CubeSat Constellation Cloud Winds (C3Winds)

A New Wind Observing System to Study Mesoscale Cloud Dynamics and Processes

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Marv and UARS Winds

- Upper Atmosphere Research Satellite (UARS)
  - Dynamics Working Group (Chair)
  - Theoretical Modelling Investigations of Dynamics for UARS (PI)

- High Resolution Doppler Imager (HRDI)
  - Strong tidal winds in the MLT region
  - Gravity wave (GW) – tides interactions
Gravity Waves from UARS MLS

Wu and Waters (1996)
Challenges to Measure Winds from Space

- **UARS/HRDI**
  - Airglow emission (upper atmos)
  - Airglow scattering-absorption (lower atmos)

- **UARS/WINDII**
  - Airglow emission (upper atmos)

- **Aura/MLS**
  - $O_2$ microwave emission (mid atmos)

- **ISS/SMILES**
  - $O_3$ and HCl microwave emissions (mid atmos)
Mid-Atmospheric Winds after UARS

Wu et al. (2008)
• Aura/MLS 118-GHz Zeeman-split O\textsubscript{2} limb emission
• 0.1 MHz spectral resolution
• Improved receiver sensitivity
• Along-track wind only

Baron et al. (2013)
• O\textsubscript{3} and HCl limb emissions at 35-80 km
• 1.2 MHz spectral resolution
• High sensitivity at cryogenic (4K) temperature
• One-component wind from ISS
Thermospheric Winds from 2.06-THz OI Emission

Yee et al. (2015)

- 2.06-THz atomic oxygen (OI) limb emission
- 1-2 MHz spectral resolution
- Receiver sensitivity $T_{sys} (DSB) = 7000$ K
- Useful wind profile at 100-140 km
Atmospheric Motion Vectors (AMVs)

- **Operation algorithms:**
  - Feature selection (e.g. contrast test, multi-layer cloud discrimination)
  - Height assignment
  - Feature tracking
  - Quality control

- **Geo-registration of images with landmark; Triplet set of images for pattern matching**

- **Where are the data gaps?**
  - Fast, dynamic regions
  - Strong vertical wind shear
  - Dry atmosphere and night
Multi-angle Imaging SpectroRadiometer (MISR) on Terra

von Kármán vortex street near Jan Mayen Island
Complexities of Tropospheric Winds and Thermodynamics

Severe Weather

- Extratropical cyclones (ETC)
- Tropopause folding
- Low-level “sting jets”

- Dynamic structures of ETCs in severe wind events?
- Variability of ETCs and tropopause folds?
- Predictability of severe weather events and processes?
## Limitations of Current AMVs

<table>
<thead>
<tr>
<th></th>
<th>MISR</th>
<th>MODIS/VIIRS MetOp A/B</th>
<th>GOES-R</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multi-Angle</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Stereo</strong></td>
<td>Yes</td>
<td>No</td>
<td>Limited</td>
</tr>
<tr>
<td><strong>Aliasing</strong></td>
<td>Along-track wind vs. height</td>
<td>Cross-track wind vs. height</td>
<td>Limited to GOES station-keeping and pointing stability</td>
</tr>
<tr>
<td><strong>Day/Night Obs</strong></td>
<td>Day only (VIS)</td>
<td>Day + Night (IR)</td>
<td>Day + Night (IR)</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>17 km</td>
<td>~20 km</td>
<td>~20 km</td>
</tr>
<tr>
<td><strong>Horizontal Wind (U, V) Unc.</strong></td>
<td>1-2 ms$^{-1}$</td>
<td>&lt; 2 ms$^{-1}$</td>
<td>&lt; 2 ms$^{-1}$</td>
</tr>
<tr>
<td><strong>Height Unc.</strong></td>
<td>0.6 - 1 km</td>
<td>2-4 km</td>
<td>2-4 km</td>
</tr>
<tr>
<td><strong>Vertical Wind (W) Unc.</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
CubeSat Constellation Cloud Winds (C3Winds)
Multi-platform Multi-angle Imaging

An Earth Venture-Instrument Proposal to NASA
C3Winds formation flight, designed for a nominal 500-km orbit to employ stereoscopic imaging with two CubeSats separated by 5-10 min in time, is extremely flexible to accommodate considerable variations in orbit.

**Orbit:** ISS (1st priority)
**LRD:** 2019
**Operation:** 2020-2021

<table>
<thead>
<tr>
<th>System and Instrument Requirements</th>
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<tbody>
<tr>
<td>Mass</td>
<td>7.65 kg</td>
</tr>
<tr>
<td>Spacecraft Dimensions (6U)</td>
<td>30 x 20 x 10 cm</td>
</tr>
<tr>
<td>Baseline Science Power</td>
<td>10.3 W</td>
</tr>
<tr>
<td>Maximum Science Power</td>
<td>14.6 W</td>
</tr>
<tr>
<td>Baseline Data Return</td>
<td>24 Gb/day (both S/C)</td>
</tr>
<tr>
<td>Maximum Data Return</td>
<td>122 Gb/day (both S/C)</td>
</tr>
</tbody>
</table>

**DNB** = Day-Night Band camera  
**IR** = InfraRed camera
Example of Daily Coverage from ISS Orbits and Sampling Priority

Two CubeSats Separated by 10 min in Formation Flight
C3Winds Science Objectives

*Transforming the stereo cloud imaging technique to make accurate wind velocity and height measurements from space for improving severe weather prediction.*

- Measure the high-resolution 3D wind fields, with good height and speed accuracy.
- Characterize and understand the ETC and TC dynamic structures.
- Demonstrate near-real-time (<3 hours) wind observations and impacts of high-res winds on severe weather prediction.
- Provide synergistic wind observations with GOES-R and Himawari.
Summary

• Winds are the key observable in characterize Earth’s climate and weather systems, and yet remain challenging to measure accurately.

• Advances in GHz and THz technologies have allowed useful wind measurements in the mid-and-upper atmosphere during day and night.

• ~70% of global tropospheric winds can be obtained by tracking cloud and water vapor features, and multi-platform multi-angle imagers can significantly improve wind/height accuracy.