



The SLR Contribution to Precision Orbit Determination in the GPS Era

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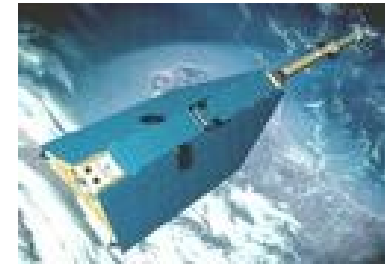


Over the past decade significant advances in the Global Positioning System (GPS), and GPS data processing algorithms and data distribution, have positioned this technology as the primary tracking to support POD in the new era of geodetic satellites.

Jason-1



CHAMP



A new generation of geodetic missions all carry aboard a dual frequency codeless GPS receiver (BlackJack) as the primary POD tool.

ICESat



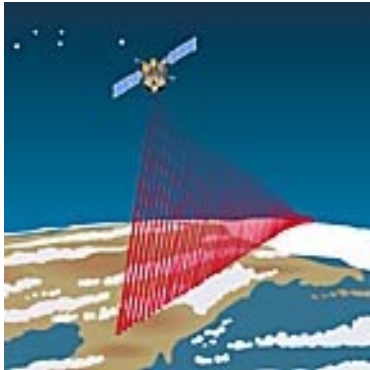
They also carry a SLR RR.

GRACE

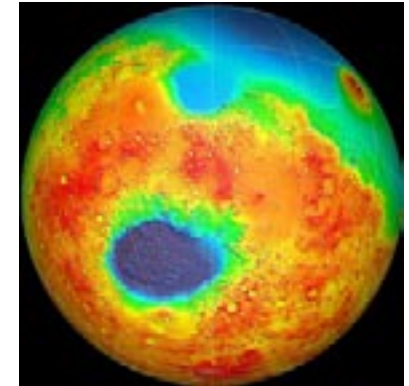




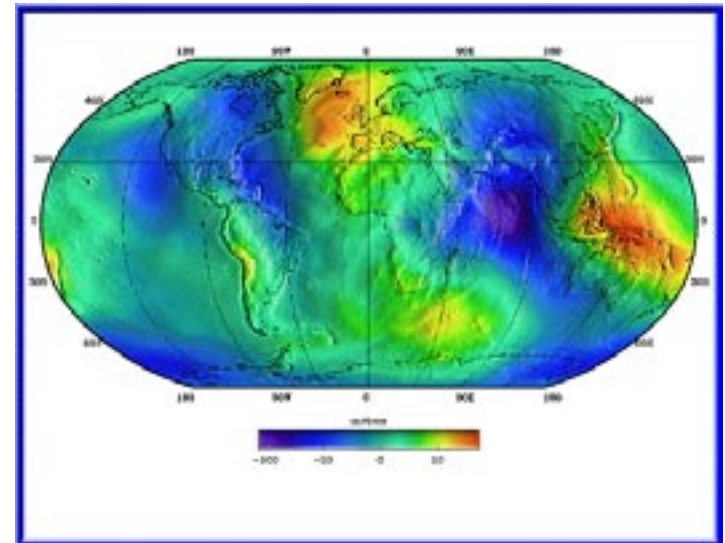
Precision Orbit Determination (POD) is a fundamental component in meeting the science goals of geodetic spaceflight missions.



For satellite radar and laser altimetry, POD enables science objectives such as the study of ocean, ice and land topography and surface change



Additionally, in several other applications, such as reference frame and gravity field determination, science is derived directly from the POD.





These new missions must take advantage of the GPS tracking geometry and near continuous coverage to meet their aggressive orbit accuracy requirements – especially true for the low altitude missions such as GRACE and CHAMP.

Jason-1 has a radial orbit accuracy goal of 1 cm !

The size of a dime!





Can the GPS alone meet the Jason 1-cm goal?

First glance at our GPS POD results might tempt you to say yes.

Jason-1 POD Summary Statistics Cycle 9 (10-days)

Solution Type	DORIS		SLR		Altimeter Xovers		SLR Hi Elev	
	# Pts.	RMS (mm/s)	# Pts.	RMS (cm)	# Pts.	RMS (cm)	# Pts.	RMS (cm)
SLR+DORIS	111304	0.402	3716	1.34	4185	6.04		
GPS	108405	0.401	3709	1.67	4185	5.76	189	1.1

Orbit Difference – SLR/DORIS vs. GPS

Radial RMS (cm)	Cross Track RMS (cm)	Along Track RMS (cm)
1.29	2.97	4.59



So, where does this leave the SLR in the world of POD?

Is it more than just a backup ?

It turns out that we need the SLR in order to fully exploit the GPS tracking.

SLR provides a highly accurate, direct and unambiguous observation of the orbit.

-This has proved necessary in fine-tuning the GPS-based orbit solutions.

The GPS tracking is an indirect, ambiguous observation of the orbit.

-This can be problematic, especially when fine-tuning the large GPS POD solution parameter set, and when sorting out systematic errors.



Nominal GPS POD Method



- 30-hr solutions
- IGS GPS precise orbits
- 33 IGS stations
- Double-difference LC ranges to account for clock errors
- Ambiguity bias determination per pass ~2700 per 30 hr. arc
- Trop. Scale factors estimated every hour per site.
- “reduced-dynamic solution”
 - Covariance constrained along and cross-track periodic empirical accelerations estimated every: 90 – 20 minutes depending on application.
 - Need to determine optimal rate, correlation time and sigma
 - Drag coefficients estimated every 6 – 1.5 hours depending on application
 - Need to determine optimal rate.
- Estimate phase center offset – need to determine which components
- ... and all the rest of the high-fidelity force and measurement modeling:
 - e.g. “box-wing” model, antenna orientation, telemetered attitude, phase windup
- Jason: ~500.000 GPS DDLC obs. in 10 days vs. ~4000 SLR obs.



If SLR were not available we would have to determine the optimal GPS solution parameter set from the GPS tracking data residual and orbit overlap performance.

As we move to a more “reduced dynamic” solution both the orbit overlap and GPS DDLC range residuals become more meaningless as an orbit precision and accuracy metric.

Estimate more parameters get a better fit.

Not necessarily a better orbit.

Increasing the frequency of the empirical accelerations –

Have less independent data for each set of parameters during overlap

Simply follows the data

“Waters down” orbit overlap metric.



If you only had the GPS tracking could you guess which is the better orbit ?

Which one is CHAMP, which one is Jason-1?

Satellite	GPS DDLC Fit RMS (cm)	Radial Orbit Overlap RMS (cm)	3D Orbit Overlap RMS (cm)
1	0.93	0.9	2.6
2	0.84	1.1	2.9

POD Summary Statistics Over Several 30-hr. arcs.



Can you figure it out now ?

Satellite	GPS DDLC Fit RMS (cm)	Radial Orbit Overlap RMS (cm)	3D Orbit Overlap RMS (cm)	Indep. SLR Fit RMS (cm)
1	0.93	0.9	2.6	1.8
2	0.84	1.1	2.9	4.5

1 is Jason-1

2 is CHAMP

We need the SLR to discriminate between solutions and to ultimately fine-tune the GPS solutions to fully exploit the GPS tracking technology.



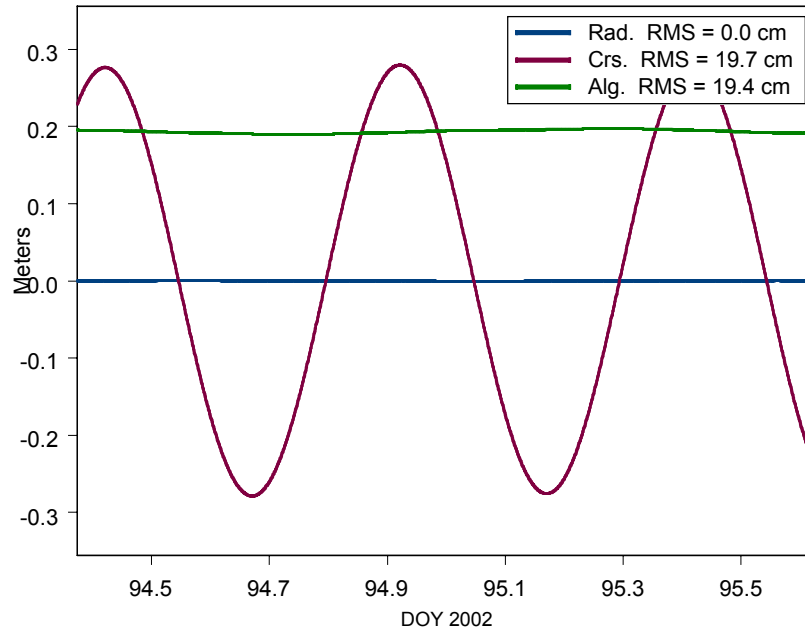
Can the GPS data alone “weed-out” gross systematic modeling errors?

First we can perform a little experiment:

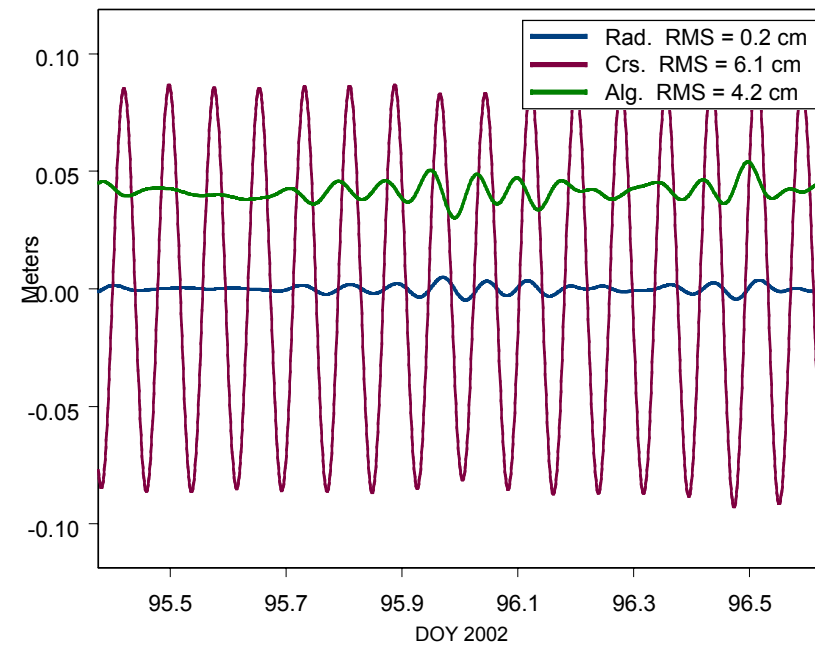
- Use Jason-1 cycle 9 GPS solutions (ten 30-hr. solutions)*
- Input a gross systematic modeling error*
 - Slightly rotate all of the GPS orbits – frame error*
- Re-determine the Jason-1 orbits*
- Using the GPS data alone, can you see the systematic error?*



Introduced GPS Orbit Error

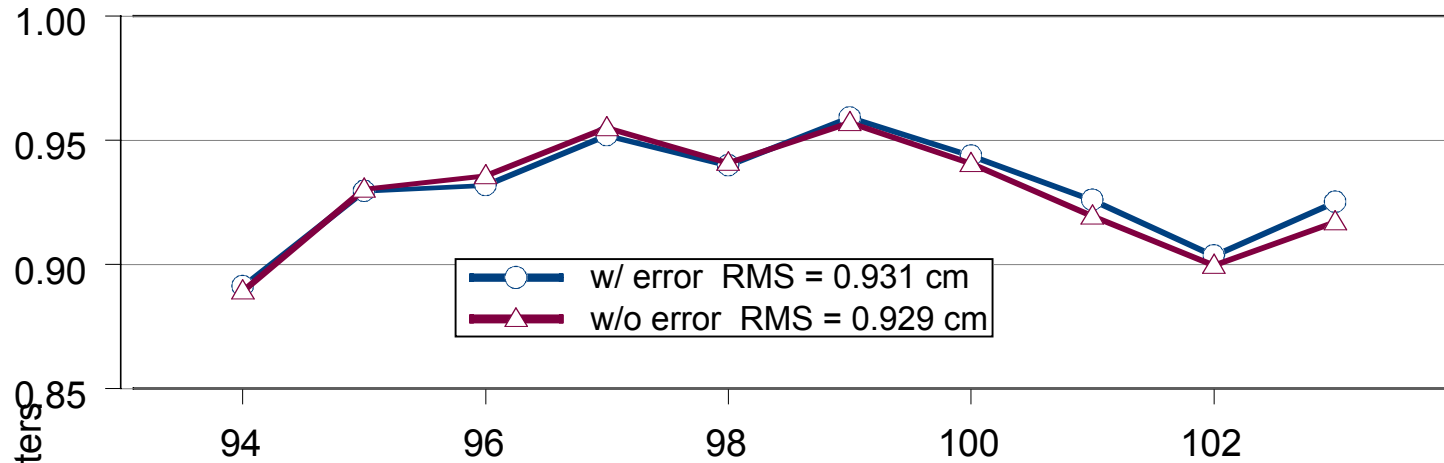


Resultant Jason Orbit Error

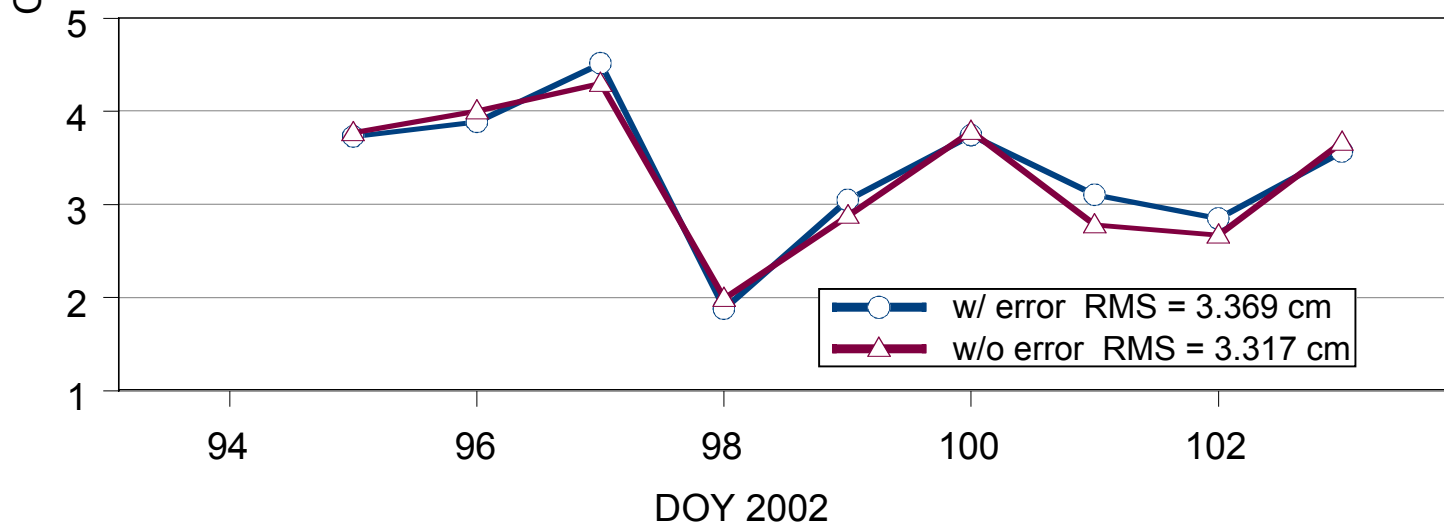




Jason GPS RMS Fit per 30-hr Arc (DD1W LC Phase)

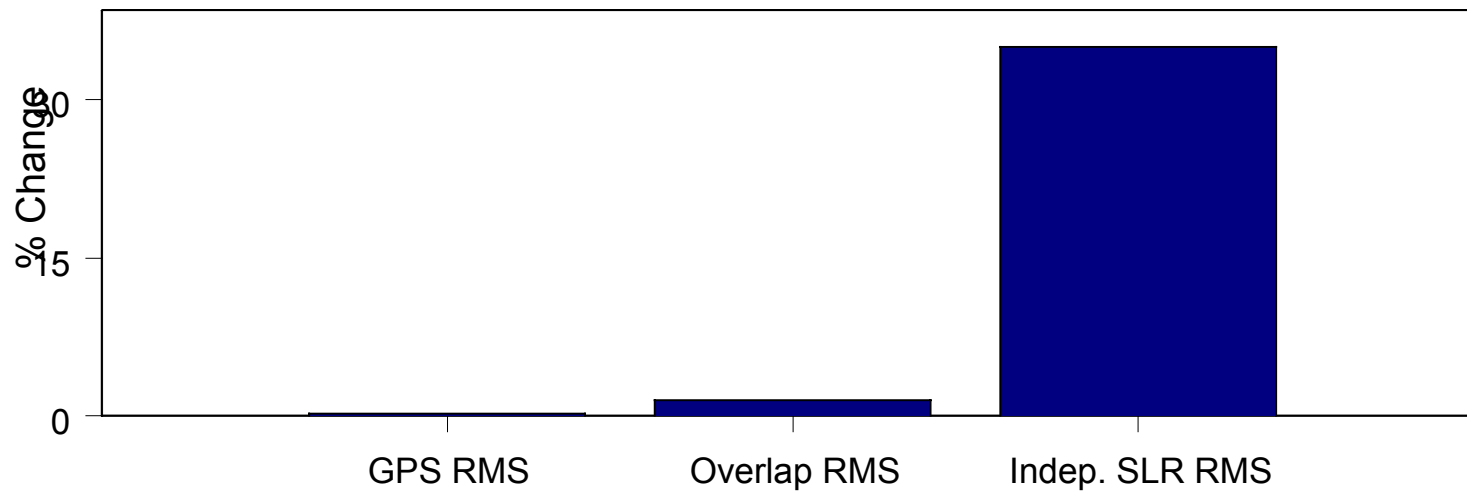
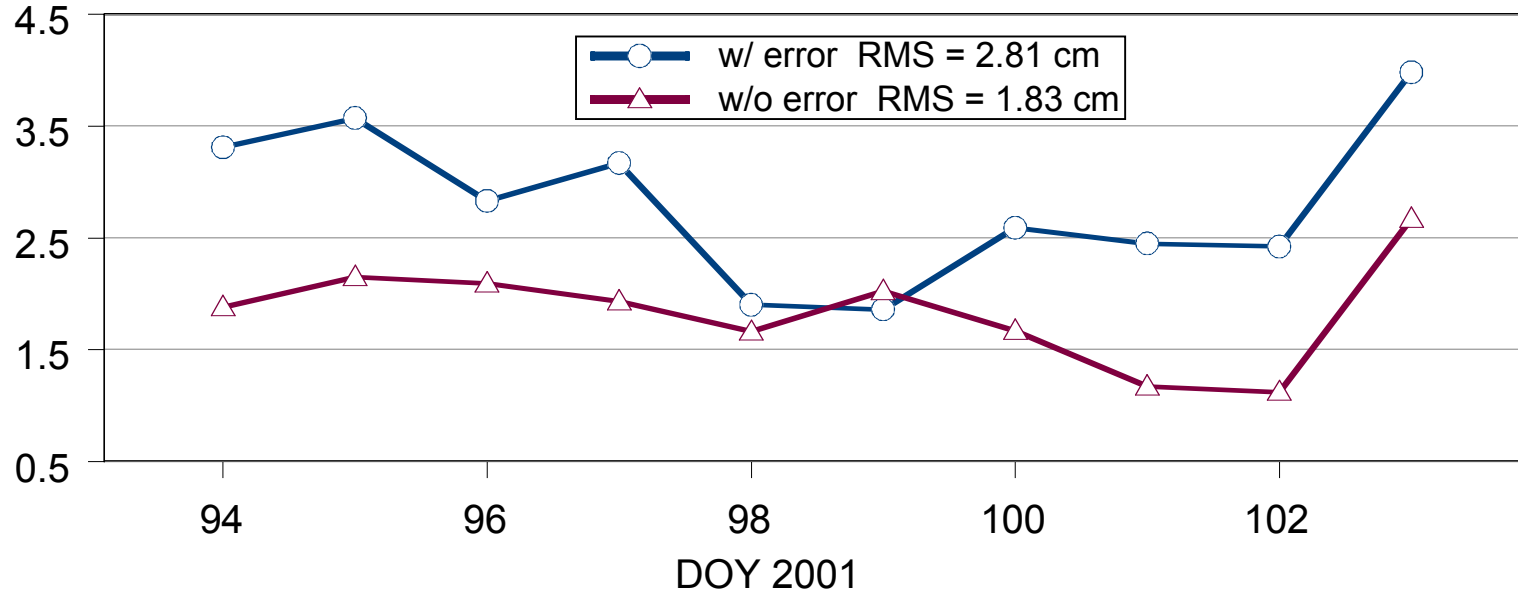


Jason Total Position Overlap RMS (6-hr. overlap)





JASON Independent SLR RMS Fit per 30-hr. GPS Solution



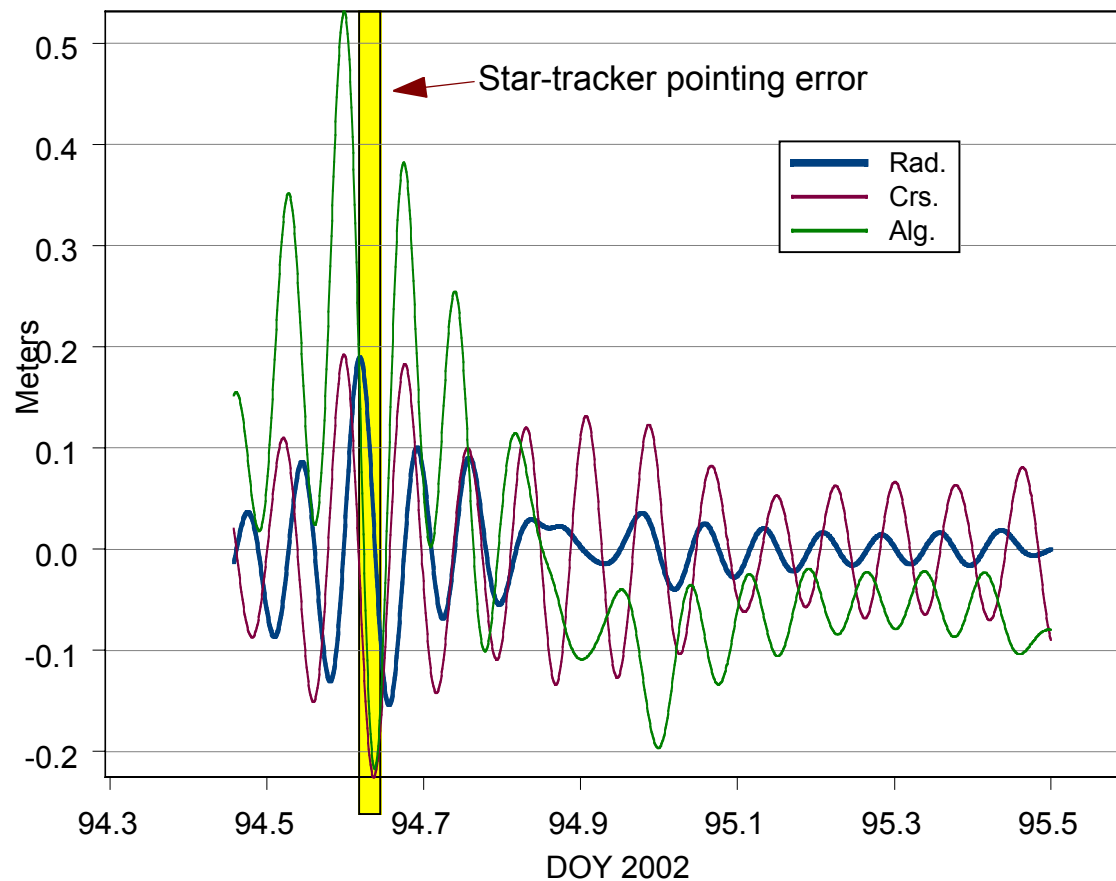


Another example of SLR “weeding out” systematic errors:

-Detect orbit errors caused by bad attitude knowledge.

-The SLR and GPS CofM tracking point offsets differ by over 1 m in magnitude.

Jason-1 Orbit Difference - GPS vs. SLR+DORIS solution





No tracking system is perfect, and the GPS is no exception.

Systematic residual signal has been traced to the knowledge of the Jason GPS antenna LC phase CofM offset.

In-orbit calibrations show that the LC phase center is significantly different than the pre-launch determined values:

$$X = 2.389 \quad Y = -0.2180 \quad Z = -0.504$$

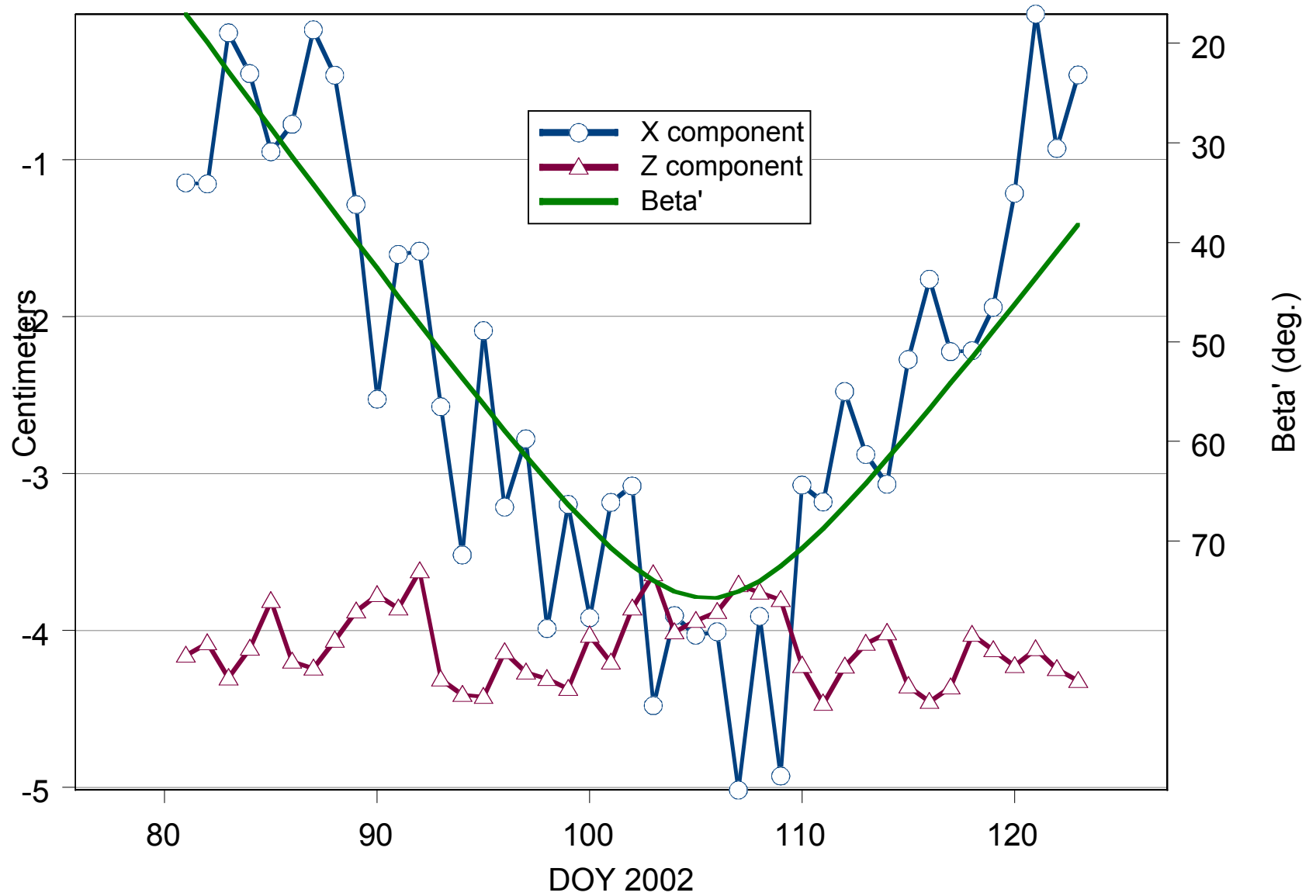
In fact, the adjustment in phase center offset is over 4 cm in the Z component – most important for an altimeter mission.

In addition, there is an observed dependence in the X component with the angle of the Earth-Sun Vector to the orbit plane.

The SLR is providing the necessary metric for the LC phase center offset calibration and validation.

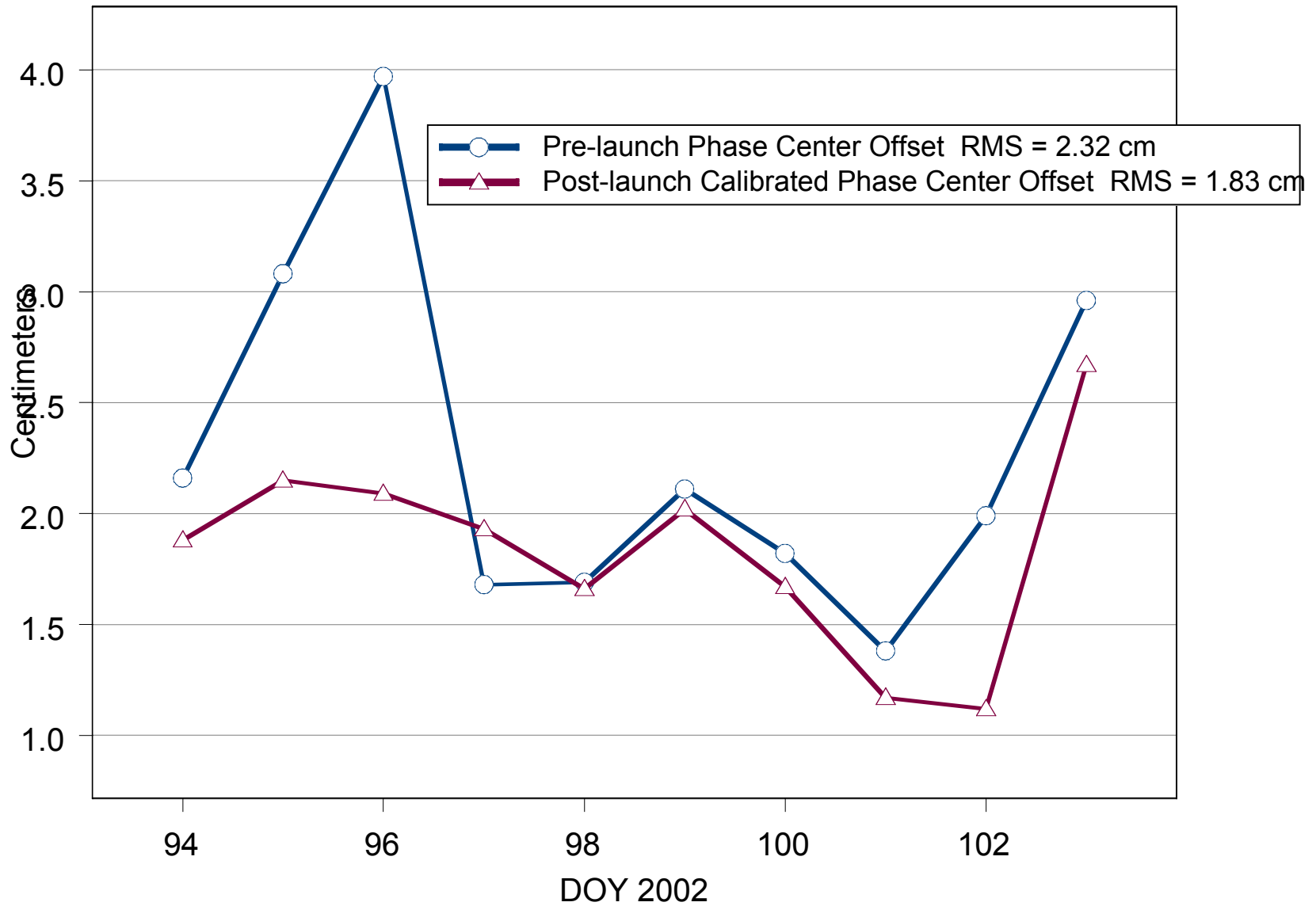


Jason-1 Estimated GPS Antenna Phase Center





Jason Independent SLR RMS Fit per 30-hr GPS Solution





SLR provides a high accuracy, direct, unambiguous observation of the orbit.

SLR is absolutely necessary in realizing the full potential of the GPS tracking data

- Fine tuning solution parameterization*
- Calibrating measurement system parameters*
- “weeding out” systematic errors*