Polar-orbiting Sounder Applications for Alaska

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Satellites with Ultra-spectral Sounders

Aqua (13:30 LST)

Suomi NPP/JPSS (13:30 LST)

Metop A & B (10:20 & 9:30 LST)
AIRS
Atmospheric InfraRed Sounder
Grating spectrometer
166 kg, 256 W
13.5 km FOV at nadir, contiguous
Launched on NASA Aqua in 2002

IASI
Infrared Atmospheric Sounding Interferometer
Michelson interferometer
236 kg, 210 W
2x2 12 km FOVs at nadir, non-contiguous
Launched on Metop-A in 2006

CrIS*
Cross-track Infrared Sounder
Michelson interferometer
146 kg, 110 W
3x3 14 km FOVs at nadir, contiguous
Launched on Suomi NPP, 28 Oct 2011
* Passive cooler with vibration isolation that was not deployed

CrIS ~ the size of HIRS
Noise Comparison

CrIS, AIRS, IASI

SNPP CrIS Performance is excellent

CrIS NEN
4x smaller in
15μm CO₂ band
Ultra-spectral Sounding

- First Demonstrated with the UW High-resolution Interferometer Sounder (HIS) from the NASA ER-2 Aircraft
- High S/N Enables Accurate De-convolution of Vertically Smeared Thermal Radiance Signals

High Vertical Resolution Provided by High Spectral Resolution

- Spectrum
  Several thousand spectral channels are observed to profile the atmosphere with high vertical resolution

- Soundings
  Ultra-spectral resolution sounder provides 1 K / 15% temperature and moisture accuracy for 1-2 km layers
The dual-regression retrieval technique* is used to retrieve the following single FOV products under clear and cloudy conditions from input direct broadcast or archived AIRS, IASI and CrIS L1 radiance files:

- atmospheric temperature [K] at 101 pressure levels
- atmospheric moisture [g/kg] at 101 pressure levels
- atmospheric ozone [ppmv] at 101 pressure levels
- atmospheric relative humidity [%] at 101 pressure levels
- atmospheric dew point temperature [K] at 101 pressure levels
- surface skin temperature [K]
- surface emissivity (at full spectrum)
- total precipitable water [cm]
- precipitable water 1 (900 hPa to surface) [cm]
- precipitable water 2 (700 to 900 hPa) [cm]
- precipitable water 3 (300 to 700 hPa) [cm]
- total ozone amount (vertically integrated) [Dobson units]
- lifted index [°C]
- convective available potential energy [J/kg]
- CO2 concentration [ppmv]
- cloud top pressure [hPa]
- cloud top temperature [K]
- cloud optical thickness
- effective cloud emissivity
- cloud mask (values: 0 clear, 1 cloud)

Available at http://cimss.ssec.wisc.edu/cspp/

- Weisz, E., W. L. Smith, N. Smith (2013), Advances in simultaneous atmospheric profile and cloud parameter regression based retrieval from high-spectral resolution radiance measurements, Accepted for publication in *JGR-Atmospheres*. 
Gulf of Alaska low pressure system (26 Sept 2012)

Suomi NPP VIIRS 0.7 μm Day/Night Band and 11.45 μm IR channel

From: http://cimss.ssec.wisc.edu/goes/blog/archives/date/2012/09/26
Gulf of Alaska low pressure system (26 Sept 2012)

CrIS 20120926 225217, 230017
BT [K] at 910.0 cm$^{-1}$

http://rammb.cira.colostate.edu/projects/npp/
Skew-T (26 Sept 2012)

CrIS 2012-09-26
Temperature [K] at 496.6 hPa

220
230
240
250
260

1
2
GDAS
RTVL
CTOP

3
4
5
6

CrIS 2012-09-26 UTC Pixel 78/11 (978)
CrIS 2012-09-26 UTC Pixel 60/82 (2850)
CrIS 2012-09-26 UTC Pixel 59/66 (5909)
CrIS 2012-09-26 UTC Pixel 44/101 (9044)
CrIS 2012-09-26 UTC Pixel 65/82 (7355)
CrIS 2012-09-26 UTC Pixel 53/132 (11843)
CrIS CTH Comparison with CALIPSO (26 Sept 2012)

CALIOP (2012-09-26T21-58-07ZD) Total Attenuated Backscatter 532 nm, CrIS granule 23:00 UTC
Sounding retrievals provide 3-d structure of storm systems
Temperature Surface to 100 hPa Movie (26 Sept 2012)
IASI, CrIS and AIRS (01 Nov 2012)

21:29 UTC
IASI 20121101 212954
BT [K] at 910.0 cm⁻¹

23:19 UTC
CrIS 20121101 231921
BT [K] at 910.0 cm⁻¹

23:47 UTC
AIRS 20121101 234731 G239
BT [K] at 911.6 cm⁻¹
IASI and CrIS differences 500 hPa RH & CTOP (01 Nov 2012)

21:29 UTC

IASI RH [%] at 497 hPa

23:19 UTC

CrIS RH [%] at 497 hPa

~ 1.8 hour change

CrIS-IASI RH [%] at 497 hPa

IASI CTOP [hPa]

CrIS CTOP [hPa]

CrIS-IASI CTOP [hPa]
CrIS and AIRS differences 500 hPa RH & CTOP (01 Nov 2012)

23:19 UTC
CrIS RH [%] at 497 hPa

23:47 UTC
AIRS RH [%] at 497 hPa

~ 38 min change
AIRS-CrIS RH [%] at 497 hPa

CrIS CTOP [hPa]

AIRS CTOP [hPa]

AIRS-CrIS CTOP [hPa]
IASI and CrIS differences 500 hPa T & LI (01 Nov 2012)

21:29 UTC
IASI Temperature [K] at 497 hPa

23:19 UTC
CrIS Temperature [K] at 497 hPa

~ 1.8 hour change
CrIS-IASI Temperature [K] at 497 hPa

IASI Lifted Index [°C]

CrIS Lifted Index [°C]

CrIS-IASI Lifted Index [°C]
CrIS and AIRS differences 500hPa T & LI (01 Nov 2012)

23:19 UTC
CrIS Temperature [K] at 497 hPa
AirS Temperature [K] at 497 hPa
CrIS Lifted Index [°C]

23:47 UTC
AirS Temperature [K] at 497 hPa
AirS-CrIS Temperature [K] at 497 hPa
AirS Lifted Index [°C]

~ 38 min change
AirS-CrIS Lifted Index [°C]
28 Jan 2013 – satellite overpasses used to create atmospheric water vapor animation

Overpasses 01-28-2013

Note: AIRS 23:53 (G239) and 23:59 (G240) from 01-27-2013
Moisture Changes and Motion from Consecutive Polar Satellite Overpasses of North Alaska

Relative Humidity [%] at 300 hPa Movie (27 - 29 Jan 2013)
AIRS and ATMS H₂O Retrieved Winds at 400hPa

AIRS 20 July 2012 0505 UTC
ATMS 20 July 2012 0551 UTC

Specific humidity retrievals.
All winds (blue); Quality controlled winds(yellow)

Consecutive Water Vapor Soundings Provide Altitude Resolved Atmospheric Motion Vectors
Summary

• There are four satellites in Polar orbit carrying ultraspectral sounding instruments

• These four satellites provide high temporal resolution sounding and imagery for the Alaskan region

• The sounder data provides quantitative interpretation of weather imagery (e.g., the altitude of cloud and moisture features)

• High temporal frequency of polar satellite soundings at high latitudes enables the observation of atmospheric tendencies (e.g., stability change) and moisture flux and wind profiles
## Comparison of CrIMSS and NUCAPS EDRs

<table>
<thead>
<tr>
<th></th>
<th>CrIMSS-EDR</th>
<th>NUCAPS-EDR</th>
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<tbody>
<tr>
<td><strong>Methodology</strong></td>
<td>Simultaneous Optimal Estimation</td>
<td>Sequential Singular Value Decomposition</td>
</tr>
<tr>
<td><strong>Channels used</strong></td>
<td>All, except non-LTE in daytime</td>
<td>Selected subsets</td>
</tr>
<tr>
<td><strong>Clouds</strong></td>
<td>Cloud clearing, 3-cluster approach</td>
<td>Cloud clearing, 9-FOV approach</td>
</tr>
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<td><strong>Forward model</strong></td>
<td>OSS for both IR and MW</td>
<td>Sarta for IR, MIT for MW</td>
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<tr>
<td><strong>Apodization</strong></td>
<td>Blackman-Harris</td>
<td>Hamming</td>
</tr>
<tr>
<td><strong>Regularization</strong></td>
<td>$T/q/O3/\varepsilon$ covariance matrices</td>
<td>$dR/dX$ for state parameters held constant + smoothing</td>
</tr>
<tr>
<td><strong>EDRs</strong></td>
<td>AVTP, AVMP, AVPP</td>
<td>AVTP, AVMP, $z(p)$, CCR, O3, CO, CO2, CH4, HNO3, SO2, N2O,</td>
</tr>
<tr>
<td><strong>IPs</strong></td>
<td>O3-IP</td>
<td>SST, LST, emissivity, cloud fraction and pressures, convective parameters</td>
</tr>
<tr>
<td><strong>RIPs</strong></td>
<td>RIPS: SST, LST, emissivity</td>
<td></td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td>42, 1-km AVTP layers</td>
<td>All profiles on 100 levels (~0.025 km)</td>
</tr>
<tr>
<td></td>
<td>22, 2-km AVMP layers</td>
<td>Full state (can compute radiances).</td>
</tr>
<tr>
<td><strong>Maturity Schedule</strong></td>
<td>Beta: July 2012</td>
<td>Beta: Apr. 2012 (internal only)</td>
</tr>
<tr>
<td></td>
<td>Provisional: Dec. 2012</td>
<td>Provisional: July 2012 (internal only)</td>
</tr>
<tr>
<td></td>
<td>Stage.1 Validated: June 2013</td>
<td>Stage.1 Validated: Feb. 2013</td>
</tr>
<tr>
<td></td>
<td>Stage.2 Validated: Dec. 2013</td>
<td>Stage.2 Validated: Apr. 2014</td>
</tr>
</tbody>
</table>
Statistics for May 15, 2012 focus day in which Aqua and NPP orbits has high coincidence.
## Trace Gas Products for Hyperspectral IR Sounders

<table>
<thead>
<tr>
<th>gas</th>
<th>Range (cm$^{-1}$)</th>
<th>Precision (Goal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O$_3$</td>
<td>1025-1050</td>
<td>10%</td>
</tr>
<tr>
<td>CO</td>
<td>2080-2200</td>
<td>15%</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>1250-1370</td>
<td>20 ppb</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>680-795</td>
<td>2 ppm</td>
</tr>
<tr>
<td></td>
<td>2375-2395</td>
<td>2 ppm</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>1340-1380</td>
<td>500%</td>
</tr>
<tr>
<td>HNO$_3$</td>
<td>860-920</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td>1320-1330</td>
<td>25%</td>
</tr>
<tr>
<td>N$_2$O</td>
<td>1250-1315</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>2180-2250</td>
<td>10%</td>
</tr>
<tr>
<td>CFCl$_3$ (F11)</td>
<td>830-860</td>
<td>20%</td>
</tr>
<tr>
<td>CF$_2$Cl (F12)</td>
<td>900-940</td>
<td>20%</td>
</tr>
<tr>
<td>CCl$_4$</td>
<td>790-805</td>
<td>50%</td>
</tr>
</tbody>
</table>
Methane Sources

- Tropical wetlands: 16%
- Rice paddies: 13%
- Biomass burning: 7%
- Animal wastes: 5%
- Domestic ruminants: 13%
- Termites: 2%
- Energy (pipes, wells, coal mines): 18%
- Landfills: 7%
- Wastewater: 4%
- Others: 7%

Ref.: Lelieveld, 1998 & Houwelling 2002 (600 Tg total)

Note: Approximately 50% of sources are anthropogenic

Trees (Keppler et al. 2005) may contribute 62-235 Tg (10-35%), mostly in tropics
AIRS CH$_4$ Kernel Functions are Sensitive to H$_2$O(p) & T(p)

- **Polar**: Isothermal vertical structure weakens sensitivity.
- **Mid-Latitude**: 
- **Tropical**: Moisture optical depth pushes peak sensitivity upwards.
Also providing the vertical information content to understand CH4 product

AIRS mid-trop measurement column

CH4 total column f/ transport model (Sander Houweling, SRON)

Fraction Determined from AIRS Radiances

Peak Pressure of AIRS Sensitivity
CMDL Flask Data Poker Flats, Alaska shows that the Seasonal cycle is a function of altitude.

- **7.5 km**
  - **385 mb**

- **5.5 km**
  - **500 mb**

- **1.5 km**
  - **850 mb**

**Surface Flasks (Barrow)**
Example of AIRS CO Product and Use of Trajectory Models

- **July 2004 Fires in Alaska**

- **CO from Alaskan fires was transported to the lower atmosphere in SE of US**

- **CO from southern Alaska Fires was transported to Europe at high altitudes (5 km)**
July 2004 AIRS Daily Global CO

AIRS CO at 500 mb on 20040701

CO Mixing Ratio (ppbv) at 500 mb

Range: 80 to 160+
Local PM MODIS Aqua AOD on 20040718

From Wallace McMillan, UMBC

Local PM AIRS CO at 500 mb on 20040718

CO Mixing Ratio (ppbv) at 500 mb