Next-Gen IR Sounding for Weather, Climate and Composition

NASA Sounder Science Team Meeting

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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

- **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

**Focus of this talk**
Higher Spatial Resolution Improves Feature Identification and Accuracy

Surface Emissivity

Current Resolution
AIRS 50 Km

Higher Resolution
(L. MODIS R. AIRS L1B)

Water Vapor

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

Supporting Hyperspectral IR Data Assimilation Study for NOAA/AOML

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

AIRS (45x45 km) d04, 13d
ARIES (2x2 km) d04, 1d
(Similar for GEO at 5km)

RMS Temperature Error (K) between Simulation and Nature Run

Average Peak in AK For Temperature

Linear retrieval to simulate AIRS

\[ x_{est} = x_o + A(x_T - x_o) \]

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

\[ f_{T,i} = a_{T,i} + b_{T,i} \ln(p_{_cld}) + \ldots \]

\[ c_{T,i} (f_{_cld}), \ i = 1 \text{ to } 23 \]

Similar for water vapor with add'l \( q_{_tot} \)

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

Global Models
- 1974: 450 Global GISS 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

- Need 1-2 km by 2025

Horizontal Resolution (km)
- MSU
- GCM Trendline
- AMSU
- ATMS
- HIRS
- AIRS
- CrIS
- HIRS-4

Year
- 1970
- 1980
- 1990
- 2000
- 2010
- 2020
- 2030

Expon. (GCM)
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

MODIS Bands Not Continued on VIIRS
MODIS: 36, VIIRS 22, 15 Bands Deleted, DNB Added

<table>
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*Capability not continued by JPSS

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, $\Delta x=1\text{km}$, $\Delta t=30\text{ min}$, 3 years of data (1999-2001) $\Rightarrow$ 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

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Higher Spatial Resolution

MWIR-Only Sounding Reduces Diffraction Limit

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Smaller Apertures
MWIR has CO₂ T-Sounding Band and Water Vapor Band

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

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

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

AIRS Large Dewar
High Efficiency Mini Dewars

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

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 m³, 40 Mbps

NGAS Pulse Tube Cooler

AIRS Dual Pulse Tube Coolers
### Instantaneous Footprint Projections

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<tr>
<td>Nadir</td>
<td>Increasing Scan Angle</td>
<td>Increasing Scan Angle</td>
<td>Increasing Scan Angle</td>
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<tr>
<td>±34.9°</td>
<td>1203 km</td>
<td>±47.6°</td>
<td>2005 km</td>
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<td>0.25 x 0.25 km</td>
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<tr>
<td>0.371 x 0.387 km</td>
<td>0.742 x 0.259 km</td>
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**OCI/A**
- Red = VIIRS Reqmt
- Gray = OCI/A, MIRIS

**MIRIS**
- “I” to 48.7° to 34.9°
- “M” All Angles to 47.6°

** DNBI**
- “DNB” Bands

**VIIRS**
- Band VSWIR MLWIR

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)
• 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