



# Improving the Science Quality of Soumi-NPP VIIRS Sensor Data Record (SDR)

-Recalibration, Reprocessing, and Reanalysis

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With contributions from the VIIRS SDR team November 8, 2017





# VIIRS reprocessing contributions from CICS staff:

- Bin Zhang: Reprocessing of VIIRS RDR to SDR
- Sirish Uprety: VIIRS DNB recalibration, M5&M7 bias correction
- Xi Shao: VIIRS DNB Straylight correction, lunar calibration
- Yan Bai: image analysis and quality assurance, DNB geolocation validation

**Contributions to the book** 







### Background

- Operational Requirements vs. Science Needs
- Four cornerstones of calibration
- VIIRS instrument characteristics

### Reprocessing Improvements

- Day/Night Band (DNB)
- Thermal Emissive Band (TEB)
- Reflective Solar Band (RSB)
- Geolocation
- VIIRS Reprocessing System
- Summary

### Science needs vs. Operational Requirements



#### **NOAA Mission Requirements**

TPIO's (Technology, Planning and Integration for Observation) Requirements and Planning (RAP) team works closely with NOAA program leaders and Subject Matter Experts (SMEs) to document observing requirements in an extensive database called the Consolidated Observing User Requirement List (**COURL**) with priorities:

- Mission Critical (Priority-1)
- Mission Optimal (Priority-2) and
- Mission Enhancing (Priority-3)

### Operational requirements do not always meet science needs - A case in point:

- VIIRS DNB is primarily designed for producing Near Constant Contrast Imagery (operational requirement)
- Scientists are using VIIRS DNB for a variety of studies, including but not limited to: air glows, power outages, socioeconomic activities, etc, etc.
  Science needs are more demanding and may push the requirements to the limit of the instrument capabilities.

### **Science needs**

### Traits of scientists:

- Curiosity,
- Creativity,
- Skepticism,
- Thinking outside the box



I have no special talent. I am only passionately curious.

-Einstein









### Calibration Metrics: Accuracy, Precision, Stability, Consistency, Uncertainty



- Albedo: 1% per decade (stability)
- Sea Surface Temperature (SST): 0.1K per decade (stability)
- Ocean Color: 0.1% (stability)
- Sea Surface Height: ~1 mm per year (stability).





# NOAA Polar Satellite Programs Continuity of Weather Observations



Calendar Year

As of March 2017



Approved: Stephenster



In orbit and operating



Planned Mission Life, from Planned Launch Date Planned Mission Life Beyond 2036

Launched before Jan 2008

Reliability analysis-based extended weather observation life estimate (60% confidence) for

satellites on orbit for a minimum of one year - Most recent analysis: July 2016



### **VIIRS Instrument Overview**



- VIIRS is a scanning imaging radiometer onboard the Suomi NPP, and JPSS satellites in the afternoon orbits with a nominal altitude of 829km at the equator, with a swath width of ~3000km;
- VIIRS Onboard calibration relies on the solar diffuser (SD), solar diffuser stability monitor (SDSM), space view (SV), and the blackbody (BB);
- Vicarious calibration also used (lunar, dark ocean for DNB, and cal/val sites);
- Calibration is performed per band, per scan, per half angle mirror side (HAM), and per detector.



### VIIRS has 22 types of SDRs:

- 16 moderate resolution (750m), narrow spectral bands (11 Reflective Solar Bands (RSB); 5 Thermal Emissive Bands (TEB))
- 5 imaging resolution(375m), narrow spectral bands (3 RSB; 2 TEB)
- 1 Day/Night Band (DNB) imaging (750m) broadband





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• Spectral Responses of the VIIRS Reflective Solar Band (RSB) and Thermal Emissive Band (TEB).





### **VIIRS RDR to SDR Processing**









- All bands have been performing very well since launch;
- Very slow degradation, except the solar diffuser; Rotating Telescope Assembly (RTA) mirror degradation stabilized;
- Numerous journal papers published, including special issues/books
- Overall, user feedbacks are very positive; reprocessing aims to address remaining issues in the mission-long/life-cycle time series







- Relative spectral response (RSR) of DNB changed continuously over time due to telescope throughput degradation.
  - However, IDPS has only one update in DNB RSR LUT (April 05, 2013).
  - Reprocessing uses time dependent DNB RSRs thus significantly improving the SDR quality.
- IDPS offset table is generated using Earth View (EV) data that is contaminated by air glow.
  - Reprocessing uses deep space observation (based on pitch maneuver data with no air glow) combined with onboard calibrator data for offset computation.
  - Significant reduction in negative radiance.
- IDPS DNB SDR data before 03/20/2012 has poor calibration due to absence of on-orbit based offset and gain ratio.
  - Reprocessing uses on-orbit based offset and gain ratio to produce all DNB SDRs.
  - Improves the calibration and hence produce more accurate DNB SDRs.
- DNB straylight correction went operational in IDPS in August 2014.
  - Reprocessing implements straylight correction for all DNB SDRs.
- DNB terrain correction (TC) went operational in IDPS in May 2015.
  - Reprocessing produces terrain corrected geolocation data for all DNB SDRs.
  - This improved geolocation accuracy from few kms at high altitude (such as Tibet, Himalayan region) to sub-pixel level (few hundred meters)



### **Day/Night Band Improvements** -Spectral and Radiometric Recalibration





- VIIRS DNB RSRs modified by the telescope degradation
- Approx. 50 time-dependent RSRs provide near-continues DNB E<sub>sun</sub> changes with steps smaller than 0.1%







Day/Night Band Improvements -Artifact Reduction



03/20/2012 (Improvement after Reprocessing)



- IDPS uses on-orbit based offset and gain ratio starting from 03/21/2012.
- Reprocessing uses on-orbit based offset and gain ratio to produce all DNB SDR
- All data before 03/21/2012 are much improved after reprocessing!





### **Straylight Correction Example**





- Reprocessing implements straylight correction for all DNB SDR.
- Significant improvements in all DNB data before August 2014.

# NORR COMPANY

# VIIRS/DNB 70% Reduction in Negative Radiance





Sample Data acquired: 01/03/2017 @00:31 UTC

A success story:

- STAR VIIRS SDR team deep dive studies in collaboration with NASA/VCST;
- New calibration method reduced negative radiance by 70%;
- Advancing calibration science as well as supporting air glow science;
- Remarkable instrument low noise floor, thanks again to the vendor.

#### Notes to users

- Improved operational VIIRS SDR data since Jan. 12, 2017
- > Reprocessing using new method is near completion

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- Operational processing: DNB terrain correction was implemented on May 22, 2014;
- Reprocessing: DNB terrain corrected geolocation were produced for the entire data record;
- Removed DNB geolocation errors up to 10 km at high scan angles.





### **Does recalibration help reanalysis?**

- Example of urban growth





2012 original



2012 reprocessed





Quantitative comparisons of night light





### **Reprocessing Sample Granules for VIIRS M13**

- Latest input parameters (LUT, including new EBBT)
- Latest version of RDR (A2/A3)
- All artifacts disappeared after reprocessing

Before (data from CLASS)

QF: Missing Data = 2 (Cal Data Missing) QF: SDR Quality = 2 (No Calibration Data), HAM side QF: Missing Data = 3 (Thermistor Data Missing)

After reprocessing: All artifacts gone





# **Thermal Emissive Band (TEB) Improvements**



### M13 Improvements (over previously saturated pixels)





The 2 previously out of limit pixels are calibrated successfully after reprocessing using the unsaturated sub-pixels.







- Thermal Emissive Bands (TEB) have little degradation (except I5)
- Anomaly during blackbody Warm-Up-Cool-Down (WUCD) cycles.
- The nominal Blackbody temperature is 292.5K.







• Sea Surface Temperature (SST) anomalies caused by quarterly Blackbody (BB) Warm-Up-Cool-Down.







- WUCD correction algorithm developed (Ltrace)
- Correction implemented in reprocessing, and results validated with CrIS:
  - Before: warm bias during blackbody cooldown;
  - After: bias removed during blackbody cool-down which becomes consistent with normal operations.
- Methodology published in peer reviewed journal (Cao et al., 2017, JGR);
- Ltrace v2 algorithm provides analytical solution for all TEB bands.







- NOAA Ocean Color team reported water leaving radiance differences between IDPS and OC-SDR.
- They proposed a new set of calibration coefficients (F-factors).



**Menghua Wang** & NOAA VIIRS Ocean Color Team, "**VIIRS Mission-long Ocean Color Data Reprocessing**", The NOAA Workshop on JPSS Life-Cycle Data Reprocessing to Advance Weather and Climate Applications, Maryland, May 17-18, 2016





- F-factor ratio (Operational / RSBAutoCal)
  - The baseline VIIRS reprocessing is preformed using the standard RSBAutoCal LUT which is delivered with official ADL code package.
  - The annual oscillation patterns between the 2012 and 2014 have been corrected which was caused by the solar vector problems.
  - The two H-factor (SD degradation) sudden changes were corrected especially in year 2014.
  - The CO equal to 0 update affected all RSB bands but it is mostly visible in band I3.





# **VIIRS RSB** Reprocessing Improvements



# Addressing Calibration Biases in Reprocessed SDR

- Two different radiometric calibrations in RSB:
  - RSBAutoCal (standard)
  - OC calibration
- Solution:
  - Introduce "Radiometric bias correction" term in reprocessed VIIRS SDR file.
  - Default is RSBAutoCal.
  - With application of the RadiometricBiasCorrection→ OC calibration
- M5 & M7 bias correction based on extensive validation







 VIIRS M5 (0.67 μm) and M7 (0.86 μm) indicate positive bias when compared with other well calibrated instruments such as AQUA MODIS and Landsat 8 OLI over Saharan desert.

VIIRS	Landsat 8 OLI	AQUA MODIS
M5	1.3% ± 0.7%	2.0% ± 1%
M7	1.7% ± 0.7%	2.2% ± 1%

Bias= (VIIRS - Ref\_Instrument)\*100%/Ref. Instrument

- Similarly, VIIRS interchannel calibration analysis also indicates positive bias for M5 and M7.
- Using band ratio technique with band 4 as a reference band, bias ranges from nearly 3% to 7% over different calibration targets.





	Using DCC AVIRIS	Using DCC Sciamachy	Libya4 (Reprocessed)	Moon
M5/M4	5.70%	2.60%	3.00%	1.5%
M7/M4	5.00%	3.40%	7.20%	4.8%

Interchannel Bias= (Band Ratio from VIIRS - Band Ratio from Ref. Instrument)\*100%/ Band Ratio from Ref. Instrument

Based on comprehensive analysis, it is recommended to use absolute bias correction of 1.5% for M5 (0.67  $\mu$ m) and 2% for M7 (0.86  $\mu$ m). These bias corrections have been included in the STAR reprocessed SDR.



### **Reanalysis of Suomi NPP VIIRS Urban Cloud Climatology**



- Obvious differences in monthly cloud cover were observed in 2012 and 2013, consistent with large differences between the NOAA operational and reprocessed bands I1-I3 radiances
- No significant change in calibration parameters for the reprocessing in 2014 and 2015. As a result, monthly percent cloud cover generated using the two datasets are very close to each other for this time period.
- The differences due to the updated geometric calibration parameters and TEB LUTs in the reprocessing are also small.



Comparison of monthly cloud covers for before and after the reprocessing (March -December, 2012).



Comparison of monthly cloud cover for before and after the reprocessing (January – December 2014).

Wang and Cao, IGARSS 2016





# Operational geolocation, 2/23/2012 – 12/31/2015



Short-term anomalies: (1) before the initial instrument to spacecraft mounting matrix update; (2) the switch of scan control electronics (SCE) from Side-B to Side-A; (3) star tracker maintenance/re-alignment.





Reprocessed geolocation, 2/1/2012 – 12/31/2015



Geolocation anomalies are removed after the reprocessing!









### Going Forward: VIIRS intercalibration between J1 and SNPP



- Transfer orbit altitude is about 10km lower than final orbit
- SNO opportunities exist if instruments are turned on and collecting earth view data before orbit raising
- There will be NO SNOs between SNPP and J1 after reaches final orbit
- The current schedule shows VIIRS nadir door will be open on day 24, which will provide SNO inter calibration opportunity





### Intercalibration Opportunities between J1 and SNPP Simultaneous Nadir Overpass (SNO)

- SNPP will be flying directly above J1 before the orbit raising
- Allows direct comparisons between SNPP and J1 earth view data (if nadir door opened)
- Support most waiver studies by comparing SNPP and J1 data (polarization, nonlinearity, data quality, consistency, etc...)



- Day 10: J1 reaches transfer orbit at ~814 km altitude with similar equator crossing as final orbit; VIIRS turn on
- Day 33: Orbit raising
- ~Day 53: J1 reaches final orbit: 50.75min separation from SNPP; same equator crossing as that of SNPP



### J1 vs. SNPP coverage





- Both on the same orbital plane
- Both have the same orbital equator crossing (LTAN)
- ~50.75 mins separation: one is observing in day while the other is at night
- Ground track repeating cycle is 16 days for each, and 8 days when combined
- Improved temporal coverage (~50 mins interval around 1:30pm)







- Day/Night Band (DNB) improvements
  - Continuous RSR changes applied in gain calculation.
  - Offset using onboard calibration to remove airglow effects: significant reduction in negative radiance.
  - Straylight correction applied since launch.
  - DNB terrain correction (TC) to geolocation since launch.
- Thermal Emissive Band (TEB) improvements
  - Mitigated WUCD related SST anomalies.
  - Removed artifacts especially for fire bands.
- Reflective Solar Band (RSB) improvements
  - Reduced early lifetime calibration uncertainties.
  - Long-term drifts are reduced by incorporating lunar calibration (most important for bands M1~M4)
  - M5 & M7 bias optional 'Radiometric bias correction'.
  - Removed sudden jumps and annual oscillations.
- Geolocation anomalies resolved.
- VIIRS Reprocessing capability developed on super computer using ADL 4.2 Mx 8.11 (8.5 days / year, with 200 T-bytes / year)
- Reprocessed VIIRS mission-long SDR provide better science quality data for EDR production and scientific research.





• Backup slides





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