Benefits of Spatial Resolution for Next Generation CrIS

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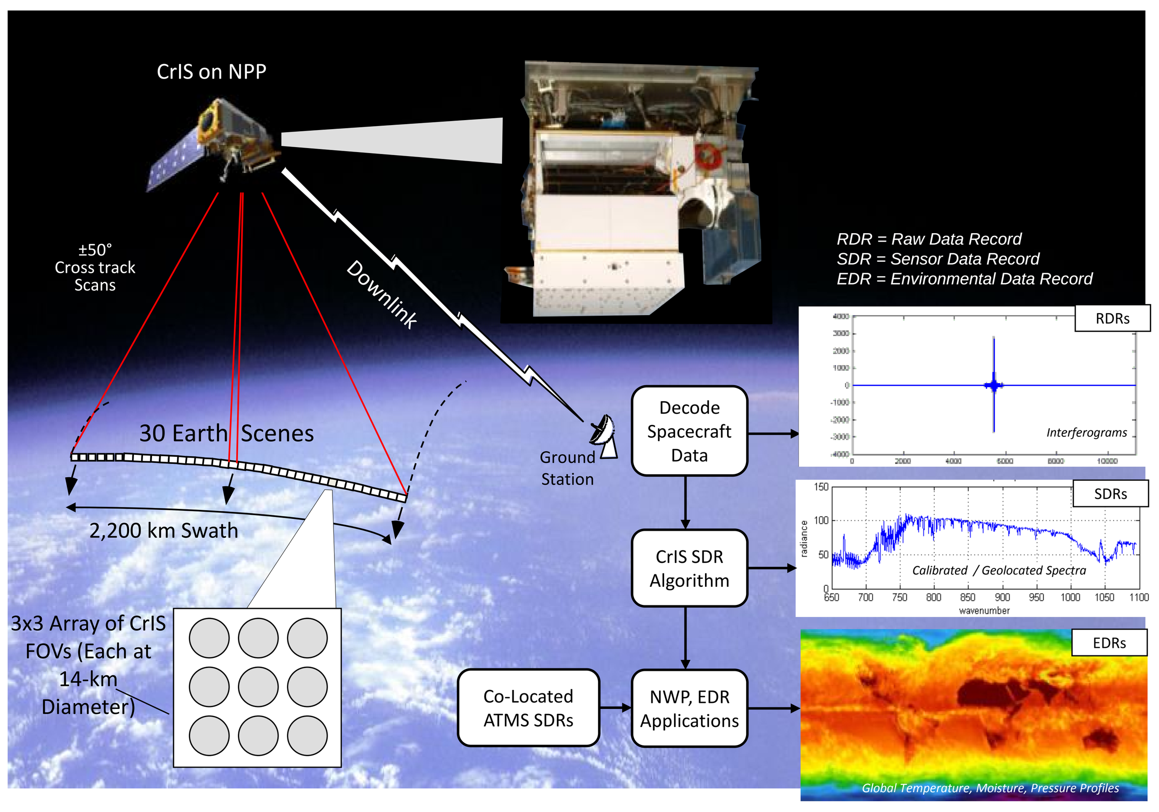
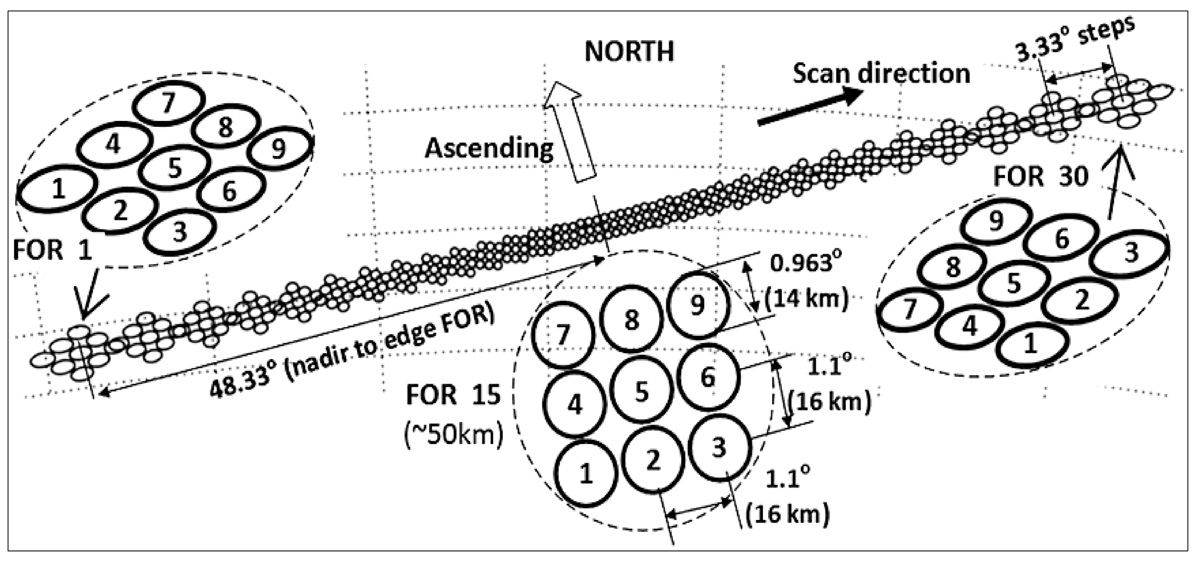
Abstract: Hyperspectral infrared (IR) radiance measurements from satellite sensors contain valuable information on atmospheric temperature and humidity profiles and greenhouse gases. These measurements are used not only to retrieve atmospheric temperature and humidity profiles, but more importantly, to be directly assimilated into numerical weather prediction (NWP) models as inputs for weather forecasting, Among them, the Crosstrack Infrared Sounder (CrIS) is a Fourier transform spectrometer, providing sounding information of the atmosphere with 1305 (normal spectral resolution) or 2211 spectral channels (full spectral resolution) over 3 wavelength ranges. CrIS was first launched on Suomi National Polar-orbiting Partnership (SNPP) satellite in October 2011 and will continue to be onboard the following Joint Polar Satellite System (JPSS) satellites. However, data assimilations of using hyperspectral radiances in current operational NWP models still mainly relies on cloud-free observations due to the challenge of simulating cloud-contaminated radiances. The limited spatial coverage of the 3 x 3 FOVs (i.e., spatial gap among FOVs) as well as relative large footprint size (14km) limits the amount of clear sky observations. Furthermore, current NWP global and regional models have horizontal resolutions of 10 km and 3 km, respectively, and in 5 years the global model resolution will be further improved. Therefore, it is essential to improve CrIS measurements to match NWP model resolutions by reducing the CrIS FOV size and thereby increasing spatial resolution. This study explores the potential benefits of future CrIS FOV configuration (including FOV size and spatial coverage) on amount of clear sky observations.

CrIS Operation Concept



CrIS is a Fourier transform spectrometer, providing sounding information of the atmosphere with 1305 (normal spectral resolution) or 2211 spectral channels (full spectral resolution) over 3 wavelength ranges. CrIS was first launched on Suomi National Polar-orbiting Partnership (SNPP) satellite in October 2011 and will continue to be onboard the following Joint Polar Satellite System (JPSS) satellites. Geolocated, radiometrically and spectrally calibrated radiances with annotated quality indicators from CrIS—the so-called Sensor Data Records (SDRs)—are used not only to retrieve atmospheric temperature and humidity profiles, but more importantly, to be directly assimilated into numerical weather prediction (NWP) models.

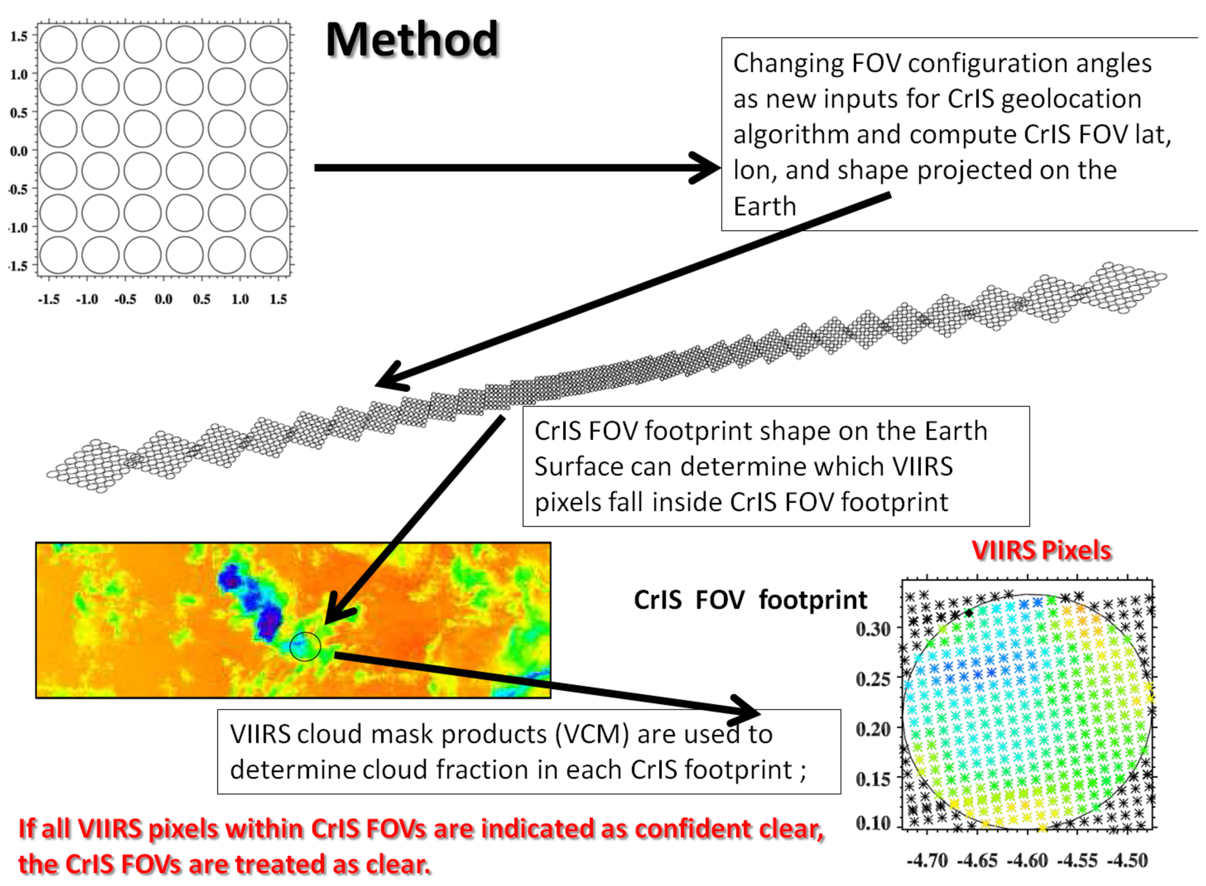
CrIS Scan Pattern



CrIS scan mirror stepwise "stares" at the Earth step by step in the cross-track direction from −48.3° to +48.3 with a 3.3° step angle, collecting 30 Fields of Regards (FORs) of the Earth scenes. Each FOR contains 3 × 3 0.963° circular detectors separated by 1.1°, corresponding a 14km circular footprint at nadir on the Earth surface.

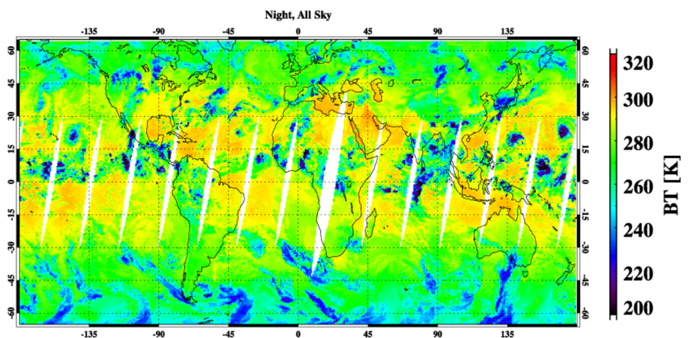
We use radiance measurements and cloud mask products (VCM) from the Visible Infrared Imager Radiometer Suite (VIIRS) to simulate CrIS clear-sky observation under different FOV configurations, including FOV size and FOV coverage. We have developed the fast and accurate collocation algorithm between CrIS and VIIRS based on line-of-sight (LOS) pointing vectors (Wang et al. 2016). The key is to generate CrIS LOS vectors under different configurations and then collocate VIIRS radiances and cloud mask to check scene characteristics.

Using VIIRS to simulate CrIS



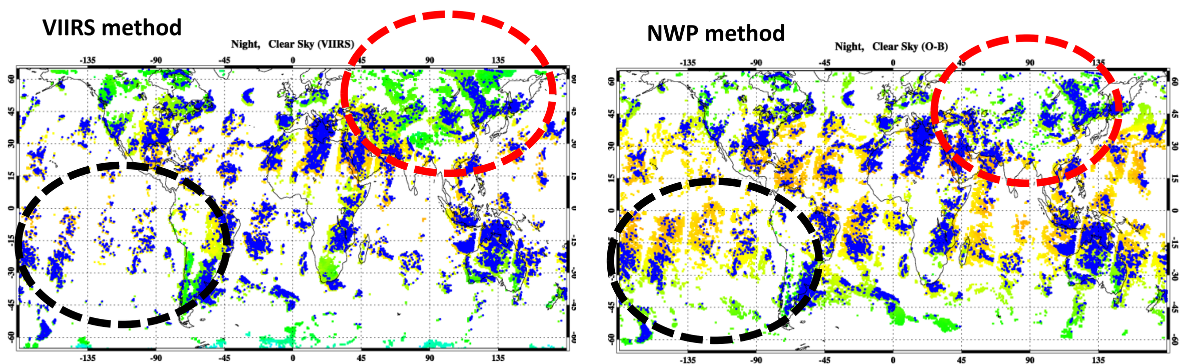
If all VIIRS pixels within CrIS FOVs are indicated as confident clear, the CrIS FOVs are treated as clear.

Clear sky detection



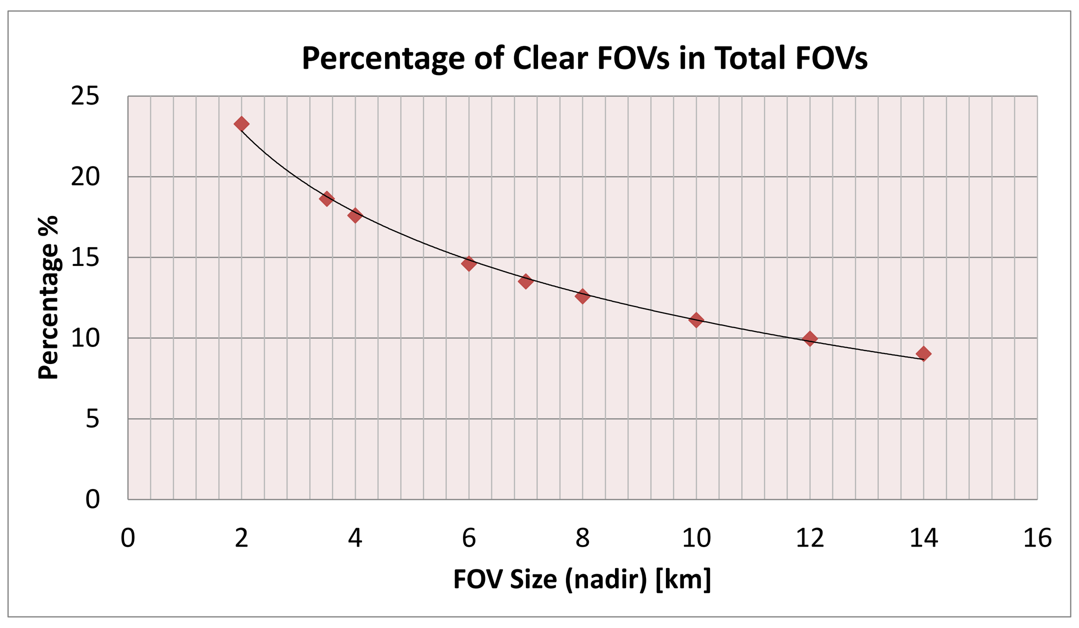
The VIIRS method represents the most conservative clear sky detection and thus can well characterize scene sub-pixel features of CrIS.

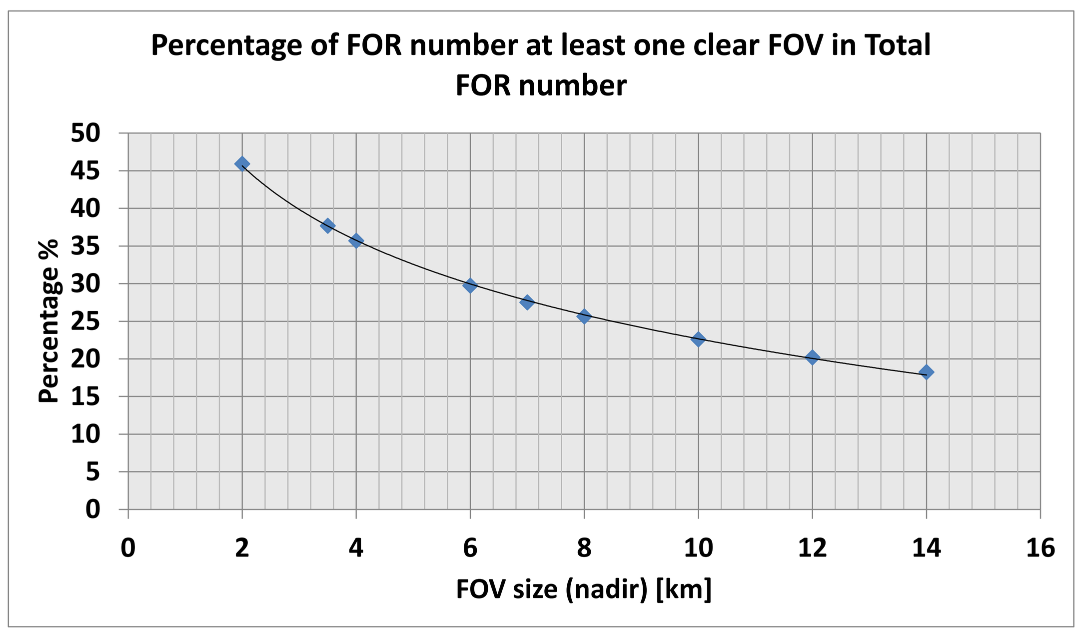
The NWP cloud-sky detection method, which is from the scheme by McNally and Watts (2003), is based on assumptions about the radiative effect of cloud on observation minus background departures. 1) More clear sky observations over sea by NWP method; 2) Missed detection of clear sky observations over land by the NWP method.



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

Experiment 1: FOV size





Current data assimilation systems perform data thinning to reduce the large satellite data sets and to retrieve the essential information content of the data for optimal use. Especially for CrIS, only one clear FOV in each FOR is used for data assimilation to avoid spatial correlation.

Experiment 2: FOV Coverage

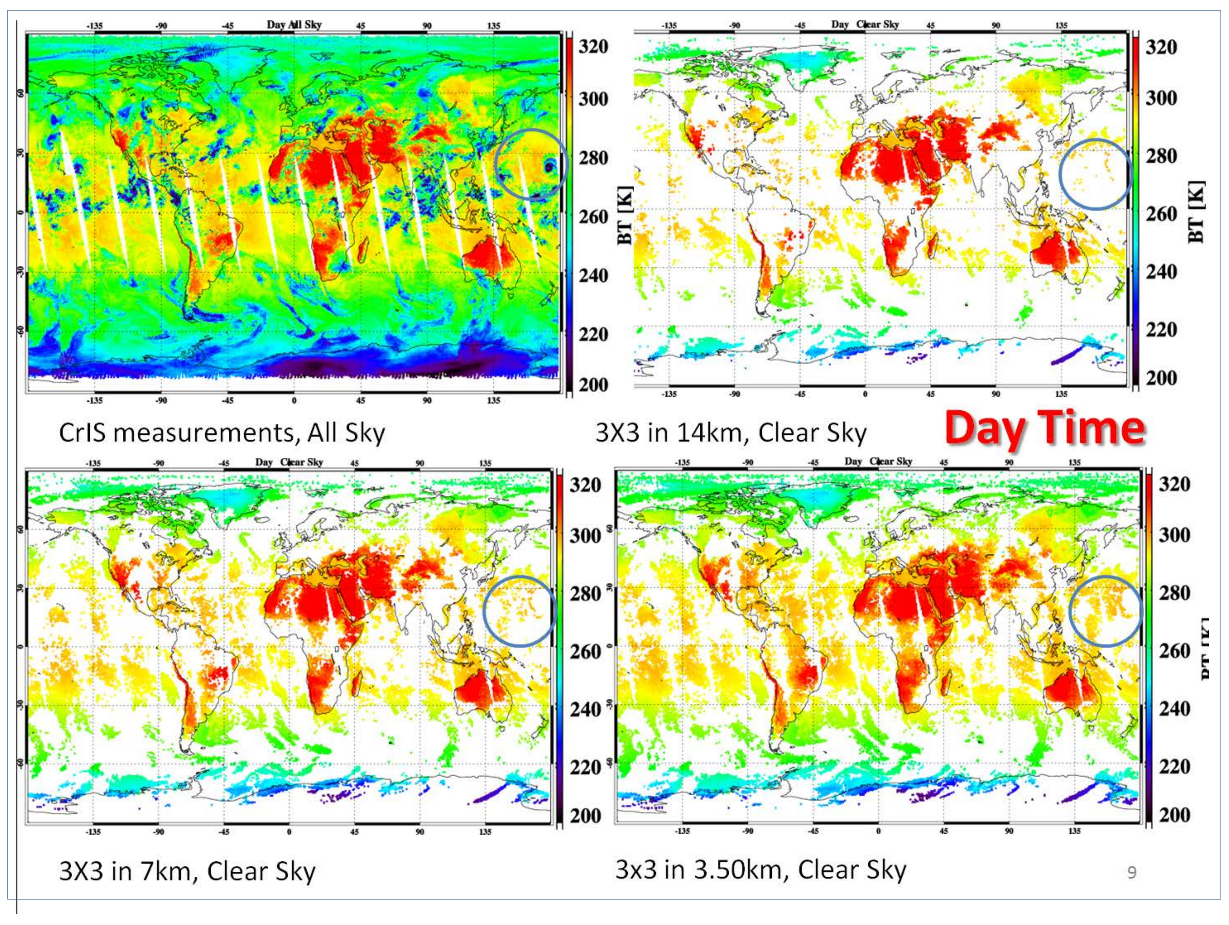
Configuration	Total FOV number	Clear FOV number	Percentage clear FOV in total FOVs (%)
3x3 in 14km	2917080	263318	9.026766
3x3 in 7km	2917080	394149	13.51177
5x5 in 7km	8103000	1095181	13.51575
6x6 in 7km	11668320	1577654	13.52083
7x7 in 7km	15881880	2146936	13.51815

Configuration	Total FOR number	FOR number at least 1 FOV clear	Percentage of clear FOR at least 1 FOV clear	FOR number at least 4 FOV clear	Percentage of clear FOR at least 4 FOV clear
3x3 in 14km	324120	59133	18.24417	N/A	N/A
3x3 in 7km	324120	89171	27.51172	46277	14.27774
5x5 in 7km	324120	106492	32.85573	71325	22.00574
6x6 in 7km	324120	112172	34.60817	79149	24.41966
7x7 in 7km	324120	116177	35.84382	85515	26.38375

Under this simulation, the total FOV samples increase with the number of FOVs in each FOR. In other words, the science data volume and rate from the CrIS instrument will scale directly with the number of FOVs. The simulation results indicate that the percentage of clear sky FOV stays the same value – around 13.5% of the total samples. This suggests that the total clear sky FOV observations will also scale directly with the total sampling FOVs .

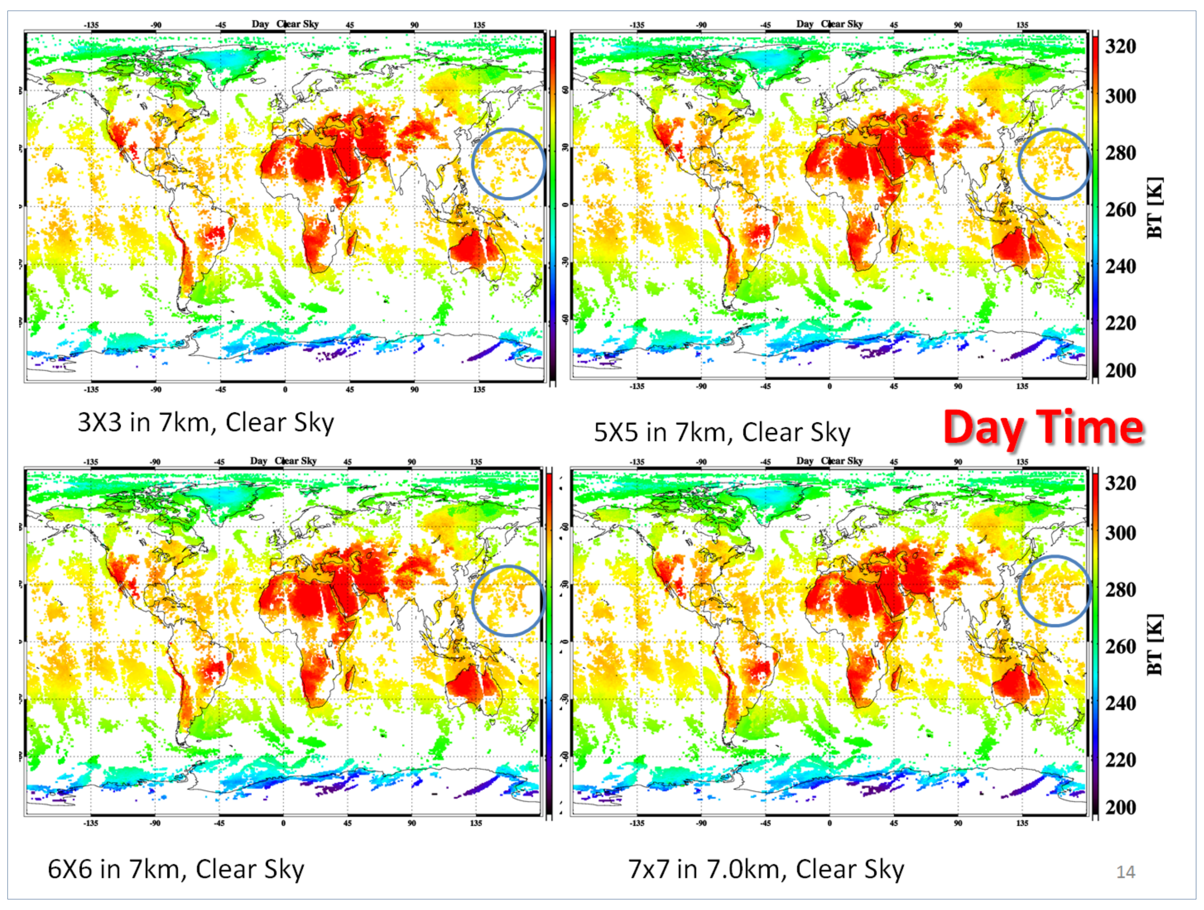
Simulation Results using VIIRS

Experiment 1: FOV size



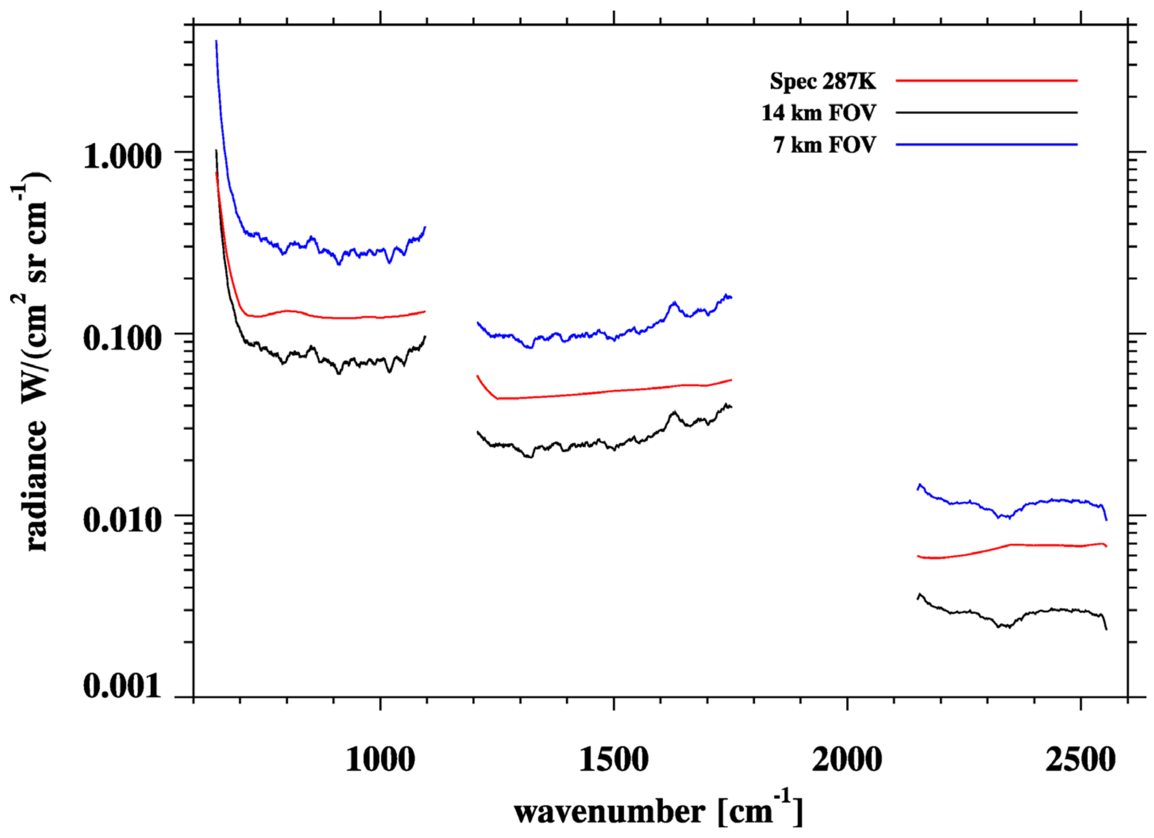
IF each FOR in future CrIS still keeps the same spatial coverage (i.e., 3x3 FOVs), how does the clear sky statistics change with different FOV size?

Experiment 2: FOV coverage



If CrIS stays the same FOV size (e.g., 7km), how does the clear sky statistics change with increasing FOV spatial coverage (i.e., 3x3, 5x5, 6x6, and 7x7)?

Noise change with FOV Size



The shrinking of the FOV size from 14 km to 7km lowers the available IR energy by a factor of 4 (related to the detector area). In order to maintain the system performance either longer dwells at each FOV are required or more sensitive detectors are needed to compensate for the loss of signal. Under current SNPP instrument configurations (all stay the same), the NEDN will increase by factor of 4 when CrIS FOV size changes to 7 km from 14km if we assume that CrIS NEdN is inversely proportional to the detector area (or FOV area).

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