NOAA Unique Products from AIRS, IASI and CrIS, and Near-Real-Time MODIS/AIRS Data Distribution

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MISSION: Provide leadership, guidance, and direction for NESDIS research, development, and applications activities with respect to satellites and satellite data.

ORA develops scientific algorithms, applications, and product processing systems for POES and GOES. ORA provides calibration of satellite instruments, algorithms to derive geophysical parameters from radiances, validates satellite products, conducts training, transfers technology to operations, and provides sustained science support in the fulfillment of NOAA’s mission.
NOAA Satellite Products

- **Atmosphere**
  - Temperature soundings
  - Moisture soundings
  - Winds
  - Clouds
  - Aerosols
  - Earth Radiation Budget
  - Precipitation
  - Ozone

- **Ocean**
  - Surface temperature
  - Ice cover
  - Surface winds
  - Color
  - Sea level

- **Land**
  - Vegetation condition
  - Snow pack characteristics
  - Other land characteristics
    (e.g., albedo, skin temperature, soil wetness, insolation)
  - Fire locations/Smoke Plumes
• Risk Reduction Activities for all NPP and NPOESS sensors and scientific algorithms, including prelaunch and postlaunch validation

• Metop Science teams –IASI, ASCAT,GOME, GRAS – provide scientific recommendations and algorithms

• Developing NOAA-unique operational products for NPOESS and METOP.
• Definition of NOAA-Unique Products
• List the NOAA-Unique Products we plan to produce from NPP
• Focus on high spectral resolution infrared sounders and risk reduction activities using AIRS.
• NOAA-Unique Products for IASI and CrIS
• Near-real-time MODIS Processing
They are products required by our customers but not provided by the core (official) NPOESS and METOP systems for a number of reasons (e.g. rapidly evolving user requirements, blended products)

Examples:
- Major NWP centers require CrIS cloud-cleared radiances using ATMS and VIIRS for cloud detection and correction instead of EDRs
- Carbon products (CO2, CH4, and CO) from CrIS and IASI
- Snow and hazard mapping products are derived from POES, GOES and EOS data
- Reformatting the data into BUFR
• Radiance Products - compressed radiance data from CriS/ATMS (Spatial, Spectral and EOF data reductions), cloud-cleared radiances, integrated VIIRS XDRs at the CrIS resolution, and carbon products
• Reformat NPOESS EDR products for AWIPS
• Radiation budget parameters (e.g. OLR) from CrIS and VIIRS
• Blended Snow Products from VIIRS, ATMS and GOES
• Blended Ozone products from CrIS and OMPS
• Vegetation – weekly global maps of green vegetation fraction and leaf area index, drought index, vegetation health
• Hazard GIS products – Smoke, Fire, Aerosols, Flash Flood, Precipitation
• Coastwatch Ocean Color Products, Coral Bleaching and Blended SST
• Microwave-only products from ATMS (temperature, moisture, cloud liquid water, precipitation, rainfall rates, surface emissivity, snow/ice)
• Daily global, regional maps (gridded data) of all EDRs and SDRs for the science community and for validation
Products:
- Water vapor (soundings, fluxes, winds)
- Temperature (sounding, stability)
- Carbon monoxide concentration (2 Layers) and total CO2 conc.
- Methane concentration (total column)
- Ozone concentration (4 Layers)
- Surface Temperature and emissivity
- Clouds (altitude, optical depth, microphysical properties, winds)
- Aerosol Concentration and Depth
Advanced IR Sounders 2002-2020

- EUMETSAT IASI - Infrared Atmospheric Sounding Interferometer (2006) (12 km)
- NPOESS CrIS - Cross-track Infrared Sounder (2006) (15 km)
- GOES-R HES - Hyperspectral Environmental Suite (2012)
Temperature Accuracy Comparisons
Moisture Accuracy Comparisons
Time series of low-level vertical moisture structure during 9 hours prior to Oklahoma/Kansas tornadoes on 3 May 1999

**Truth**

Note GIFTS retains strong vertical gradients needed to detect changes in convective instability

**Current GOES**

GIFTS traces moisture peaks and gradients with greatly reduced errors
Statistics of CO Retrieval from a simulation of a full day

RMS

Bias

Background Variability

IASI has most skill in lower troposphere
AIRS Was Launched on the Aqua Platform May 4, 2002

- AMSU-A1(3-15)
- AMSU-A2(1-2)
- MODIS
- HSB

Aqua Acquires 325 Gb of data per day

Delta II 7920
Risk Reduction Benefits

• Early demonstration of operational processing of high spectral resolution infrared sounder data prior to CrIS, IASI and GOES-R

• Early opportunity for forecast centers to learn how to assimilate advanced IR data

• Validation of EDR performance

• CrIS, IASI, GOES-R algorithms can be validated with real data
Airs & MODIS products are distributed through three main channels:

1. **NOAA NESDIS**
   - NWP Centers
     - NCEP
     - Navy
     - ECMWF
     - UK Met Office
     - more

2. **GSFC DAAC**
   - Science Community
   - Public

3. **Direct Broadcast**
   - Universities
   - Local Weather Stations
   - Brazil (INPE)
   - China
   - DoD
   - Other International

These channels include:

- **NWP Centers**
  - NCEP
  - Navy
  - ECMWF
  - UK Met Office
  - more

- **Science Community**
  - Public

- **Universities**
  - Local Weather Stations
  - Brazil (INPE)
  - China
  - DoD
  - Other International
AMSU is a critical component of AIRS
provides retrievals in overcast conditions
- drives cloud clearing

AIRS acquires 2,916,000 spectra = 35 GByte/day
AIRS/AMSU Products for a ≈50 km footprint (varies w/ view angle), 324,000 footprints/day

- Cloud Cleared Radiance
- Temperature, 1K/ 1km
- Moisture, 5%
- Ozone, 5%
- Land/Sea Surface Temperature
- Surface Spectral Emissivity
- Surface Reflectivity
- Cloud Top Pressure
- Cloud Liquid Water (AMSU product)
- Cloud Fraction (per 15 km footprint).
- Carbon Monoxide, 15%
- Carbon Dioxide, 1%
- Methane, 1%
- Cirrus Cloud Optical Depth and Particle Size
NOAA-Unique AIRS Products

- Thinned radiance datasets for NWP data assimilation, including PC scores
- Reformatting products into BUFR
- Use of MODIS to improve AIRS cloud-cleared radiances.
- Noise-filtered radiances based on eigenvector decomposition
- Thinned datasets for scientific studies, including reprocessing for climate.
Figure 1(b). 500hPa Z Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern hemisphere, January 2004

AIRS provides large positive forecast impacts
Figure 3(b). 500hPa Z Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Northern hemisphere, January 2004
Vertical structure of analysis increments ...

No radiance assimilation (NORAD) increments

AIRS only assimilation minus NORAD increments

AMSUA only assimilation minus NORAD increments

HIRS only assimilation minus NORAD increments

The size and vertical structure of increments is higher with AIRS …
• Developing an operational processing system for IASI

• The IASI/AMSU/AVHRR system is being designed to process CrIS/ATMS/VIIRS data.

• These systems will be used to generate NOAA-unique products.
NOAA Unique IASI/CrIS Products
Derived from AIRS Algorithm

• Cloud Cleared Infrared Radiances
  – Using AMSU/AVHRR for IASI
  – Use ATMS/VIIRS for CrIS

• Quality Assurance and Monitoring.
  – L2 retrieval (EDR) products are a by-product of cloud clearing and will be used for the validation of the official IASI and CrIS L2 products.

• Trace Gases Products
  – AIRS→IASI/CrIS Product Continuity: Ozone, Carbon Monoxide.
  – Research Products: Methane, Carbon Dioxide.

• Aerosol & Cirrus Cloud research products.
  – Radiance QA and correction algorithms.
  – Potential long-term microphysical products.
NESDIS processing of MODIS data at Goddard

- NESDIS provides global near real-time MODIS data

- All level0, level1, level 2 and level 3 products are processed by NESDIS using code developed by NASA science teams (which includes NESDIS scientists)

- Level 0 data is delivered to the NASA RapidFire system, used to generate near real time fire images and application, and to the NASA Ocean Group to generate ocean color and SST

- Level 1B data are provided to the NASA Short-term Prediction Research and Transition Center (SPoRT) at Marshall.

- Level 1B data are provided to the ORA and CIMSS for MODIS polar cloud drift winds product which has had an extremely positive impact at JCSDA(NCEP and GMAO) and ECMWF

- L1B data are provided to the Navy (NRL at Monterey) who produce cloud/snow and cloud/dust discrimination imagery, using their own algorithms.
L1B data (images) are provided to NAVO at Stennis.

L1B data (images) are provided to the Air Force, primarily over the Middle East, for tactical support.

L1B and L2 (Snow) data are provided to the NIC (National Ice Center).

L1B and L2 (Oceans and SST) are provided to NOAA CoastWatch.

L1B data and images are provided to the NOAA Hazards Project in SSD, via SATEPS.

NESDIS is modifying the AIRS processing package to integrate MODIS data to improve cloud clearing.

NESDIS will provide in near real-time, globally, a subset of products from the existing MODIS science team suite of ocean color and SST products, plus some NOAA unique products, from both AQUA and TERRA platforms.
Summary

• NESDIS is processing and distributing AIRS and MODIS data in near real-time to prepare users for IASI and CrIS

• Improved forecasts using AIRS have been demonstrated.

• MODIS data have received favorable user feedback especially for monitoring fires, particulates (sandstorms, unhealthy air, fire), and ocean color (harmful algae bloom).

• NOAA-Unique Products will be generated for IASI, NPP and NPOESS and the algorithms can possibly be added to the direct readout software

• Because of lessons-learned acquired from processing and utilizing AIRS and MODIS data, the public should expect earlier operational utilization of IASI and CrIS observations/products.
Additional Slides
NOAA Satellite Products

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Atmospheric Products: Examples

Winds

Total Water Vapor

Temperature 500 mb

Rain Rate

Ozone

Aerosol Optical Thickness
Land Surface Products: Examples

Vegetation Health

Snow

Solar Radiation

Vegetation Health by Climate Divisions
06/23/2002

Stress Fair Favorable

Fire risk in Western USA from NOAA-16
* Late-season 2001 fire risk contributed to
* Early-season 2002 fire risk

Quebec Fires/Smoke
7/7/02
NWP AIRS Products

• Thinned Radiance files - BUFR and HDF
  a) center of 3 x 3 from every AMSU fov, ~300 channels. + AMSU (16 mbytes per orbit)
  b) 200 principal component scores using same thinning as a)
  c) Every 2nd 3 x 3 AIRS fovs (~300 channels) plus all AMSU
  d) cloud cleared a) and b)
  e) Full resolution AMSU

• Full resolution level 2 products – temperature, moisture and ozone, cloud amount, cloud height, surface emissivity, surface temperature
Why high spectral resolution?

- Improved spectral resolution results in
  
  **Sharper weighting functions**

  “Clean” channels (e.g. temperature channels not contaminated by water vapor lines)

- Many channels with sharper weighting functions combined with low noise improves vertical resolution

- Retrieval accuracy is greatly improved (temperature, moisture, skin temperature and surface emissivity)

- Resolving individual water vapor absorption lines allow detection of temperature inversions

- High spectral resolution allow the retrieval of trace gases
Current sounders do not meet user requirements

- Both WMO and NOAA user requirements are temperatures with an average error of 1 K over 1 km layers in the troposphere and humidity with an average error of 10 - 15%
- Current sounder accuracy is 2 K and 20-30% with a vertical resolution of 3-6 km
- High spectral resolution infrared sounders will have 1 – 2 km resolution
Data Compression

- 40 PCs for granule dependent EOFs
- 100 PCs for global independent EOFs
- The residuals are at noise levels and can be compressed and stored in a separate file for lossless compression
- Most people will not want the residuals.
- The picture to the left can be also used as a form of metadata to convince the user that the lossy compression is OK.
- Users can decide whether they want the residual file

No more than 100 Principal Component Scores will reconstruct all channels to noise level >> Good way to compress and distribute high spectral resolution infrared data (2000 channels)
AIRS Retrievals

- **Microwave-only retrieval of sfc emissivity, sfc temperature, sfc type and profiles of temperature, water vapor and cloud liquid water.**

- **AIRS retrieval of cloud amount and height, cloud cleared radiances, sfc emissivity, sfc temperature, and profiles of temperature, water vapor and ozone.**

- **AIRS has two retrieval steps – very fast eigenvector regression followed by a physical retrieval algorithm.**
RMS Differences (retrieval minus ECMWF)
Temperature Bias and RMS (Land and Sea Samples) With Cloud Test

- Temperature Bias and RMS (Deg. K), NSAMP=8238 (land2_dep.txt, RAOB LS Coef, TP2_LS)

Press (mb):

- AIRS
- ATOVS
- Requirement

Temperature RMS Error (K):

- AIRS-F258+AQ:AMSU (192 P)
- N-16(ATOVS)
- AIRS-F258+AQ:AMSU(192 P)
- N-16(ATOVS)
Water Vapor Error (Land and Sea Samples) With Cloud Test

Pressure (mB)

H2O RMS Percent Error %

AIRS- F258+AQ:AMSU(192 P)  N-16(ATOVS)

COLLOCATED RADIOSONDES
Our retrieval studies have demonstrated accurate AIRS retrievals in clear (solid) and even in cloudy conditions (dash curve).

AIRS performance is much better than AMSU even in cloudy conditions.

50% coverage
Total Precip Water (mm) Dec. 2003, Rettyp=0

TPW ECMWF

TPW AIRS

TPW CDAS

Total Precip Water (mm) Dec. 2003

CDAS-ECMWF

AIRS-ECMWF

AIRS-CDAS
Critical step is cloud clearing

- Only 5% of AIRS 14 km footprints are clear.
- NWP centers assimilate clear channels
- The population of lower tropospheric channels being assimilated is quite low (5%)
- The highest vertical resolution is in the lower troposphere
- Cloud-clearing increase population to more than 50%
- Retrievals from cloud-cleared radiances are significantly more accurate than AMSU-only.
Assume Scene Is Identical in FOV’s except Fraction of Cloud

\[ R_{\text{clear}}(i) = R_1(i) + \eta \times [R_1(i) - R_2(i)] \]

\[ \eta = a_1/(a_2-a_1) \]

\[ \eta = (R_{\text{clear-est}} - R_1)/(R_1-R_2) \]
Next AIRS NWP Challenge

• Assimilate cloud-cleared radiances to improve yield of observations in lower troposphere.

• NWP forecast accuracy is highly sensitive to accuracy of input data

• Need to provide very accurate cloud-cleared radiances

• MODIS will be used to improve accuracy of cloud-cleared radiances
Information Content of AIRS, IASI, and CrIS Radiances

Eigenvalues of $[R-<R>]W[R-<R>]^T$

- airs_v02.eig
- iasi_v03.eig
- cris_v03.eig