A Study on the Benefits of Spatial Resolution for Next Generation Infrared Hyperspectral Sounder Instruments

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Introduction

- It is essential to improve the spatial resolution of hyperspectral sounders (e.g. CrIS) to match improved NWP model resolutions in the future.

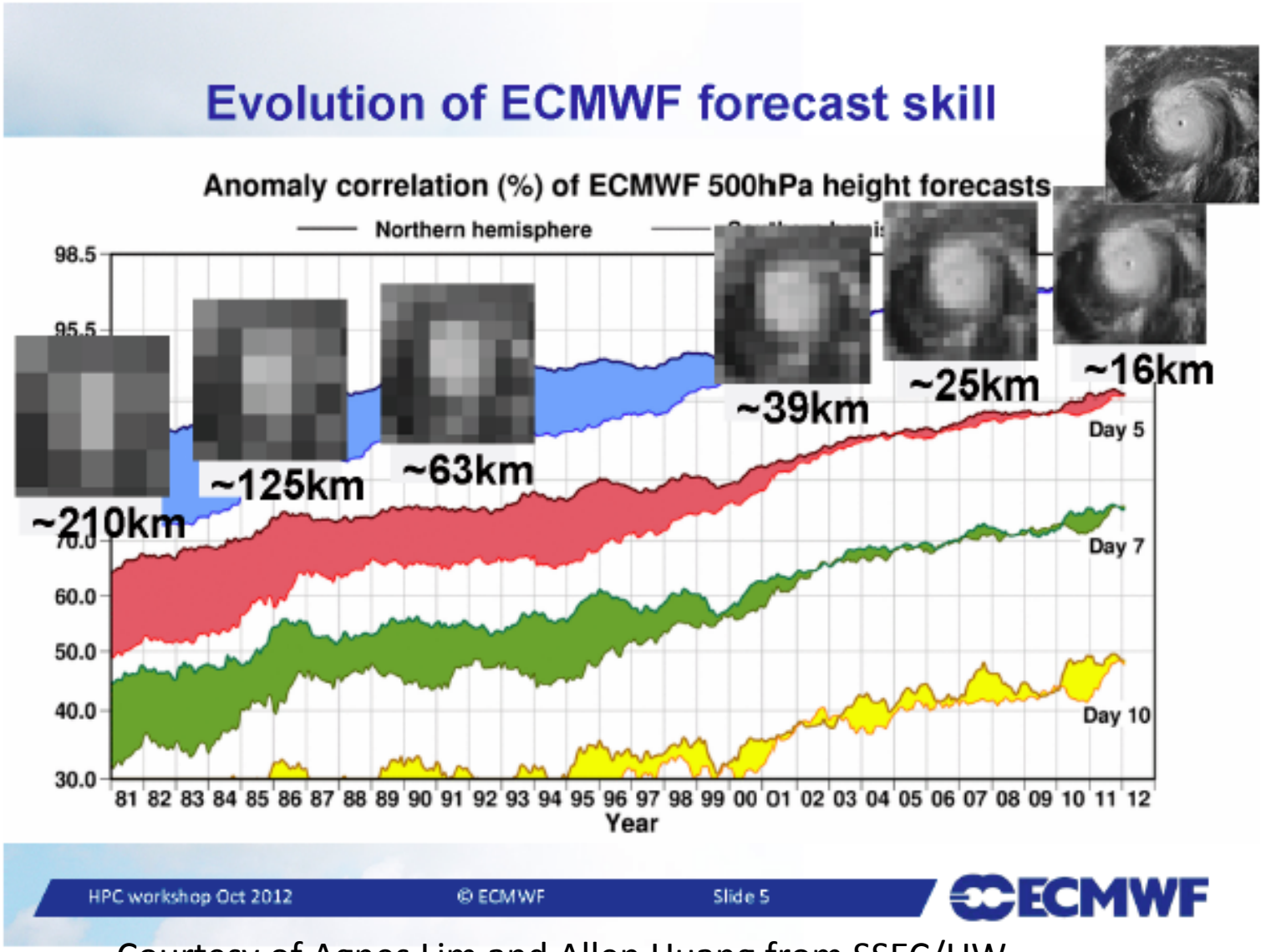
- NWP models only use cloud-free CrIS observations as inputs for data assimilation. It is believed that smaller CrIS field of view (FOV) size or more FOV number will add more cloud-free measurements. But how much?

- VIIRS M15 measurements and VIIRS Cloud Mask products on 09/05/2015 are used to simulate CrIS measurements.
  - VIIRS M15 radiances: to simulate CrIS measurements at 900 cm-1
  - VIIRS Cloud Mask: to check clear CrIS FOVs
    - Confidently Clear 0; Probably Clear 1 ; Probably Cloudy 2; Confidently Cloudy 3
    - Only **confidently clear** pixels are treated as clear pixel for simulation

- Two Experiments
  - Test 1: Keep 3×3 FOVs but change FOV size from 14.0 km to 2.0 km
  - Test 2: Keep FOV size at 7.0 km but set FOV number as 3×3, 5×5, 6×6, and 7×7
  - Field of Regard size stays the same: 50 km
  - Checking two statistics 1) clear FOVs; 2) clear FORs (at least one FOV is clear)

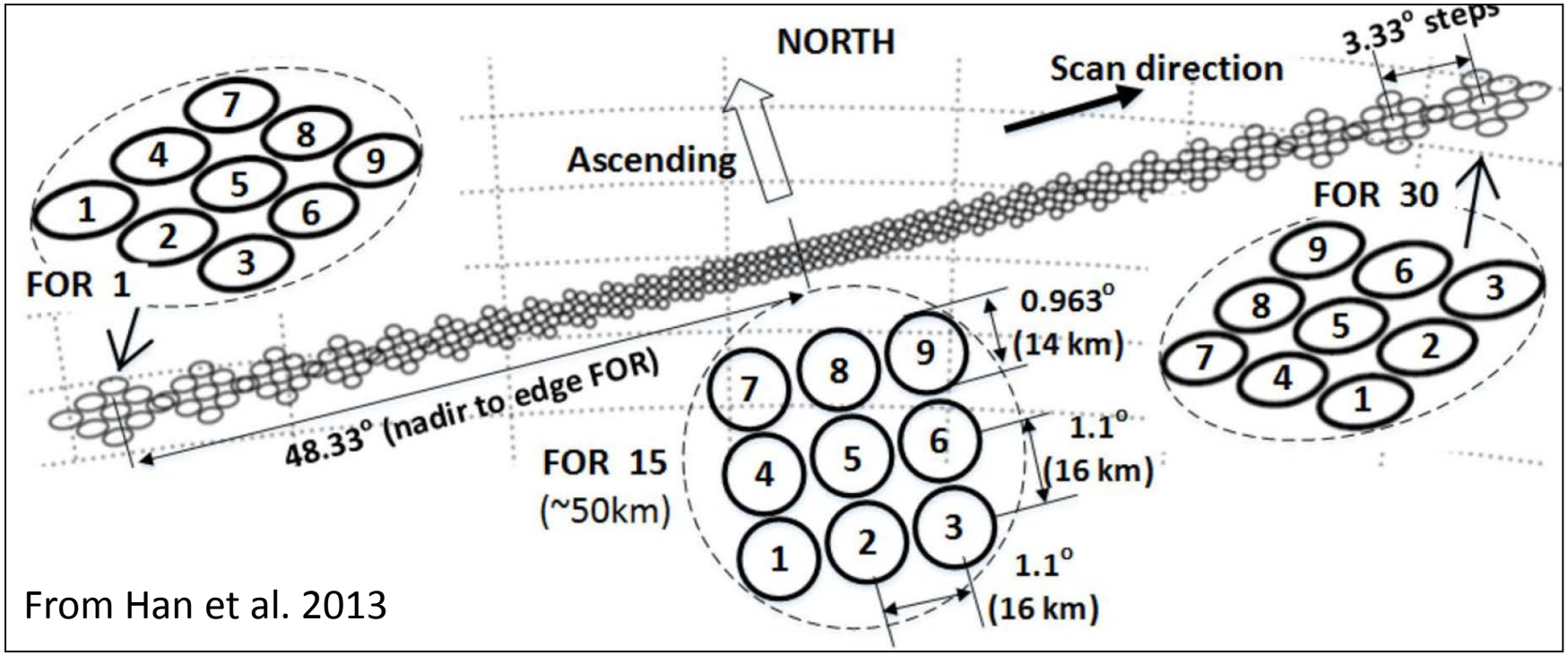
- How does smaller FOV size affect on noise and spectral calibration?.

Evolution of NWP Model Resolution



Courtesy of Agnes Lim and Allen Huang from SSEC/UW

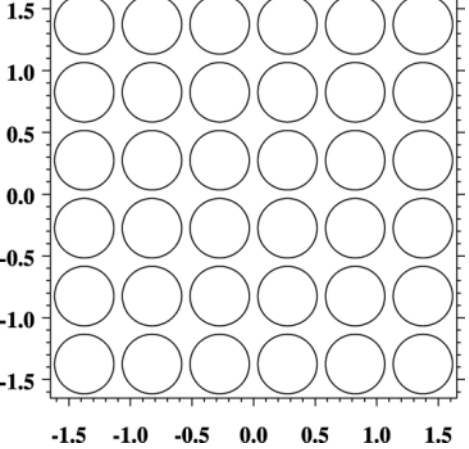
But CrIS FOV size remains the same for Suomi NPP ➔ JPSS-1 ➔ JPSS-2



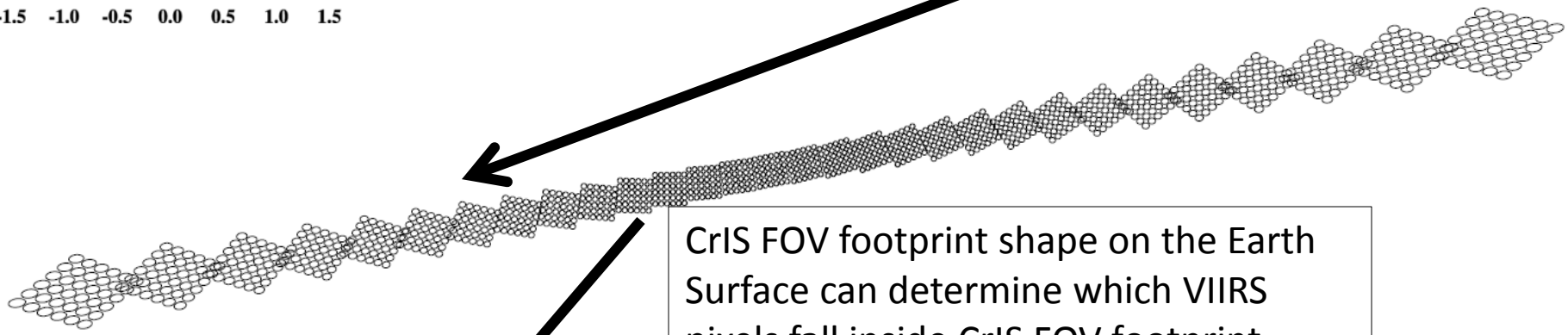
From Han et al. 2013

CrIS uses 3X3 Detector Arrays, each of which corresponds 14 km at nadir.

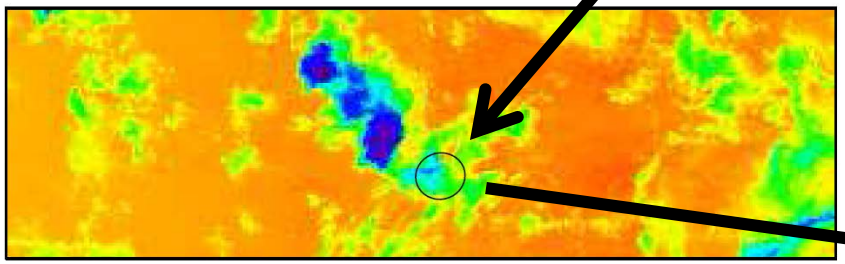
Method



Changing detector angles as new inputs for CrIS Geolocation Algorithm and compute CrIS FOV lat, lon, and shape projected on the Earth



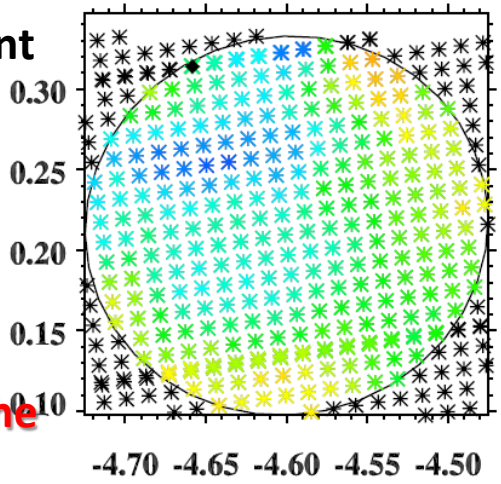
CrIS FOV footprint shape on the Earth Surface can determine which VIIRS pixels fall inside CrIS FOV footprint



VIIRS cloud mask products (VCM) are used to determine cloud fraction in each CrIS footprint ;

VIIRS Pixels

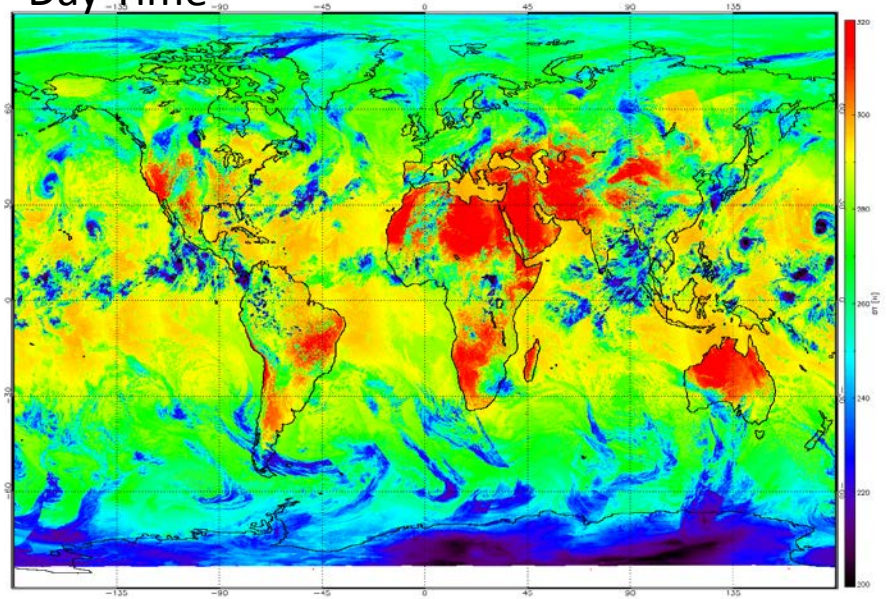
CrIS FOV footprint



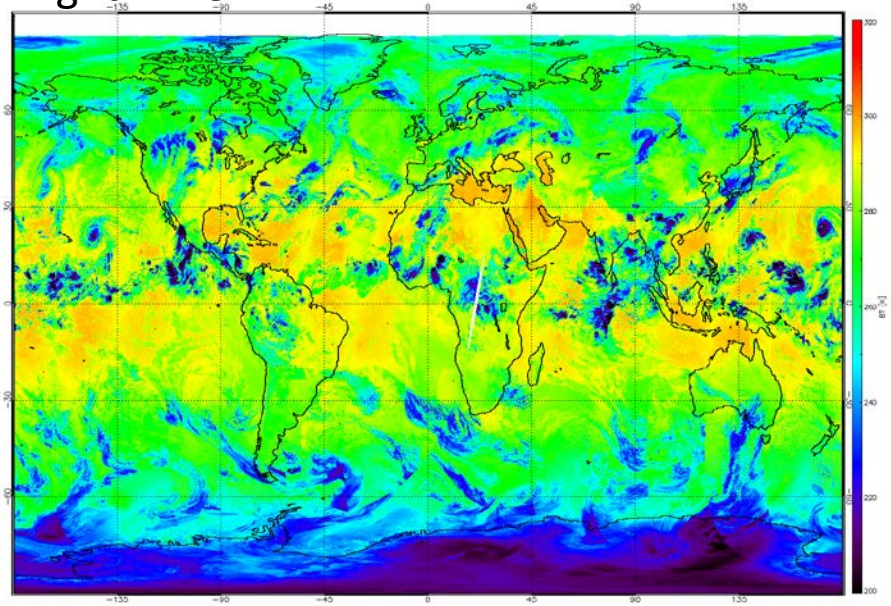
If all VIIRS pixels within CrIS FOVs are indicated as confident clear, the CrIS FOVs are treated as clear.

VIIRS

Day Time

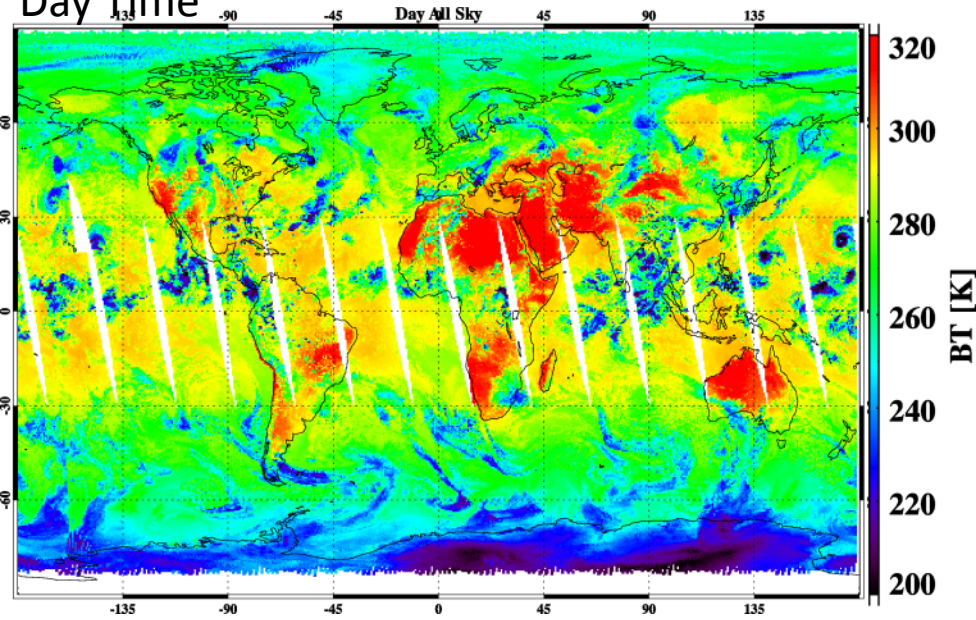


Night Time

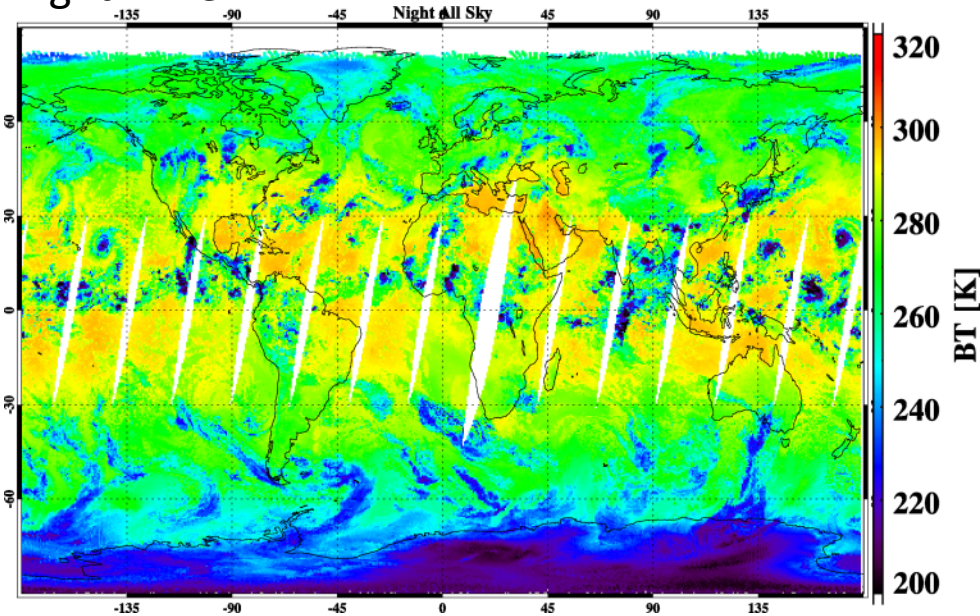


CrIS

Day Time

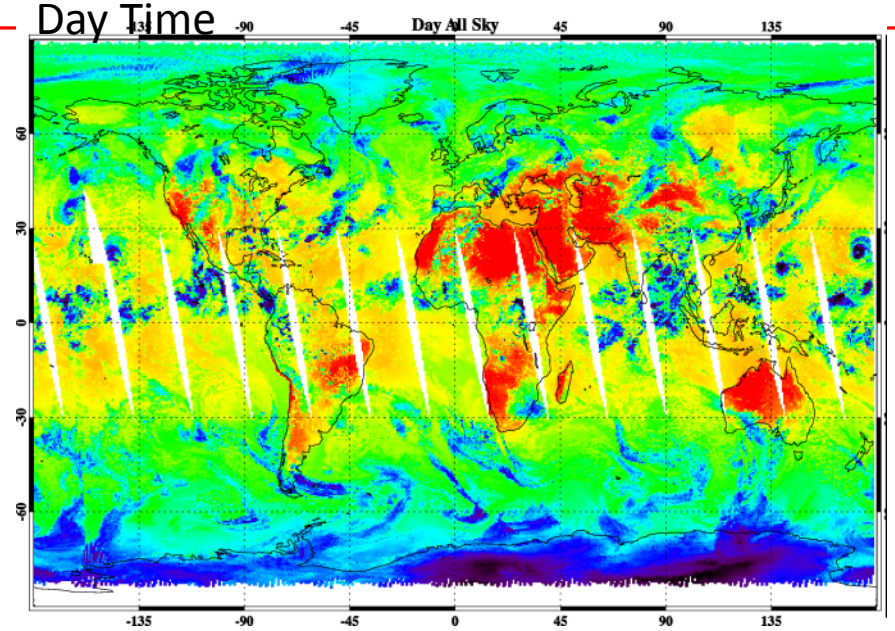


Night Time

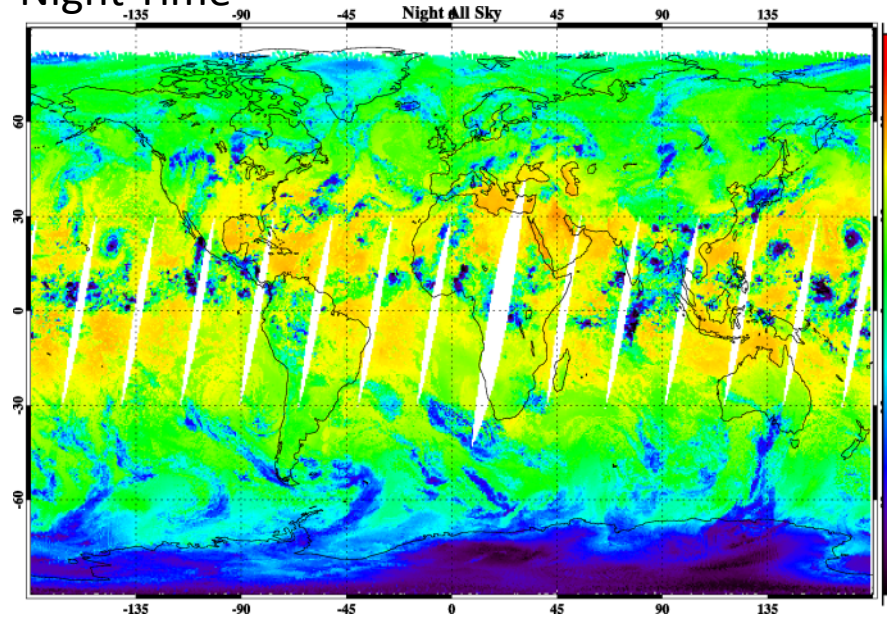


CrIS

Day Time

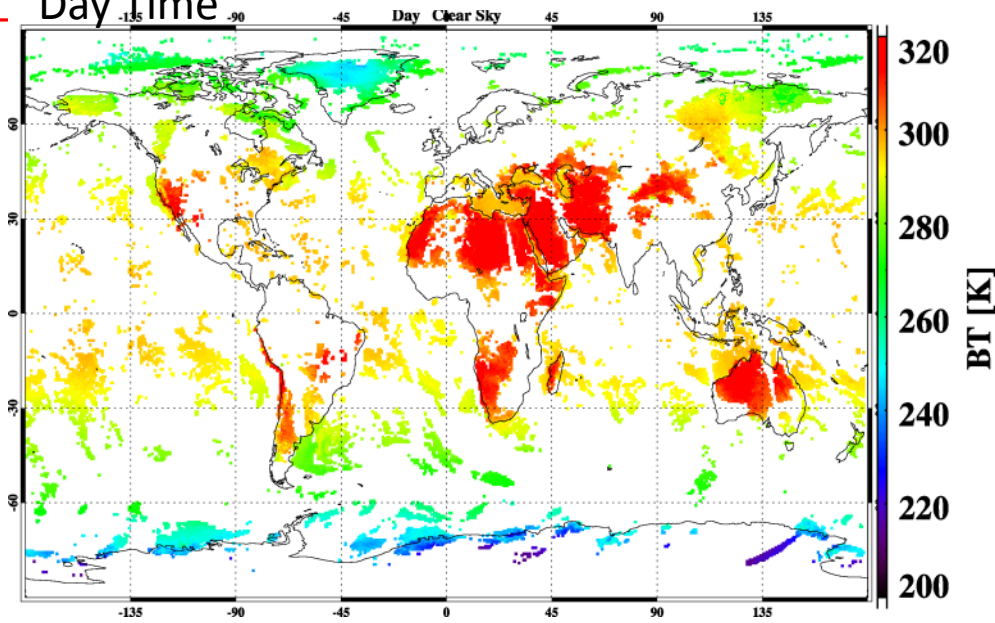


Night Time

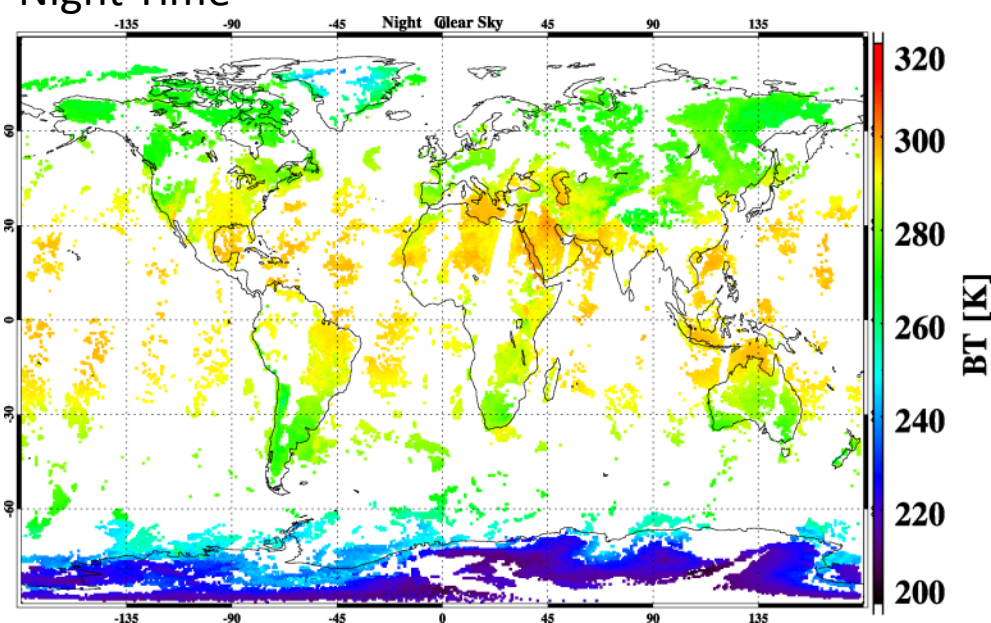


CrIS Clear

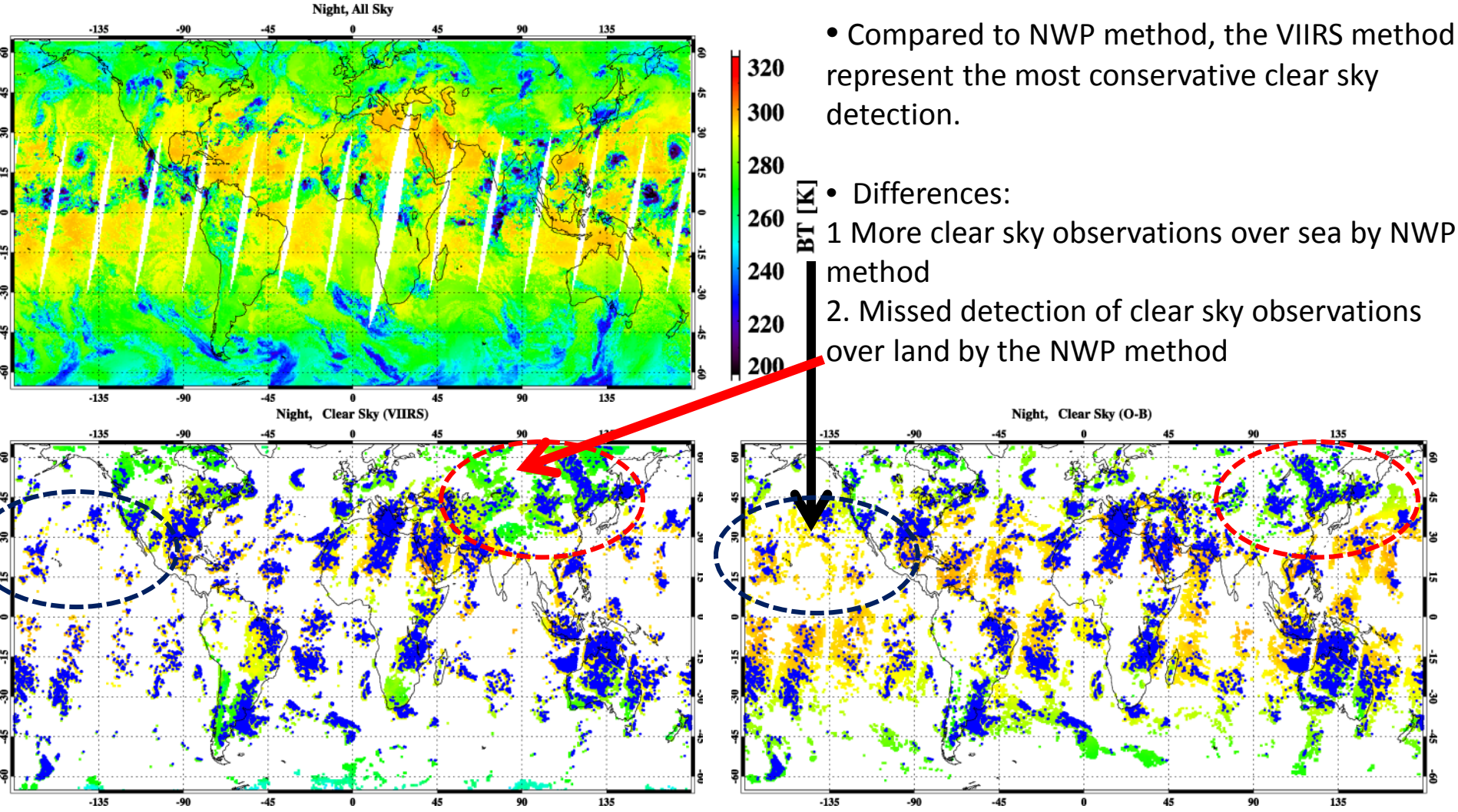
Day Time



Night Time



Clear Sky Detection Comparison (VIIRS method vs. NWP Method)



- Compared to NWP method, the VIIRS method represent the most conservative clear sky detection.

- Differences:

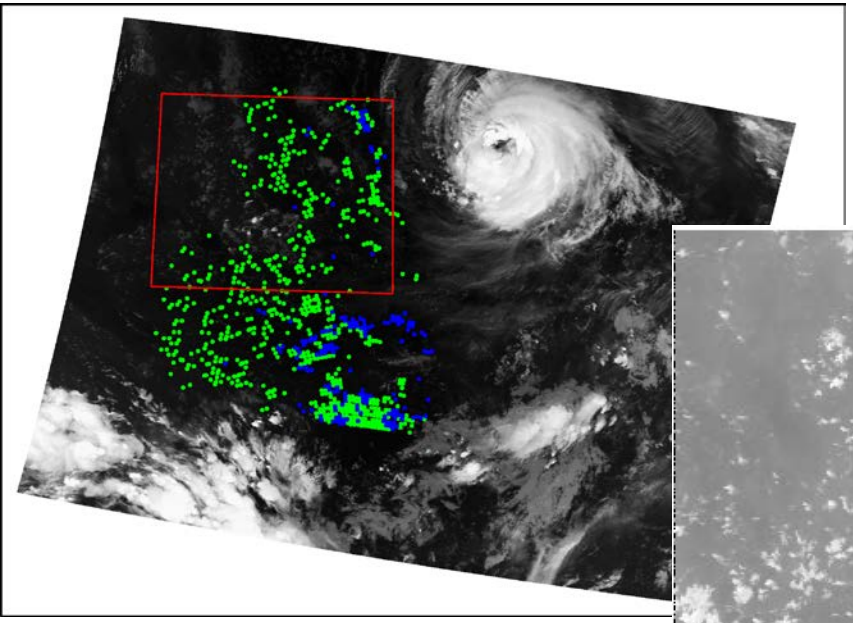
1 More clear sky observations over sea by NWP method

2. Missed detection of clear sky observations over land by the NWP method

VIIRS Method **NWP Method**

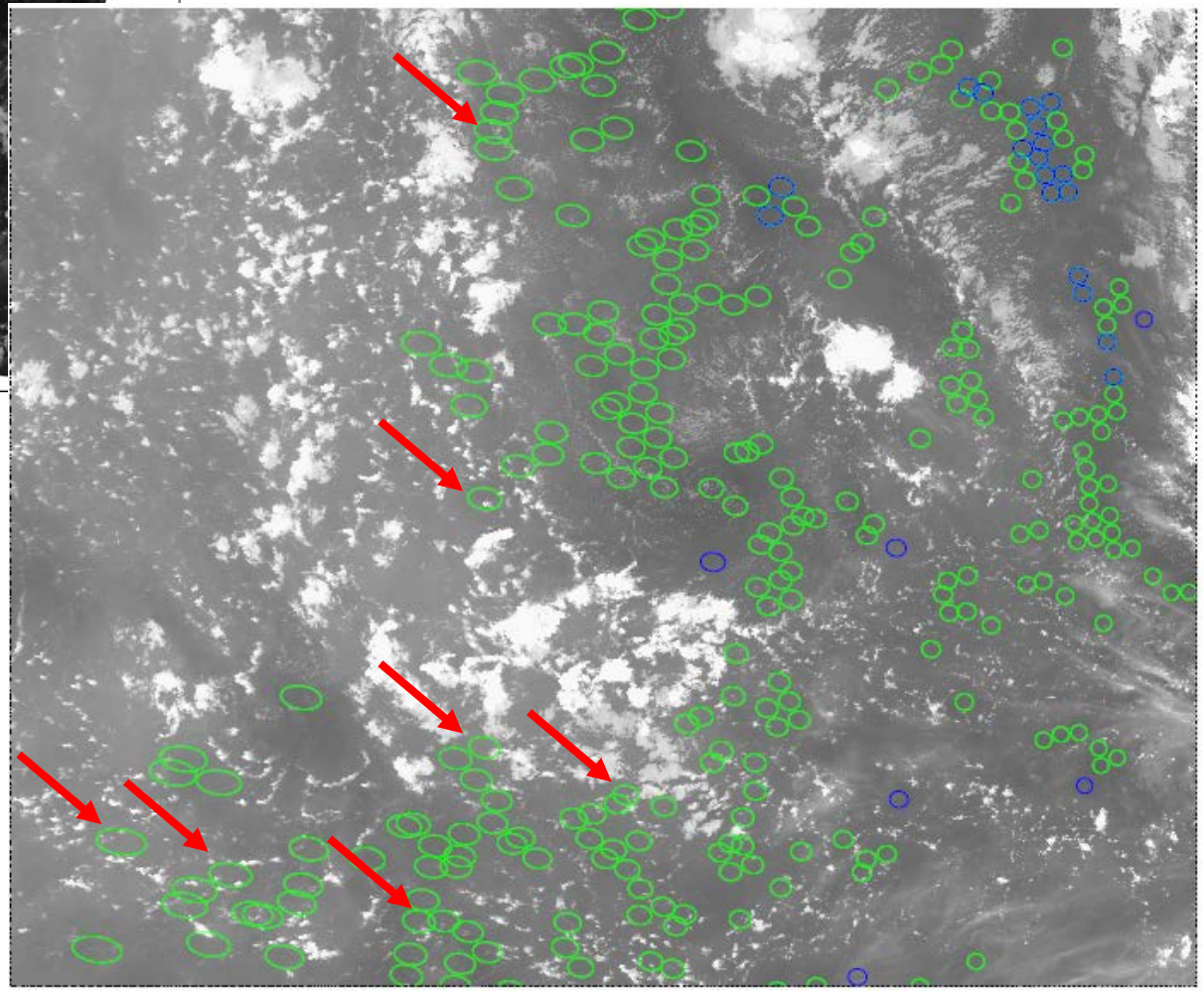
Note that blue dots indicates clear sky pixels identified by both methods.

Zoom-in broken clouds



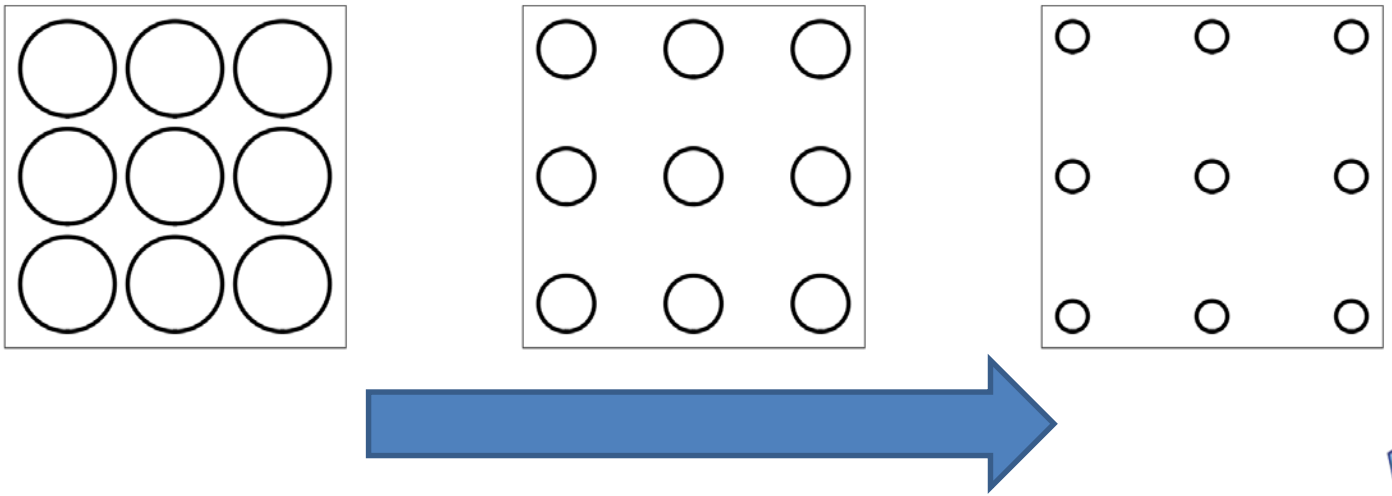
Some cloud contaminated observations are missed by NWP method.

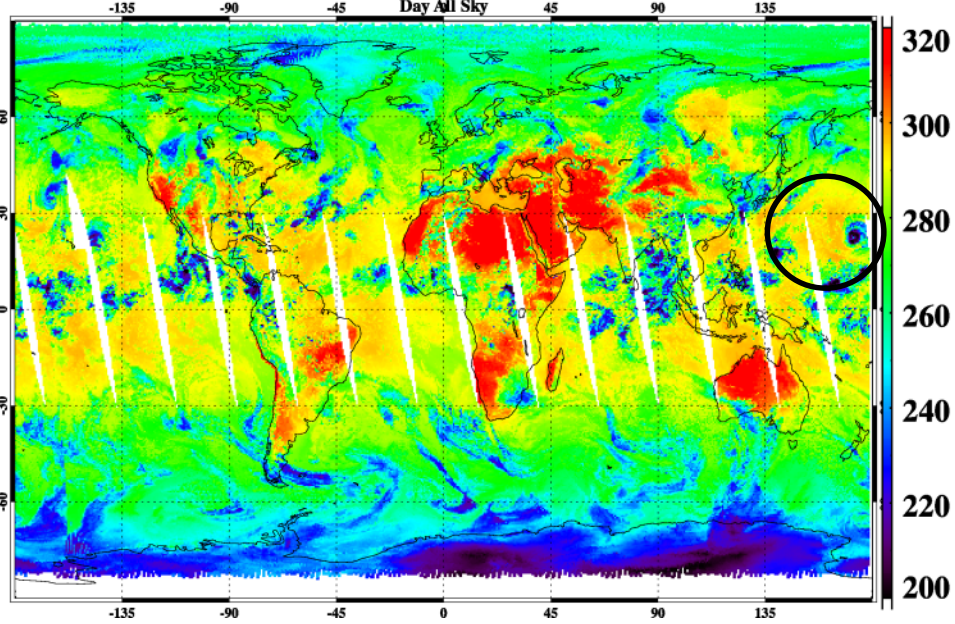
NWP method
VIIRS method



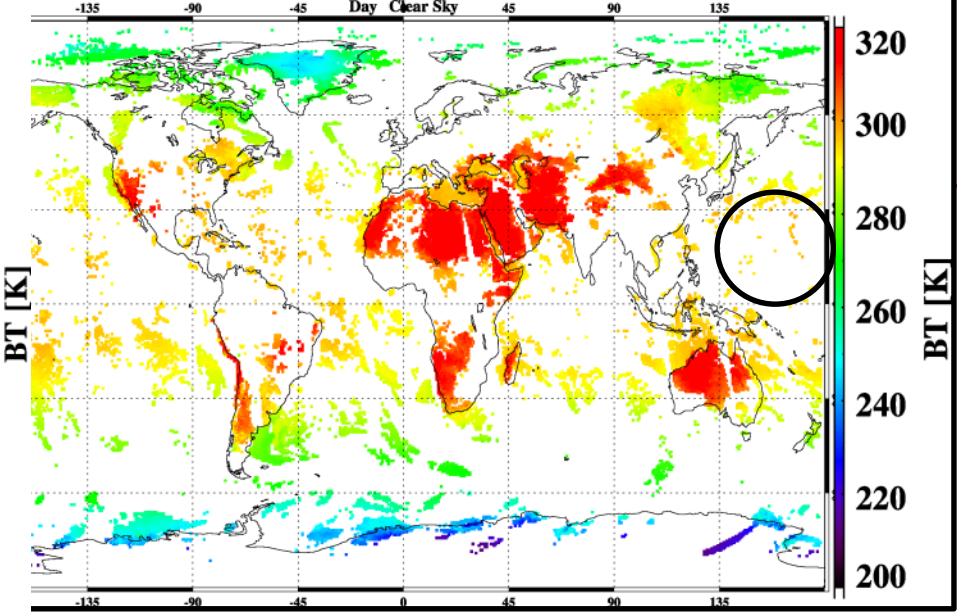
Experiment One: With 3x3 FOV configuration, how do the clear sky observations change with FOV size?

Note that FOV and FOR number keep the same under this experiment



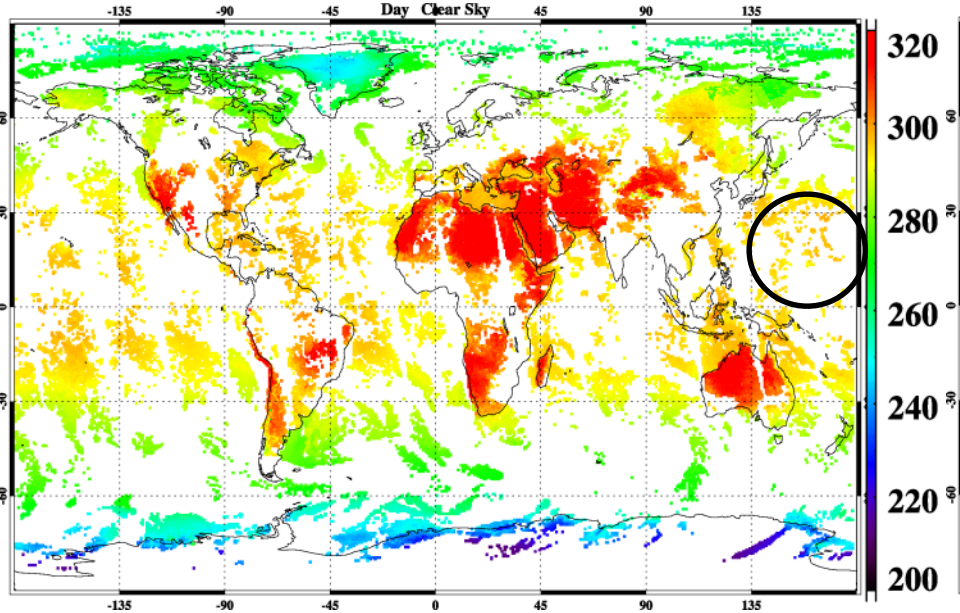


CrIS measurements, All Sky

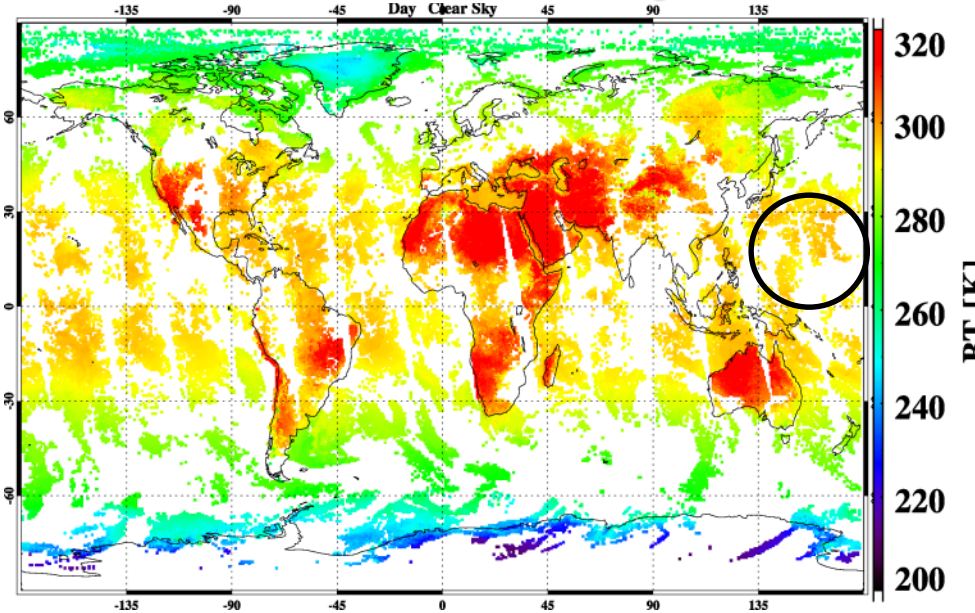


3X3 in 14km, Clear Sky

Day Time

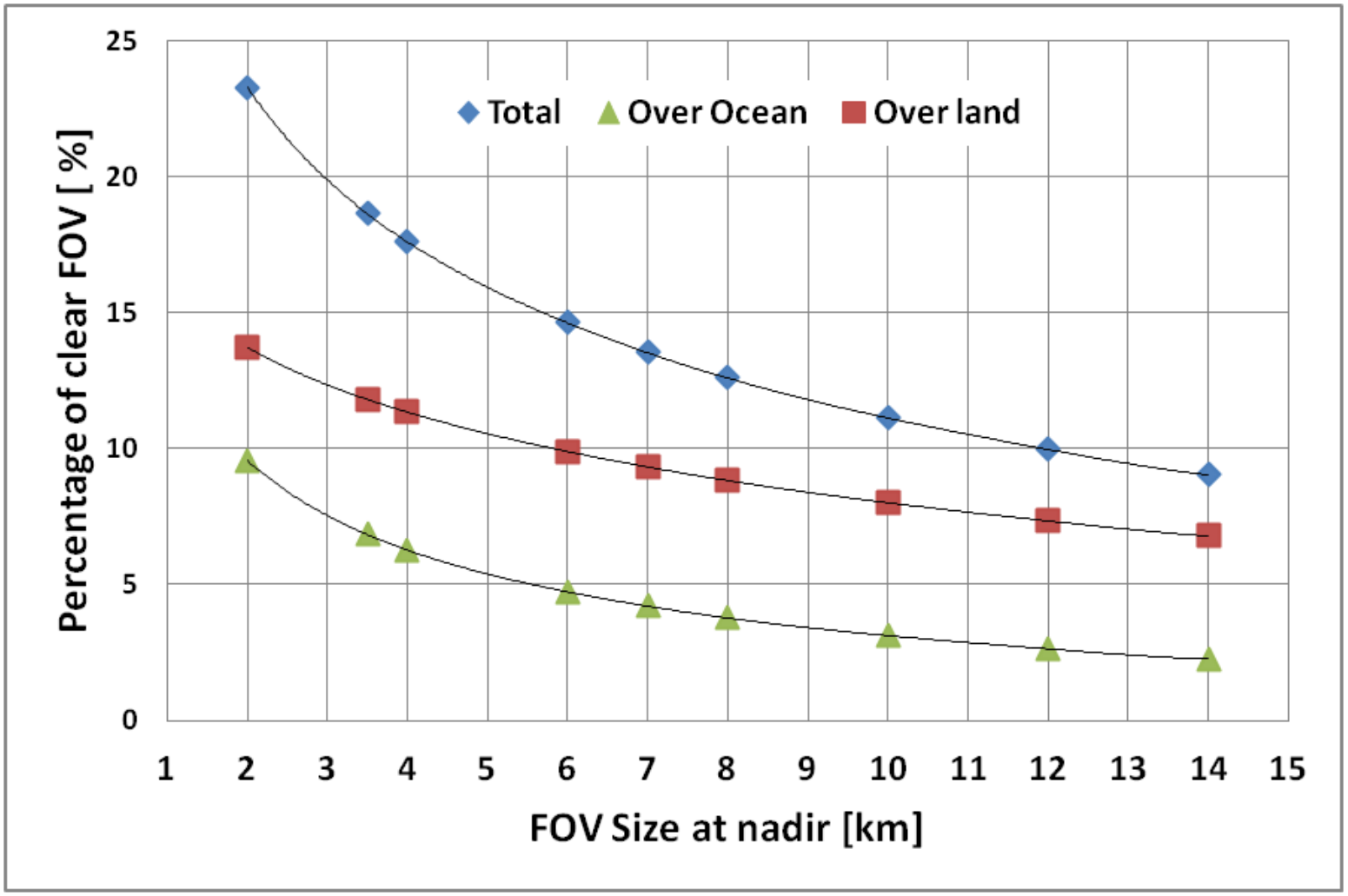


3X3 in 7km, Clear Sky



3x3 in 3.50km, Clear Sky

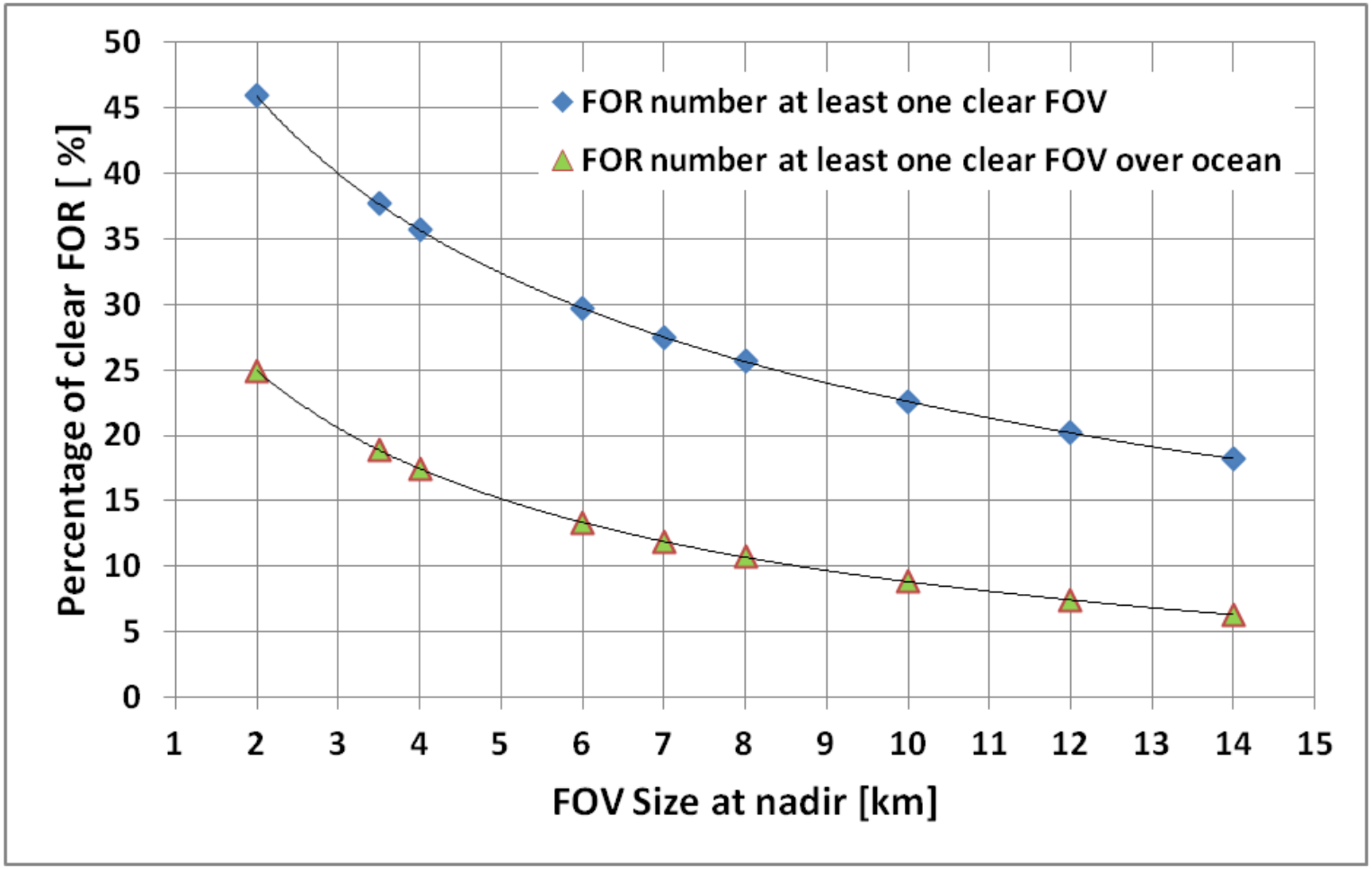
Percentage of Clear FOVs varying with FOV Size



The percentage of clear sky FOVs increases when the FOV size changes from 14km to 2 km with the same FOV coverage (3x3), both over land and over oceans.

Percentage of FOR number at least one clear FOV in Total FOR number

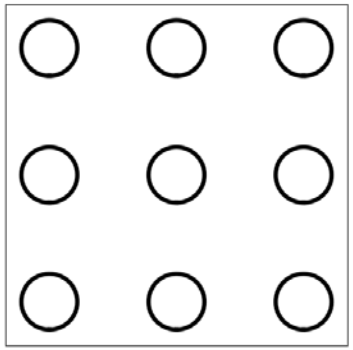
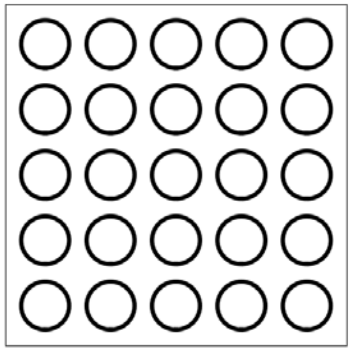
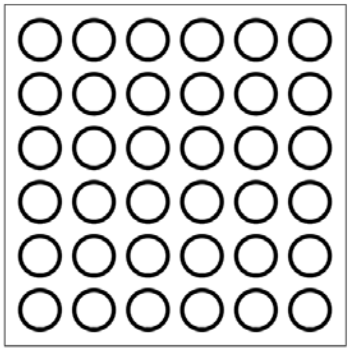
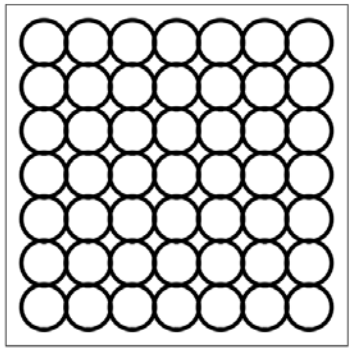
This is the way how the NWP community use the CrIS data.

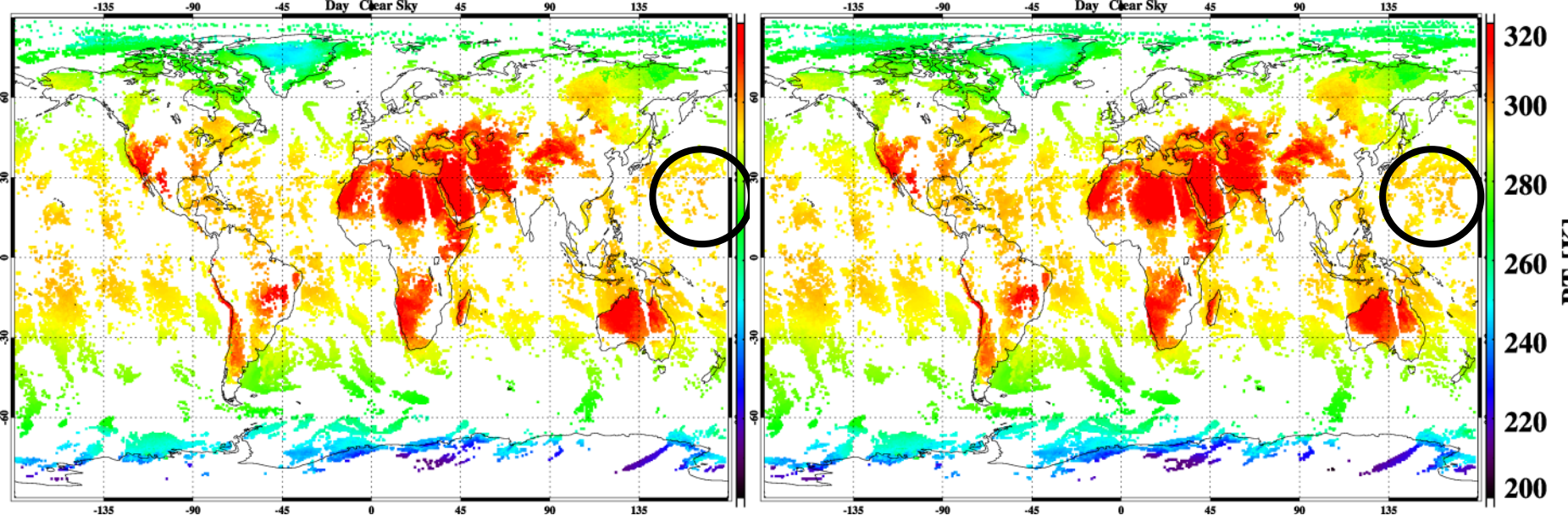


The percentage of FORs (in total FOR samplings) that contain at least one clear sky FOV (defined as clear sky FOR) also increases.

Experiment Two: With 7km FOV size, how do the clear sky statistics change with 3x3, 5x5, 6x6, and 7x7 FOV configuration?

Note that FOV number change in different FOV coverage but FOR number stays the same.

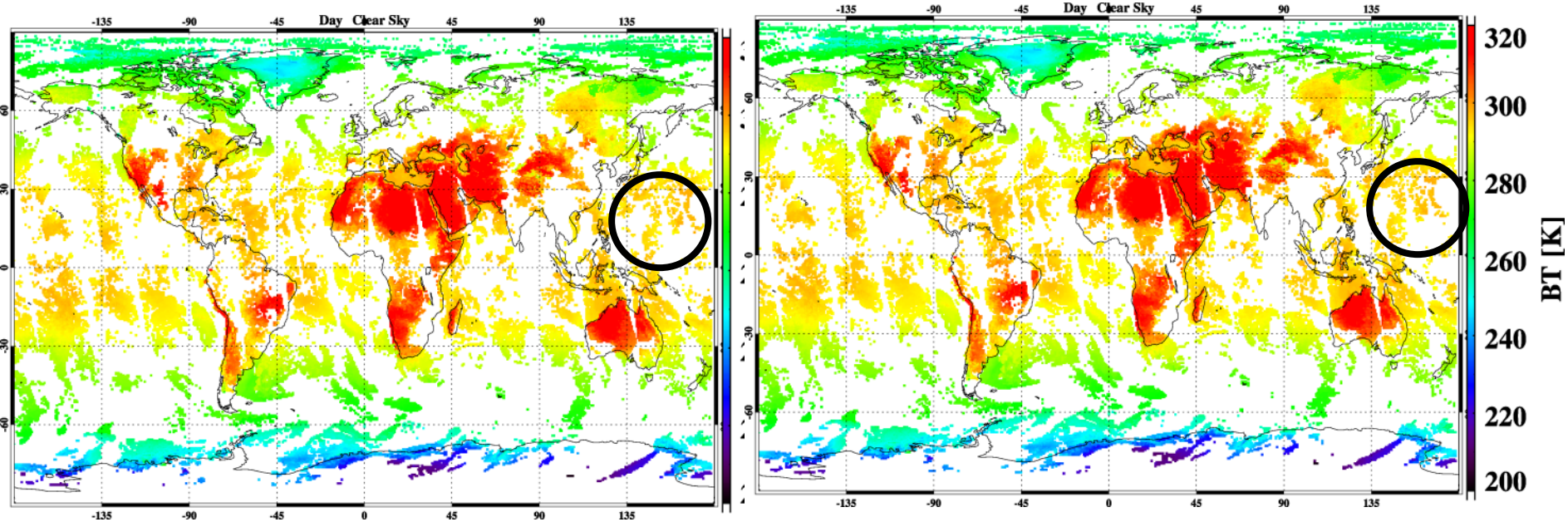







3X3 in 7km, Clear Sky

5X5 in 7km, Clear Sky

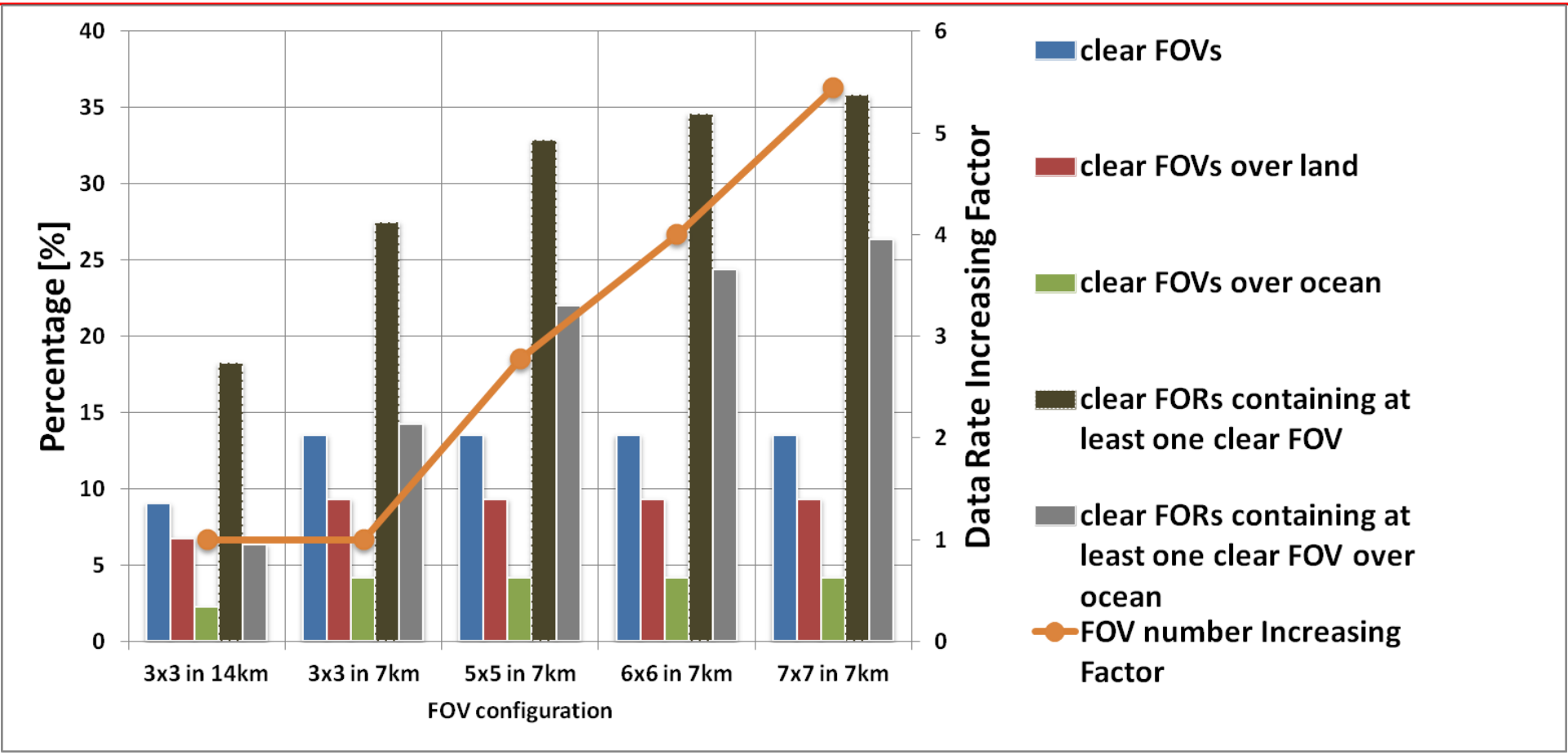
Day Time



6X6 in 7km, Clear Sky

7x7 in 7.0km, Clear Sky

Clear Sky Statistics

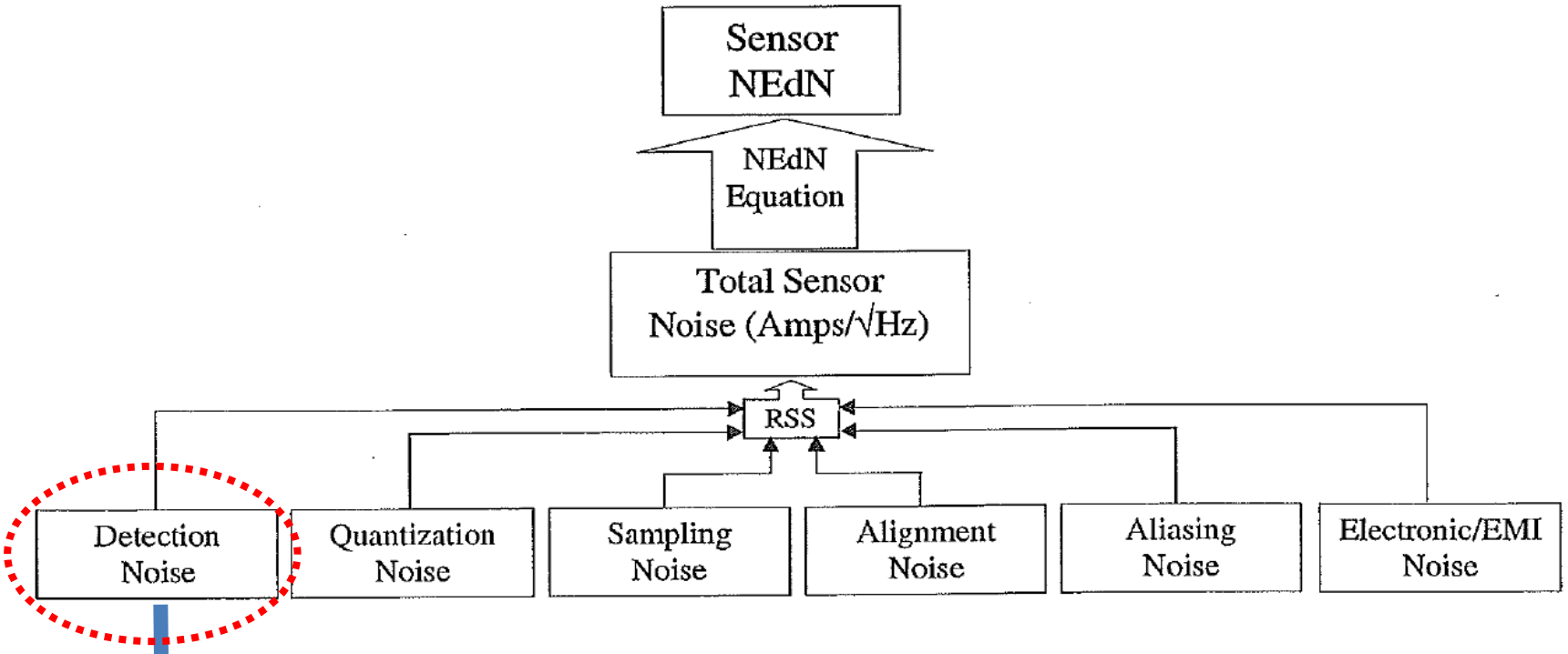


With increasing FOV coverage in each FOR and the same FOV size (i.e., 7 km), the percentage of clear sky FOVs stays the same value – around 13.5% of the total samples, suggesting that the total clear sky FOV observations are proportionally with the total sampling FOVs.

Increasing FOV coverage in each FOR can result in more clear FORs over ocean that contain at least one clear FOV, that is 14.27% in 3×3 FOVs, 22% in 5×5 FOVs, 24.42% in 6×6 FOVs, and 26.38% in 7×7 FOVs if the FOV size is constant as 7 km (FOR number stays the same).

How does the noise change with smaller FOV size, e.g. 7 km vs 14 km?

NEDN Model for CrIS



$$D^* = \frac{\rho \cdot \sqrt{A_{Detector}}}{N_{Detector}},$$

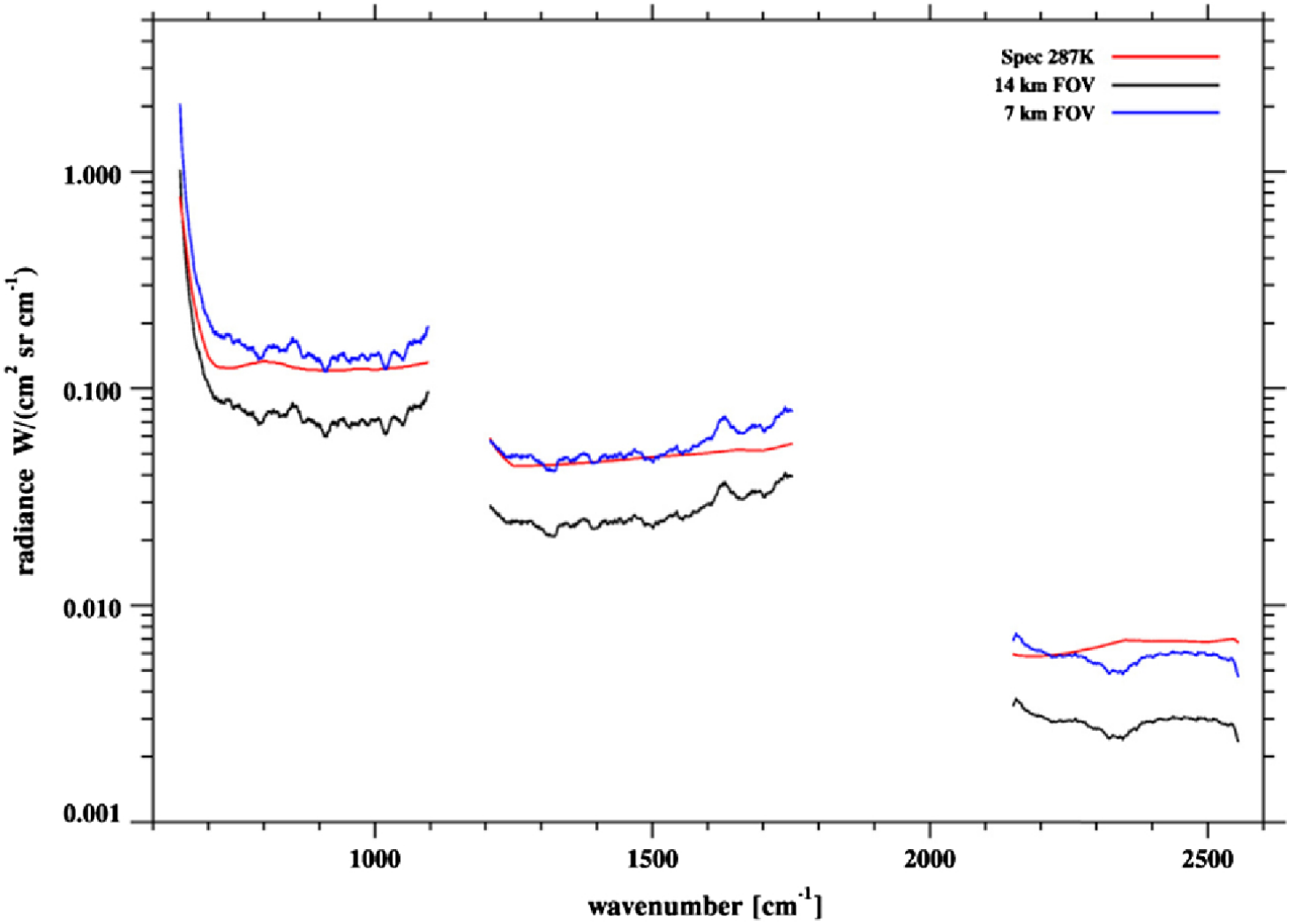
where ρ is the detector responsivity

$A_{Detector}$ is the area of the detector,

and $N_{Detector}$ is the Detection Noise.

Schwantes et al., 2002: the Crosstrack Infrared Sounder (CrIS)", Proc. SPIE 4486, Infrared Spaceborne Remote Sensing IX, (8 February 2002); doi: 10.1117/12.455128.

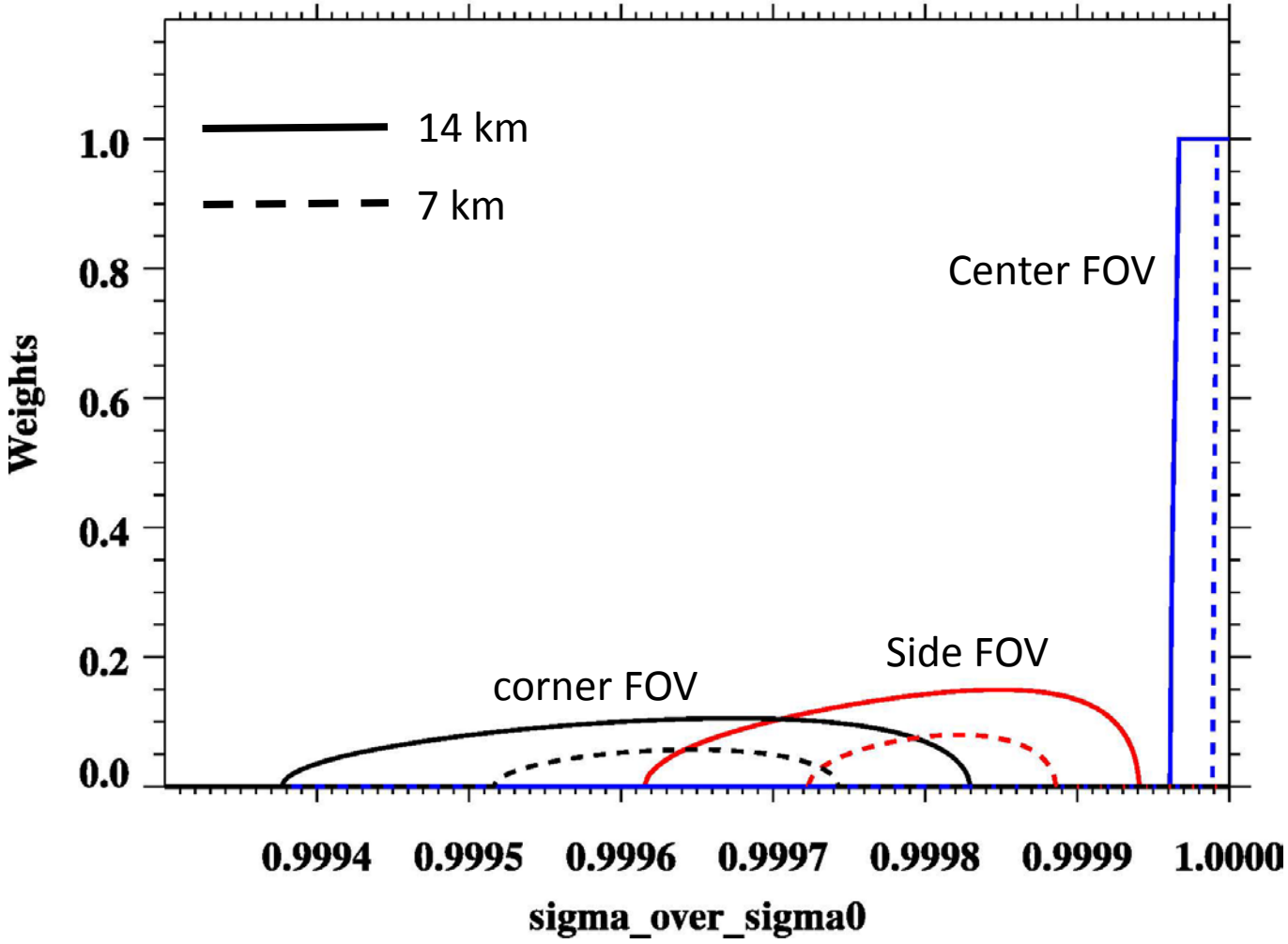
Noise Change



Same detector and same response time but only change field stop.
However, the final noise performance should rely on future optical and electrical design.

How does the Self-Apodization spectral correction change with smaller FOV size, e.g. 7km vs 14 km?

Self-Apodization correction is related to FOV size



Smaller FOV size will help the spectral correction at all three bands

Conclusion

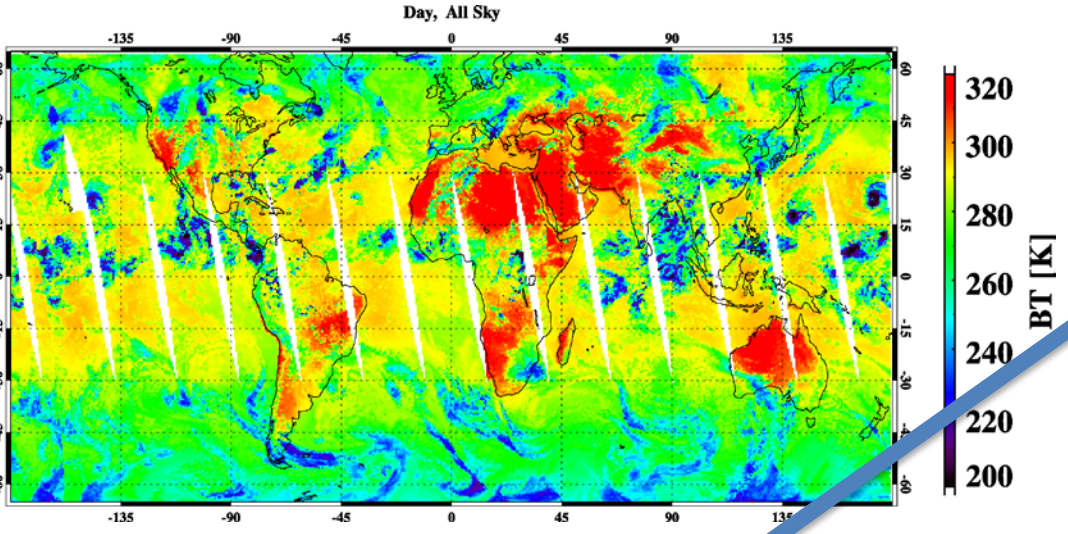
- The percentage of clear-sky FOVs increases when the FOV size changes from 14 km to 2 km with the same FOV coverage (3×3), both over land and over oceans. In addition, the percentage of FORs (in total FOR samplings) that contain at least one clear-sky FOV (defined as clear-sky FOR) also increases. Specifically, if the FOV size is reduced to 7 km from the current 14 km, the yield of clear-sky FOVs and clear-sky FORs increases by ~50%.

- With increasing FOV coverage in each FOR and the same FOV size (i.e., 7 km), the percentage of clear-sky FOVs stays the same value–around 13.5% of the total samples, suggesting that the total clear-sky FOV observations are proportional with the total sampling FOVs. Increasing FOV coverage in each FOR can result in more cleared FORs that contain at least one clear FOV, that is 14.27% in 3×3 FOVs, 22% in 5×5 FOVs, 24.42% in 6×6 FOVs, and 26.38% in 7×7 FOVs if the FOV size is constant at 7 km.

- CrIS Noise will increase by the square root of detector size if only considering detector noise. Since the actual noise of current SNPP CrIS is far below the specification, increasing the NEDN by a factor of 2 is still below or close to the specification. However, the final noise performance should rely on future optical and electrical design.

- There will be less spectral shift due to self-apodization correction for center, corner, and side FOVs with smaller FOVs. This will help the spectral correction at all three bands.

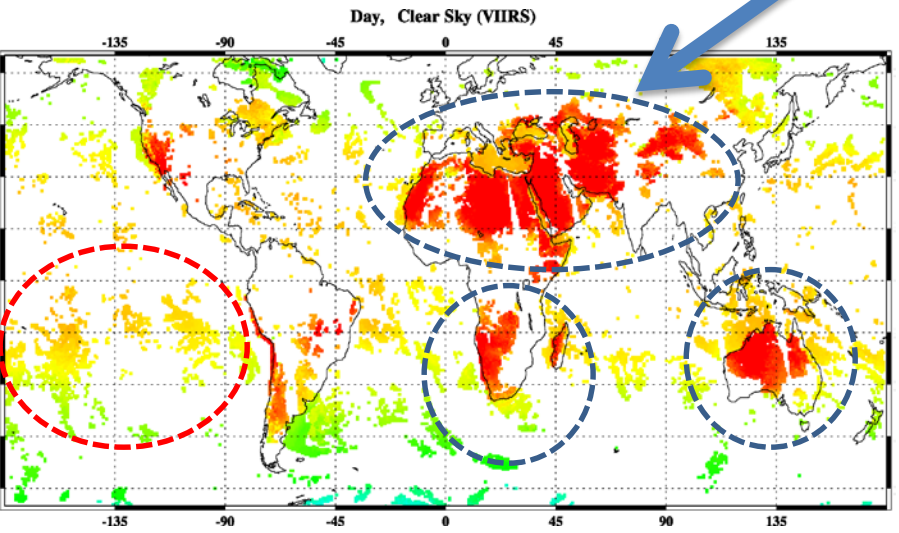
Clear Sky Detection Comparison (Day time)

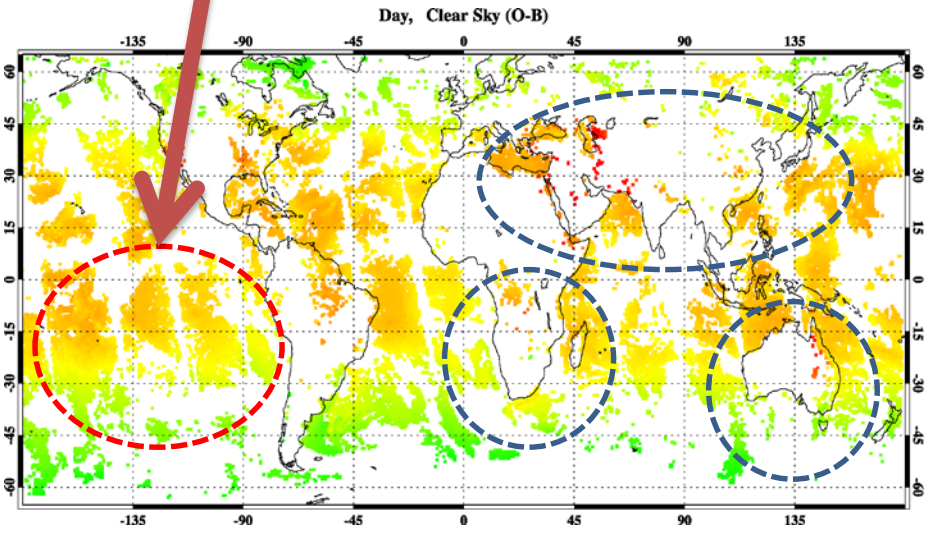


Two issues can be found that:

1) Land Surface temperate errors during day time make the RTM difficulty to simulate observations over land;

2) NWP method found more clear sky pixels over ocean. It seem warm clouds.





VIIRS method

NWP method