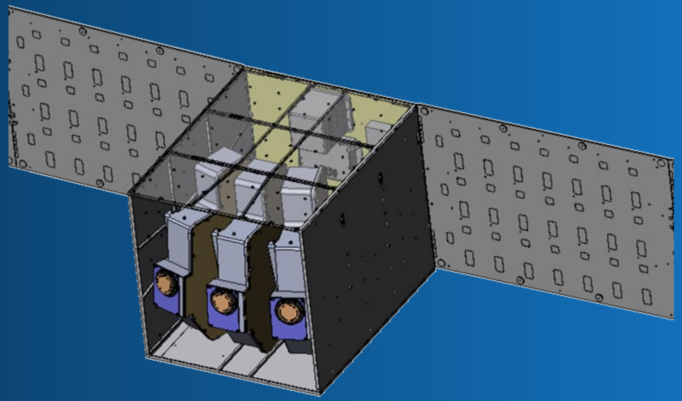
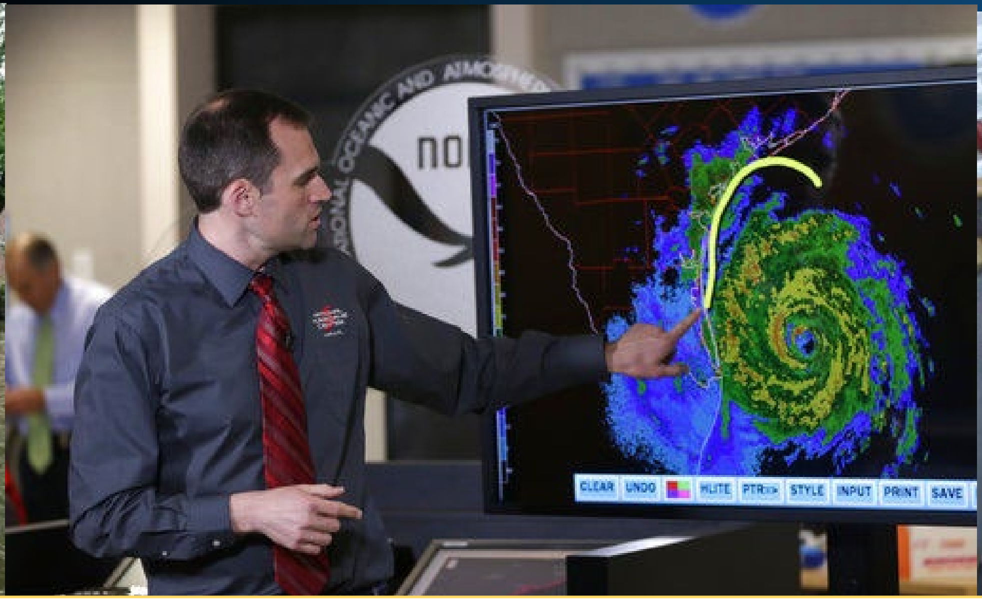


NOAA STAR Seminar:
Compact Hyperspectral Infrared Sounding Interferometer (CHISI) - an inexpensive LEO small satellite for Longwave Infrared Sounding

John Fisher (PI), Brandywine Photonics
Dave Santek, University of Wisconsin-Madison
Space Systems Engineering Center
Louis Moreau, Frederic Grandmont, ABB Inc.
June 18th, 2019



The Brandywine Mission:
To save lives and homes through better weather data.

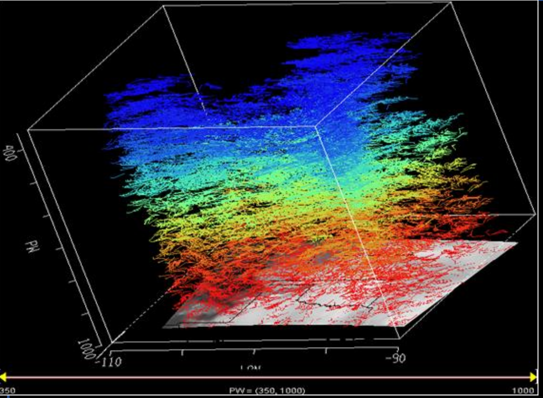


Image Credit: UWM-SSEC

What is MetNet™ FULL WEATHER™ ?

The MetNet goal is to provide high-resolution weather observations from surface-to-space, pole-to-pole, limb and nadir, EO-IR and Microwave, every half hour, 24/7, and assimilate with ground and persistent airborne observations.

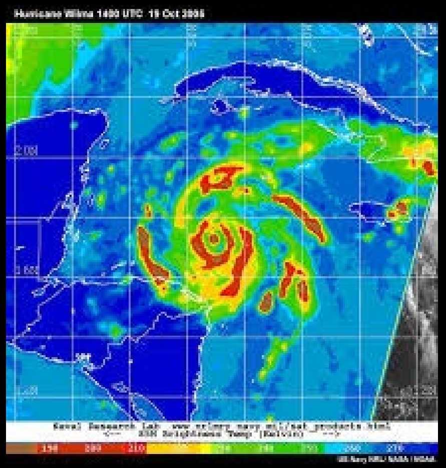
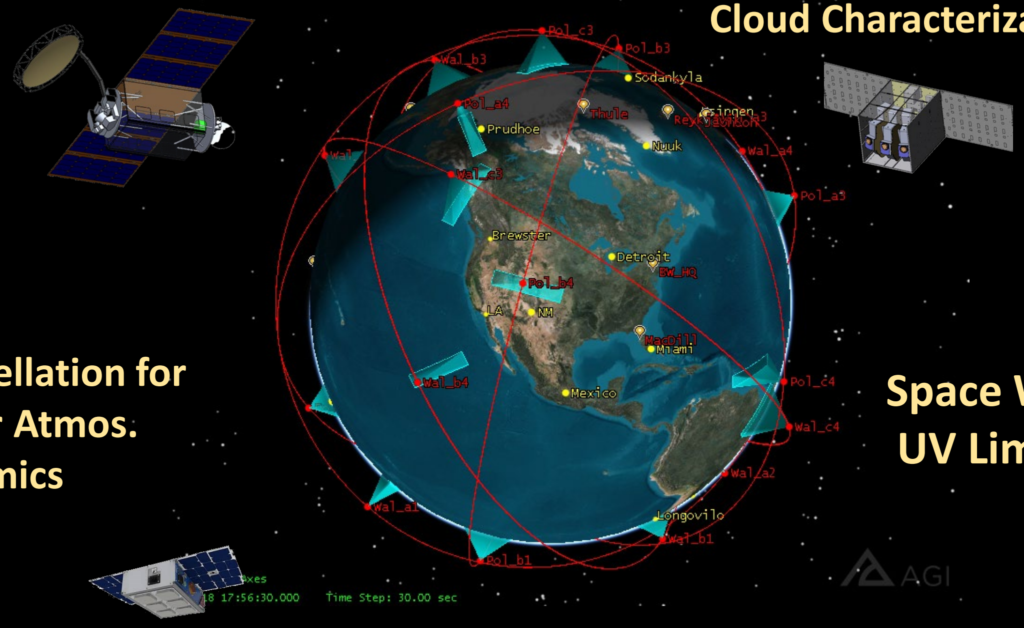


Image Credit: NRL

Microwave Sounder
Microwave Compact Imager

CHISI (IR Sounder)
Theater Weather Imaging &
Cloud Characterization Sensor



CUAD
Constellation for
Upper Atmos.
Dynamics

Space Weather
UV Limb Sensor

Image Credit: NASA

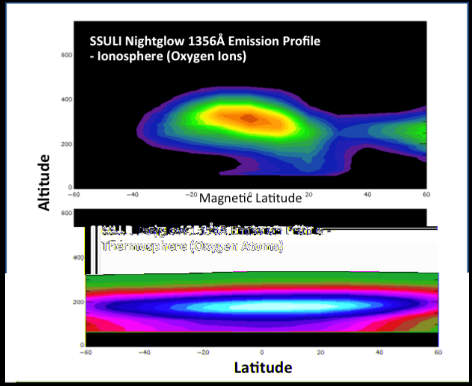
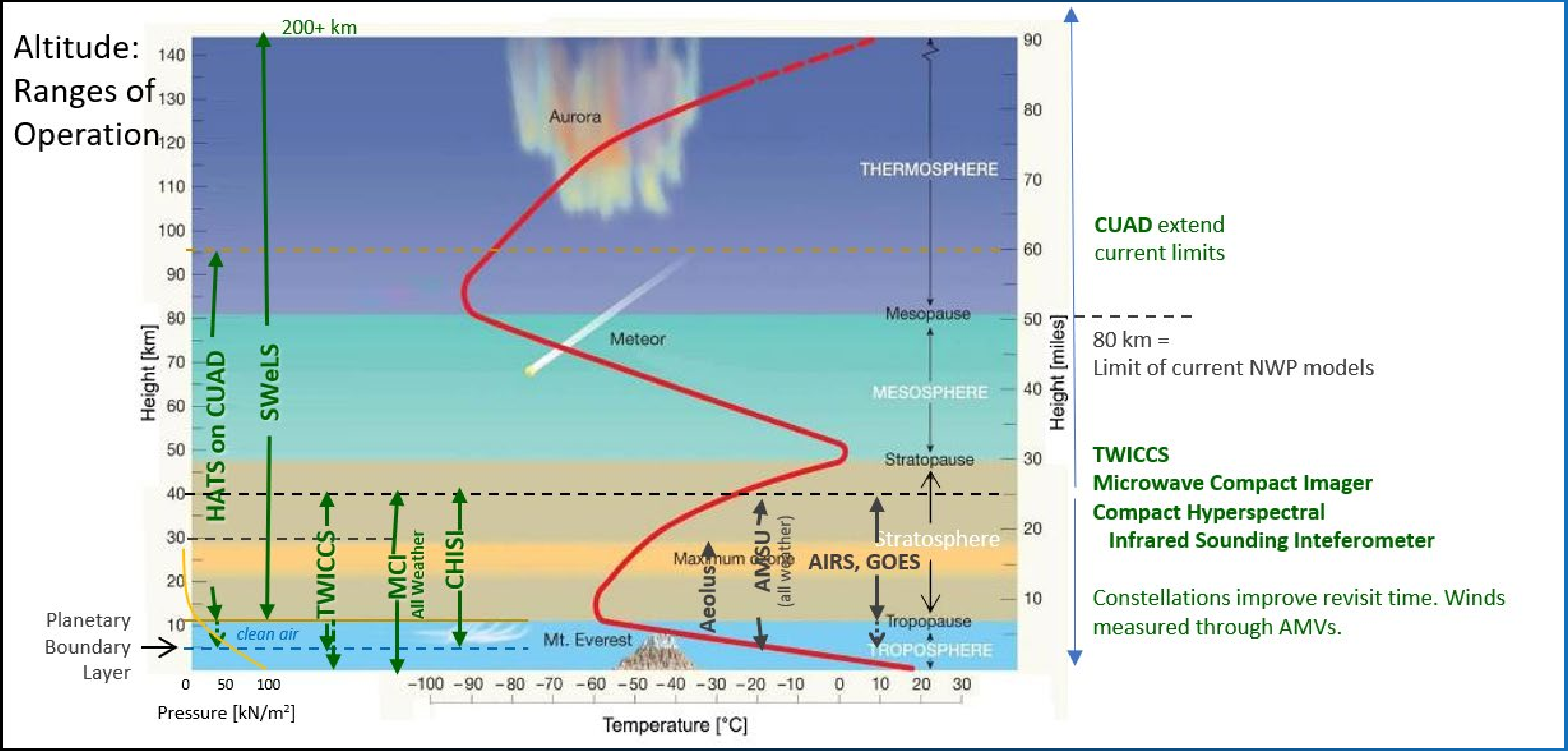


Image Credit: NRL

GATS Global Atmospheric Technologies and Sciences | ABB | BRANDYWINE PHOTONICS | BOULDER ENVIRONMENTAL SCIENCES & TECHNOLOGY | SSEC

~10 other small businesses

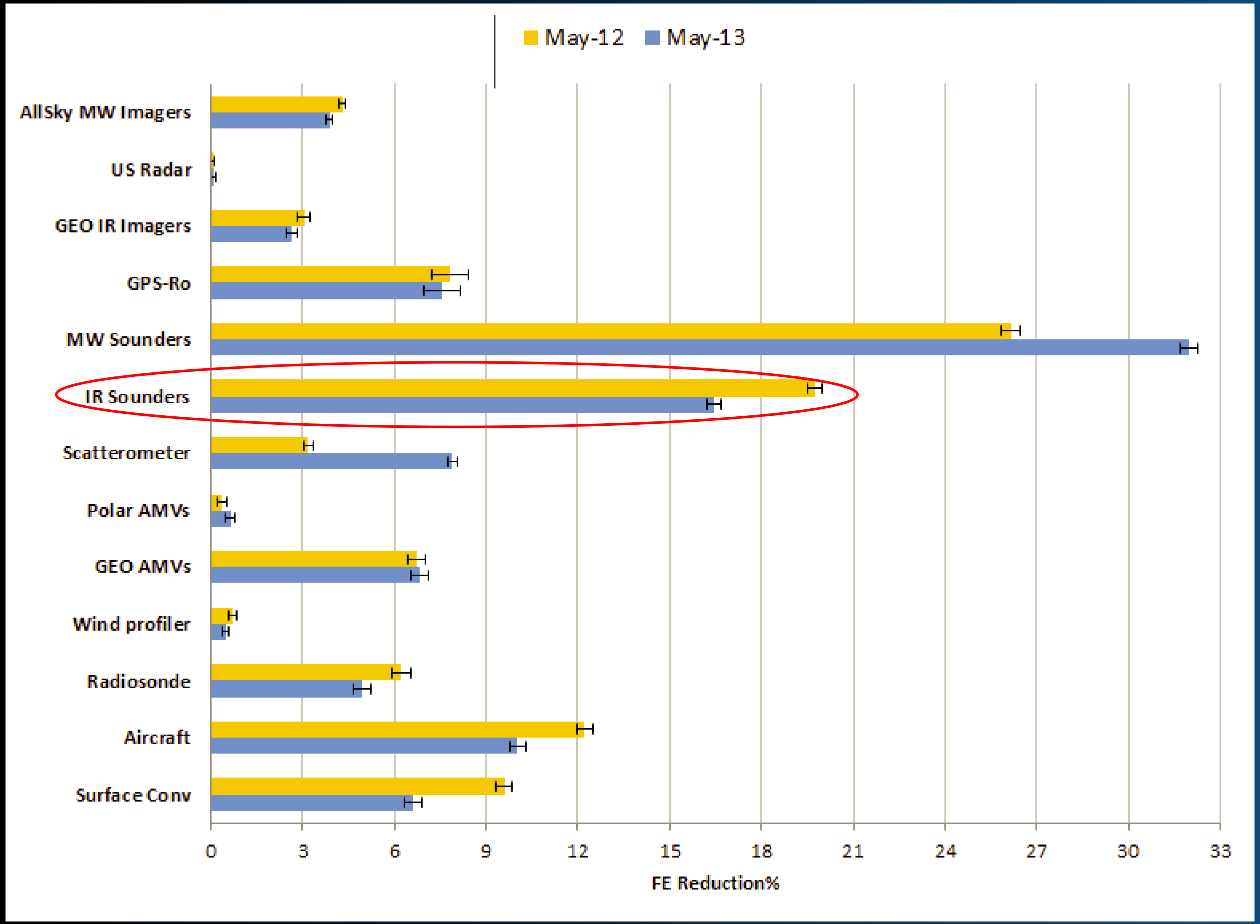
The MetNet™ goal is to provide 4-Km weather data from surface-to-space, pole-to-pole, EO and Microwave, every half hour, 24/7 for <$500M per year.



What instruments provide the best weather value?

Hyperspectral IR Sounders significantly reduces forecasting error (#2 behind microwave) and has high maturity (TRL-9), thus provides the best value with low schedule & cost risk for a Small Satellite constellation mission.

CHISI



The percentage contribution of various observation types to the total forecast error reduction (ECMWF report 711, Impact of satellite data, 2013).

Also, NRC-2017 Decadel Survey Top Priorities recommended 3D Tropospheric Wind Mission

OSSEs confirmed with AIRS moisture and ozone profiles for AMV winds.

Does not include the potential of data assimilation from constellations of limb and nadir Observing satellites.

Status of Hyperspectral IR instruments
Low Earth Orbit

Current

Satellite	Agency	Instrument	Spatial Res (km)
Aqua	NASA	AIRS	13.5
Suomi NPP	NOAA	CrIS	13.5
NOAA-20	NOAA	CrIS	13.5
Metop-A	EUMETSAT	IASI	12.0
Metop-B	EUMETSAT	IASI	12.0
Metop-C	EUMETSAT	IASI	12.0
FY-3D	China	HIRAS	16.0

CHISI LEO

Future

Satellite	Agency	Instrument	Spatial Res (km)
NOAA-21, -22, -23	NOAA	CrIS	13.5
Metop-SG-A1, -A2, -A3	EUMETSAT	IASI-NG	9x12
Metop-SG-B1, -B2, -B3	EUMETSAT	IASI	9x12
FY-3E, -F-, -G, -H	China	HIRAS	16.0

Hyperspectral IR instruments
Geostationary Orbit

Yet, the US is the undisputed leader in infrared technology and optics. Why are we behind?

Current

Satellite	Agency	Instrument	Spatial Res (km)
FY-4A	China	GIIRS	16

Future

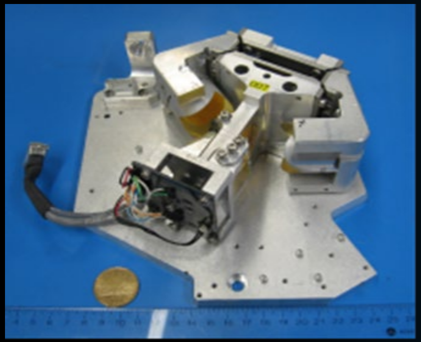
Satellite	Agency	Instrument	Spatial Res (km)
FY-4B	China	GIIRS	16
FY-4C	China	GIIRS	4-8
MTG	EUMETSAT	IRS	4

← CHISI GEO

Future geostationary satellites achieve necessary resolution of 4km to derive high-resolution and accurate 3D winds

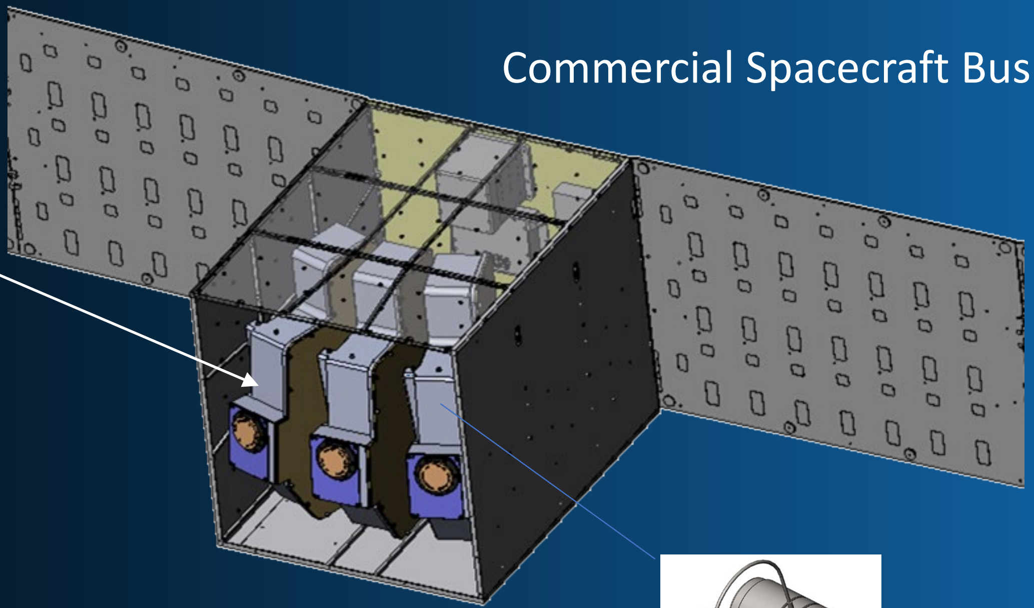
However, all non-US satellites

CHISI-LEO MicroSatellite

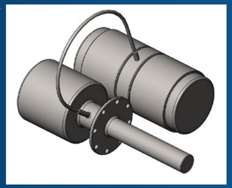


Commercial
Ruggedized
Interferometers
with
Flip-in Black Bodies

Commercial Spacecraft Bus



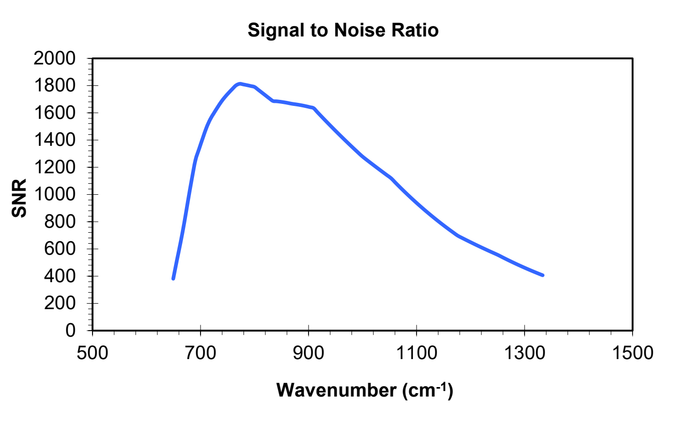
Three channels
Each 500 Km wide
For total 1500 Km Swath

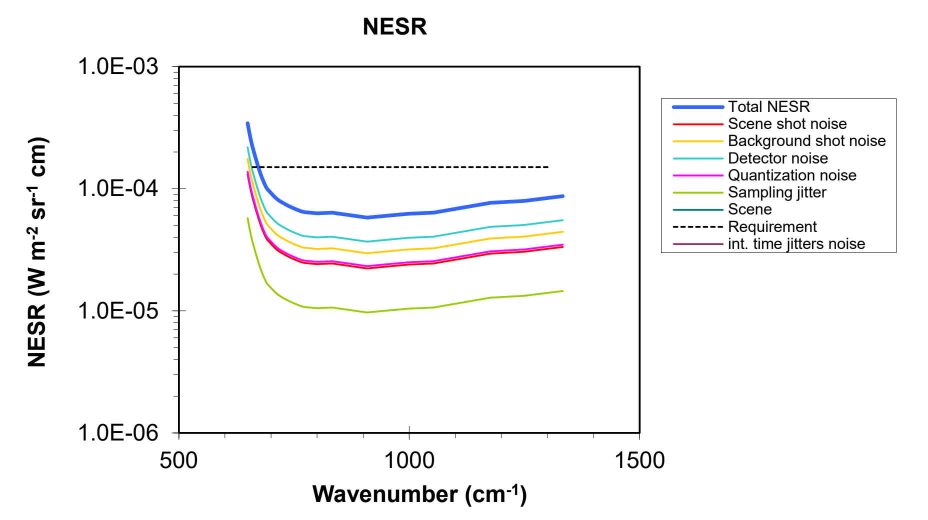


Cryocoolers with Anti-Vibration Control

CHISI-LEO Pathfinder Specifications and Estimated Performance

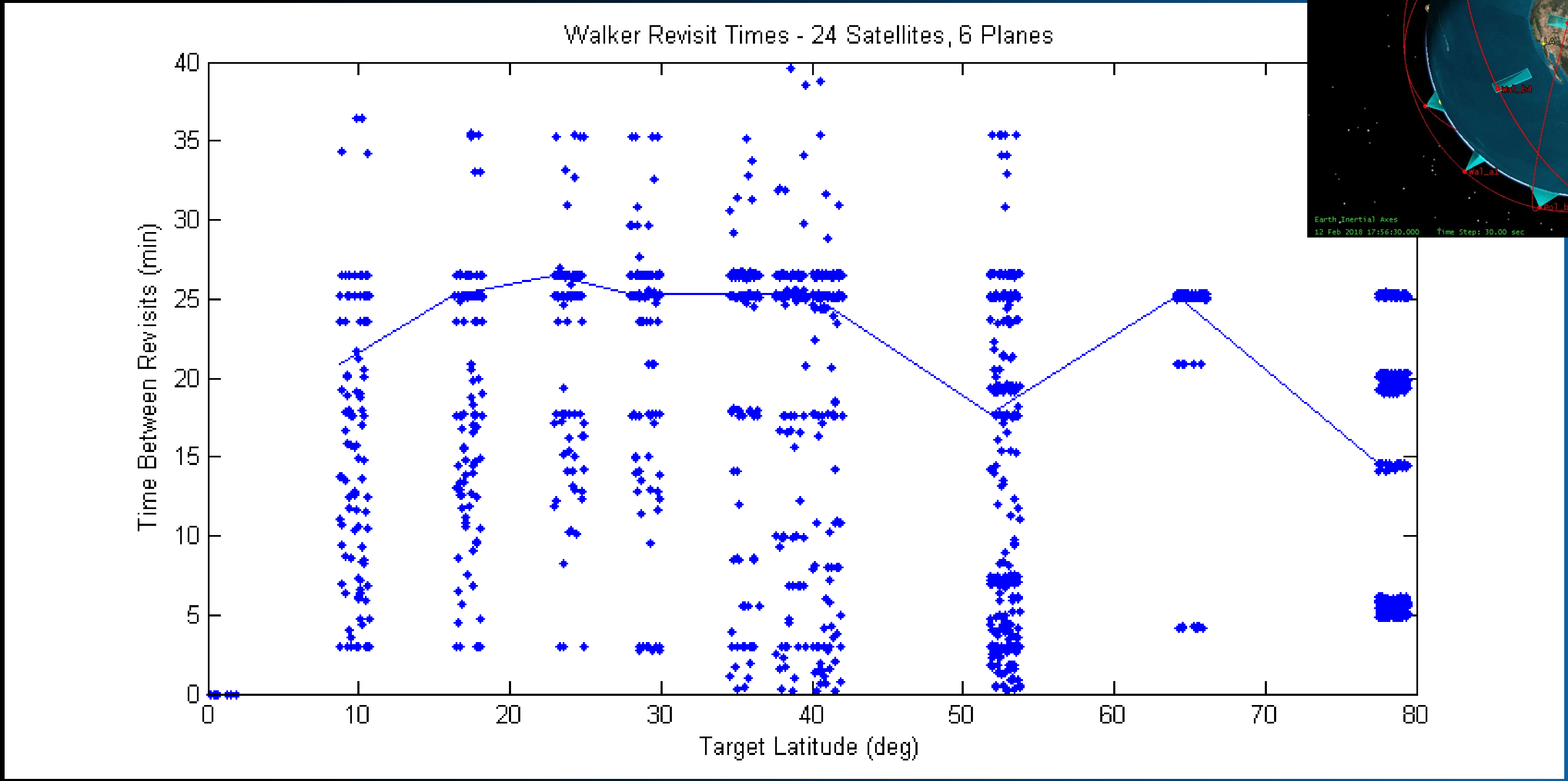
Parameter	Required value
Main measurement	Upwelling spectral radiance
Main data products	Vertical profiles of humidity Vertical profiles of temperature AMV 3D Winds (from 3 satellite constellation)
Spectral range	6.5 µm to 15.4 µm
Spectral sampling interval	≤ 0.6 cm^{-1}
Spectral resolution (FWHM)	≤ 1 cm^{-1}
GIFOV, nadir	≤ 14 km
GSD	≤ 2 GIFOV
Swath width	500 km per instrument (3 instruments recommended for simultaneous crosstrack of 1500 Km)
NESR	≤ 0.15 $mW/m^2/sr/cm^{-1}$
Radiometric uncertainty	≤ 0.5% RMS
Mass	≤ 25 kg (TBD)
Volume (total)	≤ 50 × 50 × 50 cm^3
Power	< 50 W orbit averaged (TBD)
Data rate	< 0.5 Mbps (TBD)
On orbit life time	≥ 3 years. 95%

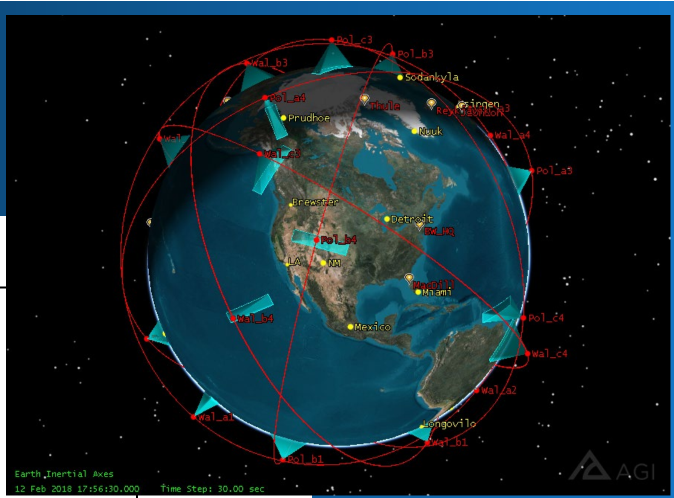




NO NEW TECHNOLOGY!

Mission – Walker-Delta with Polar Orbiters





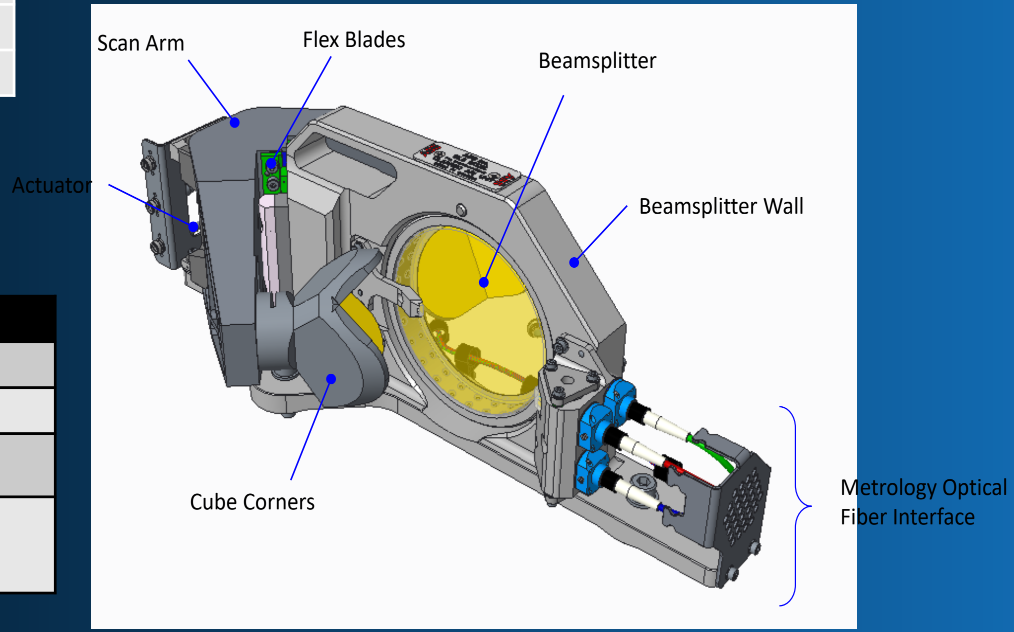
24 Satellites – Median revisit times < 30 min below plane of inclination

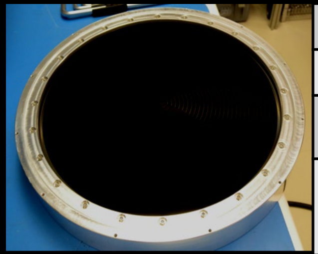
Walker constellation inclination of 56deg, helps balance out polar orbits tendency to oversample extreme latitudes. Estimate need 36 satellites to get to revisit < 15 minutes.

CHISI-GEO Specifications

Interferometer	Required Value
Aperture diameter (Interferometer Pupil)	60 – 90 mm
Spectral Range	600 – 2500 cm^{-1}
Spectral Sampling	< 0.6 cm^{-1} (~ 3000 channels)
Spatial Sampling	4 km / pixel
Sweep Rate (dwell time)	5 – 10 seconds
Transmittance	> 30 %
Modulation Efficiency	85 – 95 %
Spectral Stability	< 1 ppm between calibrations
Sampling Error	< 3 nm RMS
Speed Instability	< 1%rms
Operating Temperature	> 200 K
Reliability & Life Time	> 0.95 reliability after 7 years

6-Units Built, NASA CLARREO overstock unit available with electronics – 3 mo. ARO





Spectral range	700 cm-1 to 2200 cm-1
Emissivity	≥ 0.995
Temperature uncertainty	≤ 20 mK
Temperature range	Passive Active: ambient to 350 K

Enabling Advanced Technologies at Brandywine and suppliers

- 20-Bit High Dynamic Range Infrared Read Out Integrated Circuits (ROICS), with ability to upgrade to KHz frame rates
- LWIR nBn Detector Material with improved uniformity
- Electrical Substitution Radiometer Arrays
- Freeform (non-rotationally symmetric) optics
- High Performance Flight Processors

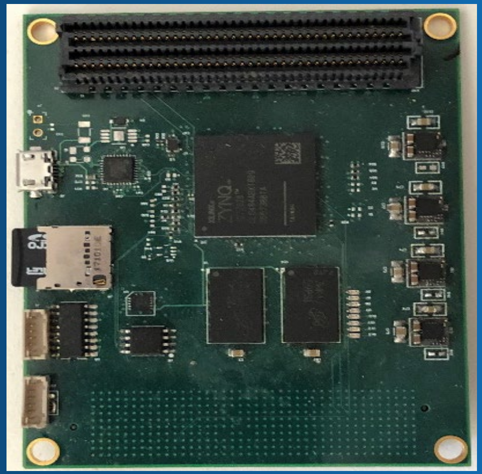
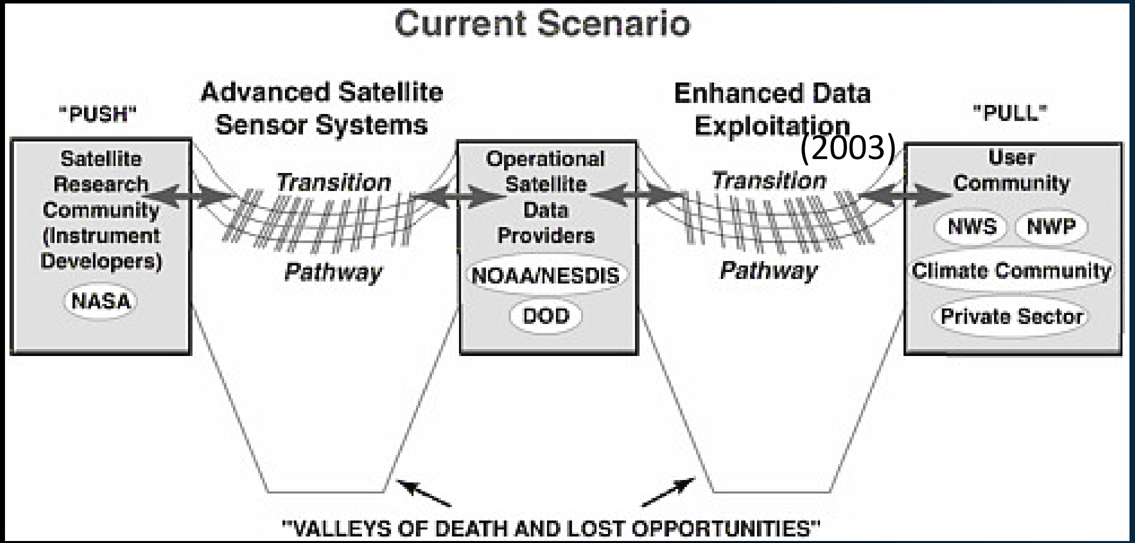
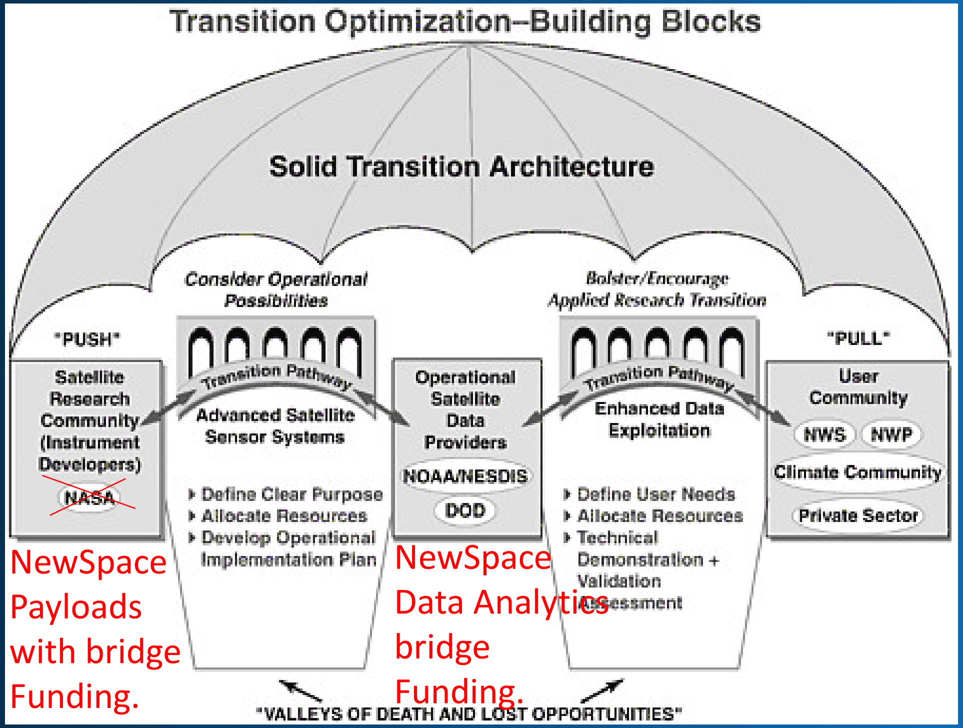


Image Credit: NASA/RocketLabs

- Low cost launch ($8M dedicated ride to 850-Km)
- Low cost bus (~$5M for 90-Kg spacecraft bus)
- Lower cost communications (Amazon Ground Station)
- Optical Comms (1 Gbps)
- Higher performance On-board Processing Algorithms

Crossing the R&D Valley of Death



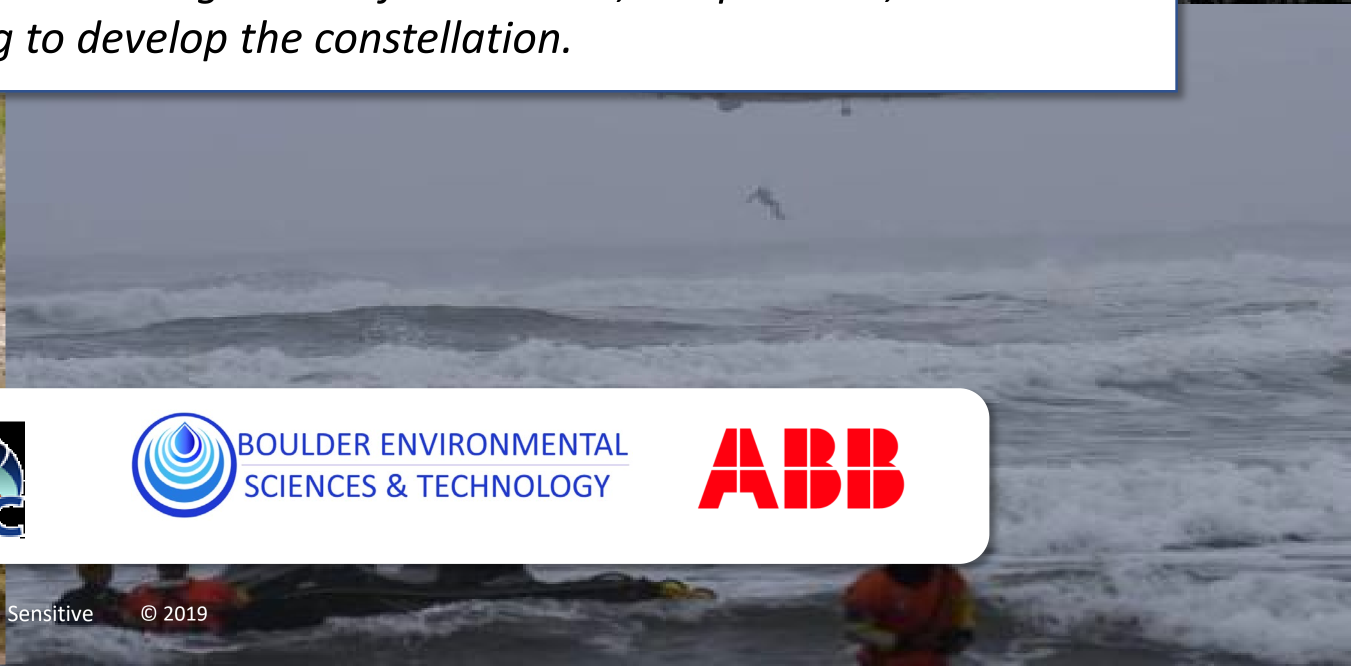


Potential Commercial Weather Data sources need bridge funding to span the 5-10 years between start and data revenues. Costs are much less than JPSS but more than an SBIR ($1.5M). Weather Missions for $30M are not the norm for Congress to allocate to NOAA, but it's in the right range for an R2O pathfinder.

Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations (2003) [*From: https://www.nap.edu/read/10658/chapter/1*](https://www.nap.edu/read/10658/chapter/1)

MetNet Space Alliance

Hyperspectral Infrared Sounding is the perfect application with proven high impact on NWP forecast models, High TRL instrumentation, and ready-to-use algorithms for moisture, temperature, and 3D winds. The missing ingredient is seed funding to develop the constellation.

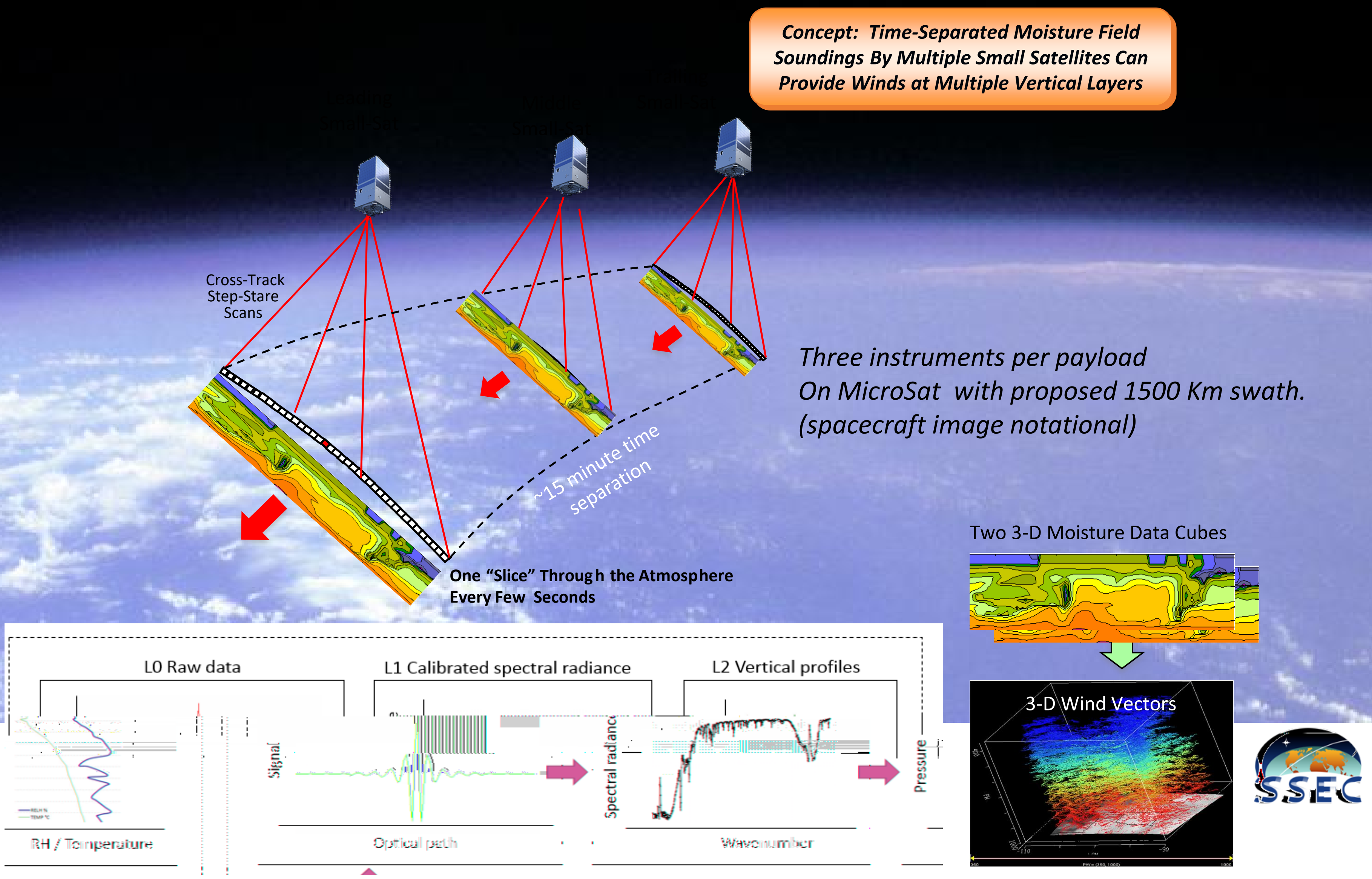


BRANDYWINE PHOTONICS — GATS Global Atmospheric Technologies and Sciences — SSEC — BOULDER ENVIRONMENTAL SCIENCES & TECHNOLOGY — ABB

Spare Slides:

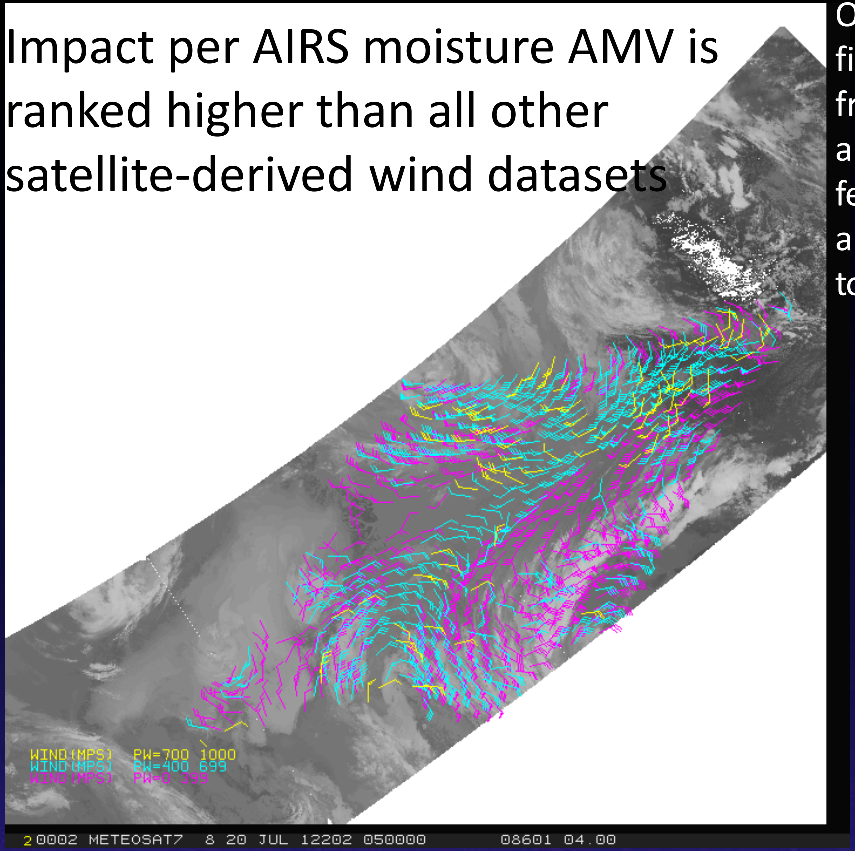
Atmospheric Motion Vectors from a Constellation of Low-Cost SmallSats

Multi-Level 2D Winds from Atmospheric Motion Vectors



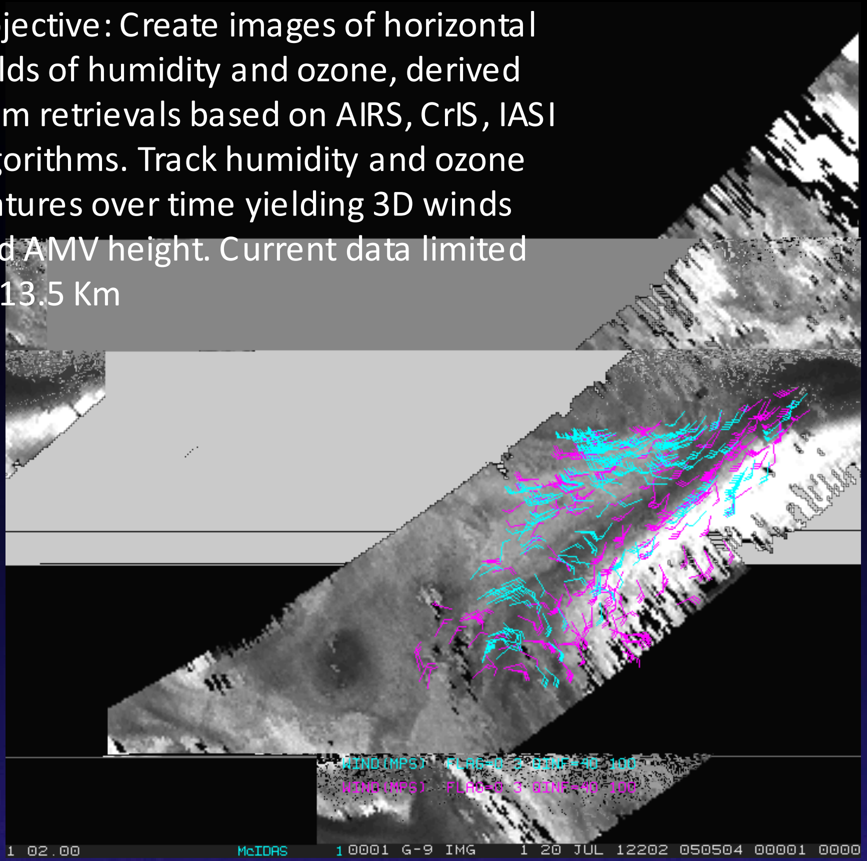
Proven 3D Winds analysis: Aqua MODIS AMVs
MODIS vs. AIRS Retrieval AMVs

Impact per AIRS moisture AMV is ranked higher than all other satellite-derived wind datasets



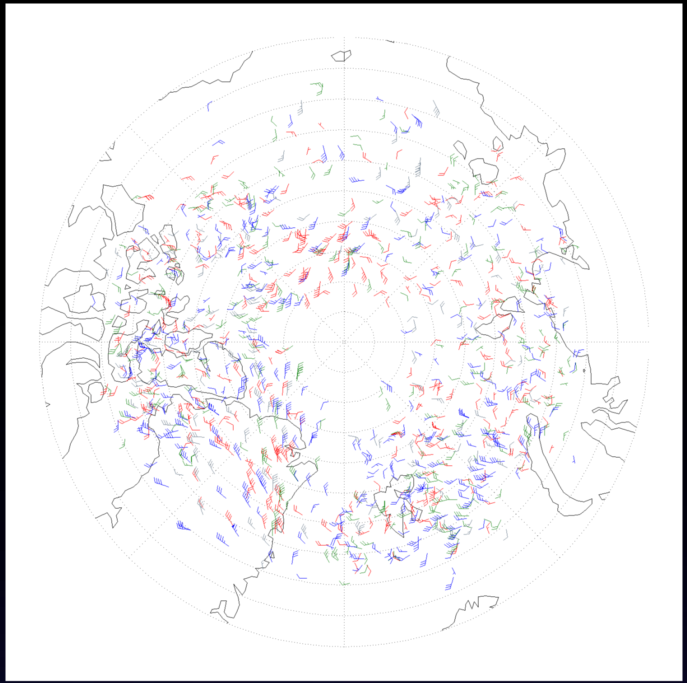
MODIS 20 July 2012 0530 UTC
Infrared and Water Vapor
(including clear sky)

Objective: Create images of horizontal fields of humidity and ozone, derived from retrievals based on AIRS, CrIS, IASI algorithms. Track humidity and ozone features over time yielding 3D winds and AMV height. Current data limited to 13.5 Km

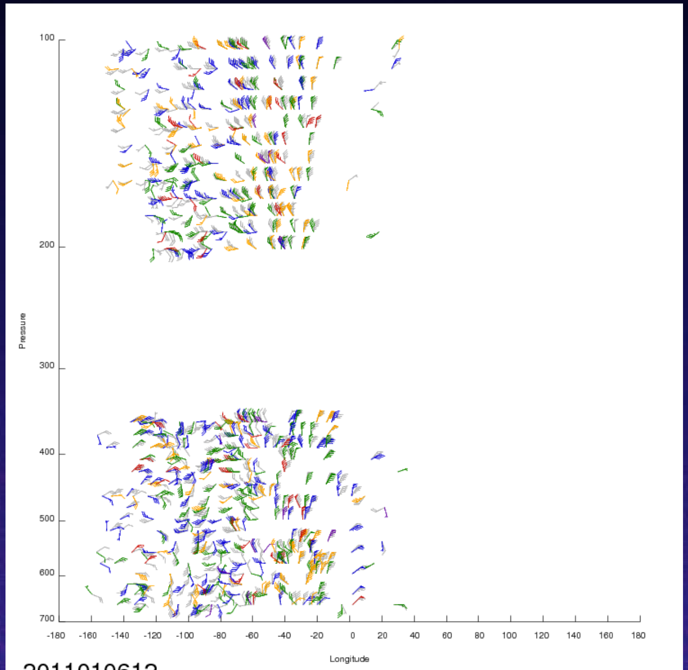


AIRS 20 July 2012 0530 UTC
Ozone: 103 to 201 hPa Moisture: 359 to 616 hPa

Spatial distribution of AIRS retrieval winds for one day. North Pole region.



Vertical distribution of AIRS retrieval winds used. North Pole region.



All derived winds from 5 January 2011. Color coded by level:

- 700 - 600 hPa (red)
- 550 - 450 hPa (green)
- 400 - 300 hPa (blue)
- 150 hPa ozone (gray)

GEOS-5 Forecast Impact: ACC

Two experiments

Control in black.

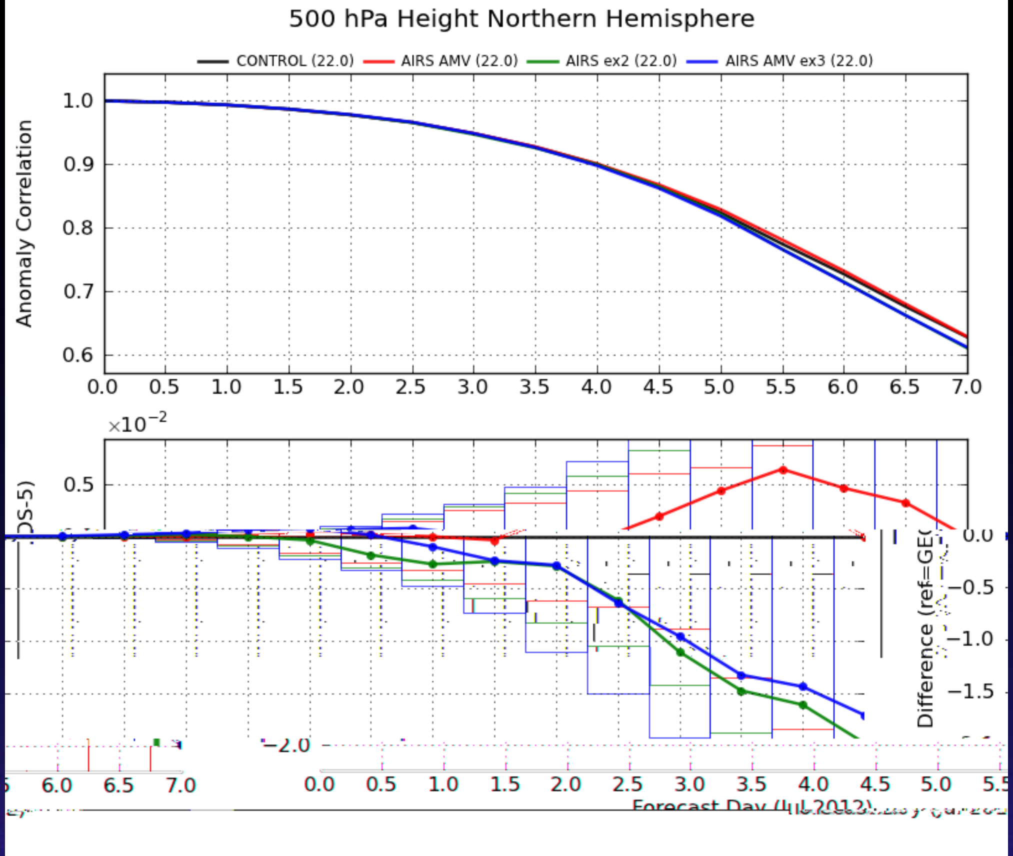
Red: Addition of AIRS AMVs. Slight improvement after Day 4 (not statistically significant).

Blue: Removal of the MODIS AMVs decreases ACC score:

•AIRS AMVs can not offset loss of MODIS AMVs

AIRS AMVs complement the MODIS AMVs

AIRS AMVs are in clear sky or above cloud regions; MODIS AMVs include cloud-tracked features.



500 hPa Northern Hemisphere
1 – 24 July 2012 00 UTC

Summary of AIRS AMVs And application to CHISI

•Impact per AIRS moisture AMV is ranked higher than all other satellite-derived wind datasets
CHISI – will expand and improve resolution and revisit rates of AMV winds based on AIRS research, with new data in the Longwave Infrared.

•Neutral, or slightly positive, forecast impact due to the addition of the AIRS retrieval AMVs is encouraging:

- AMVs only in polar region: poleward 70° latitude – *CHISI to expand this GLOBALLY*
- Impact in the longer range forecast over the entire northern hemisphere (20° – 90° N)

•AIRS AMVs are produced routinely by CIMSS – *no new science*

Preview: http://stratus.ssec.wisc.edu/cgi-bin/polarwinds?airs

Winds product: ftp://stratus.ssec.wisc.edu/pub/winds/retrieval_winds/airs/