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Next Generation Grating Spectrometer Sounders for LEO and GEO

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NASA Science Community Workshop on Polar Orbiting IR and MW Sounders Top Recommendations

- November 1,2, 2010, 140 People Registered
- Top 3 Recommendations Common to Weather, Climate and Composition Breakout Groups:
  - Recommendation I: The formation of a US based Sounding Science Team is required to identify the current and future needs of the weather, climate and atmospheric composition communities using data from the IR and MW sounders
  - Recommendation II: The JPSS enable the full spectral resolution possible with the FM-1 CrIS on NPP as soon as possible.
  - Recommendation III: NASA should begin development of an advanced IR sounder with high spatial resolution and improved spectral resolution to be ready to follow the current planned sounders expected to retire in the 2020 timeframe.
- Draft Workshop Report Available by 4/15/11 at: http://nasa-sounder-workshop.jpl.nasa.gov

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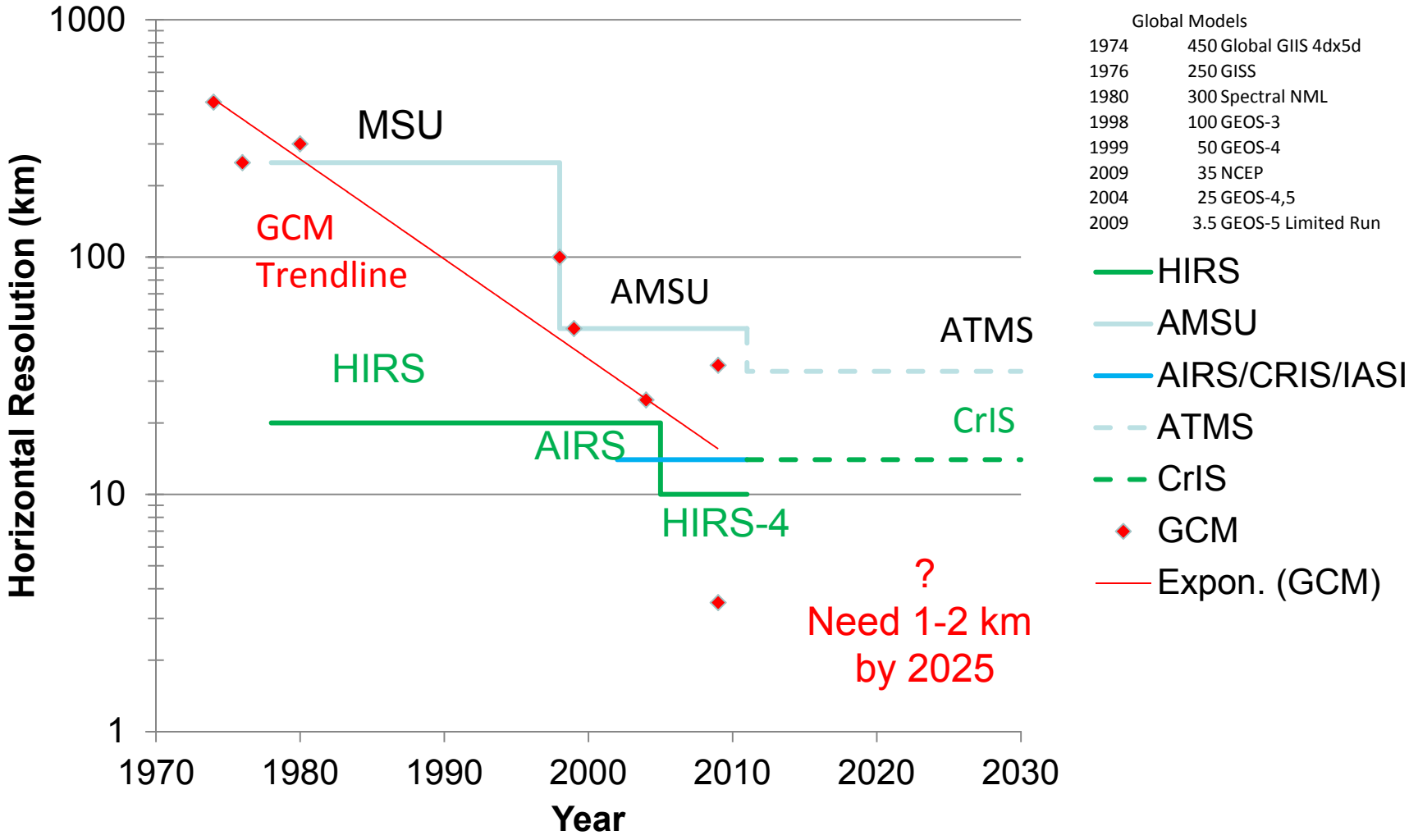
Improved Spatial Resolution from LEO Needed to Initialize & Validate GCM's



Observations of Temperature, Water Vapor, Clouds, etc. are used to initialize and validate forecast models

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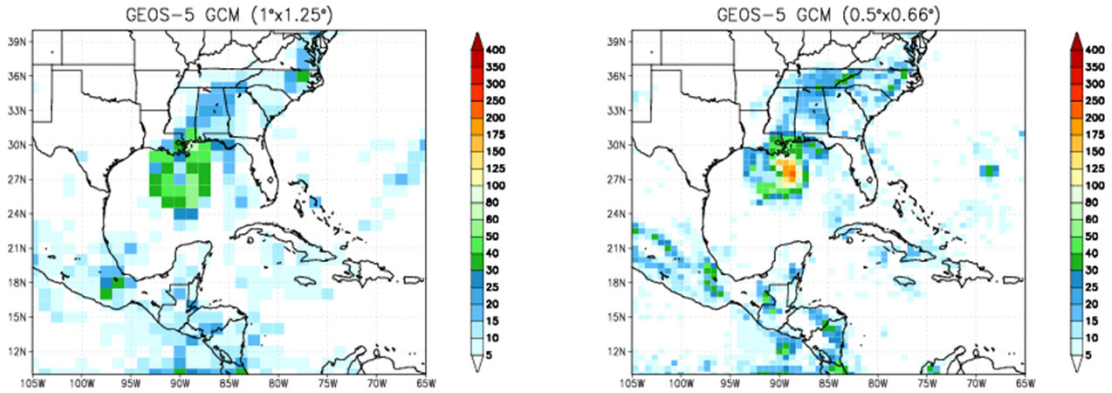
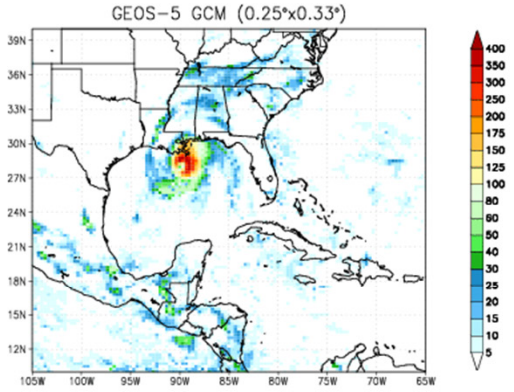
Forecast Accuracy Improves with GCM Spatial Resolution

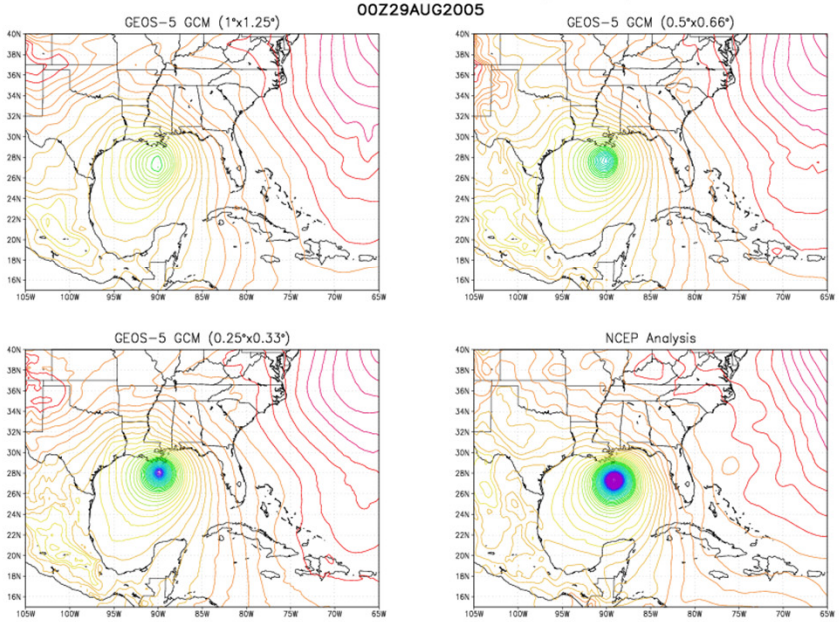
Precipitation Rate (mm/day) (Initialized: 2005 Aug 27, 12z)
00Z29AUG2005





Increasing resolution improves realism of forecasts of the details in nature
2-day Katrina forecasts

Sea-Level Pressure (Initialized: 2005 Aug 27, 12z)
00Z29AUG2005



Columbia allows high resolution and rapid time-to-solution

GMAO: M. Rienecker

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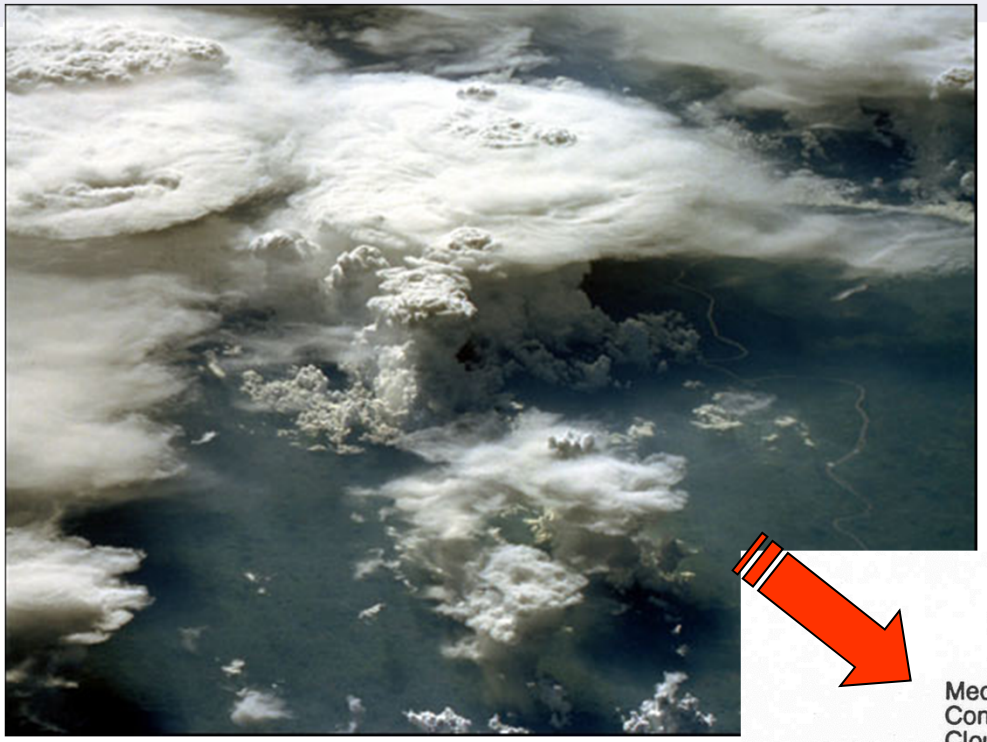
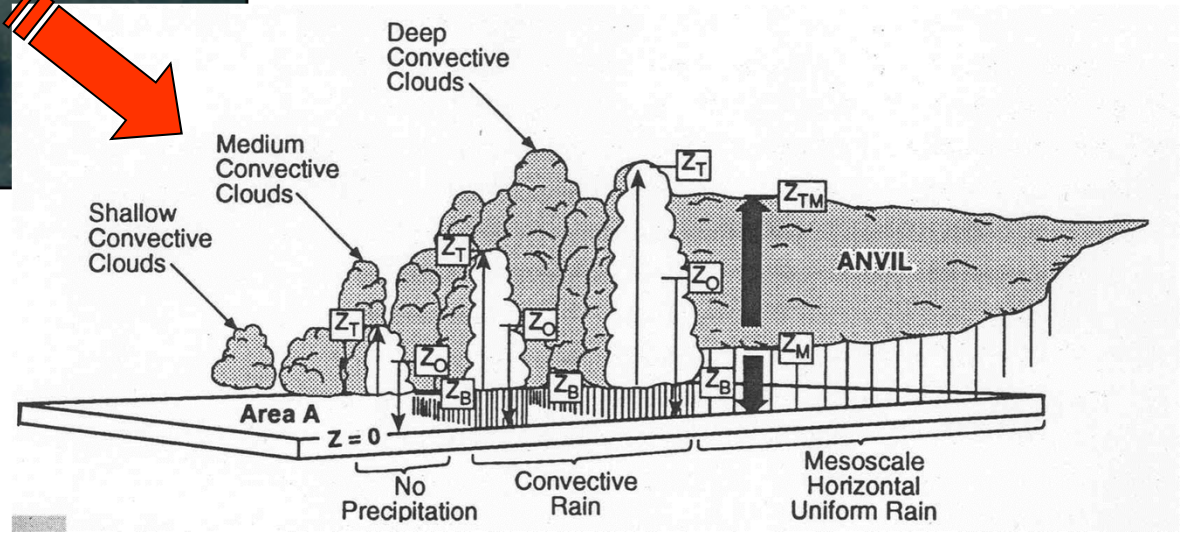
Higher Spatial Resolution Improves Ability to Sound in Presence of Clouds



- More Clear Observations
- Better Cloud Height Discrimination
- Better Characterization of Cloud Scale Dependent Variability
- Improved Boundary Layer Sensitivity



Adapted from Gettelman, 2006

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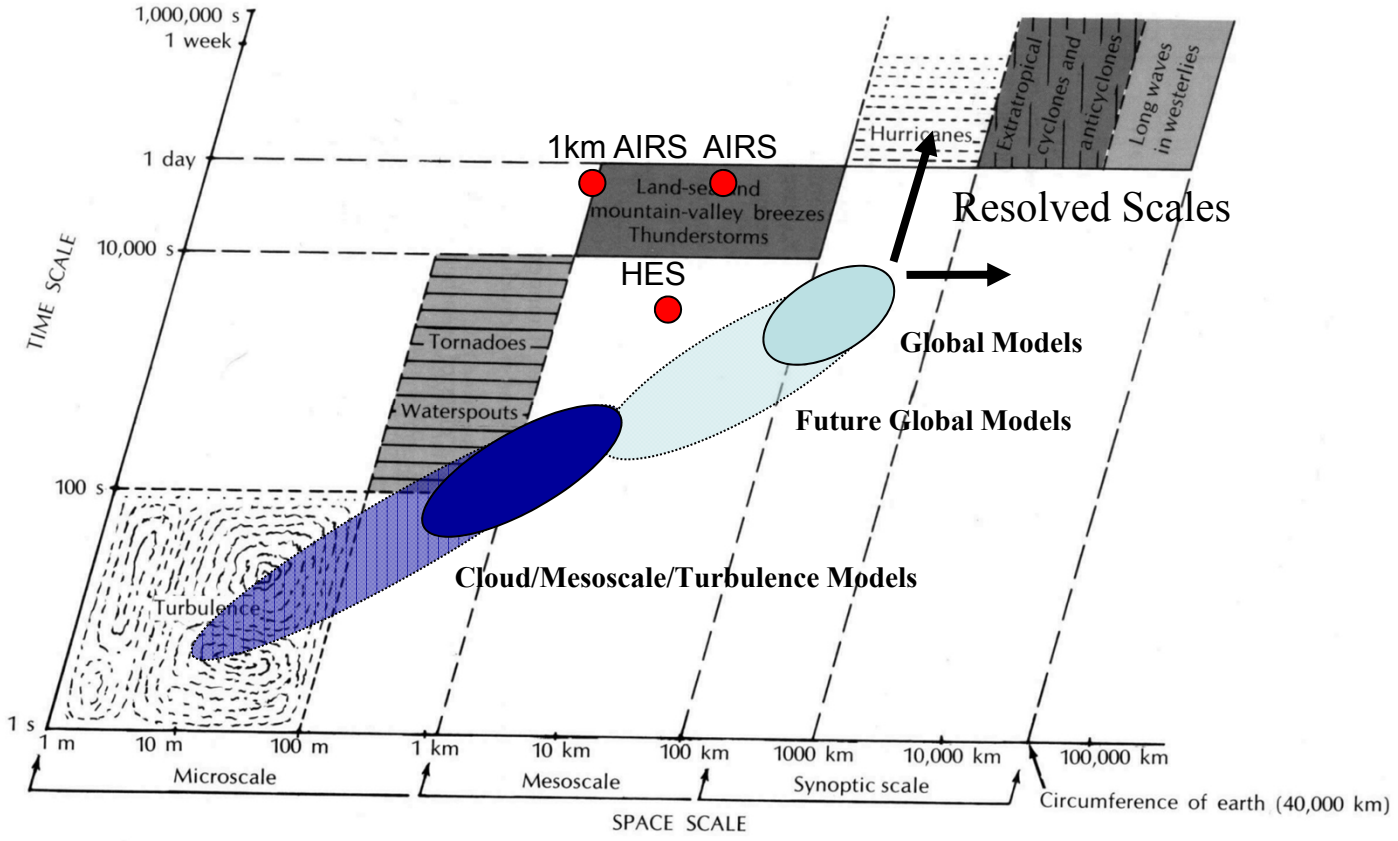
Improvements Needed in Resolution to Validate Cloud Microphysics Models

Regardless of Scale: Still need parameterizations for most things
Goal: get interactions right (Mesoscale). Also extreme events



Adapted from Gettelman, 2006, Antes 1975

National Aeronautics and Space Administration

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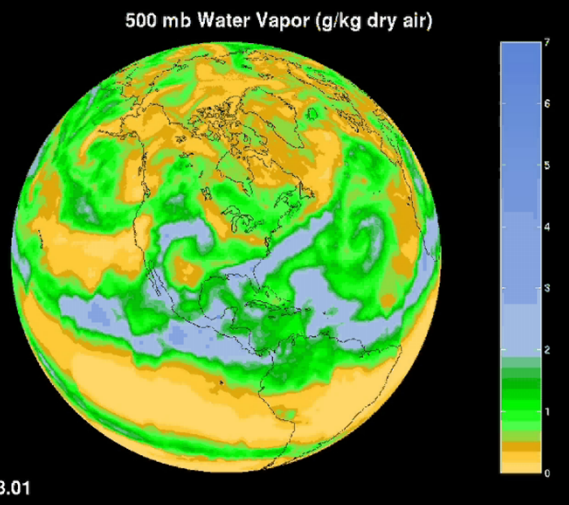
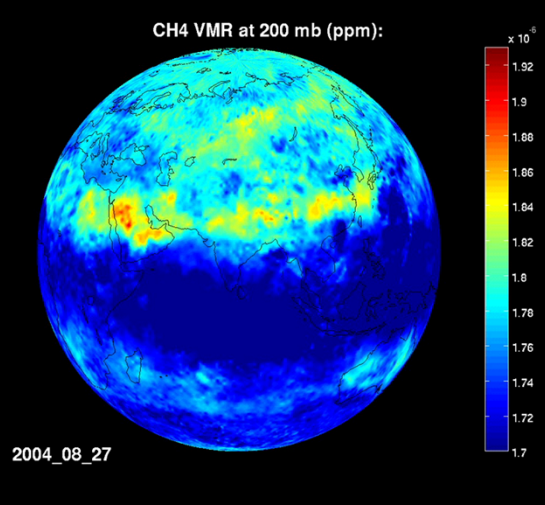
Pasadena, California

AIRS Greenhouse Gases

H_2O

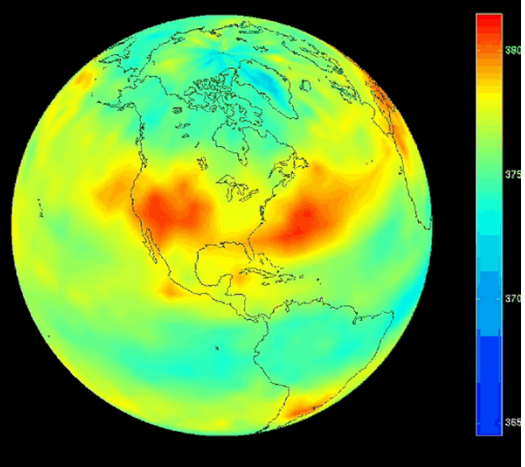


CH_4



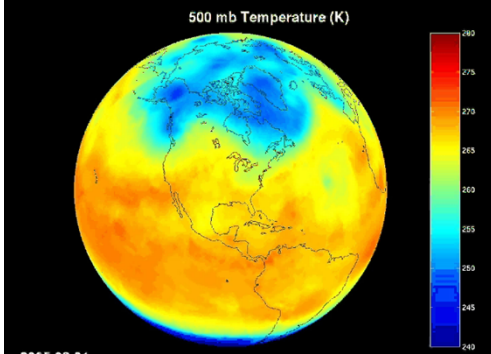
CO_2

Mid-Tropospheric CO_2 (ppm)

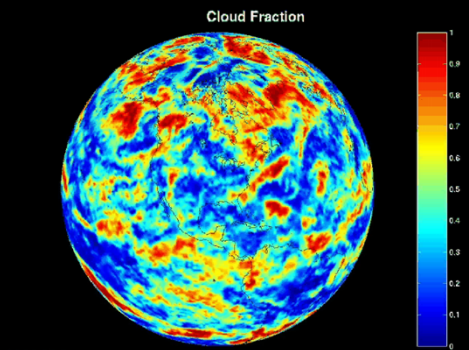


Pagano, JPL, 2009

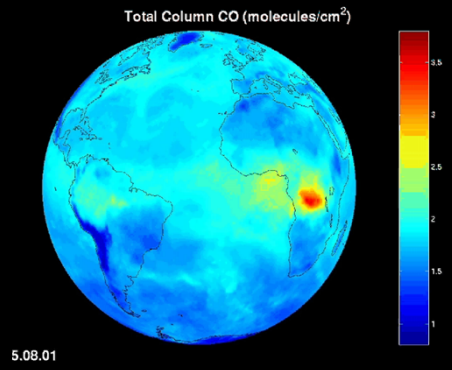
Other AIRS Atmospheric Climate Products



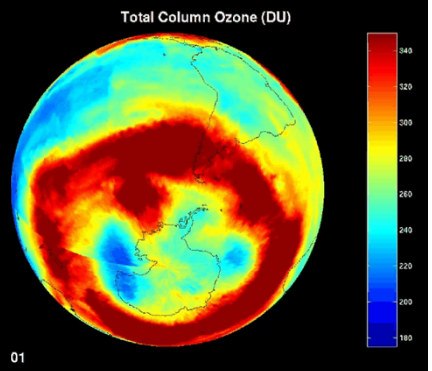
Temperature



Clouds



CO



O_3

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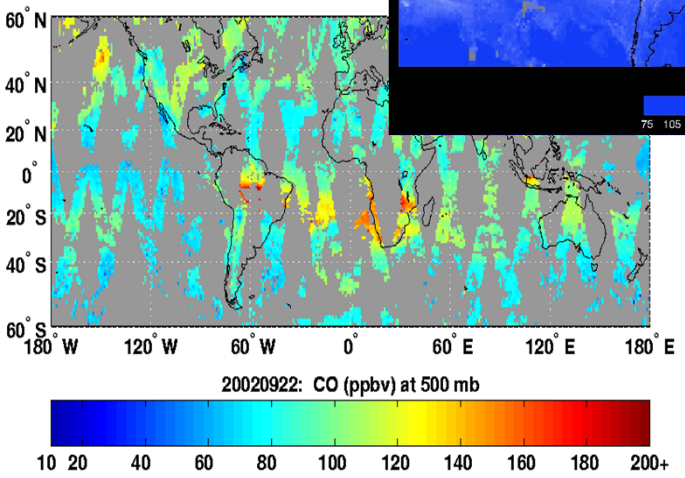
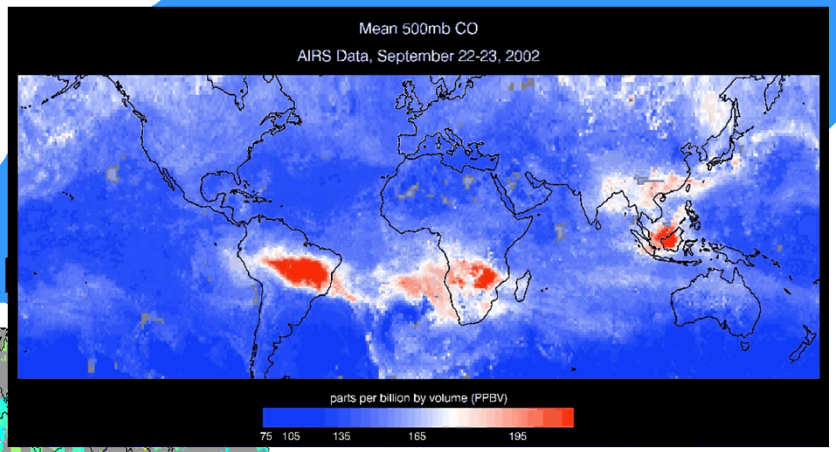
Higher Spatial Resolution Needed to Track Sources and Sinks of Trace Gases

Current: AIRS CO, Grating, 15 km IFOV Daily Global Coverage

Higher Spatial Resolution + Global Coverage
CO, CO_2, CH_4

MOPITT CO Gas Cell 22 km IFOV Monthly Global





MODIS 1km Daily Regional Coverage

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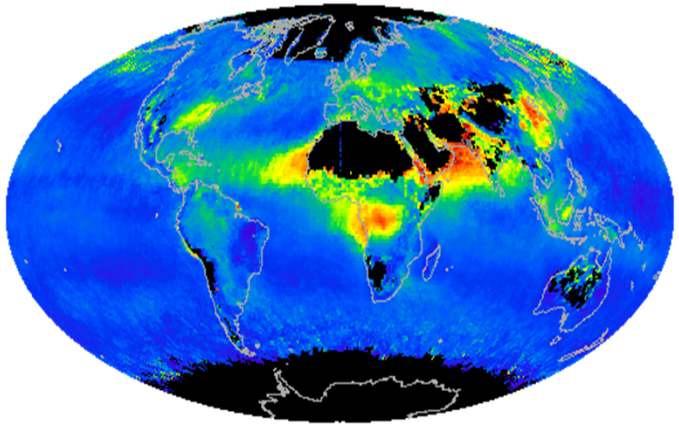
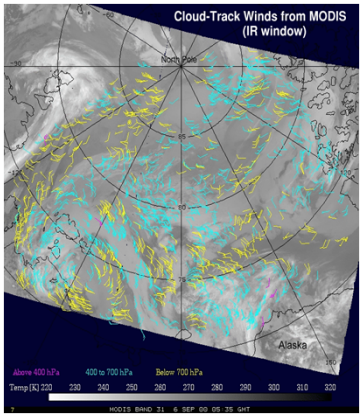
Imager Products Highly Synergistic with Sounder for Weather, Climate, GHG Flux

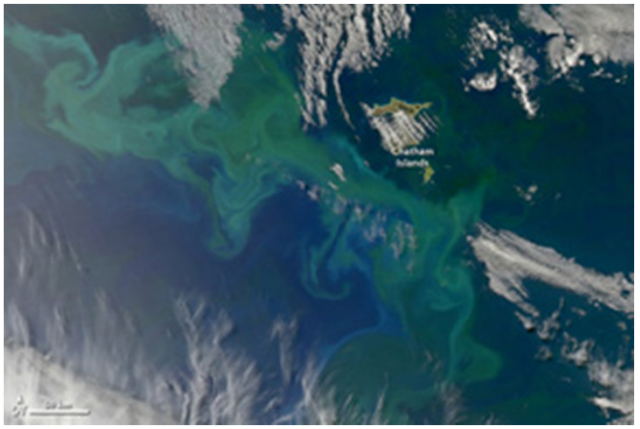
Aerosol



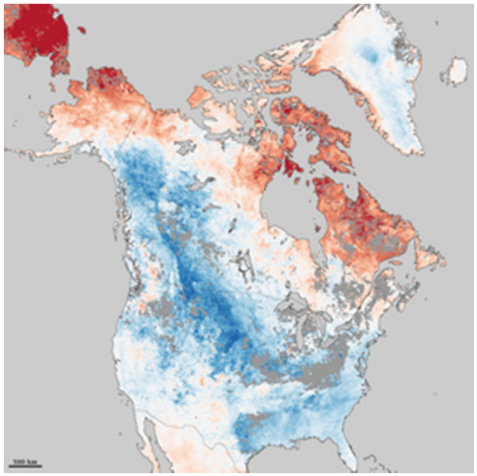
Polar Winds



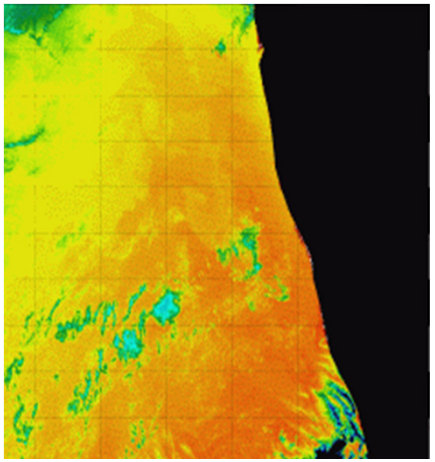
Ocean Color



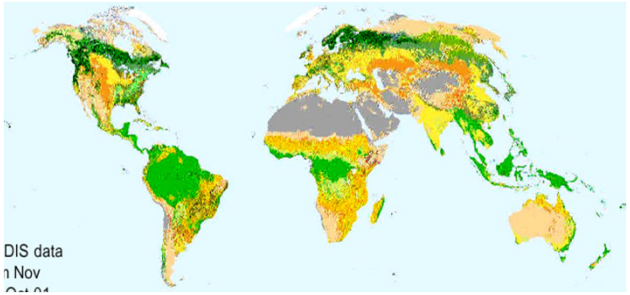
LST



SST



NDVI



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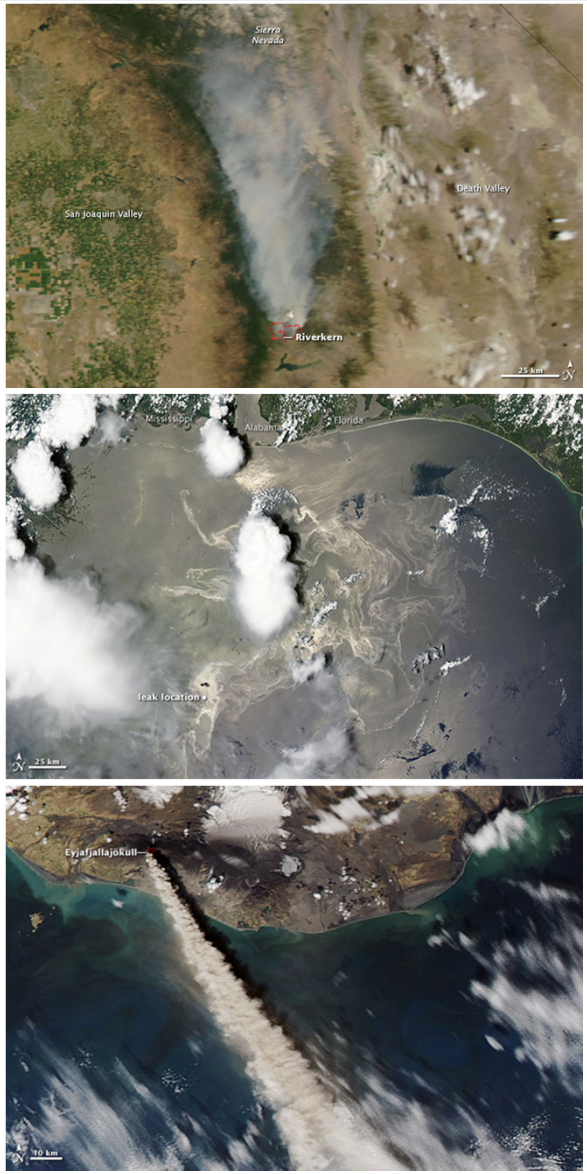
MODIS Widely Used for Operational Government and Civil Applications

- Water Vapor Winds assimilated operationally at numerous NWP Centers
- 40 NWS Centers Regularly Use MODIS IMAPP Data
- Forecast Support for Johnson Spaceflight Center Meteorology Group
- Snow/ice/cloud discrimination
- Fog detection
- Sea Surface, Land, Lake Temperature
- Aerosols used for EPA Air Quality
- Disaster Monitoring: Volcanoes, Oil Spills, Fires, Hurricanes, Floods
- Agriculture, Commercial Fishing
- Military Operations

- Over 40+ Products



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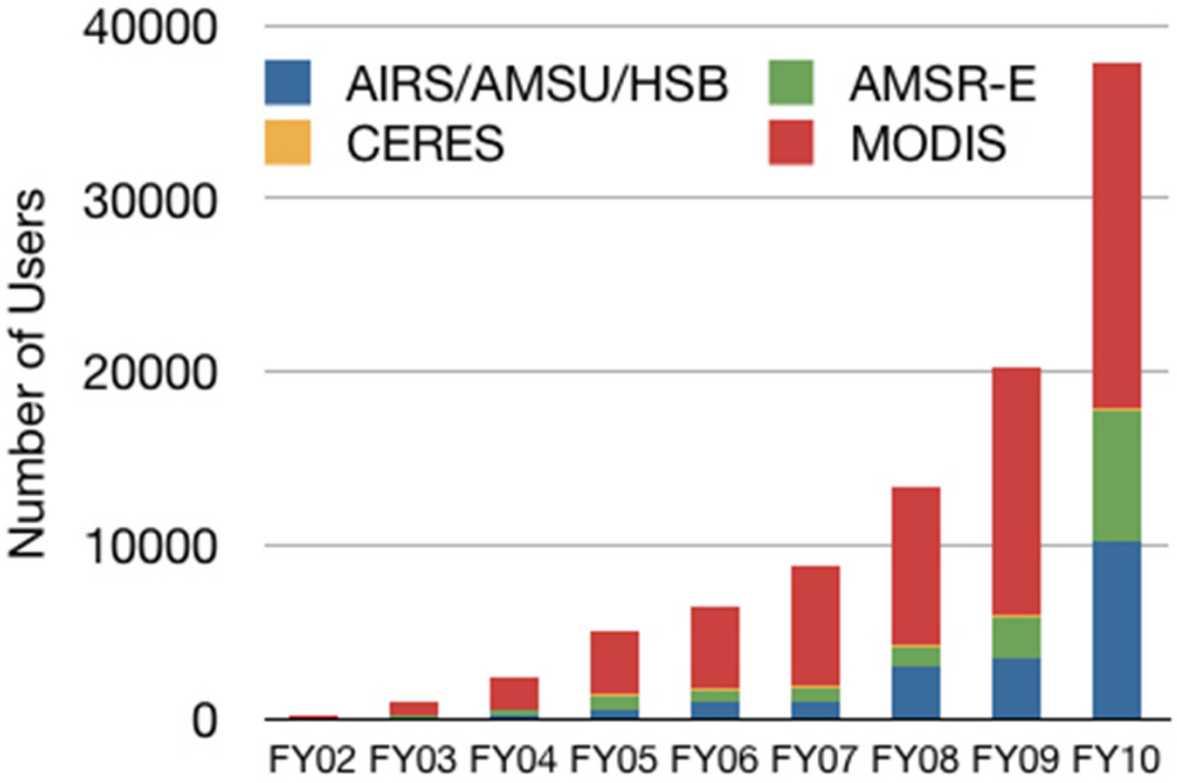
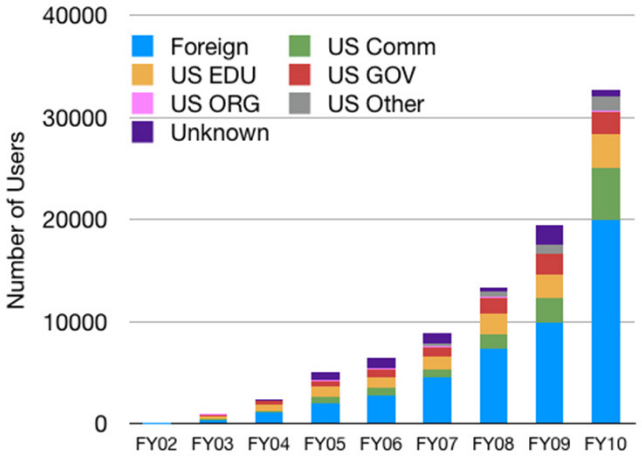
Almost 40,000 Users of Aqua Data

MODIS and AIRS have Most Users



Courtesy of GES/DISC

Most Users Foreign



LEO Imagers and Sounders are Essential to Earth Science Investigations and Must be Priority for Advancement. NASA NRC DS Assigned to NOAA

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Key Needs of Next Generation Imagers and Sounders

- Higher Spectral Resolution
  - Improved Product Accuracy and Calibration
  - Improved Sea Surface Temperature Accuracy
  - Improved LST, and Surface Emissivity
  - Improved Cloud and Aerosol Product Accuracy
  - Improved boundary layer sensitivity
  - Improved GHG observations: CH4, CO, CO_2
  - Improved Water Vapor Transport: Higher H2O Vertical Resolution, HDO
- Higher Spatial Resolution (on the order of 1km)
  - Improved regional model initialization and characterization
  - Improved yield in cloudy scenes; closer to cloud boundaries
  - Improved characterization of cloud processes and variability
  - Aviation Alerts: Volcanic Ash and SO2, Storms, etc.
  - Improved Fire Detection
  - Greenhouse Gas, CO and SO2 Emissions from Anthropogenic Sources
  - Synergy with OCO-2, CarbonSat

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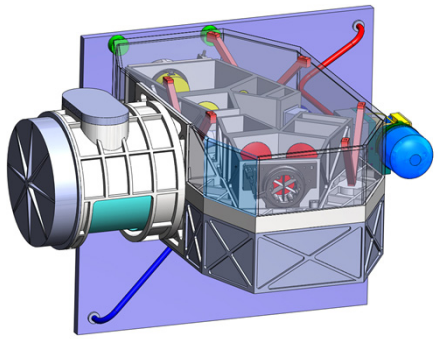
Evolving Requirements and Technology Lead to New Architecture

AIRS

AIRS on Aqua
14 km GSD, ±49.5°
2378 Channels
0.4-15.4 μm
177 kg, 256 W
0.9 m^3, 1.3 Mbps

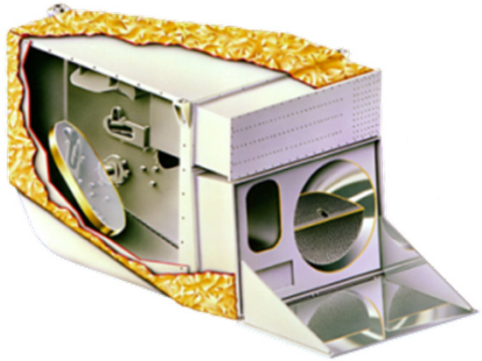
ARIES (IR Only)

Atmospheric Remote-sensing Imaging Emission Sounder



1 km GSD. ±55°
4096 Channels
3.3-15.4 μm
100 kg, 150 W
0.5 m^3, 60 Mbps
Unplanned

MODIS

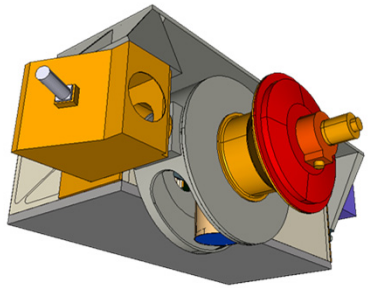


MODIS on Aqua
1 km GSD, ±55°
0.4-14.4 μm
220 kg, 160 W
1.5 m^3, 11 Mbps

AIRS and MODIS around till ~2020

ORCA+ (UV/VIS/NIR)

Ocean Radiometer for Carbon Assessment



1 km GSD. ±58°
108 Channels
0.24-2.14 μm
140 kg, 130 W
0.5 m^3, 13 Mbps
NASA Planned (For PACE)

- ***ARIES and ORCA Meet all Requirements of AIRS and MODIS + More!!!***

T.S. Pagano, C.R. McClain, "Evolution of Satellite Imagers and Sounders for Low Earth Orbit and Technology Directions at NASA', Proc. SPIE, 7807-20, San Diego, California, August 2010

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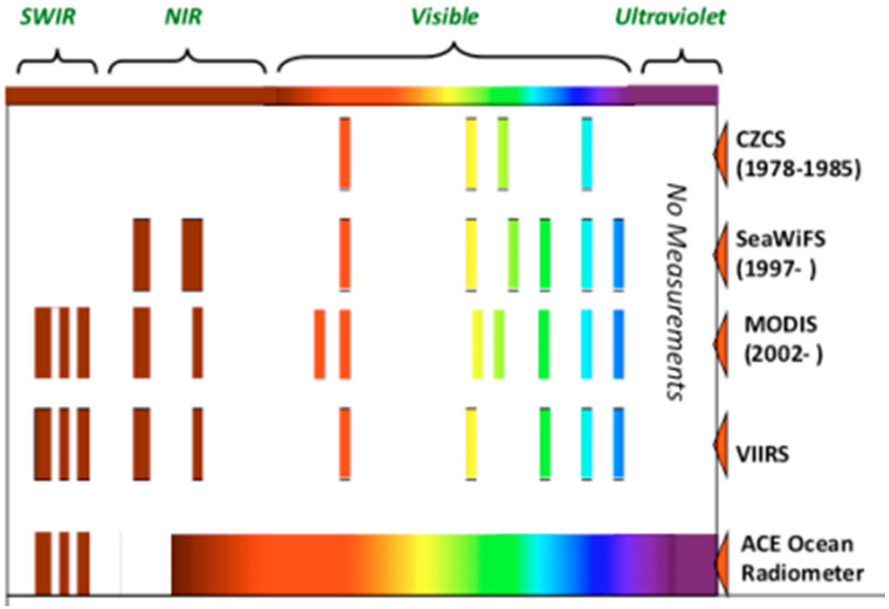
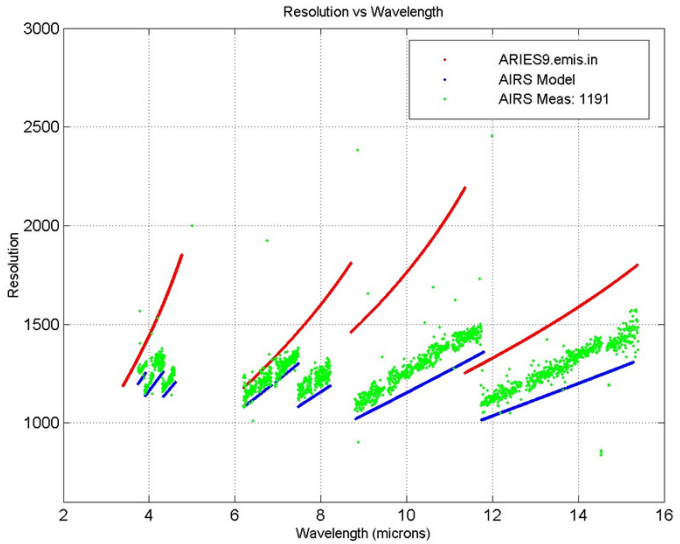
Next Gen Imaging Sounders Give Hyperspectral UV through LWIR

ORCA
108 UV/Vis/NIR Ch.
345-885 nm, $\Delta\lambda$ = 5 nm
3 SWIR Channels



ARIES
4096 Channels
~2x Better than AIRS



Band	Spectral Range	Spectral Resolution	No. Channels
MW1	2100 - 2950 cm^{-1}	1.6 cm^{-1}	1024
MW2	1150 - 1613 cm^{-1}	1.0 cm^{-1}	1024
LW1	880 - 1150 cm^{-1}	0.6 cm^{-1}	1024
LW2	650 - 880 cm^{-1}	0.5 cm^{-1}	1024

T.S. Pagano, C.R. McClain, “Evolution of Satellite Imagers and Sounders for Low Earth Orbit and Technology Directions at NASA’, Proc. SPIE, 7807-20, San Diego, California, August 2010

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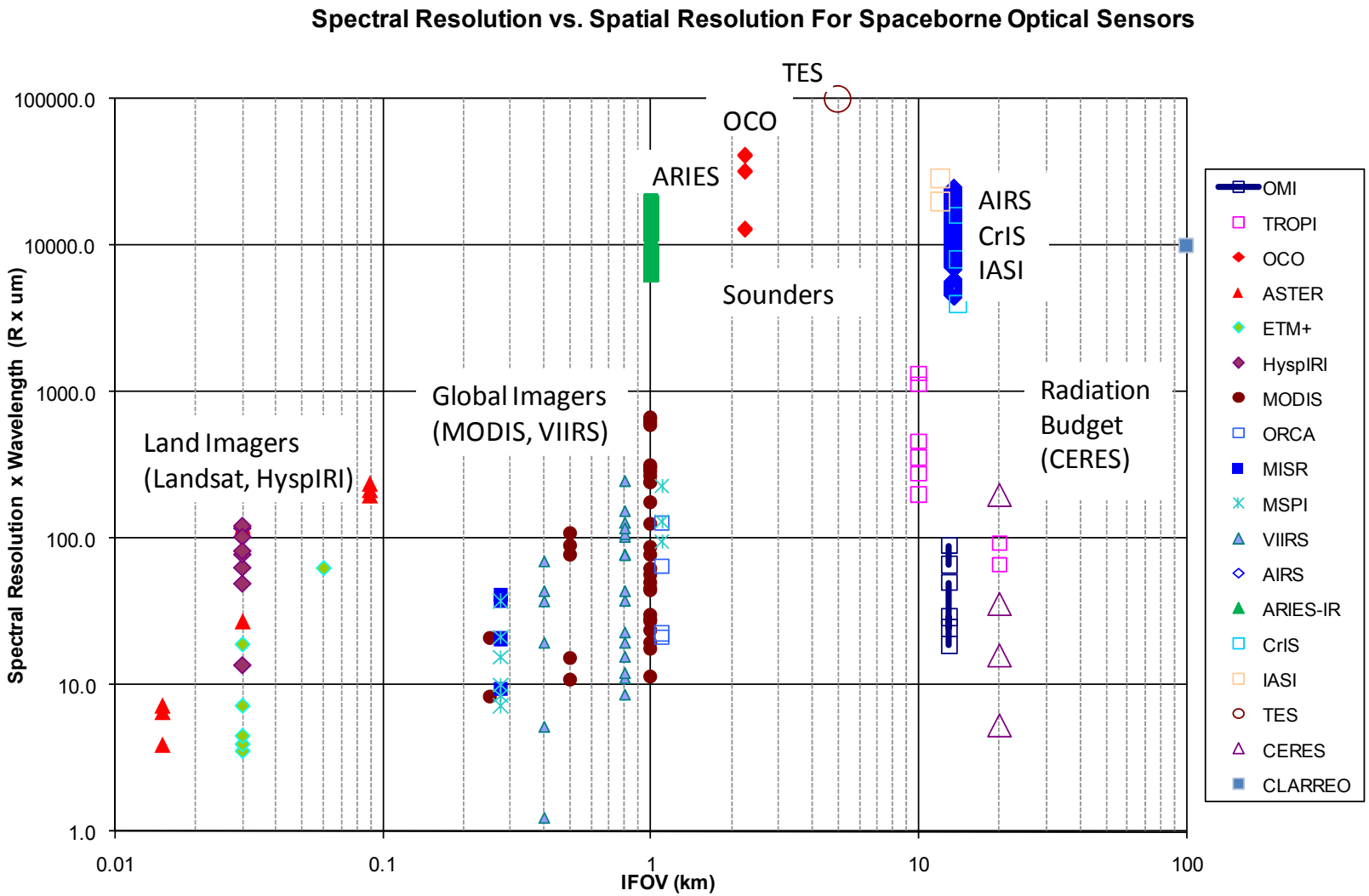
ARIES Enters New Domain of Earth Observation Spectral and Spatial Space



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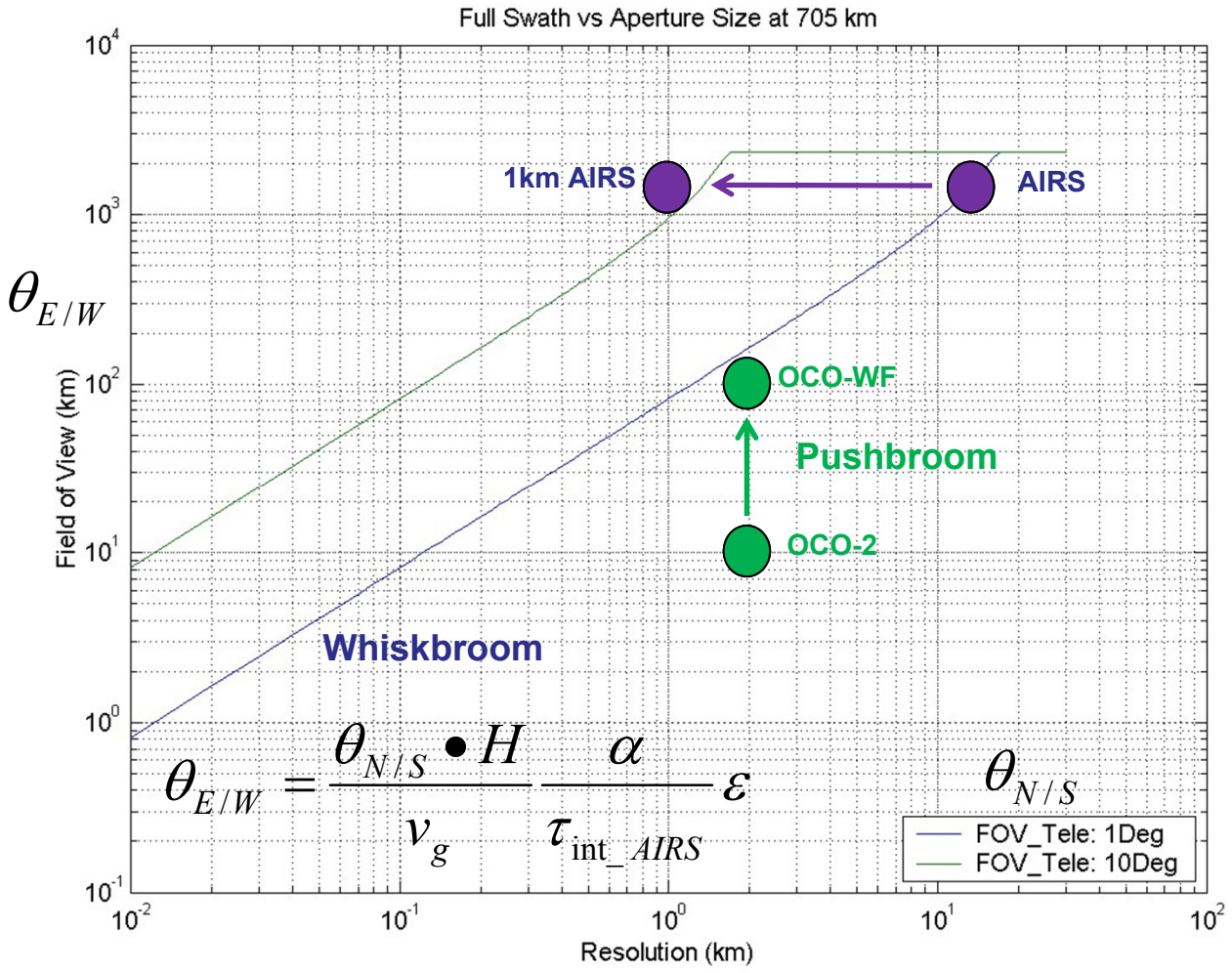
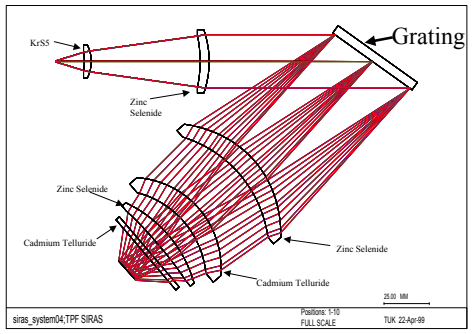
Wide Field Optics Improve Spatial Resolution and/or Coverage



- **Whiskbroom: Wide field slows scan, enabling higher spatial resolution**
- **Pushbroom: Wide field directly extends E/W Swath**

Wide Field Grating Spectrometer Demonstrated on IIP 2001



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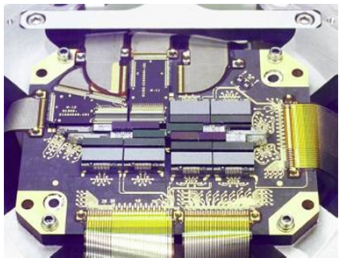
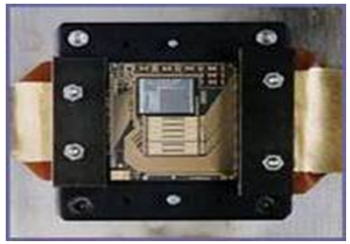
New Technologies Enable Compact Wide Field Grating Spectrometer Sounders

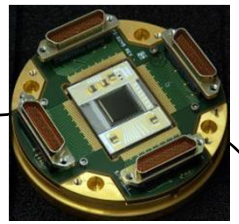
AIRS
BAE Systems
PV/PC HgCdte
17 modules
2 x ~180
100 x 50 um



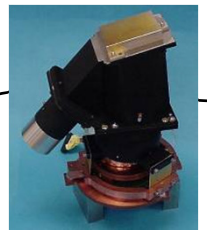
MODIS
Raytheon Vision Systems
PV/PC HgCdTe
4 FPAs
10 x ~10
400 x 400 um



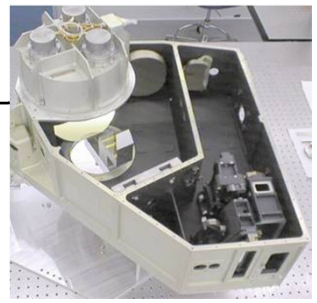
BAE Systems
HgCdTe
15 μm Cutoff
512 x 512

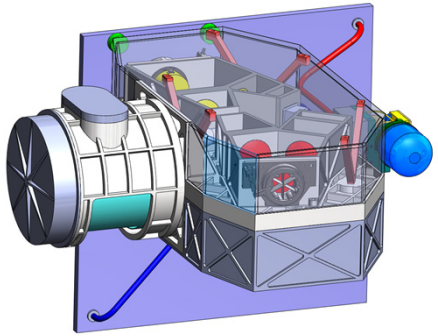


SIRAS IIP1
Refractive 16°
Grating Spectr



AIRS
Reflective 1.1°
Grating Spectr

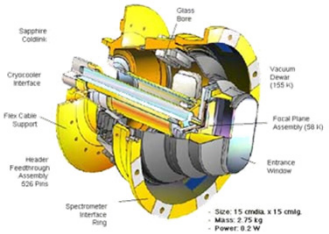




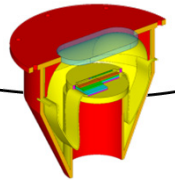
Next Generation
LEO or GEO
Sounder

TRL 5

AIRS
Large Dewar

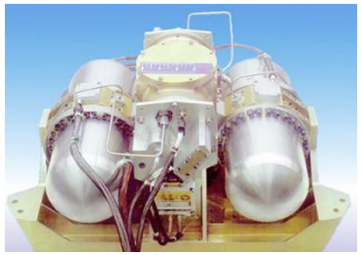


High Efficiency
Mini Dewars



NGST
Small Single
Pulse Tube
Cooler

AIRS
Large Dual Pulse
Tube Coolers



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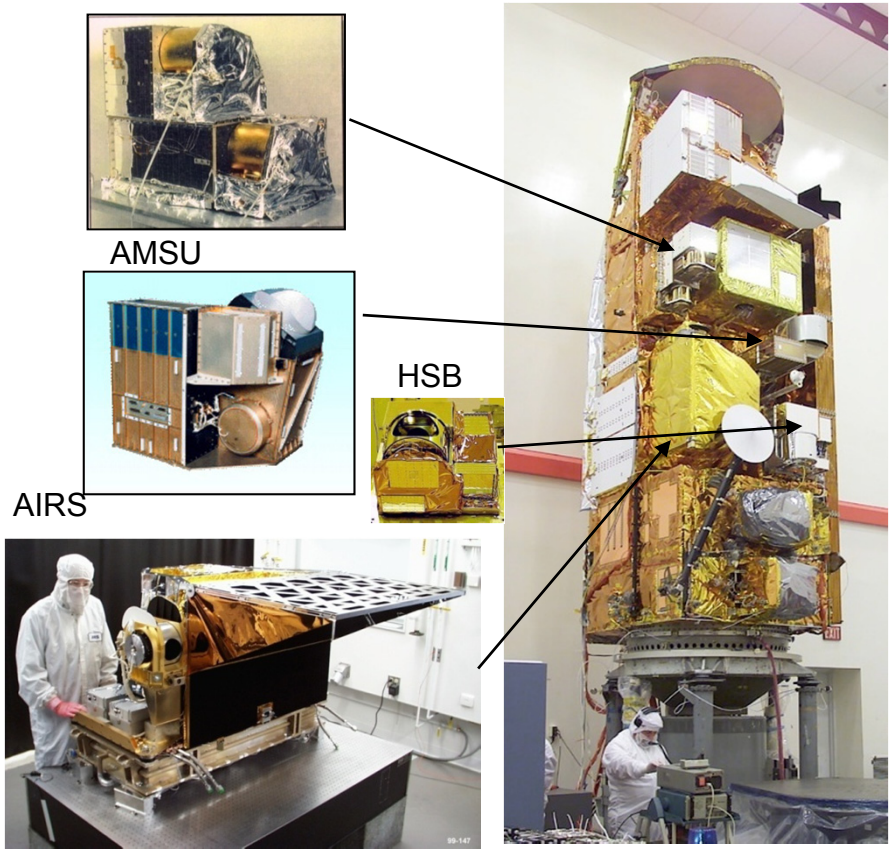
Modular Mini-Grating Spectrometers Reduce Cost and Complexity

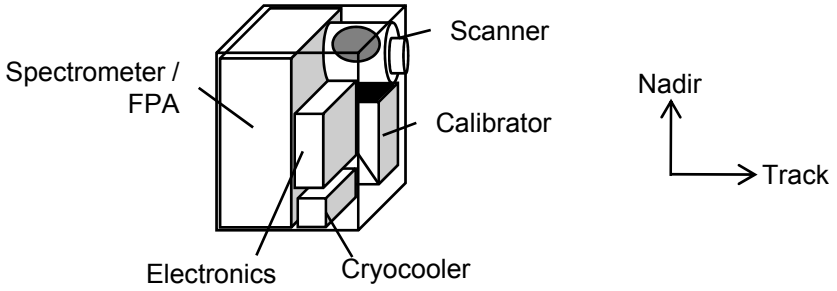
• On Aqua, IR/MW frequencies distributed amongst 4 instruments. Single Retrieval

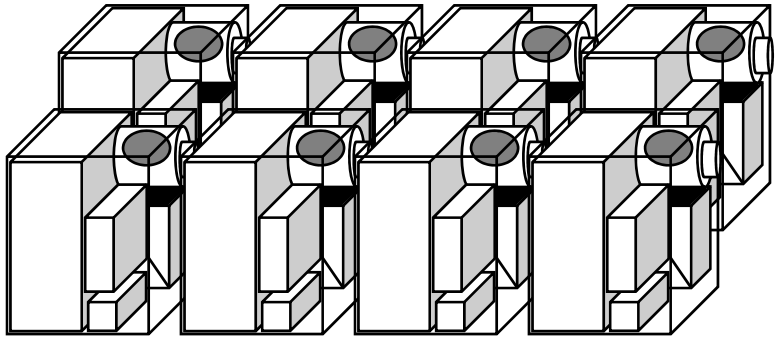


<u>Mini-Spectrometer Instrument Modules</u>

- 1 WF Grating Spectrometer / FPA per Module
- Optics / FPA Tailored for Each Band
- Commonality Reduces Cost. Low RE
- Easier to accommodate
- < 50 kg, < 50W, < 1 Mbps

TRL 5





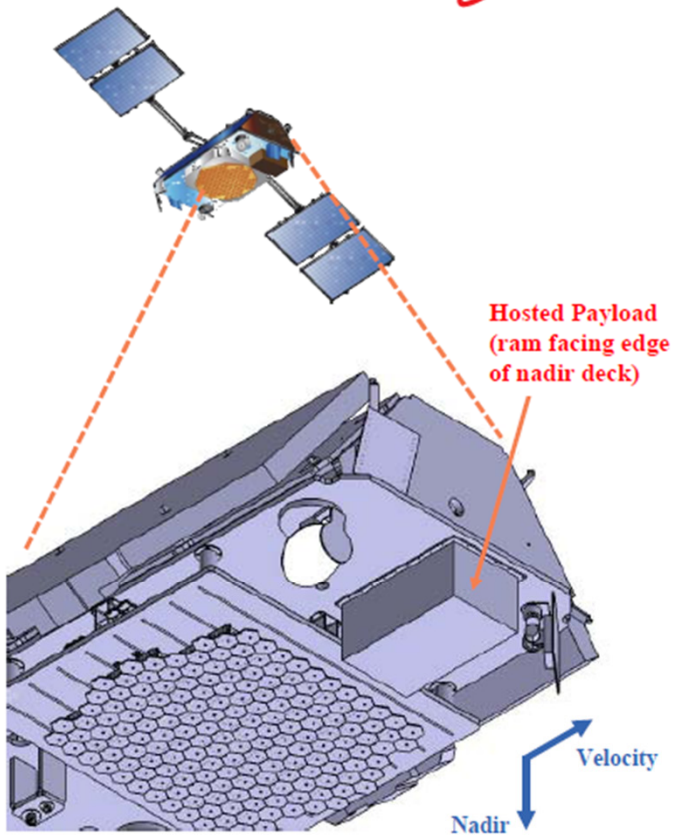
Mini Grating Spectrometers Compatible with Launch on Iridium Constellation

Iridium NEXT Hosted Payload Accommodation

Orbital

- Provides Unprecedented Geospatial and Temporal Coverage
  - Coverage –Global, Continuous, 24/7
  - Real Time Control and Low Latency – Real-time 24x7 Relay of Data to and from Payloads in Space with < 9 sec Latency
  - Cost Effective - A Fraction the Cost of a Dedicated Mission
  - Unique – No Other Similar Opportunity Likely to Be Available for Decades
- All 72 Iridium NEXT Satellites Can Host Additional Payloads

Standard Hosted Payload Accommodations	
Weight	50 kg
Payload Dimensions	30 x 40 x 70 cm
Payload Power	50 W average (200 W peak)
Payload Data Rate	1 Mbps peak, Orbit average ~100Kbps
Latency	< 9 sec
Pointing	~0.25 deg knowledge/control



C. Schueler (OSC)[24]

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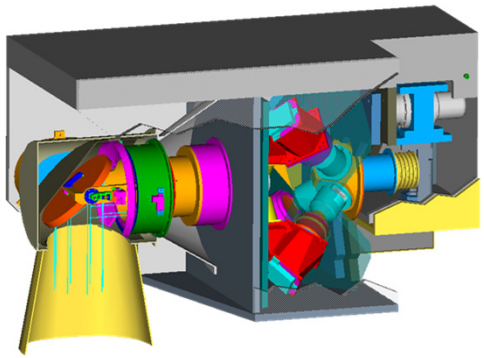
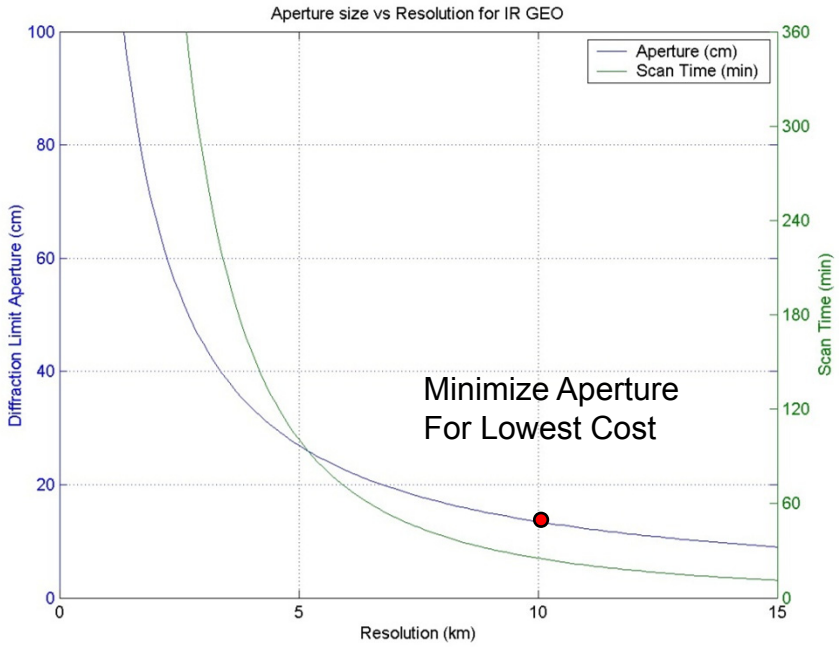
Key to Affordable GEO Instrument is Modest Set of Requirements

- Gratings offer advantages for GEO
  - High Reliability
  - Low sensitivity to pointing
  - Smaller Spectrometers (wide field allows high magnification)
  - Low Power (Minimal signal processing)
  - **But**: Fewer Channels than FTS
- GEO sounder need not be big
  - SIRAS-G, AIRS+ from GEO
  - JPL NMP Concept Proposal 1998
  - Spectrometers Same as LEO
  - Compatible with Orbital STAR





SIRAS-G (NMP 1998)		
GSD	(km)	5.0
IFOV	(km/μr)	10.0/280
Size	(m)	0.7 x 0.5 x 0.4
Mass	(kg)	100
Power	(W)	150
Aperture	(cm)	12.5
Integration	(ms)	100
No. Channels	2400	
Data Rate	(kBps))	<300

Assumptions

Aperture:
D=2.44 λ/α
λ=15.4 μm
Scan Time
3000x4000 km Region
500 km Swath N/S
Same $A_o\Omega_d T_{int}$ as AIRS

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Summary

- AIRS and MODIS Widely Used for Weather, Climate, Composition, Carbon Cycle, Cross-Calibration, and Applications
- Community asking for new capability in the 2020 timeframe
  - Hyperspectral UV to LWIR, High Spatial ≤1km IFOV
  - Maximize Synergies of Solar Reflected and IR. Synergies with OCO-2.
- Expect more users and applications of next gen LEO IR Sounder than GEO
  - Weather, Climate, GHG Monitoring, Aviation, Disaster Response
- New Direction for Imagers and Sounders
  - Separate Vis/NIR/SWIR from MWIR/LWIR Instruments Reduces Technology Risk and Complexity
  - Expect Costs to be lower than CrIS & VIIRS
- Additional Ideas to Reduce Costs:
  - Minimum Set of Requirements
  - Mini-Grating Spectrometers. Supports Constellation for Higher Revisit
  - New Technology to Reduce Instrument Size (Large Format FPA's)
  - Hosted Payloads

Issues and Recommendations

- Issues
  - Currently no plan to advance capability of LEO IR sounder at NASA or NOAA = No Study Funds
  - NRC Decadal Survey did not make IR sounders a priority at NASA
  - Currently no technology development program for LEO IR sounders at NASA or NOAA
- Recommendations
  - Initiate studies for advanced imager and sounders at NASA and NOAA
    - OSSE's, Requirements Analysis, Mission Studies, Instrument Studies
  - Initiate a technology development program focused on retiring key risk areas for next generation LEO imager and sounder

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Special Thanks to Mous Chahine for His Vision of ARIES

A Brilliant Scientist

A Great Visionary

A Gentle Mentor

A Good Friend