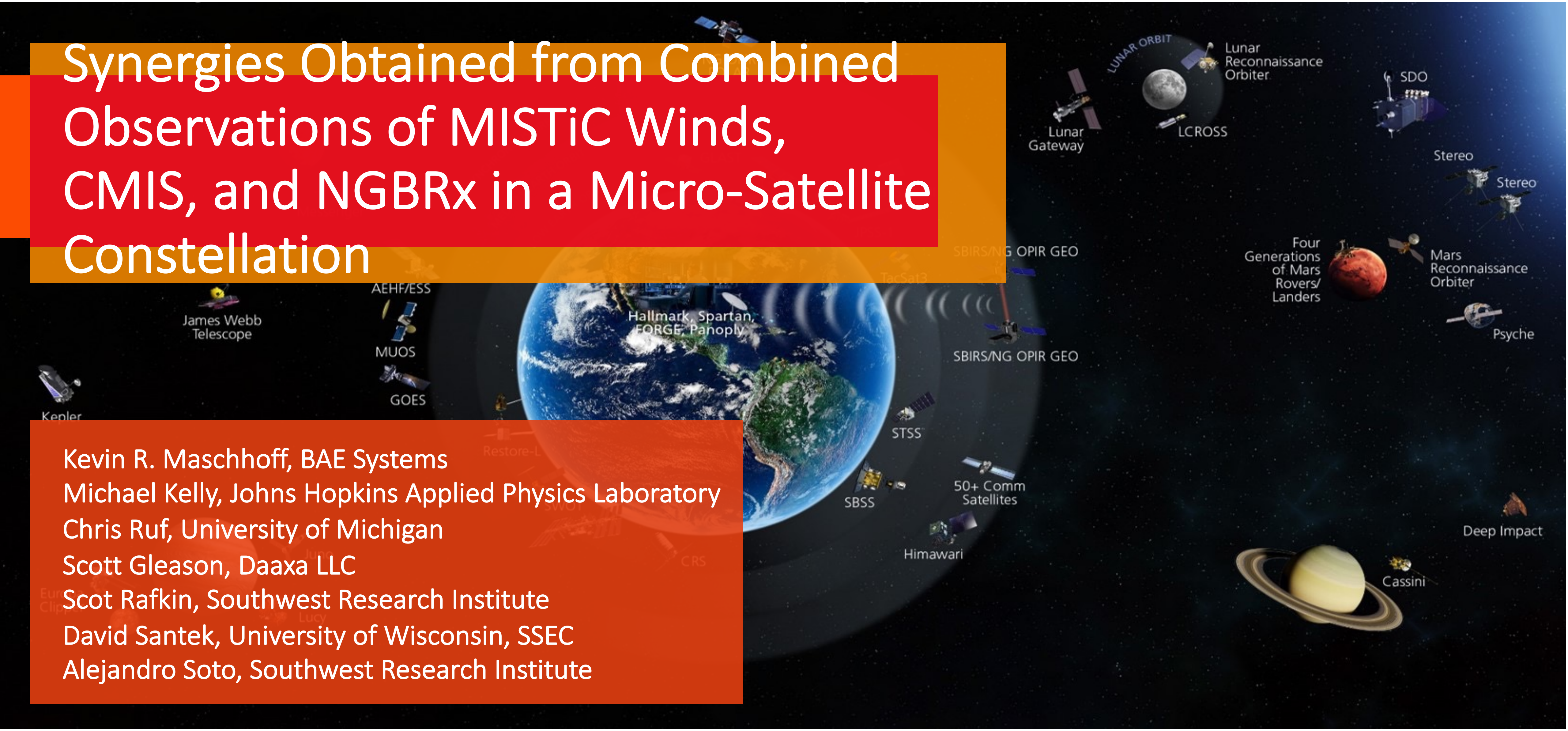
Synergies Obtained from Combined Observations of MISTiC Winds, CMIS, and NGBRx in a Micro-Satellite Constellation



Kevin R. Maschhoff, BAE Systems
Michael Kelly, Johns Hopkins Applied Physics Laboratory
Chris Ruf, University of Michigan
Scott Gleason, Daaxa LLC
Scot Rafkin, Southwest Research Institute
David Santek, University of Wisconsin, SSEC
Alejandro Soto, Southwest Research Institute

Not export controlled per ES-C4ISR-050423-0099

BAE SYSTEMS

Outline

- Introduction on Synergy for Combined Thermodynamic and Dynamic Observations
- Observing System Summary Descriptions and Coverage Geometry
- NASA and NOAA Wind Performance Goals and Estimates for New Observing Methods
- Improving Observation Level 1 Data Quality/Quantity through Synergy-an Example
- Improving Higher-Level Meteorological Data Products through Synergy-Summary
- Summary

Introduction

- Miniaturization of instrument payloads for key wind and thermodynamic vertical profile observations would enable future small-satellite LEO missions providing synergistic observation
- Wind Observations
    - Wind Vertical Profile via Water Vapor Hyperspectral AMVs (MISTiC Winds Method)
    - Cloud-Top Stereo Motion Vectors (CMIS Method)
    - Ocean Surface Wind Speed (CYGNSS Method-Updated under NGBRx)
- Thermodynamic Profile Observations
    - IR Hyperspectral Temperature/Water Vapor Vertical Profiles (MISTiC Method-derived from AIRS)
    - GPS-Radio Occultation Temperature/Water Vapor Vertical Profiles
- Approaches to Synergy include:
    - Observations assimilated into NWP
        - Current partially aggregated constellations or fully dis-aggregated constellations,
    - *Near-simultaneous/Co-registered Observations and Retrievals* ←

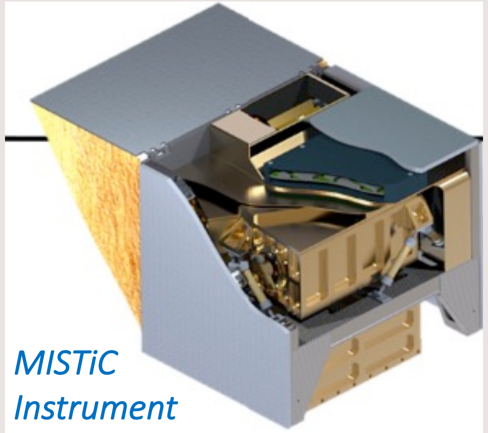
Not export controlled per ES-C4ISR-050423-0099

Complementary MISTiC, CMIS, and NGBRx Observation Methods in an ESPA-Class MicroSat Constellation

All Observation Methods Supported by NASA ESTO Funding (Instrument Incubator Program)

MISTiC Winds IR Hyperspectral AMV Wind Observation and T/q Vertical Profiles

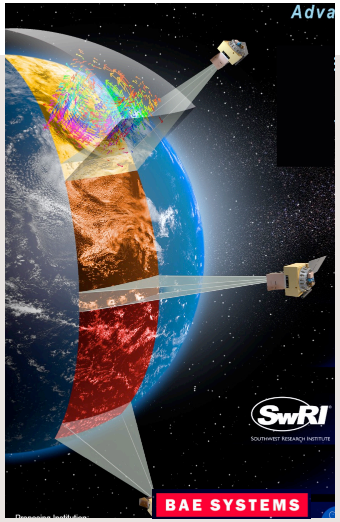
- Dispersive Hyperspectral Wide-Field Imager/Sounder (1750-2450 cm^{-1})
  - Temperature/Water Vapor Sounding (following AIRS)
  - GOES-16 ABI or better Image Resolution
- Compact 50W/17 kg Instrument



MISTiC Instrument

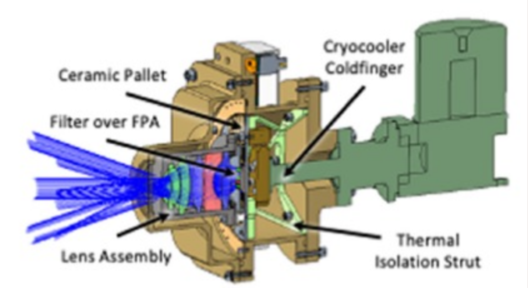
Mission Concept

- Modest Extension of SwRI BAE Systems EVM-3 Implementation
- Miniature Low-Power Instrument Payloads with TRL6 or Higher Technologies
- Mature (TRL6+) spacecraft technologies integrated into ESPA-Class bus
- Single-Launch to 700/800 km SSO
- Three S/C with LTAN separation ~ 15 min



CMIS AMV Wind Observation

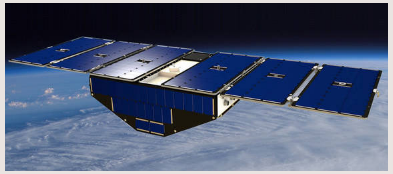
- Stereo Cloud Imager employing high resolution, (~ 1 km) MWIR Multi-Angle Camera
- Newer (III-V Strained-Layer Superlattice) technology detector allows warmer FPA
- Multiple CMIS Instr. deployed in leader-follower formation to resolve along-track velocity ambiguity of MISR Winds



CubeSat-compatible CMIS Multi-angle Imager Instrument

Next-Generation Bi-static Reflection and Refraction

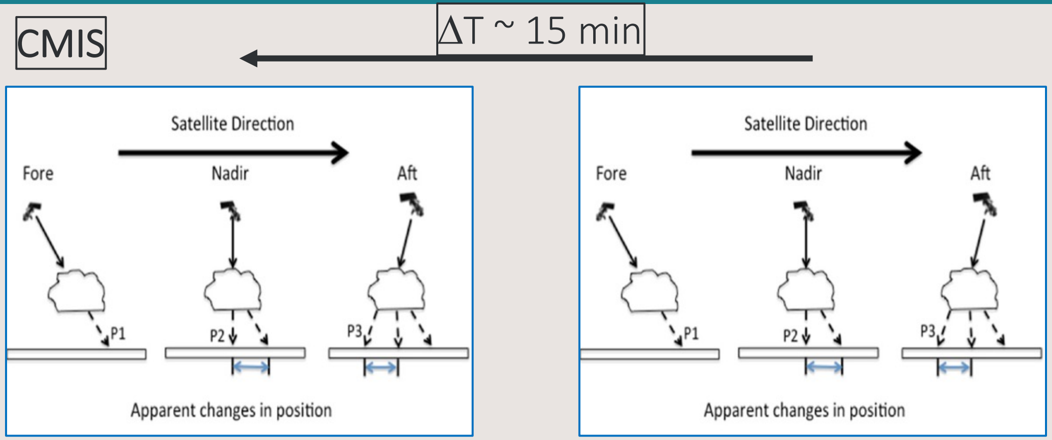
- Leveraging CYGNSS bi-static radar backscatter method for ocean surface wind speed observation
- Include additional antennas for T/q refractivity observation (GPS-RO)
  - Time-share one GPS Receiver Assembly
- Next-generation GPS Receiver -under IIP
  - Both GPS and Galileo satellites; Both low (L1/E1) and high (L5/E5) bandwidth signals • 20 simultaneous channels • Co- and X-pol • 4x CYGNSS Temporal Resolution



CYGNSS

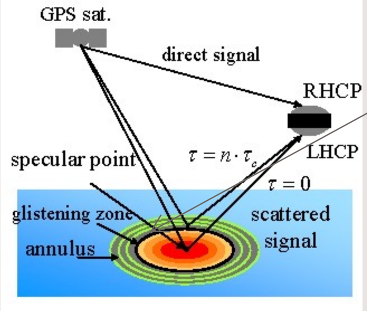
BAE SYSTEMS

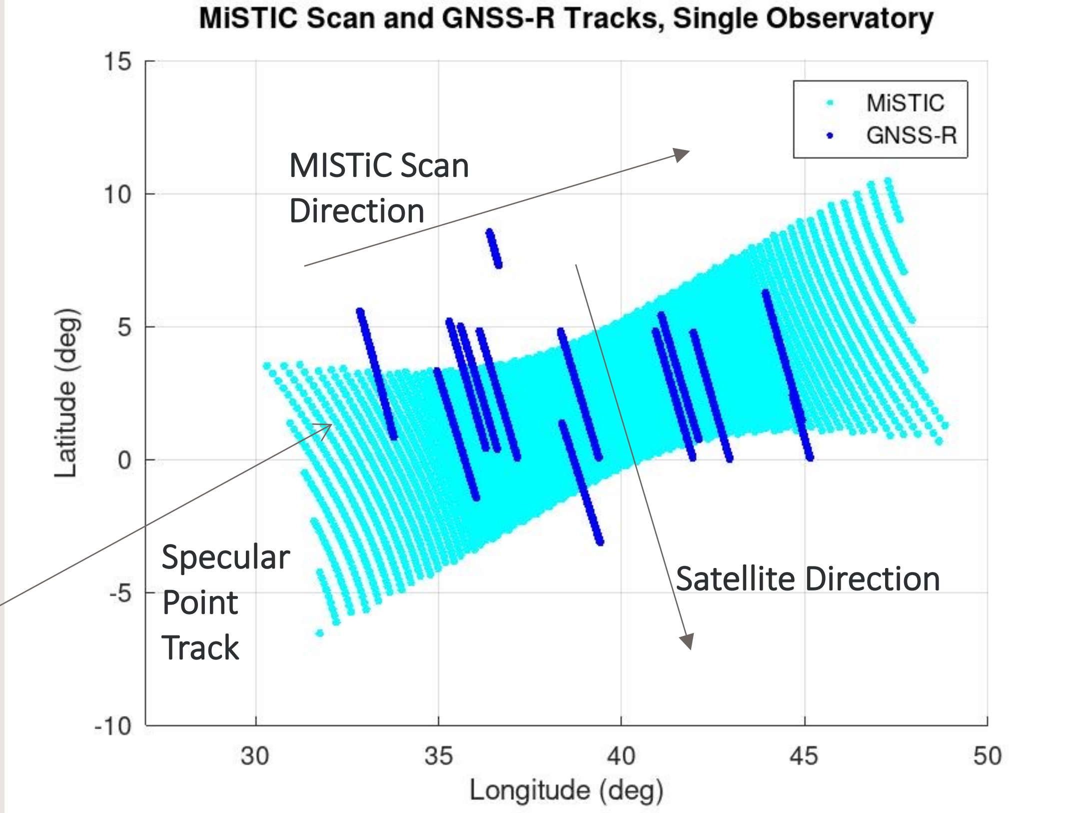
Observation Geometry Supports Synergistic Wind and Thermodynamic Profile Measurements



<u>Area Coverage Mode for Complementary Observations:</u>

- MISTiC: Linear Slit Image (along-track) scanned cross-track
- CMIS: Line Image at 3 angles push-broom scanned along-satellite track
- GNSS NGBRx:
  - Reflection: Differential Reflectivity near Specular Points
  - Refraction: Bending-Angle Observations in Limb-viewing Geometry (for and aft, along satellite track. (Not shown)





Not export controlled per ES-C4ISR-050423-0099

Wind Observation Goals and MISTiC , CMIS, and GNSS-R Observation Capabilities

For 3-Satellite AMV Triplet Constellation in 700 km orbital altitude Sun-Synchronous Orbit, 15 min separation

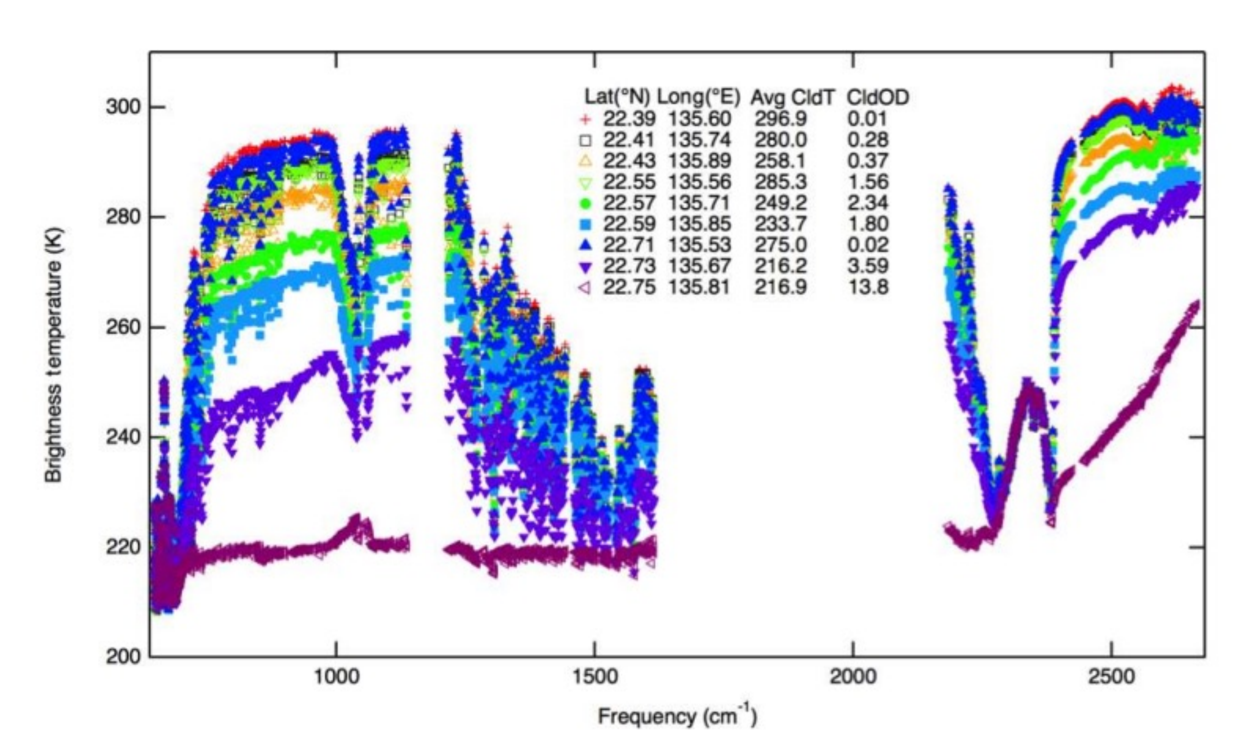
Attribute	(ESAS-'17) TO-4	NOAA BAA Mid-Point Requirement	MISTiC Winds AMV Constellation (Water Vapor (q) focus)		CMIS Constellation Performance		(ESAS-'17) TO-11	NGSS NGBRx Constellation Performance
Horizontal Resolution	5 km	40 km × 40 km @ nadir	Geometric Resolution: 6-12 km (5x10pix)	P_{Met}= 0.27-0.5 @ 500 mb P_{Met} = .05 @850mb	Geometric Resolution: <4.5-9 km (5-10pix)	P_{Met}= 0.65 near 850 mb	100 km	15 km (along-track) × < 100 km (average) (8x3 pseudo-random SP tracks cross-track)
Vertical Resolution	1 km	2 km	1 km (1.5 km near 850 mb)		< 0.5 km (Cloud Geometrical Thickness)		NA	NA
Wind Speed Uncertainty	3 m/s (1 m/s Obj)	5 m/s	2.0 m/s (@ nadir) 2.9 m/s (@ 52 off-nadir)		Horizontal: 0.5m/s @ nadir, <1.5 m/s @ 50 ° off-nadir Vertical: <0.5 m/s (TBR)		<2 m/s	< 2 m/s (for Speed < 20 m/s) <3 m/s (for Speed <30 m/s)
Vertical Extent	PBL-Middle Atmosphere	Surface to Just Above Tropopause	Surface Layer to Just Above Tropopause ~ 8 -10 Layers)		Cloud Levels-in Troposphere (1-2 levels)		NA	NA

Not export controlled per ES-C4ISR-050423-0099

Concurrent Observations of Hyperspectral Water Vapor AMVs and Stereo Cloud Attributes

- Cloud-free 10 kmx10 km Regions are Rare
- T/q retrieval quality degraded above clouds
- Approaches to Water Vapor AMV Height Assignment in Partly Cloudy conditions
  - “Cloud-Clearing” of IR Radiances (Susskind et. al.)
    - Disadvantage→ Degrades AMV spatial resolution
  - Single-Footprint IR Retrievals (Cloud Property Retrieval with T/q retrieval) (e.g. Irion et. al.)
    - Disadvantage→ Increases error in retrieved q(P(z))
  - T/q Retrieval Informed by Concurrent Independent Observation of Cloud Height/3d Shape/Temp. (CMIS)

AIRS level 1b brightness temperature observations of adjacent cloudy spectra. Data are from daytime Granule 44, 6 September 2002. Average cloud-top temperatures and cloud optical depths are estimated from coincident MODIS L2 retrievals, averaged on the AIRS spatial response



Supplementing MISTiC Winds q AMV observations with CMIS would substantially increase number of observations above cloudy layers .

Not export controlled per ES-C4ISR-050423-0099

BAE SYSTEMS

Higher-Level Atmospheric Properties from Near-Simultaneous Observations

Higher Level Product	Contributing Observations	Value and Impact
Ageostrophic Vector Wind $\vec{u} - \overrightarrow{u_{geos}}$	• MISTiC and NGBRx T/q Vert. Profile • MISTiC AMVs and CMIS AMVs	Unbalanced (ageostrophic) wind is key predictor of dynamic/severe weather- ***showing where the air will go up***.
Potential Vorticity $(\nabla \times \vec{u}) \cdot \nabla(\theta)$	• MISTiC T/q Vert. Profile • MISTiC Winds and CMIS AMVs	PV is a powerful diagnostic in Dynamic Meteorology, with multiple uses
Water Vapor Transport $(q \bullet \vec{u})$	• MISTiC 3D Moisture Field • MISTiC Winds and CMIS AMVs	Moisture flux, not just the wind or moisture alone, is the key combination
PBL Height and PBL Wind Shear	• MISTiC & NGBRx PBL T/q, CMIS Cloud Top Height; MISTiC, CMIS, and NGBRx Winds	Three independent measures of the PBL height. Surface Moisture Flux

If initial conditions are comprehensive (e.g., winds, temperature, and moisture) and of reasonably high spatial density (H and V), one has a good chance of getting the right type of data exactly where the model solution is most sensitive.

Summary

- Miniaturization of instrument payloads for key wind and thermodynamic vertical profile observations would enable future small-satellite LEO missions providing synergistic observations
  - Combined, and near-Simultaneous Thermodynamic and Dynamic Observations of the Troposphere
- The anticipated benefits of synergy include:
  - Improvements in Level-1 vertically resolved Wind observation accuracy and horizontal observation density- under partly cloudy conditions , and fully cloudy conditions above cloud-top
  - Concurrent /Co-registered observation of components of key higher-level atmospheric characteristics
    - e.g. Ageostrophic Wind , Potential Vorticity, Water Vapor Transport, PBL Height and PBL Wind Shear

Limited Aggregation of Highly Complementary Atmospheric Observations Beneficial for both Research and Operations

Acknowledgements

- This work was partially supported under NOAA study contract--- 1332KP22CNEEP0006

References

- Maschhoff, K.; Polizotti, J.; Aumann, H.; Susskind, J.; Bowler, D.; Gittins, C.; Janelle, M.; Fingerman, S. Concept Development and Risk Reduction for MISTiC Winds, A Micro-Satellite Constellation Approach for Vertically Resolved Wind and IR Sounding Observations in the Troposphere. *Remote Sens.* **2019**, *11*, 2169. https://doi.org/10.3390/rs11182169
- Kelly, M.A.; Carr, J.L.; Wu, D.L.; Goldberg, A.C.; Papusha, I.; Meinhold, R.T. Compact Midwave Imaging System: Results from an Airborne Demonstration. *Remote Sens.* **2022**, *14*, 834. https://doi.org/10.3390/rs14040834
- https://esto.nasa.gov/wp-content/uploads/2020/07/Ruf-Next-Gen-GNSS.pdf
- https://www.nasa.gov/cygnss
- Susskind, J., Blaisdell, J. M., and Iredell, L.: Improved methodology for surface and atmospheric soundings, error estimates, and quality control procedures: the Atmospheric Infrared Sounder Science Team Version-6 Retrieval Algorithm, J. Appl. Remote Sens., 8, 084994, https://doi.org/10.1117/1.JRS.8.084994, 2014
- Irion, F. W., Kahn, B. H., Schreier, M. M., Fetzer, E. J., Fishbein, E., Fu, D., Kalmus, P., Wilson, R. C., Wong, S., and Yue, Q.: Single-footprint retrievals of temperature, water vapor and cloud properties from AIRS, Atmos. Meas. Tech., 11, 971–995, https://doi.org/10.5194/amt-11-971-2018, 2018

Not export controlled per ES-C4ISR-050423-0099

Glossary of Symbols

Symbol	Definition
P_{Met}	Probability of meteorological or atmospheric conditions consistent with performing the wind observation
$\vec{u}$	Total wind velocity vector
$\overrightarrow{u_{geos}}$	Geostrophic component of the wind vector, also related to (not necessarily identical to) the Thermal Wind
θ	Potential Temperature
q	Water vapor mixing ratio, commonly expressed in g/kg

Not export controlled per ES-C4ISR-050423-0099

BAE SYSTEMS