Assessment of stability of the response versus scan angle for the S-NPP VIIRS reflective solar bands using pseudo-invariant desert and Dome C sites

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ABSTRACT

The Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi NPP (National Polar-orbiting Partnership) satellite has been in operation for over five years. VIIRS has 22 bands with a spectral range from 0.4 µm to 2.2 µm for the reflective solar bands (RSB). The Earth view swath covers a distance of ~3000 km over scan angles of ± 56.0° off nadir. The on-board calibration of the RSB relies on a solar diffuser (SD) located at a fixed scan angle and a solar diffuser stability monitor (SDSM). The response versus scan angle (RVS) was characterized prelaunch in ambient conditions and is currently used to determine the on-orbit response for all scan angles relative to the SD scan angle. Since the RVS is vitally important to the quality of calibrated level 1B products, it is important to monitor its on-orbit stability, particularly at the short wavelengths (blue) where the most degradation occurs. In this study, the RVS stability is examined based on reflectance trends collected at various scan angles over the selected pseudo-invariant desert sites in Northern Africa and the Dome C snow site in Antarctica. These trends are corrected by the site dependent BRDF (bi-directional reflectance function) model to reduce seasonally related fluctuations. The BRDF corrected trends are examined so any systematic drifts in the scan angle direction would indicate a potential change in RVS. The results of this study provide useful information on VIIRS RVS on-orbit stability performance.

Keywords: VIIRS, Suomi NPP, calibration, on-orbit, reflective solar bands

1. INTRODUCTION

The Visible Infrared Imaging Radiometer Suite (VIIRS) [1-2], built on strong heritage of the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor, on the Suomi NPP (National Polar-orbiting Partnership) satellite (http://npp.gsfc.nasa.gov/viirs.html) has been in operation for over five years. It has a constant-rate rotating telescope assembly (RTA) and a double sided half angle mirror (HAM) rotating at half the speed of the RTA. VIIRS has 22 bands with a spectral range from 0.4 to 2.2 µm (see Table 1). The Earth view swath covers a distance of ~3000 km over scan angles of ± 56.0° off nadir. Observations by VIIRS cover the entire Earth's surface

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every one or two days and the derived products provide high quality environmental and climate information for land, ocean, and atmosphere.

The VIIRS RSB on-board calibration components include a SD and a solar diffuser stability monitor (SDSM), a blackbody for the thermal emissive bands, and a space view (SV) port used to remove background signal from the raw response [3-6]. The SD and blackbody provide absolute calibration with standards traceable to those provided by the National Institute of Standards and Technology (NIST). Since both the SD and blackbody are located at fixed angles of incidence (AOI), the calibration at other AOIs requires an RVS correction that describes relative changes to those obtained at the on-board calibrator AOI. Thus, RVS characterization and on-orbit monitoring of its change are vitally important to ensure the quality of the calibrated radiance product.

The VIIRS RSB RVS was characterized prior to launch in lab ambient conditions [7-9]. These tests were conducted at a number of different scan angles to ensure a good description of the RVS over the entire scan-angle range. Since there are certain radiometric requirements from prelaunch to on-orbit calibration, any changes in on-orbit RVS need to be accounted for in order to maintain the quality of the calibrated product. One major concern for the on-orbit RVS stability is the degradation of the scan mirror, which is mainly in the blue wavelength region due to the mirror-coating surface, as it is exposed to the UV light. The degradation of the scan mirror is AOI dependent and thus it affects the shape of RVS. For MODIS RSB, it is observed that the RVS for both mirror sides have been degrading throughout the mission [10-11]. In the case of VIIRS, a four-mirror RTA is used in front of the HAM. Since the RTA absorbs most of the UV light before reaching the HAM surface, it is expected that the VIIRS on-orbit RVS is more stable than MODIS. Another advantage to the VIIRS optical design is that the HAM rotates at half the speed of the RTA. Thus, the Earth view (EV) range of AOI for VIIRS is between 28.6^{o} and 56.5^{o}, which is a 28^{o} change in AOI. This is corresponding to only about half the range of MODIS, although the corresponding scan angle range for both sensors is nearly the same. Currently, there is no adjustment to the VIIRS on-orbit RVS in the calibrated sensor data record (SDR) product.

The purpose of this study is to re-examine the stability of VIIRS RVS after its five years of mission. The study extends our previous reported results of tracking the RVS on-orbit stability to a five-year mission from 2012 to 2017[12]. Our previous results indicate that there might be greater than 1% drift in RVS for M1 to M3, while there is no noticeable drift for other RSB. These results are obtained from the top-of-atmosphere (TOA) reflectance trends over the CEOS endorsed pseudo-invariant desert sites. To validate the results from the desert sites, trending results from another pseudo-invariant snow/ice site at Dome C, Antarctica are included in this study. With more cumulative trending data is added in this study, it is expected that the latest results are more reliable than our previous results.

Table 1. List of VIIRS RSB central wavelength (CW), bandwidth (BW) and a number of scan angle parameters.

<table>
<tr><th>Band</th><th>CW (nm)</th><th>BW (nm)</th><th>Band</th><th>CW (nm)</th><th>BW (nm)</th></tr>
<tr><td>M1</td><td>412</td><td>20</td><td>M8</td><td>1240</td><td>20</td></tr>
<tr><td>M2</td><td>445</td><td>18</td><td>M9</td><td>1378</td><td>15</td></tr>
<tr><td>M3</td><td>488</td><td>20</td><td>M10</td><td>1610</td><td>60</td></tr>
<tr><td>M4</td><td>555</td><td>20</td><td>M11</td><td>2250</td><td>50</td></tr>
<tr><td>M5</td><td>672</td><td>20</td><td>I1</td><td>640</td><td>80</td></tr>
<tr><td>M6</td><td>746</td><td>15</td><td>I2</td><td>865</td><td>39</td></tr>
<tr><td>M7</td><td>865</td><td>39</td><td>I3</td><td>1610</td><td>60</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="2">Beginning of Scan Angle
-56.03 (sample 1*)</td><td colspan="2">Beginning of AOI
56.47 (sample 1)</td><td colspan="2">Nadir AOI
36.08 (sample 1600)</td></tr>
<tr><td colspan="2">End of Scan Angle
56.03 (sample 3200)</td><td colspan="2">End of AOI
29.00 (sample 3200)</td><td colspan="2">SD and BB AOI
60.18, 38.53</td></tr>
</table>

*Note sample number is based on VIIRS M-bands.

2. METHODOLOGY

The calibration of VIIRS RSB is conducted using a sunlight illuminated SD to convert the instrument response to a radiometrically calibrated spectral reflectance [3-5]. The retrieval of the radiance from VIIRS is given by

$$L_{EV} = F\,(c_0 + c_1 dn_{EV} + c_2 dn_{EV}^2)/RVS_{EV} \qquad (1)$$

where L_{EV} is the spectral band radiance at the time of the EV measurement, the calibration coefficients c_0, c_1 and c_2 are determined prelaunch and corrected for any instrument temperature variation effect, dn_{EV} is the background subtracted EV digital response, and the scale factor F would be 1.0 if the instrument performs identically as in the prelaunch conditions. As the instrument's response changes on orbit, the value of F differs from 1.0.

The RVS term in both equations (1) and (2) can be further expressed as the following

$$RVS_{EV} = RVS_{PL} RVS_{OBT} \qquad (2)$$

where RVS_{PL} is the RVS characterized prelaunch in lab ambient conditions and the RVS_{OBT} is the relative change on-orbit in RVS. If the RVS of the instrument does not show any on-orbit change, the value of RVS_{OBT} would be 1.0.

Currently, there is no on-orbit correction for the VIIRS RVS. Thus, the value of RVS_{OBT} is 1.0 for VIIRS. In order to identify potential on-orbit changes in VIIRS RVS, the TOA reflectance trends from the CEOS endorsed pseudo-invariant test sites, including a number of desert sites in the northern Africa and an ice/snow site at Dome Concordia (Dome C, 75.3°S, 123.4°E) (Figures 1 and 2), Antarctica, are used to examine their stability at various scan angles.

The TOA reflectances for the desert site are collected from 16-day repeatable orbits and corrected by a site-specific bi-directional reflectance distribution function (BRDF) with coefficients derived using observations from the first year of the mission. The BRDF model is developed based on the two-kernel driven functions [13-15]

$$R^i(\theta,\varphi,\psi) = K_0^i + K_1^i f_1(\theta,\varphi,\psi) + K_2^i f_2(\theta,\varphi,\psi) \tag{3}$$

where R is the anisotropic reflectance factor defined as π times the ratio of radiance reflected into a particular direction to the reflected flux, θ, φ and ψ are the solar zenith, view zenith and relative azimuth angles, i is the index for the band wavelength, f_1 is derived from the volume scattering component, and f_2 is the component from surface scattering and geometric shadow casting theory. Coefficients K^i_0, K^i_1 and K^i_2 are given as functions of parameters related to the physical structure and optical properties of a reflecting surface in the original model. To the first approximation, it can be assumed that K^i_0, K^i_1 and K^i_2 are dependent on surface conditions.

The TOA reflectances for the Dome C site are collected on a daily basis in the Antarctic summer seasons. This is because Dome C is a near polar site; high frequent overpasses are available every day. Even in the Antarctic summer, solar zenith angles over Dome C are mostly larger than 50°. Thus, the impact of the surface BRDF on sensor measured reflectances is significantly larger than the desert sites. However, the Dome C reflectance factors follow a simple linear relationship with solar zenith angle which is shown in Figure 3 [16]. This provides a relatively simple approach to derive a site-dependent BRDF correction.

Figure 1. A Google picture of the area surrounding the Libya-4 (28.55°N, 23.39°E) site and the zoomed picture of the site.

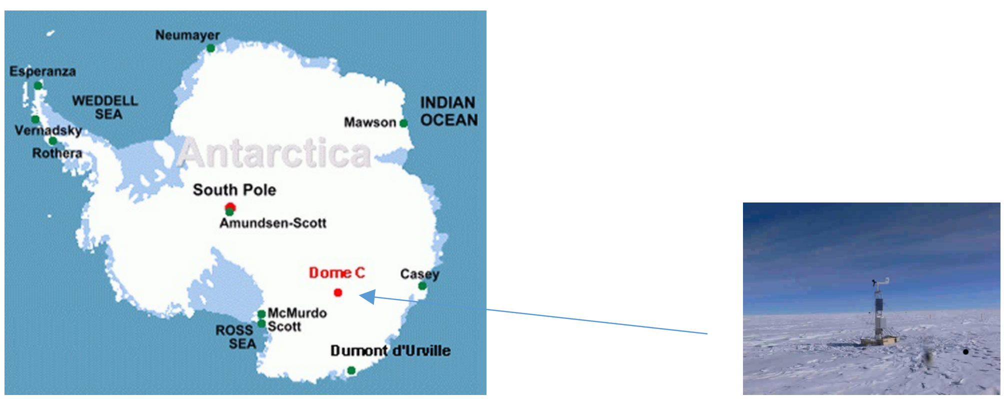


Figure 2. Map of Antarctica with location of Dome C (75.10°S, 123.40°E) highlighted in red. Also shown is the zoomed picture of the site.

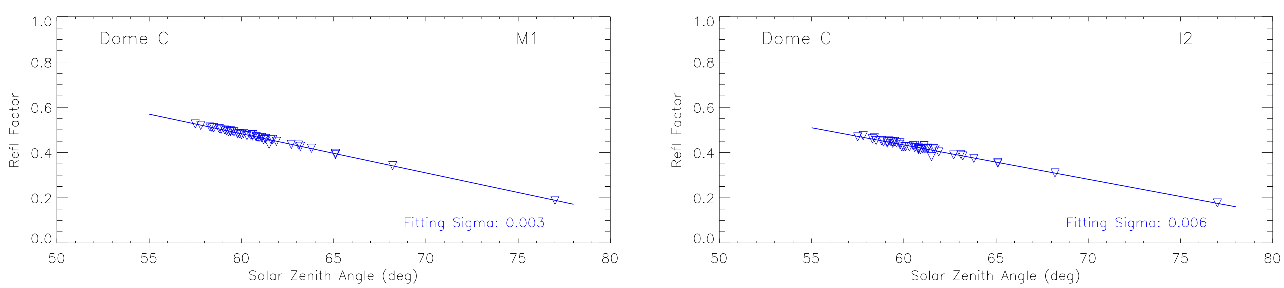


Figure 3. Reflectance factor versus solar zenith angle for VIIRS M1 and I2 over the Dome C site.

3. RESULTS

3.1. Desert

Figure 4 shows the stability of reflectance trends during the first five years of mission for VIIRS M1 and I2 at three separate sample regions (432, 1640 and 2920) near the beginning, nadir and end of the scan, corresponding to AOI angles of 50.5°, 35.6 ° and 28.6°, respectively. A linear fit is applied to the trends and the fitting uncertainties are found to be within 1.5%. The stability of the fitting is calculated using a linear fit over the entire mission period. The results of the stability is within 1% for all the three AOI. To further examine if there is any systematic bias as a function of AOI, we plot the stability versus AOI for M1, M2, I1 and I2 (Figure 5). The stabilities at the beginning and end of scan are generally more away from zero with larger uncertainties, which is expected as the trends are more subjected to the impact of the BRDF at the surface and increased atmospheric path lengths. By looking at the results between the AOI range between 30.0° and 52.0°, i.e., to exclude results from the two edges of scan, it is shown that the stabilities are well within 1%. This indicates that after five years of mission, there are still no noticeable changes in VIIRS RVS for RSB.

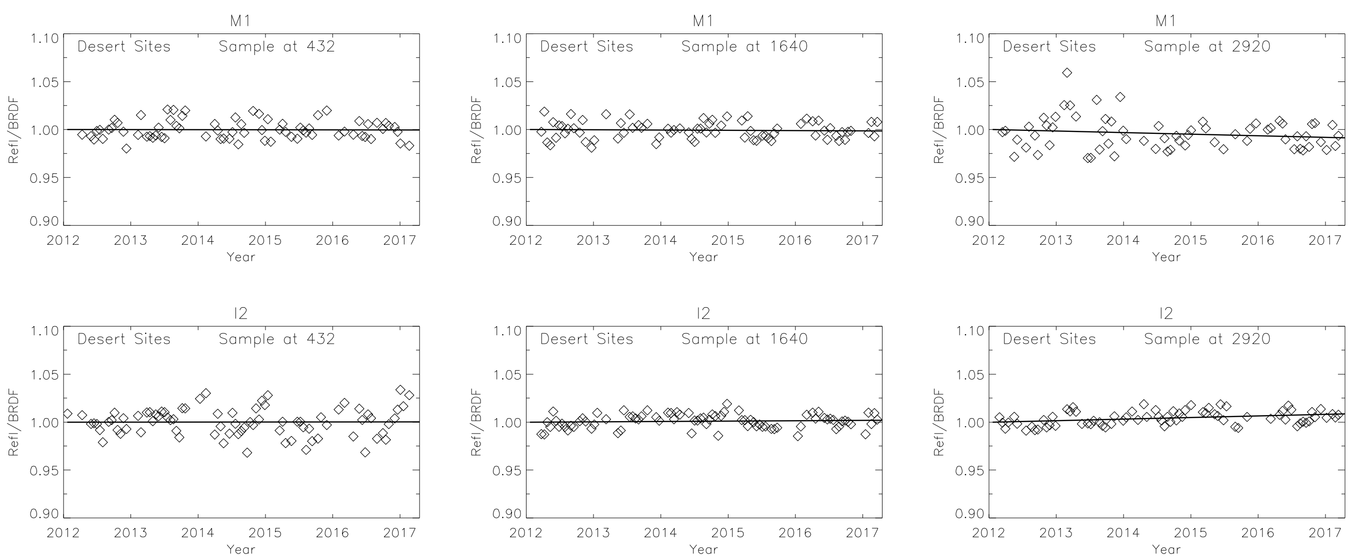
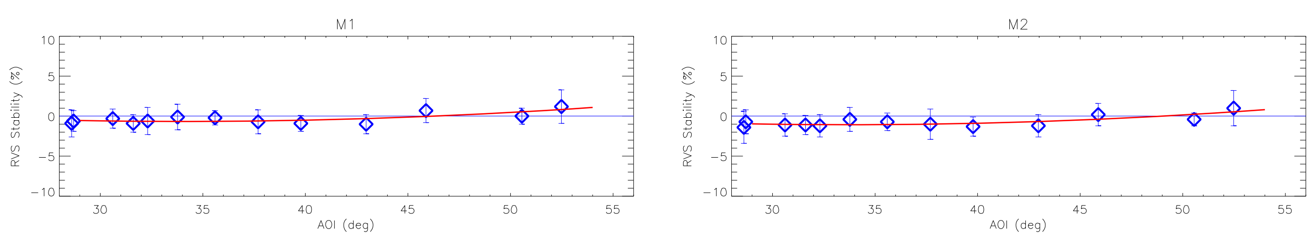


Figure 4. Trends of reflectance during the first five years of mission for NPP VIIRS M1 and I2 at three separate scan angles. The reflectances are collected from 16-day repeatable orbits over the CEOS endorsed pseudo-invariant desert sites and corrected by the site-specific BRDF.



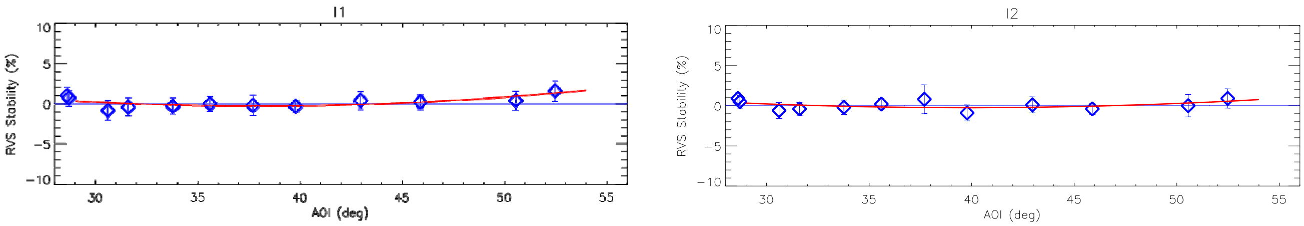
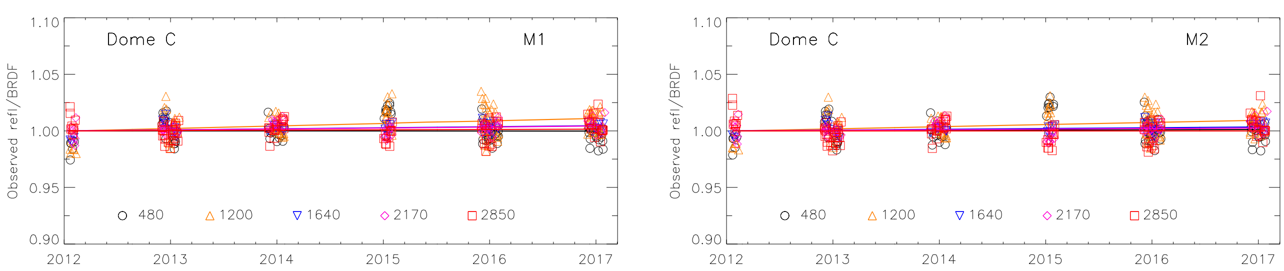


Figure 5. VIIRS RVS stability after the first five years of mission as a function of AOI for M1, M2, I1 and I2.

3.2. Dome C

Dome C is also a pseudo invariant site but covered by snow all year round. The exception for this site is that the atmosphere over the surface is extremely cold and dry, making it an excellent site to monitor sensor performance [17-19]. The disadvantage of the site is that there are only less than six months of daytime data each year. As discussed in the methodology, the Dome C reflectance factors follow a simple linear relationship with solar zenith angle, which provides a relatively simple approach to derive a site-dependent BRDF. To reduce data variations, data with solar zenith angles larger than 80^o are excluded. Examination of the fitting residuals indicates that the linear relationship works better in the VIS region than the NIR region. Similar to the results for the desert sites, a BRDF model with coefficients derived using Dome C data from the Antarctic summer 2012 - 2013 are applied to the reflectance data over mission from the same site. Figure 6 shows the VIIRS reflectance trends for M1, M2, I1 and I2. The trends for the Dome C site show a similar excellent stability within 1% from five separate sample regions (480, 1200, 1640, 2170 and 2850). It should be noted that even with a limitation of solar zenith angle, data variation in general is larger than the desert sites.



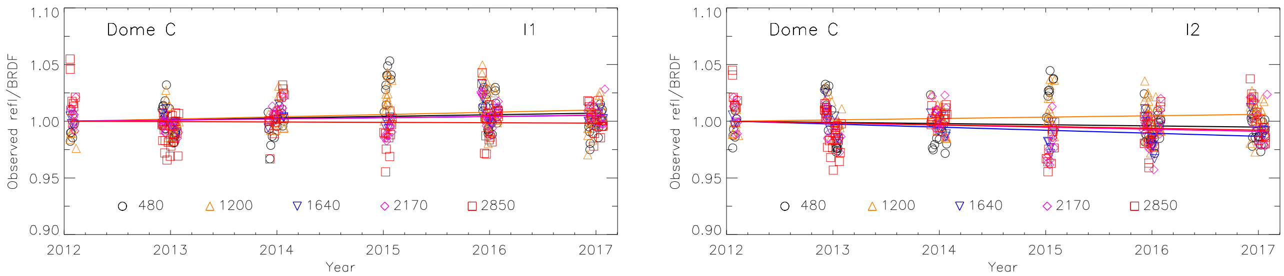


Figure 6. Trends of reflectance during the first five years of mission for NPP VIIRS M1, M2, I1 and I2 at five separate scan angles. The reflectances are collected from daily overpasses over the Dome C snow site and corrected by the site-specific BRDF.

4. SUMMARY

RVS is an important calibration parameter to the quality of the VIIRS SDR product. The VIIRS RSB RVS was characterized prelaunch in lab ambient conditions and is currently used to determine the on-orbit response for all scan angles relative to the SD scan angle. This study extends our previous reported results of tracking the RVS on-orbit stability to a five-year mission from 2012 to 2017. Results based on the trends from both desert and Dome C site show a similar excellent stability within 1% over the entire Earth view scan range. Given comparable data uncertainties and a limited number of sampled overpasses, it is indicated that there is no noticeable drift in VIIRS RSB RVS after five years of mission.

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