VCST Internal Memo

Title: Estimate of Uncertainty for Transmission Factors Derived from Yaw Maneuvers for S-NPP VIIRS
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References

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1. Introduction

Yaw maneuvers were used to characterize the transmission factors in the SD view and both SDSM views on-orbit [1-3]. It is important to characterize the uncertainties of these factors as they are critical in estimating the total uncertainty of the reflective solar bands on-orbit. This work will focus on propagating the uncertainty from various contributors to the yaw maneuver measurements to the transmission factors. The uncertainty is propagated using the standard formulation [4-5], and is described in the following section. Preliminary estimates of the uncertainties were presented in [6].

2. Uncertainty Propagation

For the purposes of this work, we follow the standard uncertainty propagation for a function y of variables x_i is described by [4-5]

$$u^2(y) = \sum_{i=1}^{N} \left(\frac{\partial y}{\partial x_i} \right)^2 u^2(x_i) + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(\frac{\partial y}{\partial x_i} \right) \left(\frac{\partial y}{\partial x_j} \right) u(x_i, x_j). \tag{1}$$

Here $u(x_i)$ is the uncertainty of the variable x_i that goes into the calculation of the y and $u(x_i,x_j)$ is the covariance between x_i and x_j.

The calculation of $\tau_{SAS}BRF_{RTA}$ first required the determination of the F factor, defined as

$$F=\frac{RVS_{SD}\left(BRF_{RTA}/\pi\right)\left(H/H_0\right)E_{sun}\cos\theta_{SD}}{c_0+c_1dn_{SD}+c_2dn_{SD}^2},\tag{2}$$

which was trended over the yaw orbits using a series of orbits before and after the yaw maneuvers [1-3]. Therefore, in order to determine the uncertainty in $\tau_{SAS}BRF_{RTA}$, the uncertainty must first be propagated through the F factor. The propagation is conducted for the following ratio,

$$\begin{aligned}\frac{u^2(F')}{F'^2}&=\frac{u^2(\tau_{SAS})}{\tau_{SAS}^2}+\frac{u^2(BRF_{RTA})}{BRF_{RTA}^2}+\frac{u^2(\cos\theta_{SD})}{\cos^2\theta_{SD}}\\&+\frac{\left[u^2(c_0)+dn_{SD}^2u^2(c_1)+dn_{SD}^4u^2(c_2)+(c_1+2c_2dn_{SD})^2u^2(dn_{SD})\right]}{\left(c_0+c_1dn_{SD}+c_2dn_{SD}^2\right)^2}\end{aligned}.\tag{3}$$

where $F'=F/(E_{sun}\cos\theta_{SD}RVS_{SD})$. Because some of the contributors to the F factor are essentially constants over this timescale (E_{sun}, $\cos\theta_{SD}$, and RVS_{SD}), they cancel in the $\tau_{SAS}BRF_{RTA}$ calculation, and hence do not contribute in the final uncertainty. $\tau_{SAS}BRF_{RTA}$, derived from [3]

$$\tau_{SAS}BRF_{RTA}=\frac{\pi F\left(c_0+c_1dn_{SD}+c_2dn_{SD}^2\right)}{RVS_{SD}\left(H/H_0\right)E_{sun}\cos\theta_{SD}},\tag{4}$$

and its total uncertainty is then

$$\frac{u^2(\tau_{SAS}BRF_{RTA})}{(\tau_{SAS}BRF_{RTA})^2}=\frac{u^2(F')}{F'^2}+\frac{u^2(\cos\theta_{SD})}{\cos^2\theta_{SD}}+\frac{(c_1+c_2dn_{SD})^2u^2(dn_{SD})}{\left(c_0+c_1dn_{SD}+c_2dn_{SD}^2\right)^2}.\tag{5}$$

Here the contributions from the c_i have been ignored; as the uncertainties from these terms constitute bias, they are correlated to the uncertainty in F'. As a result, they are not included in Eq. (5). Similarly, the non-random portion of the $\cos\theta_{SD}$ is not included in Eq. (5).

$\tau_{SAS}BRF_{SDSM}$ was derived from [2]

$$\tau_{SAS}BRF_{SDSM}=\frac{g_{SDSM-SD}\,dc_{SD}}{\cos\theta_{SD}\sin^2\psi\,E_{sun}}\tag{6}$$

where

$$g_{SDSM-SD}=\frac{\tau_{SDSM}BRF_{SDSM}\left(H/H_0\right)\cos\theta_{SD}\sin^2\psi\,E_{sun}}{dc_{SD}}.\tag{7}$$

The propagation of the uncertainties in the calculated $\tau_{SAS}BRF_{SDSM}$ is given by

$$\frac{u^2(\tau_{SAS}BRF_{SDSM})}{(\tau_{SAS}BRF_{SDSM})^2}=\frac{u^2(g_{SDSM-SD})}{g_{SDSM-SD}^2}+\frac{u^2(dc_{SD})}{dc_{SD}^2}+\frac{u^2(\cos\theta_{SD})}{\cos^2\theta_{SD}}.\tag{8}$$

Contributions from E_{sun} and $\Omega_{SDSM}\approx\pi\sin^2\psi$ are not included as they are constants in the calculation and cancel when the final $\tau_{SAS}BRF_{SDSM}$ is normalized. The final normalization also allows one to ignore all the bias uncertainties common to the entire $\tau_{SAS}BRF_{SDSM}$; as a result, only the random uncertainties contribute. For a normalized function that does not show a great deal of variation, as is the case in the work, the error propagation will result in the contributions from bias terms being subdominant..

τ_{SDSM} was derived from [2]

$$\tau_{SDSM}=\frac{dc_{sun}}{dc_{SD}}\tau_{SAS}BRF_{SDSM}\left(H/H_0\right)\cos\theta_{SD}\sin^2\psi\ .\tag{9}$$

The total uncertainty in τ_{SDSM} is described by

$$\frac{u^2(\tau_{SDSM})}{\tau^2_{SDSSM}} = \frac{u^2(\tau_{SAS} BRF_{SDSM})}{(\tau_{SAS} BRF_{SDSM})^2} + \frac{u^2(H/H_0)}{(H/H_0)^2} + \frac{u^2(dc_{SD})}{dc^2_{SD}} + \frac{u^2(dc_{solar})}{dc^2_{solar}} + \frac{u^2(\cos\theta_{SD})}{\cos^2\theta_{SD}}. \tag{10}$$

Again, the final normalization allows one to ignore all the bias uncertainties common to the entire τ_{SDSM}; as a result, only the random uncertainties contribute.

In general, the covariance terms were not directly calculated; a direct calculation of these terms is beyond the scope of this work. However, it is believed that most of these terms would be small (unless otherwise noted).

3. Individual Uncertainty Sources

3.1 Pre-launch τ_{SAS} and BRF_{RTA}

The uncertainties of τ_{SAS} and BRF_{RTA} were calculated pre-launch during the component phase of testing. The fractional uncertainties are 0.24 % (τ_{SAS}), 1.09 % (BRF_{RTA} for bands I1-I2 and M1-M7), and 1.32 % (BRF_{RTA} for bands I3 and M8-M11) [7].

3.2 $\cos\theta_{SD}$

The uncertainty in θ_{SD} was determined pre-launch [7]. The pointing accuracy was estimated, as well as potential shifts in the SD normal due to vibration, thermal effects, and gravity (before launch). The total uncertainty provided was 0.95 degrees between the calculated solar vector and the SD normal. Of this, 0.033 degrees was determined to be random uncertainty once the instrument has reached a stable operating environment. This uncertainty was propagated to $\cos\theta_{SD}$ by the following

$$u^2(\cos\theta_{SD}) = \max\left[\left|\cos\theta_{SD} - \cos(\theta_{SD} + \Delta)\right|, \left|\cos\theta_{SD} - \cos(\theta_{SD} - \Delta)\right|\right], \tag{11}$$

where Δ is the angle uncertainty. In some cases, the full uncertainty is used and in other cases, only the random uncertainty is included; this was described in more detail in the Section 2.

In addition, there was some difference in proper motion of the Sun across the SAS screen from yaw and non-yaw orbits. This was attributed to some uncertainty in the solar vector determined during the yaw maneuvers. An additional uncertainty of 0.03 degrees solar azimuth and 0.002 degrees solar declination was included. These uncertainties were propagated to $\cos\theta_{SD}$; then the RSS of this uncertainty and Eq. (11) was used as the total $\cos\theta_{SD}$ uncertainty.

3.3 SDSM SD and Solar Response

The uncertainty in the SDSM response to input signals from the SD and solar views was determined as the RSS of the standard deviation of the mean of the 5 samples in the SD or solar view and the standard deviation of the mean of the 5 samples in the dark offset view. Because of the small number of samples, the standard deviation is likely to be underestimated; however, for a sample size of 5, the estimated bias is about 6% of the standard deviation. For the purposes of this work, this correction is deemed small, and as a result, not included.

3.4 SDSM Gain and H/H_0

The uncertainties in $g_{SDSM\text{-}SD}$ and H/H_0 were estimated by taking the standard deviations of these factors determined during non-yaw maneuver orbits: 1552 – 1562, 1570, 1578 – 1581, and 1583 – 1587. Here only the relative uncertainty associated with the trending of these terms across the yaw maneuver orbits is required; the absolute uncertainty will cancel in the normalizations of the transmission factors.

3.5 VIIRS SD Response

The uncertainty in VIIRS detector response was the RSS of the standard deviation of the mean of all samples in the SD view and the standard deviation of the mean of all samples in the SV sector. Here only the random uncertainty is included. There are a number of known biases in the response; however, none of these directly affect the present calculation.

3.6 Radiometric Coefficients

The uncertainties in the c_i coefficients were determined pre-launch during RC-02 testing [8]. Here the band average uncertainty was used (the variation within a band was generally small).

3.7 Model Dependence

The equations used here include E_{sun}, which is the integral over the solar flux corrected for the Earth-Sun distance. It is possible to include the $\tau_{SAS}BRF_{RTA}$ under the integral. To account for any difference this might cause, a model dependent uncertainty factor was added (the percent difference between the F factors produced using the two different models).

Additional contributions to the uncertainty resulting from the interpolation to a regular grid needed to form the LUTs as well as the possible error in the knowledge of the angles used to determine the transmission factors from these LUTs.

4. Results

The calculated percent uncertainties for the F' factors are listed in Tables 1 and 2, along with the contributions from individual terms. Since the products delivered were band average [1-3], the uncertainties presented here are also band average. The total uncertainties range from 1.15 to 1.53 %, with the largest being M7 and the lowest being M2 and M3. The dominant term is the pre-launch BRF_{RTA}. In addition, some bands have significant contributions from the c_1 uncertainty, particularly for bands I2, I3, M7, and M8. τ_{SAS} and $\cos\theta_{SD}$ also play a small, but non-negligible role. Note that the uncertainties that contributed to the F' uncertainty were the full combinations of bias and random contributions (as outlined in Section 3).

The total uncertainty on the $\tau_{SAS}BRF_{RTA}$ is shown for each band in Tables 3 and 4. The total uncertainties range from 1.15 % for bands M2 and M3 to 1.54 % for band M7. These uncertainties are dominated by the F' uncertainty; the other terms change the total by only 0.01 – 0.03 %. As a result, the most significant contributor is the pre-launch BRF_{RTA} uncertainty (and in the case of M7, also the c_1 uncertainty). All the bias uncertainties were contained in F'; including them in any other terms (c_i, $\cos\theta_{SD}$, or model uncertainties) in the $\tau_{SAS}BRF_{RTA}$ uncertainty calculation would amount to double counting. In contrast, the random uncertainties in included in both stages of the calculation [Eq. (3) and (5)].

The estimate of the $\tau_{SAS}BRF_{SDSM}$ total uncertainty per SDSM detector is listed in Tables 5 and 6; the total uncertainties range from 0.10 and 0.17 %. The most important contributors are $g_{SDSM\text{-}SD}$ and $\cos\theta_{SD}$. The total uncertainties for τ_{SDSM} are given in Tables 7 and 8 for all SDSM detectors. The values are between 0.13 and 0.18 % with the main contributors being $\tau_{SAS}BRF_{SDSM}$ and $\cos\theta_{SD}$. In both cases, the uncertainties are higher for the high and low number detectors; this is the result of increased uncertainty in $g_{SDSM-SD}$. For both $\tau_{SAS}BRF_{SDSM}$ and τ_{SDSM}, only the random uncertainties are considered in the calculation; any bias uncertainties would cancel out when both transmission factors were normalized. The bias uncertainties are effectively transferred to another portion of the RSB calibration (in this case the F factor through $\tau_{SAS}BRF_{RTA}$).

The uncertainties given in this work represent an estimate of the total average uncertainty of all locations on the transmission factors in terms of horizontal and vertical angles. The uncertainty of a given point on any of the transmission factors may be higher (or lower).

5. Summary

Uncertainty estimates were calculated for $\tau_{SAS}BRF_{RTA}$ for all RSB bands and for $\tau_{SAS}BRF_{SDSM}$ and τ_{SDSM} for all SDSM detectors via standard uncertainty propagation methods [4-5]. These uncertainties are critical for the determination of the overall RSB uncertainty. The following is a list of findings:

- Total uncertainties for $\tau_{SAS}BRF_{RTA}$ range from 1.15 % (M2 and M3) to 1.54 % (M7). The dominant contributor is the pre-launch BRF_{RTA} uncertainty (except for band M7, where c_1 is also important).
- Total uncertainties for $\tau_{SAS}BRF_{SDSM}$ range from 0.10 % (SDSM detectors 4, 5, and 6) to 0.17 % (SDSM detector 8). The dominant terms are the SDSM gain trend ($g_{SDSM-SD}$) and $\cos\theta_{SD}$ uncertainties.
- Total uncertainties for τ_{SDSM} range from 0.13 % (SDSM detectors 3, 4, 5, and 6) to 0.18 % (SDSM detector 8). The dominant contributor is the $\tau_{SAS}BRF_{SDSM}$ uncertainty.

Table 1: Total uncertainties in the F' factor and individual contributors (in %)

	I1	**I2**	**I3**	**M1**	**M2**	**M3**	**M4**
$\boldsymbol{\tau_{SAS}}$	0.24	0.24	0.24	0.24	0.24	0.24	0.24
$\mathbf{BRF_{RTA}}$	1.09	1.09	1.32	1.09	1.09	1.09	1.09
$\mathbf{c_0}$	0.13	0.13	0.17	0.04	0.03	0.02	0.01
$\mathbf{c_1}$	0.10	0.53	0.45	0.12	0.03	0.09	0.14
$\mathbf{c_2}$	0.00	0.01	0.01	0.02	0.03	0.03	0.04
$\mathbf{dn_{SD}}$	0.16	0.23	0.28	0.08	0.07	0.05	0.04
$\mathbf{cos\theta_{SD}}$	0.26	0.26	0.26	0.26	0.26	0.26	0.26
model	0.13	0.10	0.08	0.19	0.07	0.07	0.09
total	**1.17**	**1.28**	**1.47**	**1.17**	**1.15**	**1.15**	**1.16**

Table 2: Total uncertainties in the F' factor and individual contributors (in %)

	M5	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
$\boldsymbol{\tau_{SAS}}$	0.24	0.24	0.24	0.24	0.24	0.24	0.24
$\mathbf{BRF_{RTA}}$	1.09	1.09	1.09	1.32	1.32	1.32	1.32
$\mathbf{c_0}$	0.02	0.03	0.02	0.12	0.18	0.08	0.10
$\mathbf{c_1}$	0.12	0.27	1.03	0.46	0.30	0.29	0.33
$\mathbf{c_2}$	0.06	0.07	0.03	0.01	0.01	0.00	0.00
$\mathbf{dn_{SD}}$	0.04	0.04	0.03	0.17	0.18	0.16	0.28
$\mathbf{cos\theta_{SD}}$	0.26	0.26	0.26	0.26	0.26	0.26	0.26
model	0.13	0.03	0.07	0.03	0.06	0.02	0.03
total	**1.16**	**1.18**	**1.53**	**1.45**	**1.41**	**1.40**	**1.43**

Table 3: Total uncertainties in $\tau_{SAS}BRF_{RTA}$ and individual contributors (in %)

	I1	**I2**	**I3**	**M1**	**M2**	**M3**	**M4**
F'	1.17	1.28	1.47	1.17	1.15	1.15	1.16
dn_{SD}	0.19	0.23	0.27	0.08	0.06	0.05	0.04
$cos\theta_{SD}$	0.11	0.11	0.11	0.11	0.11	0.11	0.11
total	**0.19**	**1.31**	**1.50**	**1.17**	**1.15**	**1.15**	**1.16**

Table 4: Total uncertainties in $\tau_{SAS}BRF_{RTA}$ and individual contributors (in %)

	M5	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
F'	1.16	1.18	1.53	1.45	1.41	1.40	1.43
$\mathbf{dn_{SD}}$	0.04	0.04	0.03	0.17	0.17	0.16	0.26
$\mathbf{cos\theta_{SD}}$	0.11	0.11	0.11	0.11	0.11	0.11	0.11
total	**1.16**	**1.18**	**1.54**	**1.47**	**1.43**	**1.41**	**1.46**

Table 5: Total uncertainties in $\tau_{SAS}BRF_{SDSM}$ and individual contributors (in %)

	DET 1	**DET 2**	**DET 3**	**DET 4**
$\mathbf{g_{SDSM\text{-}SD}}$	0.11	0.09	0.07	0.06
$\mathbf{dc_{SD}}$	0.02	0.01	0.01	0.01
$\mathbf{\cos\theta_{SD}}$	0.08	0.08	0.08	0.08
total	**0.14**	**0.13**	**0.11**	**0.10**

Table 6: Total uncertainties in $\tau_{SAS}BRF_{SDSM}$ and individual contributors (in %)

	DET 5	**DET 6**	**DET 7**	**DET 8**
$\mathbf{g_{SDSM\text{-}SD}}$	0.05	0.06	0.09	0.15
$\mathbf{dc_{SD}}$	0.01	0.01	0.01	0.01
$\mathbf{\cos\theta_{SD}}$	0.08	0.08	0.08	0.08
total	**0.10**	**0.10**	**0.12**	**0.17**

Table 7: Total uncertainties in τ_{SDSM} and individual contributors (in %)

	DET 1	**DET 2**	**DET 3**	**DET 4**
$\mathbf{\tau_{SAS}BRF_{SDSM}}$	0.13	0.12	0.10	0.10
$\mathbf{H/H_0}$	0.00	0.00	0.00	0.00
$\mathbf{dc_{solar}}$	0.02	0.01	0.01	0.01
$\mathbf{dc_{SD}}$	0.02	0.01	0.01	0.01
$\mathbf{\cos\theta_{SD}}$	0.08	0.08	0.08	0.08
total	**0.16**	**0.14**	**0.13**	**0.13**

Table 8: Total uncertainties in τ_{SDSM} and individual contributors (in %)

	DET 5	**DET 6**	**DET 7**	**DET 8**
$\mathbf{\tau_{SAS}BRF_{SDSM}}$	0.10	0.10	0.12	0.16
$\mathbf{H/H_0}$	0.00	0.00	0.00	0.00
$\mathbf{dc_{solar}}$	0.01	0.01	0.01	0.01
$\mathbf{dc_{SD}}$	0.01	0.01	0.01	0.01
$\mathbf{\cos\theta_{SD}}$	0.08	0.08	0.08	0.08
total	**0.13**	**0.13**	**0.14**	**0.18**