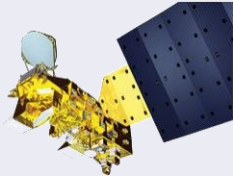
Jet Propulsion Laboratory
California Institute of Technology



Next-Gen IR Sounding for Weather, Climate and Composition

NASA Sounder Science Team Meeting

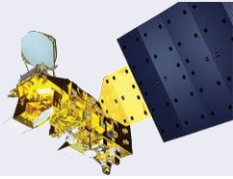
October 2, 2014

Thomas S. Pagano
Joao Teixeira, Hartmut Aumann, Bill Irion, William Mathews, Eric Sturm, Ivair Gontijo
California Institute of Technology, Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena, CA, USA 91109

with inputs from **Joel Susskind** (NASA/GSFC), **Robert Atlas** (NOAA/AOML)

tpagano@jpl.nasa.gov, (818) 393-3917, http://airs.jpl.nasa.gov

Next Generation IR Sounders Need Better Resolution



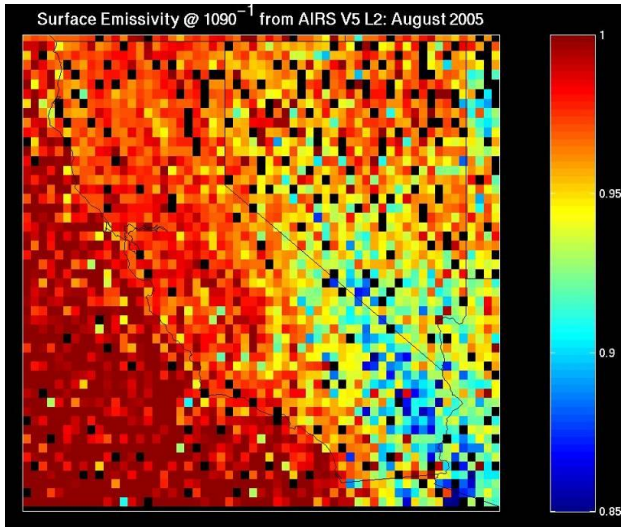
- Higher Spatial Resolution: Climate and Weather
  - Higher horizontal and vertical resolution to resolve boundary layer structure and provide more "clear" soundings
  - Low Earth Orbit, GSD: 100m – 5km, ARIES, MIRIS

Focus of this talk

- Higher Spectral Resolution: Composition
  - Higher spectral resolution to resolve trace gas species and H2O isotopes with improved precision and accuracy
  - LEO: IASI-NG, GACM
  - GEO: FTS (Broadband, e.g. PanFTS), Grating (Narrowband), GSD: 5-50 km
- Higher Temporal Resolution: Weather and Composition
  - LEO: Cubesat/Smallsat in Constellations
  - GEO: HES, GeoMetWatch (FTS), MWIR Grating

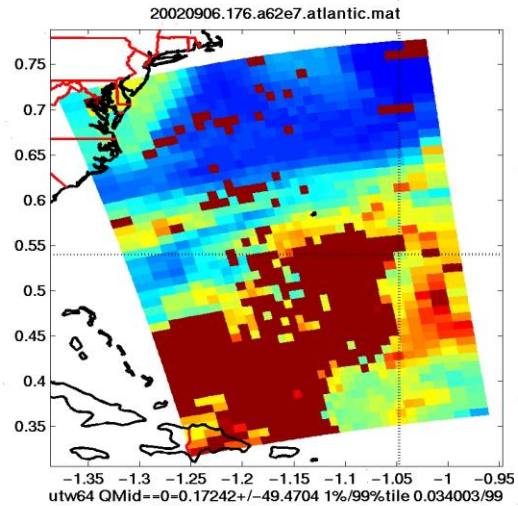
Higher Spatial Resolution Improves Feature Identification and Accuracy

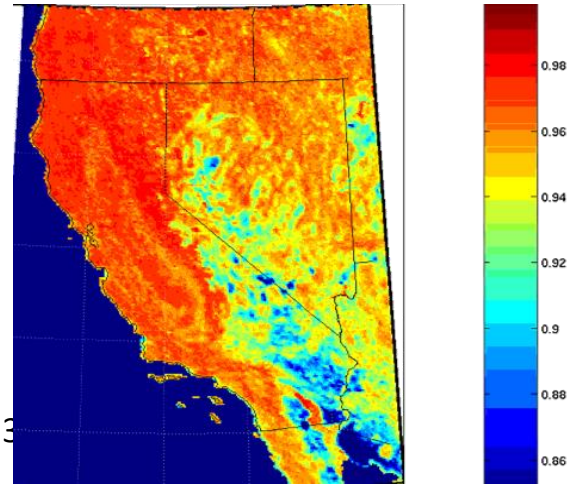
Surface Emissivity



Water Vapor

Current Resolution AIRS 50 Km

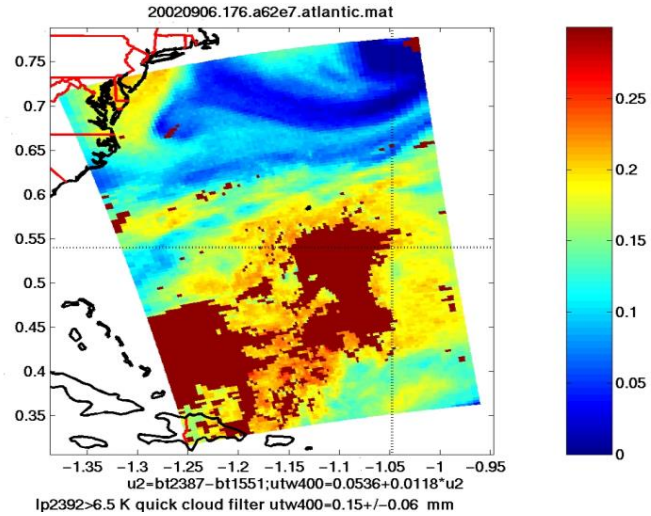




Higher Resolution (L. MODIS R. AIRS L1B)

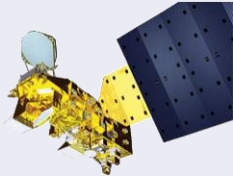
5 km

15 km



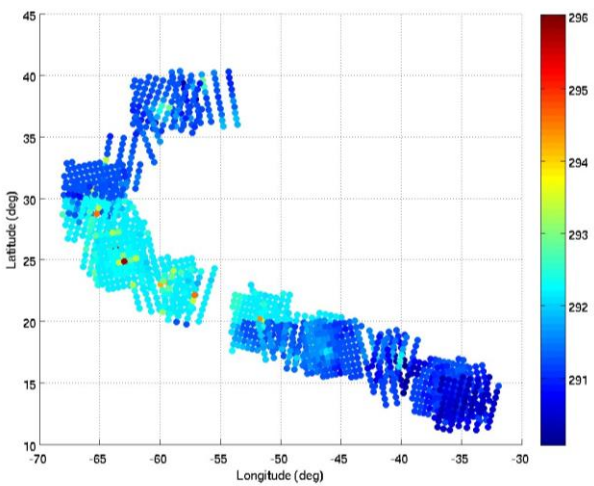
Higher Spatial Resolution Results in Better Accuracy (Less Cloud Contamination)

Jet Propulsion Laboratory
California Institute of Technology



Supporting Hyperspectral IR Data Assimilation Study for NOAA/AOML

Nature run profile sampled by AIRS scan pattern and averaged over footprint



Linear retrieval to simulate AIRS

$$x_{est} = x_o + A(x_T - x_o)$$

$$A_{i,*} = \frac{\langle A_{i,*} \rangle f_i}{\langle V_i \rangle}$$

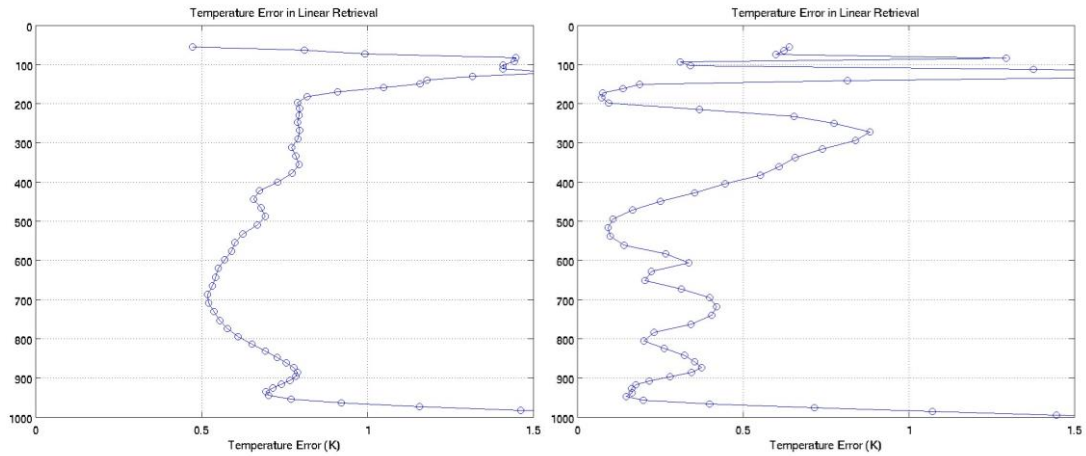
$f_{T,i} = a_{T,i} + b_{T,i} \ln(p\_cld) + \ldots$
$c_{T,i}(f\_cld)$, i = 1 to 23

Similar for water vapor with add'l *q_tot*

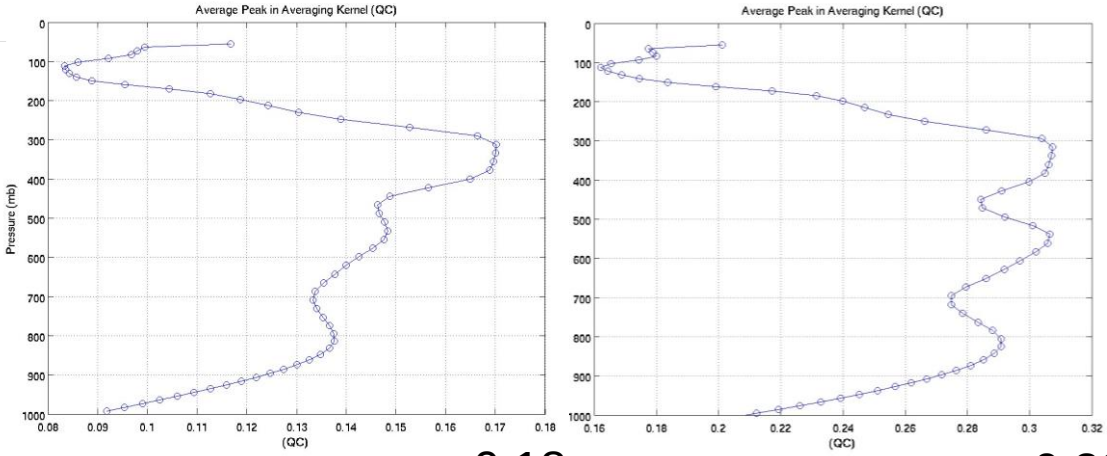
AIRS (45x45 km) d04, 13d

ARIES (2x2km) d04, 1d
(Similar for GEO at 5km)

RMS Temperature Error (K) between Simulation and Nature Run



Average Peak in AK For Temperature

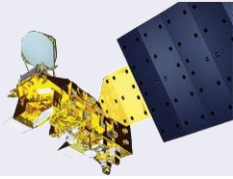


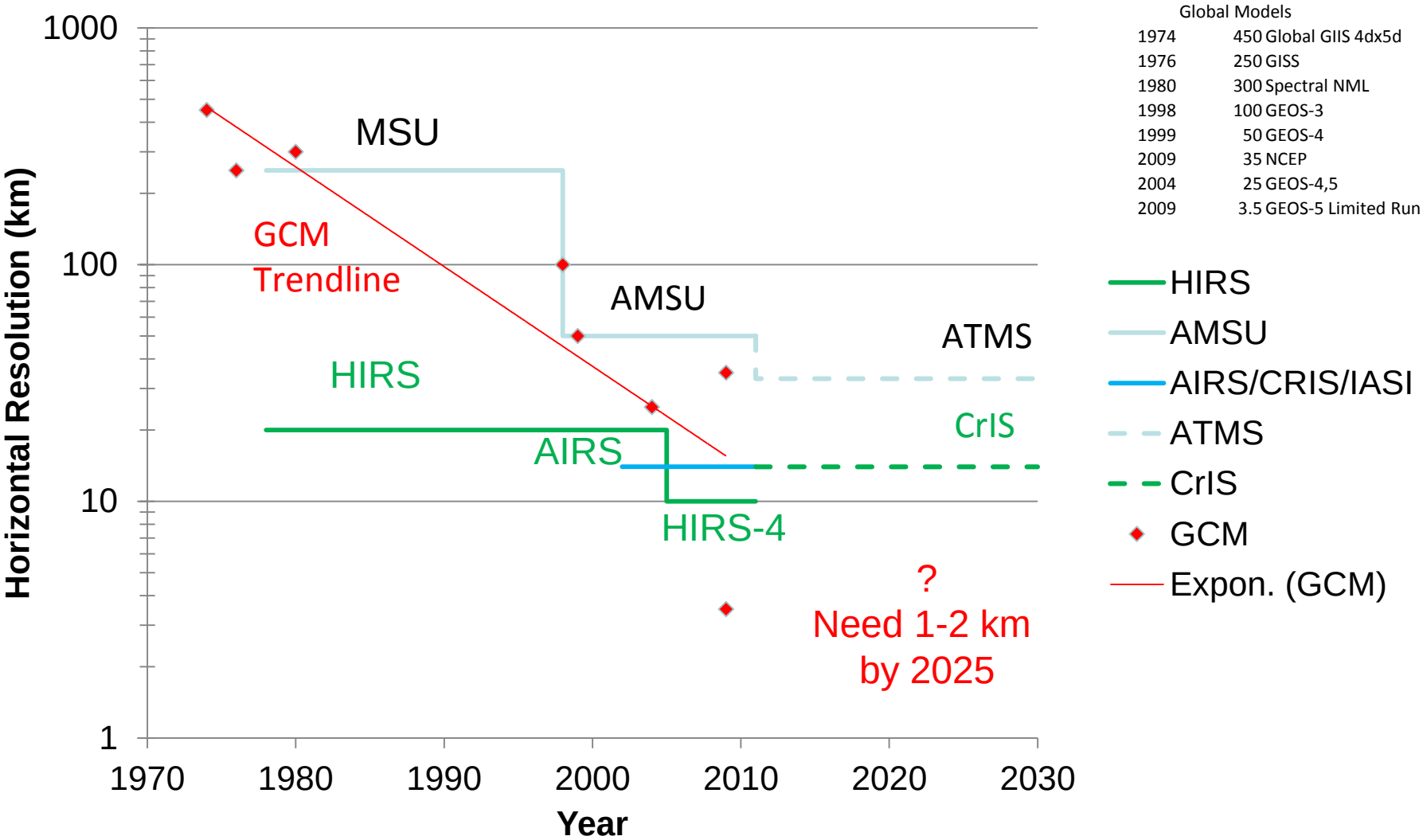
0.18

0.32

T.S. Pagano, W. Mathews, F. Irion, E. Sturm, "Simulating satellite infrared sounding retrievals in support of observing system simulation experiments (OSSEs)", Proc. SPIE 9222, San Diego, CA (2014); doi: 10.1117/12.2061468

Higher Spatial Resolution Needed to Initialize and Validate Next-Gen GCM's

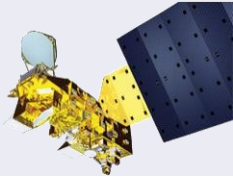




Global Models

1974	450	Global GIIS 4dx5d
1976	250	GISS
1980	300	Spectral NML
1998	100	GEOS-3
1999	50	GEOS-4
2009	35	NCEP
2004	25	GEOS-4,5
2009	3.5	GEOS-5 Limited Run

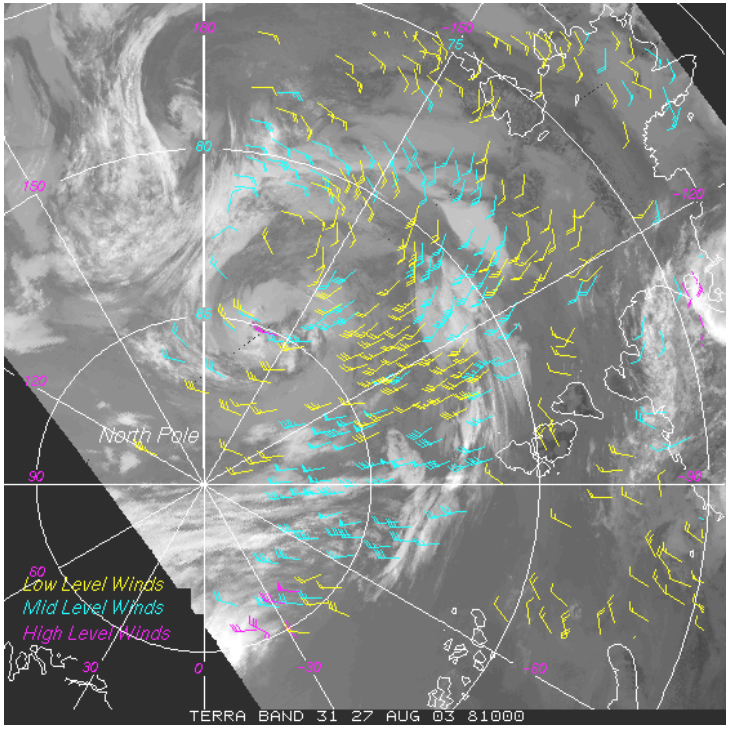
Higher Spatial Resolution Enables MODIS-Like WV Winds



Over 15 Bands on MODIS Not Continued on VIIRS; Mostly Atmospheric Products

MODIS Water Vapor Winds*

6 Hr Improvement on 5 Day Forecast



*Capability not continued by JPSS

MODIS Bands Not Continued on VIIRS

MODIS: 36, VIIRS 22, 15 Bands Deleted, DNB Added

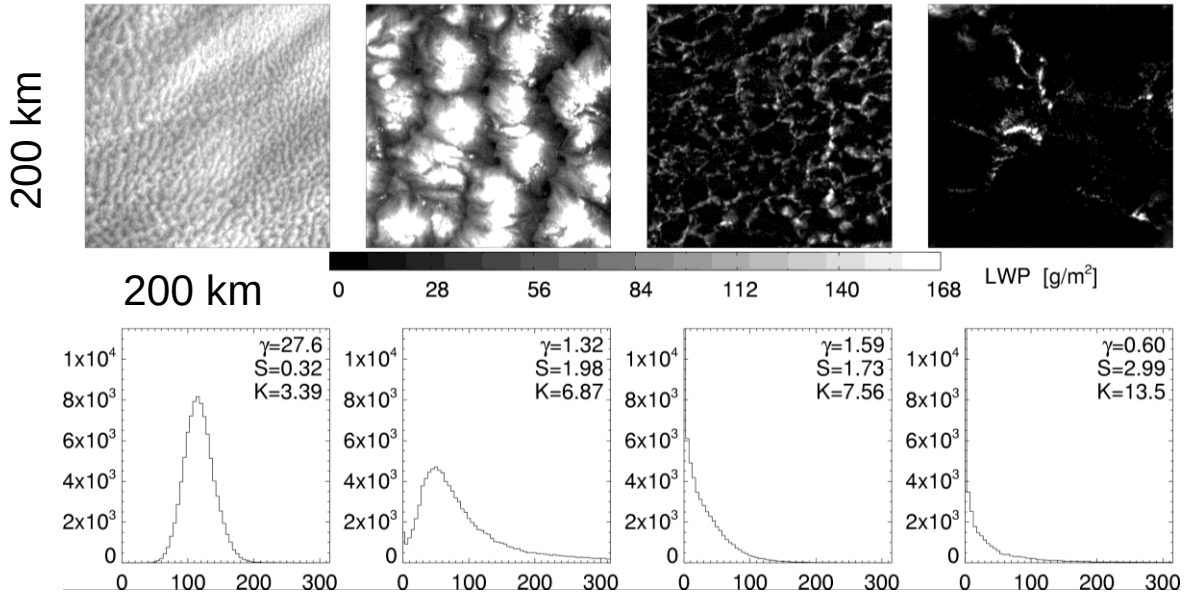
#	λctr		Δλ			Purpose
11	531	nm	10	nm		Ocean Color
14	678	nm	10	nm		Fluorescence
17	905	nm	30	nm		Precip Water
18	936	nm	10	nm		Precip Water
19	940	nm	50	nm		Precip Water
21	3.960	µm	0.06	µm		Fire Detection
22	3.959	µm	0.06	µm		SST
25	4.516	µm	0.067	µm		Atm. Temp
27	6.715	µm	0.360	µm		Atm. Water
28	7.325	µm	0.300	µm		Atm. Water
30	9.730	µm	0.300	µm		Ozone
33	13.335	µm	0.300	µm		Atm. Temp
34	13.635	µm	0.300	µm		Atm. Temp
35	13.935	µm	0.300	µm		Atm. Temp
36	14.235	µm	0.300	µm		Atm. Temp

See MiSTIC Winds Talk by Kevin Maschhoff

Higher Spatial Resolution Sounders Needed to Support Studies of Clouds and PBL

Near LA CC~100%

Near Hawaii CC~10%

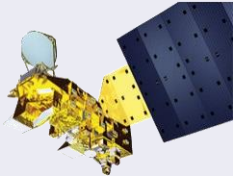


LWP from visible channel, Δx=1km, Δt=30 min, 3 years of data (1999-2001) ➔ 100,000 snapshots of 200 km^2

Kawai & Teixeira, JCLI, 2010, 2012

From Gaussian stratocumulus to skewed cumulus

Two Major Advancements Allow Higher Spatial Resolution and Smaller Apertures

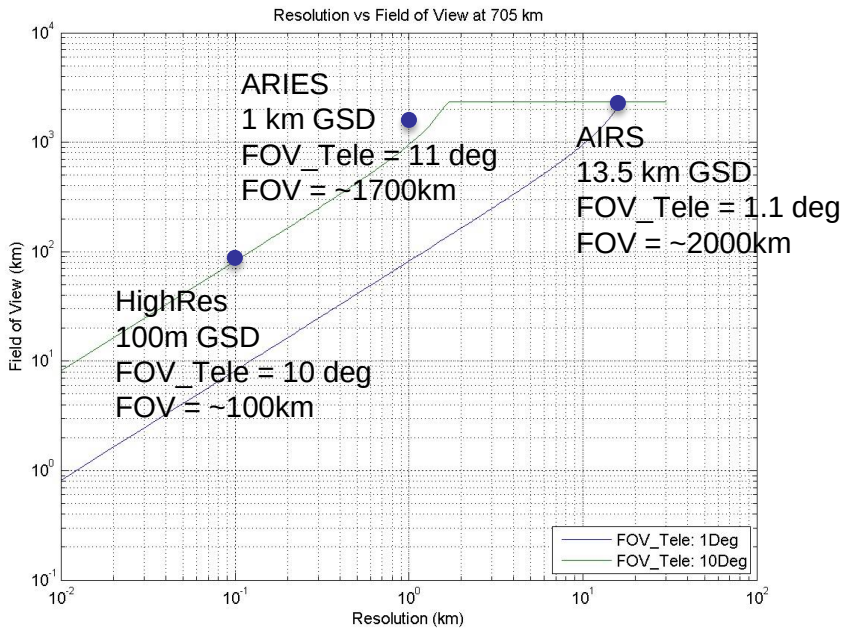


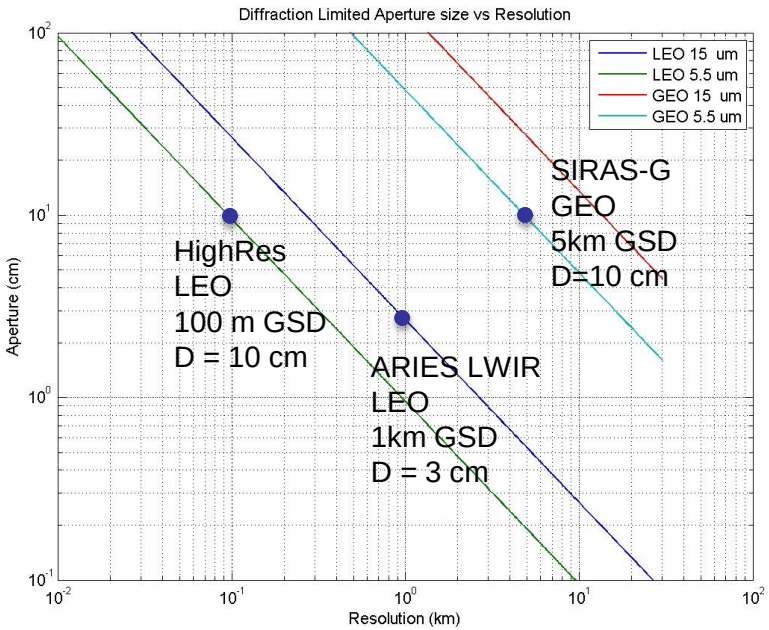
Wide Field Optics and
Large Format FPA's

Higher Spatial Resolution

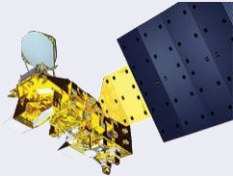
MWIR-Only Sounding
Reduces Diffraction Limit

Smaller Apertures

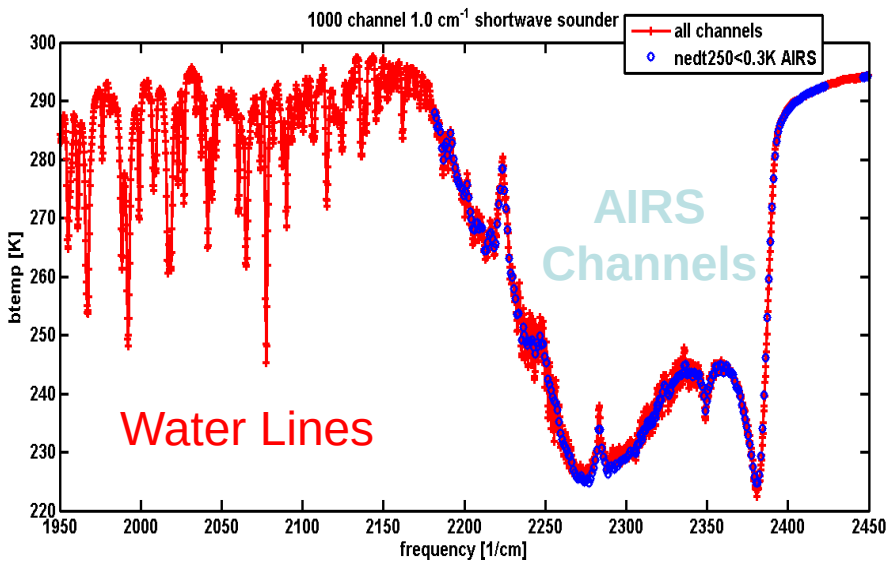




Test using AIRS data demonstrates MWIR-Only temperature sounding



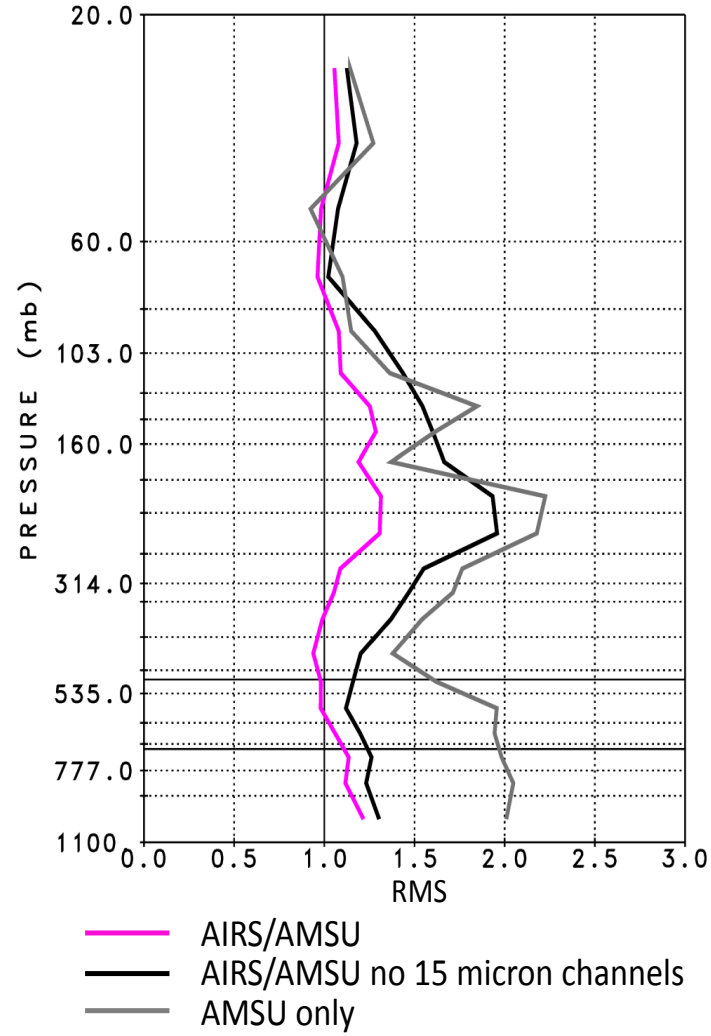
MWIR has CO_2 T-Sounding Band and Water Vapor Band



H. Aumann

IASI Spectrum

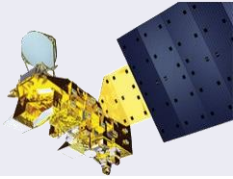
MWIR band range and resolution have been refined since this early study to improve sensitivity in water vapor



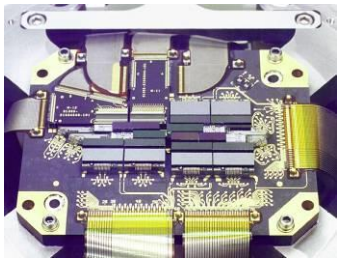
Pagano, T.S., Aumann, H., Gerber, A., Kuai, L., Gontijo, I., DeLeon, B., Susskind, J., Iredell, L., Bajpai, S., "Requirements for a Moderate-resolution Infrared Imaging Sounder (MIRIS)", Proc. SPIE 8870-7, San Diego, CA (2013).

J. Susskind (GSFC)

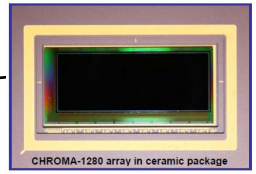
New Technologies Enable Hyperspectral and High Spatial Resolution in MIRIS



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



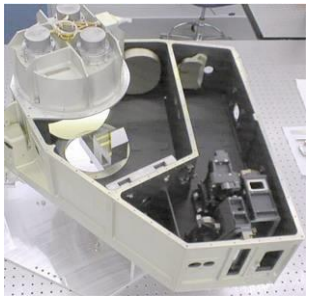
Teledyne
HgCdTe
14.5 µm Cutoff
480 x (320-1600)

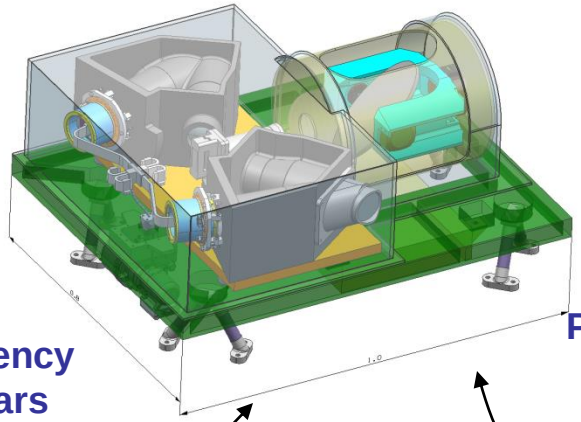


MODIS
Raytheon Vision Systems
PV/PC HgCdTe
4 FPAs
10 x ~10
400 x 400 um

SIRAS IIP1
Refractive 16˚
Grating Spectr
(Ball)

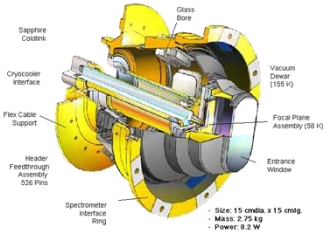
AIRS
Reflective 1.1˚
Grating Spectr



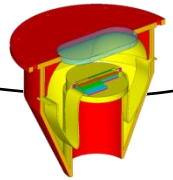


250x500m GSD. ±55˚
1920 Channels
3.7-14.5 µm
100 kg, 150 W
0.5 m^3, 40 Mbps

AIRS
Large Dewar

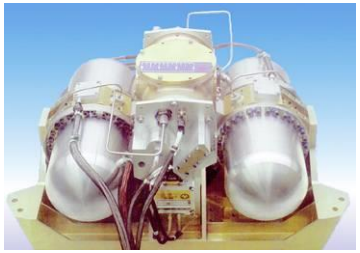


High Efficiency
Mini Dewars

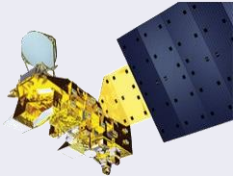


NGAS
Pulse Tube
Cooler

AIRS
Dual Pulse
Tube Coolers



PACE OCI/A and MIRIS Pixel Aggregation and VIIRS Compliance



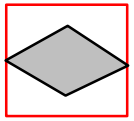
Instantaneous Footprint Projections

Nadir	±34.9° 1203 km	±47.6° 2005 km	±49.0° 2131 km	±56.1° 3039 km

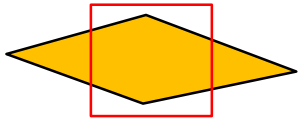
Increasing Scan Angle

OCI/A, "I" Bands

0.25 x 0.25 km
0.371 x 0.387 km



0.458 x 0.877 km
0.80 x 0.879 km

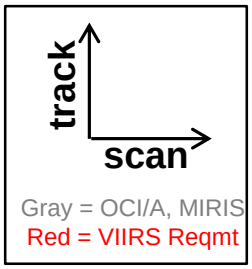


0.58 x 1.69 km
0.80 x 0.879 km

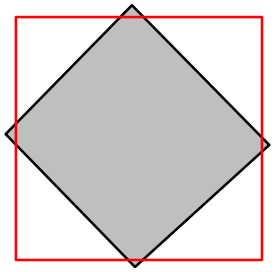
OCI/A, "M" Bands

3x1

0.75 x 0.25 km
0.742 x 0.259 km



VIIRS	OCI/A	MIRIS
Band	VSWIR	MLWIR
"I"	to 48.7°	to 34.9°
"M"	All Angles	to 47.6°

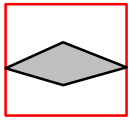


1.75 x 1.69 km
1.60 x 1.58 km

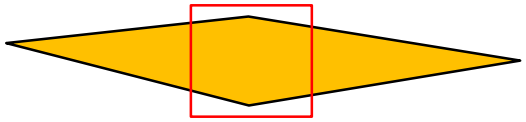
MIRIS, "I" Bands DNBI "DNB" Bands

1x2

0.25 x 0.5 km
0.371 x 0.387 km

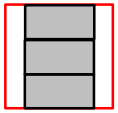


0.334 x 0.878 km
0.80 x 0.879 km



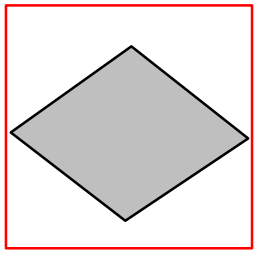
0.58 x 3.37 km
0.80 x 0.879 km

MIRIS, "M" Bands

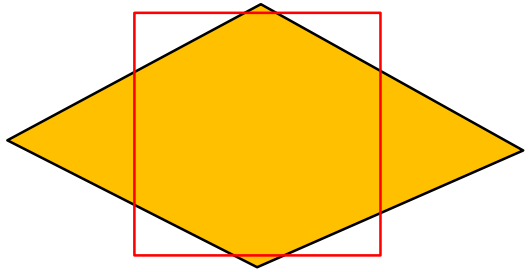


3x2

0.75 x 0.5 km
0.742 x 0.776 km



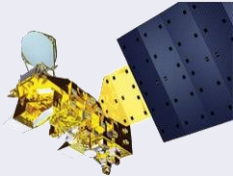
1.3 X 1.57 km
1.60 x 1.58 km



1.75 x 3.37 km
1.60 x 1.58 km

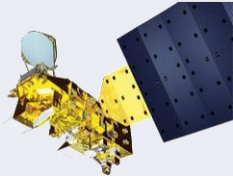
We concluded the loss of resolution at the edges of the swath has minimal impact

Challenges of New Direction for Developers of the Instruments and Data Products



- More detectors to calibrate.
- More “dead” or “bad” detectors
- Increased Cryocooling
- Higher Power Dissipation
- Spectral variability per IFOV (AIRS has 1)
- Higher Data Rates
- Increased On-board processing
- Faster retrievals with cloud handling
- Validation
- Increased Ground Processing Capacity
- Increased Data Volume
- Etc.
- Scientific and Operational users will face a whole new set of challenges (and benefits)

Summary



- Climate science, weather forecasting and applications expected to improve with higher spatial resolution IR Sounding
- Technology advancements enable significant reduction in instrument size and complexity while allowing higher resolution
- IR Imaging (like MODIS/VIIRS) and IR Sounding now possible
- New technology ready NOW to support IR sounder options
  - LEO Winds Sounder
  - GEO Sounder
  - LEO HighRes Climate Sounder
  - LEO Weather Imaging Sounder
  - LEO Composition Sounder
  - Others
- Next Steps
  - Continue Technology Demonstrations
  - Continue Retrieval and Product Simulations
  - Build Science, Operational, and Applications **User** Community Support