# Improvement of Visible Infrared Imaging Radiometer Suite Day/Night Band Image Quality

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## Abstract

The Day/Night Band (DNB) is a panchromatic visible and near-infrared band of the Visible Infrared Imaging Radiometer Suite (VIIRS) on-board the Suomi National Polar-orbiting Partnership (S-NPP) and NOAA-20 satellites. Because of its three gain stage design, i.e., Low-Gain Stage (LGS) for daytime scenes, the Mid-Gain Stage (MGS) for twilight scenes, and the High-Gain Stage (HGS) for nighttime low light scenes, the DNB is capable of quantitative measurement of light radiances from $3 \times 10^{-9}$ W·cm$^{-2}$·sr$^{-1}$ to $2 \times 10^{-2}$ W·cm$^{-2}$·sr$^{-1}$. The extreme sensitivity to low light enables numerous applications of environmental remote sensing and anthropogenic activities monitoring in nighttime. However, the three gain stage design makes radiometric calibration of the DNB's nighttime data complicated. Artifacts like striping are shown in the calibrated nighttime images. In this paper, we present our efforts for improving image quality of VIIRS DNB onboard both S-NPP and NOAA-20 by updating radiometric calibration algorithms. Our work is beneficial for applications that require high quality of DNB nighttime images.

## Introduction

- The VIIRS DNB onboard S-NPP and NOAA-20 is a panchromatic visible and near-infrared band (0.5 ~ 0.9 μm) for Earth observation both day and night.
- The DNB is effectively an integration of three separate bands, i.e., Low-Gain Stage (LGS) for daytime scenes, Mid-Gain Stage (MGS) for twilight scenes and High-Gain Stage (HGS) for nighttime scenes.
- The HGS is able to detect lunar illuminated Earth surface, clouds and artificial lights such as city light, boat, ships, street light etc.
- The extreme sensitivity to low light enables many image based applications, including monitoring of power outages after natural disasters and automated fishing boat detection.
- The three gain stage design makes radiometric calibration of the HGS complicated. Artifacts like striping are shown in the calibrated nighttime images.
- The HGS is calibrated by two key parameters that is dark offset and gain.
- The HGS dark offset is determined by tracking on-orbit change on top of the baseline HGS dark offset by the DNB observation of deep space collected during the spacecraft pitch maneuver early in the mission.
- The HGS gain is obtained by transferring LGS gain through multiplying the MGS/LGS and HGS/LGS gain ratios evaluated in the twilight region.
- The HGS dark offset, MGS/LGS and HGS/MGS gain ratios are updated monthly using data collected during new moon nights.
- In this paper, we present our efforts for improving quality of the DNB nighttime images by radiometric calibration updates.

## Correction of Striping due to Detector Nonlinearity

- Striping has been found in many aggregation zones of both the S-NPP and NOAA-20 VIIRS DNB nighttime imagery.
- Aggregation zone 21 of NOAA-20 VIIRS DNB is a typical example, shown in Figure 1.
- Because of the special aggregation option known as Option 21, about 30% pixels of a NOAA-20 VIIRS DNB image are in aggregation zone 21.
- Striping severely degrades the quality of the NOAA-20 VIIRS DNB nighttime imagery.

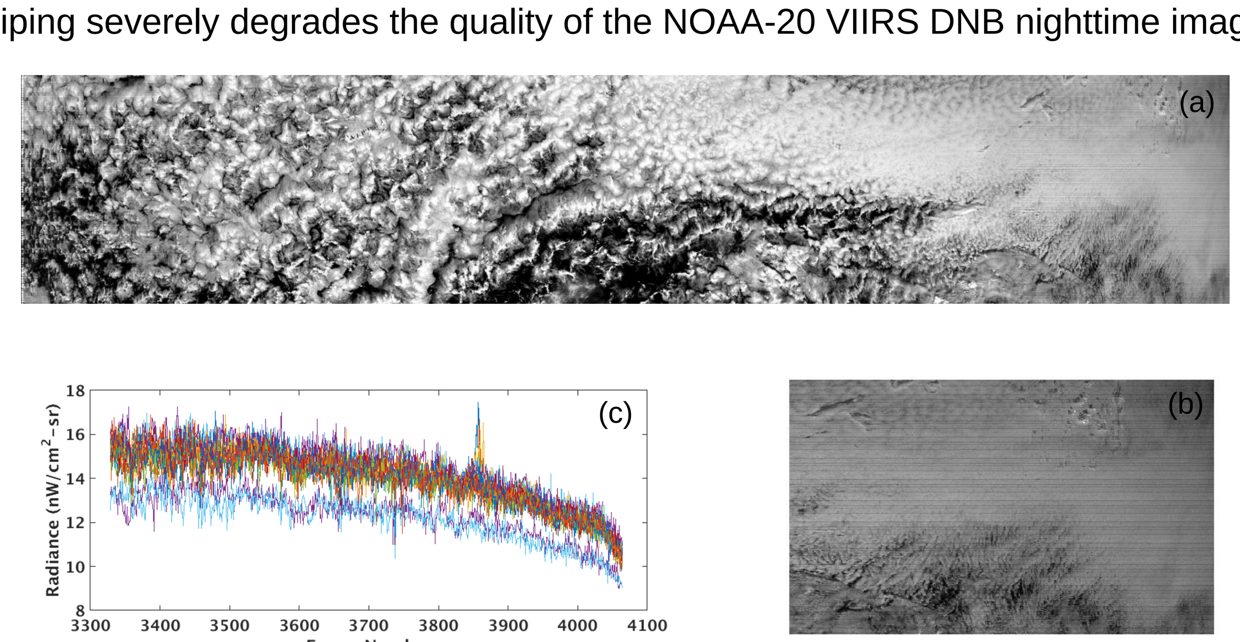



Figure 1. (a) NOAA-20 VIIRS DNB nighttime image recorded at 10:54 UTC, June 28, 2018. (b) striping in aggregation zone 21, right side of (a). (c) The detectors' radiances of a scan in (b).

- Image analysis shows that strips are from the DNB detectors with non-negligible nonlinearity in the low dynamic range.
- The MGS/LGS gain ratios of these detectors determined by the original algorithms are biased, consequently making the corresponding HGS gains biased ($G_{HGS} = G_{HGS/MGS} \times G_{MGS/LGS} \times G_{LGS}$, Figure 2).

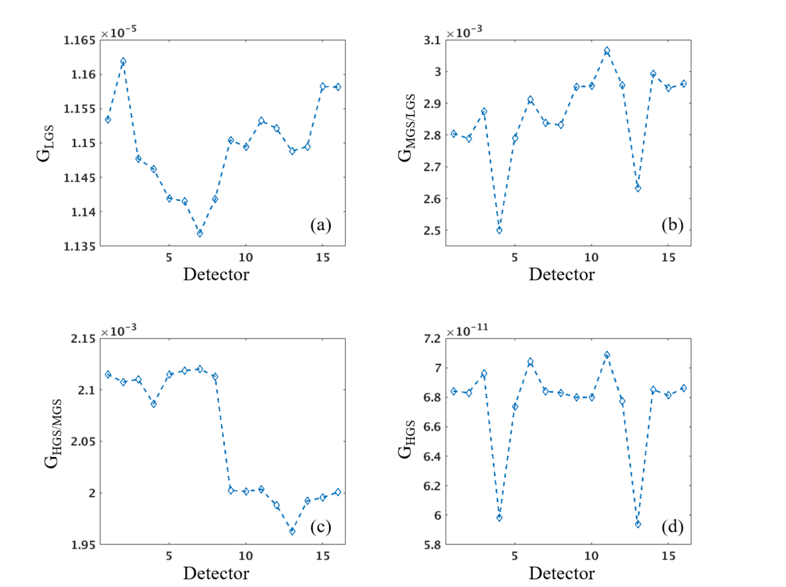



Figure 2. (a) LGS gain, (b) MGS/LGS gain ratio, (c) HGS/MGS gain ratio, and (d) HGS gain for all detectors of aggregation mode 21 used for radiometric calibration of the NOAA-20 VIIRS DNB nighttime image shown in Figure 1.

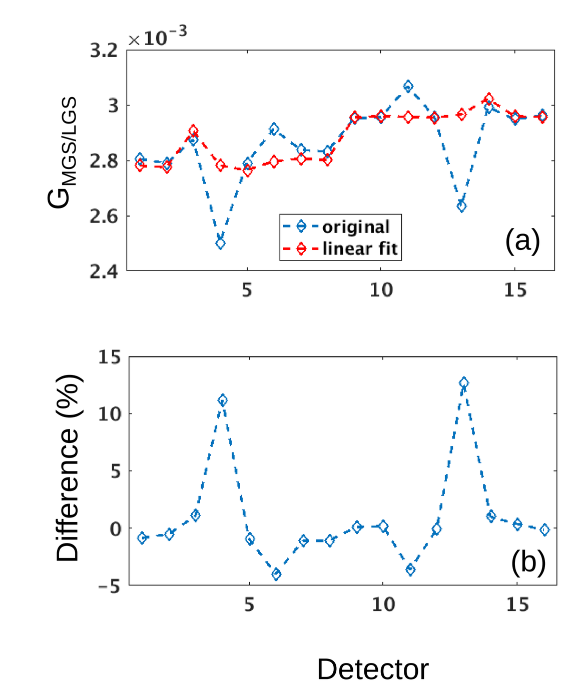



Figure 3. (a) $G_{MGS/LGS}$ determined by the original algorithm and the linear regression method. (b) Relative difference [100% × (linear - original)/linear]

- Such biased gain ratios can be corrected by the improved algorithm based on linear regression. (Figure 3).
- Striping in the reprocessed DNB nighttime images, in particular those under moonlight illumination, is significantly reduced (Figure 4).
- DNB gain ratios LUTs created by the improved algorithm have been used in operational calibration for both the S-NPP and NOAA-20 VIIRS DNB since March 2019 and November 2018 respectively.

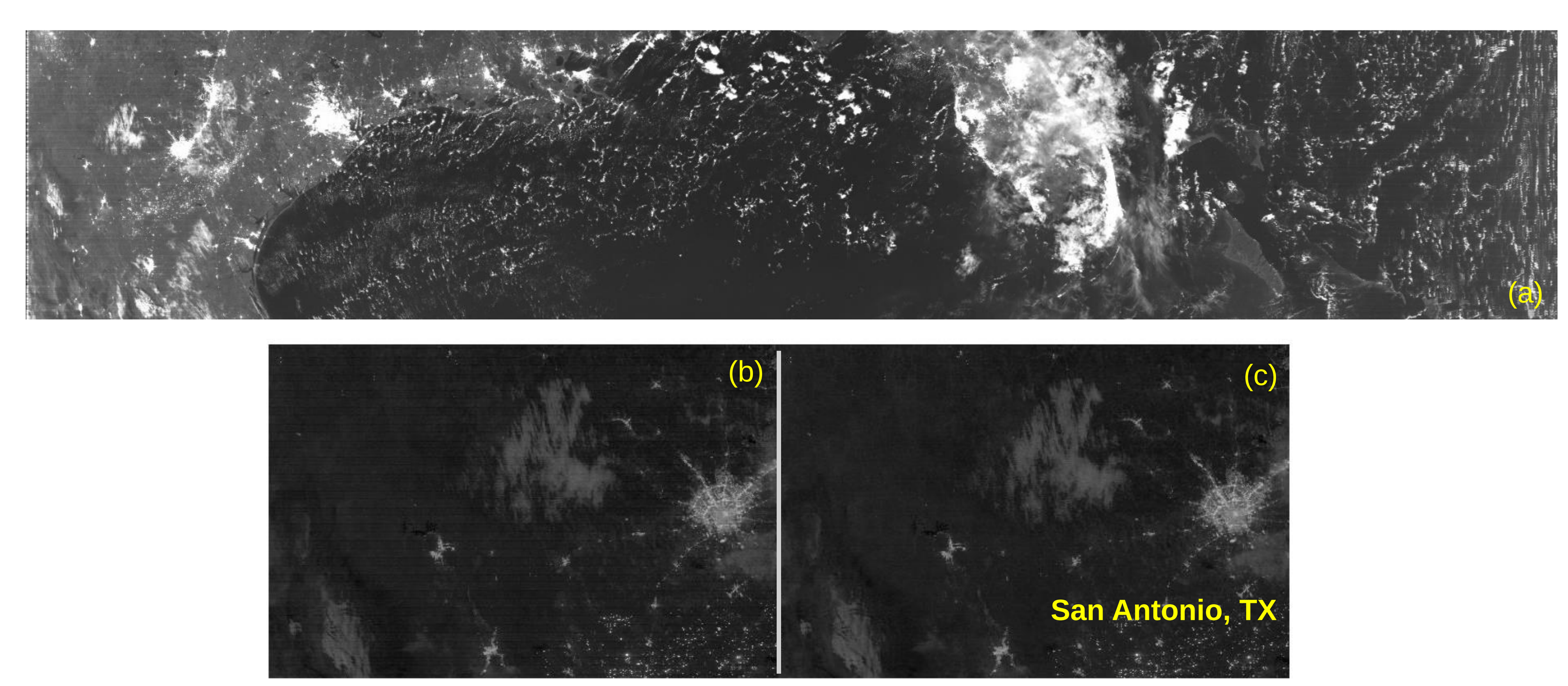



Figure 4. (a) NOAA-20 VIIRS DNB nighttime image recorded at 07:31 UTC, June 28 2018. (b) striping in aggregation zone 21, left side of (a). (c) reprocessed image by the updated gain ratios.

## Improved SNPP VIIRS DNB Image Quality after Reprocessing

Reprocessed SNPP VIIRS DNB SDRs from early mission to March 2017 accommodate calibration updates since launch

- Continuous DNB LGS gain degradation using modulated relative spectral response (RSR) function, benefiting application of nightlight time series for study of socioeconomic changes (Figure 5).

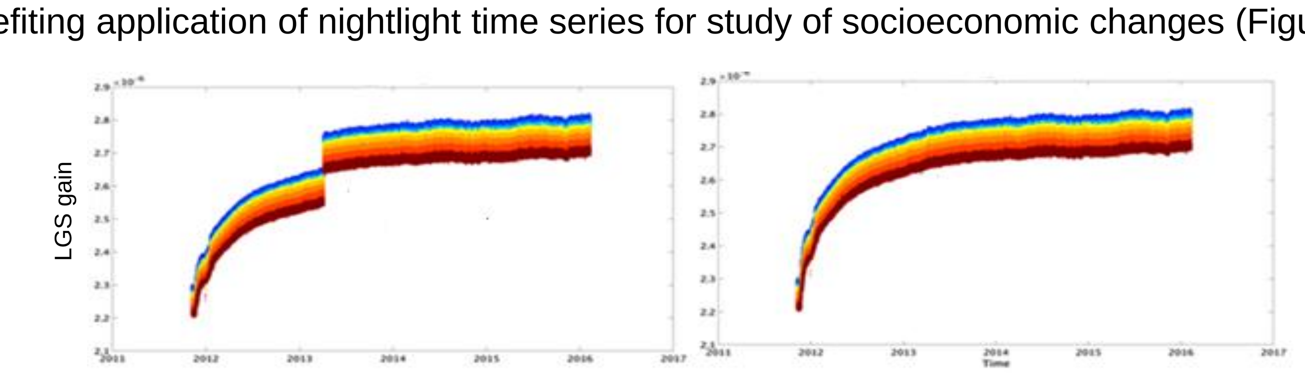
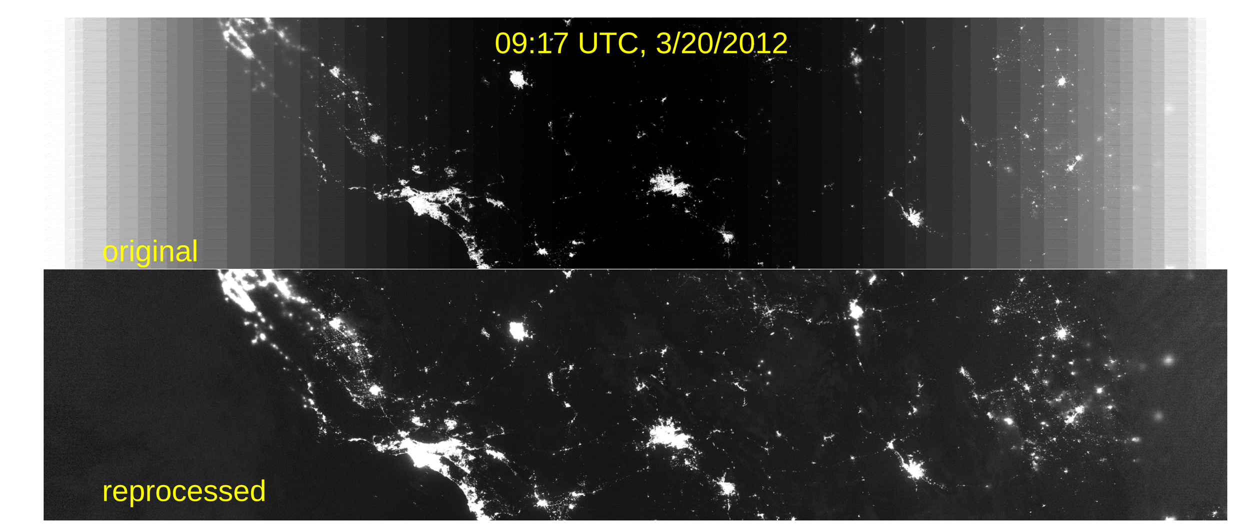
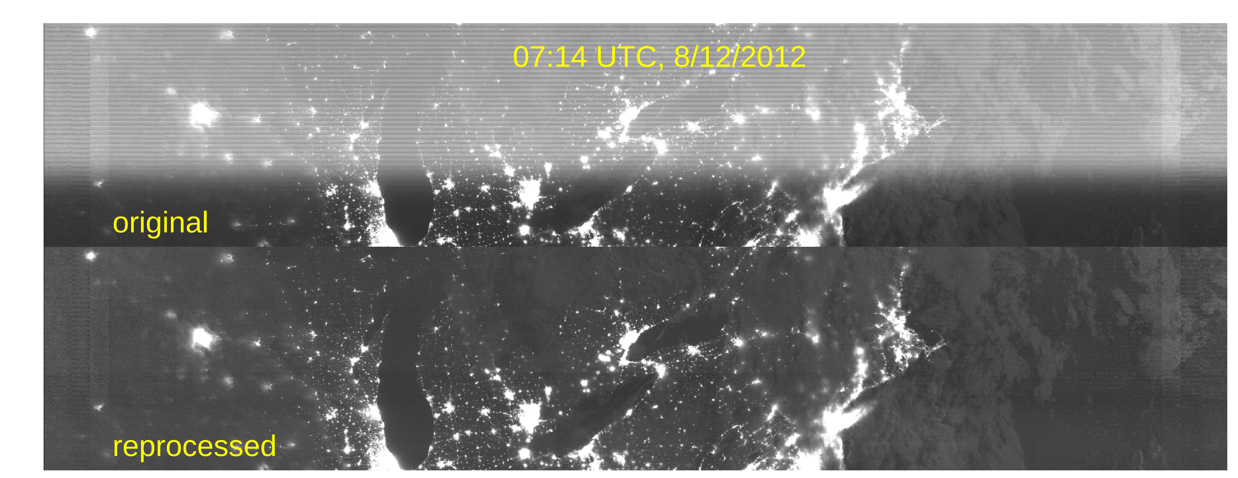



Figure 5 DNB LGS gain trends (aggregation mode 1). (a) Using only one update in RSR (April 4, 2013). (b) Using continuous sets of time-dependent RSRs for reprocessing.

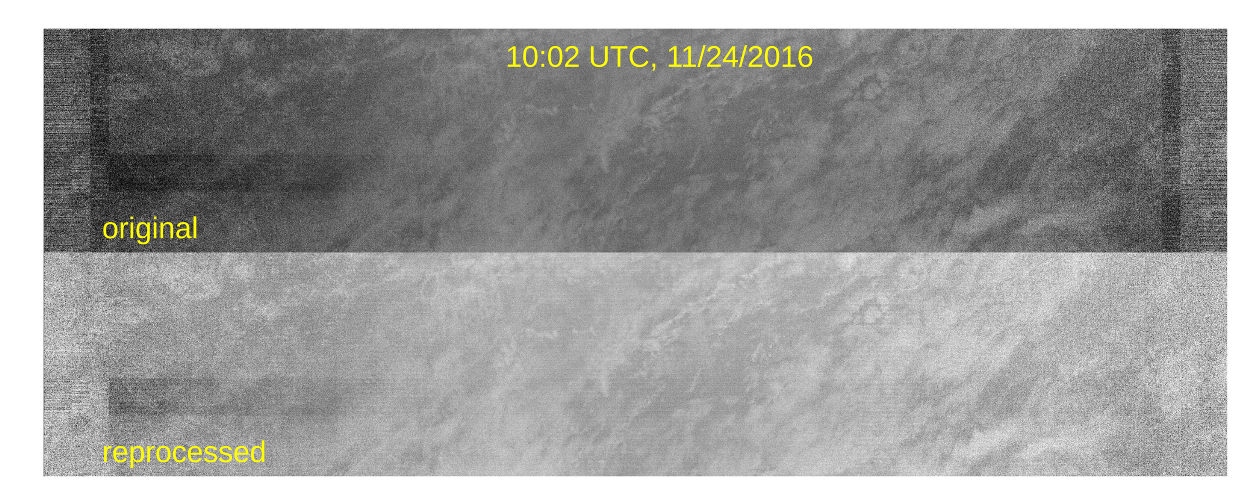
- Significantly improved quality of the DNB data collected before March 20, 2012 which were originally calibrated with the prelaunch LUTs .




- Straylight corrected DNB data available since early mission of SNPP.




- Enhanced low light detection by the deep space based HGS dark offset




## Summary

- This study summarized radiometric calibration updates for improving image quality of VIIRS DNB onboard both S-NPP and NOAA-20 satellites.
- Major improvements include:
  - Correction of striping due to detector nonlinearity
  - Continuous DNB LGS gain degradation correction by modulated RSRs
  - DNB data collected during early mission calibrated with the postlaunch LUTs
  - Straylight corrected DNB data available since early mission
  - Enhanced low light detection by the deep space based HGS dark offset
- *Reprocessed SNPP VIIRS SDR data including DNB from early mission to March 2017 are available at* https://ncc.nesdis.noaa.gov/VIIRS/index.php

***References:***

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