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Aliasing of GPS satellite phase centre model errors into site position time series

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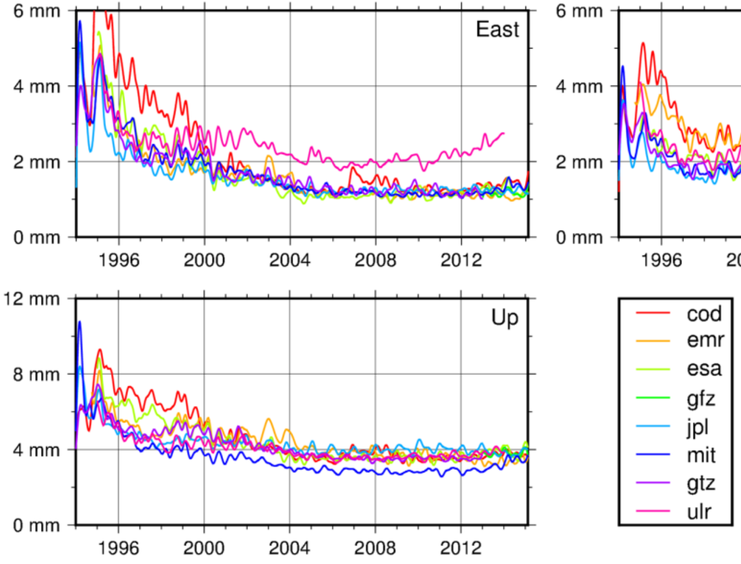
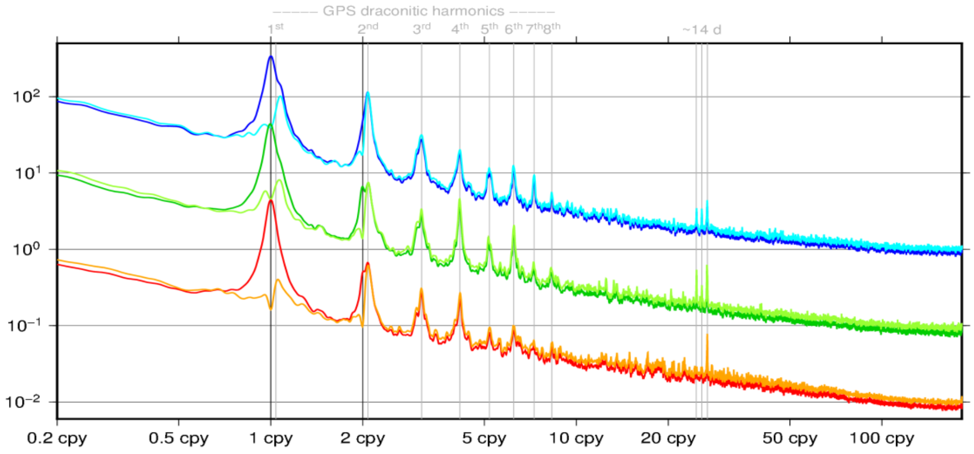
Motivation – Draconitic errors everywhere!



Smoothed daily WRMS of IGS AC – combined station position residuals



Rebischung et al, IUGG 2015

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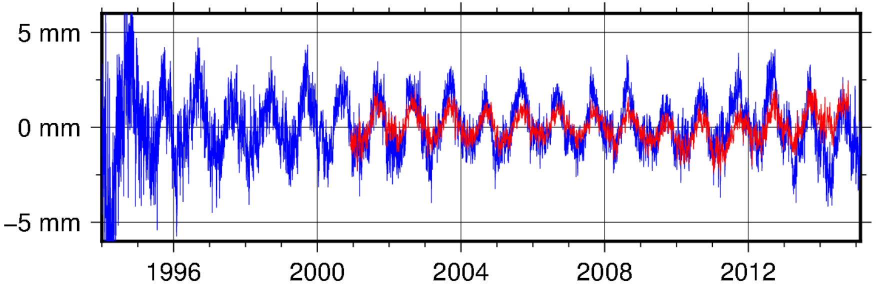
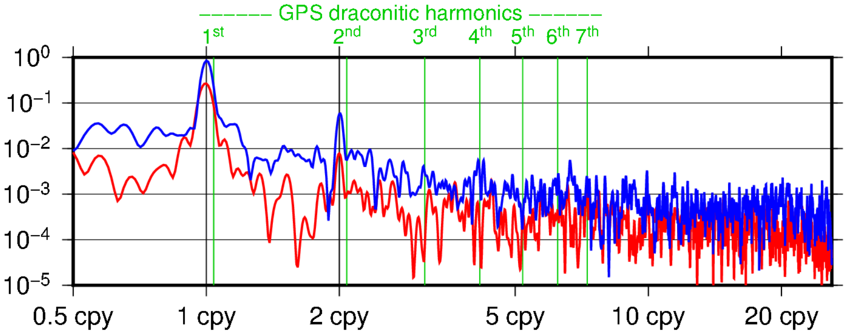
Motivation – Draconitic Errors

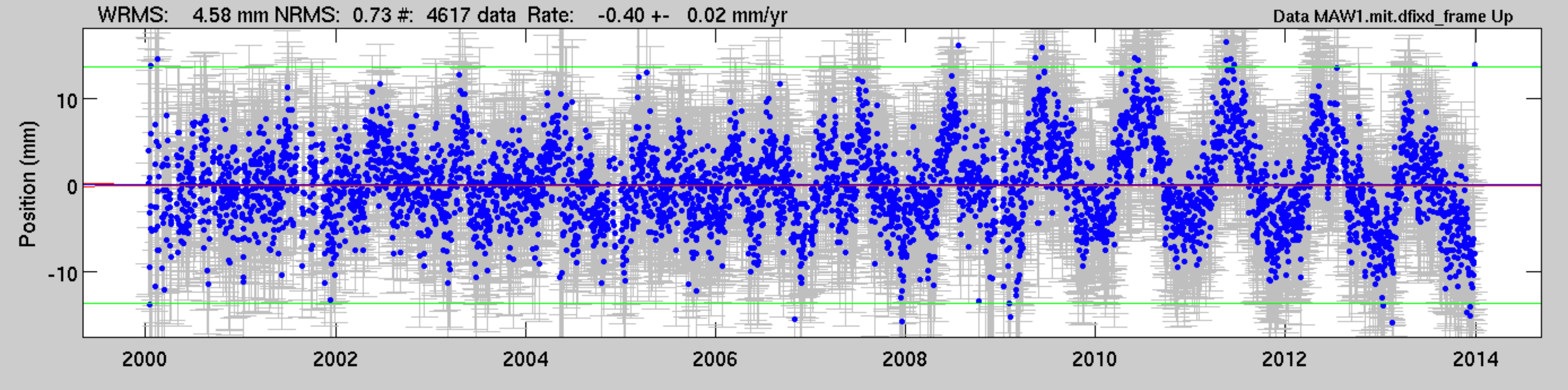




Scale factors estimated between the daily repro2 combined solutions and ITRF2008

Scale factors derived from a loading model (ECMWF+GLDAS+ECCO2; http://loading.u-strasbg.fr)

Motivation –MIT/ANU REPRO2 Antarctic time-series



- GPS time series for Antarctica station (MAW1) using standard MIT IGS REPRO2 analysis strategy and (IGS08_????.atx) values.
- Q: Is the periodic signal apparent after ~2008 geophysical in nature or spurious?

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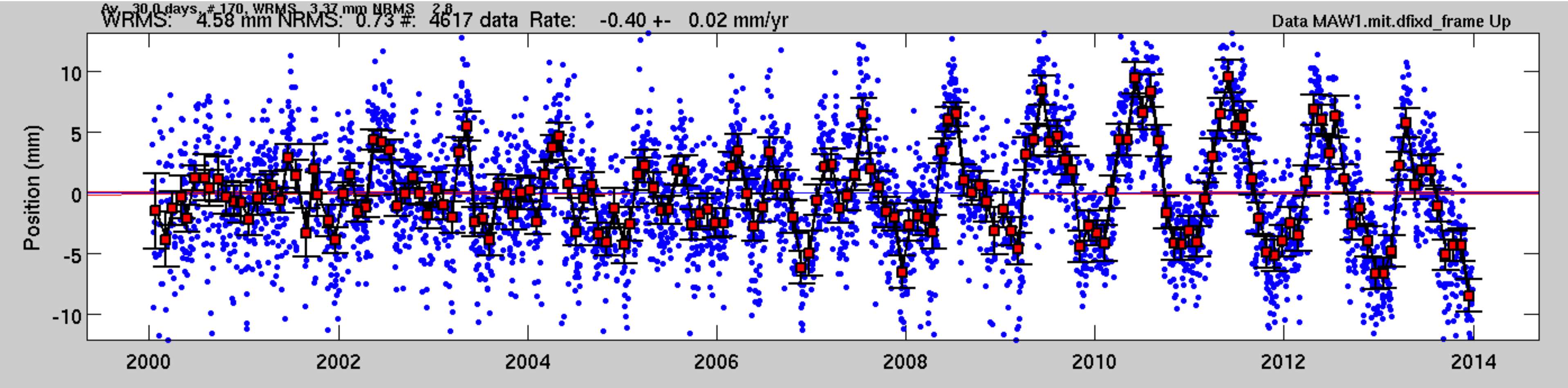
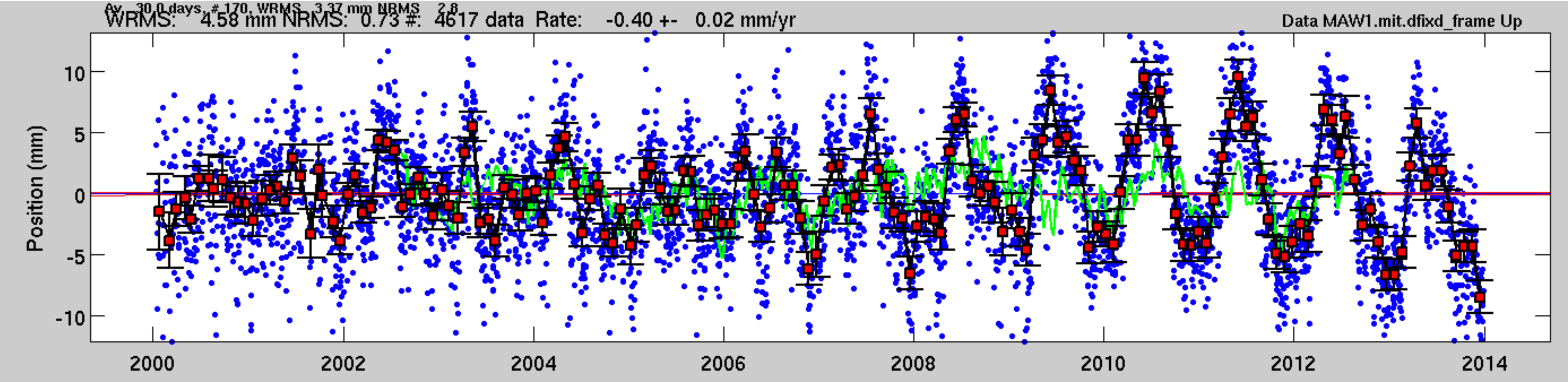
Motivation



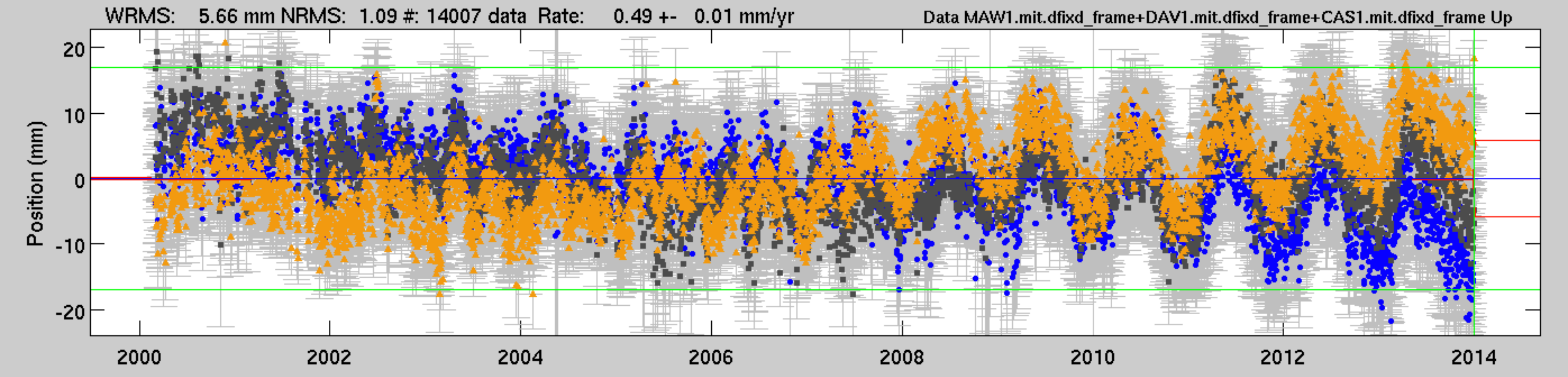
- Blue - Daily GPS time series for Antarctica station (MAW1) using standard MIT IGS REPRO2 analysis strategy and (IGS08_????.atx) values.
- Red - 30 day average values.

Motivation



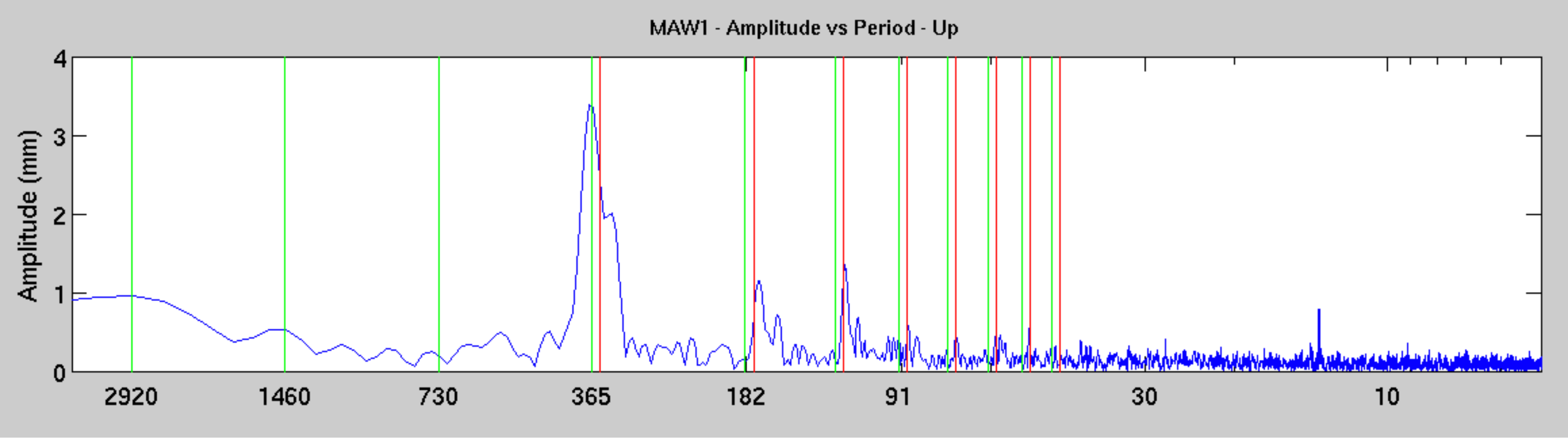
- 30 day average GPS time series for Antarctica station (MAW1).
- Green – Loading deformation at MAW1 derived from GRACE temporal gravity field (assuming all deformation is elastic).

Motivation



- Stack of MAW1, DAV1 and CAS1 time series show somewhat similar temporal behavior – periodic signal is largely, but not completely common mode….

MAW1 - Up component PDS



- MAW1 Lomb periodogram – Showing power spectral density in MAW1 Up component.
- Note significant power at solar annual GPS draconitic harmonics

GPS Satellite geometry

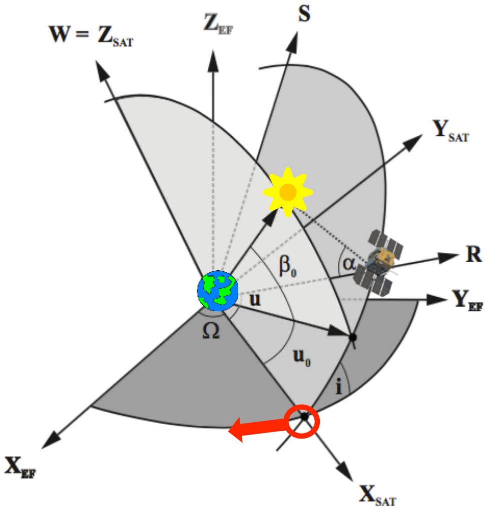


Fig. 1 Elevation of the Sun with respect to the orbital plane: Earth-fixed system $[X_{EF}, Y_{EF}, Z_{EF}]$, orbit system $[X_{SAT}, Y_{SAT}, Z_{SAT}]$, satellite system $[R, S, W]$. Right ascension of the ascending node Ω, argument of latitude u, inclination i, argument of latitude u_0 and elevation β_0 of the Sun. ⊙ symbolizes the Sun, ⊗ the satellite.

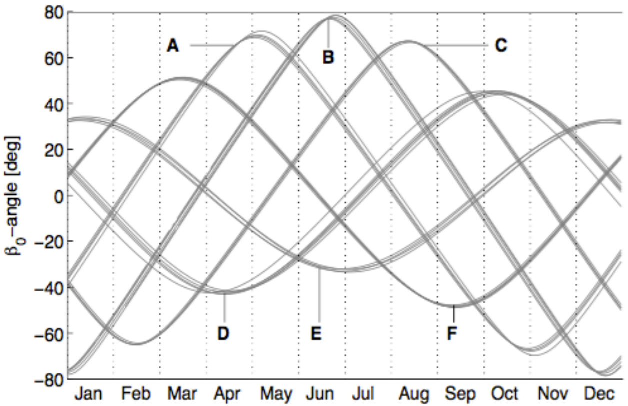


Fig. 2 Elevation of the Sun β_0 with respect to the orbital planes (A to F) for all GPS satellites in 2003.

$$\dot{\Omega} = -3\pi \frac{J_2}{T}\left(\frac{R_e}{a}\right)^2 \cdot \cos i = -14.1\,°/yr$$

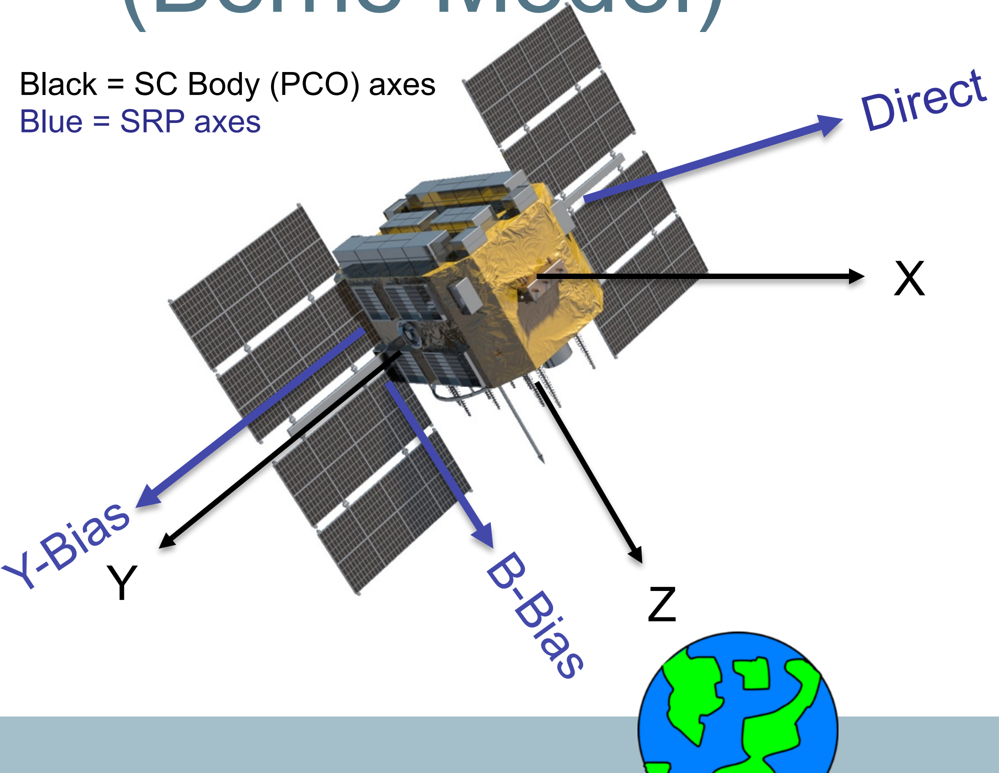
$$T_R = \frac{2\pi}{2\pi - \dot{\Omega}_{GPS} \cdot 1\ year} \cdot 365.25 \;\approx 351.5$$

Schmid et al, JoG 2007

GPS Satellite Geometry (summary)

- GPS ground tracks change only slowly with time as the longitude of ascending nodes (Ω) precesses (~-14.1°/yr ⇒ ~26 yr repeat cycle).
- This leads to GPS "draconitic" year is defined as the period (~351.5 days) with which the GPS constellation / Sun geometry repeats.
- Any systematic orbit errors related to SV / Sun geometry produce error with power at harmonics of the GPS draconitic year.
- Any systematic errors arising from mis-modeling of SV antenna offsets propagate into position errors in almost the same way each day.

GPS Solar radiation pressure model (Berne Model)

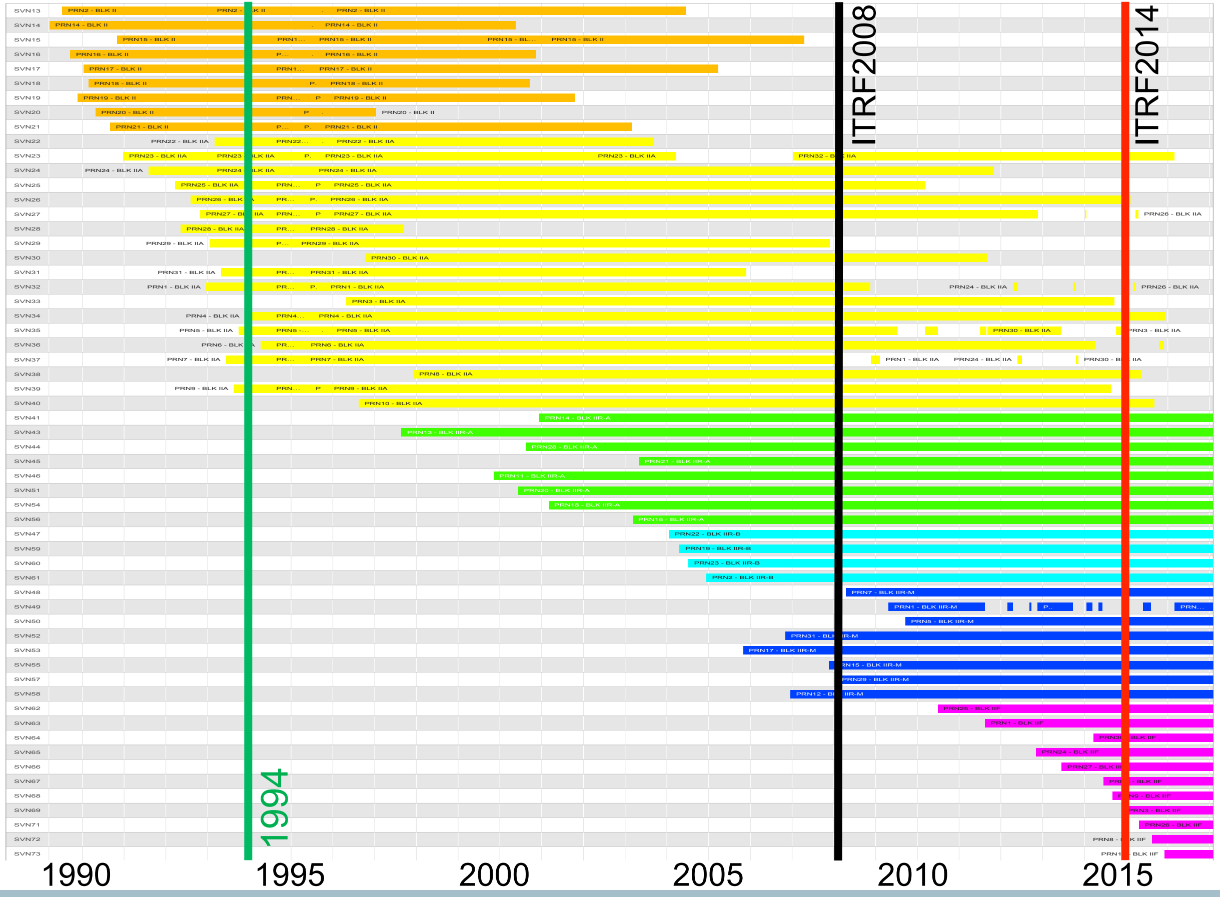


GPS SV Attitude Control (Kouba, 2008)

Attitude control of GPS satellites is dictated by two requirements or constraints, namely that the transmitting antenna always points toward the Earth and that the solar panel axis is perpendicular to the Sun direction to ensure that the panels are facing the Sun. These requirements necessitate that the satellites constantly rotate (yaw) along the antenna axis, which points toward the Earth. The *nominal yaw attitude* has the body-fixed *Z*-axis pointing to the Earth, the *Y*-axis is along the solar panels and perpendicular to the Sun direction, and the *X*-axis points either toward the Sun for Block II, IIA or away from it for Block IIR satellites, and it completes the right-handed coordinates system.

Constellation Evolution

SV BLOCK	1994	2008	2015
I	6	0	0
II	9	0	0
IIA	14	16	5
IIR-A	0	8	8
IIR-B	0	4	4
IIR-M	0	3	7
IIF	0	0	7



GPS antenna phase center models

Schmid & Rothacher, 2003

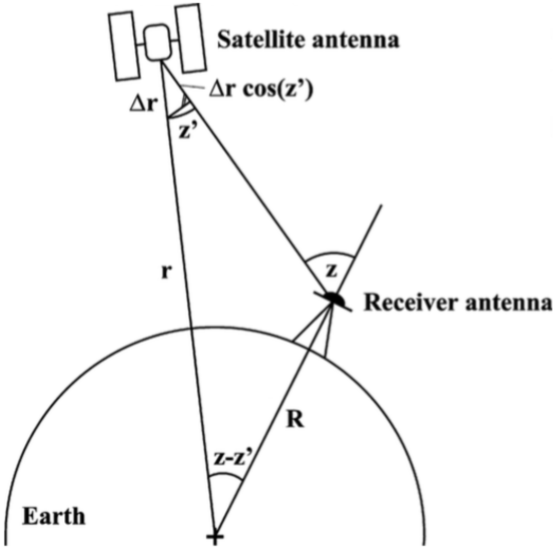


Fig. 2. Relationship between satellite and receiver antenna phase center variations, respectively between phase center offset and pattern

An easy one-to-one relationship exists between the elevation-dependent fractions of the two patterns (satellite and receiver antenna) (Rothacher 2001). The nadir angle z' at the satellite is related to the zenith angle z for the receiver at the ground by

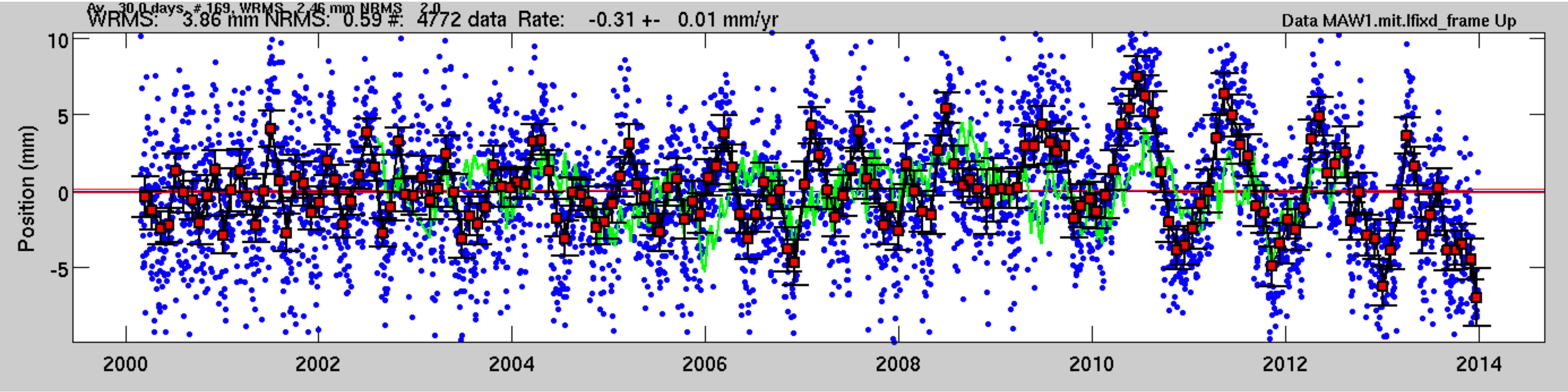
$$\sin(z') = \frac{R}{r}\sin(z) \quad (1)$$

Another correlation exists between phase center offsets and variations. In the satellite case a change Δr of the antenna phase center offset in the nadir direction can be interpreted as a cosine-dependent change of the phase pattern that is given by (see Fig. 2)

$$\Delta\phi'(z') = -\Delta r \cdot (1 - \cos(z')) \quad (5)$$

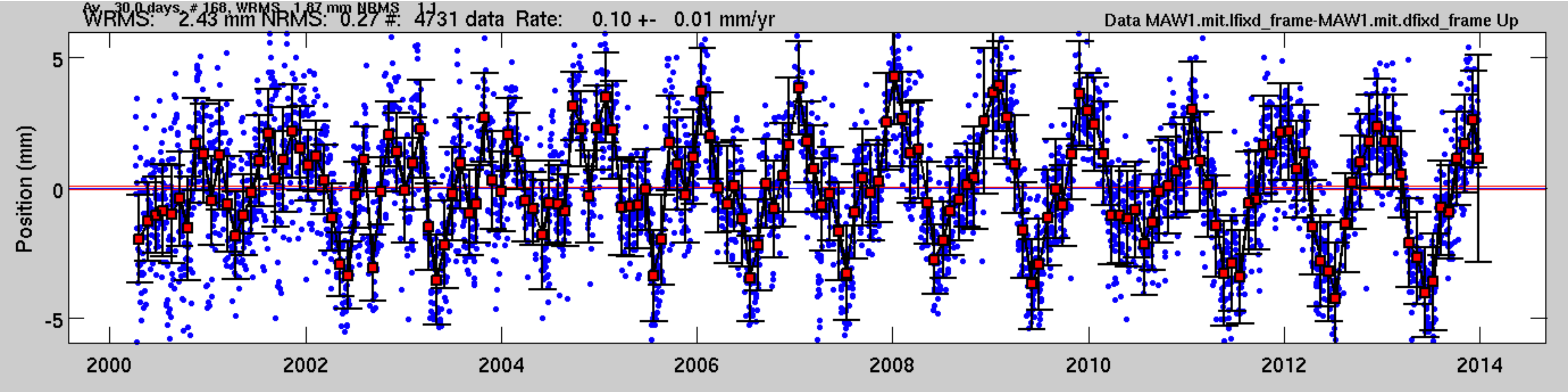
Thus, we have four fully correlated parameter groups (satellite and receiver antenna phase center offsets and variations) that cannot be estimated simultaneously from GPS data, i.e. three of the four have to be fixed. Furthermore, not only receiver antenna phase center offset and variation values have to be used consistently: introducing satellite antenna phase center offset and variation parameters requires four consistent parameter sets.

MAW1 - PCO's Estimated



- 30 day average GPS time series for Antarctica station (MAW1) using standard MIT IGS analysis strategy and (IGS08_????.atx) values. **<u>Daily PCO's estimated</u>.**

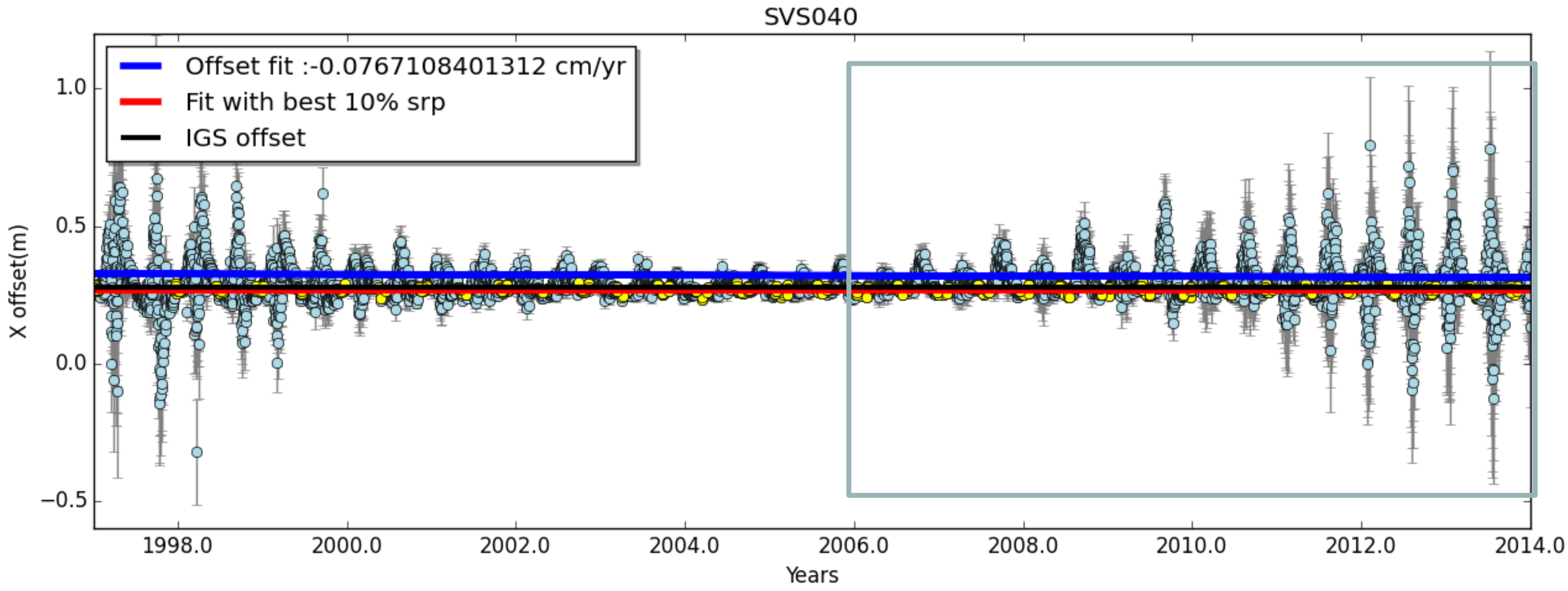
PCO Fixed vs Free



- Difference between MAW1 time series where; 1) SV PCO offsets are fixed to IGS08_????.atx values and 2) PCO offsets are estimated daily.

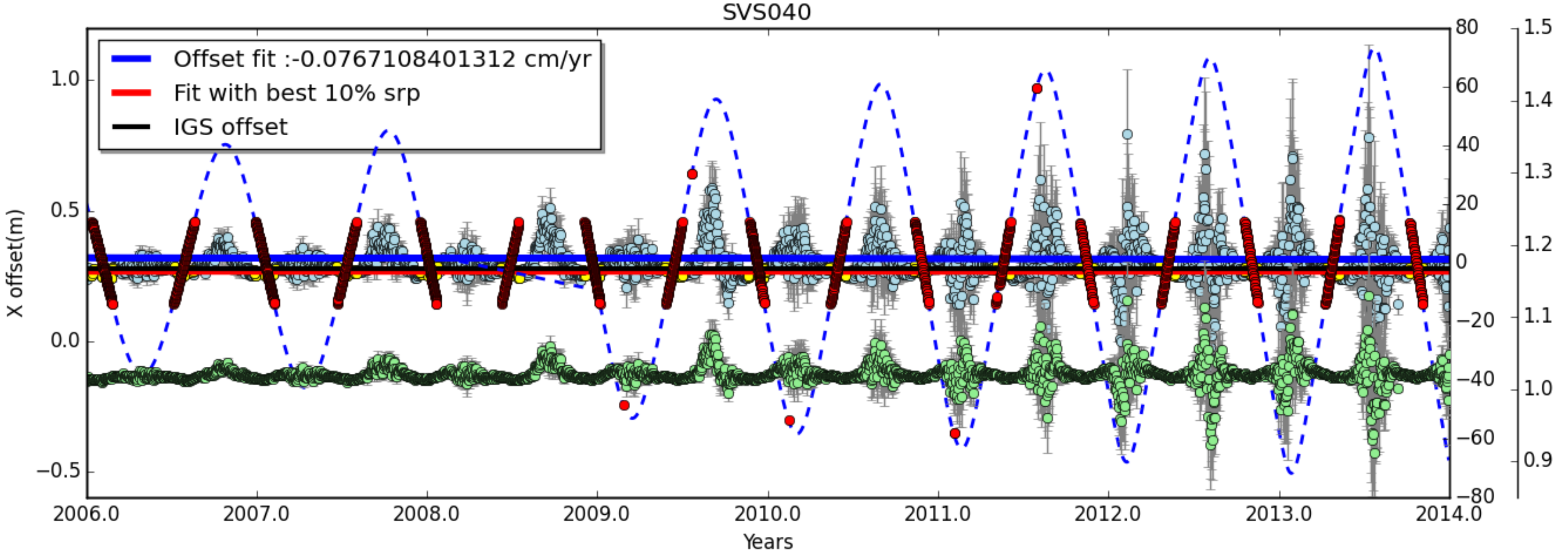
SVN 40 X-PCO

Z PCO Est, Beta Ang., Eclipse, D-Rad, Best 10% σ



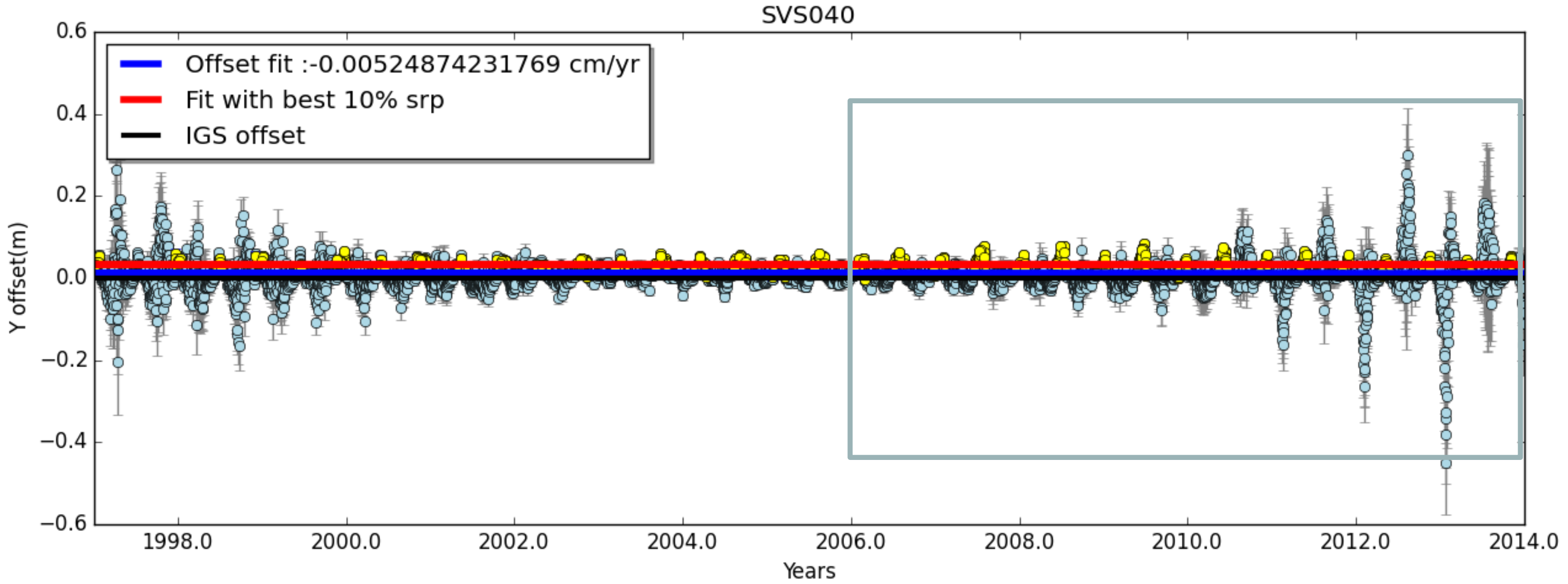
SVN 40 X-PCO

Z PCO Est, Beta Ang., Eclipse, D-Rad, Best 10% σ



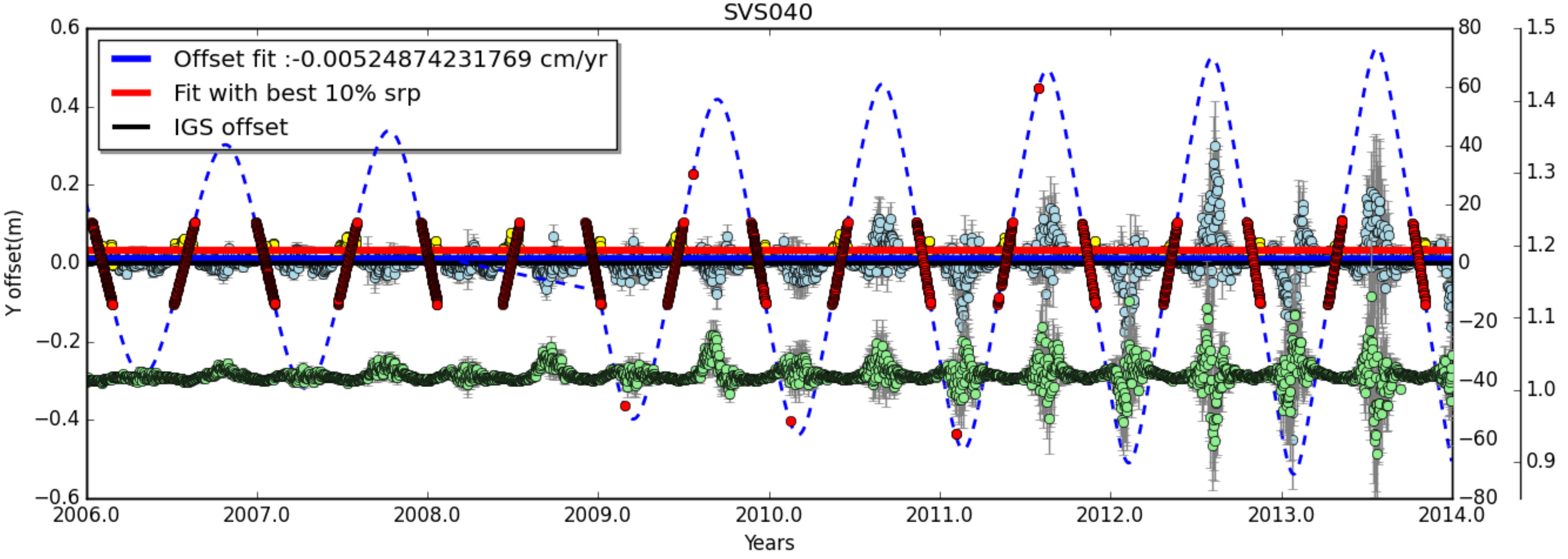
SVN 40 Y-PCO

Z PCO Est, Beta Ang., Eclipse, D-Rad, Best 10% σ



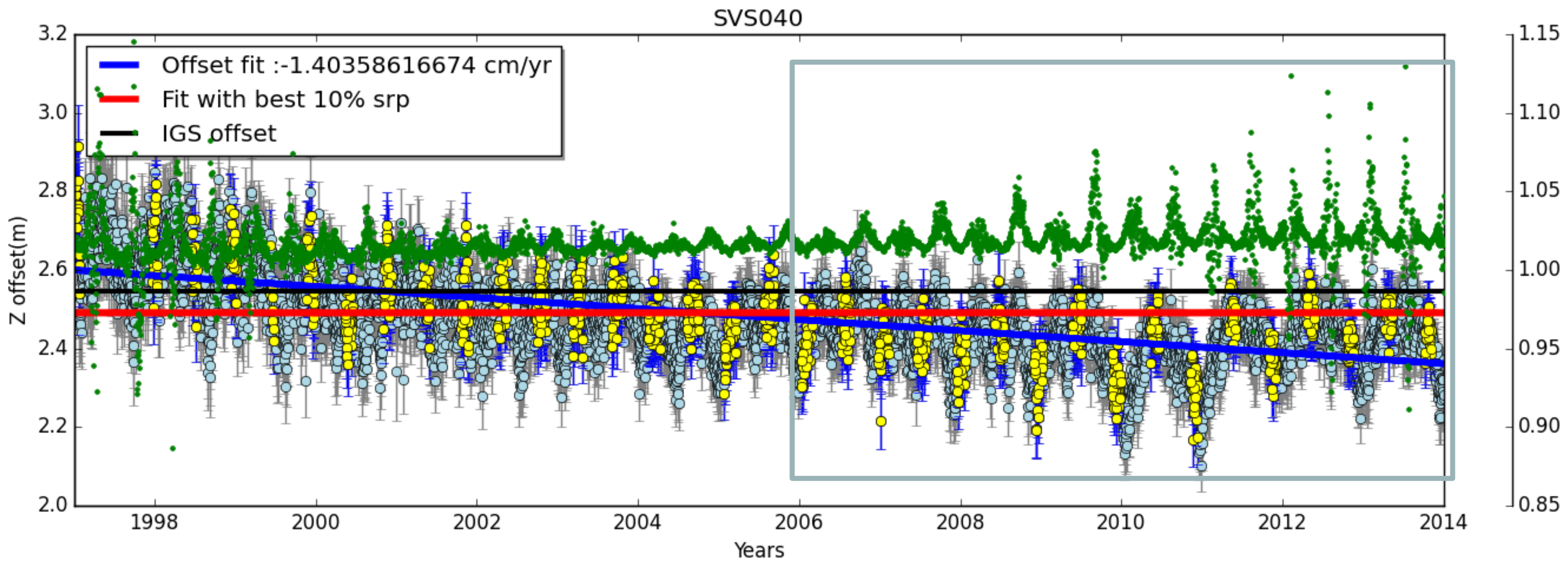
SVN 40 Y-PCO

Z PCO Est, Beta Ang., Eclipse, D-Rad, Best 10% σ



SVN 40 Z-PCO

Z PCO Est, Beta Ang., Eclipse, D-Rad, Best 10% σ



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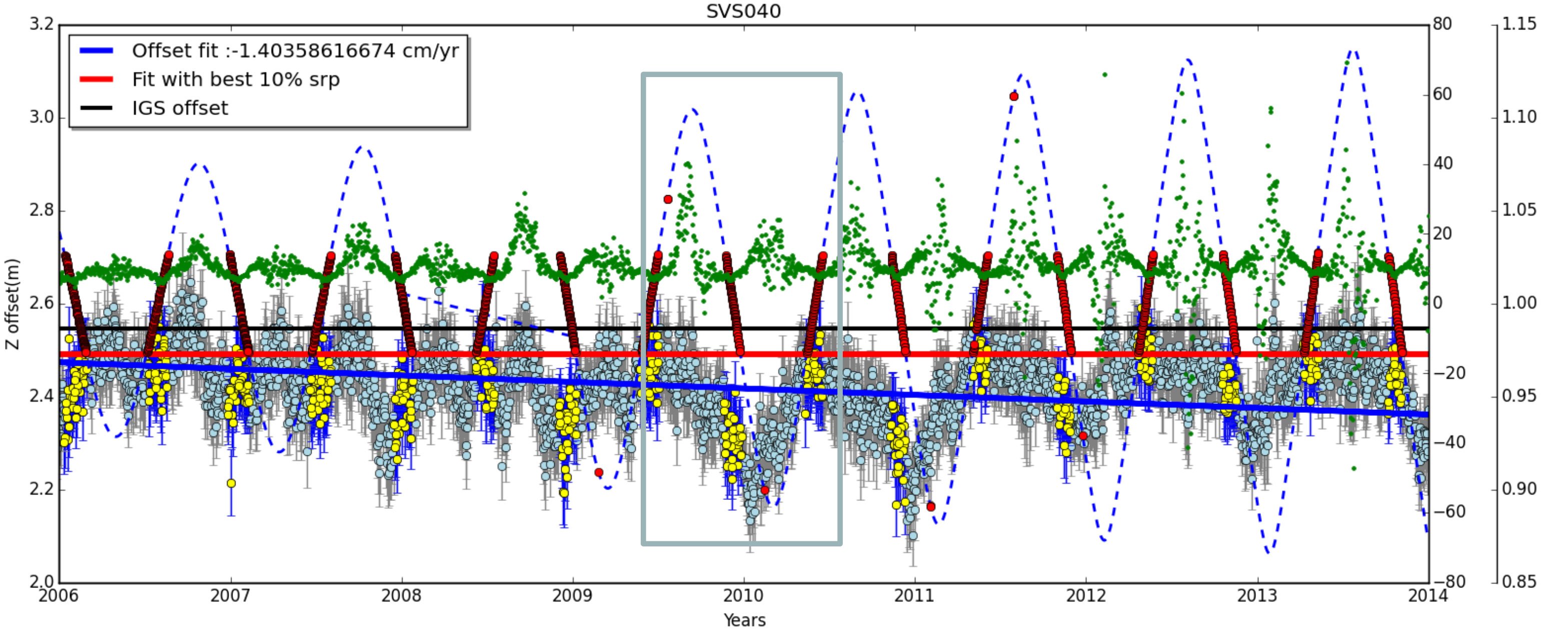
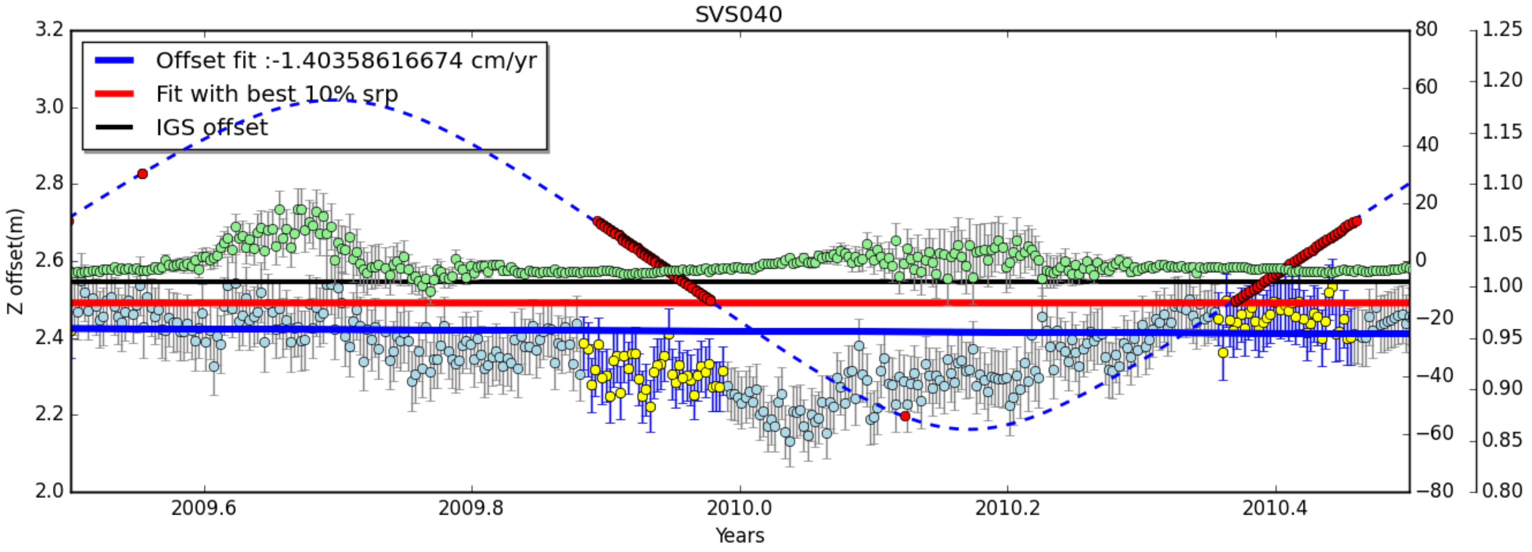
Z PCO Est, Beta Ang., Eclipse, D-Rad, Best 10% σ

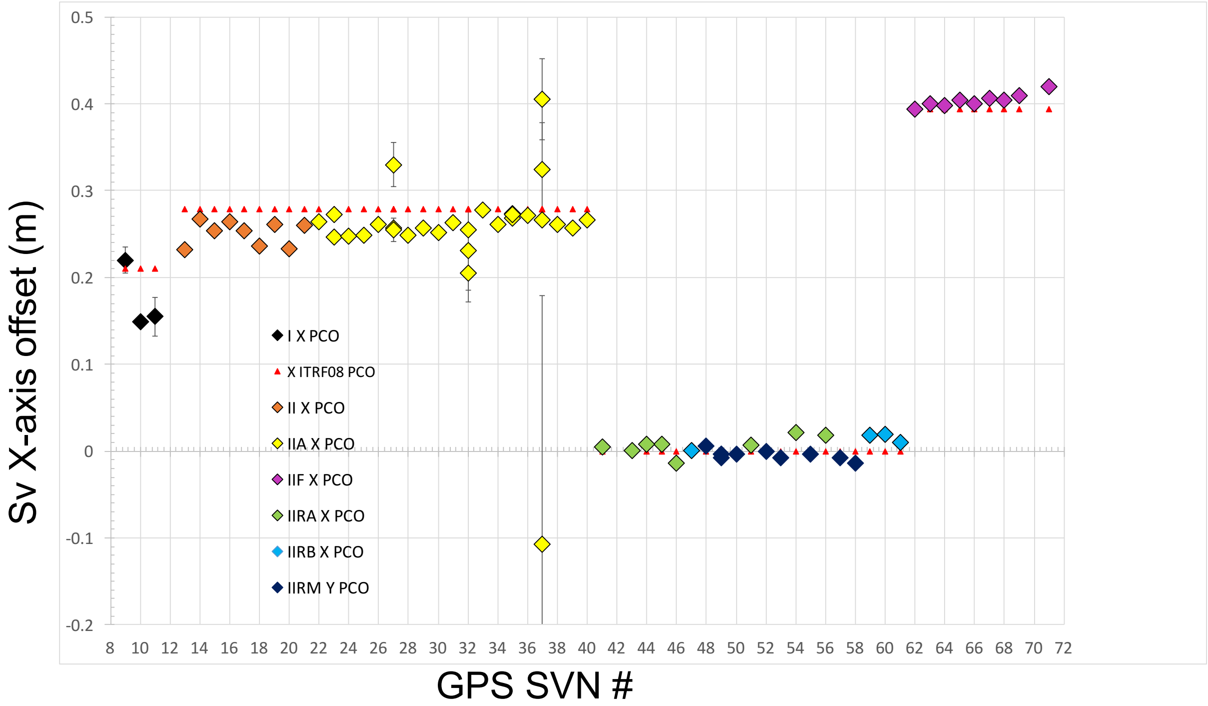


SVN 40 Z-PCO

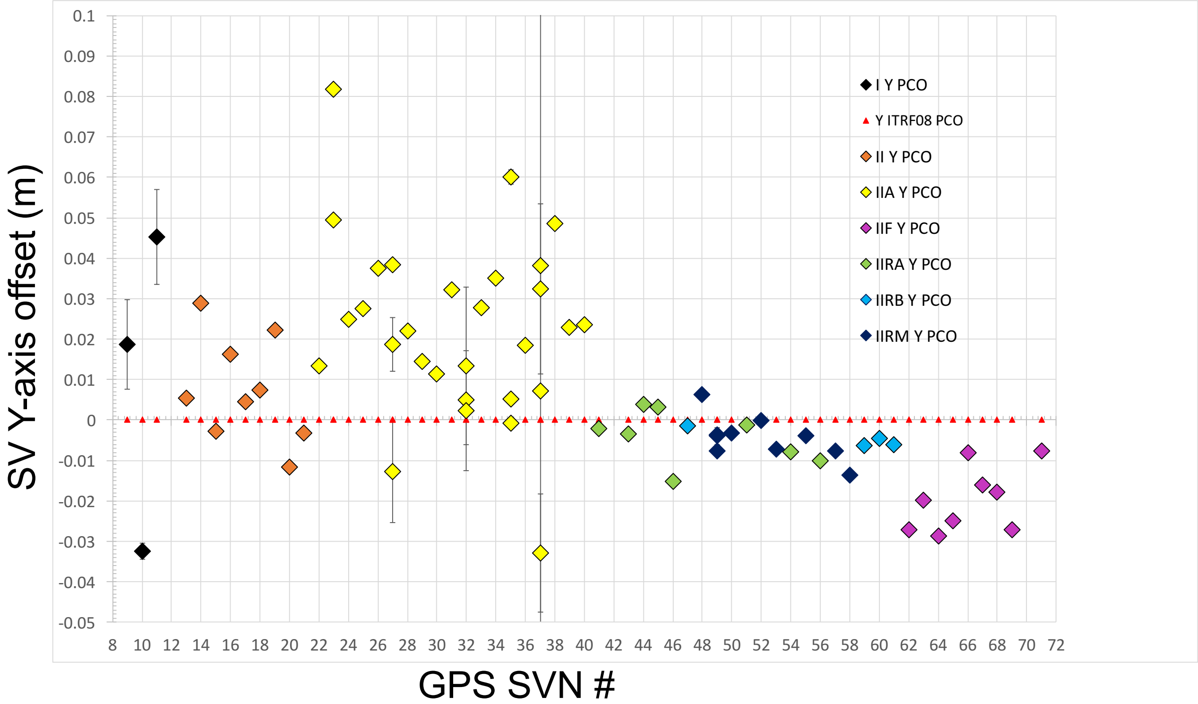
Z PCO Est, Beta Ang., Eclipse, D-Rad, Best 10% σ



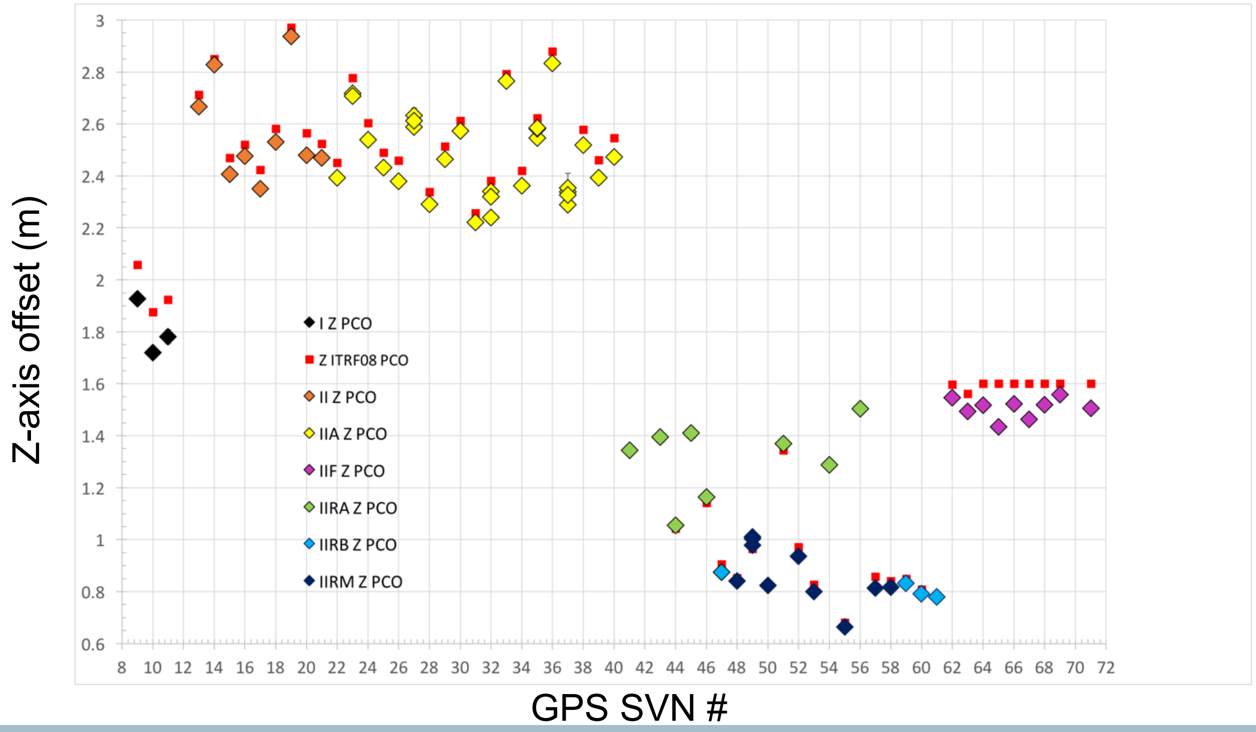
MIT.atx GPS Satellite X-axis PCO offsets



MIT.atx GPS Satellite Y-axis PCO offsets



MIT.atx GPS Satellite Z-axis PCO offsets



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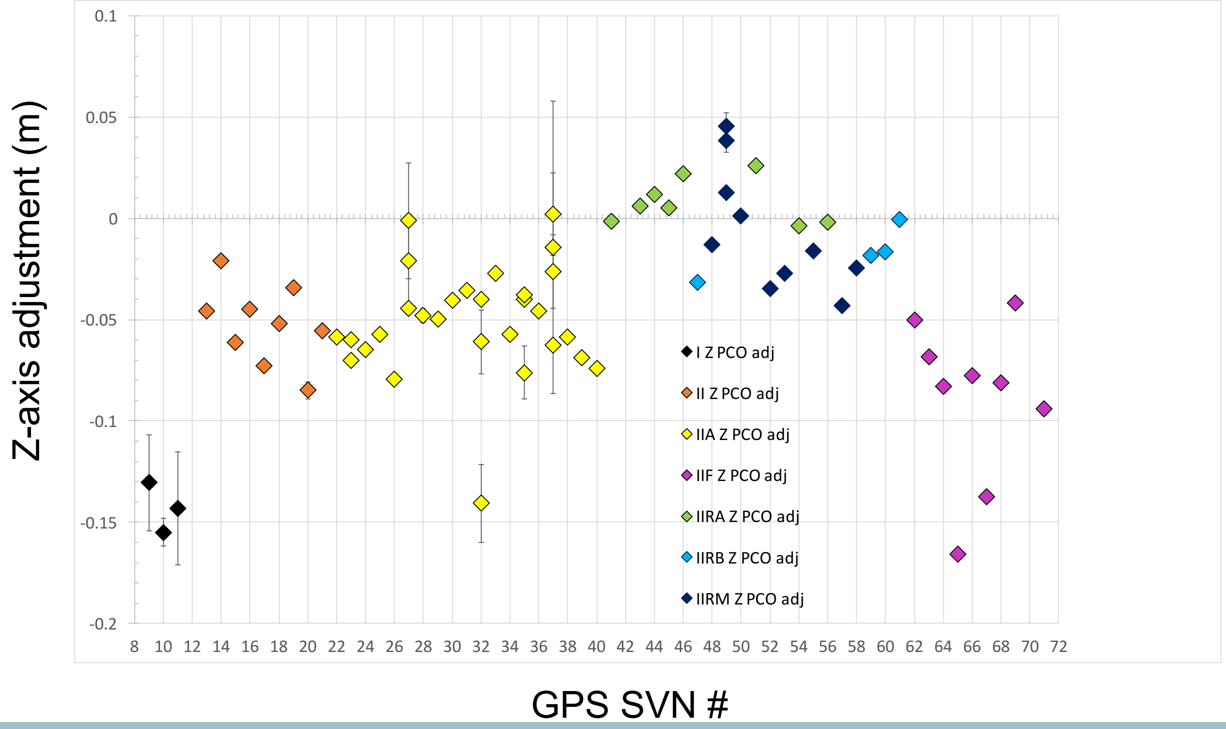
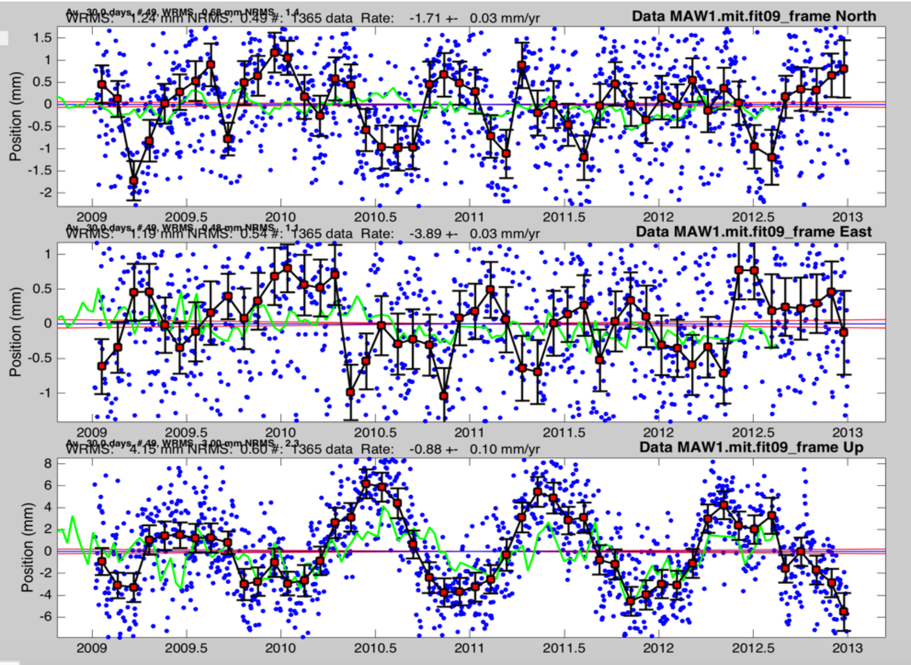
GPS Satellite Z-axis PCO offsets

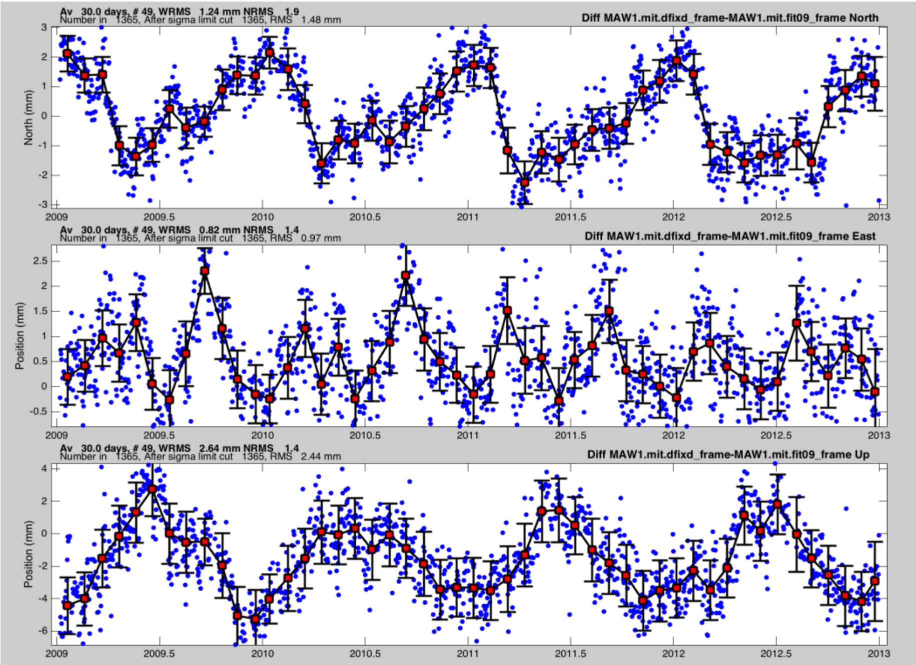


Does it make a difference

MAW1 time series: MIT.atx



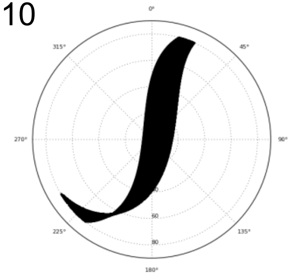
MAW1 time series: IGS08.atx - MIT.atx



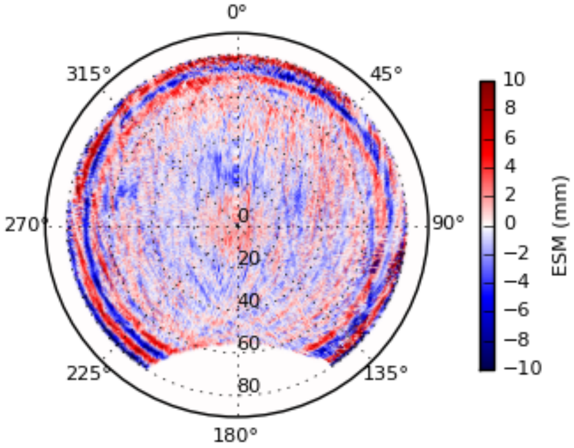
MAW1 time series (IGS08.atx PCO – ANU.atx estimated PCO’s)

GPS Satellite PCV antenna errors

4 year ground track for PRN 10



COCO Ground Ant PCV



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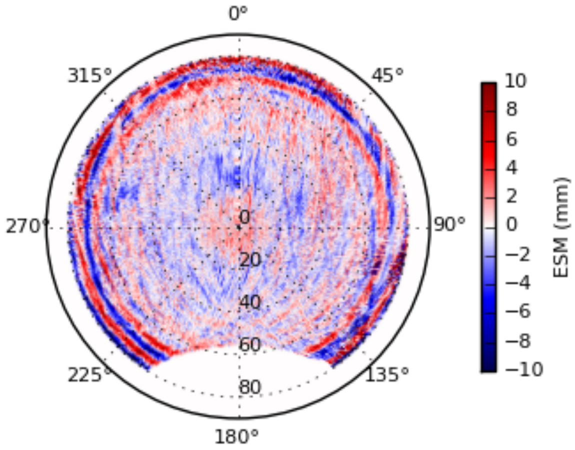
COCO ground Ant PCV + SV PCV



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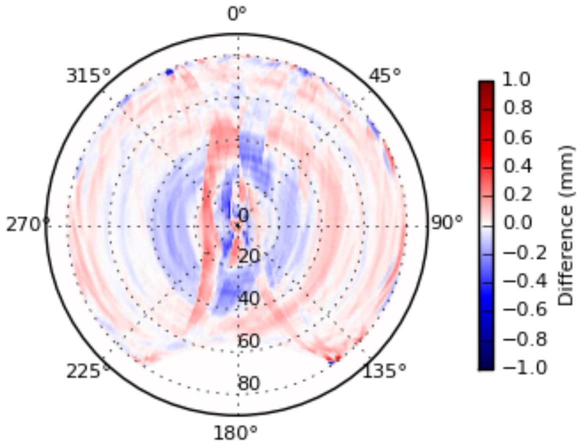
Difference

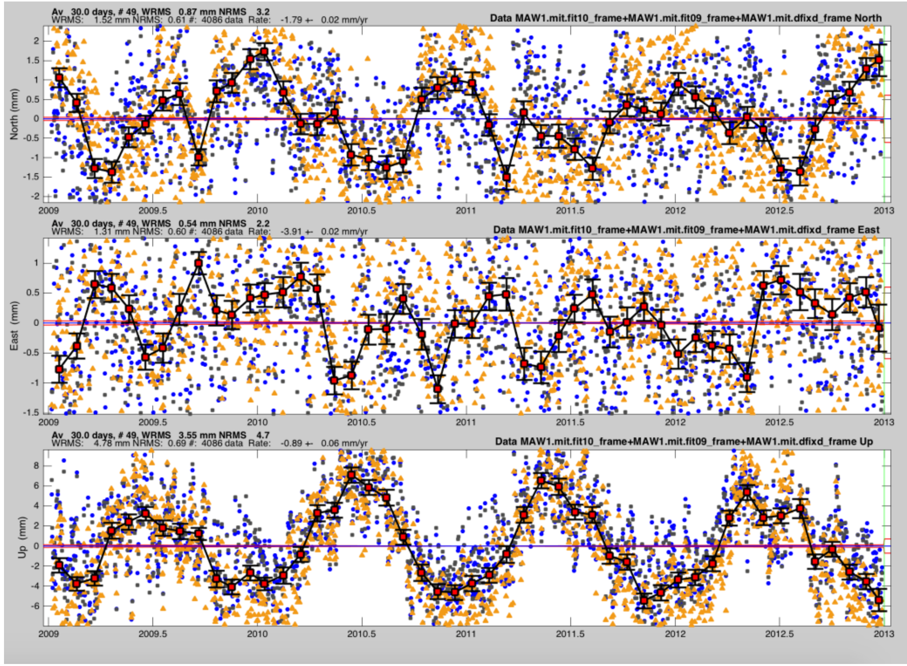


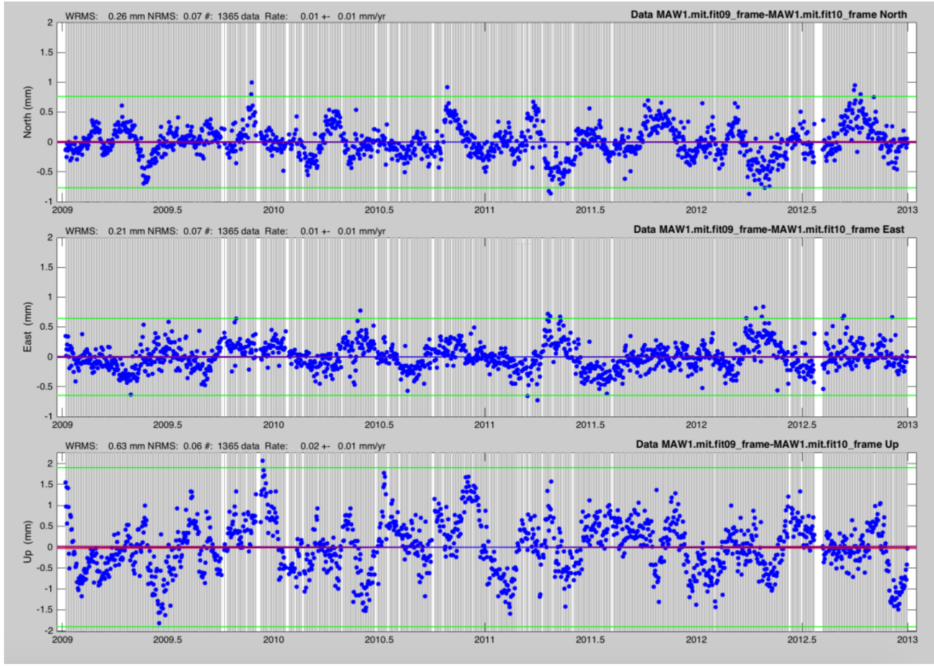
Summary

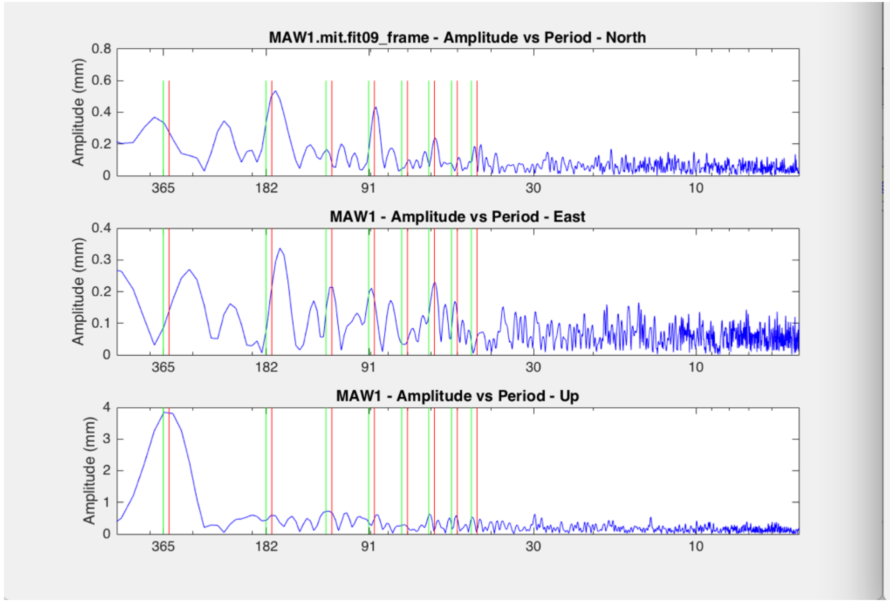
- ITRF2008 SV PCO's and PCV's (igs08.atx) are biased.
- PCO estimates highly correlated with SV radiation pressure estimates (more work needed on SRP's)
- How best to estimate PCO's (All data best data - work in progress)
- GPS satellite PCO errors are a significant source of "Draconitic" error in GPS time series.

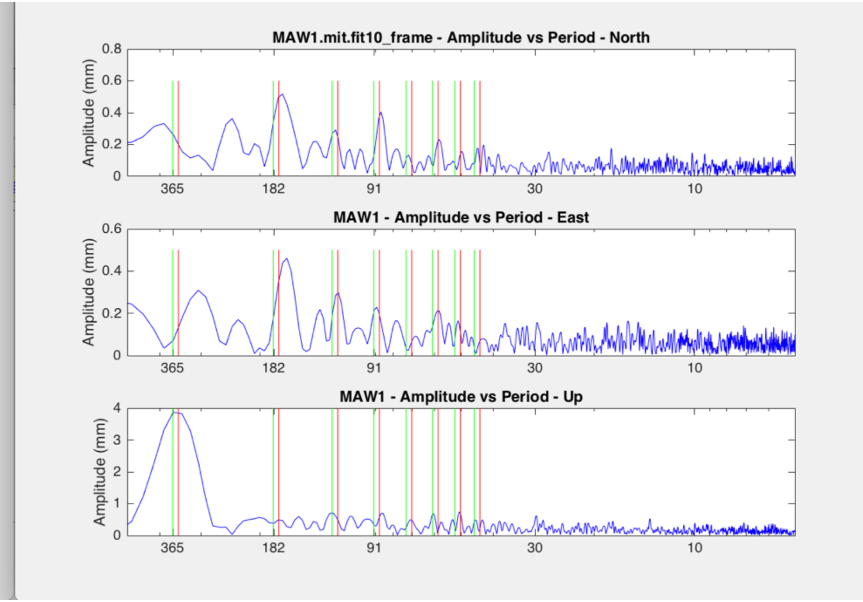
Spare Slide

Using only MIT.atx Z-PCO estimate






MAW1.mit.fit09_frame - Amplitude vs Period - North
MAW1 - Amplitude vs Period - East
MAW1 - Amplitude vs Period - Up
Amplitude (mm)
365
182
91
30
10


MAW1.mit.fit10_frame - Amplitude vs Period - North
MAW1 - Amplitude vs Period - East
MAW1 - Amplitude vs Period - Up
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365
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