EIS/AIA Coalignment

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1   Overview

Now that SDO data are routinely available at a high cadence, analyses of EIS data often include coalignment of EIS spectroheliograms with AIA images. In addition data from the IRIS satellite also require coalignment with EIS data sets and, of more importance, joint observations will require knowledge of the relationship between the EIS coordinate system and the IRIS coordinate system.

Typically users of EIS data coalign their observations with AIA on an ad hoc basis, either simply visually adjusting the EIS image or applying one of several cross-correlation programs designed for that purpose. This document reports on a systematic investigation of the relationship between the solar coordinate system provided in the EIS level 0 data files and the solar coordinate system provided in the AIA level 1 data files. The result of the analysis is an IDL function for predicting the time-dependent coordinate offsets between EIS and AIA. The resulting corrections have been implemented as user options in the EIS planning software.

2   Data Selection and Analysis

In 2012 May, the EIS team initiated a regular program of taking slot images at Sun center during one or more of the daily XRT synoptic observations. Data in both the 40 arcsec slot (EIS Study 354, PRY_slot_contextLITE) and the 266 arcsec slot were routinely acquired. This analysis includes all the useful 40 arcsec slot data. Each data set was first processed using EIS_PREP. Using the DATE_OBS and DATE_END keywords in the resulting level 1 FITS files, the VSO AIA database was queried for full resolution AIA 193 Å images taken during the time of the EIS observations. Typically 14 or 15 data sets were available. The VSO_GET IDL function was then used to retrieve the middle image of the set.

For each EIS data set the analysis followed the same procedure:

1. The level 1 195 Å image was retrieved Using EIS_READSLOT and solar coordinate arrays were constructed using the appropriate FITS keywords.

2. A margin of 70 arcsec was added on all sides of the coordinate ranges and the x- and y-limits were used to extract a region from the AIA image.

3. The AIA subimage was resampled to the EIS pixel size using CONGRID and new x and y AIA coordinate arrays were constructed.

4. Using the SSW KORREL function, the two images were used to determine the x- and y-offsets necessary to bring them into alignment.

Figure 1 shows an example of the results of this analysis. The left panel shows the EIS slot raster taken on 2012 August 4 beginning at 06:02:19 UT. The coordinate system on the figure was produced using the keywords in the EIS FITS file. The right panel shows the AIA image taken at 06:03:42 after it has been resampled to the EIS pixel size. The coordinate system on the figure was produced using the keywords in the AIA FITS file. The dashed-line box on the AIA figure shows the location of the EIS raster based on the coordinates in the EIS data file. The solid-line box shows the EIS raster location that results from using the output of the KORREL function to adjust the EIS coordinates. In this case the shift required is +9.0 arcsec in x and +14.2 arcsec in
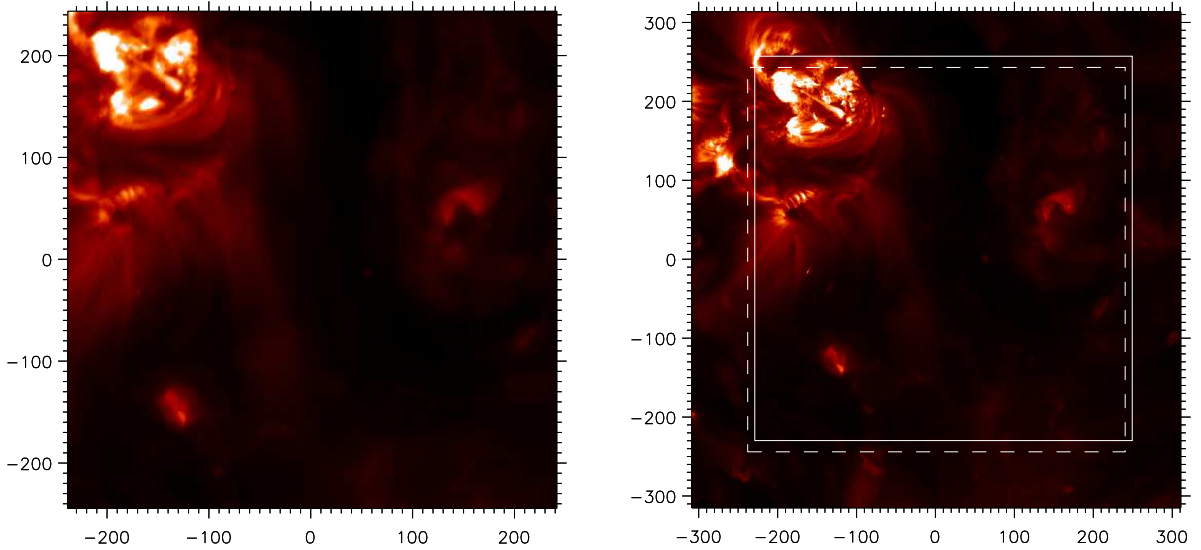
Figure 1: EIS and AIA data showing the shift required to coalign the two data sets.

y. If the analysis is repeated with different margins for the AIA region, the results are generally the same to within 1 arcsec.

Figure 2 shows the offsets computed in this manner for all the available EIS data sets. Positive numbers mean that the values must be added to the EIS coordinate for it to agree with the AIA coordinate. Both the x and y data sets appear to have roughly the same scatter—about 5 arcsec. Since repeated coalignments with the same data sets are good to about 1 arcsec, this scatter is probably showing the inherent variations due to fluctuations of spacecraft pointing. The results cover more than two years of systematic observation and show that the general pattern of the fluctuations in pointing offsets repeats year to year. In the y coordinate, the largest excursion is clearly centered on the annual Hinode eclipse season, which begins in May and lasts until September. In the x coordinate the variations are more complex, with the largest excursion in December. The dashed red lines in the figure mark the dates of EIS heater setting changes. These changes noticeably impact both the x and y coordinate variations.

Figure 3 shows all the data averaged in five-day bins and then plotted as a function of the day of the year. This demonstrates that the yearly pattern repeats with only minor variations and suggests that it should be possible to develop software to predict the offsets for any day of the year.

3   Predicting Coordinate Offsets

Based on the apparent year-to-year reproducibility of the x and y offsets, the best approach to predicting them is to construct a table of averaged offsets and then use an IDL function to interpolate into the table for any desired date. That is the approach that has been implemented.

The current table was constructed by binning all the offset measurements made from 2012 May 1 to 2015 May 1 into 73 five-day date bins. This size is sufficient to capture enough data to provide
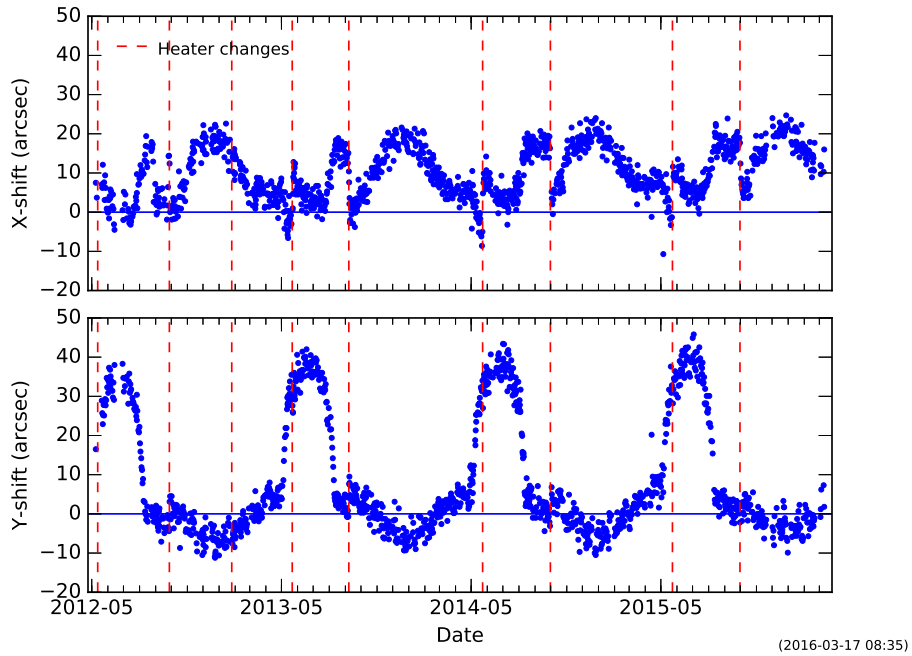
2

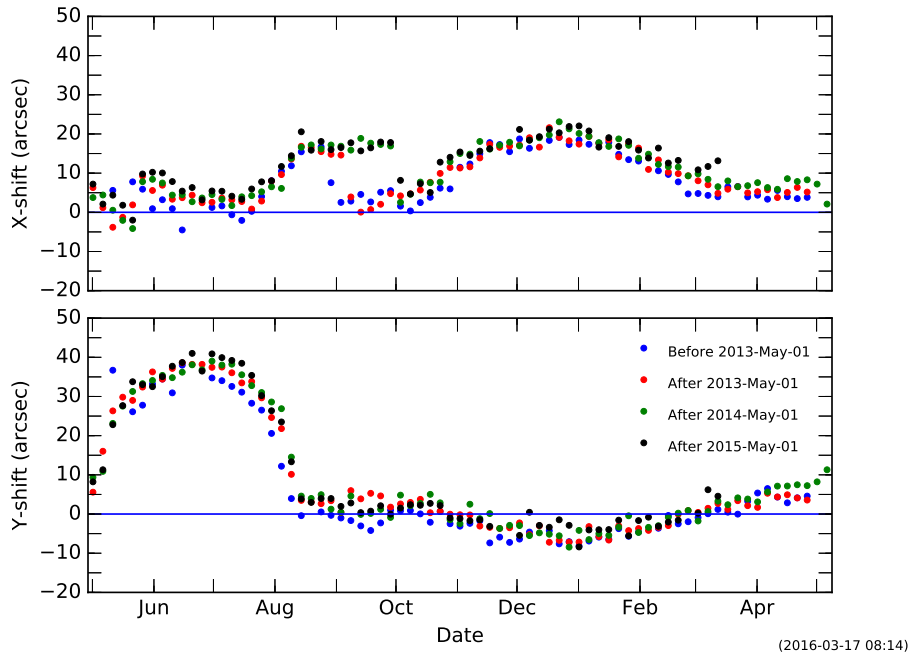Figure 2: Offsets between EIS and AIA as a function of time.

Figure 3: Averaged offsets between EIS and AIA as a function of day of year.

useful values in each bin, yet small enough to display properly the trends in the data. Comparison of the five-day averaged data with the interpolated values showed a small secular variation in
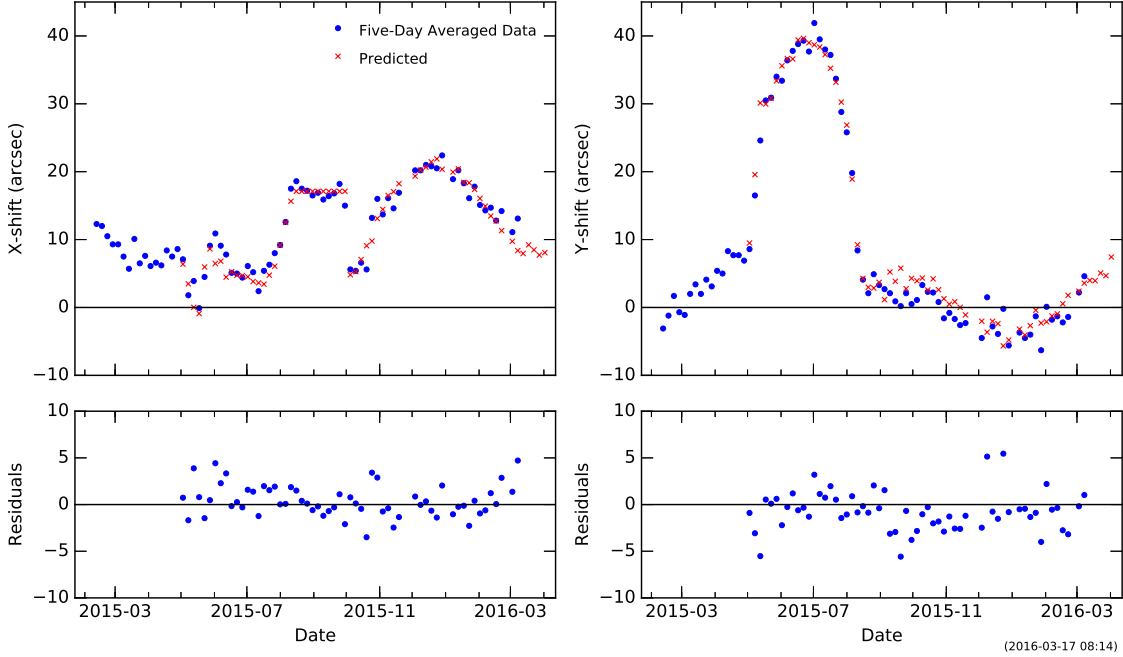
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Figure 4: Averaged offsets between EIS and AIA as a function of time compared with predicted offsets based on averaging three years of measurements.

the residuals, which has been accounted for by fitting the residuals with straight lines. Thus for any given date the process of computing the offsets consists of interpolating in the table and the applying the small additional correction for the secular trend. This process has been implemented as IDL function EIS_AIA_OFFSETS, which is located in $SSW/hinode/eis/idl/atest/mariska in the SolarSoft distribution. The needed interpolation file, eis_aia_yearly_average_v3.txt is stored in $SSW/hinode/eis/data/eis_aia_offset. That directory also contains plots showing the performance of the software over roughly a one year interval. Also included are current versions of the plots in shown in Figure 2. All the plots are updated several times a week as new coalignment studies are processed.

Figure 4 shows a comparison between recent five-day averaged data and the model predictions. The predicted offsets represent the data well with the residuals generally less that ±5 arcsec.

4 Using Coordinate Offsets for Observation Planning and Data Analysis

With EIS often participating in observations with IRIS and also ground-based observatories, there is increased need for EIS planners both to place EIS observations in positions dictated by other instruments and to give positions of EIS observations in the solar coordinate systems used by other instruments. The computed offsets necessary to shift the EIS coordinate system to the AIA, and presumably IRIS, coordinate system can be used in a number of ways. This section summarizes the relationships among the EIS, SOT, and AIA coordinate systems. The relationships outlined here have been implemented as options in the EIS planning software.

4

In this section

- EIS_coord are the EIS coordinates provided in the EIS planning software.

- AIA_coord is the AIA coordinate system provided in their level 1 data files. This document assumes that IRIS uses the same coordinates.

- SOT_coord are the coordinates provided by the SOT team at planning meetings. Aside from special cases mentioned below, they are the same as AIA_coord.

- pointing_file_coord are the coordinates in the Hinode pointing files.

Assuming that IRIS and AIA coordinates are the same, we have four cases the EIS planner may need to consider:

1. The planner has planned an observation, has an EIS pointing at a specific time, and wants to communicate that to IRIS.

$$\text{AIA\_coord} = \text{EIS\_coord} + \text{shift\_from\_table} \tag{1}$$

   where shift_from_table comes from IDL function EIS_AIA_OFFSETS.

2. The planner has been provided with an IRIS pointing at a specific time and wants to position EIS there.

$$\text{EIS\_coord} = \text{AIA\_coord} - \text{shift\_from\_table} \tag{2}$$

3. The planner has been provided coordinates by SOT. The coordinates provided by SOT are good in absolute terms. So we have

$$\text{EIS\_coord} = \text{SOT\_coord} - \text{shift\_from\_table} \tag{3}$$

   In this case, EIS would report the SOT_coord to IRIS as the EIS pointing.

4. The planner is using pointing coordinates from the pointing file and wants to place EIS at the same location that SOT is observing—IRIS takes care of itself. SOT is offset from the Hinode spacecraft pointing. Get the latest values for this correction by doing

   grep SBOPS_SC /home/flare/slb/sotco/.cshrc

   on EISCO. This currently (2014-Aug-1) outputs

   setenv SBOPS_SC_XCORR 24
   setenv SBOPS_SC_YCORR 15

These values are also available at the daily planning meeting. In the Hinode pointing tool underneath the tracking curve definitions they are listed as "Offset of SOT from Hinode." Finally, we have:

$$\begin{aligned} \text{EIS\_coord} &= \text{SOT\_coord} - \text{shift\_from\_table} \\ &= (\text{pointing\_file\_coord} + \text{SOT\_correction}) - \text{shift\_from\_table} \end{aligned} \tag{4}$$

Note that the SOT planner sometimes shifts the FOV on the CCD. To attain the highest accuracy, consult the SOT CO.

If EIS wanted to communicate its pointing to IRIS, it would report it using the equation in case 1 above.

In the EIS planning software, the first case is the default. The second case corresponds to the case listed as EIS aligned with AIA, and the fourth case corresponds to the case EIS aligned with AIA and SOT. For that case, there is a pull-down menu available to allow entry of the latest SOT offsets. The EIS Observing Timeline web page (`http://solar-b.nrl.navy.mil/cgi-bin/timeline.cgi`) contains a column that shows which pointing option the planner selected for each study placed on the timeline. In addition the summary text file produced by the planning software provides information on the pointing option used for each timeline entry.

5 Automated Updating of Offset Data

While the yearly variations in the EIS pointing relative to the AIA coordinate system generally repeat, there is some evidence for gradual changes over longer time periods. Thus, additional data will need to be acquired and analyzed on a regular basis. The necessary observations are generally made during the regular XRT synoptic observations. Analysis of those data is managed using a cron task that runs on magnolia.nrl.navy.mil. Once each day this task searches the EIS asrun catalog for all recent occurrences of EIS study 354 that have been made near Sun center and produces level 1 data files for any observations that have not yet been processed. The software then identifies and downloads AIA data for each EIS file, does the coalignment, appends the offset information to a text file, and updates the offset information in the Oslo EIS Subversion software repository. The resulting data files and plots are in the directory $SSW/hinode/eis/data/eis_aia_offset.

A few times a year, the averaged data file will be regenerated using added EIS data. That data file is currently version 2 and uses two full years of observations. The IDL function that computes offsets for any given date automatically finds the highest version number of the file.

The plots of all the offset data in Figure 2 show some discontinuities when the EIS heater settings are changed. To the extent it is possible, making those heater changes close to the same dates each year will improve the accuracy of the averaged data table that EIS_AIA_OFFSETS uses to compute values. In one case, the September heater changes were made at a different time from other years, resulting in the differences visible in the x- offsets shown in Figure 3. To allow anaysis of EIS data obtained in that interval, the EIS_AIA_OFFSETS function contains logic to modify the offsets in that interval.

A   Revision History

Revision	Date	Author(s)	Description
1.0	2014 Aug 25	John Mariska	Creation
1.1	2015 Jan 14	John Mariska	Minor revisons and update figures
1.2	2016 Mar 17	John Mariska	Minor revisons and update figures