Initial Results from the Airborne Test Campaign of the Compact Midwave Imaging System (CMIS)

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Challenging Problems

• Decadal Survey-Incubation identifies global PBL heights as a high priority
  - Multi-platform stereo photogrammetry based on a constellation of affordable compact imagers provide a promising technique for globally mapping PBL heights and 3D winds
  - Wind fields are derived from atmospheric motion vectors (AMVs) based on tracking clouds and aerosols

• Height assignment
  - Limitations with IR method
  - Limitations with single-platform stereo (e.g. MISR)
  - Stereo height from multi-angle, multi-platforms

• Small or hosted satellite solutions to provide affordable, yet better spatio-temporal coverage
  - LEO-GEO
  - GEO-GEO
  - Future: LEO-, GEO-CubeSat Constellation
Passive-Sensing Stereo Methodology

- Fly midwave imagers to enable day/night stereo calculations using same techniques/bands
- Use imagers on two spacecraft several minutes apart to eliminate ambiguity in along-track direction between winds and cloud heights for atmospheric motion vectors (AMVs)
- Utilize cloud-top altitude for AMV height assignment to avoid large errors for thin clouds and temperature inversions

**Advantages:**
- Estimated CMV/CGH accuracy: ±0.5 m/s, ±200 m assuming 1/4-pixel relative geolocation accuracy (Carr et al 2018)
- Minimum detectable along-track precision: <1 m/s
- Wide-field of view coverage to complement future active instruments
- Flexible satellite accommodation – CubeSats or hosted on weather satellite
Compact Midwave Imaging System

- JHU/APL developed a compact shortwave/midwave imager with a 640x512 focal plane array (FPA) based on high operating temperature (HOT) technology:
  - Designed for day/night observations in the SWIR/MWIR
  - Enables global data collection of cold and warm temperatures between the poles and tropics due to wide dynamic range
  - Provides a novel capability to detect objects and weather with same FPA
- Employs multi-angle views (fore, nadir and aft) to retrieve heights and motions of objects
- Requires modest size, weight and power (SWaP) which permits accommodation on 6U CubeSats

### Specifications

<table>
<thead>
<tr>
<th>Field</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-Spectral</td>
<td>2.25, 3.75, 4.05 μm</td>
</tr>
<tr>
<td>Multi-Angle</td>
<td>20°, 0°, -20° views at 3.75 μm</td>
</tr>
<tr>
<td>Weight, Power</td>
<td>&lt; 3 kg, 7 W</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>150 K</td>
</tr>
<tr>
<td>NEdT</td>
<td>&lt; 1 K for 230 K and 400 K</td>
</tr>
<tr>
<td>Readiness</td>
<td>Radiation, vibration tested</td>
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</table>

**Airborne Model**

[Image of airborne model]
Successful Airborne Flight Demonstration

CMIS Snapshot

- Provides multi-angle, multi-spectral imagery based on striped filter
- **Proved** that low-cost compact imager can provide high-quality datasets
- Could include wavelength stripes to support atmospheric motion vectors, cloud heights, and *weather*, for example

Filter design

NASA GIII

Airborne Test Campaign
22 Jan-8 Feb 2021
NASA Langley
Stereo Methodology

- Applicable to weather and non-weather features
- Does not need multiple wavelengths for cloud heights
- Do not need multiple wavelengths to discriminate between snow/clouds
Science Flight #1 – 27 Jan 2021

Aircraft position since turning on the IMU: +60min

- Hold D
- Hold E
- Case G
- Hold F
Prepared Imagery for StereoBit* Pipeline

Hold F2

- Initial coarsely aligned triplet of CMIS fore, nadir, aft imagery
- Gray region indicates overlap between all three in the triplet
- Color separation indicates parallax and/or motion

AIST-18-0082
StereoBit: An ESTO AIST project to enable onboard processing of stereo images
Retrieval for Hold F2

- Disparities measure the apparent difference in location between fore-nadir and nadir-aft
- Notice two sets of disparities with one corresponding to ground and other to clouds at 1000 m

Median DEM Height ~275 m
Night Flight – 8 Feb 2021

Purpose: Underfly Aeolus and GOES
Nighttime data collection
Collect on cold surface and Lake Michigan at night
Hold J1 Retrievals

- Along-track winds specified from GOES-GOES retrieval
- Disparities well separated due to high winds
- Primary altitude for clouds is ~4 km and winds 36 m/s
Heat maps for Hold J

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>median</th>
<th>min</th>
<th>max</th>
<th>sigma</th>
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</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>4201</td>
<td>4126</td>
<td>3781</td>
<td>4994</td>
<td>294</td>
</tr>
<tr>
<td>XT Wind (m/s)</td>
<td>-35.77</td>
<td>-35.83</td>
<td>-39.48</td>
<td>-31.06</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Inter-Comparison with GOES and Aeolus

- CMIS heights, cross-track winds consistent with Aeolus and GOES
- Primary cloud-top altitude and winds for this case are ~4-5 km and 35.83 m/s
- CMIS demonstrated good sensitivity to small-scale variability
Summary and Conclusions

- Initial results/comparison with Aeolus and GOES very encouraging
- **Demonstrated** that low-cost compact imager can provide high-quality datasets for science
- Aircraft Problem *more difficult* than Spacecraft Problem
- Success of airborne campaign demonstrates CMIS readiness for spaceflight
Comparison with Aeolus

- CMIS coverage slightly east of the Aeolus coverage
- CMIS heights, cross-track winds consistent with Aeolus
- Primary altitude for clouds is ~4.126 km and winds 35.83 m/s
Motion Vectors

Fore: Overlap region (visible)

Fore: Radiance thresholded cloud mask

Fore: Clouds only

T+0 sec
Motion Vectors

Observed: predominantly *eastward* cloud motion across fore-aft overlap region

T+58.7 sec