Doris phase measurements

Implementation and improvements

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Summary

Future IDS solutions must use Rinex files

- help documents for users

Improvements in the current altimetry POD software (Zoom) for the 2015 reprocessing campaigns

- ground beacon clock modelling in the phase measurement
- precise relativistic corrections for receiver clock

Applications

- effects on the orbits
- vertical station positioning

Phase measurement, IDS

IDS : documents for Doris phase measurement use

Doris models and solutions (F. Mercier)
The Doppler observation equation in the GINS software (J.M. Lemoine)

- phase and pseudo-range measurements : the only measurements available for future satellites

- these measurements are used in the altimetry POD since beginning f Jason 2
  (initial reference : JASR publication, F. Mercier- L. Cerri)
  improvements for the new orbit solutions

- current Doris 1b files are obtained using the Rinex data files

Users must have the choice for their measurement formulations

Improvements since the first implementation :

- model for the beacon frequency (not clear in the JASR publication)
  significant effect for station vertical positioning
  negligible effect on the orbits
  no change in the Doris 1b file

- relativistic periodic effects (receiver clock), neglected since the beginning of Doris
  no relativistic correction applied in Doris 1b (implicit correction for bias and drift)
  is this significant ?

Possible formulations

Two main approaches, for the phase measurement :

- GPS like equations (Zoom)
- Doris like equations, use of average frequencies (GINS)

Zoom formulation
Other formulations

Anyway, it is recommended to use phase variations (~Doppler)

for a representative model of the oscillators mid term behaviour :
random walk is better than bias+noise

Measurements epochs time tag and receiver frequency :

- direct use of the Rinex clock offset
  - the on board frequency model (polynomial) must now be estimated by the user
    - using directly the rinex frequency data
    - or the frequency obtained by derivation of the receiver clock offset
    - or adjustment using the Doppler equation (first Doris solutions (Topex))

- compute the time tag using the pseudo-range measurements C1,C2
  - on board frequency is obtained by derivation of the receiver clock offset
  - or direct adjustment using the Doppler equation

- how to handle relativistic effects on the receiver clock
  (for phase and pseudo-range)

Remarks : other changes

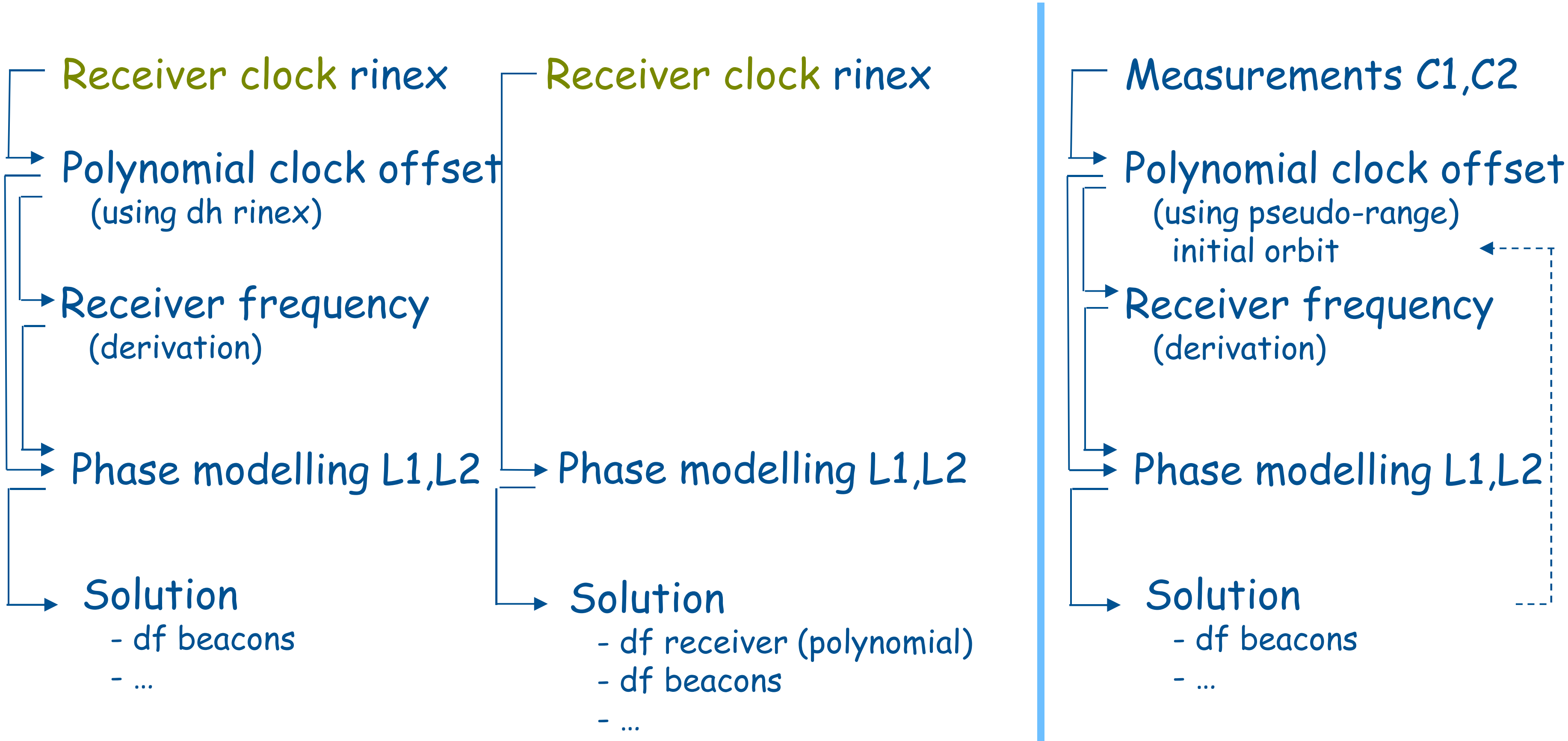
From Doris1b to Rinex : other characteristics to update

- 'iono-free' phase combination :
  correct phase centre (not the 2GHz phase centre)
  antenna phase map

- Attitude and satellite geometry :
  the Doris1b geometry correction is no more available

- Tropospheric delay : use of a complete model
  adjusted tropospheric delay was available in the Doris1b file
  must always be adjusted

Example of solutions



* Auxiliary data from rinex file

Arc length ? : MOE, two days, clock offset estimated on extrapolated orbit
POE, 7, 10 days, use of MOE orbits for the clock offset estimation

Measurement models

Phase Q and pseudo-range C (meters)

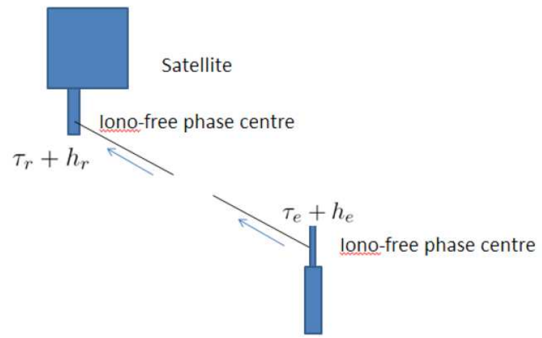
Receiver proper time — Clock bias

$$Q = c((\tau_r + h_r) - (\tau_e + h_e)) + Q_0$$

$$= c(t_r - t_e) + c(\delta_r^{rel} - \delta_e^{rel}) + c(h_r - h_e) + Q_0$$

$$= D_\Phi(t_r) + c(\delta_r^{rel} - \delta_e^{rel}) + c(h_r - h_e) + Q_0$$

Model — Coordinate time — Relativity



$$C = D_C(t_r) + c(\delta_r^{rel} - \delta_e^{rel}) + c(h_r - h_e)$$

coordinate time <==> TAI

h_r function of τ_r

h_e function of τ_e

Standard approach (current):

no term $c(\delta_r^{rel} - \delta_e^{rel})$

δ_e^{rel} equal to 0 for time beacons

δ_e^{rel} bias and drift for other beacons
(will be taken in the parameterisation for the beacon frequency)

Clocks relativistic effect

Main effect : frequency bias between proper time and coordinate time
a frequency offset is always adjusted (clock polynomials)

Then :

h_r polynomial in τ_r → h_r polynomial in t_r

h_e polynomial in τ_e → h_e polynomial in t_e

For the phase measurements processing ,
the δ_r^{rel} periodic terms are not negligible

(negligible for the synchronisation, the precision of a linear model is sufficient)

Periodic satellite clock relativistic terms

Different approaches:

- GPS like, approximation not correct for low orbits $-2\frac{m(t).v(t)}{c^2}$
  (central attraction, Keplerian orbit)

- use of the complete gravitational potential
  difficulty : extracting only the periodic terms

$$\begin{aligned}\tau_b - \tau_a &= \int_{t_a}^{t_b} (1 + \tfrac{1}{c^2}(U - \tfrac{1}{2}v^2))dt \\ &= t_b - t_a + \int_{t_a}^{t_b} \tfrac{1}{c^2}(U - \tfrac{1}{2}v^2)dt\end{aligned}$$

Coordinate time

Possible approximations : central term for U
central term + J2 for U
complete U
} very close

Jason case

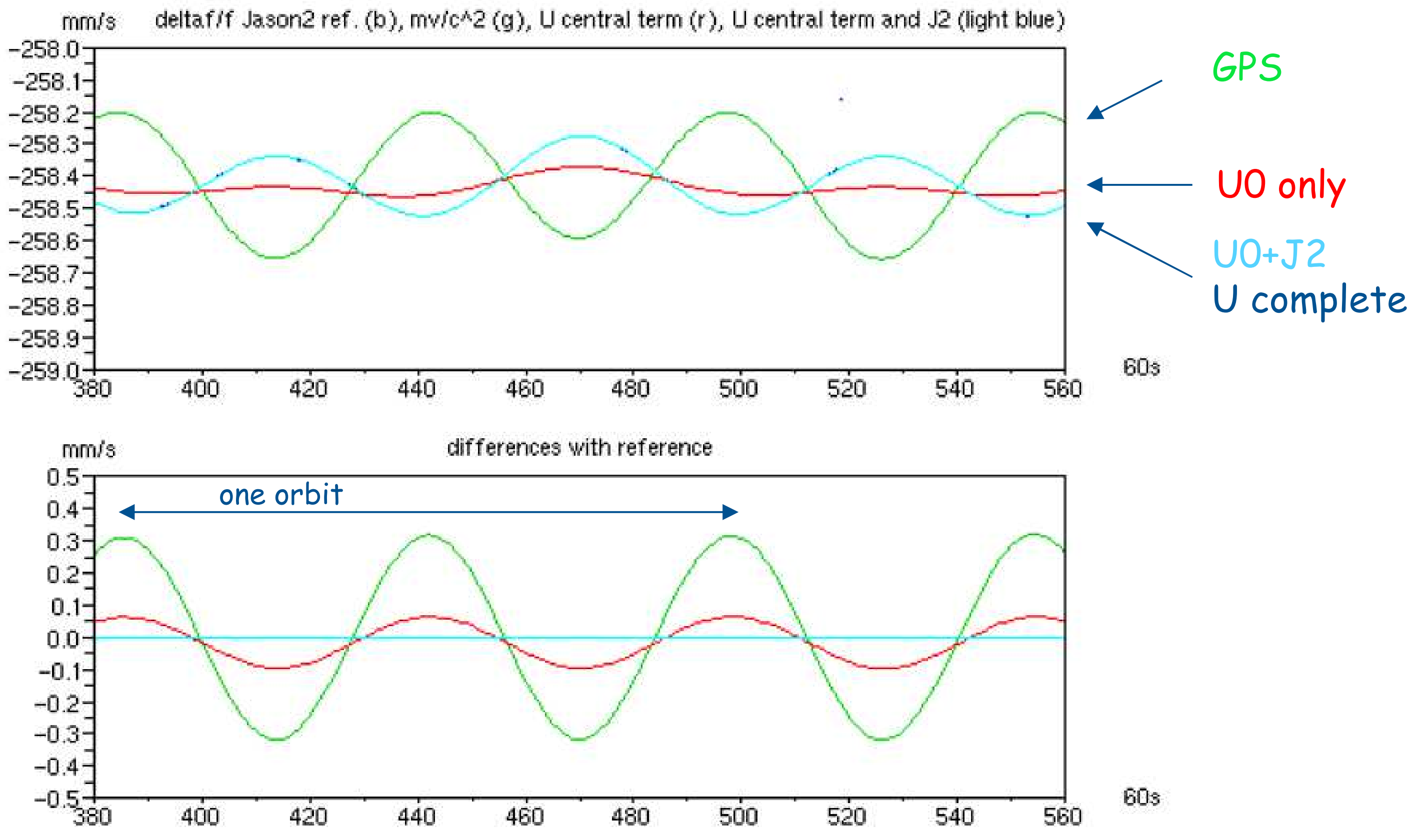


FIG. 2 – $\Delta f/f$ for Jason 2 , complete (blue), U central term (red), U central term and J_2 (ceil), GPS formula (green)

Cryosat case

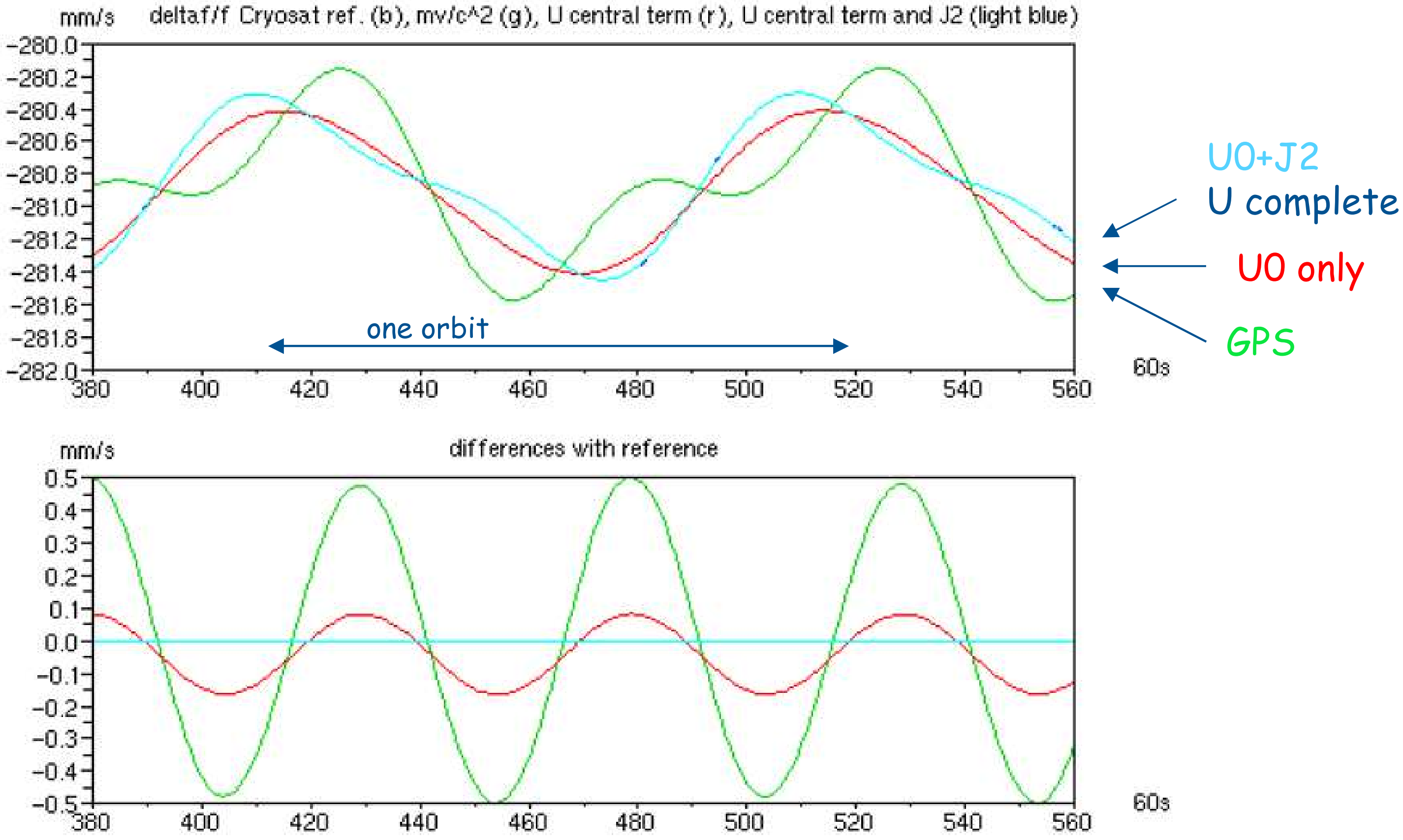
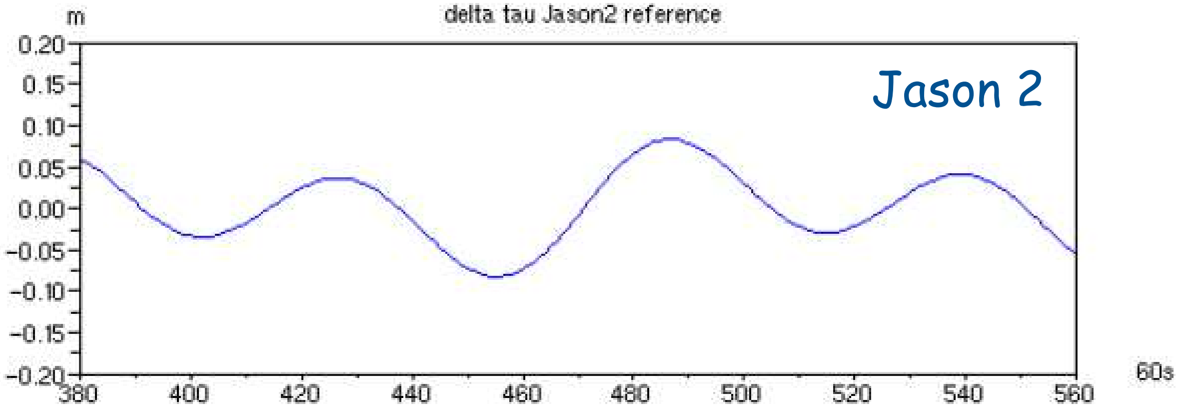
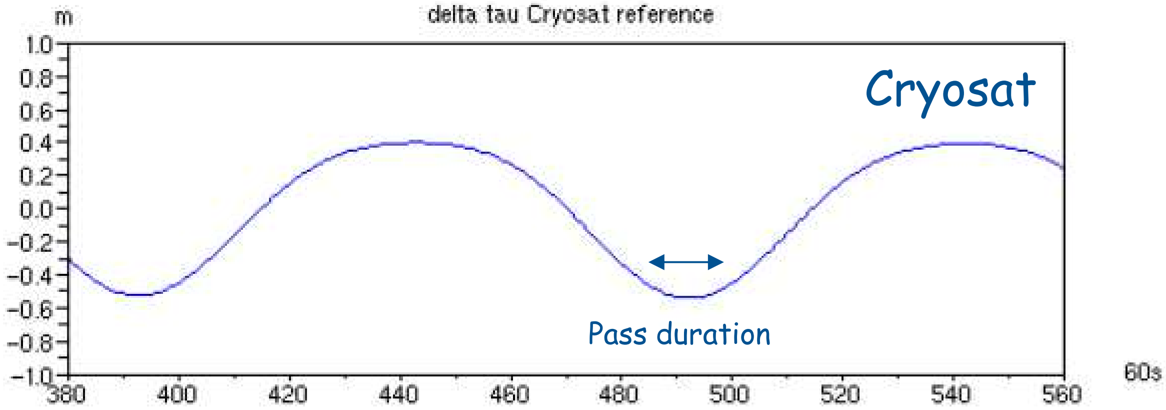


FIG. 3 – $\Delta f/f$ for Cryosat , complete (blue), U central term (red), U central term (ceil) and J_2, GPS formula (green)

Possible effects on positioning

Phase errors (in meters)





Parabolic effects on some passes, several cm, effect on position ?

- Jason case, geographically correlated effect (frozen eccentricity)
- Not corrected in the Doris1b file

Beacon clock processing

h_e linear in t_e

→ Not a linear function of the coordinate time t_r
(current version, h_e function of t_r)

Drawback : other linear terms in t_r are not compensated
if a polynomial in t_e is adjusted
(case of shifted beacon frequencies)

Specific formula for shifted frequency beacons (K factor):

$$f_K = (1 + a_K)f \longrightarrow \begin{aligned} Q_{corr} &= \lambda\Phi_r - \lambda_K\Phi_e \\ &= \lambda_K(\Phi_r - \Phi_e) + (\lambda - \lambda_K)\Phi_r \\ &= \lambda_K(\Phi_r - \Phi_e) + c\frac{\Phi_r}{f}\frac{a_K}{1+a_K} \end{aligned}$$

($\frac{\Phi_r}{f}$ → t_r)

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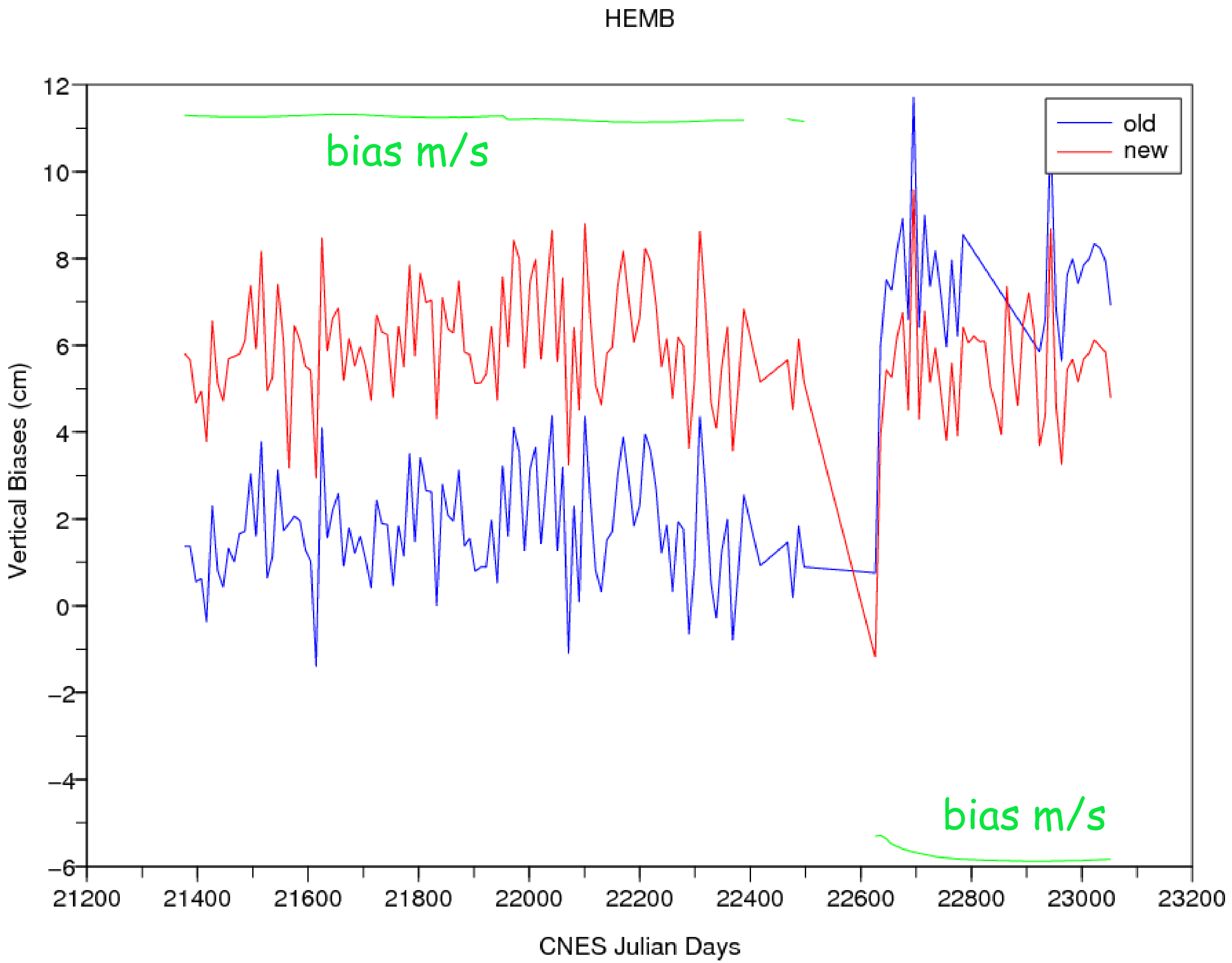
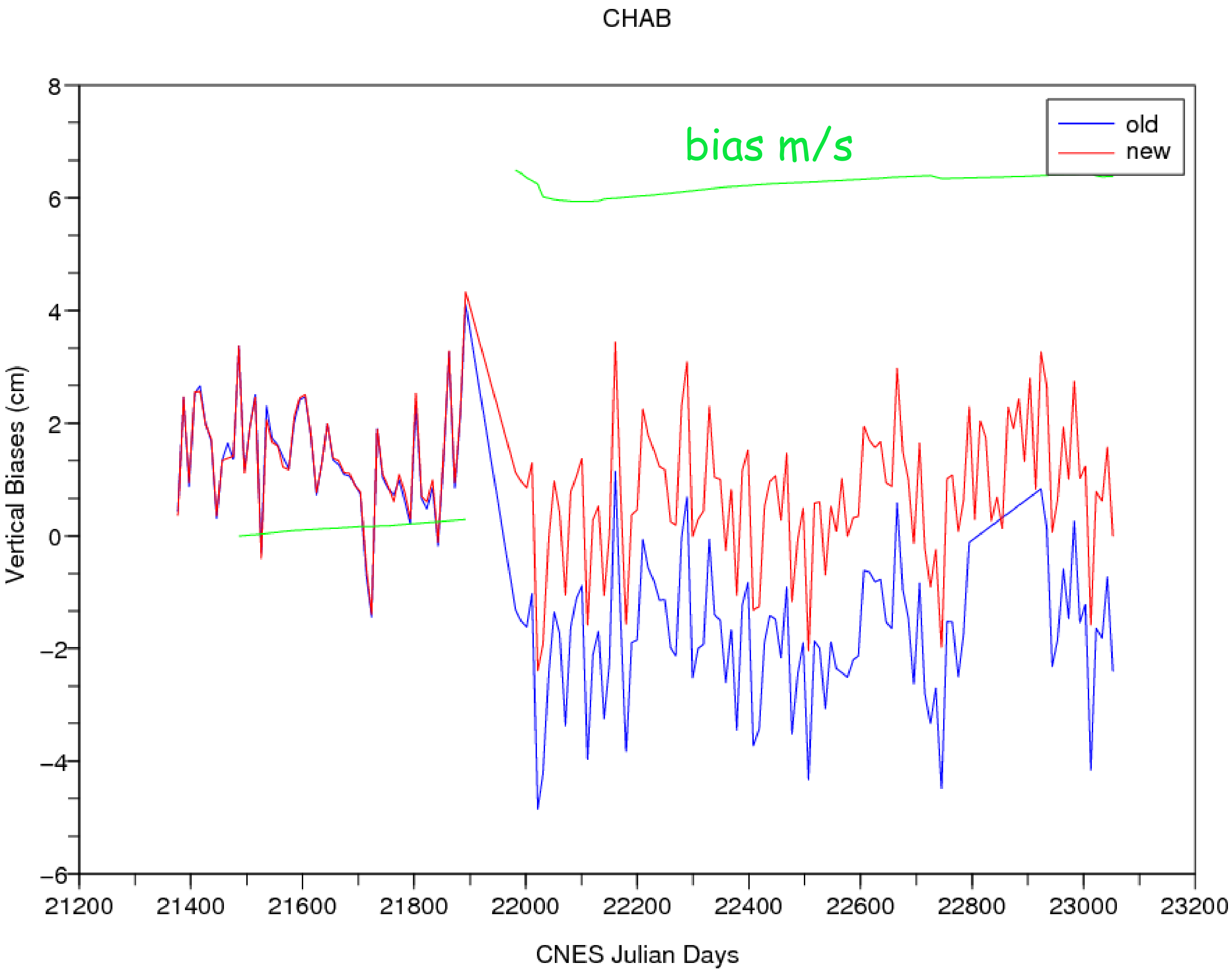
HEMB : beacon change, frequency offset

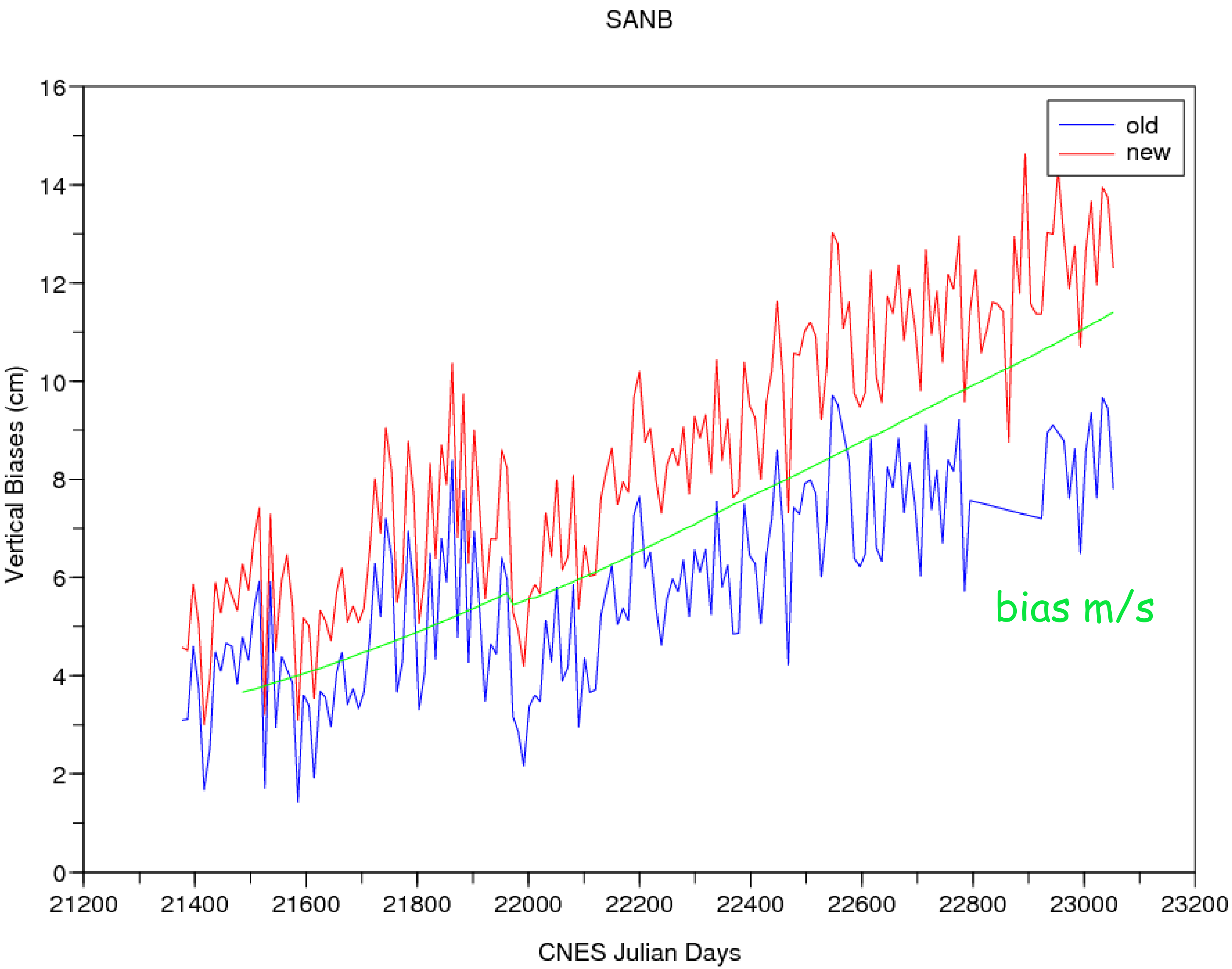


CHAB



CHAB
bias m/s
old
new
Vertical Biases (cm)
8
6
4
2
0
−2
−4
−6
21200
21400
21600
21800
22000
22200
22400
22600
22800
23000
23200
CNES Julian Days

SANB


SANB
old
new
bias m/s
Vertical Biases (cm)
CNES Julian Days
0
2
4
6
8
10
12
14
16
21200
21400
21600
21800
22000
22200
22400
22600
22800
23000
23200

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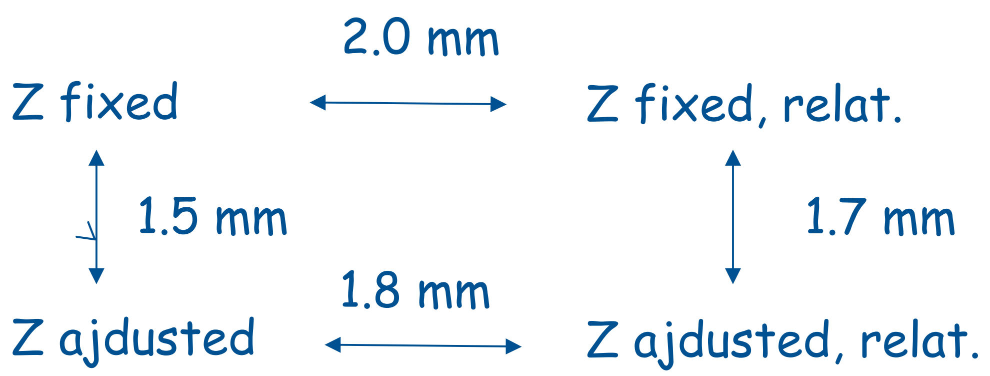
Applications, orbits

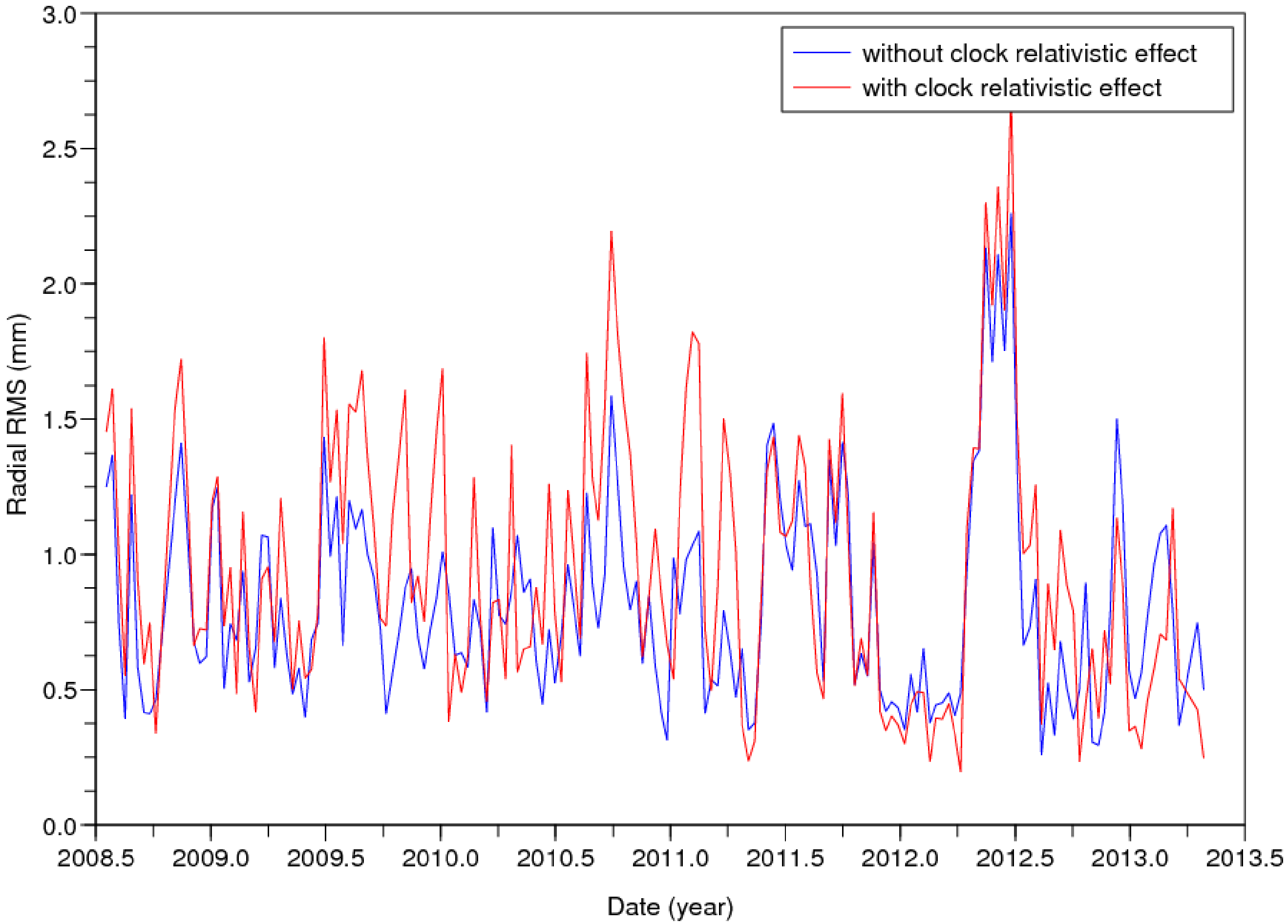
Periodic relativistic correction effects
Vertical displacement effects

the two effects are coupled with the ZTD adjustment
elevation cutoff 20 degrees



Changes in rms radial

Station vertical displacement effect on orbits



Jason 2 : ~2 mm on the radial rms value, negligible
small impact of relativistic correction

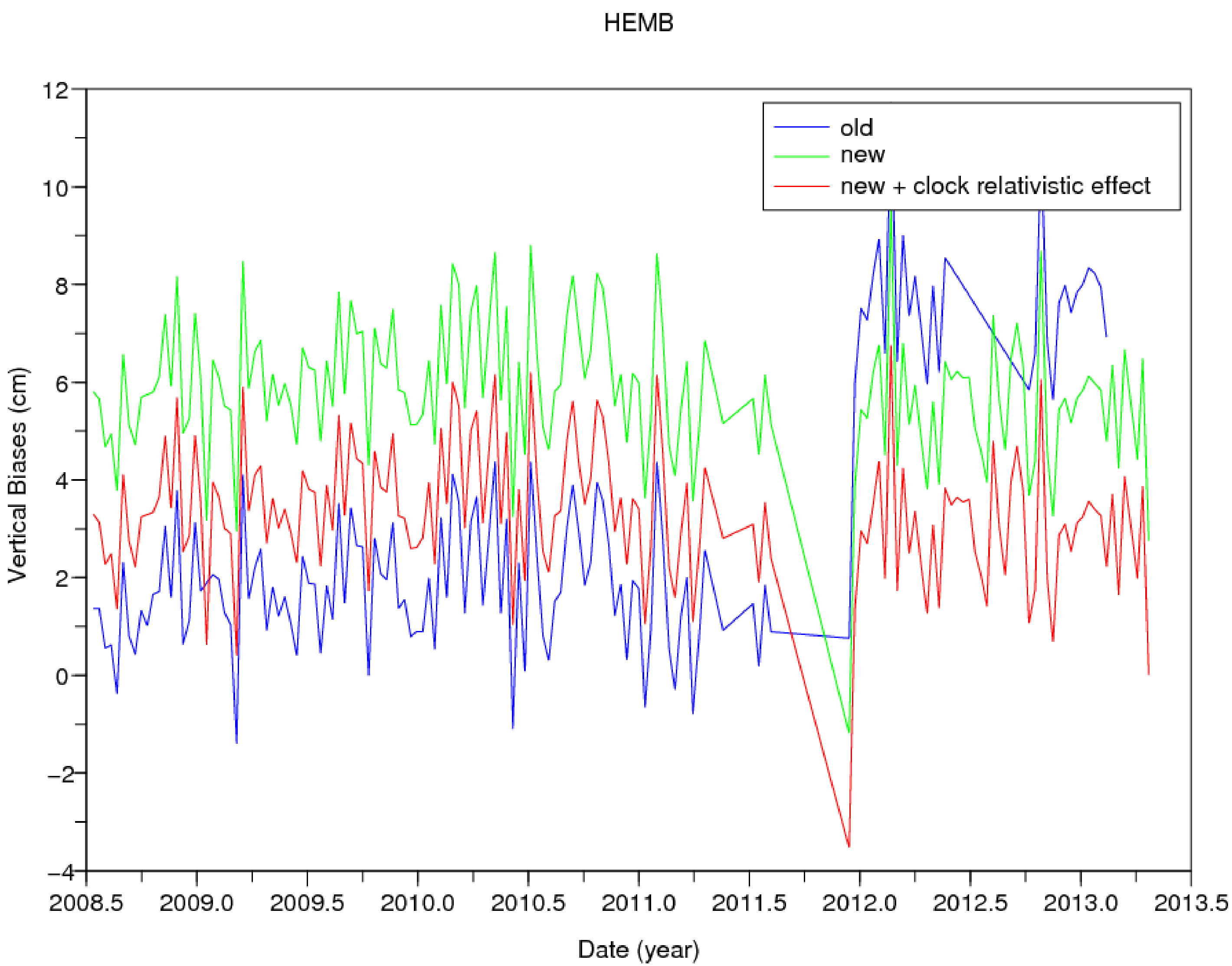
Station vertical displacements

Stations vertical displacements

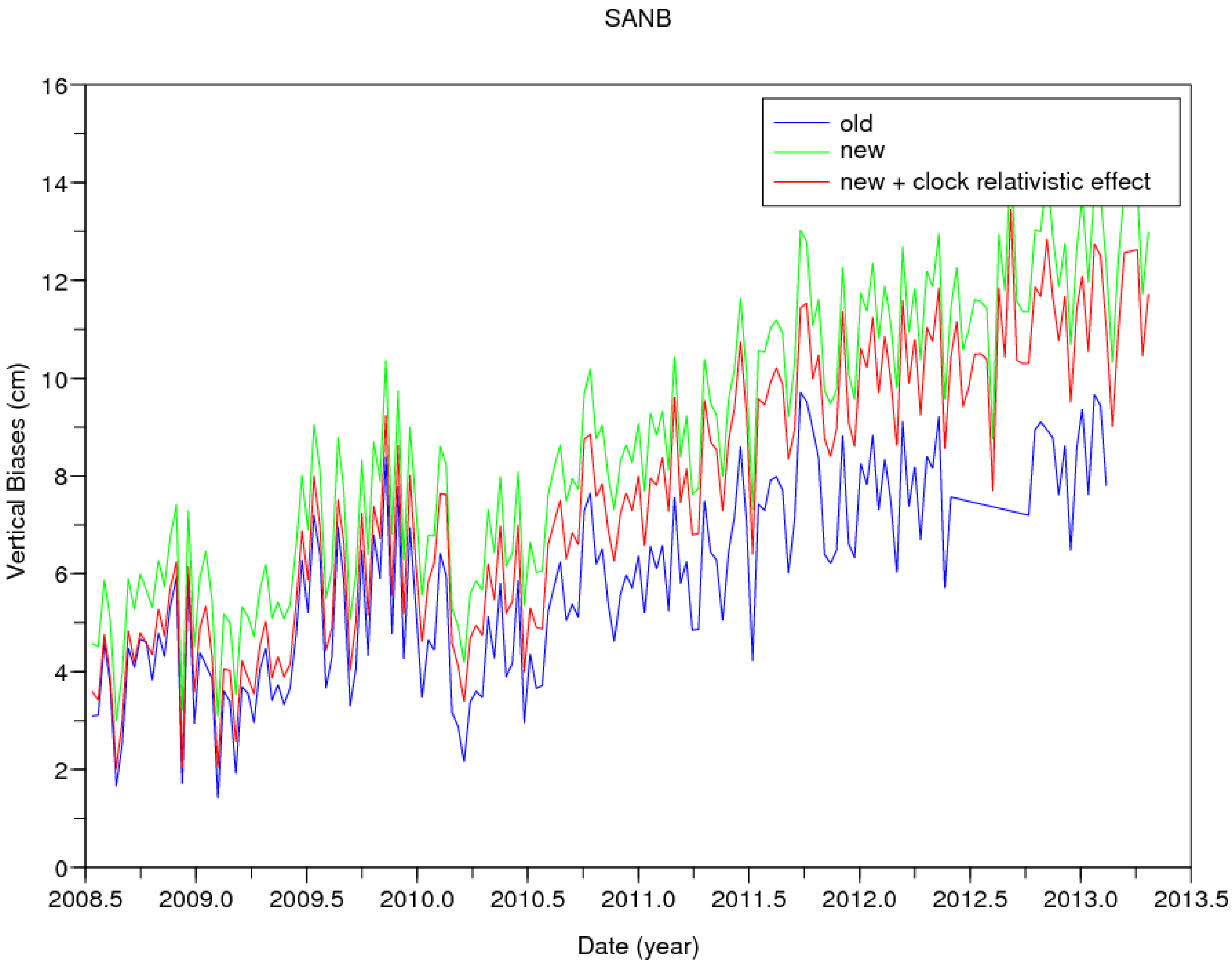
with or without relativistic periodic terms

effects on station positioning, latitude effects

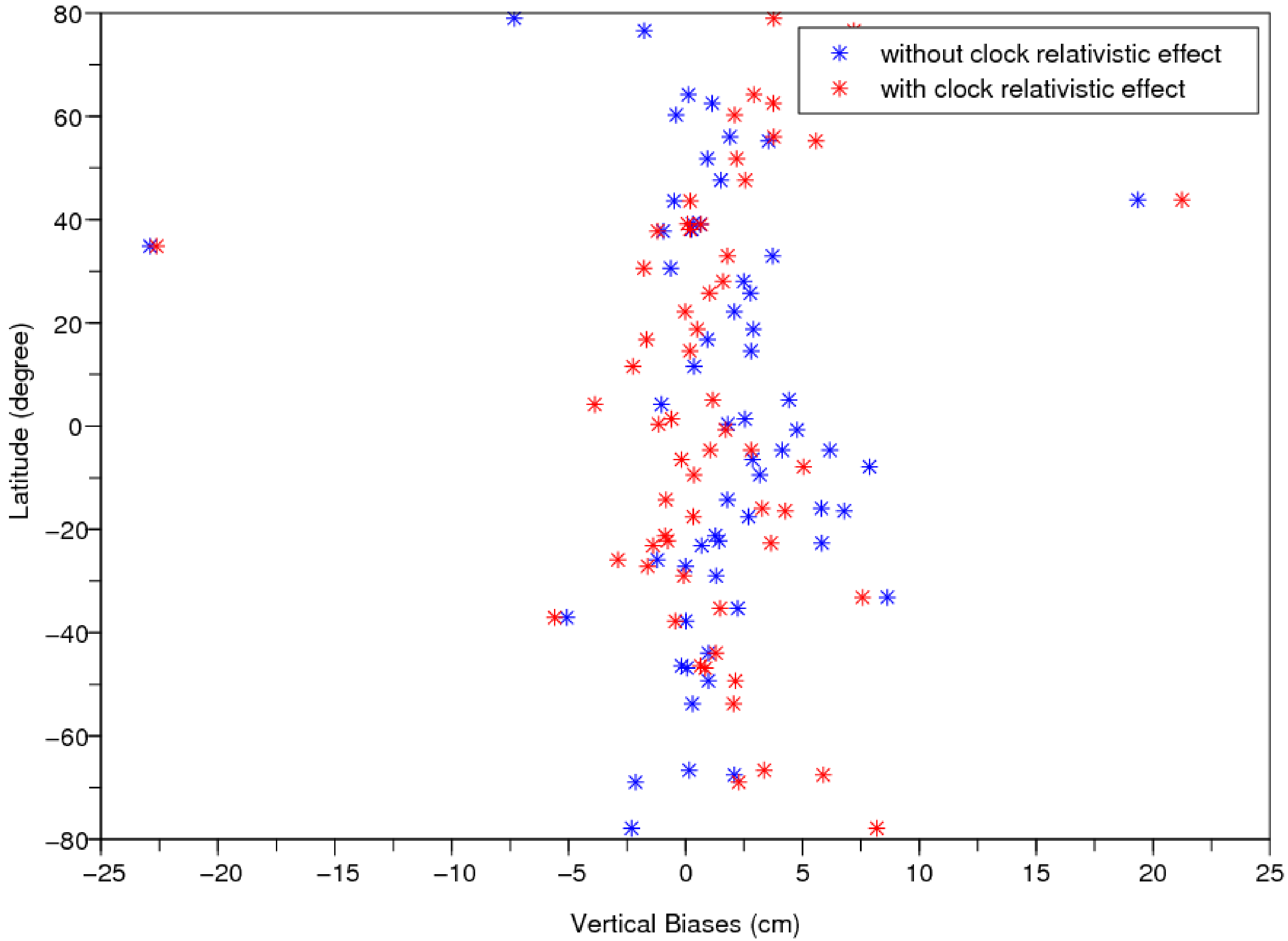
Station positioning : HEMB



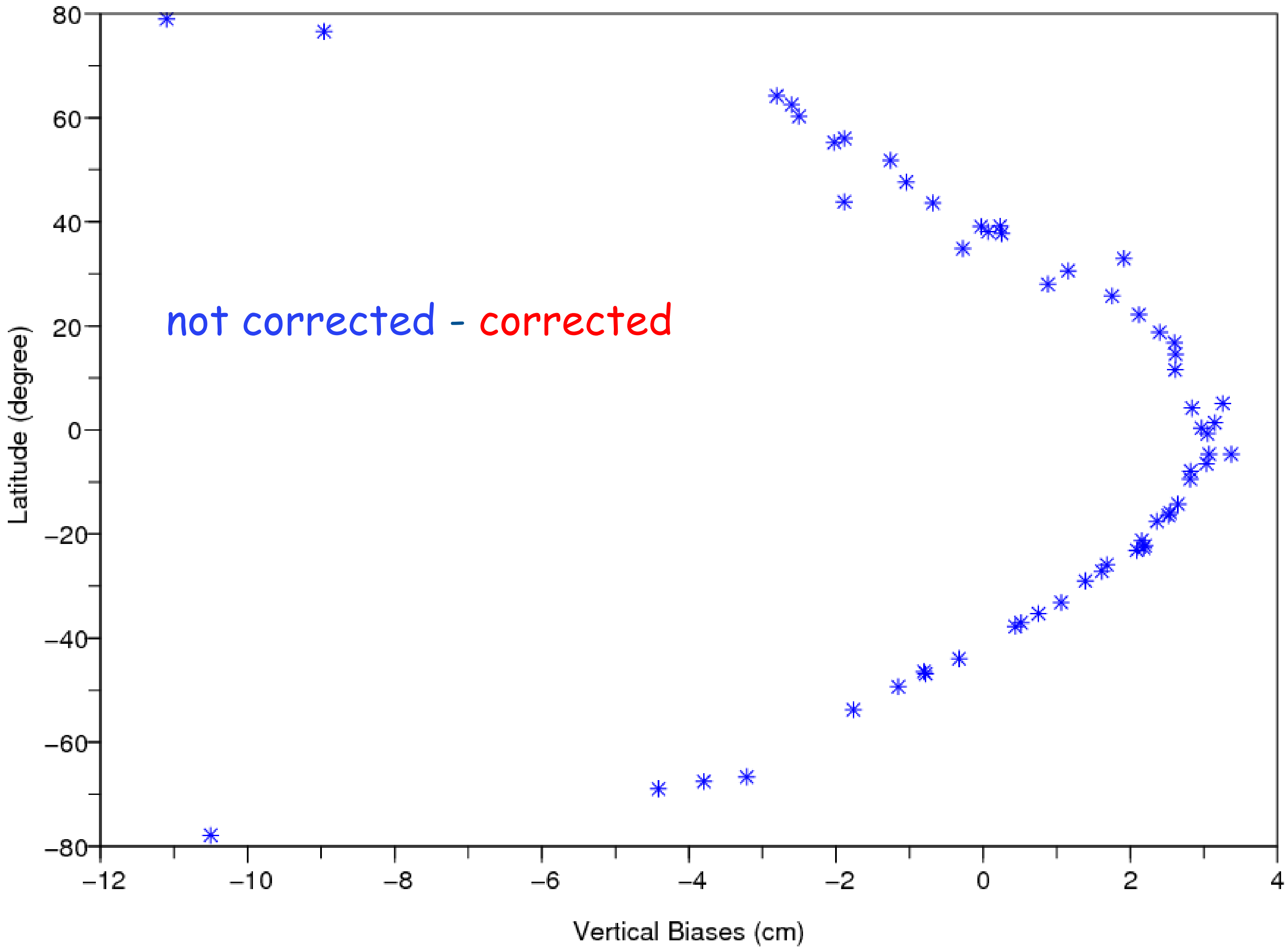
Station positioning : SANB



Adjusted vertical offsets (relative to ITRF), Jason 2



Positioning bias due to relativistic effect, Jason 2



Conclusion

Solutions with Rinex files (IDS)

- user documents for IDS
- different possible strategies (synchronisation, use of pseudo-range …)
- how to estimate the receiver frequency ?

- use of phase variations (Doppler solution)

- improvement of beacon frequency model

Receiver clock periodic relativistic terms are not negligible

- classic GPS formula not valid
- true trajectory with central term and J2 is sufficient

- millimetres orbit radial perturbations
- several centimetres station vertical displacements
- important systematic geographic effects for Jason 2

this order of magnitude is very important, to be confirmed by further studies

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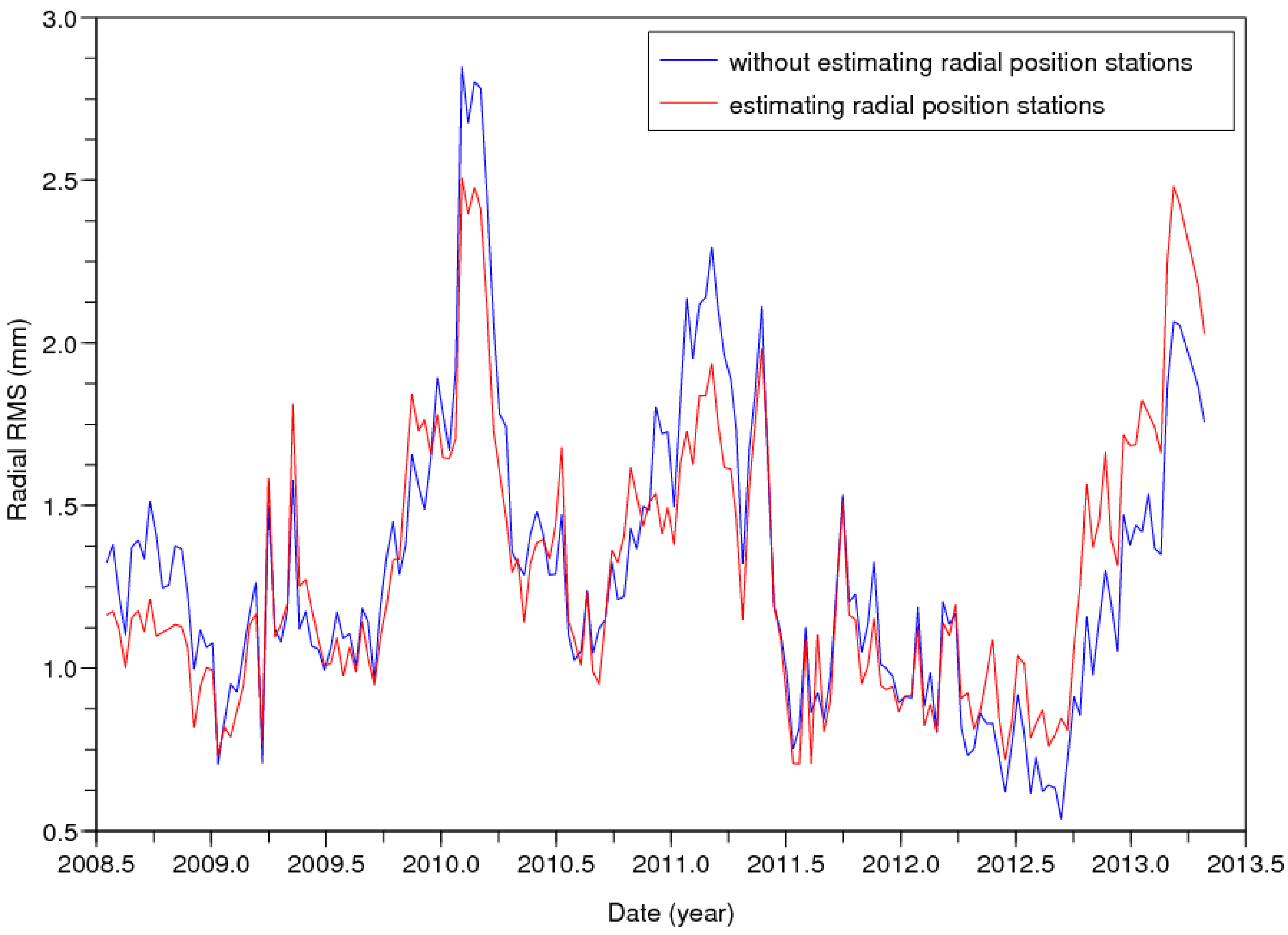
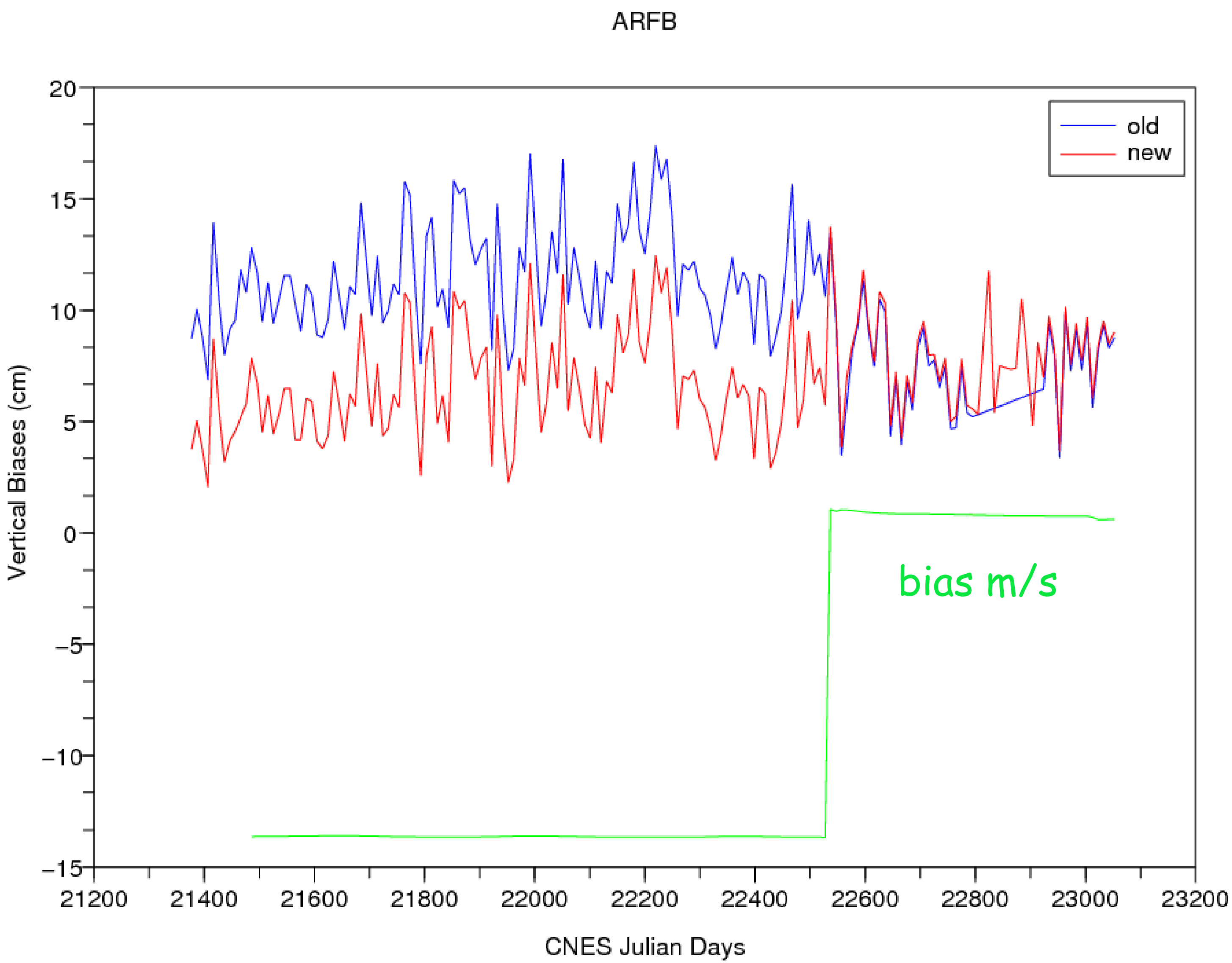
Thank you

Orbits, effect of the clock relativistic correction



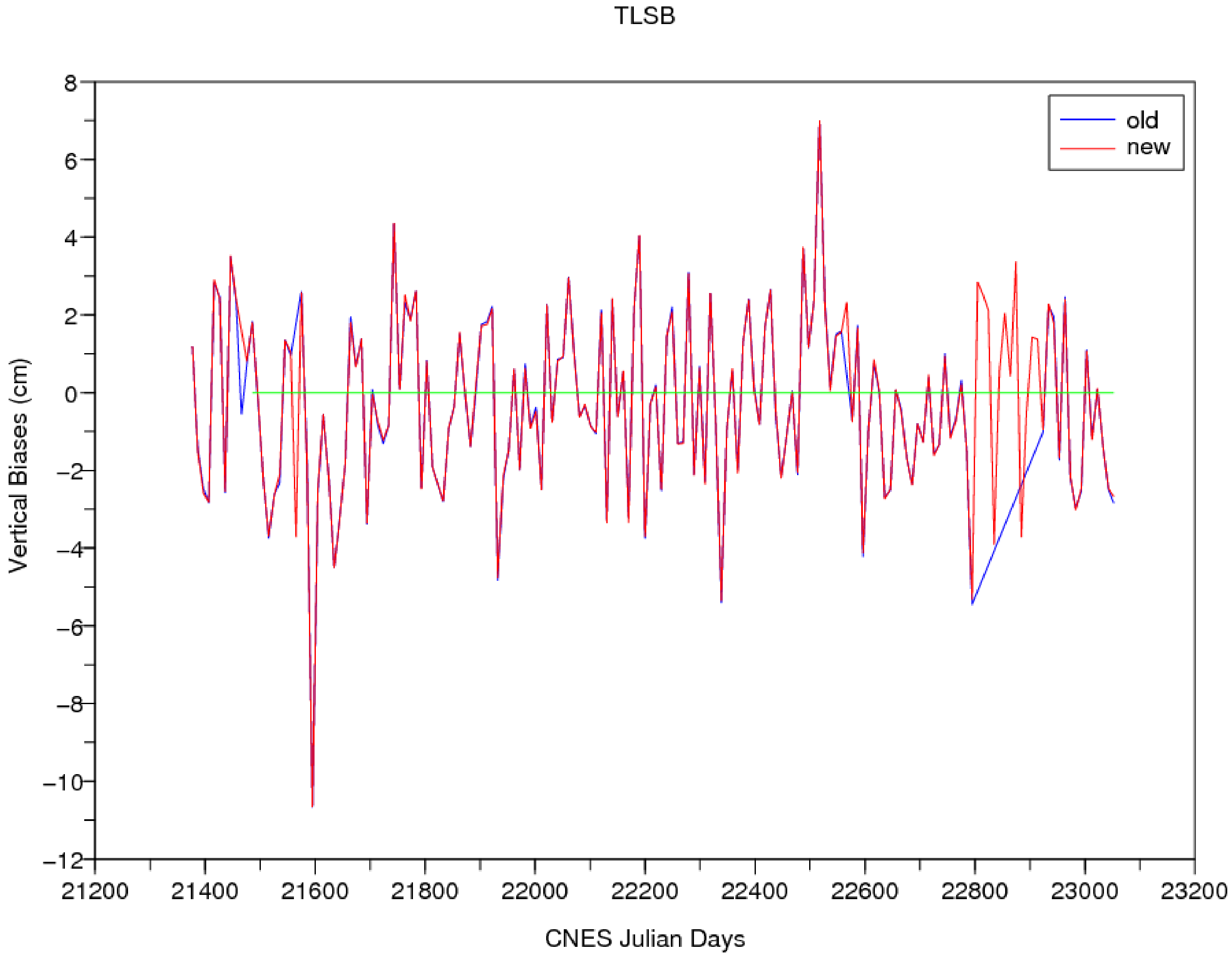
Jason 2 : ~2.5 mm on the radial rms value, negligible

ARFB

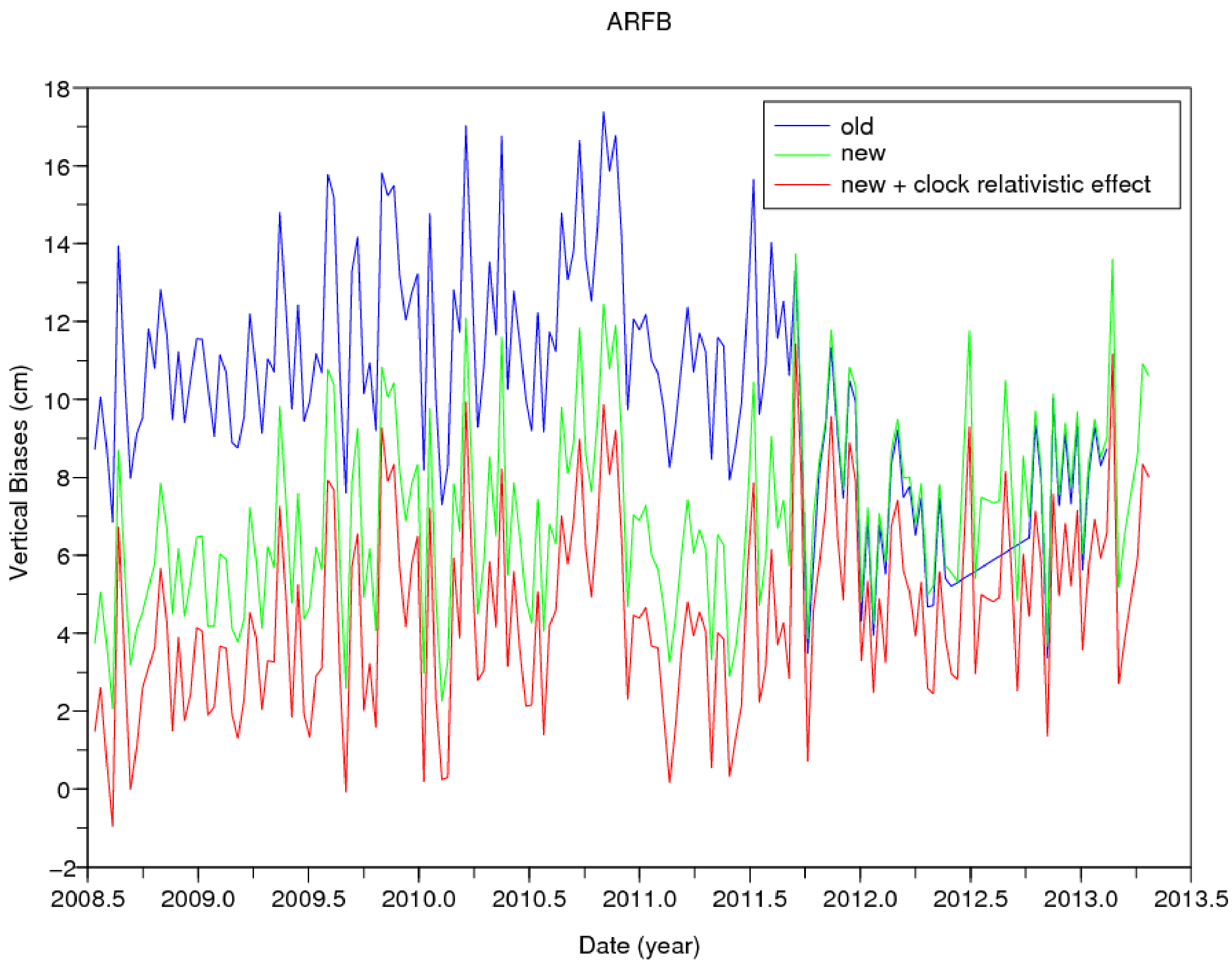


ARFB
old
new
bias m/s
Vertical Biases (cm)
20
15
10
5
0
−5
−10
−15
21200
21400
21600
21800
22000
22200
22400
22600
22800
23000
23200
CNES Julian Days

TLSB (reference beacon)

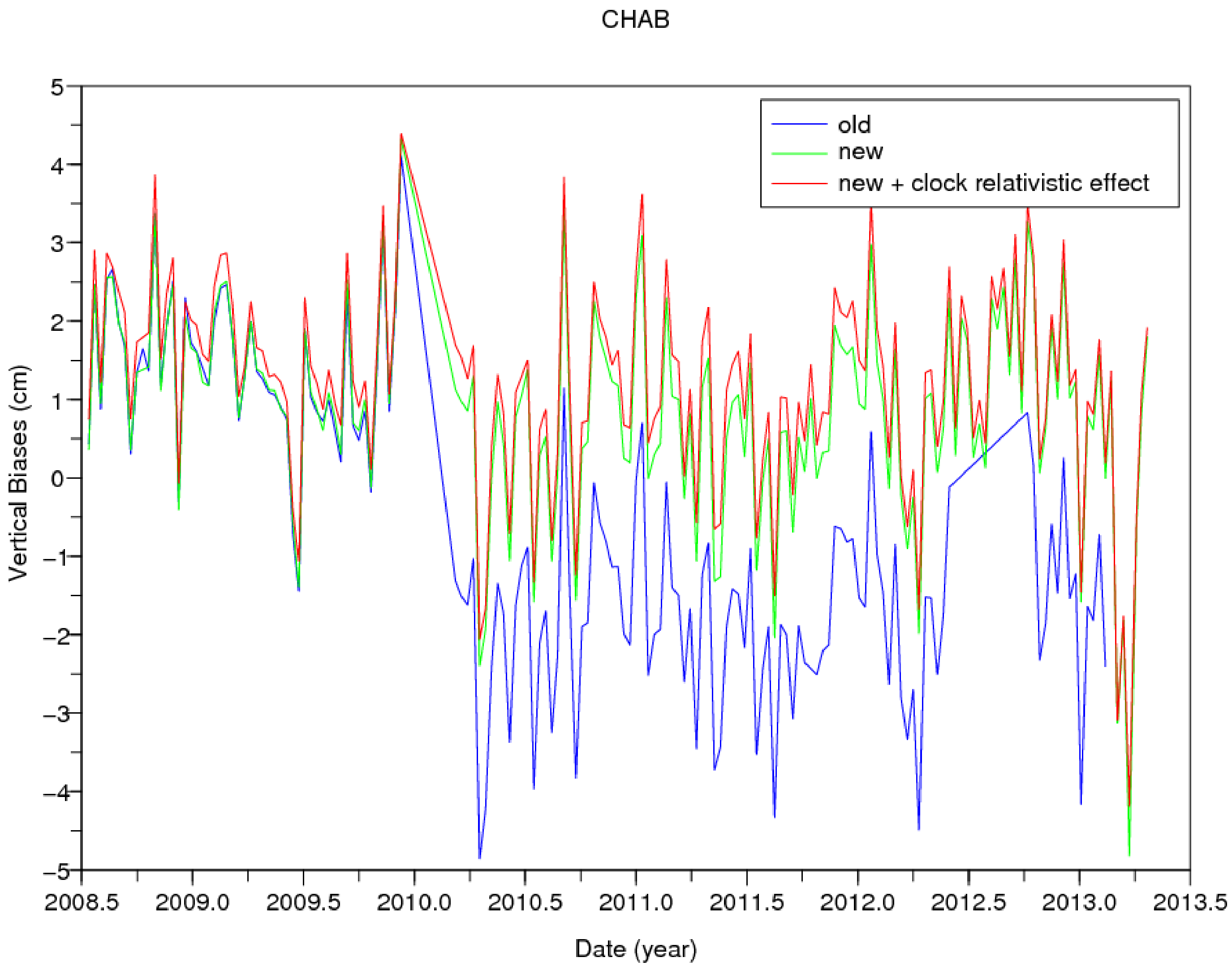


ARFB



ARFB
old
new
new + clock relativistic effect
Vertical Biases (cm)
18
16
14
12
10
8
6
4
2
0
−2
2008.5
2009.0
2009.5
2010.0
2010.5
2011.0
2011.5
2012.0
2012.5
2013.0
2013.5
Date (year)

CHAB


CHAB
old
new
new + clock relativistic effect
Vertical Biases (cm)
Date (year)
5
4
3
2
1
0
−1
−2
−3
−4
−5
2008.5
2009.0
2009.5
2010.0
2010.5
2011.0
2011.5
2012.0
2012.5
2013.0
2013.5