Sounder PEATE Services for Assessment of CrIMSS xDRs

Evan Fishbein

JPL/NASA

Overview and Context – NPP
NPP Mission Concepts

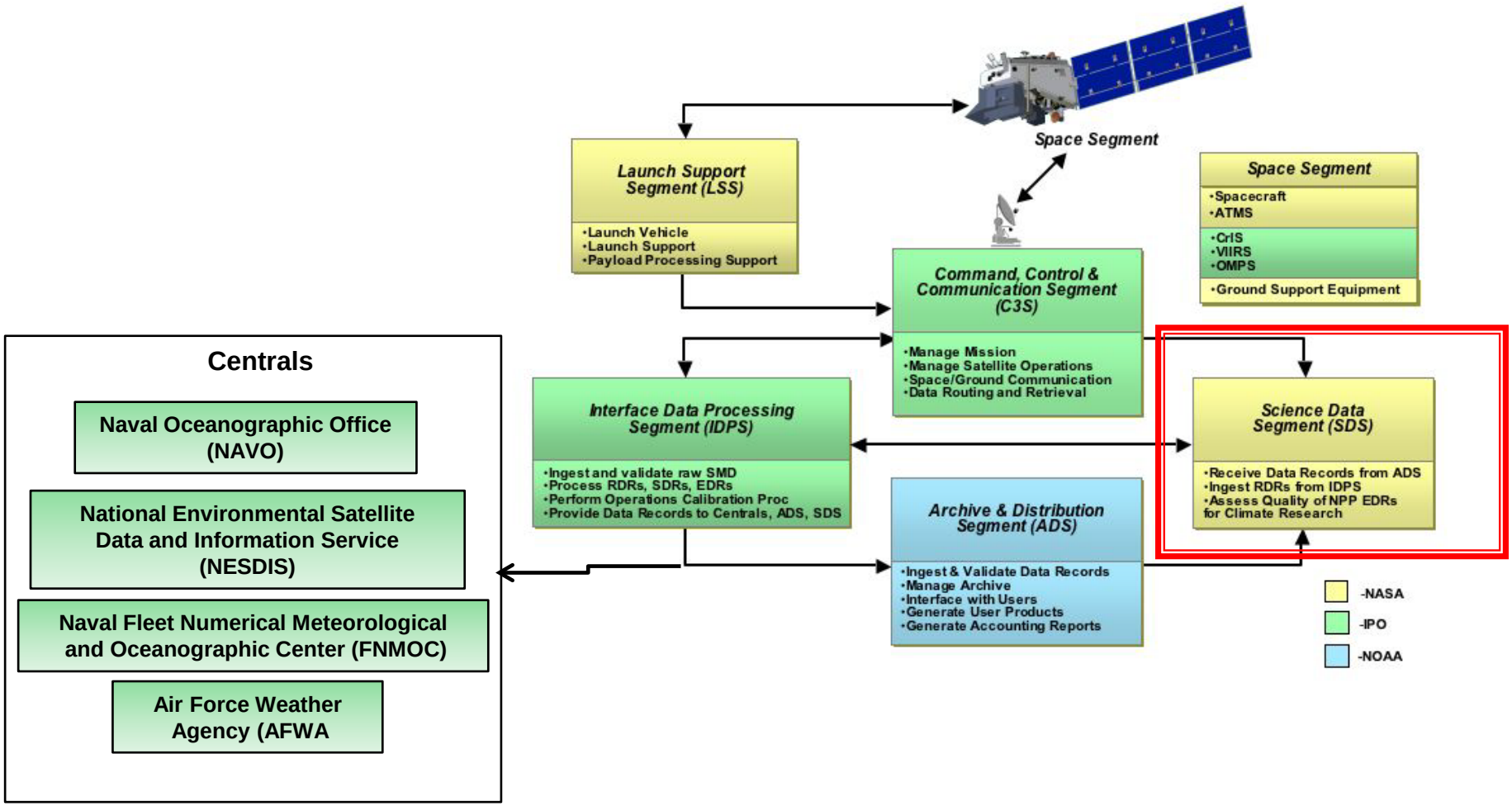
New Sensors

- Visible Infrared Imager Radiometer Suite (VIIRS): Multispectral scanning radiometer with 22 spectral bands
- Cross-Track Infrared Sounder (CrIS): Michelson interferometer with 1305 channels
- Advanced Technology Microwave Sounder (ATMS): Passive microwave radiometer with 22 channels
- Ozone Mapping & Profiling Sensor (OMPS): three hyperspectral imaging spectrometers (Nadir Mapper, Nadir Profiler, Limb Profiler)
- Clouds and the Earth's Radiant Energy System (CERES): Radiometer with 3 broadband channels (shortwave, longwave, total)

- The National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP)
  - Joint Mission involving NASA, NOAA and DOD
  - Managed jointly by the NPOESS Integrated Program Office (IPO)
- The NPP mission collects and distributes remotely-sensed land, ocean, and atmospheric data to the meteorological and global climate change communities
  - Responsible for transition from existing Earth-observing missions to the NPOESS.
- NPP provides risk reduction for NPOESS
  - Provides opportunity to demonstrate and validate new instruments and processing algorithms
  - Demonstrate and validate aspects of the NPOESS command, control, communications and ground processing capabilities prior to the launch of the first NPOESS spacecraft.

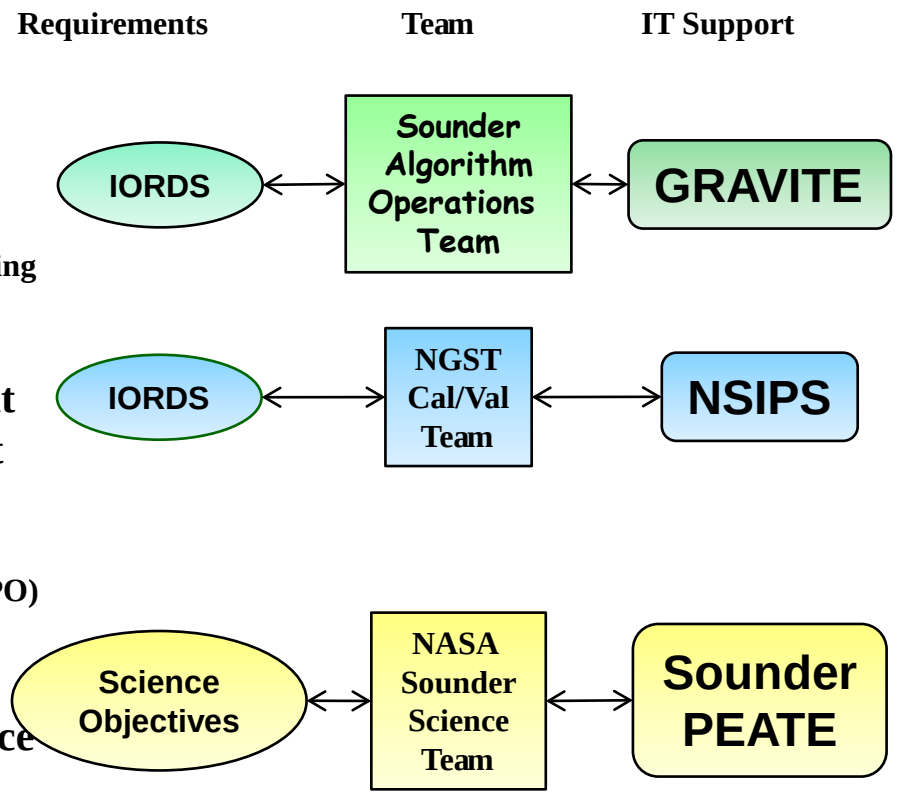
Overview and Context – The Science Data Segment

Top Level NPP System Diagram



Product Assessment Teams

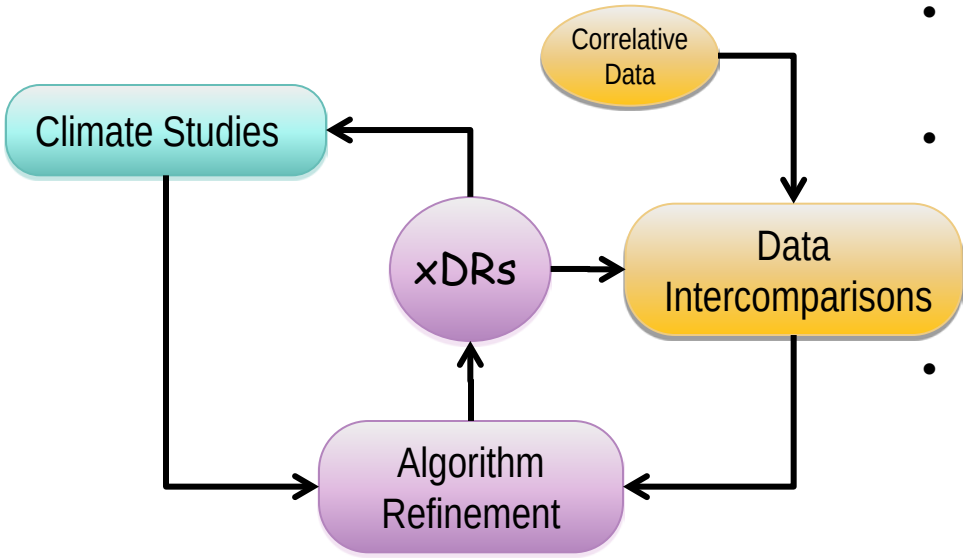
- **The NGST Cal/Val team (NCVT) supports assessment, updates and monitoring to ensure NPP/NPOES meet NPOESS Integrated Operational Requirements (IORD).**
  - **NSIPS – NPOESS Science Investigator-led Processing System (NGST)**
- **SOAT provides advise to IPO, independent assessments and recommendations to assist in meeting requirements**
  - **GRAVITE - Government Resource for Algorithm Verification, Independent Test, and Evaluation (IPO)**
- **NASA Sounder Science Team (NSST) assesses NPP products for continuing science from EOS platforms.**
  - **PEATE – Product Evaluation and Test Elements**



The Sounder Science Team assessments supports NASA science program by addressing impacts of measurement errors on characterizing climate trends, processes and modeling

Science Perspective

Roadmap for Obtaining Climate Data



- Iterative process of intercomparison and algorithm refinement
- Climate studies provide ultimate test of climate worthiness of data
- Climate studies include
  - **Trend analysis**
  - **Climate characterization and variability**
  - **Process studies**
- Algorithms evolve to produce data characterizing increasingly subtle phenomena
  - **Data is not suddenly "climate quality"**
- Goal is to produce data limited by instrument specs, not algorithms

The Sounder PEATE provides data, tools and infrastructure for facilitating each process above.

Assessment Strategies

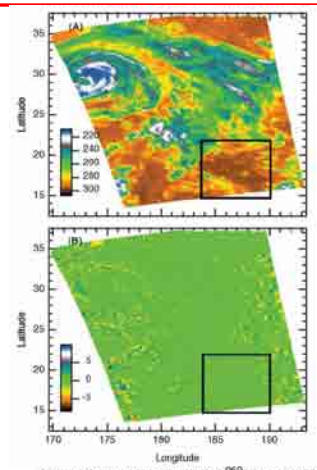
NSST, NCVT and SOAT have identified similar assessment strategies

- **Collect, analysis and summarize calibration data**
- **Offline IDPS and "science" EDR and SDR algorithms testing**
- **Use of "focus days" and intensive inter-comparison periods to reduce data volume**
- **Assessment based on scenes complexity and state-dependent sampling error**
- **Comparisons with correlative data**
- **Intercomparisons of observed and calculated radiances (BT)**
- **Cross-platform comparisons (SNO)**
- **Production of gridded products to facilitate scientific analyses**
- **Derived products (saturation) to improve usability and detect errors**
- **Retrieval of trace gases for atmospheric chemistry and improved T,q**

Calibration Data

Analyze and provide scientists with tools to interpret observations

- **Spatial "top hat" functions for characterizing clouds and scene heterogeneity**
- **Spectral Calibration**
- **Radiometric Stability**



From Kahn etal (2007): AIRS T_b^{960}(K) and AIRS - AIRS synthesized from MODIS

Application of AIRS spatial response functions to MODIS radiances

AIRS IR Radiometry Extremely Stable

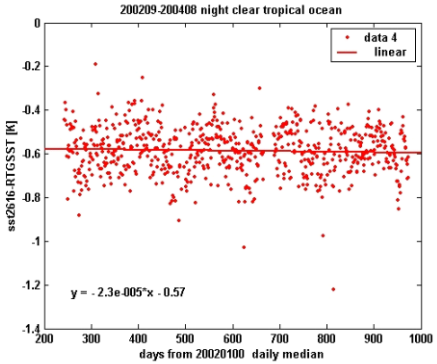
Instrument Stability
Fundamental to
Weather and Climate
Quality Observations

SST2616 compared to
RTG.SST at night
-0.57K bias observed
-0.37K bias expected

First principles using
NIST traceable
calibration

Stability better than
8 mK/Year

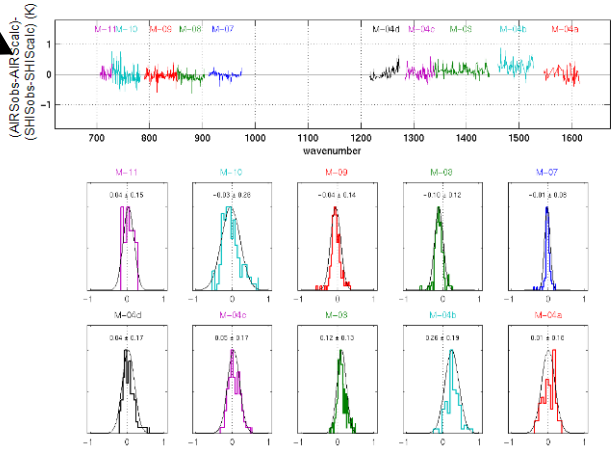
difference between observed
and expected bias
due to cloud contamination



Aumann et al 2004 "Evaluation of AIRS Data for Climate Applications"
SPIE 5570b Las Palmas September 2004

AIRS Radiometric Stability <8mK/Y
H. Aumann (JPL)

Final "Comparison 2" (21 November 2002)
Excluding channels strongly affected by atmosphere above ER2



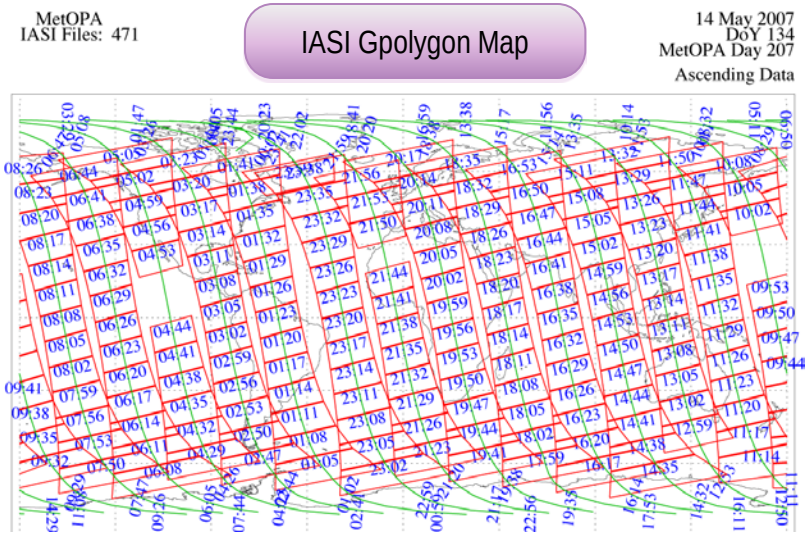
Scanning HIS Validates Rad Accy to 0.2K – H. Revercomb (UW)

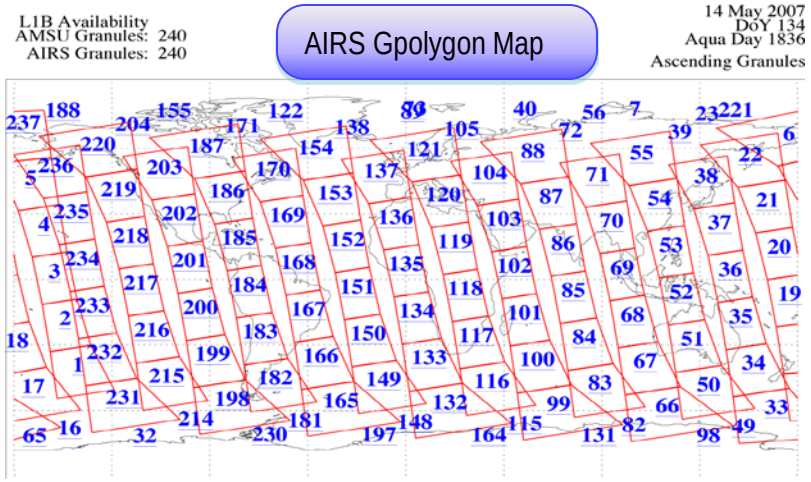
Scene Selection

Gpolygon Maps and Focus Days

- Gpolygon maps – a simple graphical display showing:
  - What data is available, and where it is located
- IASI, AIRS and CrIS gpolygon maps aid in identifying regions of coincident observations
- Supports campaigns and analyses focused on location or weather
- **Focus Days**
  - Selection based on orbit repeat cycle of AIRS
  - NPP orbit is not as controlled as Aqua

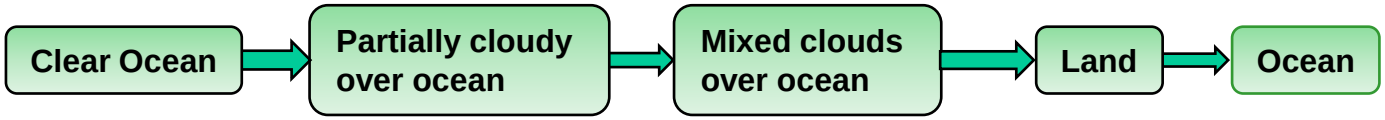
Platform	Repeat Cycle	Number of Orbits
Aqua	16 days	233 orbits
MetOp-A	29 days	423 orbits
NPP	16 days	230 orbits





Scene Categorization and Subsetting

- **Validation involves hierarchy of complicated scenes**



- **Implementing CrIS and IASI "calibration" subset processing to identify clear scenes**
  - **Clear assessment independent of EDR algorithms**
  - **Implementing "clear flag" processing based of radiances to build clear and partially clear scene data sets.**

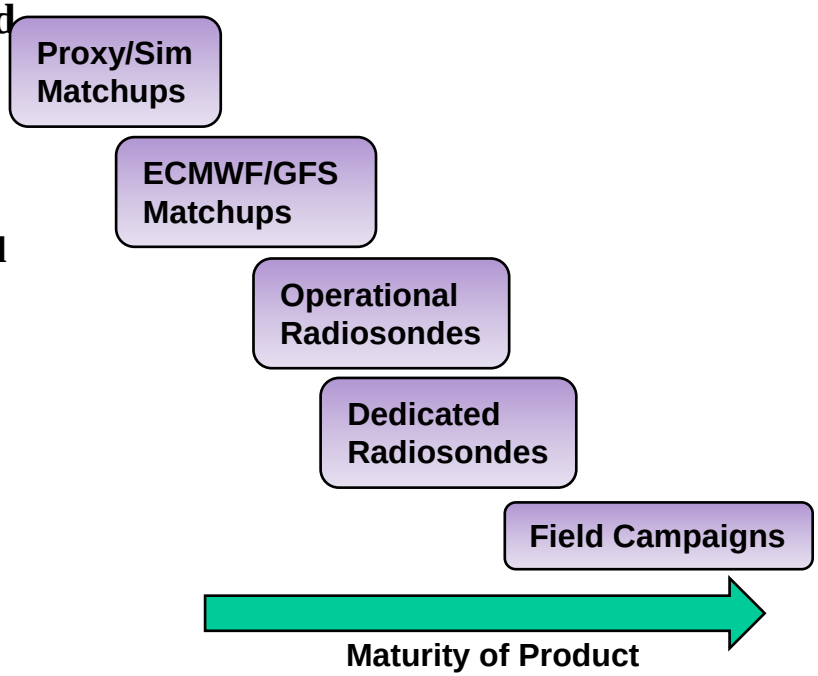
- **Creation of random footprint data sets to improve assessment of state sampling from focusing on correlative sites, clear scenes or intensive campaign periods and focus days**

- **Will collect requirements for ATMS/MHS subset datasets**
  - **Implement and add precipitation and cloud liquid water flags**

- **Will collect requirements for subsetting based on cloud type**

EDR
Correlative Data Comparisons

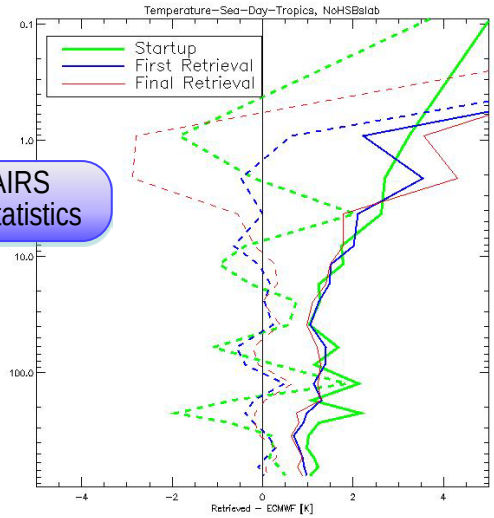
- **Proxy/simulated data**
- **Analysis matchups (ECMWF or GFS) interpolated to IASI/AMSU/MHS and CrIMSS footprints**
- **Operational radiosonde matchups**
  - **Q/C and reformatting required to make this a useful data set**
  - **Profiles are aliased by sampling to mandatory levels**
- **Dedicated radiosondes**
  - **Global radiosonde upper-air network (GRUAN)**
  - **ARM-CART sites**
  - **Funding opportunities and data shared TBD.**
- **Field campaigns and aircraft underflight**
  - **Characterize sub pixel variability, trace gases and dust/aerosols**
  - **Availability TBD.**



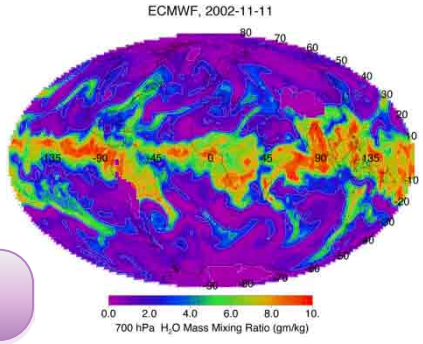
Comparisons with Correlative Data
Analysis Matchups

- **Analysis matchup produces "matchup products" by interpolating analysis to footprints**
  - **Using ECMWF and NCEP global analyses**
- **Analysis matchups include**
  - **Radiances compared with calculated from analysis state**
  - **ECMWF and CrIMSS states comparisons**
  - **CrIMSS cloud-cleared radiances and calculated from analysis state**
- **Analysis matchups are used to validate gridding algorithms**
- **Analysis matchups facilitate inter-platform comparisons by reducing spatial-temporal mismatch.**
- **Matchup products will interface with RTA packages for clear and cloud-cleared radiance assessments**

ECMWF −AIRS temperature statistics



ECMWF



Comparisons with Correlative Data
Radiosonde Matchups

- Radiosonde profiles matched to EDRs
- AIRS – radiosonde matchups required careful QC before full use
- Early and more effective use by
  - Rejection of low quality radiosondes
  - Quality control during matchup processing
  - Normalization and remapping to a common vertical grid and inclusion in matchup files
  - Simple and consistent file format across sources
  - Traceability to original source and format

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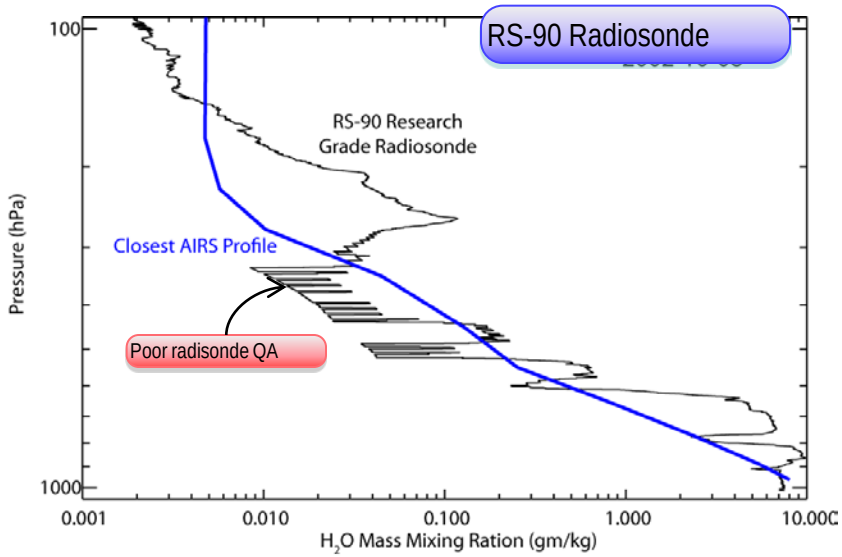
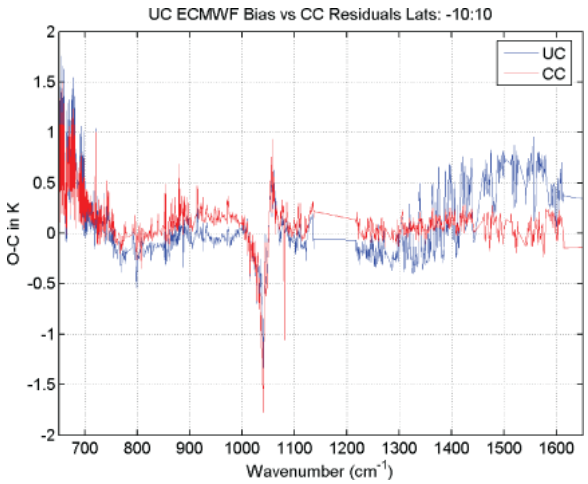


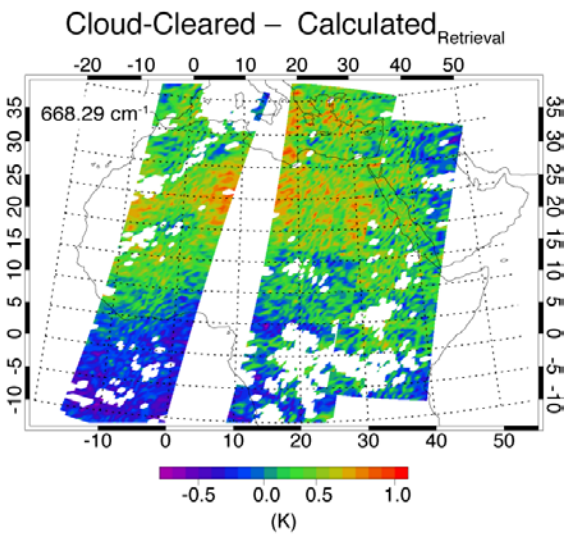
•Water vapor profile from "research-grade" RS-90 radiosonde.
•Mid troposphere oscillation is artifact of radiosonde telecommunication problem
QC will either correct or remove data

Comparisons with Correlative Data
Calculated Radiances

- Comparisons of observed and calculated radiances will be an important diagnosis tool
- Upper panel of AIRS cloud-cleared – calculated from ECMWF
  - **Warm bias in upper troposphere water sounding channels.**
  - **ECMWF analysis is dry in upper troposphere.**
- Lower panel of AIRS cloud-cleared – calculated from EDR solution
  - **Shown is a lower troposphere/surface temperature sounding channel.**
  - **Warm bias in Sahara shows difficulty fitting surface emissivity.**
  - **Cold bias in tropics indicates cloud leakage into cloud-cleared radiances.**
  - **Residuals in observed – calculated from solution indicate additional information in radiances.**

ECMWF −AIRS radiance statistics





Cross-Platform Comparisons
Simultaneous Nadir Observations

- Long-term multi-platform data sets require cross comparisons during simultaneous observations
- Sensitivity to scene heterogeneity and diurnal cloud variability make merging data sets especially difficult

- Simultaneous nadir observations (SNO) provides a tool for comparing observations from similar instruments on different platforms
  - SNO sampling can have spatial biases, especially for sun-synchronus polar orbits with different equator crossing local-solar times.

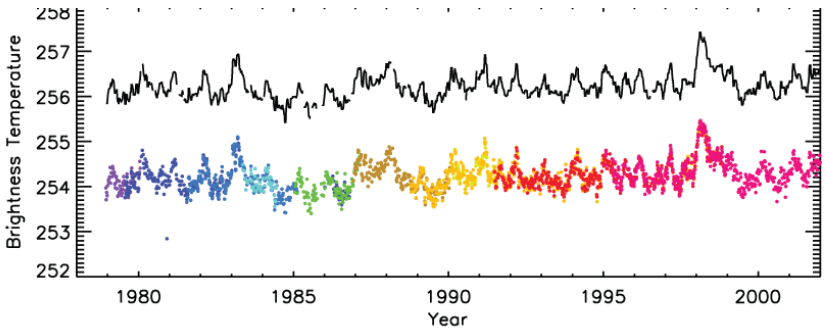


Fig. 3. Merged global ocean-only MSU TB pentad time series through the end of 2001. Data from individual satellites are shown in color in the lower curve, offset by 2K for clarity, while the upper curve is the final merged series, filtered by a 5 pentad moving average median filter.

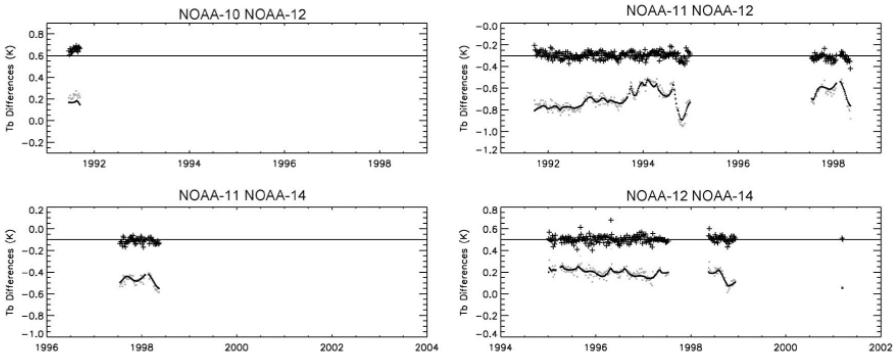


FIG. 8. Results of the satellite merging calculation, plotted separately for each satellite pair. In each plot, gray dots represent oceanic pentad averages of brightness temperature differences between pairs of satellites, and the black dots are a fit to the differences, using only both constant satellite offsets and target factors. The black crosses are the residuals to the fit, offset for clarity. The line through the black crosses is a horizontal line at zero residual to guide the eye.

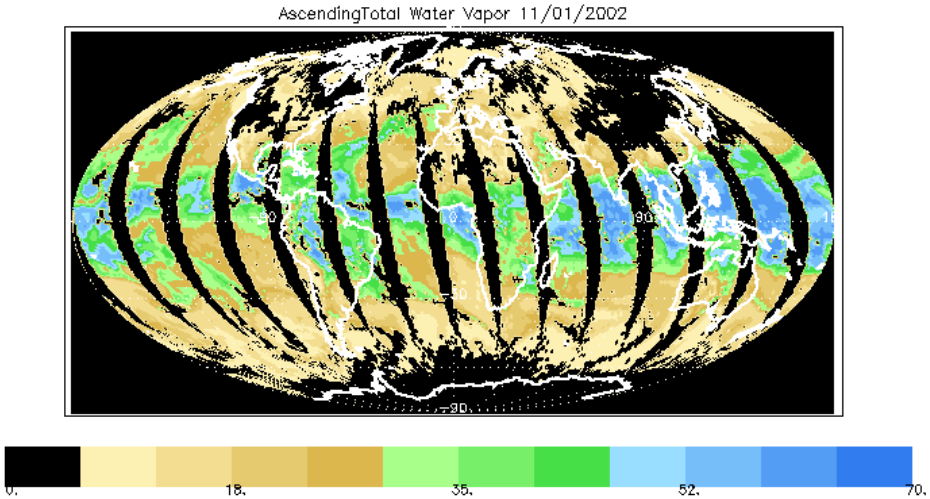
Schabel, M.C., Mears, C.A. and Wentz, F.J. 200, Stable Long-Term Retrieval of Tropospheric Temperature Time Series from the Microwave Sounding Unit, *IGARS*, 0-7803-7537-8/02.

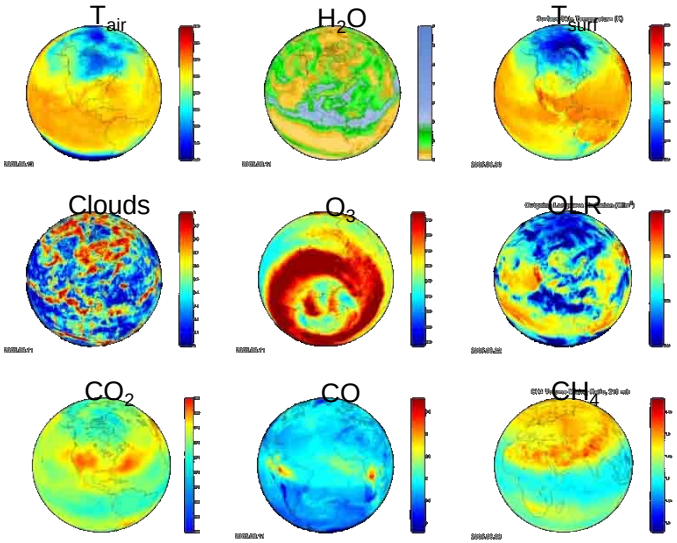
Wentz, F. J., and M. Schabel, 1998: Effects of orbital decay on satellite-derived lower-tropospheric temperature trends. Nature, 394, 661-664.

•Merged data sets from operations MSUs have been especially valuable at detecting climate trends
•Figures shows BT time series before and after instrument/LST corrections

Gridded Products

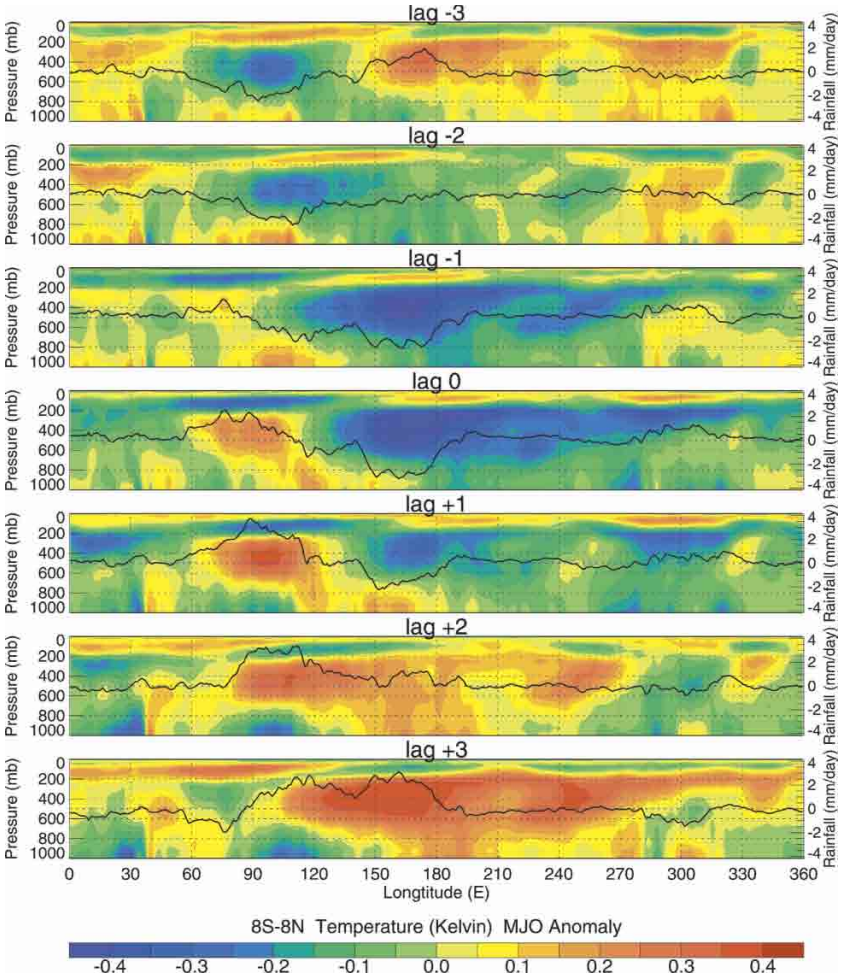
- PEATE generated gridded products will facillitate use in research
- PEATE will generate gridded products from CrIMSS xDRs
- Sample image of gridded total water vapor from AIRS
- Multiple days products are built from single day to reduce gores
  - **Daily, 8 day and monthly were created for AIRS**
- Consistent QC and gridding is required for building multi-sensor time series





Gridded Products
Madden-Julian Oscillation

- Madden-Julian Oscillation is an important diagnostic of model performance
  - **Is a tropical Pacific, eastward propagating wave.**
  - **Has a 30-60 day period**
  - **Evolution of vertical cross section of thermal structure has 0.5K range.**
- Was studied early in the AIRS mission
  - **Its analysis is insensitive to biases or sampling errors.**
- PEATE will support MJO analyses by producing gridded products.



Tian et al 2006, J. Atmos. Sci., 63, 2462-2485.

Derived Products
Saturation of Upper Troposphere

- H_2O is the dominant greenhouse gas
- CrIMSS will measure upper trop H_2O and temperature allowing direct measurements of saturation
- AIRS observed high occurrence of super-saturation in upper troposphere (shown at right)
- Saturation constraints in CrIMSS EDR algorithms may prevent accurate super saturation measurements
- The PEATE will provide tools for generating consistent relative humidity from EDRs
- Very difficult to interpret IR/MW observations with detailed consideration of clouds

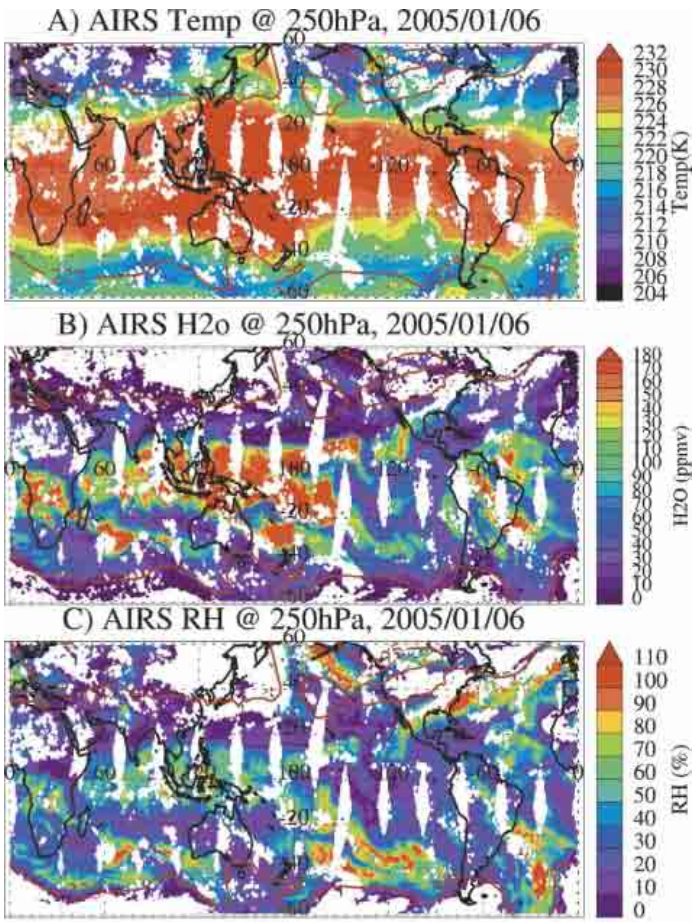


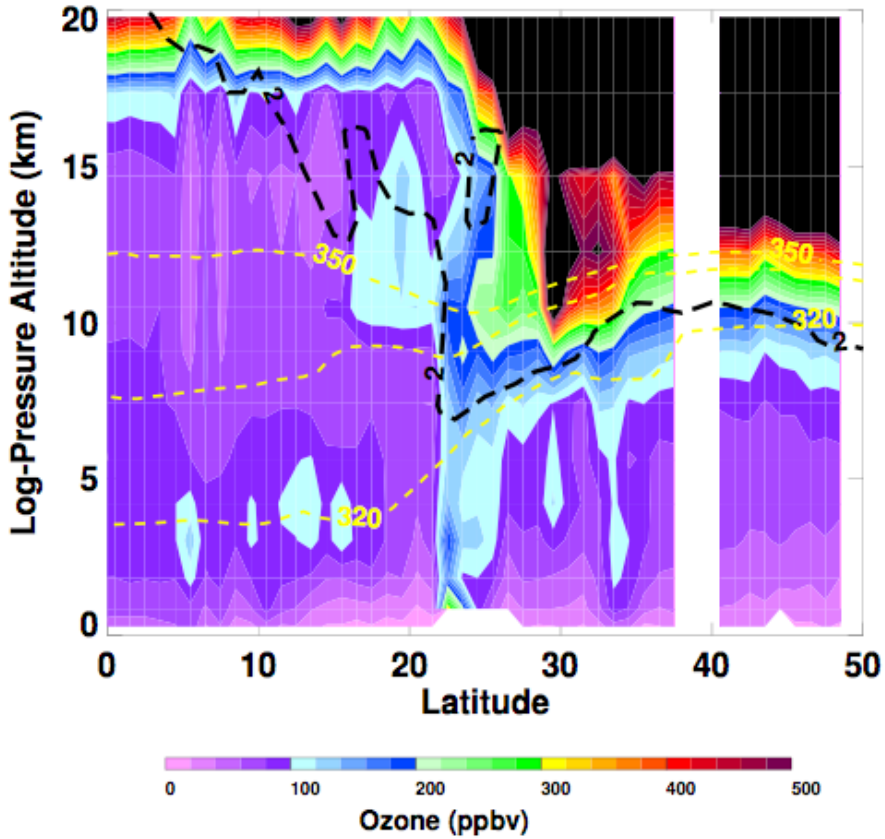
FIG. 1. Gridded AIRS data at 250 hPa for 6 Jan 2005: (a) Temperature (K), (b) water vapor (ppmv), and (c) relative humidity (%). Solid line is NCEP – NCAR reanalysis tropopause pressure on this day.

Gettelman et al, J Climate, 2006,19, 6104-6121.

Trace Gases
Ozone

- O_3 is measured day and night
- O_3 is difficult to measure, but the AIRS O_3 product has continually improved.
- CrIMSS O_3 can not be assessed separately from other xDRs.
- Shown is a cross section of AIRS O_3 across a tropopause fold.
  - **Important mechanism for strat-trop exchange.**
- Processes of strat−trop exchange are characterized by coincident O_3, H_2O and T measurements.

AIRS Ozone 4 March 2004 5ºE



Presented by L. Pan at Oct 2007 AIRS Science Team Meeting

Challenges and Progress

- **Agreements and funding for correlative data sets and campaigns**
- **Coordination of activities, algorithm development and sharing of products between three Cal/Val teams**
- **Access to calibration data sets and supporting documentation**
- **ITAR and intellectual properties rights**

- **Meetings between teams are increasing**
- **Commitment to solve problems and find work-arounds**
- **Progress in reaching data sharing agreements with external centers**

Matchup Data Products

Matchup Data Products
Design Requirements

- **Develop a modular design applicable to a large class of comparisons with many platforms, instruments and correlative data sources**
- **Design products for climate community and self documenting**
- **Add or enhance capabilities for microwave sounders and imagers**
- **Add capabilities for sub-footprint variability**
- **No penalty when minimal capabilities are used**
- **Easily extensible and suitable for diagnostic output from EDR algorithms**
- **Build off of existing RTP format**

Implementation
Field Names

- Use common data dictionary across data sets, instruments and platforms
- Standard field-naming convention
  - > Profiles parameters are prefixed by ‘p’,
  - > Surface parameters by ‘s’,
  - > Infrared properties by ‘ir’
  - > Microwave by ‘mw’
  - > Counters by ‘n’
  - > Totals by ‘t’
  - > Ordered n, t, ir, mw, p, s
- Use of groups to link fields from a common source and to facilitate standard field naming conventions
- Conventions for errors, averaging kernels and Jacobians not specified, but required

Implementation
Surface and Atmosphere

- Variable number of gas profiles with general representations
- Generalized representation of temperature profiles beyond level values and layer averages
- Machine readable metadata to indicate measurement units and vertical representation, e.g.
  - Mass mixing ratio, volume mixing ratio, kg/m^3, $molecules/m^2$. …
  - Trapezoids, layer-averaged, column amount, piecewise linear …
- Complex representation of surface properties
  - Height, type composition, vegetation cover, wind speed
  - Radiative properties
- Options for derived types such as EOF's and correlations

Implementation
Instrument data

- Measurement specific data for an instrument is contained in one group
- Like fields from different instruments have the same field names
- Contains
  - Scan and viewing parameters
  - Geolocation data
  - Radiances and/or brightness temperature
  - Calibration data such as noise, frequencies or channel number
- Complexities of calibration data and instrumental differences will limit usefulness for some calibration and SDR assessments
- Maintain 1-to-1 correspondence between states and observations
  - Exceptions: representation of sub footprint variability and imagery
- Support for large spectra such as IASI and correlative instruments
- Calculated radiances and diagnostics when states are present

Implementation
Matchups

- A file contains matched states, infrared sounder, a microwave sounder and an imager
  - Possibility of two microwave sounders at native resolution, e.g. NOAA, MetOp and Aqua platforms AMSU-A/ AMSU-B(HSB, MHS)
  - One platform per file, except states
- Matchup across platforms or mutiple data of the same type realized with multiple files to keep file format simple
- Checksums and metadata to maintain integrity of matchups across files and with derived products from matchups.

Matchup Data Products
Programming Implementation

- Compound data types are not easily extensible or efficient – not practical
- Implement FORTRAN, C, Matlab and IDL read/write APIs
- Extensibility with provided API
  - Define and add new fields, e.g. transmittances, Jacobians and averaging kernels…
  - Unfilled fields are not written to file
- Provide “high-level” API that mimics rtp1 and rtp2 interfaces
- Use masks and “pfield” to indlicates which groups and fields are written to file
- Use netCDF with climate-forecast (CF) metadata standards
  - Initial implementation in netCDF-3.6
  - Transition to netCDF-4 (hdf5-1.8 based) as standard becomes more established

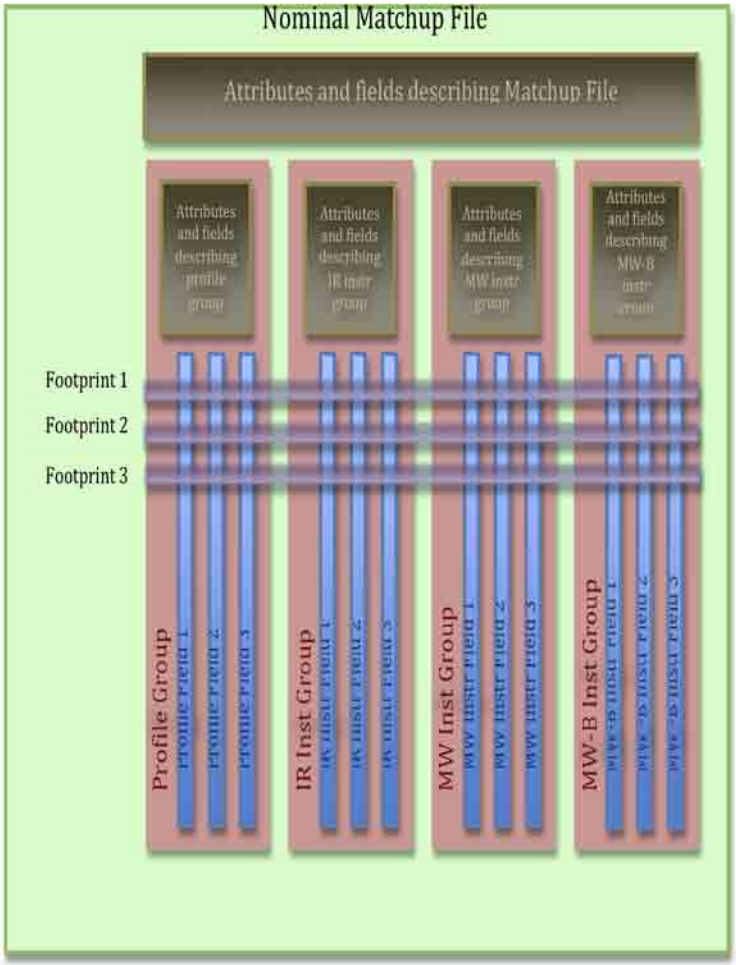
Matchup Data Products
Groups

State	Atmosphere, surface and cloud properties – not instrument specific
IrInst	Infrared sounder specific parameters such as geolocation, radiance, noise and calibration parameters or infrared parameters modeled from State – instrument specific, e.g. CrIS, IASI, AIRS, sHIS
MwInstr	Parameters observed by a microwave sounder or modeled from State – instrument specific, e.g. ATMS, AMSU
MwbInstr	Parameters observed by a secondary microwave sounder or modeled from State, but at a higher spatial resolution than State, IrInst or MwInstr.
Imager	Parameters observed by an imager or modeled from state and at a much higher resolution
IrbInst	Parameters observed by an infrared sounder, but at a higher spatial resolution than state.

- Groups are implemented in netcdf-3 using fieldnames prefixed by group name
- Hidden within API and transparent with transition from netCDF-3.6 to netCDF-4

Matchup Data Products
Representation and Summary

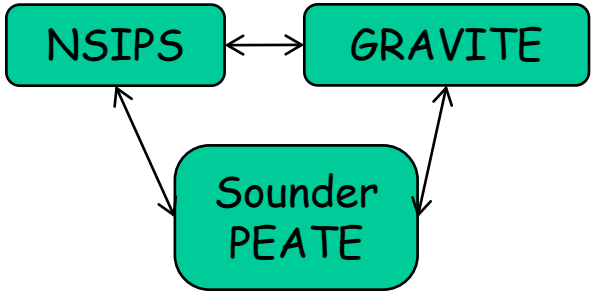
- This matchup format for products defined in discussion
- NetCDF format is easier than HDF
- CF metadata is self documenting
  - Using long_name attribute to include a description of every parameter
  - Issues with standard_name and non standard units (molecules)
- File description document by early summer
- Requesting input and comments



Summary

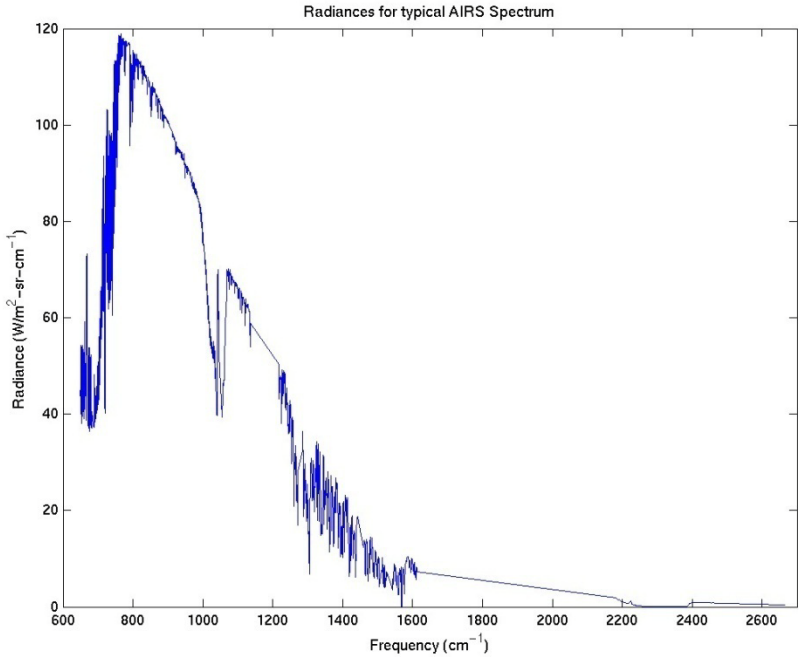
Data Centers Supporting Assessments

	CENTERS		
PERIOD	PEATE	GRAVITE	NSIPS
Pre-launch	X	X	X
Launch & Activation			X
On-orbit check out	X		X
Intensive Cal/Val	X	X	X
Long Term Monitoring	X		



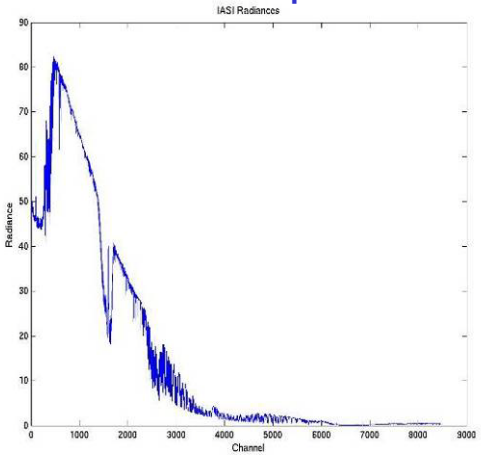
Spectral Archive Spanning Three Instruments

Typical AIRS Spectrum

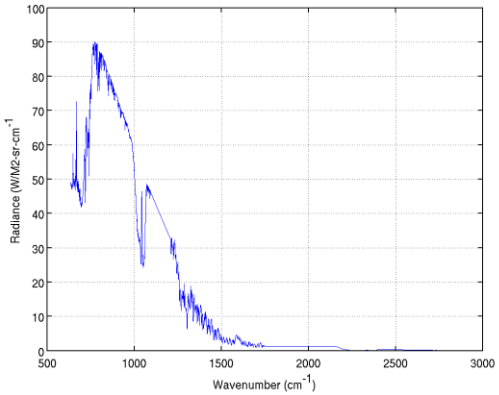


AIRS Brings a Legacy of 5 Billion Spectra:
- a Climate Record of 5 five years
- will continue to grow

Recent IASI Spectrum



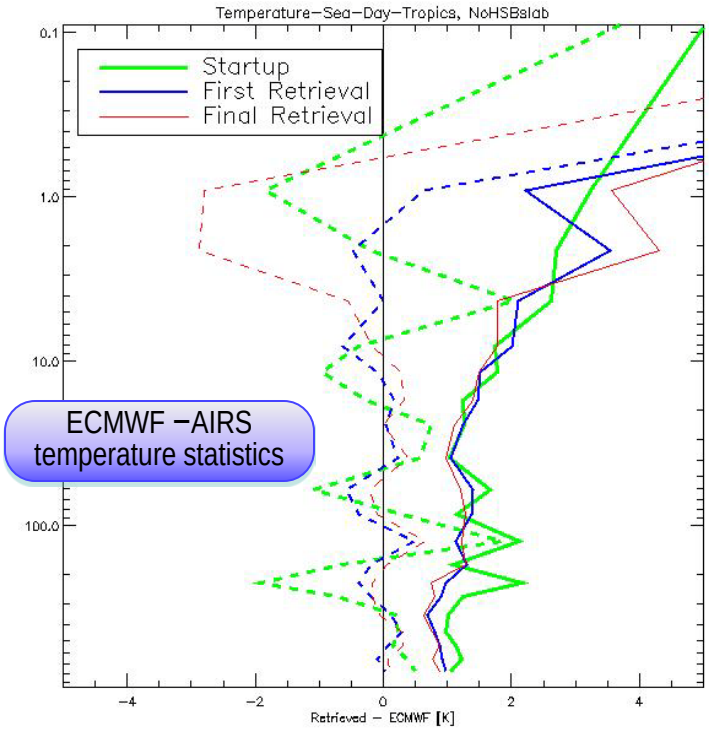
Modeled NPP CrIS Spectrum



Data Products

Analyses Matched to Retrieved Profiles

- Matchup processing collects and sorts coincident CrIS, ATMS and correlative data
  - **Aids intercomparisons by quality controlling correlative data**
  - **Matchup products will interface with RTA packages for cloud-cleared radiance assessments**
- Will be generated from analyses, radiosondes and campaign data
- AIRS − analysis matchups provide large data volume for early stages of assessment
  - **Shown is an intercomparison between AIRS and ECMWF temperature**
  - **Data includes many focus days and thousands of profiles**



Presented by S-Y Lee at 14 Dec 2005 AIRS Science Team Net Meeting

Science Perspective – Data Intercomparisons

Supporting Data Intercomparisons

- Collect, catalog and store correlative data
- Provide tools to identify and geolocate data
- Provide products of matched CrIS/ATMS with correlative data
- Perform quality controlling and normalization of matched correlative data
- Generate calculated radiances on xDRs and correlative data
- Subset data into “climate subsets” for focused analyses
- Perform routine comparison analyses between xDRs and correlative data and derived radiances

Satellite-to-Satellite Matchups

- Simultaneous nadir observations (SNO)
  - Coincident matched footprints of similar instruments on different platforms
  - Can be generalized for non-nadir views
    especially useful for infrared sounders
- Are used to characterize and correct
  - Calibration error
  - Local-solar-time sampling error and orbital drift
  - Sampling (null-space) error between different instruments
  - Algorithm differences
    - AIRS and CrIS L2 products
- Build datasets spanning multiple platforms
  - AIRS (Aqua) ➔ IASI (MetOp-A) ➔ CrIS (NPP)
  - MSU (TIROS-N) ➔ MSU(NOAA-6) ➔ … ➔ ATMS(NPP)

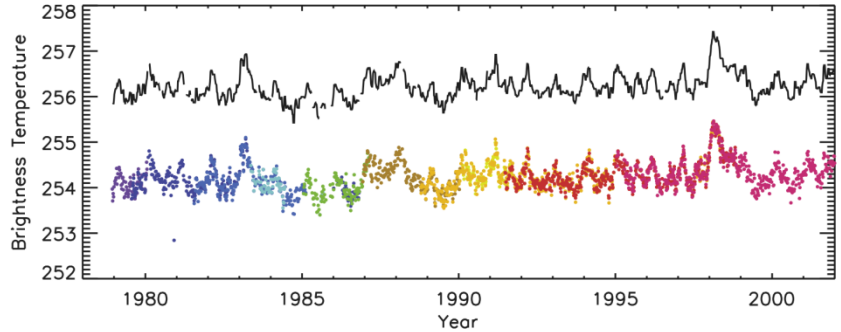


Fig. 3. Merged global ocean-only MSU TB pentad time series through the end of 2001. Data from individual satellites are shown in color in the lower curve, offset by 2K for clarity, while the upper curve is the final merged series, filtered by a 5 pentad moving average median filter.

Example constructing 25 year record from MSUs on NOAA platforms

- Pentads of simultaneous non-coincident observations are used to reduce sampling error
- Upper panel shows time series of BT before and after sampling corrections (mostly LST)
- Lower panels show BT differences for four pairs of simultaneous observations

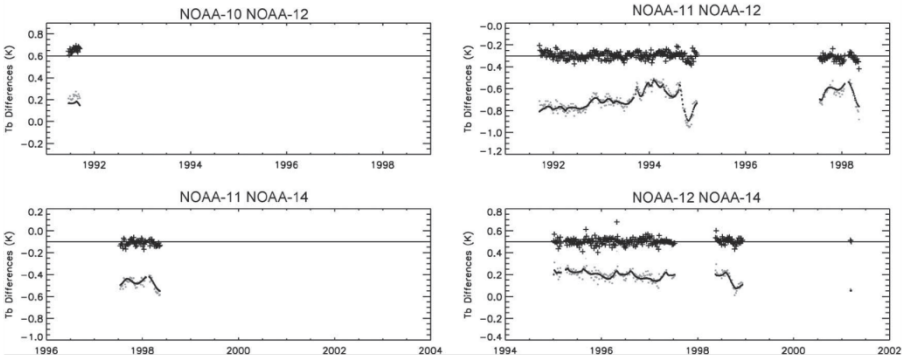


FIG. 8. Results of the satellite merging calculation, plotted separately for each satellite pair. In each plot, gray dots represent oceanic pentad averages of brightness temperature differences between pairs of satellites, and the black dots are a fit to the differences, using only both constant satellite offsets and target factors. The black crosses are the residuals to the fit, offset for clarity. The line through the black crosses is a horizontal line at zero residual to guide the eye.

Multi-platform data sets of IR observations are especially sensitive to cloud variability and coincidence is especially important

Schabel, M.C., Mears, C.A. and Wentz, F.J. 200, Stable Long-Term Retrieval of Tropospheric Temperature Time Series from the Microwave Sounding Unit, *IGARS*, 0-7803-7537-8/02.

Wentz, F. J., and M. Schabel, 1998: Effects of orbital decay on satellite-derived lower-tropospheric temperature trends. Nature, 394, 661-664.