Preliminary study for improving the VIIRS DNB low light calibration accuracy with ground based active light source

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ABSTRACT

There is a growing interest in the science and user community in the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) low light detection capabilities at night for quantitative applications such as airglow, geophysical retrievals under lunar illumination, search and rescue, energy use, urban expansion and other human activities. Given the growing interest in the use of the DNB data, a pressing need arises for improving the calibration stability and absolute accuracy of the DNB at low radiances. Currently the low light calibration accuracy was estimated at a moderate 15%-100% while the long-term stability has yet to be characterized. This study investigates selected existing night light point sources from Suomi NPP DNB observations and evaluates the feasibility of SI traceable nightlight source at radiance levels near 3 nW·cm\textsuperscript{-2}·sr\textsuperscript{-1}, that potentially can be installed at selected sites for VIIRS DNB calibration/validation. The illumination geometry, surrounding environment, as well as atmospheric effects are also discussed. The uncertainties of the ground based light source are estimated. This study will contribute to the understanding of how the Earth’s atmosphere and surface variability contribute to the stability of the DNB measured radiances, and how to separate them from instrument calibration stability. It presents the need for SI traceable active light sources to monitor the calibration stability, radiometric and geolocation accuracy, and point spread functions of the DNB. Finally, it is also hoped to address whether or not active light sources can be used for detecting environmental changes, such as aerosols.

Keywords: Suomi NPP VIIRS DNB, Night light stability, Ground based light sources

1. INTRODUCTION

The outstanding performance of the Suomi NPP VIIRS Day/Night Band (DNB) enables a new era of low light imaging at night [1]. Its extreme sensitivity to low lights has already been demonstrated in numerous emerging applications, such as the study of air glows, aurora, and assisting the rescue of a crab fishing vessel trapped in ice in the Bering Sea. This unprecedented capability greatly relies on its onboard calibration, which unfortunately has a significant limitation: it uses the sun as the calibration source which is more than seven orders of magnitude brighter than the faint lights from fishing vessels. As a result, the absolute calibration accuracy for the low night light is no better than 15% (or up to 100% according to specifications). Also, the stability of the calibration for low light over time cannot yet be verified. Any significant calibration drift may diminish the ability in distinguishing fishing vessels from noise. Furthermore, since the fishing light is typically a point source, both radiometric and spatial response of the DNB must be evaluated together, which is difficult with traditional methods.

This leads to the need for accurate active light sources at night to validate and monitor the DNB responses to characterize its performance and make adjustments as needed. This will allow us to continue assisting in search and rescue of manmade faint light objects under severe weather conditions such as Hurricanes and Ice storms, helping the society to prepare for and respond to weather related events. It will also allow us to monitor the light intensity of human settlements and their energy use, and many other natural low light phenomena over time, study climate change and its anthropogenic contributions.

The current study investigates the radiometric stability of existing night light point sources near Lmin (3 nW/cm\textsuperscript{-2}·sr) observed from the Suomi NPP VIIRS DNB, and their suitability for monitoring the instrument performance. Lights
from selected bridges, oil platforms, power plants, and flares are evaluated. The advantages and limitations of those lights are explored. The need for specially designed light sources for calibration purposes is discussed.

2. METHODOLOGY AND DATA SETS USED

To evaluate the stability of existing night light point sources, we selected samples from Suomi NPP VIIRS DNB observations to construct time series. Several sampling strategies are used. 1) samples are selected based on the 16 day orbital repeating cycles, where the observation geometries are the same to eliminate uncertainties due to view angles and positions on the focal plane array. 2) successive orbit samples are collected to evaluate the stability from different view geometries, which also allows the evaluation of radiance vs. scan angle (or frame number).

For each sampling scheme, two methods are used to process the samples: the first approach is to take averages of the samples within the area of interest; the second approach is to take the maximum values near the target of interest.

The targets selected in this study include:
1) The San Mateo bridge: this is the bridge located between the San Francisco and San Jose on the San Francisco Bay. The bridge lights consist of LEDs and are assumed to be stable over time. This area is also relatively free of clouds, and with low aerosol loading. Details about these lights can be found in [2]. For the San Mateo data set, the mean radiance values of the bridge lights for each observation over the entire bridge are calculated after anomalous values are excluded. These values are used in time series analysis. Furthermore, the values extracted from the CLASS data are compared with those from the NASA LandPeate data source. In addition, two focused sample points are used. One is the maximum radiance value at the mid-point of the bridge, and the other is the bright spot on the east end of the bridge near the toll plaza.

Other bridges investigated include the Baharin bridge, the Incheon airport bridge, and the Shanghai east Sea bridge. By comparison, the nightlights from the San Mateo bridge has the best quality due to mostly clear skies, the stability of the LEDs, and the radiances being around Lmin.

2) Oil platform holly (latitude: 34.389816, longitude: -119.906489): this platform (Figure 1) is part of the Ellwood Oil Field which is located approximately 19 km west of the city of Santa Barbara, beginning at the western boundary of the city of Goleta, proceeding west into the Pacific. The climate there is Mediterranean, with an equable temperature regime year-round, and most of the precipitation falling between October and April in the form of rain. Freezing temperatures are rare. The South Ellwood Offshore field is entirely beneath the Pacific Ocean, about 3 km from the main onshore oil field. Currently the only production from this field is from Platform Holly, which is in 64 m of water, about 3 km from the coast at Coal Oil Point. Numerous directionally-drilled oil wells originate at the platform, and several pipelines connect the platform to an onshore oil processing facility adjacent to the Sandpiper Golf Course. The Platform Holly was built by ARCO in 1966, and began drilling wells into the various zones in the South Ellwood Offshore field. Peak production from the field was in 1984. Mobil operated Platform Holly until 1997, at which point Venoco, Inc. acquired all rights to the field. Currently three pipelines – one oil, one gas, and one for utilities – connect the platform to the processing plant on the mainland [source: Wikipedia].

Figure 1. Location of the Oil platform Holly on VIIRS DNB
The size of the Oil Platform Holly is estimated to be 50m x 29m, which is a point source relative to the pixel size of 742x742 of the VIIRS/DNB. For this dataset, a semi-automated procedure is used to search for, and extract the data from the online archive of the VIIRS DNB data. Once the data are obtained, a pixel search software is used to find the brightest pixel at the location of the platform holly. Since this is a point source, only one pixel is identified for each observation. The observation is subjected to noise due to small sample, and occasionally due to clouds.

3) Point source over land: night lights from power plants.  
It was believed that power plant night lights are stable over time since the operating cost is negligible to the power that the plant generates (Sullivan, 2015, personal communications). Several power plants are examined from VIIRS DNB images, which included the Arizona nuclear power plant near Tonopah, AZ (latitude: 33.476077, longitude: -113.113194), the Dickerson generating station on the Potomac river near Poolsville, MD, and the Calvert Cliffs Nuclear Power plant in Lusby, MD. While conceptually the nightlights from power plants are relatively stable, there are practical problems. Since most of the power plants are over land, the light signal is mixed with lunar reflection from the land surface. There is also potential light contamination from nearby cities or neighborhoods.

4) Other point sources: gas flares in the mid-east  
Gas flares can be observed from both VIIRS DNB and infrared bands as point sources (Figure 2). Gas flare is a gas combustion device used in industrial plants such as petroleum refineries, chemical plants, natural gas processing plants as well as at oil or gas production sites having oil wells, gas wells, offshore oil and gas rigs and landfills. In this study we focused on gas flares in the Persian Gulf (Figure2). Gas flares typically appear as point sources on the VIIRS DNB images. Although they may last for a long time, they may not be stable especially compared to LED lights.

Figure 2. Gas flares in the Persian Gulf (left: VIIRS I5 infrared; right: VIIRS DNB)

3. RESULTS AND DISCUSSION

The time series of the VIIRS DNB radiances show that bridge night lights from the San Mateo bridge, averaged over the entire bridge, appears to be the most stable light source among all sources investigated. The typical radiance values are near Lmin of DNB, although higher values are expected when there is lunar illumination over clouds.
In Figure 3, each data point represents the averaged radiance of all pixels on the San Mateo bridge from the VIIRS DNB at a sample interval of 16 days. There are several features in this figure. First, the radiance value range is between 2 and 6 nW/cm²-sr, excluding one data point around 12/1/2013 which is believed to be due to lunar illumination of clouds. Second, the radiance value is not highly correlated with lunar phase. This is because 1) in clear sky, the lunar reflection from water is very low, while the total reflected lunar radiance from the bridge is also low because the bridge is very narrow. 2) The lunar elevation at the time of observation is also a major factor in addition to the lunar phase. However, lunar elevation analysis also shows low correlation with the bridge radiance values because of 1) discussed above. 3) lunar impact becomes large when the area is covered with clouds, in which case the lunar radiance from cloud reflection dominates the DNB observed radiances. Therefore, it was found that night light point sources over water in clear sky have a distinct advantage of relatively immune from lunar illumination.

Another major finding from Figure 3 is that the radiances from the two datasets (CLASS vs. LandPeate) are not exactly the same despite from identical VIIRS observations. The radiance from LandPeate are consistently higher (about 15%) than those from that of the CLASS. Note that these are the values for the same pixels from the same VIIRS DNB and therefore the differences are likely due to calibration coefficients used. It is known that in the LandPeate processing, the VIIRS DNB offset and gain ratio in the calibration were determined using onboard calibration, while the VIIRS Recommended Operating Procedure (VROP702/705) was used to observe the darkest part of the ocean during new moon in generating the calibration coefficients for the CLASS data sets. This difference may have contributed to the radiance differences in the observations. Also, independent verification shows that the low gain values for the DNB for the LandPeate and CLASS datasets are comparable, which could not have contributed to the 15% differences in the high gains.

Excluding the anomalous values in Figure 3, the nominal radiance values range from 2-4 nW/cm²-sr which has a variability about 100%. This variability is due to several factors, including but not limited to: atmospheric variability such as cloud fraction and aerosol changes, bridge surface reflection changes due to rain and other factors, air glow which is at a value up to Lmin [3], traffic light changes on the bridge, and finally the stability of the calibration. Unfortunately, these factors cannot be clearly separated from each other without extensive studies of each. On the other hand, the relative consistency between the CLASS and LandPeate data shown in Figure 3 suggests that the calibration is probably relatively stable, in which case the variability would be mostly due to non-calibration related factors such as actual changes in the atmosphere, bridge surface, and light intensity. However, since too many factors are involved, it is difficult to further reduce the variability and uncertainties using this bridge light source. This also leads to the belief that an actively controlled light source, with sufficient ground truth, would be a better source for the calibration and validation of the VIIRS DNB at low lights.
Compared to the 16 day nadir observations from VIIRS DNB, the successive orbit observations from different angles in Figure 4 shows that the radiance value range is larger, up to 15 nW/cm²-sr. This suggests that the radiances are probably higher at high scan angles. The radiance vs. frame# in Figure 5 confirms that this is indeed the case, although this relationship is more apparent for high radiance values, which suggest that cloud might be involved.

The response vs scan angle effect is even more obvious for the bright spot on the east end of the bridge, as shown in Figure 6 below. Note that the radiance range is approximately from 10-40 nW/cm²-sr. This raises additional questions whether the DNB zones across scan are consistently calibrated for Suomi NPP VIIRS, or there may be an aggregation...
dependent calibration bias, which is a known problem for the J1 VIIRS DNB, although has not been investigated for Suomi NPP VIIRS DNB.

![San Mateo bridge (east end) vs. radiance](image1)

Figure 6. Scan angle (Frame#) vs. radiance show high radiance at high scan angles at the east end of the San Mateo bridge

Similar patterns are found for the oil platform Holly data as shown in Figure 7, where the radiance values are on the order of 3nW/cm$^2$-sr at nadir, while much higher at 15 nW/cm$^2$-sr near the edge of the scan. Although the root cause is not clear, this analysis will help us better understand the radiometric bias especially for J1 VIIRS DNB due to its related waiver in bias at high aggregation zones. This further demonstrates that a well characterized ground light source will be very helpful in quantifying the VIIRS DNB performance at all scan angles.

![Oil Platform Holly vs. radiance](image2)

Figure 7. Scan angle (Frame#) vs. radiance show high radiance at high scan angles at oil platform Holly

For the other datasets we analyzed, the power plant data sets are very noisy due to the factor that it is affected by reflection from the land (lunar illumination). As a result, we tend to believe that night light source over land is not as useful as over water for our study. As for the gas flares, the radiometric values in the Persian Gulf region is typically on...
the order of 3e-5 W/cm²-sr, which is much higher than the Lmin. The stability is much less than desired (variability on the order of 100%). On the other hand, in most cases the night light sources can be used for geolocation monitoring.

4. THE 2015 NOAA SBIR PROJECT FOR DEVELOPING AN ACTIVE LIGHT SOURCE

The previous sections demonstrate that a vicarious source is needed for DNB night light validation. The results so far show that while bridge lights are relatively stable, their variability (up to 100%) is much larger than what is desired (a few percent). There are many causes for the variability and environmental factors appear to play a strong role, while the lack of ground truth information is a major impediment for further improvements. Given the limitations of the existing light sources available, it is desirable to develop active night light sources which are well characterized and maintained to improve the calibration accuracy and stability of the VIIRS DNB.

In 2014, in a collaborative effort between NOAA and NIST scientists, an SBIR proposal was submitted and selected by NOAA program office to fund a study for accurate active light source (AALS). In Spring of 2015, proposals are solicited and evaluated by a team of experts from NOAA, NIST, and NASA. The project is expected to begin in the second half of 2015. The following is a short description of the SBIR project that directly addresses the concerns discussed in this paper.

The goals of the SBIR project are to develop and deploy accurate active light sources (AALS) to selected calibration sites for the calibration/validation of the VIIRS DNB low light performance. The long term stability of the AALS, after characterizing and correcting any systematic drift, should be maintained at 1%, and the absolute accuracy of the light sources should be better than 5%. The AALS will only need to be turned on during the VIIRS DNB overpass at night around 1:30am local time. The light intensity should be higher than 3×10⁻⁹ W/cm²-sr in order to be useful for DNB calibration. These light sources will be used as benchmarks for comparisons with objects of interest on the DNB imagery. Once the methodology is demonstrated at one site, it can be expanded to many other sites, potentially internationally.

In phase I of the study, it focuses on the feasibility of using SI traceable active night light source for the calibration/validation of VIIRS DNB for low light conditions at the top of the atmosphere in clear sky conditions with radiances between 3×10⁻⁹ to 10×10⁻⁹ W/cm²-sr. Investigation involves performing trade studies with different approaches, such as direct illumination versus reflected target; choices of light sources; predicting the long-term stability and absolute accuracy given the best and worst case scenarios; analyzing the error budgets both at the light source and top of the atmosphere; evaluating alternative methodologies that may complement the active light source; and developing concept of operations for accurate active light sources that can be deployed to selected sites to be detected by VIIRS DNB within ±10 degree scan angles; the absolute accuracy of the light source in radiances should be better than 5% in clear sky conditions. If phase I study is successful, a phase II study may be continued.

It is noted that the current study can help the SBIR project in many ways. For example, based on analysis of VIIRS DNB observations, we found that ideal light sources should be installed over water where the lunar reflection is negligible, and clear sky is always preferred which limits the geographic location of the installation to certain parts of the world. We will work closely with the SBIR recipient to ensure the success of the project which in turn will benefit the low light calibration of the VIIRS DNB.

5. SUMMARY

Given the growing interest in the use of the DNB data, a pressing need arises for improving the calibration stability and absolute accuracy of the DNB at low radiances. This study investigated selected existing night light point sources from Suomi NPP DNB observations and evaluates the feasibility of SI traceable nightlight source at radiance levels near 3 nW·cm⁻²·sr⁻¹, that potentially can be installed at selected sites for VIIRS DNB calibration/validation. Preliminary results show that existing night light sources, while there are many choices among lights from bridges, oil platforms, gas flares, and power plants, they unfortunately all have large uncertainties than desired. The current knowledge of the uncertainties in the VIIRS DNB prohibits us from retrieving small signals such as aerosols at night. Part of the uncertainties is due to lack of ground truth, while others due to atmospheric variability. As a result, it is difficult, if at all possible, to diagnose calibration stability with a reasonable certainty. This leads to the need for active night light source.
for the calibration/validation of the VIIRS DNB, for which an SBIR project is currently being developed. This study provides additional guidance on the view geometry and background type for the active light source. It appears that light source over water is more desirable than over land due to lunar illuminations, while clear sky is always preferred. It is anticipated that with further studies, active night light sources can be developed and used to establish the traceability of the VIIRS DNB radiances, as well as the monitoring of the geolocation accuracy.

REFERENCES

