CubeSat Constellation Cloud Winds (C3Winds)

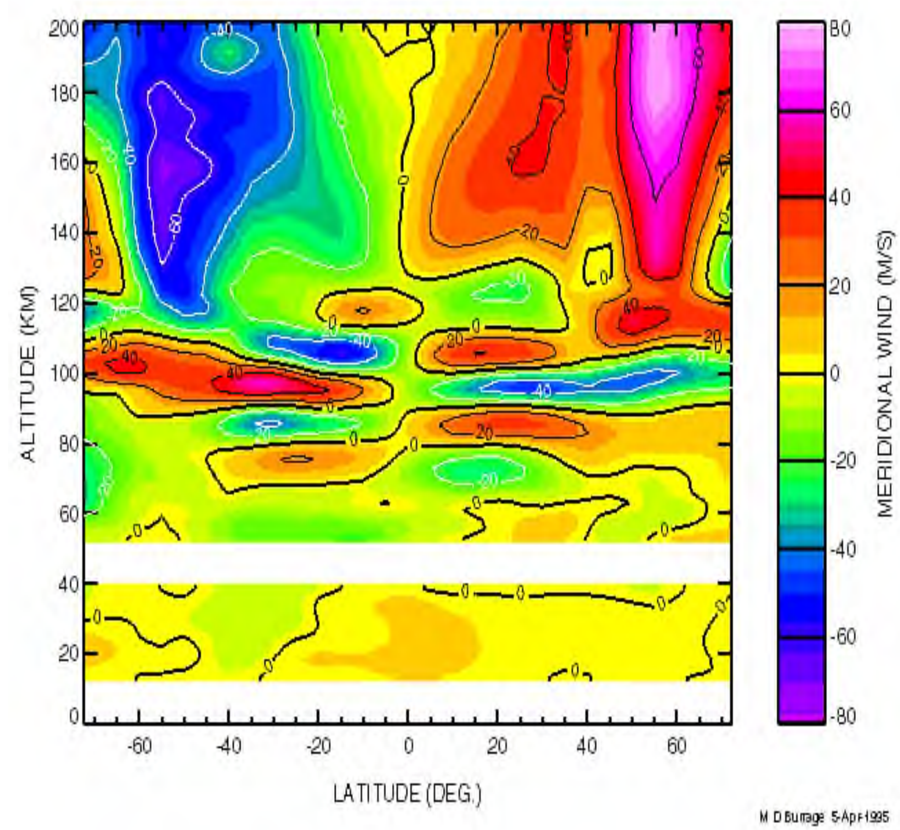
A New Wind Observing System to Study Mesoscale Cloud Dynamics and Processes

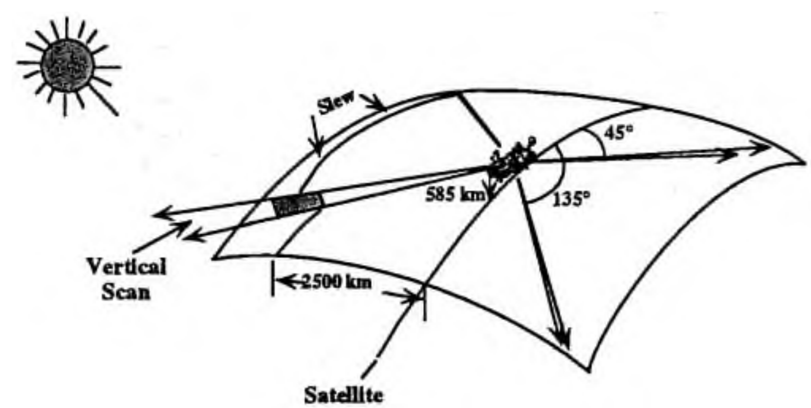
D. L. Wu[1], M. A. Kelly[2], J.-H. Yee[2], J. Boldt[2], R. Demajistre[2], E. L. Reynolds[2], G. J. Tripoli[3], L. D. Oman[1], N. Privé[4], A. K. Heidinger[5], and S. T. Wanzong[6]

1. NASA Goddard Space Flight Center, Greenbelt, MD
2. Johns Hopkins University Applied Physics Laboratory, Laurel, MD
3. University of Wisconsin, Madison, WO
4. Morgan State University, Greenbelt, MD
5. NOAA/NESDIS Center for Satellite Applications and Research, Madison, WI
6. University of Wisconsin, SSEC/CIMSS, Madison, WI

Marv and UARS Winds

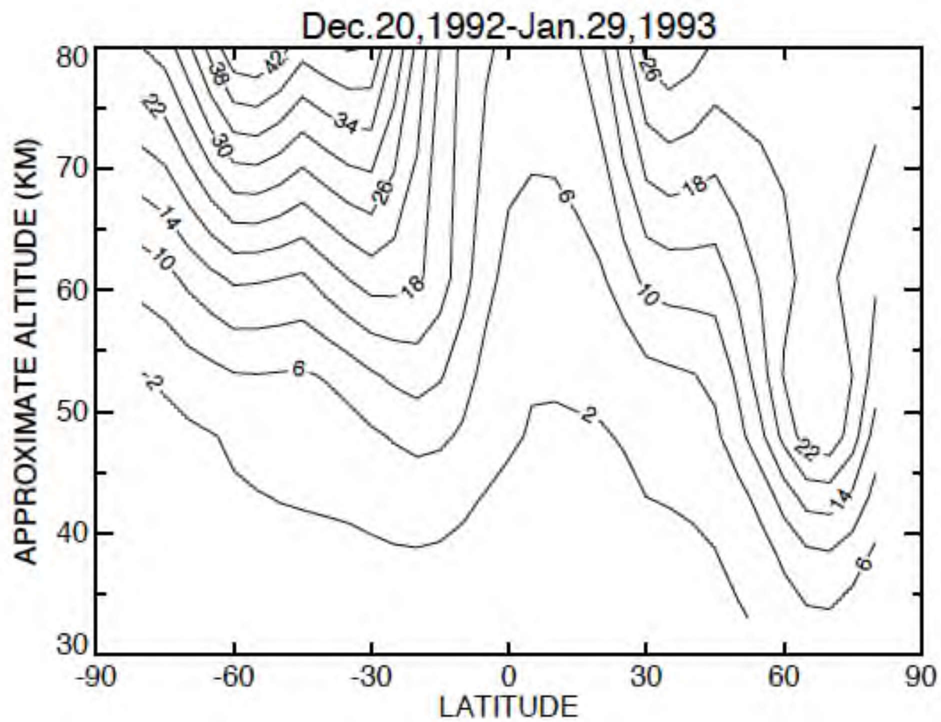
- Upper Atmosphere Research Satellite (UARS)
  - Dynamics Working Group (Chair)
  - Theoretical Modelling Investigations of Dynamics for UARS (PI)
- High Resolution Doppler Imager (HRDI)
  - Strong tidal winds in the MLT region
  - Gravity wave (GW) – tides interactions

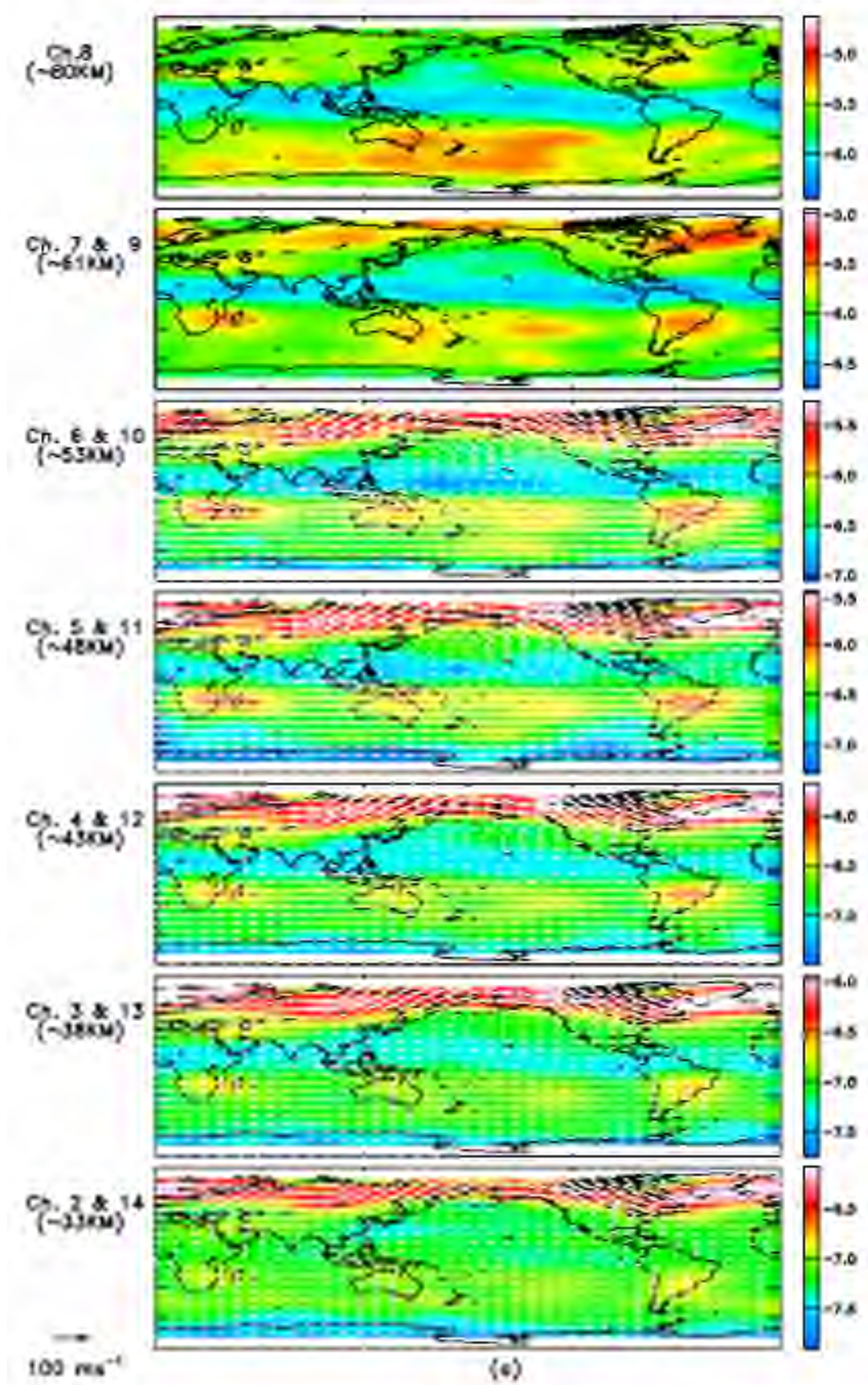




Gravity Waves from UARS MLS

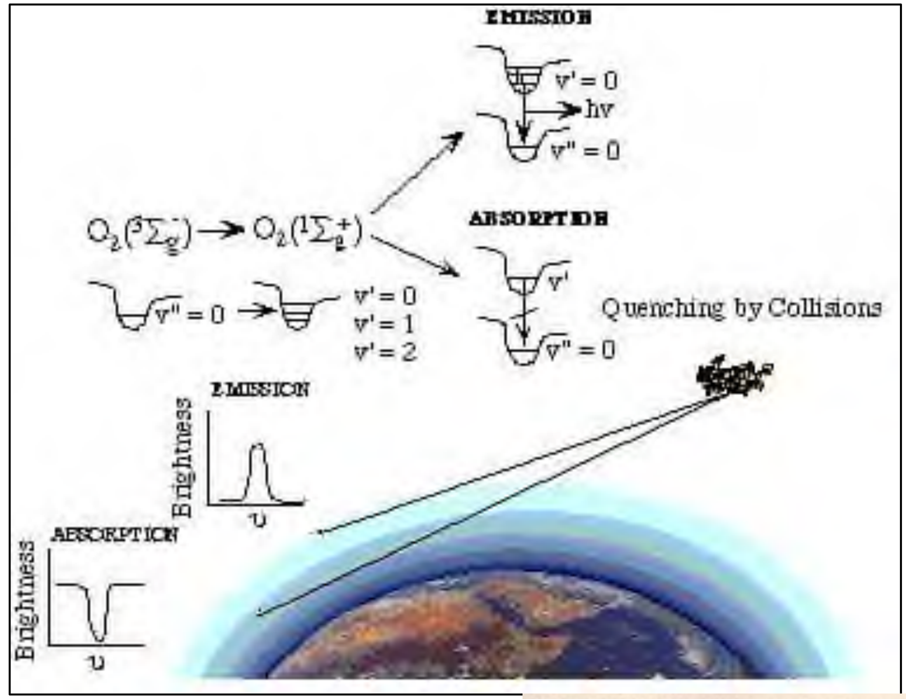
Wu and Waters (1996)



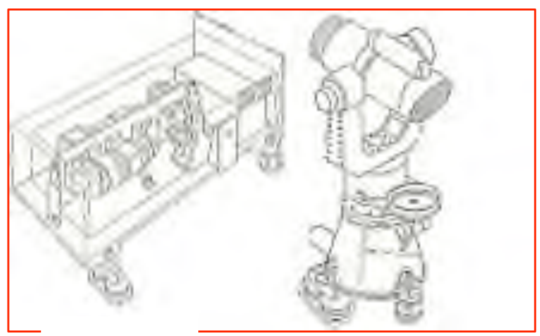


Challenges to Measure Winds from Space

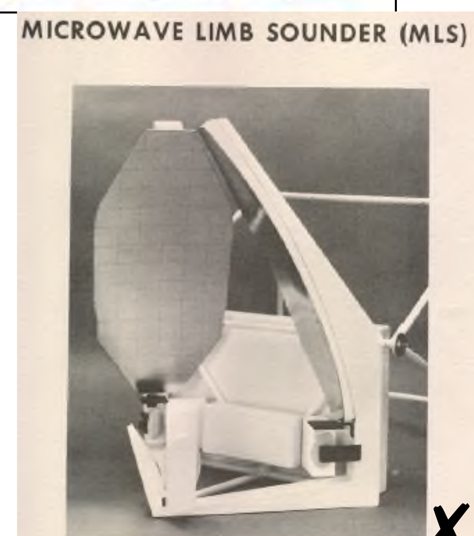
- UARS/HRDI
  - Airglow emission (upper atmos)
  - Airglow scattering-absorption (lower atmos)
- UARS/WINDII
  - Airglow emission (upper atmos)



- Aura/MLS
  - O_2 microwave emission (mid atmos)
- ISS/SMILES
  - O_3 and HCl microwave emissions (mid atmos)



HRDI



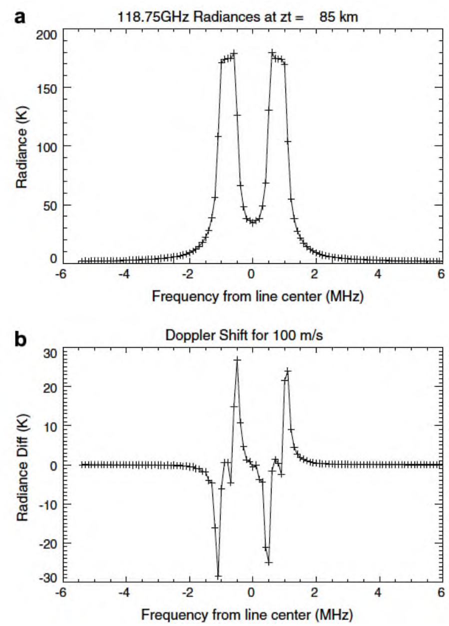
Mid-Atmospheric Winds after UARS

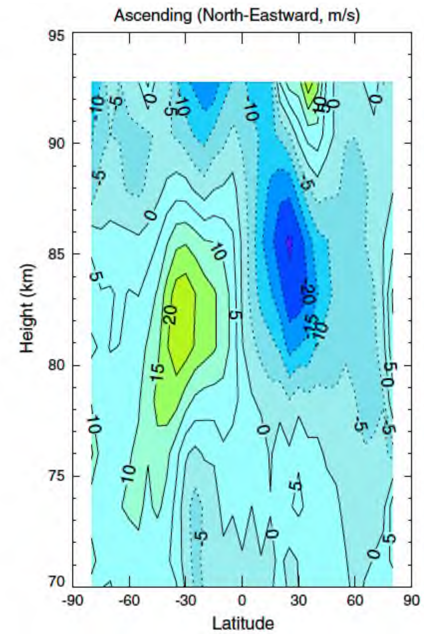
Wu et al. (2008)

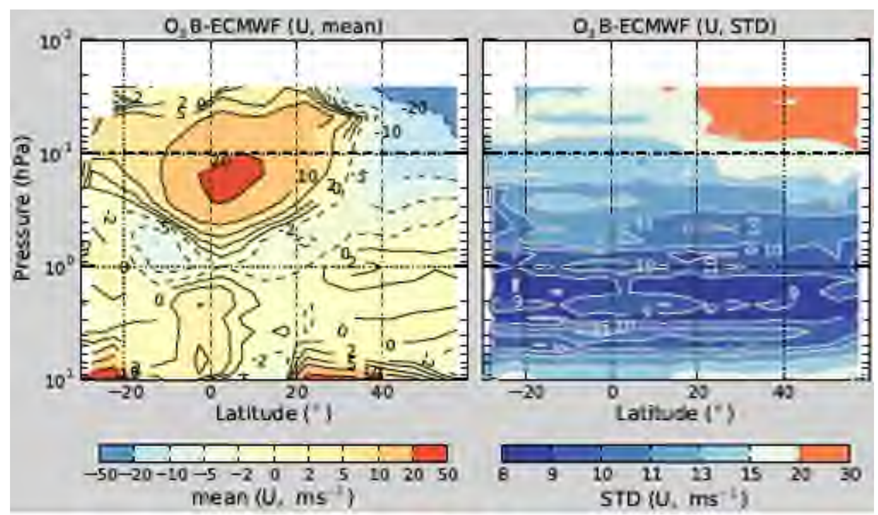
- Aura/MLS 118-GHz Zeeman-split O_2 limb emission
- 0.1 MHz spectral resolution
- Improved receiver sensitivity
- Along-track wind only

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





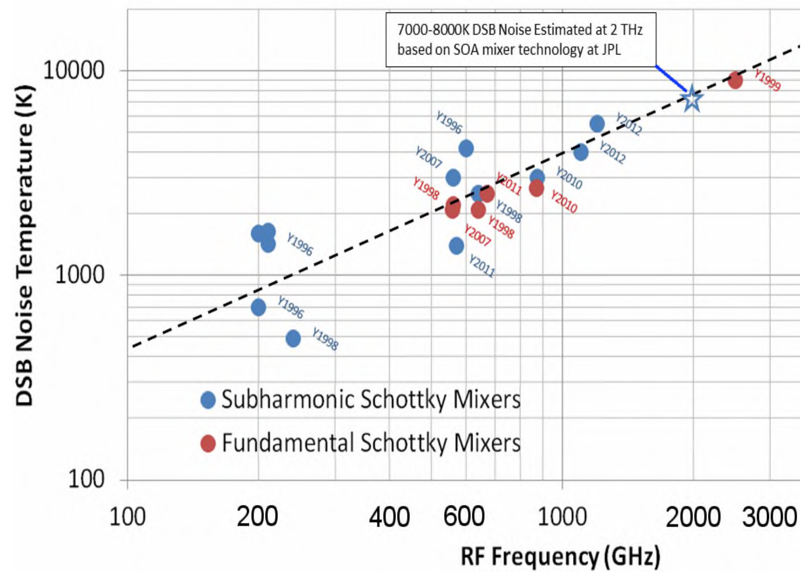


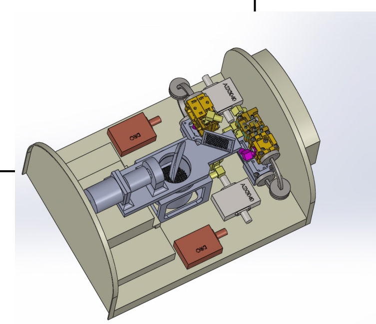
Thermospheric Winds from 2.06-THz OI Emission

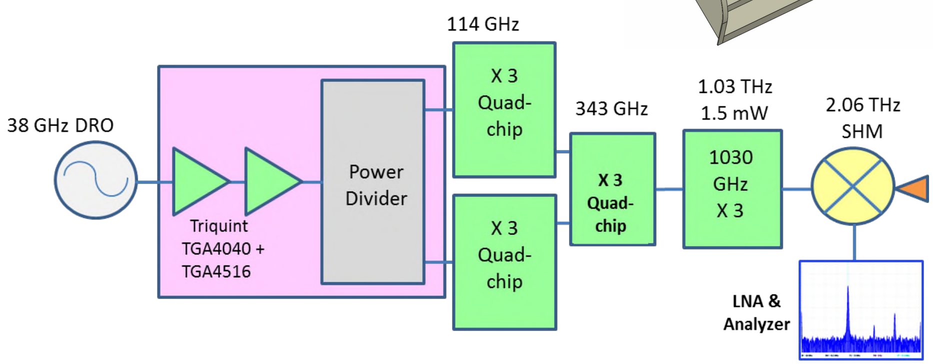
Yee et al. (2015)

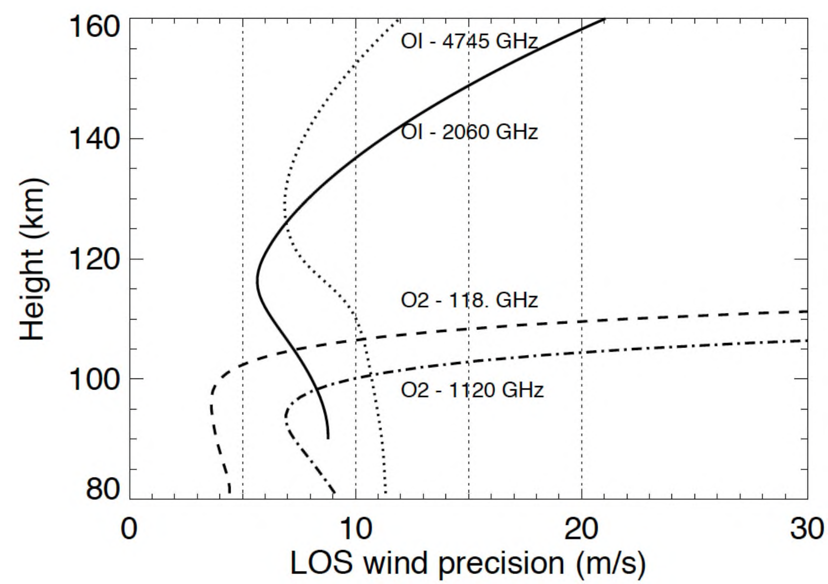
- 2.06-THz atomic oxygen (OI) limb emission
- 1-2 MHz spectral resolution
- Receiver sensitivity

  Tsys (DSB)= 7000 K
- Useful wind profile at 100-140km

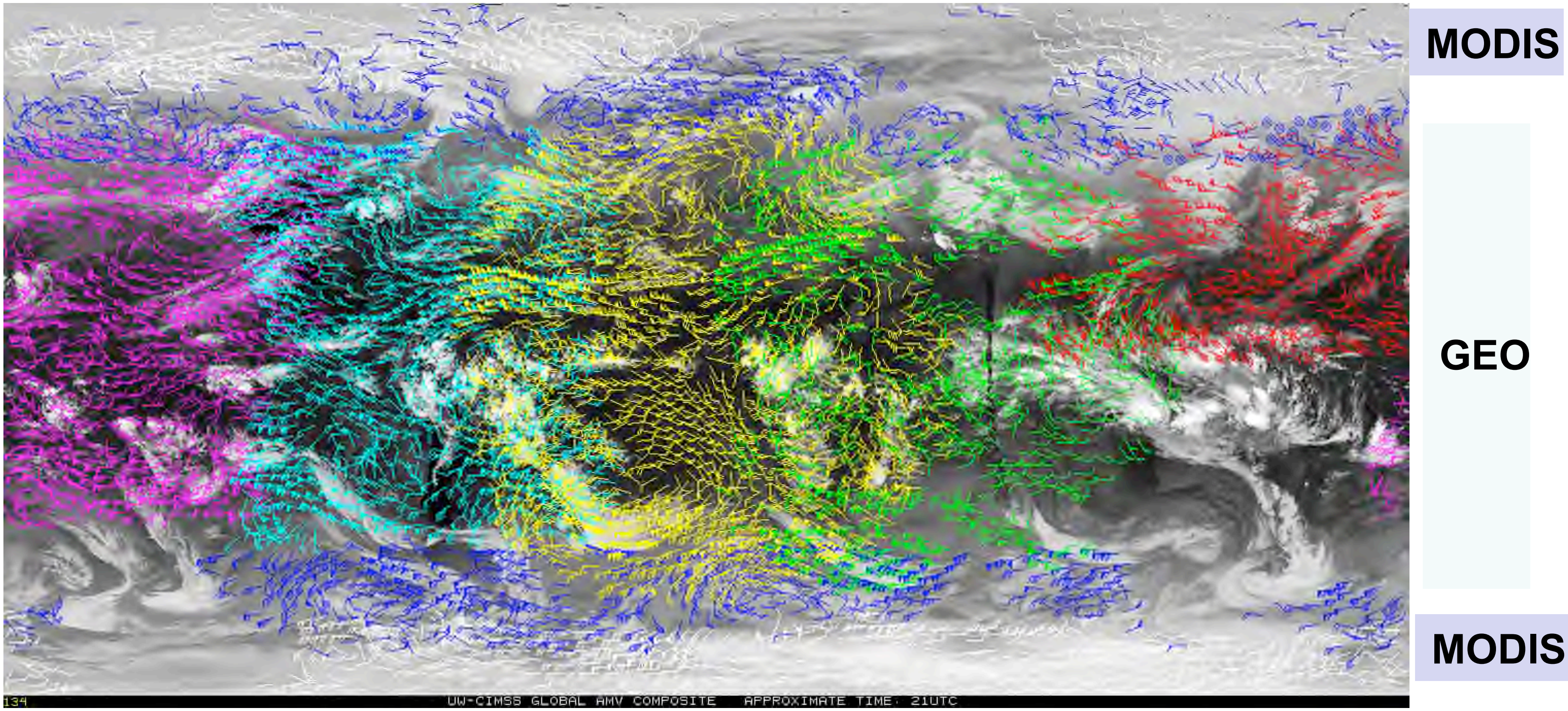




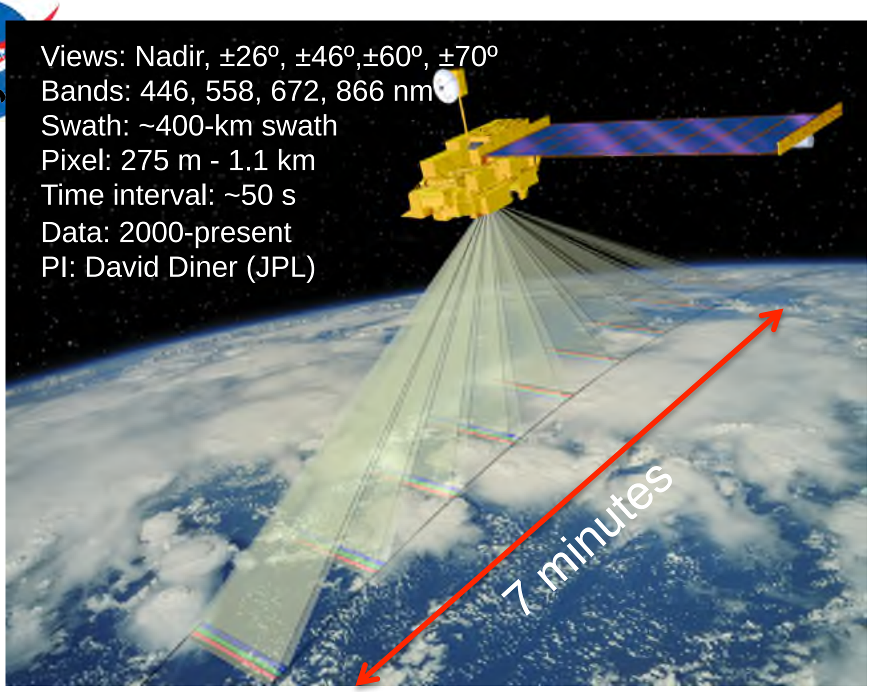




Atmospheric Motion Vectors (AMVs)



- 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

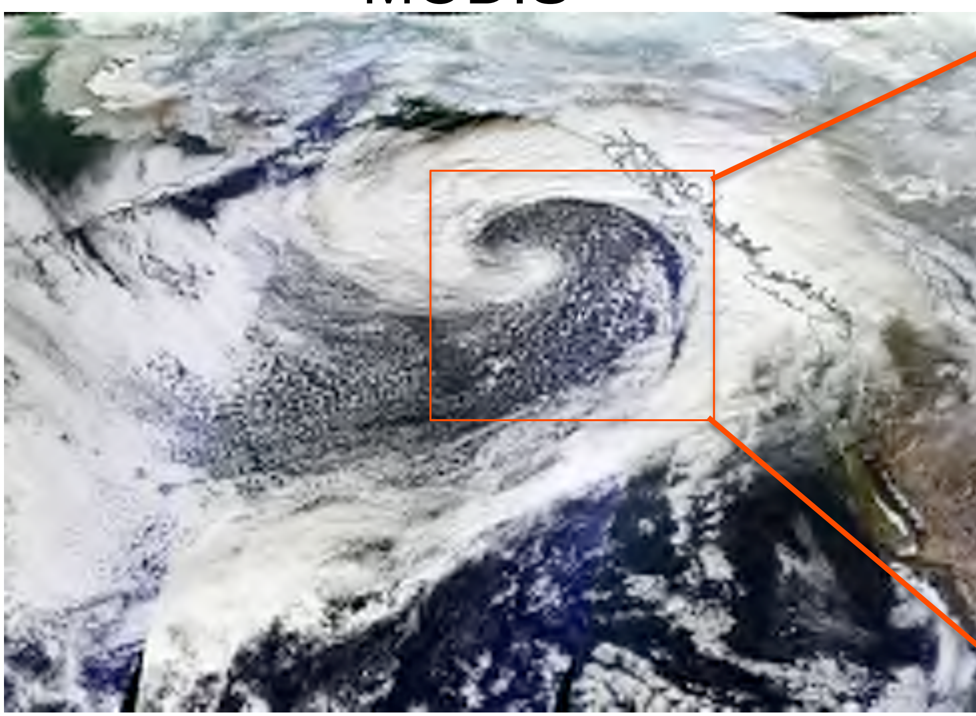
Complexities of Tropospheric Winds and Thermodynamics

Severe Weather

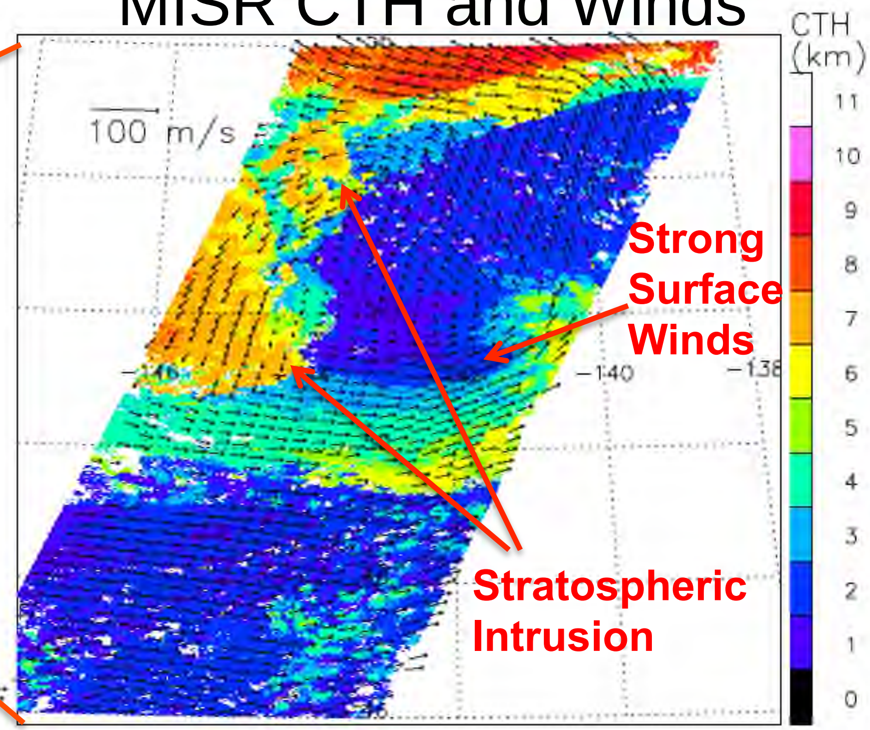
- Extratropical cyclones (ETC)
- Tropopause folding
- Low-level “sting jets”

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

MODIS



MISR CTH and Winds



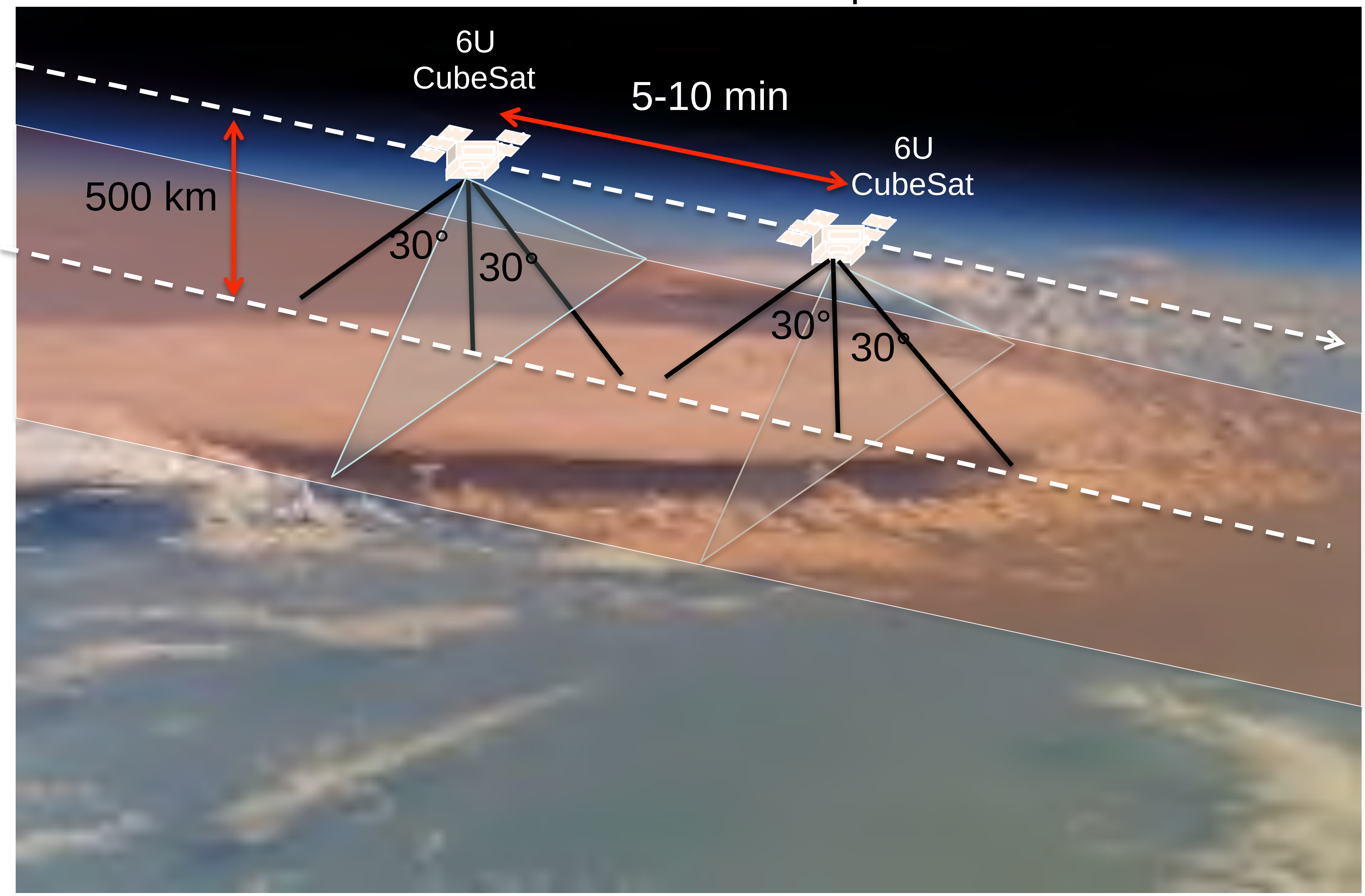
Limitations of Current AMVs

	MISR	MODIS/VIIRS MetOp A/B	GOES-R
Multi-Angle	Yes	No	No
Stereo	Yes	No	Limited
Aliasing	Along-track wind vs. height	Cross-track wind vs. height	Limited to GOES station-keeping and pointing stability
Day/Night Obs	Day only (VIS)	Day + Night (IR)	Day + Night (IR)
Resolution	17 km	~20 km	~20 km
Horizontal Wind (U, V) Unc.	1-2 ms^{-1} 2 - 4 ms^{-1}	< 2 ms^{-1}	< 2 ms^{-1}
Height Unc.	0.6 - 1 km	2-4 km	2-4 km
Vertical Wind (W) Unc.	No	No	No

CubeSat Constellation Cloud Winds (C3Winds)

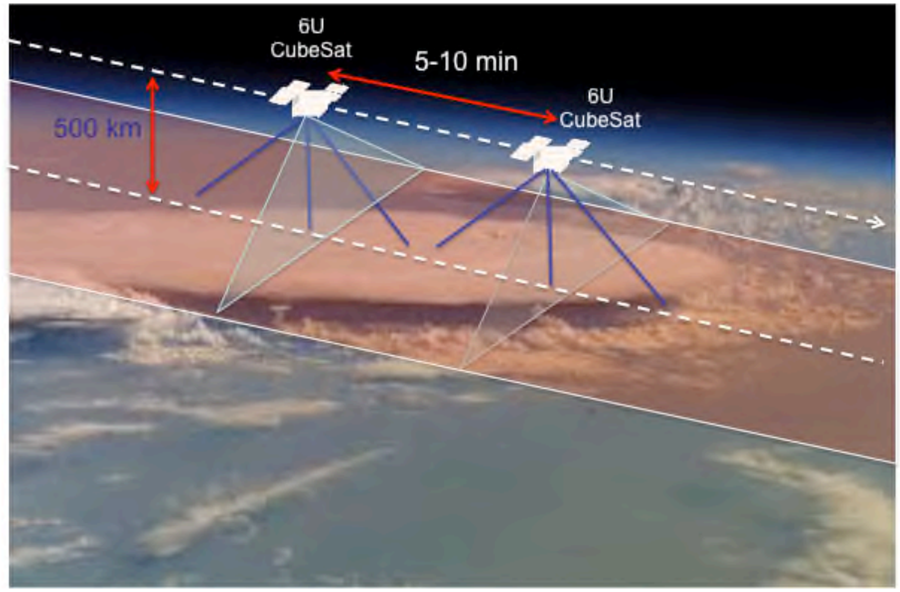
Multi-platform Multi-angle Imaging

An Earth Venture-Instrument Proposal to NASA



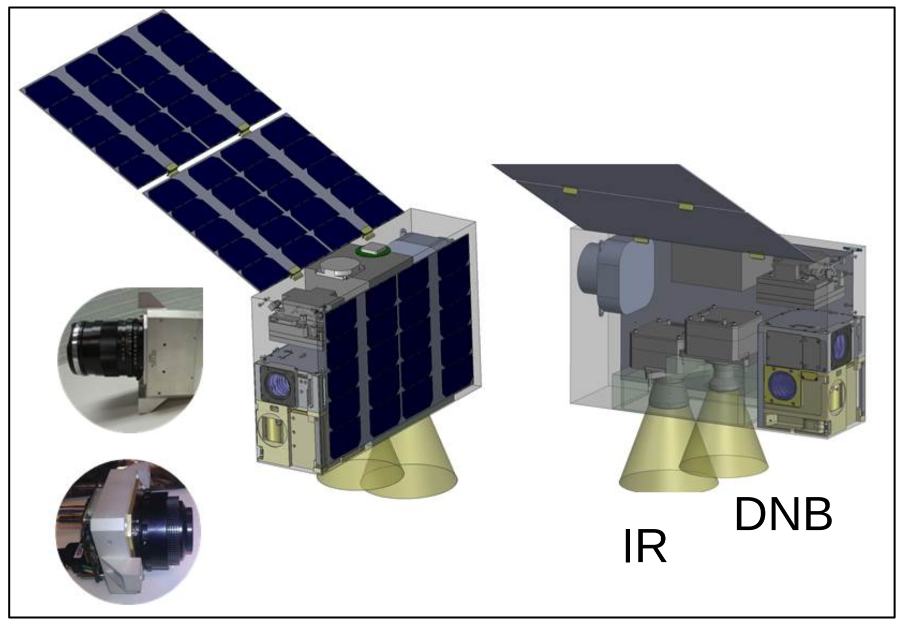
NASA EVI-3 Mission Proposal and Instrument Design

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

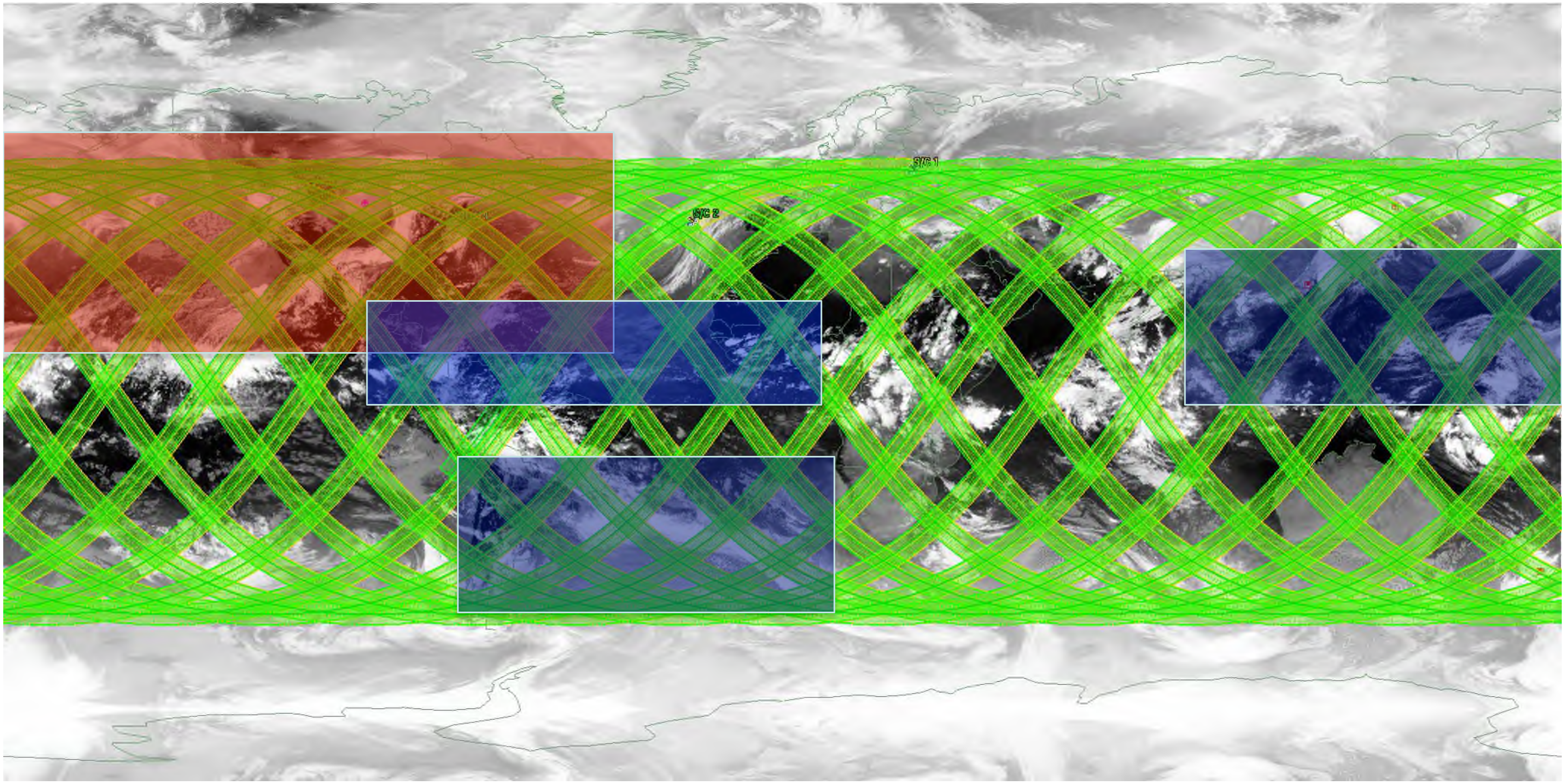
System and Instrument Requirements	
Mass	7.65 kg
Spacecraft Dimensions (6U)	30 x 20 x 10 cm
Baseline Science Power	10.3 W
Maximum Science Power	14.6 W
Baseline Data Return	24 Gb/day (both S/C)
Maximum Data Return	122 Gb/day (both S/C)



DNB = Day-Night Band camera
IR = InfraRed camera

Example of Daily Coverage from ISS Orbits and Sampling Priority

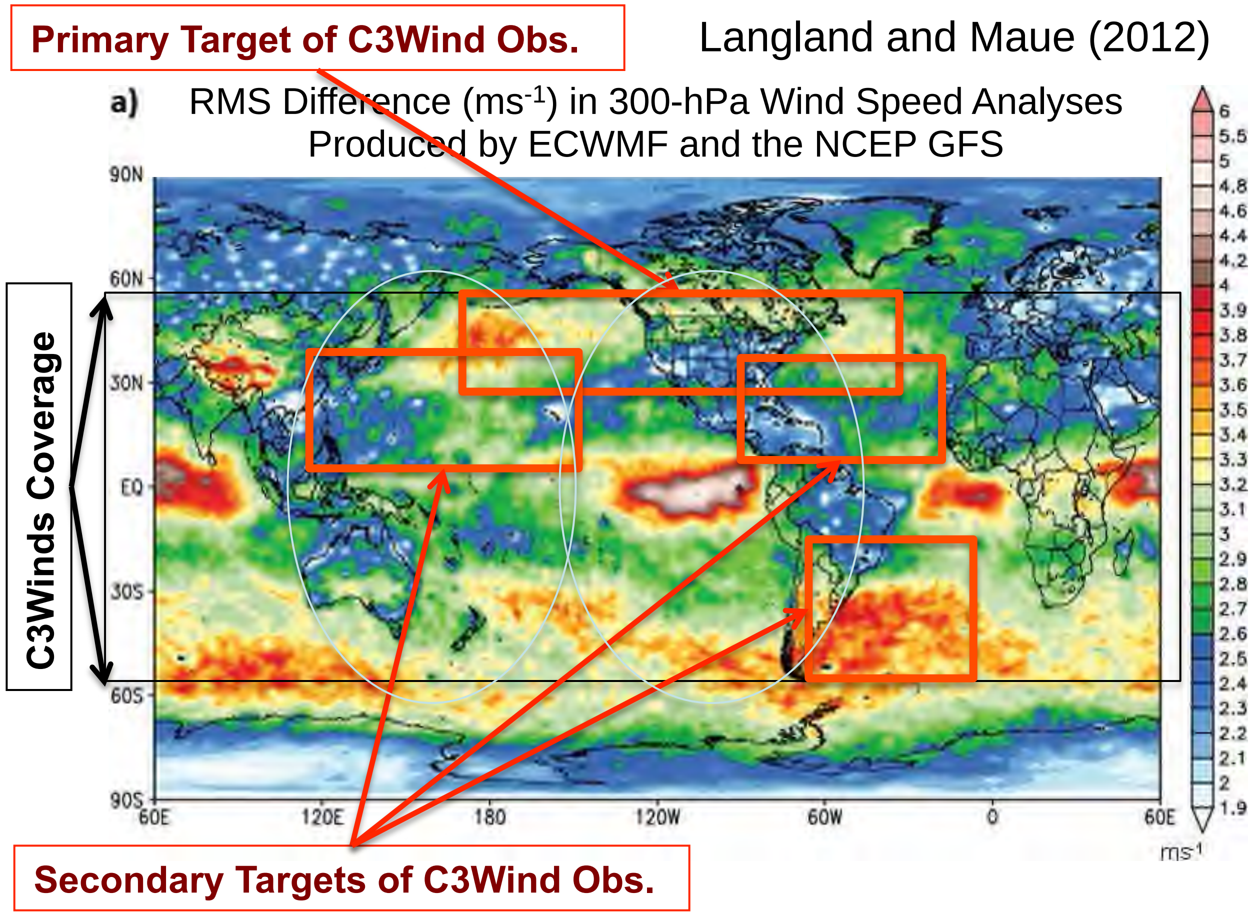
Two CubeSats Separated by 10 min in Formation Flight



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.