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 $O_2$ limb emission
- 0.1 MHz spectral resolution
- Improved receiver sensitivity
- Along-track wind only

Baron et al. (2013)

- $O_3$ 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 100-140km
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”

**MODIS**

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

**MISR CTH and Winds**

- Strong Surface Winds
- Stratospheric Intrusion
## 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>
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<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>
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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 × 20 × 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

RMS Difference (ms⁻¹) in 300-hPa Wind Speed Analyses Produced by ECWMF and the NCEP GFS

Primary Target of C3Wind Obs.  

Secondary Targets of C3Wind Obs.  

Langland and Maue (2012)
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.