VIIRS GSFC Ocean Science Team Report and Ocean Color Environment Data Record (EDR) Assessment

K. Turpie (OBPG)

Final version

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CURRENT NPP CDR SHOWSTOPPERS

CALIBRATION MANEUVERS ARE NOT YET APPROVED

• Lunar roll maneuvers are a minimum requirement for NASA data continuity; needed to track trends in detector degradation during the mission.
• Yaw maneuver is required to characterize calibration system on-orbit only once or twice during the mission.
• [One-time pitch-over maneuver is also necessary to characterize RVS for SST.]

THERE IS NO MISSION-LEVEL REPROCESSING

There is no support for the application of vicarious gain across the entire data record, or to address on-orbit anomalies, or to address major algorithm changes. Mission-level reprocessing is a critical minimum requirement for a climate data record or to meeting product performance specifications.

ALGORITHMS ARE OUTDATED AND INCONSISTENT

Current operational NPP algorithms are inconsistent with NASA climate data record. Atmospheric correction is missing several years of development. Chl-α algorithm was demonstrated to perform more poorly than current NASA selected algorithm.

These are currently unresolved, and preclude NPP from producing ocean color climate data records (CDR).
**RISKS: Instrument Performance**

**Crosstalk** - Optical crosstalk could have a significant impact on ocean color data quality. Polarization sensitivity, electronic crosstalk, and other uncertainty sources hamper characterization.

**Out-of-Band Response** - Larger than MODIS light leaks have been found in VIIRS; especially high in 412 & 551nm channels.

**Spectral Characterization Uncertainty** - Characterization of crosstalk and out-of-band response show signs of significant uncertainty, which could hamper on-orbit correction. *There is a plan for NIST to test spectral response at S/C level with SIRCUS.*

**SNR** - Signal-to-noise ratio is comparable, but lower than MODIS in the 3:1 agg zone, but drops at higher scan angles. Impact to coverage needs to be evaluated.

**Gain switch anomaly** - At ~90% gain switch point, VIIRS has increased non-linearity and noise. Note that detectors do not switch at the same radiance (0-20% of $L_{\text{max}}(\text{HG})$). M1 was observed switching below the $L_{\text{max}}(\text{HG})$ switch point, but red light leak may have pushed gain transition low in lab.

*Risks to meeting NASA’s data continuity requirements.*
RISKS: Calibration System

System Level Calibrator Test - RSB Calibrator system remains untested and considered at high risk. There is a plan for NIST to test calibrator at S/C level with SIRCUS.

Calibration Packets for band M4 & M5 - Calibration packets were being substitute by DNB data during calibration, but this has been remedied. This was verified in FP-18 Day-in-the-Life testing data. It was noted however that transition between day and night mode is staggered over at least three scans.

SDSM misalignment - SDSM was manufactured with wrong orientation; may reduce number of measurements of the sun with characterized portion of SDSM screen.
RISKS: Postlaunch Activities

Vicarious Calibration Infrastructure Support - Potential assets and resources identified in IPO Ocean Cal/Val Plan: future support not completely clear.

Validation Data Collection - Tasks and potential resources are identified in the IPO Ocean Cal/Val Plan. NASA SeaBASS possible repository for data. Are enough resources adequately supported?

OC Calibration Analysis Team - To meet minimum requirements it is critical to have a dedicated team to evaluate calibration data, including vicarious and lunar calibration data, and handle instrument calibration trends or anomalies. Personnel are identified in IPO Ocean Cal/Val Plan, but agency agreements are not in place.

Independent Assessment Team - An independent team to evaluate data quality is recommended. Tasks and personnel are identified in the IPO Ocean Cal/Val Plan, but agency agreements are not in place.

Recommendation: Perform gap analysis for Cal/Val resources and assets, in context of what is now known about VIIRS performance.
RISKS: Postlaunch Activities

Algorithm Change Pathway Long and Slow -

There are too many decision gates to approve algorithm changes. Working with the ocean color community for algorithm development is likely to be hampered.
INSTRUMENT PERFORMANCE
### NPP VIIRS Radiometric Performance

<table>
<thead>
<tr>
<th>Feature</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polarization Sensitivity</strong></td>
<td>&lt; MODIS, better characterized</td>
</tr>
<tr>
<td><strong>Signal-to-Noise Ratio</strong></td>
<td>&lt; MODIS in visible bands, best in 3:1 agg zone, high in NIR</td>
</tr>
<tr>
<td><strong>Noise</strong></td>
<td>Systematic noise spikes, esp. blue bands (M1-3), ~3x10^-6 freq.</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>12 bits. (+1 for dual gain bands)</td>
</tr>
<tr>
<td><strong>Dynamic Range</strong></td>
<td>M1 (412nm) and M8 (1240nm) thought to switch gain lower than expected, but M1 probably due to red light leak artifact.</td>
</tr>
<tr>
<td><strong>Linearity</strong></td>
<td>Linearity &lt; 0.15% for ocean bands. Characterization Uncertainty in spec.</td>
</tr>
<tr>
<td><strong>Uniformity</strong></td>
<td>Only the NIR (748 &amp; 865nm) bands pass spec for gain uniformity.</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>Within 0.3% over one orbit for bus voltage, temperature.</td>
</tr>
<tr>
<td><strong>Response Verses Scan</strong></td>
<td>Meets requirements.</td>
</tr>
<tr>
<td><strong>Near-field Response</strong></td>
<td>comparable to MODIS, better than SeaWiFS. M7 does not pass EOL specification.</td>
</tr>
<tr>
<td><strong>Stray Light</strong></td>
<td>Meets spec with large margin (50-100%)</td>
</tr>
</tbody>
</table>
Dual-gain Bands - samples aggregated on ground.
Singe-gain Bands - samples aggregated on-board (only M6 for ocean bands).

source: MDFCB, 4 Nov 2004
During EDU, anomalies in various tests were observed that were traced back to communication between band detectors.

Three main types of crosstalk were identified (other flavors exist of much less concern):

- Optical
- Static Electronic
- Dynamic Electronic

Optical crosstalk is claimed to be an order of magnitude larger than static electronic crosstalk and has been considered the main concern.

Dynamic crosstalk was greatly reduced by adding bonding wires to the focal plane assembly and is only expected to produce an effect along edges of very bright targets.

In addition, a strong out-of-band response was discovered in FU1 during spectral response characterization.
FILTER LEAKS IN NPP VIIRS

Hyperbolic Cut

- Scatter centers in filter direct light at specific out-of-band wavelengths to exit the filter in high-angle cones.
- In the scan direction, this extraneous out-of-band light is transmitted to other bands as “inter-band” optical crosstalk.
- In the track direction, the same produces out-of-band stray light that has been called “intra-band” crosstalk.
- In the principal tests to characterize spectral response, “intra-band” crosstalk is indistinguishable from directly transmitted (non-scattered) out-of-band leakage.
- Polarization causes exiting light to form lobes in the direction of the E vector.

Circular Cut

Based on 5-10 second exposure photos by Pete Fuqua (Aerospace Corp.)
Feb 11, 2009
EDR ASSESSMENT
(Modeling Crosstalk)
NPP VIIRS Crosstalk Impact Assessment

• Work by Northrop Grumman, Raytheon, MIT Lincoln Labs, Aerospace and NASA have contributed over three years to understanding crosstalk in VIIRS, leading to a model heavily based on characterization data.

• As a numerical experiment, this model was extended to predict the result if MODIS had crosstalk similar to VIIRS.

• Unlike previous exercises that focused on the worst case scenario, this current experiment excludes the out-of-band influence in the crosstalk model.

• Out-of-band effects are more difficult to evaluate since their characterization are an integral part of the ocean color algorithm.
LIMITATIONS

The current model and this analysis of the results are entirely preliminary (caveat emptor!).

There are many sources of uncertainty that have not been bounded.

In modeling VIIRS crosstalk in MODIS:

• A crude model of point-to-point propagation is applied,
• Interpolation and weighting schemes are used to map to and between MODIS bands, and
• Electronic crosstalk is not included in the modeling.

Also, further stratification of results will be needed to assess impact to specific science questions.
# NPP VIIRS Crosstalk Impact Assessment

**L2 Flags used to select high quality pixels**

<table>
<thead>
<tr>
<th>Flag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATMFAIL</td>
<td>Atmospheric correction failure</td>
</tr>
<tr>
<td>LAND</td>
<td>Pixel is over land</td>
</tr>
<tr>
<td>CLDICE</td>
<td>Probable cloud or ice contamination</td>
</tr>
<tr>
<td>HILT</td>
<td>TOA radiance is high</td>
</tr>
<tr>
<td>STRAYLIGHT</td>
<td>Straylight contamination is likely</td>
</tr>
<tr>
<td>HISATZEN</td>
<td>Satellite zenith threshold &lt; 60 degree</td>
</tr>
<tr>
<td>COCCOLITH</td>
<td>Coccolithofores detected</td>
</tr>
<tr>
<td>LOWLW</td>
<td>Very low water-leaving radiance (cloud shadow)</td>
</tr>
<tr>
<td>CHLFAIL</td>
<td>Derived product algorithm failure</td>
</tr>
<tr>
<td>CHLWARN</td>
<td>Derived product quality is reduced</td>
</tr>
<tr>
<td>NAVWARN</td>
<td>Bad navigation</td>
</tr>
<tr>
<td>MAXAERITER</td>
<td>Aerosol iterations exceeded max</td>
</tr>
<tr>
<td>ATMWARN</td>
<td>Atmospheric correction failure</td>
</tr>
<tr>
<td>HISOLZEN</td>
<td>High solar zenith</td>
</tr>
<tr>
<td>NAVFAIL</td>
<td>Bad navigation</td>
</tr>
<tr>
<td>FILTER</td>
<td>Pixel rejected by user-defined filter</td>
</tr>
<tr>
<td>SSTWARN</td>
<td>SST quality is reduced</td>
</tr>
<tr>
<td>SSTFAIL</td>
<td>SST quality is bad</td>
</tr>
<tr>
<td>HIGLINT</td>
<td>High sun glint</td>
</tr>
</tbody>
</table>

**RED** - Flags used for coastal scenes with fewer ideal pixels

200 pixels trimmed from swath edge to remove bow tie effect.
Three scenes were selected: one open ocean near the vicarious calibration site and the other two with coastal and in-land waters.

Special thanks to NICST for all their hard work in creating these modeled scenes.
A20051071815 - East USA 17 April 2005
869 and 443nm bands show the most effect for TOA radiance. Other bands show tolerable levels of crosstalk impact.

Based on current data, optical crosstalk alone produces a modest, but significant impact to ocean color products - but less than previous worst case scenarios.

NASA algorithm is more resilient to crosstalk than the operational NPP algorithm which appear to be devastated by this effect.
Region Bias and Variation Summary Stats

**L1 Median Relative Error**

- **Argentina**
- **Hawaii**
- **East USA**

**nLw Median Relative Error**

- **Argentina**
- **Hawaii**
- **East USA**

**L1 Median Relative Error**

Interpercentile Dispersion [(r95-r05)/4]

- **Argentina**
- **Hawaii**
- **East USA**

**nLw Relative Error**

Interpercentile Dispersion [(r95-r05)/4]

- **Argentina**
- **Hawaii**
- **East USA**
EDR ASSESSMENT
(Out-of-Band Light Leaks)
NPP VIIRS Spectral Performance

NPP VIIRS FU1 has a much larger out-of-band response than EDU (or MODIS).

* NICST now predicts a value comparable to the other teams for M5.
NPP VIIRS Spectral Performance

NPP VIIRS FU1 results have yielded significant differences between detectors and between analysis teams.
NPP VIIRS Spectral Performance

Taking the differences of the radiometric errors from the OOB response when measuring a blue ocean and the solar diffuser provide an estimate of the reflectance error.

$E_{\text{cal}}$ for Blue Ocean
SUMMARY
SUMMARY

NPP VIIRS RISKS:

• **NPP VIIRS simply cannot** produce science or climate quality ocean color data without 1) reprocessing, 2) maneuvers, and 3) current NASA selected and developed algorithms.

• A gap analysis is recommended for Cal/Val resources and assets in the context of what is now known about VIIRS performance; agency agreements need to be in place for IPO Cal/Val plan to be successful.

• VIIRS spectral response and crosstalk issues remain a major concern, especially regarding uncertainty and whether any on-orbit correction will be viable.

• VIIRS radiometric performance would otherwise be good, barring concern for moderate SNRs and possible striping.
CROSSTALK EDR ASSESSMENT:
Very preliminary, crosstalk model, based on the latest data, was applied to three MODIS scenes (one open ocean, two with coastal and inland waters).

RESULTS
• Impact is smaller without out-of-band, but significant crosstalk was still produced in the 443nm and 869nm channels of the MODIS data (~0.3% and ~0.4%, respectively, for TOA radiance).
• Normalized water-leaving radiance and Chl-\(a\) showed regional biases and variation that often met NPP EDR performance requirements, but consumed a large amount of the error budget.
• Data products for coastal and inland water had the greatest impact.
• NASA Chl-\(a\) algorithm (OCM3) was more robust in the presence of crosstalk than the NPP operation algorithm, especially in coastal waters.
OUT-OF-BAND LIGHT LEAK:

- **A significant** out-of-band response was found in the FU1 spectral characterization.
- Only the 443nm and 865nm channels remain clearly within specifications; all other ocean bands fail spec.
- It is not clear, given the currently poorly bounded uncertainties, whether conventional methods of correction would be adequate.
- Further study of correction method’s efficaciousness will be needed to complete EDR assessment.

**Uncertainty and complexity** in the characterization/modeling of crosstalk and out-of-band response are of great concern.
SUMMARY

PATH FORWARD:

• Determine an upper bound for uncertainty in the effects of crosstalk and out-of-band response.

• NIST SIRCUS might assist in quantify some of the net uncertainty.

• Assess the viability of existing out-of-band correction schemes given magnitude and uncertainty of the behavior.

• Evaluate techniques to mitigate crosstalk effects, given uncertainty.

• Assess performance on-orbit in context of what was learned prelaunch.
BACKUP SLIDES
SNR Performance

There are detectors in all bands except M6-M7, which do not satisfy the specification.
A20031711810 - Argentina 20 June 2003
Lt Relative Difference (x10) A20040332355 - Hawaii 2 February 2004

412nm 443nm 488nm 547nm 667nm 748nm 859nm

nLw Relative Difference
Lt Relative Difference (x10)  
A20031711810 - Argentina 20 June 2003

412nm  443nm  488nm  547nm  667nm  748nm  859nm

nLw Relative Difference
Lt Relative Difference (x10)  A20051071815 - East USA 17 April 2005

412nm  443nm  488nm  547nm  667nm  748nm  859nm

nLw Relative Difference
The East USA scene was specifically selected to look at particular geographic regions. The above inset shows the neritic Atlantic waters that are fed by the Chesapeake and Delaware bays. Differences in response between turbid and clearer water can be seen.
Region Bias and Variation Stratified by Value

A20040332355 - Hawaii 2 February 2004
Region Bias and Variation Stratified by Value

APU Metrics for Chlor a (OCM3)

APU Metrics for Chlor a (Carder)

A20040332355 - Hawaii 2 February 2004

All Flags Used
Region Bias and Variation Stratified by Value

A20031711810 - Argentina 3 June 2003

L2 Flag Subset
Region Bias and Variation Stratified by Value

A20031711810 - Argentina 3 June 2003
Region Bias and Variation Stratified by Value

APU Metrics for nLw (412 nm)

APU Metrics for nLw (443 nm)

APU Metrics for nLw (488 nm)

APU Metrics for nLw (547 nm)

A20051071815 - East USA 17 April 2005

All Flags Used
Region Bias and Variation Stratified by Value

APU Metrics for Chlor a (OCM3)

APU Metrics for Chlor a (Carder)

A20051071815 - East USA 17 April 2005

All Flags Used
NPP VIIRS Spectral Performance

NOTES ON SOURCES OF UNCERTAINTY FOR OCEAN BANDS:

• Test Configuration:
  ➔ Detector-to-detector differences were observed, possibly from slit alignment and non-uniformity in source along track.
  ➔ Bulb instability was possibly observed, especially in toward the blue end; there has been resistance to further evaluation.
  ➔ Bulb used to measure 865nm band (M7) burnt out before it was properly characterized.
  ➔ TVAC chamber window characterization.

• Polarization:
  ➔ Source is polarized; VIIRS crosstalk and OOB RSR are polarization sensitive.
  ➔ Degree of Polarization can be high for crosstalk, moderate for RSR OOB.
  ➔ Polarization uniformity along track of source not verified.
  ➔ Polarization response of crosstalk was measured for only a few wavelengths, for a few bands, at only for polarization angles.
NPP VIIRS Spectral Performance

NOTES ON SOURCES OF UNCERTAINTY FOR OCEAN BANDS:

• Point-to-point Propagation:
  ➔ Tests only characterized a fully illuminated filter and may not translate well to partial illumination from spatial structure in image.
  ➔ Point-to-point propagation of light from is roughly known and behavior is not completely consistent from band to band, detector to detector, or wavelength to wavelength.
  ➔ Current point-to-point model predicts striping from crosstalk.
  ➔ Maybe impossible or infeasible to model point-to-point propagation on orbit to remove striping.
NPP VIIRS Spectral Performance

NOTES ON SOURCES OF UNCERTAINTY FOR OCEAN BANDS:

• Measurement and Processing Error:
  ➔ Measurement noise (inc. dark count); repeatability has been demonstrated to be poor.
  ➔ Biases from stitching together in-band and out-of-band data sets.
  ➔ Electronic crosstalk could produce an addition uncertainty in optical crosstalk characterization and on-orbit correction.
  ➔ 1nm uncertainty in wavelength calibration could also introduce biases. May also be smile uncertainty along track.

NIST is expected to use SIRCUS to characterize the VIIRS spectral response after the instrument is integrated on the spacecraft.