Visible Infrared Imaging Radiometer Suite

# Vicarious Calibration of VIIRS Day Night Band

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# Outline

- Vicarious validation of VIIRS-Day Night Band (DNB) using DOME-C/Greenland under moon light
  - Event selection
  - Lunar irradiance model and TOA reflectance estimation
  - Validation and trending of DNB radiometric performance
- Preliminary radiometric calibration of DMSP-OLS using VIIRS-DNB through vicarious calibration

(In collaboration with Chris Elvidge and Michael Von Hendy of NOAA/NGDC)

- Future work

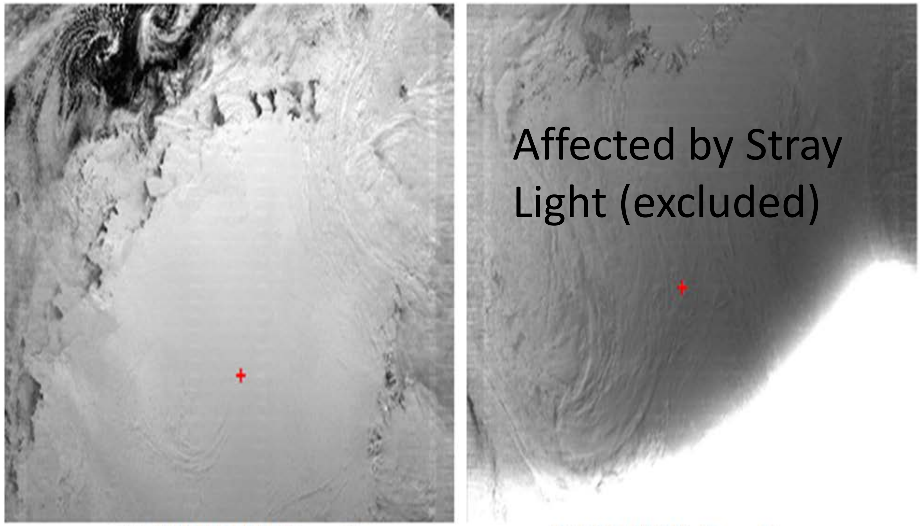
# VIIRS-DNB

- The Day Night Band (DNB) of VIIRS provides imagery of clouds and other Earth features over illumination levels ranging from full sunlight to quarter moon.
- Three gain stages. The low gain stage (LGS) gain values are determined by the daytime onboard solar diffuser data.
- The medium and high gain stage values are determined by multiplying the LGS gains by the MGS/LGS and HGS/LGS gain ratios derived from data collected at solar terminator region, respectively.

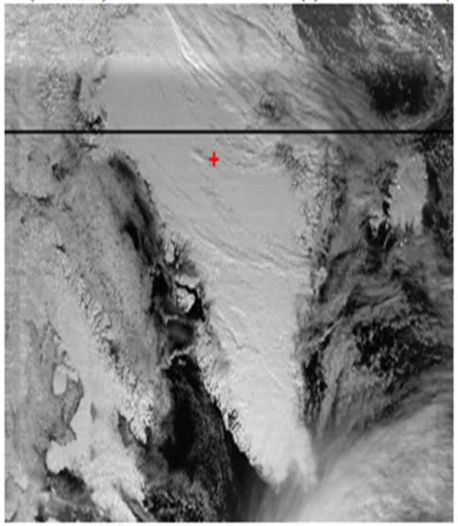
# Key DNB Radiometric Characteristics

| | Specification | Prelaunch Performance | On-orbit performance |
|---|---|---|---|
| Spectral passband center | 700±14 nm | 707 nm | Model estimate: 694 nm |
| Spectral passband bandwidth | 400±20 nm | 379 nm | Model estimate: 375 nm |
| Dynamic Range ($W/cm^2$-sr) | $3\times10^{-9}$ to 0.02 | $3\times10^{-9}$ to 0.021 | $3\times10^{-9}$ to 0.0186 |
| Calibration Uncertainty (HGS) | 30%/100% (Transition from MGS/Lmin) | 11% | 15% (1σ) [2.8%, -15%] |

Adapted from Liao et al., 2013




(a) 7/4/2012 15:05 (Dome C) (b) 7/1/2012 7:42 (Dome C)

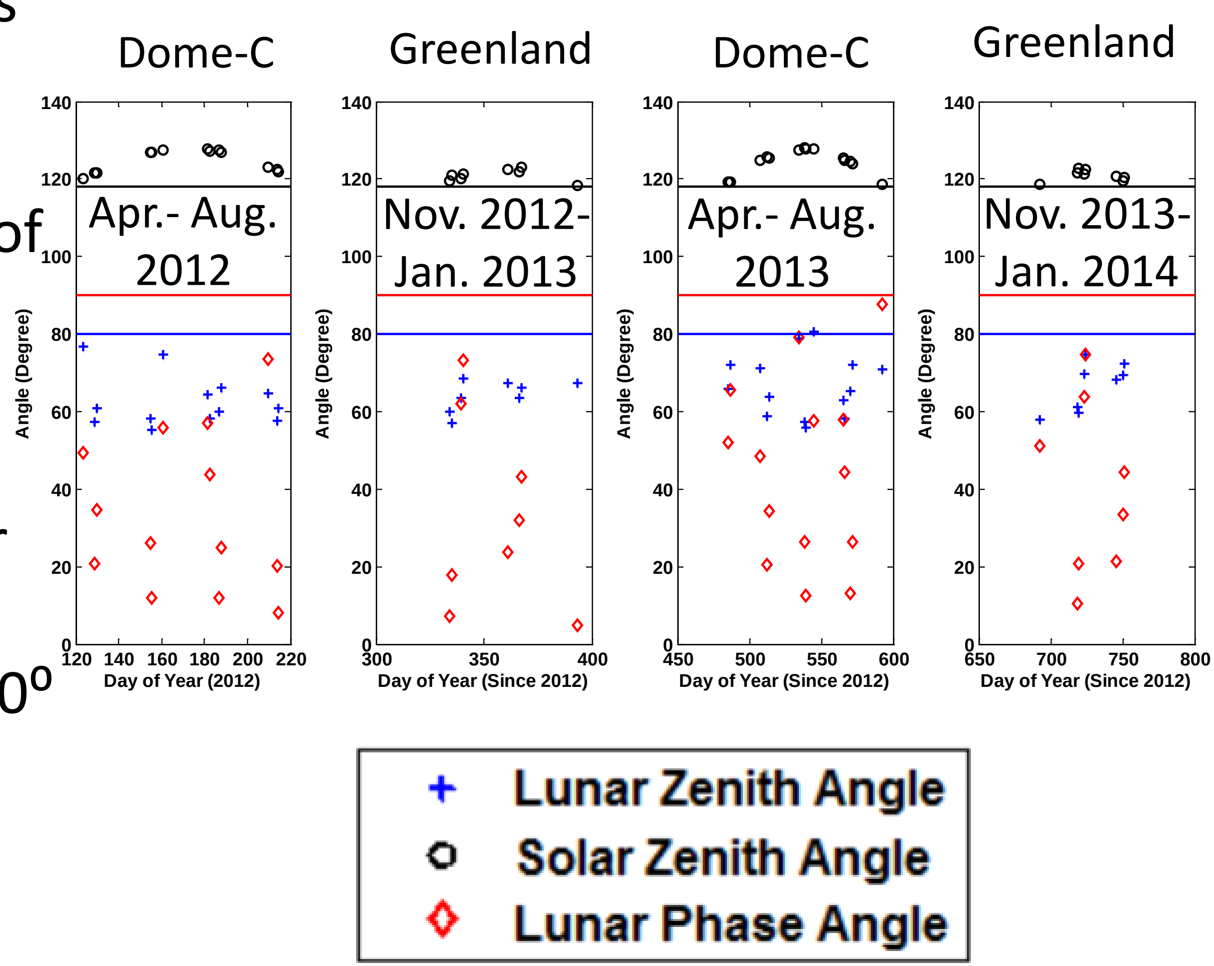


(c) 11/30/2012 6:01 (Greenland)

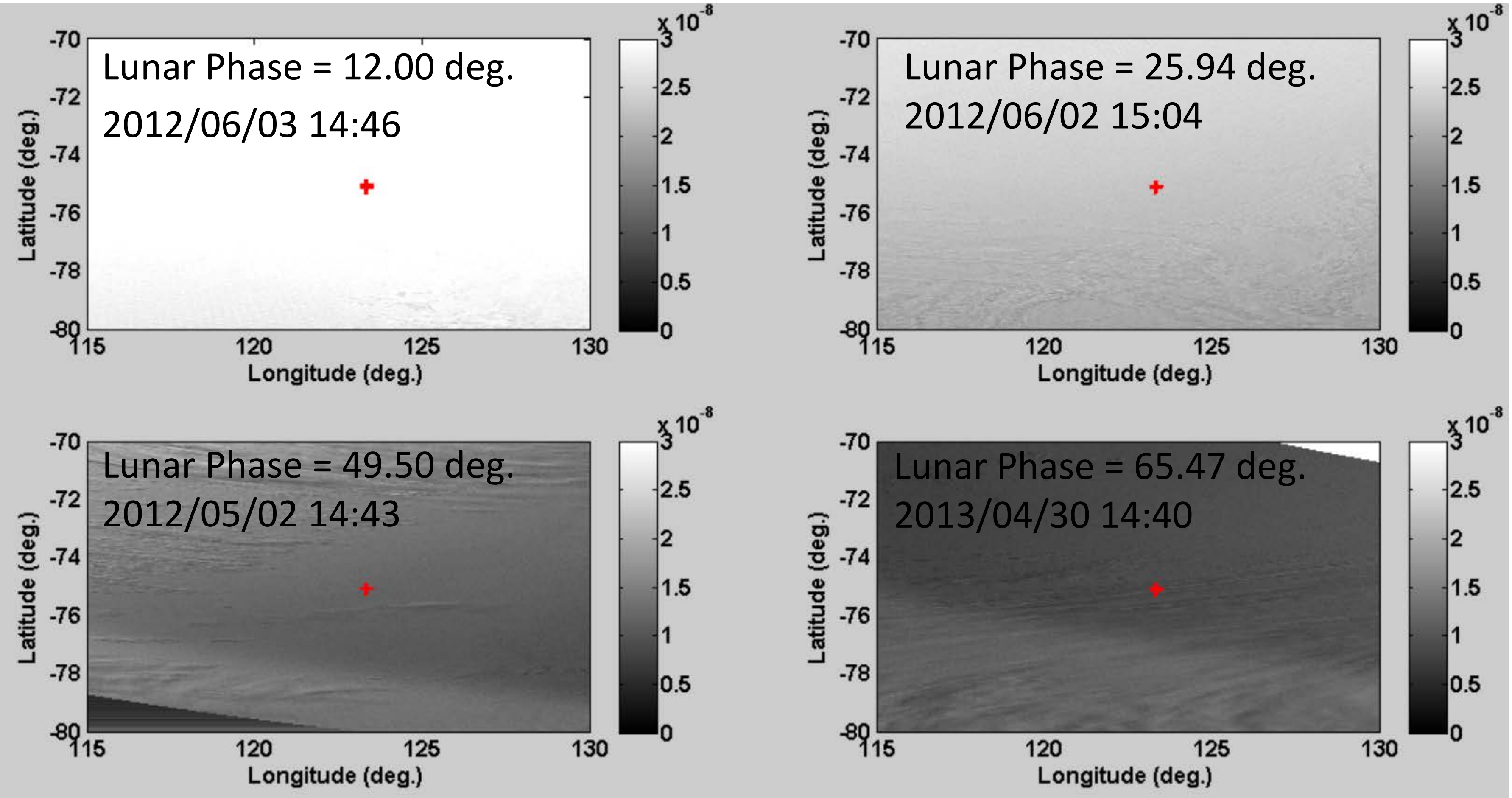
- Observations from perpetual night
  - Dome-C at Antarctic (Apr.-Aug.)
  - Greenland (Nov. – Jan.)
- Both sites
  - High reflectance
  - Stable atomosphere
  - Uniformity
- Dome-C
  - Radiometric calibration site for CEOS

# Data Selection Criteria

- Suomi-NPP overpasses the ROI
- Solar zenith angle >118.4º. No influence of stray light effects
- Lunar phase angle < 90º, i.e. lunar phase is larger than the quarter moon.
- Lunar zenith angle < 80º
- Both above conditions ensure that adequate lunar light illuminates the vicarious sites.



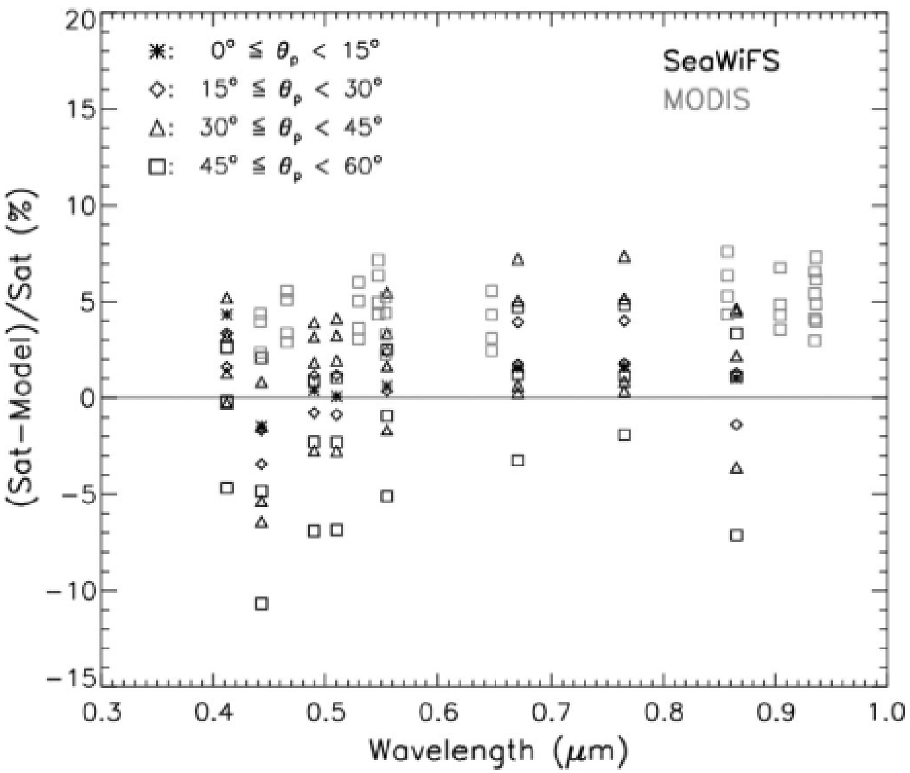
# DNB observations of Dome-C at different lunar phases




- To derive TOA reflectance at Dome-C/Greenland from DNB Observations
  - Lunar Irradiance Model
  - Reference reflectance at vicarious sites for comparison

# Use of Miller-Turner (MT2009) Lunar Spectral Irradiance Model to derive TOA Reflectance

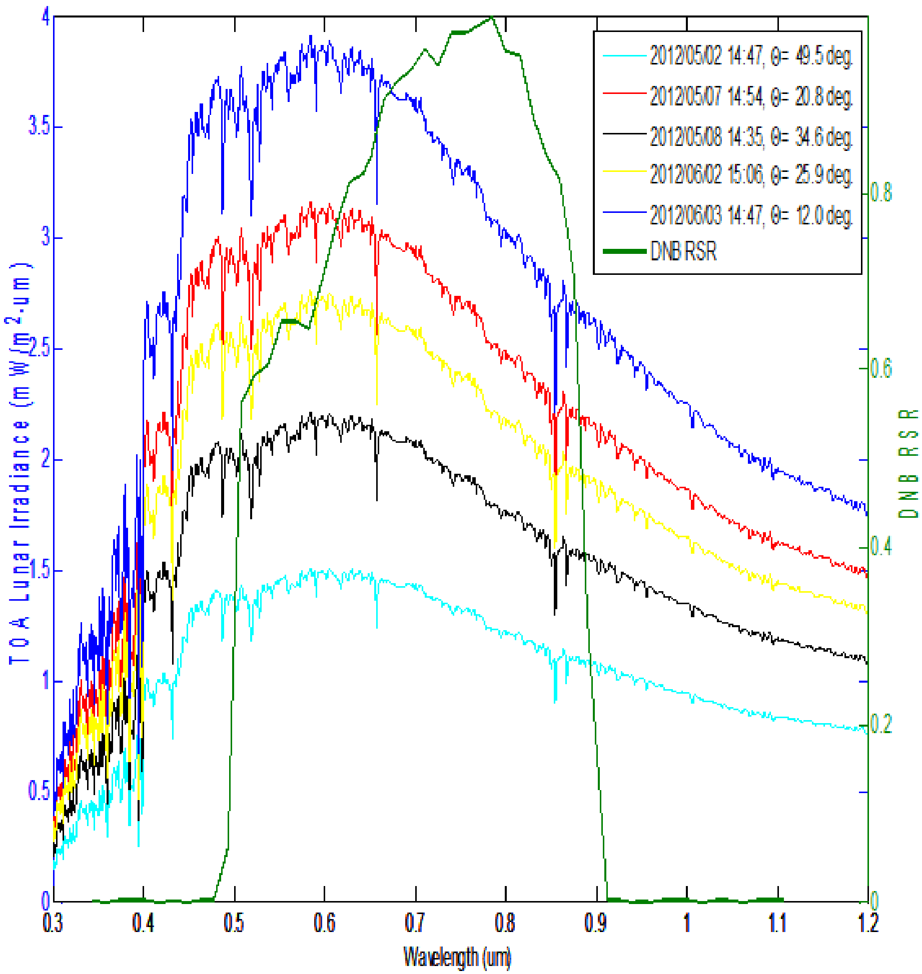
Miller-Turner (2009) Model vs. SeaWiFS and Aqua MODIS




- Miller-Turner (2009) model
  - Developed in preparation for Suomi-NPP VIIRS DNB calibration
  - Quantify spectral irradiance of Moon
  - Incorporated state-of-the-art
    - Solar source observation
    - Lunar spectral albedo data
  - Account for Sun/Earth/Moon geometry and lunar phase
  - Covering **0.3-2.8 um** spectra with 1-nm resolution.
  - Benchmarked against observation, and ROLO model
  - **Publically available**

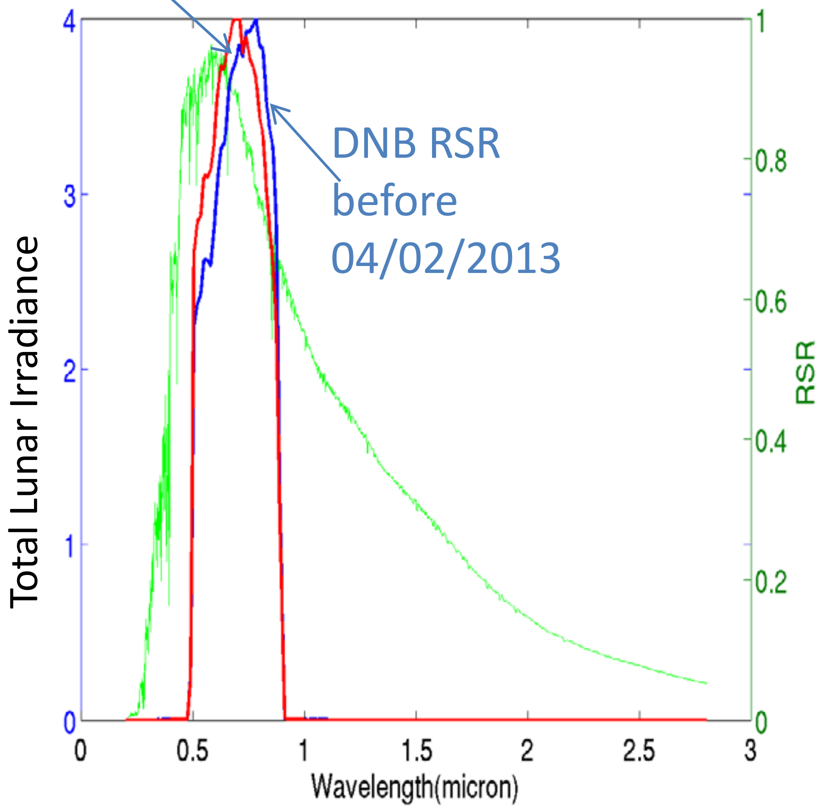
# Lunar Irradiance Model and DNB RSR

Miller-Turner 2009 Lunar Irradiance Model




DNB RSR after 04/02/2013

DNB RSR before 04/02/2013

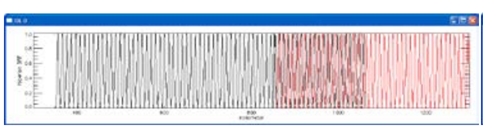


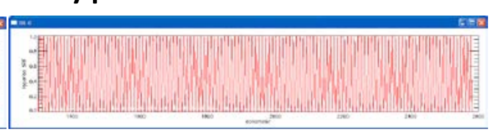

Change in RSR causes ~3-4% increase in lunar radiance.

# Characterization of DOME-C/Greenland Reflectance from Hyperion Observations

- Hyperion is on-board of the Earth Observing One (EO-1) Mission, launched in November, 2000.
- 242 spectral channels covering visible and SWIR (0.35 to 2.57 um)
- Pushbroom sensor with two spectrometers. 256 pixels, 30 m on the ground, 7.65 km swath.

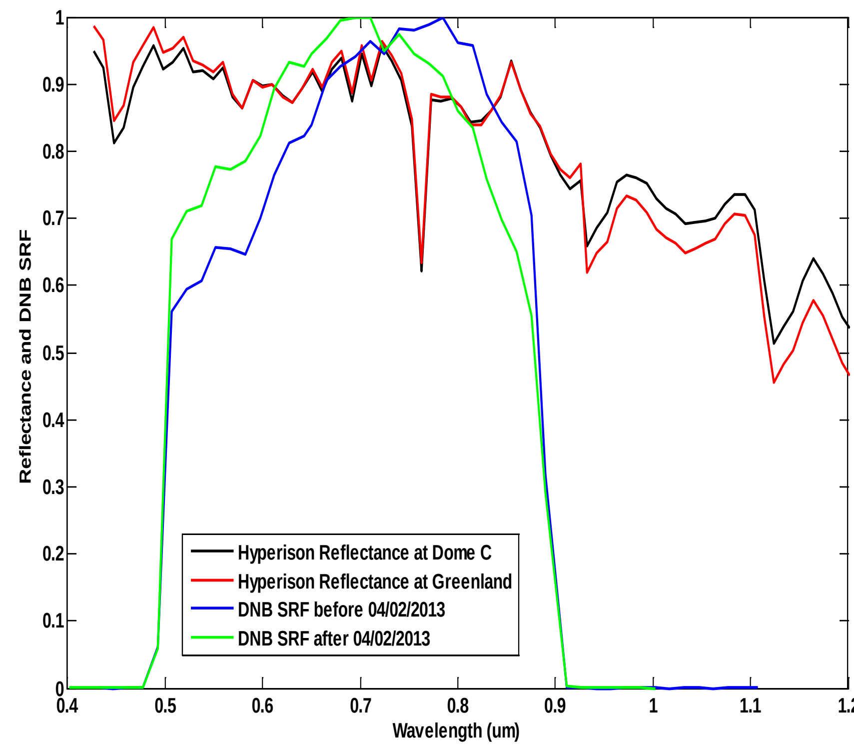
Spectral response functions for 242 channels of Hyperion





Visible bands Near infrared bands

**Characteristic Reflectance of Vicarious Sites from Hyperion**




DNB RSR before 04/02/2013

$\rho_{Dom\ C,Hyp} = 0.886$ $\rho_{Greenland,Hyp} = 0.892$

DNB RSR after 04/02/2013

$\rho_{Dom\ C,Hyp} = 0.889$ $\rho_{Greenland,Hyp} = 0.894$

# Results: DNB Observation vs. Model

TOA lunar radiance above the ROI sites

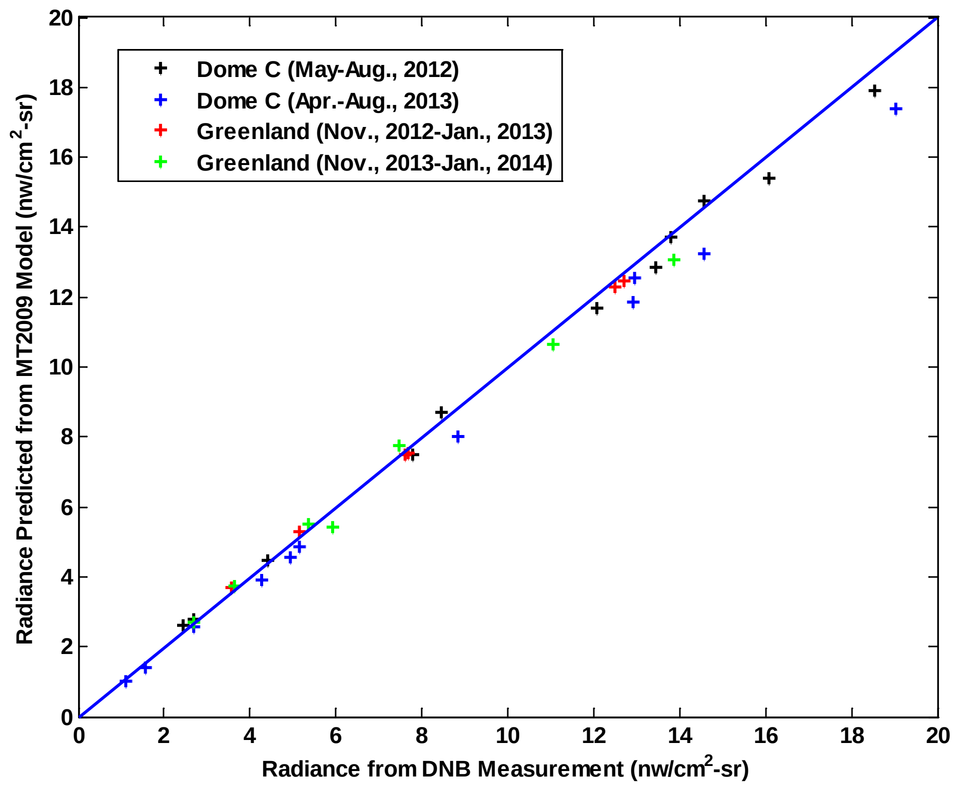
$$L_{MT2009} = \frac{E_m}{\pi}\cos(\theta_m)$$

$E_m$ downwelling top-of-atmosphere (TOA) luna

$$E_m = \frac{\int_{\lambda_1}^{\lambda_2} I_{MT}(\lambda) SRF(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} SRF(\lambda) d\lambda},$$

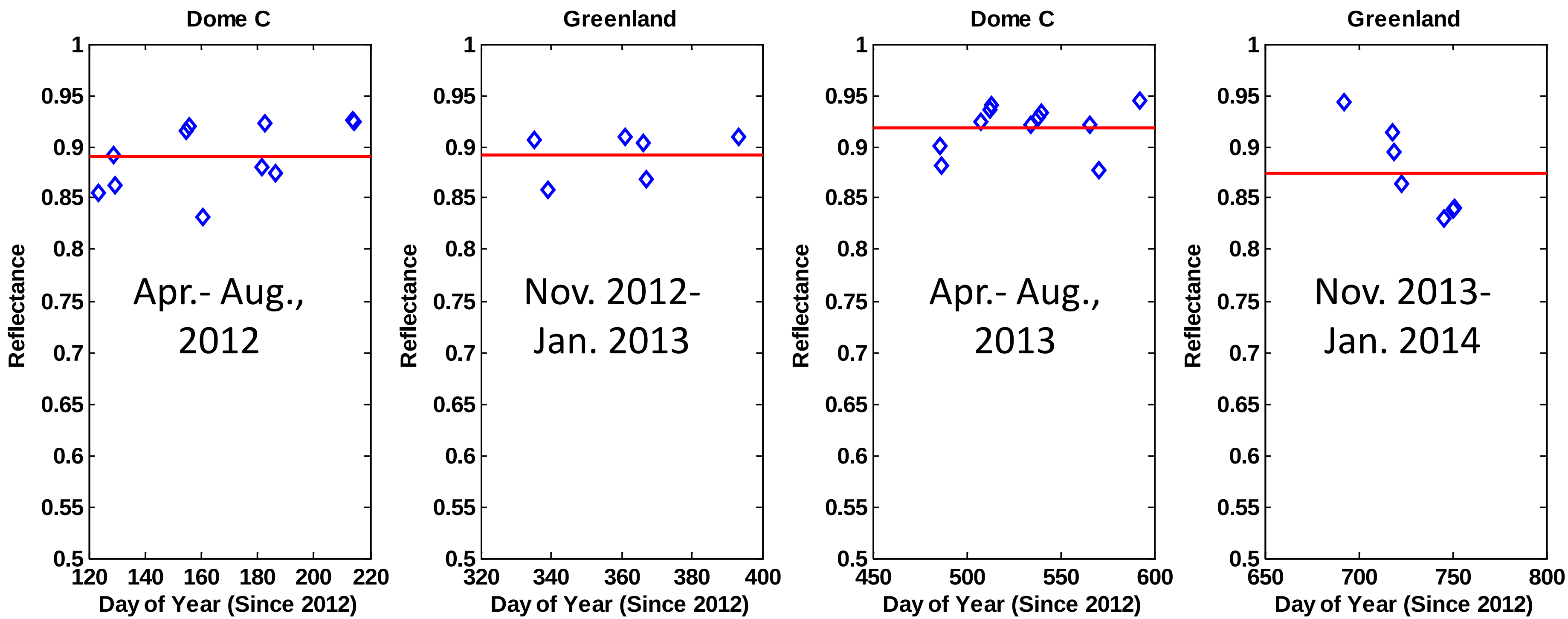
SRF is the spectral response function of DNB sensor.

$$\rho_{DNB} = L_{DNB}/L_{MT2009}.$$




Total: 35 observations;
$R^2$ = 0.989, RMSE = 0.529

# Trending of TOA Reflectance derived from DNB Observations

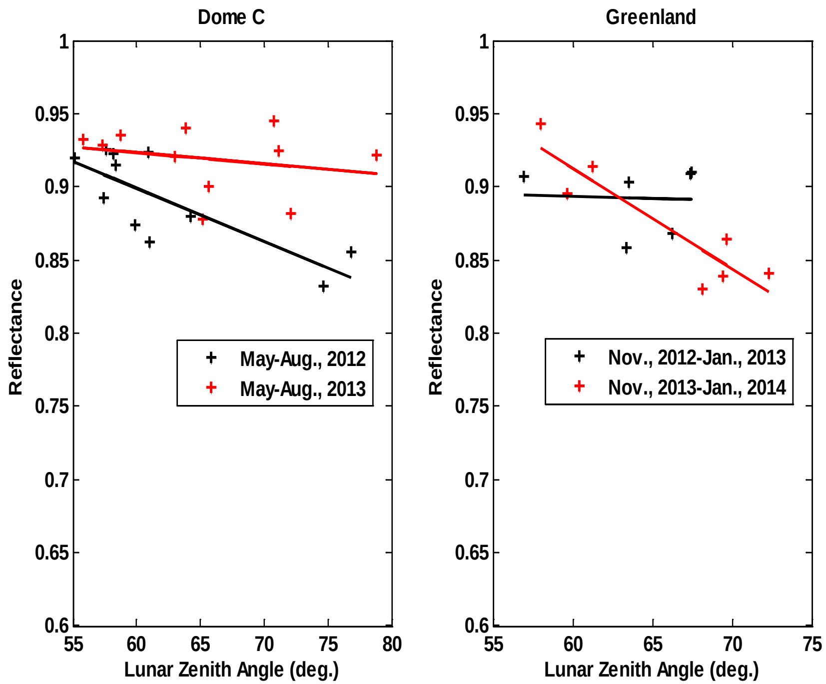



| $\rho_{Hyperion}$ | 0.886 | 0.892 | 0.889 | 0.894 |
|---|---|---|---|---|
| Mean $\rho_{DNB}$ | 0.891 ±0.033 | 0.892±0.023 | 0.919±0.023 | 0.875±0.043 |
| Mean $\rho_{DNB}/\rho_{Hyperion}$ | 1.006±3.7% | 1.0±2.6% | 1.034±2.6% | 0.979±4.8% |
| Range of $\rho_{DNB}/\rho_{Hyperion}$-1 | [-6.1%, 4.5%] | [-3.8%, 2.0%] | [-1.3%, 6.3%] | [-7.6%, 5.0%] |

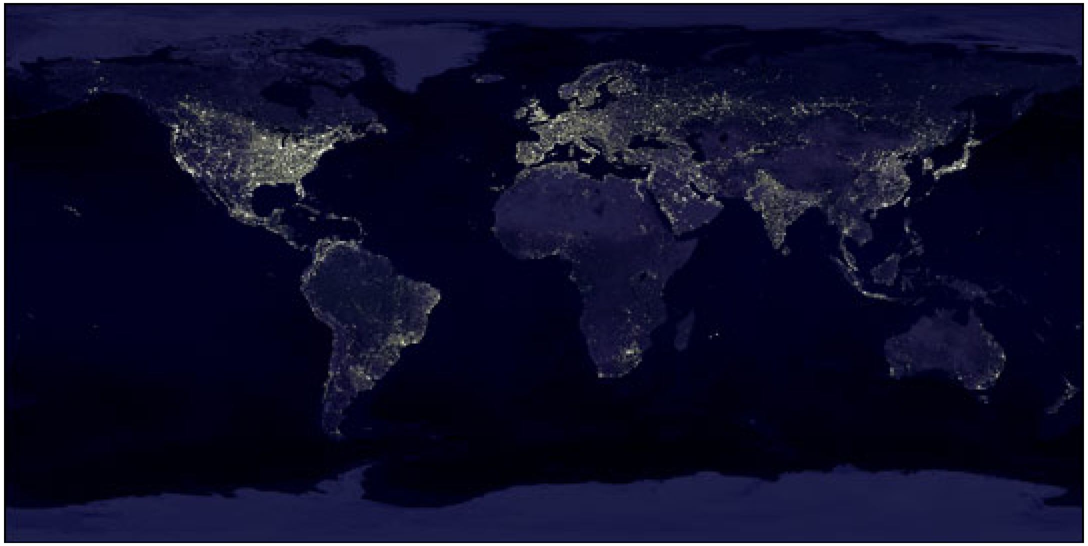
# Radiometric Uncertainty of VIIRS-DNB

- DNB HGS radiometric variability (relative accuracy) ~8% is within the DNB specs (30%) and smaller than the 15% from post-launch performance analysis by Liao et al., 2013.
- Difference w.r.t. Liao et al., 2013 analysis
  - 2012-2014 vs. Mar.- Oct. 2012
  - Vicarious sites selection (Dome-C/Greenland vs. Railroad Valley Playa)
  - Events with stray light effects excluded in our analysis
  - Various lunar phases in our analysis vs. Near full moon in Liao et al., 2013
  - Different lunar irradiance model
- Residue variability in our analysis can be from lunar irradiance model, atmospheric absorption/scattering and its variability, BRDF of vicarious sites.

Reflectance vs. Lunar Zenith Angle



# Preliminary radiometric calibration of DMSP-OLS using VIIRS-DNB through vicarious calibration



- Onboard series of DMSP-OLS (Defense Meteorological Satellite Program/Operational Linescan System) (F4-F19) satellites
- Collecting night low light imaging data for more than 40 years
- Various applications such as military surveillance, estimating population, monitoring social-economic development and power consumption, and providing weather and climate related data.

# VIIRS-DNB vs. DMSP-OLS

| Variable | DMSP-OLS | SNPP-VIIRS |
|---|---|---|
| Builder / Operator | U.S. Air Force | NASA – NOAA Joint Polar Satellite System (JPSS) |
| Orbit | Polar – 850 km altitude, 98.8 degree inclination, 102 minutes | Polar – 827 km altitude, 98.7 degree inclination, 102 minutes |
| Swath | 3000 km | 3000 km |
| Nighttime overpass | ~19:30 | ~01:30 |
| Low light imaging bandpass | Panchromatic 0.5 to 0.9 um | Panchromatic 0.5 to 0.9 um |
| Additional spectral bands | Thermal infrared (10 um) | 21 additional bands spanning 0.4 to 13 um. |
| Quantization | 6 bit | 14 bit |
| Saturation | Common in urban cores | No saturation |
| Calibration | None for low light imaging band. | Solar diffuser used to calibrate daytime DNB data. Calibration extended to low light imaging mode using data collected along solar terminator. |

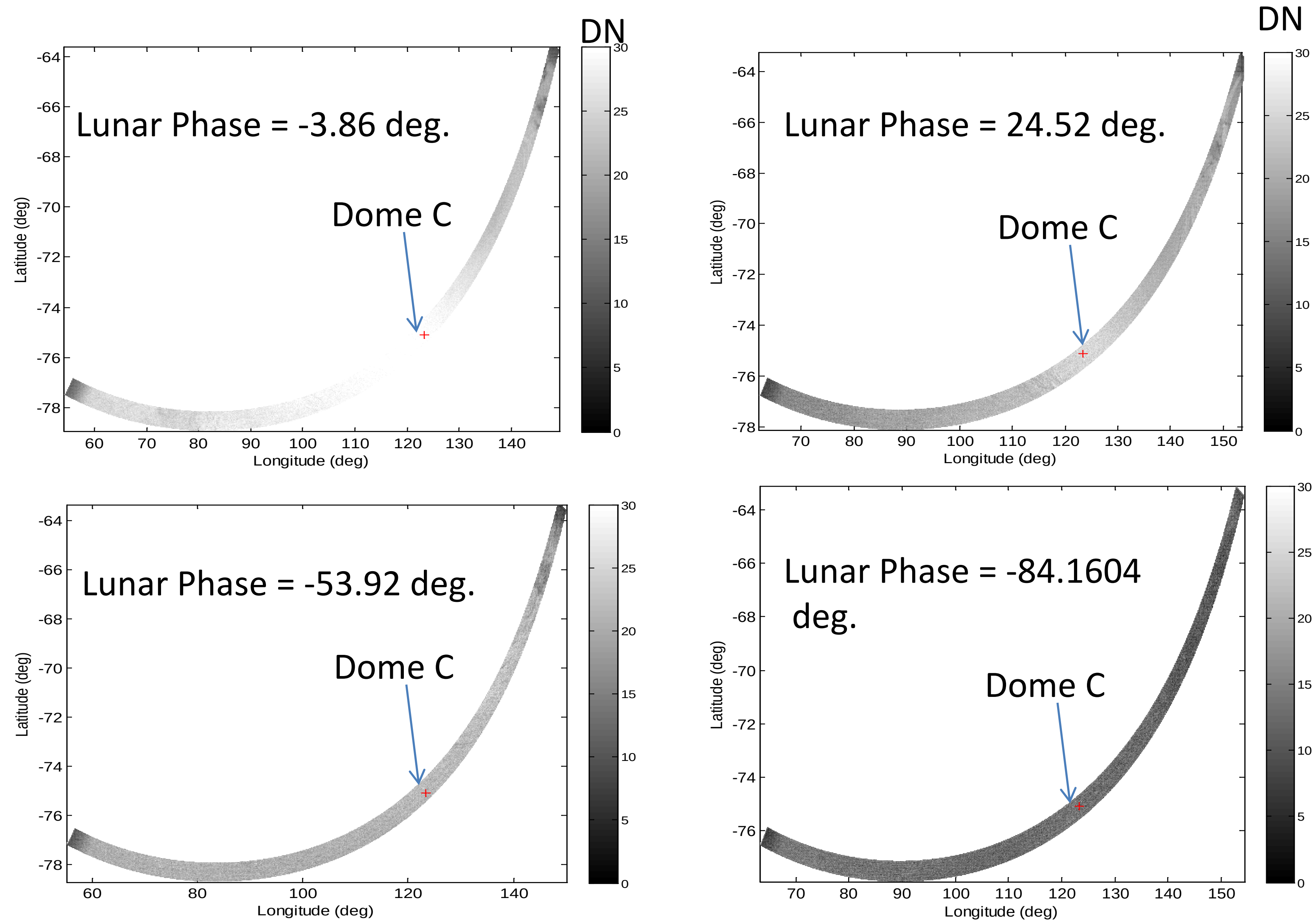
Elvidge et al., 2013

- Perform vicarious calibration of DMSP- OLS using VIIRS-DNB
- Convert DN of DMSP-OLS into radiance unit

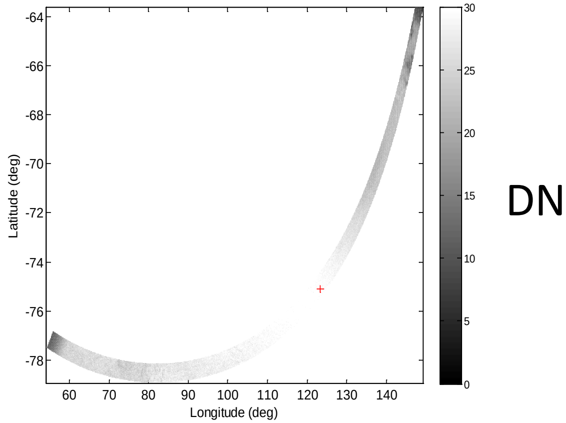
# Screening Criteria

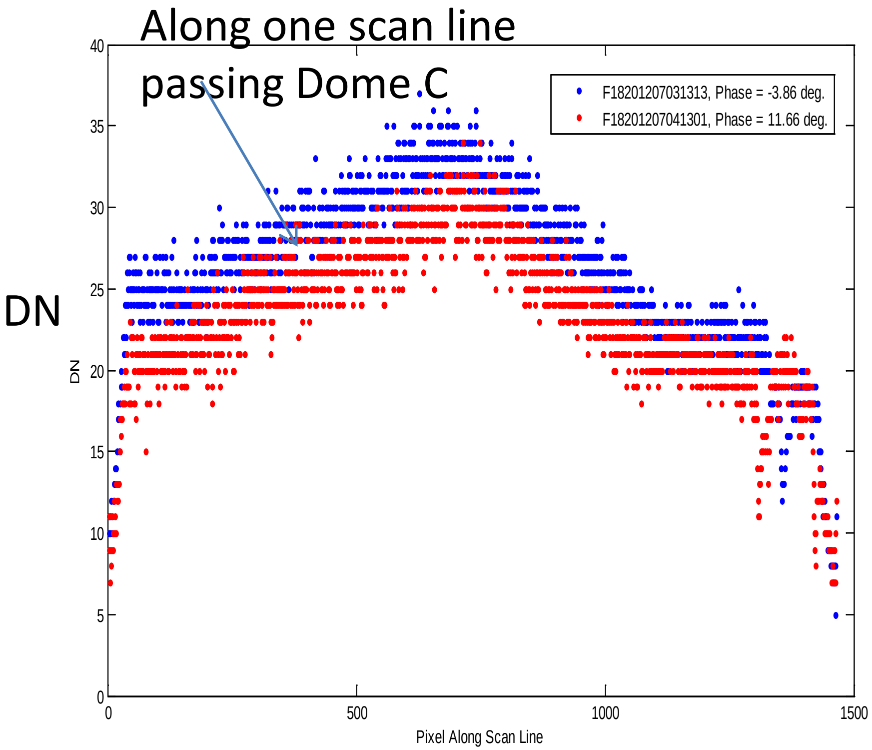
- ROI: Dome-C (Latitude: -75.1; Longitude: 123.25);
- DMSP-OLS overpasses the ROI, i.e. the nadir distance to DOME-C is < 300 km.
- Solar zenith angle >118$^{o}$. Overpass occurs at night and there are no influence of stray light effects
- Lunar phase angle is less than 90 degree, i.e. moon is larger than the quarter moon.
- Lunar zenith angle <80 degree
- Over all, 8 observations are selected from DMSP data from May to July, 2012.

# DMSP-OLS F18 Observation of Dome C under moon light with different lunar phases



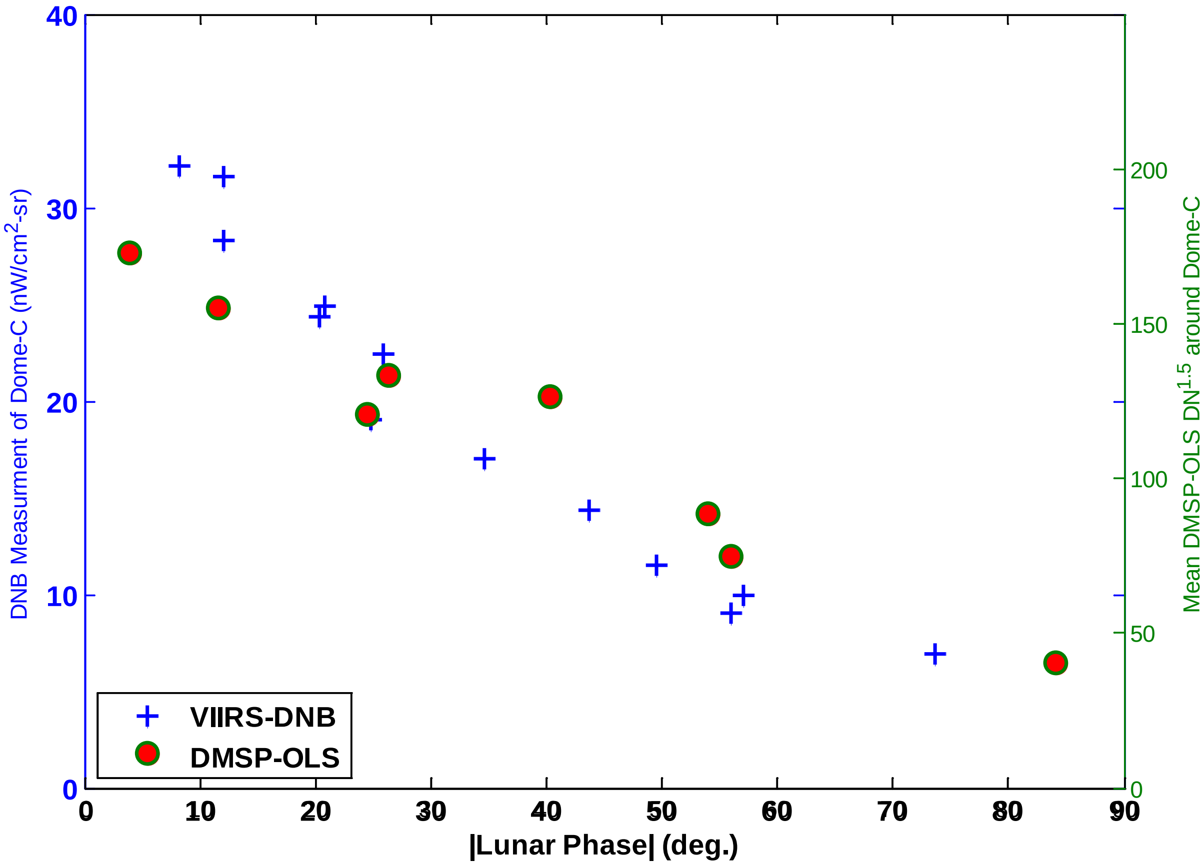
# Deriving Mean DN$^{1.5}$ at Region of Interest from DMSP-OLS data




- Strong scan-angle dependence of DMSP-OLS data
- We derive mean DN$^{1.5}$ within 10 km around nadir of DMSP-OLS in the Dome-C region.
- Correct for Sun-Moon and Moon-Earth Distance.
- Arrange data w.r.t. lunar phase angle together with that from VIIRS-DNB during 2012.

# Estimation of conversion coefficient of DMSP-OLS ($DN^{1.5}$) to Radiance Unit

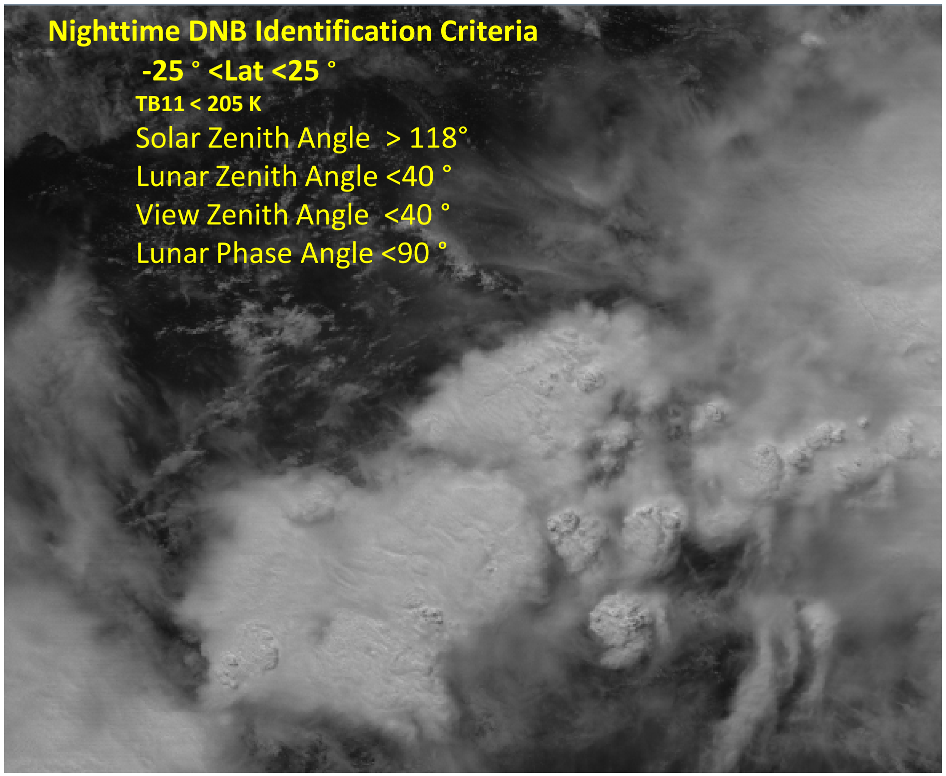



- DMSP-OLS Radiance = $\alpha$ $DN^{1.5}$ ($W/cm^2$-sr), $\alpha \sim 1.6 \times 10^{-10}$ ($W/cm^2$-sr)
- Further analysis of 2013 data will be performed

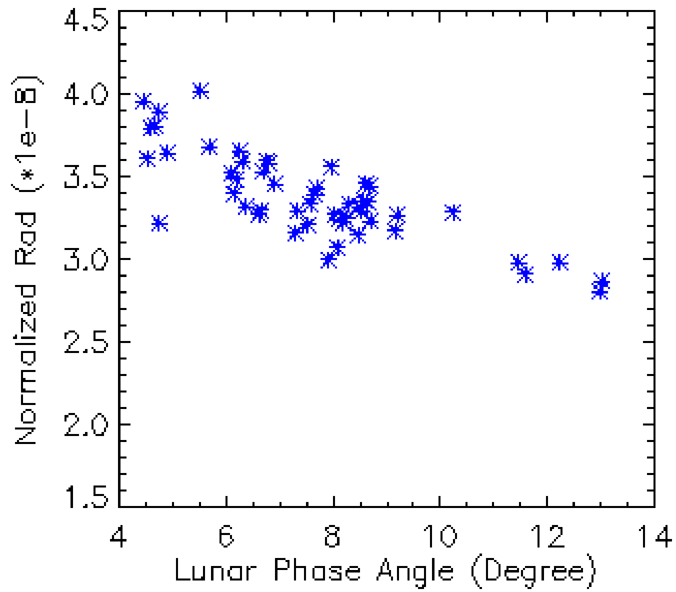
# Future work: Calibration of VIIRS-DNB with Deep Convective Clouds

## DCC Under Moonlight

(Granule d20140116_t1432272_e1433514 )




Preliminary Analysis




Granule avg. nighttime DNB DCC radiance (adj. for lunar zenith angle effect) vs. Lunar Phase Angle

# Summary

- Validated and performed trending of the radiometric performance of VIIRS-DNB with vicarious sites (Dome-C/Greenland) under moon light
- Performed preliminary radiometric calibration of DMSP-OLS using VIIRS-DNB through vicarious calibration
- Future work
  - Continue radiometric validation/calibration and trending of DNB using vicarious sites (Dome-C, Greenland and others) and DCC
  - Improve lunar irradiance model, characterization of BRDF of vicarious sites to reduce uncertainty
  - Study vicarious observations with stray light corrections being applied and assess the radiometric performance of DNB.
  - Cross-calibrate with DMSP-OLS.