JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

STereo Atmospheric Remote Sensing (STARS) for Retrieval of Cloud Geometric Heights and Motion Vectors

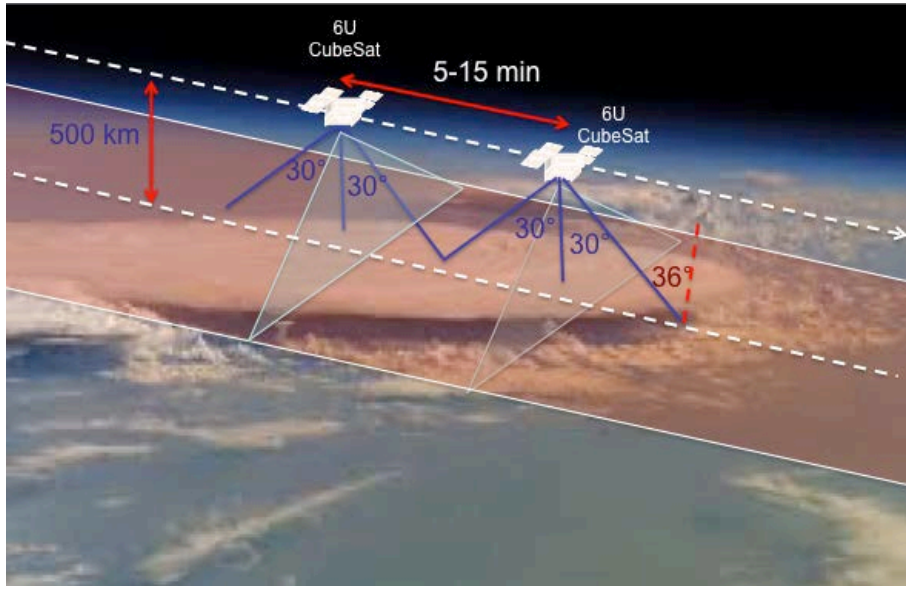
Michael Kelly
michael.kelly@jhuapl.edu
Ph: 240-228-0788

D. Wu, NASA/GSFC
J. Boldt, JHU/APL
A. Goldberg, JHU/APL
J. Carr, Carr Astronautics
J. Wilson, JHU/APL
I. Papusha, JHU/APL
F. Morgan, JHU/APL
S. Yee, JHU/APL
A. Heidinger, NOAA
R. Stoffler, Air Force

2nd Workshop
CGMS International Cloud Working Group
30 Oct 2018

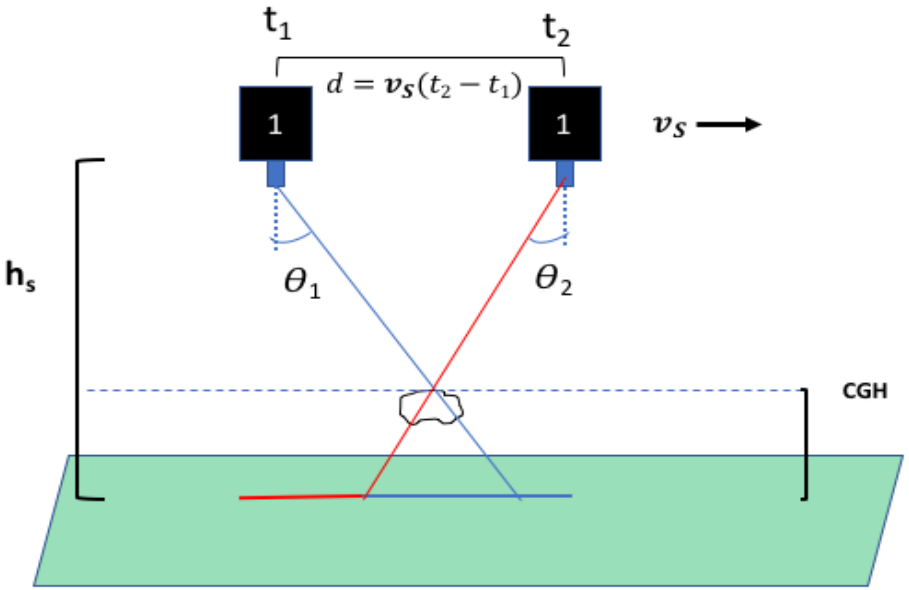
Acknowledgment: Work supported by NASA ESTO IIP grant

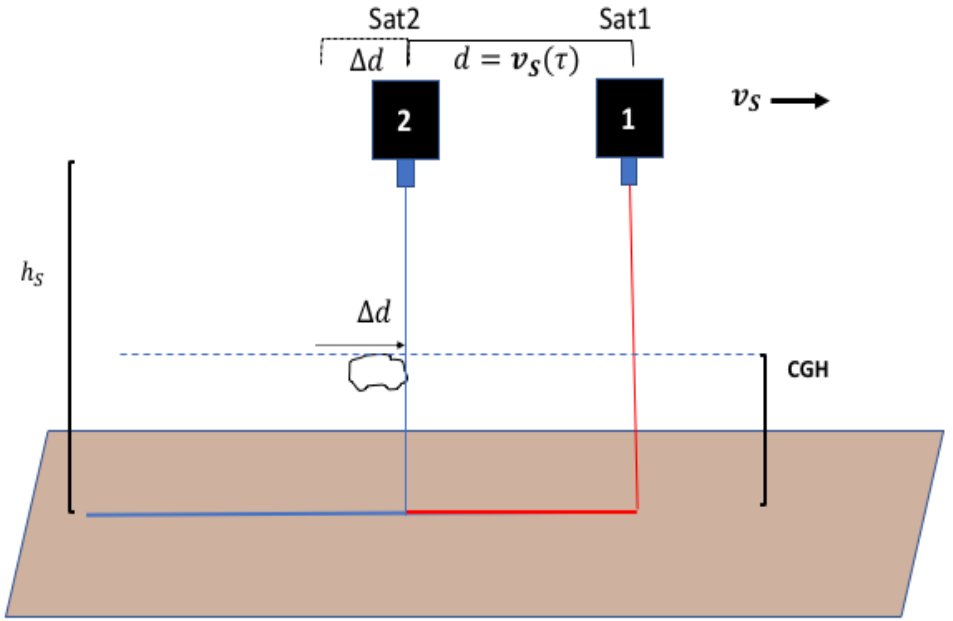
STereo Atmospheric Remote Sensing (STARS)



- Fly imagers on leading and trailing spacecraft to perform stereo calculations
- Payload includes 3-bandpass LWIR, 3-bandpass MWIR, and 3-bandpass visible day-night band (DNB) to obtain 24/7 cloud motion vectors and cloud geometric heights with accurate height assignment
- Improve accuracy of CMV/CGH with **two** spacecraft several minutes apart to eliminate ambiguity in along-track direction between winds and cloud heights
- Estimated CMV/CGH Precision: ±1 m/s , ±250 m assuming ½-pixel relative geolocation accuracy

Cloud Motion Vectors and Height Assignment





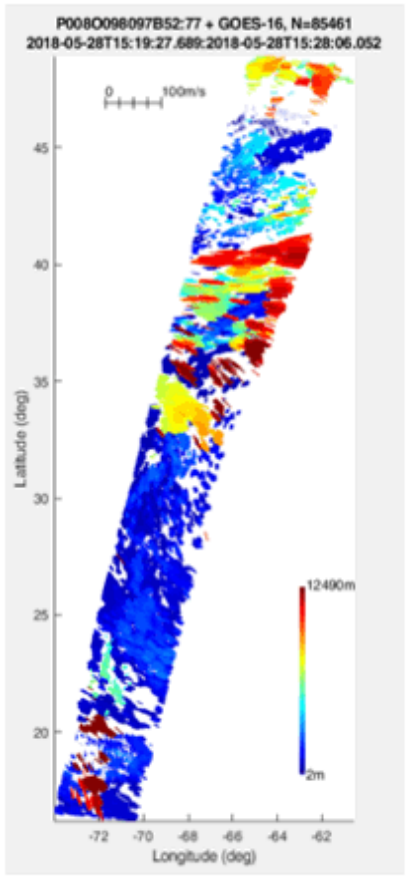
$$h_c = h_s - \frac{1}{tan(\theta_1)+tan(\theta_2)} d \equiv h_s - \alpha d$$

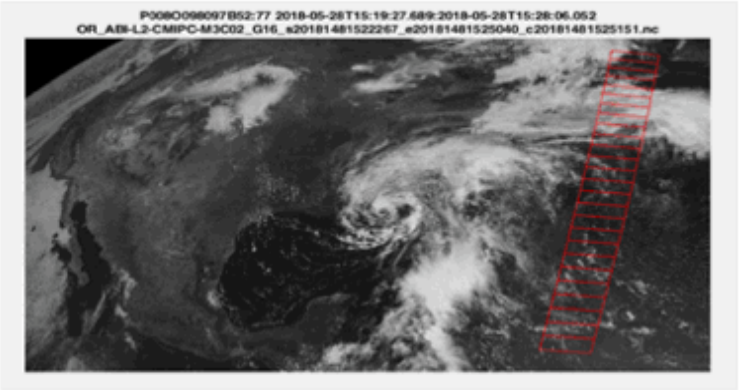
- Uses parallax effect to retrieve cloud height regardless of time of day, surface brightness/temperature, atmospheric lapse rate
- Relies on matching cloud patterns between two images several minutes apart
- Derives CMVs based on the distance travelled by the cloud pattern between images on **two** satellites

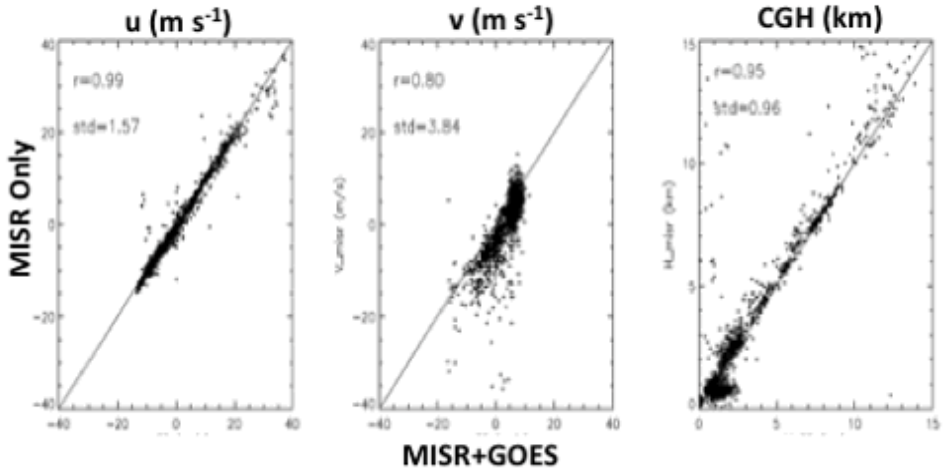
Two-satellite approach

- Carr et al. (2018, minor revision) describe capability to derive winds and cloud heights using MISR+GOES
- Demonstrate improved height assignment in LEO-GEO overlapped regions
- Demonstrate improved along-track winds
- Develop a cost-effective approach (**CMIS**) for joint LEO-GEO wind and stereo height measurements

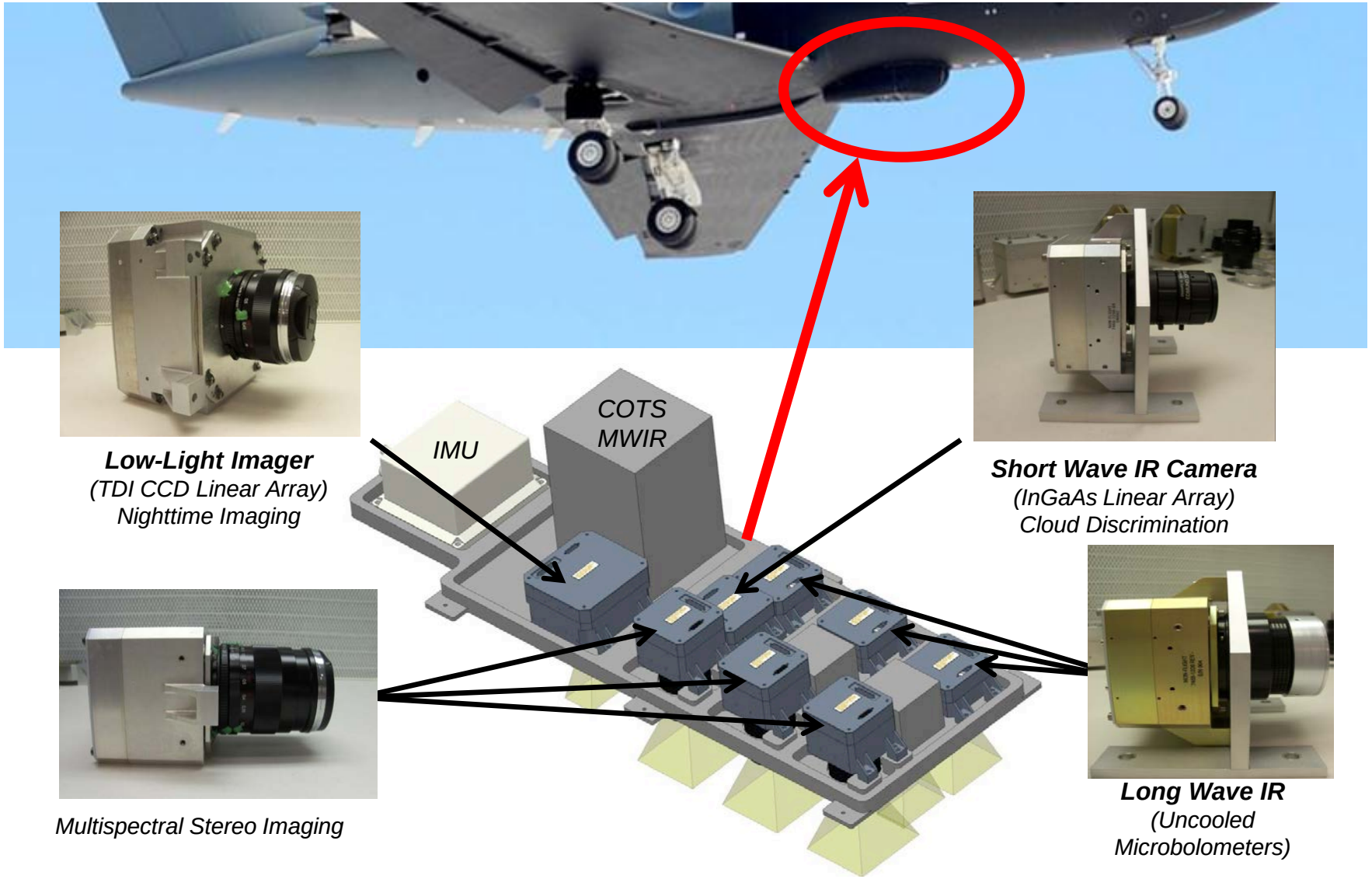
Example of Dual Approach (MISR+GOES)







Heritage



Low-Light Imager
(TDI CCD Linear Array)
Nighttime Imaging

Short Wave IR Camera
(InGaAs Linear Array)
Cloud Discrimination

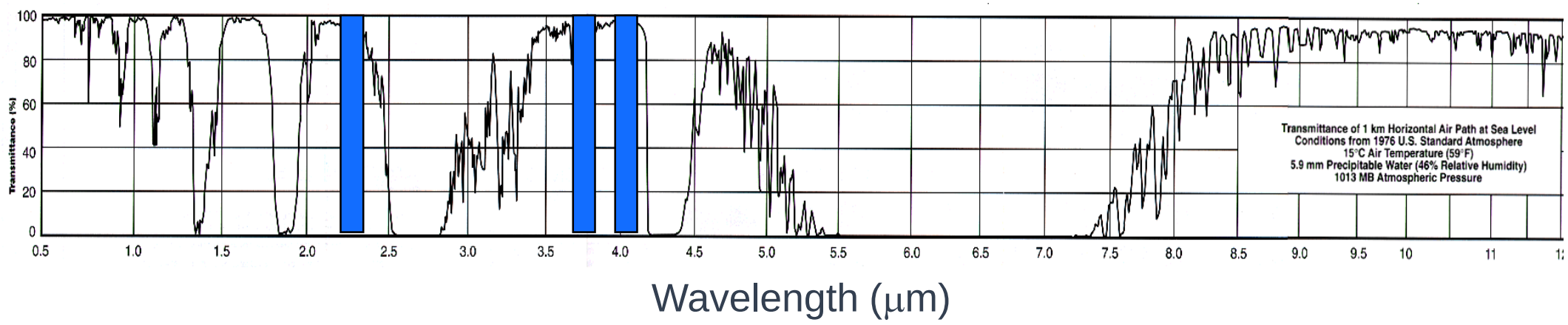
Multispectral Stereo Imaging

Long Wave IR
(Uncooled
Microbolometers)

MSIS Test Campaign

- Integration: 16 Nov – 1 Dec 2013
- Data Collection: 2 Dec – 20 Dec 2013
- Objectives: Collection of Multi-spectral data of cloud and ground conditions needed to assess MSIS performance against METOC measurement requirements.

Midwave Bands

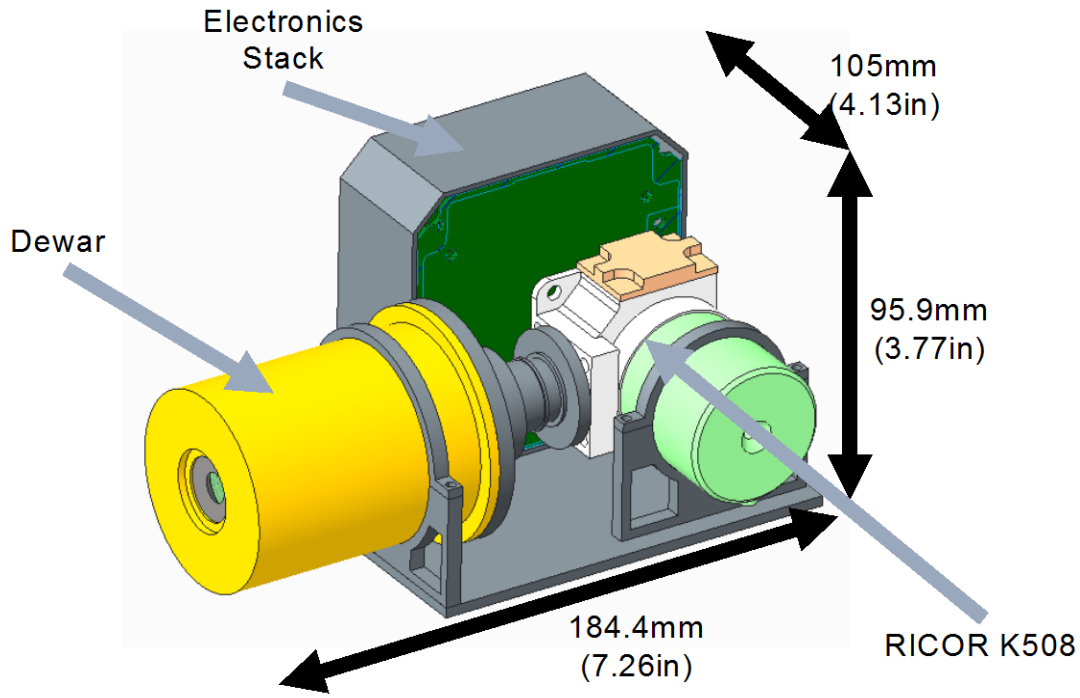


Wavelength (μm)

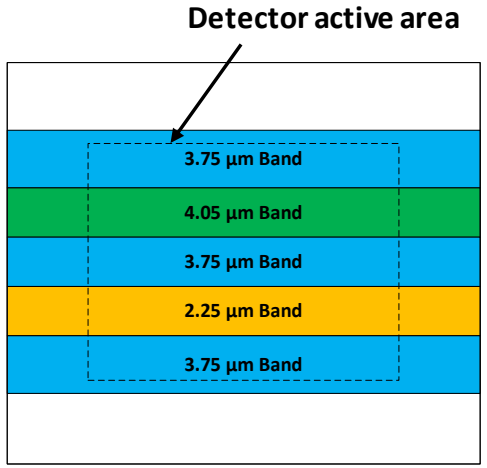
- CMIS bands shown in blue – located in window regions in SWIR/MWIR
- Performs the observations at 2.25, 3.75, and 4.05
  - Employs 3.75-μm band for cloud motion vectors and stereo observation
  - Uses 2.25-μm and 4.05-μm bands to assist with removal of solar component, temperature estimation, aerosol discrimination
  - Can also use 4.05-μm band for fire detection

CMIS Design

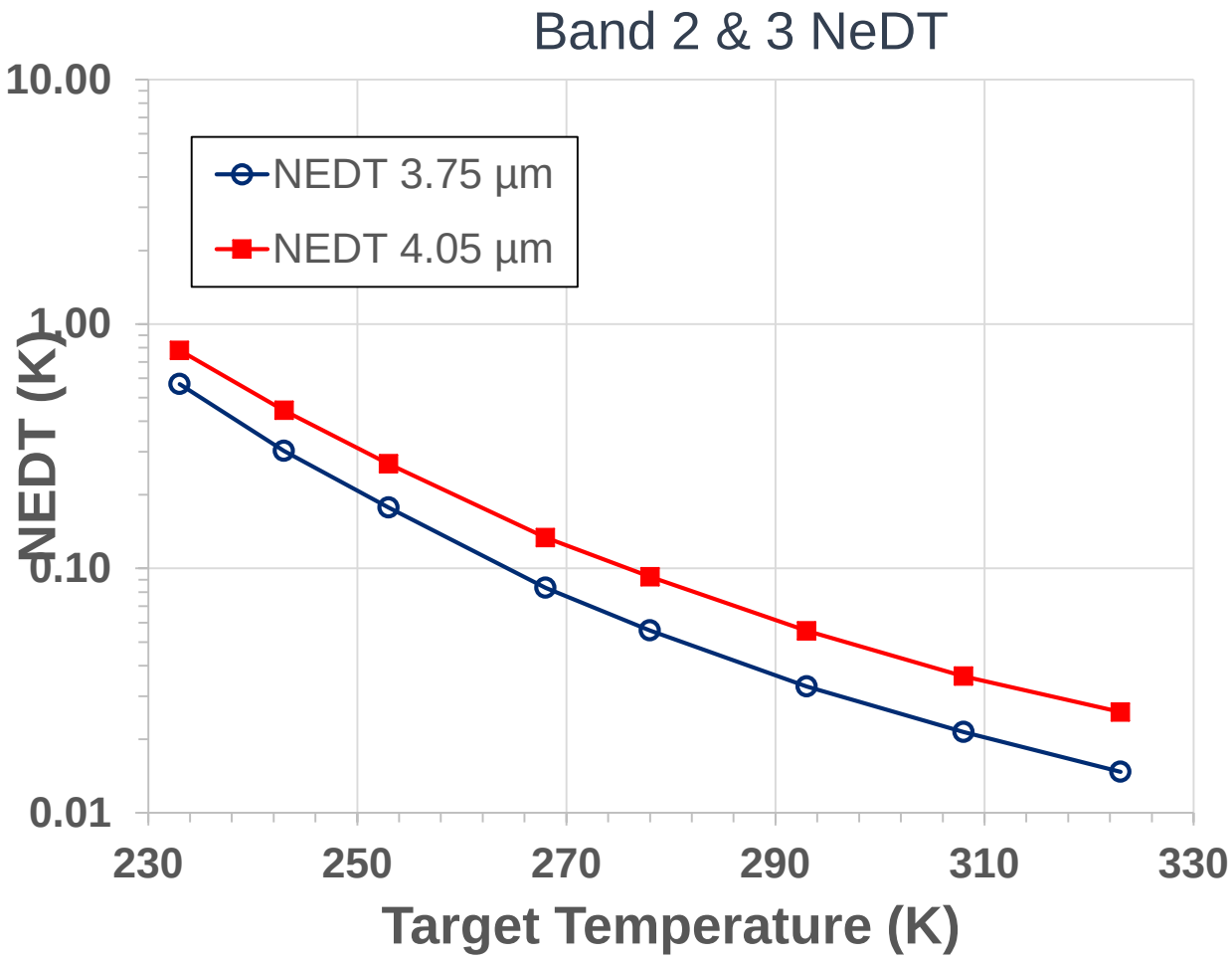
- Telecentric to avoid frequency shift across the detector
- Bands at 2.25, 3.75, and 4.05 µm
- 640 x 512 focal plane array
- Field of view: 53° cross-track
- Type-2 Superlattice detector cooled to 150K
- Integrated dewar assembly for airborne flight tests

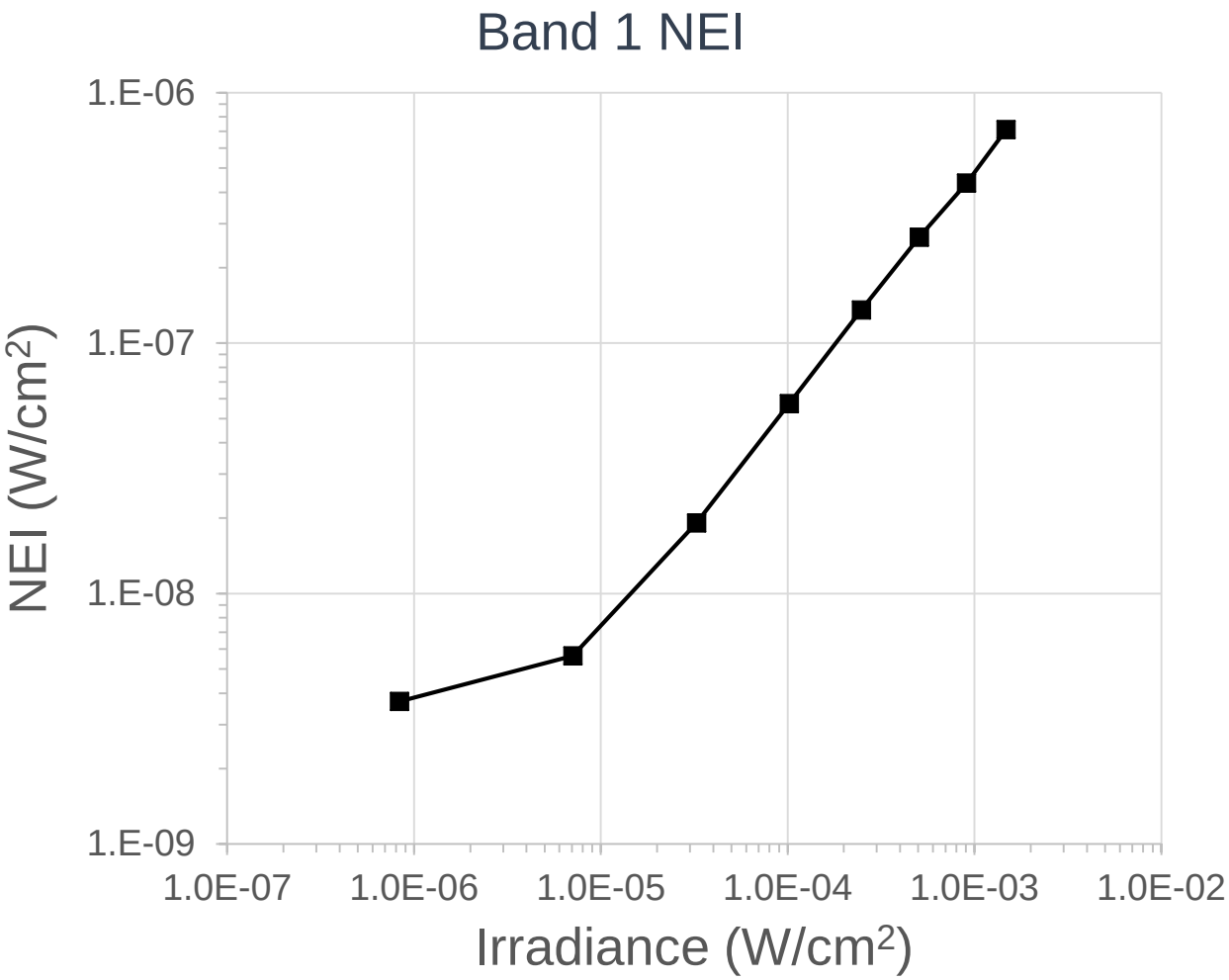


Stripe Filter



Sensitivity

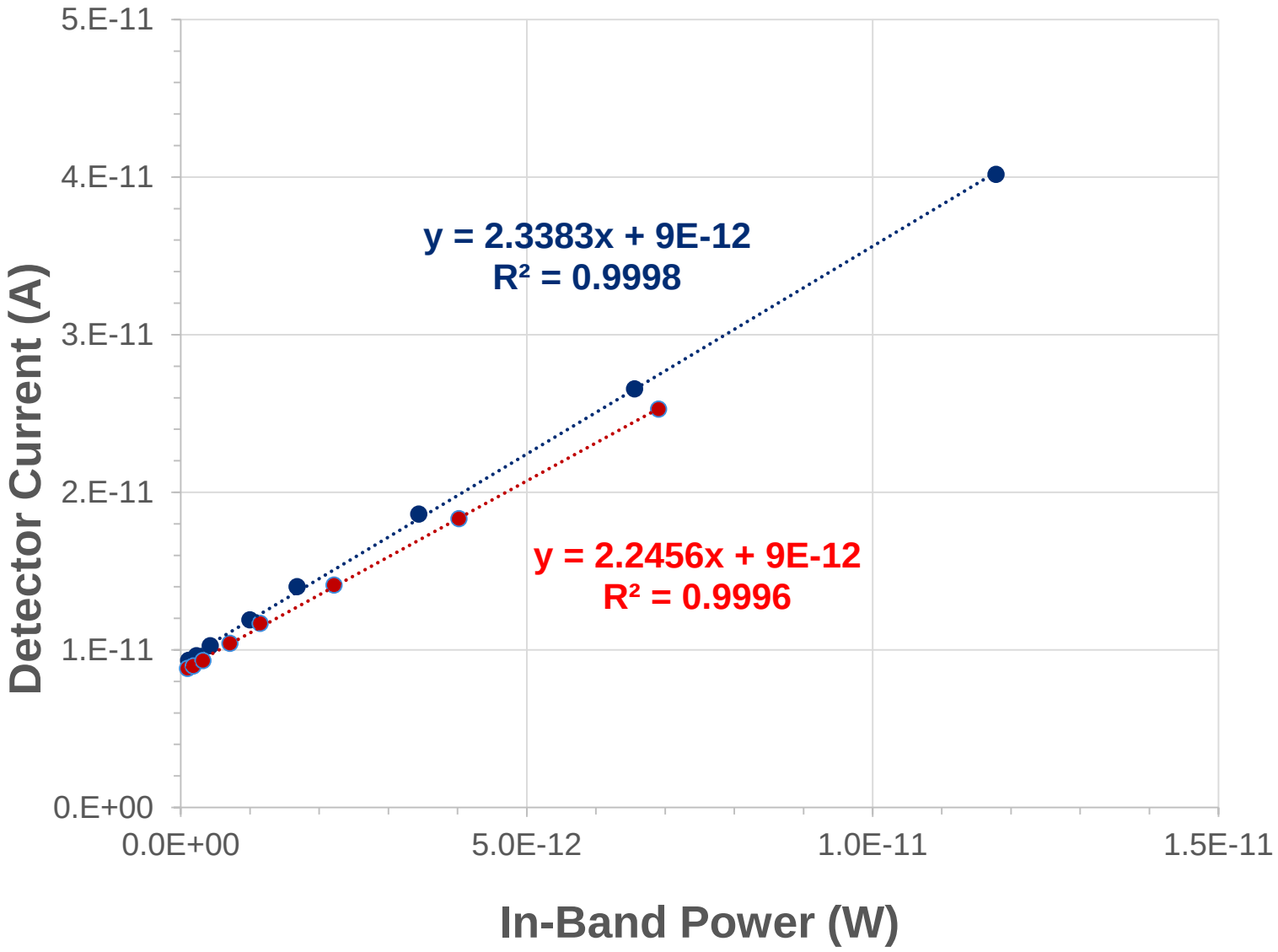




Use TDI to detect cloud clouds at 200 K

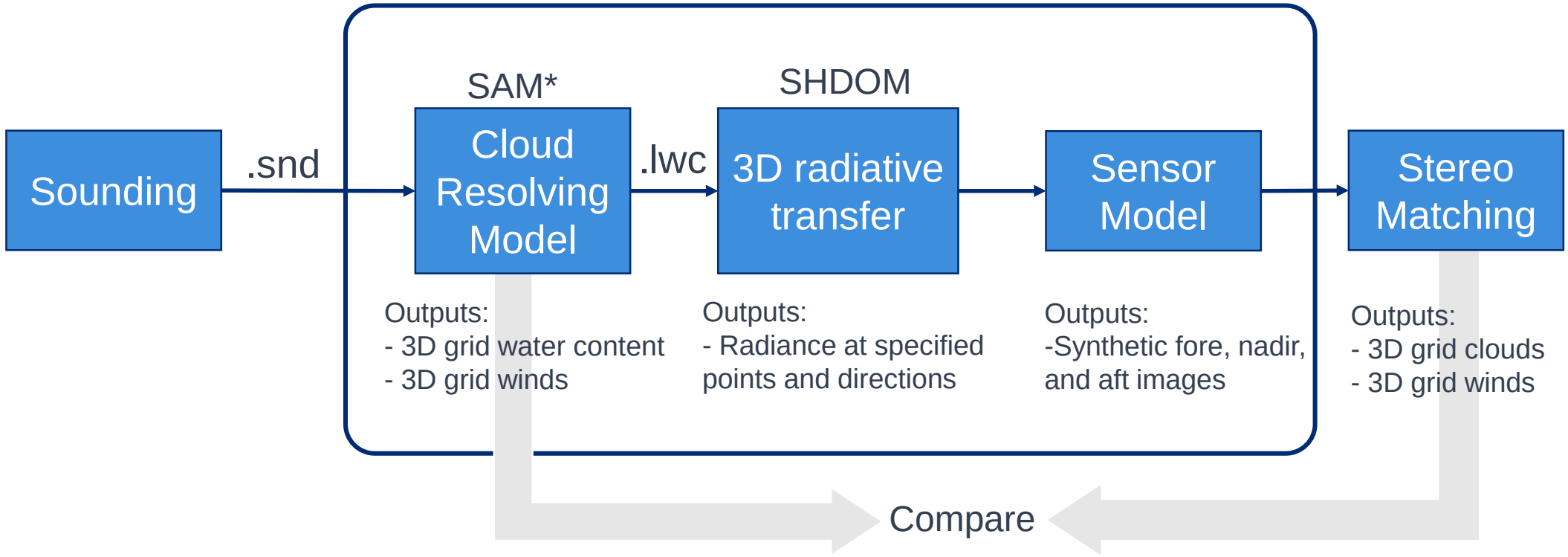
SNR ≥100 for 2.25

Response Linearity



- Excellent response linearity over several orders of magnitude in all 3 bands.
- Implication: On-board calibration sources do not have to cover the entire scene dynamic range to provide accurate scene/target temperatures (bands 2 &3) or reflected sunlight radiance (band 1).
- Reduces necessary SWaP for the instrument.
- Temperature measurement accuracy will be confirmed by extensive laboratory calibration.

CMIS Simulator

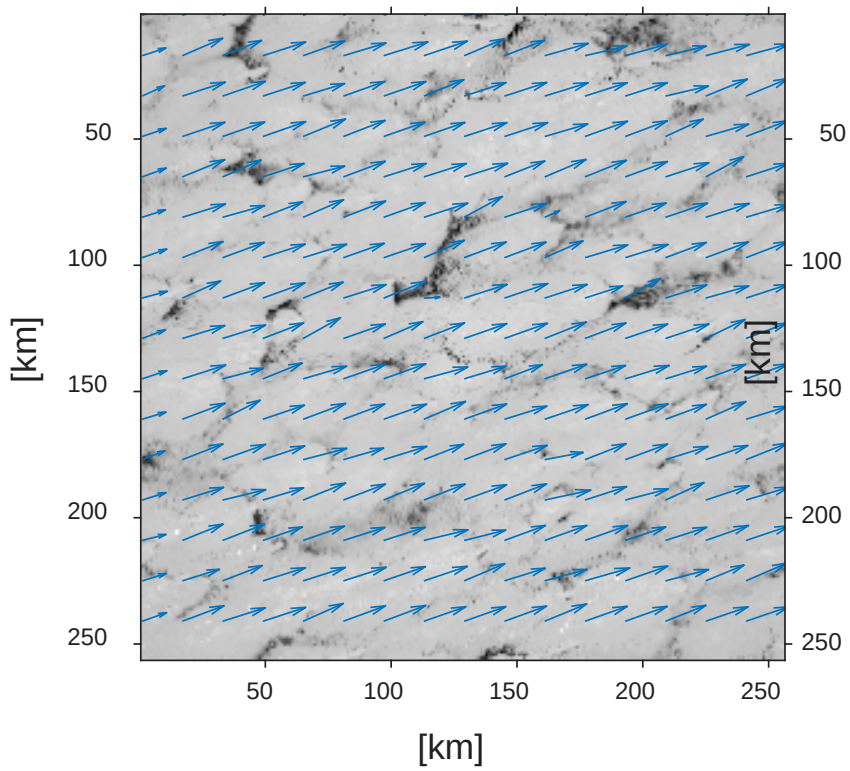


*Khairoutdinov, M. F. and D. A. Randall 2003. Cloud resolving modeling of the ARM Summer 1997 IOP: Model formulation, results, uncertainties, and sensitivities. J. Atmos. Sci. 60, 607–625.

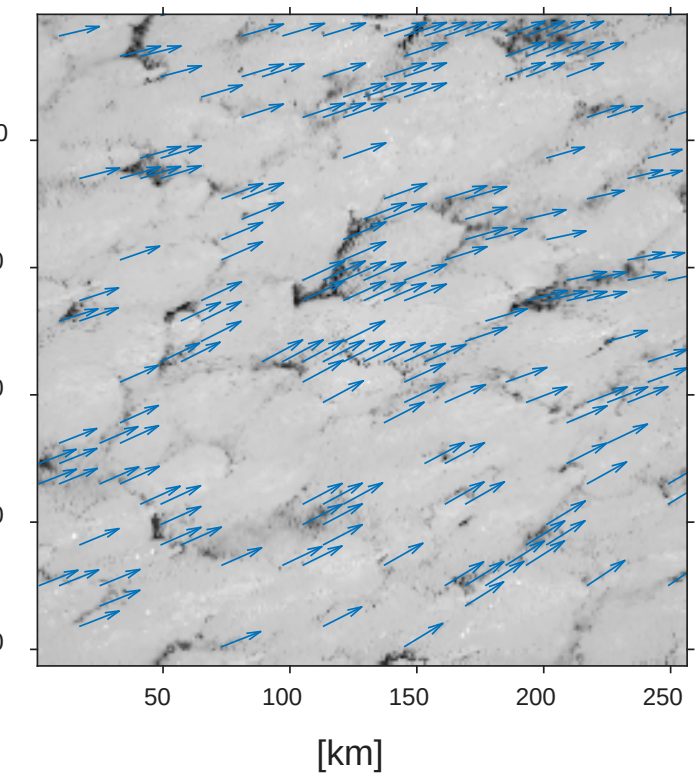
Modeled marine stratocumulus

- Marine nocturnal non-precipitating stratocumulus layer off the California Coast
- Simulation:
  - 256x256x96 domain (dx=1km, dy=1km, dz~5m), dt=2sec
  - 4 days simulation time (takes ~33hrs on 32 processors)
  - large scale wind forcing (u, v) = (3+0.0043*z, -9+0.0056*z) m/s
- Sounding:
  - Approx. constant wind (~8-10 m/s)
  - T=288.3K below 800m, goes up to 304K between 800m-1600m

SAM horizontal wind

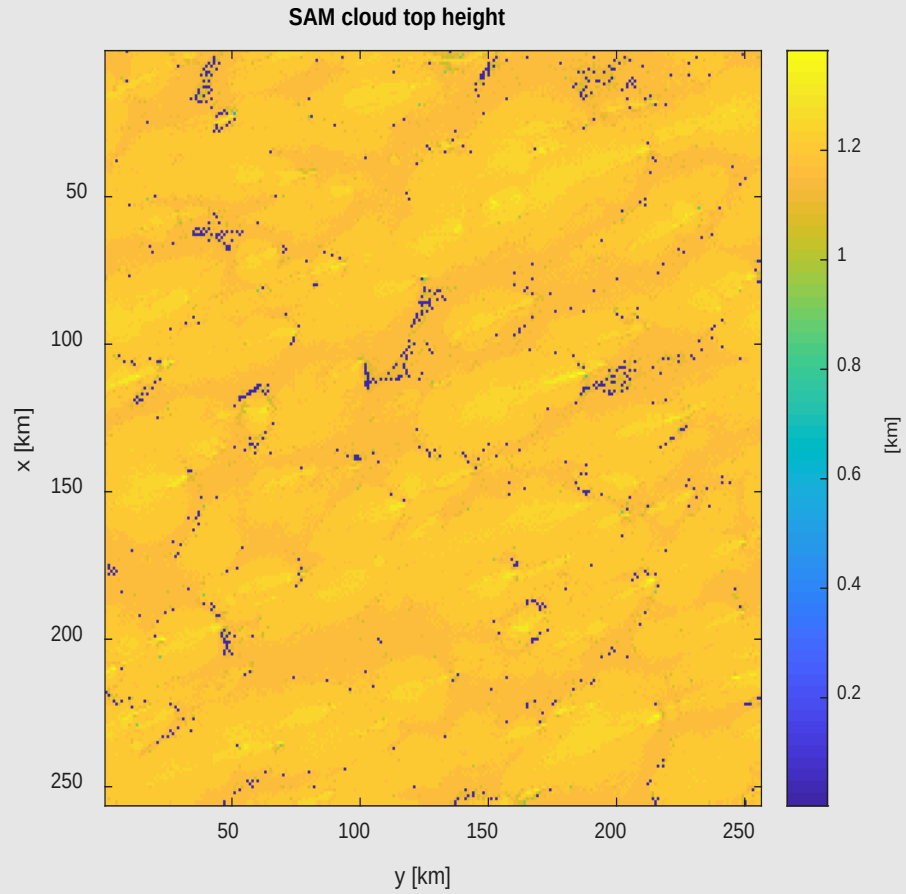


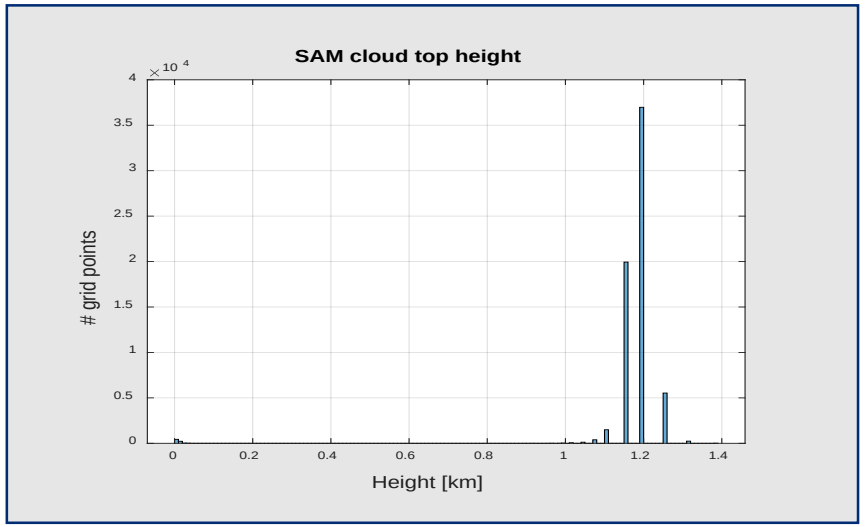
Retrieved horizontal wind



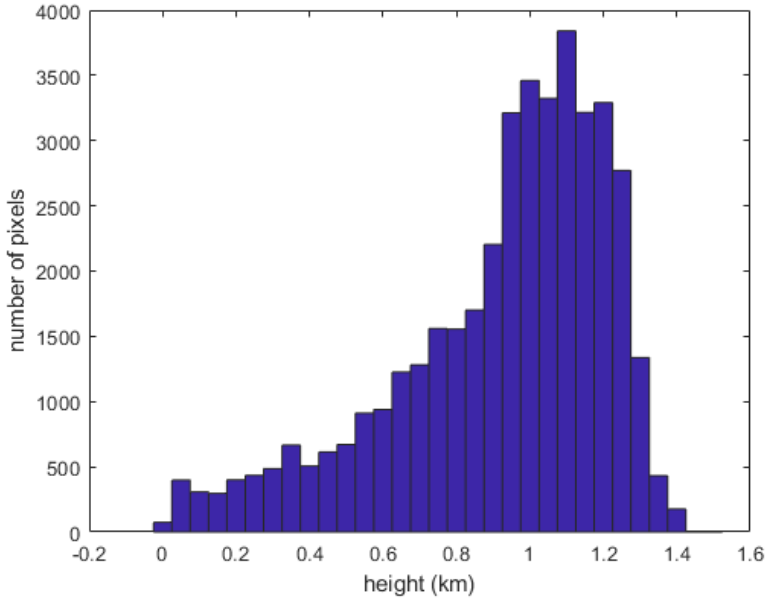
Stereo cloud top heights

"Truth"





Cloud top: highest point with water content at least 0.03 g/kg

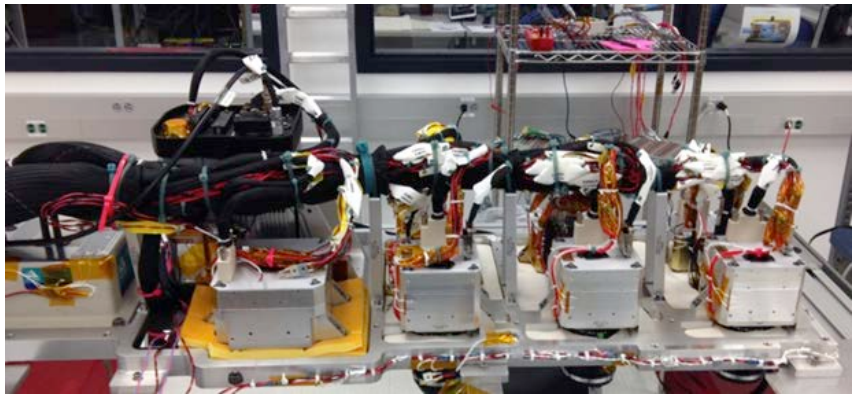


Wind-Corrected Cloud Heights based on Farneback algorithm

CMIS Performance Demonstration: Airborne Tests

NASA Gulfstream-3

	Duration (Hour)	Function
1	4	Engineering test Campaign dry-run Measurement mode Survey
2	4	Daytime collection with ground and ocean background
3	4	Nighttime collection
4	4	Daytime collection with snow background and cloud cover



The CMIS performance in an airborne environment and its measurement capability will be demonstrated on *three dedicated* NASA Gulfstream-3 flights out of LaRC flight facility, in Hampton.

Gulfstream-3 can accommodate both the nadir-viewing CMIS and a suite of previously flown visible and thermal-IR imagers equipped with GPS and IMU to provide needed complementary cloud measurements and critical position and attitude data for analysis.

One of the objectives for the flight demonstration is to cross-compare the CMIS airborne stereo retrievals with those constructed from VIIRS and GOES

Summary and Conclusions

- Multi-platform and multi-angle imaging from space provides a cost-effective complement for day/night cloud-height detection and 3D wind retrieval
- Provides synergy with other systems (GEO imagers, LEO scatterometers) for study of PBL processes/feedbacks
- Model analysis underway to define accuracies/precisions of CMIS retrievals

Acknowledgment: This work was supported under NASA ESTO Grant NNX17AG65G