Cloud Properties using Lunar Reflectance from S-NPP VIIRS

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Motivation

- Nighttime cloud properties for optically thick clouds are not commonly available though clouds are known to have large diurnal cycles
- With the added capability we can
  - Provide improved ceiling and icing products to the aviation community.
  - Provide cloud microphysics for precipitation retrievals
  - Provide day/night consistent products for NWP verification.
  - Study day/night biases and variations for climate studies.
- The DNB band from VIIRS provides an unprecedented opportunity to study nighttime clouds, specifically we are exploring the impact of the DNB Lunar reflectance on …
  - ➢ Cloud Detection
  - ➢ Cloud Overlap Detection
  - ➢ Cloud Optical and Microphysical Properties
  - ➢ Dust Remote Sensing

DNB Radiance → Lunar Reflectance

- The radiance to reflection retrieval was developed by Steven Miller (CIRA)

- In contrast to solar irradiance the computation of down-welling lunar irradiance is a complex task due to many components which have to be considered:
  - Lunar phase
  - Lunar spectral surface albedo
  - Moon-Earth-Sun orbital geometry
  - Lunar zenith angle

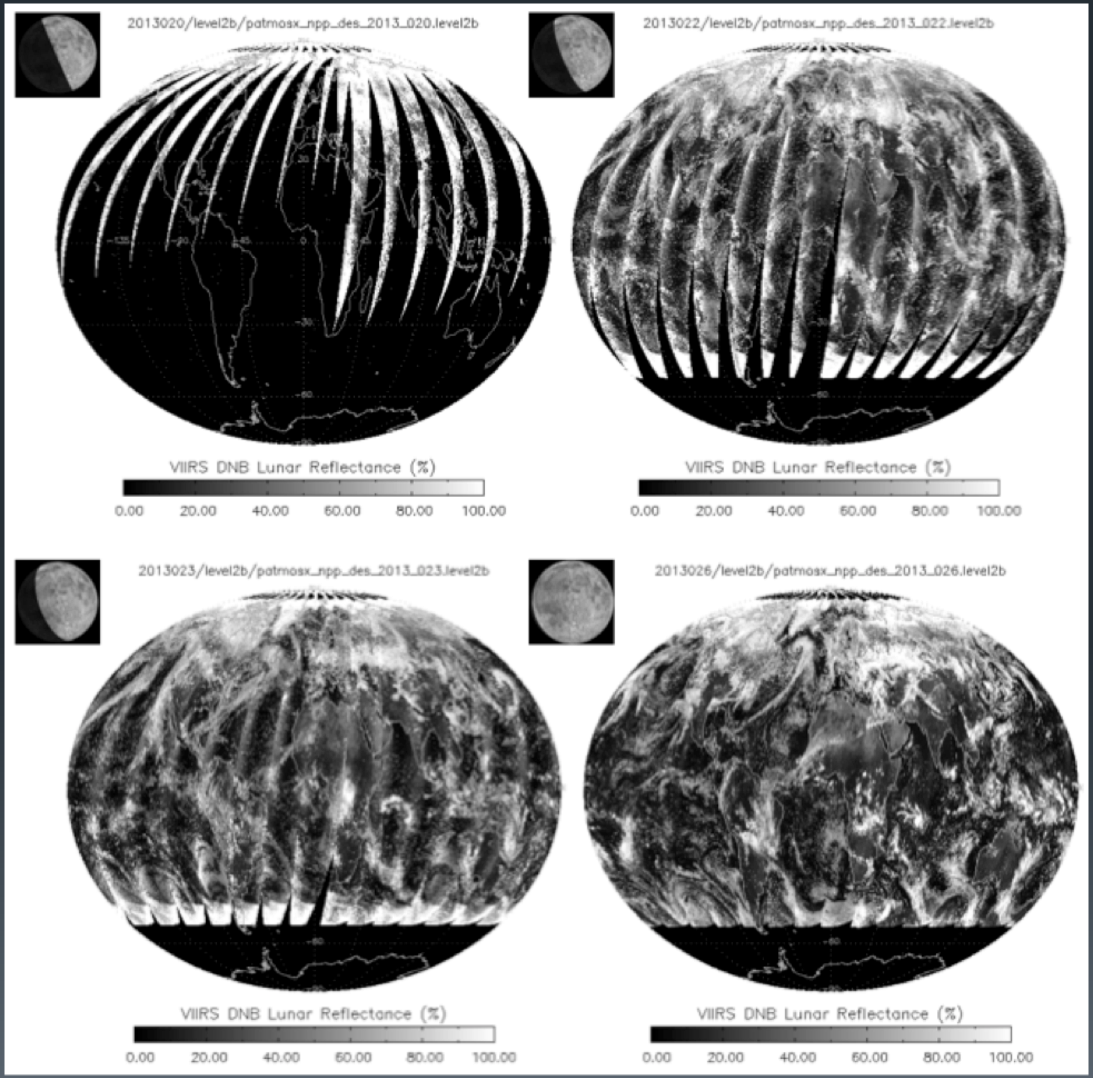
- We expect an overall uncertainty in lunar reflection of 5% with recent corrections for lunar phase-dependent albedo variations.

- Remaining errors are primarily related to libration and phase-dependent **spectral** albedo changes.

- Implemented in CLAVR-x and plans for SAPF but time-line unknown. DNB pixels mapped to M-bands

Global Coverage of Calibrated Lunar Reflectance

- Lunar cycle is about 29.5 days
- Lunar reflectance requires filtering of solar zenith (19 below the horizon)
- Sufficient global lunar reflectance coverage is ~70% of nighttime
- Winter poles have coverage most of the time



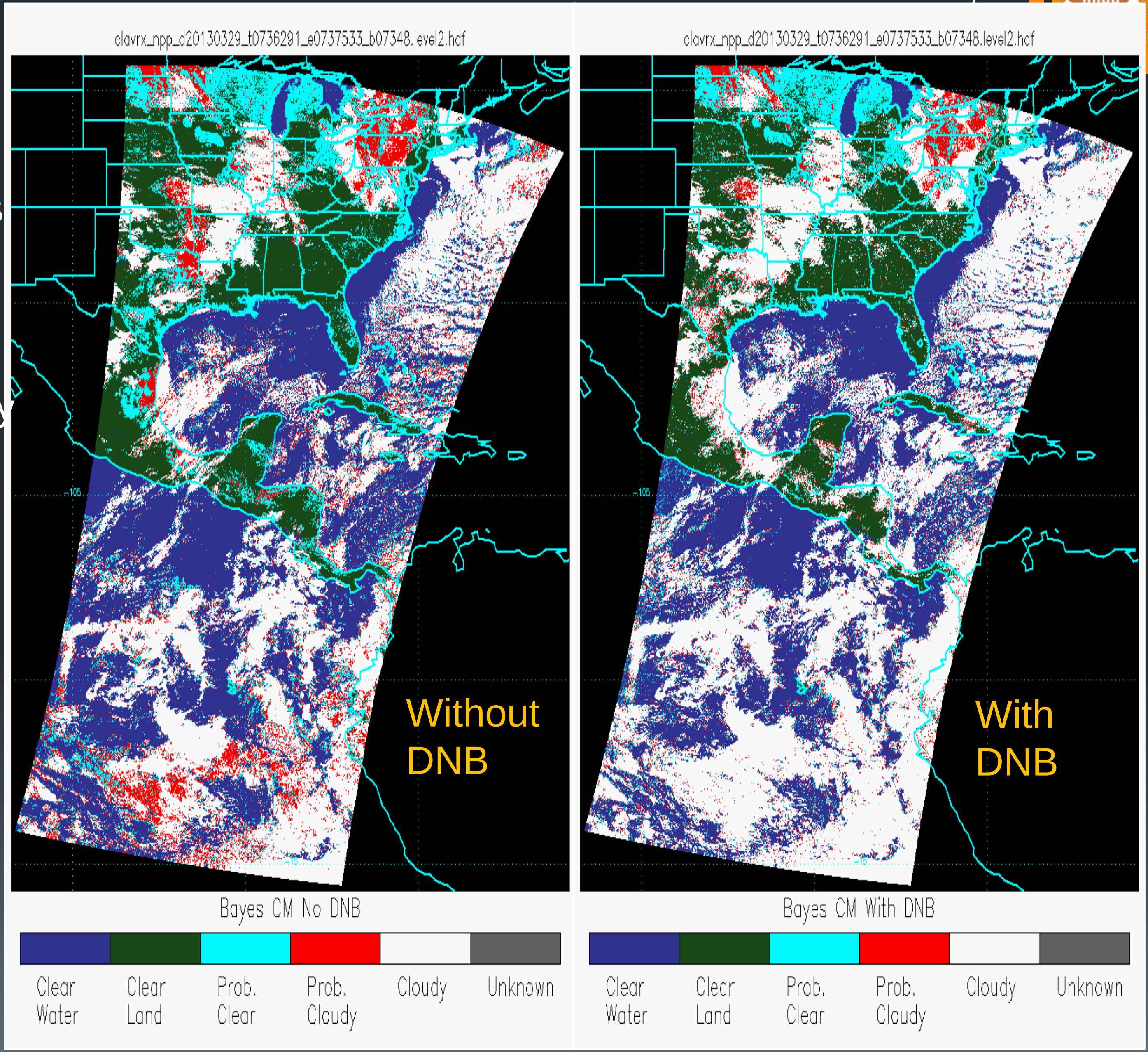
Cloud Detection

Using VIIRS DNB Lunar Reflectance for Cloud Detection

- NOAA Enterprise Cloud Mask (CLAVR-x) has been modified to use the lunar reflectance in its naïve Bayesian Cloud Detection Algorithm.
- We do this to try and improve day/night consistency.
- Clear-sky estimate computed using a combination of 0.63 and 0.86 μm MODIS surface reflectance.
- Cities detected using DNB radiance threshold. Gas Flare detection still being developed.
- No explicit treatment for Auroras.

Impact of Lunar Reflectance on Cloud Mask Detection

- Less uncertainty to cloud mask when DNB is used
- Originally probably cloudy scenes are identified as confidently cloudy
- Global Stats:
  - POD values increase from 90% to 93%. (relative to CALIPSO)
  - cloud fraction increases by 3%
  - Probably cloudy amount drops in half.



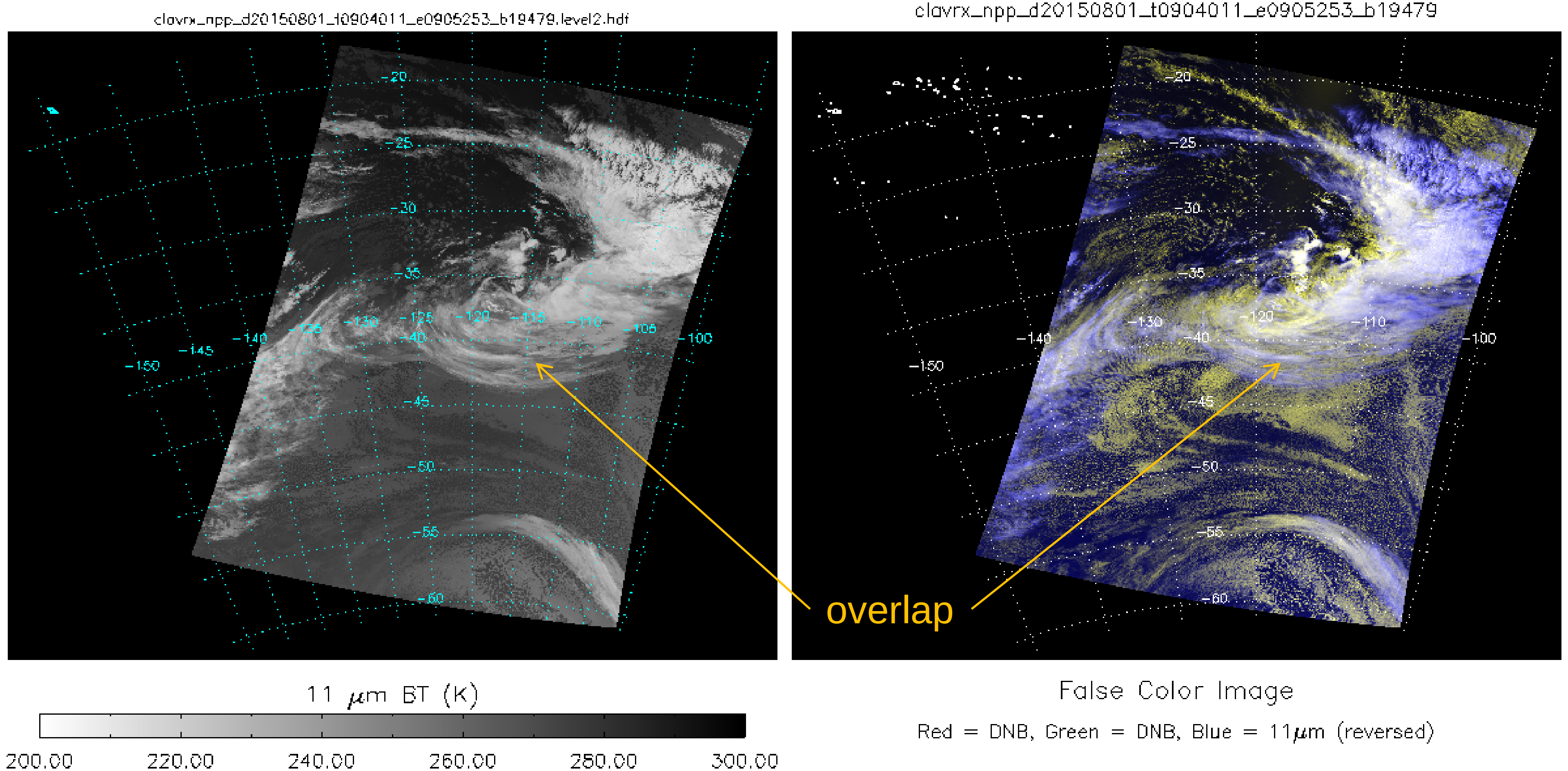
Cloud Overlap Detection

Motivation for Overlap Detection

- Knowledge of cloud overlap is important since our retrievals often fail when this occurs and we don't handle it.
- Ability to detect depends on spectral information.
- GOES-R AWG (Pavolonis et al) approach utilizes IR absorption channels which are missing on VIIRS.
- Visible + IR methods are applicable to VIIRS but not at night.
- We are exploring DNB based augmentation to improve cloud overlap detection.
- Important for height retrievals and these impact VIIRS Winds.

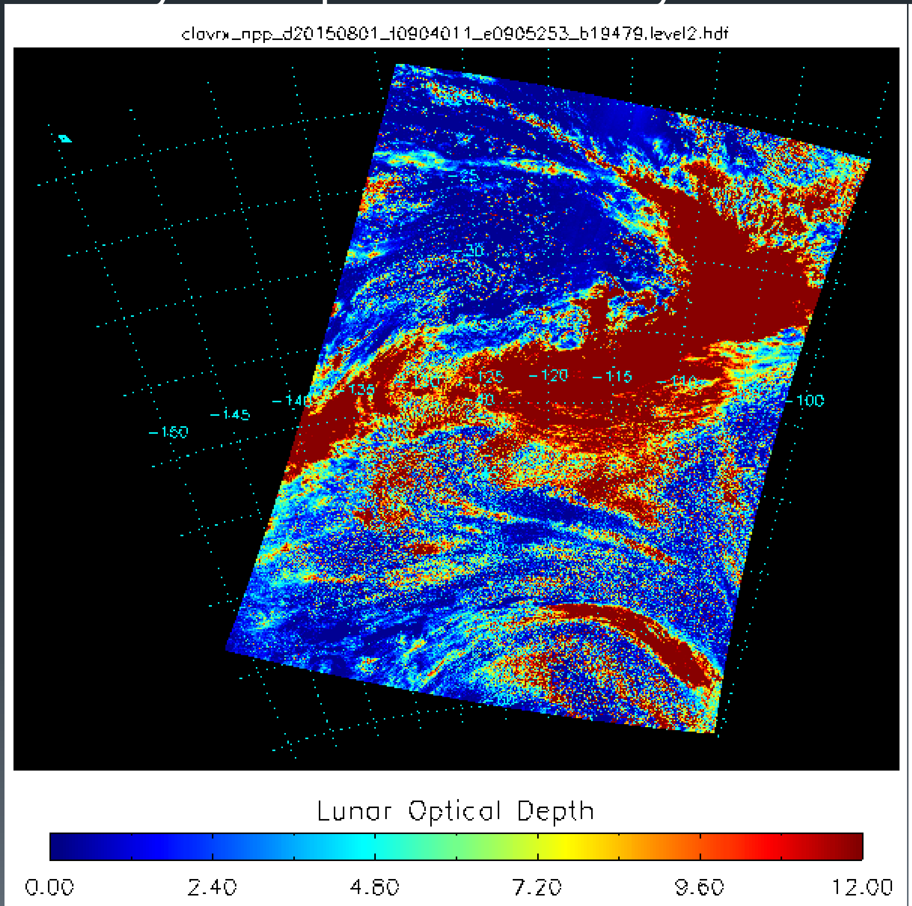
Example Of Overlap Detection with Lunar Reflectance

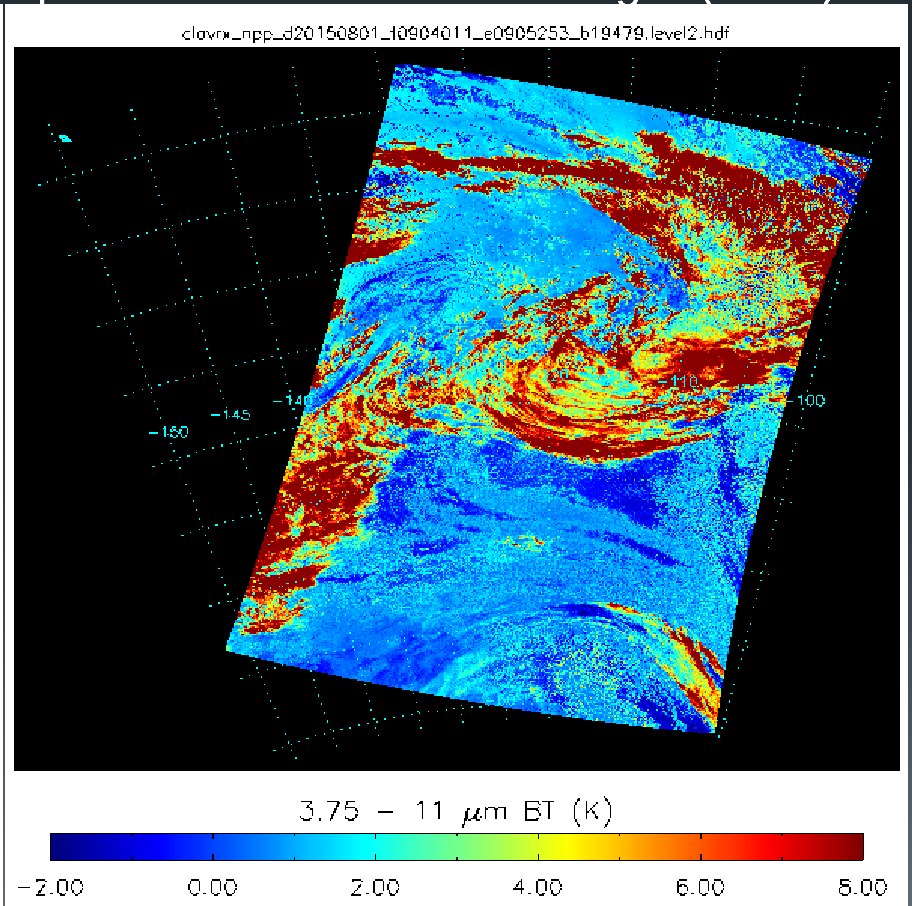
- S-NPP VIIRS August 1, 2015 (Nearly Full Moon)
- Window thermal bands are inconclusive on presence of overlap.
- Addition of Lunar Ref to a false color image shows overlap clearly.



Method

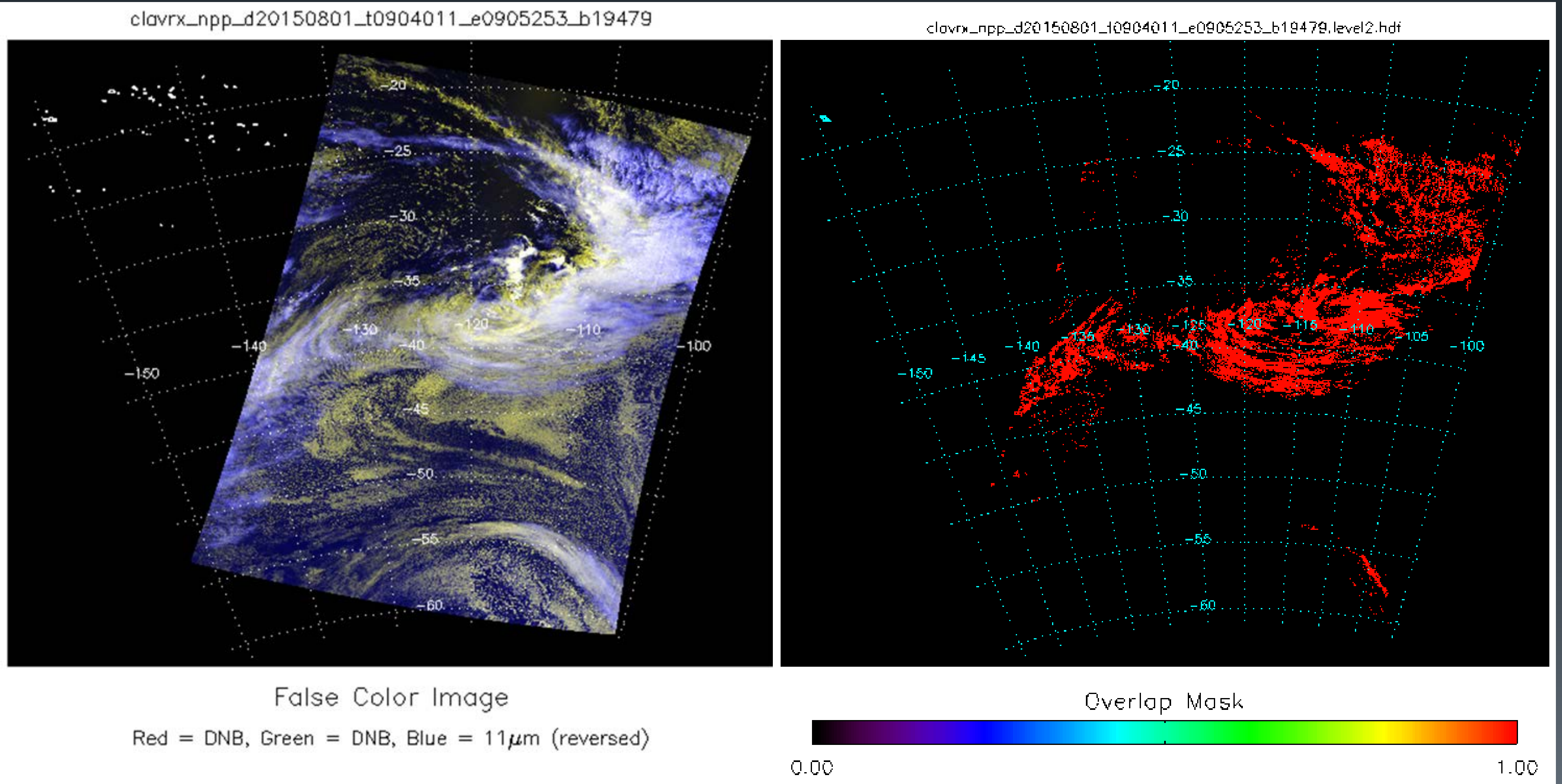
- Overlap detection is often accomplished by detecting spectral inconsistencies.
- We know cirrus clouds are semi-transparent and should exhibit large 3.75-11 μm BT and small values of reflectance or optical depth.
- Overlapped clouds (high over low) can give both high optical depths and high values of 3.75-11 μm BT.
- Below we show these two quantities. Pixels that are red in both images, are likely overlap. Similar to day-time technique in Pavolonis and Heidinger (2004)





Results

- Here is the resulting overlap detection for this scene.
- Goal is to finalize this and test impact to the official NOAA Enterprise Cloud Typing Algorithm.
- In a similar effort for CCL, we are using CrIS radiances with a similar goal.

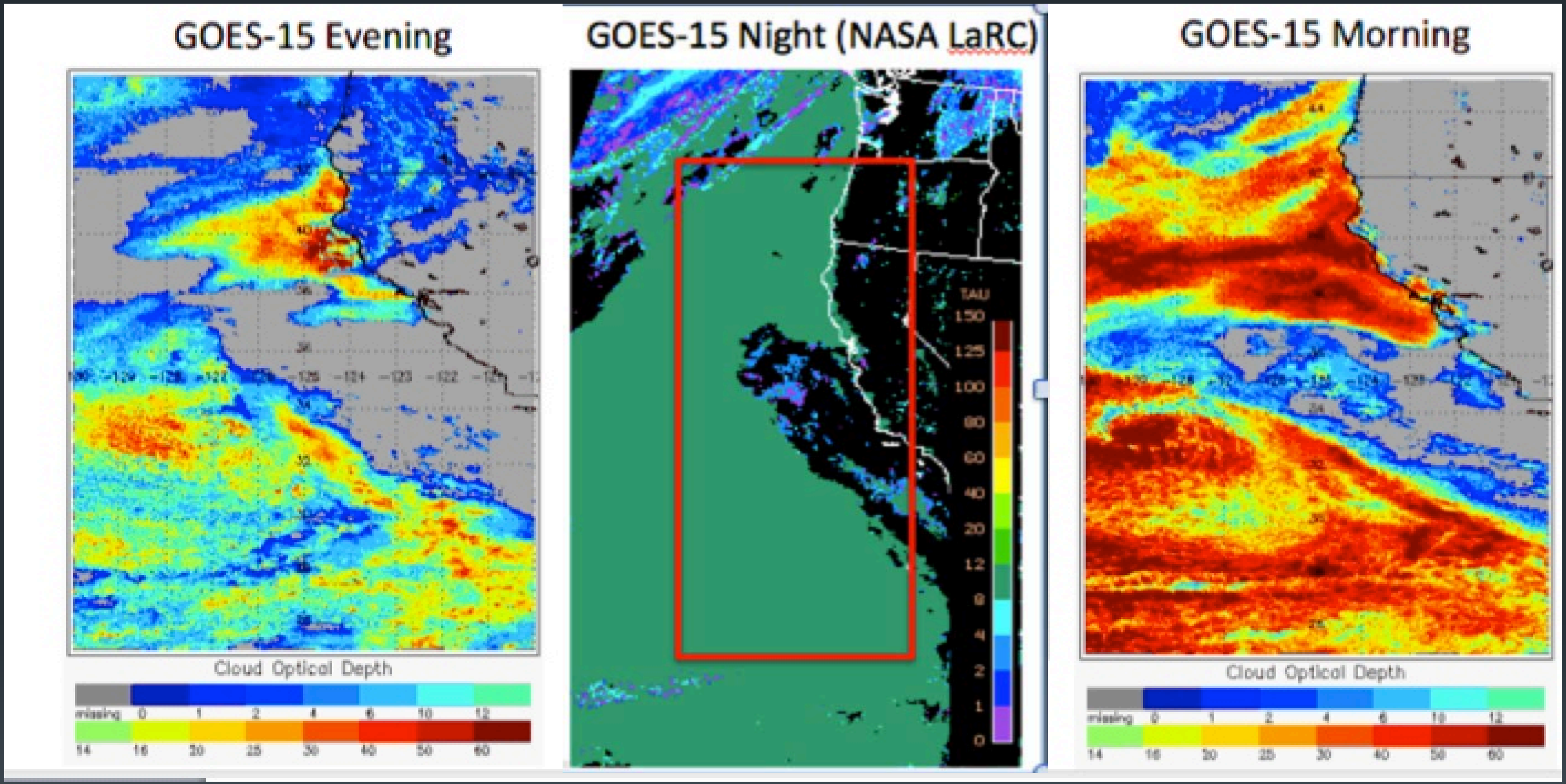


Cloud Micro and Optical Properties (NLCOMP)

The Nighttime Lunar Cloud Optical and Microphysical Properties (NLCOMP) retrieval

- Is the nighttime adaption of the daytime equivalent DCOMP (Daytime-COMP)
- Retrieves Cloud Optical Thickness and Effective Radius, those can be used to derive cloud water path.
- Input parameter: DNB visible lunar reflectance and M-12 (3.75um) brightness temperature
- NLCOMP products has higher uncertainty than DCOMP due to higher uncertainty of lunar reflectance in contrast to solar reflectance.
- Limitations: City lights, ships, diffuse lights, etc..

NLCOMP: Filling the nighttime gap: Cloud Optical Thickness



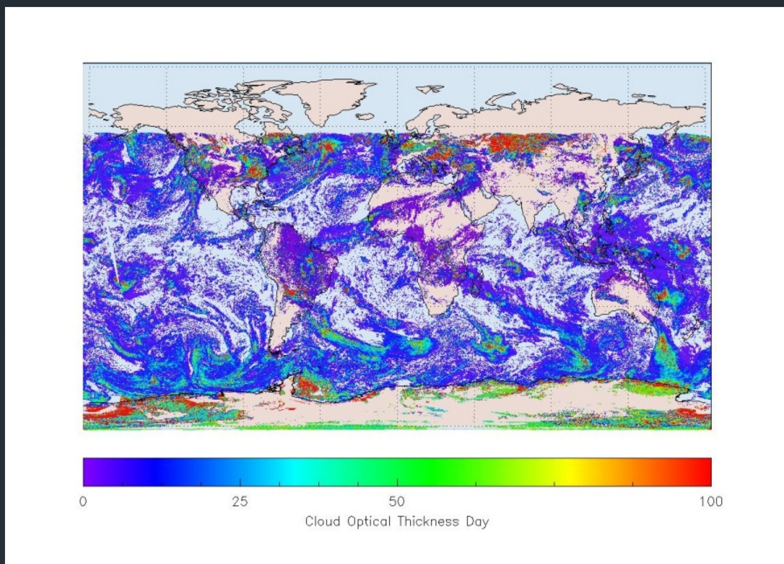
DCOMP
06:30PM

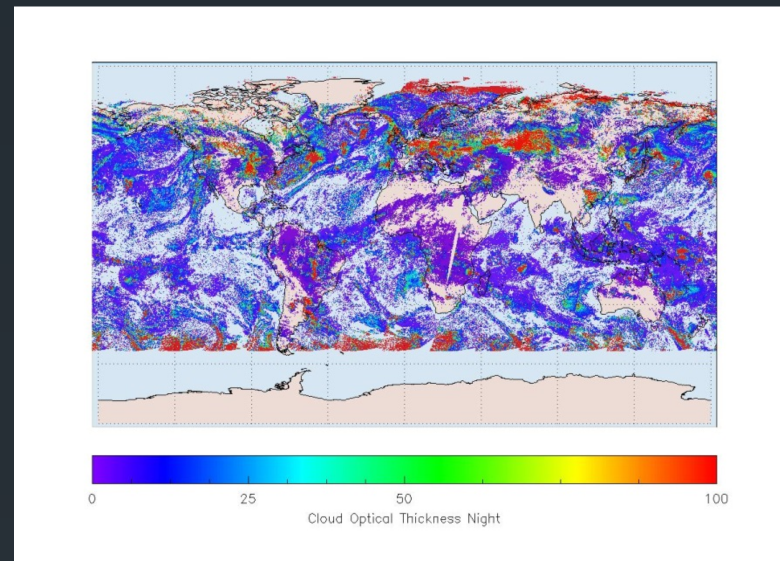
IR-based
01:30AM

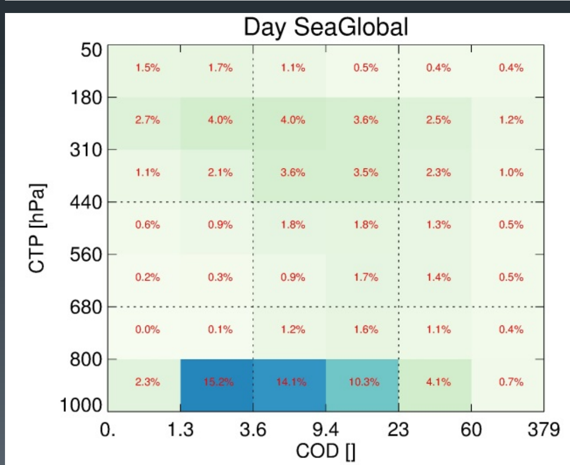
LARC Shortwave Infrared Infrared Split Window Technique (SIST) algorithm (Minnis et al., 1998).

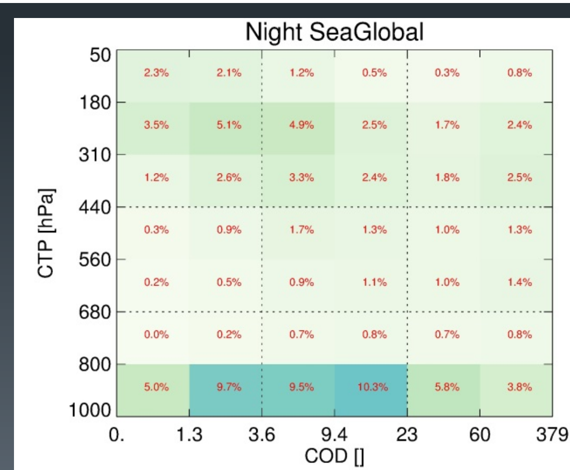
DCOMP
09:30AM

Global daily composite: 27 Jan 2013







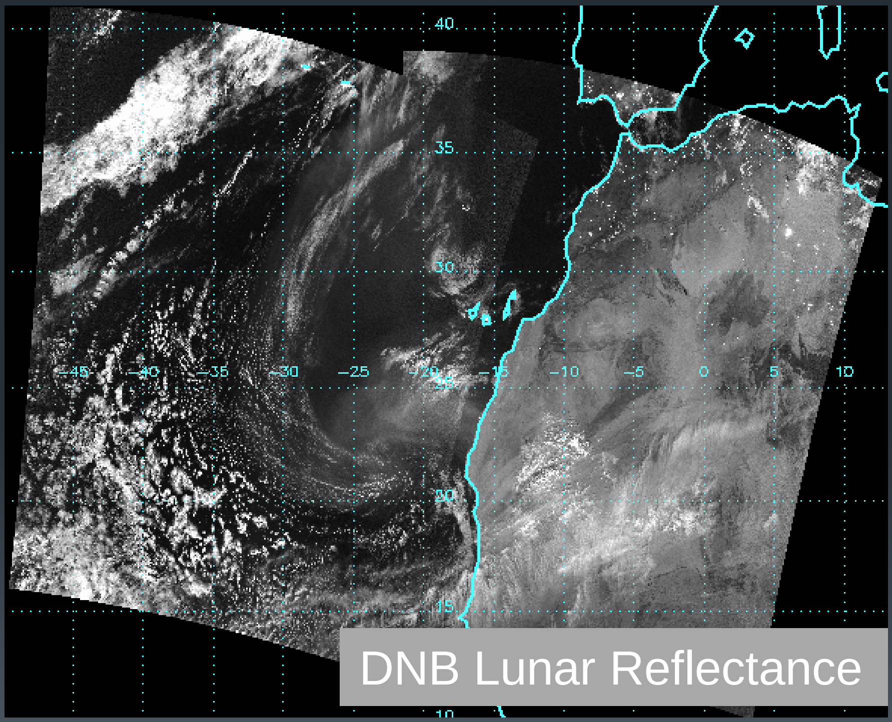


Aerosol Remote Sensing Potential

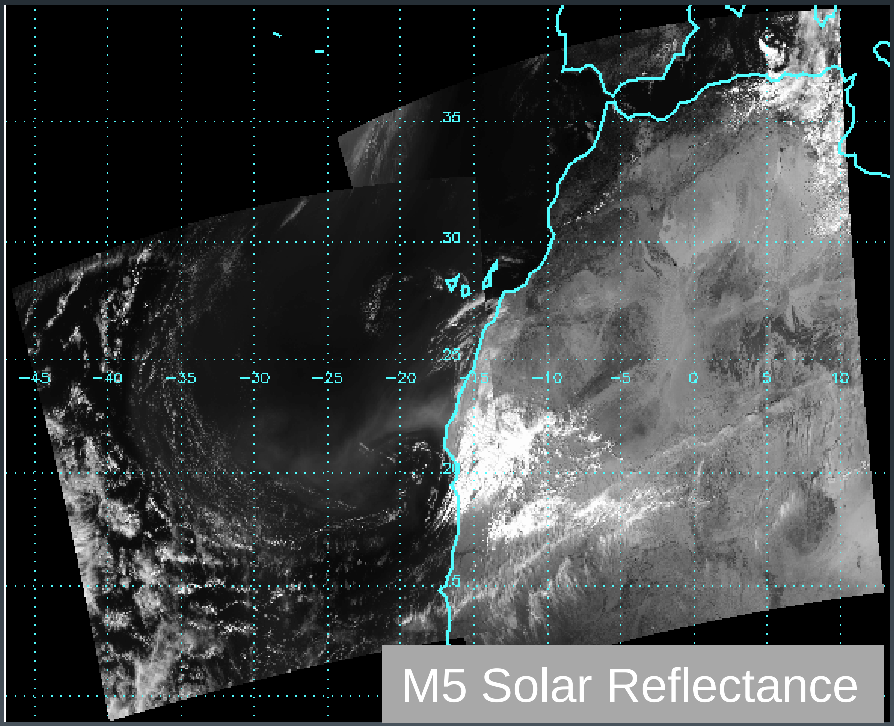
Lunar Reflectance of Aerosol

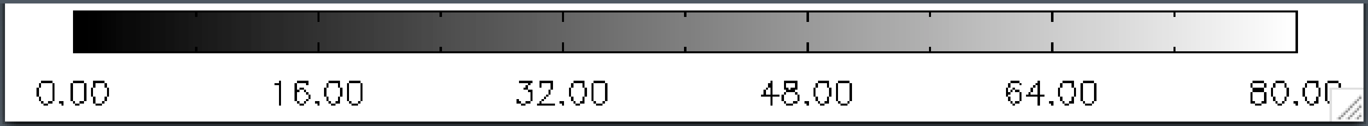
- Thick Aerosol (Dust) is well observed in Lunar Reflectance
- On nights with sufficient illumination, noise appears to be low.

March 9, 2015 Night



March 9, 2015 Day



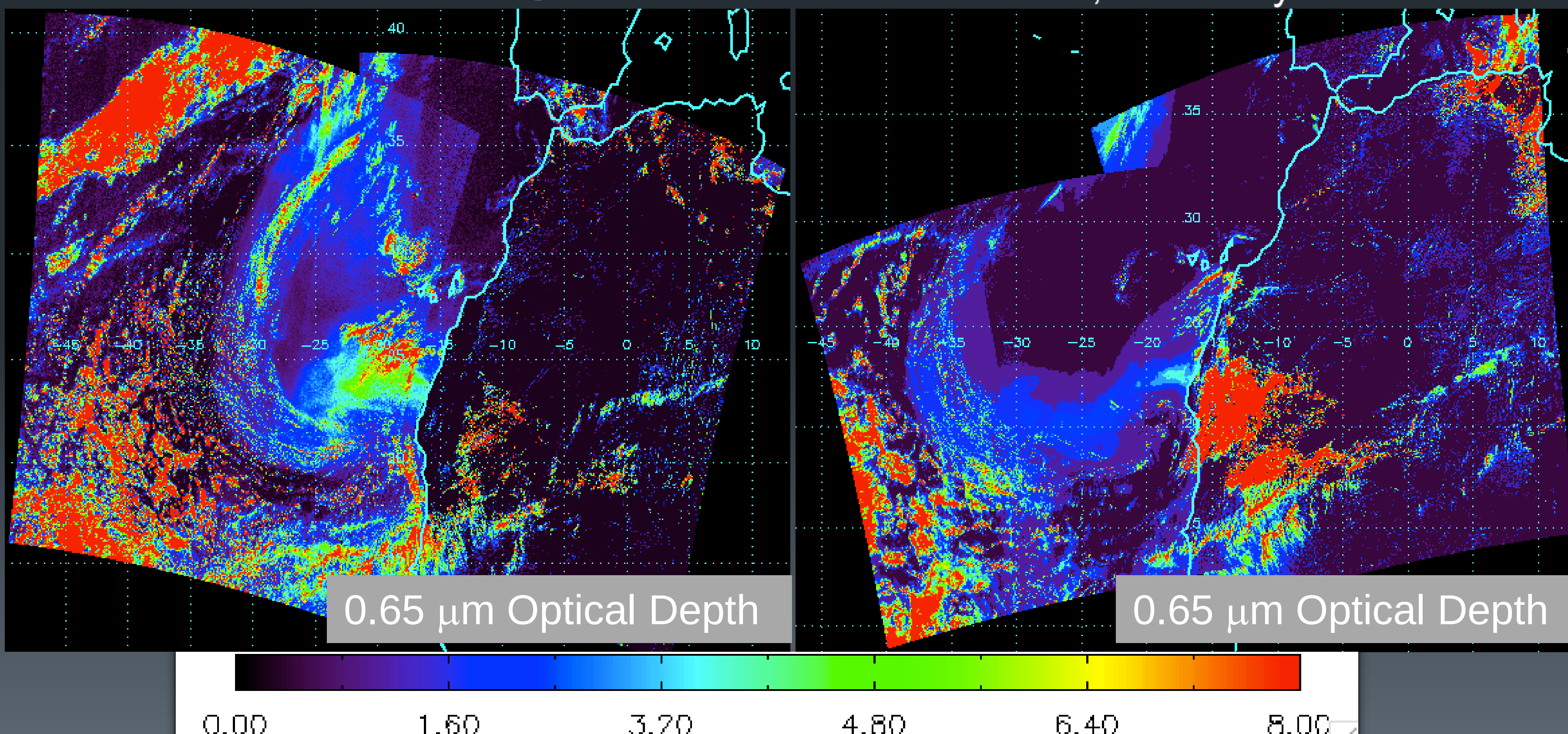


“Dust” Optical Depths From Lunar Ref.

- In the next version of the cloud mask, we will make optical depths everywhere assuming a liquid phase cloud with R_{eff} = 10 microns. Optical depths will replace our reflectance tests.
- Images below show these optical depths for the dust scene.
- Noise also does not appear to be an issue.

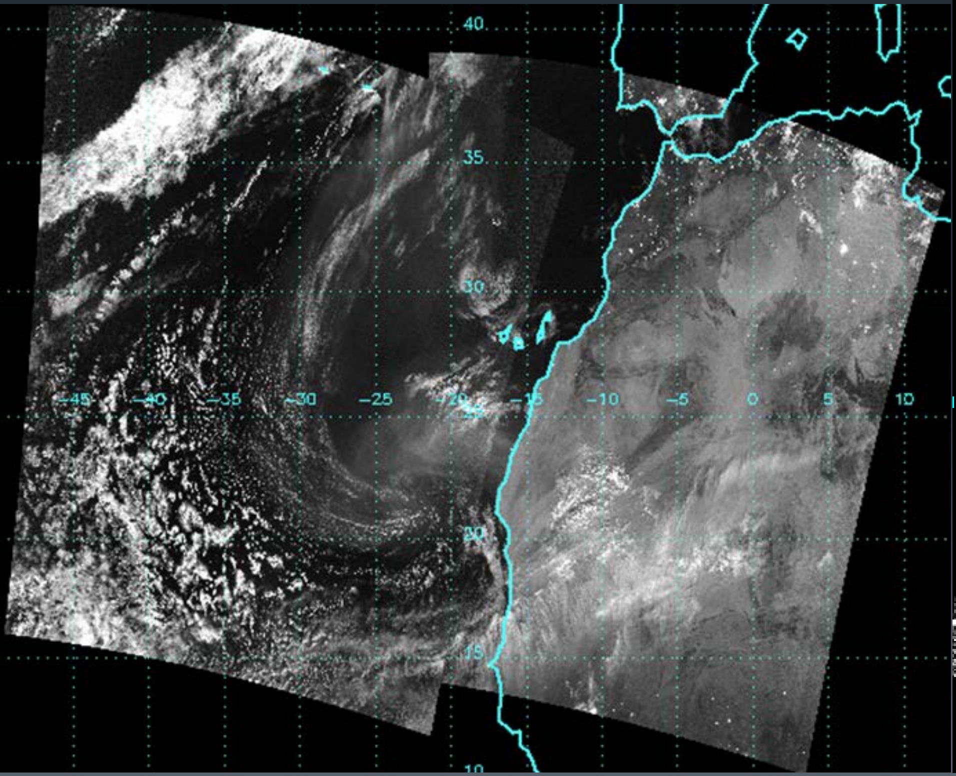
March 9, 2015 Night

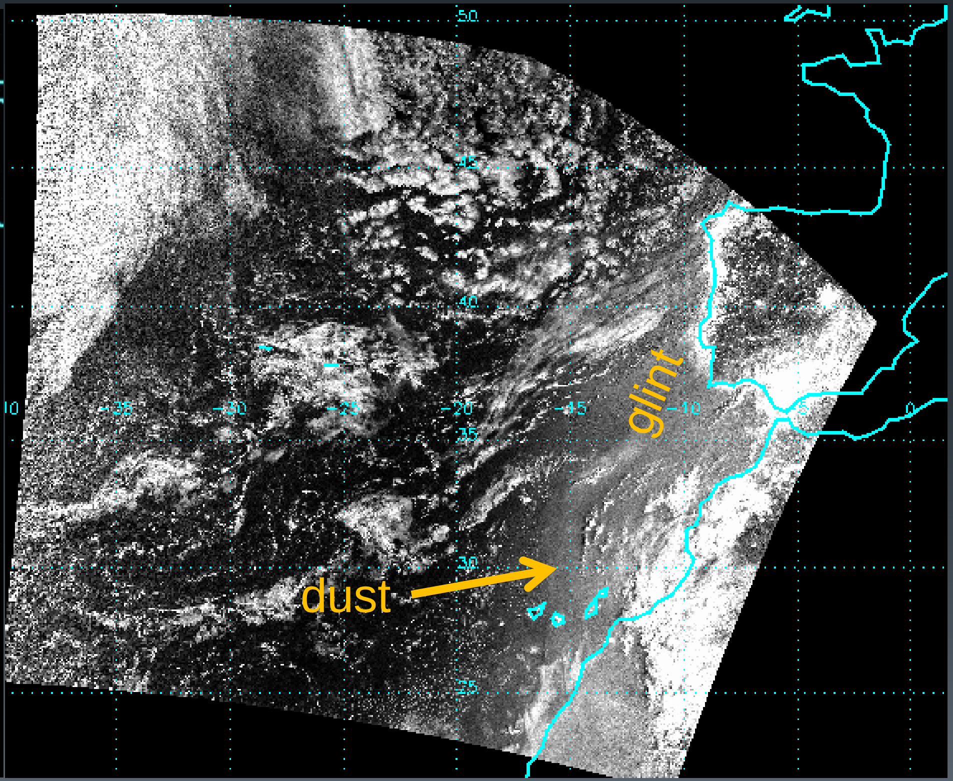
March 9, 2015 Day



Viewing Dust at Different Moon Phases

Noise may be an issue at the limit of illumination (quarter moon) for dust retrievals





Summary

- Lunar reflectance is being used in several ways by the cloud team
  - Improvement nighttime detection in the NOAA Enterprise Mask of low-level cloud (making it more consistent with the daytime).
  - Improving detection of overlapped (multi-layer) cloud with VIIRS at night.
  - Extending retrievals of cloud micro and optical properties to night – where had no similar capability before.
- Aerosol/Dust remote sensing at night is one where area where the Cloud and Aerosol Teams can collaborate. Cloud team plans on using Lunar Ref and needs to detect Dust.
- We plan on serving these in the OCONUS PG and in the Alaska Cloud Products project.
- Thank you JPSS RR for support!

Extra Material

From DNB radiance to Lunar Reflectance

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- In contrast to solar irradiance the computation of down-welling lunar irradiance is a complex task due to many components which have to be considered:
  - Lunar phase
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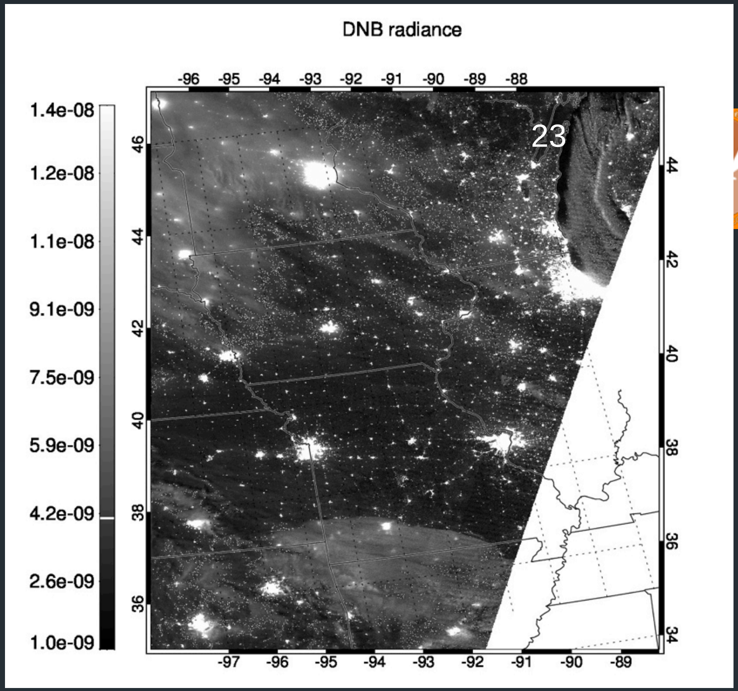
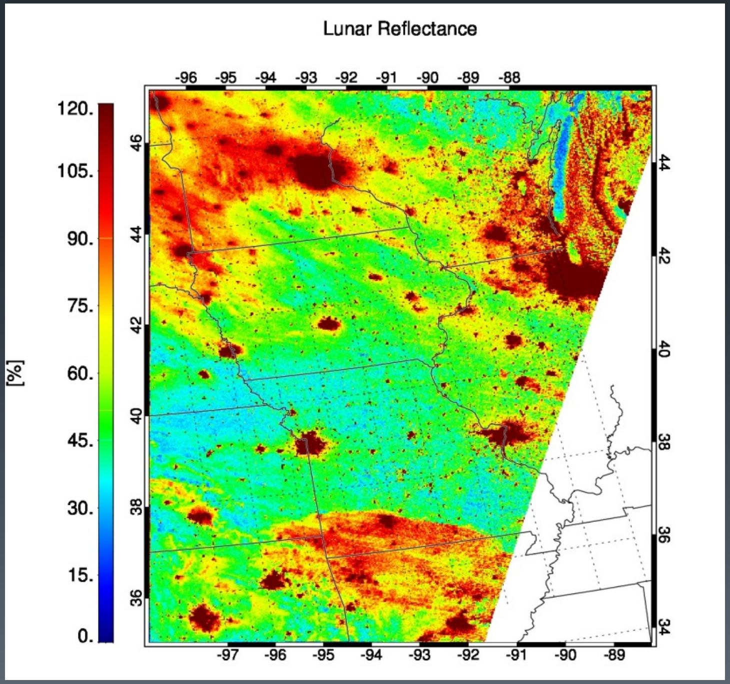
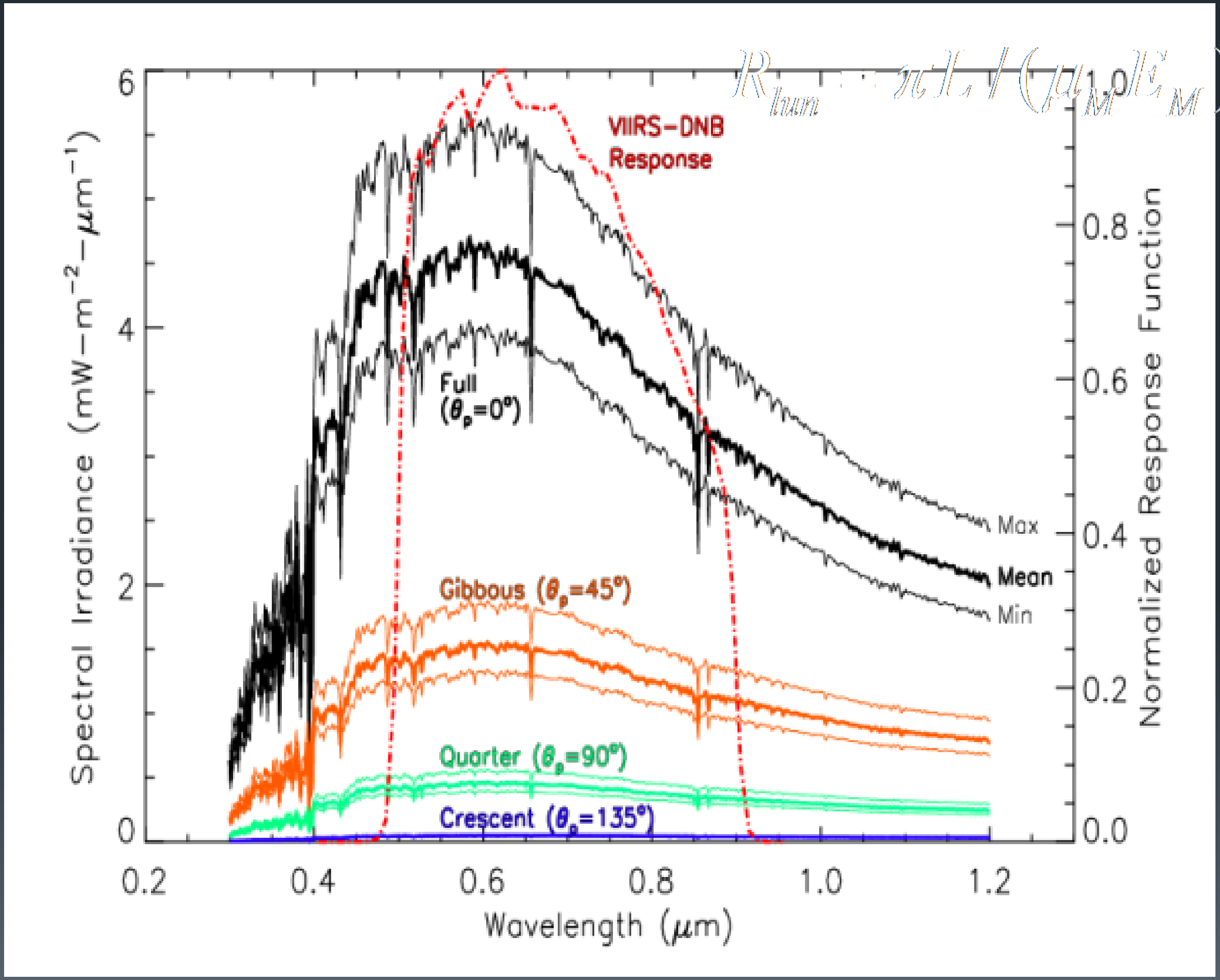
- Implemented in CLAVR-x and plans for SAPF but time-line unknown.

- DNB pixels mapped to M-bands.





Variations of lunar irradiance with lunar phase

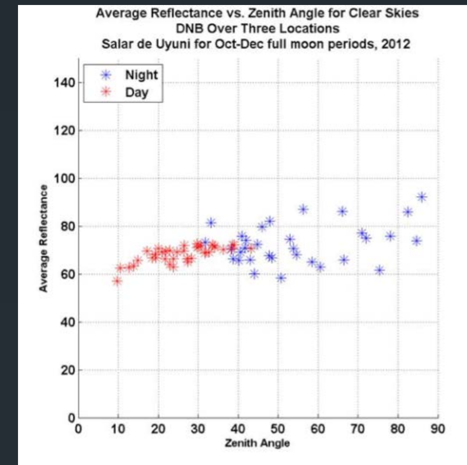


$$R_{lun} = \pi L / (\mu_M E_M)$$

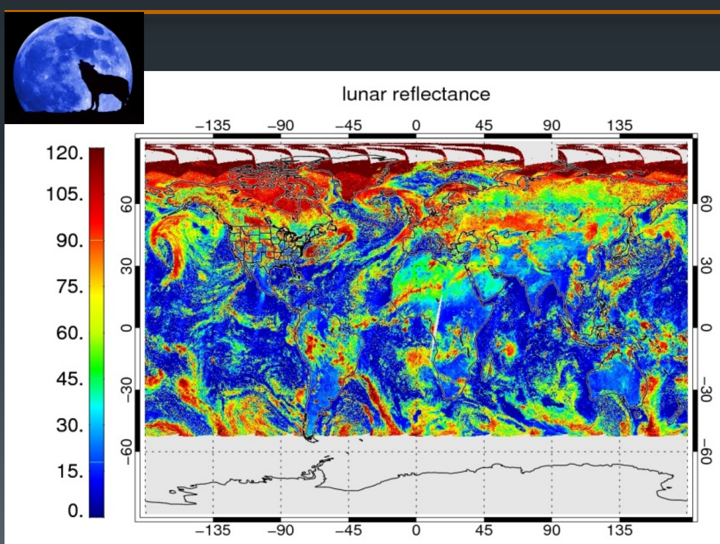
From Miller and Turner 2009

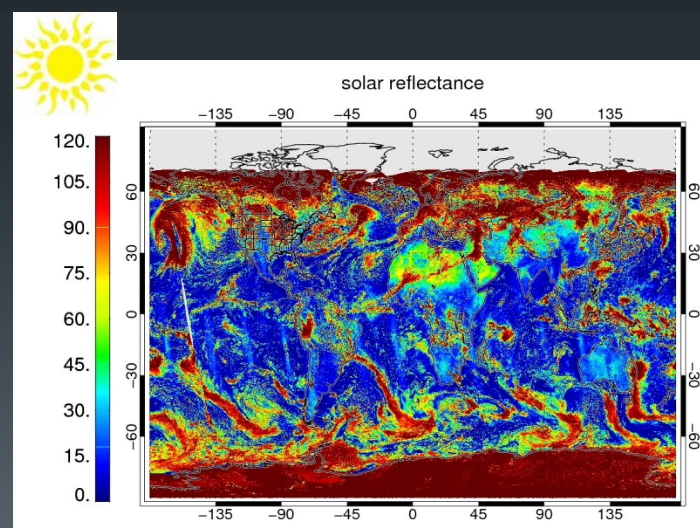
Consistency of lunar and solar reflectance

Lunar and solar reflection results for cloud-free scenes at the Salar de Uyuni salt flat ("Salzpfanne") in Bolivia.



Results show agreement which is consistent with assumed uncertainties of the lunar model.



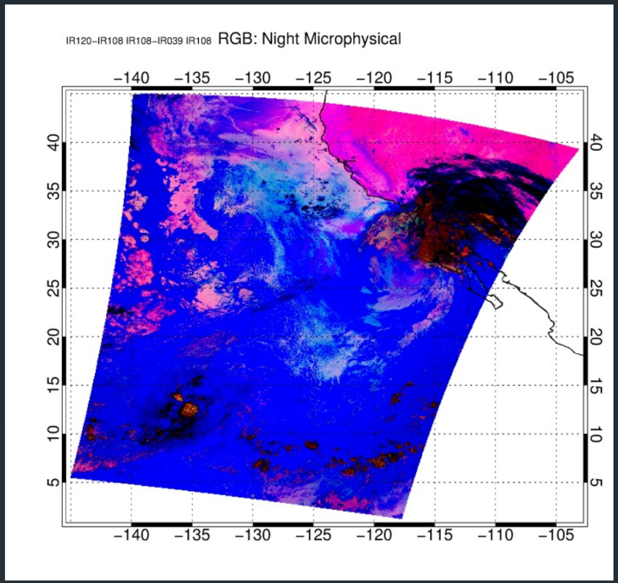


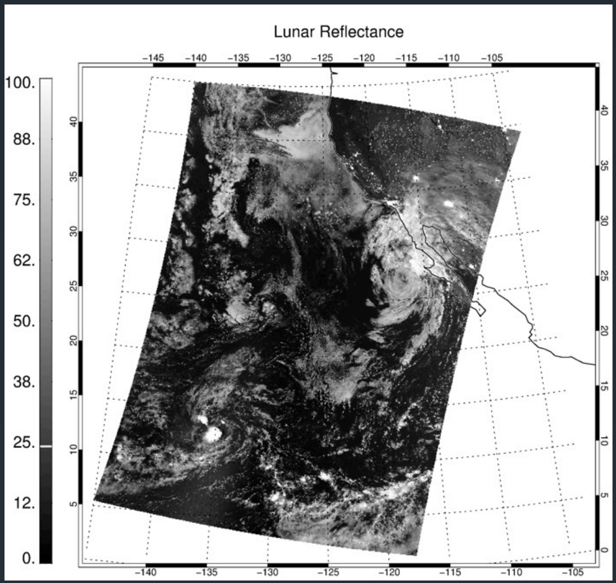
Global daily composites show also good agreement

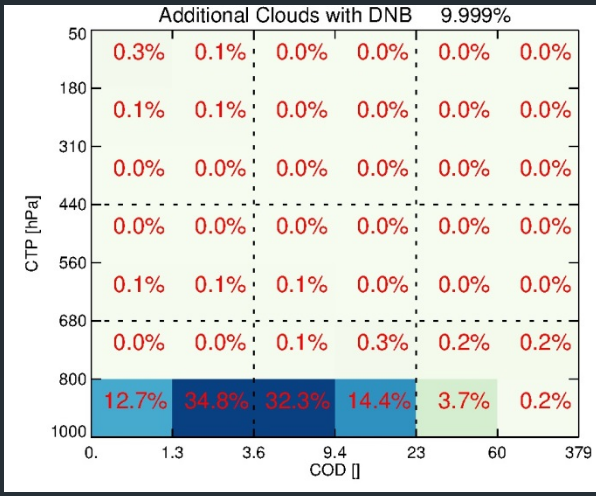
DNB and moon light for quantitative cloud retrievals in CLAVR-x

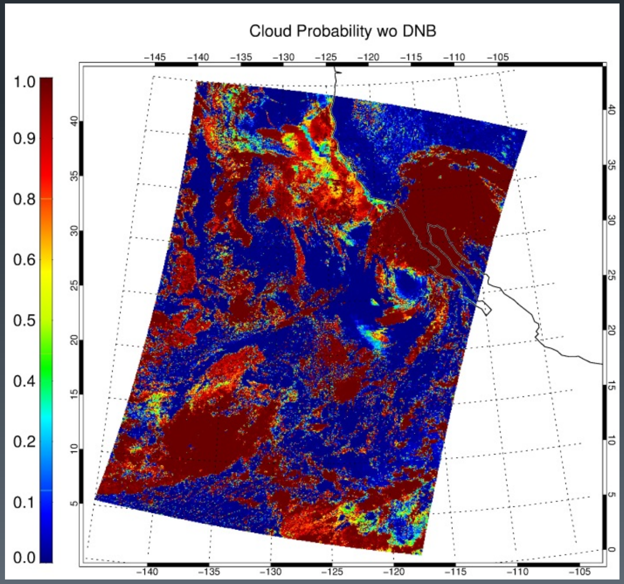
- Moon light is about 250 000 dimmer than sun (~10^{-5} W m^{-2} sr^{-1} μm^{-1} at full moon)
- Current sensors (MODIS, AVHRR, etc..) in visible spectrum are only able to detect signals from around 10^{0}-10^{2} W m^{-2} sr^{-1} μm^{-1}
- DMSP-OLS offered low-light images, but the data were not calibrated, with low information depth (6-bit) and low spatial resolution.
- DNB VIIRS onboard NPP-Soumi is the first channel which is both, highly sensitive to low-light in visible spectrum and providing a sufficient data depth (down to 10^{-5}W m^{2} sr^{-1} as a band average with a 14-bit resolution)
- DNB spatial resolution is uniformly 740m along and across the swath from nadir to the edge of the swath.
- DNB has to be collocated with VIIRS M-band channels those pixels grow from nadir to the edge (up to 5 times larger pixels) for retrievals.

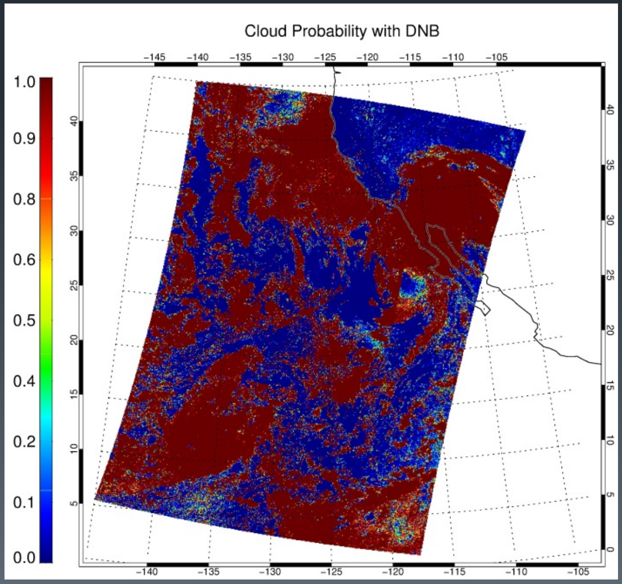
Cloud Mask improvement with DNB

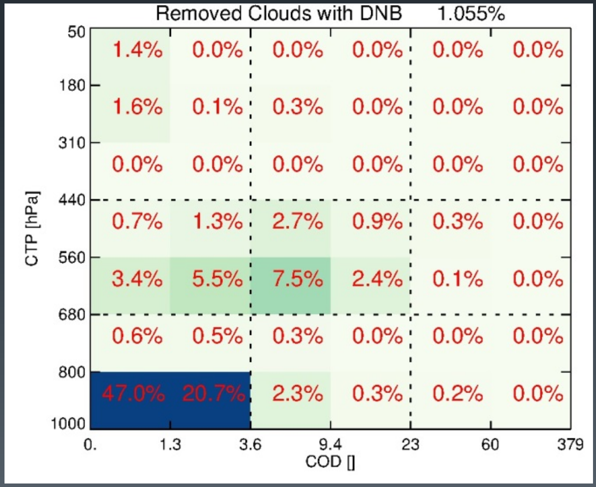






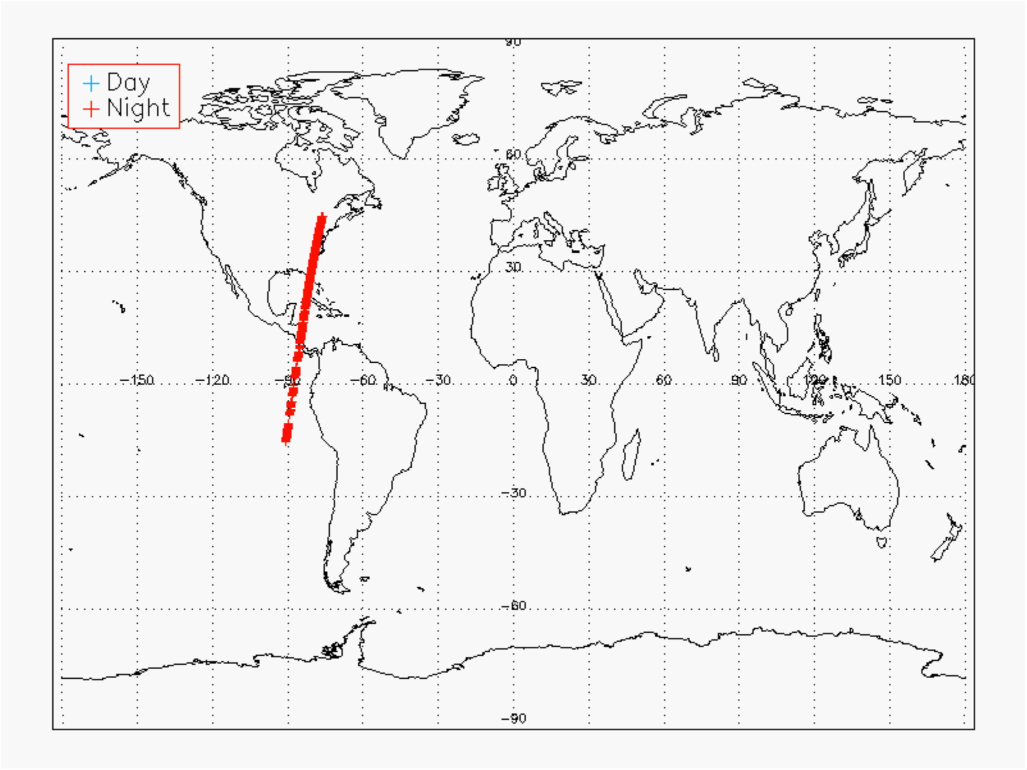






Cloud Mask Validation

CALIOP - VIIRS Matchup
Pixels with Maximum
± 0.2 Hour (± 12 Minutes)
Time Difference;
03/29/2013

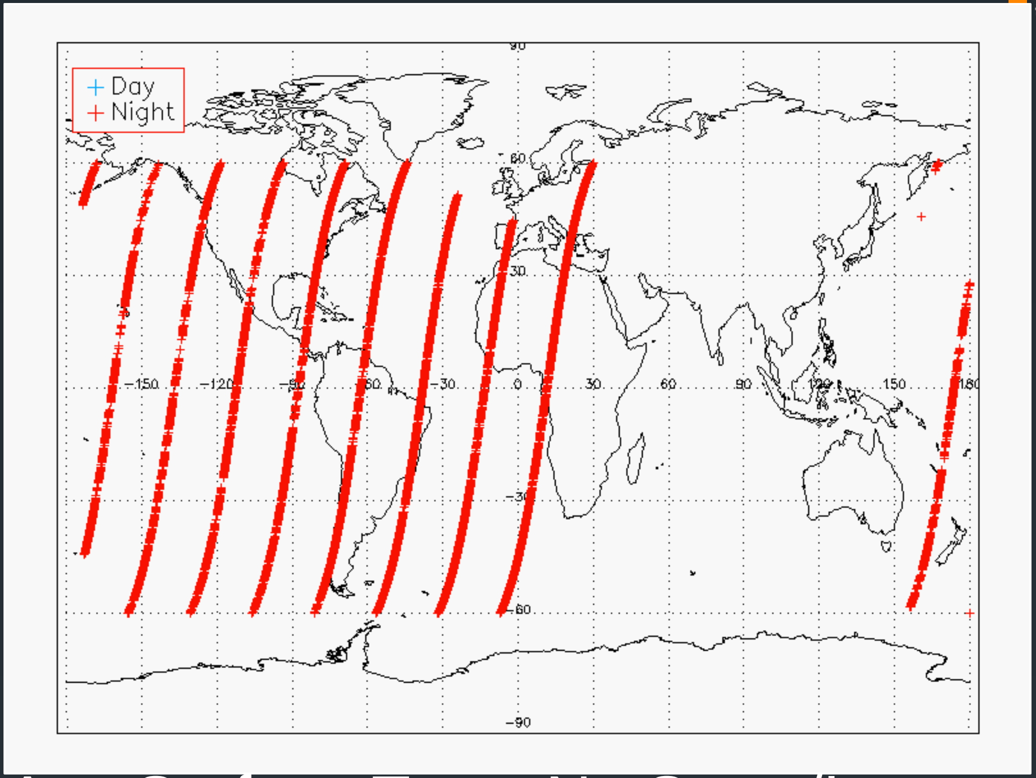


90N – 90S, Day/Night, Any Surface and Any Condition

Cloud Mask Algorithm	Sample Size	Cloud fraction				Probability of		
		Active	Passive	Pr. Clear	Pr. Cloudy	Detection	False D.	Leakage
CLAVR-x No DNB	6213	0.565	0.452	0.099	0.168	0.883	0.002	0.115
CLAVR-x DNB	6213	0.565	0.515	0.040	0.080	0.921	0.014	0.065
VCM	5911	0.574	0.470	0.072	0.046	0.892	0.002	0.106

Cloud Mask Validation – a more global view

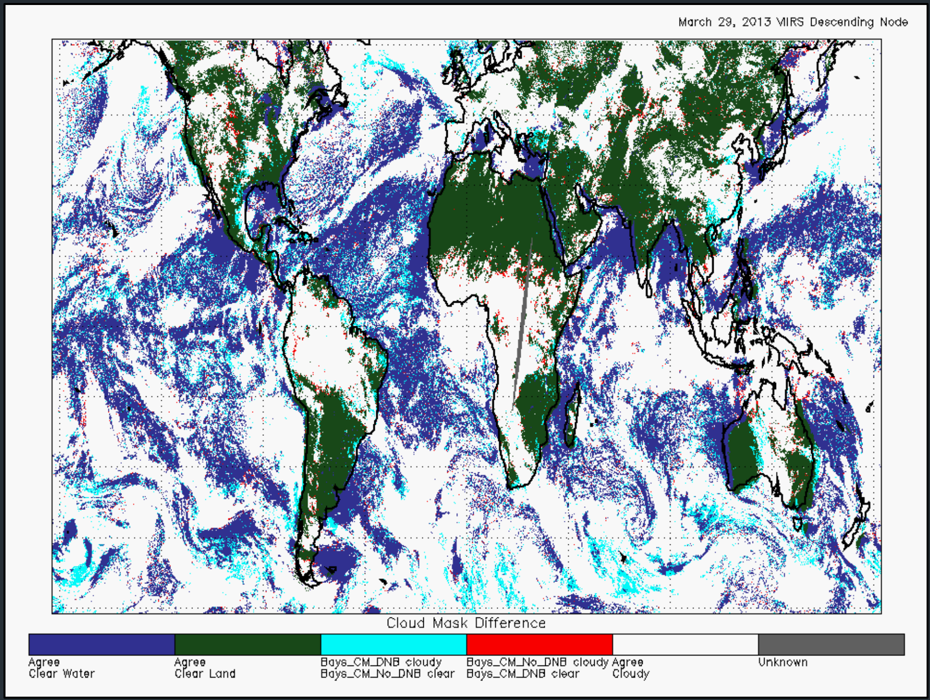
CALIOP - VIIRS Matchup Pixels with Maximum ± 0.2 Hour (± 12 Minutes) Time Difference; 03/29/2013

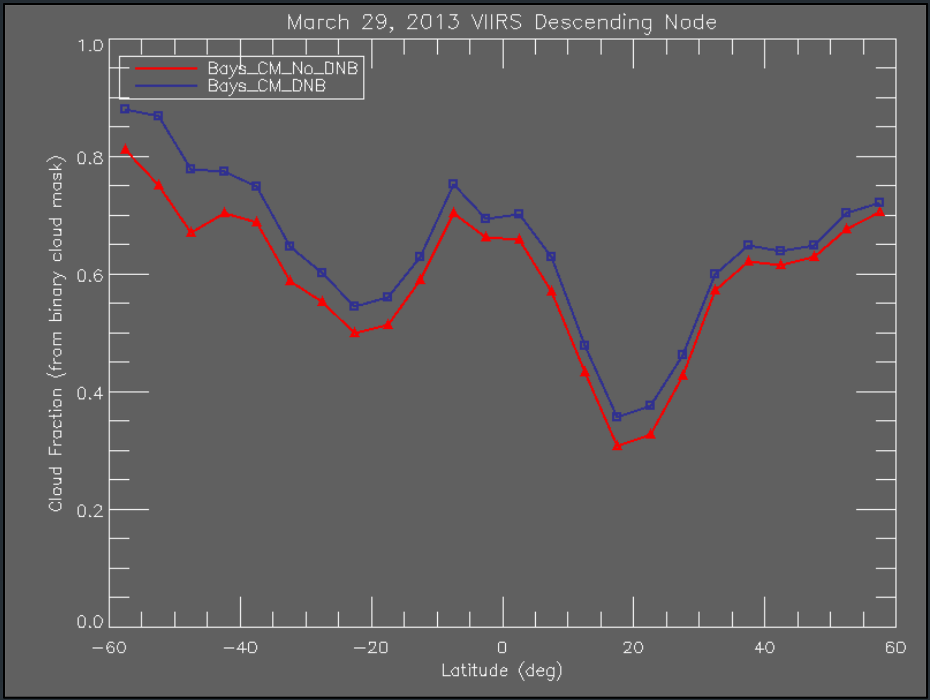


60N – 60S, Night, Any Surface Type, No Snow/Ice

Cloud Mask Algorithm	Sample Size	Cloud fraction				Probability of		
		Active	Passive	Pr. Clear	Pr. Cloudy	Detection	False D.	Leakage
CLAVR-x No DNB	96688	0.713	0.641	0.080	0.117	0.903	0.013	0.084
CLAVR-x DNB	96688	0.713	0.674	0.056	0.052	0.932	0.015	0.053

Cloud Mask Validation – A Global view

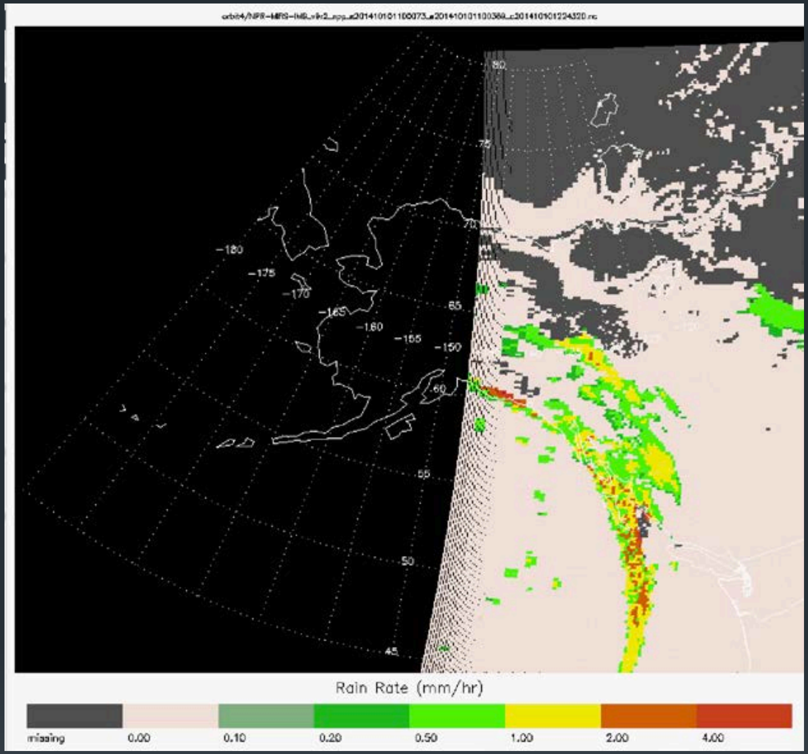




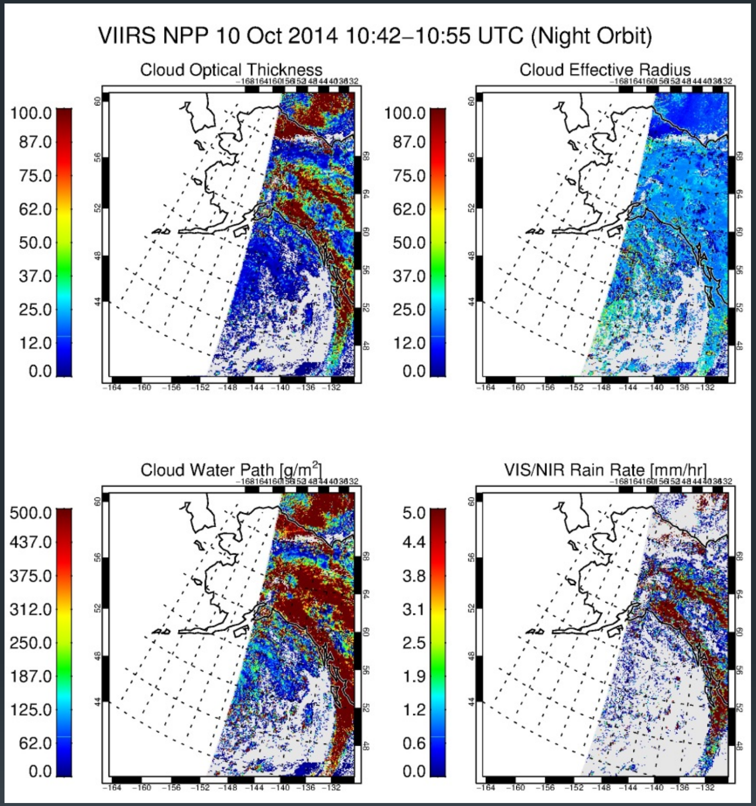
Bayesian CM Difference
No DNB – With DNB

Bayesian CM Zonal Fraction

NLCOMP: Filling the Arctic winter gap: Precipitation



ATMS sensor on NPP provides MW–based rain rate



NLCOMP cloud products and rain rate estimates using (Roebeling 2009)