



# CubeSat Constellation Cloud Winds (C3Winds)

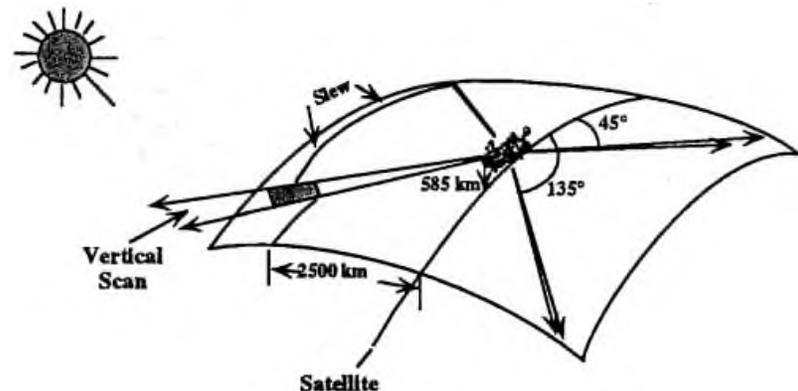
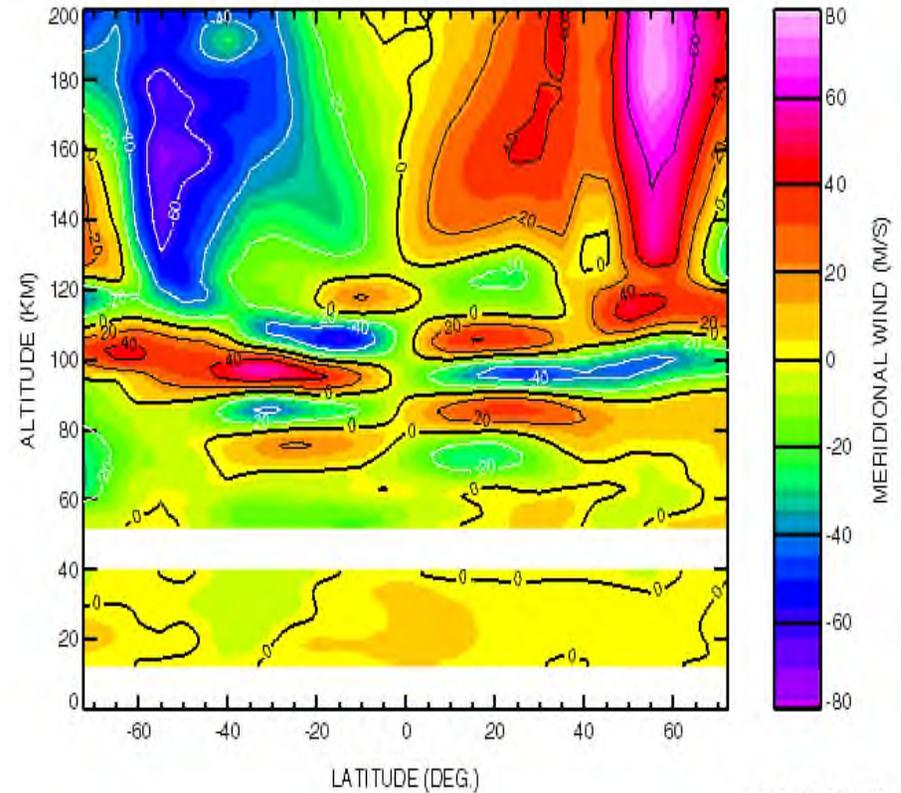
*A New Wind Observing System to Study Mesoscale  
Cloud Dynamics and Processes*

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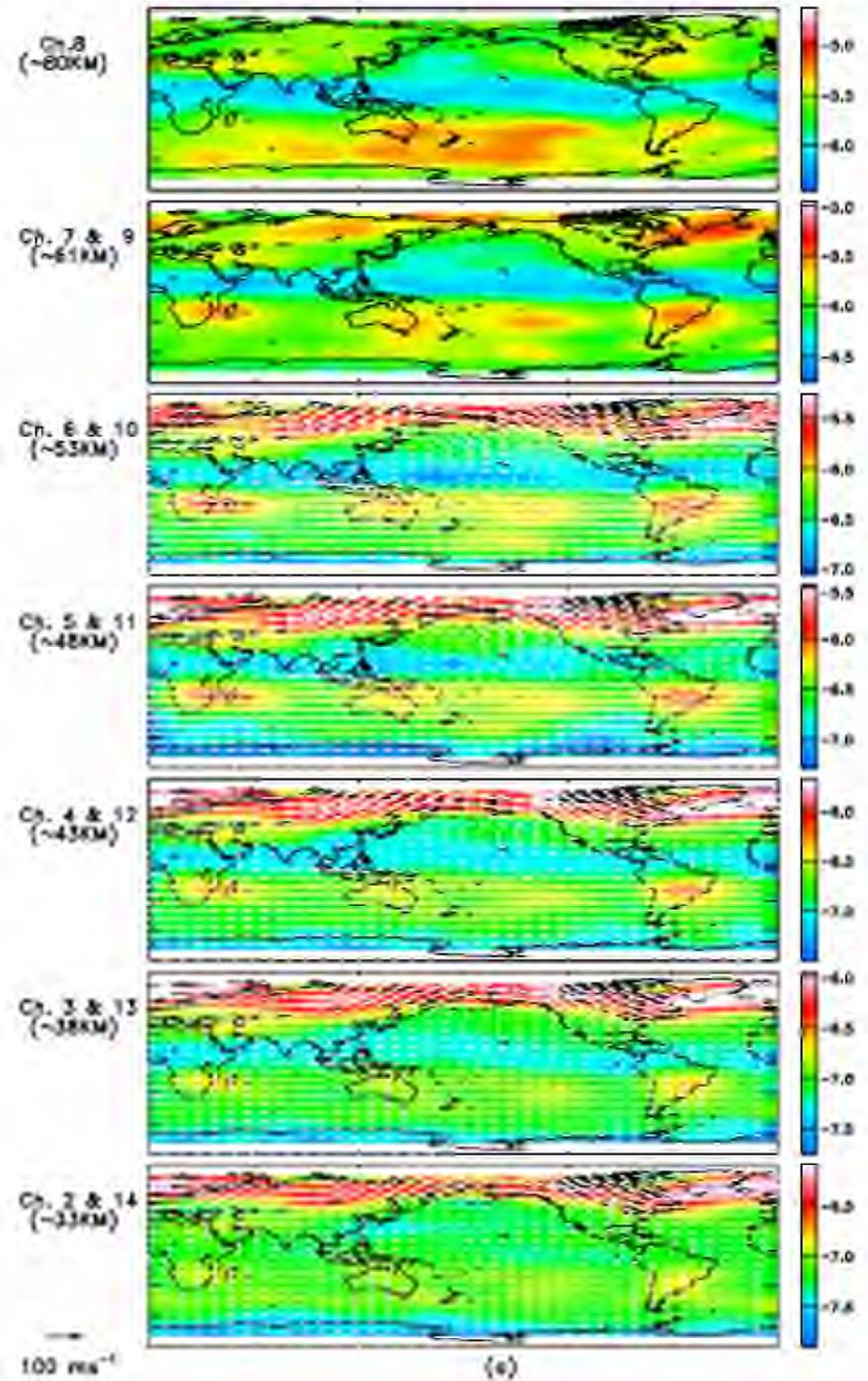
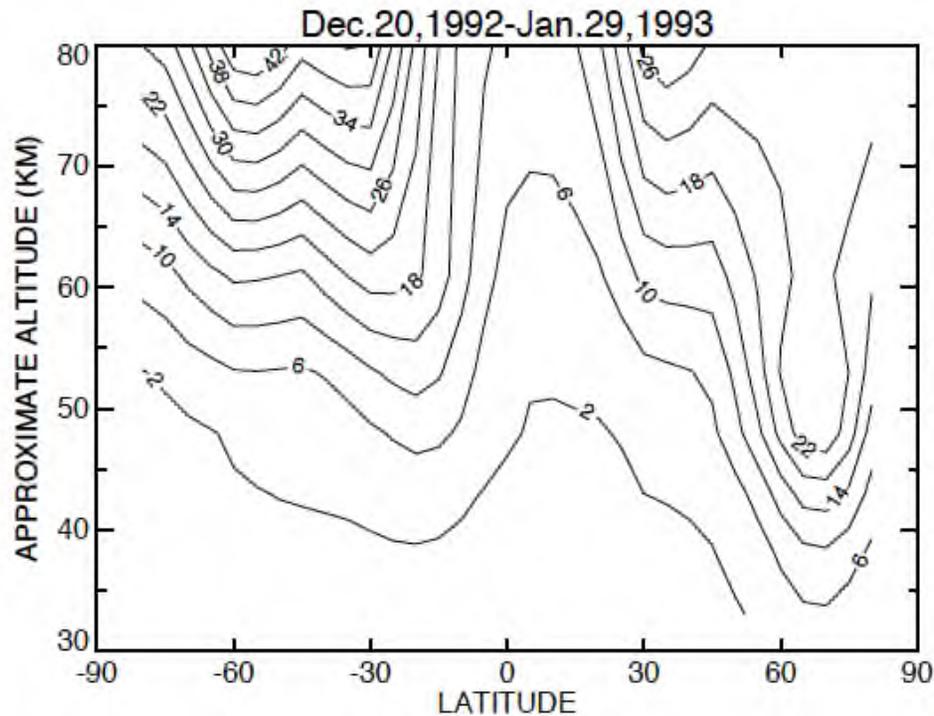
# Marv and UARS Winds

- 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



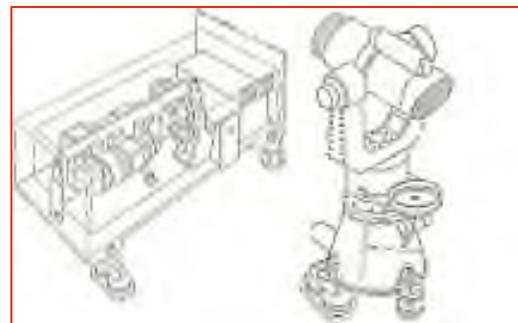
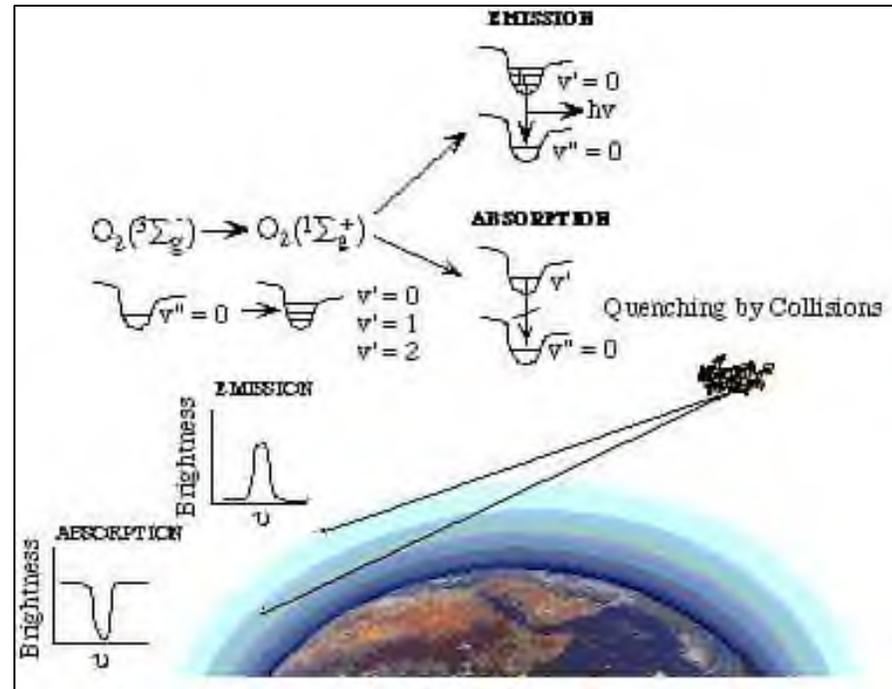
# Gravity Waves from UARS MLS

Wu and Waters (1996)



# Challenges to Measure Winds from Space

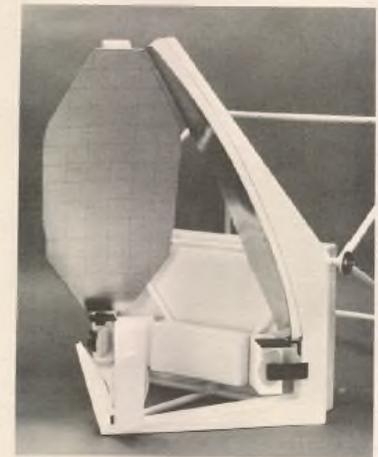
- UARS/HRDI
  - Airglow emission (upper atmos)
  - Airglow scattering-absorption (lower atmos)
- UARS/WINDII
  - Airglow emission (upper atmos)
- Aura/MLS
  - O<sub>2</sub> microwave emission (mid atmos)
- ISS/SMILES
  - O<sub>3</sub> and HCl microwave emissions (mid atmos)



**HRDI**



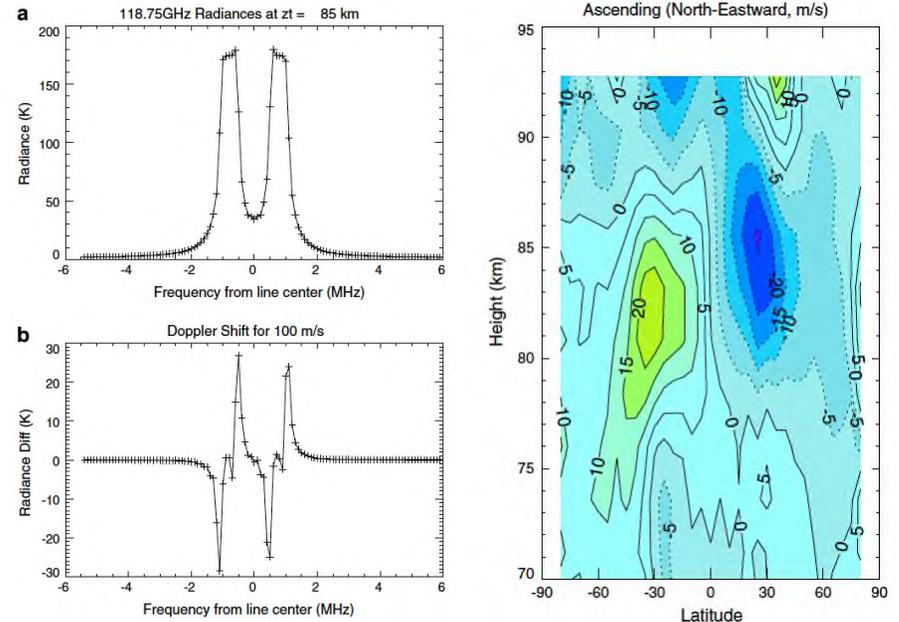
MICROWAVE LIMB SOUNDER (MLS)



# Mid-Atmospheric Winds after UARS

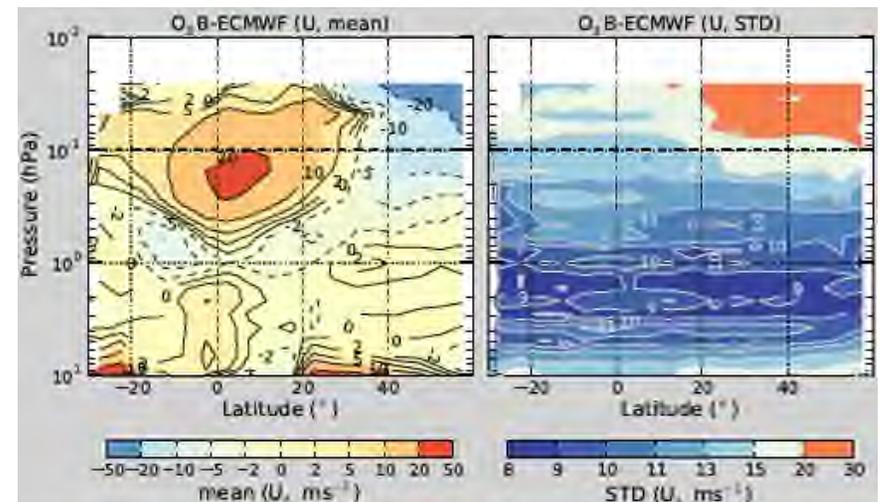
## Wu et al. (2008)

- Aura/MLS 118-GHz Zeeman-split O<sub>2</sub> limb emission
- 0.1 MHz spectral resolution
- Improved receiver sensitivity
- Along-track wind only



## Baron et al. (2013)

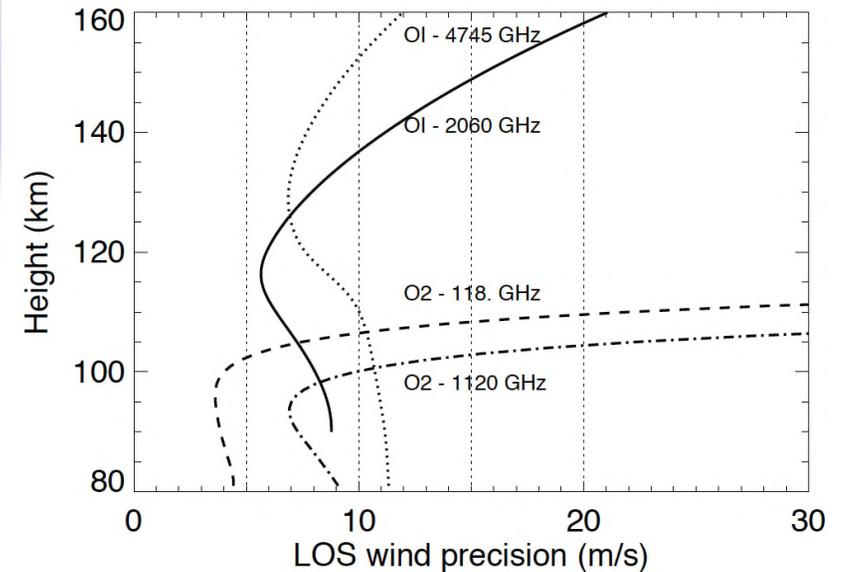
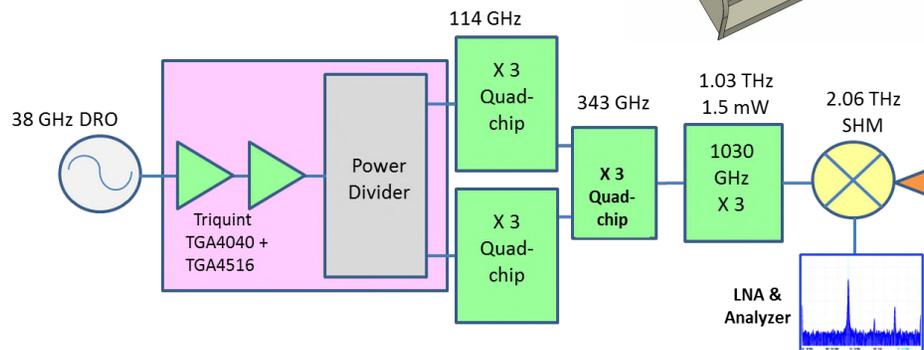
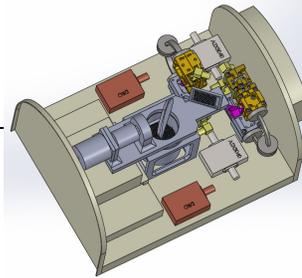
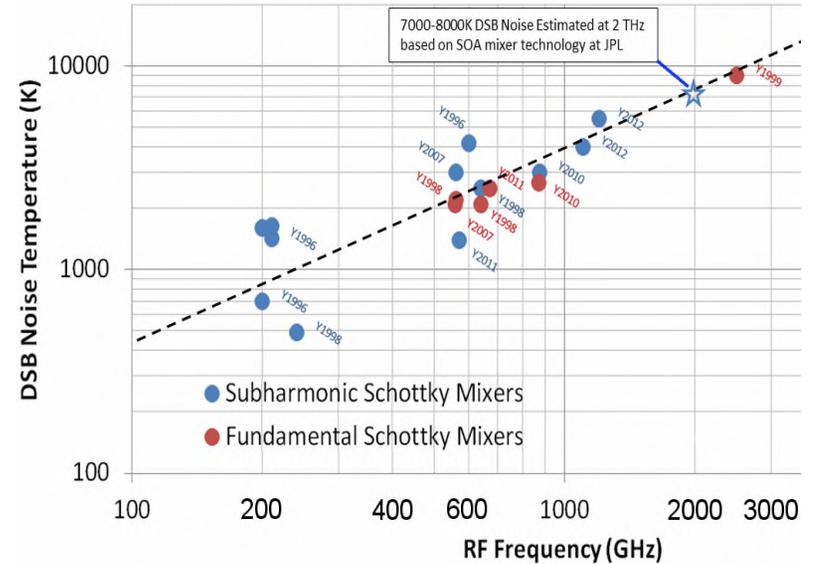
- O<sub>3</sub> and HCl limb emissions at 35-80 km
- 1.2 MHz spectral resolution
- High sensitivity at cryogenic (4K) temperature
- One-component wind from ISS



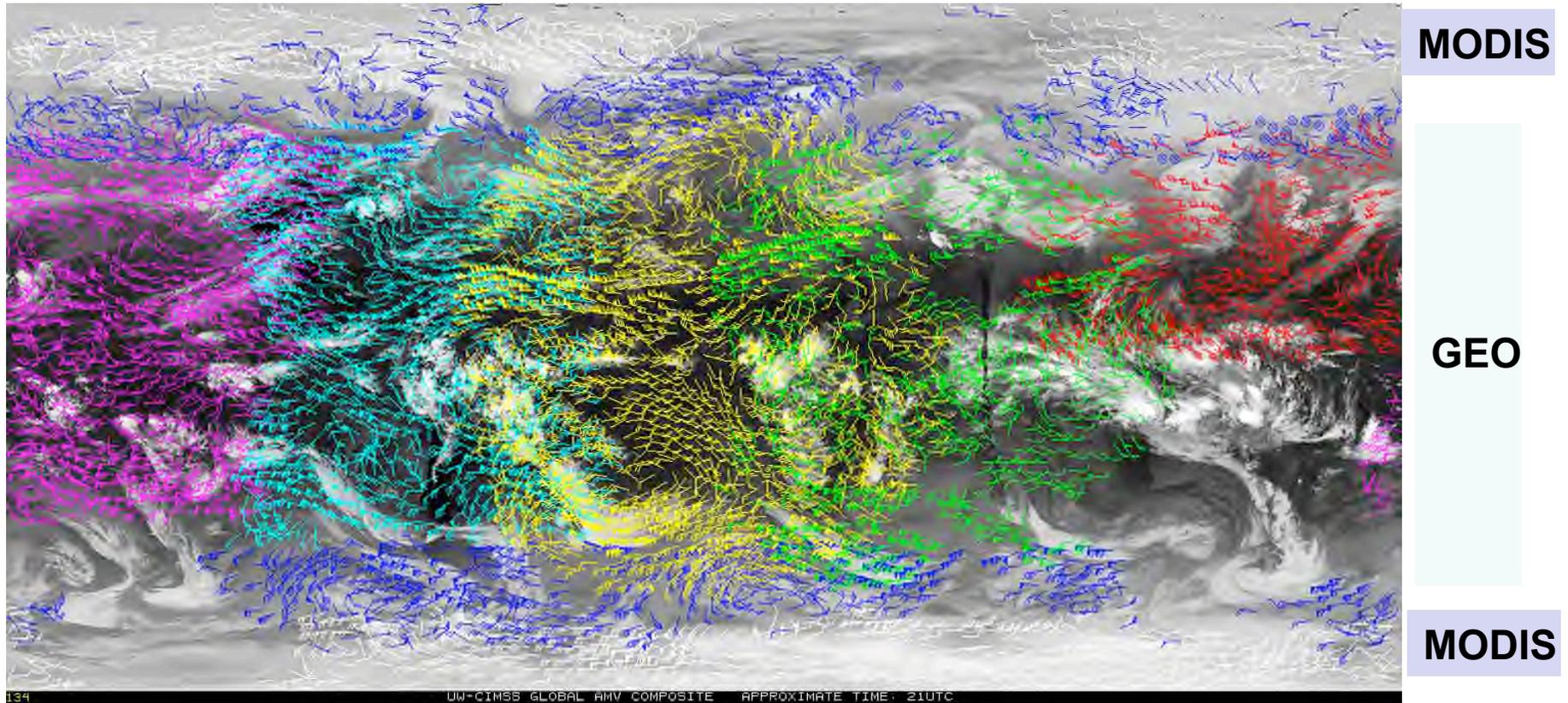
# Thermospheric Winds from 2.06-THz OI Emission

Yee et al. (2015)

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



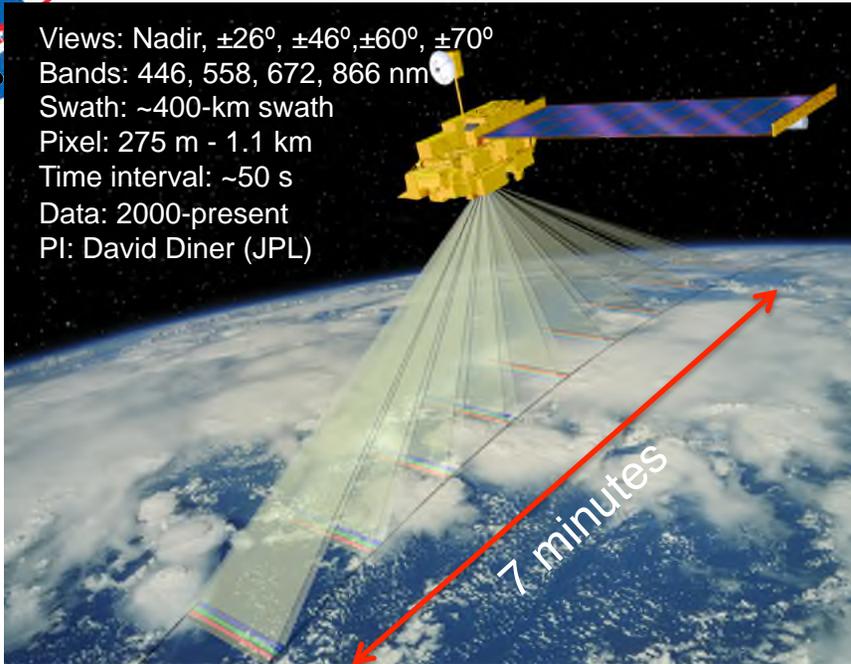
# Atmospheric Motion Vectors (AMVs)



- 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



Views: Nadir,  $\pm 26^\circ$ ,  $\pm 46^\circ$ ,  $\pm 60^\circ$ ,  $\pm 70^\circ$   
Bands: 446, 558, 672, 866 nm  
Swath: ~400-km swath  
Pixel: 275 m - 1.1 km  
Time interval: ~50 s  
Data: 2000-present  
PI: David Diner (JPL)



# Multi-angle Imaging SpectroRadiometer (MISR) on Terra

von Kármán vortex street near Jan Mayen Island



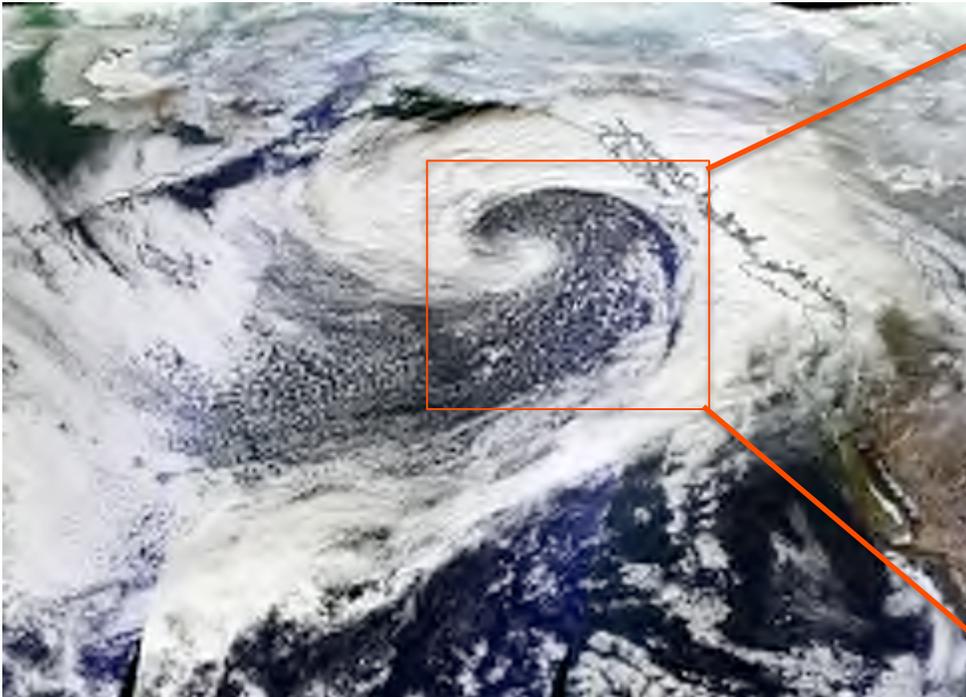
# Complexities of Tropospheric Winds and Thermodynamics

## Severe Weather

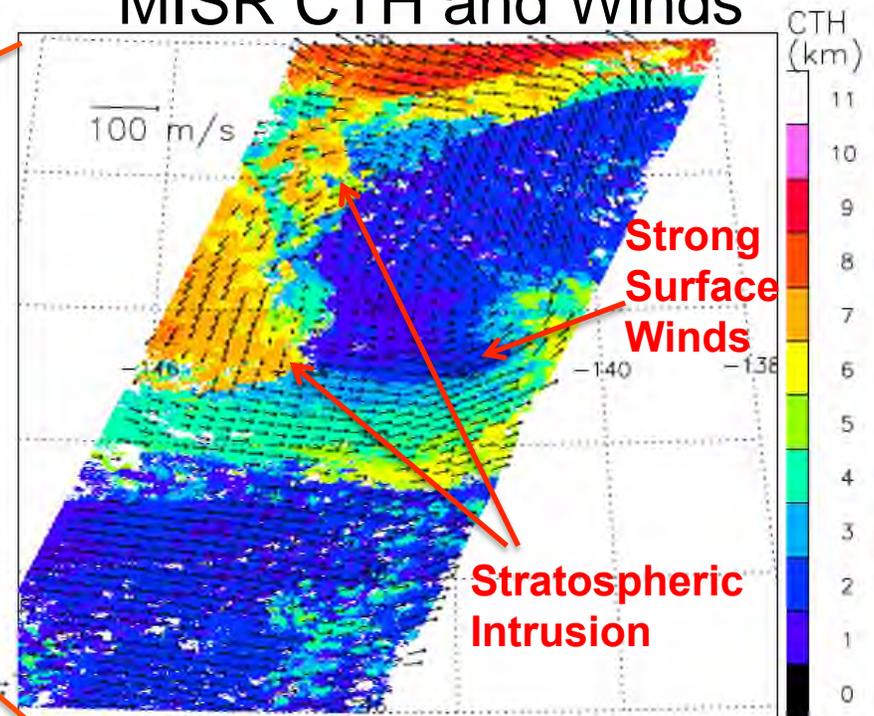
- Extratropical cyclones (ETC)
- Tropopause folding
- Low-level “sting jets”

- 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

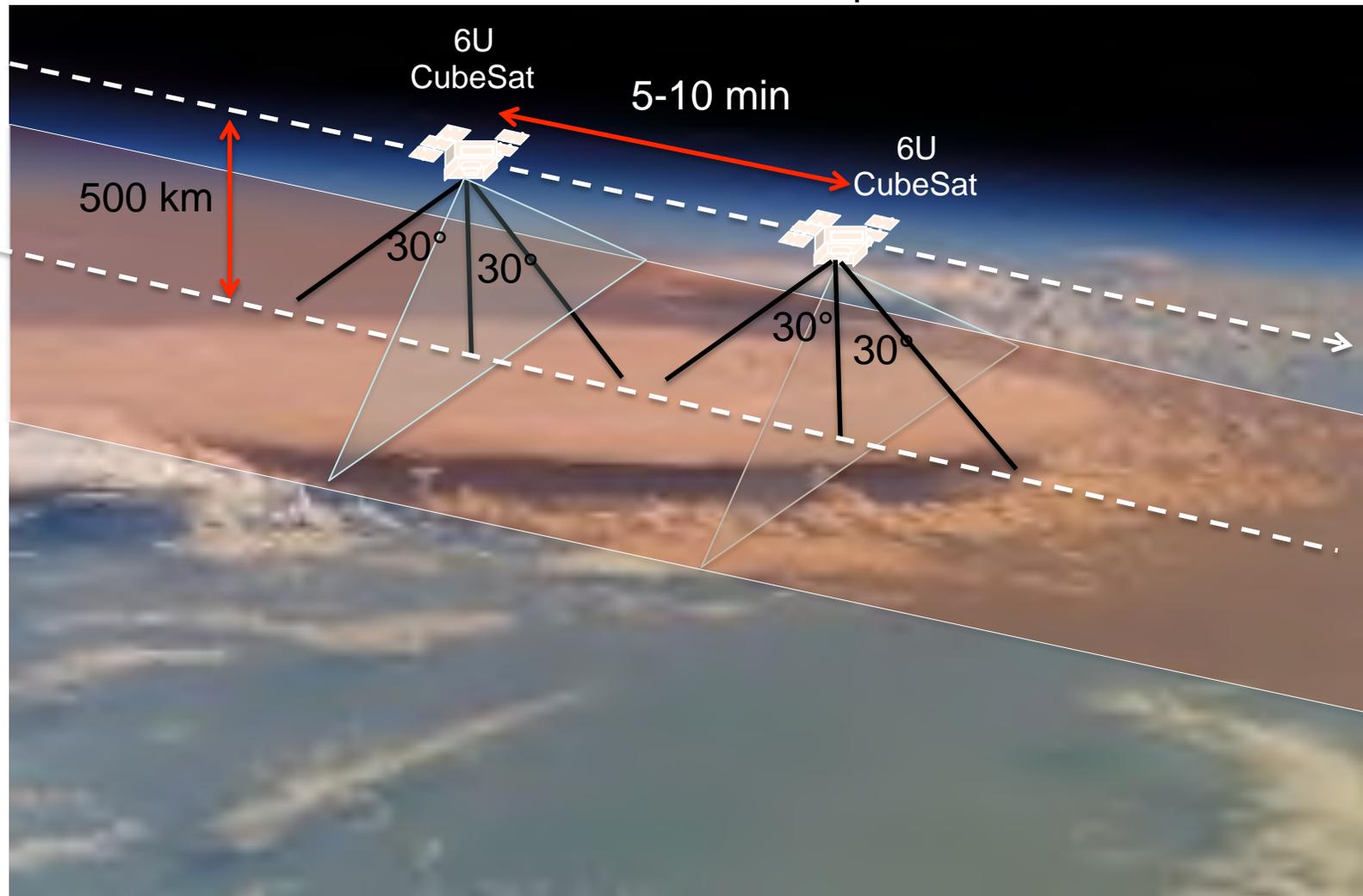
	MISR	MODIS/VIIRS MetOp A/B	GOES-R
<b>Multi-Angle</b>	Yes	No	No
<b>Stereo</b>	Yes	No	Limited
<b>Aliasing</b>	Along-track wind vs. height	Cross-track wind vs. height	Limited to GOES station-keeping and pointing stability
<b>Day/Night Obs</b>	Day only (VIS)	Day + Night (IR)	Day + Night (IR)
<b>Resolution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



# CubeSat Constellation Cloud Winds (C3Winds)

## Multi-platform Multi-angle Imaging

An Earth Venture-Instrument Proposal to NASA





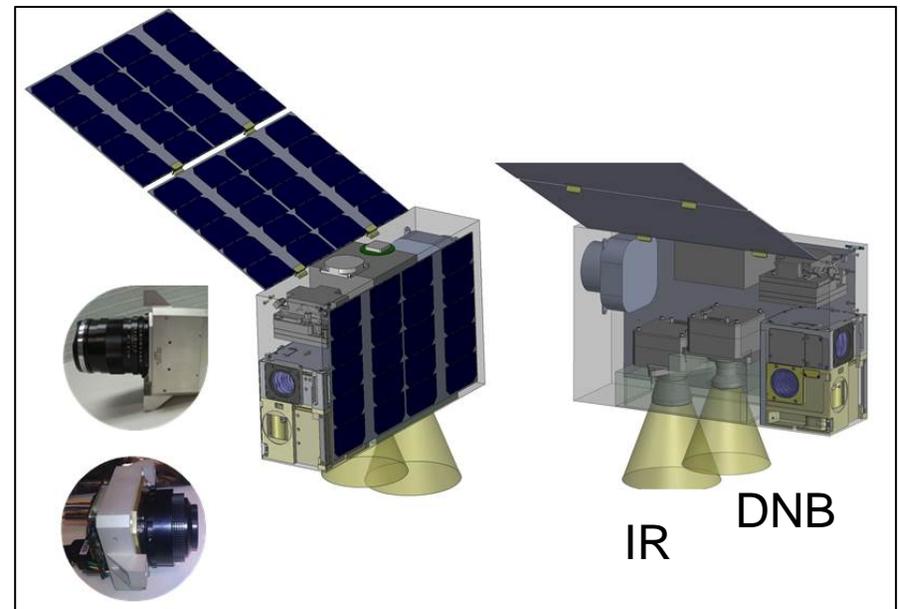
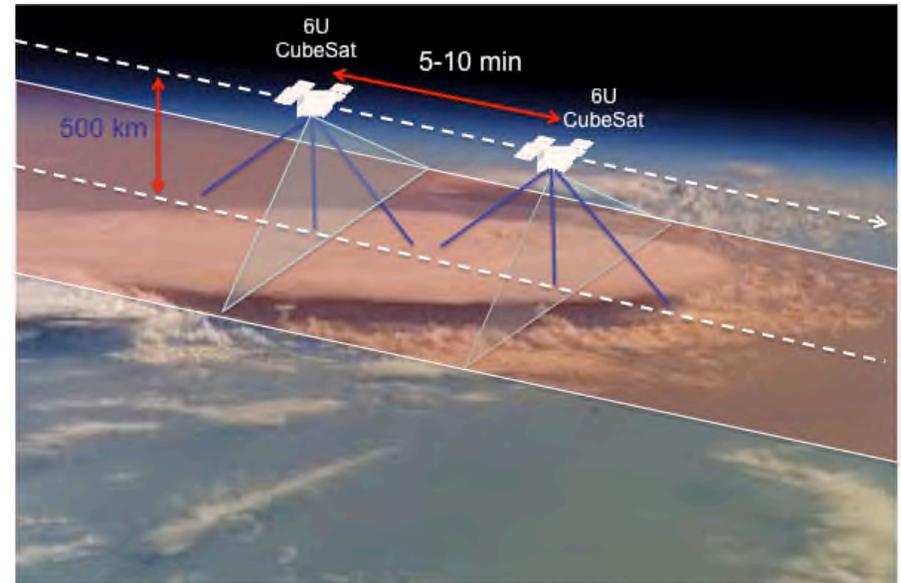
# NASA EVI-3 Mission Proposal and Instrument Design

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 (1<sup>st</sup> 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)

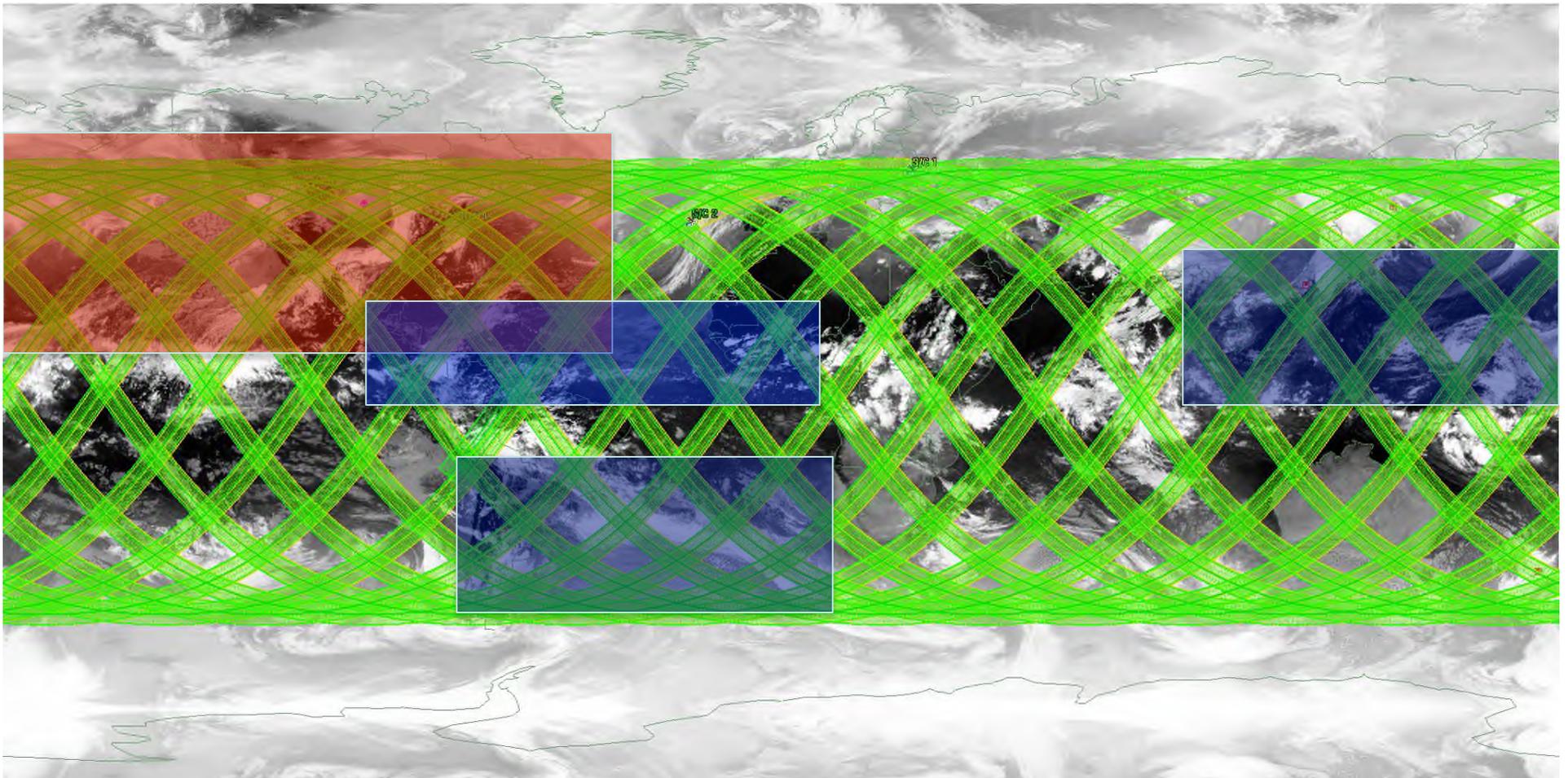
DNB = Day-Night Band camera  
 IR = InfraRed camera





# Example of Daily Coverage from ISS Orbits and Sampling Priority

Two CubeSats Separated by 10 min in Formation Flight



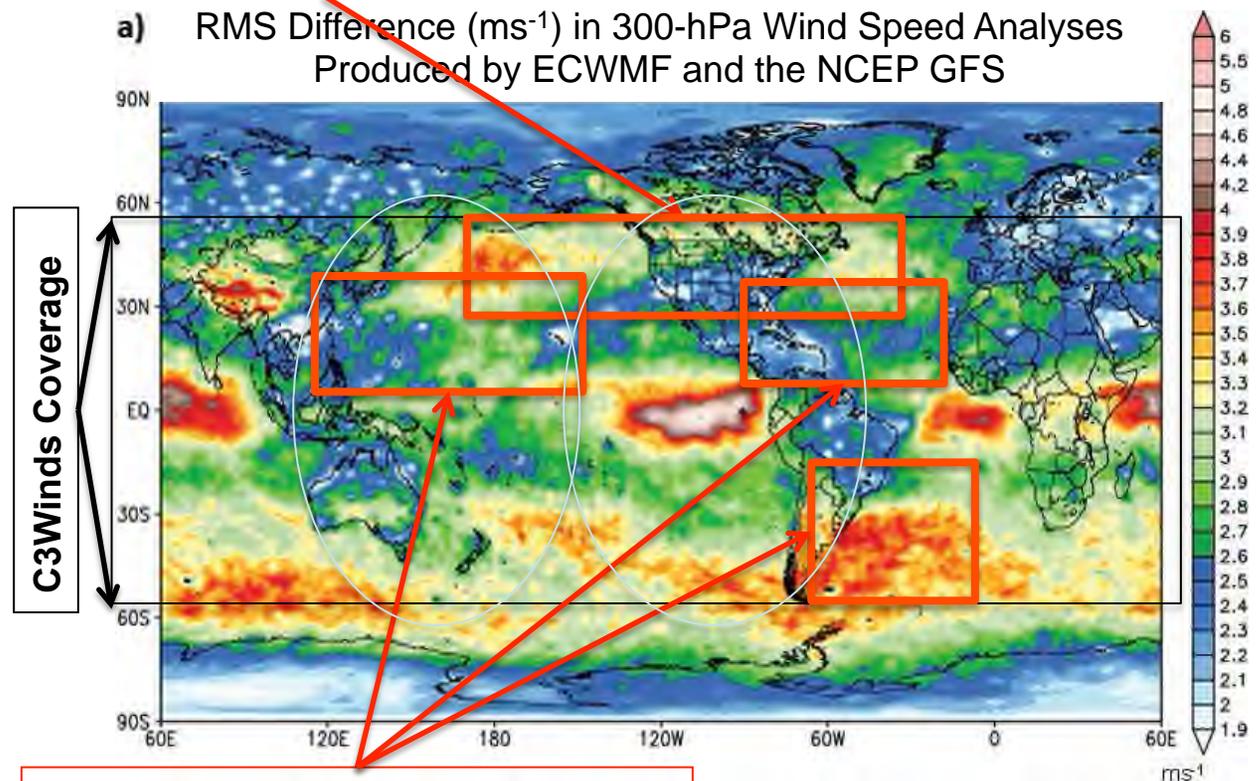
# C3Winds Science Objectives

*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

**Primary Target 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.