S-NPP Solar Vector Error with the Common GEO Code: The Correction and the Effects on the VIIRS SDR RSB Calibration

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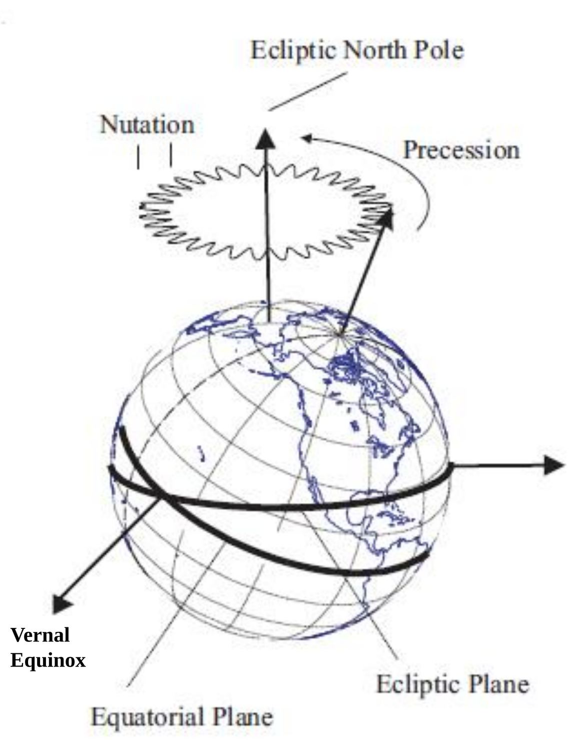
Introduction

The **V**isible **I**nfrared **I**maging **R**adiometer **S**uite (VIIRS) uses the Sun as the primary radiometric calibrator for the Reflective Solar Bands (RSB). The calibration relies upon the once-per-orbit measurements of sunlight incident upon the Solar Diffuser (SD), which happens once per orbit. Further, the status of the reflectivity of the Solar Diffuser relies upon the measurements made with the Solar Diffuser Stability Monitor (SDSM), which also uses the Sun as the calibration light source. Both calibrations, as well as several EDR data products, require an accurate solar (and/or lunar) position vector in order to calibrate their SDR and/or EDR products. The vector is used in the transmission functions of the SD and SDSM screens, the calculation of the SD BRDF, and solar incident angles. In early 2014, it was shown that the NPP solar vector was in error.

Geocentric Inertial Reference Frames



The source of the error is the misuse of two Earth-Centered Inertial (ECI) reference frames. The SDR code was calculating the relative position of the spacecraft and the Sun in "True of Date" (TOD) coordinates, where the x- and z-axes are defined by the direction of the vernal equinox and the North Pole at the ephemeris time. However, the rotation from ECI to the spacecraft coordinates is in J2000 coordinates, where the axes are locked to their positions at 12 UT 01/01/2000.

The TOD and J2000 systems are identical at that time, but drift apart due to the changing orientation of the poles and the orientation of the Earth's orbit. The error in early 2014 had grown to about 0.2 degrees.

Magnitude of the Solar Vector Error

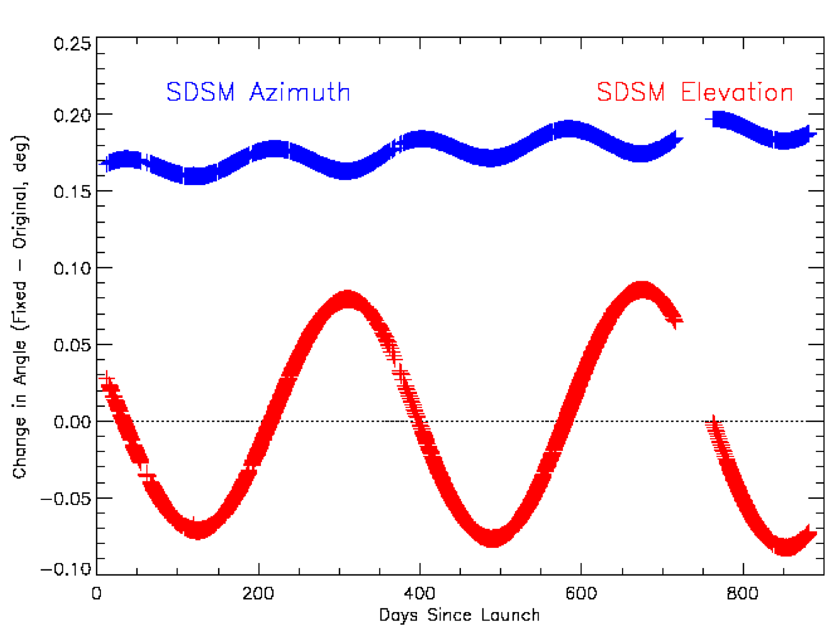


Figure 1. The difference in the SDSM Sun View elevation and azimuth angles as a function of time between the "wrong" value returned by the SDR code and the "fixed" values after recalculation. The error grows with time, but there is also an annual cycle.

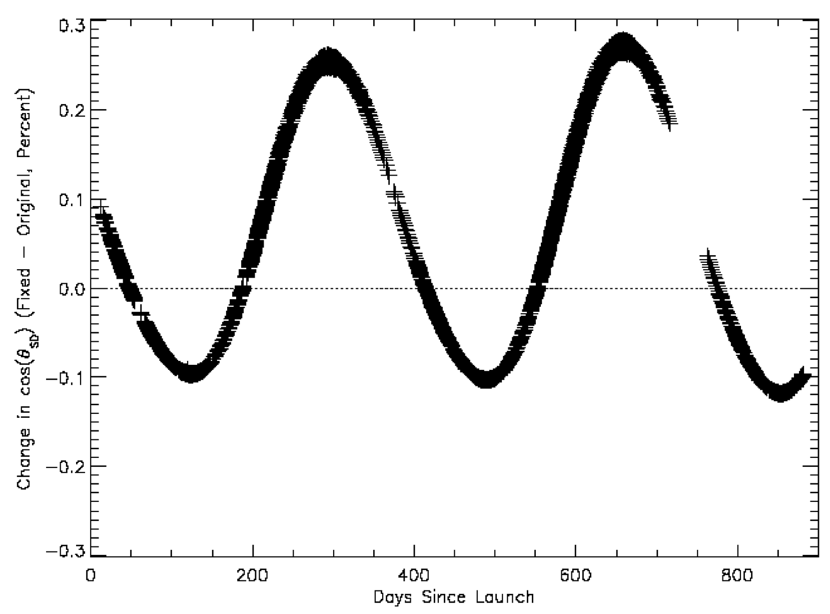


Figure 2. The difference in the cosine of the angle of solar incidence to the SD panel normal. This value is used in both the SDSM and SD algorithms. The magnitude of the change (about 0.4% peak-to-peak) is a potentially larger effect than the angle error to the screen transmission values.

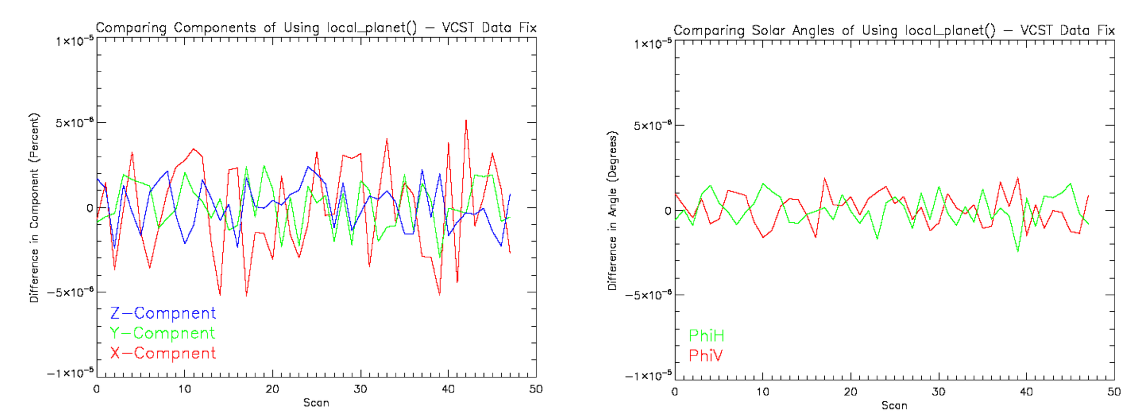
Fixing the Error in the SDR Code

The SDR code calculates the solar vector (the vector from NPP to the Sun) and lunar vector (Moon to NPP) in TOD coordinates using the Common GEO routine topo_planet() (from the USNO "NOVAS-C" package). This inputs for this package include the time, the spacecraft position (from the Spacecraft Diary), and polar wander parameters.

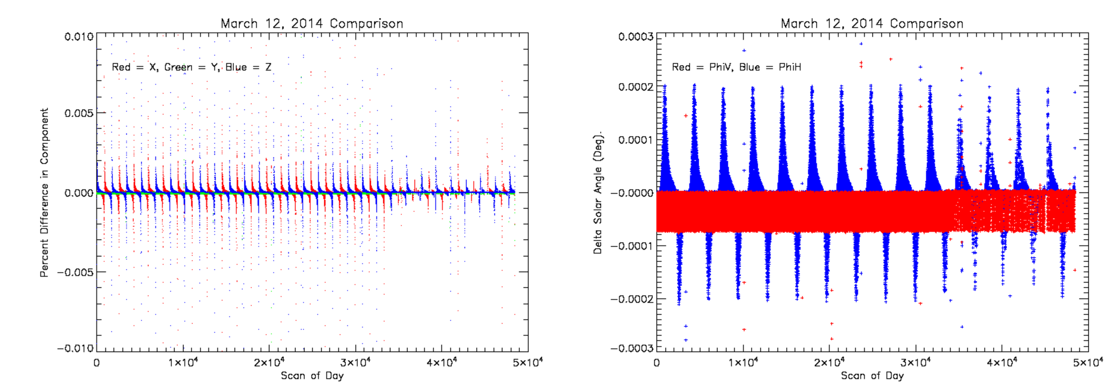
The Common GEO package includes a similar routine called local_planet(). It uses the same input parameters, but it produces output in the J2000 coordinate system. Replacing topo_planet() with local_planet() the two times it occurs in the code fixes the problem.

The fix was tested using routines from the NASA/NAIF "CSPICE" package. The test data does not include polar wander and invoked a different method to interpolate the spacecraft attitude rotation data, which leads to the small differences seen below.

Comparison of "Fixed" Solar Vectors



Figures 3 (left) and 4 (right). The difference in the solar vector components (in percent; left) and the SDSM Sun View elevation and azimuth angles (in degrees; right) for a sample 48-scan granule.



Figures 5 (left) and 6 (right). The difference in the solar vector components (in percent; left) and the SDSM Sun View elevation and azimuth angles (in degrees; right) for a full day. The periodic larger differences are due to the different quaternion interpolation methods (the VCST method uses the "slerp" method commonly used by 3-D animation software). The offset is due to the VCST method not including polar wander. The differences, however, are much smaller than the 0.02 degree uncertainty in the spacecraft attitude data as given in the Spacecraft Diary.

Revising the Mission Data Archive

The solar vector error has been in the SDR code since launch. All OBCIP files contain this solar and lunar vector error.

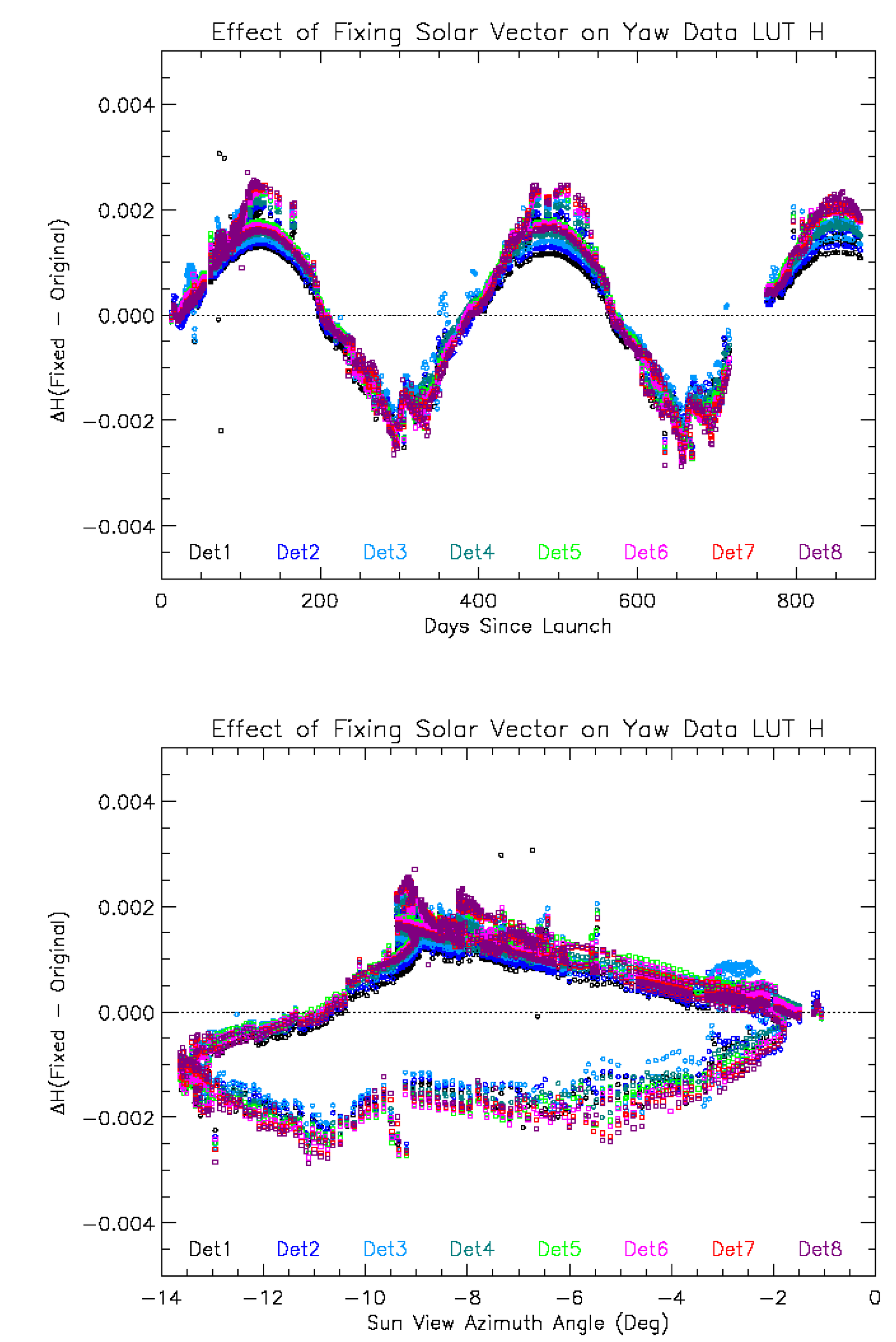
One solution is to recreate all the OBC files using a revised SDR code. There are practical concerns on the amount of computing time and bandwidth necessary for the reprocessing and delivery of the product.

For internal use, VCST has developed an algorithm that takes the present solar and lunar vectors as found in the OBC files as input. These vectors are in spacecraft frame* coordinates. They are then "de-rotated" to TOD frame coordinates using Spacecraft Diary information. Then the TOD frame vector is rotated to the J2000 frame by the known transformation between the two. Finally, the Spacecraft Diary attitude data are again used to rotate the vector back into spacecraft frame. This correction is fast and can be done "on the fly" if one has the Spacecraft Diary information available.

Alternatively, a separate solar/lunar vector LUT could be created for each time period (day, orbit, or granule) to be read in replacing the present data.

***Note:** Many of the calibration algorithms assume "instrument coordinates", which are slightly rotated from "spacecraft coordinates", but this rotation is not presently included in the SDR code.

Effect of Solar Vector Correction on H-factors



Figures 7 (top) and 8 (bottom). The difference in H-factors from before and after the solar vector correction as a function of time (top) and SDSM Sun View azimuth angle (bottom). The change in H-factors over the lifetime of the mission is dominated by the seasonal variation, which is itself dominated by the change in $\cos\theta_{SD}$.

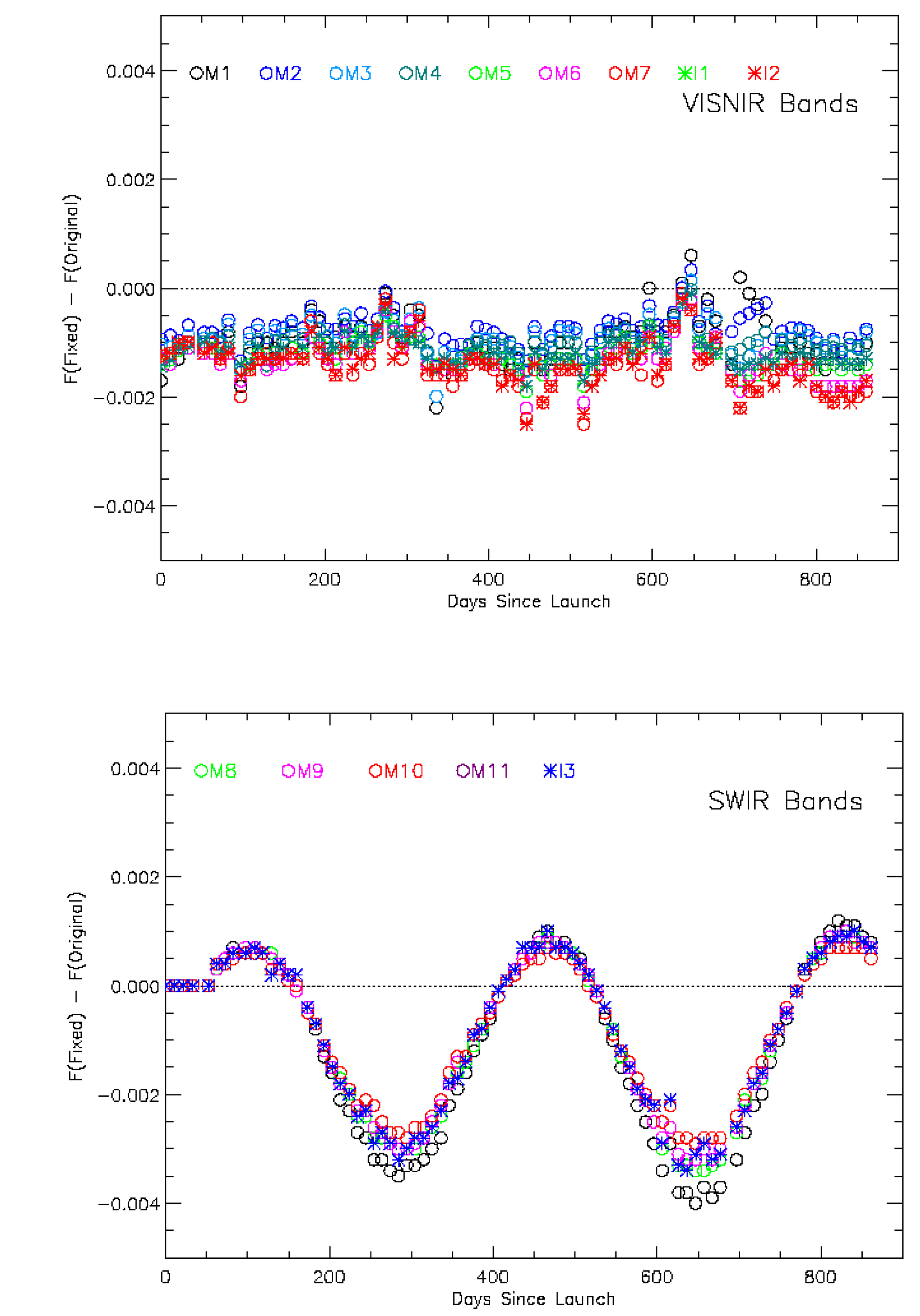
Revising the H-factors requires more than just fixing the input solar vector. The screen transmission functions are defined by data from the yaw-maneuvers and other on-orbit data. If the screens were created with the original solar vector data, then they are incompatible with the new, fixed solar vectors.

Therefore, VCST re-created the τ_{Sun} and τ_{SD}*$BRDF_0$ functions from on-orbit data using the corrected solar vector throughout the process.

The results are shown above. The dominant feature is the seasonal variation in the change in H-factors, which is a result in the change in $\cos\theta_{SD}$ (see Figure 2). The H-factor is proportional to $1/\cos\theta_{SD}$ which is why the seasonal variations are the opposite of what is seen in Figure 2. There is a slow growing offset, too, but this is small in comparison to the seasonal trend.

The H-factors are normalized to H = 1 for all bands at launch. This minimizes the effects of the offset in angles from before launch.

Effect of Solar Vector Correction on F-factors



Figures 9 (top) and 10 (bottom). The difference in f-factors from before and after the solar vector correction as a function of time for the VISNIR bands (top) and the SWIR bands (bottom). The change in $\cos\theta_{SD}$ cancels for the VISNIR bands, but for the SWIR bands, the value of H is forced to be 1.

As for the H-factors, the τ_{SD}*$BRDF_0$ screen for the main VIIRS detectors had to be derived again from the beginning to incorporate the effects of the change in solar vector. The F-factor is proportional to H and $\cos\theta_{SD}$, and for the VISNIR bands (M1-M7, I1-I2 and the DNB) the H-factor is proportional to $1/\cos\theta_{SD}$, so the effects cancel out. The offset -0.001 offset in the VISNIR bands is due to the renormalization of the H-factors at t = 0, which means that normalization factor is not removed.

For the SWIR bands, the assumption is that the SD panel does not degrade at those wavelengths. As a result of that assumption, H_{SWIR} = 1. That means there is no canceling of the $\cos\theta_{SD}$ effect.

An important additional note: The change in the F-factors seen here is not enough to resolve the differences between the F-factors derived by lunar and SD methods (see poster by Z. Wang). It will not even directly explain the F-factor seasonal fluctuations over the year for the SD VISNIR bands.

Acknowledgements

We thank members of the VCST GEO Team, especially Masahiro "Mash" Nishihama and Gary Lin for their valuable assistance, especially their help in the identification of topo_planet() as the source of the error.

Conclusions and Further Effort

The solar vector error is large enough to require careful consideration of its effects on the RSB calibration. The changes will not cause wholesale revisions of the radiometric calibration, but it may explain some, but not all, of the seasonal variation seen in the F-factors.

There are other aspects of the solar and lunar vector error that are not addressed here (such as the effect on lunar intrusion into the Space View port), so further work is required.

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