
- Clock modelling
- GRACE kinematic orbit determination
  - With estimated 30 s GPS clock corrections
  - Clock modelling
- Earth gravity field determination
- Conclusions

The GRACE Mission: Overview

- GRACE: Gravity Recovery and Climate Experiment
- Primary goal: to accurately map variations in the Earth's gravity field
- GRACE is two twin satellites in co-planar orbits, separated of ~220 km ~450 km above the surface of the Earth
- The distance between the satellites is accurately measured by a microwave ranging system (K-Band)
- The changes in the distance between the two satellites relates to the difference in acceleration felt by each of them

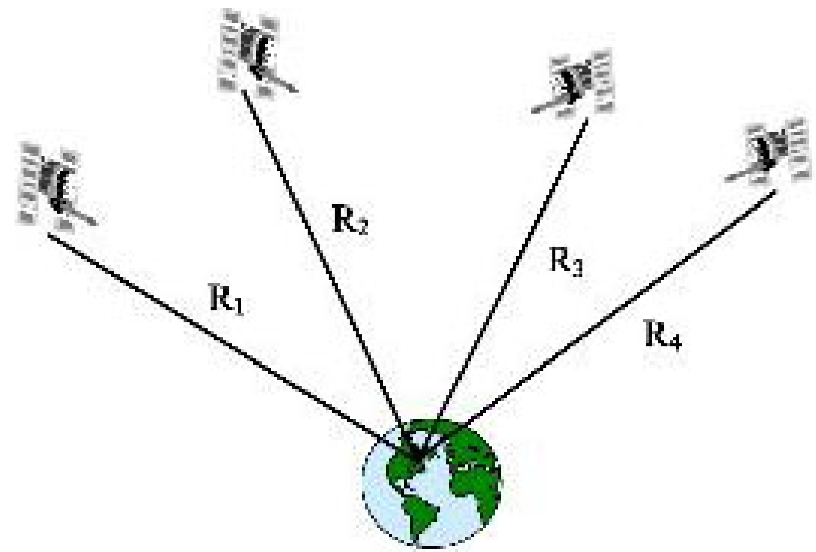
The GRACE Mission: Overview (2)

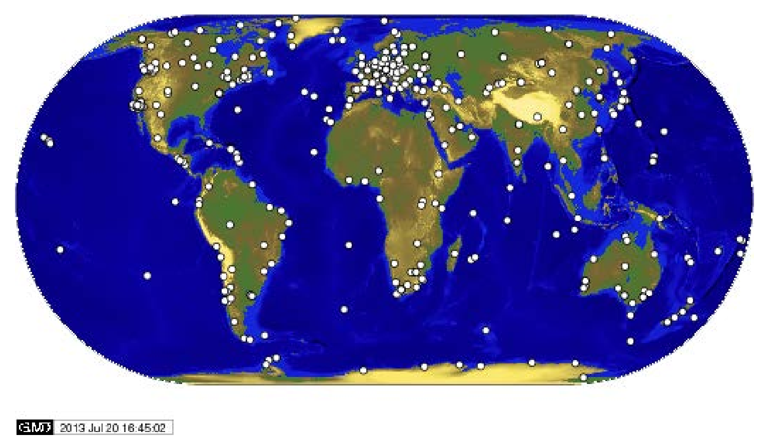


- GRACE has provided Earth's gravity fields with an unprecedented accuracy
- Gravity fields can be determined on a monthly basis e.g., giving essential information on mass distribution and flow on and within the Earth
- The positions of the satellites can be accurately determined using their onboard GPS receiver

Kinematic Precise Point Positioning (PPP)

- If the satellite positions (orbits) and clocks are accurately known, the position of a receiver can computed at the cm level
- PPP can be applied to static and kinematic (GRACE) receivers
- Compared to reduced-dynamic orbits, kinematic orbits don't make use, in particular, of an a gravity field
- Orbits and clocks are computed using a global network of static ground GNSS stations (e.g. IGS Network)





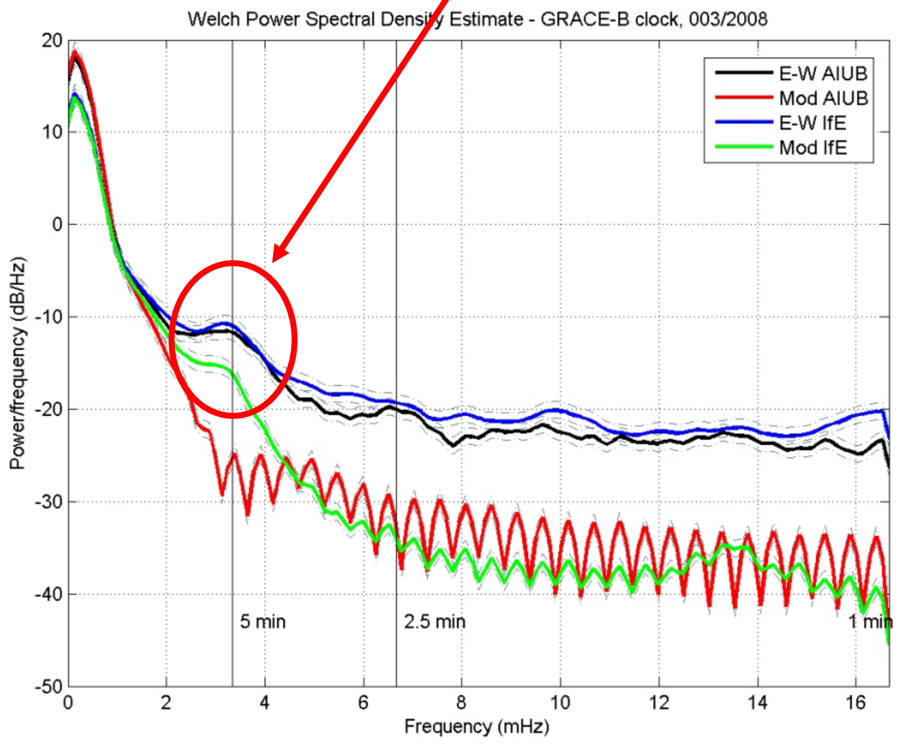
Computation of Satellite Clock Corrections (CODE)

- In a first processing, based on **double-difference** observations (eliminating clock parameters) and a global network of ~240 stations, satellite orbits are computed, together with troposphere parameters and station coordinates
- In a second processing, the results obtained in the first one are introduced as known in a **zero-difference** network solution (reduced optimized nework of 120 stations), in order to estimate satellite and receiver clock corrections
- 30 s satellite clocks are estimated in a two-step procedure (32 x 2880 = 92'160 parameters per day):
  - Clocks are estimated at 5 min (pre-elimination & back-substitution)
  - Clocks are interpolated epoch-to-epoch using the phase observations down to 30 s, using the technique described in [Bock et al., 2009]

PART I: GRACE RECEIVER CLOCK SPURIOUS SIGNAL

Motivations for first Investigation

- Earlier processing of GRACE data revealed some power at **~5 min** in the clock power sprectrum



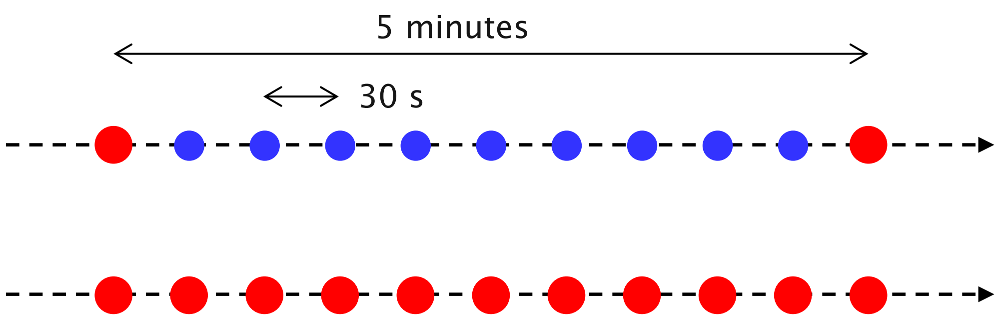
The bulge is software independent

5 min corresponds to the sampling rate at which GPS satellite clocks are estimated, before being interpolated using phase observation down to 30 or 5 s.

Is this an artefact from the GPS satellite clock corrections generation procedure?

Estimated 30 s GPS Satellite Clocks

- To decide, we produced a new set of GPS satellite clock corrections, estimated at **30 s**.



Assuming 32 GPS satellites, 1 day:

32 x 24 x 12 = 9,216 clock par.

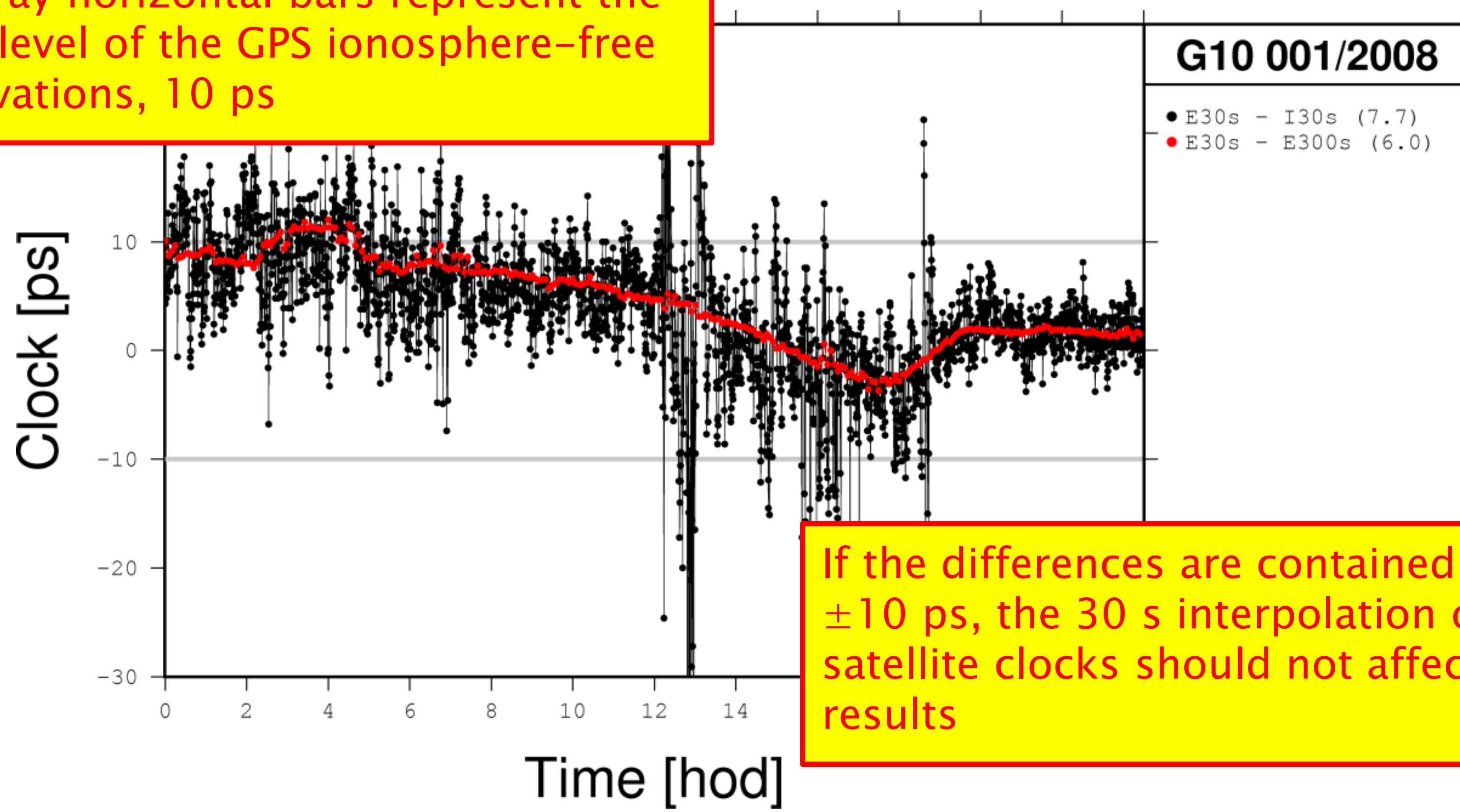
32 x 24 x 120 = 92,160 clock par.!!

- Altough the epoch-wise parameter pre-elimination / back-substitution scheme is very efficient, estimating 30 s clock parameters remains much more cumbersome than the «traditional» approach of clock interpolation.

Estimated vs «interpolated» GPS clocks

- Typical time series for GPS satellite G10 over the first day of the period considered (Jan 1st 2008)

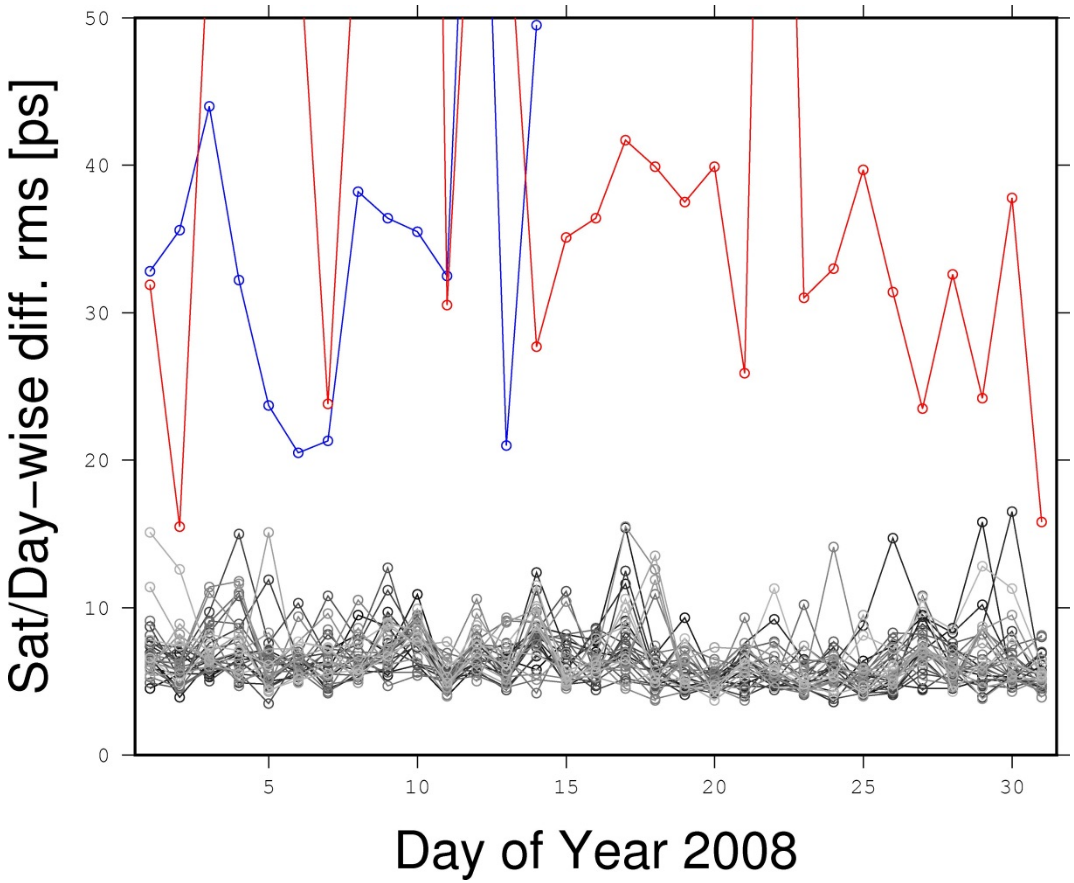
The gray horizontal bars represent the noise level of the GPS ionosphere-free observations, 10 ps



If the differences are contained within ±10 ps, the 30 s interpolation of satellite clocks should not affect the results

Estimated vs «interpolated» GPS clocks

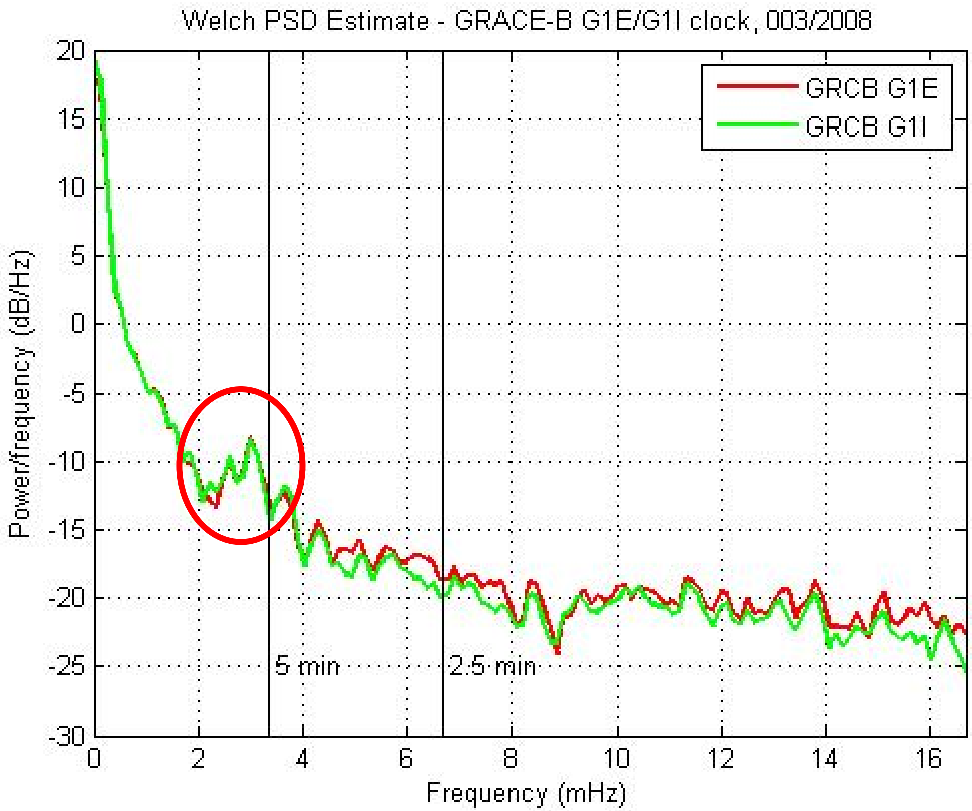
- Daily RMS of the epoch-wise (30 s) differences over Jan 2008 (2 unhealthy satellites: G32 and G07)



Appart from unhealthy satellites, the differences are well contained within the GPS observation noise level of 10 ps

So, from those results, we do not expect the interpolated clocks to be the source of the extra power in the GRACE clock PSD

GRACE-B Clock Power Sprectrum



- DoY 003 of 2008

As expected from looking at the difference on the GPS satellite clocks, the power at ~5 min is present in both time series

Further investigations will be necessary to understand the origin of the «anomaly»

PART II: GRACE RECEIVER CLOCK MODELLING

GRACE Receiver Clock Modelling

- GRACE satellites carry ultra-stable oscillators
- In theory, their stabitity should allow the clocks to be modelled, at least over a few epochs
- Modelling the clock is expected to improve the solution, in particular in the radial component, through the decorralation of clock parameters and positions
- Improved kinematic orbits should lead to improvements in the recovery of gravity fields
- For ground (static) sites treated as kinematic, a reduction factor of the variation in the Up direction up to 2.6 was obtained for sites connected to a H-Maser
- However, H-Maser clocks are hardly portable... GRACE satellites are probably the only truly kinematic objects equiped with a GPS receiver connected to a highly stable clock

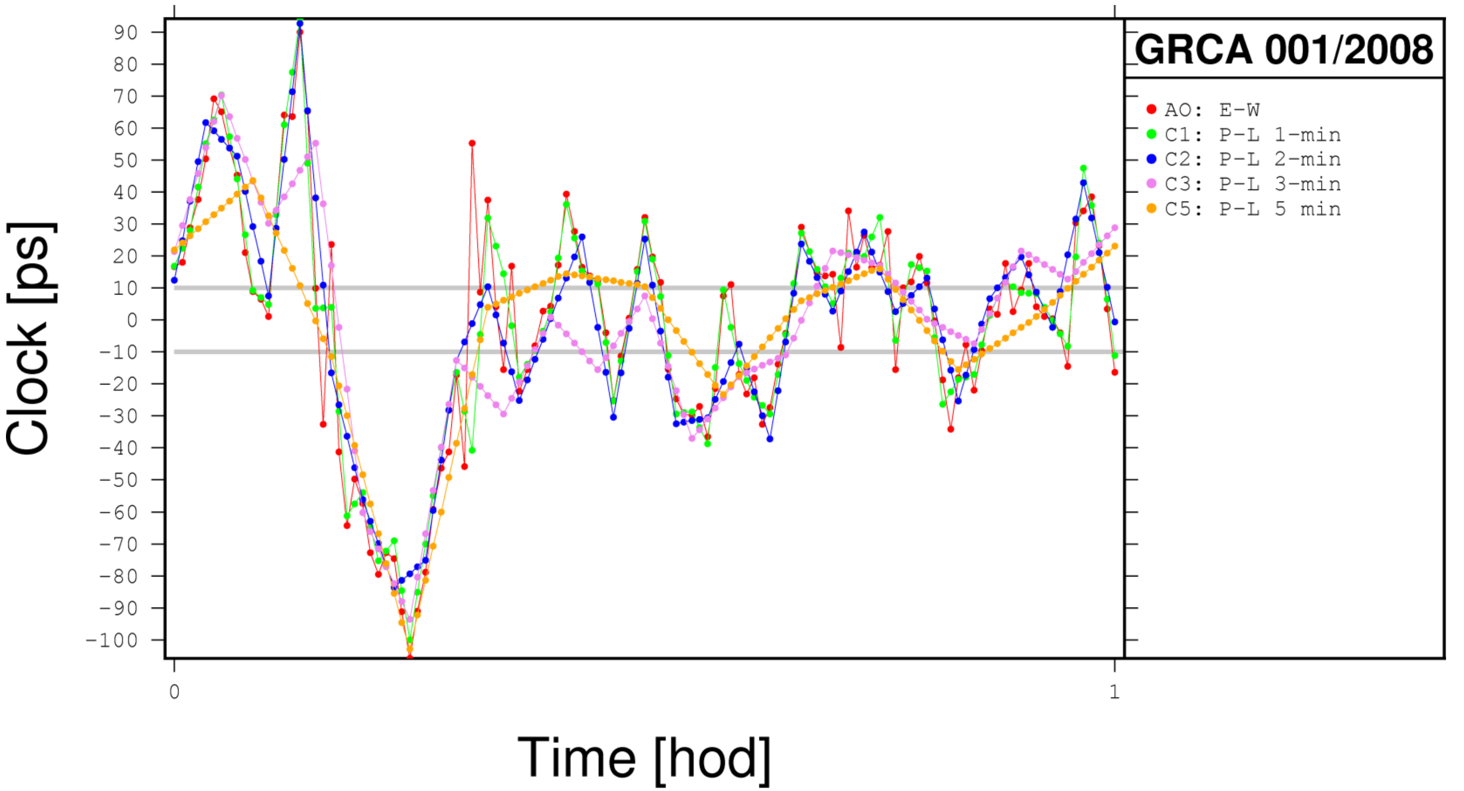
GRACE Kinematic Orbit Solutions

- A set of 5 solutions was produced over Jan 2008 for GRACE-A and -B
- Data processed with a sampling rate of 30 s over ~24 hour sessions

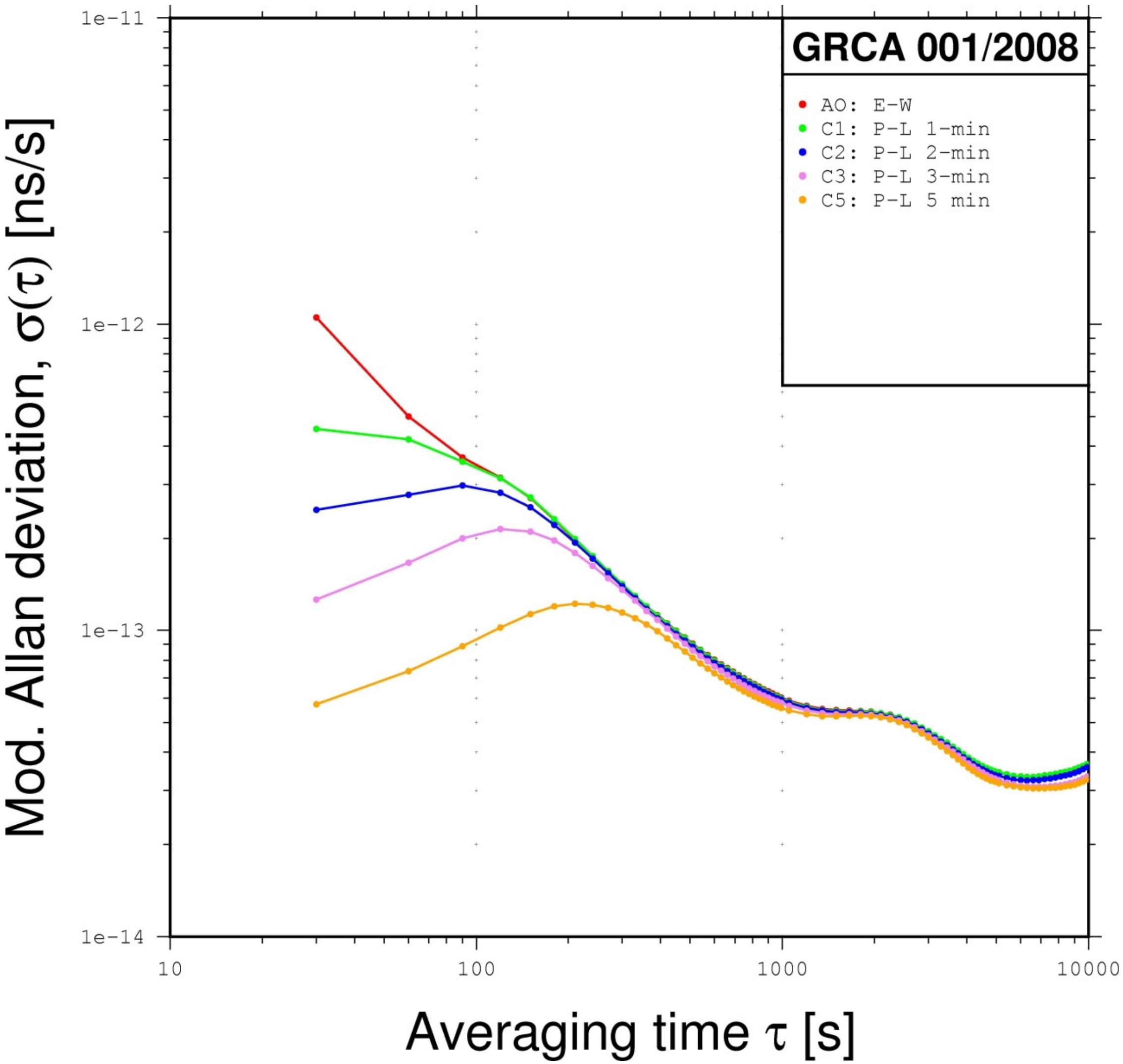
Solution ID	Description	Nb. of clock parameters per day
A0	«Standard» solution no clock modelling; clock parameters estimated every epoch	2878
C1	Clock modelled with a piece-wise linear function with 1-min knot spacing	1439
C2	As C1, but with a knot spacing of 2 min	719
C3	As C1, but with a knot spacing of 3 min	479
C5	As C1, but with a knot spacing of 5 min	288

GRACE Clock Time Series

- GRACE-A on the first hour of the first day (Jan 1st 2008)

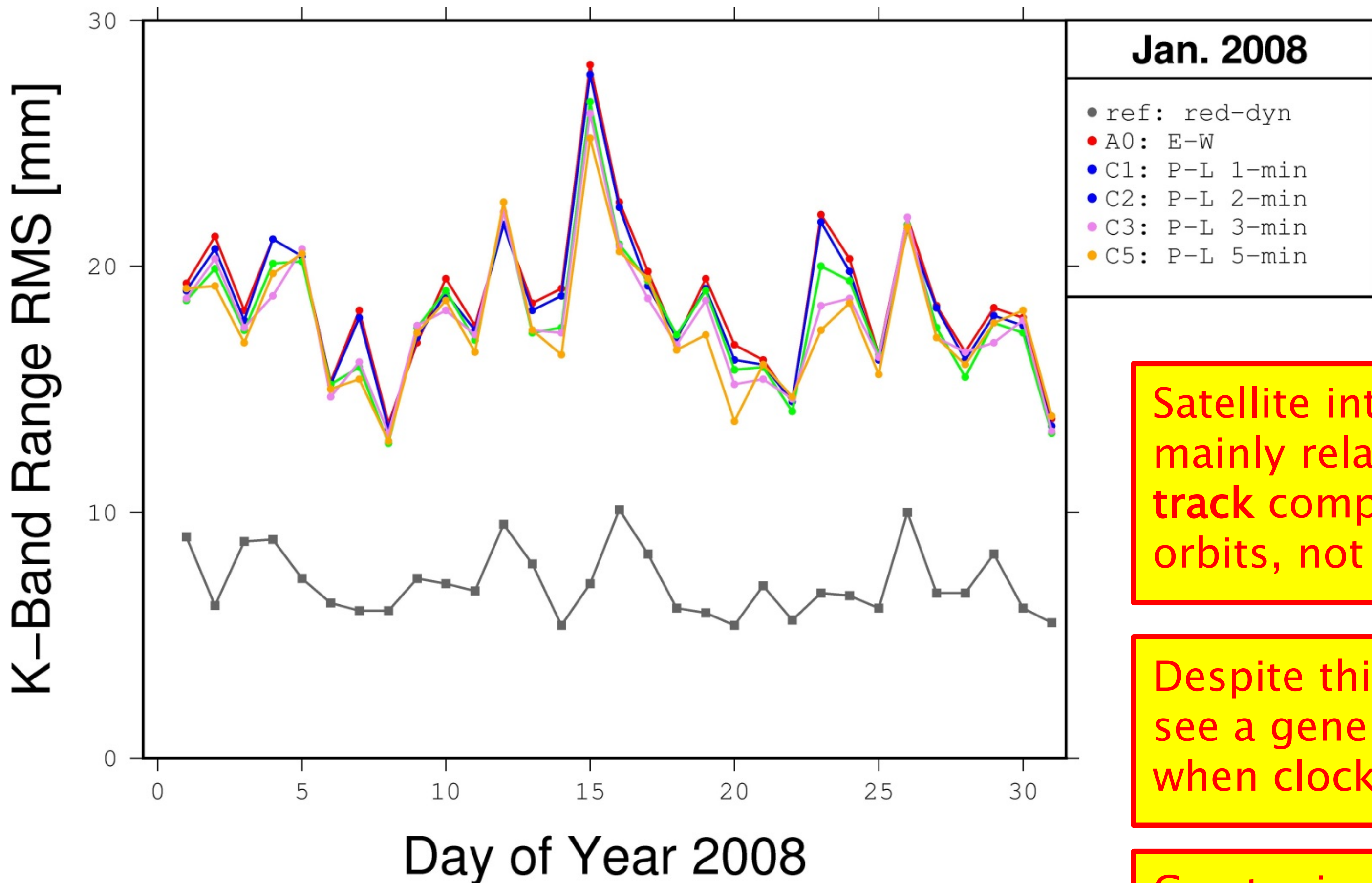


GRACE Modified Allan Deviation Plots



- GRACE-A on Jan 1st 2008 (24 hours considered)
- The clock modelling works as expected: short time intervals are affected (stabilized), but not the longer ones (> 2-3 times the knot spacing)

Comparison With K–Band Ranges



Satellite inter-distance mainly related to the **along-track** component of the orbits, not the radial one

Despite this fact, one can see a general improvement when clocks are modelled

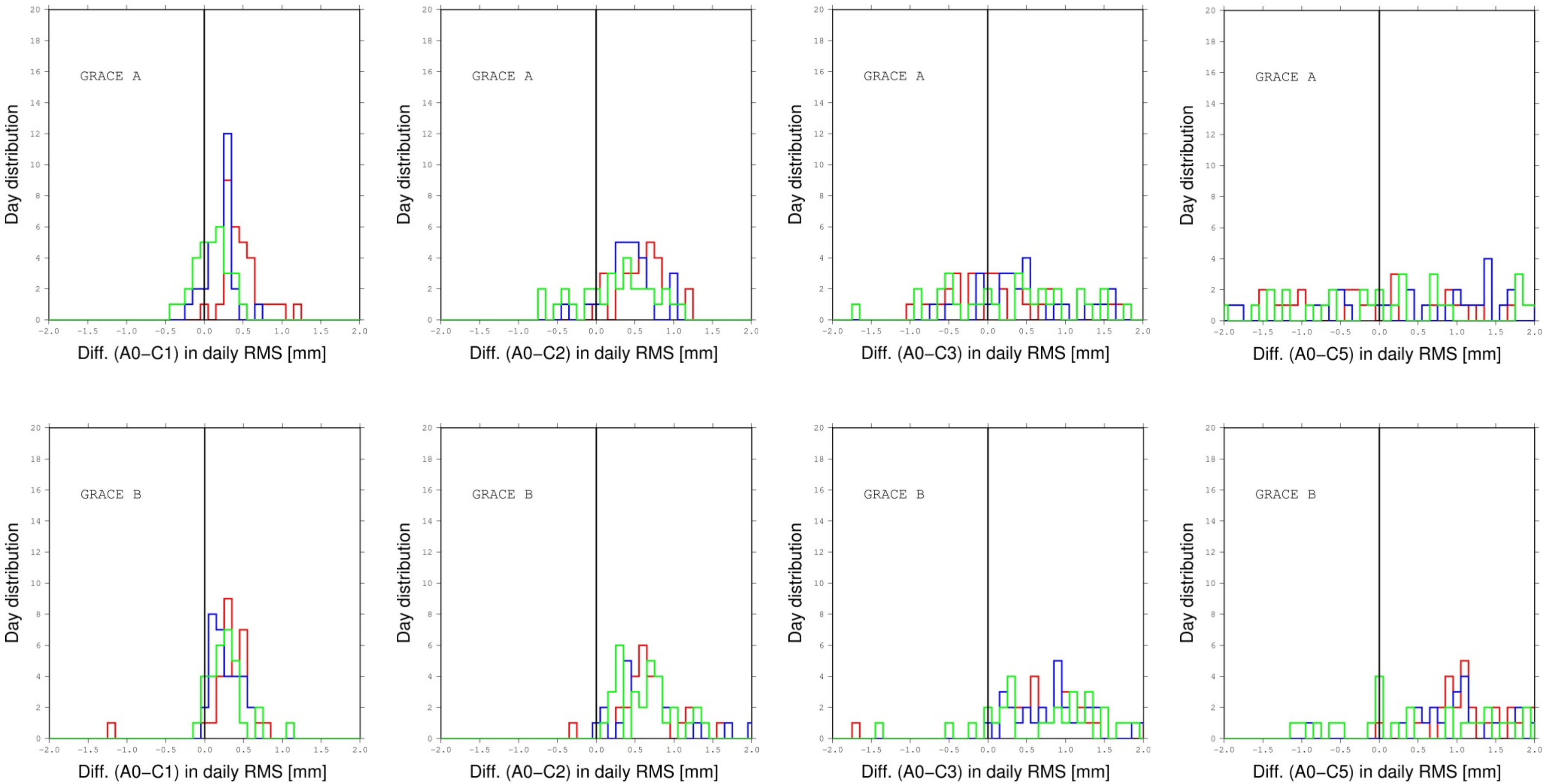
Greater improvement is obtained with greater knot spacing

Kinematic vs Reduced-Dynamic Orbits

- A reduced-dynamic orbit solution is used as a reference to assess the impact of clock modelling in the kinematic orbit solutions.
- We look at daily RMS of the epoch-wise differences between the kinematic and reference solutions
- If the RMS for solutions with modelled clocks (C1, C2, C3, and C5) is reduced compared to the standard kinematic solution (A0), the clock modelling was benefic
- That is, a difference $(RMS_{A0} - RMS_{CX}) > 0$ indicates a positive effect of the clock modelling

Distribution of daily RMS differences

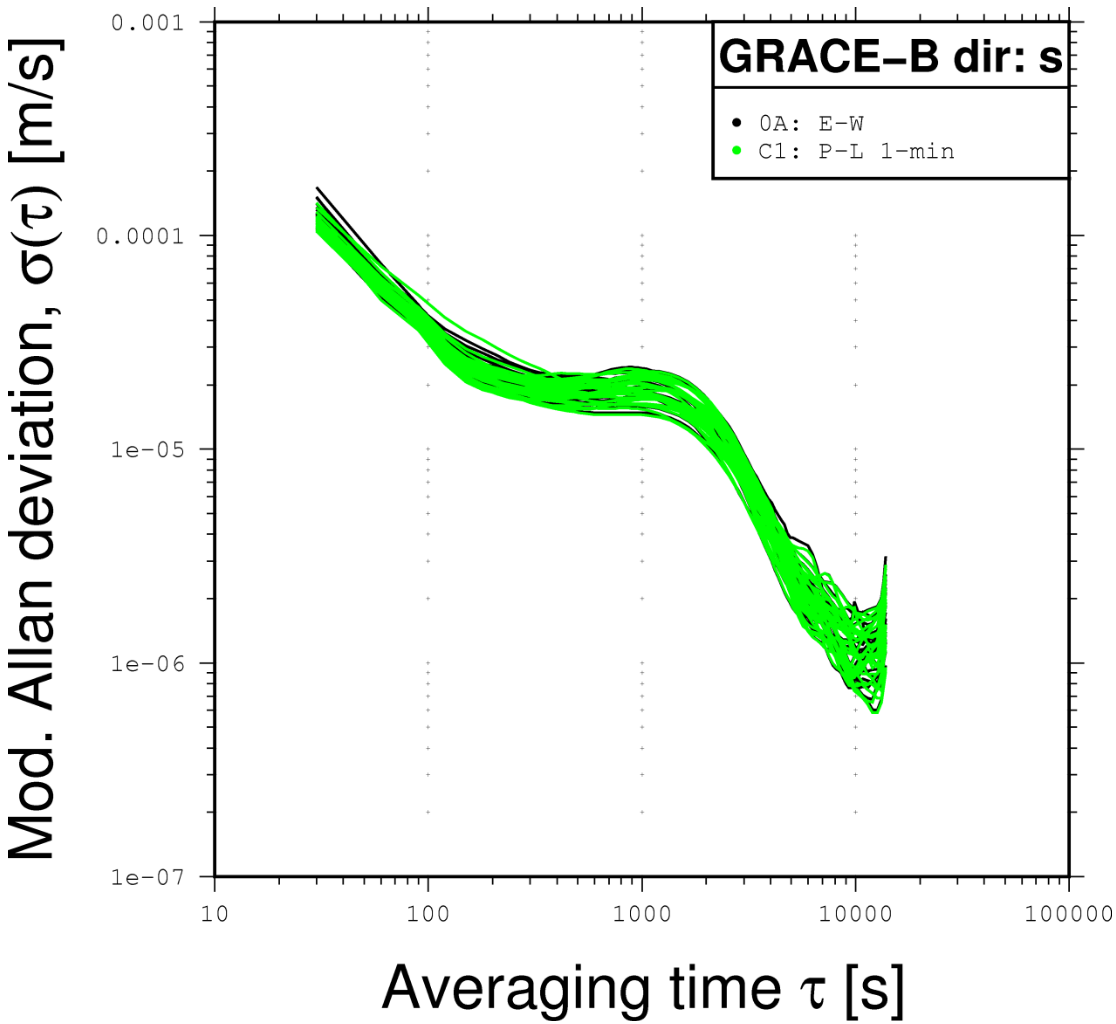
R, S, W



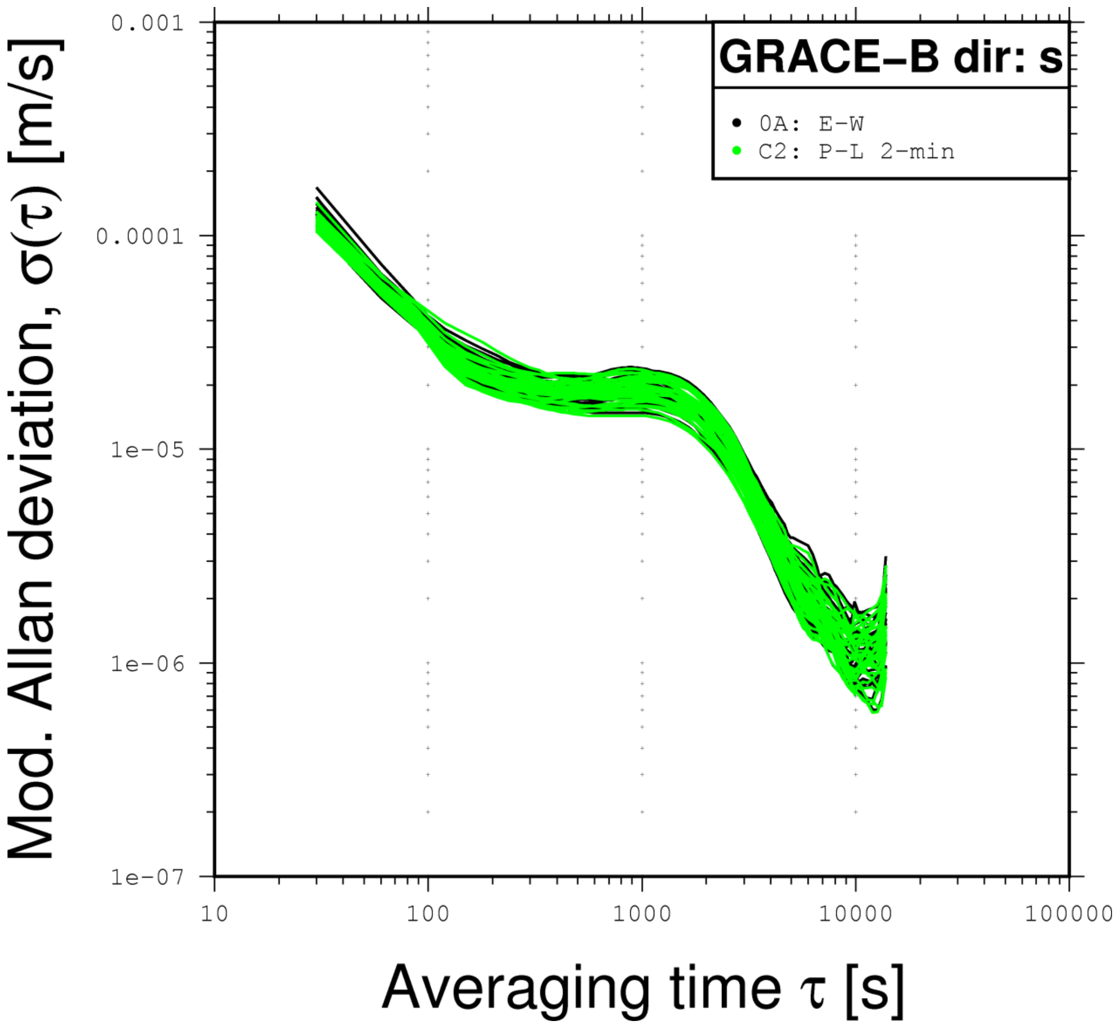
GRACE-B, C1 systematic but small improvement

With increasing knot spacing, the improvements are more heterogeneous

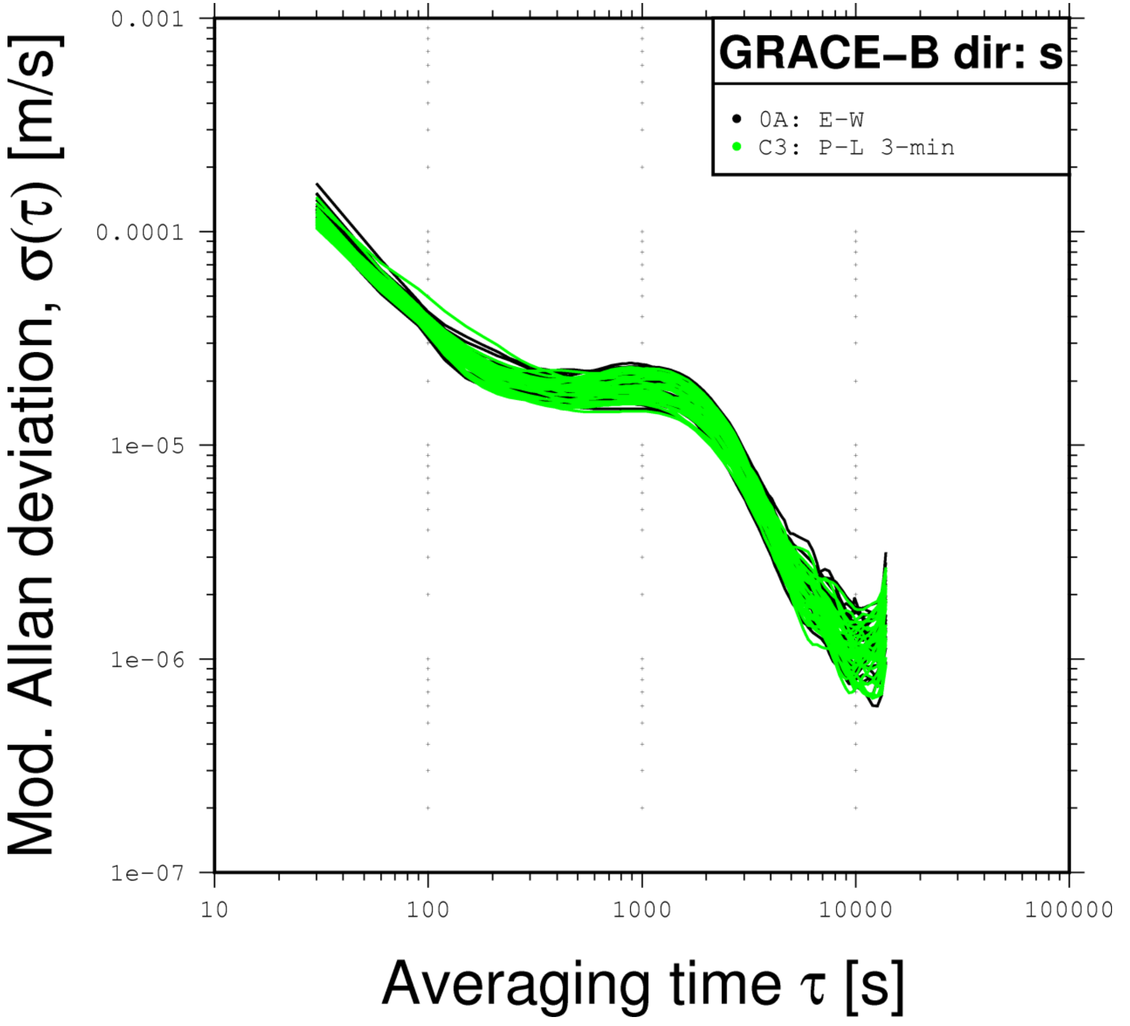
GRACE-B MDEV for Along-Track Position Residuals



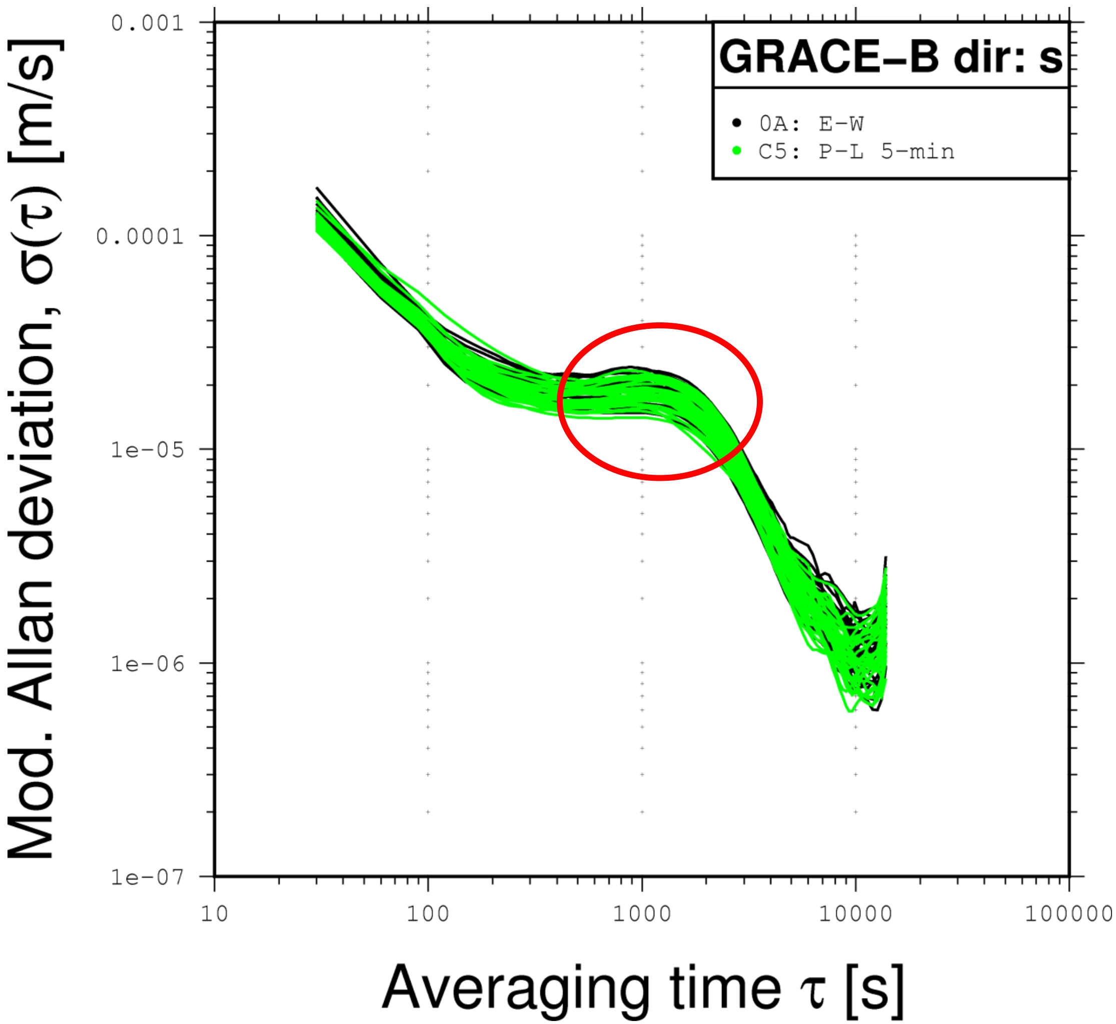
GRACE-B MDEV for Along-Track Position Residuals



GRACE–B MDEV for Along–Track Position Residuals



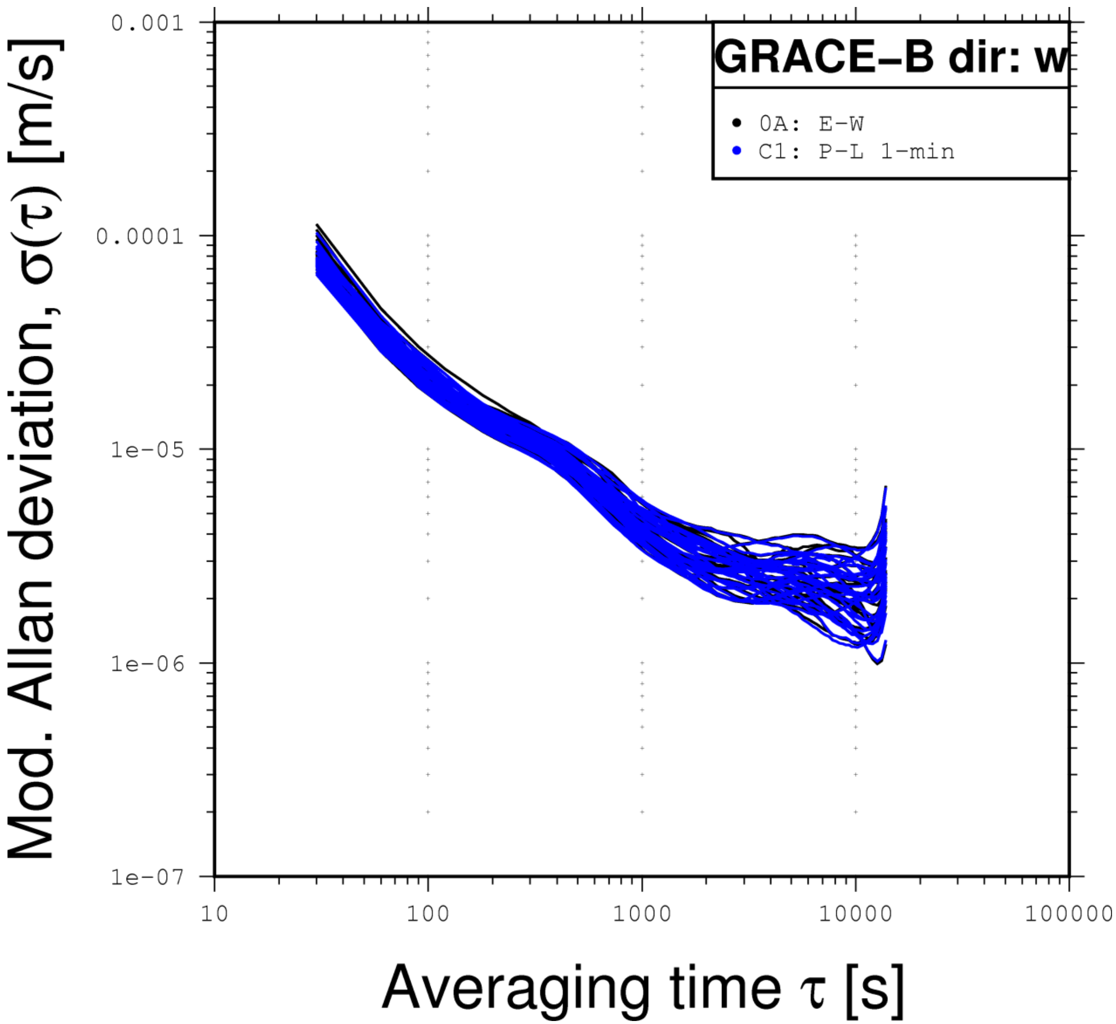
GRACE-B MDEV for Along-Track Position Residuals



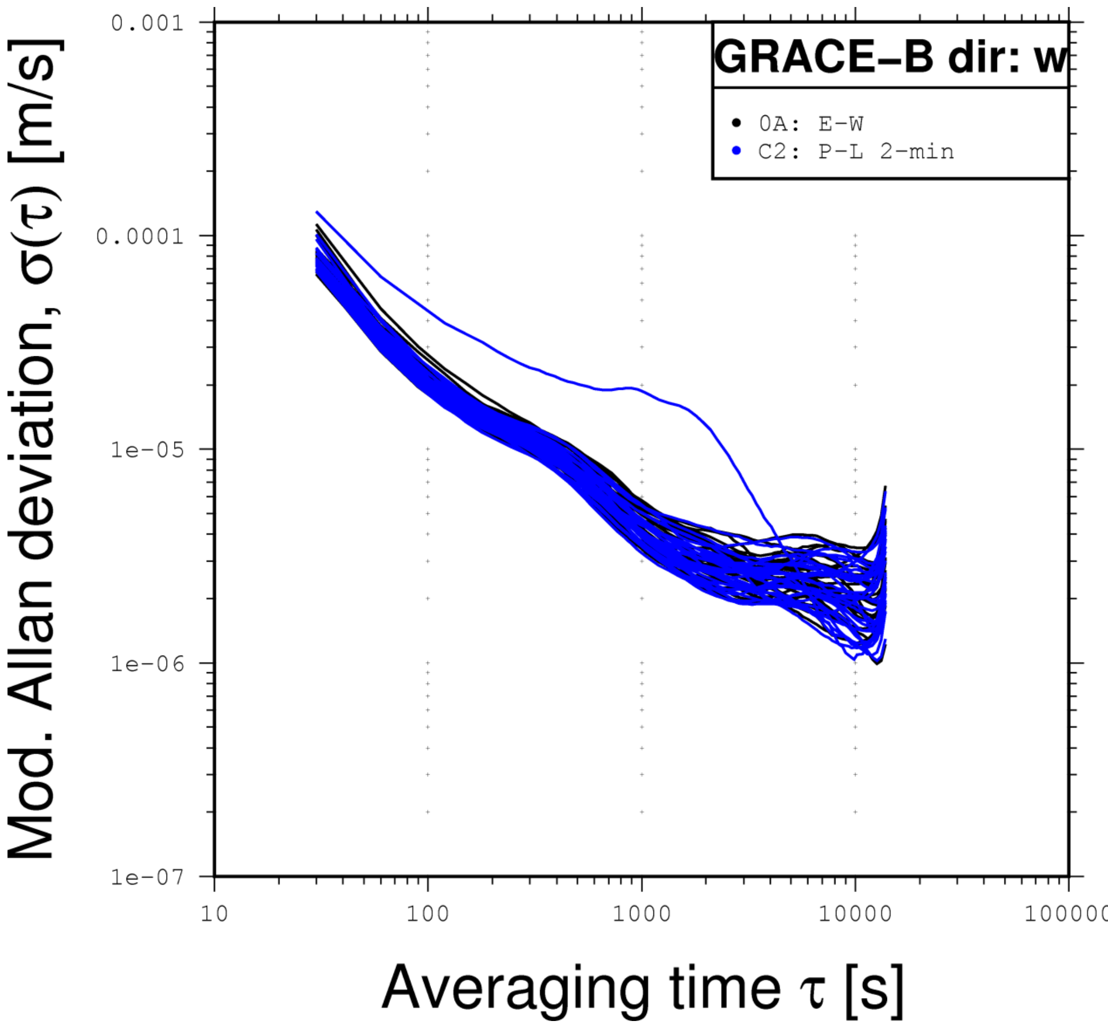
On the along-track component, all solutions show a bulge at ~15 min, not linked to clock modelling

The spread of the curves, indicating the consistency with the reduce-dynamic solution, is similar for all clock models

GRACE–B MDEV for Cross–Track Position Residuals

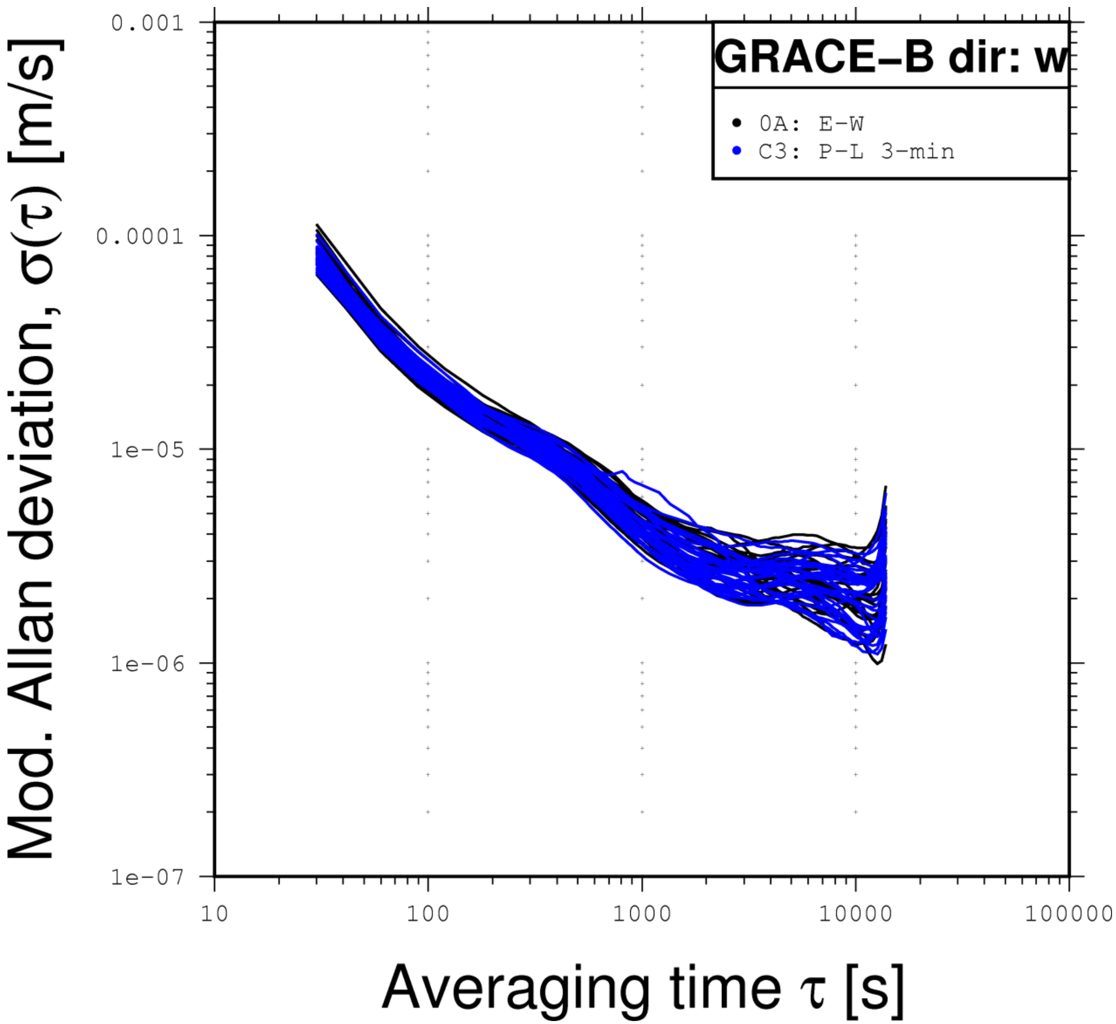


GRACE-B MDEV for Cross-Track Position Residuals

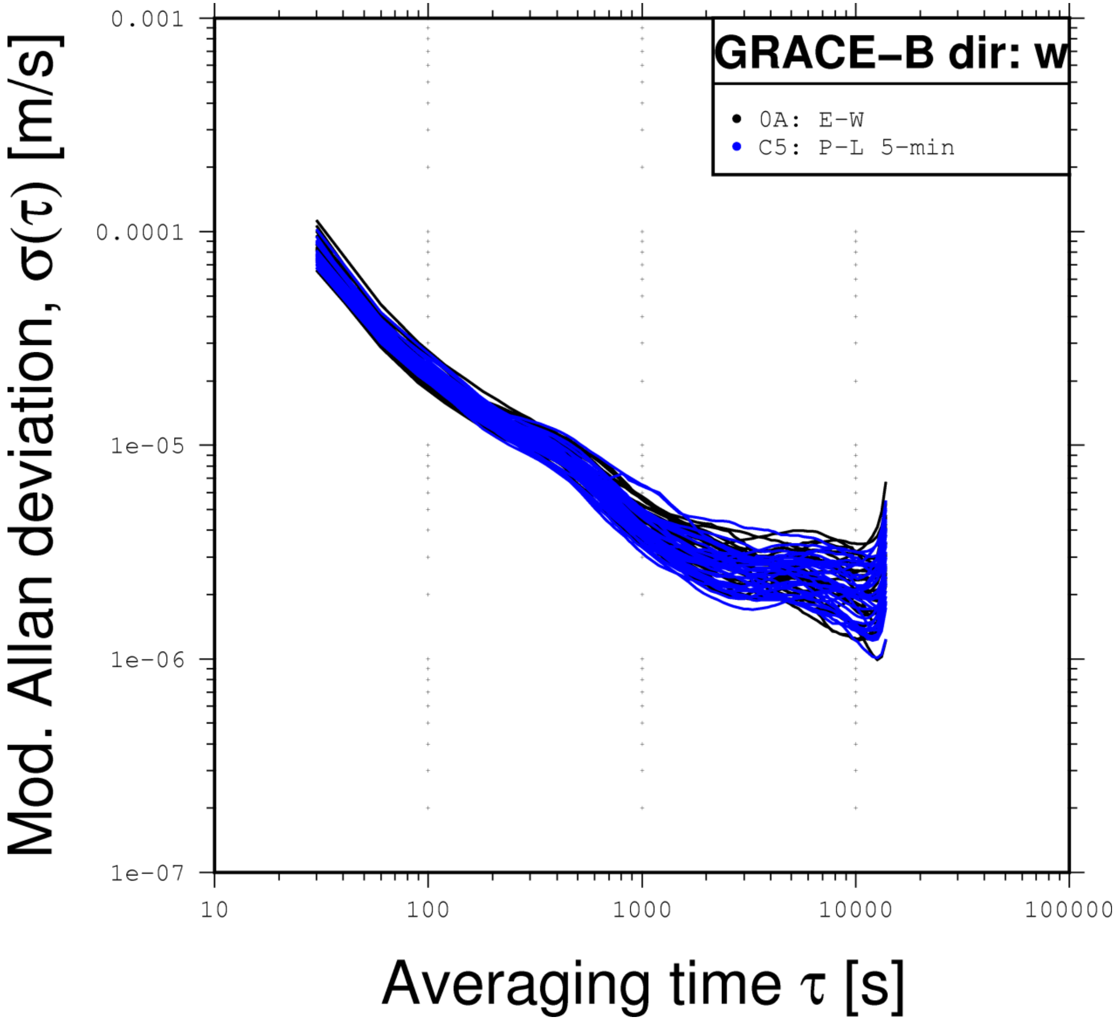


Problemati day

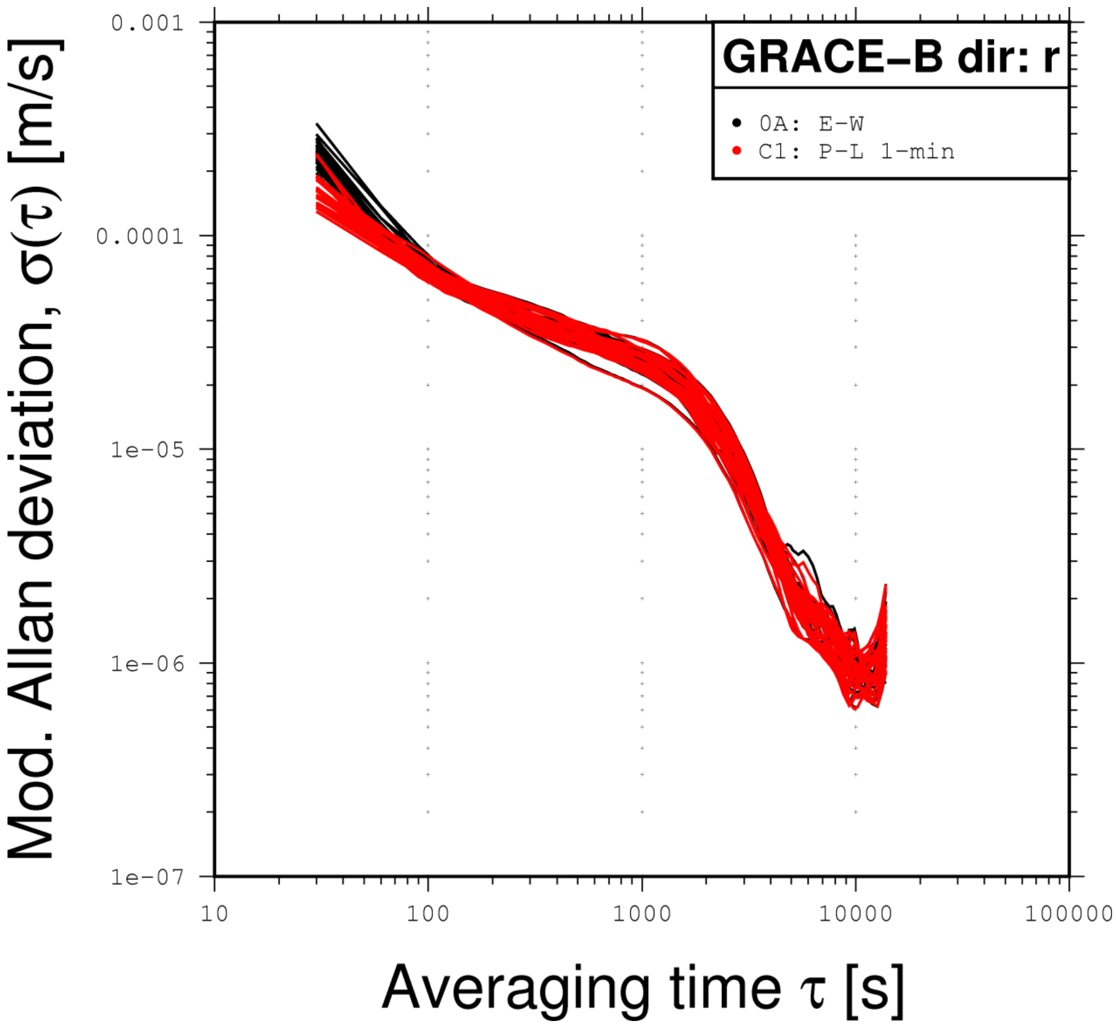
GRACE-B MDEV for Cross-Track Position Residuals



GRACE-B MDEV for Cross-Track Position Residuals

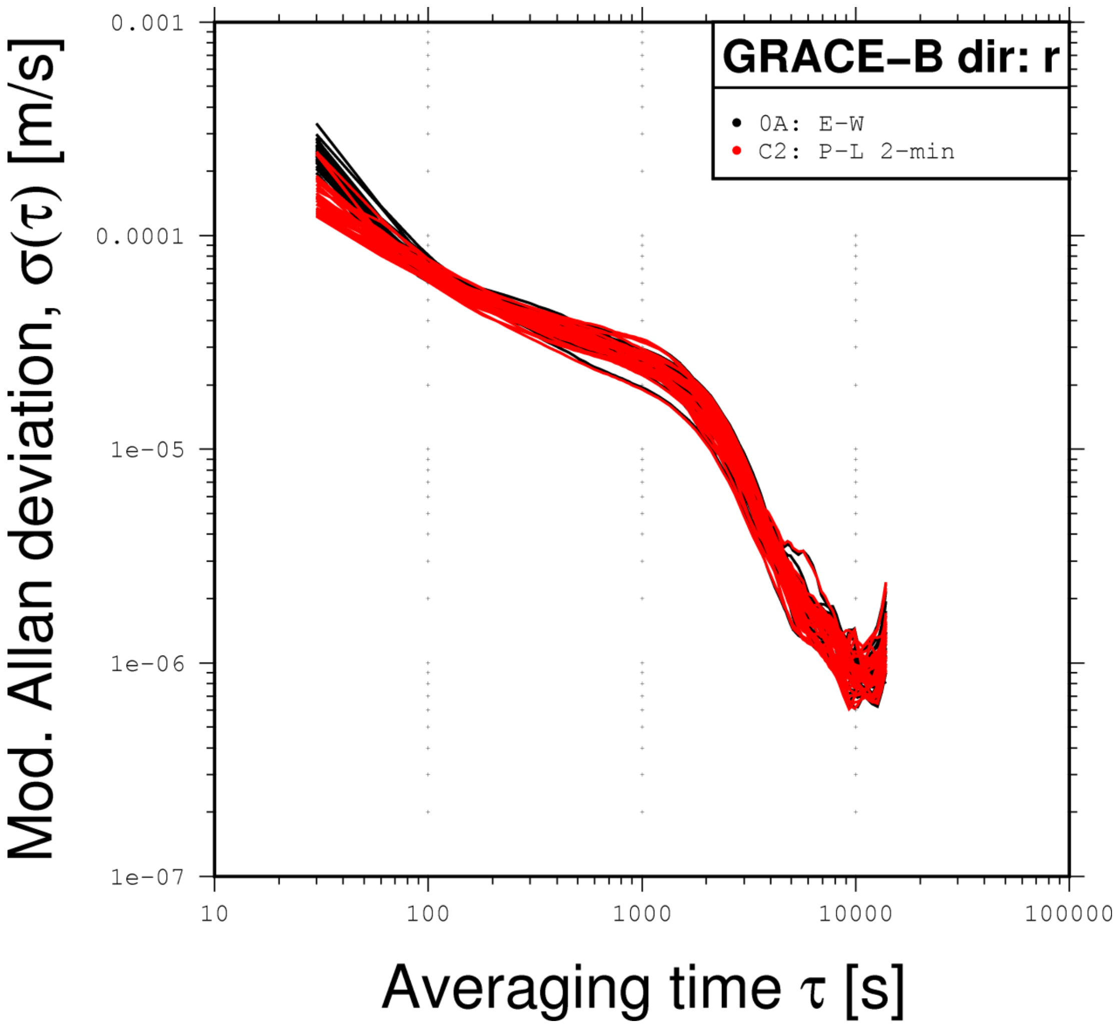


GRACE-B MDEV for Radial Position Residuals



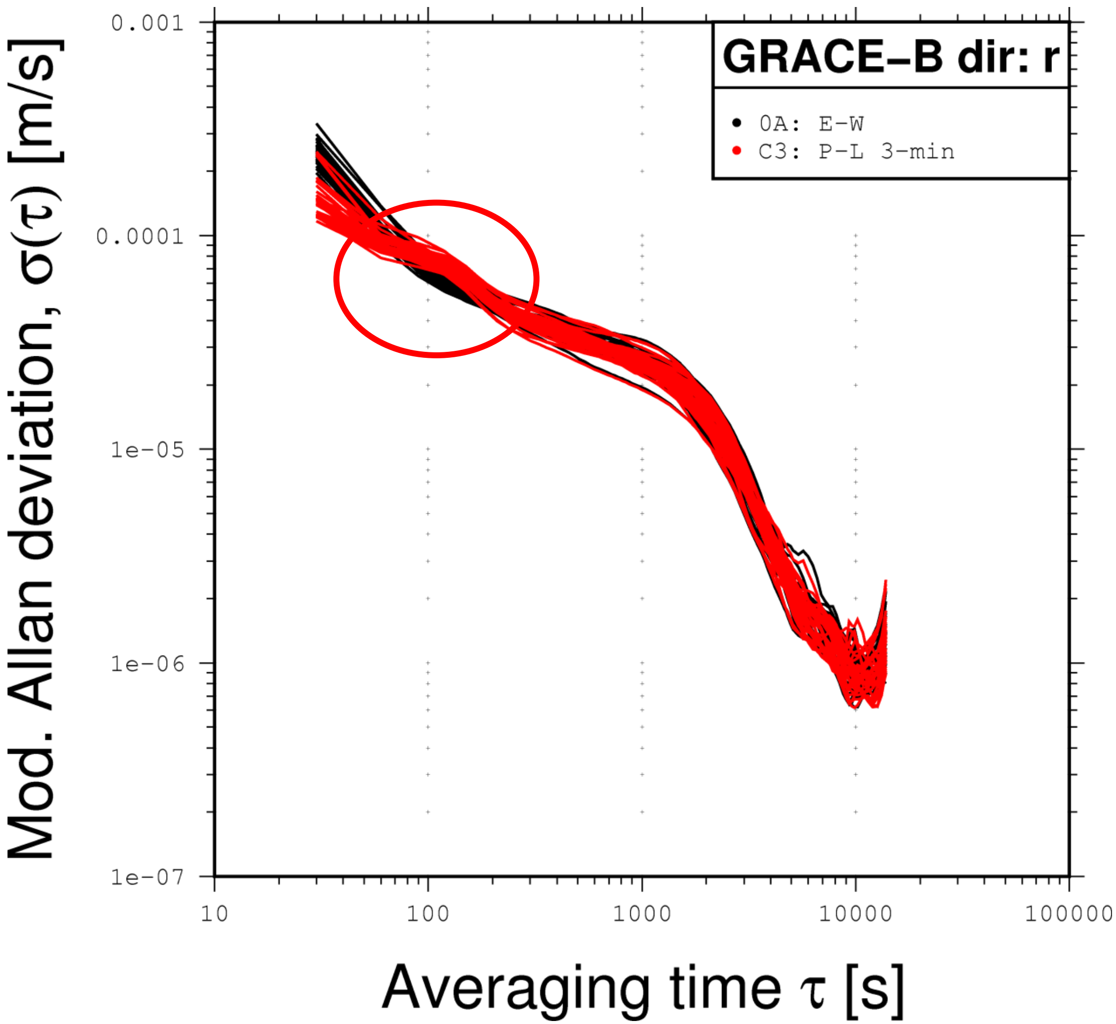
For P-L 1-min, improvement is obtained for short averaging times, with no apparent degradation

GRACE–B MDEV for Radial Position Residuals



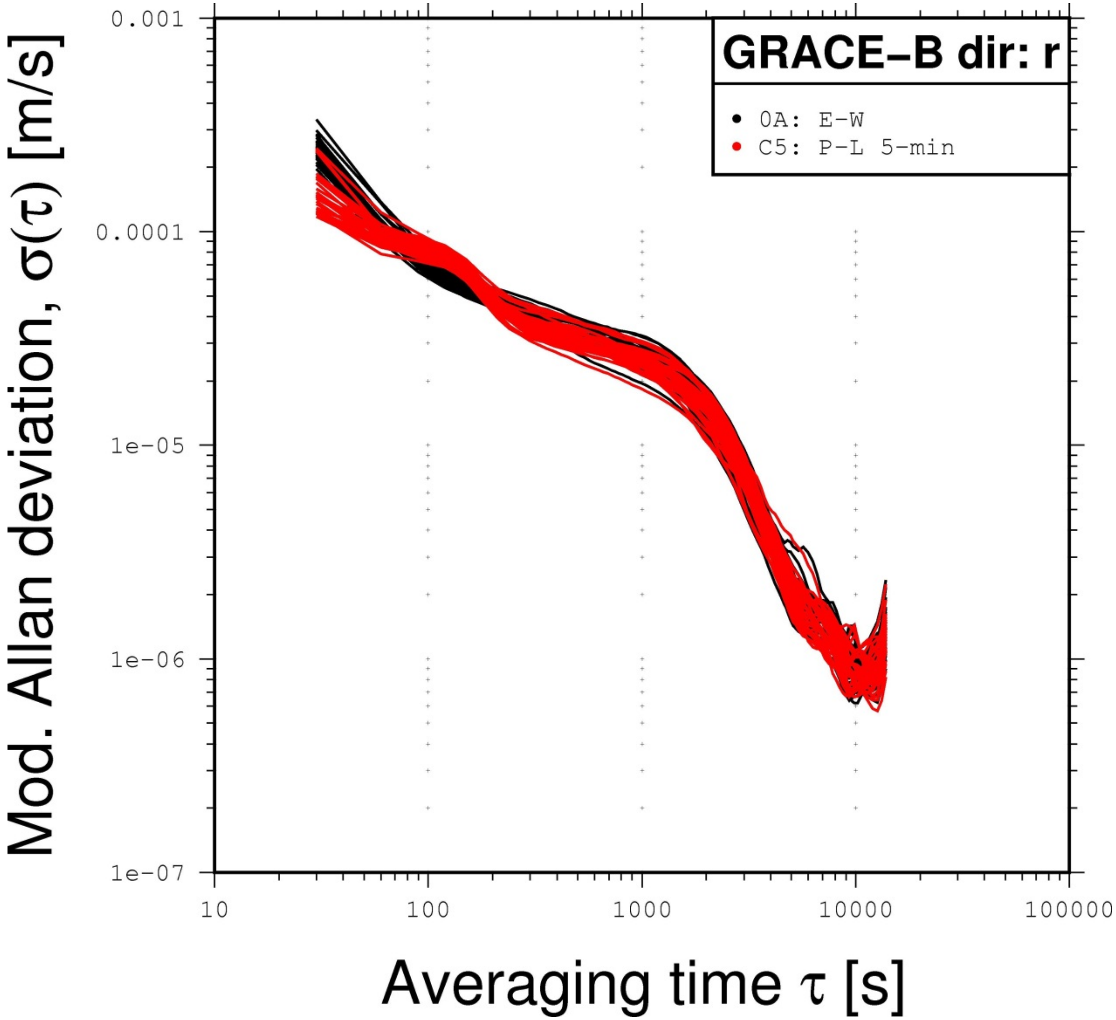
For P–L 2-min, the situation is similar to P–L 1-min, appart a slight increase in the spread of the curves

GRACE-B MDEV for Radial Position Residuals



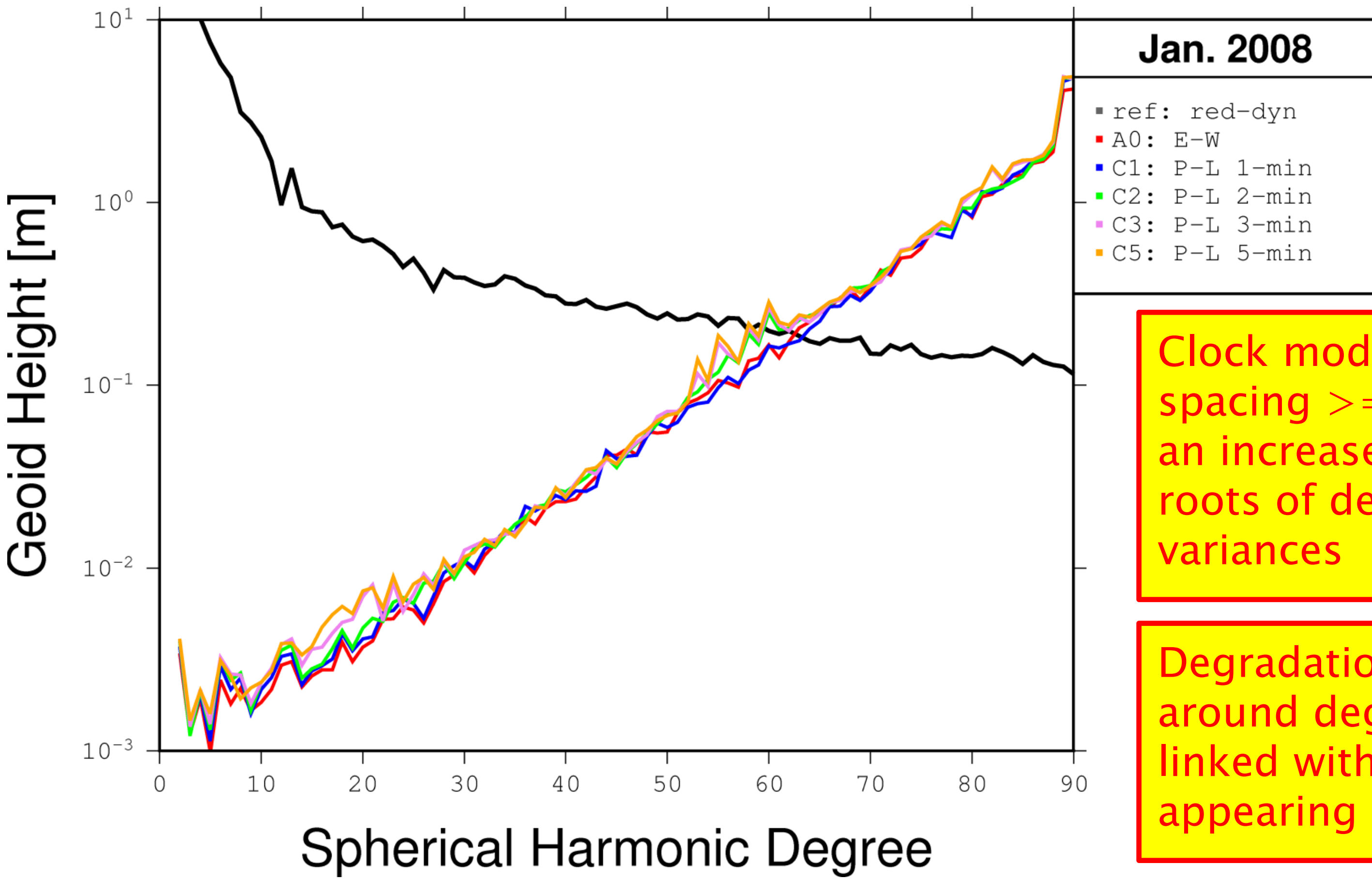
For P-L 3 min, a bulge at ~2 min appears

GRACE–B MDEV for Radial Position Residuals



Less spread of the curves for shorter knot spacing, indicating a greater overall consistency with the reduced-dynamic solution

Monthly Gravity Field Solution for Jan. 2008



Clock modelling with knot spacing >= 2 min results in an increase of the square-roots of degree difference variances

Degradation for C3 and C5 around degree 80 to be linked with the bulge appearing ~2 min

Conclusions

- The CODE approach for generating 30 s GPS satellite clock produces results similar to estimating clock corrections directly
- The approach is not responsible for the extra power seen in GRACE receiver clock PSD at ~5 min
- From the K-Band ranges comparison and comparison with reduced-dynamic orbits, clock modelling with piece-wise linear functions with knot spacing no larger than 2 minutes seems to be beneficial
- However, this does not yet translate in an improvement in the recovery of the gravity field from kinematic orbits
- Further investigations are needed

Thank you for your attention!