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SOHO-SEM

Version 4 Science Product Release Notes

Contributors

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Rev	Change Description	By
A	Migration of science processing responsibility from USC to LASP	DW

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0.3 References

D.L. Judge, et al., “First solar EUV irradiance obtained from SoHO by the CELIAS/SEM”, Sol. Phys., 177, 161, 1998.

Judge, D. L., McMullin, D. R., Ogawa, H. S., Hovestadt, D., Klecker, B., Hilchenbach, M., Mobius, E., Canfield, L. R., Vest, R. E., Watts, R., Tarrio, C., Kuhne, M., Wurz, P., ed. Pap, J. M., Frohlich, C., and Ulrich, R. K., “First Solar EUV Irradiances Obtained from SOHO by the CELIAS/SEM”, *Solar Electromagnetic Radiation Study for Solar Cycle 22*, 1998, Springer Netherlands, Dordrecht, p. 161-173, isbn=978-94-011-5000-2

0.4 Acknowledgements

We want to thank all of the people that worked so hard over the years to help make SEM data available to the public to support science research. In particular, we want to thank Leonid Didkovsky for shouldering the responsibility for so many years at USC. We also thank the good people that helped from Space Sciences Center for their hard work: Seth Weiman, Andrew Jones, Don McMullin and Harold Ogawa. We thank Dave Bouwer and Kent Tobiska for helping to pass the torch by creating a robust processing system. We thank the people from the SOHO project and the CELIAS team at the University of Maryland, particularly Scott Lasley for all his help and retrieving the mission data for LASP to use. We thank Tom Woods for all of his support and having the insight into the value of keeping SEM going. We also thank Darrell Judge for providing leadership in the early days.

In particular, we thank Andrew Jones for his new role in leading the SEM science effort at LASP.

1.0 Introduction

1.1 SOHO Spacecraft

The Solar and Heliospheric Observatory (SOHO) spacecraft is a joint project between NASA and ESA. The purpose of SOHO is to meet its scientific objectives related to studying the sun including monitoring the full-disk solar extreme ultraviolet (EUV) emission.

The SOHO spacecraft orbits the sun in the vicinity of the sun-earth barycenter (L1), so it is able to continuously observe the sun. However the distance to earth is so great that the deep space network (DSN) is needed for communication. The DSN is in high demand for many other purposes so contact with SOHO is not continuous, but SEM data is stored on board and sent when communication is possible.

1.2 SEM Instrument

The Solar EUV Monitor (SEM) instrument provides high cadence (15 second) EUV monitoring and is integrated into the Charge, Element, and Isotope Analysis System (CELIAS) instrument suite. The SEM is a transmission grating spectrograph with 3 photodiodes in fixed positions that define the bandpass for each diode. The central diode is the zero order (channel 2), and the other two diodes are positioned an both sides to collect the important He II 30.4 nm emission in +/-1 order (channel 1 and channel 3). The first order measurement is the average of channel 1 and 3.

The SEM science products provide central (or zero) order and first order measurements of the solar EUV with bandpasses from approximately 0.1-50 nm and 26-34 nm, respectively.

1.3 Science Processing Responsibility

SOHO-SEM has a rich science history built on the successes of the USC Space Sciences Center, and with the assistance of Space Environment Technologies (SET), and now the Laboratory for Atmospheric and Space Physics (LASP). In June 2021, the retirement of the USC researcher responsible for the SEM data processing placed the science production in jeopardy. In order to prevent the loss of this great science resource to the world scientific community, while it continues to operate, LASP has taken responsibility for continuing the science processing releasing new data products, and providing access to the data products.

Version 4 data products are produced at LASP and use the same algorithm concepts as the final version 3 data products produced at USC. The appendix shows some validation and comparisons between the LASP version 4 software results and the final version 3 results from USC.

2.0 Caveats

There is a known issue with SEM data showing what appears to be uncorrected long-term degradation. We thank Dr. Masumi Shimojo and the team from ALMA project, National Astronomical Observatory of Japan for their analysis suggesting SEM degradation is occurring and that it may be correctable with radio observations. Version 4 has not altered or added any degradation corrections that were not present in version 3. Currently we cannot exclude the possibility that there may be wavelength-dependent degradation that could be changing the bandpass over time.

The first order channel is believed to have contributions from reflected light off the wall of the case. Previously, this was modeled using a contribution from the 17.1 nm Fe IX line.

3.0 Science Products

There are two types of science products for SEM to serve the different needs of the science community.

3.1 15-second Irradiances

Version 4 15-second irradiances are grouped into day-length ASCII files. Data product files can be accessed using this link that will show a list of directories for years.

https://lasp.colorado.edu/eve/data_access/eve_data/lasp_soho_sem_data/long/15_sec_avg/

Individual day-length files are sorted into their corresponding year directories. The naming convention of these files was retained from previous versions. The header also retains the same number of header lines as version 3 as well as the descriptions. An example is 21_01_01_v4.00 would correspond to 2021Jan 1 for version 4.

A partial file example is shown here that is largely retained from previous versions. Note that the word "flux" is used to indicate the calibrated solar irradiance in columns 12 and 13.

```
;SEM 15 SECOND AVERAGE FULL SOLAR DISK FLUX at 1 AU
;==============================================
;
;Data Revision: December 11, 2008  (v4.00, LASP version of SET version of USC v3, November 3, 2006)
;----------------------------------------------
;Column 0-      Julian date (mid point of sample)
;Column 1-      Year (UT)
;Column 2-      Day of Year (UT)
;Column 3-      Seconds of day (UT)
;Column 4-      CH1 (1)
;Column 5-      CH2 (1)
;Column 6-      CH3 (1)
;Column 7-      X (2)
;Column 8-      Y (2)
;Column 9-      Z (2)
;Column 10-     R (3)
;Column 11-     R (AU)
;Column 12-     First Order Flux at 1AU (4)
;Column 13-     Central Order Flux at 1AU (5);
;
;-----------------------------------------------
;(0) Blank or Zero values = no data
;(1) 15 second average (raw) count rate at SOHO
;(2) SOHO Heliocentric location, X, Y, & Z (km)
;(3) SOHO Distance, R = sqrt( X^2 + Y^2 + Z^2 )
;(4) Flux at 1AU
;               Range:    26 - 34 nm flux
;               Units:    photons cm^-2 s^-1
;               Value:     15 second average
;               Derivation:  average of CH1 and CH3
;(5) Flux at 1AU
;               Range:    0.1 - 50 nm flux
```

```
;               Units:    photons cm^-2 s^-1
;               Value:     15 second average
;               Derivation:  CH2
;
;===============================================
; University of Colorado, LASP, Boulder, CO 80303
;
; blank lines used to preserve header length
;-----------------------------------------------
;
;
;Contact: Don Woodraska/Andrew Jones, don <dot> woodraska or andrew <dot> jones <at> lasp.colorado.edu
;Website: https://lasp.colorado.edu/eve/data_access/eve_data/lasp_soho_sem_data/
;===============================================
2459215.500150 2021 001 13 120.00 2133.33 89.07 -2.68937e+07 1.43357e+08 7.40076e+04 1.45858e+08 9.75001e-01
8.28658e+09 1.58057e+10
2459215.500498 2021 001 43 120.00 2133.33 88.80 -2.68946e+07 1.43357e+08 7.40084e+04 1.45858e+08 9.75001e-01
8.26812e+09 1.57717e+10
…
2459215.500671 2021 001 58 119.73 2133.33 88.80 -2.68950e+07 1.43357e+08 7.40088e+04 1.45858e+08 9.75001e-01
8.24739e+09 1.57334e+10
```

3.1.1 Daily Average Irradiances

The version 4 daily average irradiances are calculated from the 15-second products and grouped into year-length ASCII files. This is the same as in version 3. Version 4 files can be downloaded from this link.

https://lasp.colorado.edu/eve/data_access/eve_data/lasp_soho_sem_data/long/daily_avg/

This shows one file for each year and the filename convention from version 3 is retained as YY_v4.day.

An example of the file contents are shown here.

```
;SEM DAILY AVERAGE FULL SOLAR DISK FLUX at 1 AU
;==============================================
;
;Data Revision: December 11, 2008  (v4.00, LASP version of SET Java version of USC C/C++ v3, November 3, 2006)
;----------------------------------------------
;Column 0-      Julian date (mid point of sample)
;Column 1-      Year (UT)
;Column 2-      Day of Year (UT)
;Column 3-      CH1 (1)
;Column 4-      stdev CH1
;Column 5-      CH2 (1)
;Column 6-      stdev CH2
;Column 7-      CH3 (1)
;Column 8-      stdev CH3
;Column 9-      X (2)
;Column 10-     Y (2)
;Column 11-     Z (2)
;Column 12-     R (3)
;Column 13-     R (AU)
;Column 14-     First Order Flux at 1AU (4)
;Column 15-     Central Order Flux at 1AU (5)
;
;-----------------------------------------------
;(0) Blank or Zero values = no data
;(1) Daily average (raw) count rate at SOHO
;(2) SOHO Heliocentric location, X, Y, & Z (km)
;(3) SOHO Distance, R = sqrt( X^2 + Y^2 + Z^2 )
;(4) Flux at 1AU
;               Range:    26 - 34 nm flux
;               Units:    photons cm^-2 s^-1
;               Value:     daily average
;               Derivation:  average of CH1 and CH3
;(5) Flux at 1AU
;               Range:    0.1 - 50 nm flux
;               Units:    photons cm^-2 s^-1
```

```
;               Value:     daily average
;               Derivation:  CH2
;
;===============================================
; University of Colorado, LASP, Boulder, CO 80303
;
; blank lines used to preserve header length
;-----------------------------------------------
;
;
;Contact: Don Woodraska/Andrew Jones, don <dot> woodraska or andrew <dot> jones <at> lasp.colorado.edu
;Website: https://lasp.colorado.edu/eve/data_access/eve_data/lasp_soho_sem_data/
;===============================================
2459216.000000 2021   1 119.81 6.43583e-01 2103.89 2.91339e+01 89.28 4.56221e-01 -2.81566e+07 1.43112e+08 7.51286e+04
1.45863e+08 9.75055e-01 8.28665e+09 1.57986e+10
2459217.000000 2021   2 119.24 5.21740e-01 2080.70 1.61603e+01 88.69 4.95710e-01 -3.06760e+07 1.42594e+08 7.72753e+04
1.45863e+08 9.75055e-01 8.20206e+09 1.56367e+10
…
```

New users will note that the daily average irradiances are in columns 14 and 15.

Note that one new aggregate product is being produced and updated daily. This is a merged product of all the daily average files for each year together into one netcdf file. It is the hope that this enables more widespread use of SEM data to the wider scientific community.

https://lasp.colorado.edu/eve/data_access/eve_data/lasp_soho_sem_data/long/daily_avg/sem_mission_merged_v4.nc

We will work with the LISIRD (https://lasp.colorado.edu/lisird) team to enable access through the LaTiS API.

Appendix A - Validation

There are some minor discrepancies between the USC version 3 data and the LASP version 4 data.

The LASP team wishes to thank Scott Lasley for his assistance in retrieving the entirety of the SEM low level data used to create the science products.

Initially, LASP intended to create a science processing implementation to validate reproducibility of the USC values from recent time periods. This enabled faster comparisons and showed some weaknesses in the previous implementation.

Difference are listed here

1. One difference in the comparisons is that the LASP dataset is more complete than the USC dataset, especially for older data. This is believed to impact the value of the daily averages in 2005 and we believe this is the cause of small differences before 2005. Version 4 has more data than version 3.

2. Previous versions used the lower level files directly in processing, however, those usually do not contain the first measurements of the day, and they usually contain additional data from the next day. Previous versions used that data to determine daily averages. Version 4 fixes this bug and uses all the data for the UTC day and none from other days.

3. Another difference is that version 3 was not all generated from one set of software. The oldest data was processed using earlier USC software (C source code), but not reprocessed with the software provided by SET (Java source code). This is detectable because the spacecraft orbit position LASP uses is the same set of FITS files used by the early USC software where the agreement is best. Small differences in the files used in the SET software (ASCII files) are believed to exhibit a loss of precision from the fixed format that does not use scientific notation. https://sohowww.nascom.nasa.gov/data/ancillary/orbit/predictive There are other differences early in the mission that may be related to not using the best orbit files.

4. The spacecraft orbit position values are noisy in version 3, but not in version 4 starting in 2006. This directly maps into irradiance discrepancies after 2006 where the count rates agree.

3.2 Irradiance Comparisons

The time series of the first order irradiance is shown below where version 4 is in the red color overplotted onto the black version 3 irradiance. At this scale the primary differences occur for just a few days in 2005 where the version 3 data appears to be too low.

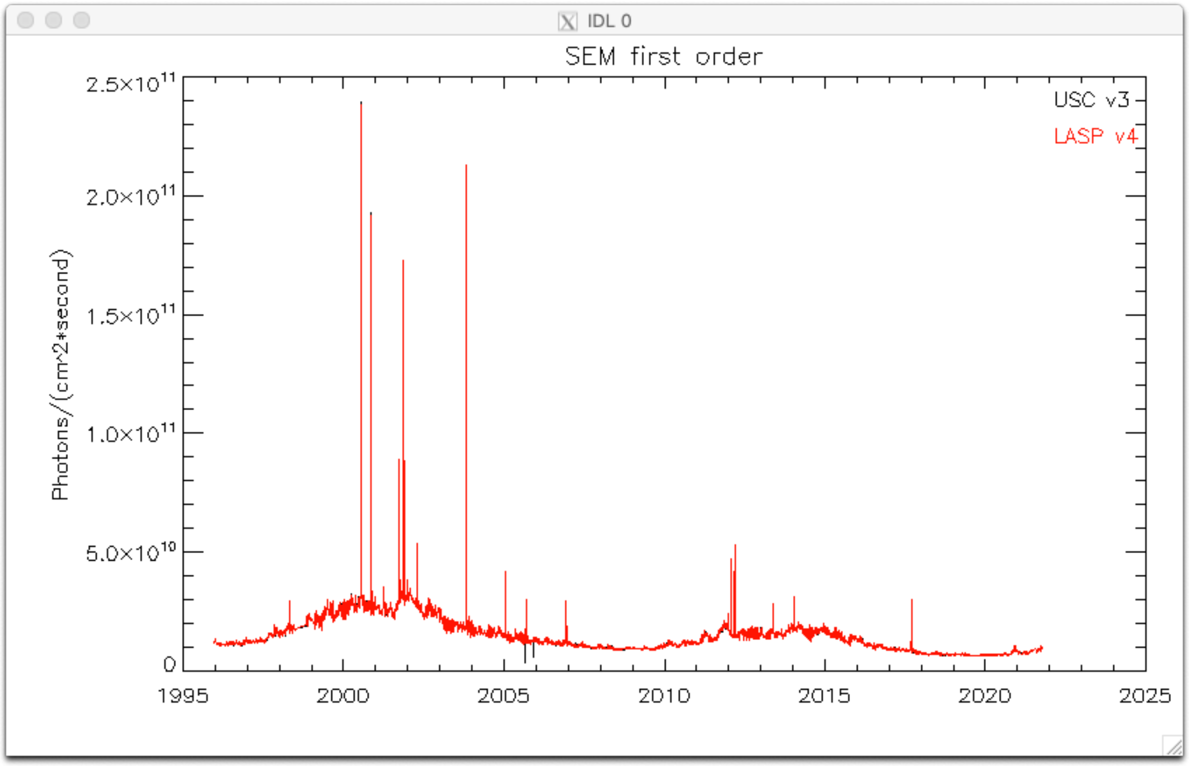

Figure 1 SEM first order irradiance time series

A closer examination is provided below with the ratio of version 4 to 3 showing the full scale range, and a zoomed in range of +/-3%. The 2005 discrepancy over a few days that was noted in the time series above is nearly a factor of 4, and excellent agreement occurs between 2001-2005 with the ratio being very nearly 1.

There are interesting annual cycles observed in the ratio that can rise to 2%. This is known to be caused by the different spacecraft position information that is used where version 3 uses the ASCII files and version 4 uses the FITS files. We assume the previous USC processing code was also using the FITS files to produce such good agreement. In 2006 the USC processing software changed from C to the SET Java implementation. The version 4 processing software is based on the SET Java source code, but the spacecraft orbit files were changed to use the FITS files. We speculate that perhaps there is some precision loss, or perhaps the FITS files contain updated information.

Also of interest is the recovery from the well-known 1998 SOHO “vacation”. This appears to show about a 1% effect over a short time period.

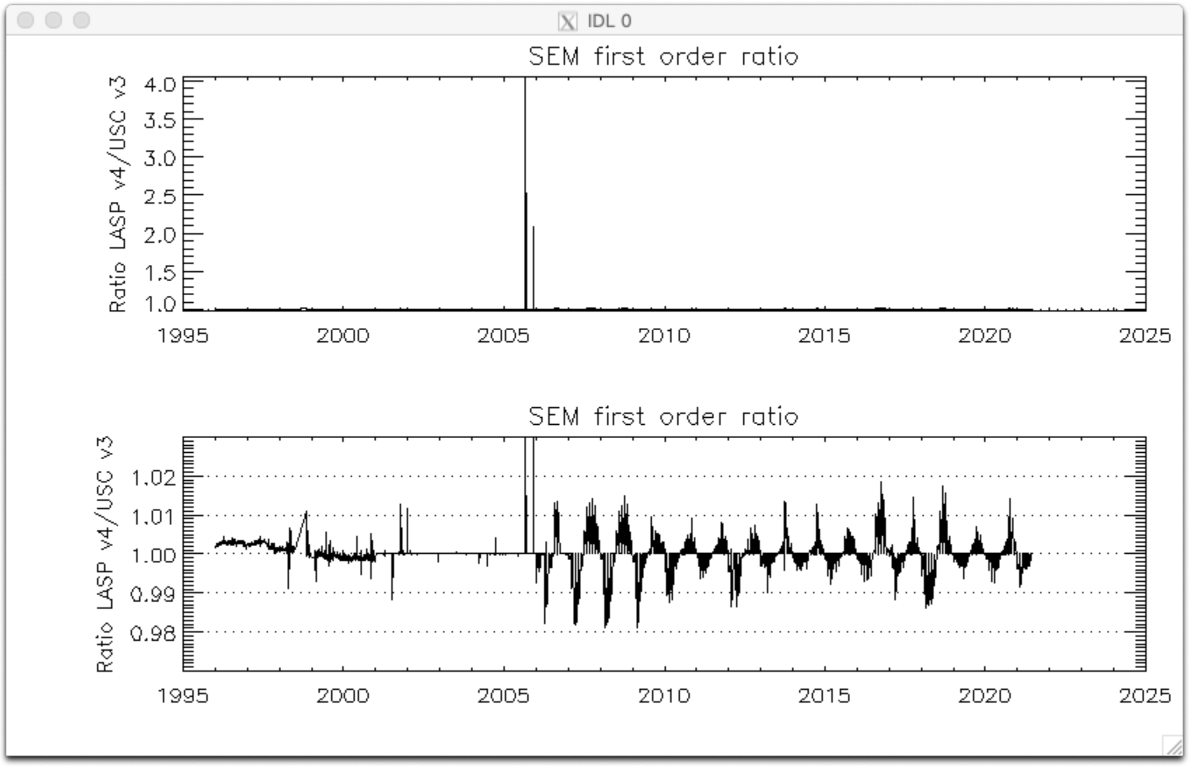

Figure 2 SEM first order irradiance version ratios

The central order (zero order) channel irradiance shows the same behavior as the first order channel irradiance.

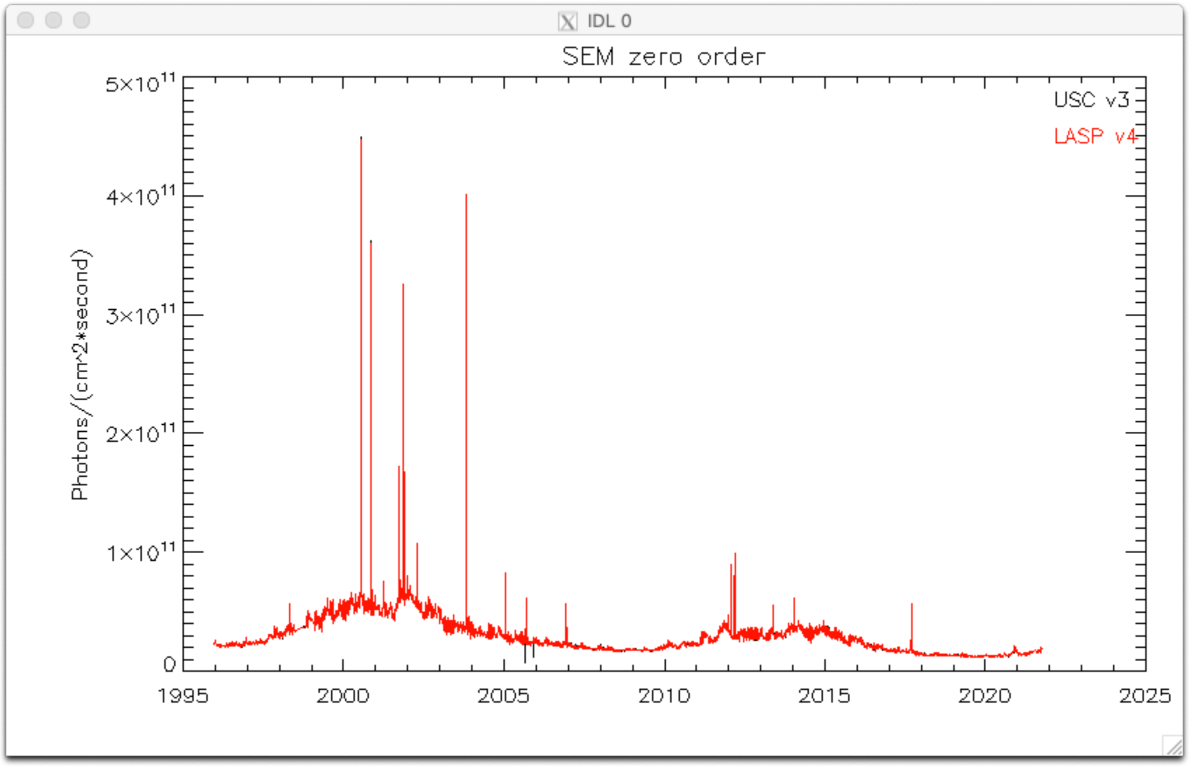

Figure 3 SEM central order irradiance timeseries

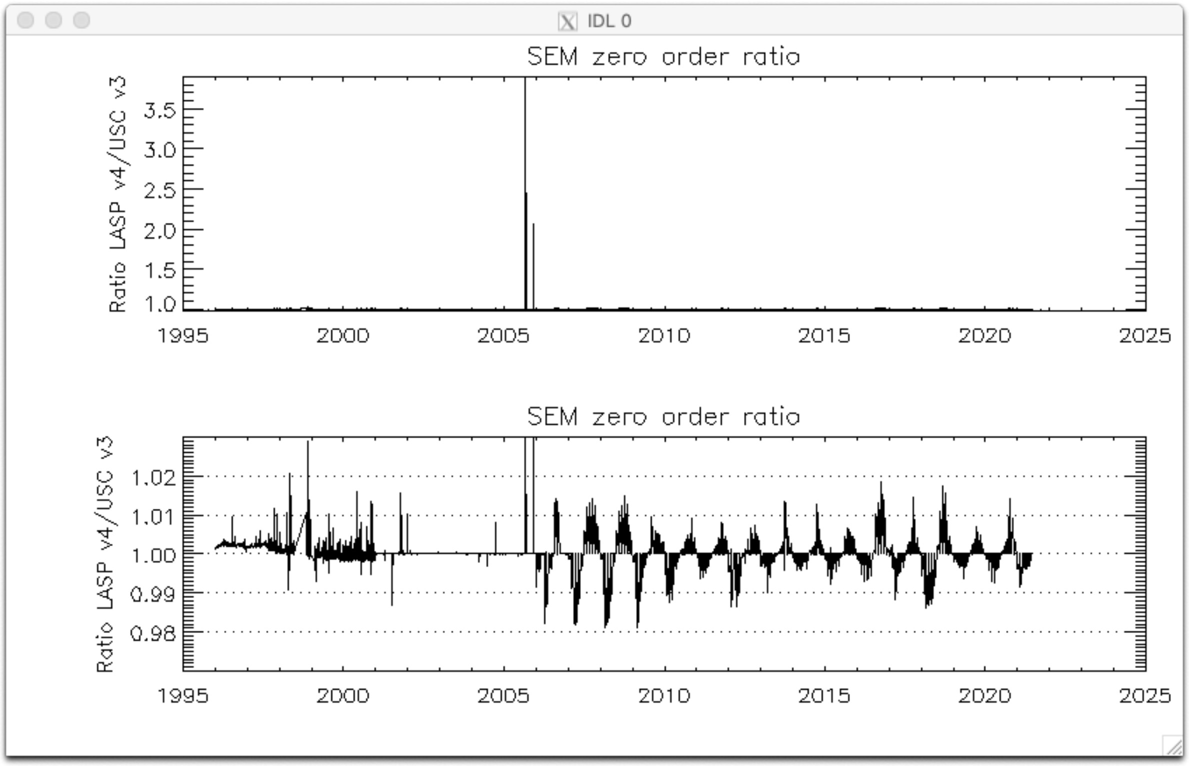

Figure 4 SEM central order irradiance ratios

3.3 Count Rate Comparisons

The count rates for channel 1 are also compared. This gives insight into whether or not the low level data are different between version 3 and version 4. The 2005 discrepancy noted in the irradiance also appears in the count rate data.

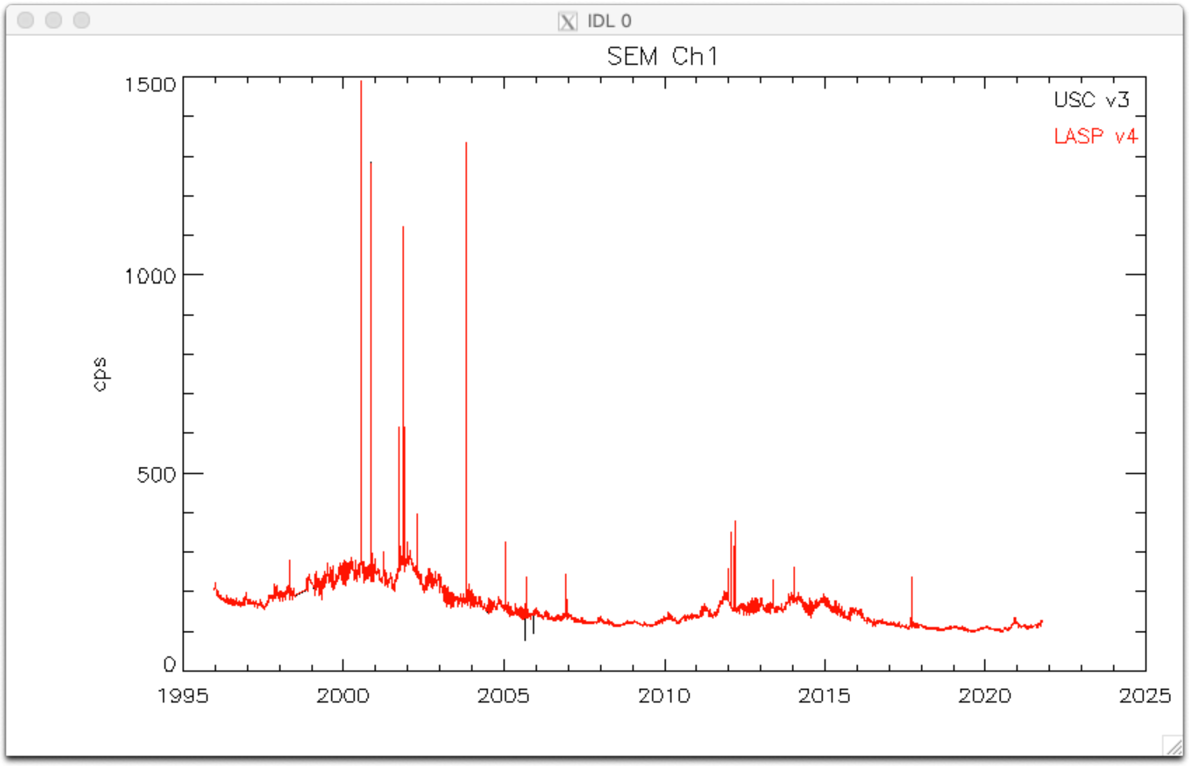

Figure 5 SEM channel 1 count rate timeseries

The ratio shows about a factor of 2 for the worst day. A closer look shows seemingly random small differences throughout the mission.

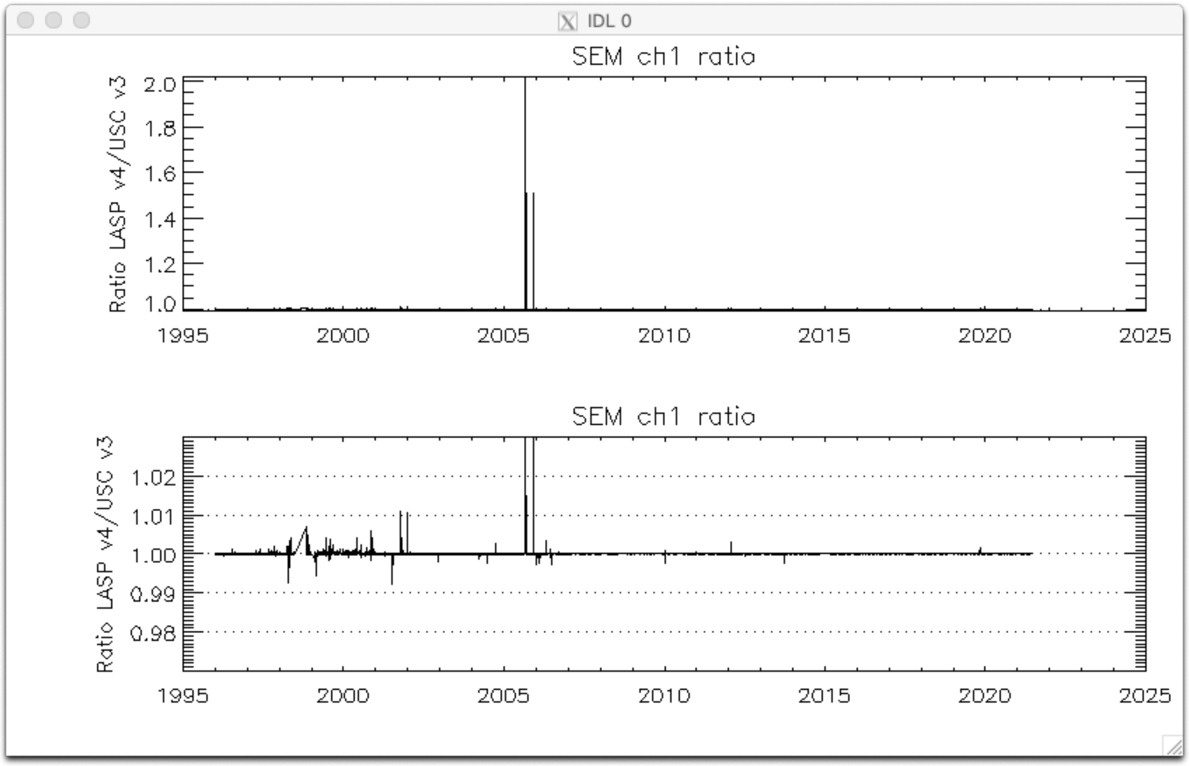

Figure 6 SEM channel 1 version ratios

The channel 2 irradiances also show a discrepancy in 2005, but at this scale it is difficult to observe small difference.

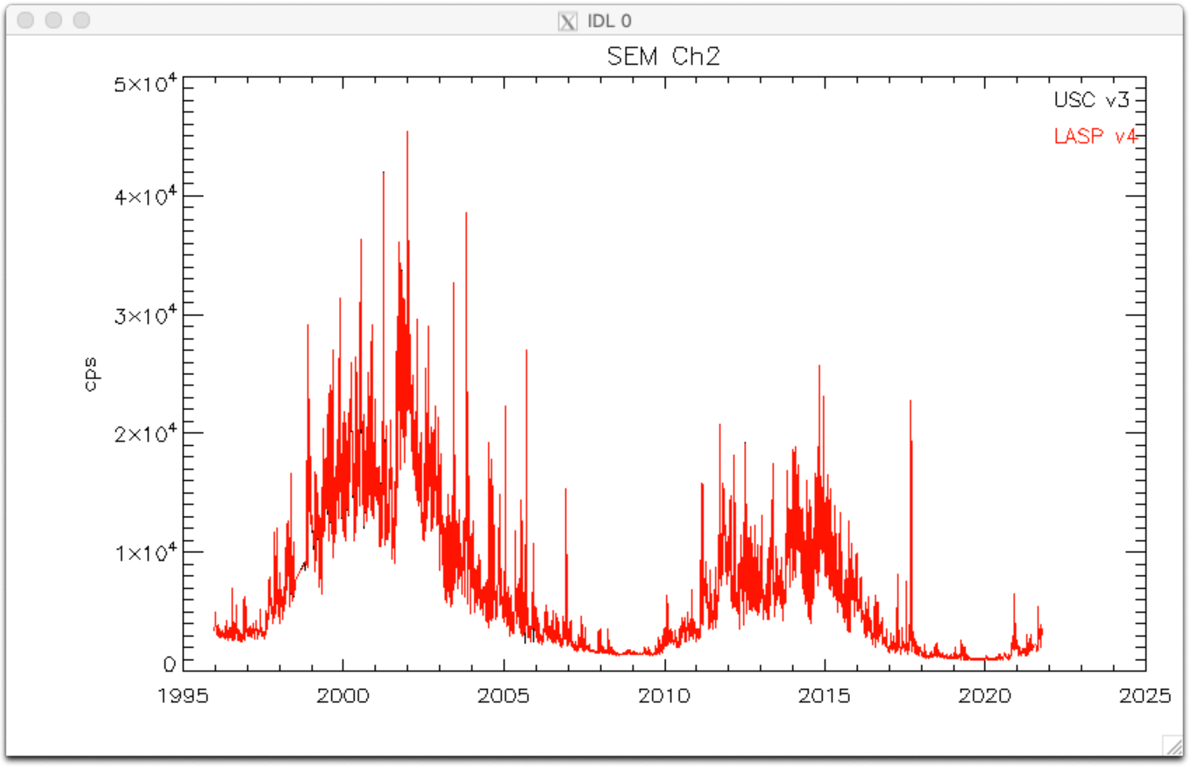

Figure 7 SEM channel 2 count rate timeseries

The ratio highlights the discrepancies. Prior to 2001 there appears to be significant noise in the ratio rising up to 20% sometimes. This noise almost completely disappears after 2001. This may be traceable to data completeness issues in the early mission in version 3. For version 4, the entire mission was reproduced for LASP processing.

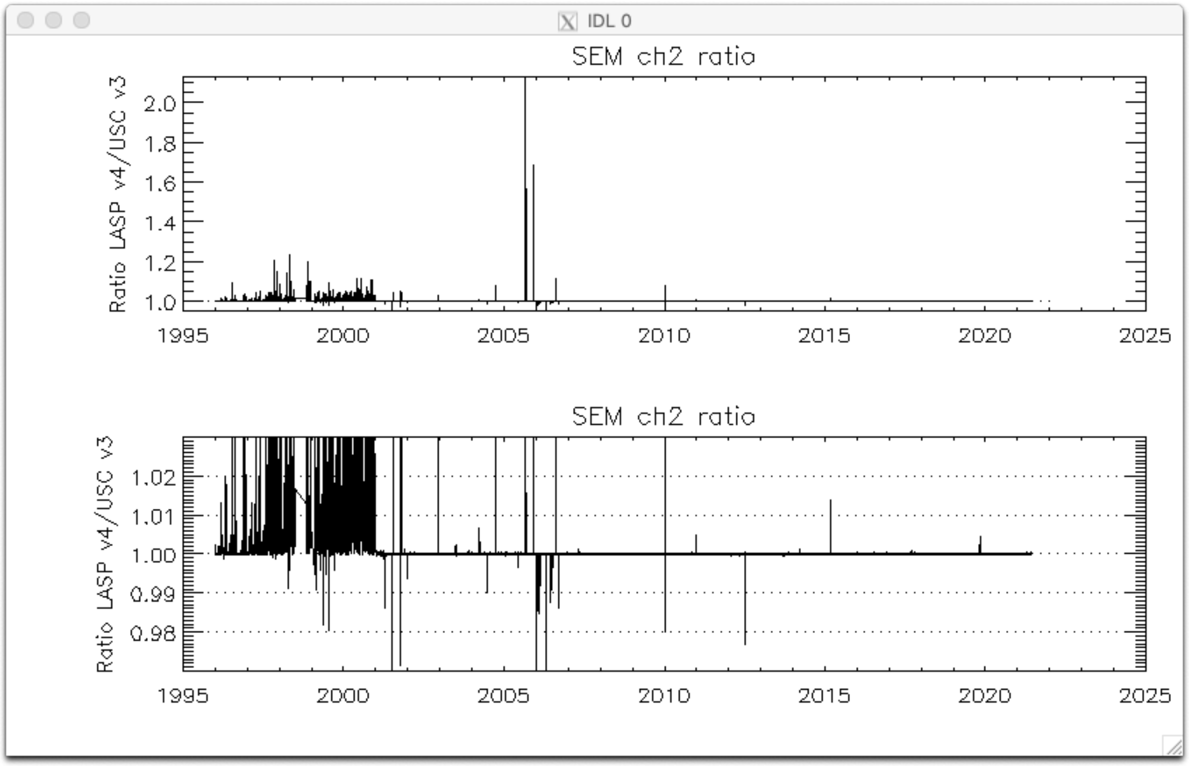

Figure 8 SEM channel 2 count rate ratios

As expected the channel 3 count rates appear to be very similar to the channel 1 comparison.

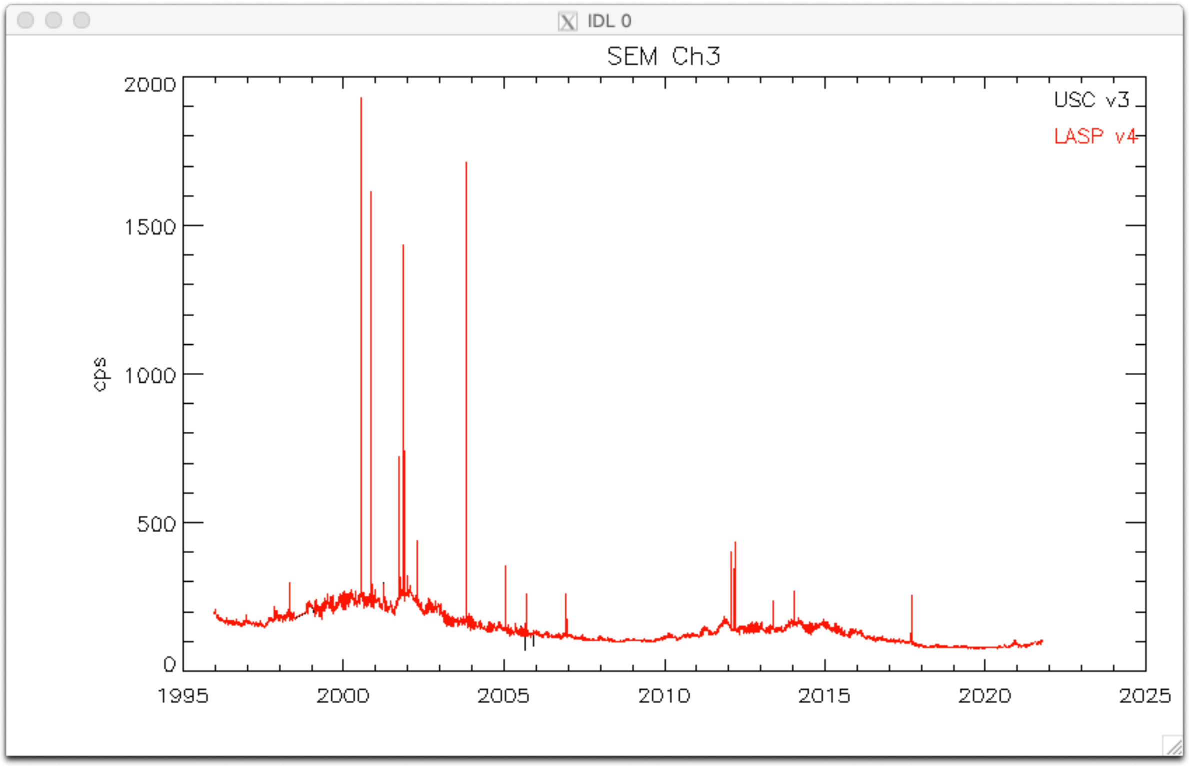

Figure 9 SEM channel 3 count rate timeseries

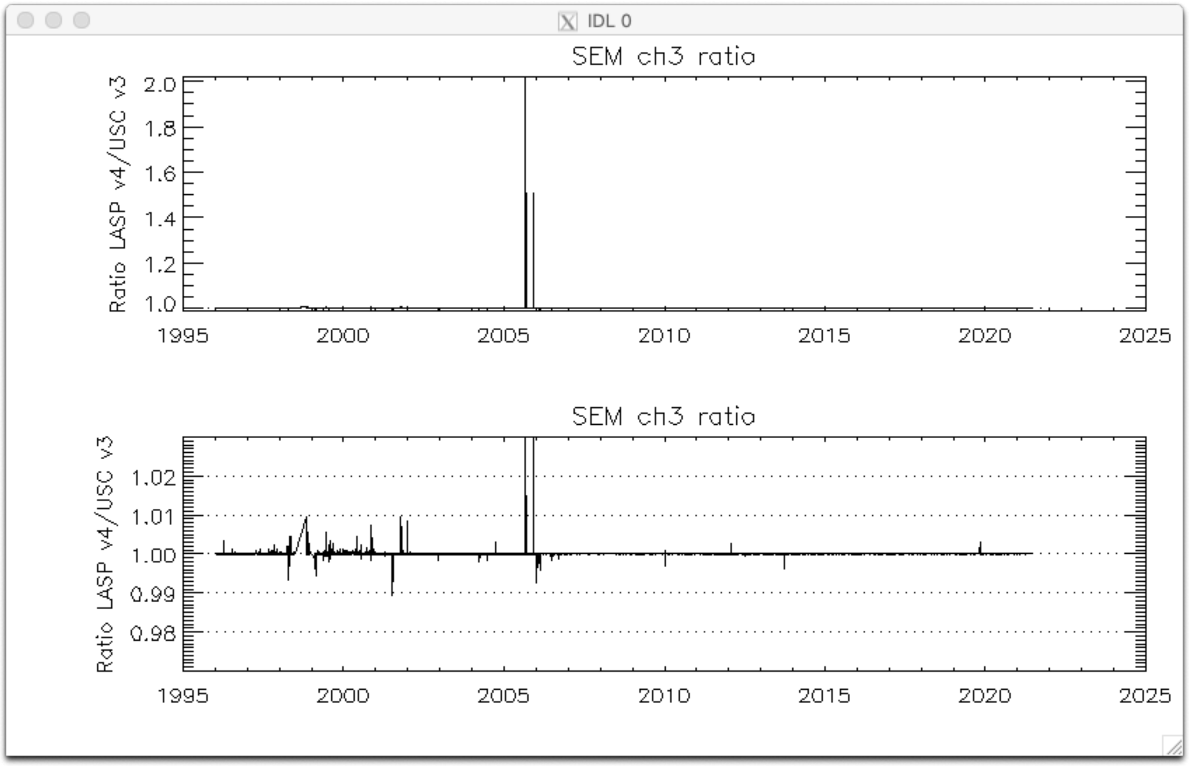

Figure 10 SEM channel 3 count rate ratios

3.4 Spacecraft Position Comparisons

The spacecraft position vector components are compared here. It is important to remember that each position component can be zero, so comparing ratios of small numbers would produce a periodic cycle. There is a marked difference starting around 2006. This is believed to be the time when the processing software was last changed at USC. Excellent agreement occurs in the X component between 2001 and 2005 showing smooth sinusoidal annual variation. The version 3 data become significantly less smooth in 2006 and the version 4 do not show that raggedness. This gives confidence that the version 4 data product should have fewer position-errors than version 3. The discrepancy in position may not be small, but the impact on the irradiance is small and less than about 2% most of the time.

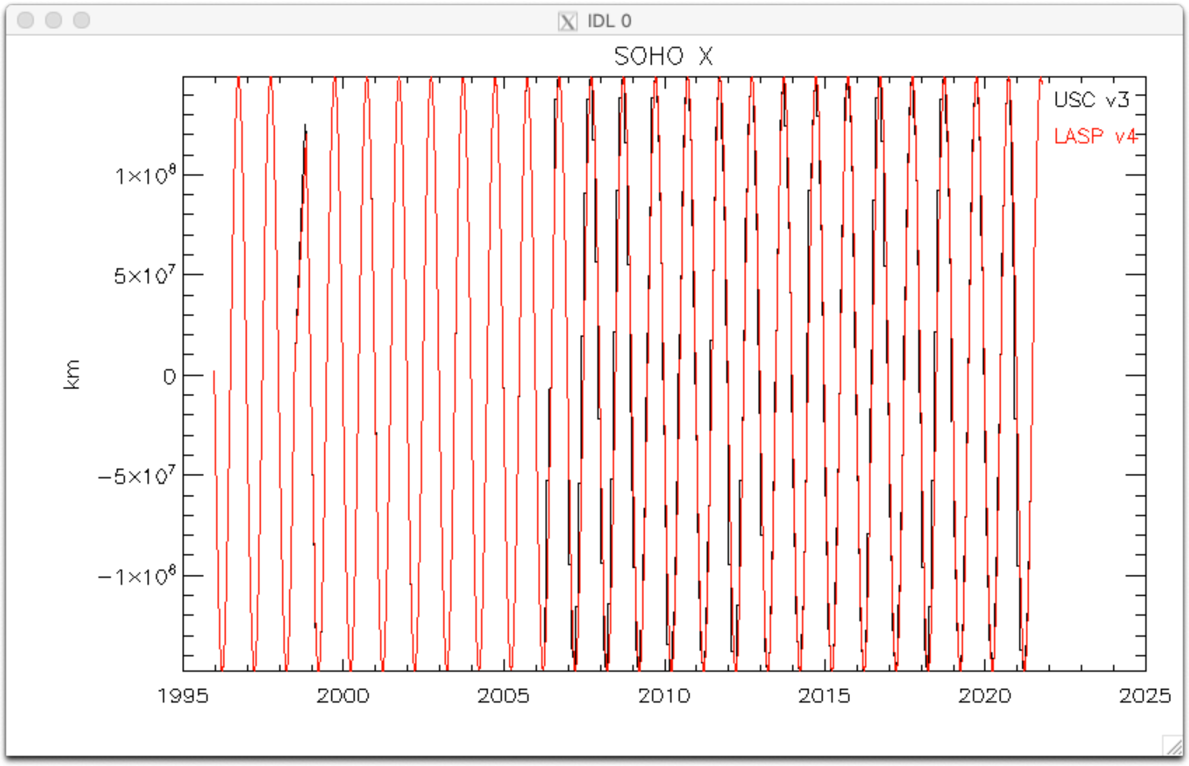

Figure 11 SOHO X-component position timeseries

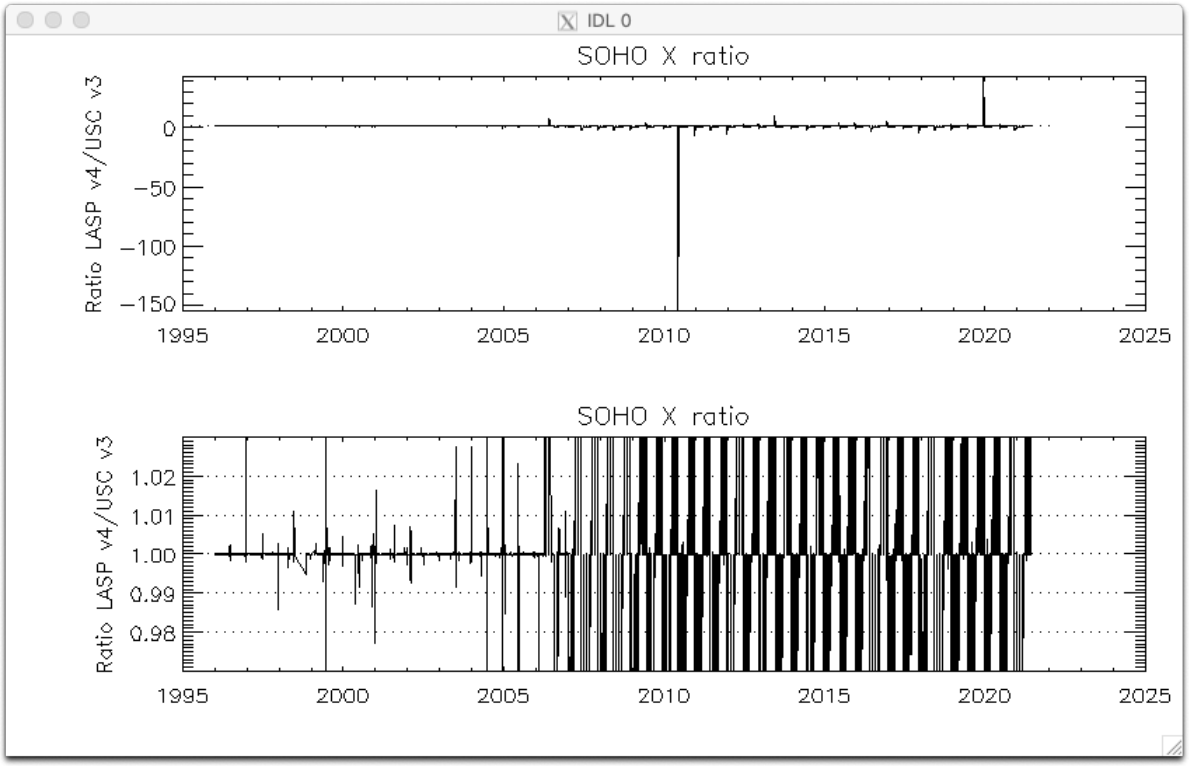

Figure 12 SOHO X-component position ratios

The comparison of the Y component of spacecraft position is similar to the X component.

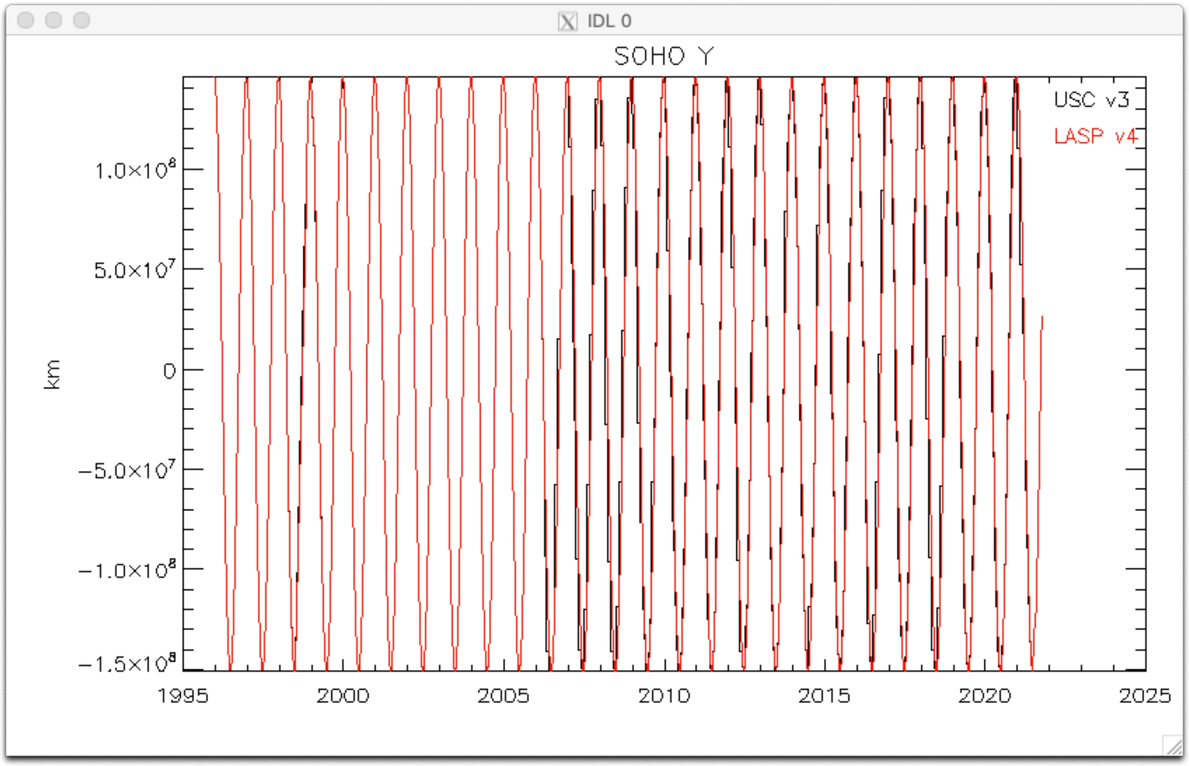

Figure 13 SOHO Y-component position timeseries

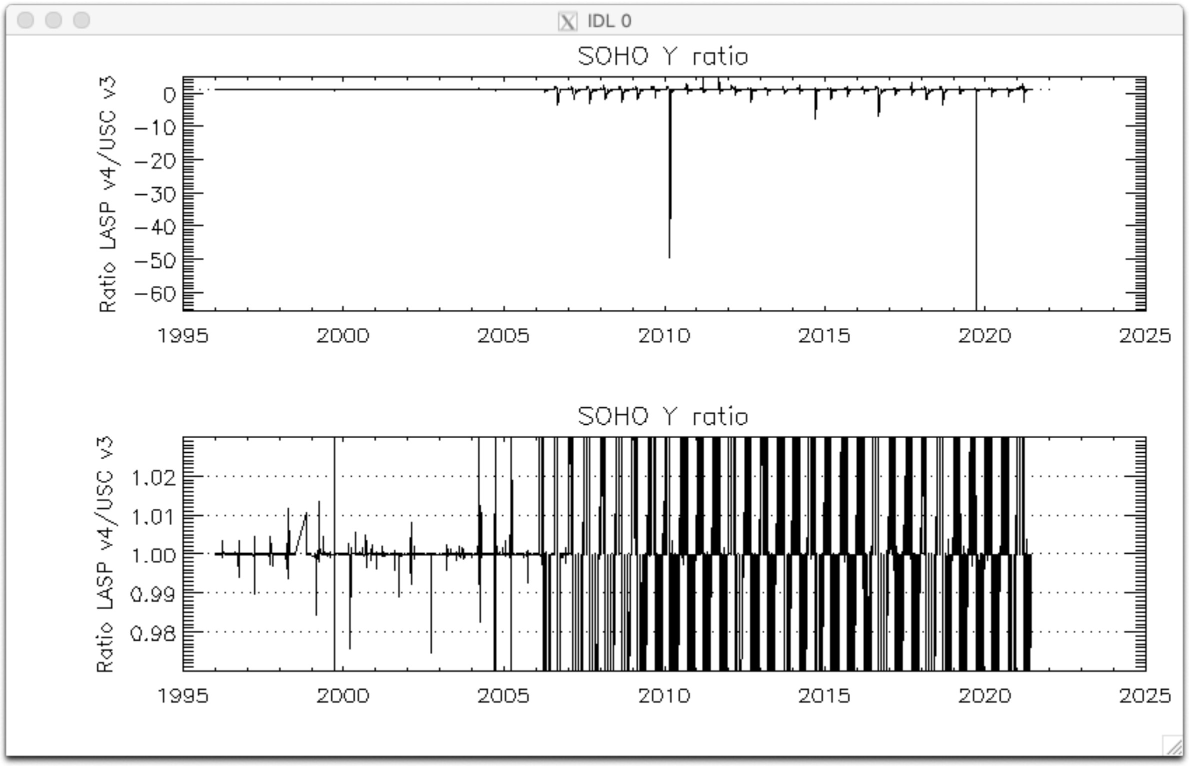

Figure 14 SOHO Y-component position ratio

Comparison of the Z component of spacecraft position is a little different. Larger differences are noticeable.

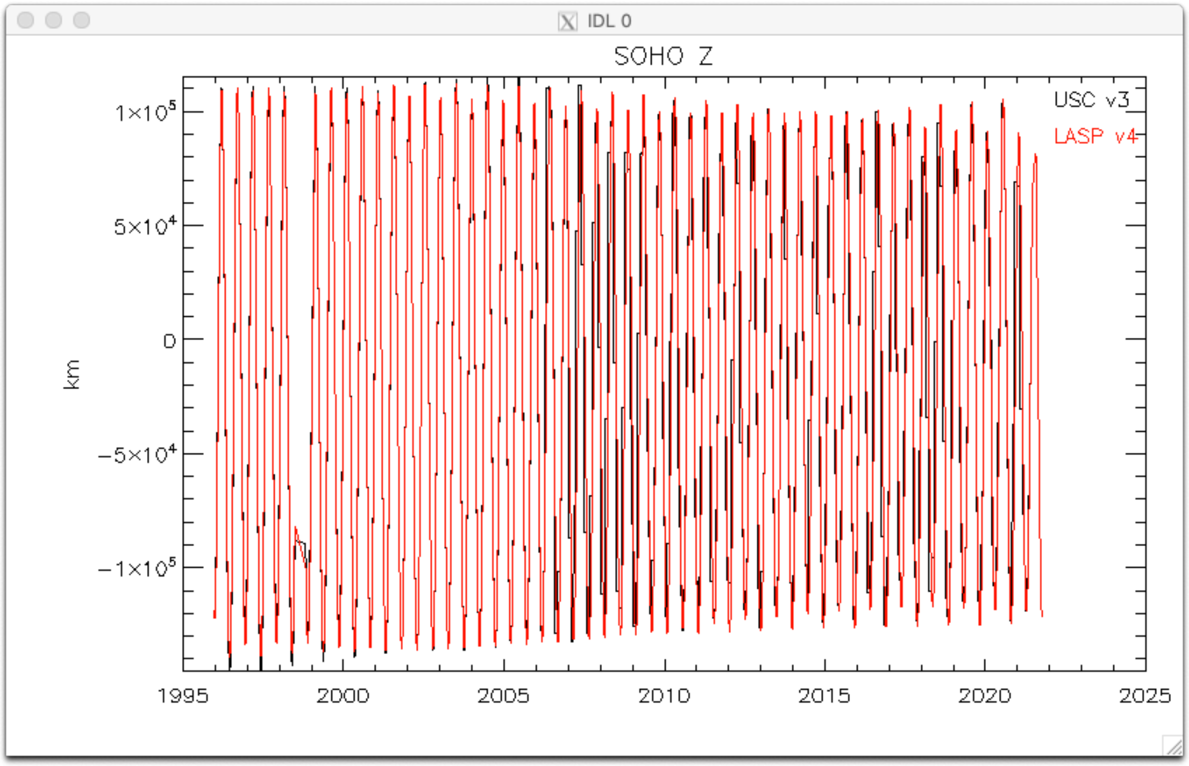

Figure 15 SOHO Z-component position timeseries

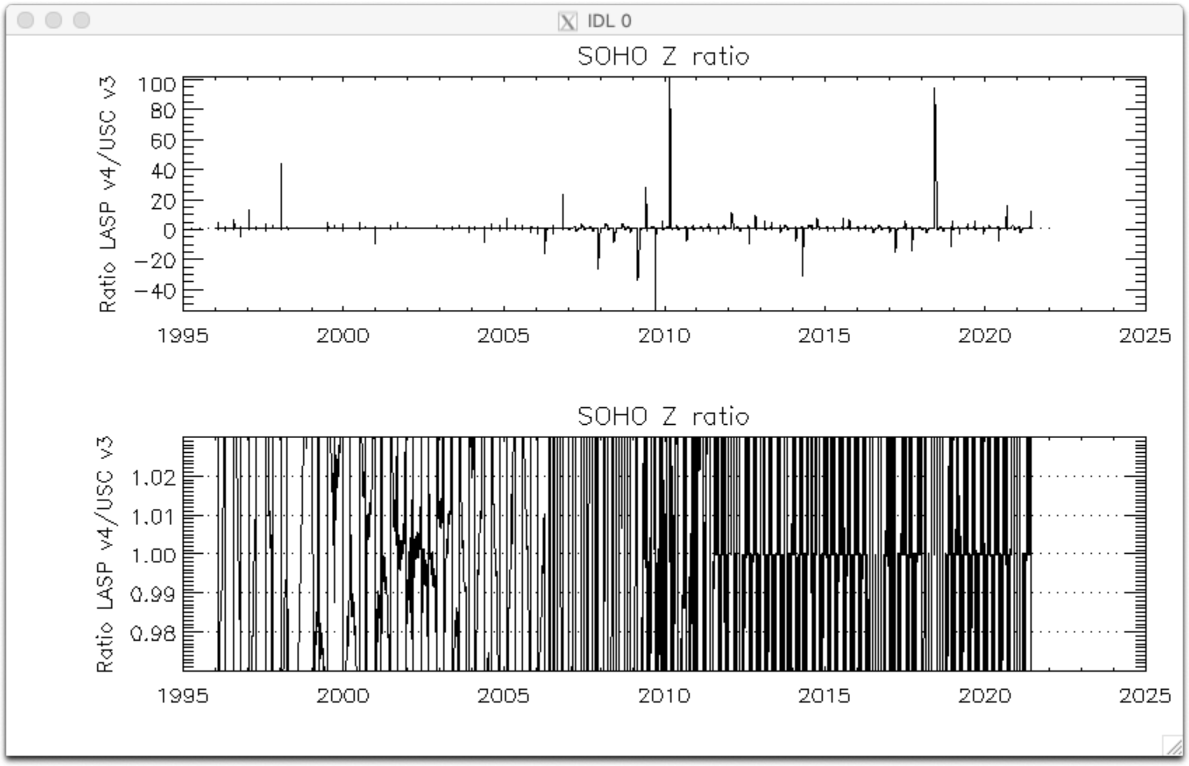

Figure 16 SOHO Z-component position ratio

Ultimately, the position vector is used to determine the spacecraft to sun distance to remove the annual variation and adjust the irradiance to the mean 1-AU earth to sun distance. This is the equivalent irradiance that would be observed at earth. It inherits all of the issues with the individual components.

Interestingly, the ratio in the R shows excellent agreement prior to 2006. From 2006 forward in time there are noisy periodic discrepancies up to 1%. This is the cause of the periodic issues in version 3 irradiance comparisons.

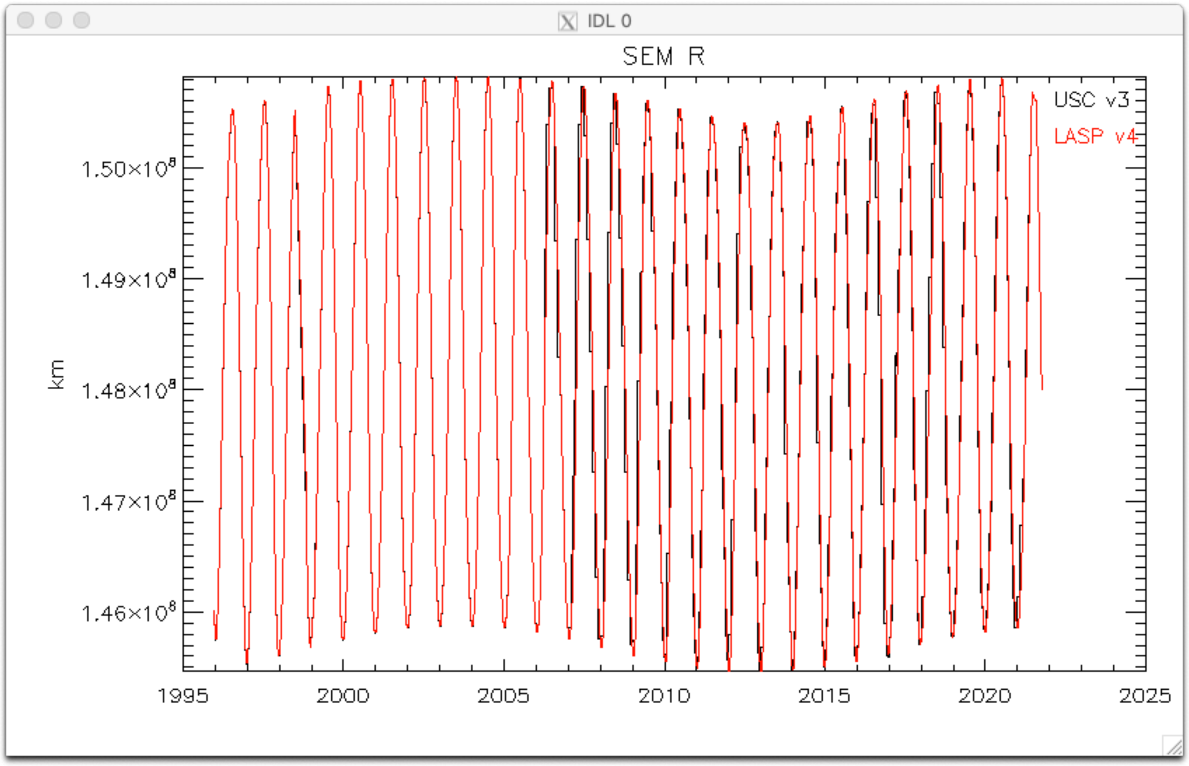

Figure 17 SOHO to sun distance timeseries

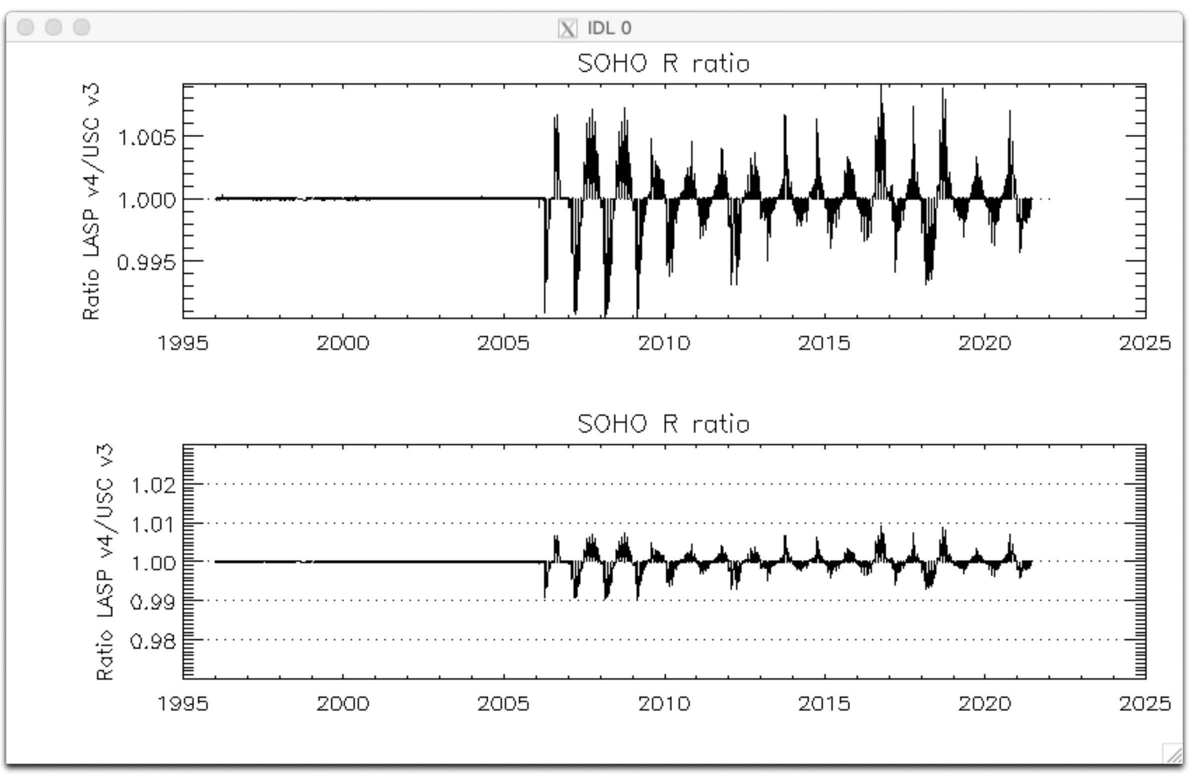

Figure 18 SOHO to sun distance ratio

For completeness, the version 4 to version 3 comparison of R_AU is also shown, but it is basically the same as comparing R.

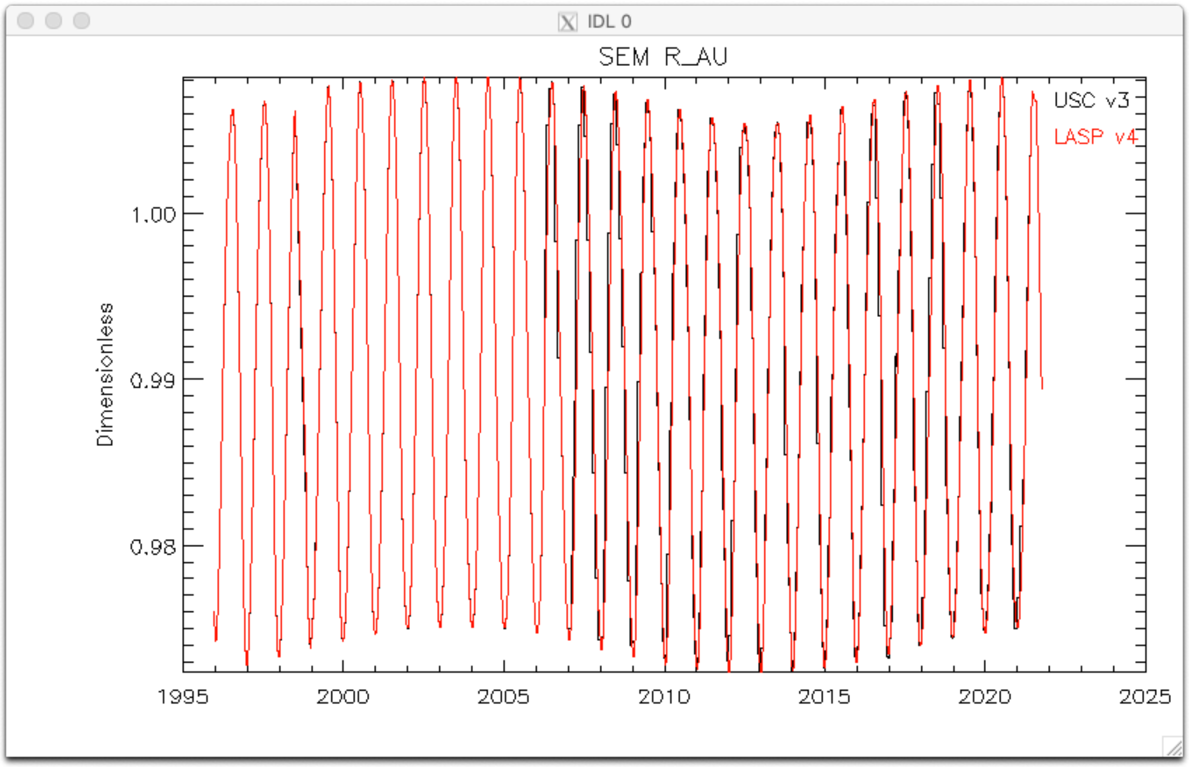

Figure 19 SEM AU distance correction timeseries

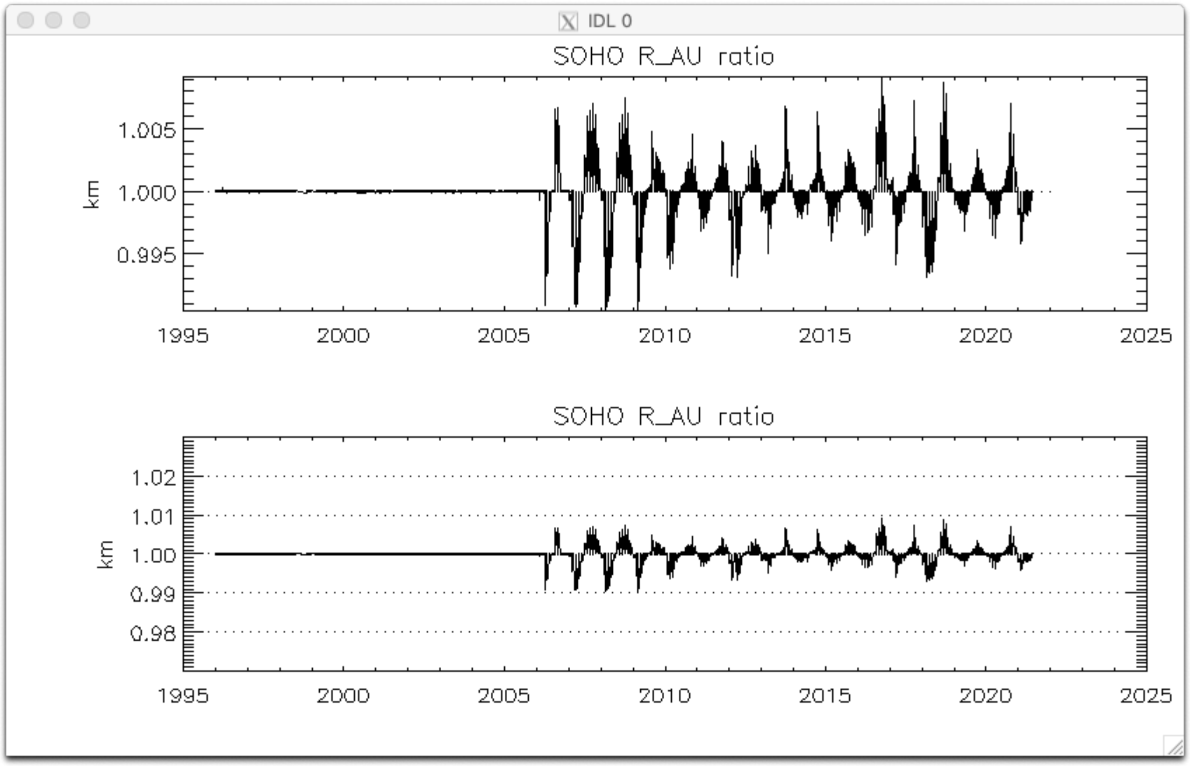

Figure 20 SEM AU distance correction ratio