Overview of the CrIMSS (CrIS/ATMS) Retrieval Algorithm and Application to AMSU, NAST-I and AIRS Data

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Cross-Track Infrared and Microwave Sounder Suite (CrIMSS)

- Infrared component – Cross-track Infrared Sounder (CrIS)
- Microwave component – Advanced Technology Microwave Sounder (ATMS)
- AER is the Environmental Data Record (EDR) algorithm developer for CrIMSS
  - Algorithm used to "convert" Sensor Data Records (SDRs) into EDRs
  - Algorithm used by ITT for sensor design trade studies and performance evaluations
  - Algorithm designed for transition to operational environment
- Physical retrieval approach extracts maximum Information from CrIMSS Data
  - fast forward model based on AER's Optimal Spectral Sampling (OSS) technique
    - Excellent (less than 0.05K) agreement with LBLRTM
    - Efficient Jacobians calculation
      - Enables simultaneous retrieval of all parameters
  - Modified maximum-likelihood Inversion
    - Explicit treatment of non-linearity
    - Empirical Orthogonal Function (EOF) transformation of the retrieved variables to compress the state vector and stabilize the inversion
- Algorithm has been adapted to analyze AMSU/AIRS/NAST-I data

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Modular Design For Easy Algorithm Updates

- CrIMSS EDR algorithm consists of 7 modules
  - Initialization
  - Pre-processing
  - MW-only retrieval
    - Provides first guess for cloud clearing algorithm
    - Used by for clear sky identification
    - Provides information below clouds under overcast condition
  - Scene Classification
    - Determines number of cloud formation (NCF)
    - Identifies Clear FOVs
    - Groups 9 FOVs into several clusters for maximum horizontal reporting
    - Setup appropriate cloud retrieval strategy
  - Combined IR+MW retrieval
    - Further improves EDR performance by using both IR and MW radiance
  - Quality control
  - Post-processing

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ATMS Microwave Retrieval Provides First-Guess for CrIS Infrared Retrieval

- Performs simultaneous retrieval of all parameters
  - No need to estimate errors due to fixing some parameters during inversion process
  - Non-linear inversion is very robust
    - even in the presence of clouds (non-linear effects)
  - Delta T $(T_{skin} - T_{sfc})$ is retrieved instead of Tskin
    - No need to keep the correlation in the covariance matrix
    - No need to carry multiple covariance matrices for different terrains
- EOF transformation of temperature and water vapor profiles
  - Stabilizes and constrains solution
  - Speeds up inversion by decreasing the number of retrieved variables
- Covariance and background stratification provides better EDR performance
  - Based on retrieved surface temperature and emissivity
  - Improves retrieval for dry atmosphere and cold surface

Retrieved Parameter	# of elements
Temperature	20 EOFs
Water Vapor	10 EOFs
Skin Temperature	1 ($\Delta T = T_{skin} - T_{sfc}$)
Surface Emissivity	5 EOFs
Cloud Liquid Water	1
Cloud Top Pressure	1

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Scene Classification Module Determines Scene Variability and Setup Cloud Retrieval Strategy

- Number of cloud formation (NCF) determined by Principal Component Analysis
  - Cloud Clearing (CC) needs more FOVs than NCF to remove clouds effect
  - NCF is used to stabilize the CC inversion (highly effective for low contrast scenes)
- Clear FOVs identified by comparing observed CrIS radiance with that generated using MW retrieval and IR forward model
  - Used to distinguish overcast from clear scenes under low contrast condition
  - Can be enhanced use external data (VIIRS, MODIS…)
- FOV-clusters formed according to NCF and surface inhomogeneity
  - Coastlines are not grouped with ocean
  - Account for terrain variations
- Three retrieval strategies setup
  - Clear retrieval
    - Average radiances (or do nothing for a single FOV)
  - Cloud Clearing
    - generate cloud-cleared radiance
  - Overcast
    - Use sub-set of IR channels to retrieval properties above cloud top
    - MW channels used to retrieval properties below clouds
  - No-retrieval

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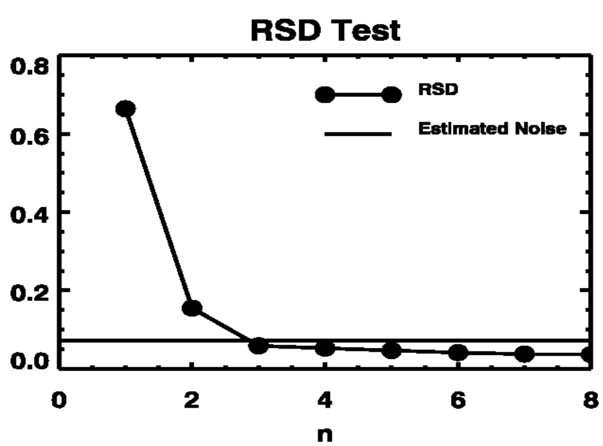
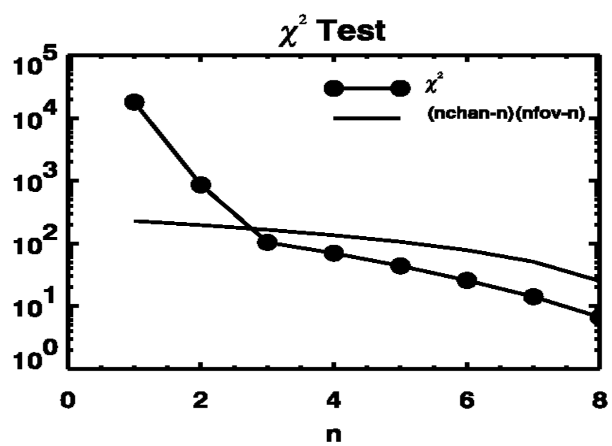
Principal Component Analysis (PCA) Used to Identify Different Cloud Formations

- PCA applied to cloud-sensitive channels (709-746 cm^{-1})
  - Uses spatial and spectral information for all FOVs within one filed of regard
  - Detects surface inhomogeineity
  - Has high sensitivity for high clouds
- NCF determined from Residual Standard Deviation (RSD) and Chi-Square (χ^2) tests
  - Sensor noise level used as threshold for sensitivity
  - Automatic and objective
  - Max value from the two tests is selected

$$RSD(n) = \left[\frac{1}{nchan * (nfov - n)} \sum_{j=n+1}^{nfov} \lambda_j \right]^{1/2}$$

$$\chi^2(n) \equiv \sum_{i=1}^{nchan} \sum_{k=1}^{nfov} \frac{\left[R_{ik} - \hat{R}_{ik}(n) \right]^2}{\sigma_{ik}^2}$$





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Second Stage of Retrieval Uses Both CrIS and ATMS Radiances to Better Handle Clouds

- Simultaneous retrieval of all parameters using MW and IR radiances
  - Both MW and IR use OSS forward model
  - Robust inversion algorithm
- Accommodates all 3 retrieval strategies in a single inversion loop
  - Cloud Clearing is an integral part of the inversion
    - No-need to have multiple iterations after cloud-cleared radiance is generated
    - NCF is used to constrain the CC inversion via Singular Value Decomposition
    - State vector errors covariance (in EOF domain) from MW retrieval is used to calculate correlated radiance errors before CC inversion
  - Provides retrieval under overcast condition
    - Automatically selects IR channels to retrieval properties above cloud top
    - MW channels used to retrieval properties below clouds
- ATMS is used together with CrIS to provide best performance
  - MW Chisq from 1st and 2nd stage retrievals can be used to assess the success of CC
  - 2nd stage MW Chisq will be large if there are cloud signatures in the cloud-cleared radiances

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All Parameters Related to ATMS and CrIS Retrieved Simultaneously

- EOFs used to compress state vector
- Column amount is retrieved for trace gases
  - Tropopause information is used to adjust the profile shapes of CH4 and N2O
  - Scaling factors are retrieved relative to initial profiles

Retrieved Parameter	# of elements
Temperature	20 EOFs
Water Vapor	10 EOFs
Skin Temperature	1
Ozone	1 (column correction)
MW Surface Emissivity	5 EOFs
MW Cloud Liquid Water	1
MW Cloud Top Pressure	1
IR Surface Emissivity	12 hinge points
IR Surface Reflectivity	12 hinge points
CO_2	Currently 0
N_2O	1 (column correction)
CH_4	1 (column correction)
CO	1 (column correction)

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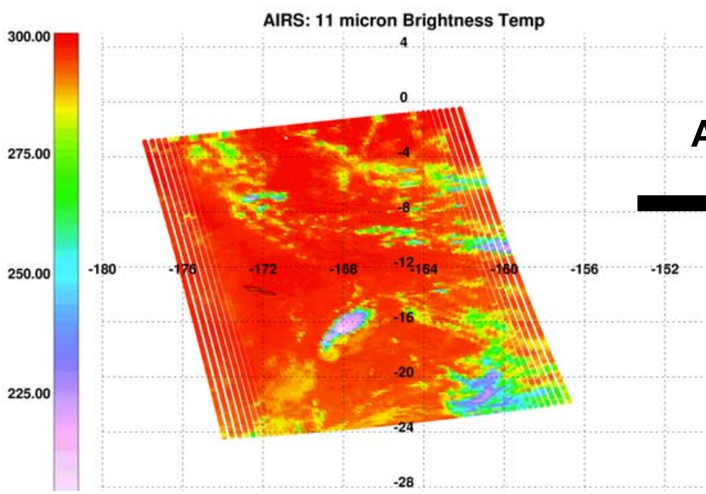
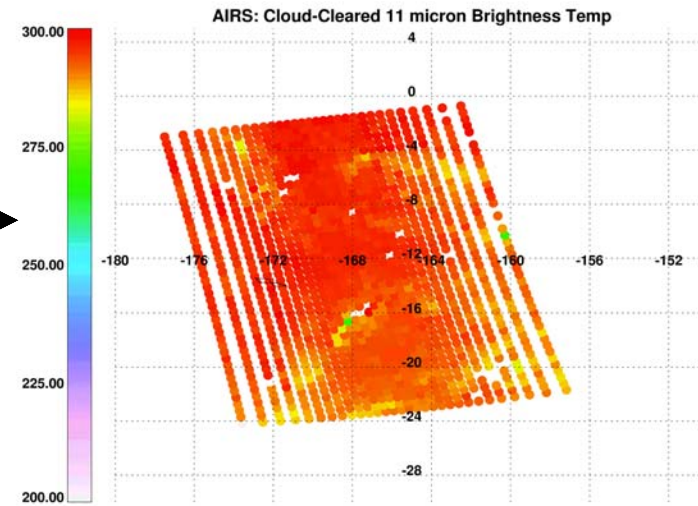
Application of CrIMSS Algorithm to AIRS Retrievals: For 10-04-03 Granule 008

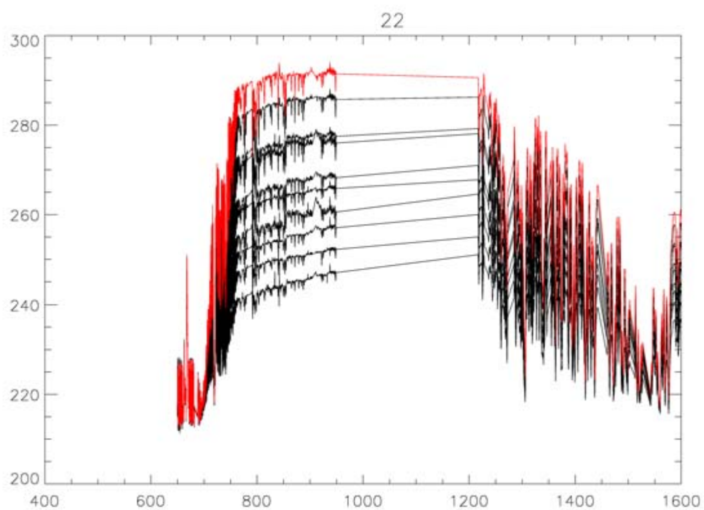
11 micron Brightness Temps

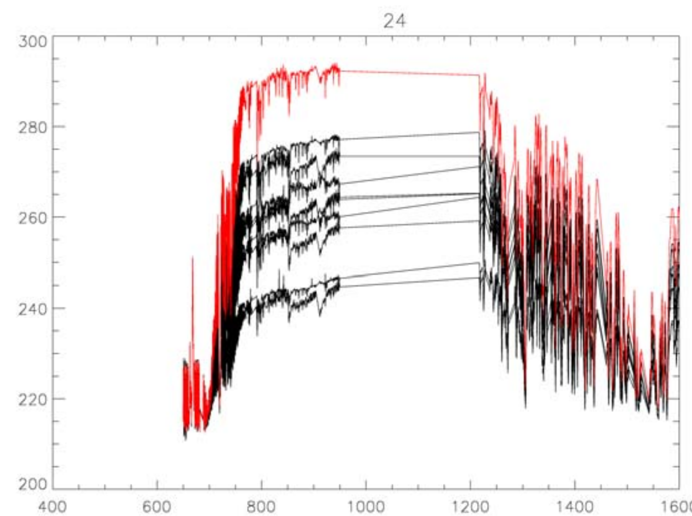


Cloud-Cleared Radiances



Apply CC Algorithm





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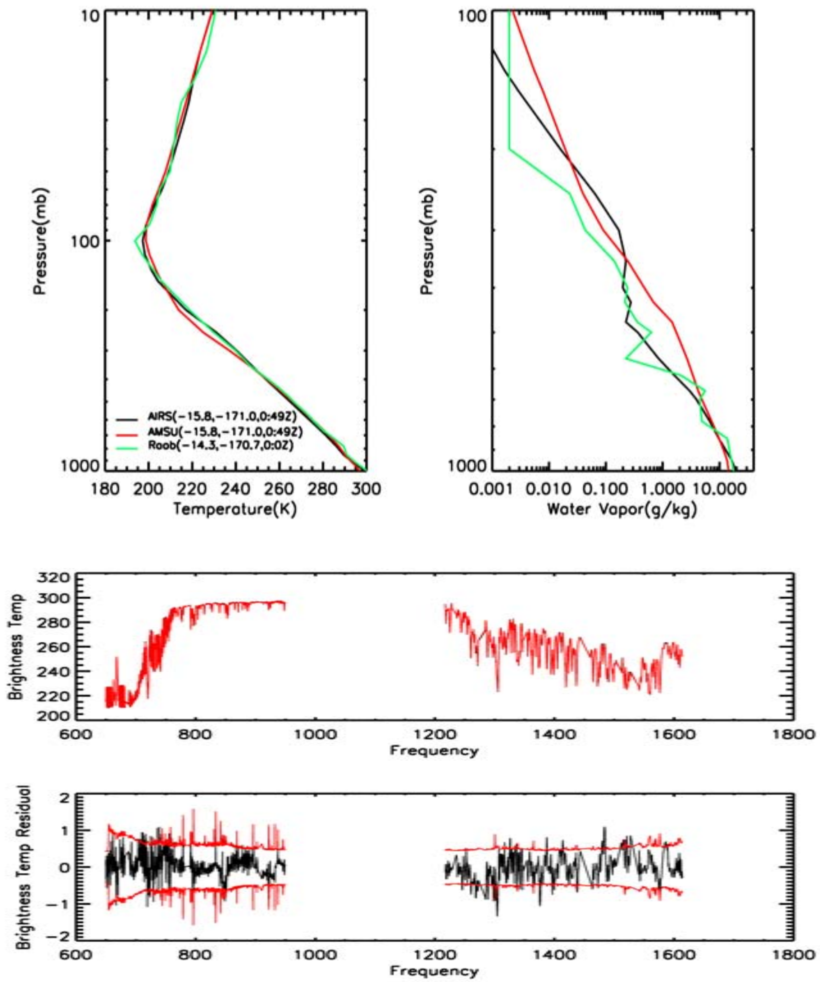
AIRS Retrievals: For 10-04-03 Granule 008



Co-located raob and AIRS/AMSU retrieval

Raob at (-14.4/-170.7/0.0Z)

Red: AMSU
Black: AIRS
Green: Raob

- Sonde and AIRS is 49 min. apart
- AIRS provides better temperature and moisture retrieval than AMSU
  - No HSB to provide moisture profile for MW
  - TPW is retrieved well for MW

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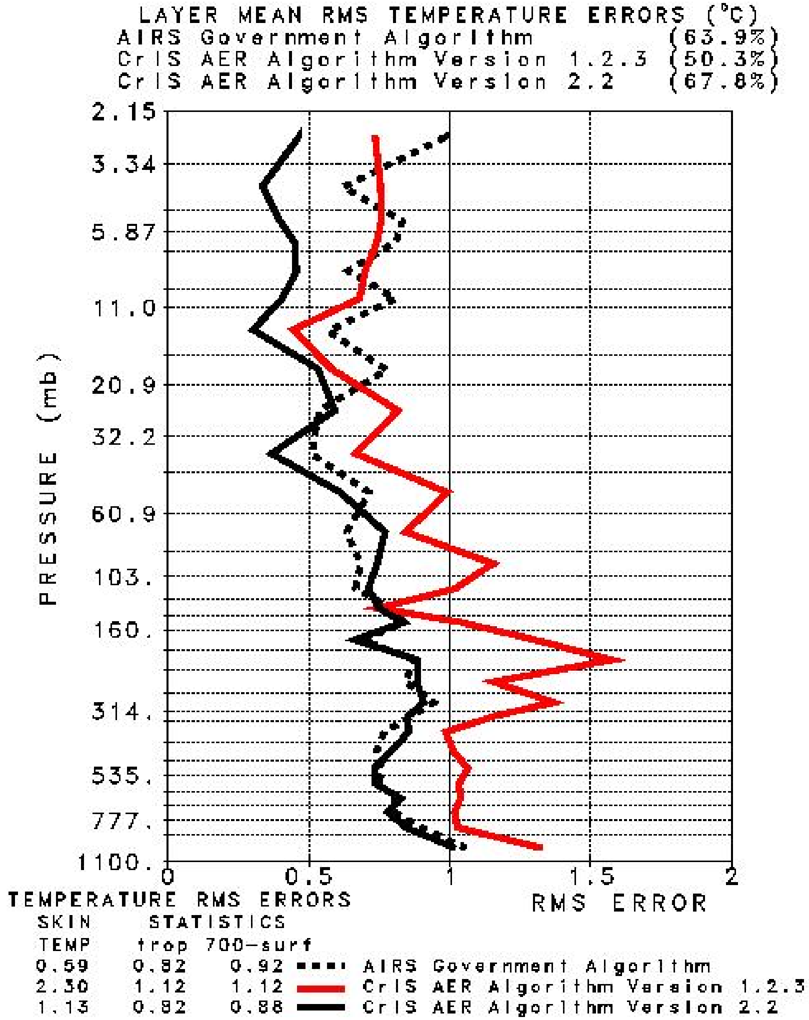
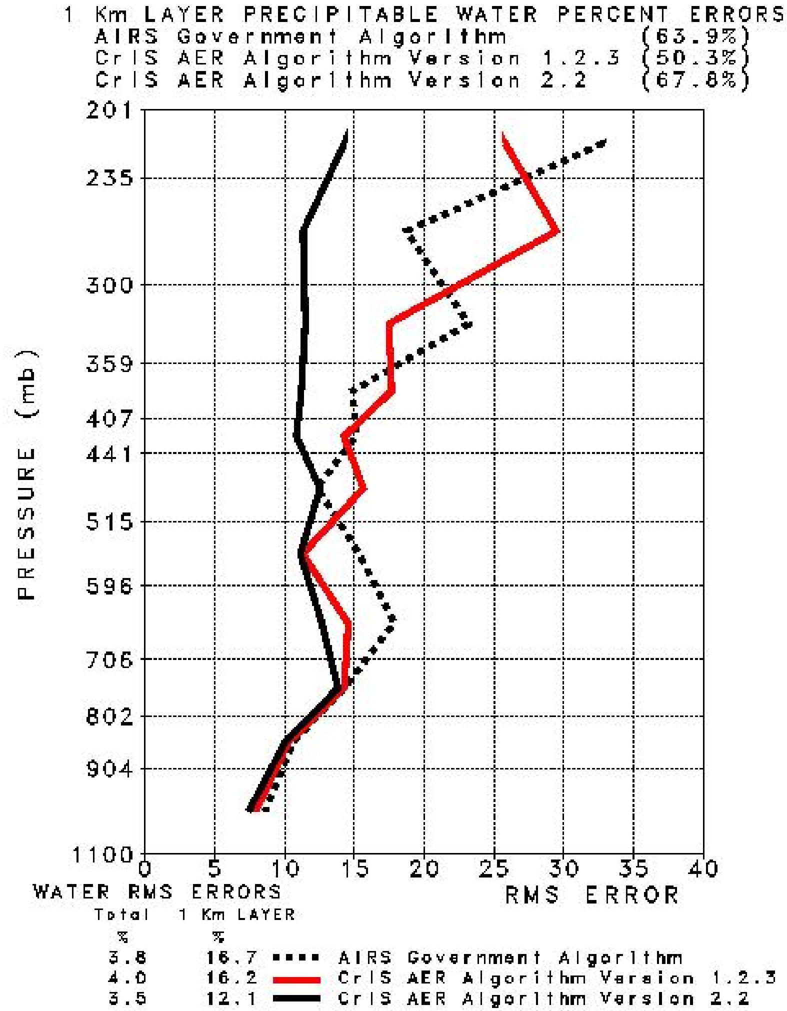
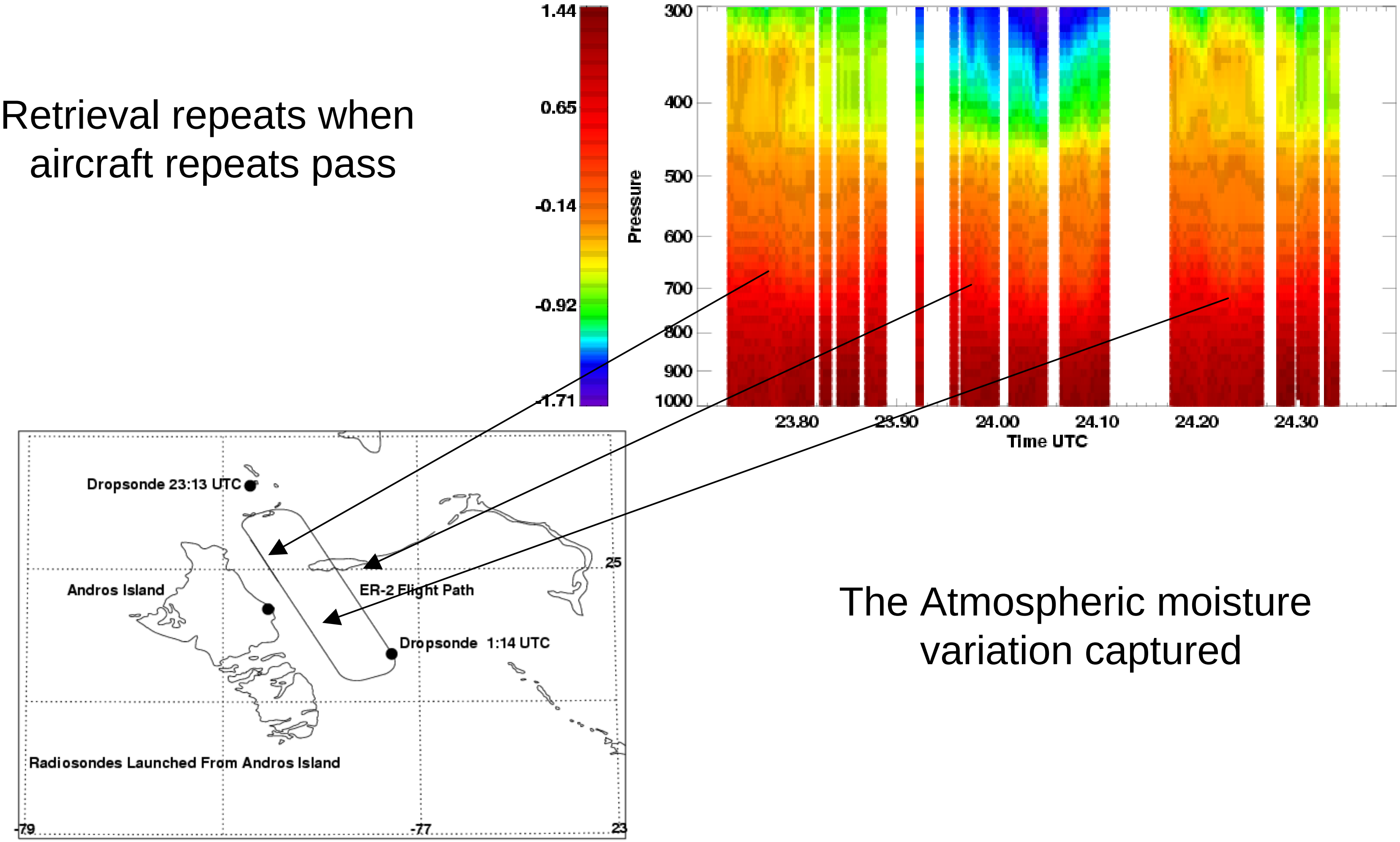
Application of CrIMSS and NASA-Goddard AIRS Algorithms to Simulated CrIS and AIRS Scanline Scenes (Courtesy of Joel Suskind)





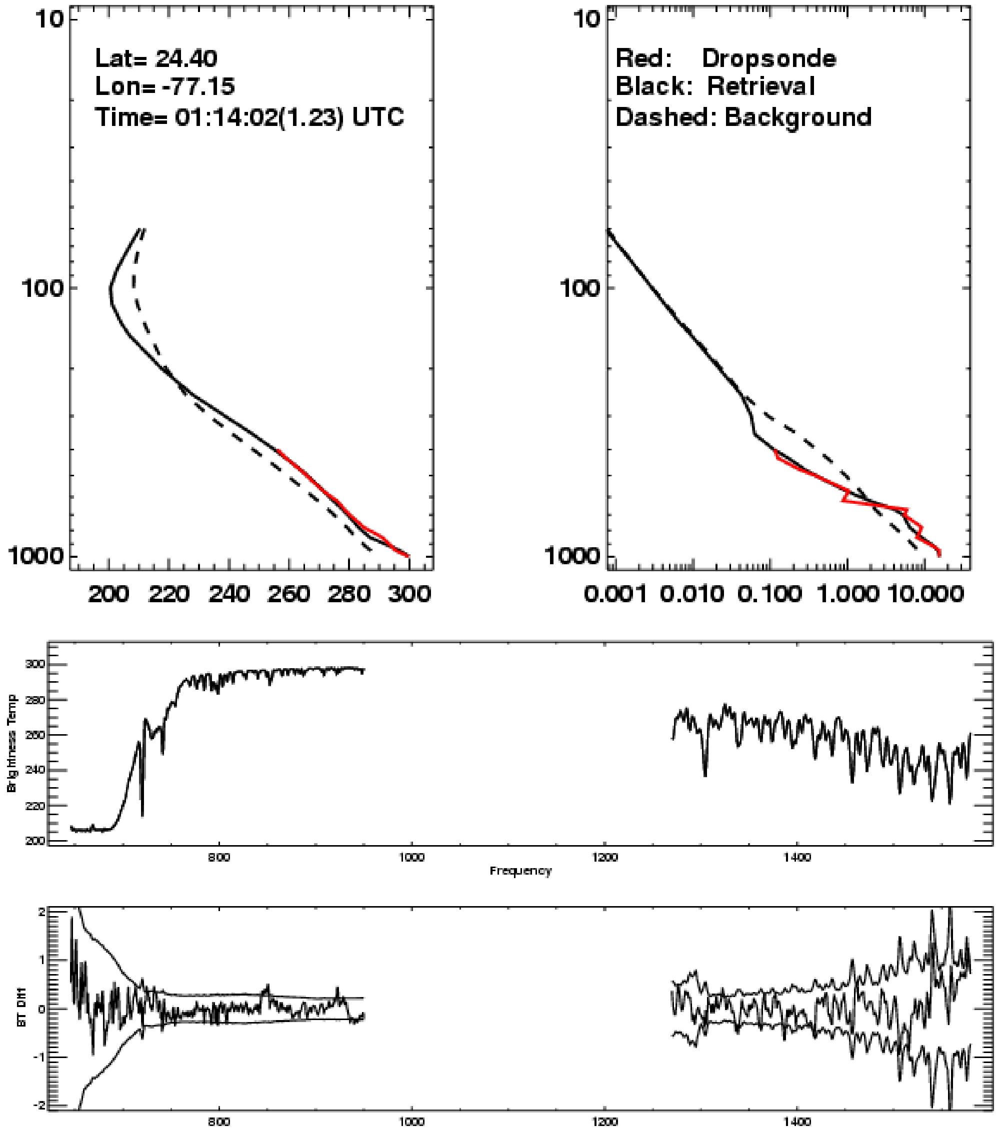
Cross-section for NASTI Retrieval (Degraded to CrIS Resolution): Off Coast of Andros Island

Retrieval repeats when aircraft repeats pass



The Atmospheric moisture variation captured

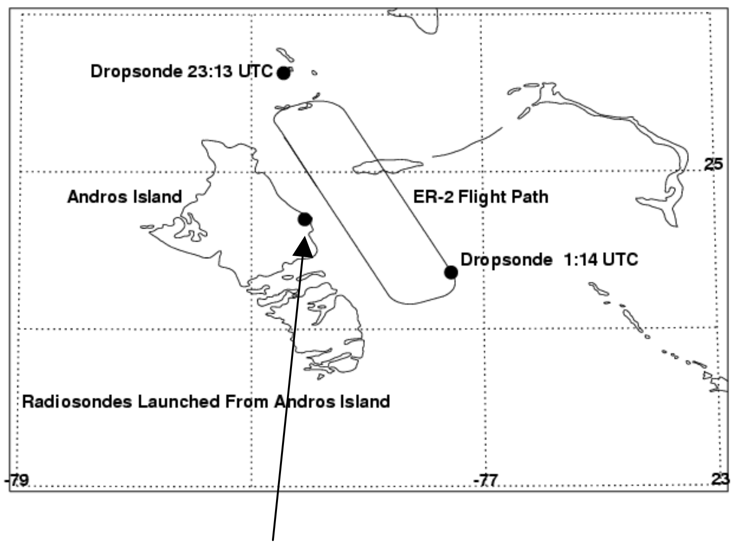
Comparison of CrIS NAST-I Retrieval with Drop Sonde



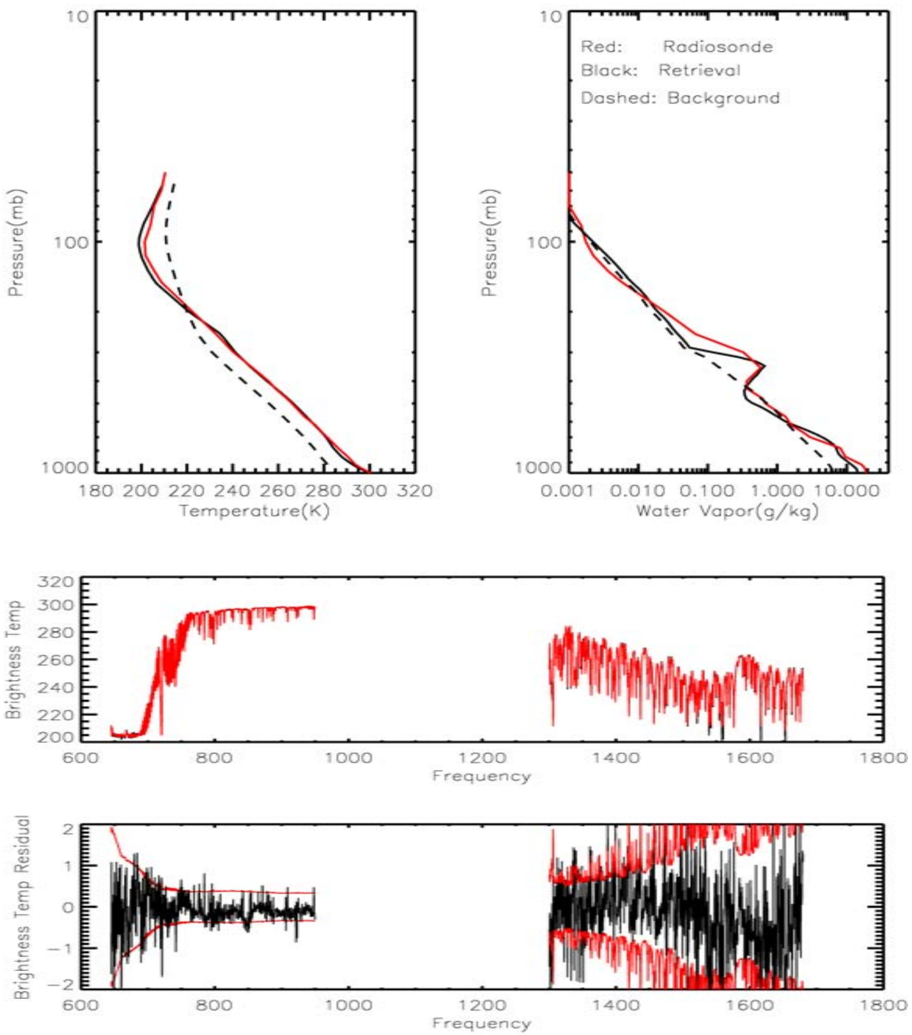
Direct High Spectral Resolution NAST-I Retrieval: CAMEX-3 Andros Island

Higher spectral resolution (as compared to degraded to CrIS resolution) captures the moisture vertical structure better

Red: Radiosonde
Black: Retrieval
Dashed: Background



Radiosonde Location



AMSU Retrievals: Comparison With Raobs

AER testbed has been collecting radiosondes and collocated AMSU measurements for over a year

Criteria: +/- 6 hours and 200km

Compiled over 8000 matches for NOAA-16 data

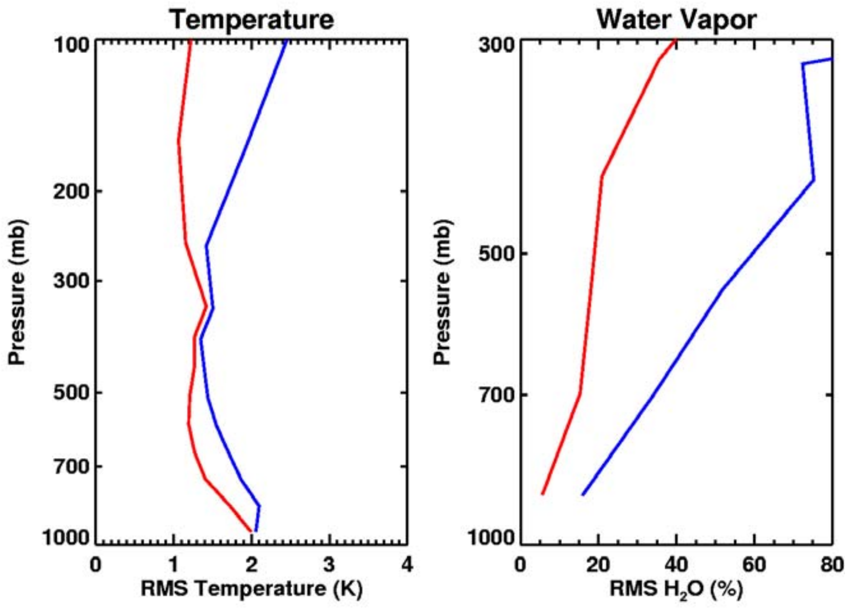
Started to compile RAOB matches for EOS AIRS/AMSU data

Error analysis performed upon retrieval which retrieve clw<0.05 kg/m^2

Moisture field deviates more from simulation/retrieval study

- More variable than T
- Collocation error
- Unreliable data for upper atmosphere

RMS difference between RAOBs and Retrievals



- Red: First simulate observation using RAOB profile, then perform retrieval
- Blue: Retrieval performed on AMSU measurement

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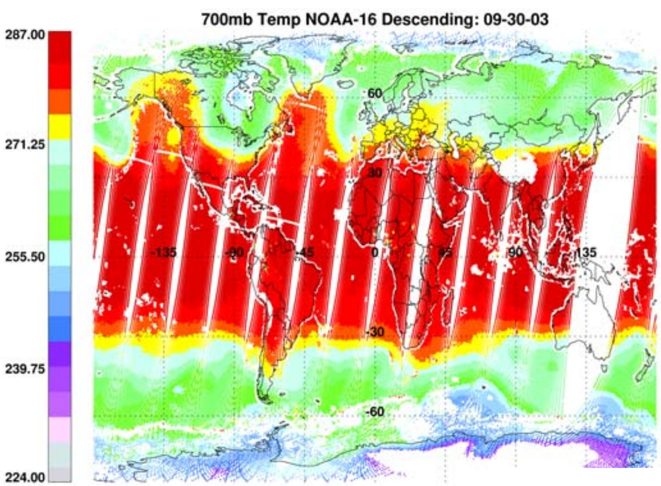
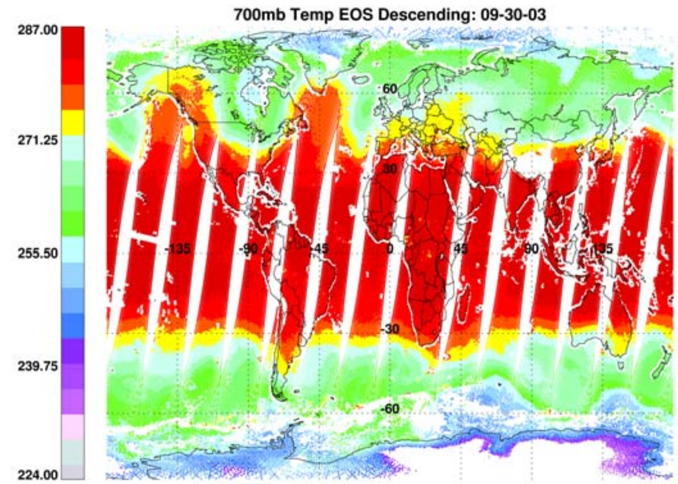
AMSU Retrievals: Both NOAA-16 and EOS

700 mb Temperature

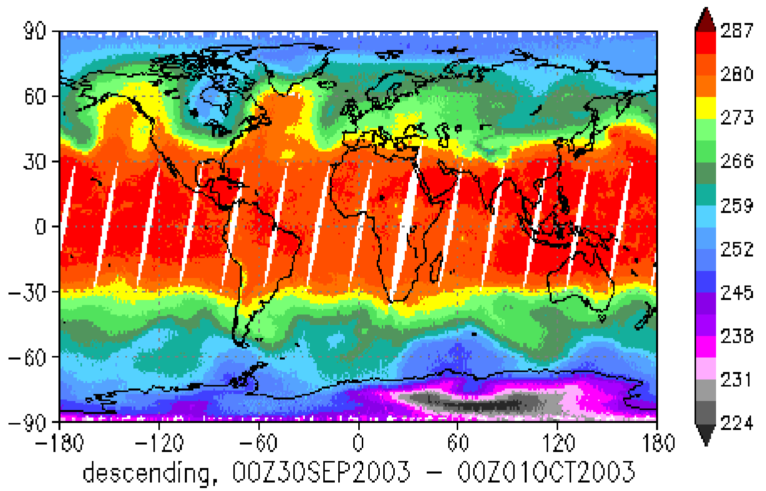


NOAA-16

EOS



NOAA-NESDIS Retrievals: from Mitch Goldbergs Web site http://orbit-net.nesdis.noaa.gov:80/crad4/zcheng/amsuclimate/noaa16



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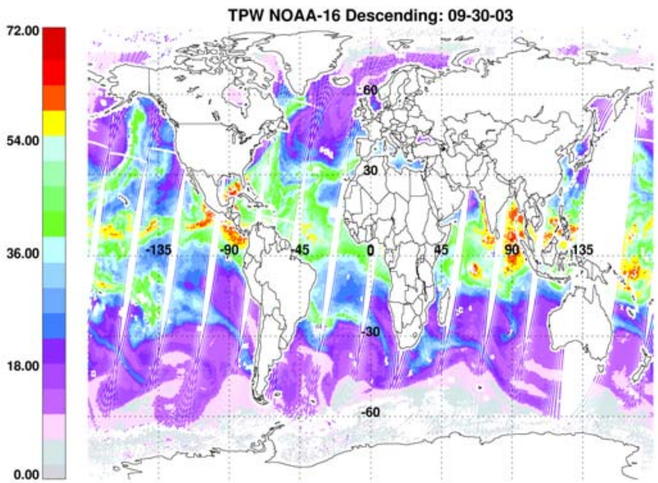
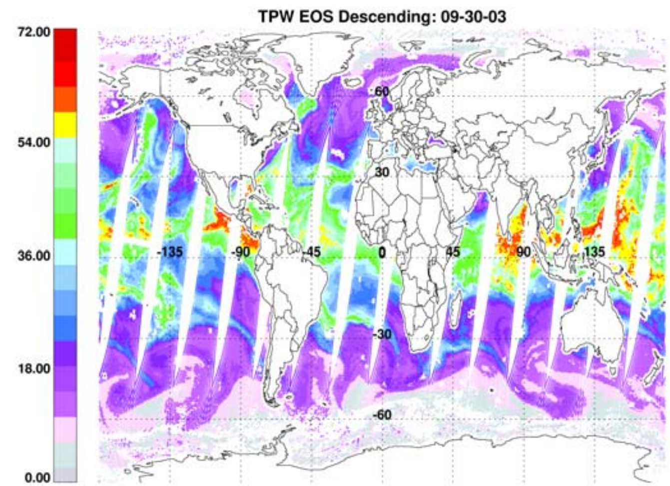
AMSU Retrievals: Both NOAA-16 and EOS-Aqua

TPW Retrievals



NOAA-16

EOS



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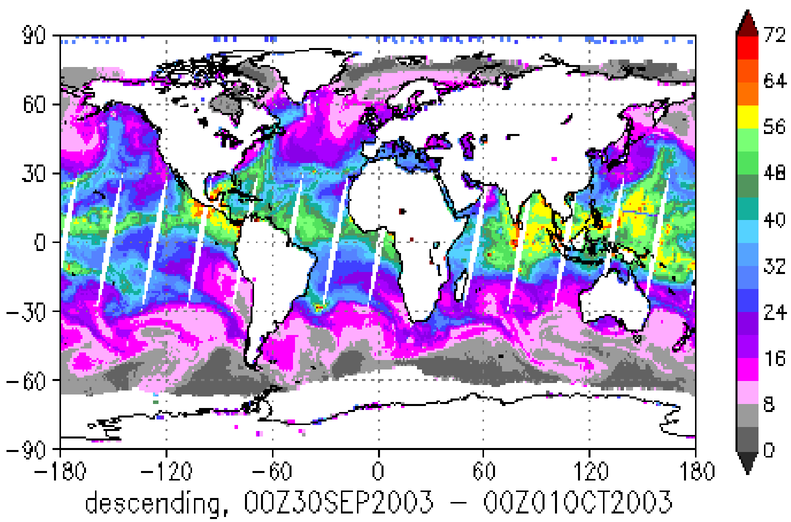

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Conclusions

- EDR retrieval algorithm for CrIMSS is robust and efficient
  - OSS is a fast and accurate forward radiative transfer model
  - EOF transformation is used to compress the number of retrieved parameters and stabilize the inversion
  - Algorithm allows for inclusion of *a priori* information and accounts for non-linearity in the inversion
  - Simultaneous retrieval approach minimizes errors and provides optimal retrieval
  - Multi-functioned scene classification module maximizes spatial and and spectral information
  - Second stage IR+MW retrieval handles different cloudy conditions
- MW component of retrieval algorithm tested with AMSU-A/B data
  - Results are consistent with NOAA retrievals
  - Results are consistent between sensors on NOAA-16 and EOS platforms
  - Results compare favorably with co-located radiosonde data
- IR component of retrieval algorithm tested with NAST-I data
  - Results are consistent with retrievals performed by NASA Langley
  - Results compare favorably with co-located radiosonde and drop-sonde data
- Algorithm tests started using AIRS data
  - Initial (successful) processing of combined AMSU/AIRS data
  - Results compare favorably to co-located radiosonde data
  - Further algorithm tuning required for complete validation