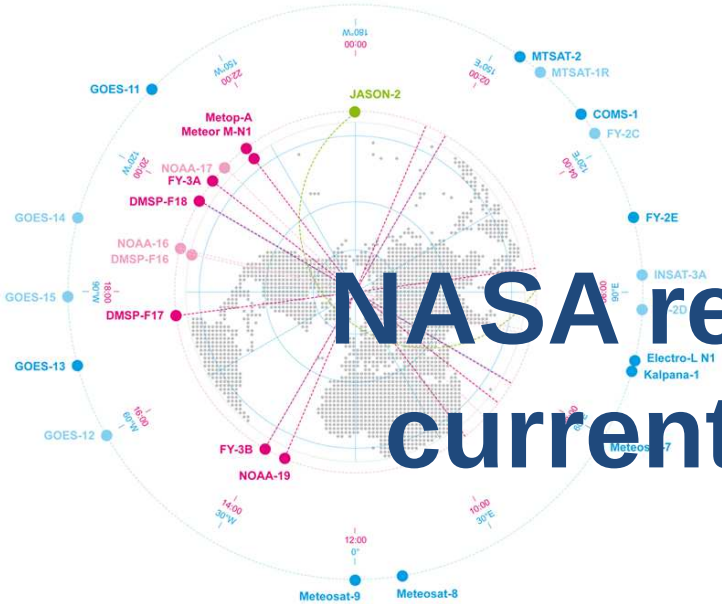

NASA report on the status of current and future satellite systems

Presented to CGMS-44 Plenary Session, Agenda Item D.2

Presenter: Jack Kaye[1]

Report prepared by:
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Coordination Group for Meteorological Satellites

Overview of NASA's current and future satellite systems

Mission	Launch	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
QuikSCAT	1999																										
Terra	1999																										
NMP EO-1	2000																										
GRACE	2002																										
Aqua	2002																										
SORCE	2003																										
Aura	2004																										
CALIPSO	2006																										
Cloudsat	2006																										
Jason-2	2008																										
Suomi-NPP	2011																										
GPM Core	2014																										
OCO-2	2014																										
RapidScat-ISS	2014																										
CATS-ISS	2015																										
SMAP	2015																										
DSCOVR	2015																										
SAGE-III-ISS	2016																										
LIS-ISS	2016																										
CYGNSS	2016																										
GRACE-FO	2017																										
ICESat-II	2017																										
OCO-3-ISS	2018																										
ECOSTRESS-ISS	2018																										
GEDI-ISS	2019																										
SWOT	2020																										
CLARREO-PF	2020																										

Current Missions – 17 total (as of May 2016)
** End dates reflect NASA "Senior Review" approved dates, but these missions will likely operate longer.*

Future: 13 missions and 7 instruments.
Typical NASA missions are planned for 3 to 5 years but have operated much longer in the past.

Future missions and instruments with launches >2020
(not shown in the figure)
NI-SAR, TEMPO, PACE, CLARREO, ASCENDS, HyspIRI, GEO-CAPE, ACE, MAIA, TROPICS

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Current NASA Satellites ... Recent News

- NASA is currently operating **17 Earth Science missions**.
- No new missions have launched since CGMS-43, but 3 are planned for the coming year. These include: **CYGNSS, ISS-SAGE III** and **ISS-LIS**.
- The **Aquarius** mission ended data collection on June 7, 2015 due to a failure of the SAC-D satellite platform. The **SMAP** mission was commissioned for routine operations but suffered a failure of its active instrument.
- All missions are currently producing data, but several also show signs of aging resulting in reduced data collection for two (**GRACE and SORCE**), ISS-RapidScat has experienced unpredictable changes in receiver signal levels, and one mission (**EO-1**) is currently scheduled for **decommissioning** in the next 12 months.
- Not mentioned in the last CGMS-43 report was the Deep Space Climate Observatory (**DSCOVR**) mission for solar wind measurements. DSCOVR was successfully launched by the US Air Force in February 2015, reached the Lagrange (L1) point in June, and transitioned successfully from NASA to NOAA operations in October 2015.

Current NASA Satellites ... More Mission News

- 5 of NASA's missions (Aqua, Aura, Calipso, Cloudsat, OCO-2) are part of the international **"A-Train" Constellation** with OCO-2 joining the A-Train in 2014. A major international A-Train Science Symposium is planned for California in 2017.
- Battery aging is observed on QuikSCAT, GRACE, CloudSat and SORCE, which reduces data sampling.
- Instruments with reduced capability are QuikSCAT's SeaWinds (antenna no longer rotates, used primarily to cross-calibrate with other on-orbit scatterometers), Terra's ASTER (SWIR module is no longer functional), Aqua AMSU (Channels 4,5,7 have failed), Aura's TES (no global survey).
- Instruments that are not operating are Aqua's HSB and AMSR-E, Aura's HIRDLS and SMAP's L-Band Radar.
- Data continuity is enhanced by post-mission processing to the data preservation specification: https://earthdata.nasa.gov/standards/preservation-content-spec
  - TRMM will conduct a final reprocessing of 17+ years of data and it will become part of the GPM mission dataset.
  - A final processing of the Aquarius ocean salinity dataset (3 years and 9 months) will be completed by the end of 2017.
  - Final post-mission datasets for the ACRIMSAT and Jason-1 missions were delivered to the Distributed Active Archive Centers.

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Current NASA Satellites ... Non-Mission News

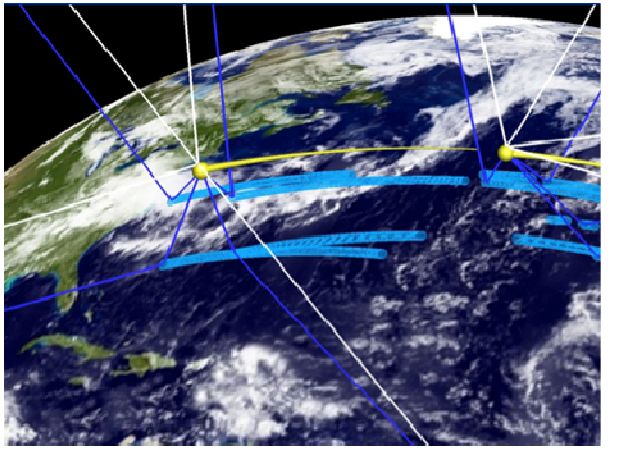
- NASA's missions were conceived as research missions, but have supported **operational and near-real-time applications** due to their recognized value, longevity, sustained calibration and validation, and data quality.
- Continued operation of the missions is determined through a biennial science review process, called the "**Senior Review**", which considers operational use but primarily uses science for defining factor for continuation. Continued operations (2 more years) was approved for all NASA missions, except EO-1, in mid-2015. The next Senior Review is scheduled for 2017.
- **Direct Broadcast** is currently available for three NASA missions including: Aqua, Terra, and Suomi-NPP. More information can be found at NASA's Direct Readout Laboratory (DRL) website: http://directreadout.sci.gsfc.nasa.gov
- NASA also provides access to **Near Real-Time (NRT)** products from the MODIS (on Terra and Aqua), OMI and MLS (on Aura), and AIRS (on Aqua) instruments in less than 2.5 hours from observation from the Land and Atmosphere Near real-time Capability for EOS (LANCE) data system at http://earthdata.nasa.gov/lance

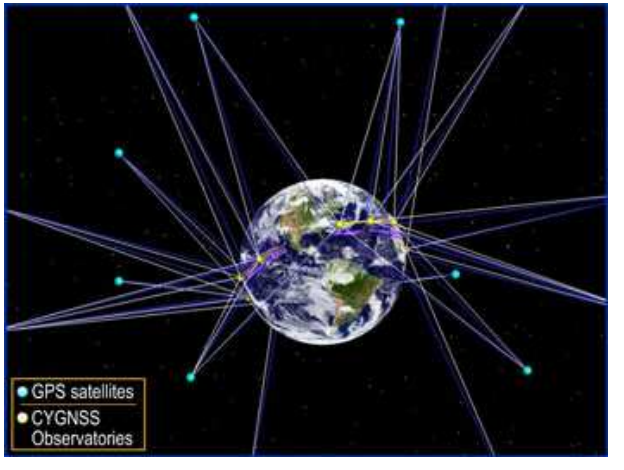
Future NASA Satellites

- NASA's plans include the launch of **13 missions and 7 instruments** in the future.
- **CYGNSS** is scheduled for launch in October 2016 and will provide measurements of ocean surface winds with high temporal sampling in all precipitating conditions. (see next chart)
- **ISS-SAGE III** and **ISS-LIS** are both hosted instruments to be deployed onto the International Space Station (ISS) in 2016. SAGE-III will measure stratospheric ozone, aerosols, and water vapor and LIS will measure lightning.
- NASA is formulating and/or developing 17 more future missions and/or instruments including:
  - Ice, Cloud, and Land Elevation Satellite (**ICESat-2**) mission
  - Gravity Recovery and Climate Experiment Follow-On (**GRACE-FO**) mission
  - Surface Water Ocean Topography (**SWOT**) mission
  - Tropospheric Emissions: Monitoring of Pollution (**TEMPO**) instrument on a GEO host mission
  - Orbiting Ocean Observatory 3 (**OCO-3**) instrument
  - ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (**ECOSTRESS**)
  - Global Ecosystem Dynamics Investigation (**GEDI**) instrument on ISS
  - Climate Absolute Radiance and Refractivity Observatory (**CLARREO**) mission
  - CLARREO Pathfinder (**CLARREO PF**) instrument on ISS
  - NASA ISRO-Synthetic Aperture Radar (**NI-SAR**) mission
  - Pre-Aerosols, Carbon and Ecosystems (**PACE**) mission
  - Active Sensing of Carbon dioxide Emissions over Nights, Days and Seasons (**ASCENDS**) mission
  - Aerosols, Clouds and Ecosystems (**ACE**) mission
  - Geostationary Coastal and Air Pollution Events (**GEO-CAPE**) mission
  - Hyperspectral Infrared Imager (**HyspIRI**) mission
  - Multi-Angle Imager for Aerosols (**MAIA**) mission
  - Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (**TROPICS**) mission

NASA Cyclone Global Navigation Satellite System (CYGNSS) Mission

- U. Michigan, Dr. Chris Ruf, PI
- Launch October 2016; 2 year lifetime
- 8 small satellites
- 510 km, 35 degree inclination, 12 minutes apart
- Ocean surface winds
- GPS signals scattered from ocean surface
- 4-channel bistatic radar receiver
- Measure distortion from surface roughness
- Similar to traditional scatterometers
- Focus on tropical cyclone/hurricane understanding and forecast improvement
- Surface winds in and near hurricane inner core including eye wall and intense inner rain bands
- Revisit time 1.5 hours (median), 4 hours (mean)





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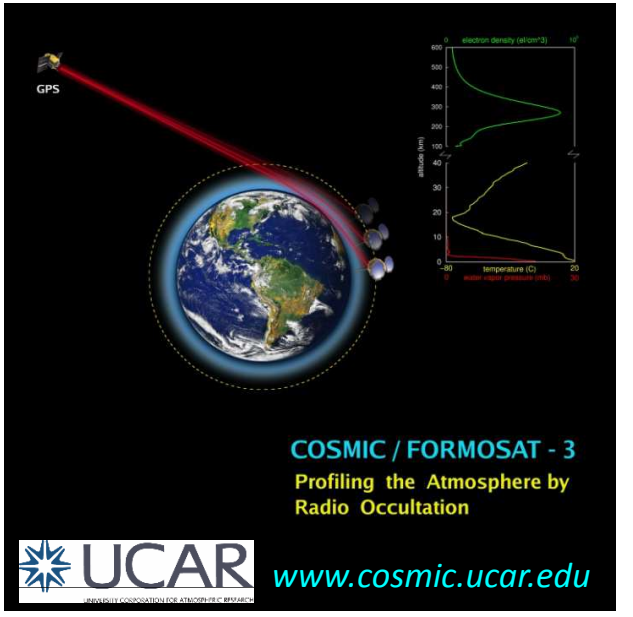
Additional Topics of Relevance to CGMS

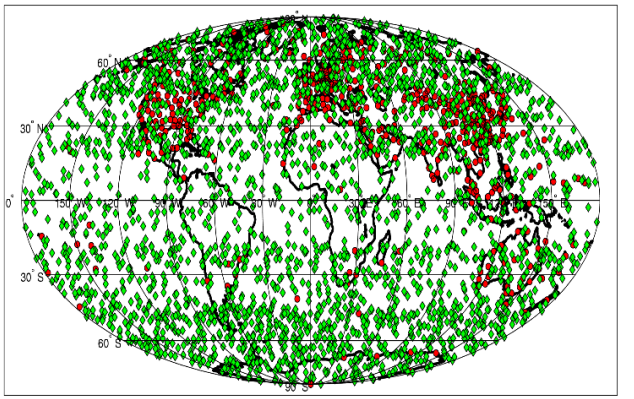
- **COSMIC** (Constellation Observing System for Meteorology, Ionosphere and Climate)
- Earth Venture Suborbital Investigations
- CubeSat Technology Satellite Demonstrations
- Global Wind Measurements

COSMIC

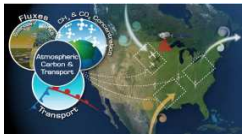
- **Joint US/Taiwan GPS Radio Occultation mission**
  - 6 Satellites launched in April 2006
  - NASA/JPL developed GPS RO receiver
  - UCAR COSMIC Program performing mission operations, data processing, and research
- **Mission Objective: Global soundings for weather, space weather and climate applications**
  - Atmosphere: profiles of bending angle, refractivity, temperature, pressure, humidity
  - Ionosphere: total electron content, electron density profiles, scintillation
- **COSMIC-1 still providing ~600-1,400 RO soundings per day from 3 active satellites**
  - Demonstrated positive impact on NWP forecasts
  - ~6.3M high-resolution profiles available for research
  - ~440 COSMIC publications between 2006-15
  - ~3,500 users from 86 countries
- **UCAR/COSMIC currently funded by NASA and NSF to continue COSMIC-1 mission operations and research**



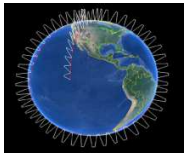
Occultation Locations for COSMIC, 6 S/C, 6 Planes, 24 Hrs



Earth Venture Suborbital-2 Investigations

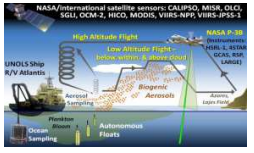


ACT-America (*Atmospheric Carbon and Transport – America*): Quantify the sources of regional carbon dioxide, methane, and other gases, and document how weather systems transport these gases

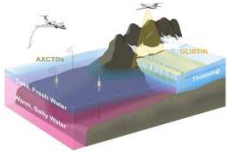


ATom (*Atmospheric Tomography Experiment*): Study the impact of human-produced air pollution on certain greenhouse gases

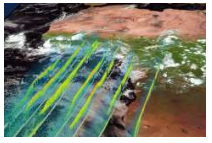
CORAL *(COral Reef Airborne Laboratory)*: Provide critical data and new models to analyze the status of coral reefs and predict their future



NAAMES (*North Atlantic Aerosols and Marine Ecosystems Study*): Improve predictions of how ocean ecosystems would change with ocean warming



OMG (*Oceans Melting Greenland*): Investigate the role of warmer, saltier Atlantic subsurface waters in Greenland glacier melting



ORACLES (*ObseRvations of Aerosols Above CLouds and Their IntEractionS*): Probe how smoke particles from massive biomass burning in Africa influences cloud cover over the Atlantic

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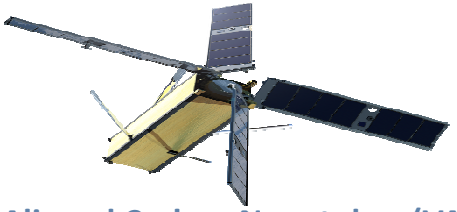
3U CubeSats Manifested to Launch 2016 - 2017

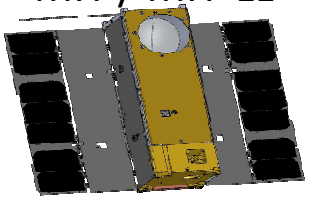
RAVAN
APL/JHU



Vertically Aligned Carbon Nanotubes (VACNTs)

Validate VACNTs as radiometer absorbing material and calibration standard for **total outgoing radiation**

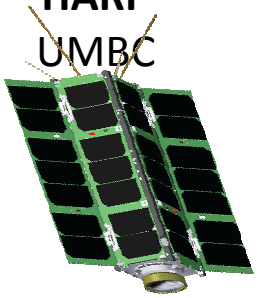
MiRaTA
MIT / MIT-LL



3 Frequency Radiometer and GPSRO

Validation of new microwave radiometer and GPSRO technology for **all-weather sounding**

HARP
UMBC

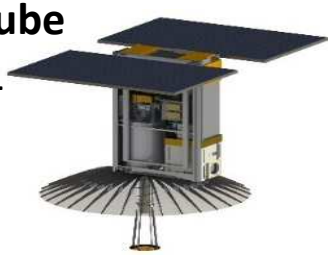


Wide FOV Rainbow Polarimeter

Validation of 2-4 km wide FOV hyperangular polarimeter for cloud **& aerosol characterization**

6U CubeSats In Development for 2018 - 2019 Launch Readiness

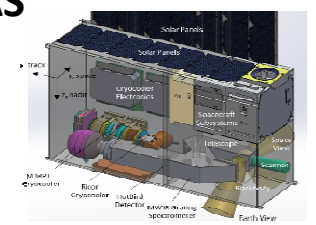
RainCube
JPL



Precipitation Radar

Validate a new architecture for **Ka-band radars on CubeSat platform** and an ultra-compact deployable Ka-band antenna

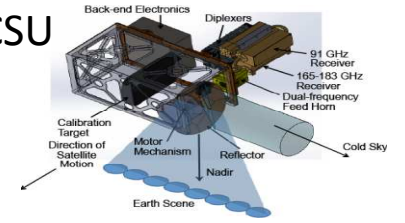
CIRAS
JPL



Infrared Atmospheric Sounder

Demonstrate ability to measure spectrum of upwelling infrared radiation and validate 2D infrared detector material, a micro pulse tube cryocooler, and a grating spectrometer

TEMPEST-D
CSU



5 Frequency mm-Wave Radiometer

Technology demonstrator **measuring the transition of clouds to precipitation**

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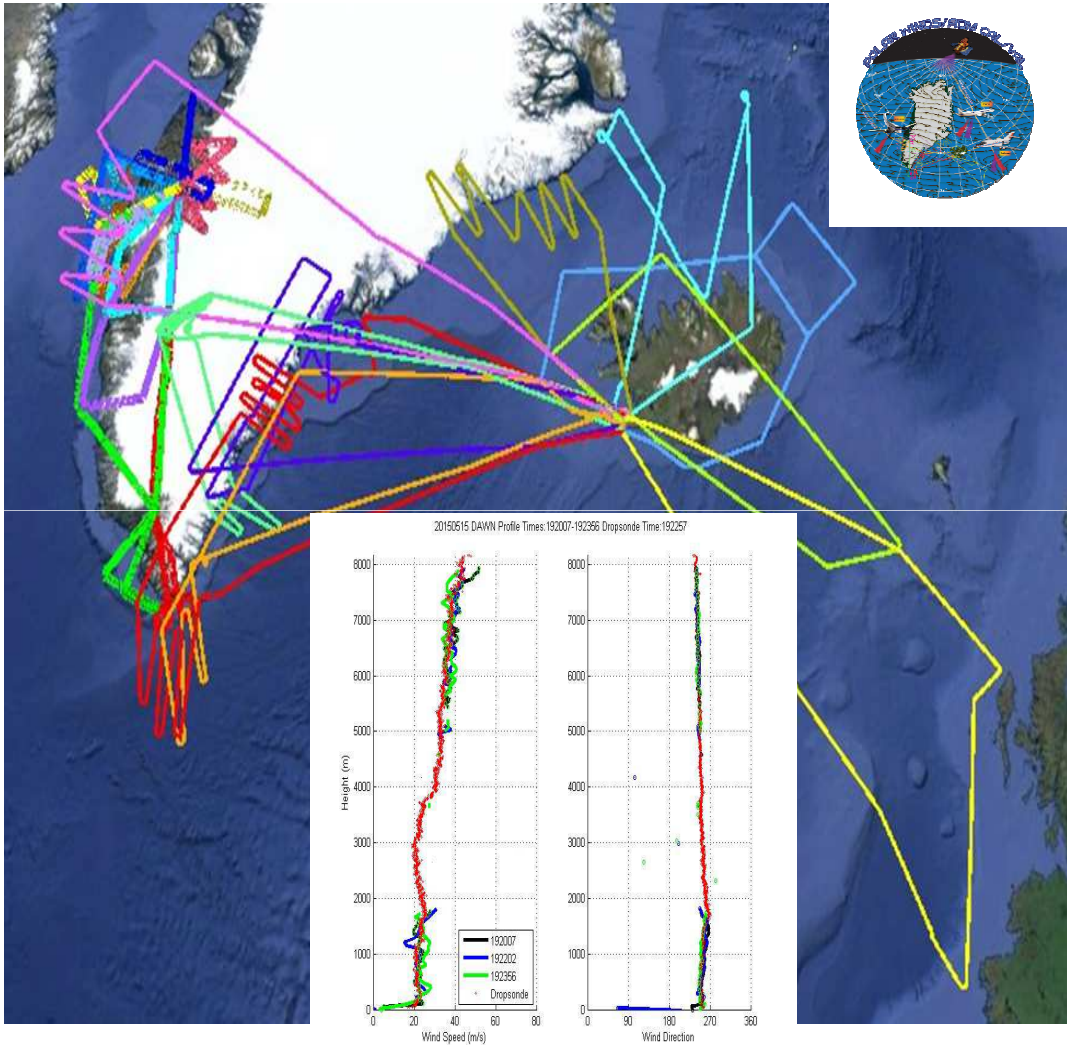
ESTO

CGMS

NASA/ESA ADM Cal/Val Demonstration and NASA Polar Winds Airborne Campaigns



- Campaign I
  Oct. – Nov. 2014; Kangerlussuaq, Greenland
  NASA UC-12B with DAWN
- Campaign II
  May 2015; Keflavik, Iceland
  NASA DC-8 with coherent and direct Doppler lidars, dropsondes
  ESA/DLR Falcon with coherent and direct Doppler lidars
- NASA Objectives
  Demonstrate airborne DWL and dropsonde capability for ADM cal/val
  Polar warming/ice loss science; validate models
    Greenland tip jet
    Barrier winds off Greenland east coast
    Katabatic winds along Greenland coast
    Boundary layer rolls and OLEs over water
    Flow over transitional ice and water zones
    Flow over Greenland ice cap
- Utilize new NASA DAWN coherent Doppler lidar
  Eyesafe, pulsed, 2-micron, 250 mJ, 10 Hz laser with 15 cm telescope designed to be most capable" coherent airborne lidar
- Inset: example DAWN vs. dropsonde wind profile
  Speed (left) and direction (right)
  0 to 8 km wind profiles
  dropsonde (red) vs. 3 consecutive DAWN profiles (black, blue, green)

David Emmitt (Simpson Weather Associates)
Michael Kavaya (NASA Langley Research Center)

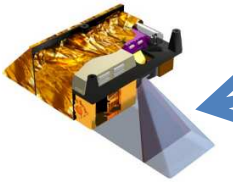
MISTiC Winds: Midwave Infrared Sounding of Temperature and humidity in a Constellation for Winds

PI: Kevin R. Maschhoff, BAE Systems
Co-Is/Partners: J. Susskind, NASA GSFC; H. Aumann, JPL

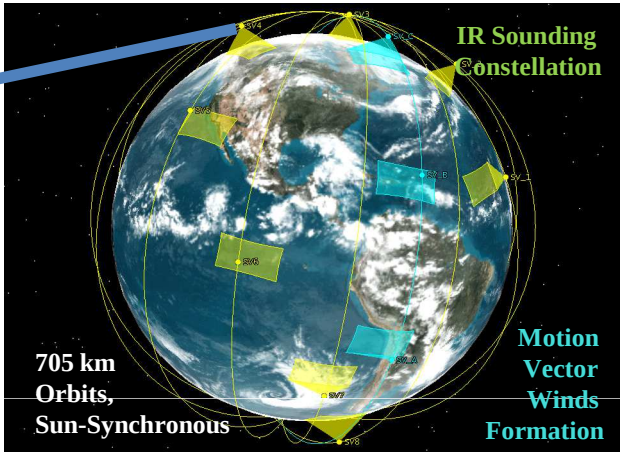
Objective

Advance the readiness of a miniature, high resolution, wide field, thermal emission imaging spectrometer to measure vertically resolved tropospheric profiles of temperature and humidity for deriving global 3-D wind measurements.

- Provide ~ 2-3 km spatial resolution temperature and humidity soundings of the troposphere using an AIRS-like (Atmospheric Infra-red Sounding) method.
- Enable a LEO constellation approach that provides 3-D Wind field measurements and atmospheric state and transport observations at low system cost.
- Reduce technology risks with the Infrared Focal Plane Array (IRFPA) and spectrometer technologies critical for significant instrument size, weight and power reduction (20 x 30 x 30 cm, 15 kg, 50 W).



MISTiC Instrument will fit on a 27U CubeSat or a ESPA-Class Micro-Sat



Approach

- Optimize and refine space-based measurement approach based on experience with AIRS, AIRS-Light and small satellite provider experiences.
- Demonstrate calibration stability of miniature MWIR spectrometer (4.08 - 5.8 microns) in ground testing.
- Demonstrate robustness of spectrometer by performing space level thermal fluctuation testing and vibration testing to launch levels.
- Verify instrument measurement capability of 3-D cloud-drift and water vapor motion vector winds on high altitude balloon or high-altitude fixed-wing platform.
- Demonstrate IRFPA space radiation tolerance (> 25 krad).

Key Milestones

	Month/Year
• Instrument science and payload requirements review	10/14
• Instrument science and payload concept review	12/14
• Airborne demonstration plan review	06/15
• Detector/ROIC radiation test/analysis complete	09/15
• Spectral calibration stability test complete	06/16
• Airborne instrument design/build complete	07/16
• Airborne demonstration complete	3/17
• Airborne demonstration data analysis complete	5/17

NASA

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Contributions to this report were made by the following:

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Thomas Pagano, Anthony Mannucci
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William Schreiner
University Corporation of Atmospheric Research

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Earth and Space Research

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