Reducing Striping and Non-uniformities in VIIRS Day/Night Band (DNB) Imagery

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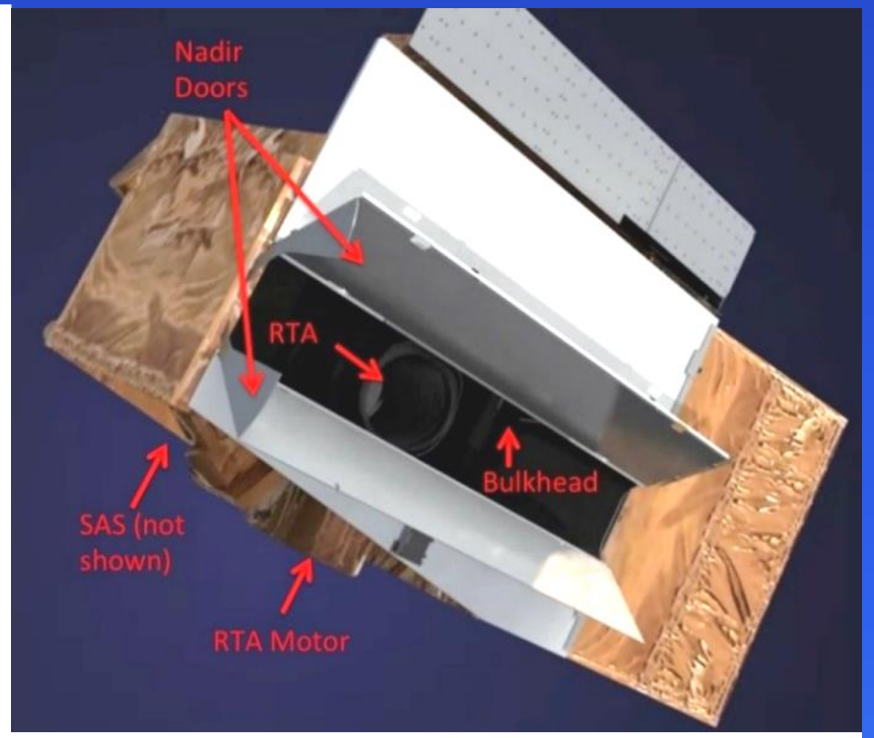
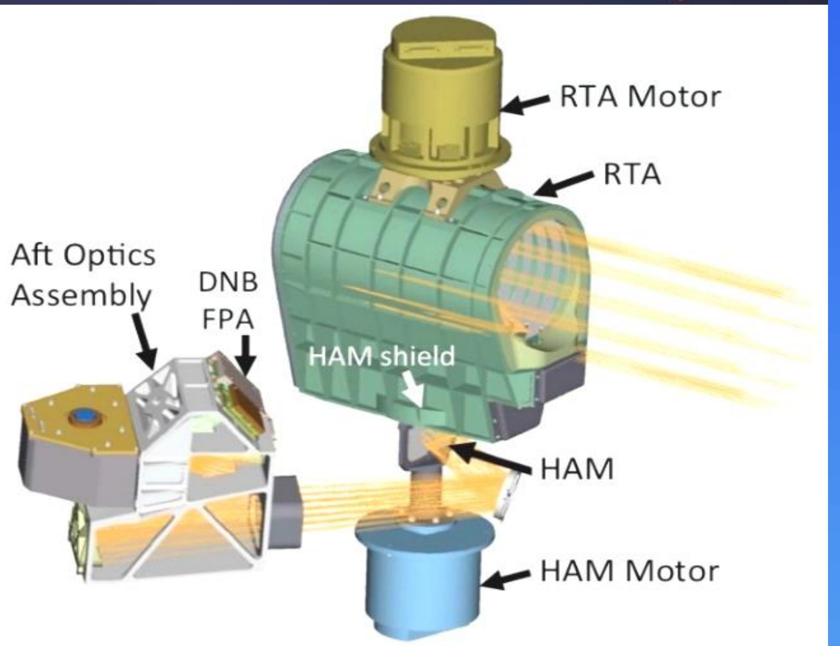
Summary

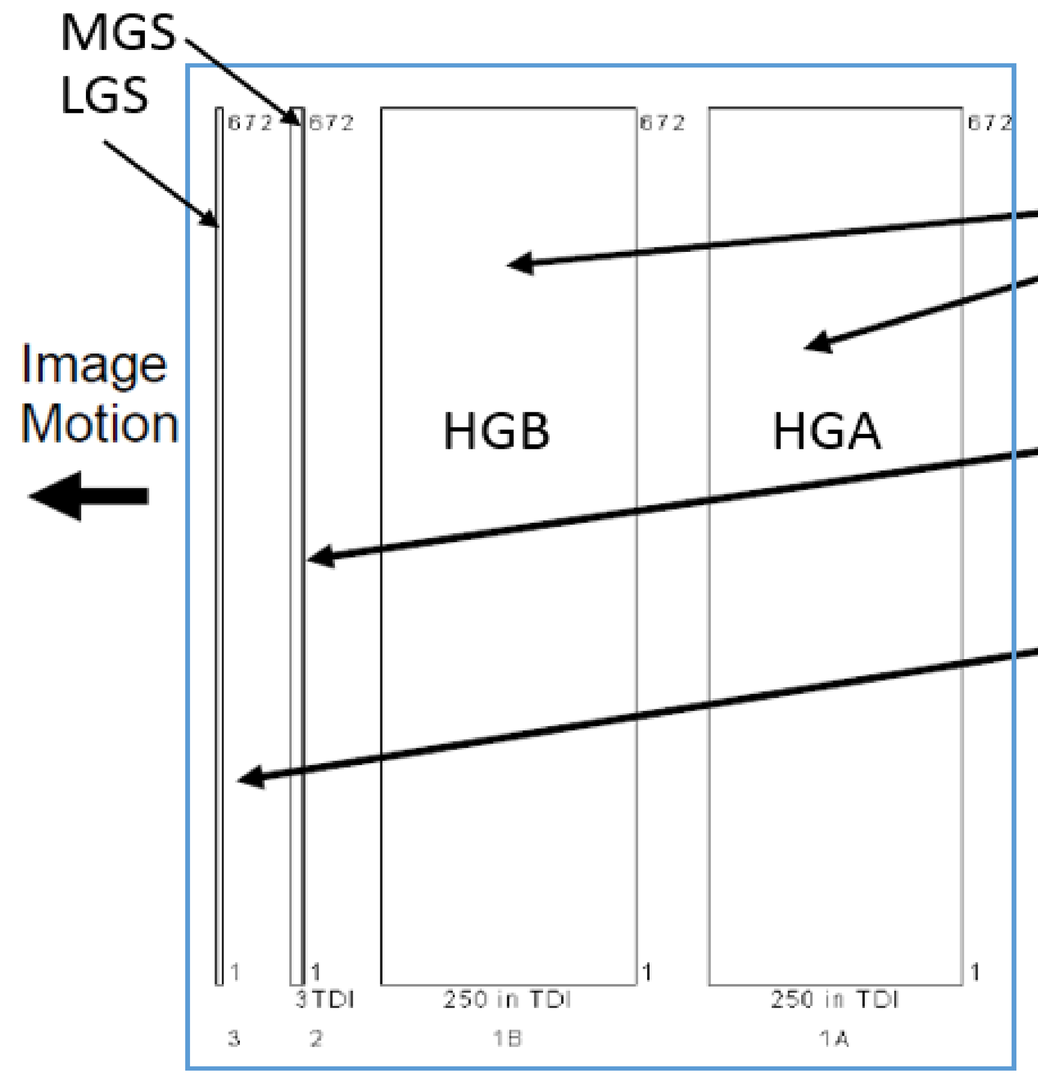
- S-NPP VIIRS Day-Night Band (DNB) offers quantitative measurements of visible and near-infrared light over a dynamic range from full daylight to the dimmest nighttime scenes
  - This range presents a challenge to radiometric calibration such that striping and banding are still visible, day or night, but especially in low-light scenes.
  - Causes may be cross talk, stray light, hysteresis or nonlinearity in the data used for calibration.
- This destriping algorithms removes almost all striping from DNB imagery without reducing the overall radiometric accuracy for daytime, twilight or night
  - DNB calibration is complicated by the existence of 32 aggregation modes used across its scan.
  - Histogram equalization is shown to be effective for minimizing striping and banding.
  - Stray light is filtered out, but improved uniformity is seen even in areas where stray light contamination exists.
- Low-light detection capabilities of VIIRS DNB have opened up exciting areas of research
  - Includes the detection of nightglow and features illuminated by nightglow.
  - These new areas of investigation have pushed the usefulness of DNB data beyond the original design limits, so that striping has become limiting factor.
  - Areas include observation of city lights through thin clouds and haze; study of airglow; observation of clouds illuminated only by airglow; study of the auroras near the poles.
  - All of these applications will benefit greatly by eliminating non-uniformities in the DNB radiance product.

VIIRS Optical Design

- Rotating Telescope Assembly
- Half-Angle Mirror (HAM)
- Calibration Sources
  - Space-View (SV) for dark offset
  - Black Body (BB) for emissive gain
  - Solar Diffuser (SD) reflective gain
- Solar attenuation screen (SAS)
  - allows sunlight onto SD
- Aft-Optics Assembly reimages light from HAM onto detectors
- HAM shield & bulkhead
  - prevent stray light from getting to Aft-Optics/arrays







Operating temperature = -20 C

DNB Array Design

One CCD array sectored into 4 parts

- Two identical high-gain stages (HGS)
  - Allows filtering of radiation impacts
  - 250 detectors in TDI
- One mid-gain stage (MGS)
  - 3 detector TDI
  - No filter
- One low-gain stage (LGS)
  - No TDI
  - 35x Neutral Density Filter
- 672 detectors in-track aggregated to 16 virtual detectors with variable aggregation for constant footprint
- Aggregation in-scan and in-track performed electronically as part of the read-out circuit using 32 aggregation modes
- Ground res. about 750x750 m across entire swath

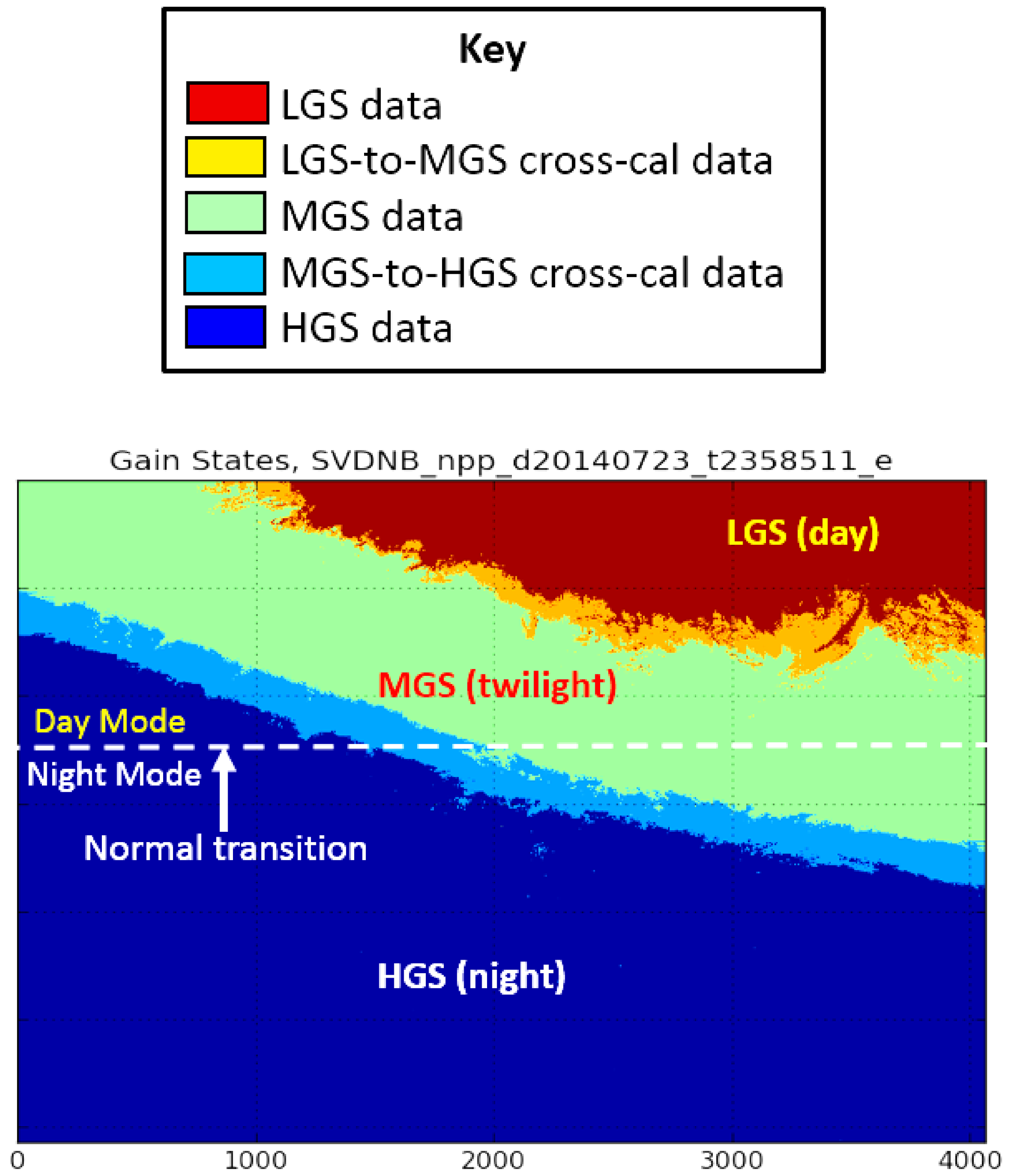
Acknowledgements: Renaissance Man Engineering, Inc.

Contact: smills@stellarsolutions.com

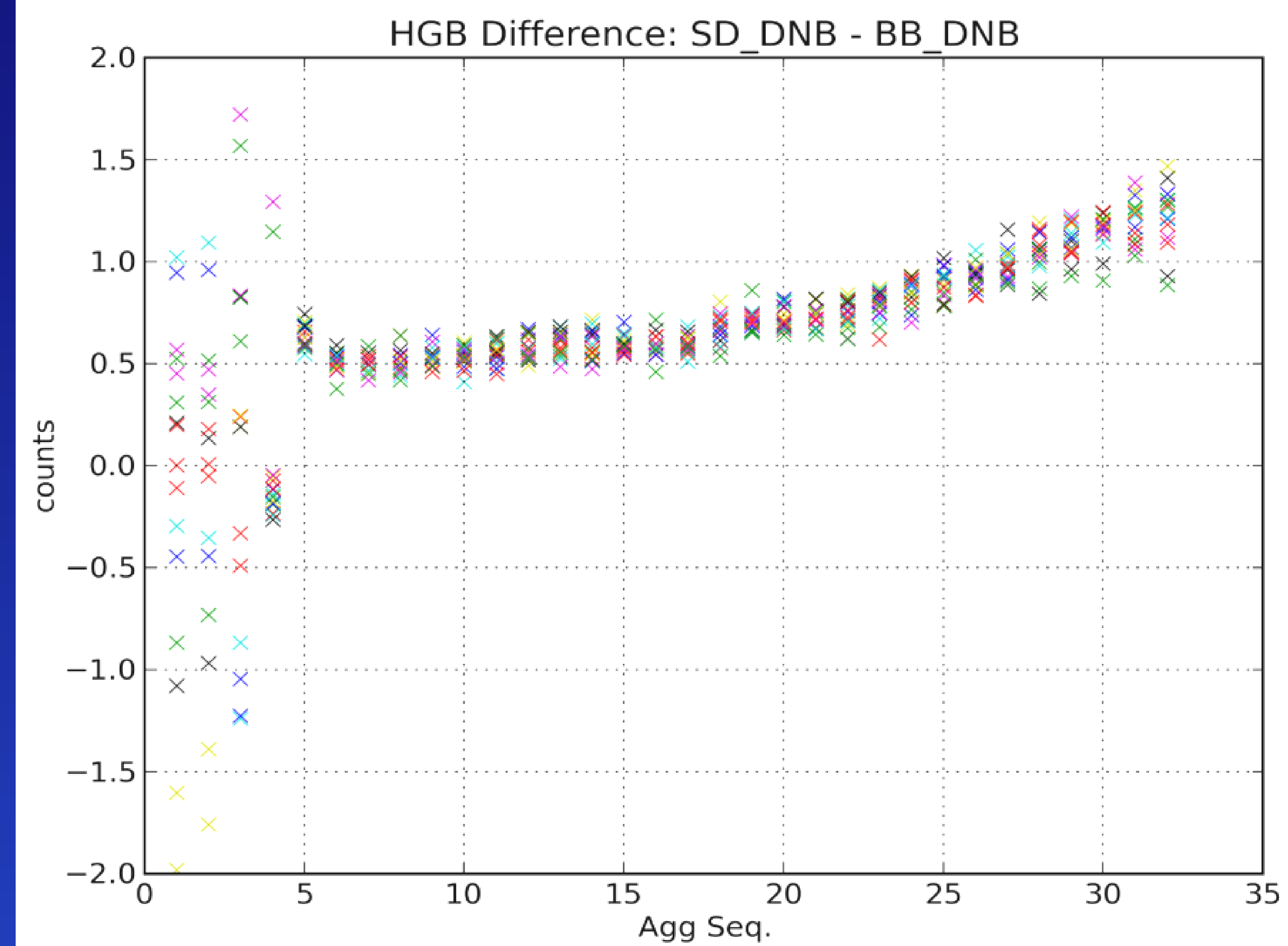
Methodology

Monthly Calibration Using Earth-View

- Original process at time of SNPP launch
- Offsets are determined using view of dark south Pacific during New Moon.
  - Cal sector not used because offsets are different in Earth-view
  - MGS and LGS transmission is enabled as a special process
  - HGS is normally transmitted at night, so no special process
  - Electric lights are filtered out
- LGS gain calibration
  - uses SD in normal way similar to other reflective solar bands (RSB)
- Gain transfer to MGS & HGS uses special process viewing twilight region around day-to-night terminator crossing
  - Day-to-night mode transition started earlier while VIIRS still viewing daytime, so some data lost
  - LGS-to-MGS taken near the top of the MGS dynamic range, and LGS/MGS gain ratios determined
  - MGS-to-HGS taken near the top of the HGS dynamic range, and MGS/HGS gain ratios determined
  - Gain and uniformity errors from lower stages transfer to higher stages



High Gain B (HGB) SD-to-BB Cal Offset Difference

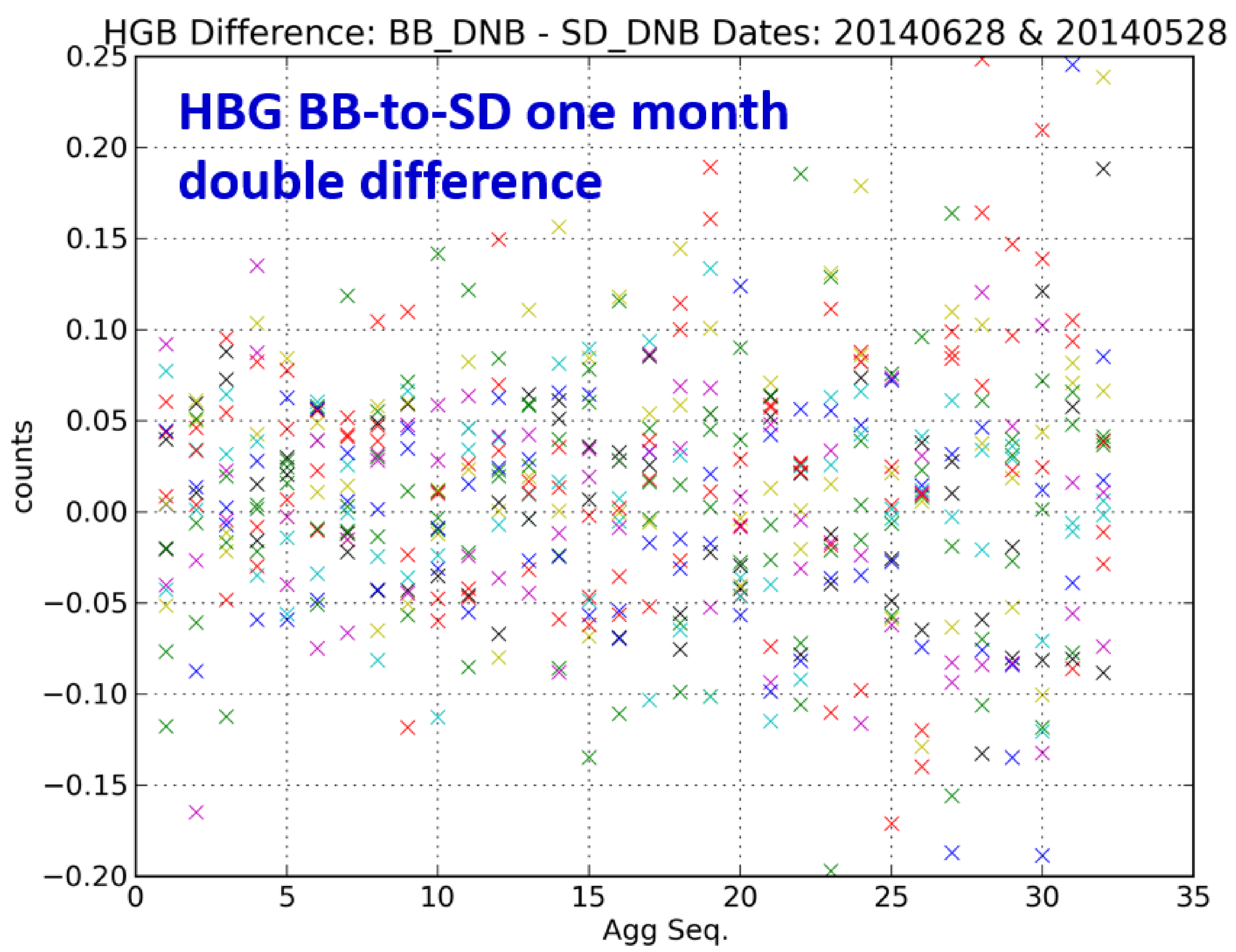


- Slight increase past agg. seq. # 15 may be due to airglow illuminating SD through the SAS
- Differences of several counts in agg. seq. # 1 to 4. These are where offset non-uniformities are worst.
- In the lower agg. seq. , 1 count=2×10^{-10} W $cm^{-2}sr^{-1}$, about the level of nightglow illumination

The HGA SD-to-BB mean daily differences are similar

Are offsets between cal sectors stable?

$$\Delta dn_{SD-BB}(t_0,t_1) = [DN_{SD}(t_1) - DN_{BB}(t_1)] - [DN_{SD}(t_0) - DN_{BB}(t_0)]$$



- Double difference determines whether or not sectors are drifting in parallel
- May be a proxy for the BB-to-Earth-view drifts if mechanism that causes cal-to-cal offsets is same as cal-to-EV
- RSBautocal offset process is based on assumption that cal-to-EV drifts are parallel
- 1 month results show no biases
- No significant spread among detectors, so uniformity should be preserved

Fixing DNB Striping

- Better calibration alone is not the answer
  - Inherent differences between cal sector and Earth view exist and cannot be entirely characterized
  - The other RSB have much less striping than DNB does in the LGS, even though they use essentially the same calibration process
- Many destriping techniques have been developed for other sensors
  - All these techniques use the Earth view scenes themselves to maximize uniformity
  - If done correctly, radiometric uncertainty is not increased
  - The large dynamic range of the DNB presents a particular challenge
- Moment matching technique
  - Determines variance and mean for each detectors over many scenes
  - Minimizes difference among detectors by applying a scaling and offset
  - Does not work well where there is a saturation limit or lower limit
  - This technique has been used for HGS destriping
- Histogram matching technique
  - An extension of the moment matching technique, takes cumulative histograms for each detector
  - Differences among the detector histograms are minimized through scaling and offset
  - Can also be used to adjust for nonlinearities
  - Works with saturation and lower limits, which is useful for MGS
- These are only destriping techniques.
  - Other techniques are needed for non-uniformities at aggregation zone boundaries

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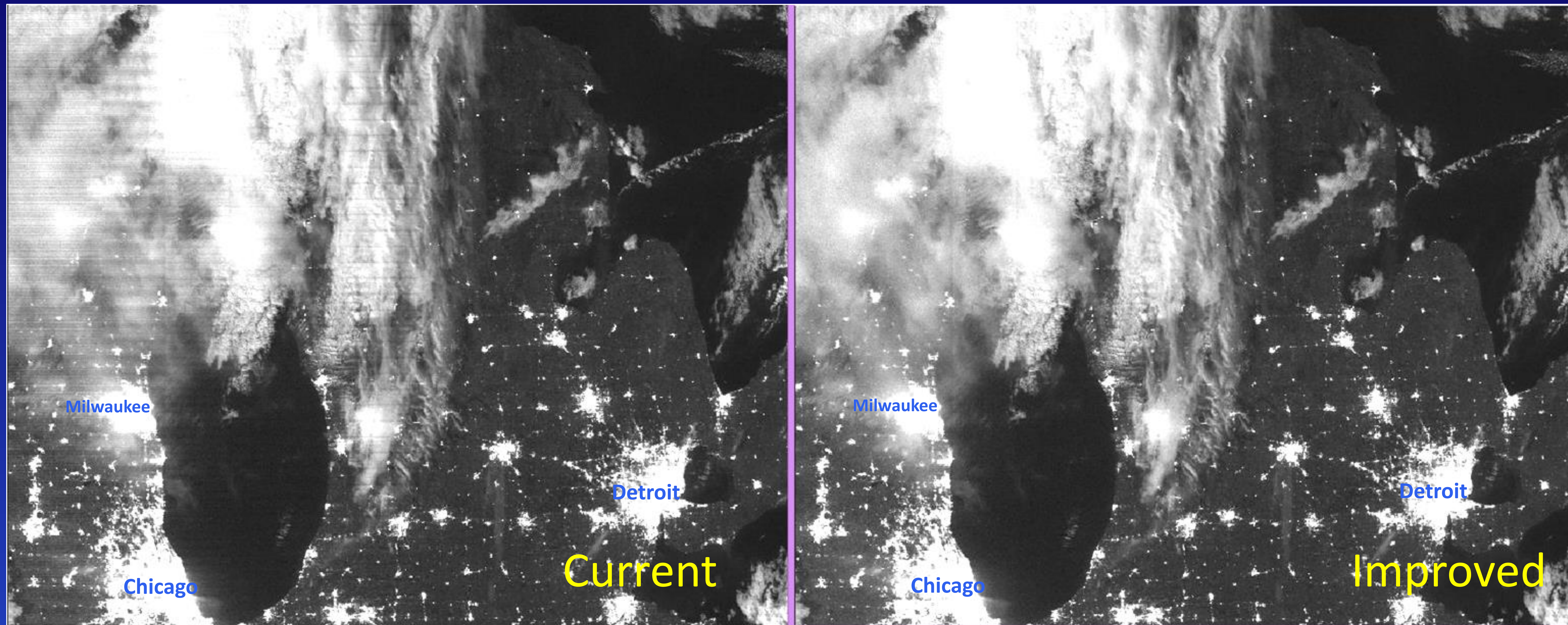
Results



City Lights and Clouds in Midwest

Time: 10/07/2014, 06:45 UTC; full moon illumination; located at start of swath; gray scale is linear from 8×10^{-10} to 2.1×10^{-8} W $cm^{-2}str^{-1}$; the DNB is in the HGS.

The destriping here in nearly perfect. City lights and lighted roadways are clearly visible. With thin clouds, the light penetrates through the clouds and scatters, creating a halo effect. The spread of the halo helps reveal the optical depth of the clouds and their structure.

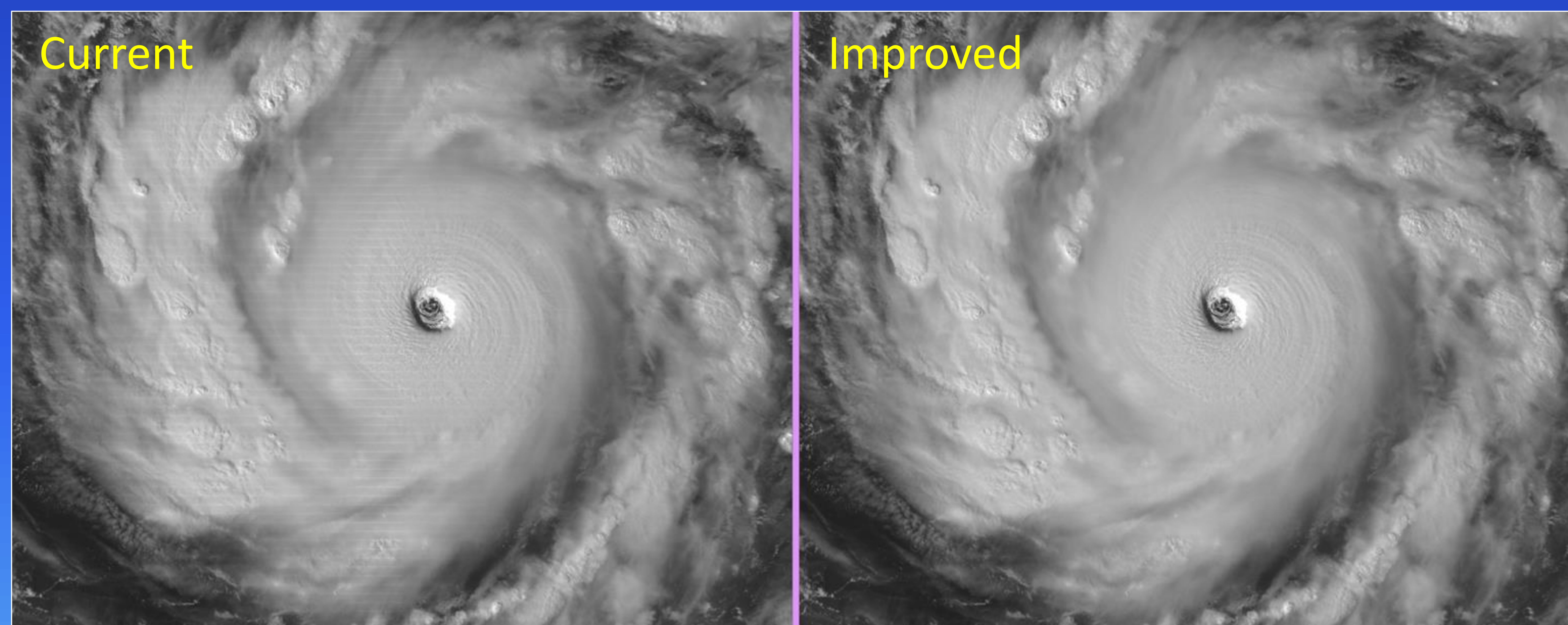
Compared with the DNB's heritage instrument (DMSP-OLS) DNB has about 5 times better resolution, and this has opened new areas of research involving anthropogenic lights at night. Destriping helps in taking full advantage of this.

Typhoon Vongfong by Moonlight

Time: 10/07/2014, 17:03 UTC; full moon illumination; located near center of swath; gray scale is linear from 2×10^{-9} to 3.6×10^{-8} W $cm^{-2}str^{-1}$; in the range of HGS.

The destriped image appears to be perfect with no residual stripes. This storm had a remarkably concentric structure in this image. Visible images of storms reveal structural features that are not seen in the emissive IR imagery. By removing striping moonlight reflectance combined with thermal emissive data in algorithms help better understand these storm systems.

The "current" image was released to the press, but without the distraction of striping, it would have better conveyed the power of Vongfong.



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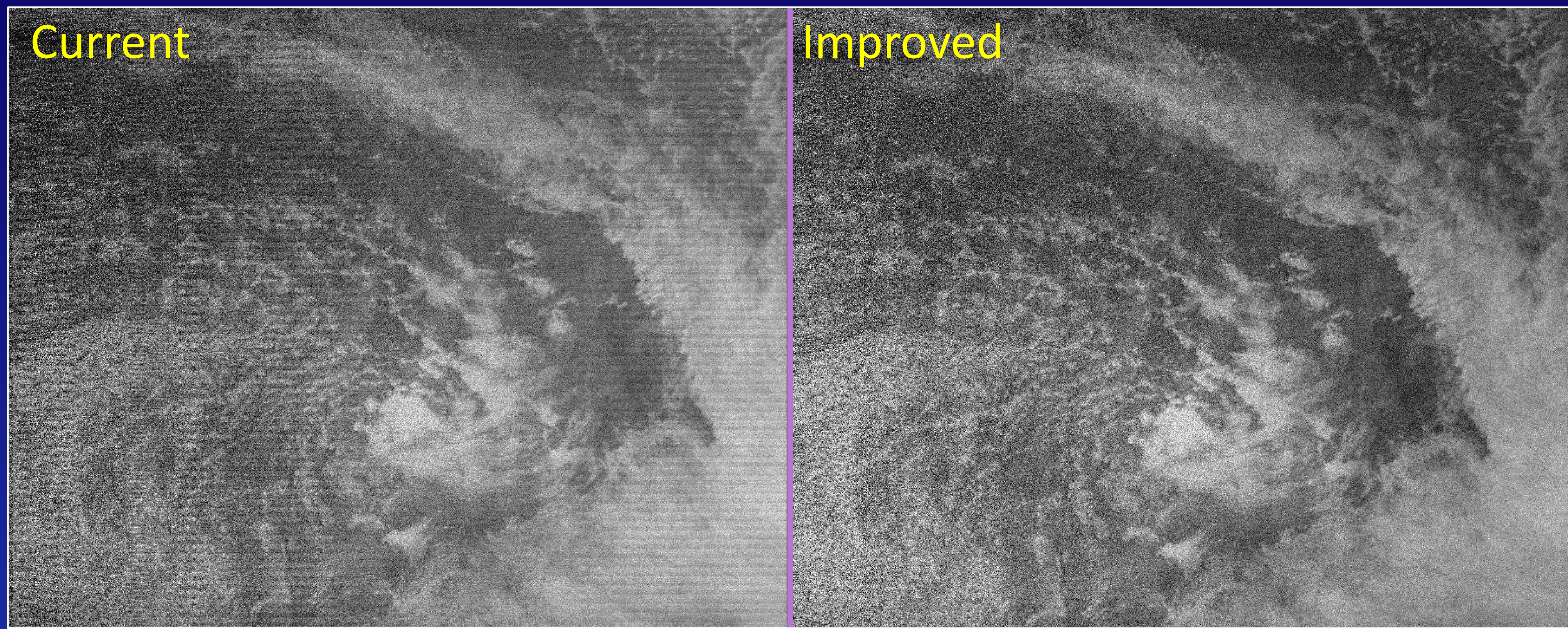
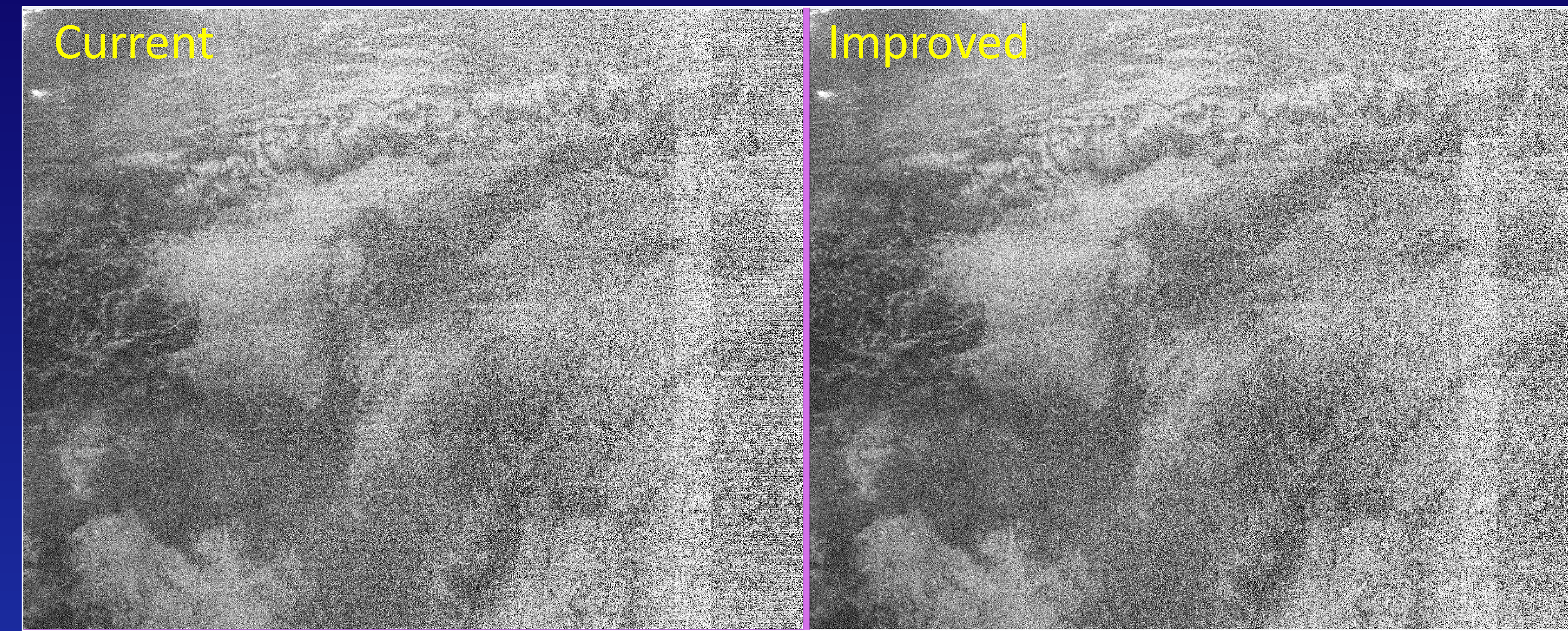


Moonless Night, Clouds Illuminated by Nightglow

Time: 05/28/2014, 01:37 UTC; located near start of swath; gray scale is linear from 0 to $5x10^{-10}$ W $cm^{-2}str^{-1}$; in HGS.

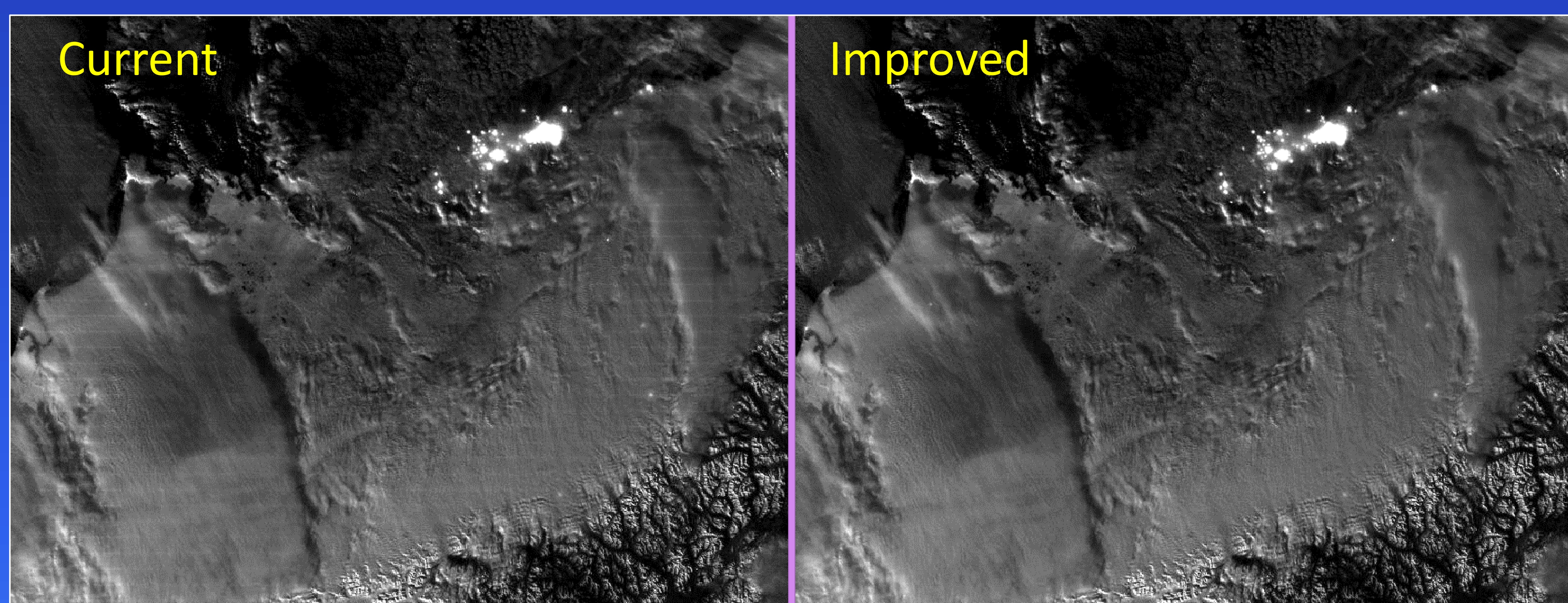
The DNB is so sensitive as to be capable of imaging clouds with only nightglow as illumination. This image has very low SNR <2, but cloud shapes are visible. The striping, however, is very visible on the left but is mostly removed with the destriping on the right. This image is truly noise limited.



Moonless Night, Clouds Illuminated by Nightglow

Time: 09/22/2014, 00:05 UTC; located at end of swath; gray scale is linear from zero to $5x10^{-10}$ W $cm^{-2}str^{-1}$.

Without lunar illumination, the clouds are illuminated only by nightglow. Comparing the "current" image from 05/28/14 with the "current" image above, there is less striping, because of recent improvements to the ground calibration implemented that tracks the offset drifts using the calibration sector data. Even so, there remains residual striping that is mostly removed by the algorithm.



Fairbanks, Alaska and Denali N. P. Illuminated by Full Moon

Time: 10/07/2014, 13:25 UTC; located mid-swath; gray scale is linear from $8x10^{-10}$ to $1x10^{-8}$ W $cm^{-2}str^{-1}$; the DNB is in the HGS.

The destriping here appears to be perfect. Despite a full moon, the scene is fairly dark because the moon is low to the horizon. The polar regions have twilight or night illumination through most of the winter, and so the DNB is more critical in supplying imagery for understanding the weather here.

Greenland & Clouds Over Baffin Bay Illuminated by Full Moon

Time: 10/07/2014, 04:56 UTC; view located at start of swath; gray scale is linear from $7x10^{-10}$ to $1.4x10^{-8}$ W $cm^{-2}str^{-1}$; DNB in the HGS.

This striping may be at least partly due to the stray light. This image reveals information about clouds not available from the IR bands and moonlight reflectance would be useful in future algorithms.

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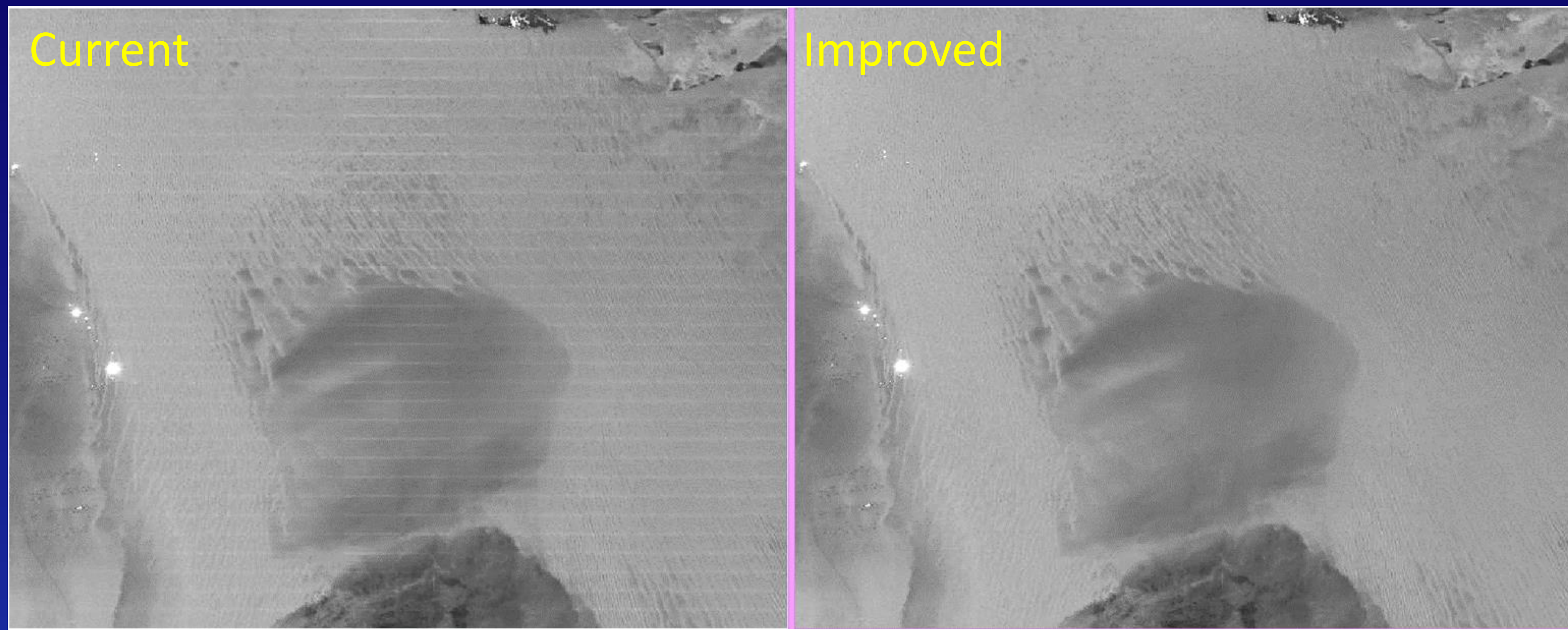
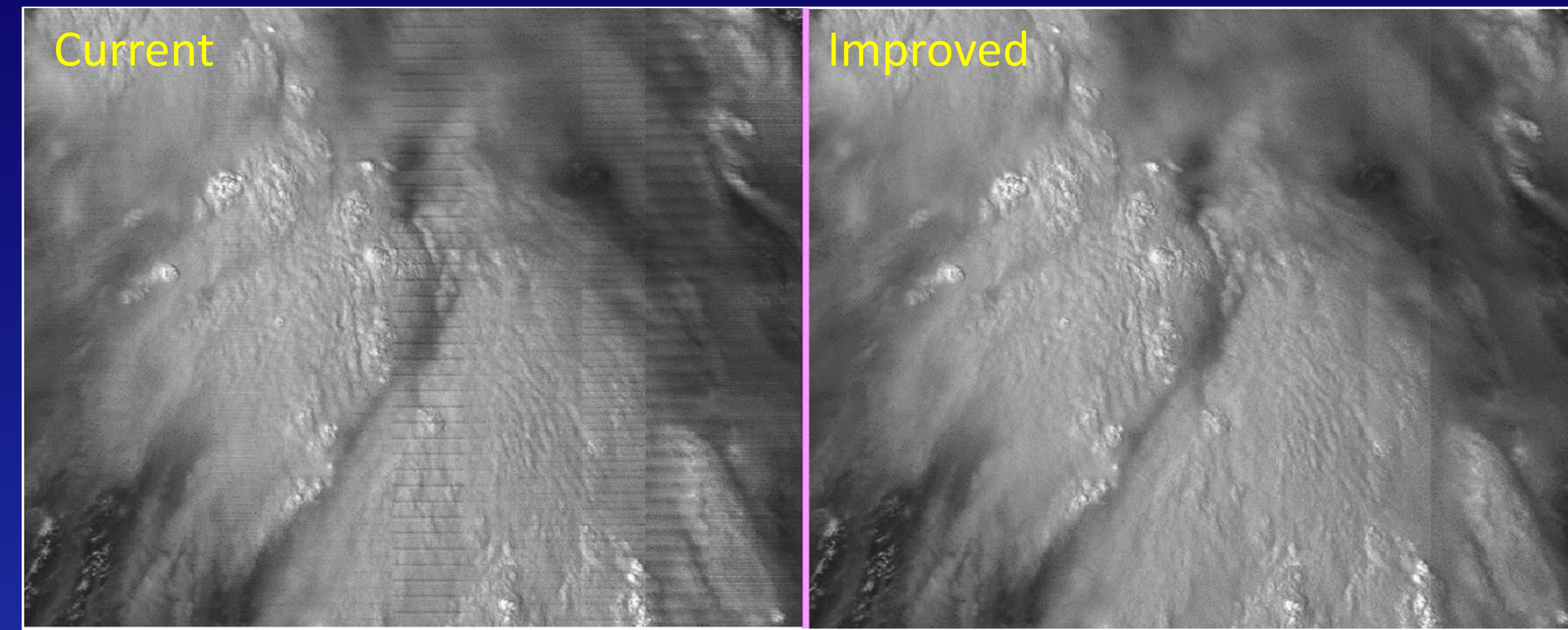


Moonlit Libyan Desert Scene

Time: 10/07/2014, 00:00 UTC; full moon at night; located near center of swath. The destriping here appears perfect with no residual stripes.

This region is almost always clear with nearly uniform dunes, and is often used to validate satellite sensors for uniformity in reflective bands. Blowing dust & sand indicate wind direction and strength. These are difficult to detect using emissive bands, so a destriped DNB makes remote observation using moonlight easier.



Moonlit Stratocumulus Clouds over Pacific

Time: 10/07/2014, 17:02 UTC; full moon at night; located at edge of swath.

The destriping here is nearly perfect. In the daytime, manual and automatic cloud identification is performed by combining visible & thermal emissive IR bands, and with the DNB these same techniques can be used for moonlit scenes and removing striping makes this more effective. Manual cloud identification also benefits from destriping.

Civil Twilight in Antarctica

Time: 10/07/2014, 22:37 UTC; located at start of swath; gray scale is logarithmic from $1x10^{-5}$ to $3x10^{-4}$ W $cm^{-2}str^{-1}$. DNB in MGS

This twilight imagery is used to produce Near Constant Contract (NCC) imagery, which removes the exponential change in radiance in twilight scenes, so that there is continuous imagery of clouds from full day to full night. The NCC, however, magnifies striping, if it is not corrected.

Nautical Twilight in Antarctica

Time: 10/07/2014, 22:35 UTC; gray scale is linear from $1x10^{-7}$ to $1.2x10^{-5}$ W $cm^{-2}str^{-1}$; located at end of swath; in MGS mode.

The destriping here is good but there is some residual stripes on the upper right edge. Nautical twilight in MGS is the most difficult to destripe, and histogram equalization was needed for this. The DNB is in MGS only about 2% of the time, so there is a dearth of data for destriping.

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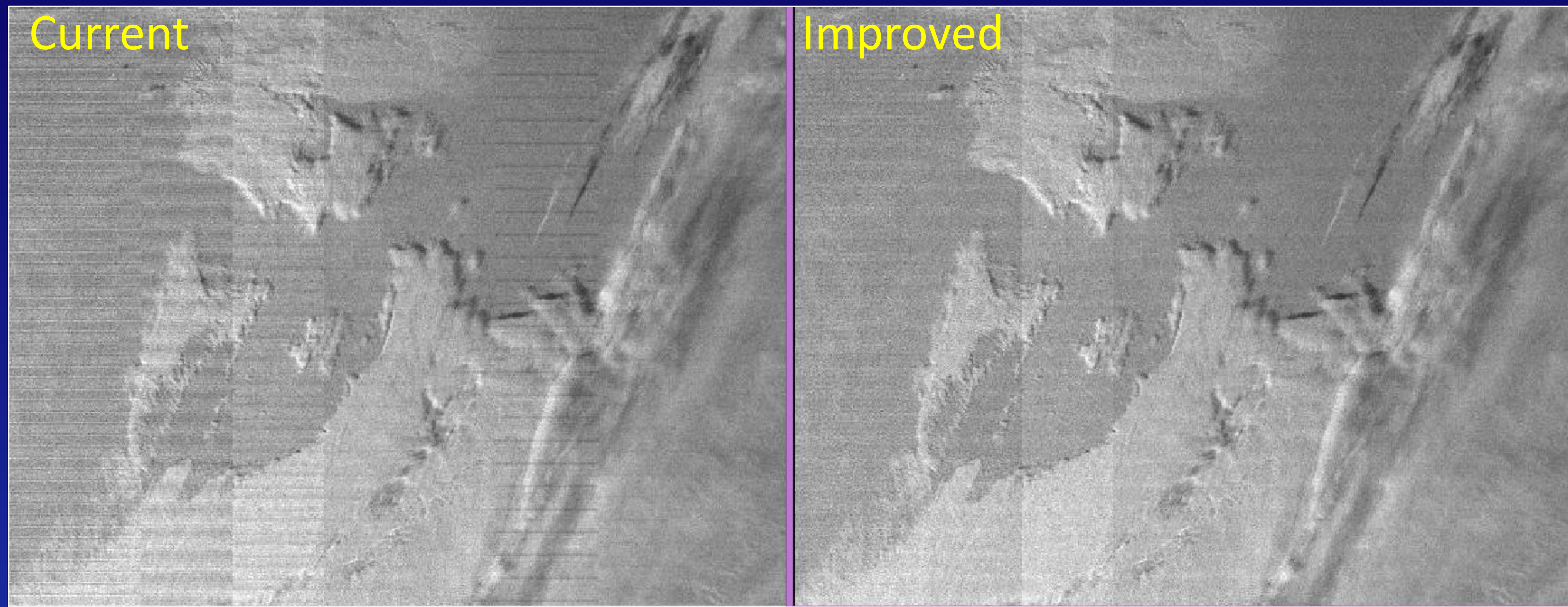
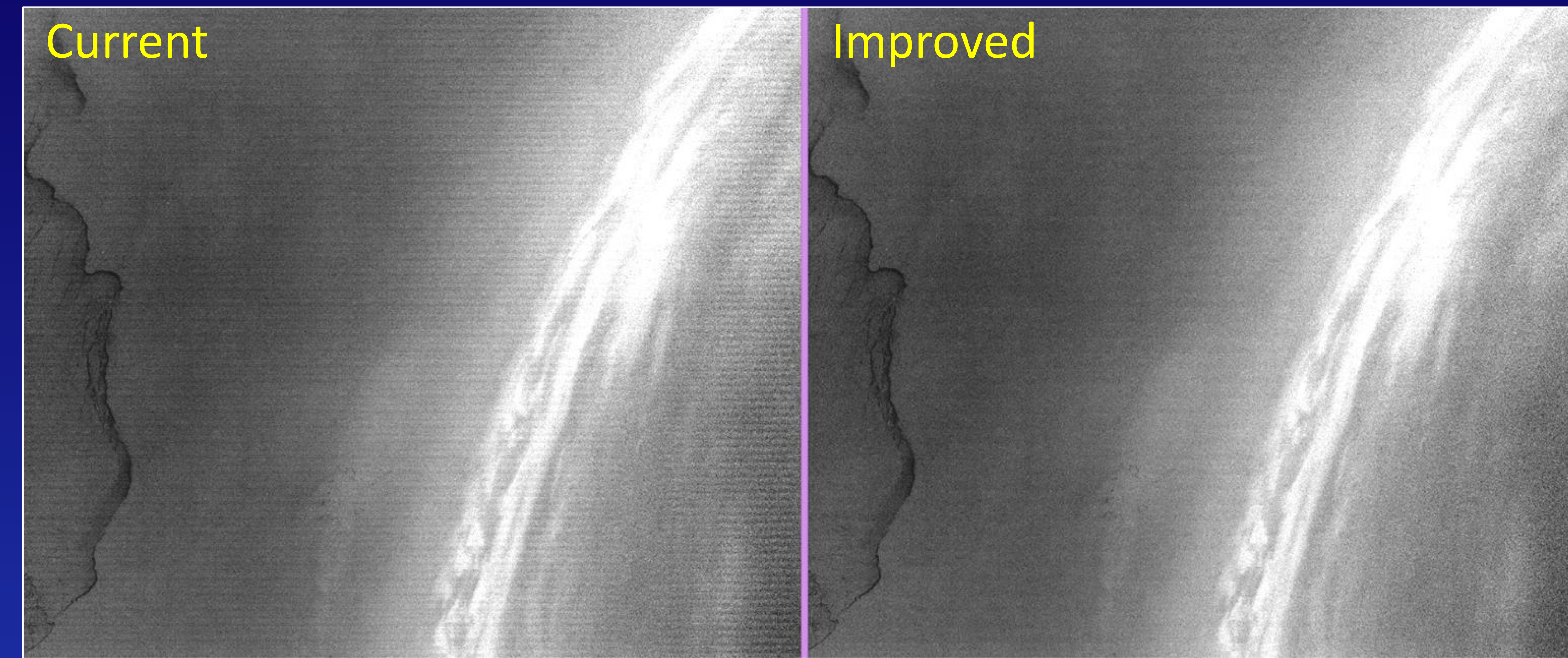


Fog Over Northern Greenland Ice

Time: 10/07/2014, 03:14 UTC; located at start of swath; gray scale is linear from 6×10^{-10} to 1.2×10^{-8} W cm^{-2}str^{-1};

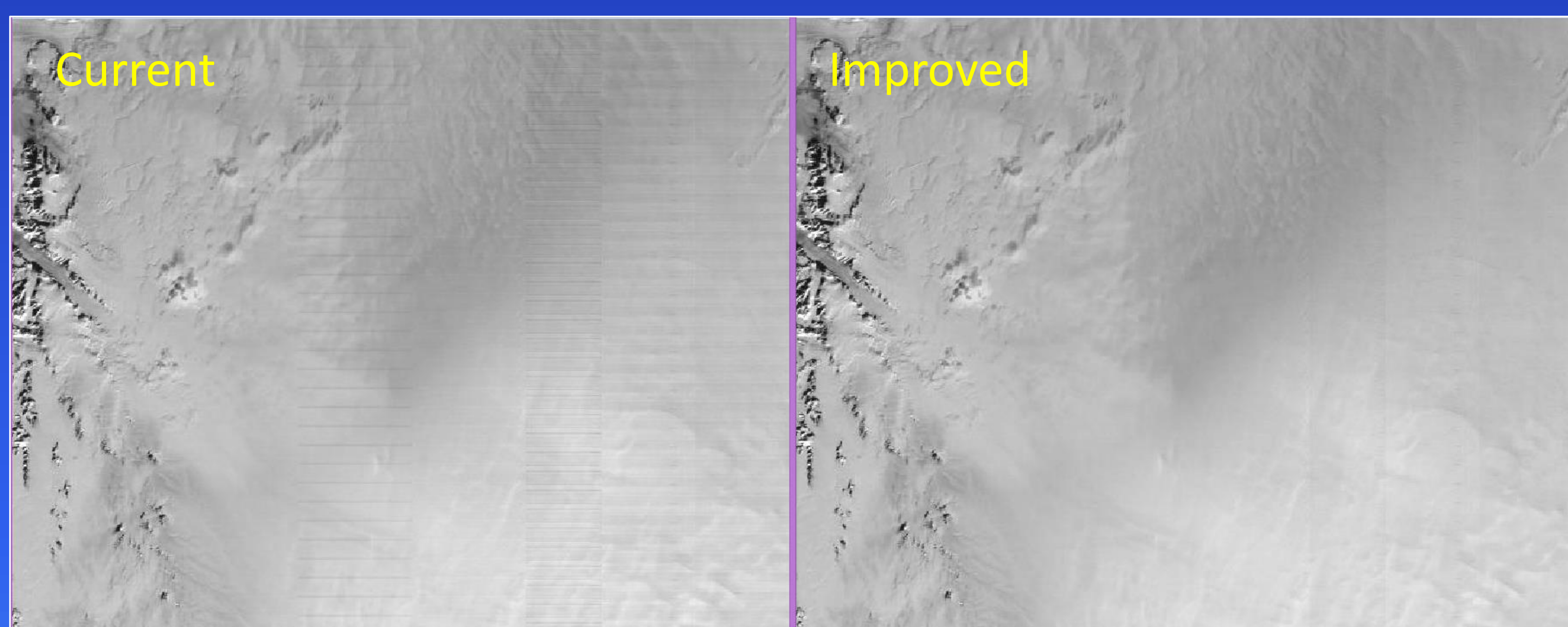
Residual stripes are on the left edge. This may be due to uncorrected stray light. Because low clouds & fog are so close to the surface, it often not possible to detect it with IR. Lunar reflectance from the DNB makes this possible at night & could contribute to more accurate weather models in the Arctic.



Aurora Over Antarctica

Time: 10/07/2014, 00:06 UTC; located near center of swath; gray scale is linear from zero to 7×10^{-10} W cm^{-2}str^{-1}.

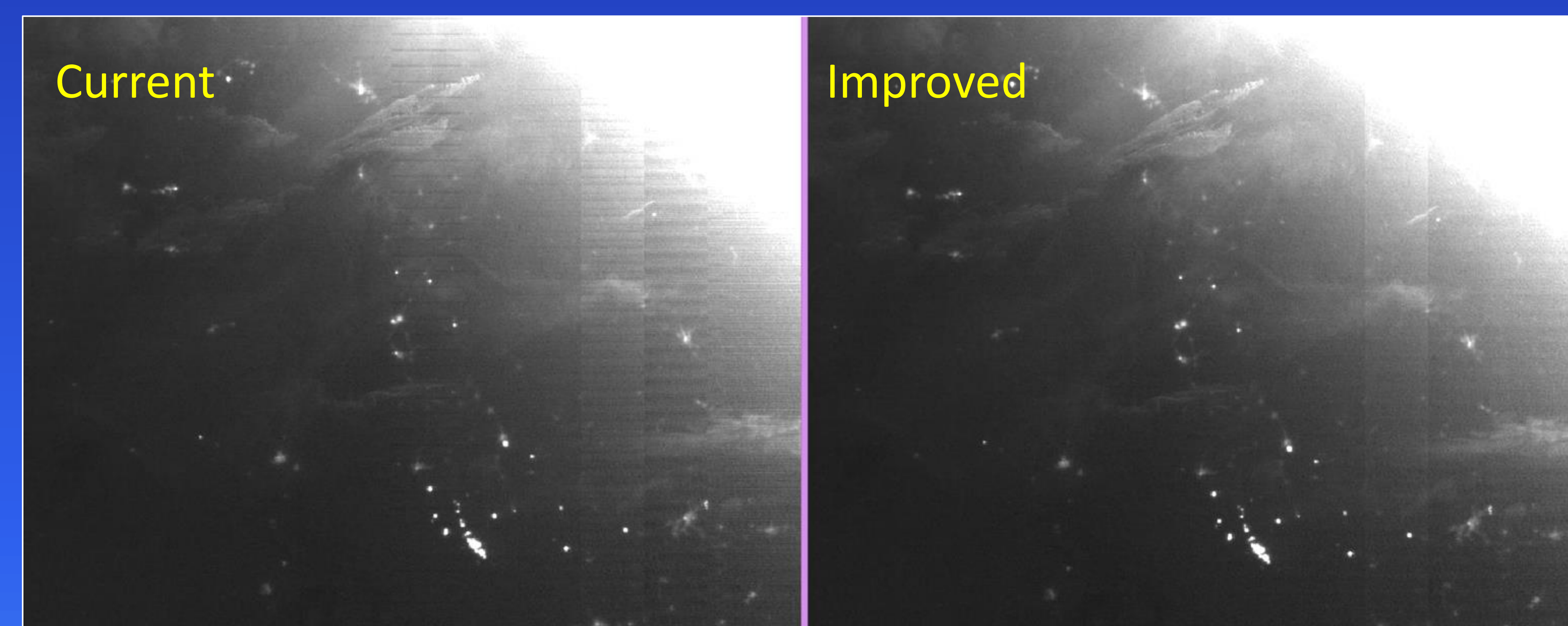
This is during a new moon, and the illumination here is from the aurora, which is bright enough to illuminate the edge of the ice sheet. The destriping here is good but there is some residual striping due to uncorrected stray light. The auroras offers another illumination source even when there is no moonlight.



Daylight in Antarctica

Time: 10/07/2014, 02:23 UTC; located at end of swath; gray scale is linear from 4×10^{-4} to 6.5×10^{-3} W cm^{-2}str^{-1}; DNB is in the LGS here.

The destriping here is good but there is a faint vertical bar that remains on the right. Striping in day scenes from the LGS is not as strong as with the MGS or HGS. Nevertheless, LGS striping is visible at both the start and end of the swath, and can be corrected with this algorithm.



Astronomical Twilight, North Finland

Time: 10/07/2014, 03:14 UTC; located at end of swath; gray scale is linear from 8×10^{-10} to 2.7×10^{-8} W cm^{-2}str^{-1}; DNB is in the HGS.

Some residual striping remains on the right edge that may be due to uncorrected stray light. Although there is a full moon on this date, the moon is below the horizon in this area so is not providing any illumination.

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