IGS WORKSHOP 2014

CALIBRATING GNSS SATELLITE ANTENNA GROUP-DELAY VARIATIONS USING SPACE AND GROUND RECEIVERS

June 23-27, 2014 - PASADENA, CALIFORNIA

Plenary PY06: Infrastructure and Calibration

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European Space Agency

INNOVATING SOLUTIONS

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GBICS PROJECT

GBICS: GNSS Bias Calibration System

ESA's General Studies Program

[2012-2013]

European Space Agency

INNOVATING SOLUTIONS

Objective

Development of a demonstrator of a system able to estimate GNSS MEO satellite SIS biases among different frequencies with an accuracy better than a few centimetres, using GNSS receivers on-board LEO satellites

GNSS RECEIVERS ON LEO SATELLITES

	CHAMP	JASON-1	JASON-2	MetOp-A
Launch Date	July 15th, 2000	December 7th, 2001	June 20th, 2008	October 19th, 2006
Altitude	454 km	1336 km	1336 km	817 km

Criteria for selection of candidate LEO satellites:

- GNSS data freely accessible
- Altitude: higher orbits are preferable
- Geometry of the orbit and measurement sampling rate

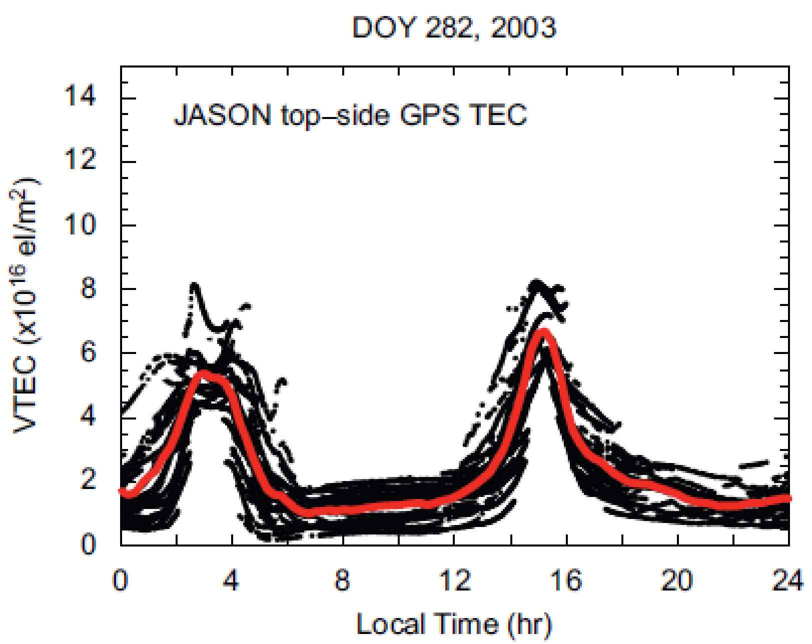



[J. Fernández, *Automated Operational Multi-Tracking High Precision Orit Determination for LEO MIssions*]

IONOSPHERE/PLASMASPHERE IMPACT

The question is…

- When are LEO GNSS observables not affected by ionosphere/plasmasphere delays?
  - Spatial variations (maximum at equatorial regions)
  - Temporal variations
    - Solar cycle
    - Annual
    - Daily
  - Geomagnetic variations



[http://www.mwatelescope.org/science/shi/is.html]

IONOSPHERE/PLASMASPHERE IMPACT

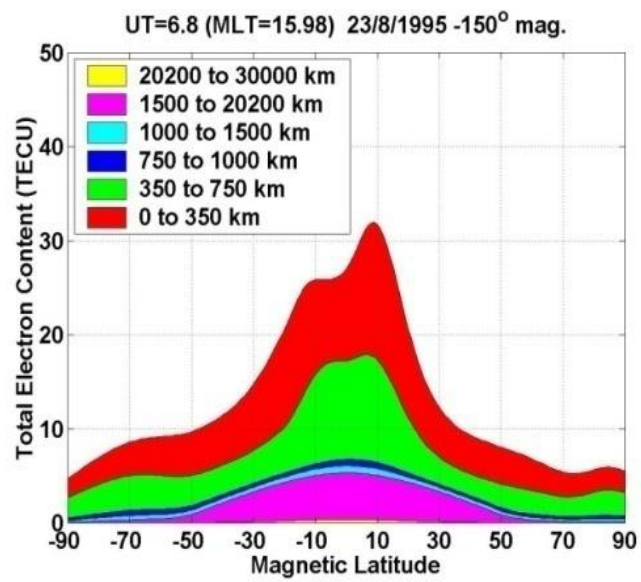
Analysis

- Inputs:
  - Observation RINEX. Observables: P1, P2, L1, L2
  - GPS Navigation Message (BRDCs)
  - LEO Satellite Orbits
- Observables: Ionosphere Combination

$$PR^i_{j,I} = PR^i_{j,f2} - PR^i_{j,f1} = (\gamma - 1)\cdot I^i_{j,f1} + \left(TR^i_{f2} - TR^i_{f1}\right) + \left(RX_{j,f2} - RX_{j,f1}\right)$$

$$\phi^i_{j,I} = \phi^i_{j,f1} - \phi^i_{j,f2} = (\gamma - 1)\cdot I^i_{j,f1} + \left(N^i_{j,f1}\lambda_{f1} - N^i_{j,f2}\lambda_{f2}\right)$$

- Scenarios
  - Different solar activity conditions
  - Different geomagnetic latitudes

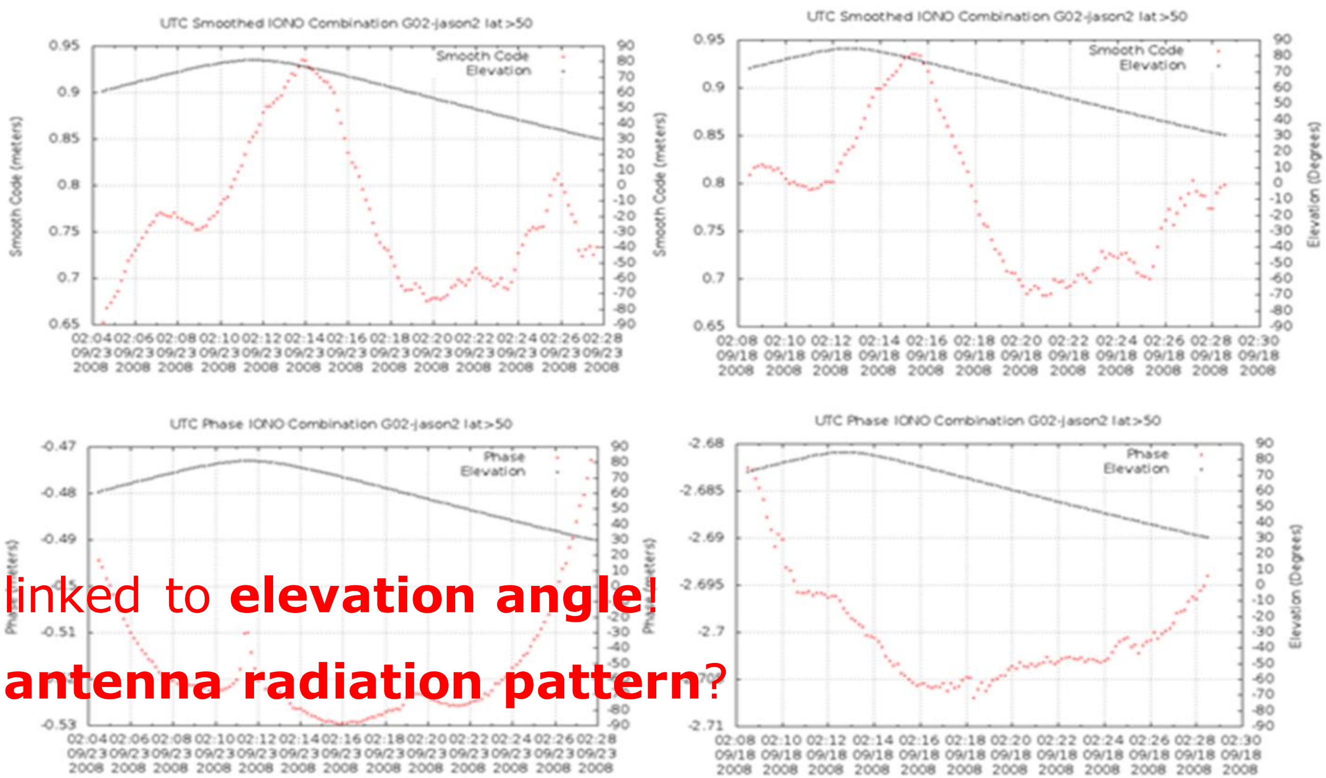


[P. Webb et al., *Electron density measurements of the plasmasphere: experimental observations and modelling studies*]

IONOSPHERE/PLASMASPHERE IMPACT

- Results
  - A clear repeatable pattern was detected for periods with the same geometry disposition of the sun, the GPS satellite and the LEO GNSS receiver

2008/267 **2008/262**



Example
- Jason 2 observables
- Geo lat > 50º
- IONO combination
  - Code evolution
  - Phase evolution

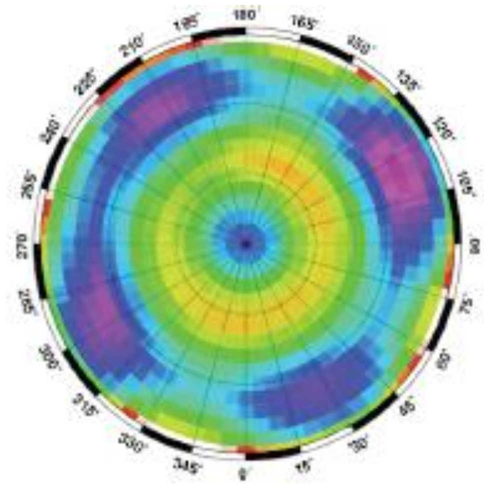
⇨ Repeatibility linked to **elevation angle!**

⇨ Effect of the **antenna radiation pattern**?

GROUP DELAY EFFECT ON LEO GNSS MEASUREMENTS

GNSS Antenna radiation pattern

- Same effect observed every 5 days (geometry LEO-GNSS satellite repetition cycle).
- Effect can vary up to 80 cm for IIR & IIR-M satellites.



[B. Haines et al., *Improved Models of the GPS Satellite Antenna Phase- and Group-Delay Variations Using Data from Low-Earth Orbiters*]

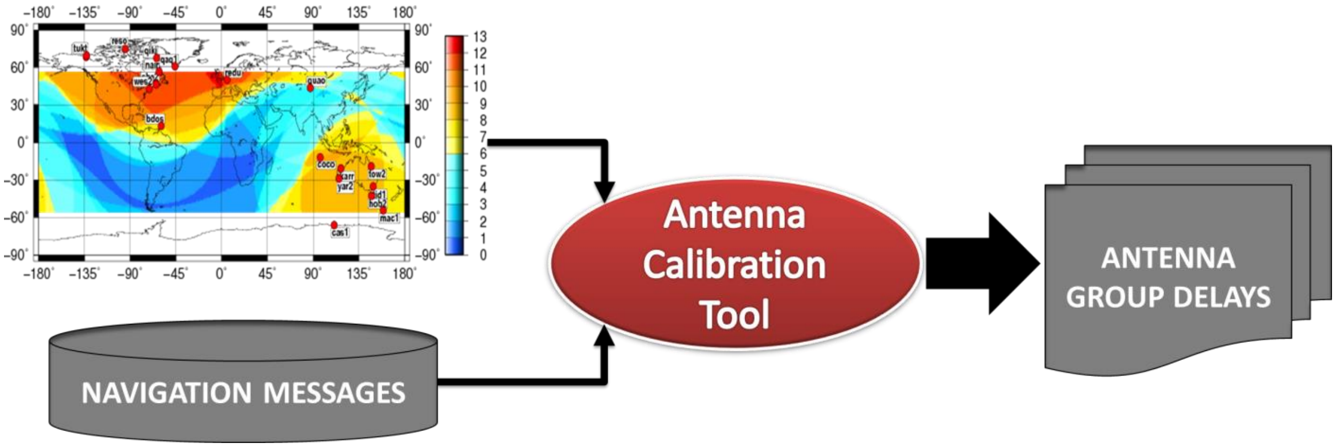
Both pseudorange and phase measurements are affected by HW biases and two components can be distinguished in each one:

- *Component 1: user dependent and attributed to the antenna (DOT Direction of transmition).*
- *Component 2: common for all users and attributed to the payload, and to the mean behaviour (among DOT) of the antenna.*

GROUP DELAY CALIBRATION ALGORITHM

Overview

- Input data:
  - Ionophere-free and geometry-free combination of phase and code observations
  - Several weeks of data from a dense station network (receivers without smoothing are preferred)
- Processing:
  - Observables processed in bins, depending on the nadir angle
  - Antenna contribution to phase measurements is corrected using IGS antex values



GROUP DELAY CALIBRATION ALGORITHM

Procedure

1. New observable (P) as combination of one code (C) and 2 phase (φ) measurements

$$P_a = C_a + k_a\varphi_a + k_b\varphi_b \mid K_a, K_b \text{ make } P_a \text{ iono\&geometry free}$$

$$P_a = \varepsilon(t) + \phi_{C_a}^{tx}(DOT,t) + k_a\phi_{\varphi_a}^{tx}(DOT,t) + k_b\phi_{\varphi_b}^{tx}(DOT,t) + \phi_{C_a}^{rx}(DOT,t) + k_a\phi_{\varphi_a}^{rx}(DOT,t) + k_b\phi_{\varphi_b}^{rx}(DOT,t) + N$$

2. Derivative wrt DOT to remove constant terms
3. Split into elevation bins and compute mean
4. Correct phase delays from IGS antex
5. The calibrated group delay is obtained by integrating the mean value per bin
   - Hypothesis: Receiver group delays are negligible when data are gathered with a high masking angle (<20º)

GROUP DELAY CALIBRATION RESULTS

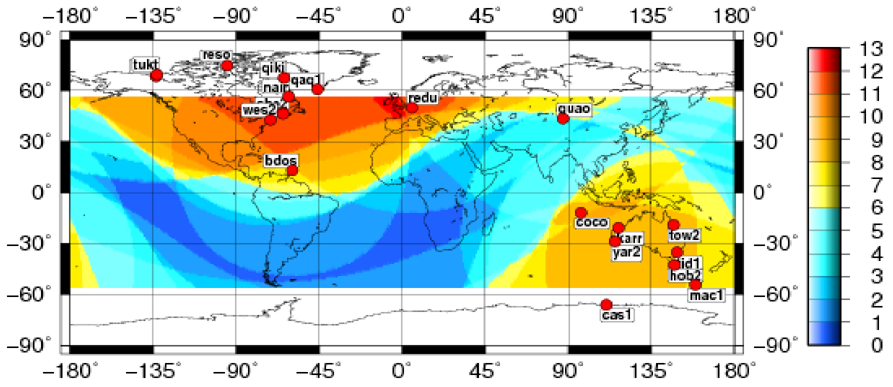
Objective:

- Calibrate antenna group delays (iono-free observables), i.e. the effect of the antenna radiation pattern

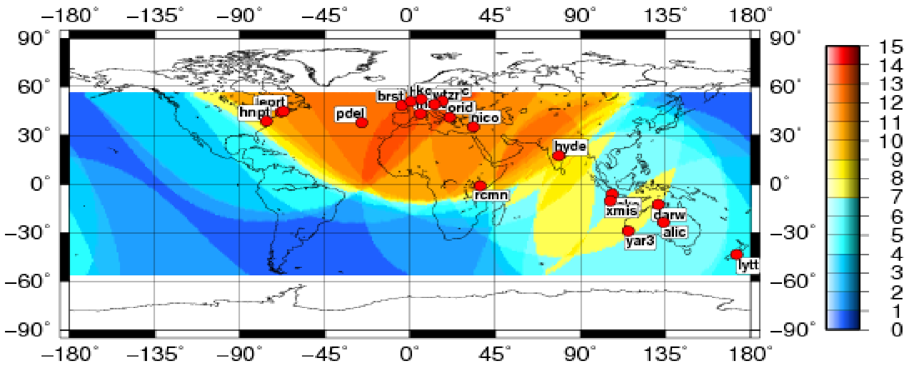
Scenarios:

- Minimum elevation = 20º, Bin size = 1º nadir
- Two station networks

Ashtech UZ-12 receivers

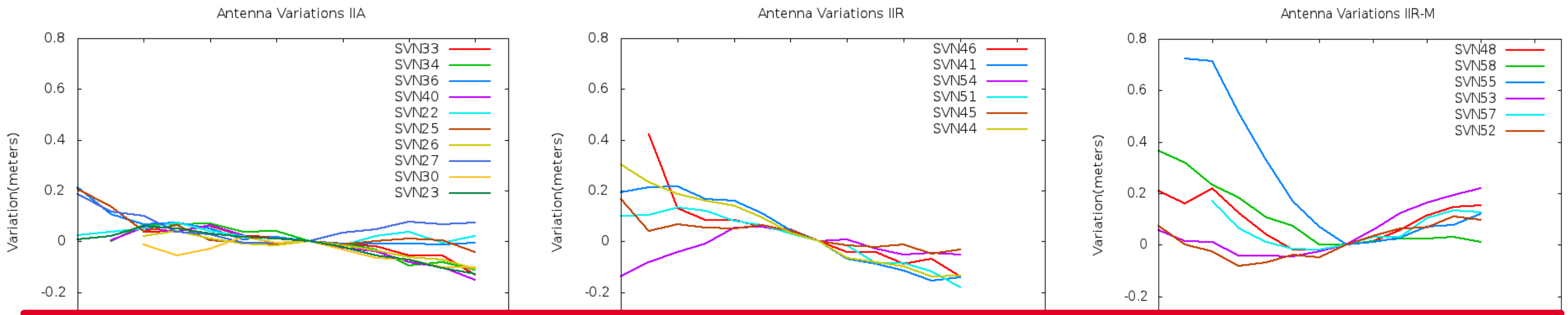


Leica GRX1200GGPRO receivers



GROUP DELAY CALIBRATIONS

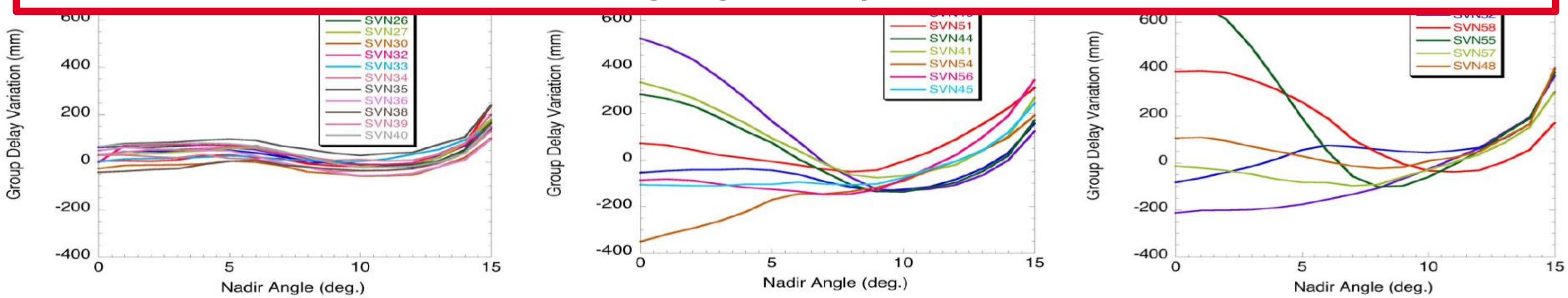
Ashtech UZ-12 Receiver (1 year)



JPL

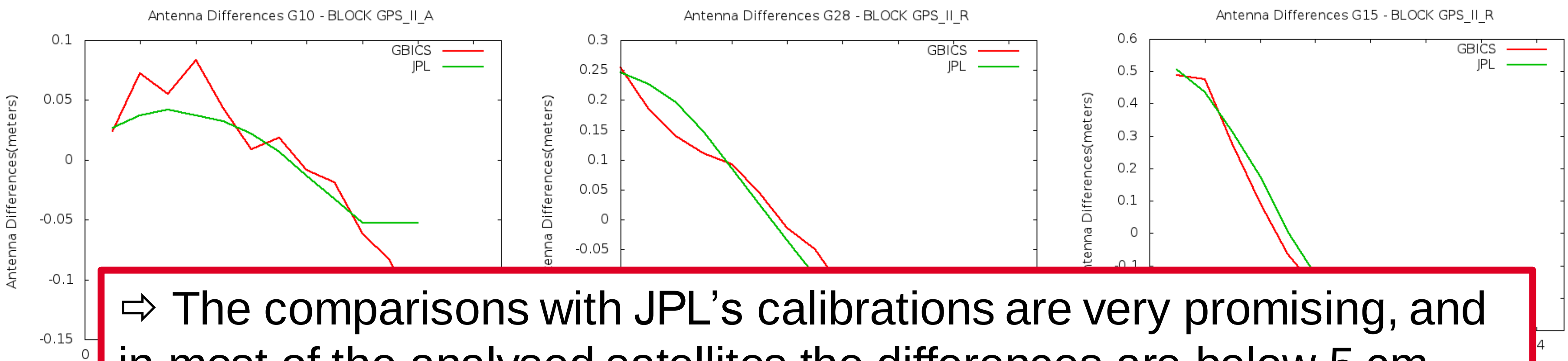
⇨ The proposed algorithm essence is correct and the antenna trends have been characterised

⇨ Special interest has the calibrations for satellites of blocks IIR and IIR-M, whose variations range goes up to 80 cm



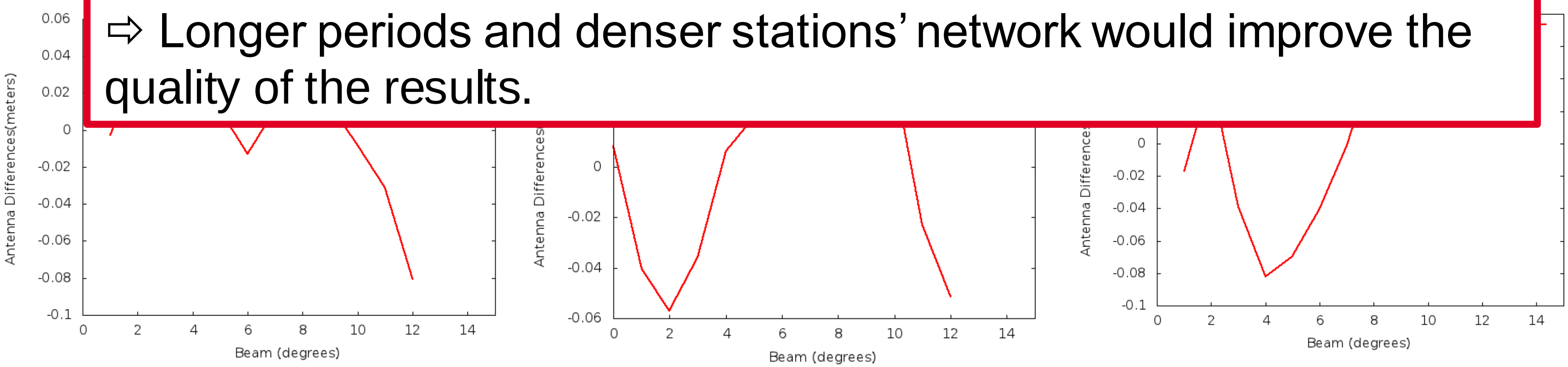
GROUP DELAY CALIBRATIONS

Comparing JPL and Ashtech



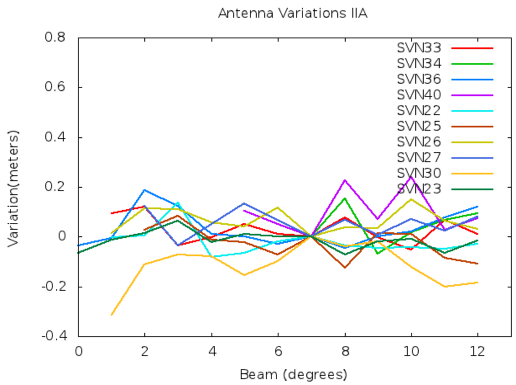
⇨ The comparisons with JPL's calibrations are very promising, and in most of the analysed satellites the differences are below 5 cm RMS.

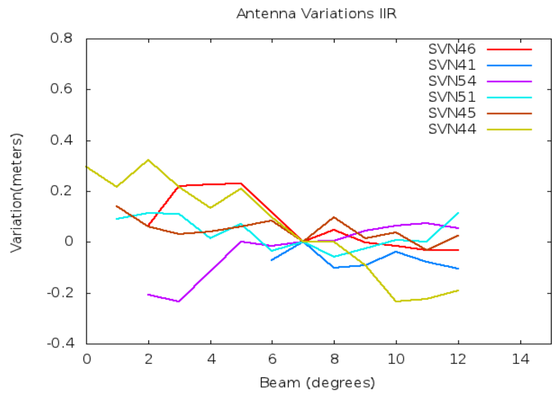
⇨ Longer periods and denser stations' network would improve the quality of the results.

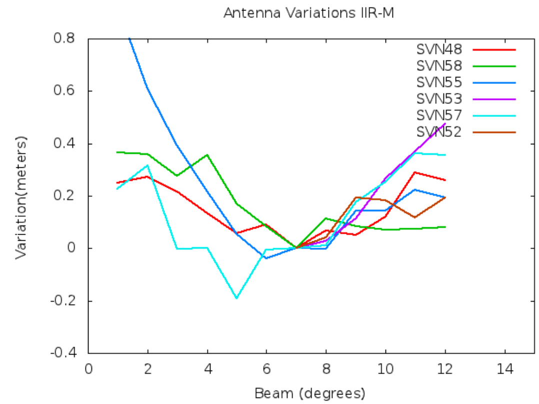


GROUP DELAY CALIBRATIONS

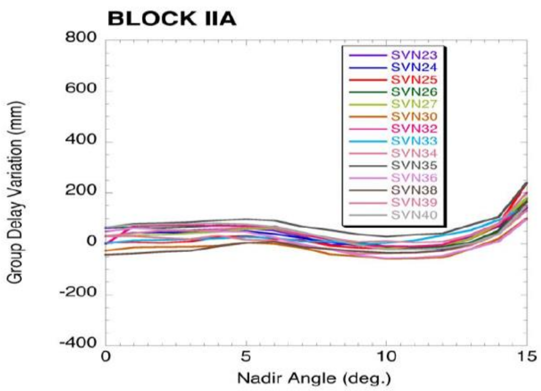
Leica GRX1200GGPRO Receiver (70 days)

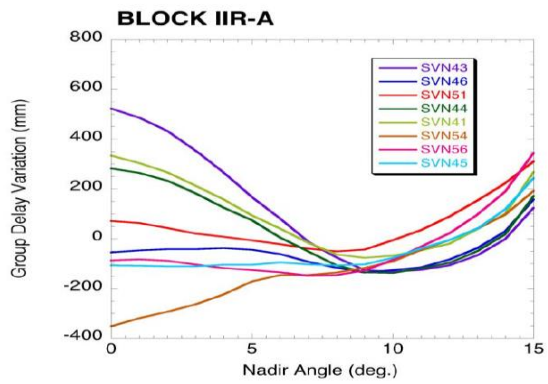


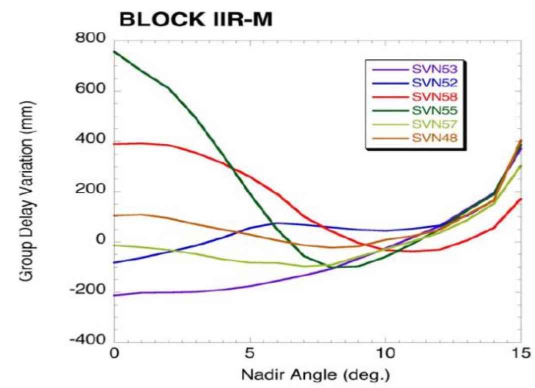




JPL's results based on GRACE data

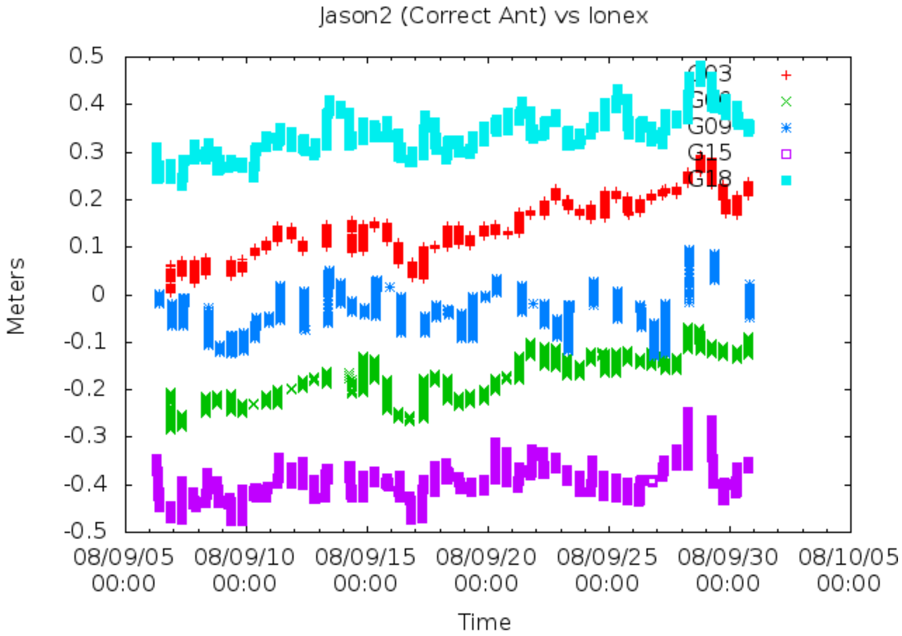


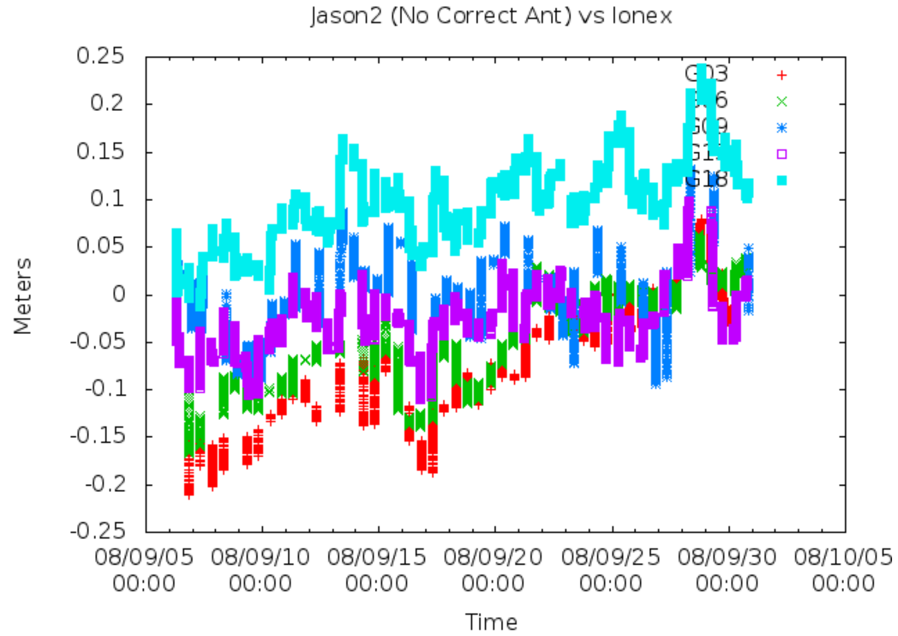




IMPACT ON CALIBRATED HW BIASES

Comparison with IONEX data





- More significant differences when correcting the antenna (IONEX calibrations do not take this effect into account)
- Bigger differences for block IIR and IIR-M satellites (antenna variations are bigger)

CONCLUSIONS

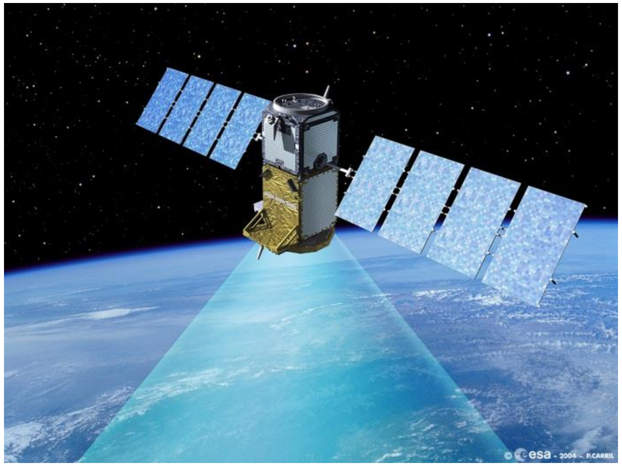
- The algorithm works correctly and the pattern of the group delay variations has been estimated properly.
- The effect of the antenna radiation pattern can vary up to 80 cm in blocks IIR and IIR-M.
- It is very important to use a dense station network and a period of at least one year to get fine results (JPL comparison <5cm RMS)
- The algorithm works with GNSS measurements from different receivers

Application of Calibrated HW Biases

- Better ionosphere delay estimation for SF users
- Better accuracy performance for DF and MF users thanks to the calibration of antenna group delays
- Improved performance for ionosphere applications

FUTURE WORK

- Data from receivers with same antenna model and with the same configuration
- Correct contribution of the receiver's antenna (group delay per signal)
- Discard measurements from satellites in eclipse
- Discard measurements during periods of fast attitude change (singular points of the attitude law)



Thank you