Characteristics of the Cloudy Atmosphere Observed by AIRS

Evan Fishbein
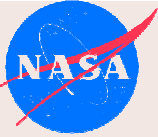
Luke Chen

Sung-Yung Lee
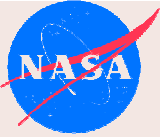
JPL

Procedure

- Overview of AIRS Products – Global Performance
- Use exemplar footprints to characterize dependence of product on cloudiness – 3 examples
  - Cloud-free
  - Low stratocumulus
  - Tropical cumulus convection
- Types of analyses - consistency between radiances
  - Observed (Obs)
  - Cloud-cleared (CC)
  - Calculated from ECMWF forecast ($Calc_{ECMWF}$)
  - Calculated from retrieved solutions ($Calc_{AIRS}$)
- Consistency of CC water vapor radiances and dynamics

Overview

- ## 2002 September 9 (AIRS Focus Day 3)
  - ### Successful MW retrievals: 94%
  - ### Successful MW & cloud clearing: 93%
  - ### Full MW/IR Retrievals: 67%
  - ### Clear Retrieved Footprints (AIRS, AMSU):
    - #### NaF < 0.5:   0.2%
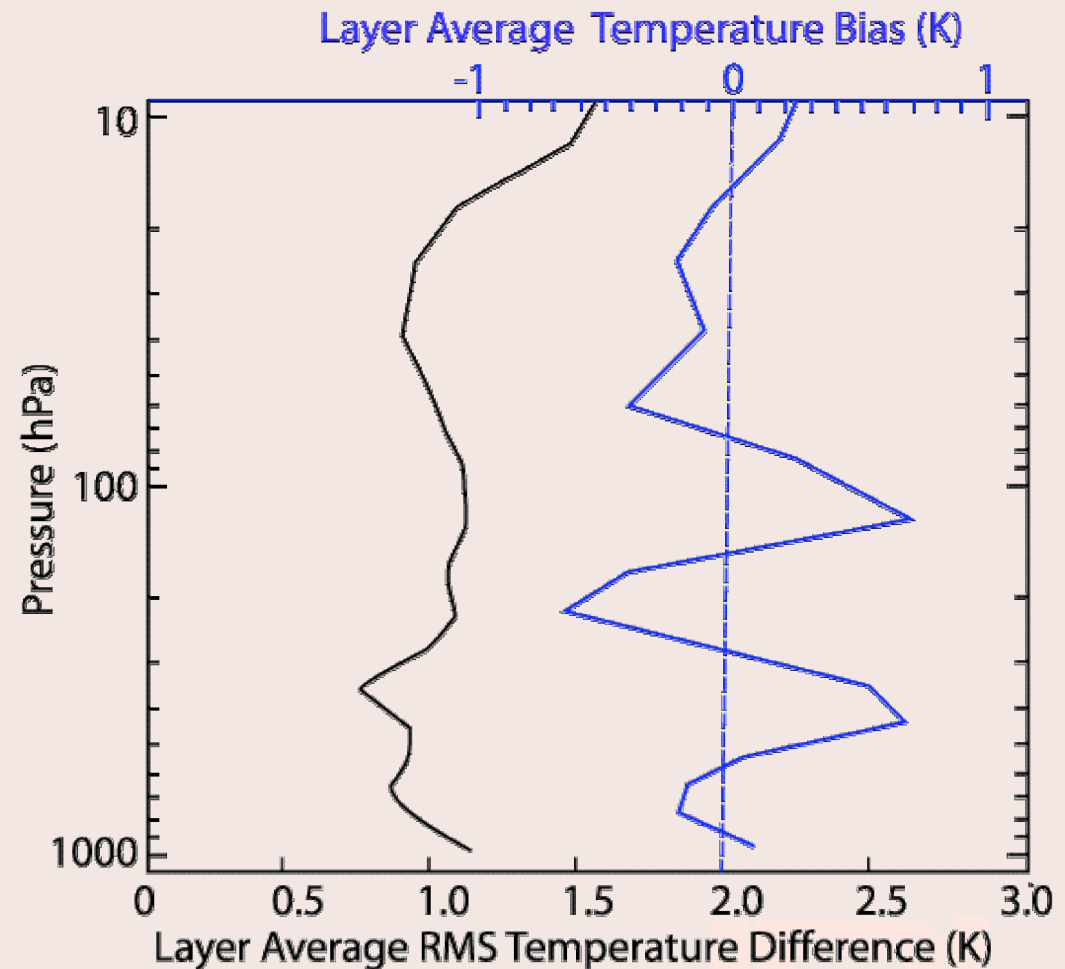   - #### **Surface Channel Cloud Contamination < 0.1K**:   11%   5.0%

$$\sum_{i} f_i \left\{ T_b^{Surf} - T_{bi}^{Cloud} \right\}$$

    - #### Total Cloudiness < 1%:   10%   3.8%
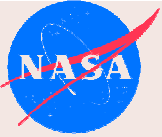
Temperature Profile Characteristics

- Comparison between AIRS retrievals and interpolated ECMWF

- RMS difference is an estimate of sum of forecast and retrieved errors (assumed uncorrelated)
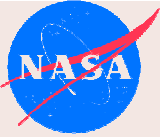
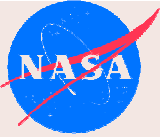# Theoretical Basis for Cloud-Clearing

- Assumptions
  - Clouds are gray absorbers
  - Most parameters are homogeneous (independent of horizontal coordinates) within an AMSU footprint
    - Surface properties: emissivity, reflectivity, skin temperature
    - Profiles: temperature, water vapor, trace gases
    - Cloud properties: cloud top pressure, emissivity and reflectivity
  - Clouds are localized, i.e. cloud cover varies between AIRS footprints.

Characterization of Cloudiness

- Prediction of sea surface temperature
  - 21 LW channels (800 – 1000 cm^{-1}) SST
  - Cloud contamination characterized by departure from correlative SST
  - 0.8K precision

- Radiance coherency between adjacent footprint
  - Standard deviation of predicted SST in 3x3 AIRS footprints
  - 0.2K precision

- Noise amplification by cloud clearing

3 Study Footprints Presented

- 26/10/39
  - Low LW incoherency
  - Low SST discrepancy
  - Identified cloudy by retrieval
  - Thin cirrus
- 68/12/66
  - High LW incoherency
  - Identified clear by retrieval
  - Low stratocumulus
- 27/46/53
  - Moderate LW incoherency
  - Identified cloudy by retrieval
  - Tropical mesoscale cumulus systems
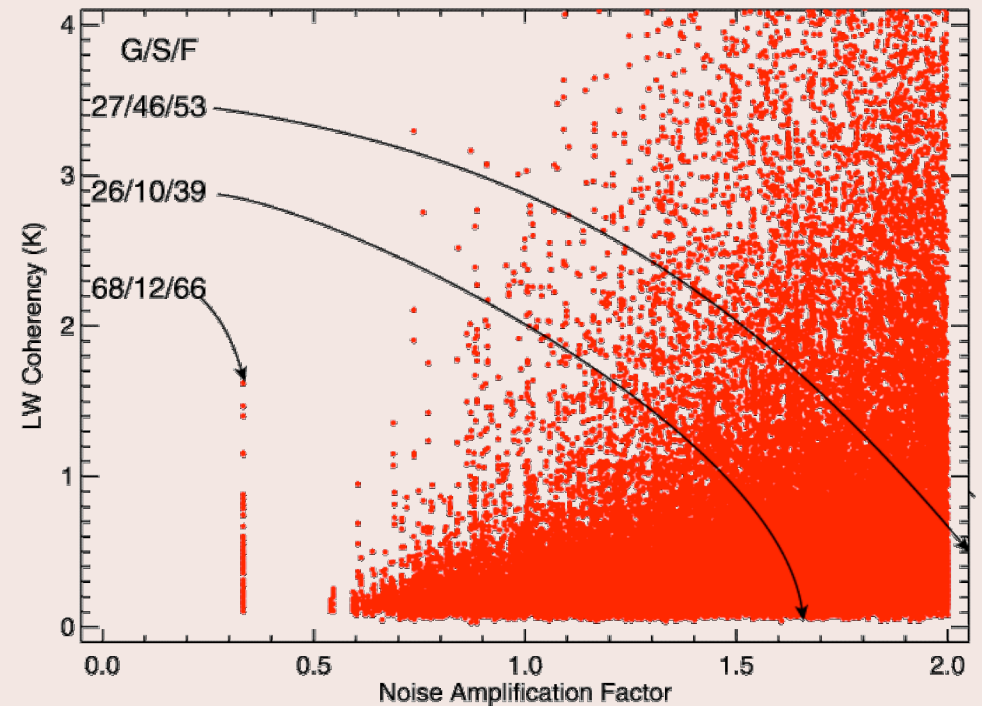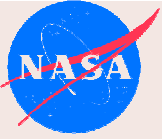
Cloud-Free Region (1)

- 6 September 2003
- G/S/F: 26/10/39

  (Granule/Scanline/Footprint)

- Noise Amplification Factor (NaF)   1.28
- LW Coherency: 0.05K
- LW SST Pred Err: 0.26K

Cloud Signatures

ECMWF - Obs
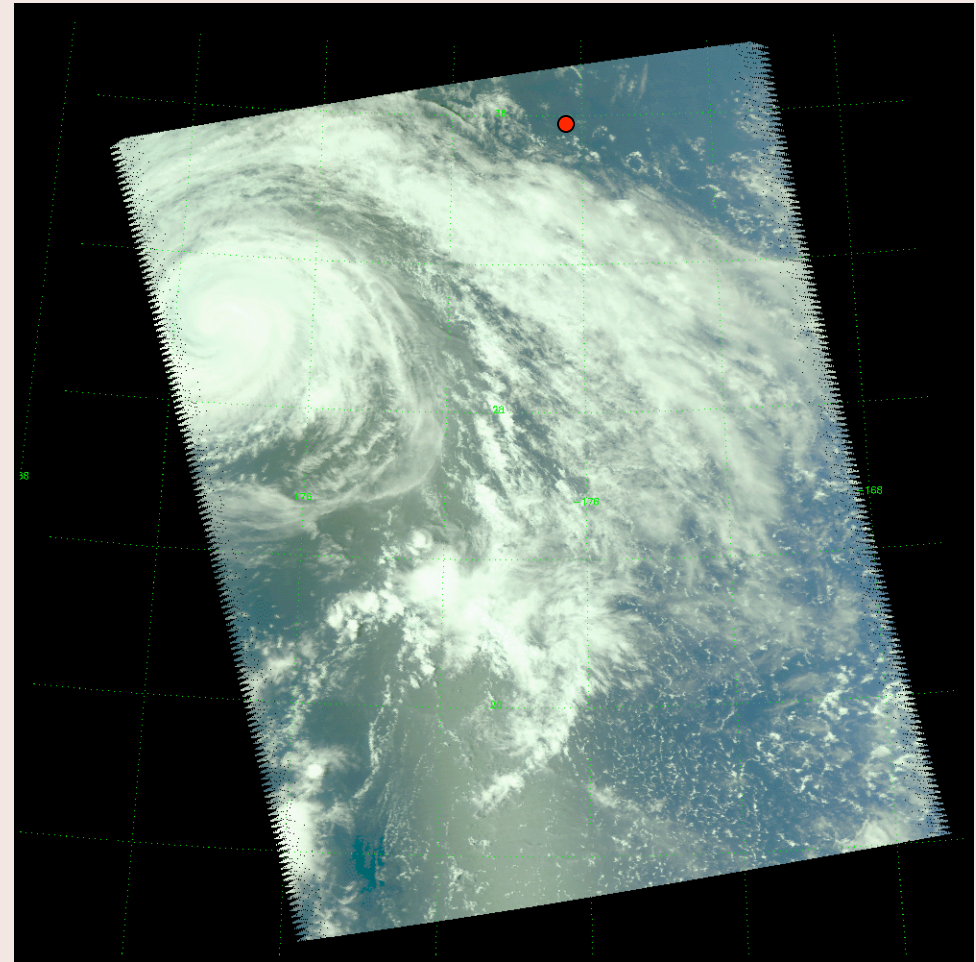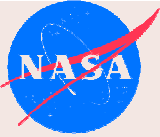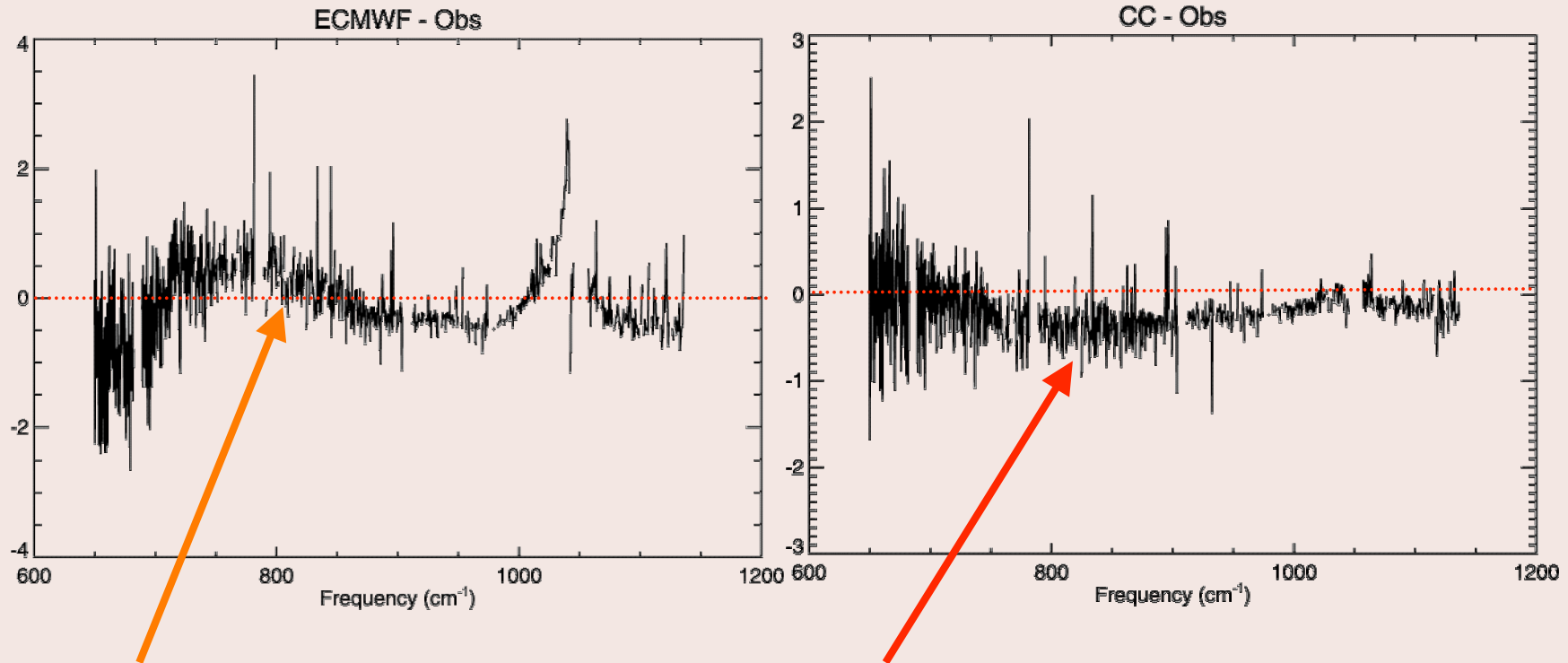
CC - Obs

Surface Channels show droop indicative of cirrus

CC – Obs do not show removal of cirrus signature

CC are cooler than observed in window channels.

CC and ECMWF-calculated are within 0.4K in these surface channels
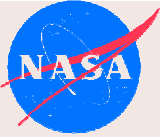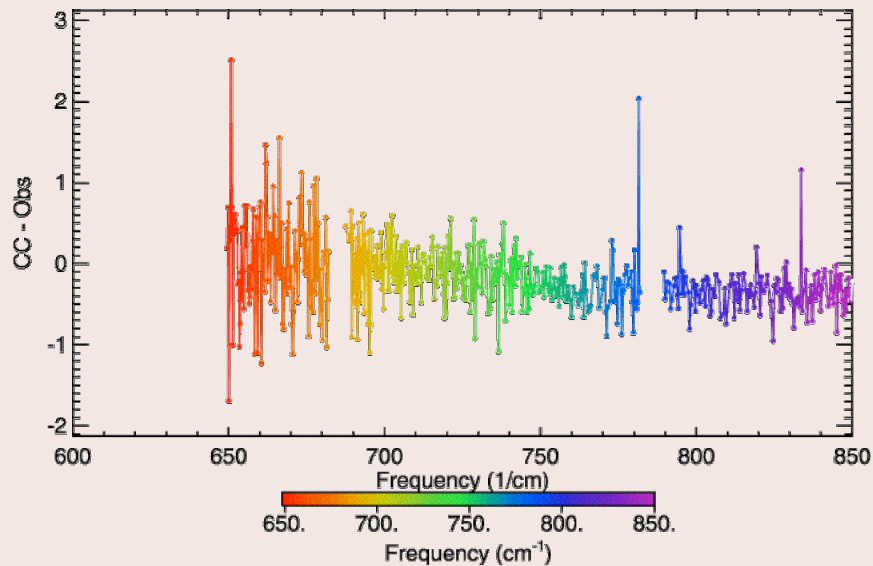
Cloud-Cleared – Obs
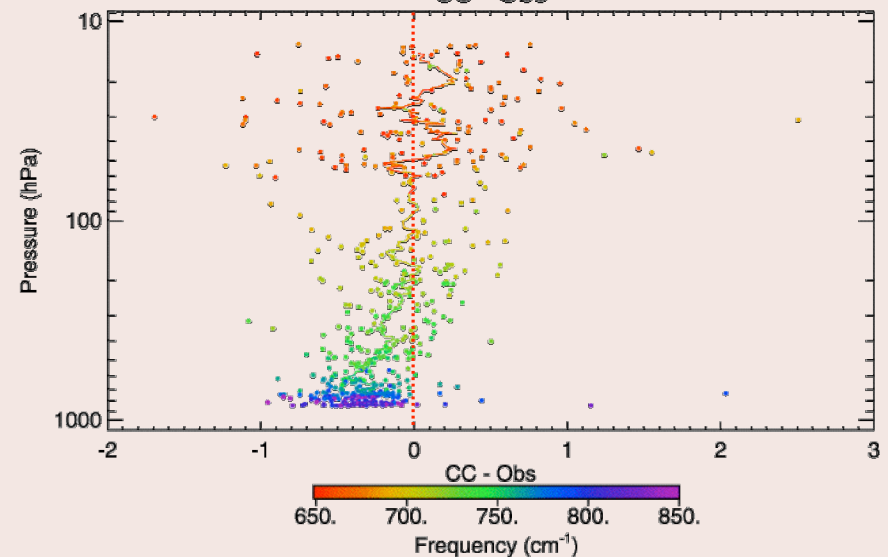
Map radiances onto pressure using P centroid of weighting functions.

Smoothed differences shown by line (method is dubious near surface)

# Cloud-Cleared – Calc (AIRS)

- CC Radiances calculated from retrieved state, Retrieval Type 0
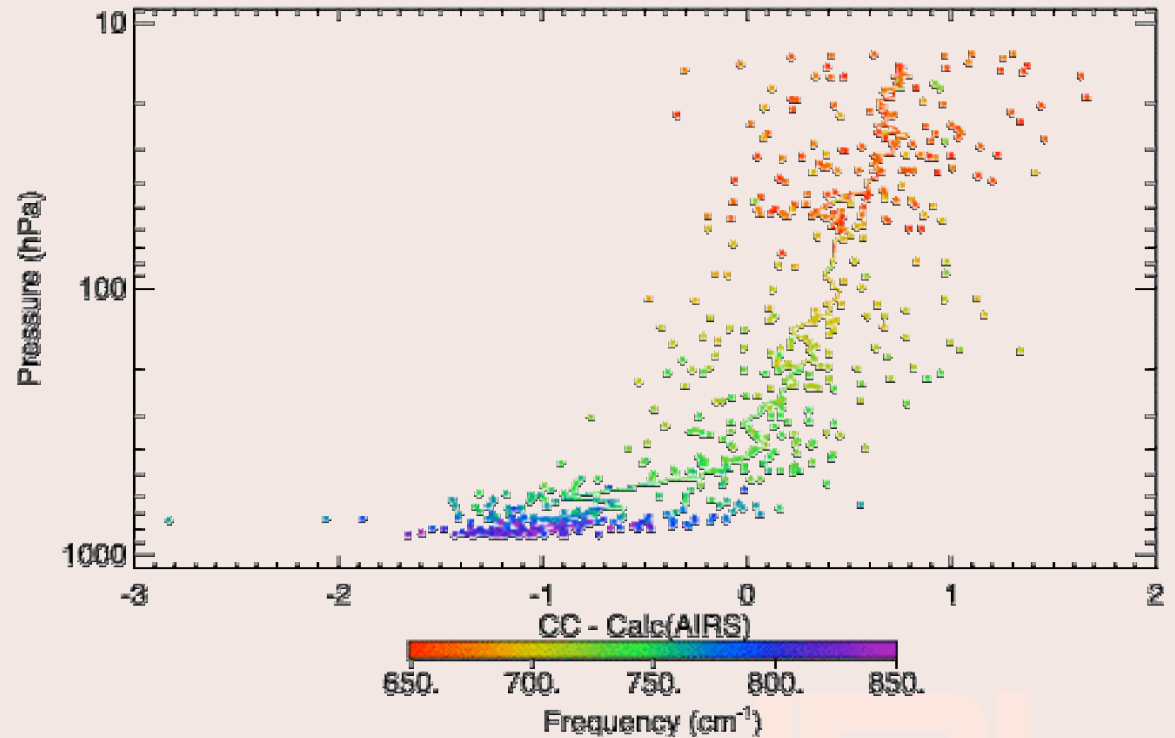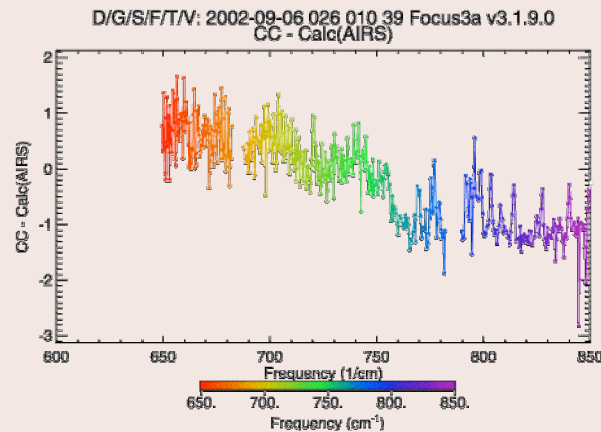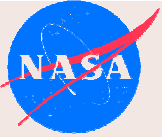
Summary for Example 1

- Retrieval is detecting false cloud
  - Primitive cloud spectral model does not fit spectral shape of clouds
- Cloud-cleared - radiances calculated from solution
  - Poor in stratosphere and lower troposphere
  - Error propagates upward and downward through profile
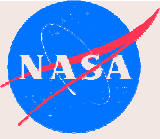
Cloudy Region Flagged Clear (2)

- Retrieval Set contains both G/S/F: 68/12/66 and 68/10/65 (Night)

  (Coherency employs moving window)

Freq=715.94 cm⁻¹(Ch 232) 20020906 G-68
Cloud Cleared BT

258 260 262 264 266

Freq=715.94 cm⁻¹(Ch 232) 20020906 G-68
CC - Obs

2 4 6

Channel: 232
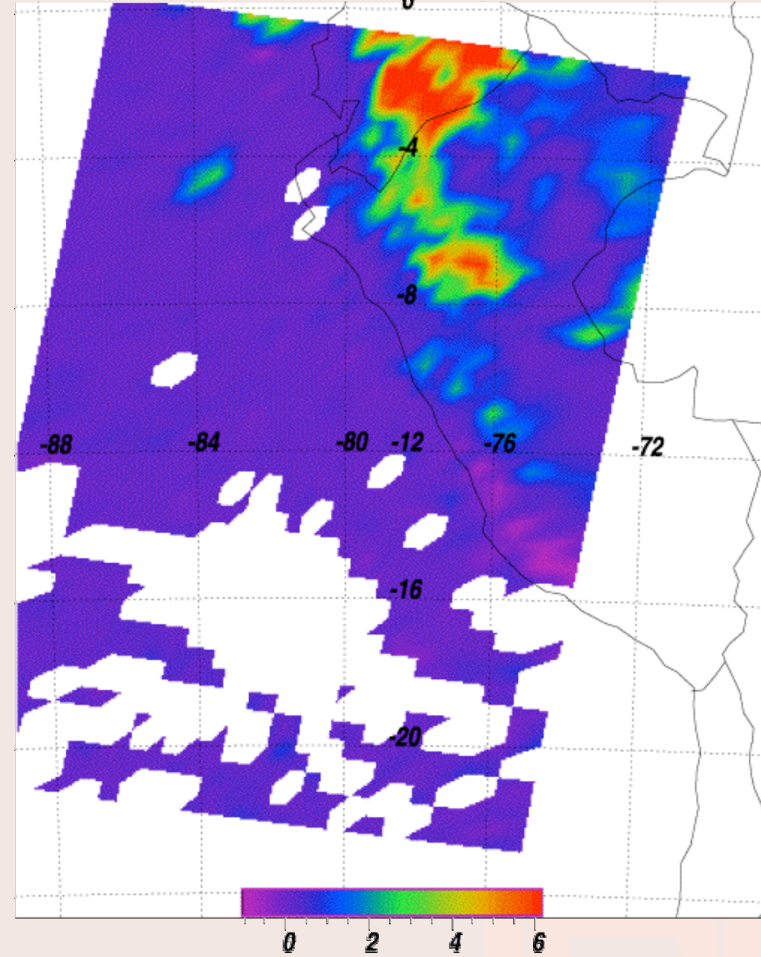Freq: 715.94
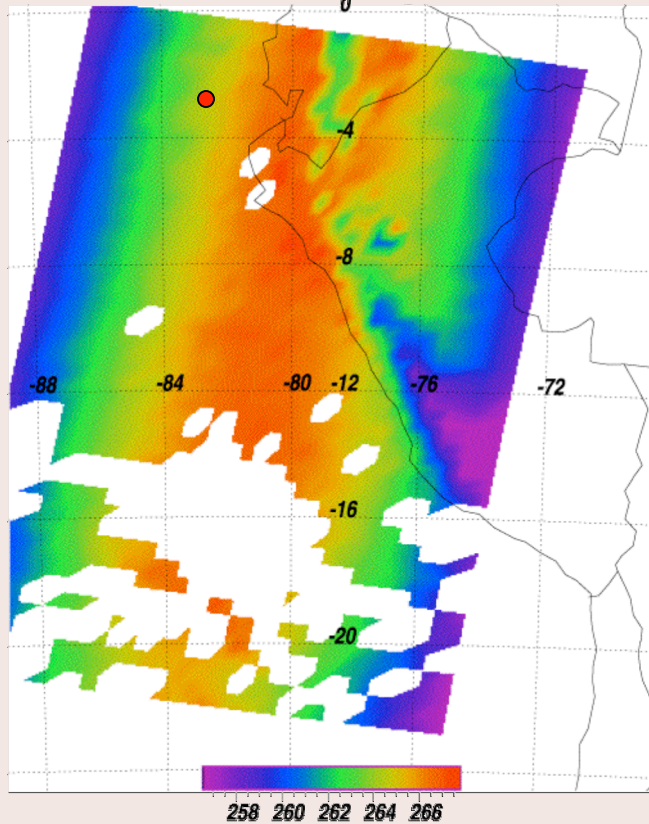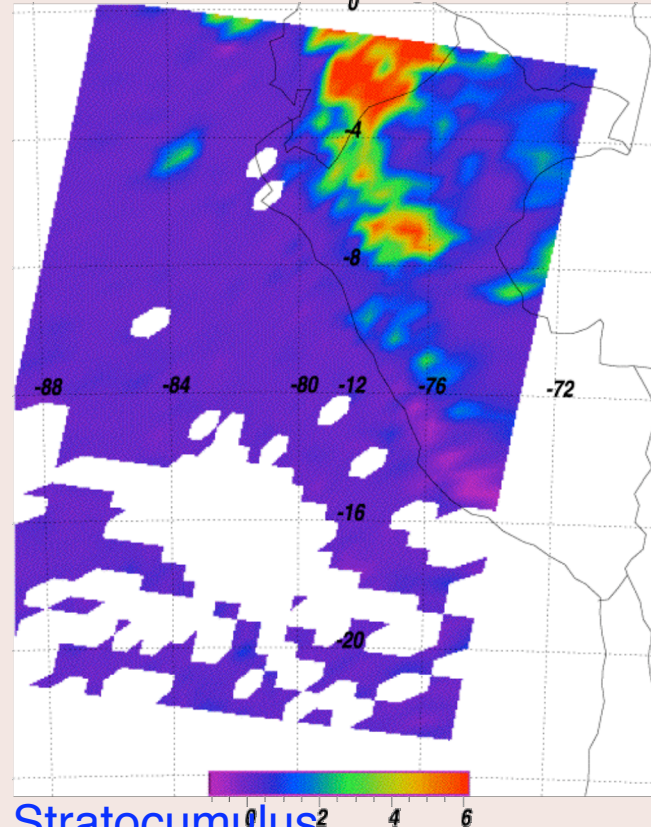
Low Stratocumulus
Coast of Peru

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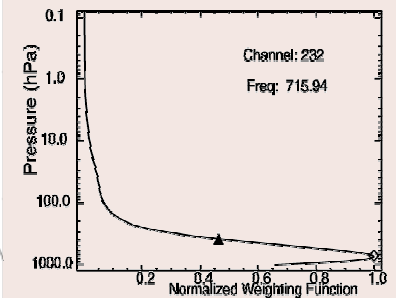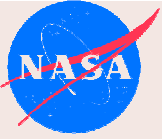
Consistency of Cloud-cleared and Calculated Radiances

Freq=715.94 cm^{-1} (Ch 232) 20020906 G-68

CC - Calc(AIRS)
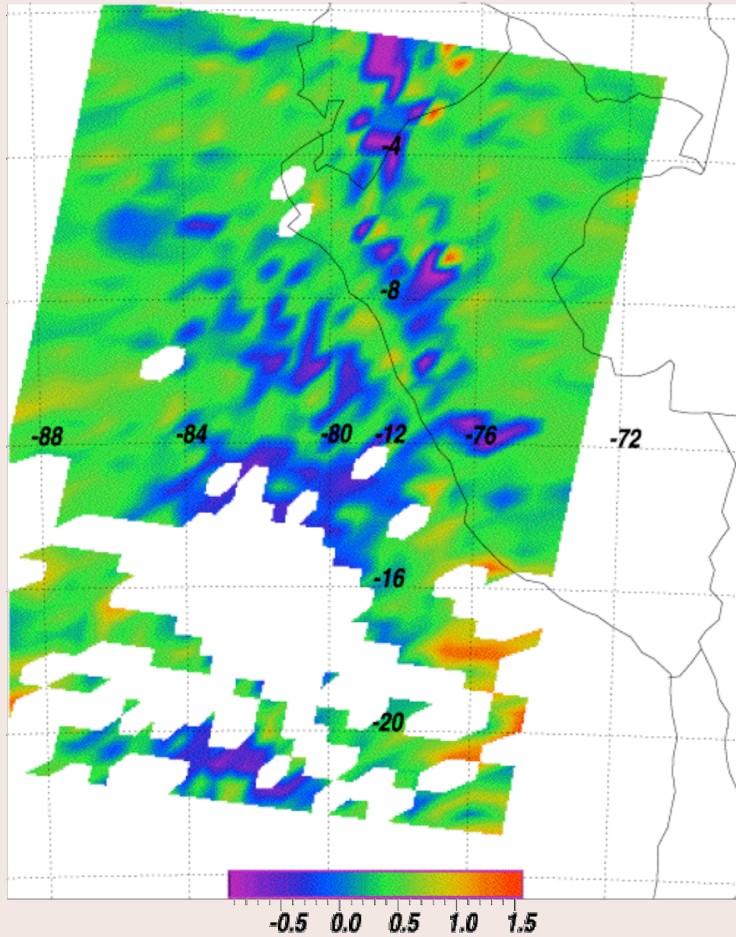
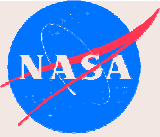Freq=715.94 cm^{-1} (Ch 232) 20020906 G-68
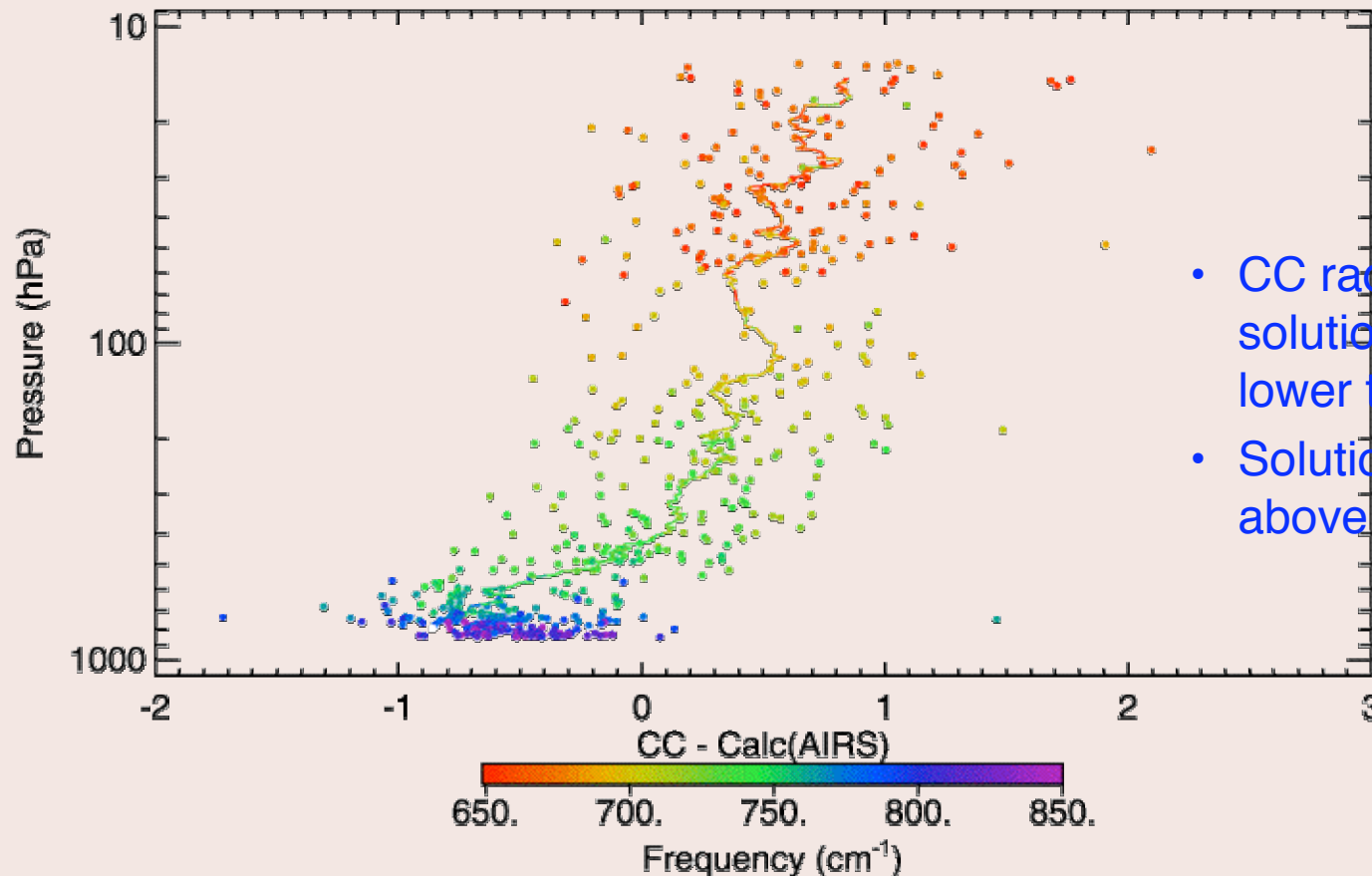
CC - Obs
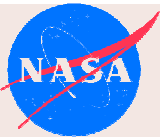
Cloud Signatures
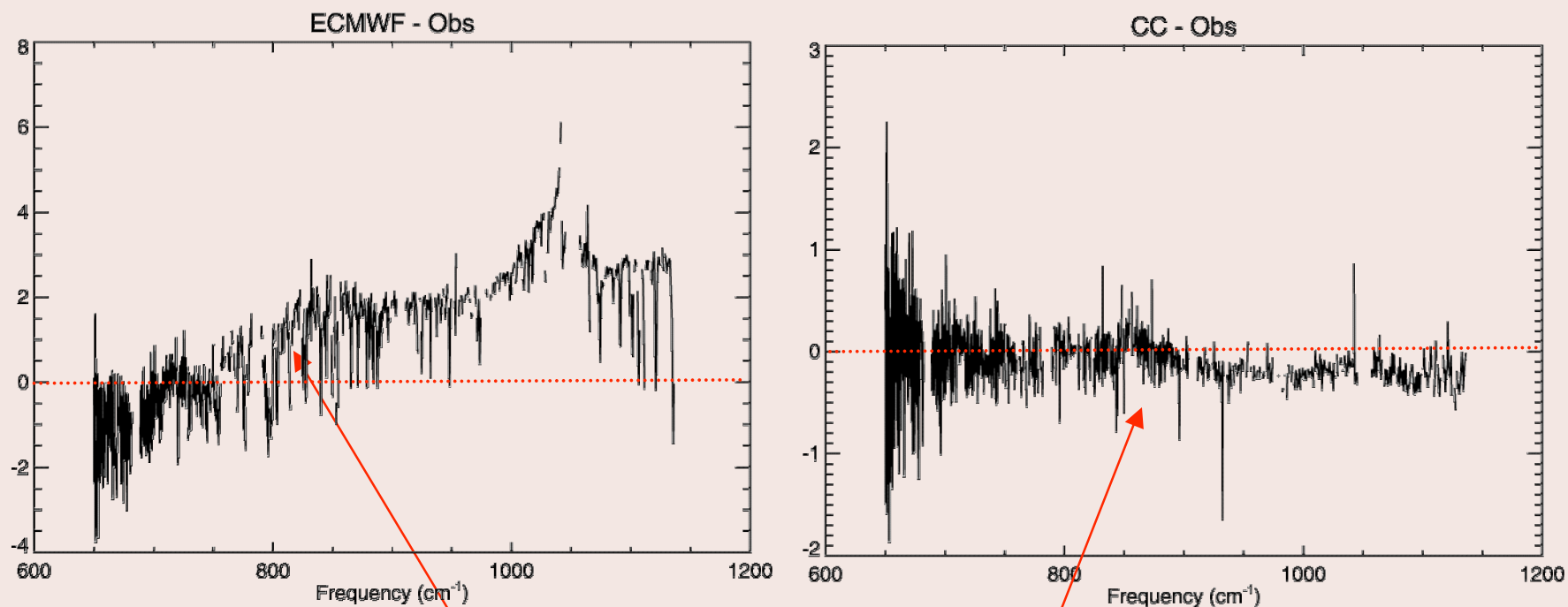
Difference with ECMWF shows spectra signature of water clouds
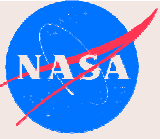
Observed and Cloud-cleared radiances are the same

Consistency of Cloud-cleared and Fitted Radiances

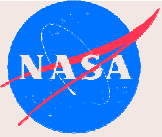D/G/S/F/T/V: 2002-09-06 068 012 68 Focus3a v3.1.9.0
CC - Calc(AIRS)

- CC radiances are warmer than solution-derived radiances in lower troposphere
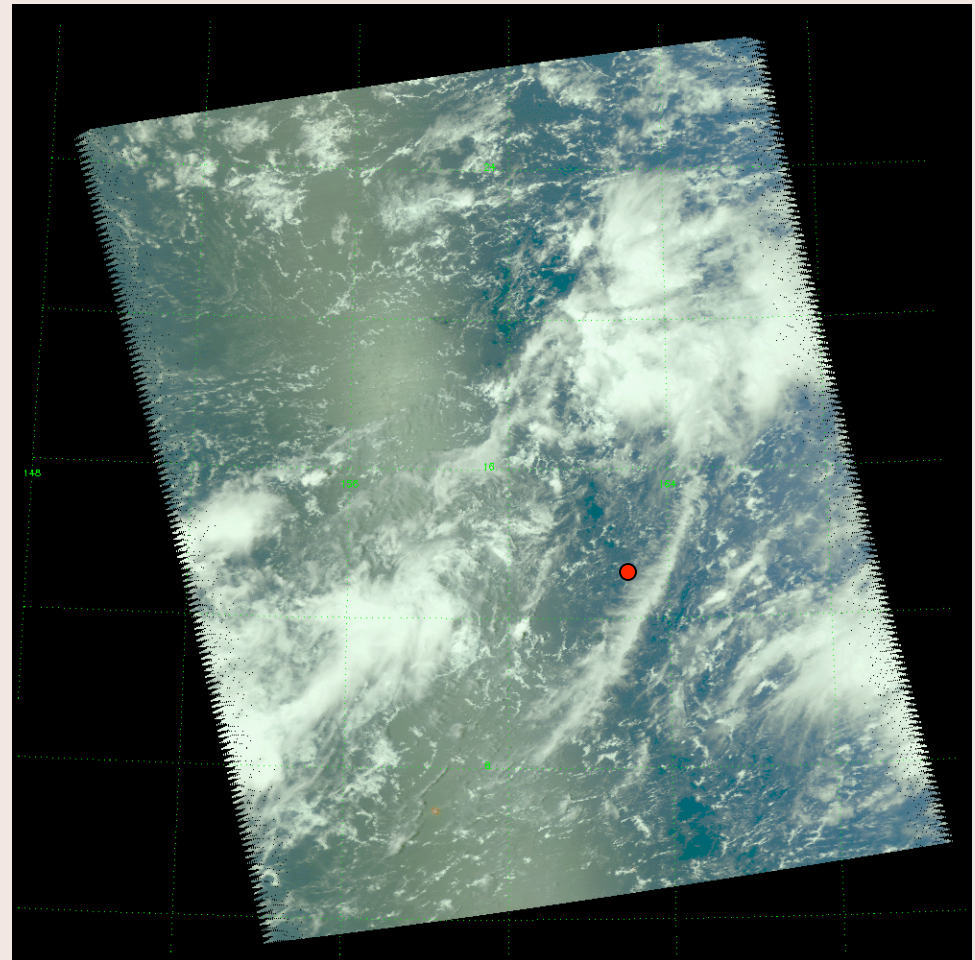- Solution radiances are warmer above clouds

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Summary of Example 2

- Low Stratocumulus not detected
  - Signature of liquid water clouds
- Fit to radiances within 1K in 1 km layers
  - Differences are correlated with height
- Radiances contain information not used by retrieval
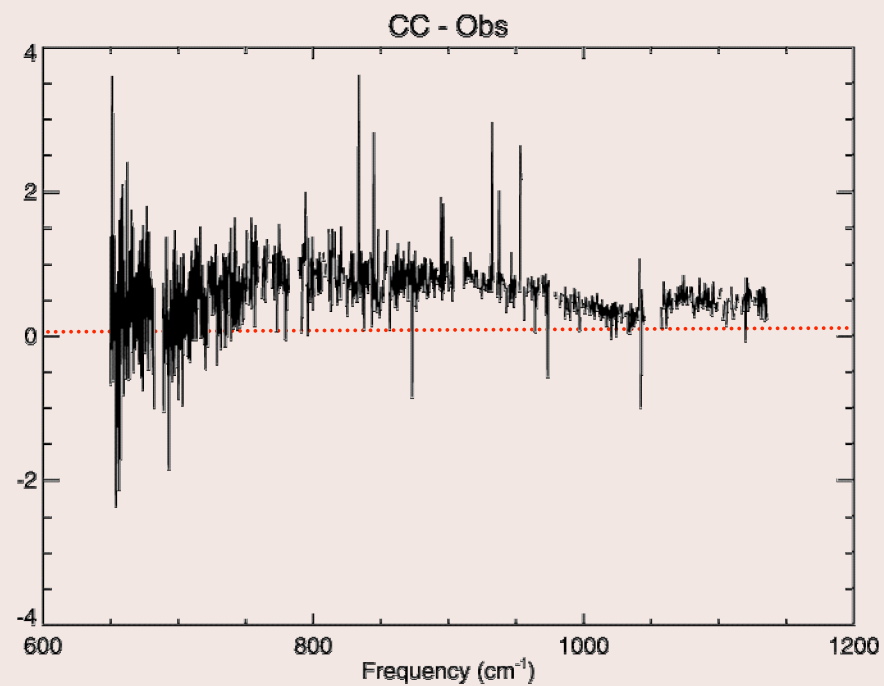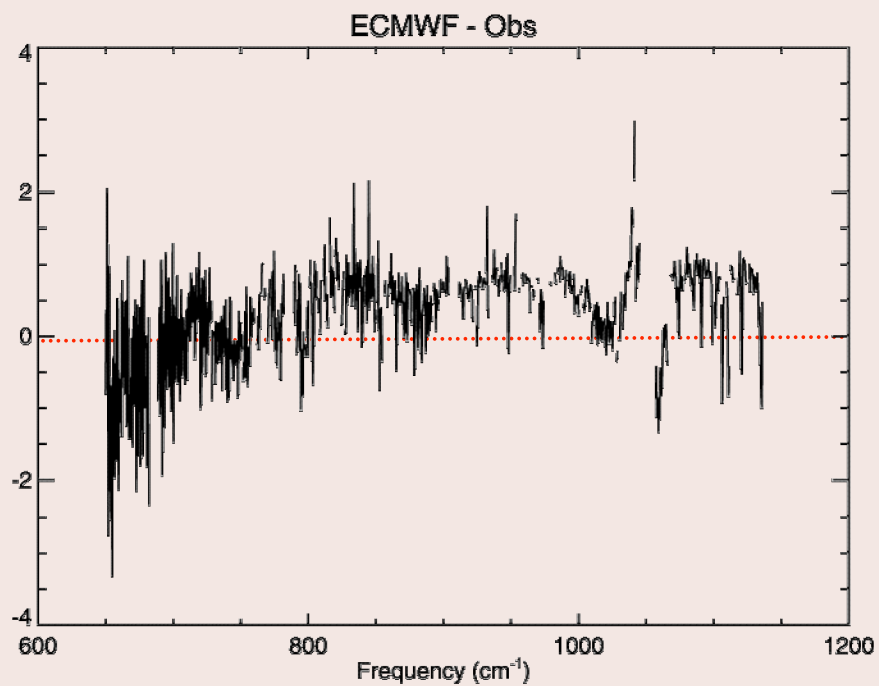
Tropical Cumulus

- Tropical Western Pacific
- GSF: 27/46/53
- 12.26 ° N, 161.7° E
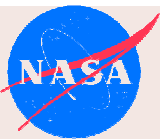- NaF: 3.1

- Mesoscale Convective Systems

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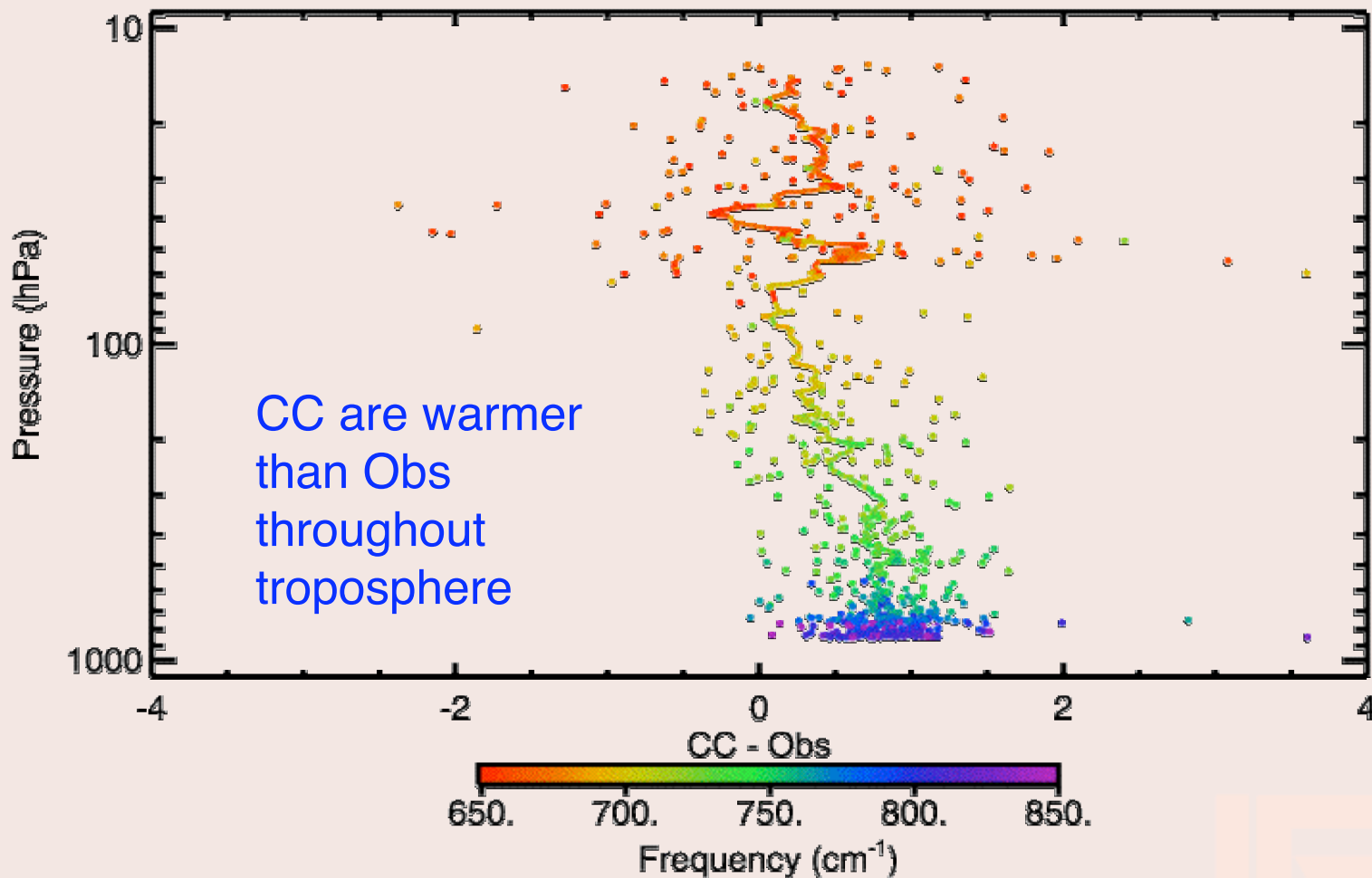# Cloud-cleared

ECMWF - Obs

CC - Obs

Cloud-cleared – Obs

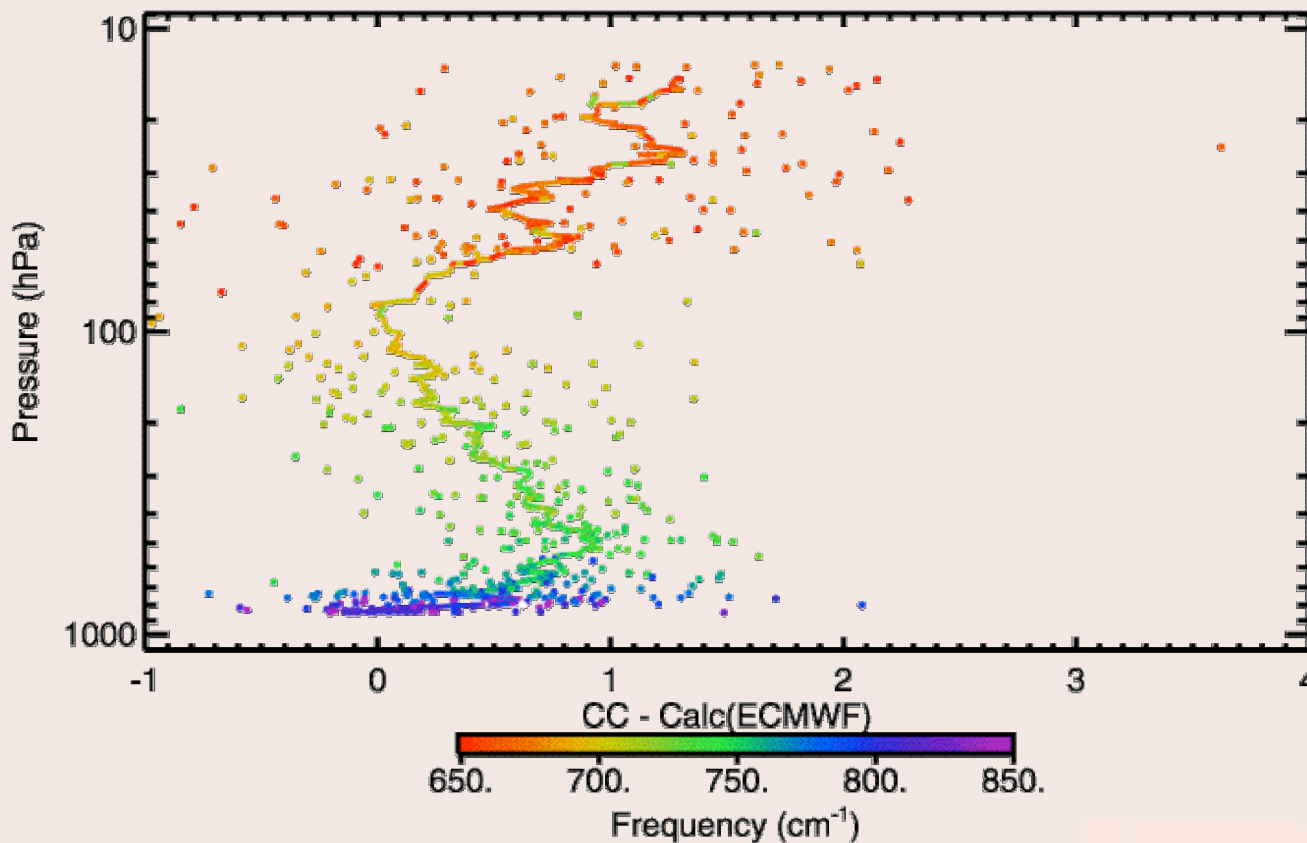D/G/S/F/T/V: 2002-09-06 027 046 53 Focus3a v3.1.9.0
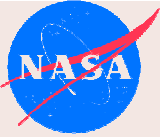

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Cloud-cleared – Calc (ECMWF)

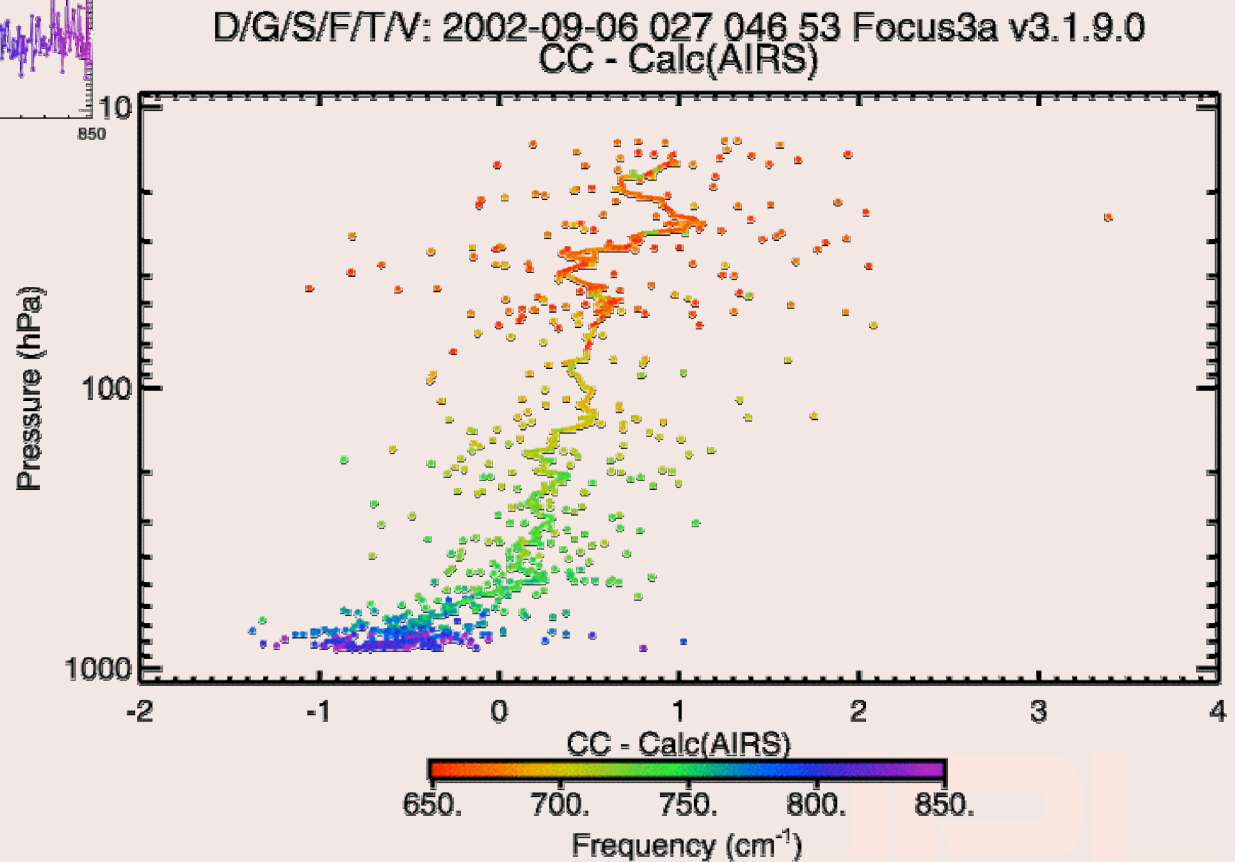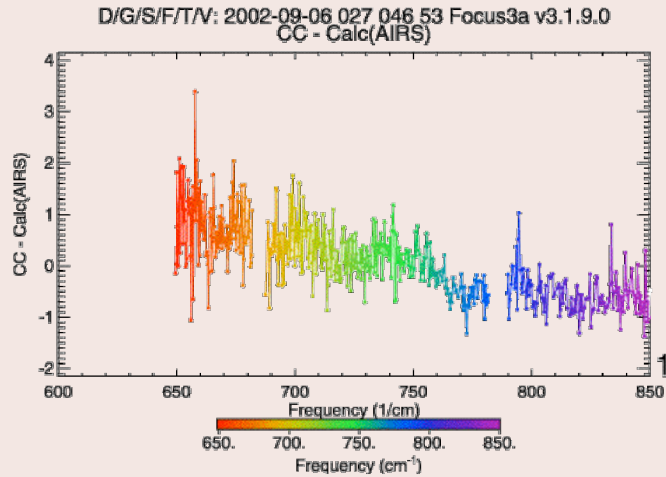D/G/S/F/T/V: 2002-09-06 027 046 53 Focus3a v3.1.9.0
CC - Calc(ECMWF)
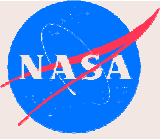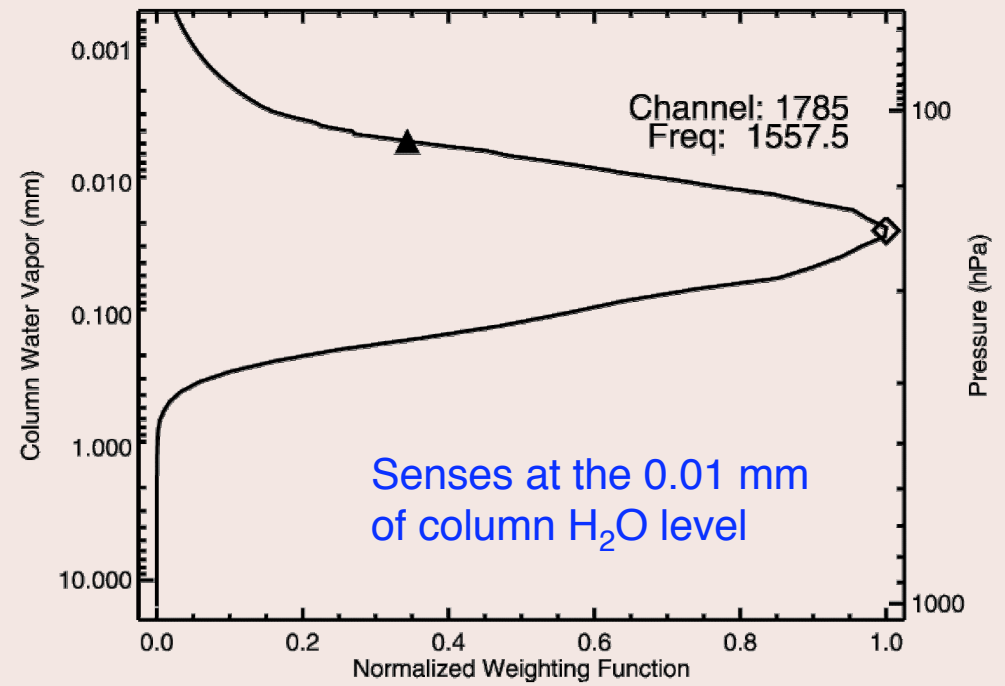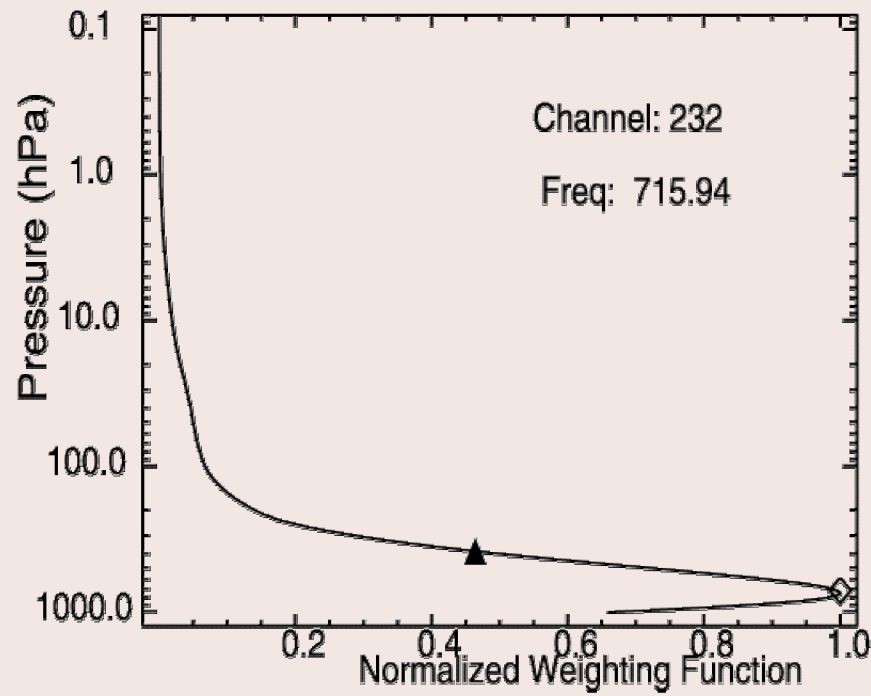
Cloud-cleared – Calc(Retrieval)

Fitted radiances match CC to 0.5K through mid and upper troposphere
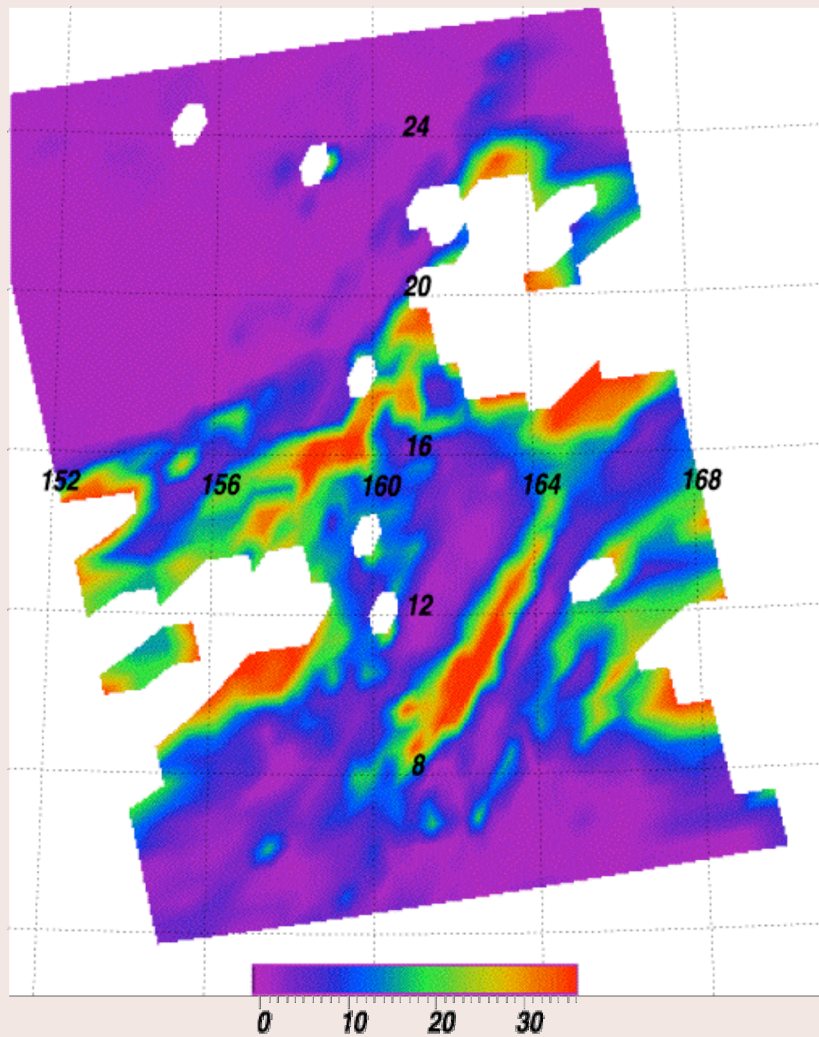
Spatial Variability of Temperature and Water Vapor
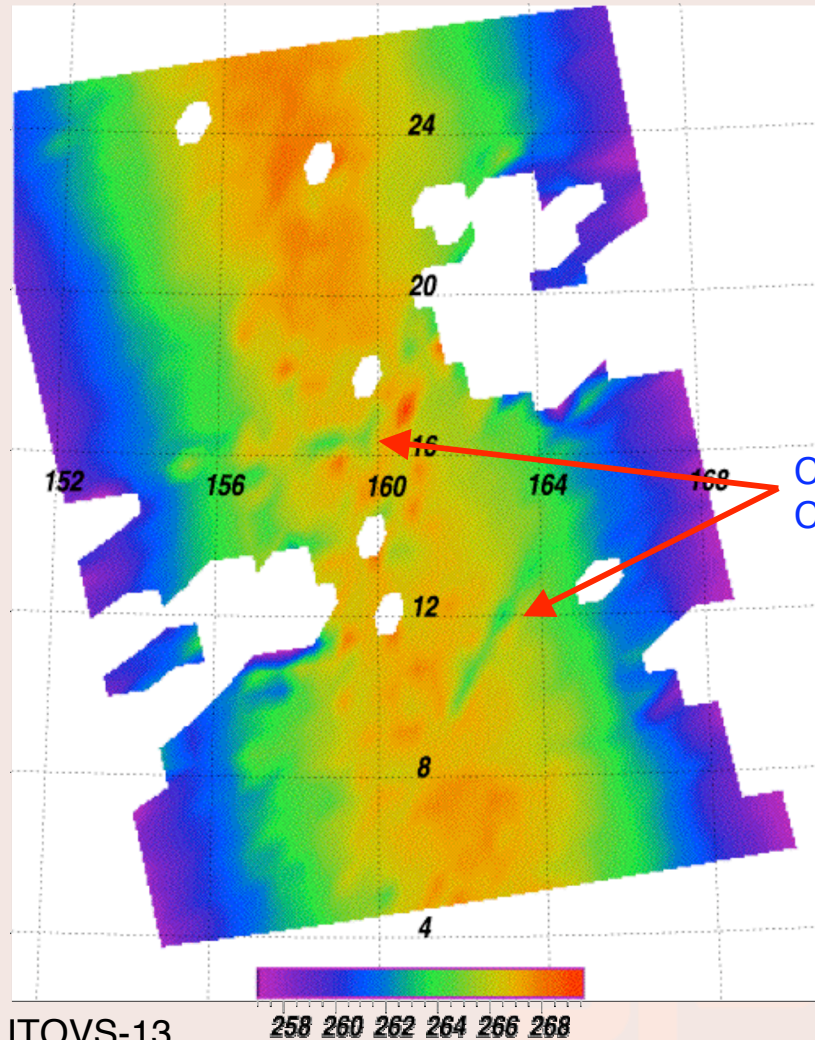
Spatial Variability
Accuracy of Cloud Clearing

Freq=715.94 cm⁻¹(Ch 232) 20020906 G-27

CC - Obs
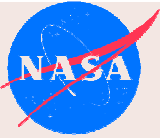
Freq=715.94 cm⁻¹(Ch 232) 20020906 G-27

Cloud Cleared BT

Cloud Contamination

Upper-Trop Water Sounding Channel
Correlation with Clouds
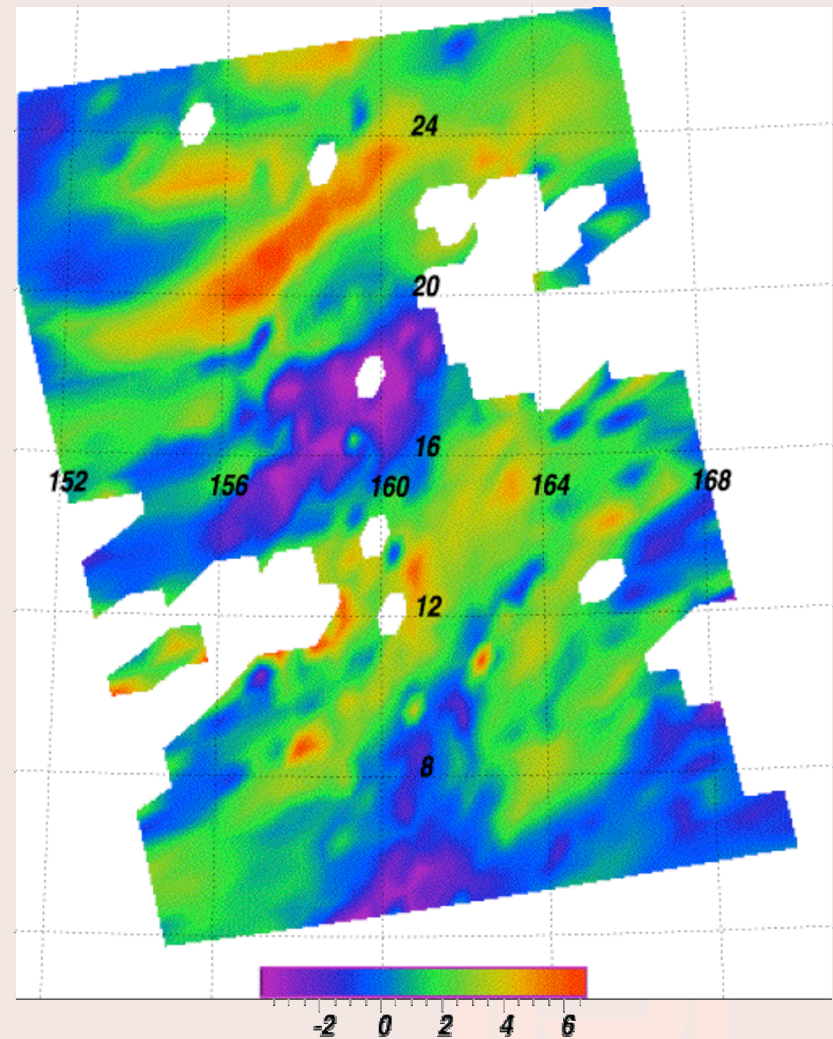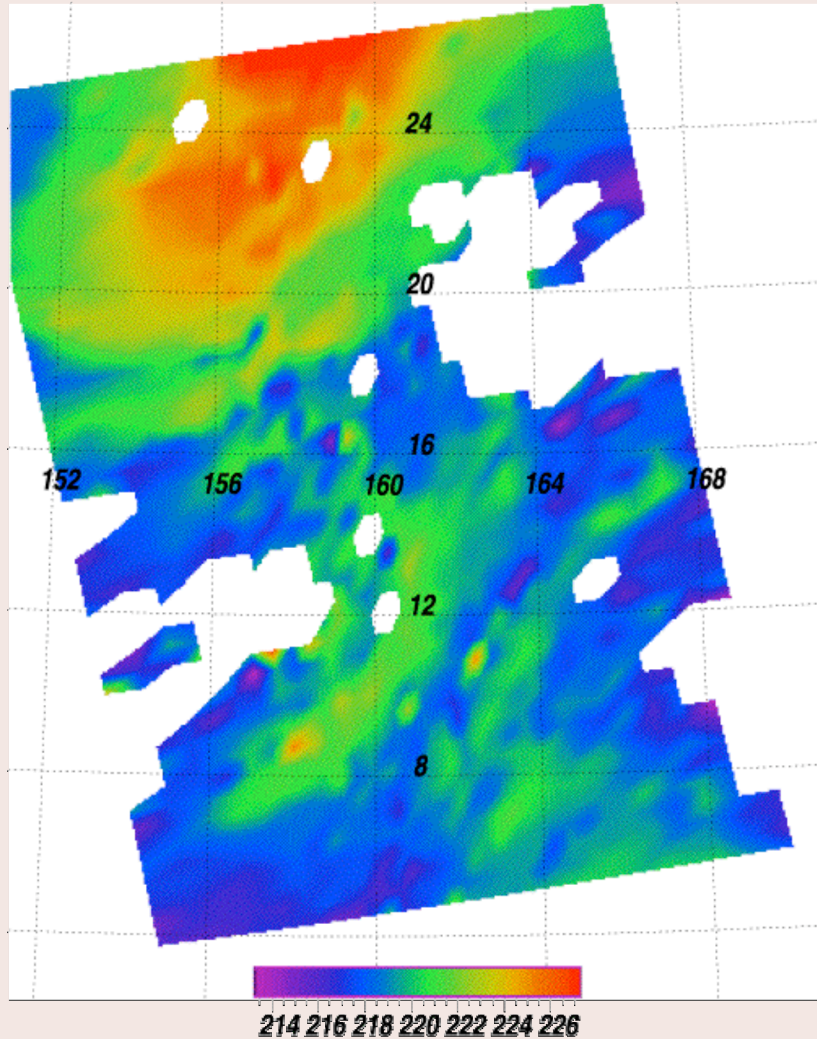

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Upper-Trop Water Sounding Channel
Spatial Variability compared with ECMWF

Freq=1557.48 cm⁻¹ (Ch 1785) 20020906 G-27

Cloud Cleared BT

Freq=1557.48 cm⁻¹ (Ch 1785) 20020906 G-27

CC - Calc (ECMWF)

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Upper-Trop Water Sounding Channel
Radiance Closure
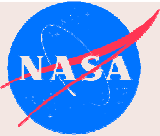

Freq=1557.48 cm^{-1} (Ch 1785) 20020906 G-27

CC - Calc(AIRS)

Freq=1557.48 cm^{-1} (Ch 1785) 20020906 G-27

CC - Calc (ECMWF)

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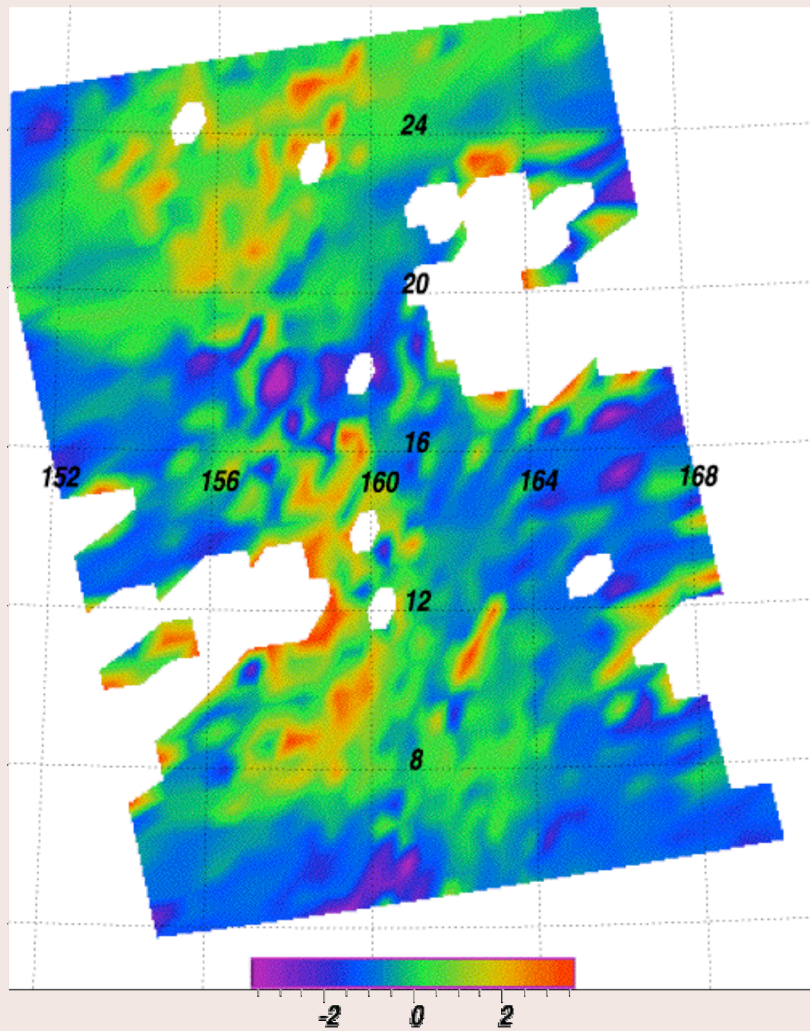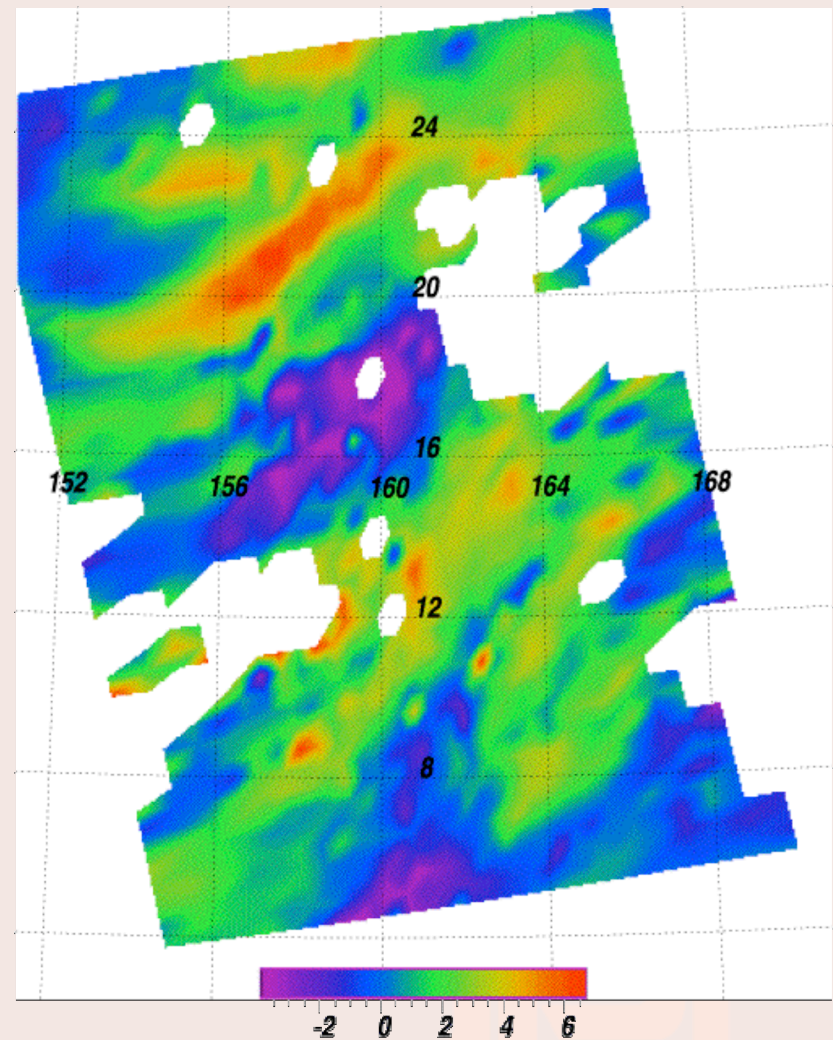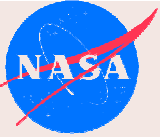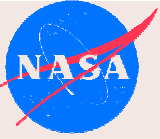
Water Vapor Spatial Variability

- Water vapor CC radiance shows greater variability then temperature
- Increases mixing ratio uplifts the 0.01 column water vapor surface,
  - 1557 cm^{-1} radiances is cooler
- Variability is correlated with clouds, but
- Radiance is consistent with:
  - vertical transport in squall
  - subsidence forward of squall

Conclusions

- Algorithms have difficulty detecting low clouds (previously known)
- Calculated radiances from solution do not agree with cloud-cleared radiances when low clouds are present
  - Implies more information can be extracted from measurement
- Algorithms appeared to be optimized for high clouds, e.g. tropical cumulus
- Mid through upper tropospheric cloud-cleared water vapor radiances show variability consistent with dynamics
- Studies of individual footprints elucidate algorithmic improvements and limitation
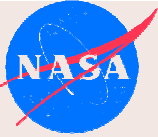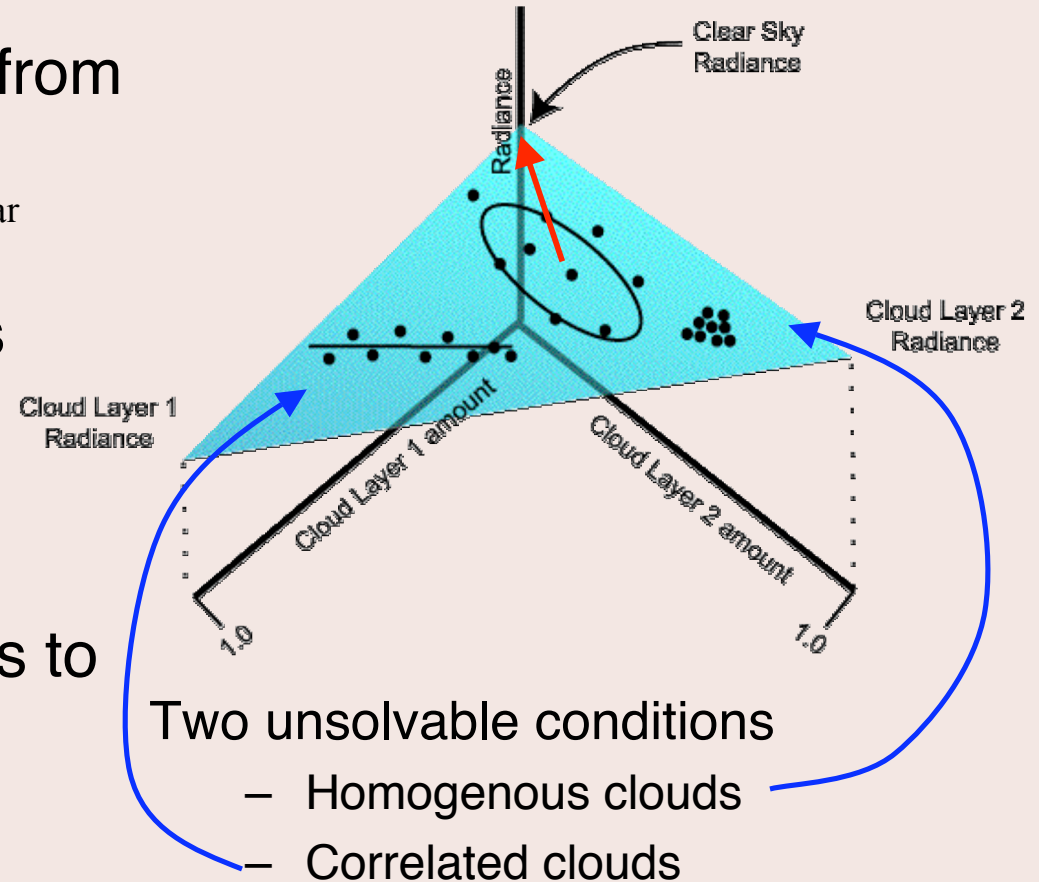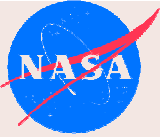
Cloud–Clearing Procedure

- Predict clear radiances from microwave radiances

$$R_{\text{iwave}} \rightarrow T, q \rightarrow R_{\text{IR}}^{\text{Clear}}$$

- Estimate cloud fractions from cloudy and pre-dicted clear radiances (predictor channels)

- Extrapolate all radiances to clear conditions
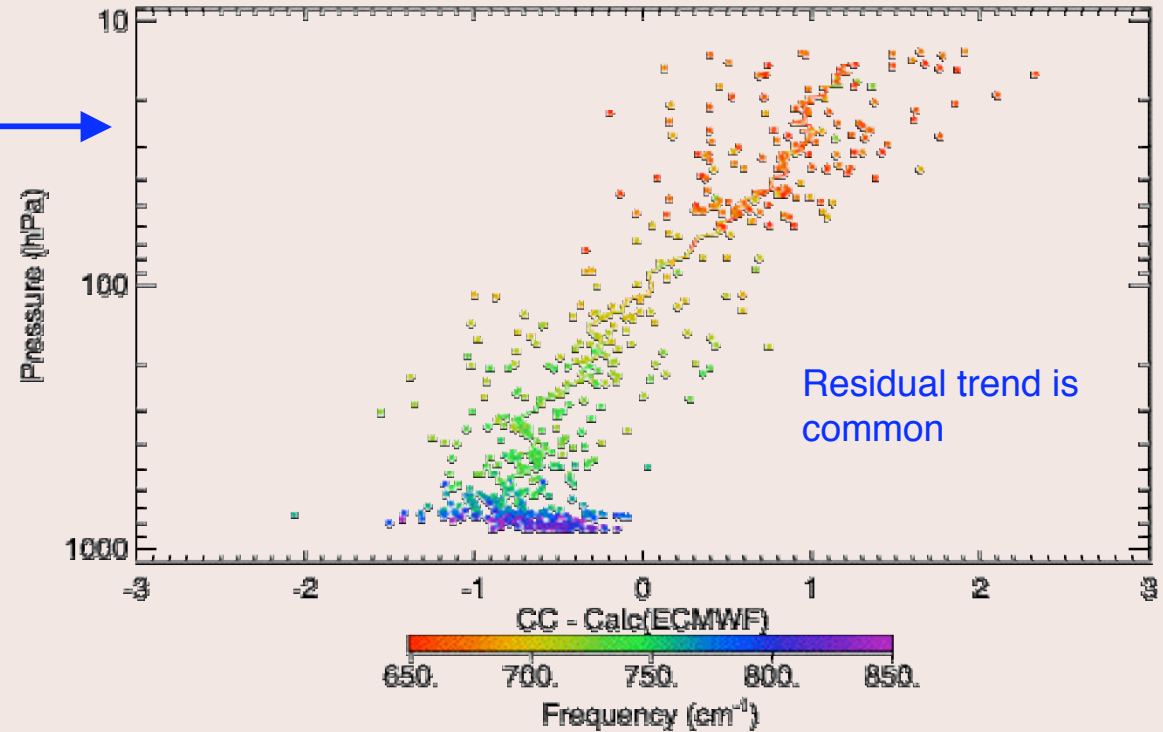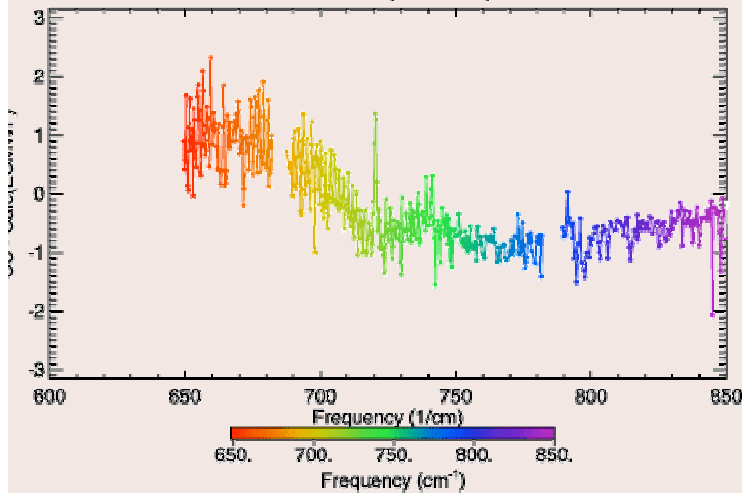 - Noise amplification

Clear Sky Radiance

Radiance

Cloud Layer 2 Radiance

Cloud Layer 1 Radiance

Cloud Layer 1 amount

Cloud Layer 2 amount

1.0

1.0

Two unsolvable conditions
  - Homogenous clouds
  - Correlated clouds

Cloud-Cleared – Calc(ECMWF)

Residual trend is common

Map radiances onto pressure using P centroid of weighting functions.

Smoothed differences shown by line (method is dubious near surface)

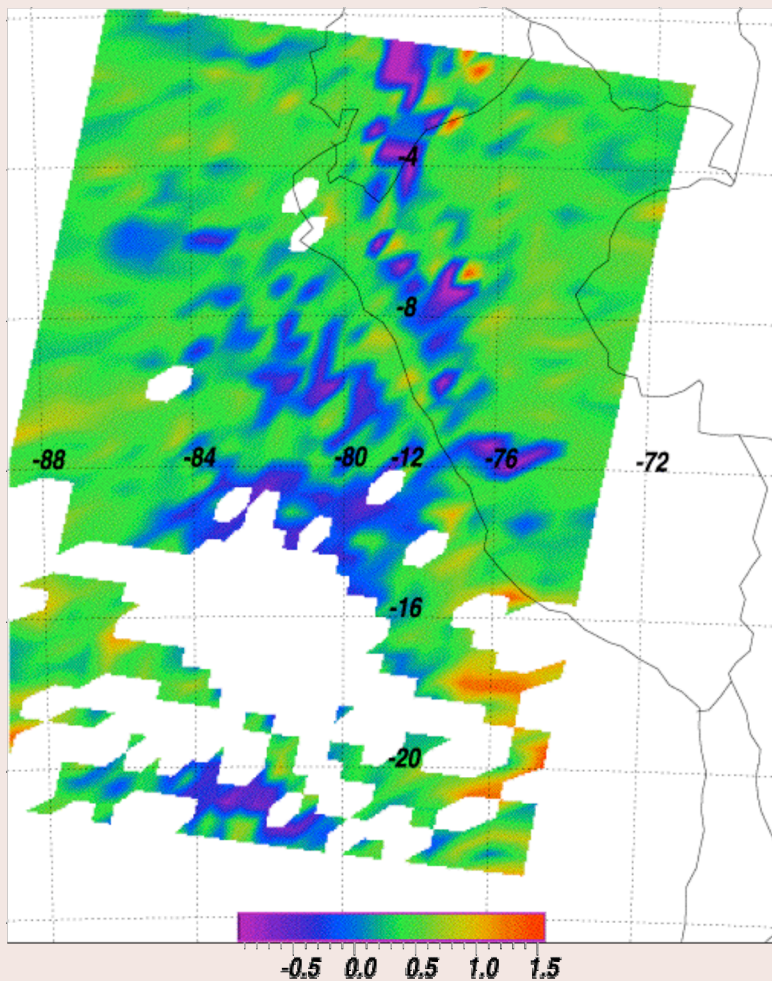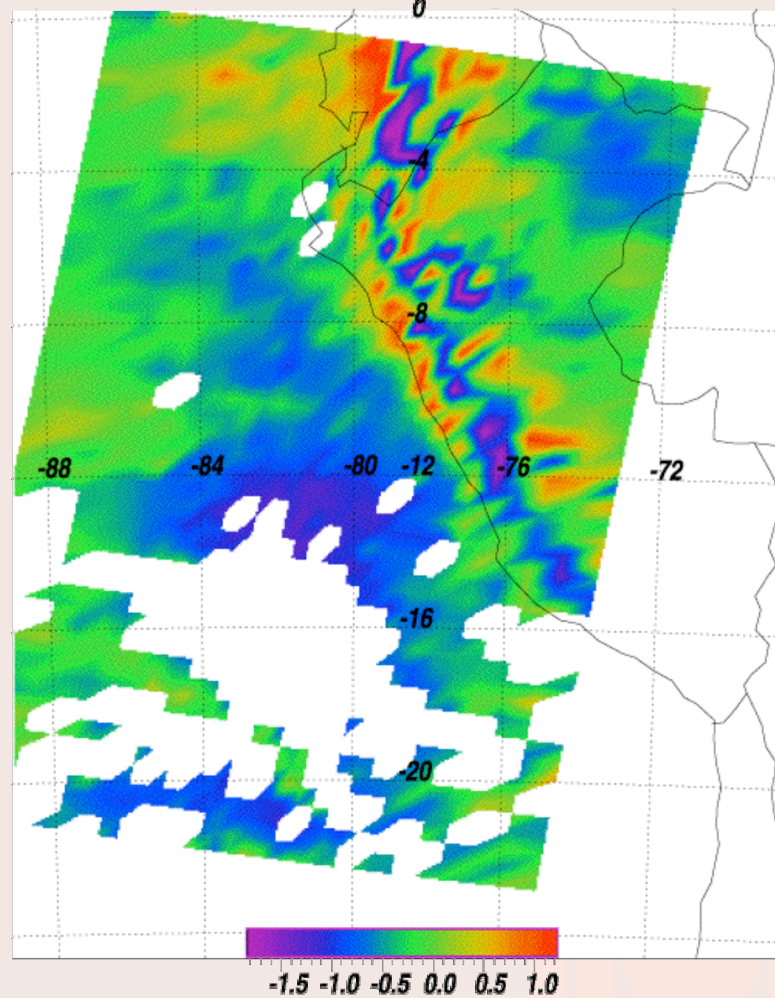# Consistency of Cloud-cleared and Calculated Radiances

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