JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Expected Performance of the Compact Midwave Imaging System

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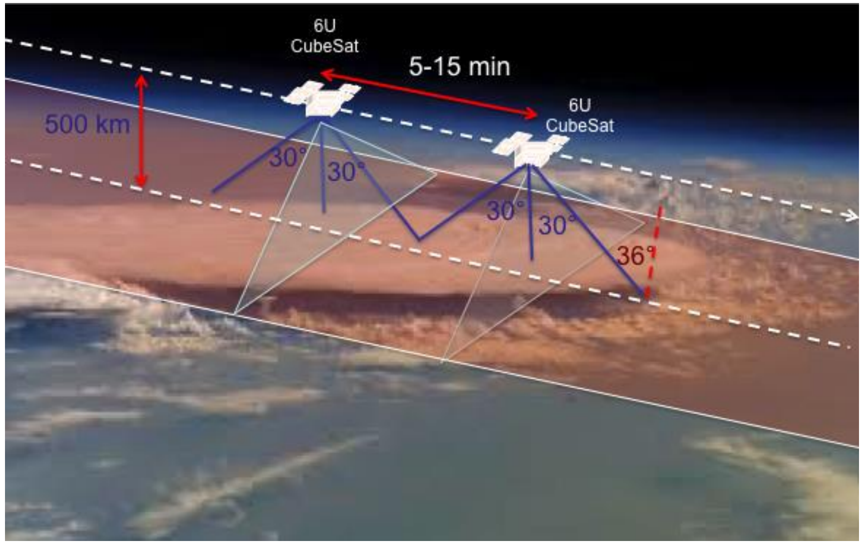
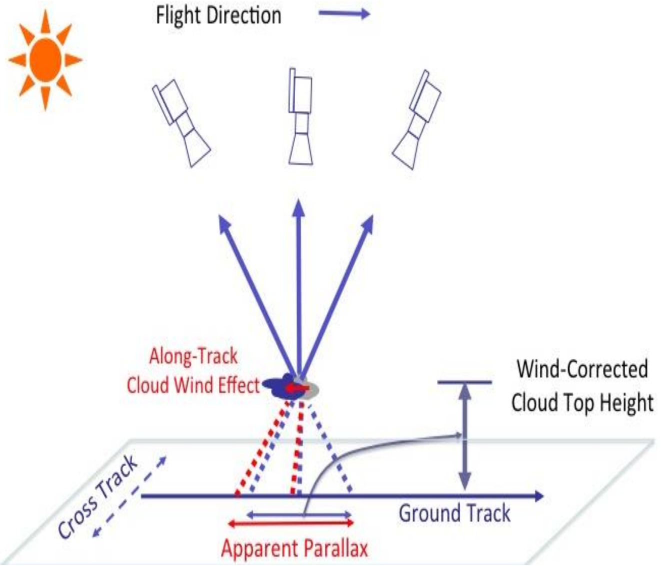
STereo Atmospheric Remote Sensing (STARS)



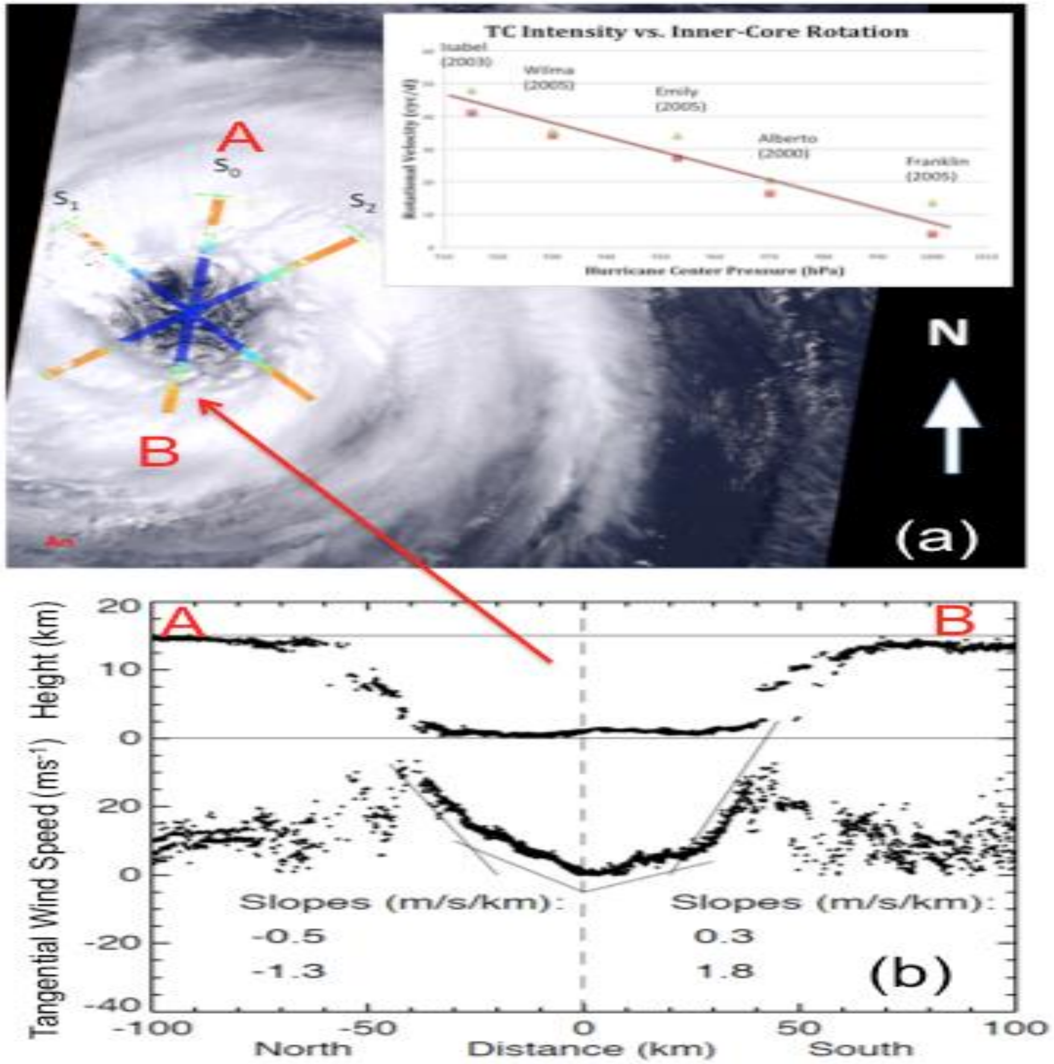


- **Concept:**
  - Fly weather cameras on leading and trailing spacecraft to perform stereo calculations
  - Payload includes 3-bandpass LWIR, 3-bandpass MWIR, and 3-bandpass visible day-night band (DNB) to obtain 24/7 cloud motion vectors and cloud geometric heights with accurate height assignment
  - Accurate CMV/CGH requires cameras on **two** spacecraft several minutes apart to eliminate ambiguity in along-track direction between winds and cloud heights
  - Stereo sensing complements highly sensitive sensors needed to discriminate clouds from bright background surfaces (e.g. snow, desert)

AMVs called out by 2017 Decadal Survey

Tropical Cyclone Intensity

Wu et al. 2010 (IWWG)

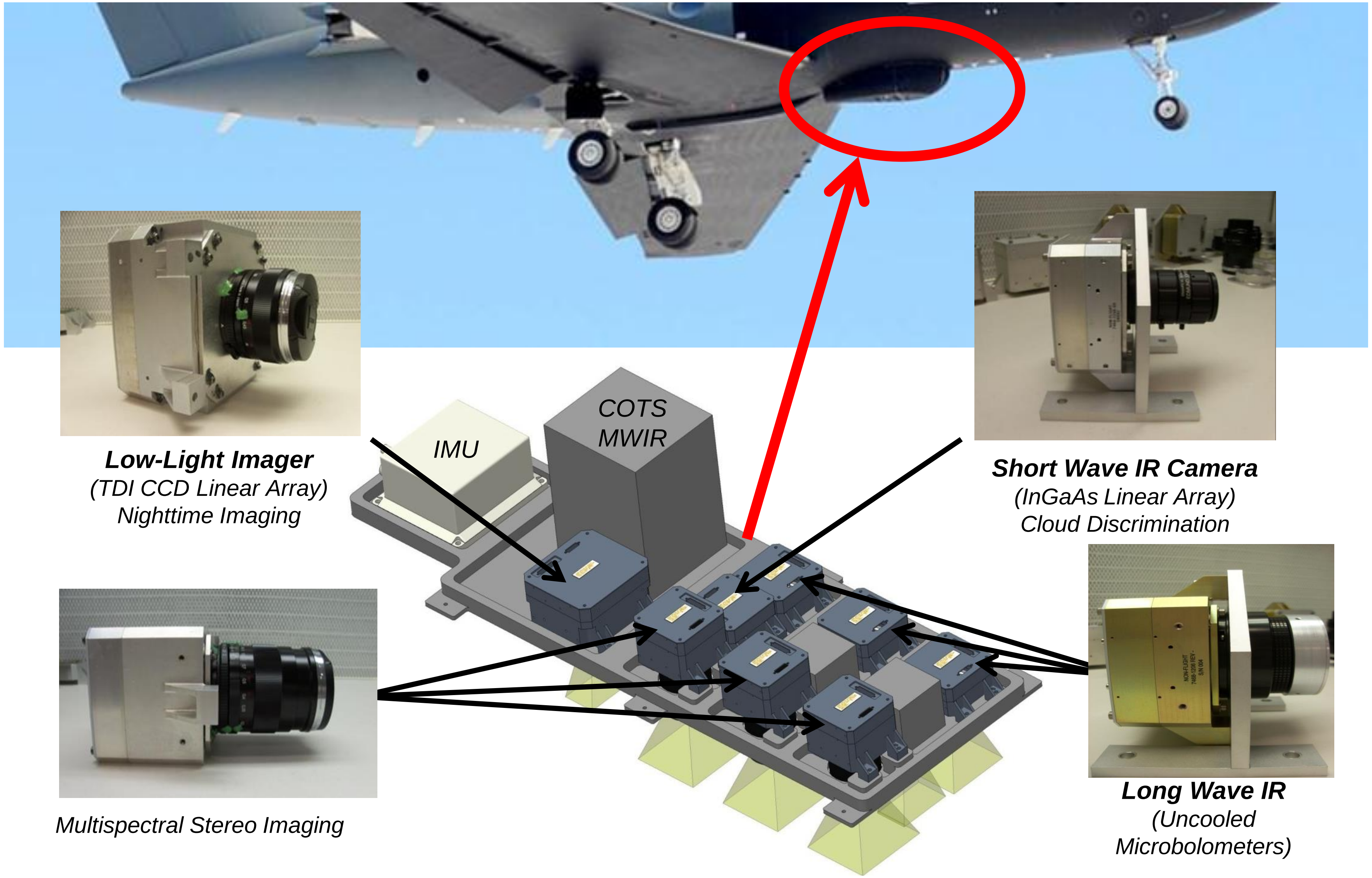


Dynamics inside hurricane eyewall provide a direct connection to cyclone intensity and reveal large variability near its eyewall rotation:

(a) Hurricane Alberto (2000) eyewall image from MISR, and relationship between the near-eye wall rotation and center pressure (embedded)

(b) Inner-core rotational velocities derived with stereo techniques from MISR

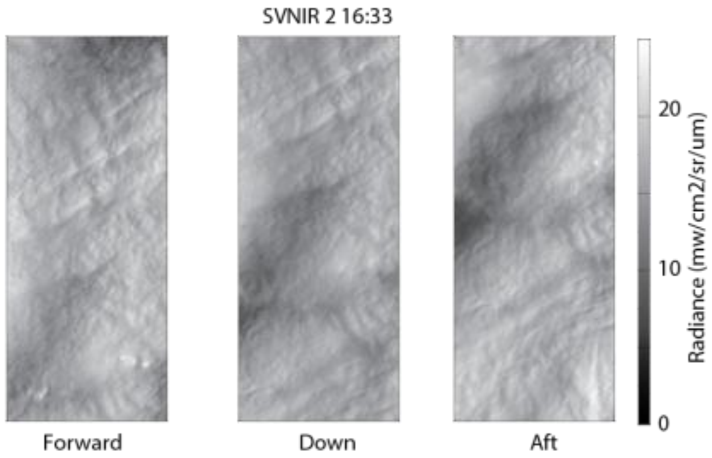
Heritage

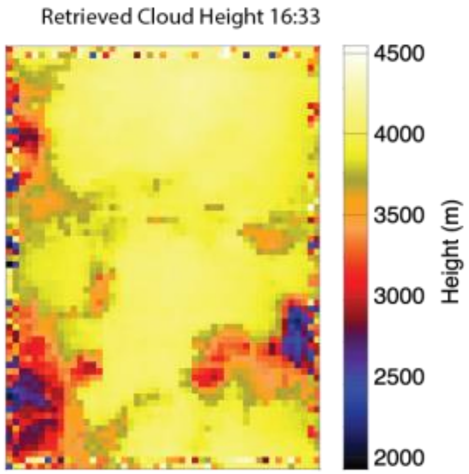


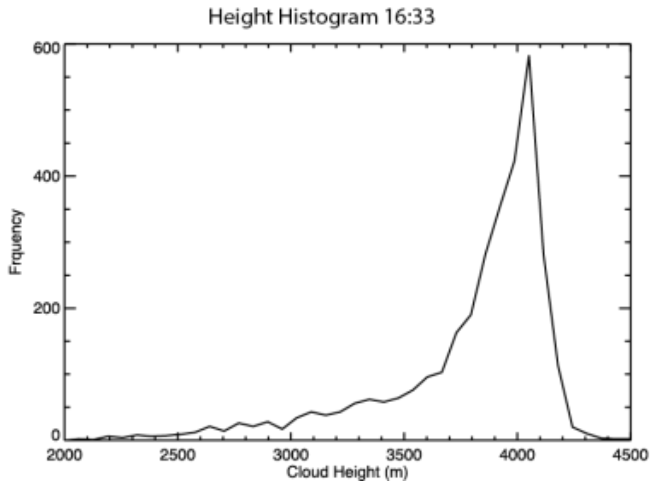
MSIS Test Campaign

- 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.

MSIS Airborne Flight Test Results





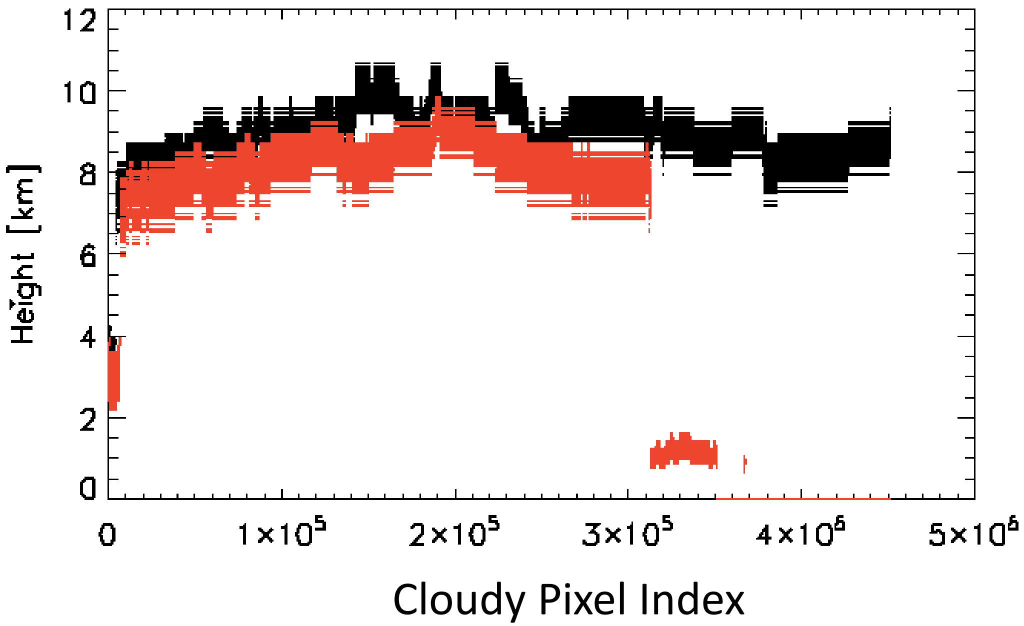


Stereo imaging

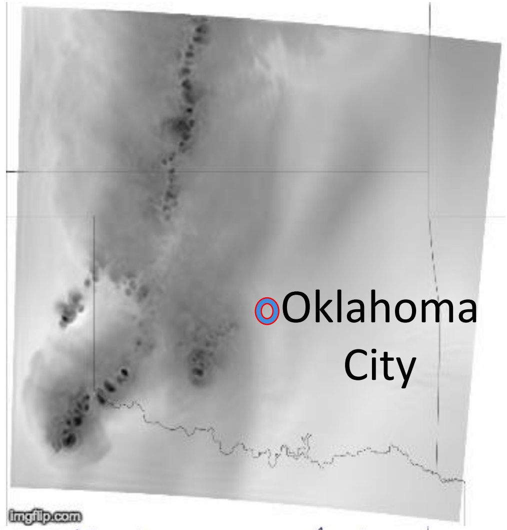
- Comparison between MODIS and MSIS visible stereo calculation on 10 Dec 2013 at 16:33 UTC
- Employed the forward, nadir, aft views to perform the stereo calculation
- Comparison with MODIS cloud height product within 100-400 m (12 minutes later)
- Clouds were moving toward the east, plus no wind correction applied

WRF Simulation and Cloud Height

- 20% coldest cloudy pixels => AMV pattern height
- IWC = 1 mg/m3 => True cloud top height
- CO2 slicing (tau ~ 1) => Retrieved cloud top height
- Retrieved height < True height

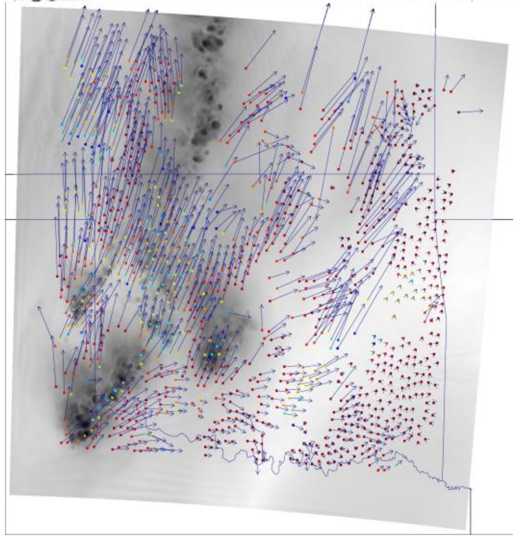


7µm
Radiances
at 10 min
Interval



Feature-Track
Winds

Atmos
Motion
Vector
(AMV)



Courtesy of J. Gong

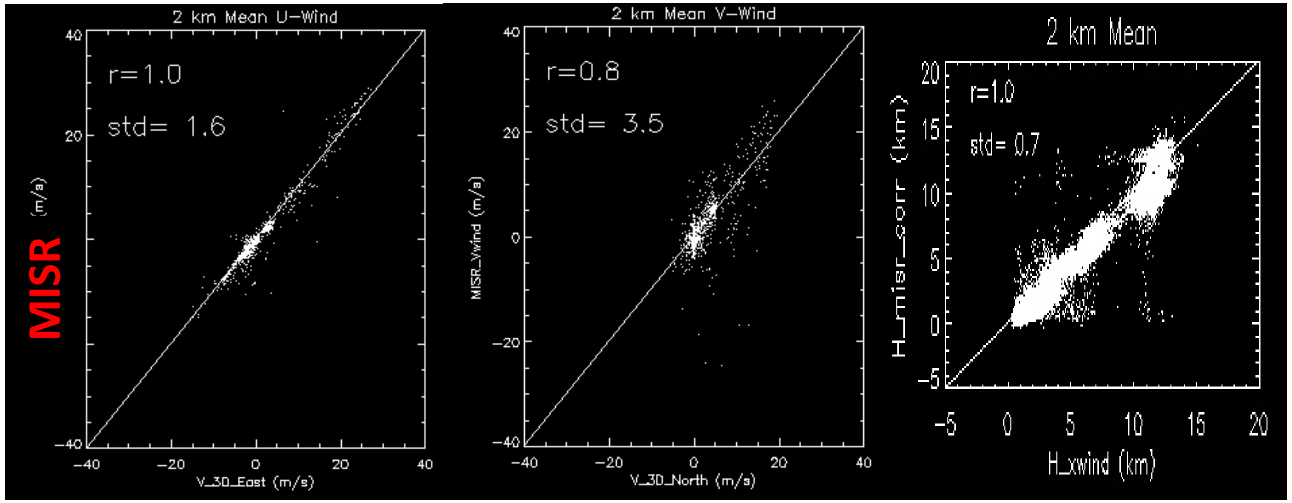
Multiple-Satellite Approach

- Develop a cost-effective approach (**CMIS**) for joint LEO-GEO wind and stereo height measurements
- Demonstrate improved height assignment in LEO-GEO overlapped regions

Stereo Height = AMV Height

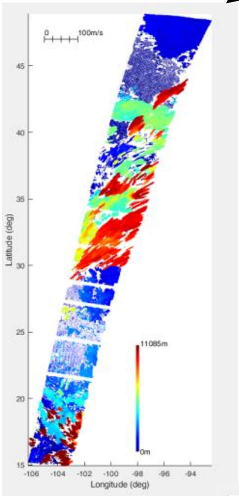
U Wind V Wind Height

MISR

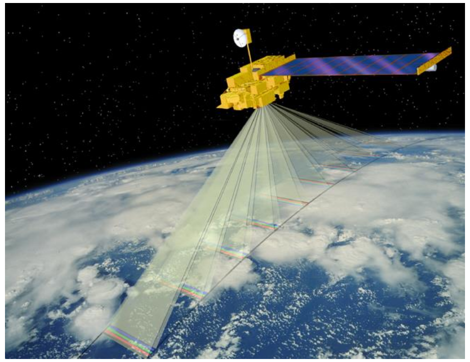


GOES+MISR

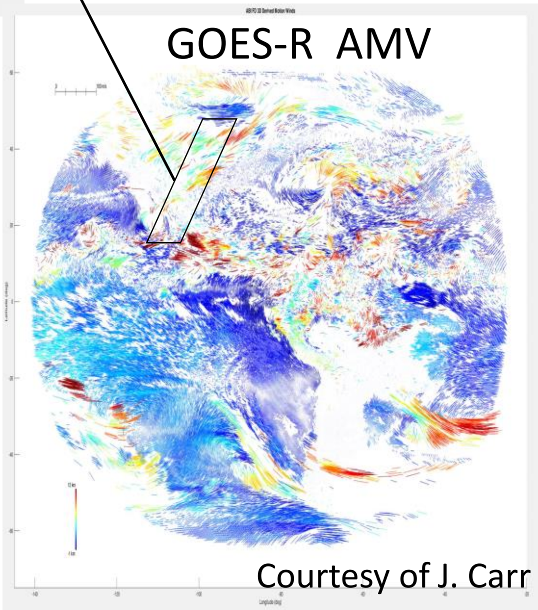
Joint MISR-GOES Winds and Heights



MISR



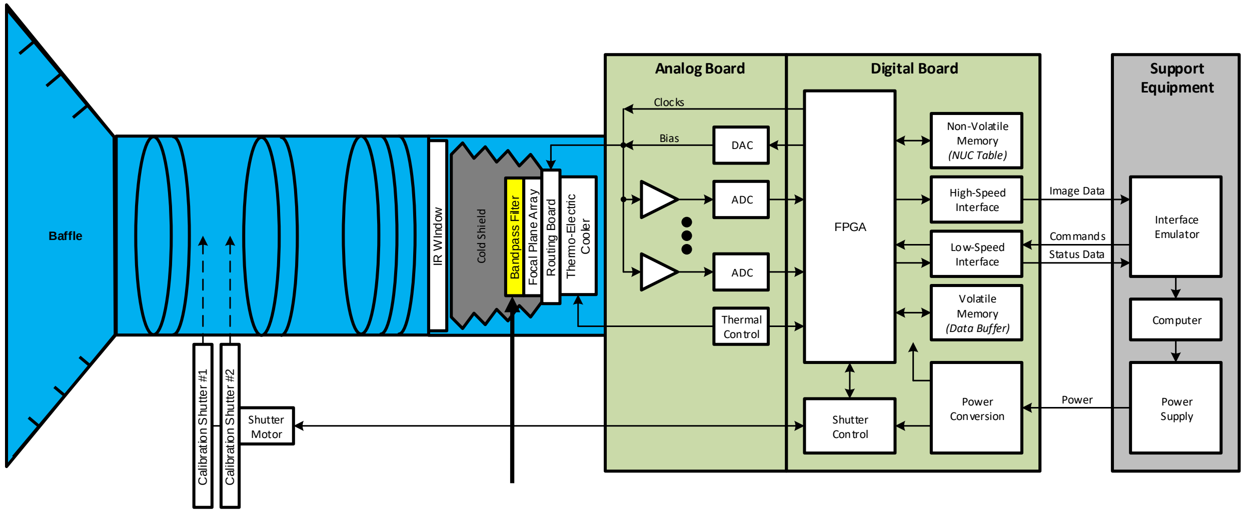
GOES-R AMV



Courtesy of J. Carr

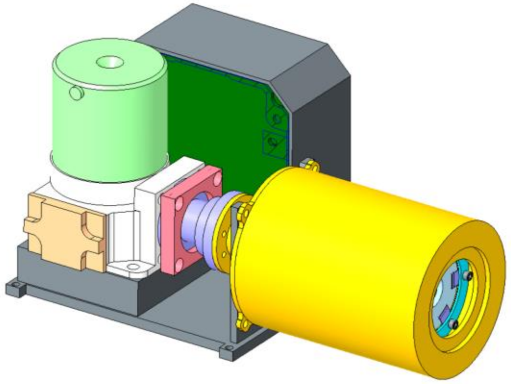
Compact Midwave Imaging System (CMIS)

- 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: 50° cross-track
- Type-2 Superlattice detector cooled to 150K
- Integrated dewar assembly for airborne flight tests



Filter at focal plane

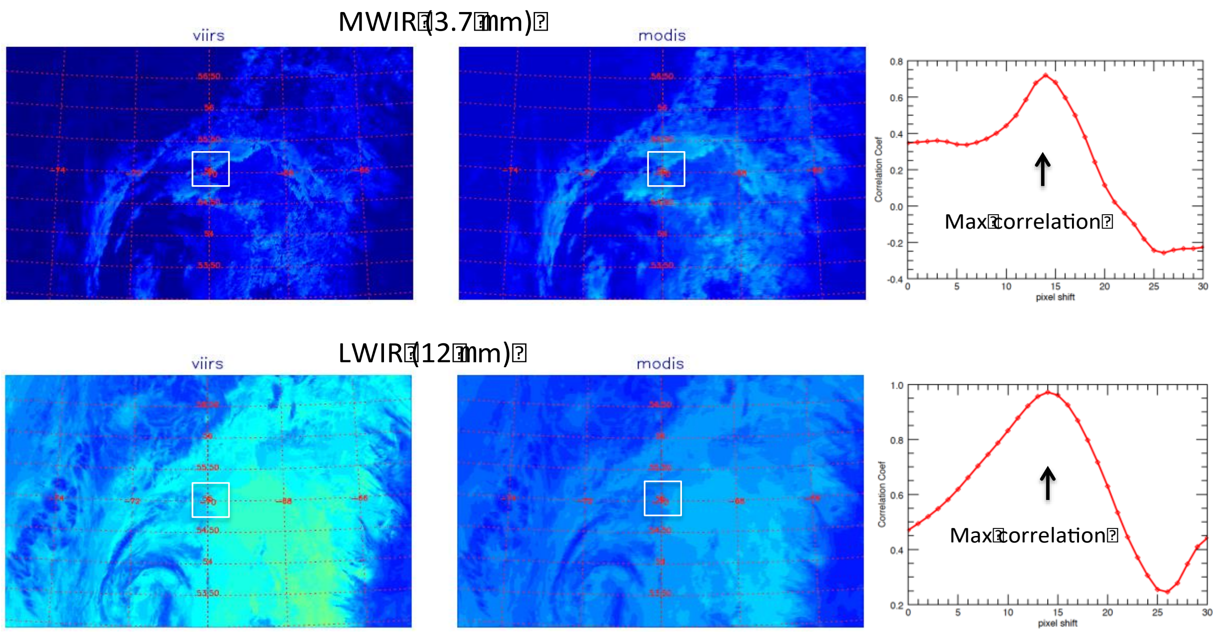
- NEdT for 3.75, 4.05 µm ~0.5K at 230 K



- **Length: 178 mm**
- **Width: 100 mm**
- **Height: 88 mm**

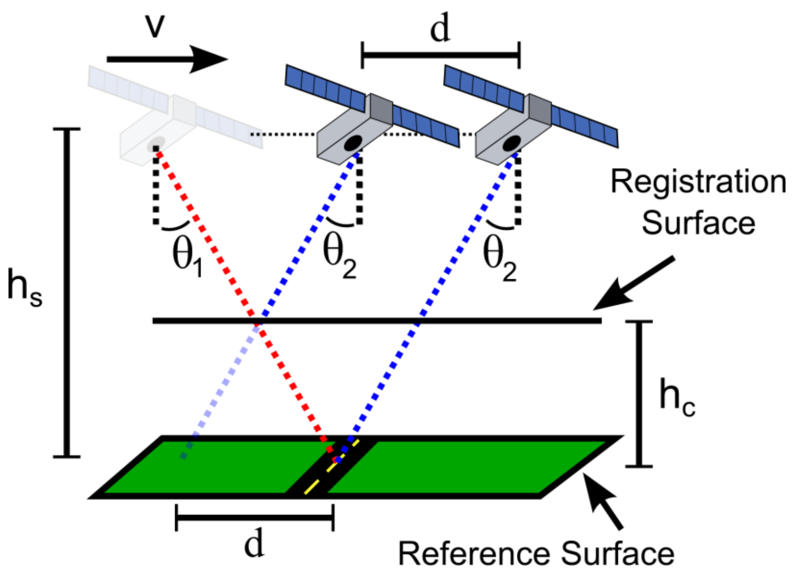
Objective: Enhance TRL and prove out capabilities with airborne flights

Cloud Heights/Motion Vectors in the Midwave



- Compared to 12 μm, 3.75 μm (day and night) exhibits more cloud features and structure 24/7
- Very valuable for motion tracking as shown by correlation curve
- Provides spatial resolution that is potentially comparable to visible channels

Sources of Error



2D Cloud Retrieval

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

Zong et. al (2002), J. App Met and Clim

Error Analysis

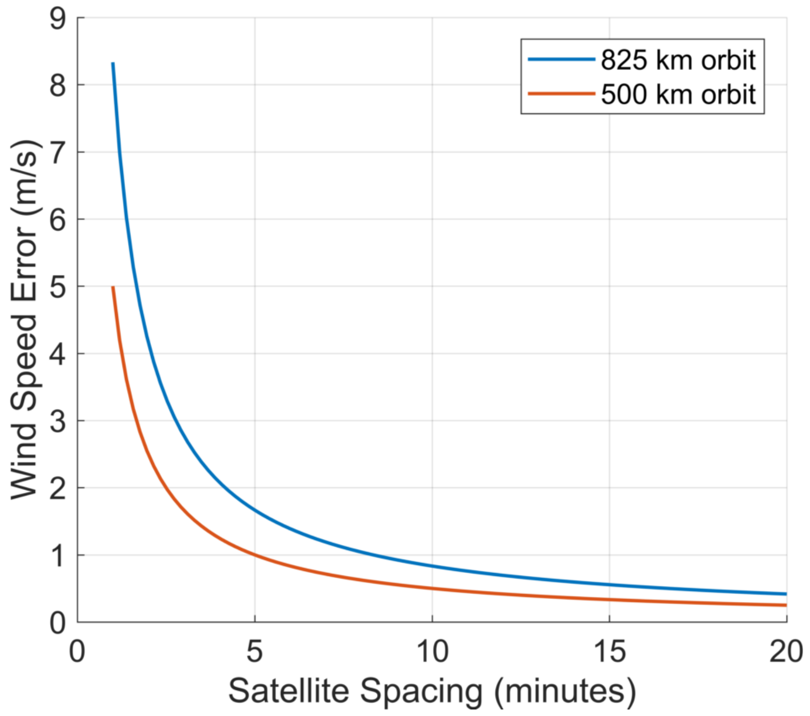
$$\delta_z = \alpha(\delta_t v + \delta_w \Delta t + \delta_R)$$

Timing Alongtrack registration

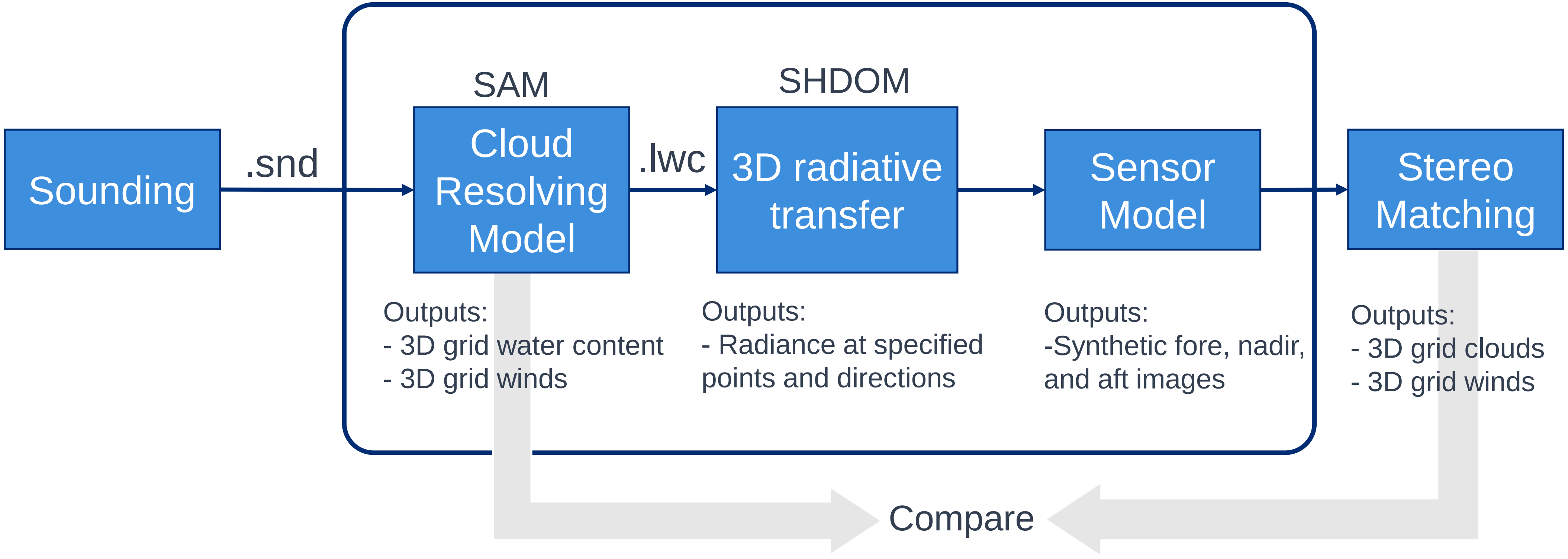
- Error in cloud height driven primarily by GSD and registration
- Two satellites independently calculating cloud height can also reduce error (or give estimate of vertical wind)

Initial Error Analysis

- Assumptions: Wind speed used to correct cloud height, image registration accurate to ½ pixel, 500 km altitude, 50° FOV, average looks between satellites
- **STK simulations** take ideal cloud locations and adds errors into ground projection
- Clouds are randomly distributed across FOV
- Altitude: 500 km
  - Height Retrieval Errors: mean 295 m
- Developing error statistics to participate in OSSE



CMIS Simulator



System for Atmospheric Model (SAM6.11) Results

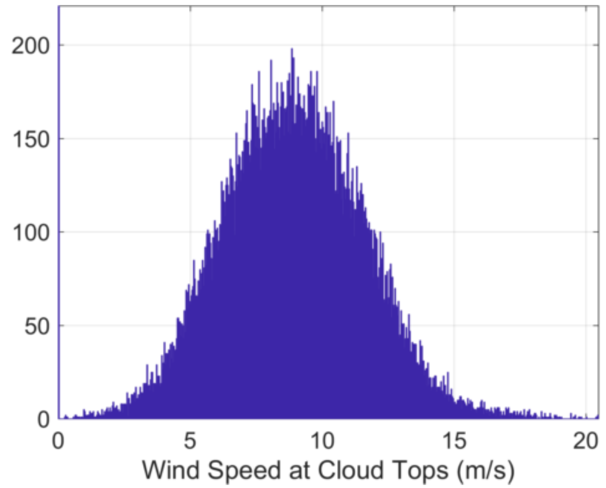
Using soundings from Dulles, SAM model was used to generate water content in atmosphere.

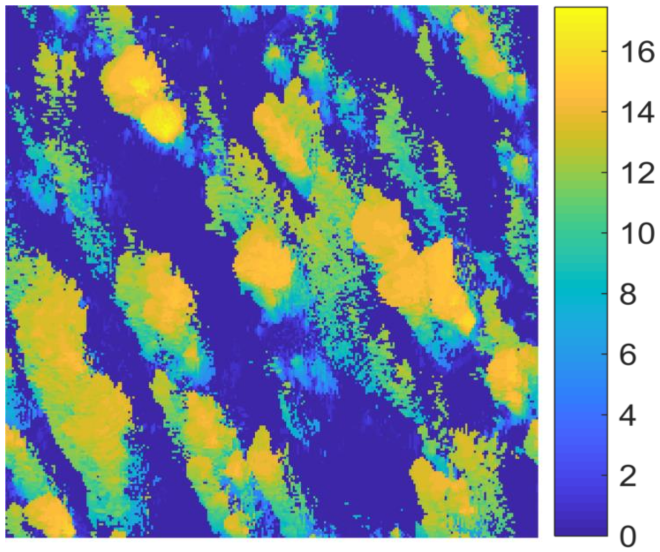
Input: Sounding from UW for KIAD 72403:

Observations at 12Z 14 May 2018

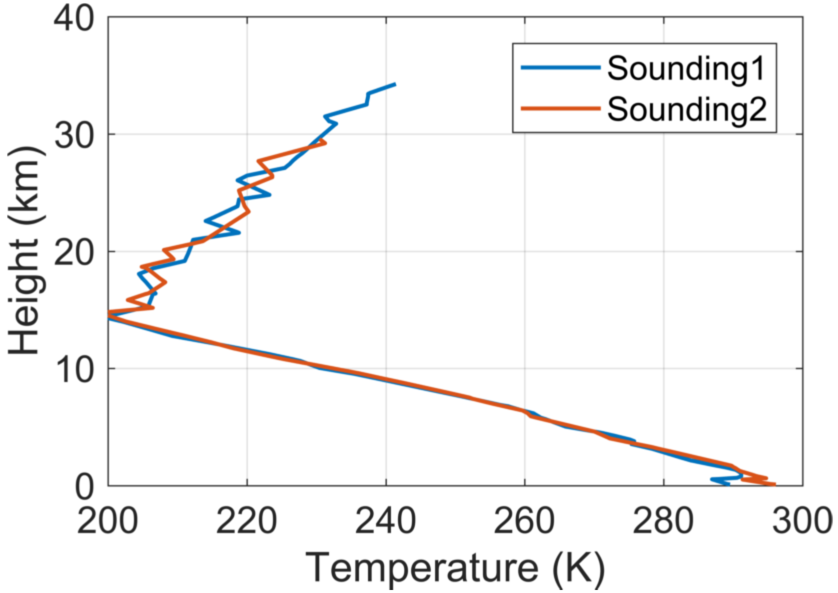
Observations at 18Z 14 May 2018

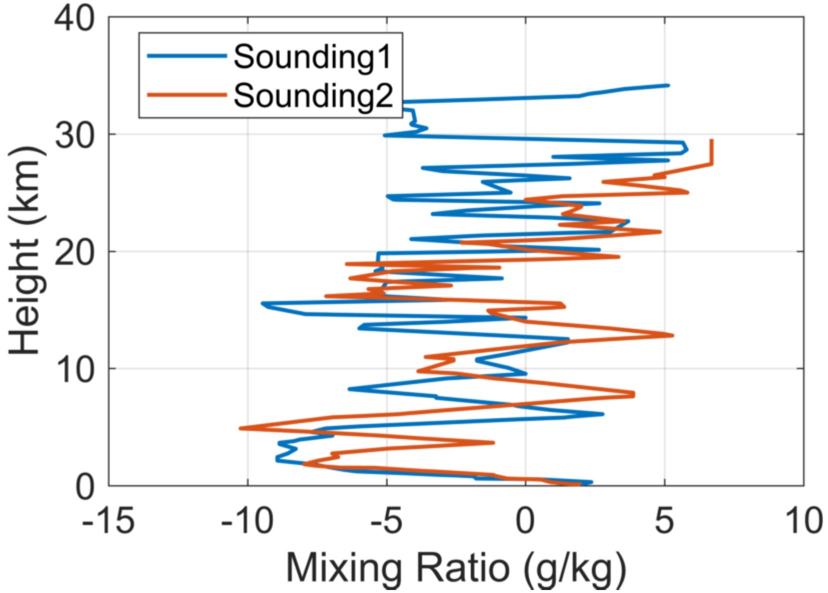
Output: Water content, wind speeds

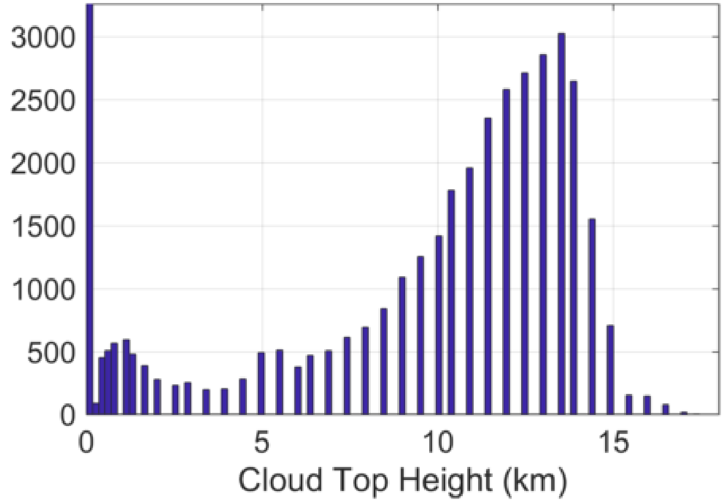




Cloud Top Height (km)



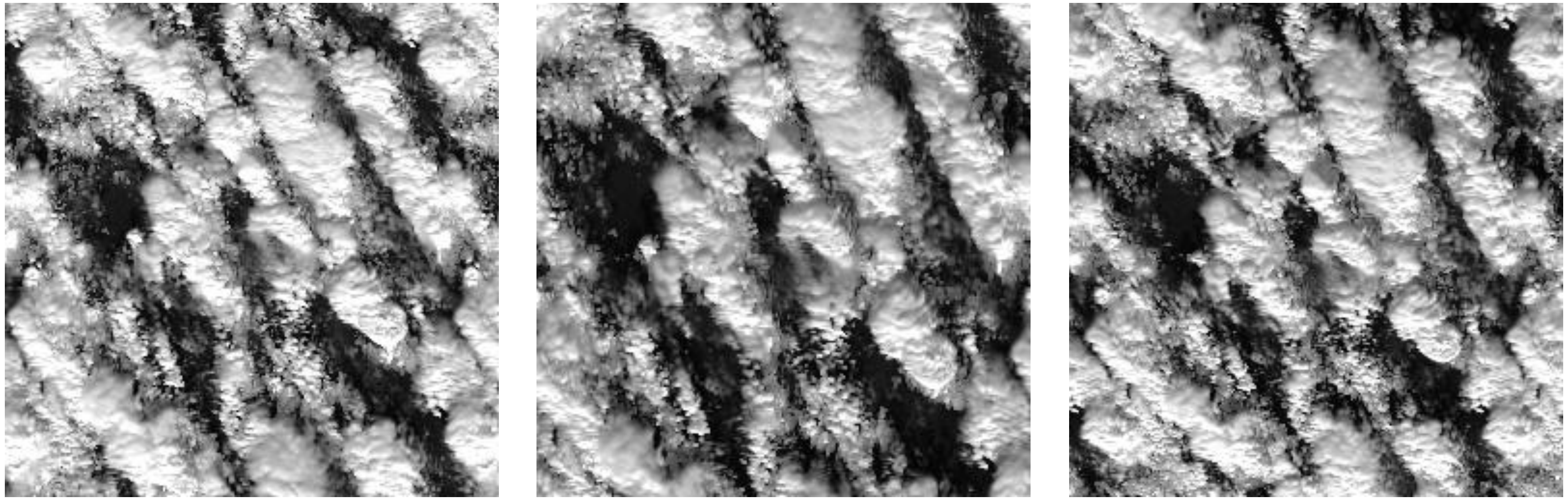


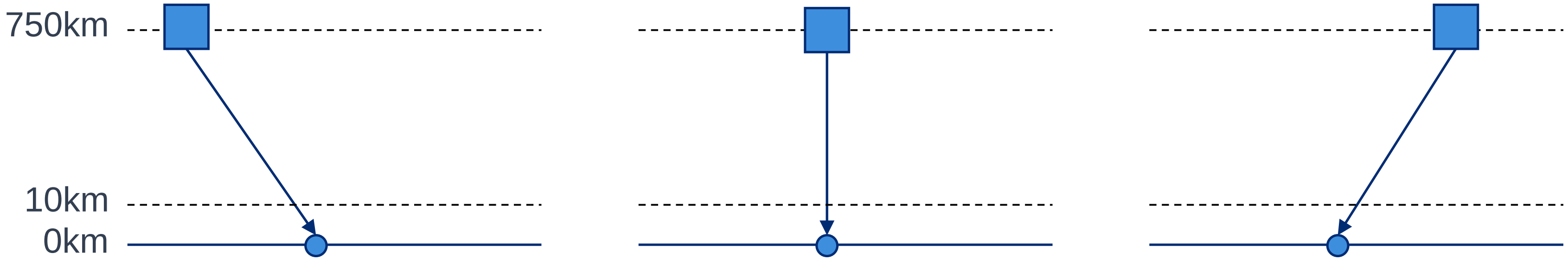


SHDOM Results (Dulles Run)

Fore View (30°) Nadir (0°) Aft View (-30°)

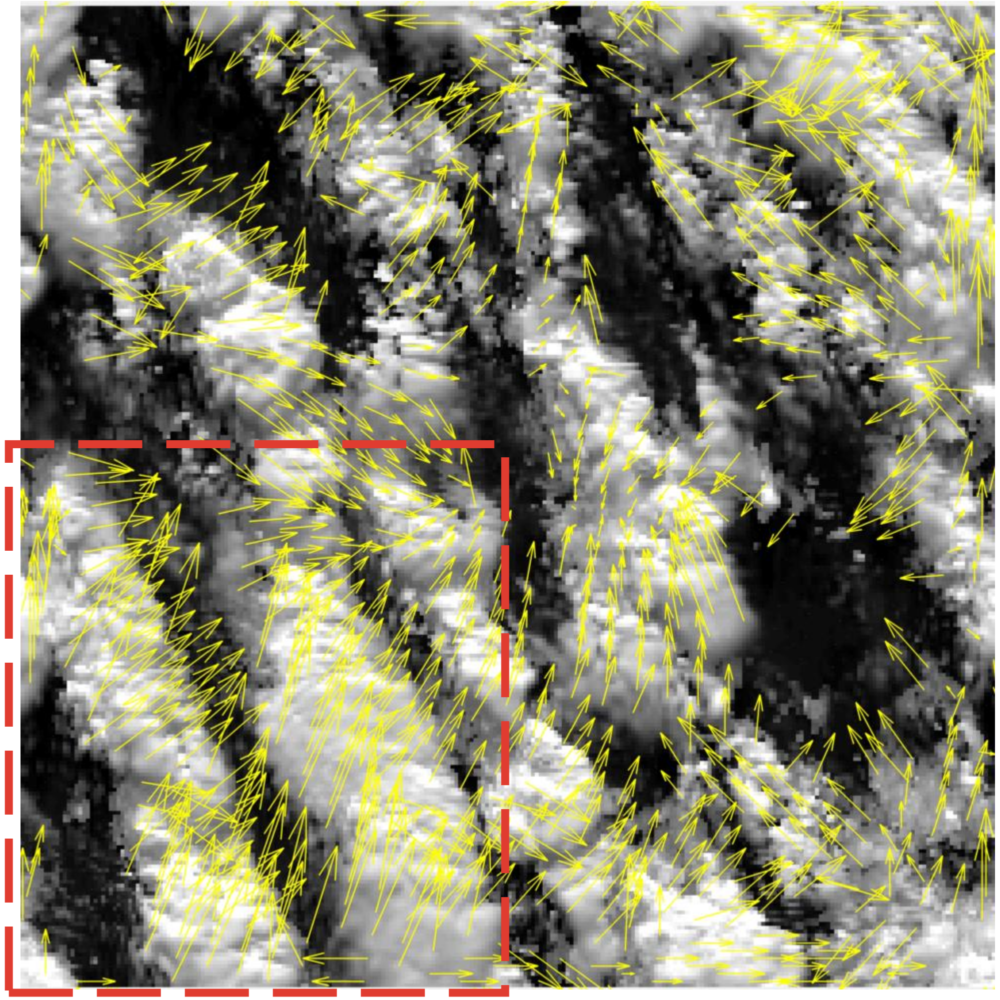
750km



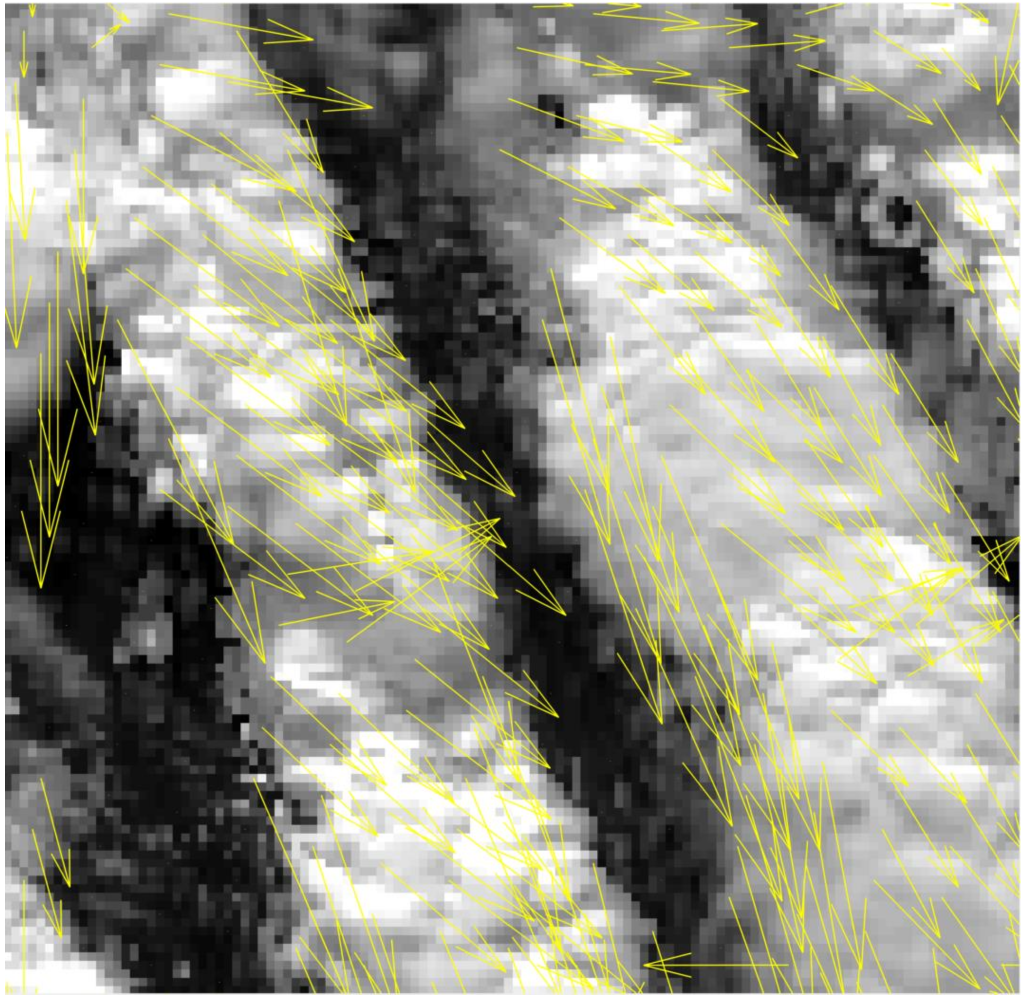


- 256x256x64 grid
  - 1km x/y resolution,
  - ~0.44km vertical resolution
- Periodic boundary conditions
- Fore/aft/nadir views
- 0.67um band (solar only)

Initial SAM AMVs



Unzoomed



Zoomed

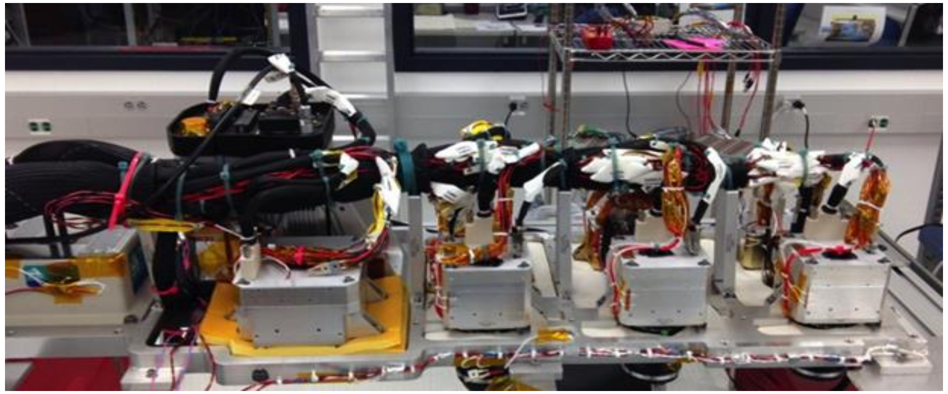
Next Steps

- Validate the pattern matcher and segregate AMV calculations by cloud height
- Perform pixel-by-pixel comparisons with “truth” data input as soundings to SAM
- Run multiple cases under a wide range of scenarios to assess the performance of CMIS
- Evaluate the capability of the CMIS simulator to handle “difficult” scenes (e.g. multi-layer clouds)
- Use the CMIS simulator for the airborne test campaign

Performance Demonstration: Airborne Tests

NASA HU-25C Guardian Falcon

	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 HU-25C flights out of LaRC flight facility, in Hampton.

HU-25C 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 measurements with those collected from VIIRS and/or MODIS under the satellite tracks.