ICESat Calibration Results From Integrated Residual Analysis

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Introduction

- Pointing / "effective pointing" Cal/Val
  - Pointing calibration performed using range residual analysis for all observation periods and numerous releases
  - Use Direct altimetry from Ocean Scans (OS), Round The World scans (RTW) and dynamic crossovers
  - ~200 OSs and RTWs, ~5.5 million observations processed

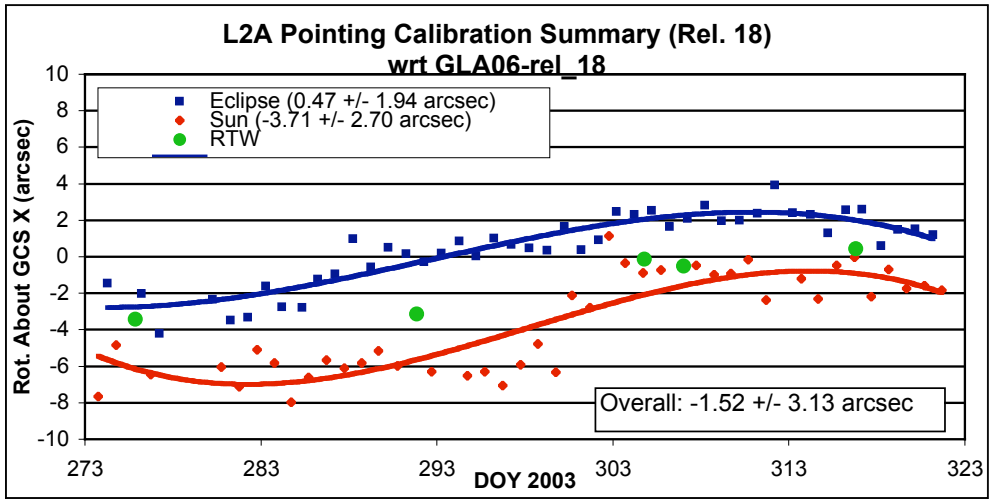
- Pointing recovered using range residual analysis includes the effects throughout the laser path:
  - Transmit (e.g. laser variation, IST variation, biases)
  - Receiver (e.g. FOV shadowing and FOV shadowing variation)
  - "Effective Pointing" - correct FOV shadowing range errors

- Range bias calibration
  - Remaining pointing errors induce significant variation in range bias
  - Independent validation of pointing corrections

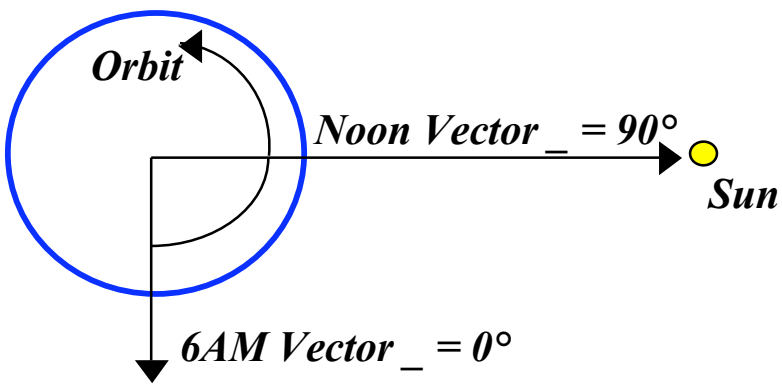
Effective pointing calibrations capturing long period and orbital variations

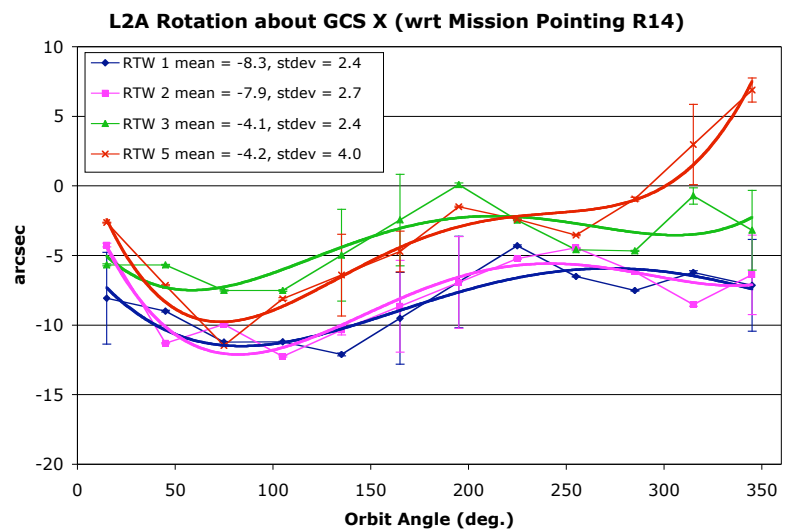
- **Capture biases, long period variation and orbital variation as a function of orbit angle.**

L2A GCS X Example



- ***Estimate orbital pointing variation as a step function in orbit angle for both GCS X and Y***

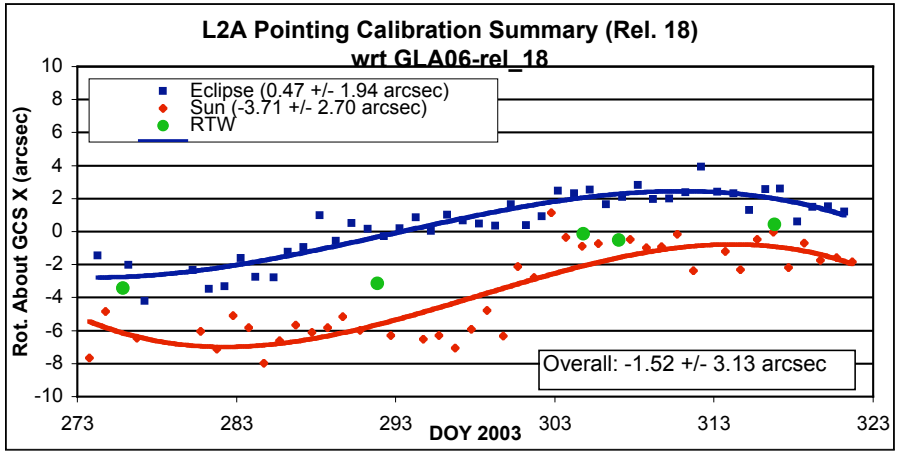




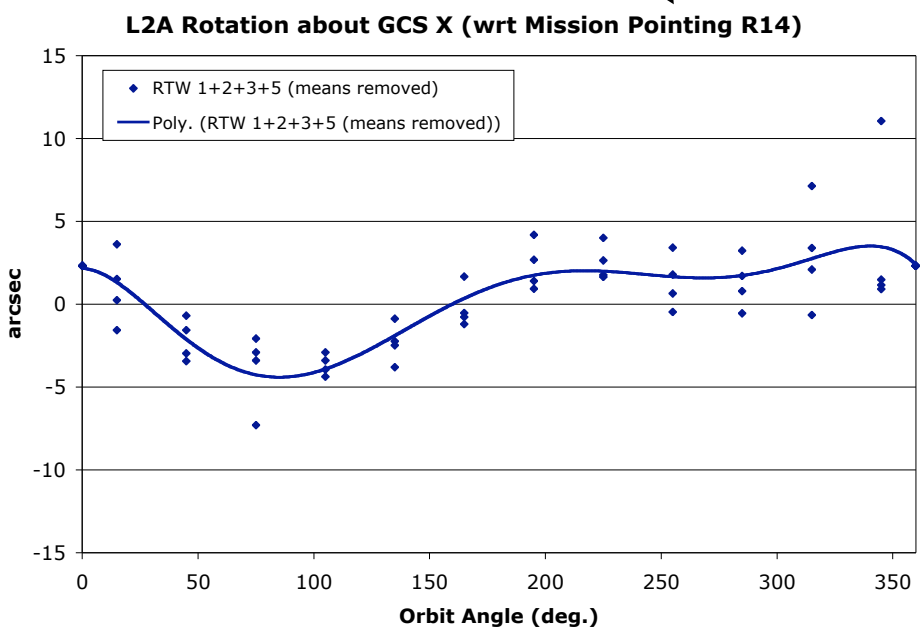
Effective Pointing Error Functions

- **Fit both OS and RTW calibrations to develop long-period and orbital variation error functions:**

Example: Polynomial fit to long-period variation for L2A GCS x.



Example: Polynomial fit to L2A GCS x orbital variation observed using RTWs 1, 2, 3 and 5.



- **Effective pointing error functions can now be used to:**
  - **Understand the temporal and geographic systematic ranging errors they induce through an error propagation.**
  - **Ultimately correct the data.**
  - **Examples follow….**

Overall "Effective" Pointing Error Estimate

Below is a summary of the remaining "effective" pointing error for each observation period. The estimates were obtained from ocean scans (OS) and round the world scans (RTW) calibration results. The errors are dominated by long period and 1-cycle-per-rev (1CPR) systematic errors and represent global and temporal bias + 1 standard deviation. At any given time and location the actual pointing error can be smaller than that shown in the last column or can be as large as bias + 3 standard deviation. The purpose of this table is to understand the overall and relative errors remaining in each observation period. L1 has only 4 OSs and one "synthetic" RTW constructed from 9-days of crossover data. The last row represents the error estimate from our first attempt to empirically correct the pointing.

"Effective" Pointing Error Estimate From Ocean Scans and RTWs

Global Summary over each observation period

In arcsec

Laser / Ops.	GLA06 Release	About GCS X (Bias ± Stdev)	About GCS Y (Bias ± Stdev)	RSS (Bias ± Stdev)	Bias + 1Stdev
L1	18	1.59 ± 3.00	-0.03 ± 3.00	1.59 ± 4.24	5.83
L2A	18	-1.52 ± 3.13	0.44 ± 3.22	1.58 ± 4.49	6.07
L2B	16	-0.17 ± 4.72	2.20 ± 3.48	2.21 ± 5.86	8.07
L2C	17	-12.36 ± 5.81	3.90 ± 9.37	12.96 ± 11.03	23.99
L2A emp. corrected	1st cut at emp. corr.	0.00 ± 1.16	0.00 ± 1.80	0.00 ± 2.14	2.14

Overall Ranging Error Estimate

Below is a summary of ranging error induced by the estimates of remaining "effective" pointing error for each observation period (previous chart). The results are given for three different incidence angles. Incidence angle is a combination of attitude control off-nadir pointing and local surface slope. See the previous chart for an explanation of the "effective" pointing error estimates.

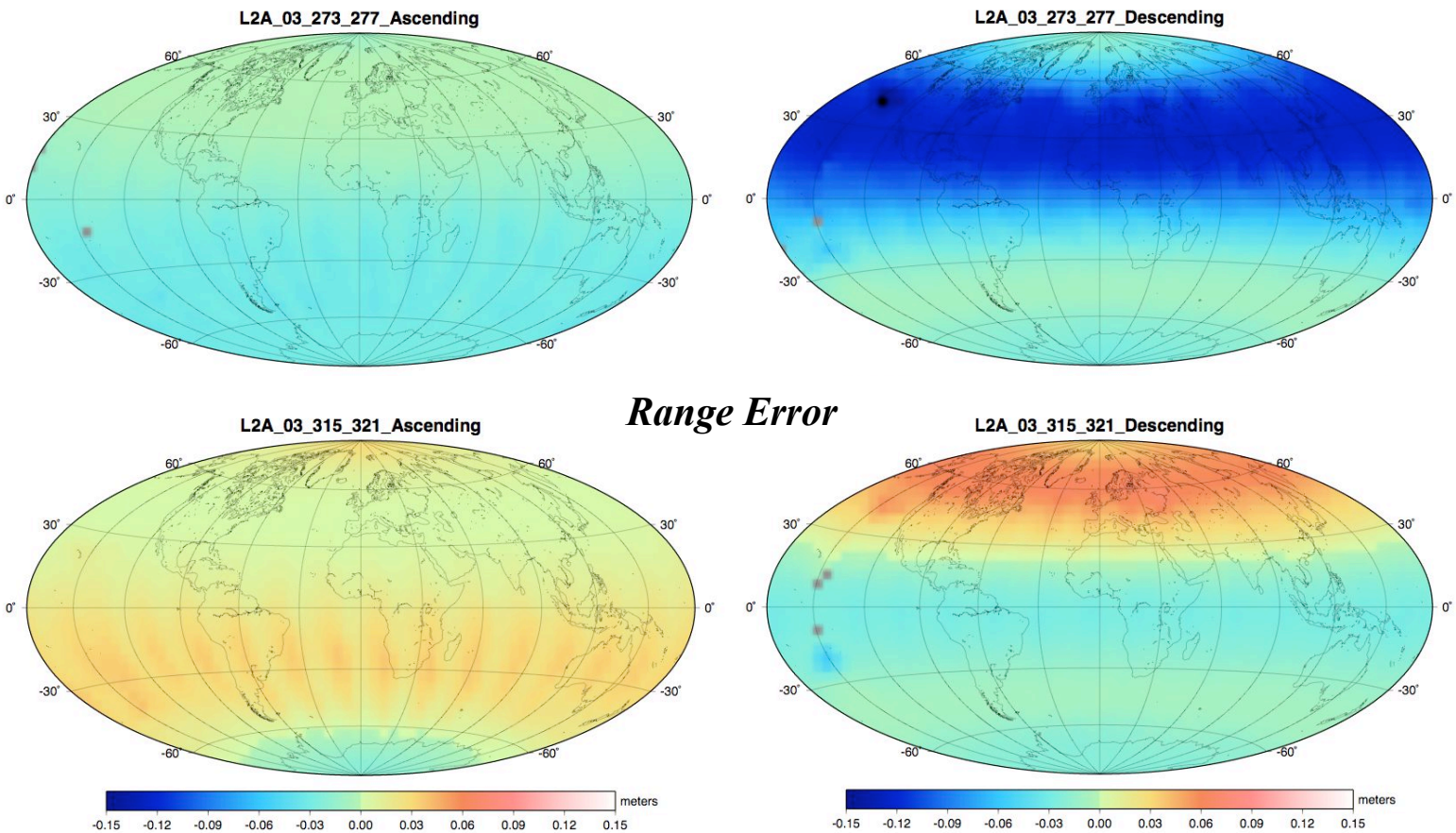
Range Error Estimate From Ocean Scans and RTWs Global summary over each observation period					
Laser / Ops.	GLA06 Release	Horizontal (m)	0.5° incidence Range (cm)	1.5° incidence Range (cm)	3.0° incidence Range (cm)
L1	18	16.95	14.81	44.45	89.04
L2A	18	17.65	15.42	46.27	92.71
L2B	16	23.46	20.49	61.50	123.21
L2C	17	69.73	60.89	182.77	365.16
L2A emp. corrected	1st cut at emp. corr.	6.22	5.44	16.32	32.69

L2A GCS-x Effective Pointing Error Propagation - nominal spacecraft pointing only ("no surface slope")

Only nominal spacecraft pointing considered for incidence angle. This is what normally occurs from attitude control ~ 0.23 ± 0.13 degrees. This is the "no surface slope" case. ***Current remaining "effective" pointing error induces a significant time varying, geographically correlated range error, even without considering surface slope. This impacts change detection, range bias estimation……***

DOY 273-277 →

DOY 315-321 →



Range Error

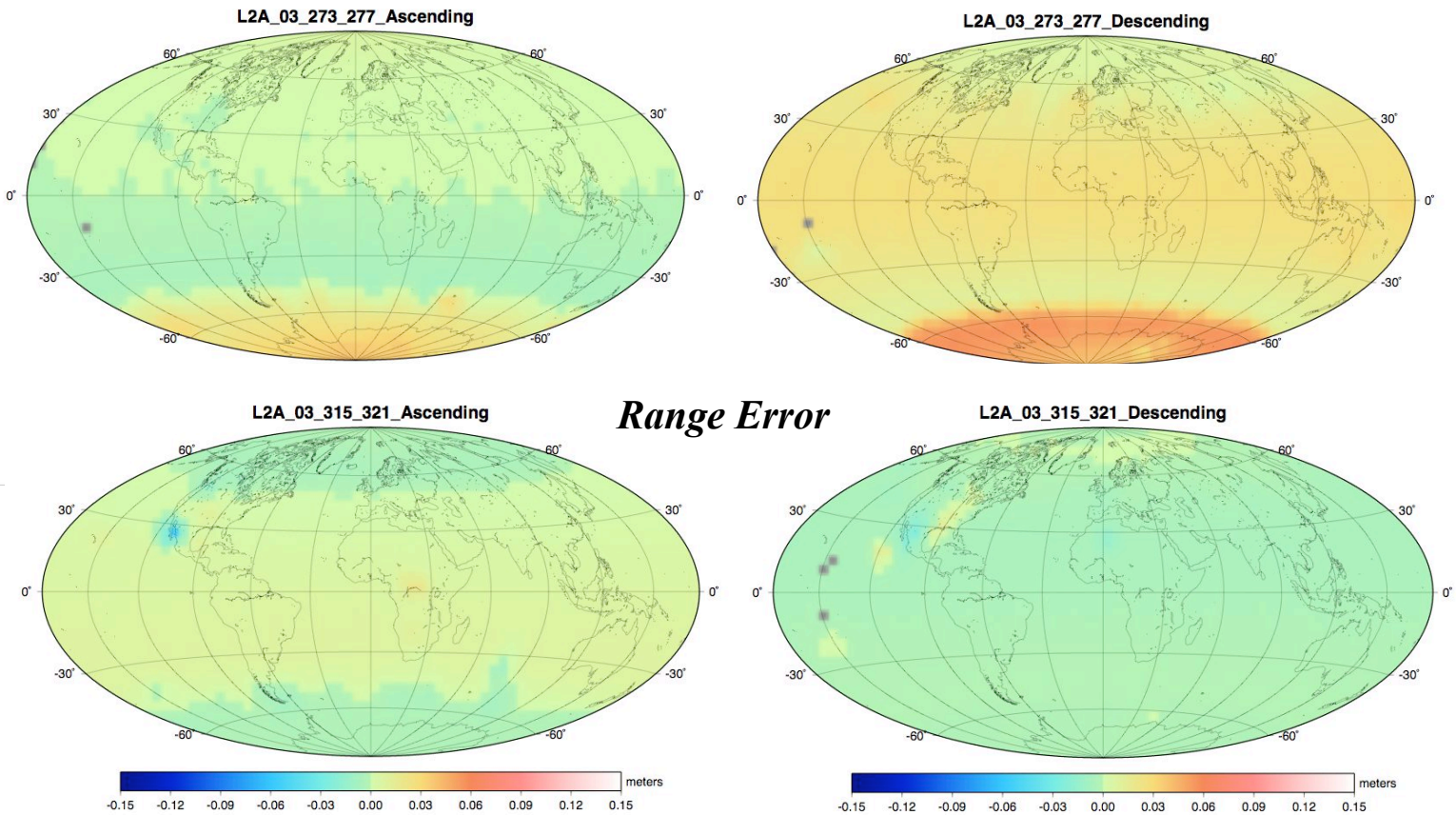
-0.15 m ***Eclipse*** **0.15 m** ***Sun***

L2A GCS-y Effective Pointing Error Propagation - nominal spacecraft pointing only ("no surface slope")

Similar to previous chart, but now this is the range error induced from the GCS-y "effective" pointing error. The overall error is much smaller than that shown in the previous chart because much of the nominal off-nadir pointing is due to the forward pitch, and therefore, causes the largest range errors with the GCS-x pointing error (previous chart).

DOY 273-277 →

DOY 315-321 →



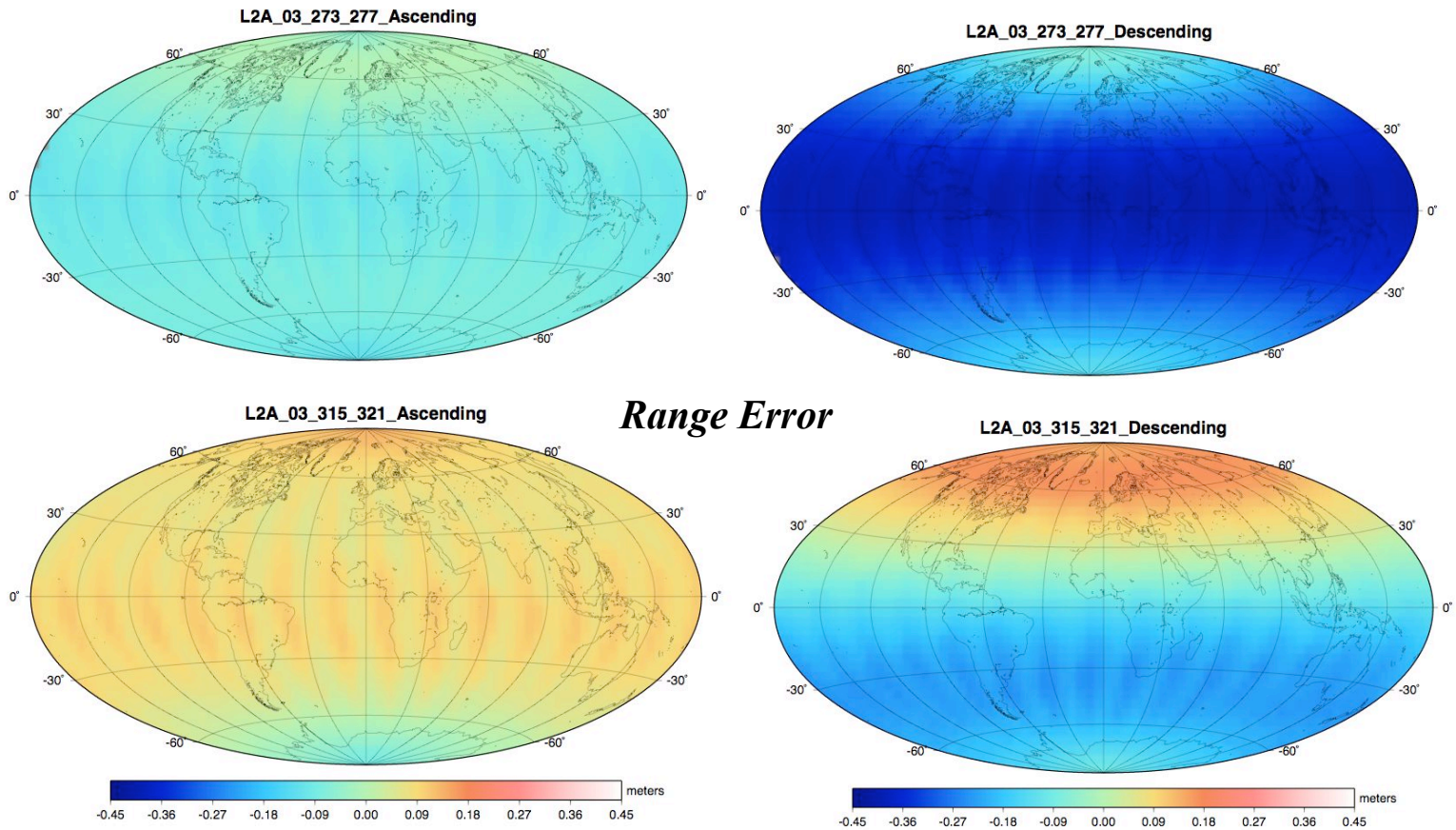
-0.15 m ***Eclipse*** **0.15 m** ***Sun***

L2A Effective Pointing Error Propagation - 1 deg. along-track slope/incidence angle

This case considers a constant 1 deg. incidence angle oriented along track. Again, significant time varying geographically correlated range error is induced from the current remaining "effective" pointing error. Note the scale change from the previous charts.

DOY 273-277 →

DOY 315-321 →



Range Error

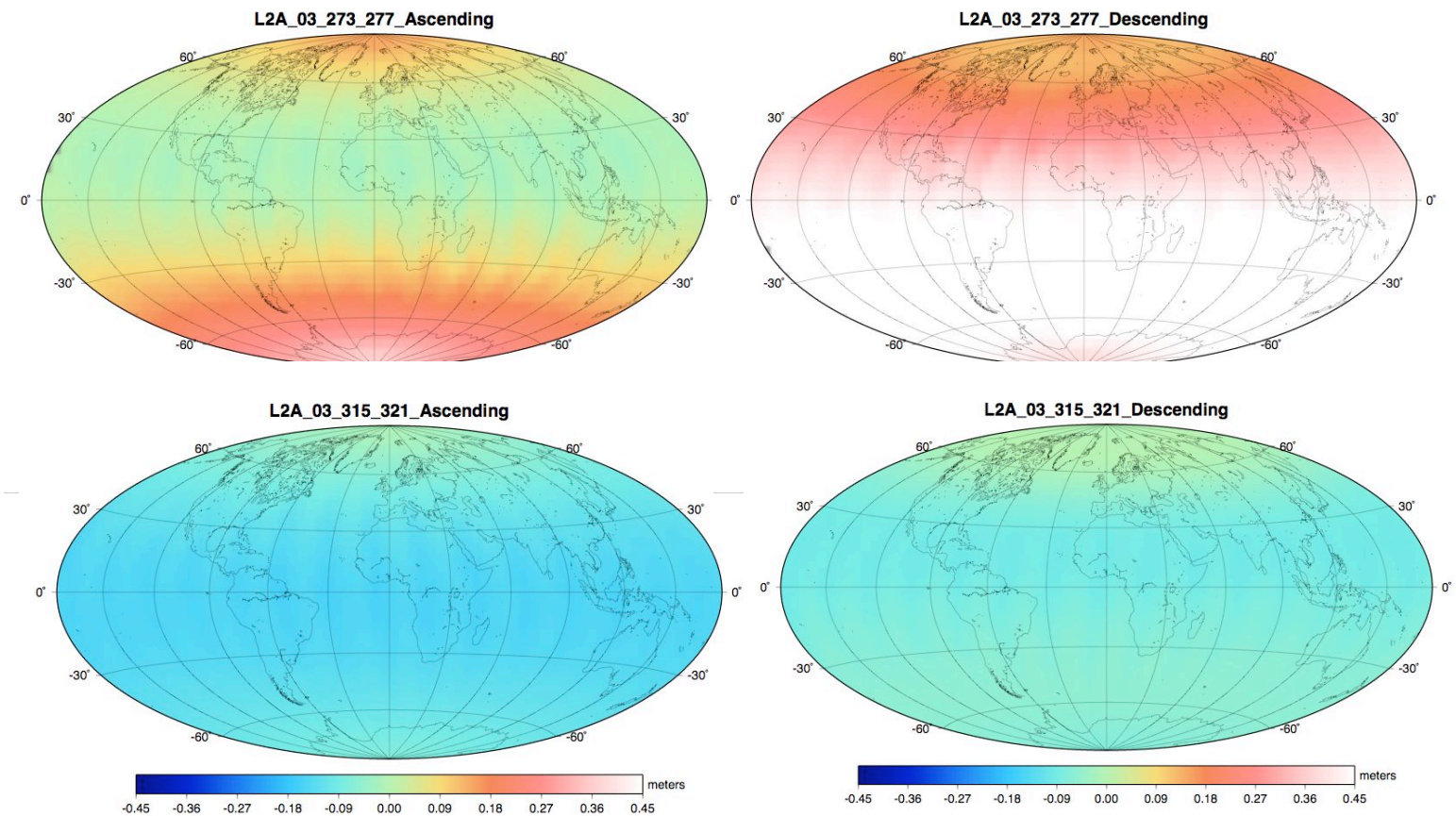
-0.45 m ***Eclipse*** **0.45 m** ***Sun***

L2A Effective Pointing Error Propagation - 1 deg. cross-track slope/incidence angle

This case considers a constant 1 deg. incidence angle oriented cross track. Again, significant time varying geographically correlated range error is induced from the current remaining "effective" pointing error.

DOY 273-277 →

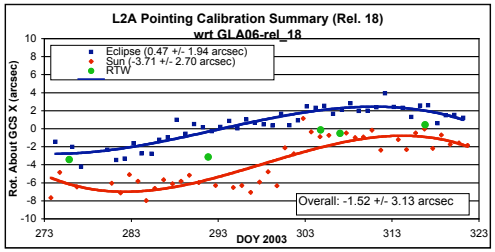
DOY 315-321 →

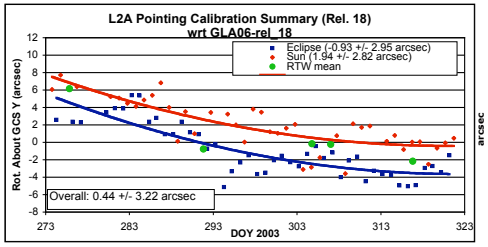


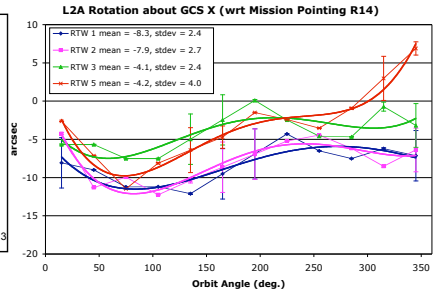
-0.45 m ***Eclipse*** **0.45 m** ***Sun***

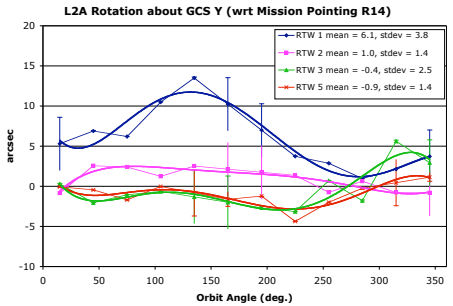
Further Corrections - "Effective Pointing"

L2A calibration results based on Rel. 14 (with SRS)



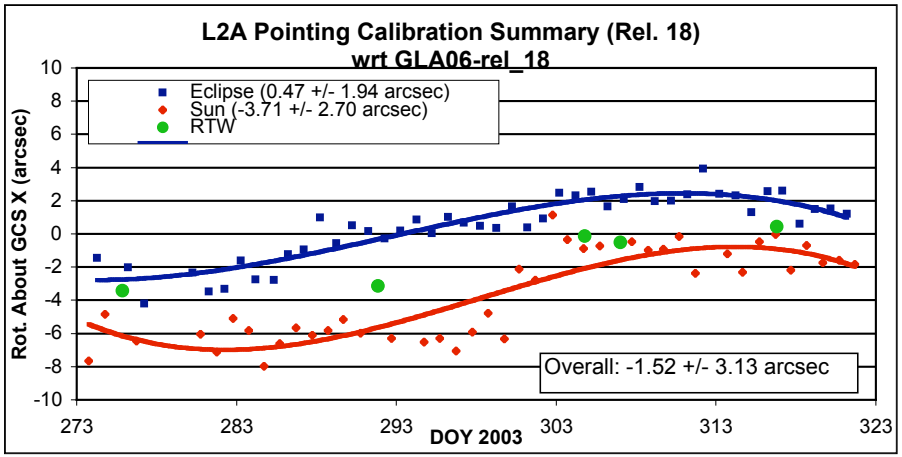


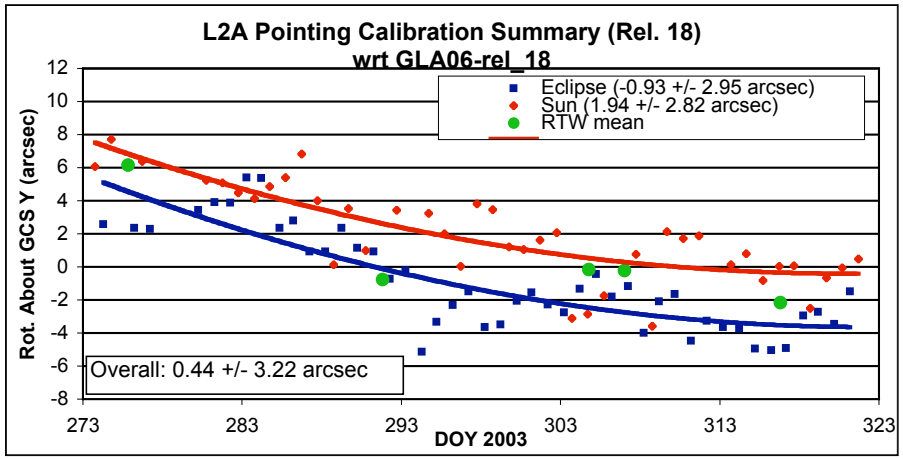




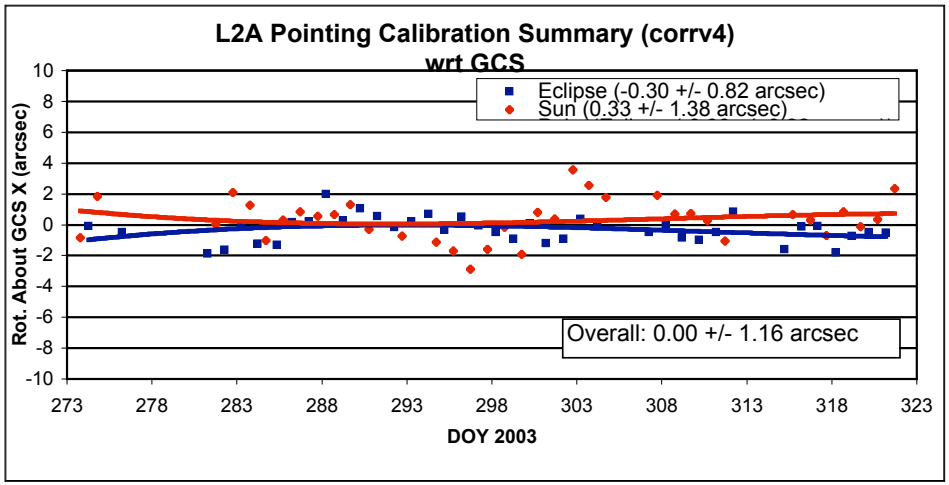
- *The remaining long period and orbital pointing variations observed above could be due to FOV shadowing variations - "motions of the receiver".*
- *Regardless, we must determine if these "effective pointing" corrections improve the resulting elevation accuracies.*
- *Towards this end, we have developed algorithms and software to correct the PAD solutions (in both obatt and ANC09 file format) based on functional fits to the orbital and long period effective pointing calibrations.*
- *We have computed corrected PAD for the whole of L2A.*
- *We are currently in the process of internally validating the obatt and ANC09 files before releasing for further testing.*
- *It should be noted that this is a first order attempt at correcting the PAD with the intention of proving the validity of the approach. If this approach proves to be fruitful, then a much more robust correction model will be developed based on temperature data and crossovers in addition to OS and RTW calibration data.*

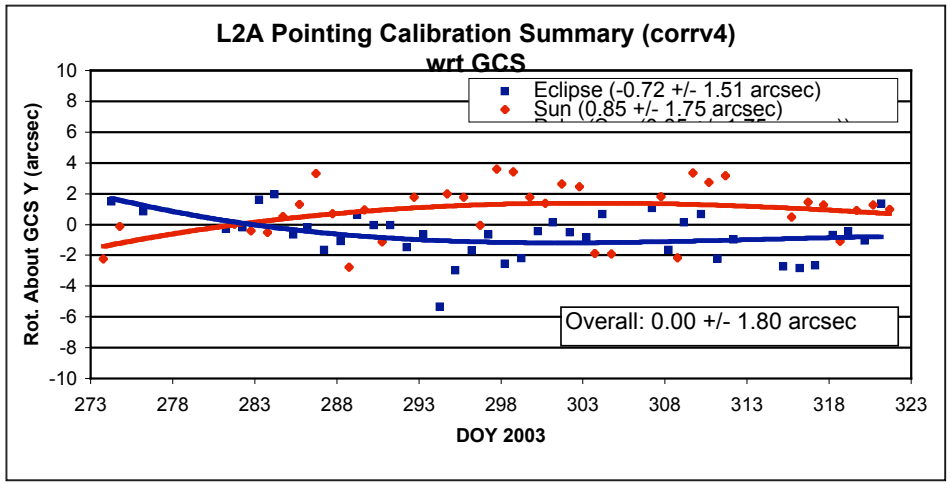
L2A OS Calibrations - Improvement from CorrV4





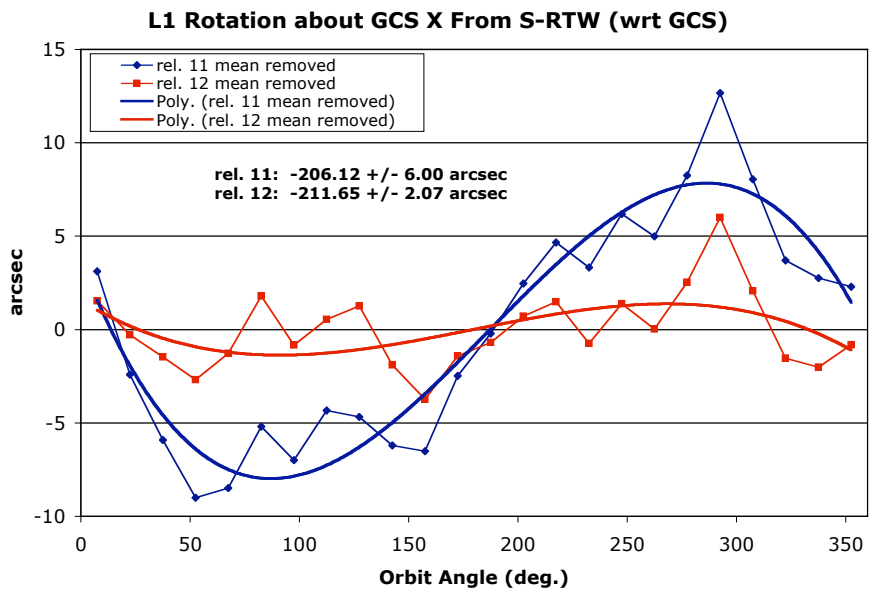
CorrV4 Correction - "effective pointing correction"

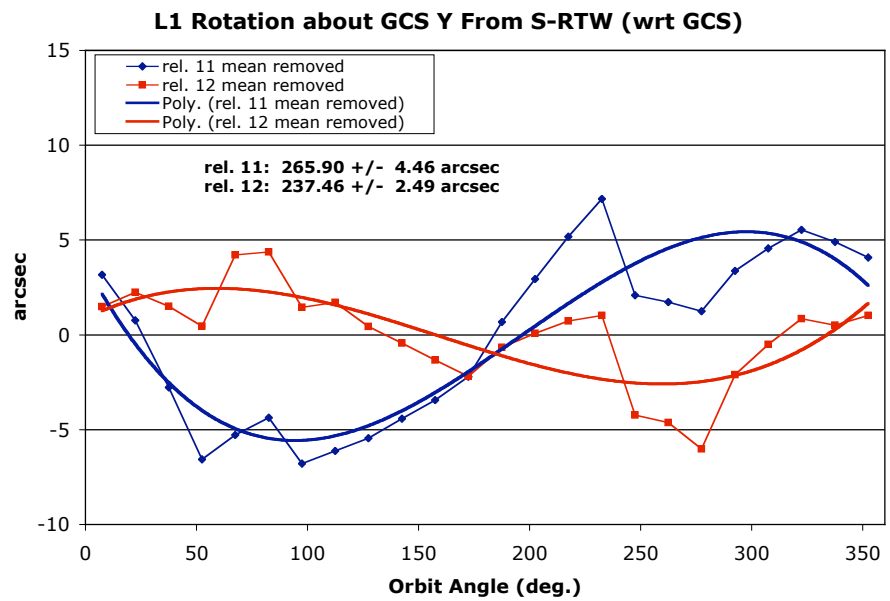




L1 Orbital Pointing Variation Reduction using Rel. 12 PAD

The orbital pointing variation calibration presented here was determined from a combination solution based on four Ocean Scans (OS 1-4) and 9-days of crossovers (cycle 3 track 59 - cycle4 track 74, March 8th - 17th). Therefore, this is the residual orbital pointing variation averaged over 134 orbits determined using both Release 11 and Release 12 PAD.



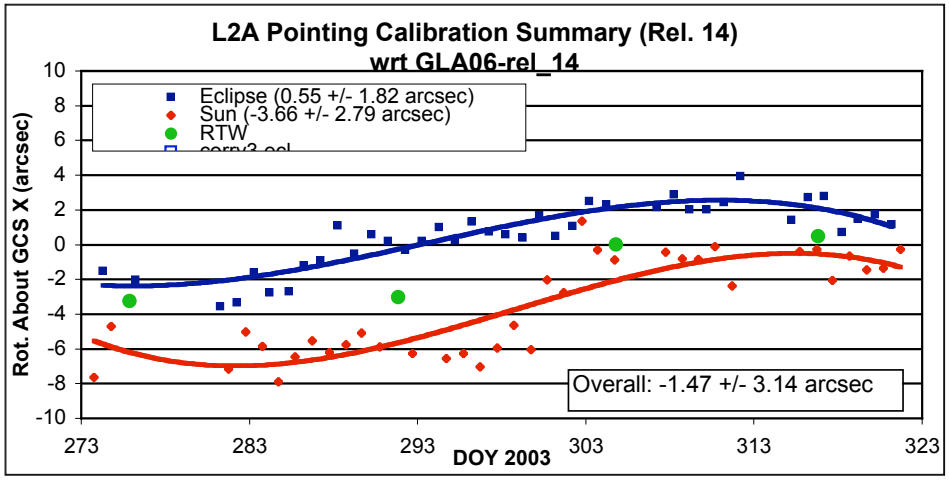


A significant reduction in the orbital pointing variation has been achieved using the new Rel. 12 PAD. We observe a 6.78 arcsec (1σ) reduction in the average orbital pointing variation over our Marth 8th - 17th test period. The remaining orbital variation is consistent with "FOV effects" observed during other operations periods (e.g. L2A).

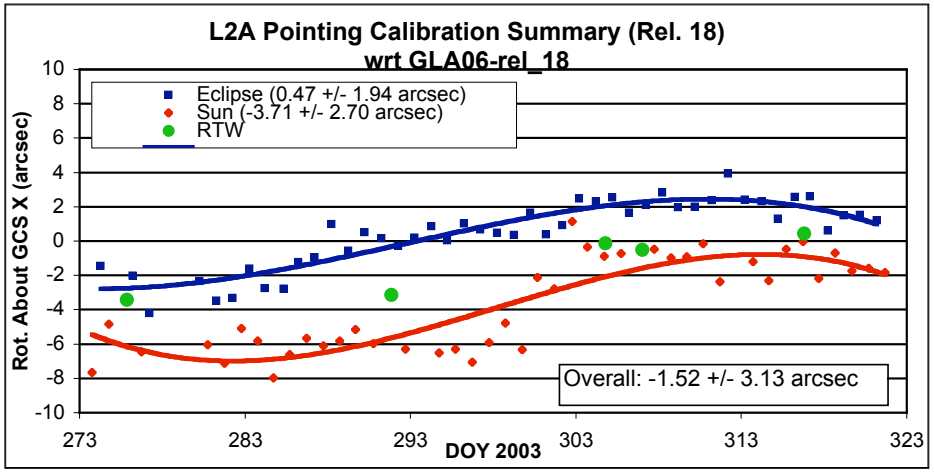
L2A rel. 14 vs. 18 Long Wavelength Calibration from OSs

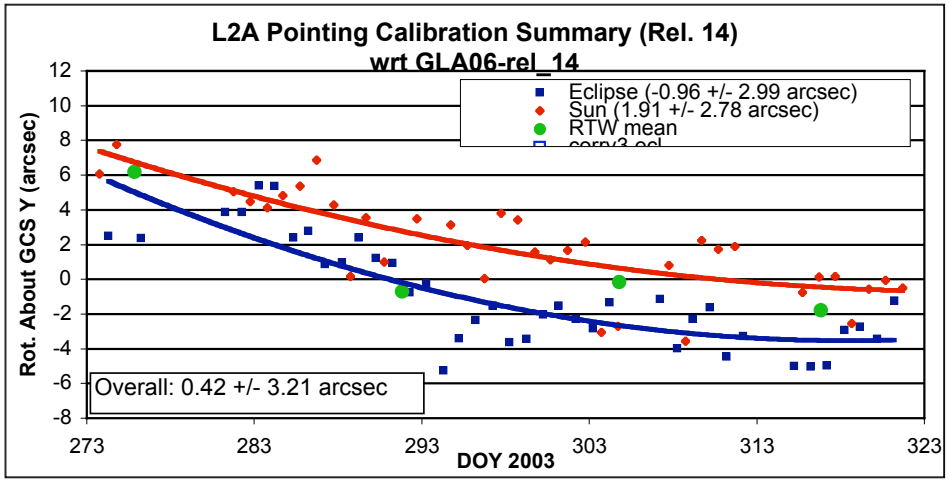
Current results from ocean scans and RTWs do not show any noticeable improvement in the orbital and long period pointing variation from the use of release 18 over release 14.

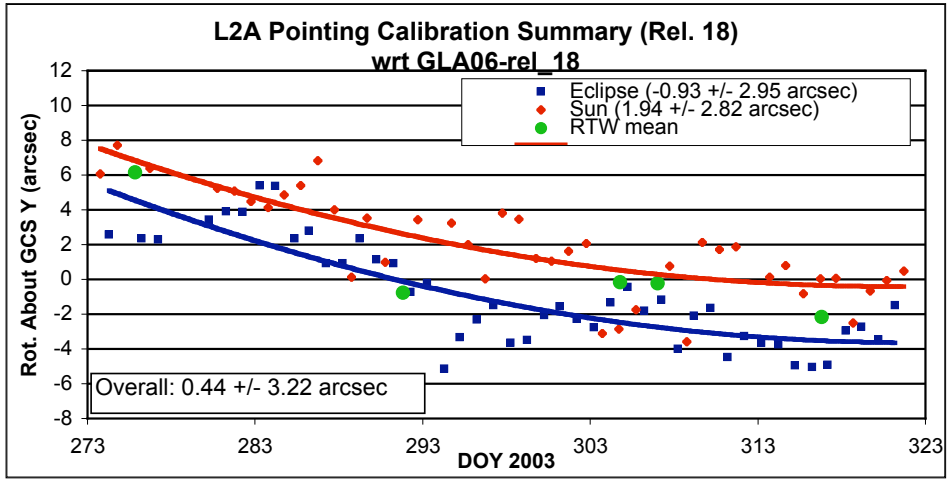
L2A rel. 14



L2A rel. 18

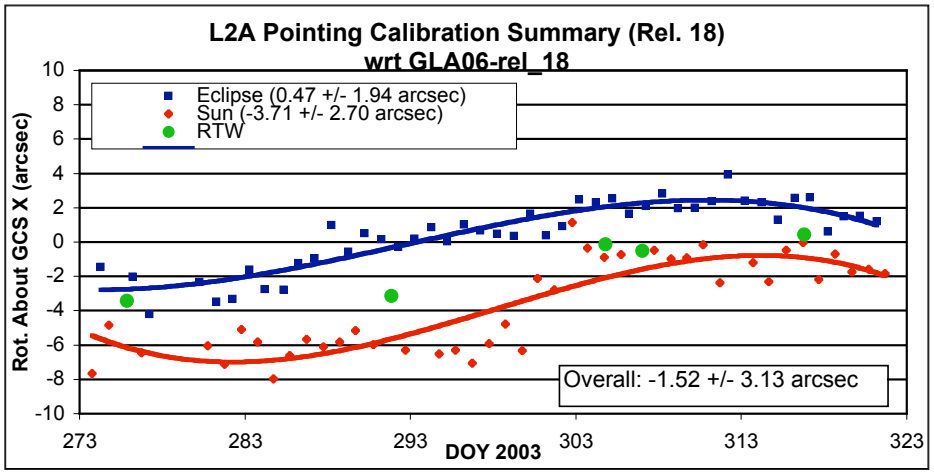




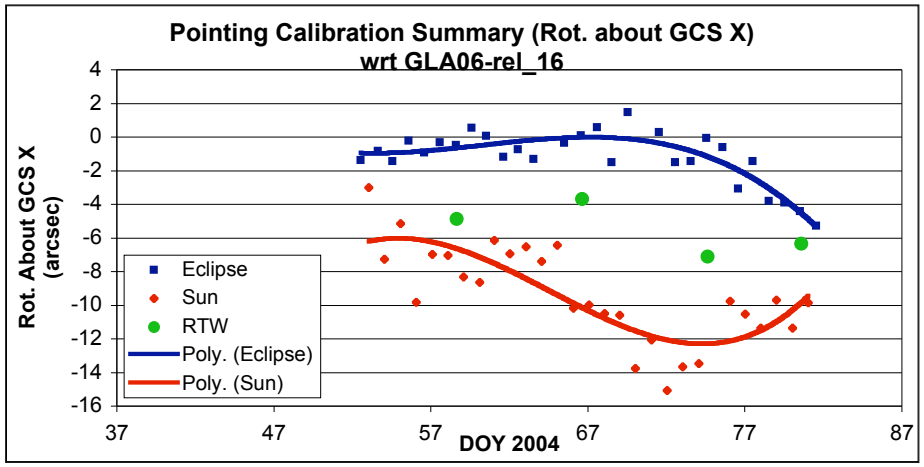


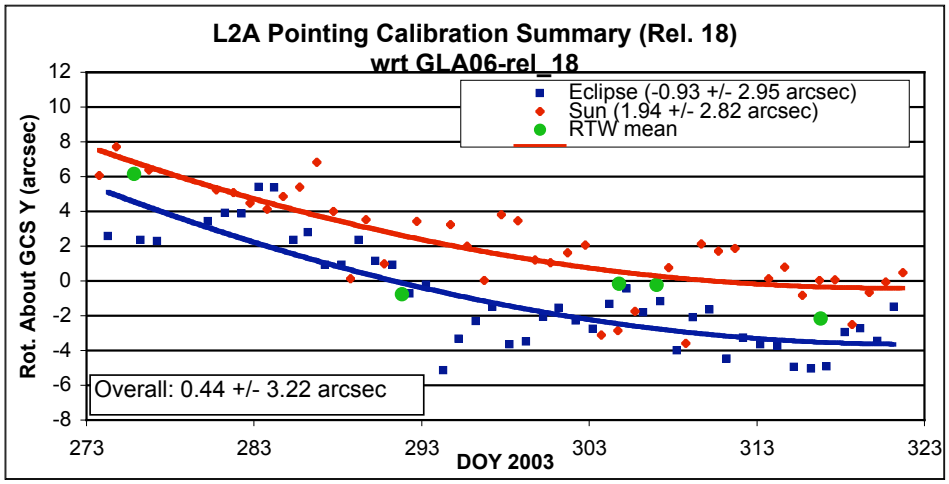
L2A+B Long Wavelength Calibration from OSs

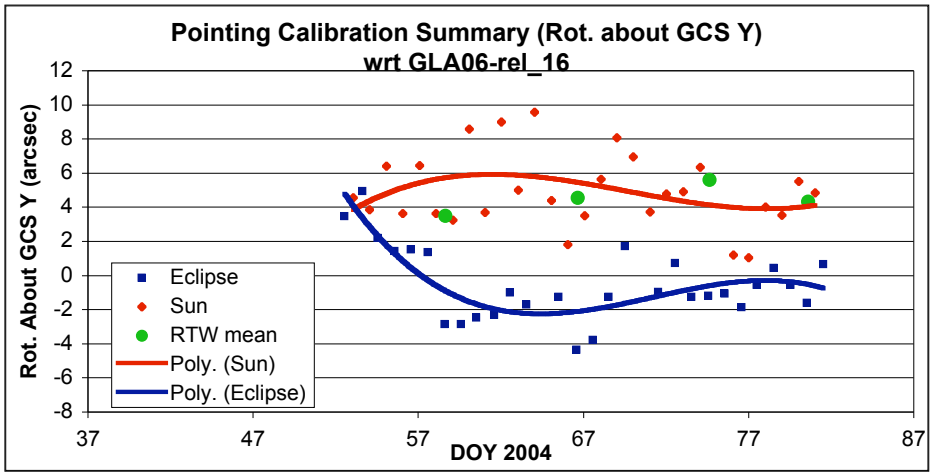
L2A with SRS



L2B with SRS

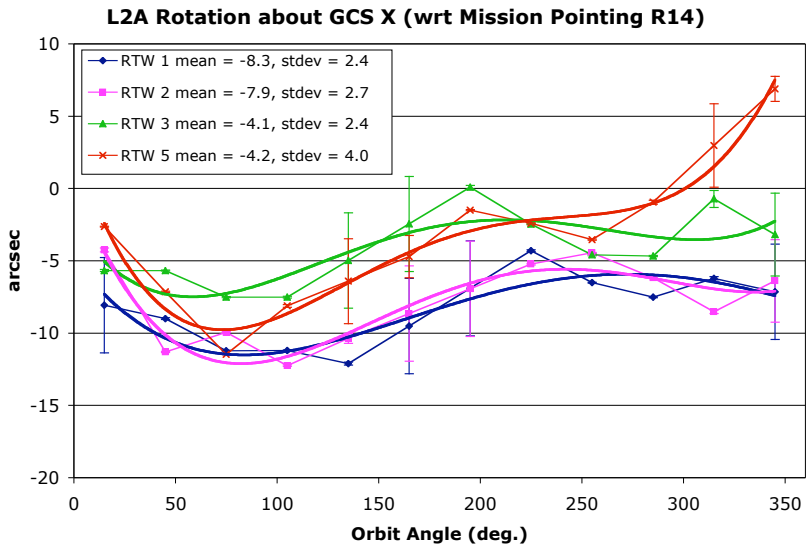


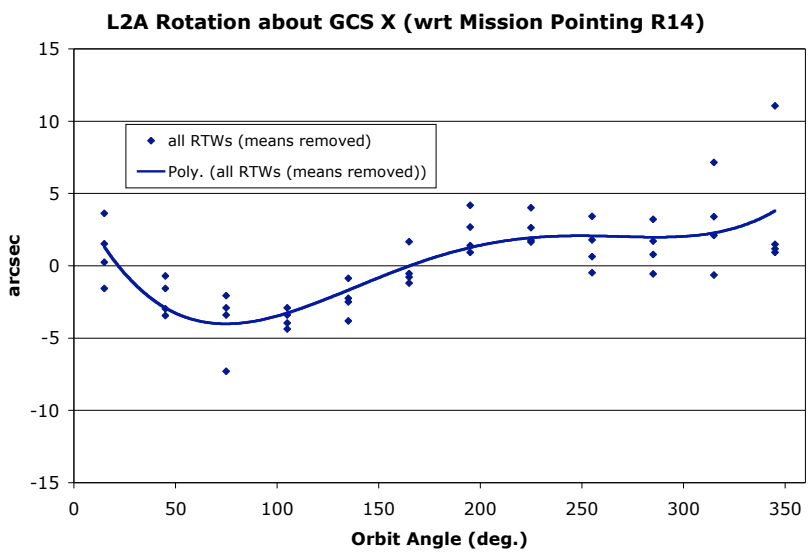




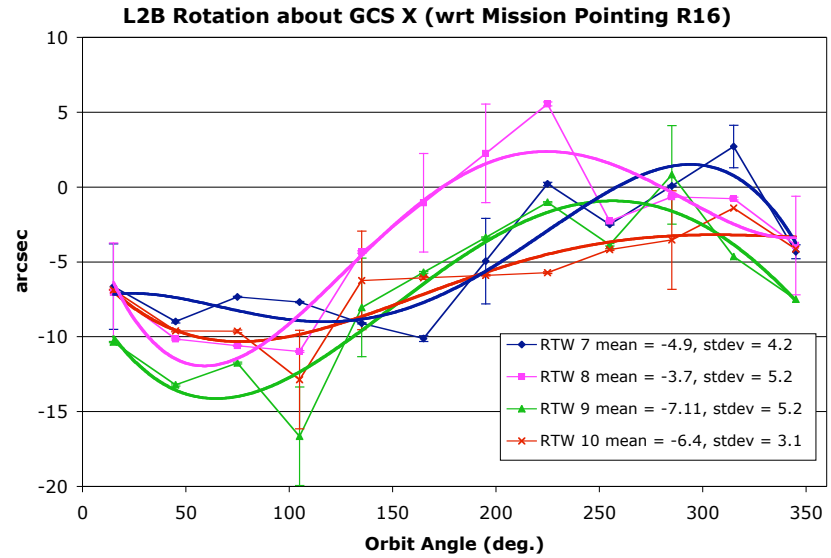
Orbit Variation Calibration from RTWs (GCS X)

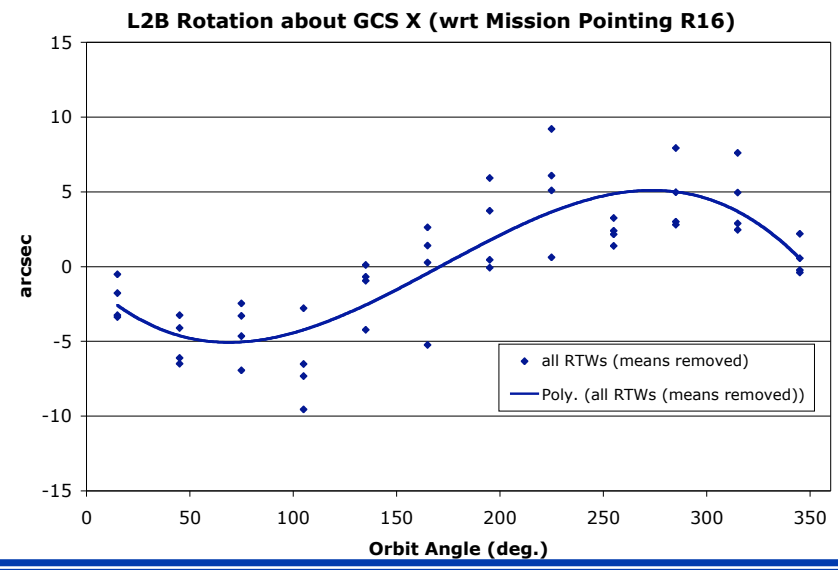
L2A





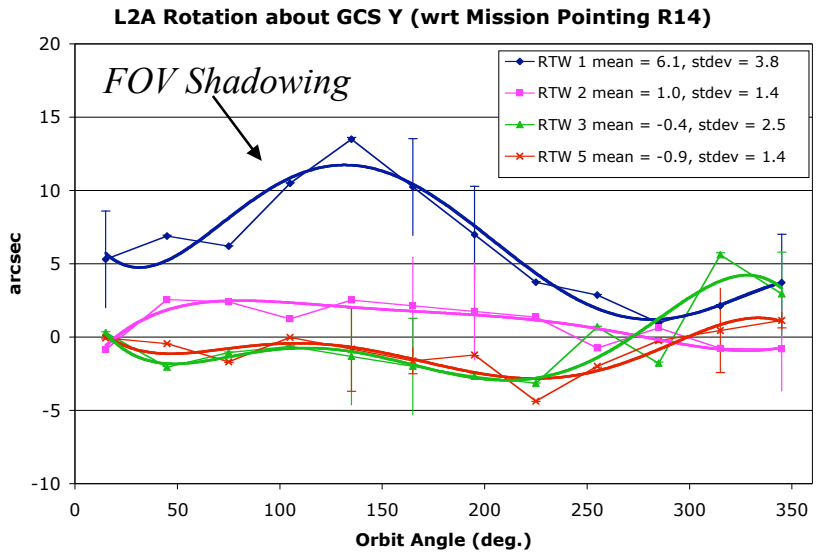
L2B

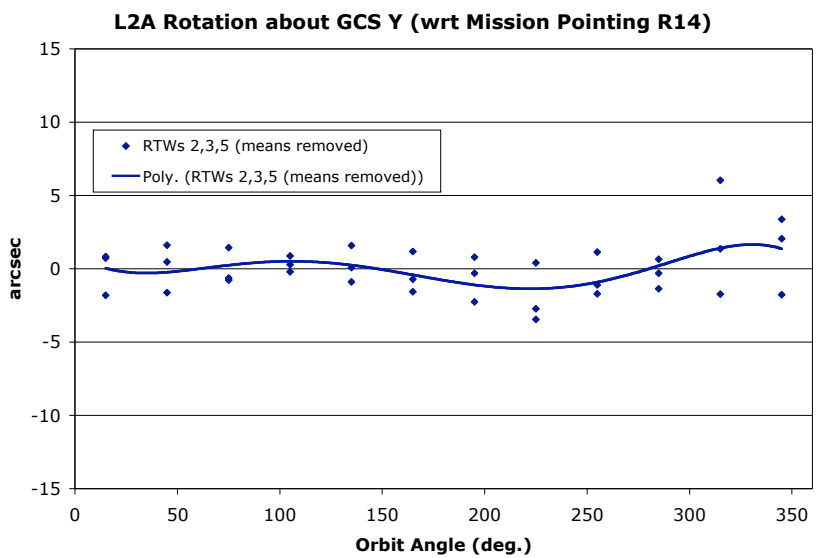




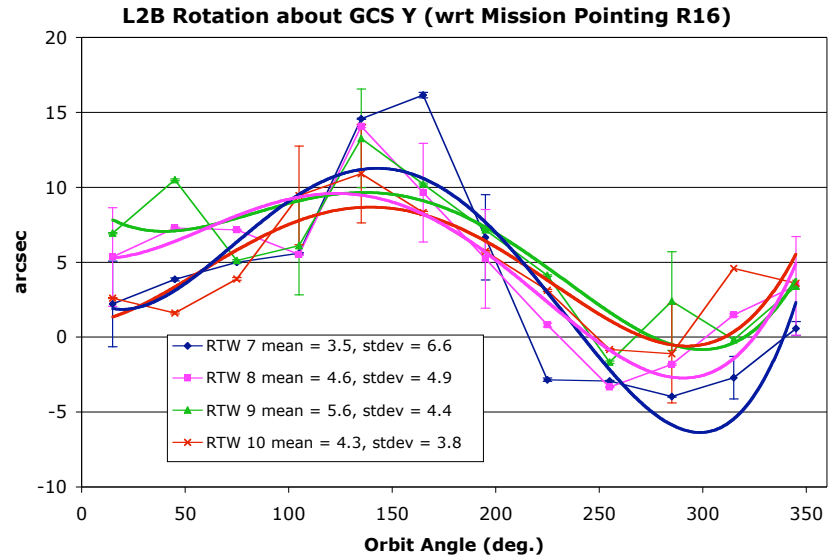
Orbit Variation Calibration from RTWs (GCS Y)

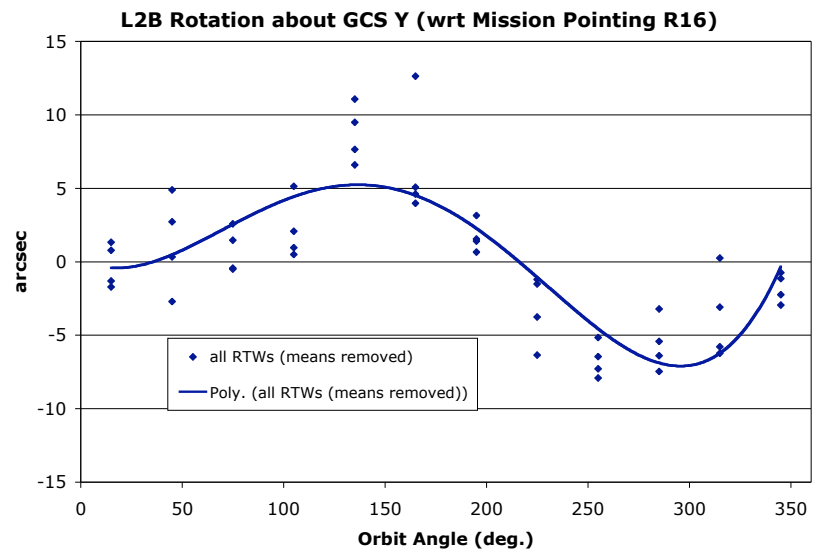
L2A





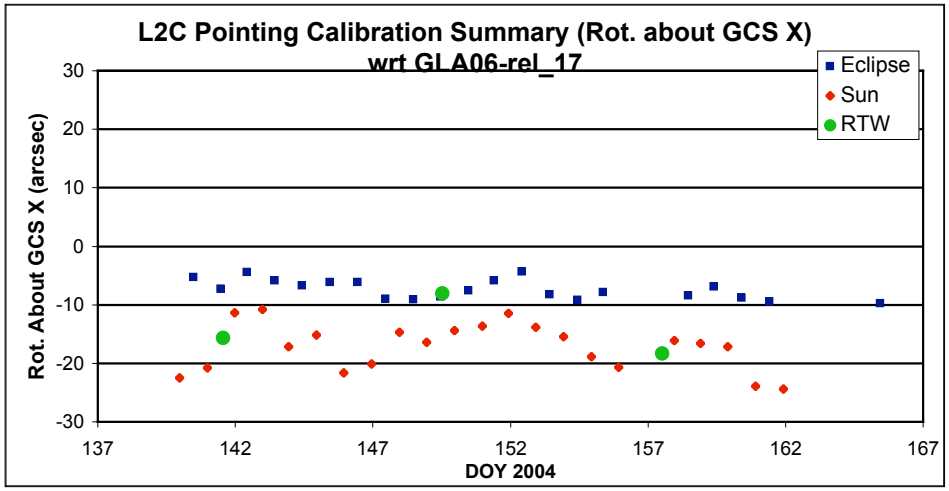
L2B

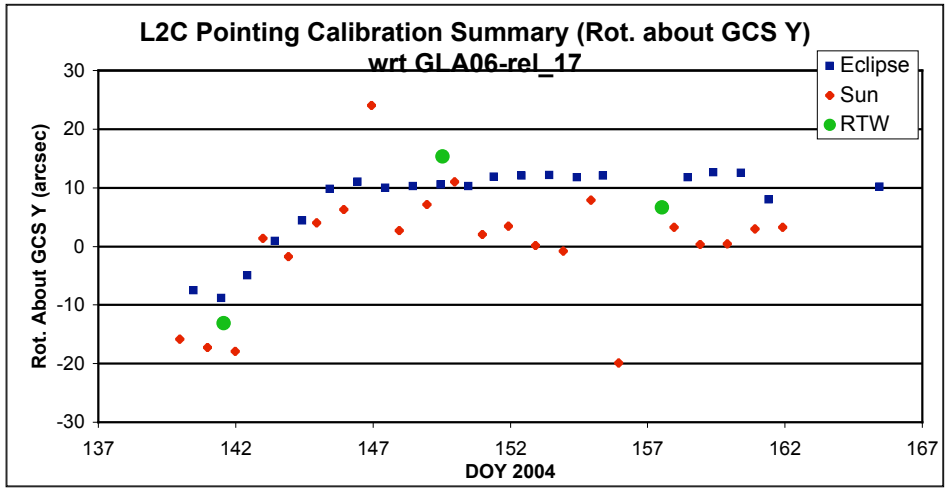




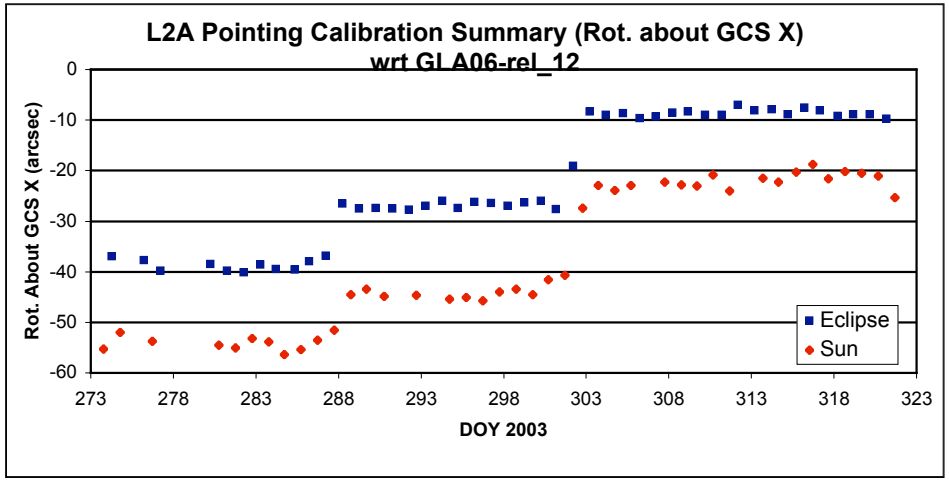
L2C OS Calibrations

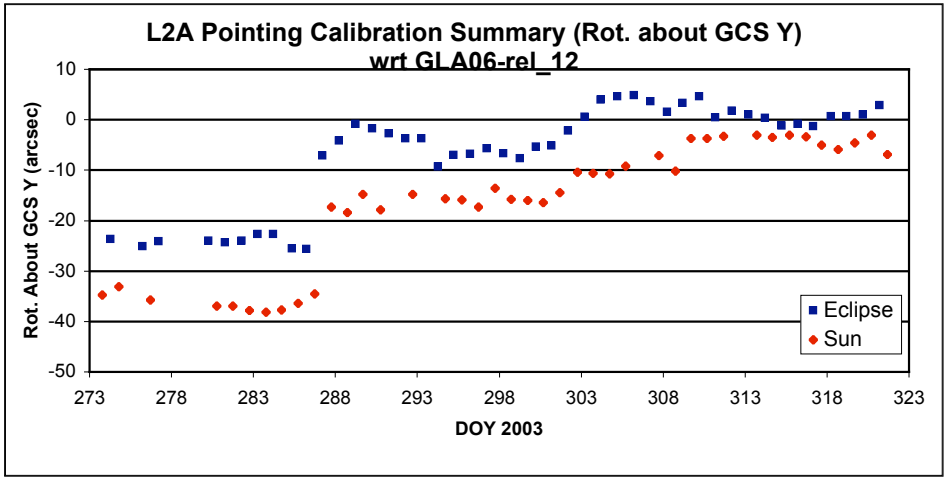
Rel. 17 does not includes SRS data



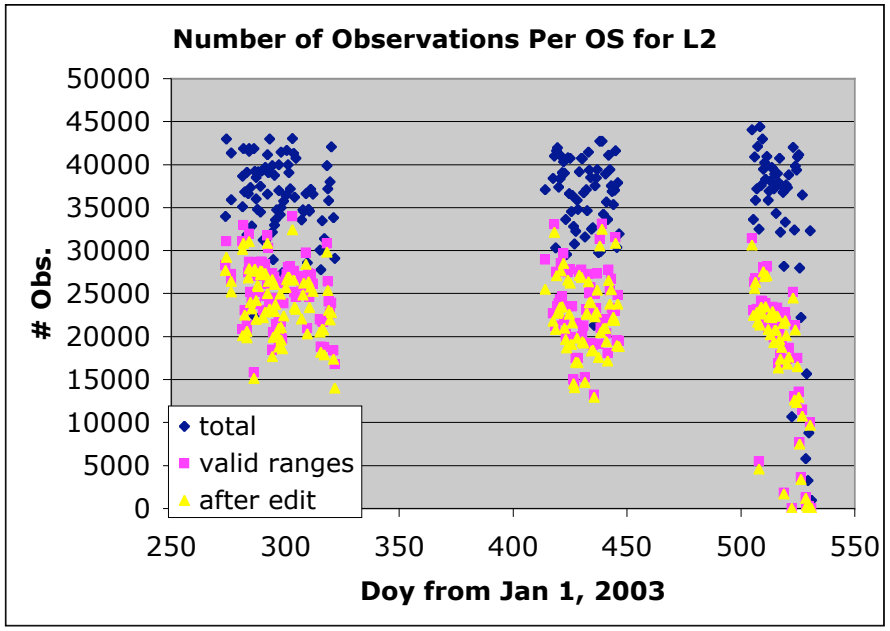


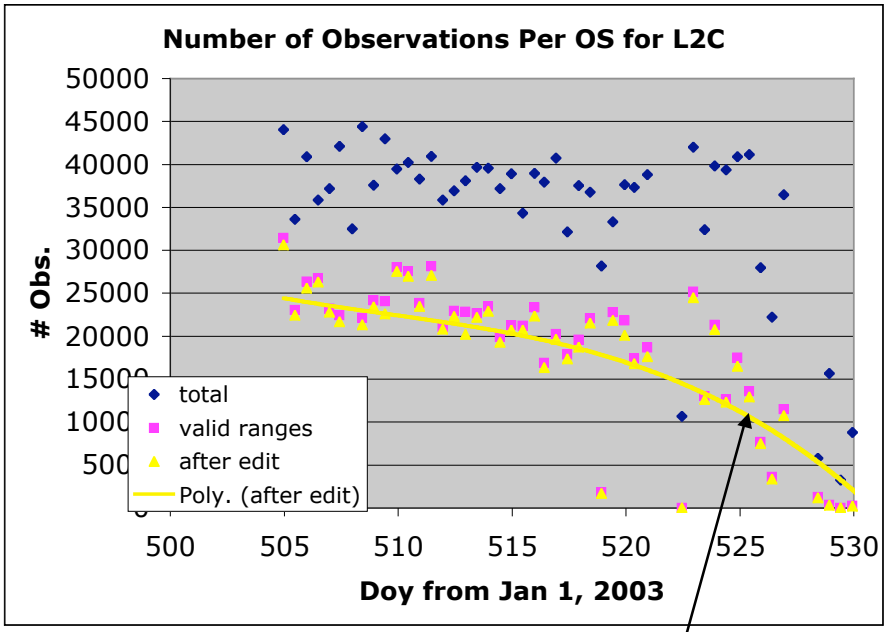
Comparison to L2A Rel. 12 (no SRS)

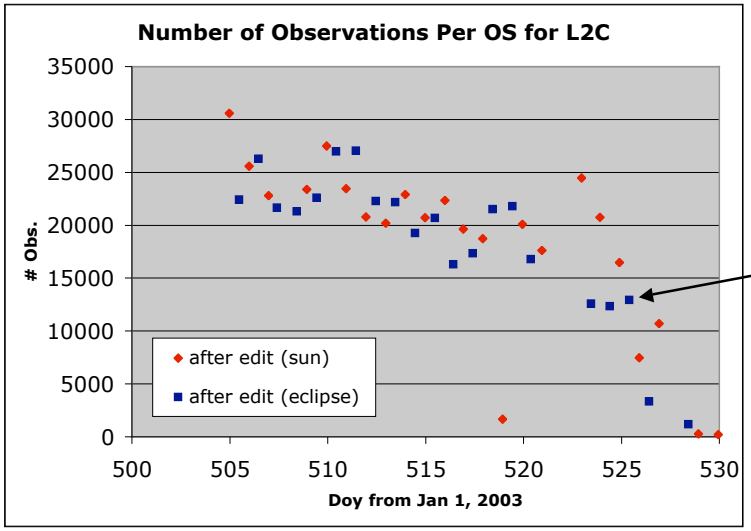




L2 # Obs. Per OS







Observe continuous reduction in useful observations during L2C.

Significant reduction in useful observations after June 9th, 2004.

Summary / Conclusions

- L1 Release 12 PAD / Release 18 represents a significant improvement with respect to the reduction of the overall pointing orbital variation.
- No noticeable improvement in the orbital and long period pointing variation is obtained from the use of release 18 over release 14
- FOV shadowing is observed in the "effective" pointing calibrations. This dominant error is present in all observation periods.
- The remaining effective pointing errors cause significant time varying geographically correlated range error even for the case of no surface slope (incidence angle from nominal spacecraft pointing). Range errors are much worse for sloping topography, or off-pointing.
- Because of the above, caution must be taken when performing range bias calibrations until the pointing is further refined.
- Error functions derived from the "effective" pointing calibrations can be used to correct for FOV shadowing.
- Correcting the data:
  - Currently we have developed the method and software to correct ANC09, obatt and GLA06 files for the observed effective pointing errors.
  - We have performed this correction on L2A release 14, and have performed very limited tests - looks good so far!
  - The next step is to correct the latest release 18 L2A data, perform more extensive tests and distribute for independent assessment.
  - Then we can start to refine our corrections using temperature data….