Analysis of possible errors in computation of CRLN_OBS for HMI and AIA

PHS, 11 July 2019.

Comparison with JPH Horizons Carrington longitude.

JPH Horizons computes various coordinate for astronomical objects, including spacecraft. I ran the program with the target of the Sun with parameters:

Ephemeris Type [change] : OBSERVER
Target Body [change] : Sun [Sol] [10]
Observer Location [change] : Solar Dynamics Observatory [500@-136395]
Time Span [change] : Start=2010-05-01, Stop=2019-07-01, Step=6 h
Table Settings [change] : QUANTITIES=13,14,20,31
Display/Output [change] : download/save (plain text file) and observer as SDO.

The parameters for quantities 13,14,20, and 31 are:

Date__(UT)__HR:MN Ang-diam Ob-lon Ob-lat delta deldot ObsEcLon ObsEcLat

The resulting 13393 records were saved in the file: 6hour_horizons_results.txt

Then I used lookdata.html to obtain the current DRMS recorded values for the same time span from the series hmi.M_720s. I saved:

['DSUN_OBS', 'CRLN_OBS', 'CRLT_OBS', 'CAR_ROT', 'RSUN_OBS', 'T_REC']

Then a Python program read each set of values and computed the difference between the Carrington longitude values. The mean difference CRLN_OBS – JPLcrln is 0.0865 degrees. About 3 HMI pixels with the DRMS values showing longitude higher, westward, from the correct values. The JPL values are in units of 0.01 degrees. The plot of the about 13,000 differences with the mean removed shows a slight drift to higher DRMS values of less than 0.001 degrees per 10 years.

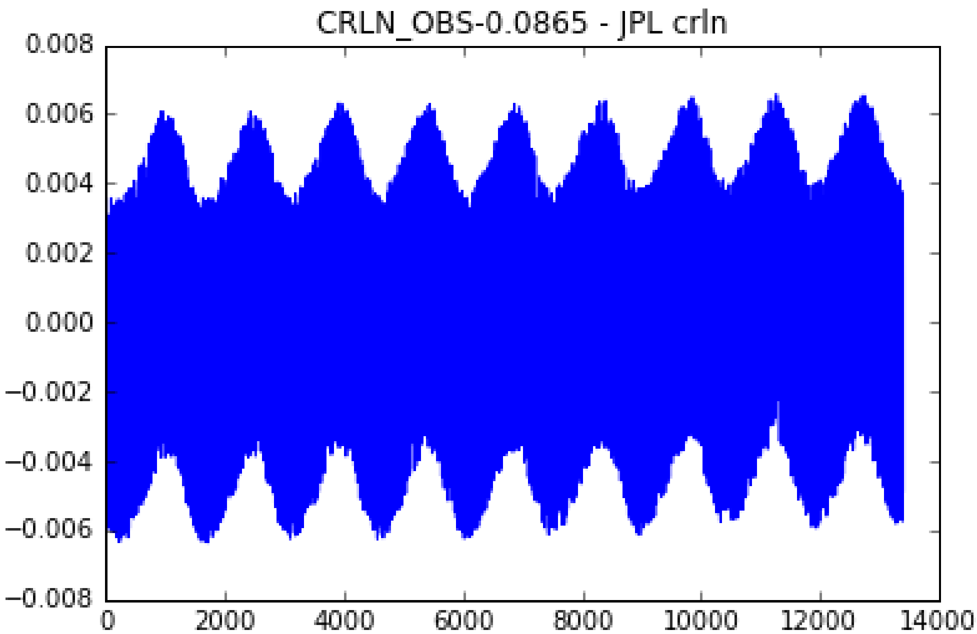

Figure 1. Difference between JSOC calculated Carrington longitude of disk center and JPL computation of disk center longitude as seen by SDO for the same time. All days from 1 May 2010 to 1 July 2019 with QUALITY >=0 in hmi.M_720s were used at a 6-hour cadence. The annual sinusoidal variation with amplitude of about 0.001 degree is consistent with the known and accepted error in the JPL computations. See Urban & Kaplan, 2007.

From descriptions in the Explanatory Documents of the Astronomical Almanac current version (2012) states that as of the 2009 Almanac the IAU blessed calculation of the location of the Carrington prime longitude is:

W_0 = 84.176 degrees
W = W_0 + 14.1844000 * t (degrees)
where t is time in days since the J2000 reference (JD 2451545.0).

The code in iorbit.c (JSOC/proj/libs/astro/iorbit.c) for the same quantity is (Python version):

```
CARR_DEGDAY = 14.1844000      # Adopted degrees per day, includes precession
TCARR  =  -3881476800.0          # sscan_time("1854.01.01_12:00_TAI")   Carr ref epoch
solrots = CARR_DEGDAY * (t - tlight - TCARR)/86400 - 0.125  # (degrees)
```

As I recall, the 0.125 degree was inserted to make the then 154 years to 2010 result match the JPL values in 2010 for some range of dates. To estimate an offset to the Carrington zero point I should have subtracted the over estimate of 0.160 degrees (to account for the difference between Carrington's 25.380 days = 14.184397 degrees per day) and added the 499 seconds of average light travel time, 0.082 degrees for a net correction of -0.078. So my correction of -0.125

degrees is too negative by 0.042 degrees. I neither removed the average Earth-Sun aberration (0.005 degrees) from the formula nor added the actual aberration in the calculation so -0.042 of my -0.125 correction is not understood.

From the plot above, it is apparently about 0.0865 degrees too small in the final reported longitudes. But note that the numbers above are total degrees of rotation of the prime meridian which is the number subtracted from the longitude of the observer to get the CRLN_OBS. Disk center longitude decreases with time. So the correction of -0.0865 turns into an addition of 0.0865 to the present -0.125 so the -0.125 used should have been -0.0385. It is curious that the correction needed, +0.0865 in the formula, is close to the light travel time.

Noting that the "new way" used in calculating the Almanac has a yearly variation in the range +- 5 arc-sec or about 0.0014 degrees, or +- 8.5 seconds in time. Given HMI's 45 second integration time and 0.03 degree maximum pixel size, and goal of knowing Carrington longitude to 0.01 degree, this variation can be ignored for now.

I maintained the calculation using the Carrington reference epoch for consistency with the WSO and SOHO/MDI methods.

Two changes were made in 2009 in the IAU agreed definitions. These included:

1. Remove light travel time from Sun to Earth to allow simple calculations for observers not on the Earth. Light travel time now is explicitly removed so the longitude is valid at the Sun.
2. Remove aberration, 20 arc-sec for Sun seen from Earth.

The combination of the two puts the solar prime meridian calculation the same basis as all other objects in the solar system, making calculations easier from different observer locations.

Going forward we could subtract 0.0865 from all of our CRLN_OBS keywords and change the code to either the new method or adjust the correction from -0.125 to -0.0385.

As a side note, the Explanatory document also point out that while Carrington said that 25.38 days sidereal is the rotation at 14 degrees latitude, he actually used 851 arcmin per day. This is 14.183333 degrees per day.

References:

Sean E. Urban and George H. Kaplan, “Investigation of Change in the Computational Technique of the Sun’s Physical Ephemeris in The Astronomical Almanac”, March 22, 2007, USNO Technical Note re IAU/IAG WGCCRE. Copy at http://sun.stanford.edu/~jsoc/keywords/Carrington_Coords/

Explanatory Supplement to the Astronomical Almanac 3rd Edition, Sean E. Urban (Author, Editor), P. Kenneth Seidelmann (Editor), 2012, ISBN-10: 1891389858. Copy at Phil’s office.