Compact Midwave Imaging System (CMIS)

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

Dong Wu, NASA/GSFC
John Boldt, JHU/APL
Arnold Goldberg, JHU/APL
John Wilson, JHU/APL
Kyle Ryan, JHU/APL
Sam Yee, JHU/APL
Andrew Heidinger, NOAA/NESDIS
Ralph Stoffler, Air Force/Pentagon

NASA NNX17AB65G
JHU Grant 125182
PoP: Jan 2017-Dec 2019

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

ESTF 2017, Caltech, Pasadena, CA

Outline

- **CMIS Background**
- **Cloud Detection and Motion Vectors**
- **Applications**
- **PbSe Technology**

CMIS started in Jan 2017 – 6 months into the effort

CMIS Objectives

- Develop a compact midwave infrared system (CMIS) to be small volume, light weight, and low power
  - Employ new PbSe technology to operate CMIS at warmer temperatures and eliminate the need for cryogenic cooling
- Validate the sensitivity and performance of CMIS to meet NASA's goals in the Earth Science *Weather, Atmospheric Composition, Climate* areas
  - Enable measurements of cloud detection and characterization for climate and forecasting
  - Show feasibility for fire detection, sea surface temperature, aerosols
- Demonstrate potential of CMIS to fill critical science needs yet to be addressed due to the large size and cost of existing technologies
  - Enable small-satellite constellations to perform midwave measurements to study dynamical structure of global cloud regimes
  - Enable day/night stereo wind retrieval with accurate height assignment (re: GOES) and unambiguous along-track and cross-track components (re: MISR)

CMIS Team

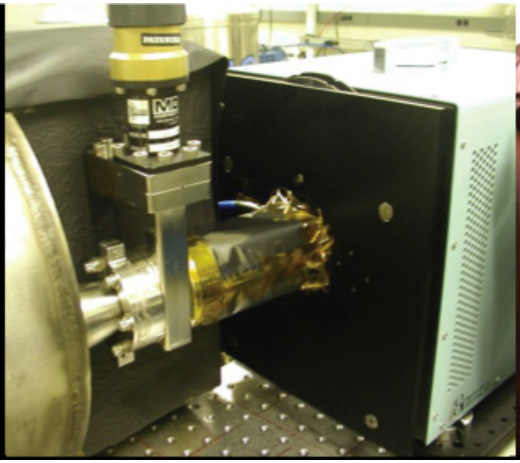
Science Team

- **Andrew Heidinger, NOAA/NESDIS**
- **Karl Hibbitts, JHU/APL**
- **Michael Kelly, JHU/APL**
- **Ralph Stoffler, AF/A3W**
- **Dong Wu, NASA/GSFC**
- **Sam Yee, JHU/APL**

Space Simulation Laboratory:

- Temperature Range: -190 °C to +200 °C
- Pressure range: Ambient to 10^{-7} Torr
- Class 100,000 to 1,000 clean rooms

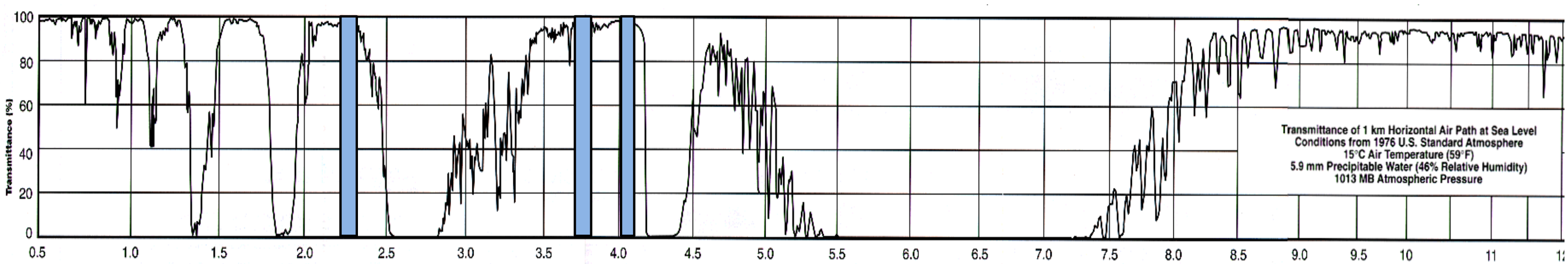
OCF Collimator and Monochrometer



OCF Blackbody Calibration Source

External Spectrolon Calibration Target

Midwave Imager – Why important

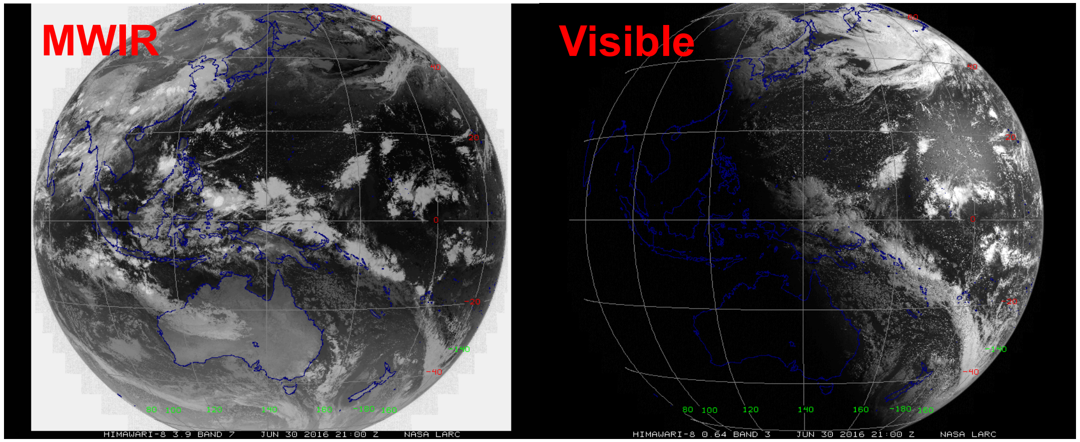


Wavelength

- CMIS bands shown in blue – located in atmospheric window regions
- Performs observations at bands 2.25, 3.75, and potentially 4.05 which are similar to AVHRR, MODIS, and VIIRS
  - 2.25 micron for cloud optical depth and equivalent radius
  - 3.75 micron for discrimination of night-time clouds
  - 4.05 for sea surface temperature (SST) and fire detection
- Relies on PbSe detectors operated at higher temperature which removes the need for cryogenic cooling
  - Improves reliability, reduces costs, simplifies operations, enables more payloads
- Provides flexible options – cubesat through large missions

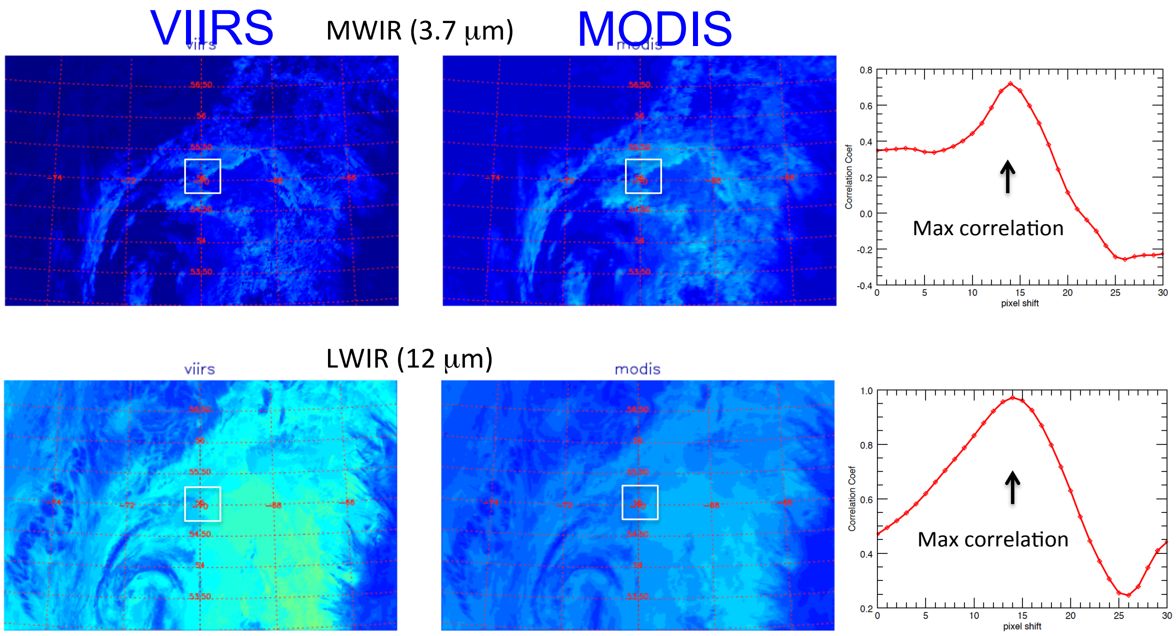
Cloud Detection

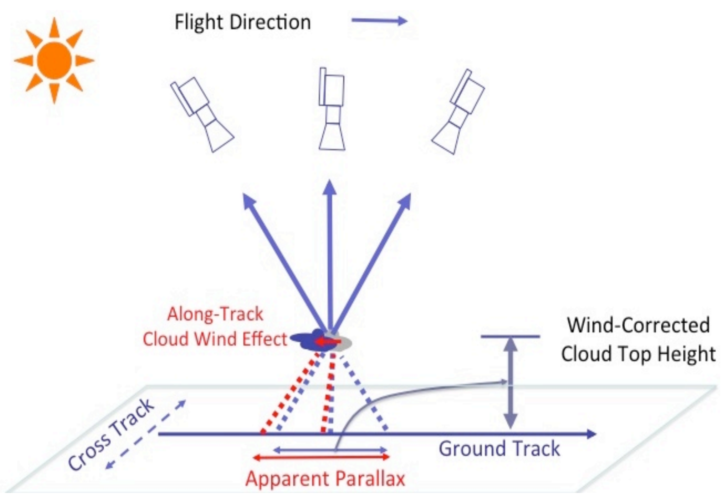
- Low cloud discrimination (e.g. Bell and Wong 1981)- Bispectral: $T_{11} - T_{3.75}$
- Snow/cloud discrimination (Hutchison et al. 1997) – 3.75 ”albedo”
- Thin cirrus detection (Hutchison, Hardy, Gao, 1995) – 3.75
- Cloud optical depth and equivalent radius (0.6, 2.25, 3.75; Walther and Heidinger 2012, van Diedenhoven 2015)
- Used in cloud products in forecasts by NOAA and military



Himawari MWIR and visible images at 21 UTC on 30 June 2016 show the extended cloud images at night from the MWIR band

Cloud Geometric Height and Motion Vectors

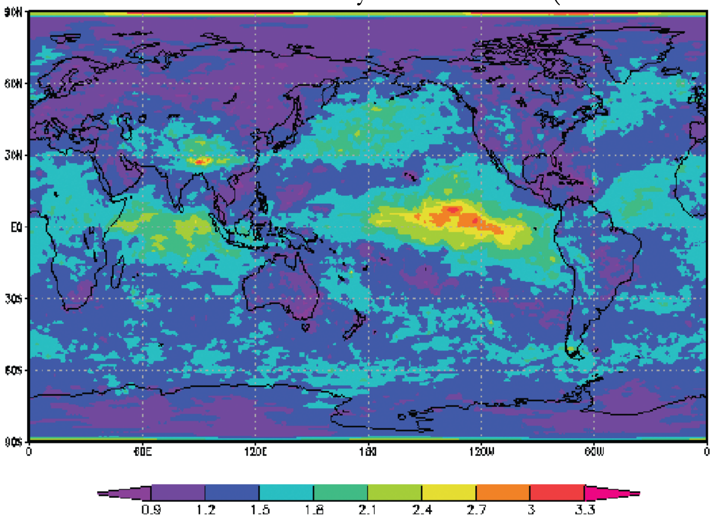




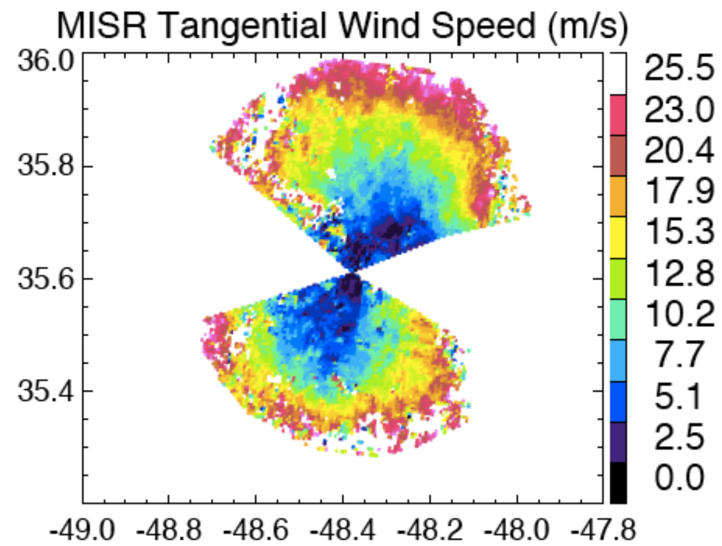
- Compared to 12 µm, 3.75 µm (day and night) exhibits more cloud features and structure
- Very valuable for motion tracking as shown by correlation curve
- Stereo capability adds excellent height assignment – ideal for data assimilation in forecast models

Applications

Spread of Multi-center Wind Analysis at 500 mb (Wei et al 2010)



Wei et al 2010



MISR V_t for Hurricane Alberta
19 Aug 2000, 14:20 UTC

- Can provide global wind measurements currently lacking for assimilation into models to reduce of spread of wind analysis
- Support weather forecasting by NOAA and military to analyze growth of extra-tropical and tropical cyclones
- Complementary to future LIDAR mission

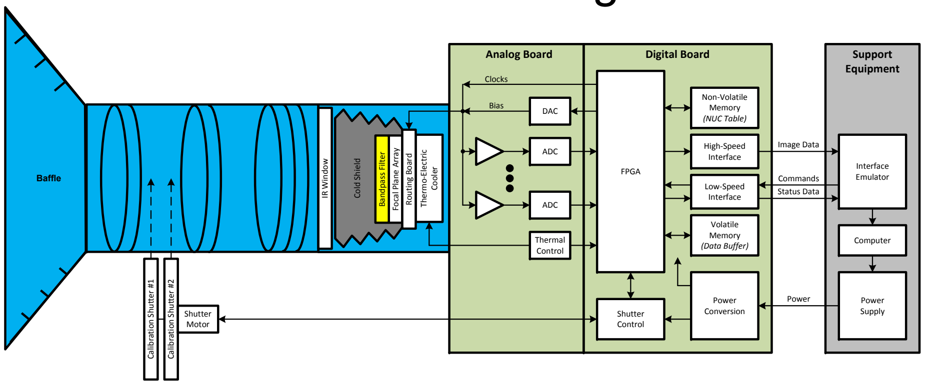
Baseline MWIR Design Specification and Performance

- Pushbroom imaging
- 320 x 240 focal plane array
- Bands at 2.25, 3.75, and 4.05 µm
- Field of view: 40°
- PbSe detector cooled to 230K
- Integrated dewar assembly for airborne flight tests

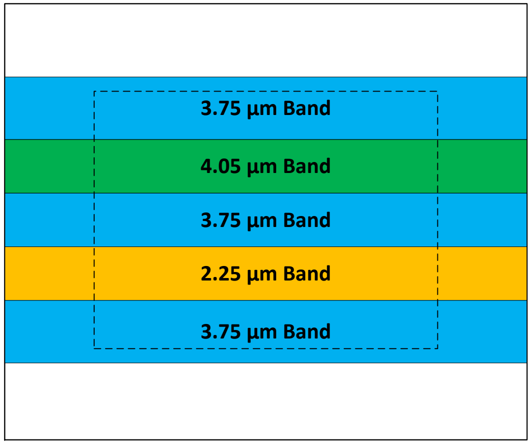
▪ NEdT for 3.75 and 4.05 µm ~1 K

▪ SNR for 2.25 µm >90

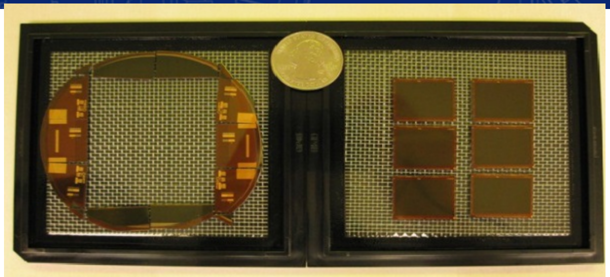
CMIS Block Diagram



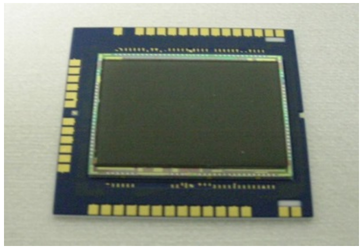
CMIS Filter Layout



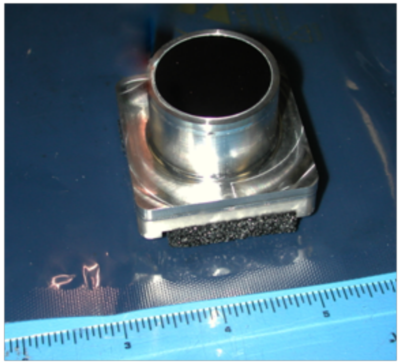
PbSe Detector



Completed PbSe FPA die diced from the processed ROIC wafer



PbSe FPA mounted on a chip carrier.



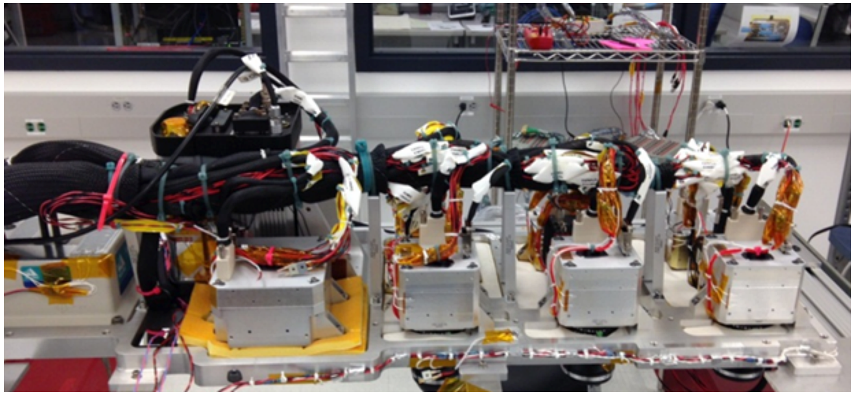
PbSe camera core integrated with TEC.

- Developed for the Army's PICS program.
- Detector material deposited directly on the ROIC (no bump bonding).
- Unit cell circuitry in the ROIC make it capable of "electronic chopping" of the incident signal at high frequencies which mitigates the effects of 1/f noise.
- Current FPA format is 320×240 with 6-µm pitch.
- Efforts are under way to grow the array size and shrink the pixel size.
- Detector process licensed for non-military uses to merchant supplier St. Johns Optical Systems (SJOS).

CMIS 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



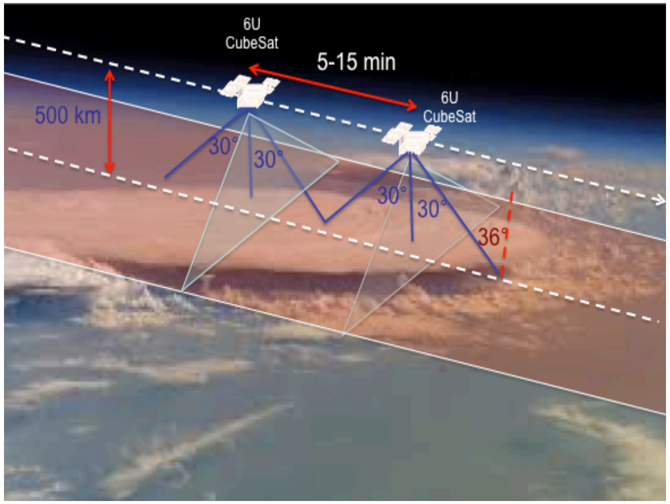
The CMIS performance in an airborne environment and its measurement capability will be demonstrated on *three dedicated* NASA HU-25C flights out of LaRC flight facility, in Hampton.

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.

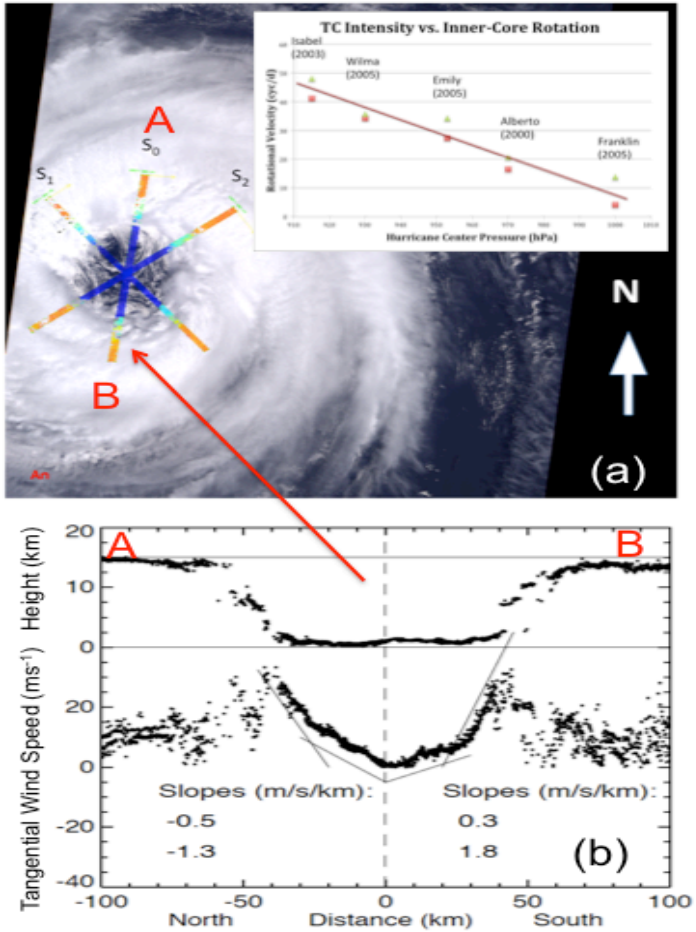
One of the objectives for the flight demonstration is to cross-compare the CMIS airborne measurements with those collected from VIIRS and/or MODIS under the satellite tracks.

Looking Beyond this IIP

- **Earth Observing**
  - Develop and participate in future satellite missions by adding midwave capability to previous EV-I/EV-M concepts to support 2007 *NRC Decadal Survey* call for global 3D winds and emerging science requirements
- **Airborne Science and Validation**
  - Fully calibrated and characterized instrument suite in the VNIR, SWIR, MWIR, LWIR to support science and validation for satellite missions, e.g. ICESAT-2



Wu et al 2010



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

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 geostationary satellites by improving height assignment of CMVs with stereo capability
- Forms 3D winds by passive imaging that are complementary to lidar winds, by providing wide horizontal coverage.
- PDR design complete; moving toward CDR

Bottom Line: Complements the current Earth Observing System