Analysis of accuracy of *Yohkoh* ATT data.

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Abstract

The analysis of SXT images is used to estimate the accuracy of *Yohkoh* pointing information contained in the ATT database. I conclude that SXT data are inadequate to establish ATT accuracy beyond 2.5 arcsec, the angular size of an SXT full-resolution pixel.

1 Attitude Specifications

The *Yohkkoh* attitude control system uses momentum wheels, magnetic torquers, control-moment gyros, an inertial reference unit (IRU) comprising 4 gyros, along with 2 Sun sensors, a Canopus star tracker, and geomagnetic sensors to achieve pointing determination to better than 1 second of arc [Ogawara *et al.*1991]. Data from the IRU, fine sun sensor and the limb sensors built into the Hard X-ray Telescope (HXA) are recorded in the so-called ATR database. The pointing information for the Hard (HXT) and Soft (SXT) X-ray Telescopes is derived from the HXA and IRUs and resides in the ATT database. These are the data used by all analysis software for co-alignment and absolute solar coordinate purposes. The accuracy of attitude determination from the HXA and IRU data are stated by Kosugi, *et al.*, [Kosugi *et al.*1991] as "... approximately 1 or 2 sec accuracy." Actual data-analysis experience indicates that this accuracy was typically achieved until late in the mission when gyro drift rates became excessive.

2 Co-alignment of SXT Optical Images

Up until November 1992 the SXT routinely acquired full-disk solar optical images for use in instrument-specific attitude determination and alignment cross-calibration with the spacecraft and the HXT. In principle, these images can be co-aligned with standard analysis software and used to test the quality of the ATT data by determining how precisely the images overlap. A seemingly straight forward way to do this is to fit a circle to the limb of each solar image and examine the scatter diagram of the sun center positions (in pixel units) thus derived.

This procedure has been used by Aki Takeda to examine co-alignment quality for level-3 SXT aspect sensor images taken in December 1991 and October 1992. Her results for October 1992 are shown in Figure 1. Clearly, the co-alignment quality and, presumably, the ATT data are much worse than 1 second of arc.

As a further test I have done a similar analysis for half-resolution narrow-band images taken in June 1992. First I used level-3 images from the YLA (Figure 2) with a similar result as Takeda (Figure 2). I then proceeded to do the same analysis but beginning with level-0 data to check that there was nothing amiss with the level-3 data.

Upon examination of the solar radius returned by these limb fits (Figure 3-A) shows that the radii of the fits scatter badly and do not reproduce well the ephemerus value of the solar radius. Apparently, most of the scatter in Figure 2 results from problems with the limb fitting to the pixelated images. Figure 3-B further

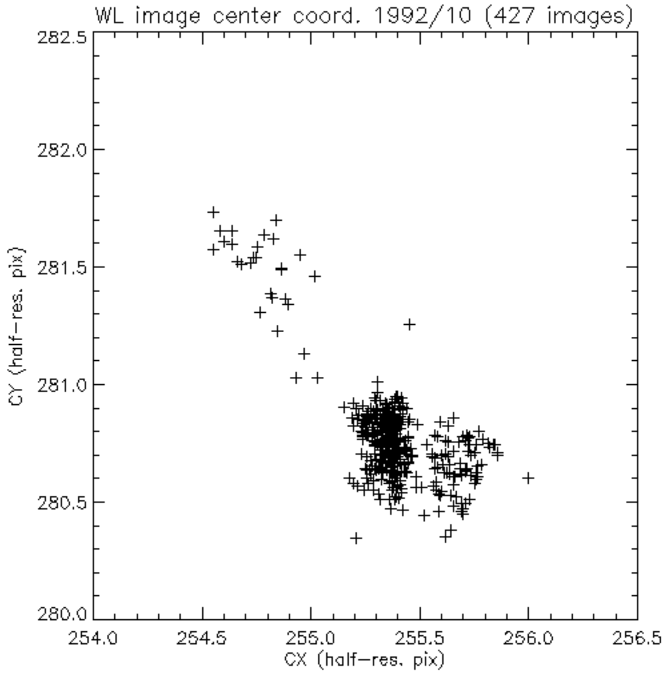

Figure 1: Scatter diagram of sun-center positions for co-aligned half-resolution narrow-band SXT aspect images taken October 1992.

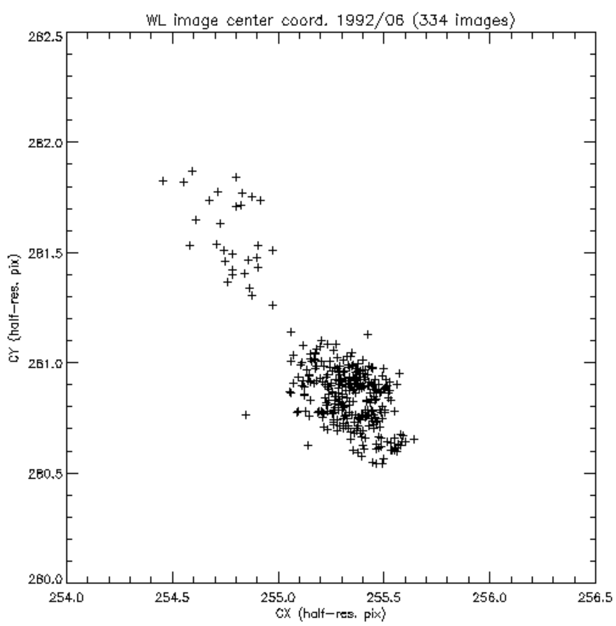

Figure 2: Scatter diagram of sun-center positions for co-aligned half-resolution narrow-band SXT aspect images taken June 1992.

demonstrates that the apparent attitude errors reflect the sign of the radius errors. Thus, one must conclude that this method of analysis is not useful for evaluation of ATT errors.

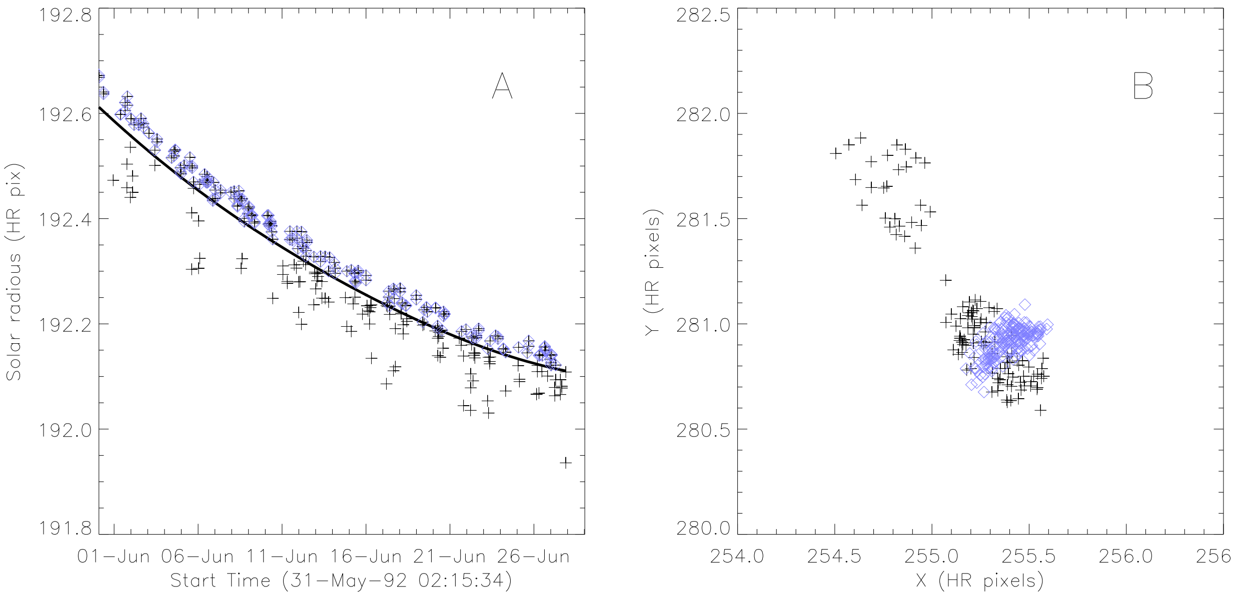

Figure 3: Limb filling analysis of SXT half-resolution narrow-band optical images for June 1992. Panel A displays the fitted value of the solar radius. The symbol color is used to indicate whether the fitted radius is larger or smaller than the ephemerus value which is indicated by the solid line. Panel B shows the sun center position derived from the limb fits. The color coding is the same as for A. Note that fits with undersize radii have a much greater scatter in B.

It is instructive, however, to notice that for the most orderly (blue symbols) fits the scatter in pointing positions fall within a box one-half of a half-resolution pixel (2.455 arcsec) on a side, comparable to the scatter in radius of the blue points in Figure 3-A, indicating that the attitude data are probably better than 2 arcsec. Another unquantified source of error may result from subtle image intensity distortions introduced by the IDL program POLY2D.PRO which is used to generate the sub-pixel shifts of the co-aligned images.

It should be noted that ATT quality depended on proper positioning of the solar image on the HXA limb sensors. During the mission an effort was made in selecting *Yohkoh* pointing to assure that this condition was fulfilled. In conclusion, my belief is that, at their best, the *Yohkoh* ATT data are good to one second of arc or better.

3 Fraction of erroneous ATT

Co-alignment errors of one or more half-resolution SXT pixels (4.91 arcsec) are quite evident when observing a time sequence of SXT x-ray images in movie mode. For such cases it is often possible to improve the ATT record by limb-fitting the x-ray image. The ATT version in use at the end of the *Yohkoh* mission (version 8 or ATT08) had none of this kind of manual corrections applied. In subsequent years a major effort was made to make such corrections whenever possible for SXT full-frame (FFI) images in order to improve the quality of the SXT mission-long movie. Such corrections aren't possible for partial-frame (PFI) images because the limb isn't available or, when within the image, the length of the limb is too short or obscured by x-ray structures for reliable fitting.

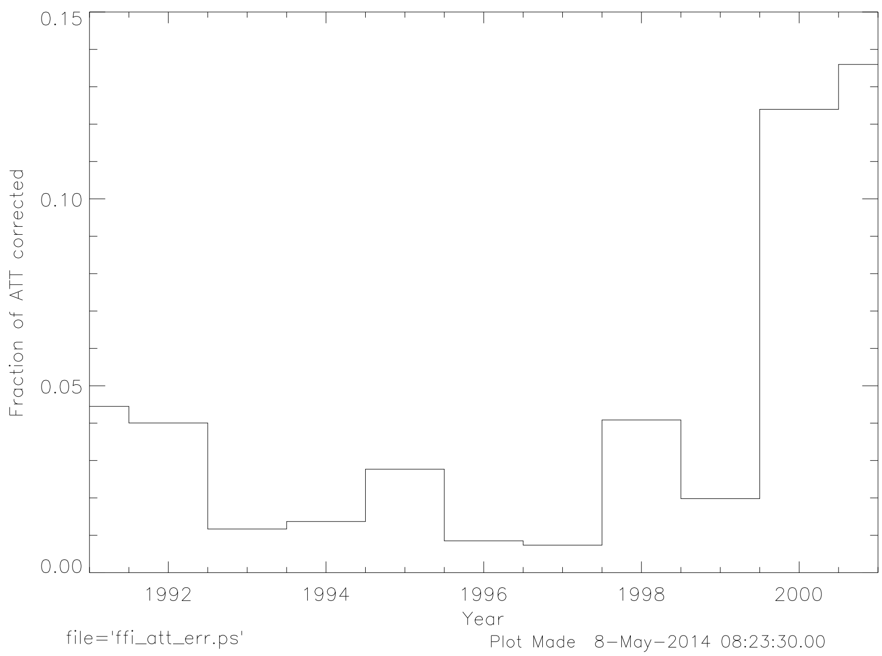

Figure 4: Fraction of ATT records manually corrected by limb fitting of x-ray images.

By the 23rd ATT version (ATT23) this work was complete so that it is possible to determine what fraction of FFI ATT values were altered between ATT08 and ATT23. The result of this analysis is shown in Figure 4 for each year of the mission. Note that up until the year 2000 when gyro drift became excessive more than 95of FFI ATT values were good enough (say, better than 5 arcsec) as to not demand correction. The corrected ATT are certainly inferior to the best quality ATT – but superior to the uncorrected values. For PFI ATT records it is reasonable to assume that they had errors at about the same rate as FFI ATT. Thus, up until 2000 *Yohkoh* ATT is probably good to the order of one second of arc for 95 percent of the records.

References

[Kosugi *et al.*1991] Kosugi, T., Masuda, S., Makishima, K., Inda, M., Murakami, T., Dotani, T., Ogawara, Y., Sakao, T., Kai, K., Nakajima, H.: 1991, The hard X-ray telescope (HXT) for the Solar-A mission. **136**, 17 – 36. doi:10.1007/BF00151693.

[Ogawara *et al.*1991] Ogawara, Y., Takano, T., Kato, T., Kosugi, T., Tsuneta, S., Watanabe, T., Kondo, I., Uchida, Y.: 1991, The Solar-A Mission - an Overview. **136**, 1 – 16. doi:10.1007/BF00151692.