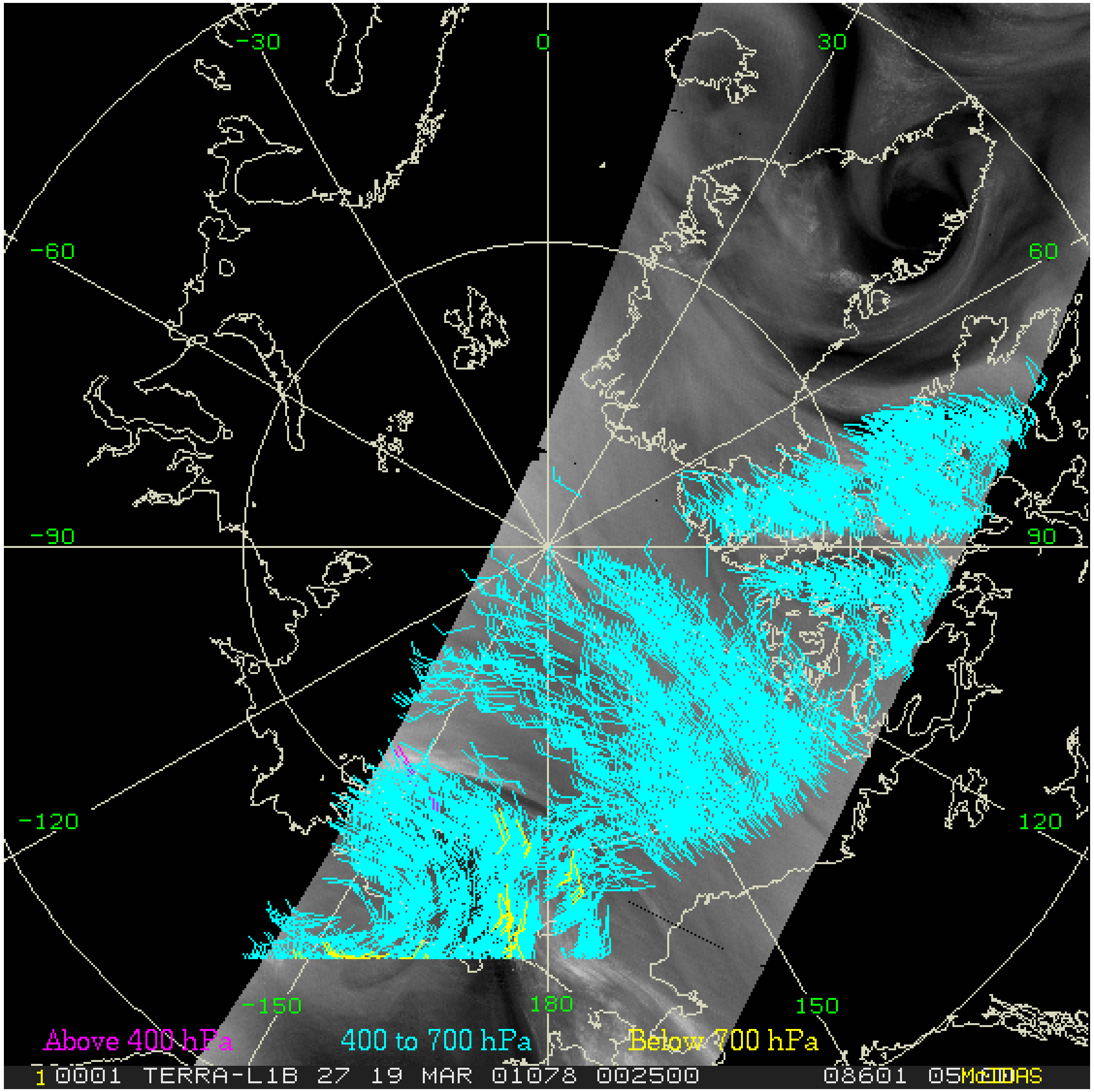
Water Vapor Band Trade Study

Slawomir Blonski, ERT, Inc.
Chris C. Moeller, CIMSS, U. Wisconsin
Changyong Cao, NOAA/NESDIS/STAR

JPSS Annual Science Team Meeting (August 9, 2016)

Background



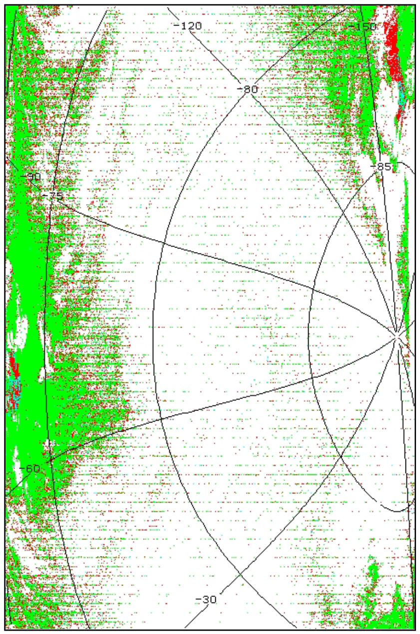
MODIS band 27 water vapor images and derived wind vectors over the North Pole
Courtesy of Paul Menzel, U. Wisconsin

- Polar wind vectors derived from satellite observations of cloud drift and water vapor motion improve weather forecasting
- MODIS instruments provide the cloud- and moisture-tracked winds currently assimilated into numerical weather prediction models
- Next generation weather observations are provided by VIIRS on S-NPP and future JPSS satellites
- VIIRS currently lacks a water vapor band at 6.7 µm, allowing only for cloud-tracking of winds
- An addition of a water vapor band to future VIIRS instruments has been proposed
- Potential impacts of the proposed modifications on VIIRS SDR are presented here

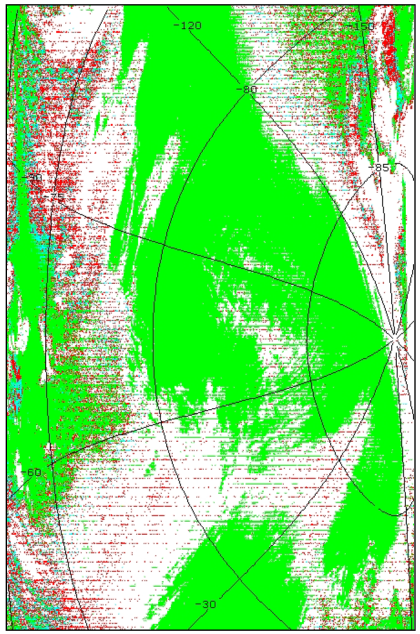
Additional Benefits of VIIRS Water Vapor Band

Improved cloud detection in polar night

Cloud detection over Antarctica
VIIRS data simulated from MODIS
23:40 UTC on 4 June 2001



VIIRS cloud mask w/o 11-6.7μm test

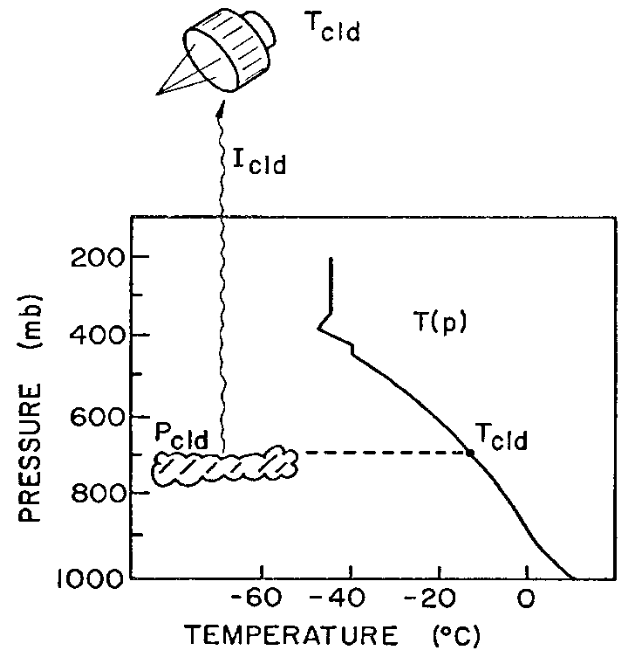


VIIRS cloud mask with 11-6.7μm test

green - clear
white - cloud
red - uncertain

- Better determination of night-time clear sky conditions

Improved cloud height/property retrievals



- Traditional relation of opaque cloud height and atmospheric temperature T(p) fails when radiation below cloud leaks thru, e.g., thin cirrus
- VIIRS is struggling to continue the MODIS cloud record without any CO_2 or H_2O sensitive bands

Water Vapor Channel Options

Three options for modifying the instrument have been identified:

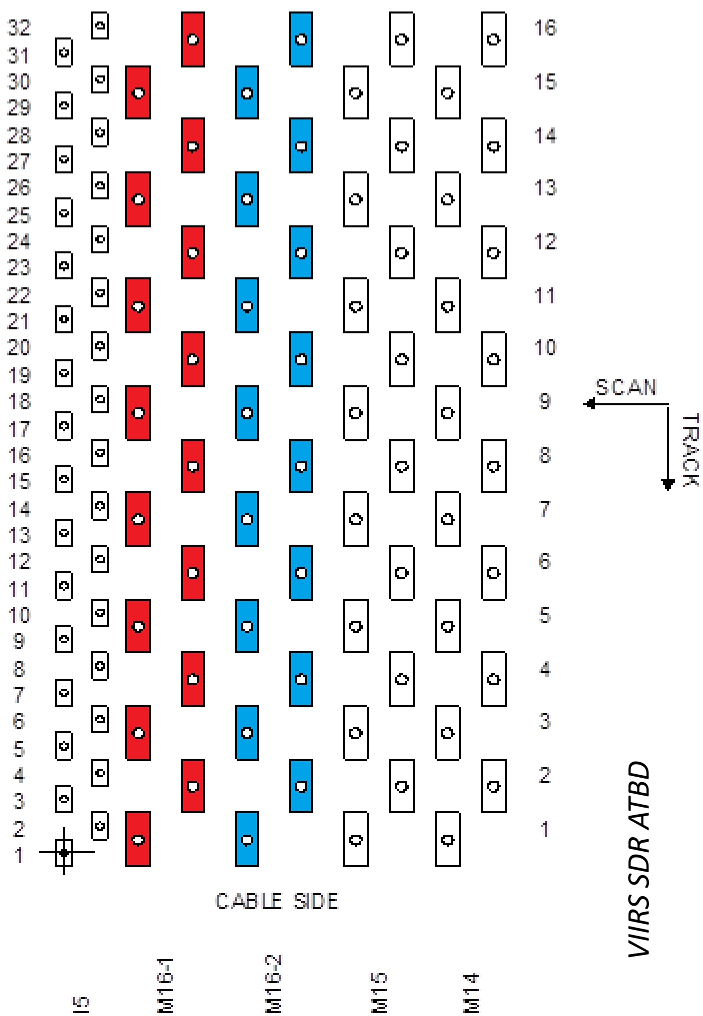
1. Adding to the LWIR (long-wave infrared) FPA (focal plane array) one or more bands in the 6.7 µm water vapor spectral region
2. Replacing one of two TDI (time-delay and integration) stages of the M16 band with a water vapor band
3. Replacing an existing, but seemingly redundant spectral band such as M10 with a water vapor one

Option 1 has been studied (Puschell, Kim & Menzel, *AIAA SPACE 2010 Conference & Exposition*), and its feasibility has been confirmed, but necessary changes to the LWIR FPA and electronics can make this option very expensive:

- Additional filters, detectors and associated electronics for water vapor spectral bands
- Possible increase in Dewar window size and possible change in dichroic mirror design
- More mass from additional detector arrays, filters and electronics
- Higher data rate from additional detector samples
- Higher power required for additional detector arrays and electronics
- More heat dissipated by additional detectors and electronics in cold focal plane assembly, which affects cooler margin

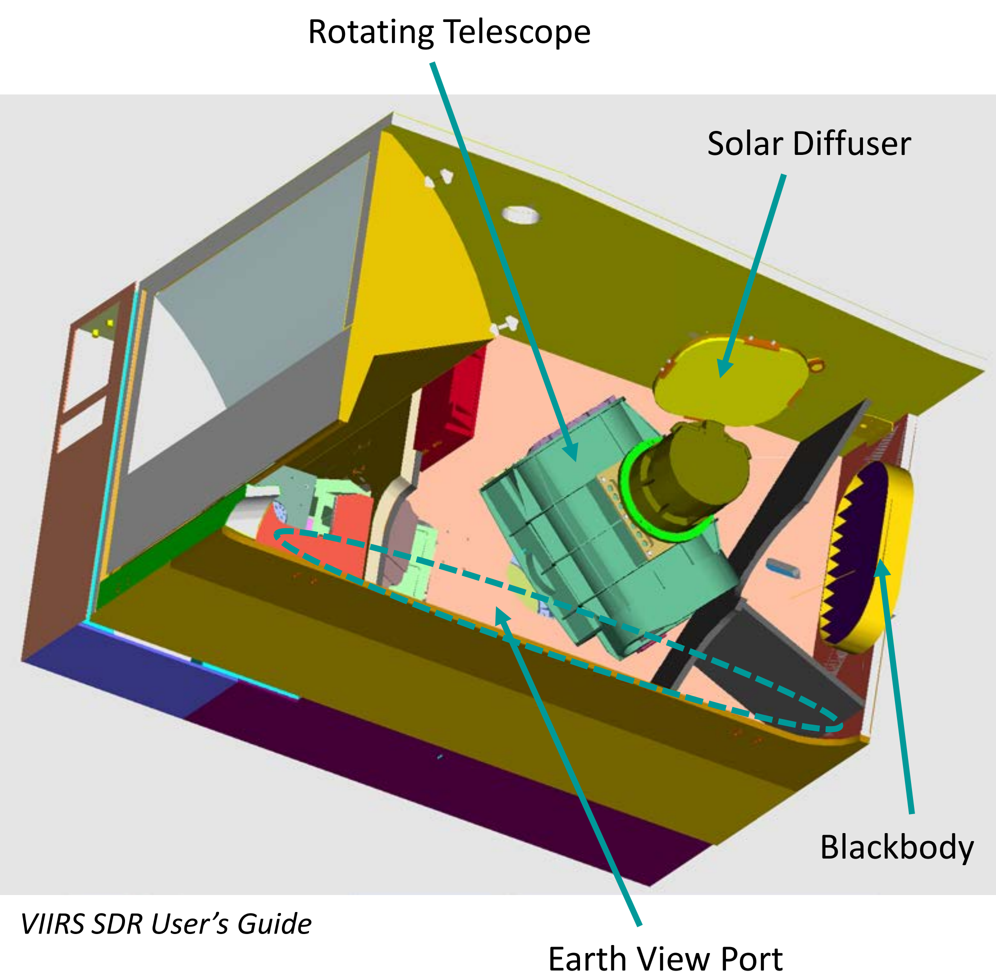
M16 TDI Replacement Option

- Out of the three options, option 2 is perhaps the least expensive since it requires only minimal modifications, mainly to the spectral filter and possibly the microlenses: Puschell & Herbst, *Proc. SPIE* **8516** (2012) 851604
  - Band M16 uses TDI from its two components, M16A and M16B, to increase SNR (signal-to-noise ratio) of the measurements
  - Based on on-orbit performance of the S-NPP VIIRS, this redundancy may not be necessary, meaning that M16A alone can meet the performance requirements, and M16B can be changed to a water vapor band
  - In this option, no substantial change occurs in VIIRS system level size, mass, power, and heat dissipated by detectors and electronics in the LWIR FPA
  - In the study presented here, effects of implementing option 2 on M16 SNR have been investigated to assess potential impacts of the modifications on the VIIRS data product users



LWIR FPA

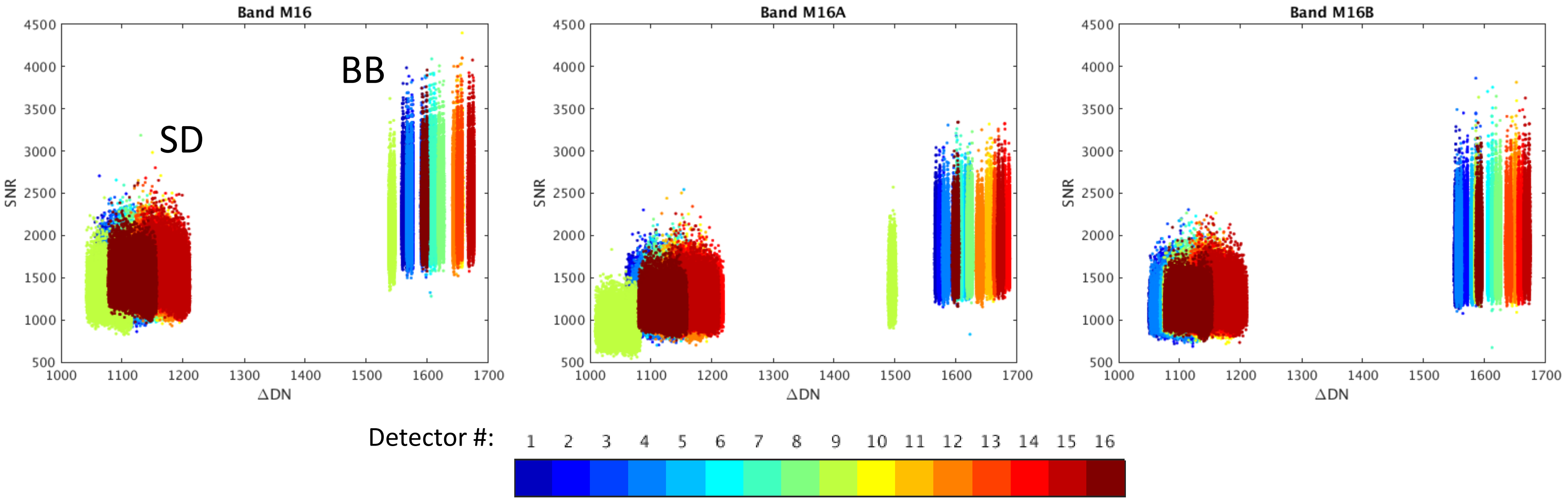
M16 SNR Measurements



VIIRS SDR User's Guide

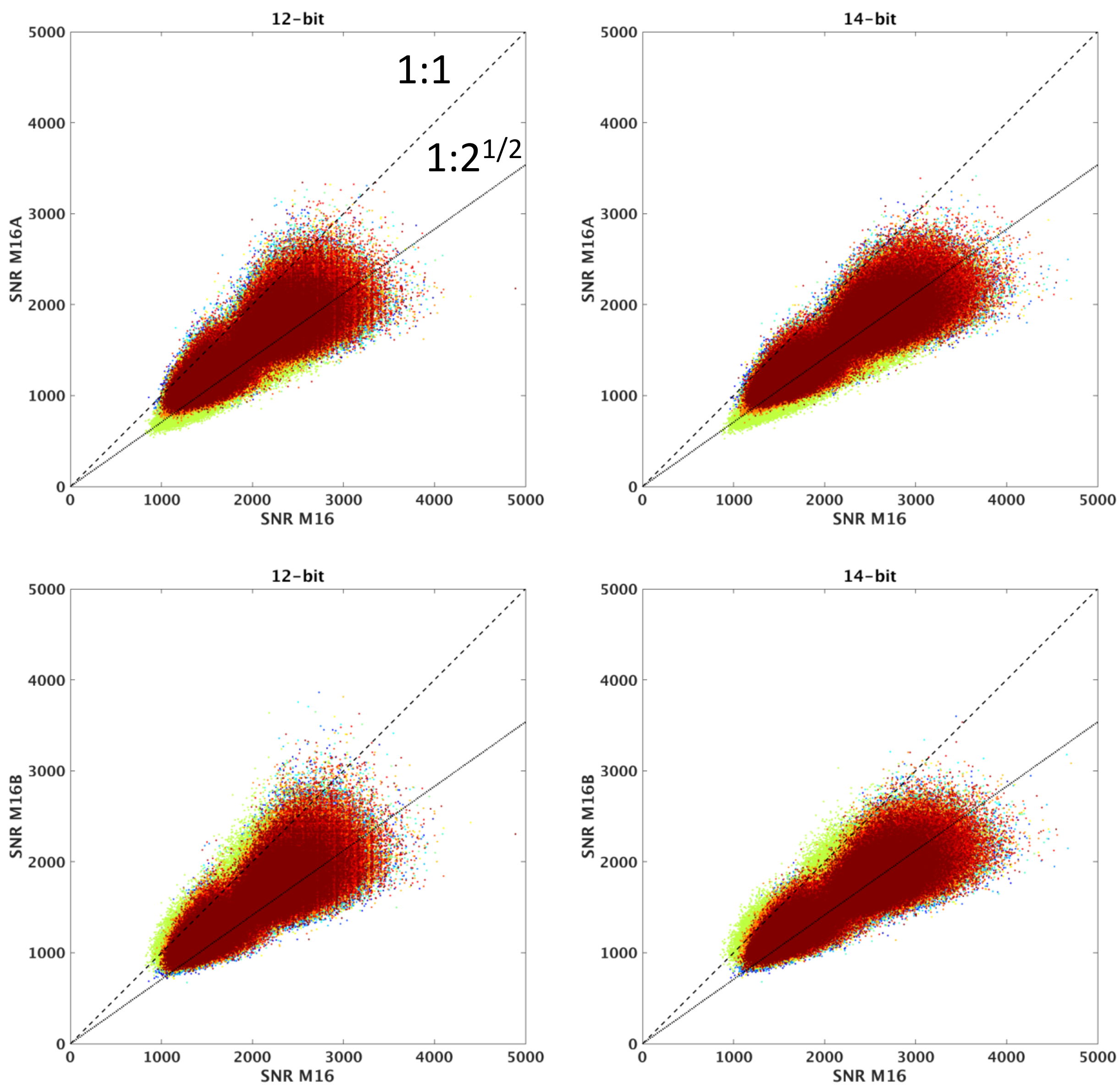
- In addition to scanning Earth during each telescope revolution, VIIRS also measures radiance emitted from the blackbody (BB) and from the solar diffuser (SD), which are parts of the onboard calibrator
- While only the combined M16 data are available from the Earth observations, the BB/SD calibrator data are provided separately for M16A and M16B
- During each scan, 48 measurements are collected for each M16 detector from BB and SD as well
- **SNR = mean(ΔDN) / st.dev.(ΔDN)** is calculated from the 48 samples (without outlier rejection); the signal (ΔDN) includes Space View (SV) subtraction

SNR Comparison for BB and SD Measurements



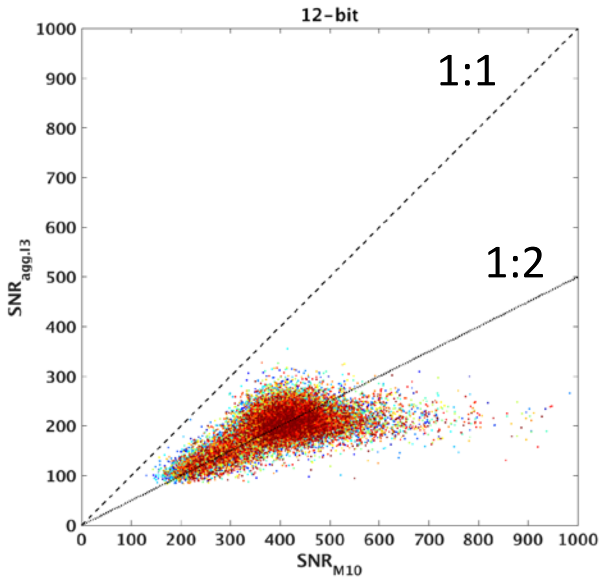
- BB and SD data from all S-NPP orbits on September 23, 2015 are analyzed (~48,000 scans) for each of the bands M16, M16A, and M16B
- SNR data for each detector are shown on the graphs with a different color, with both HAM (half-angle mirror) sides analyzed together
- 14-bit BB/SD measurements are truncated to 12 bits to match the Earth observations
- BB temperature is stable throughout each orbit while SD temperature varies
- M16 SNR improvement by averaging M16A and M16B can be seen
- M16A detector #9 is out-of-family with lower gain and SNR;
  TDI partially mitigates this non-uniformity

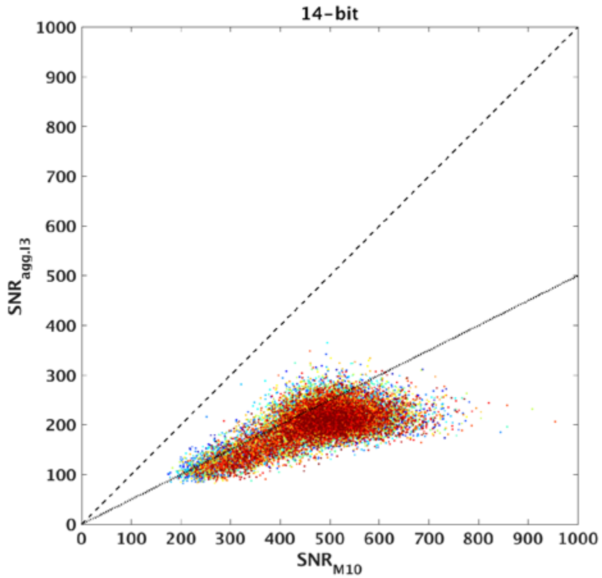
M16A/B vs. M16 SNR Comparison



- M16 SNR is larger by the factor of square root of 2 than SNR for either M16A or M16B, as predicted by statistics
- There is only a small impact from the 12-bit quantization
- M16 NEΔT measured in prelaunch tests and on orbit has a large margin (~100%) from the NEΔT requirement
- Without TDI, M16 NEΔT would still be within the requirement (increase from 0.03 K to ~0.04 K)
- However, potential FPA non-uniformity would not be reduced

SNR for M10 Replacement with Aggregated I3

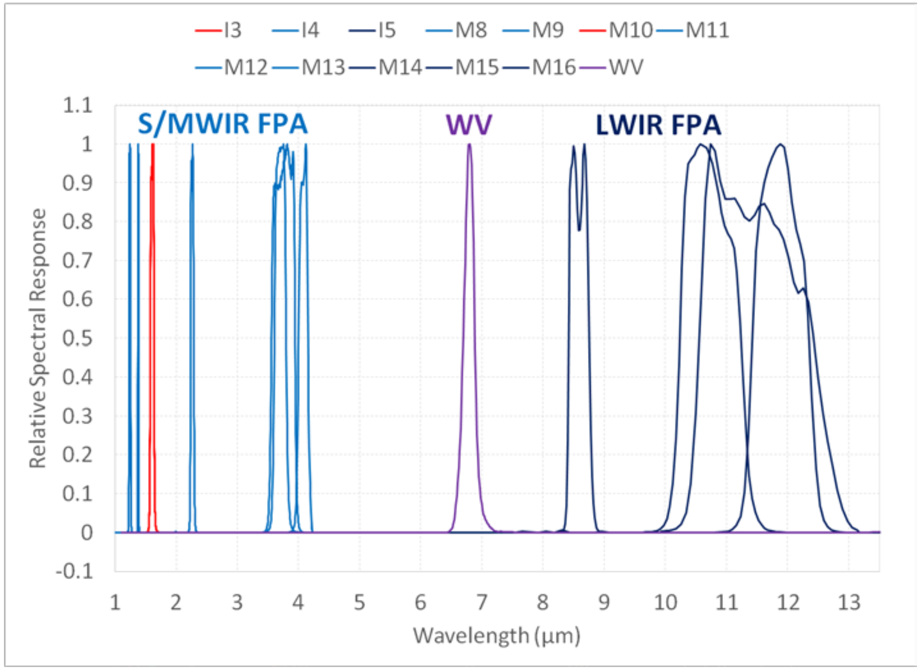




- In option 3, the additional, water vapor channel could replace a 750-m channel at 1.6 µm (M10) that shares spectral response characteristics with a 375-m channel (I3)
- M10 data would then be synthesized by the 2-by-2 aggregation of I3 pixels
- SNR for the actual and synthesized band M10 was calculated from measurements of light reflected from the SD during solar calibration events occurring on each satellite revolution around the Earth near the night/day terminator crossing in the southern hemisphere
- September 23, 2015 data were used in this study
- SNR of synthesized M10 (aggregated I3) is always lower than SNR of actual M10
- On averaged, SNR differs by a factor near 2 (especially with the 12-bit quantization)
- Apparently, pixel field-of-view and integration time differences between the I3 and M10 bands are not compensated by the spatial aggregation of the I3 pixels
- Band I3 with the 2-by-2 pixel aggregation can be substituted for M10, but with a reduced SNR

Option of Replacing M10 with Aggregated I3

- Prelaunch tests have shown that the M10 SNR exceeds the requirements by a factor larger than two
- Thus, even with the 50% reduction shown on the previous chart, the synthesized M10 should fulfill the requirements, although with only a small margin



- However, detectors for bands M10 and I3 are located on the S/MWIR (short-/mid-wave infrared) FPA, and all bands from that FPA have spectral responses in the range of 1.2 to 4.1 µm
- Since the water vapor (WV) band is proposed to be at 6.7 µm, extensive modifications of the S/MWIR FPA may be needed to ensure the required spectral response of the water vapor band

Summary

- From the three options that were identified for adding a water vapor band to VIIRS, creating new detectors on the LWIR FPA is preferable for the data users because of the minimal impact on the other bands, but this option also requires the most extensive hardware modifications
- Removing TDI from band M16 and using the second set of the M16 detectors for the water vapor band will increase M16 noise, but a substantial margin from the noise requirement will remain
  - Without TDI risk of non-uniformity for M16 will be similar to the other thermal emissive bands such as M15
  - This option may be preferable because it requires fewer hardware modifications than the one above
  - Additional analysis using M16A and M16B data will be needed to fully assess the impact on SST
- Replacing M10 with aggregated I3 data and using the M10 detectors for the water vapor band will reduce M10 SNR to a level that would leave no margin from the requirements
  - This option may also require extensive hardware modifications because of the large wavelength difference between the water vapor band and the one it would replace