Apperception* of Clouds in AIRS Data

Hung Lung (Allen) Huang
CIMSS/SSEC, Univ. of Wisconsin-Madison

- Clouds in AIRS Data – Almost Everywhere in Anytime
- AIRS Spectral Signature
  - Spatial, Noise, Spectral, Optical, and Clouds feature
- Cloud Clearing Issue
  - Clear vs. cloud cleared vs. Cloudy Sounding
  - Current Operational C.C. Characteristic
  - Hyperspectral IR Cloud Forward Modeling (if time permit)
- Summary

Workshop on Assimilation of high spectral resolution sounders in NWP
June 28- July 1, 2004 ECMWF Reading, UK

* 1. Conscious perception with full awareness.

2. The process of understanding by which newly observed qualities of an object are related to past experience.

% Other hyperspectral Data as well

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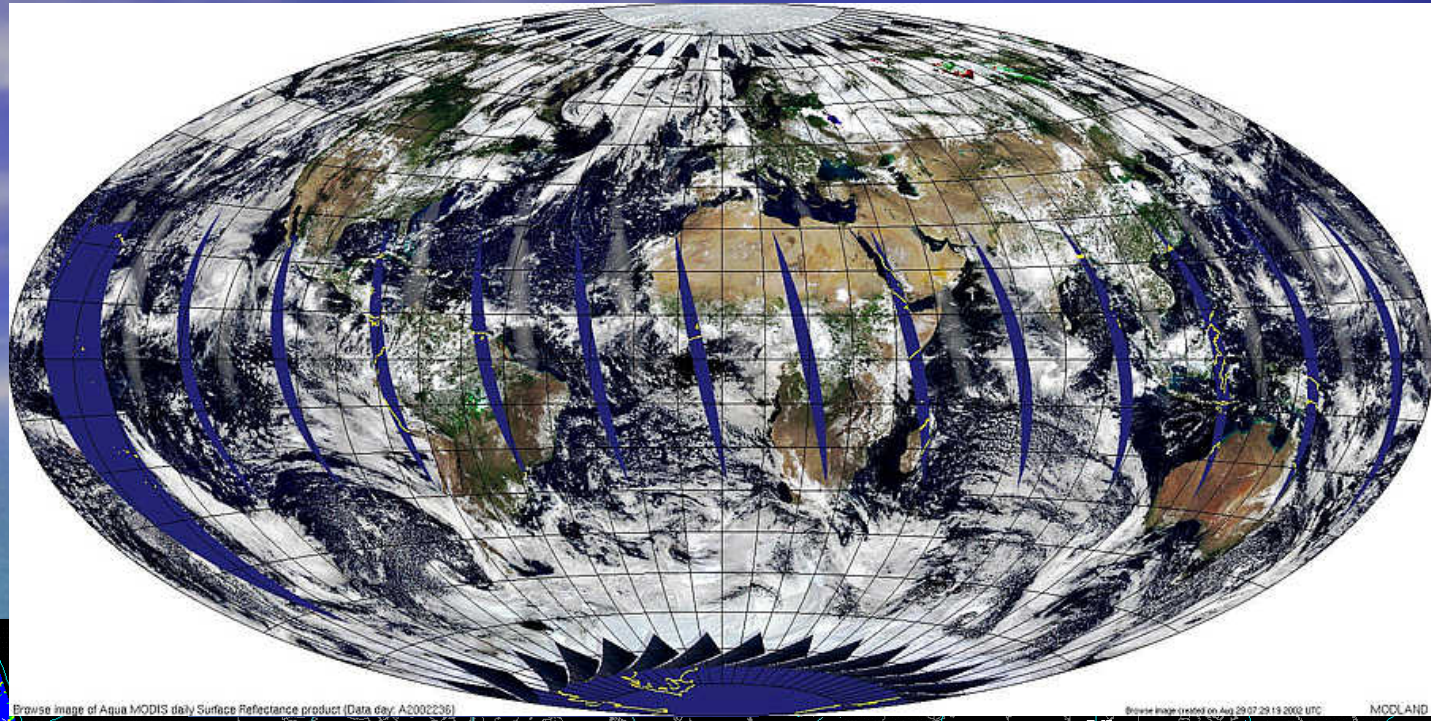
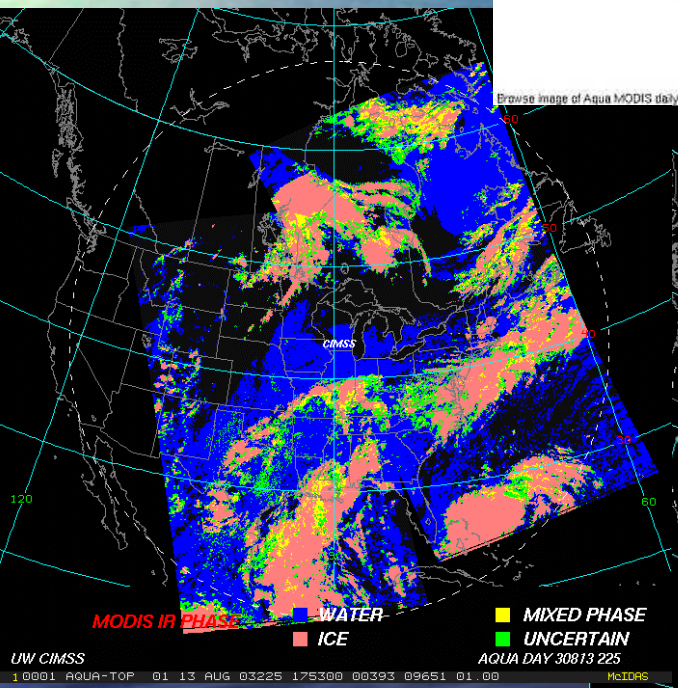
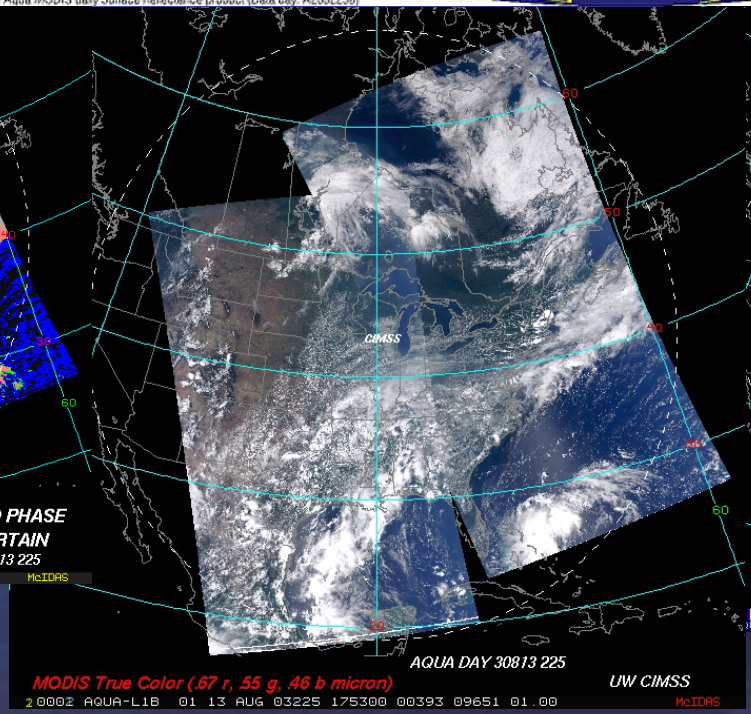
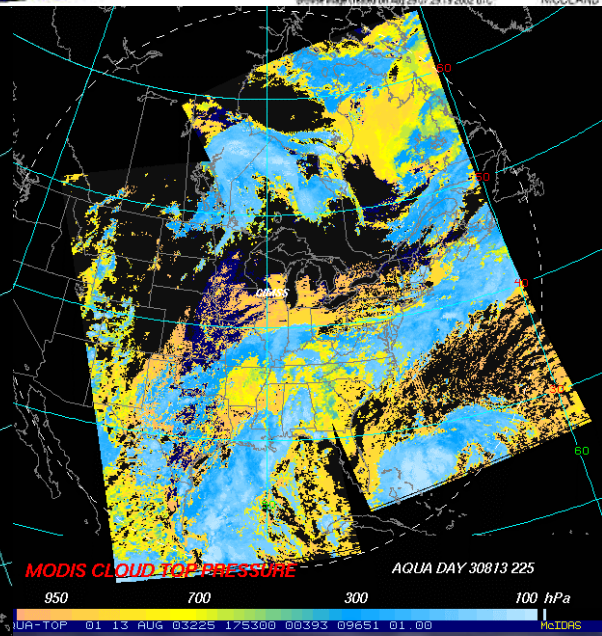
Clouds are everywhere





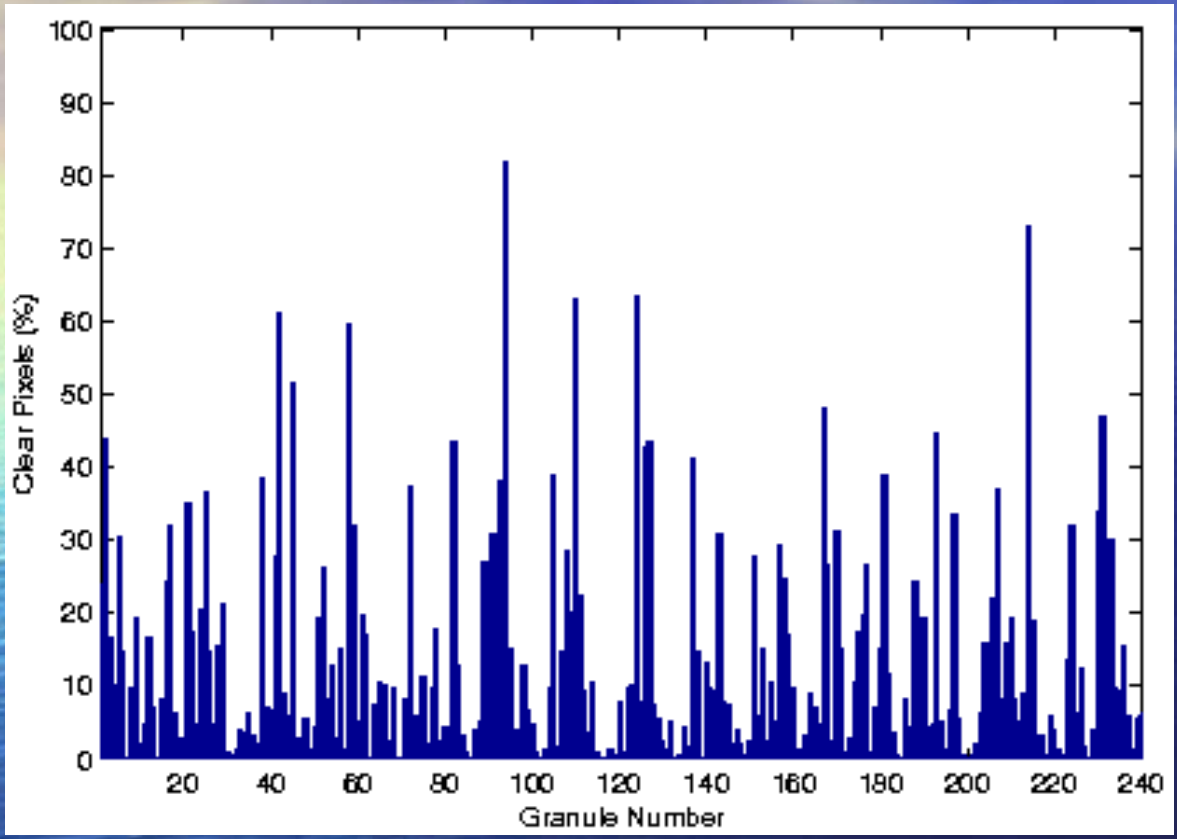




June/2004

3/Allen H

AIRS Single FOV Cloud Free Probability



240 granules/day
90x135 fovs/granule

Note: using MODIS cloud mask
Clear:
if
{(#99%+#95%CLEAR)/Ntotal}>0.95

Clear percentage: 13.7 %
Clear and Land percentage: 6.4% (i.e. ~47% of clear)
Clear and Water percentage: 7.3% (i.e. ~53% of clear)

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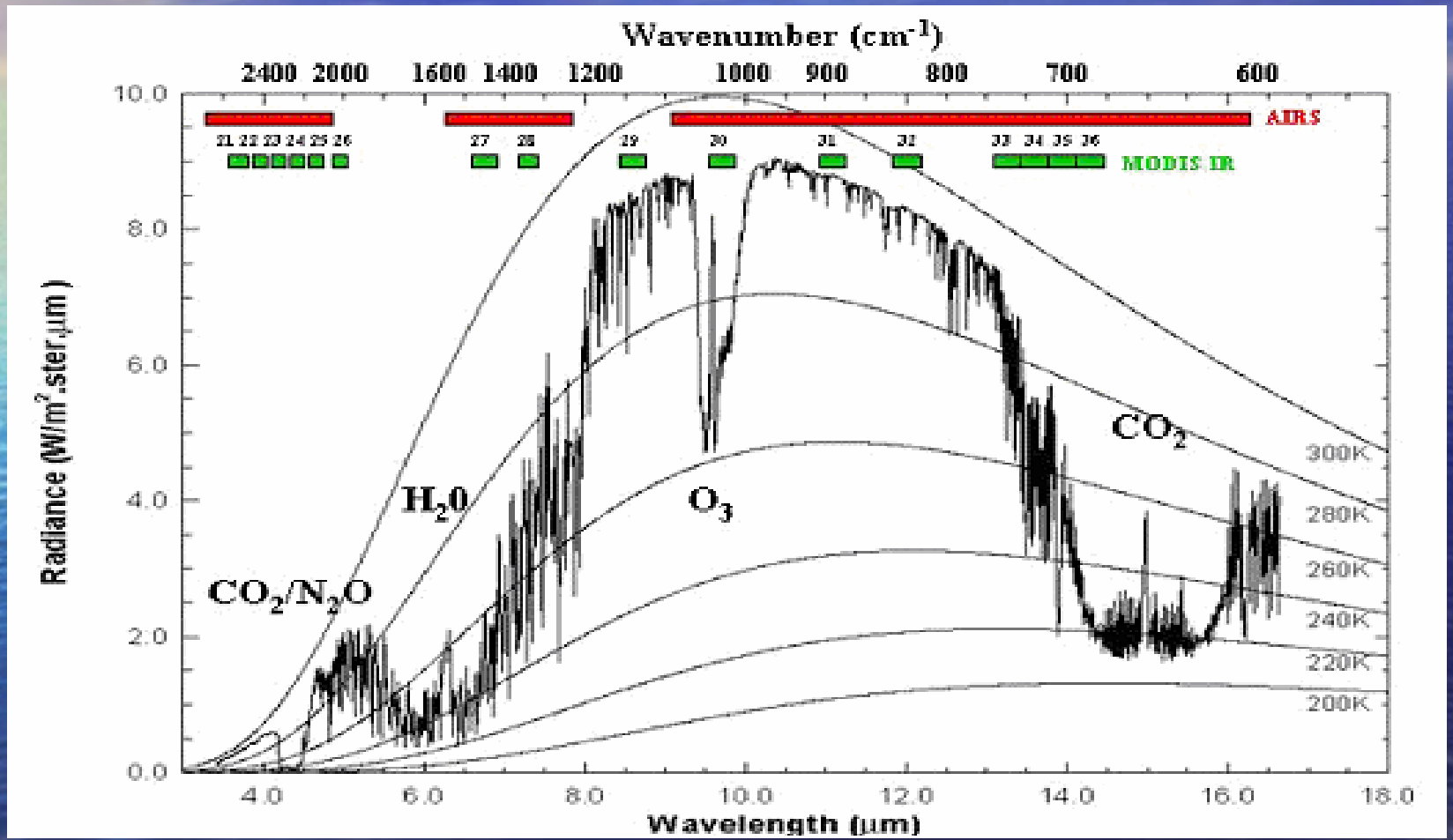
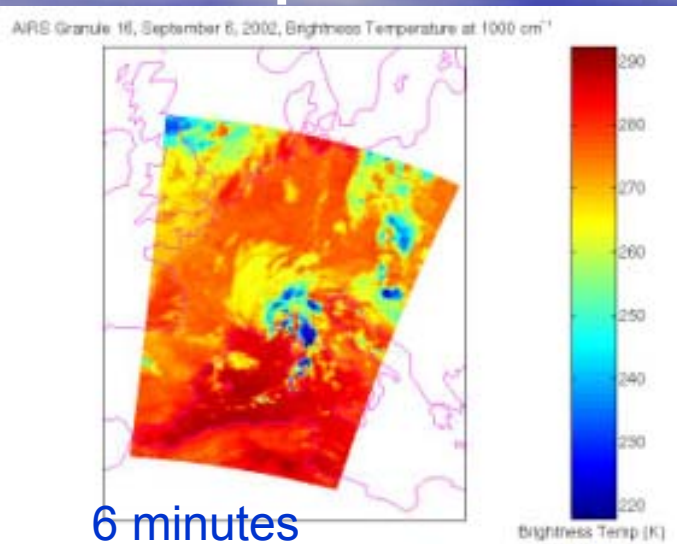
High Spectral Resolution Sounder (AIRS) & High Spatial Resolution Imager (MODIS) Measurements

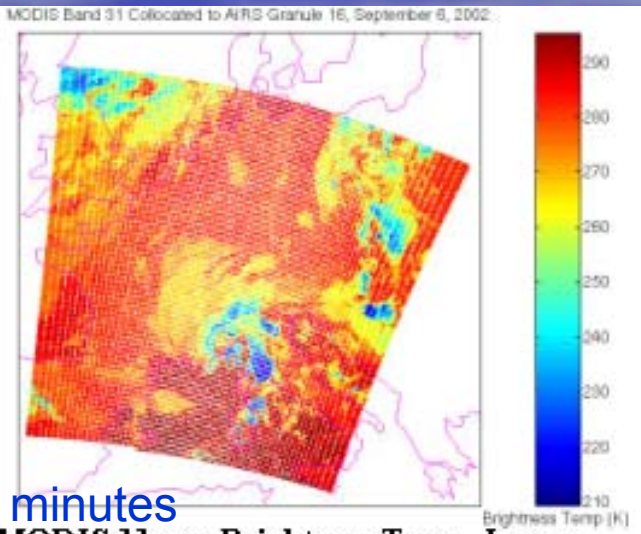


AIRS Spatial Features Seen from MODIS



6 minutes

AIRS 10 μm Brightness Temp. Image

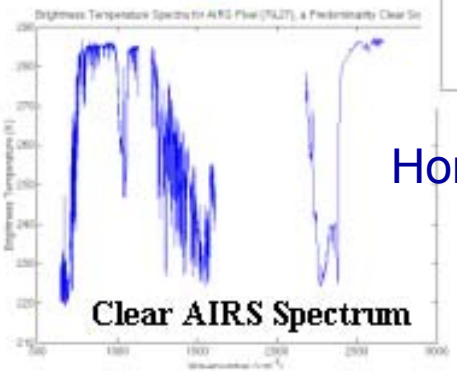


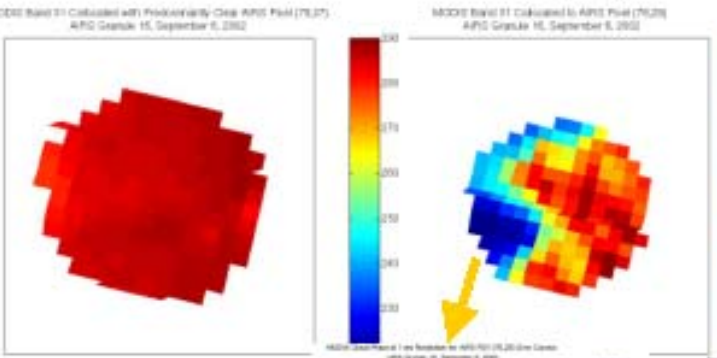
5 minutes

MODIS 11 μm Brightness Temp. Image

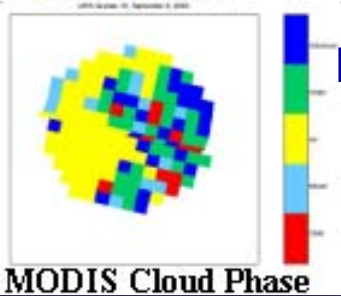
(only pixels collocated with AIRS are shown)

MODIS Clear Pixels (within one Single AIRS FOV)



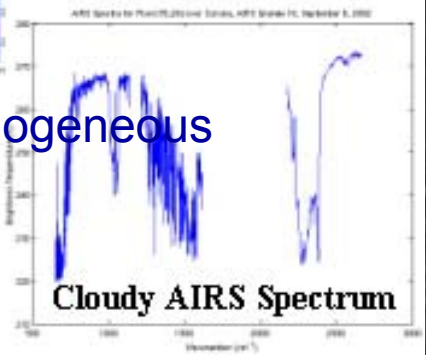


Homogeneous



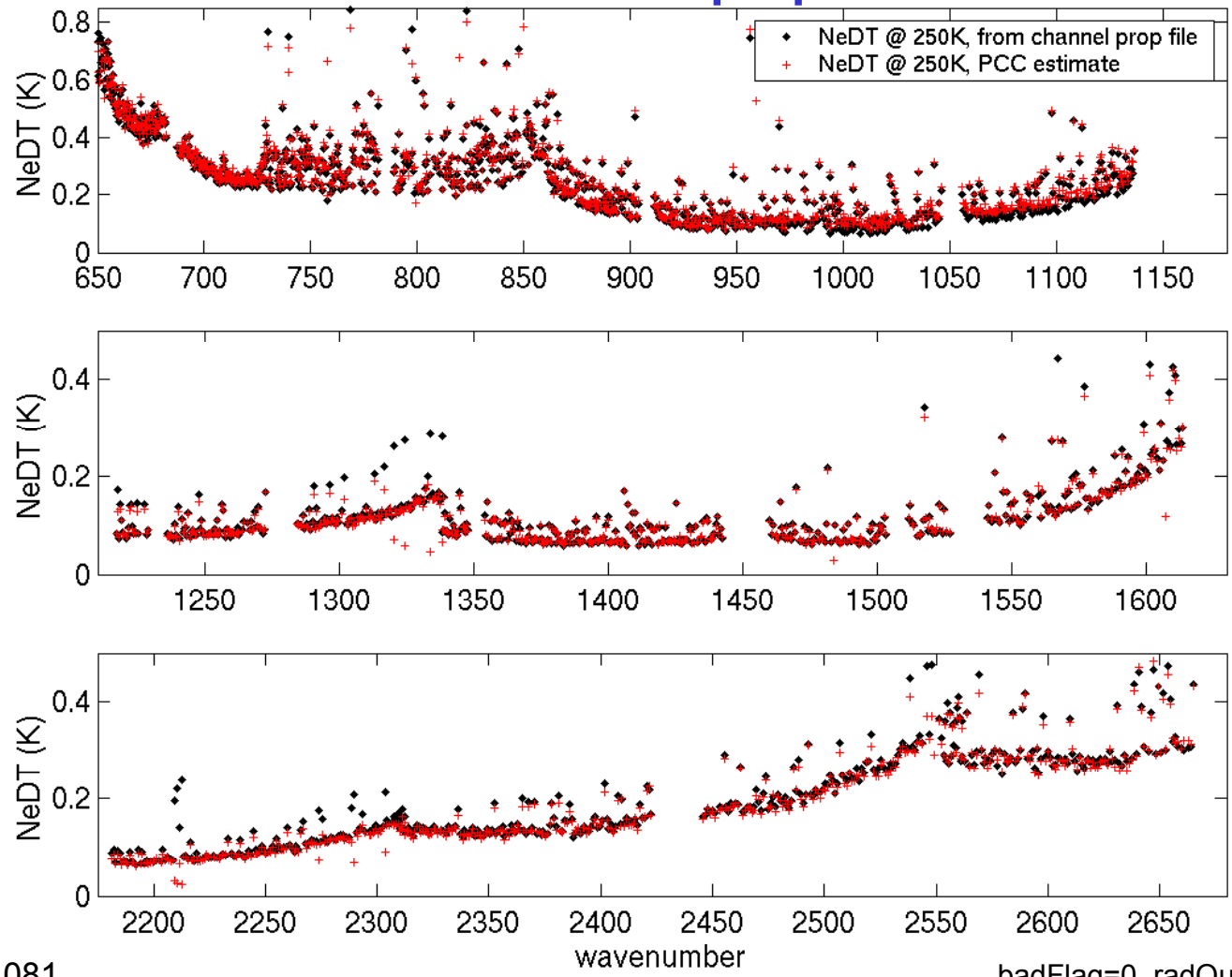
Inhomogeneous

MODIS Cloudy pixels (within one Single AIRS FOV)



AIRS Noise Characterization using Principle Component Analysis (PCA) of Earth Scene Data

NeDT@250K: estimated from granule 081 and values from channel properties file



Granule 081

badFlag=0, radQuality <=2

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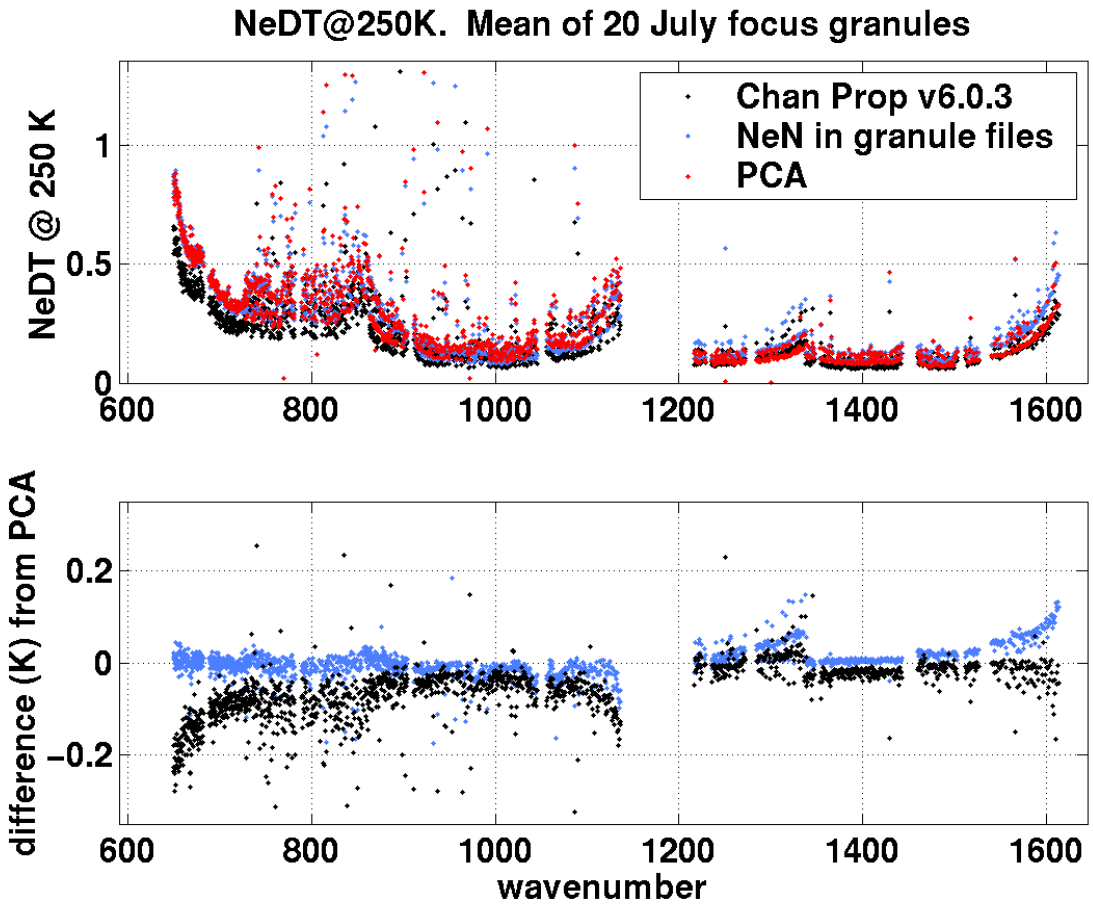
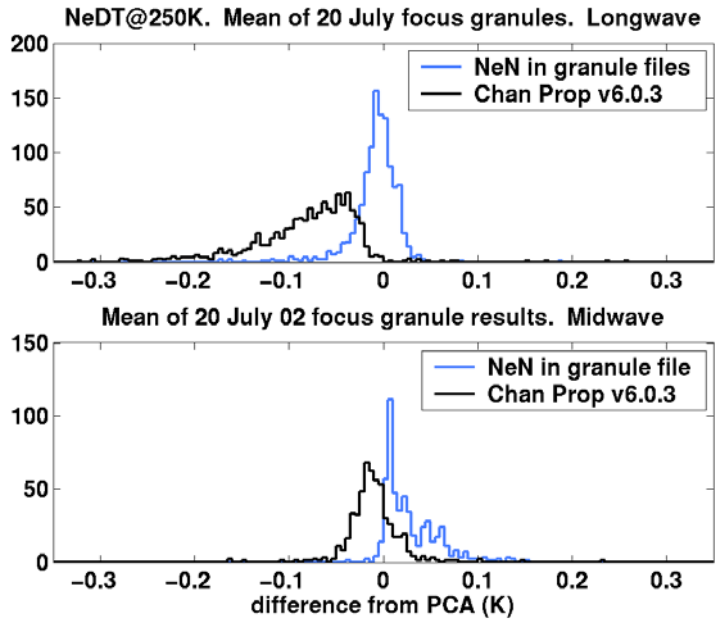
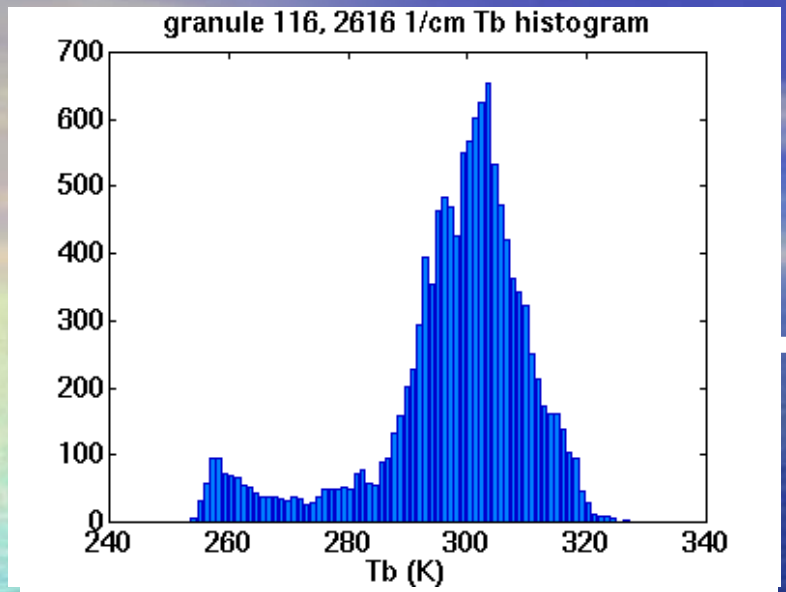
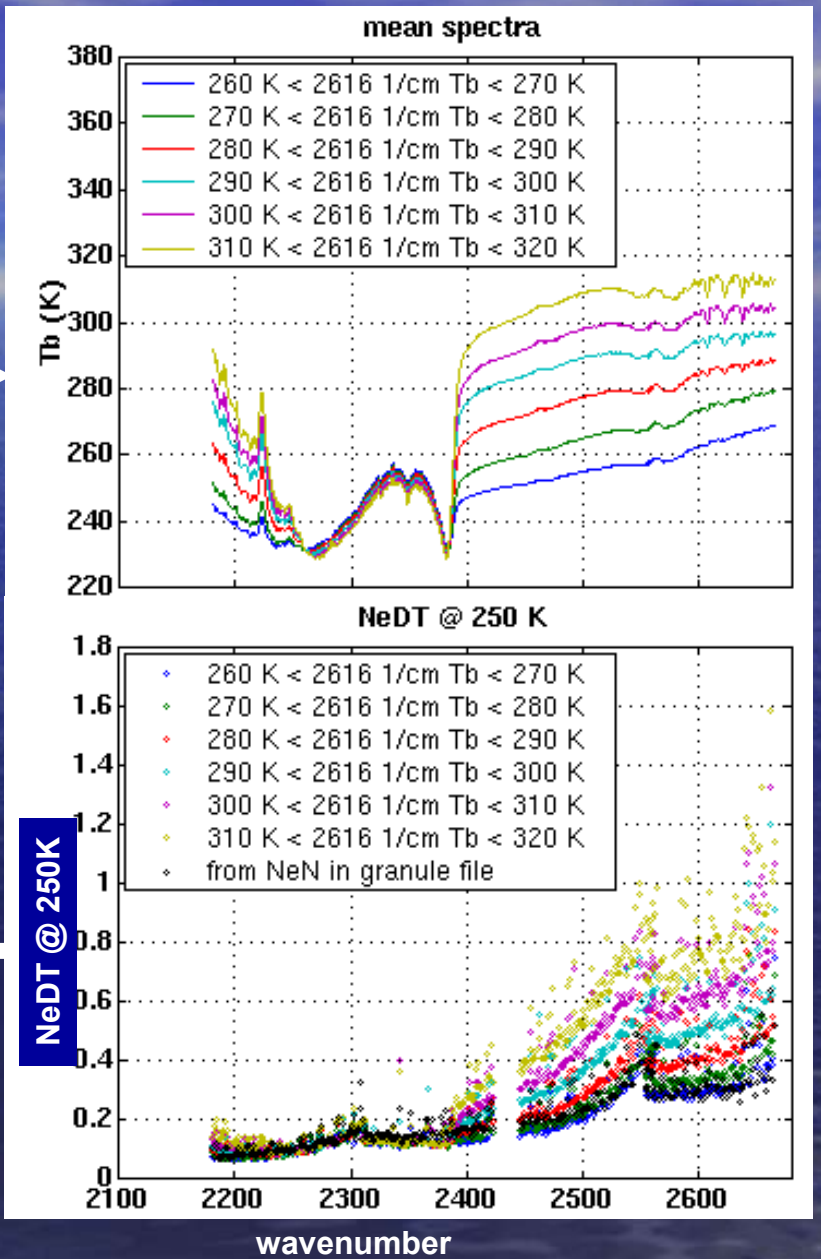


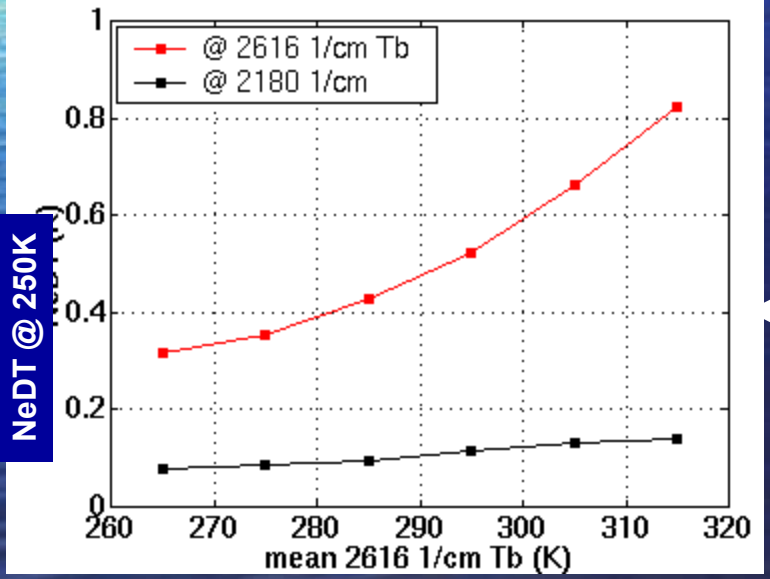


Courtesy of Dave Tobin

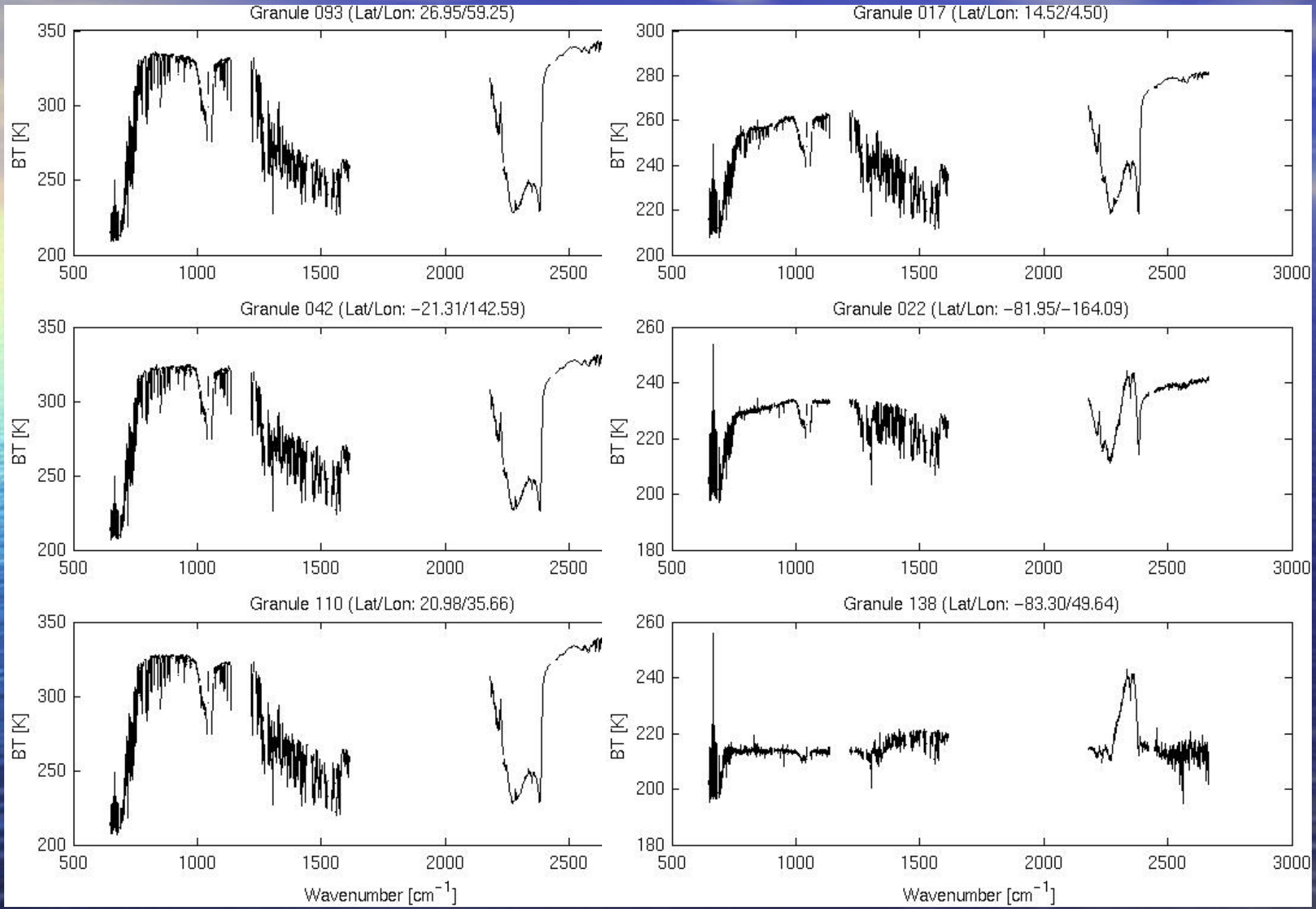
Scene dependent photon-limited shortwave noise



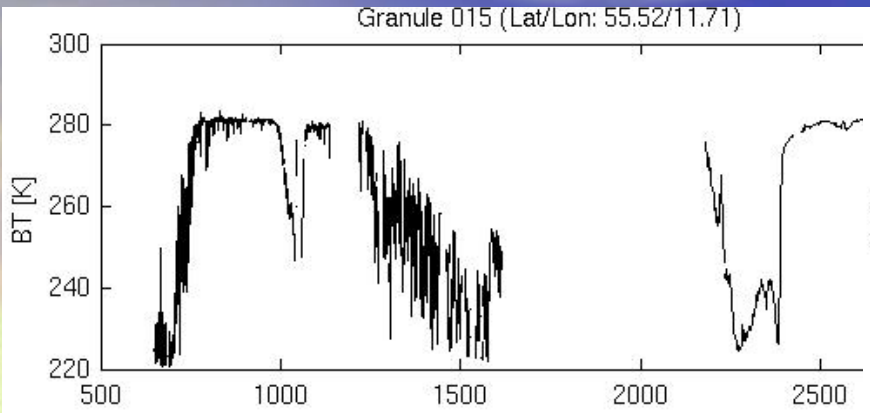


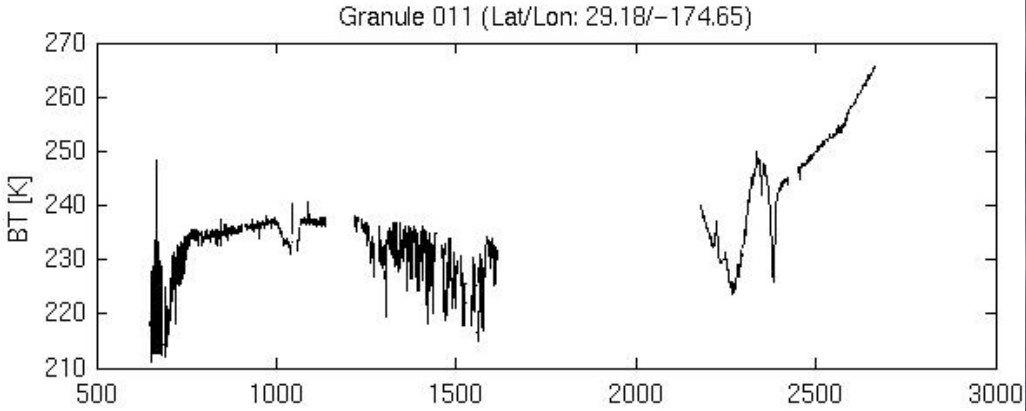


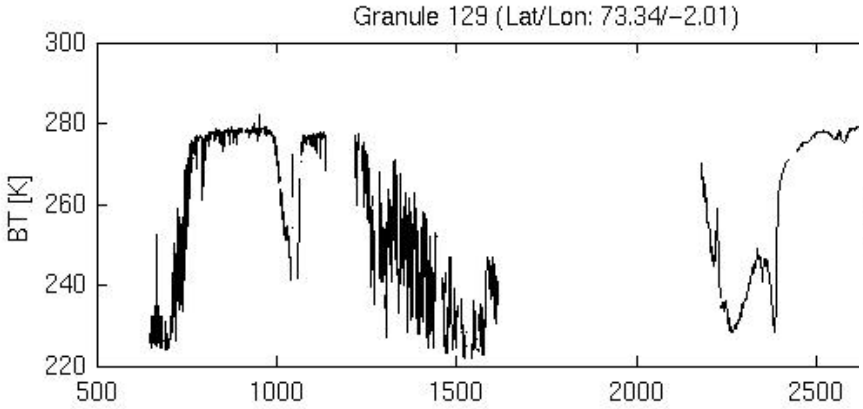
Clear AIRS Spectra Cloudy

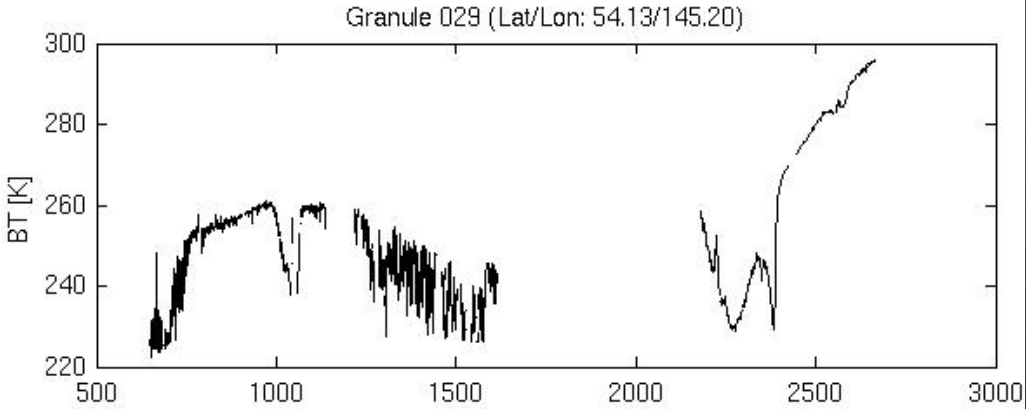


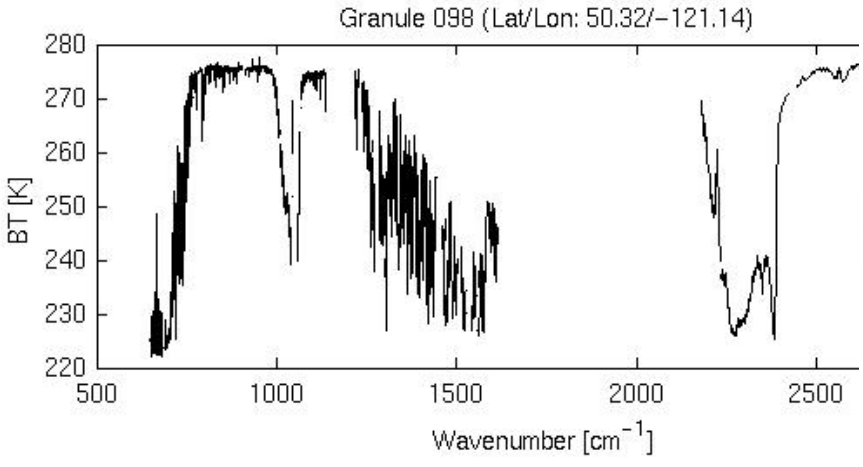
Clear AIRS Spectra Cloudy

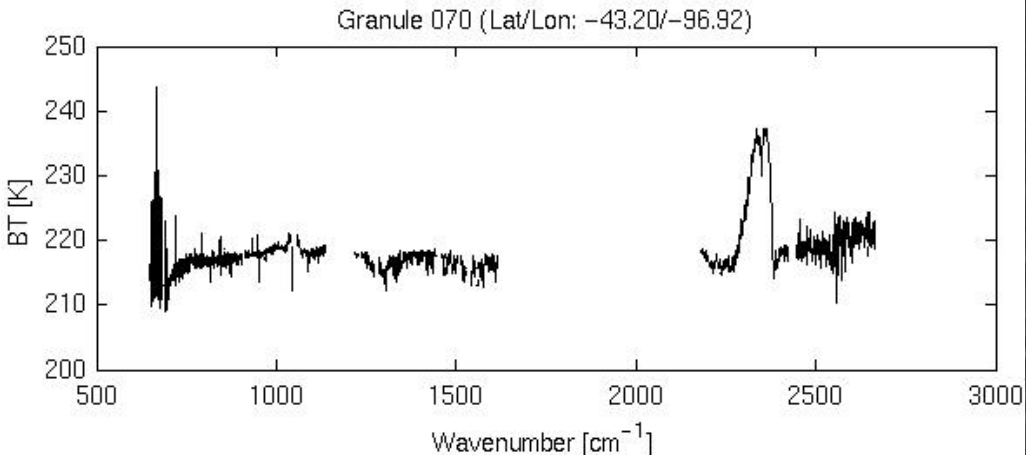




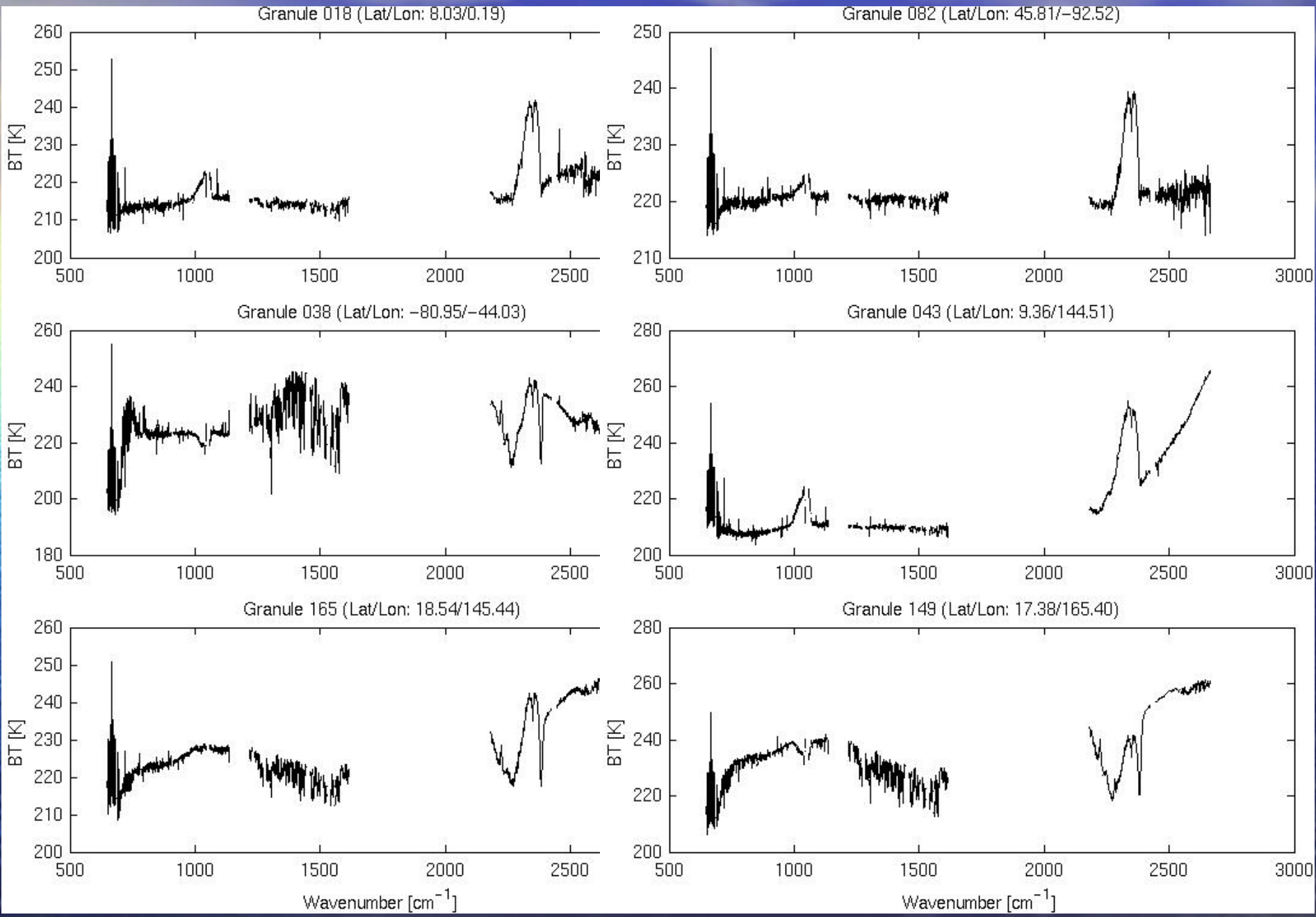




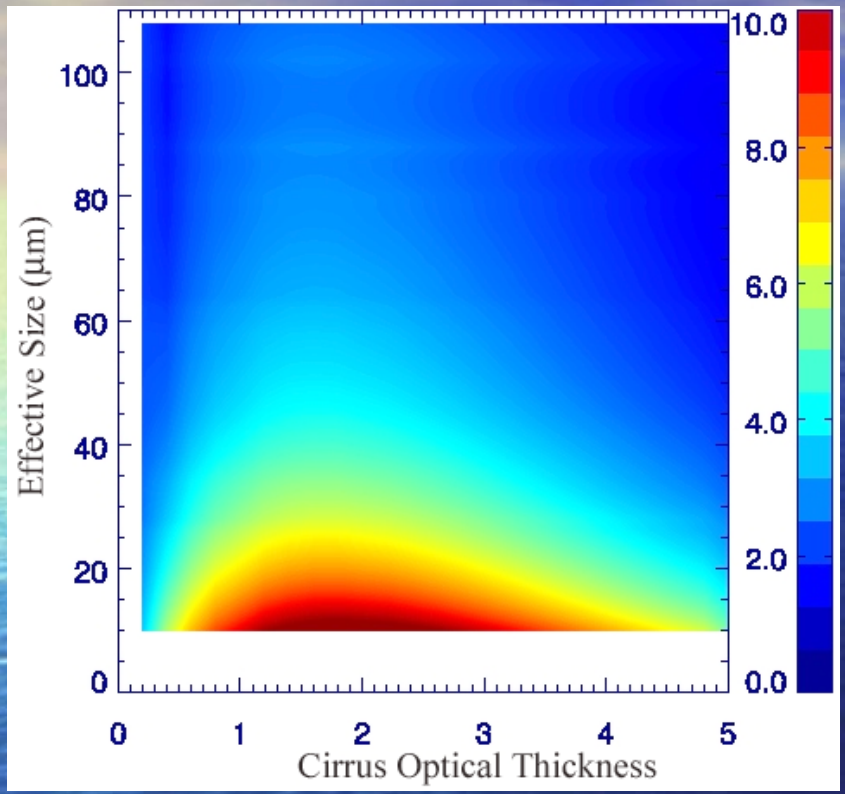




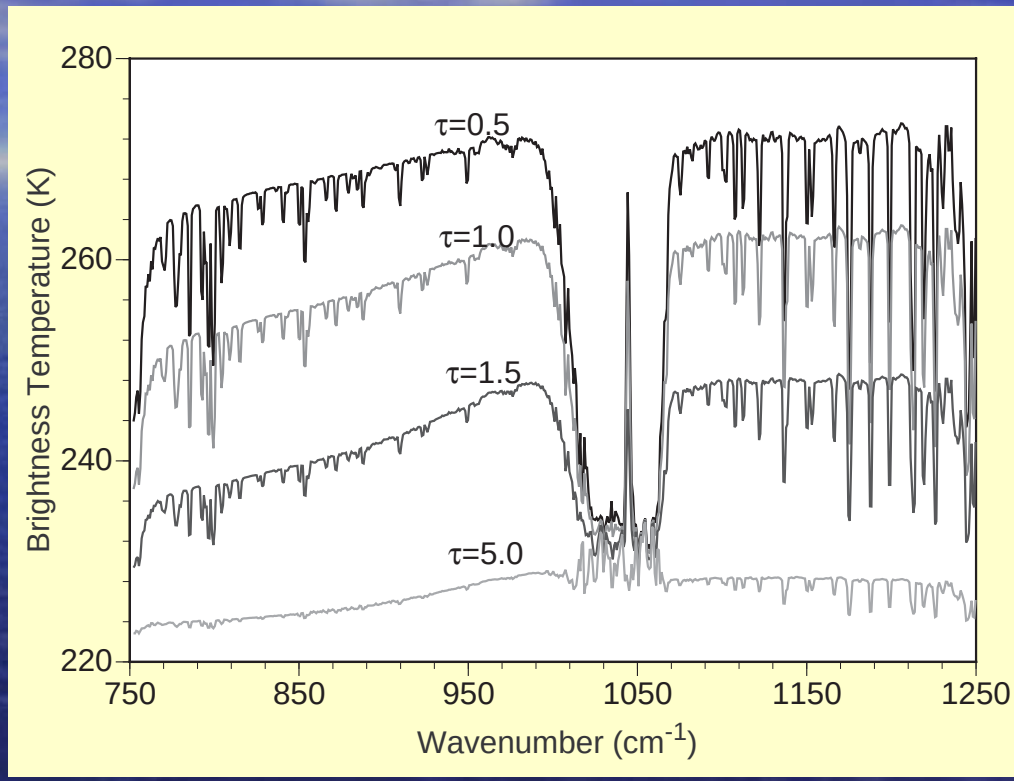
Cloudy AIRS Spectra Cloudy



Sensitivity of Hyperspectral IR Measurements on Cloud Property

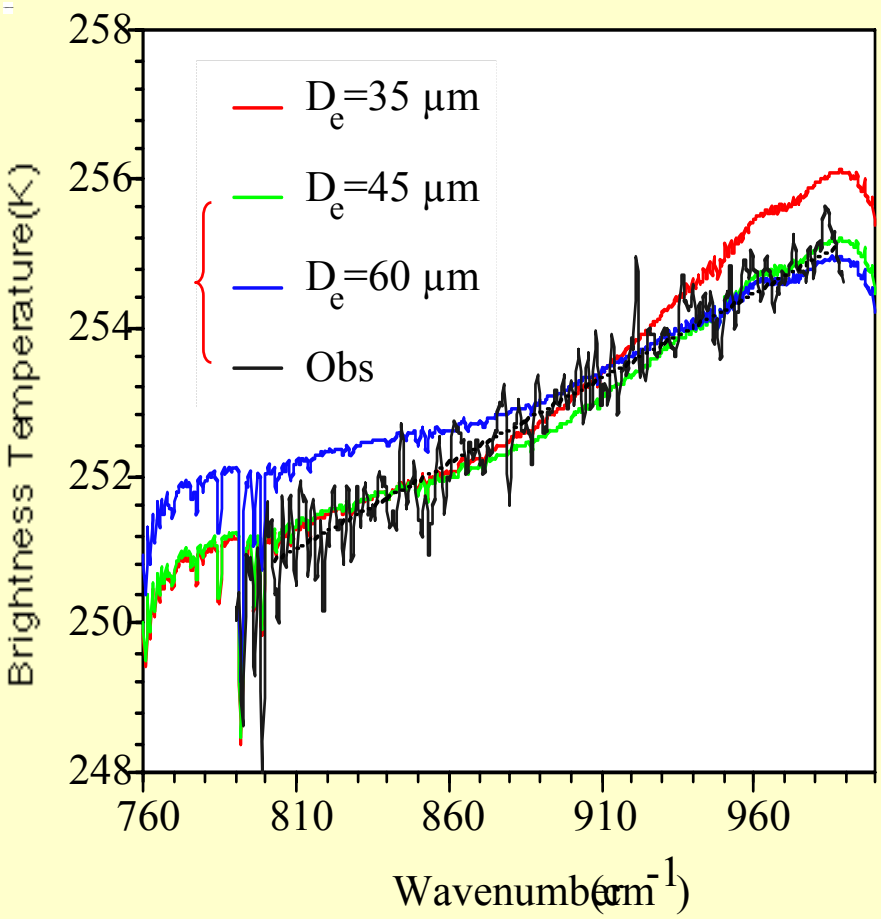


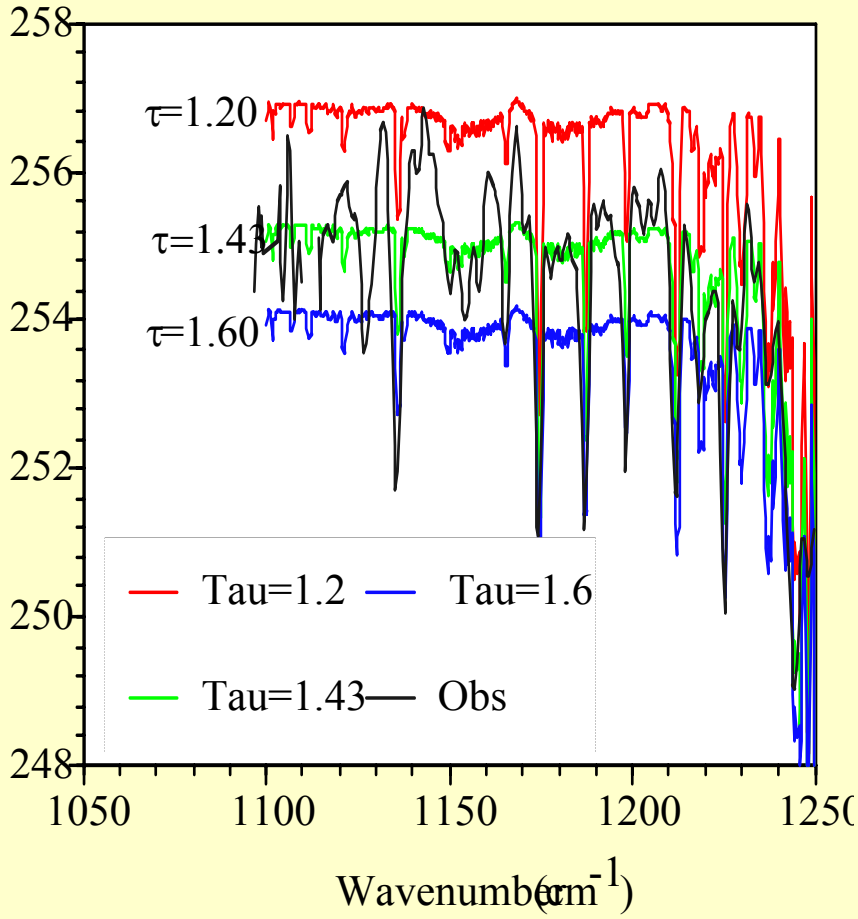
Effect of optical thickness and particle size on the slope of the spectral brightness temperatures and wavenumber between 790–960 cm^{-1}.



The sensitivity of spectral brightness temperature to the cloud optical thickness. The assumed effective particle size is fixed at 30 μm.

The simultaneous retrieval of the effective size and optical thickness from HIS spectra





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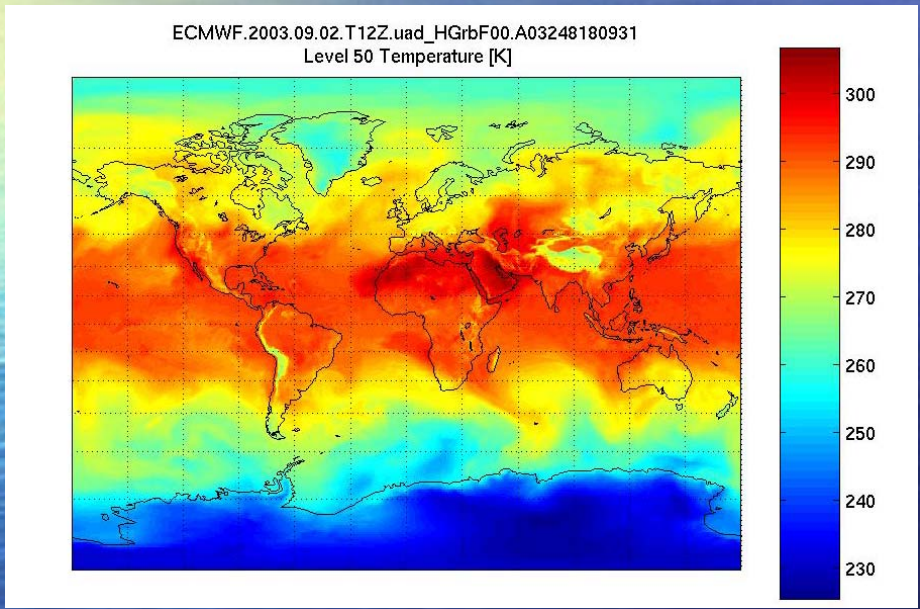
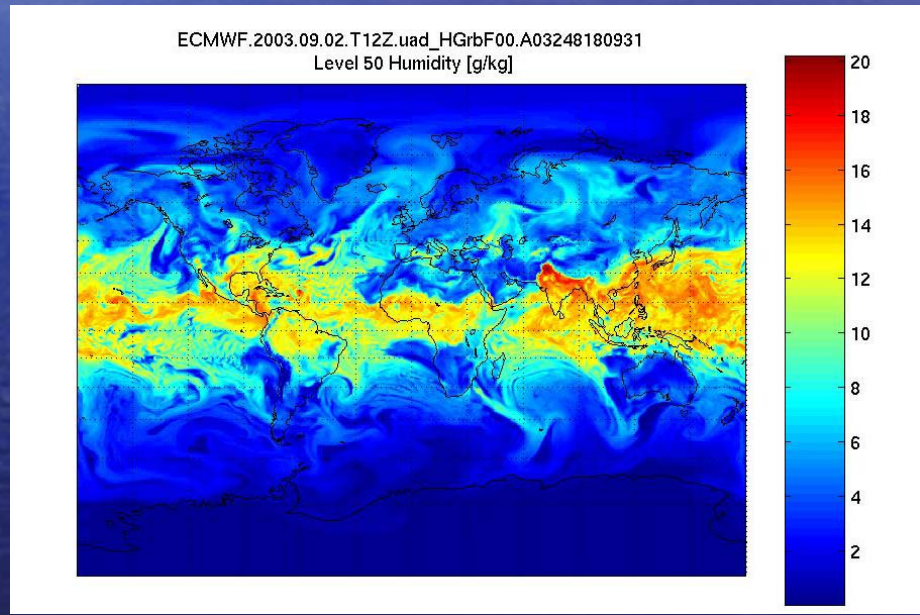
129960 ECMWF profiles (every 2nd profile)

(T12Z, 2003-09-02)



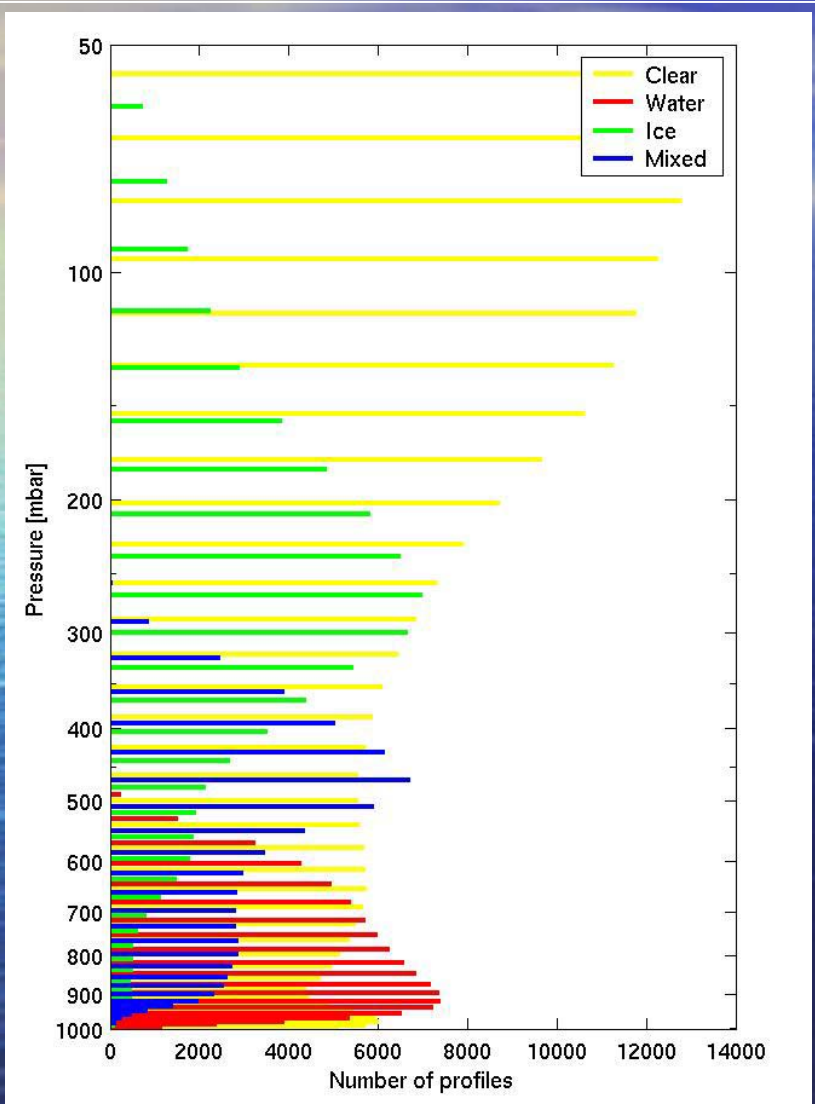
Near Surface Temperature

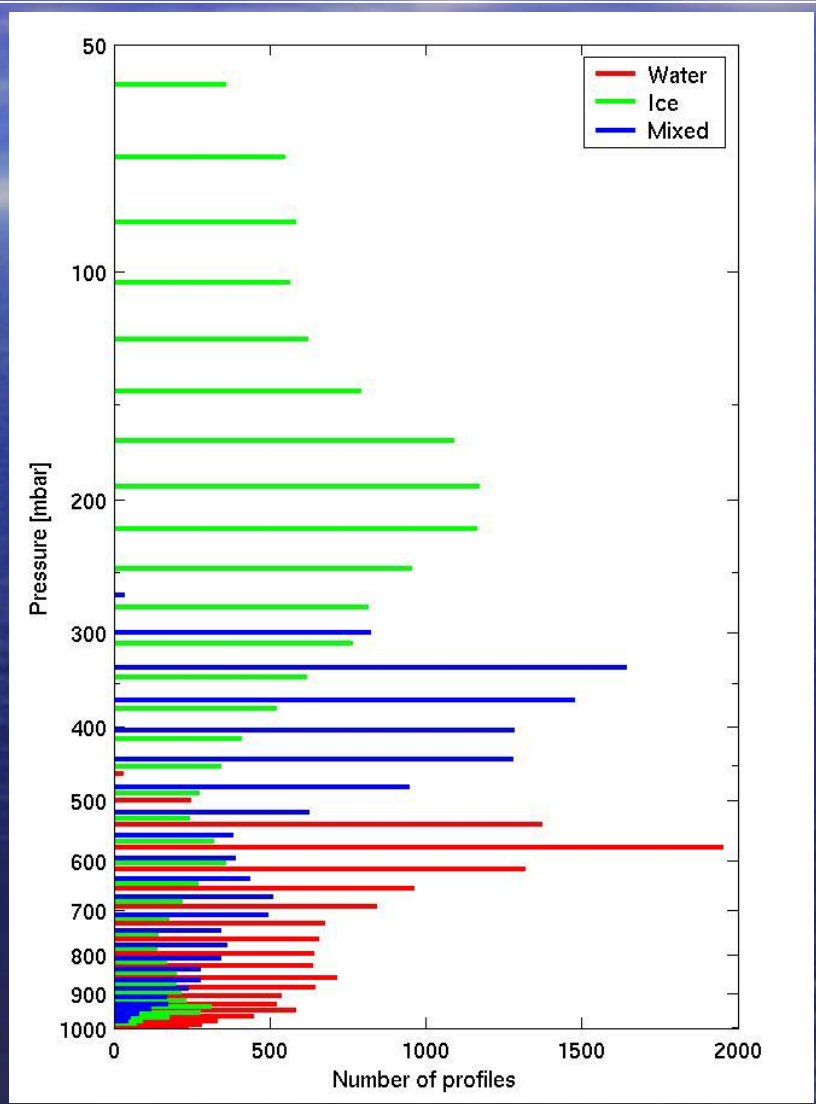


Near Surface Temperature

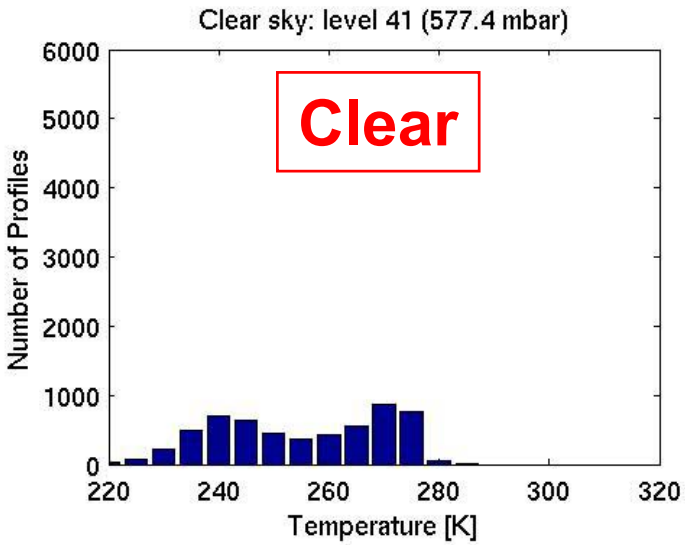
Left: Number of profiles with LWC or IWC > 0 vs. pressure levels

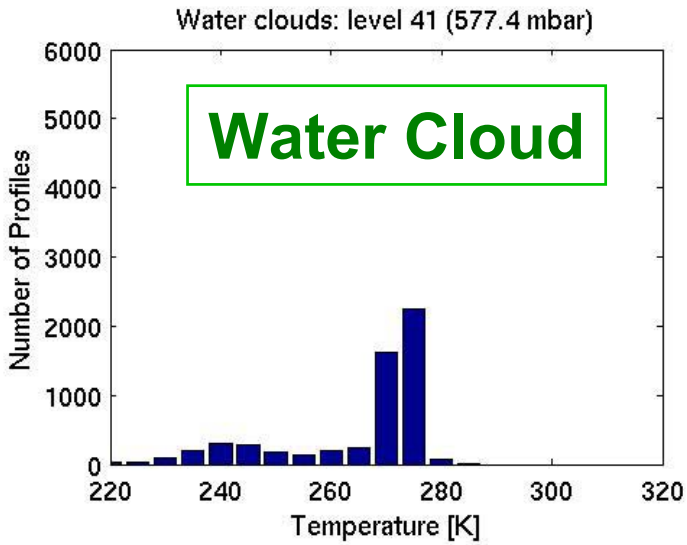
Right: Number of profiles with Ctop at certain pressure levels

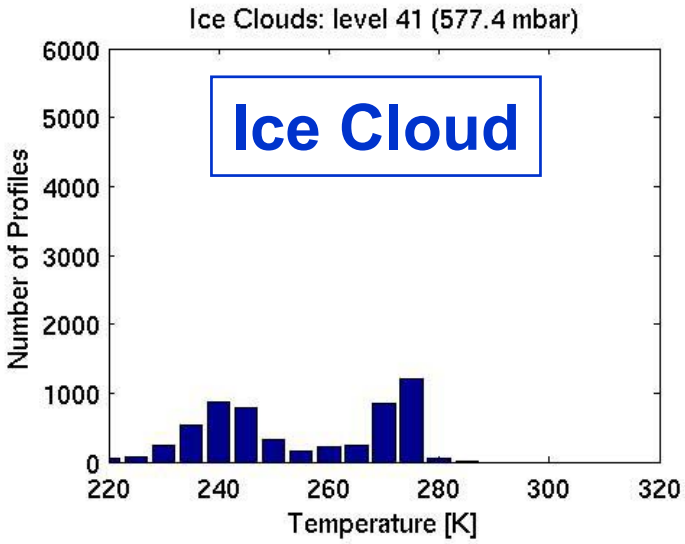


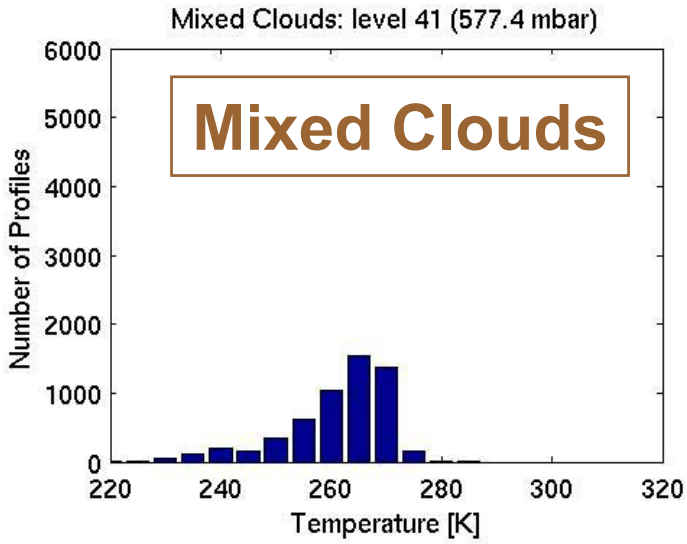


Temperature vs. number of profiles for level 41 (577.4 mbar)

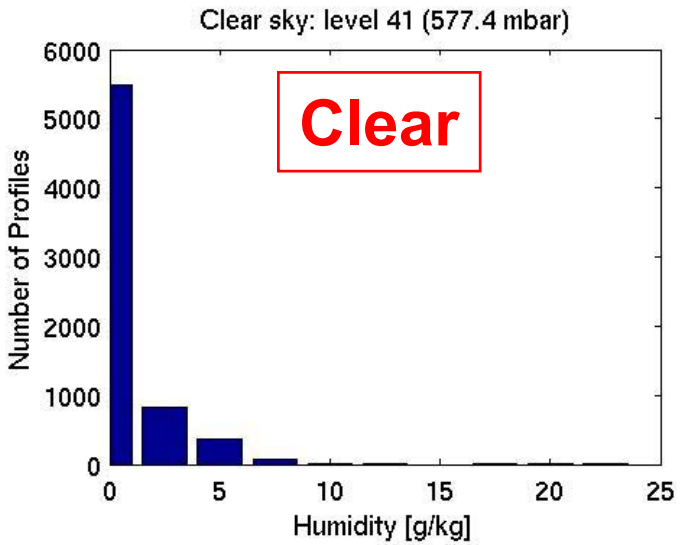


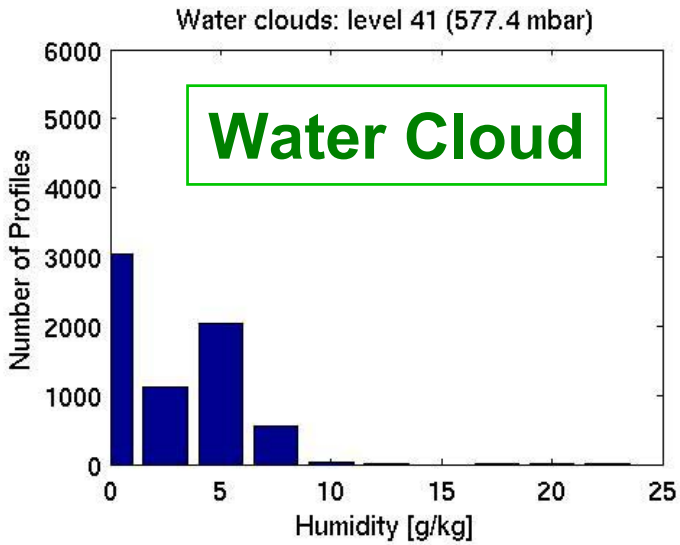


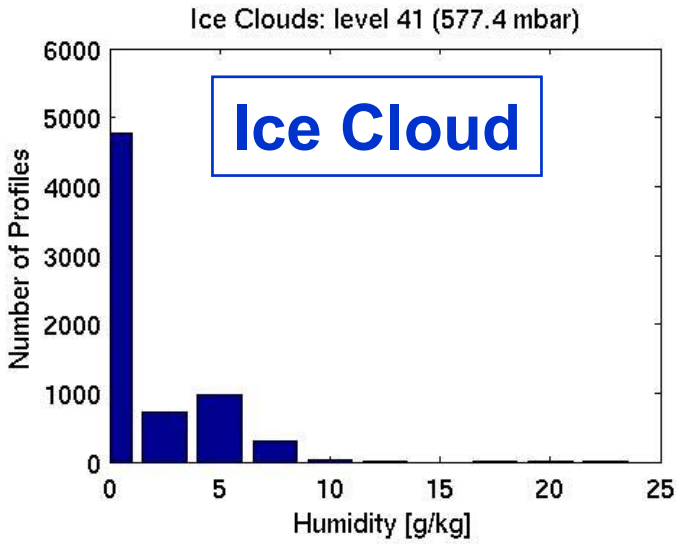


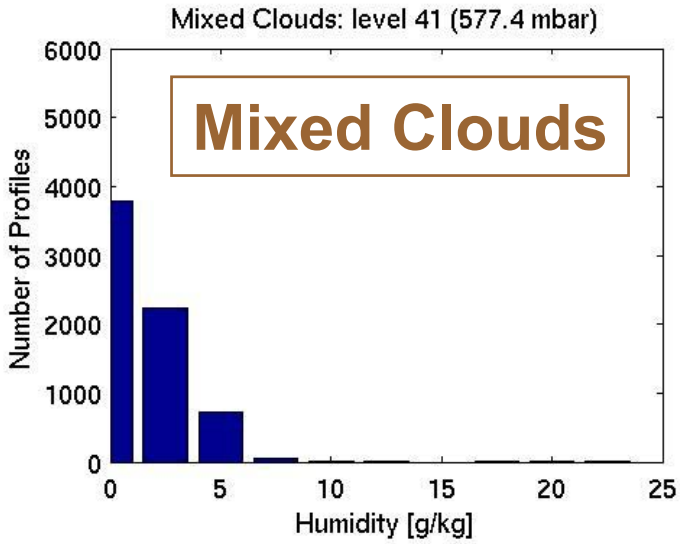


Humidity vs. number of profiles for level 41 (577.4 mbar)

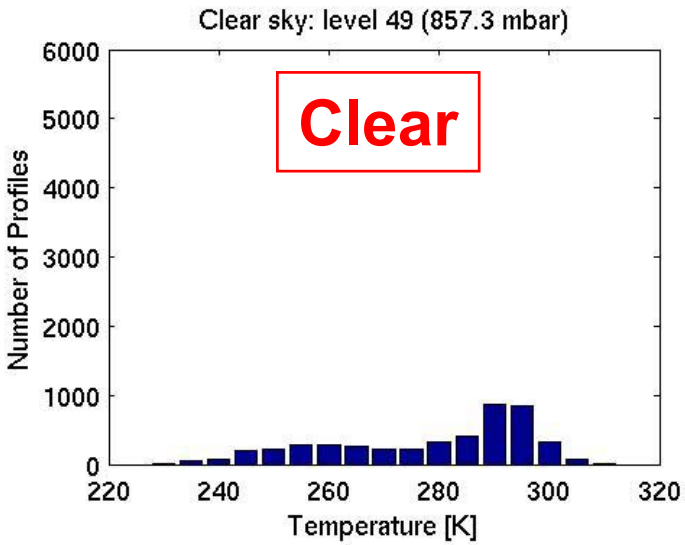


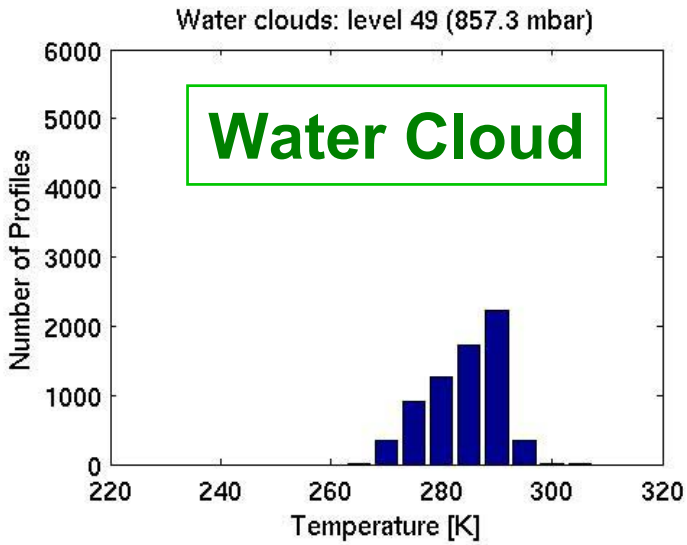


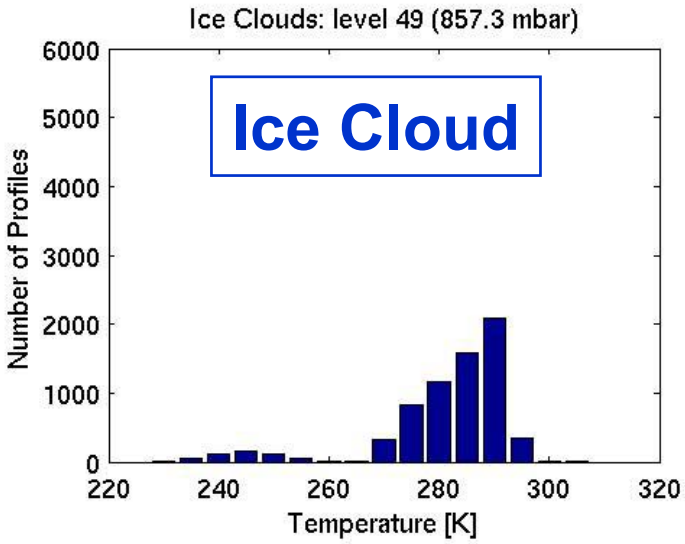


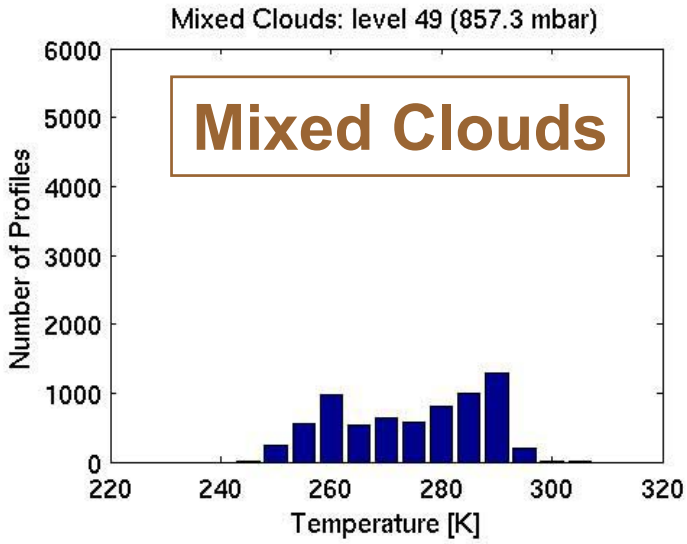


Temperature vs. number of profiles for level 49 (857.3 mbar)

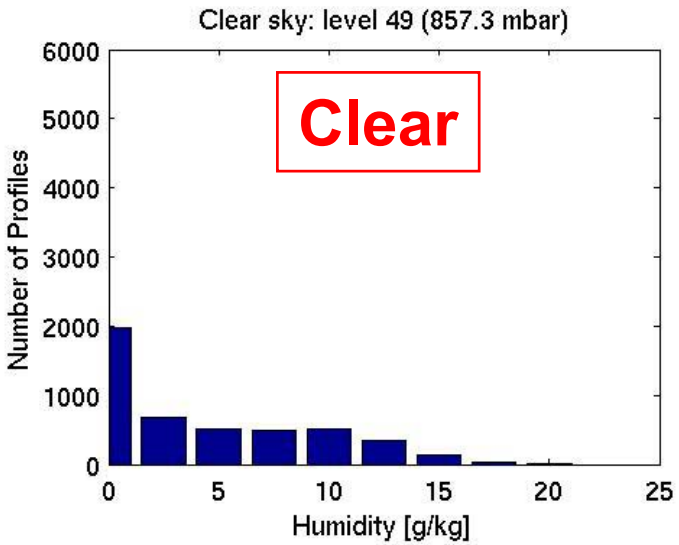


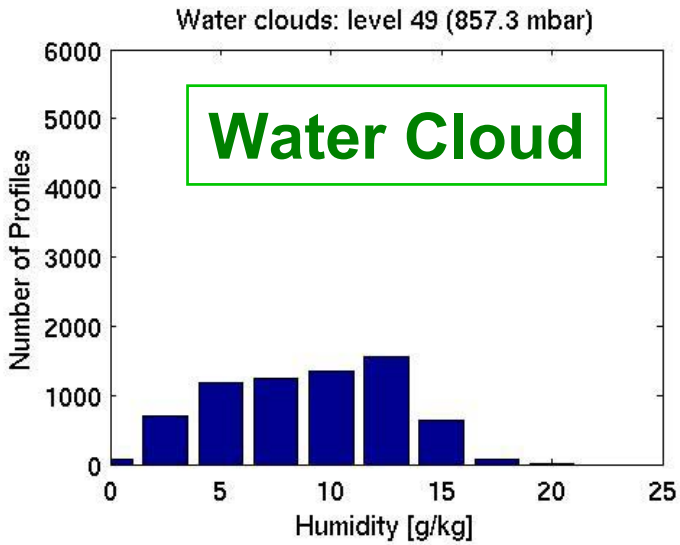


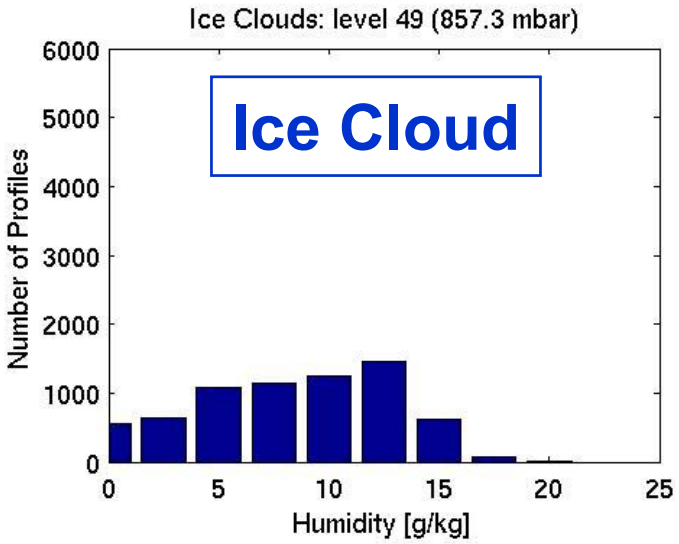


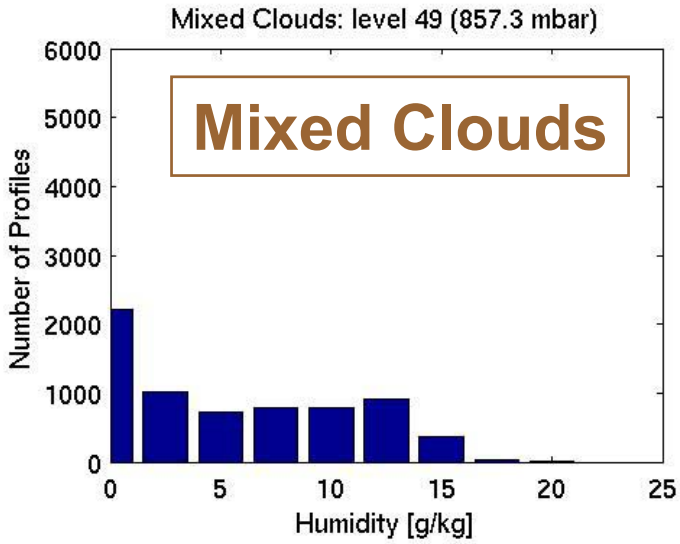


Humidity vs. number of profiles for level 49 (857.3 mbar)

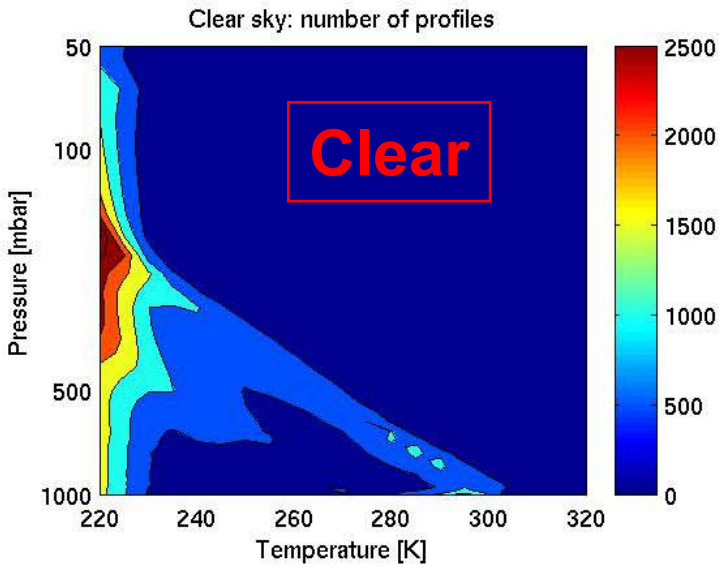


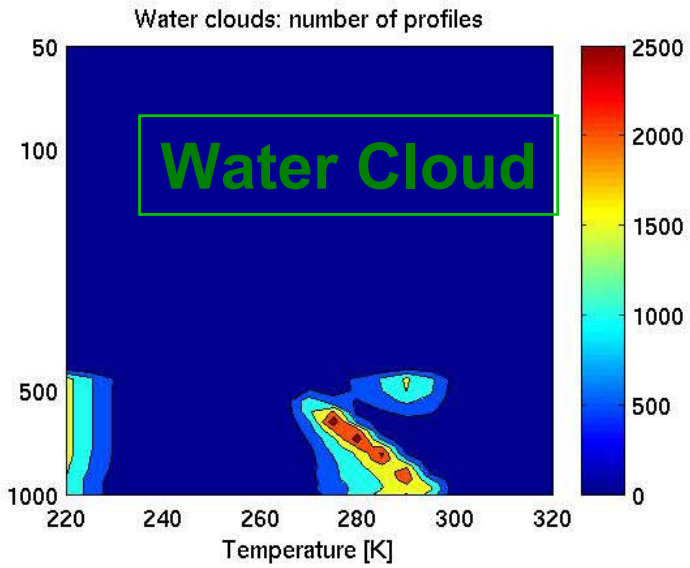


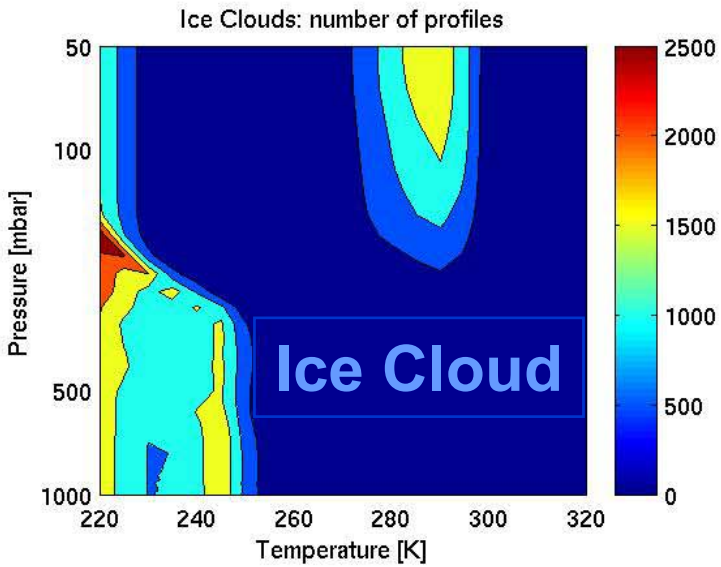


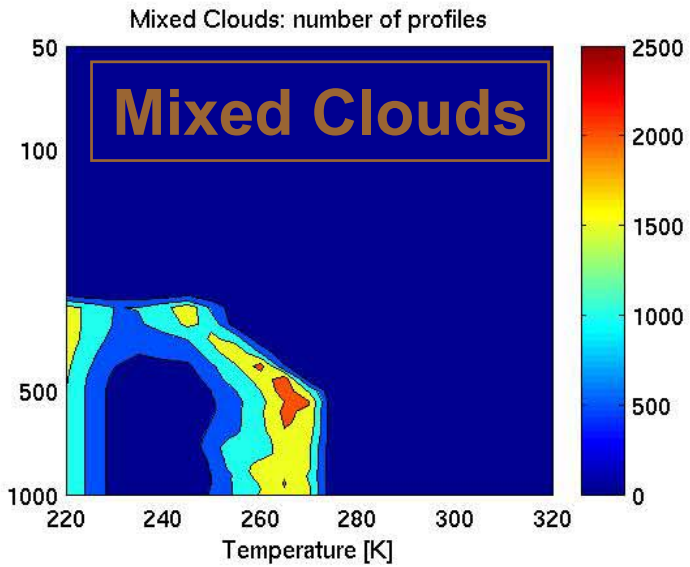


Contour plot of number of profiles for temperature

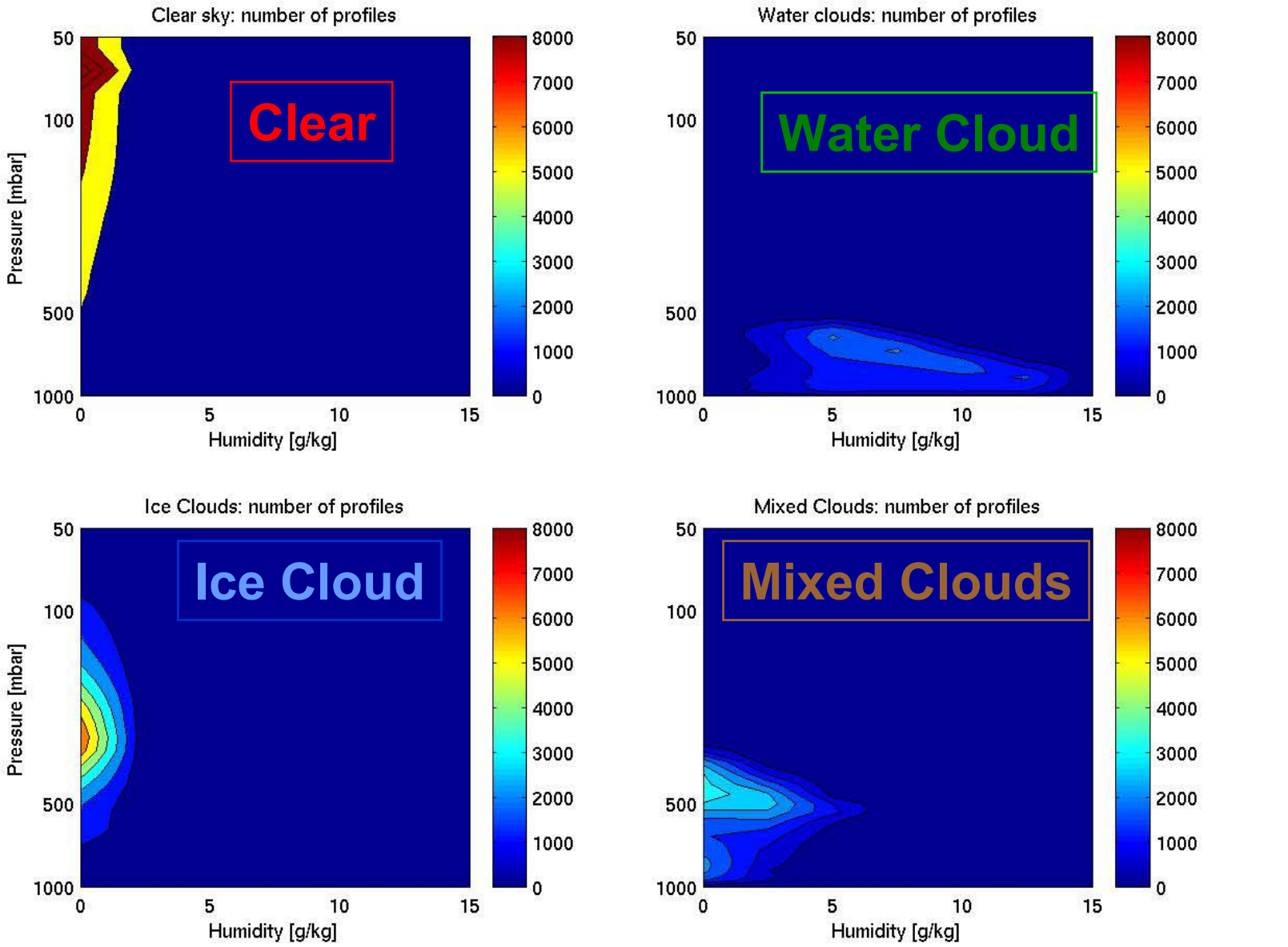




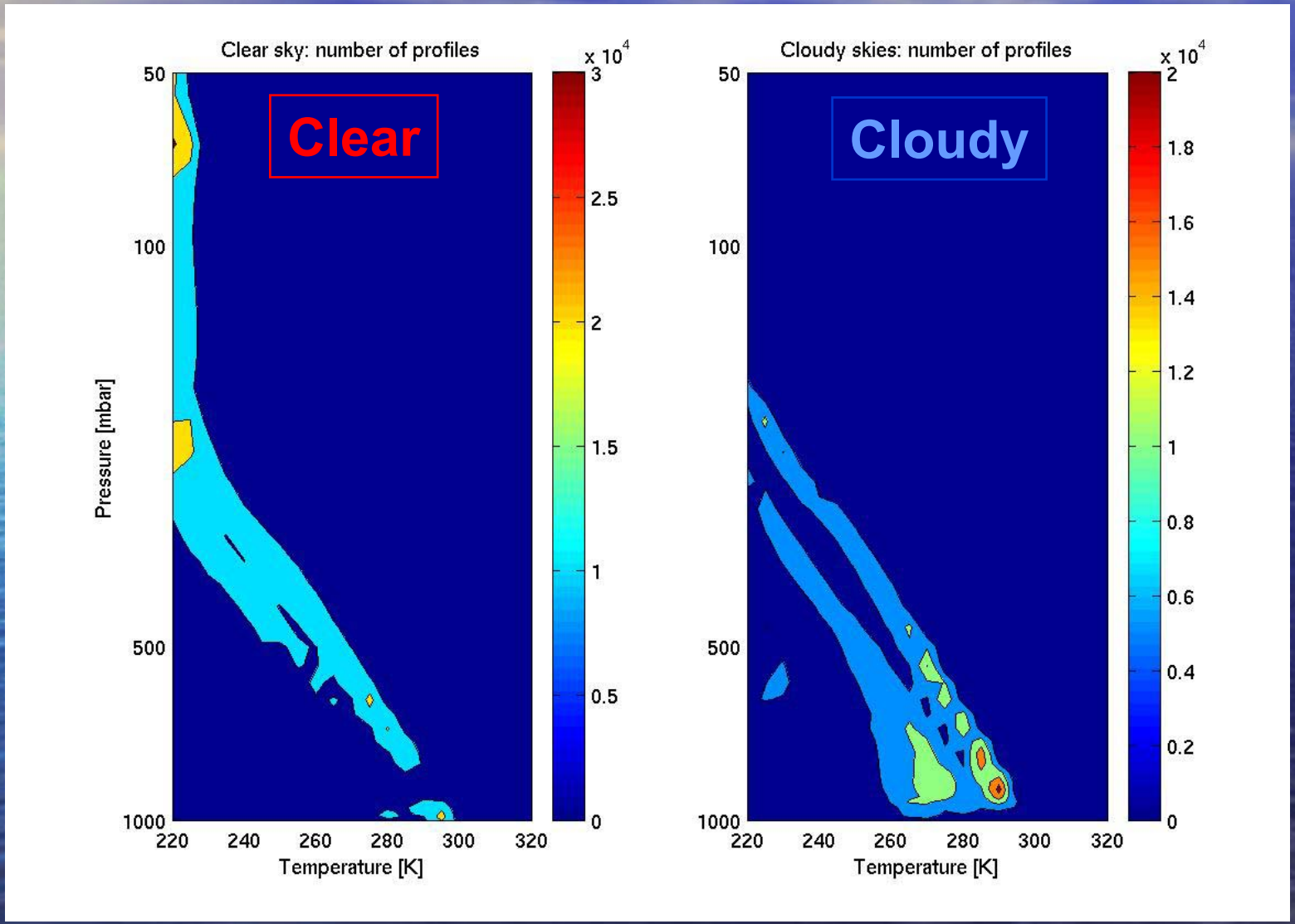




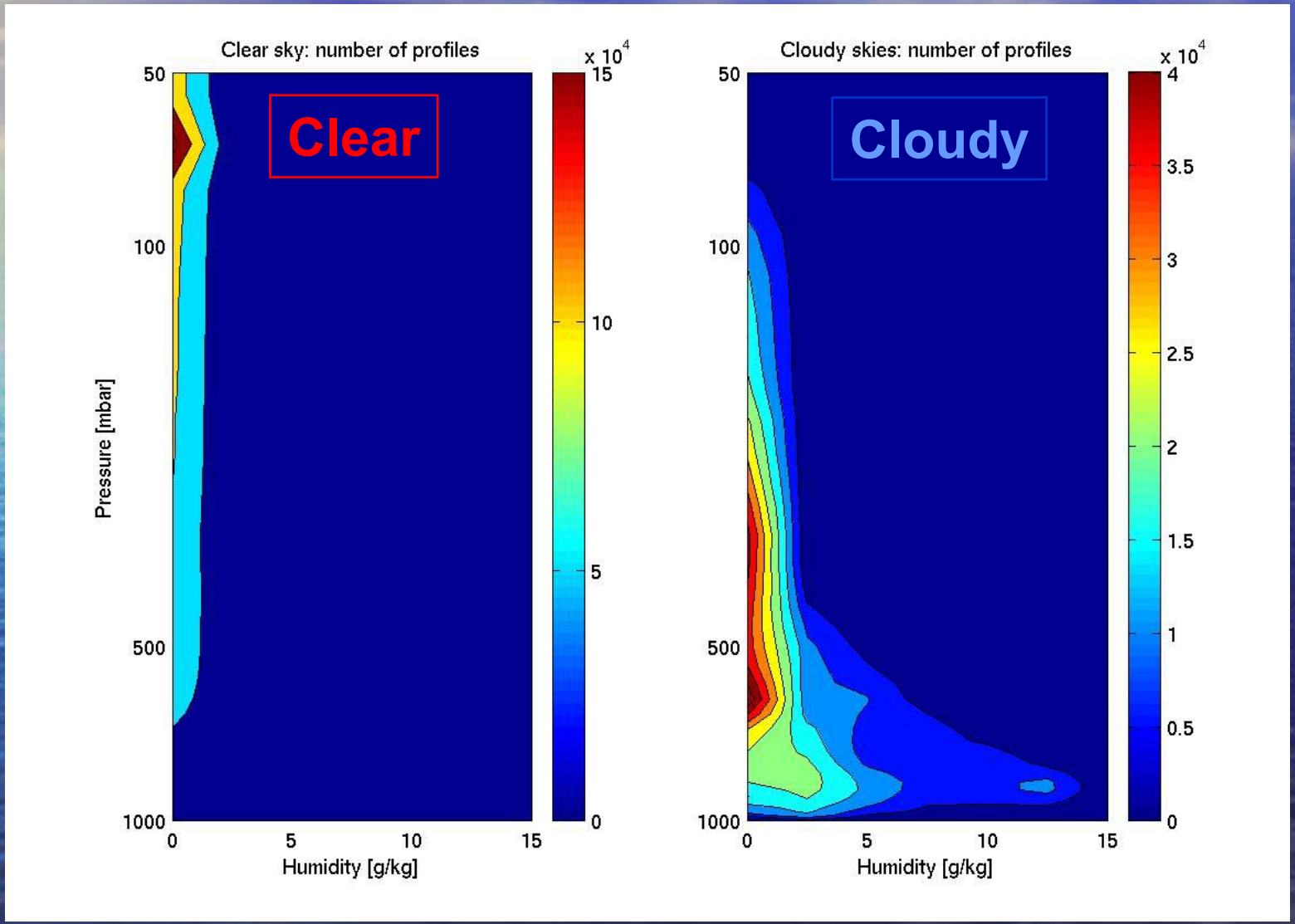
Contour plot of number of profiles for humidity [g/kg]



Contour plot of number of profiles for temperature

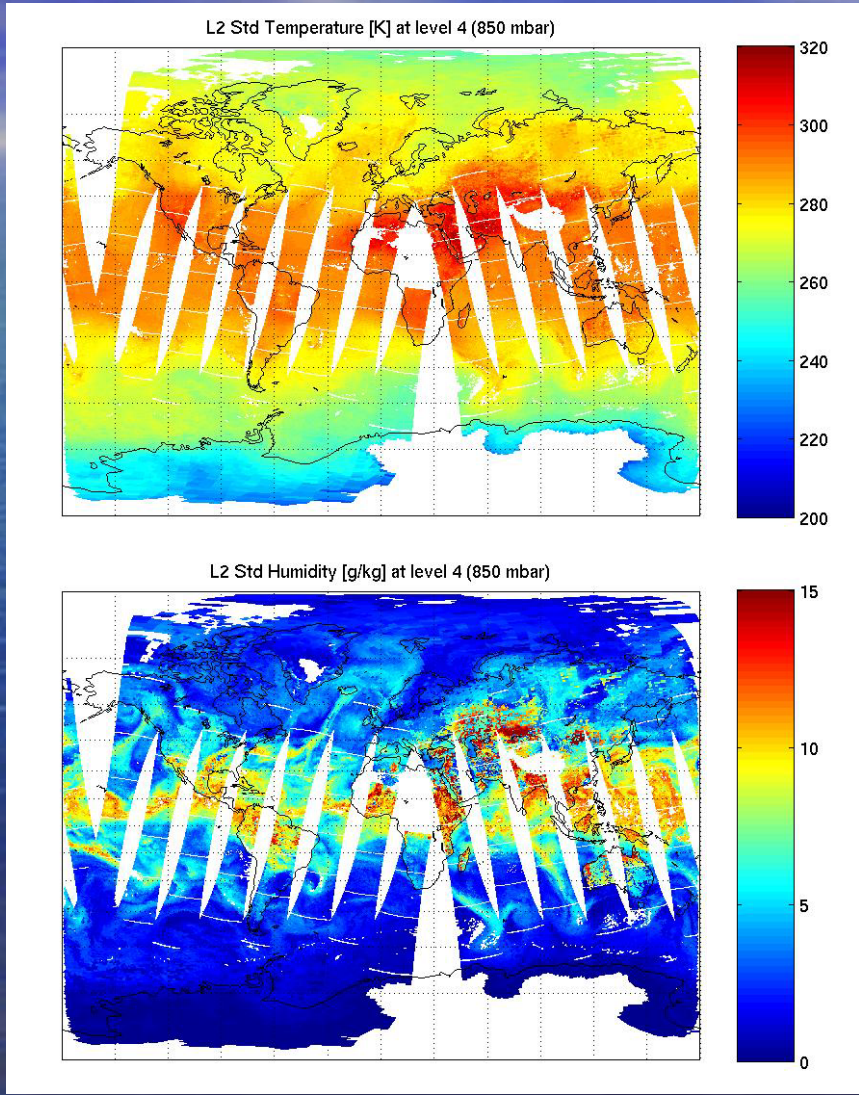


Contour plot of number of profiles for humidity [g/kg]



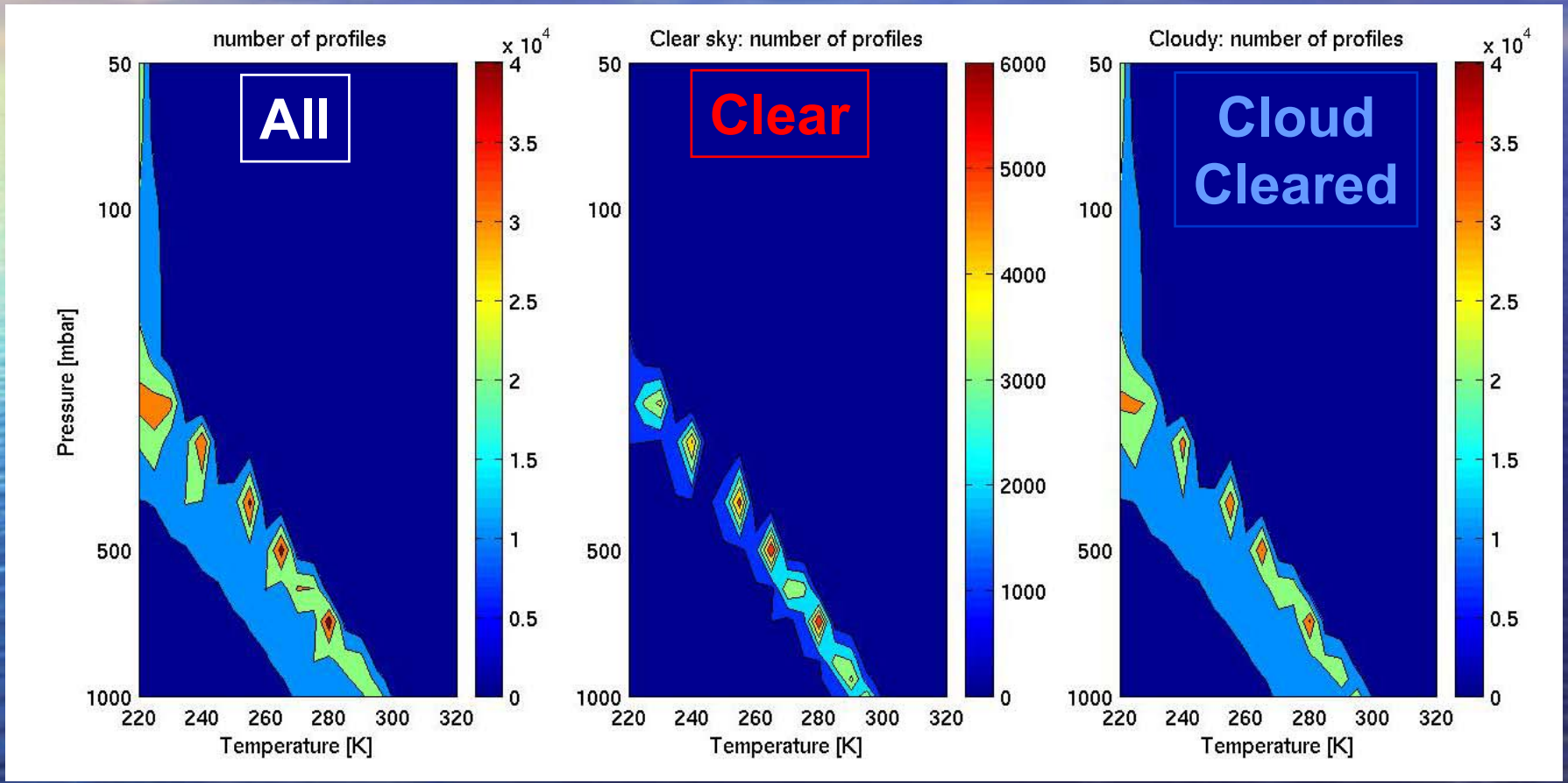
AIRS 162000 L2 Std product retrieval profiles

(2003-09-02, granules 1-120)



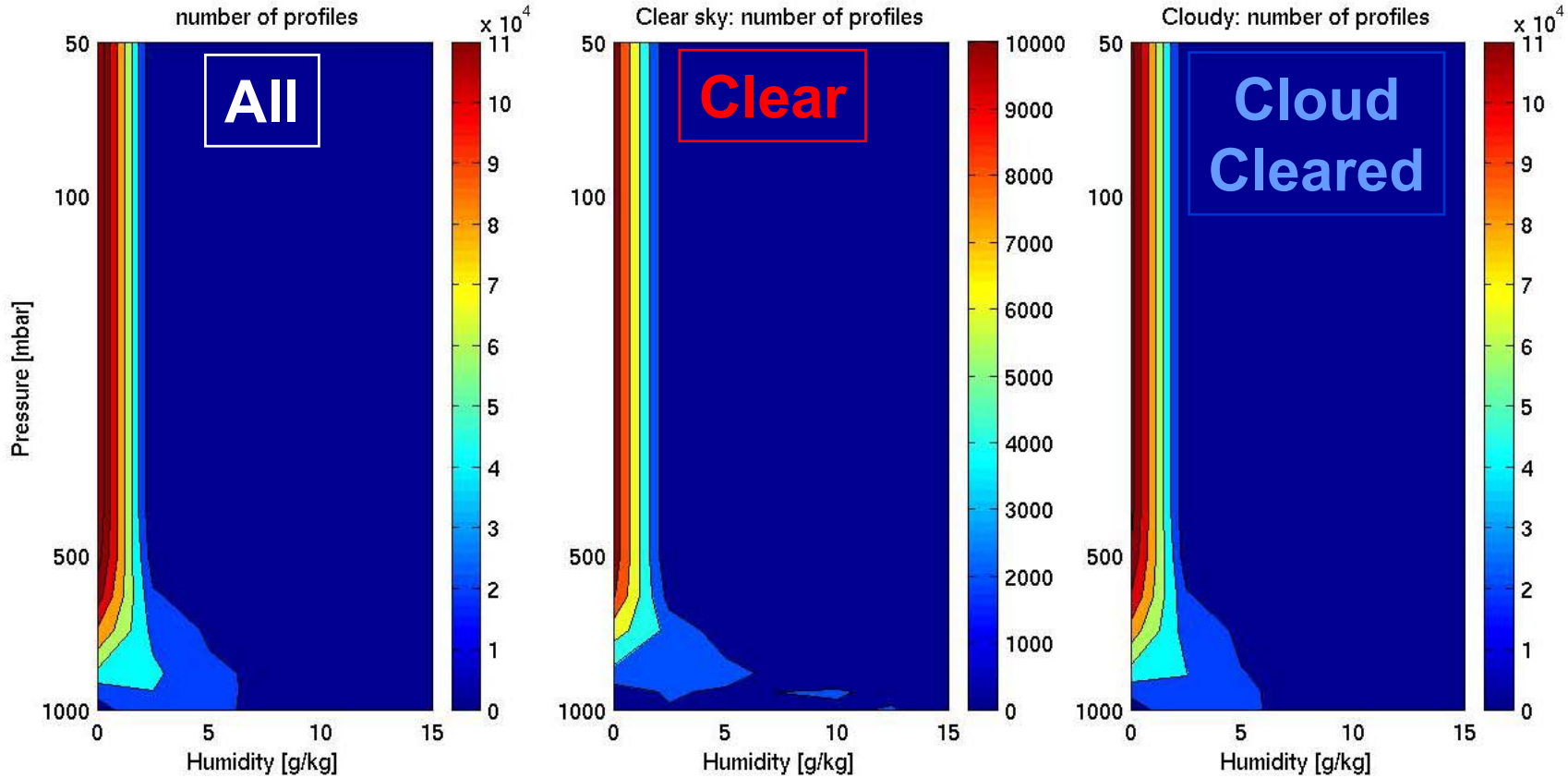
Contour plot of number of profiles for temperature [K]

Using L2 standard product 'clear_flag' for clear/cloudy scene identification



Contour plot of number of profiles for humidity [g/kg]

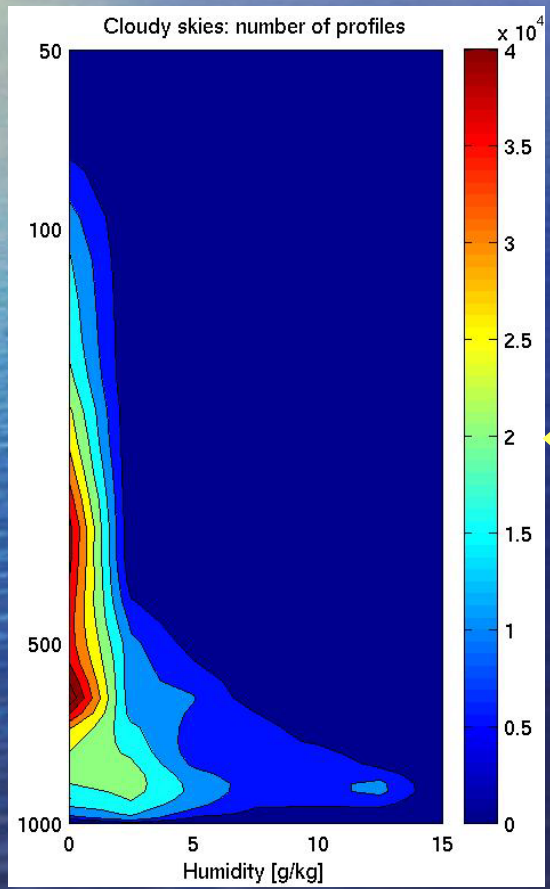
Using L2 standard product 'clear_flag' for clear/cloudy scene identification



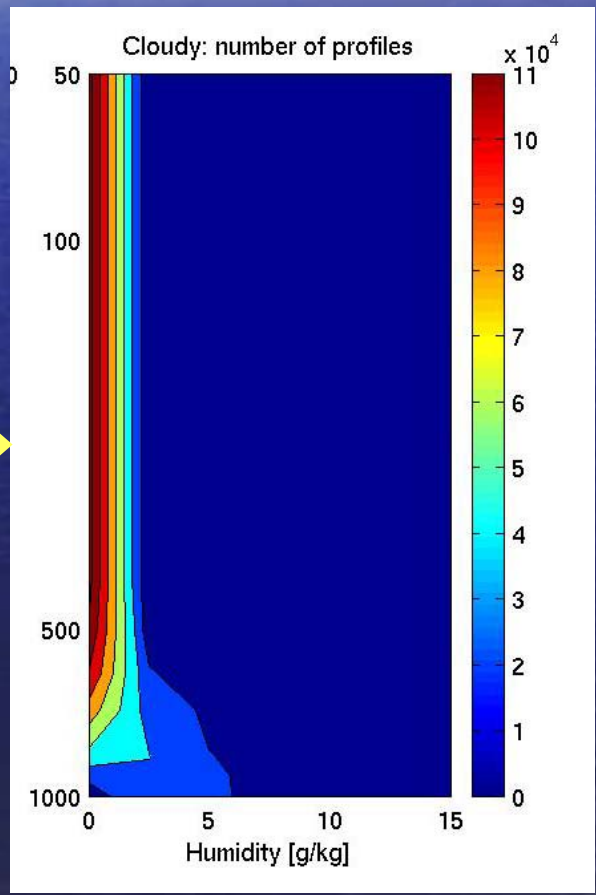
Contour plot of number of profiles for humidity [g/kg]

ECWMF Cloudy Vs. AIRS Cloud Cleared

ECMWF Cloudy Profile



AIRS Cloud Cleared Retrieval



Apperception* of Clouds in AIRS Data

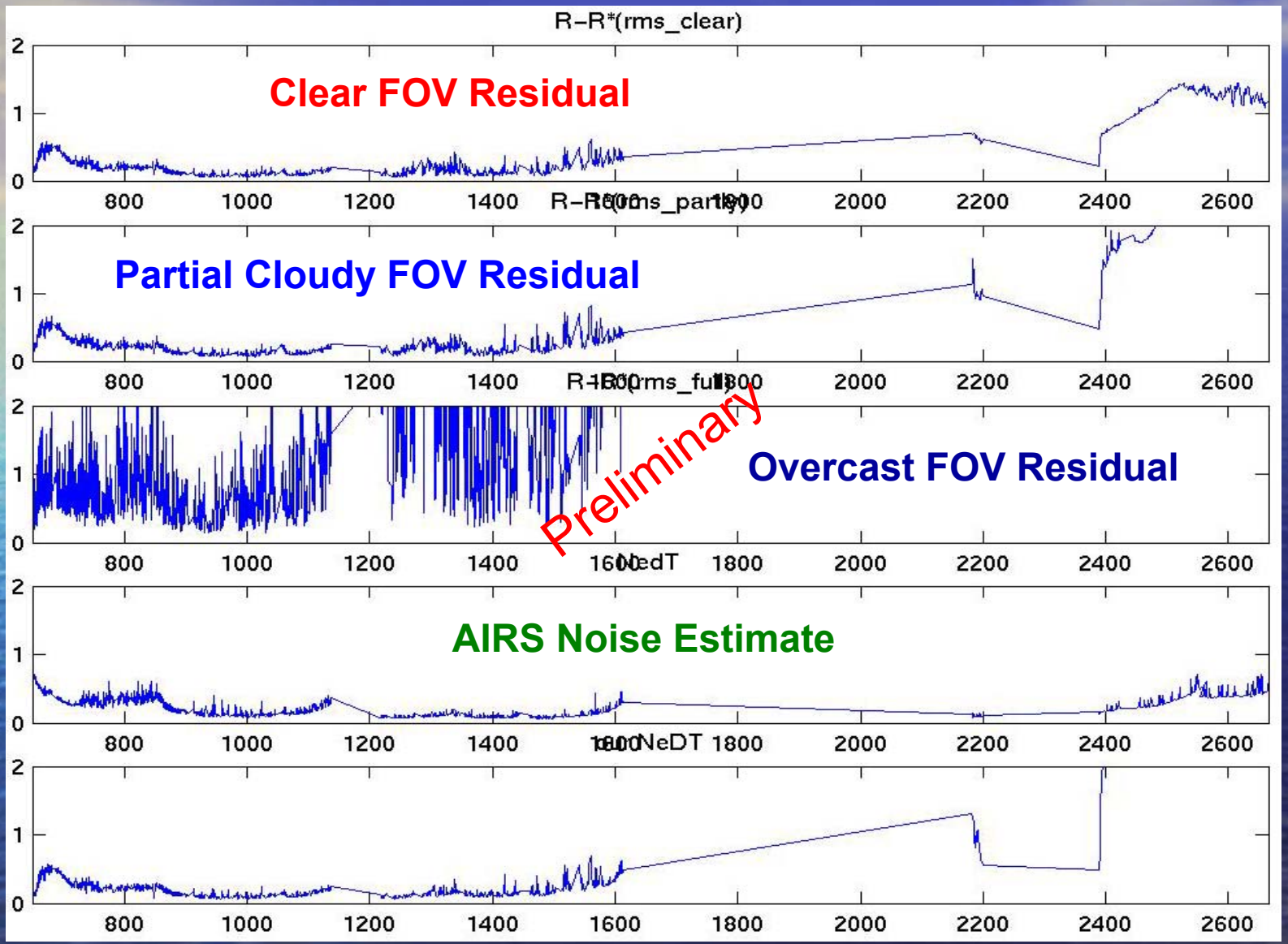
Presentation Outline

- Clouds in AIRS Data – Almost Everywhere in Anytime
- AIRS Spectral Signature
  - Spatial, Noise, Spectral, Optical, and Clouds feature
- **Cloud Clearing Issue**
  - Clear vs. cloud cleared vs. Cloudy Sounding
  - **Current Operational C.C. Characteristic**
  - Hyperspectral IR Cloud Forward Modeling
- Summary

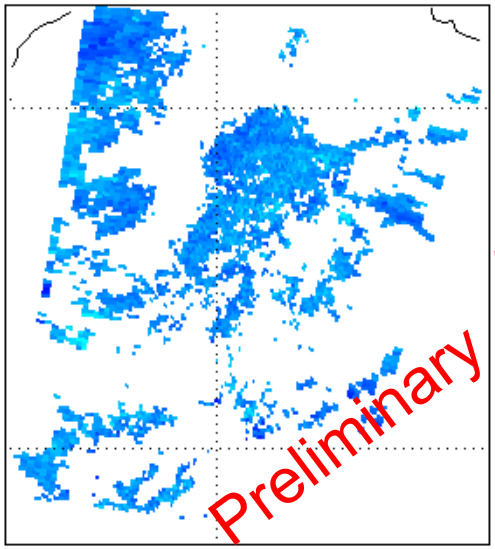
AIRS Cloudy Channel Determination - Approach

1. Estimate Channel Noise (NEdR)
   1. Dependent Principal Component Derivation from all, "clear and cloudy", pixels
   2. Estimate measurement noise, NEdR, as the absolute value of difference of R_{obs} and R_{rec}, where R_{rec} is reconstructed from 20 largest DPCs (from step 1.1)
2. Derived Clear DPC
   1. Selected AIRS clear pixels only (defined by the co-located MODIS cloud mask where 99% of MODIS pixels within AIRS pixel are confident clear)
   2. Use spectra of clear AIRS pixels only to derive Clear DPC
3. Cloudy Channel Determination
   1. Confident Cloudy Channel Decision
      Determine cloud channel as the absolute value of difference of R_{obs} and R_{rec}, where R_{rec} is reconstructed from 20 largest Clear DPCs (from step 2.1), that is larger than 1.5 times of NEdR (from step 1.2)
   2. Suspected Cloudy Channel Decision
      Same as Confident Cloudy Channel except the absolute value of difference of R_{obs} and R_{rec} is smaller than 1.5 times of NEdR but larger than NEdR

AIRS Cloudy Channel Determination - Criteria



Number of cloudy channels G017 (clear p



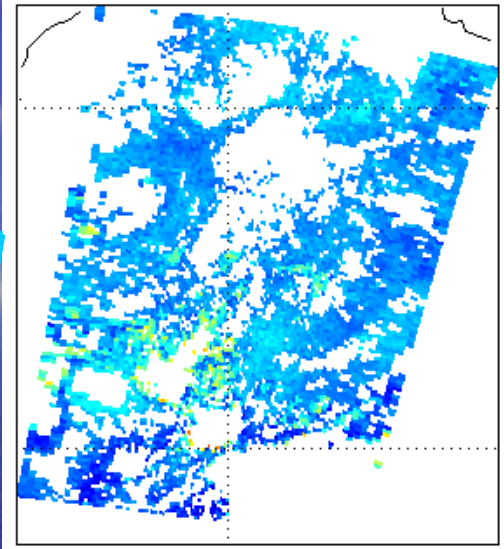
full cloudy

partly cloudy

clear

not useful

cloudy channels G017 (partly cloudy pixels)



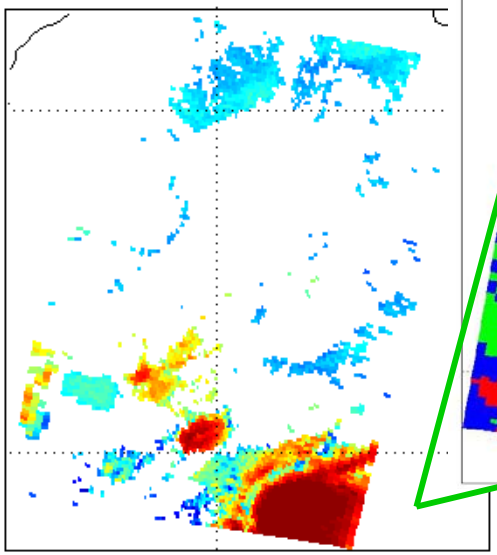
1400
1200
1000
800
600
400
200

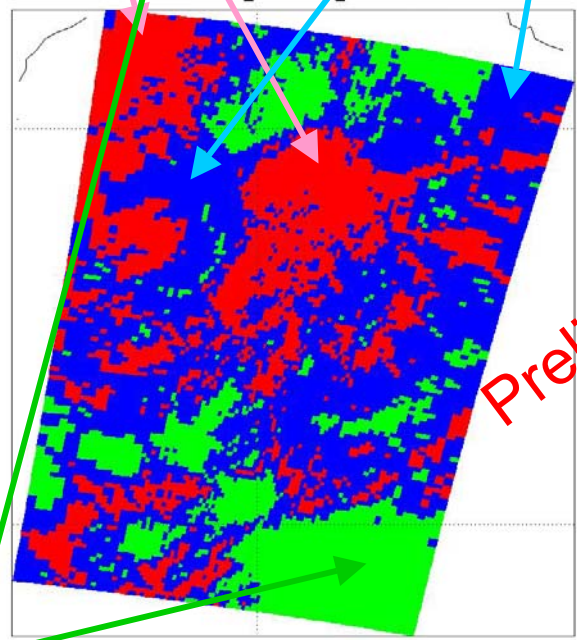
Clear - 3289

Partly Cloudy - 6103

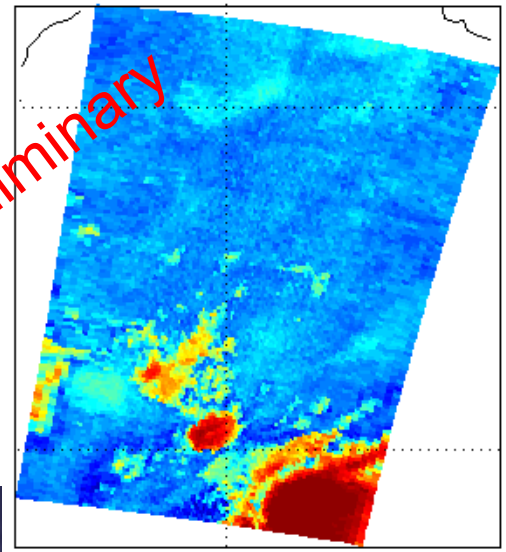
Overcast - 2758

Number of cloudy channels G017 (over





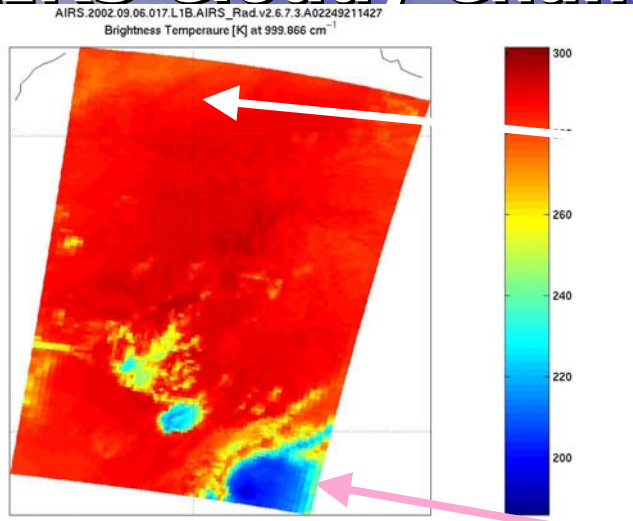
Number of cloudy channels G017



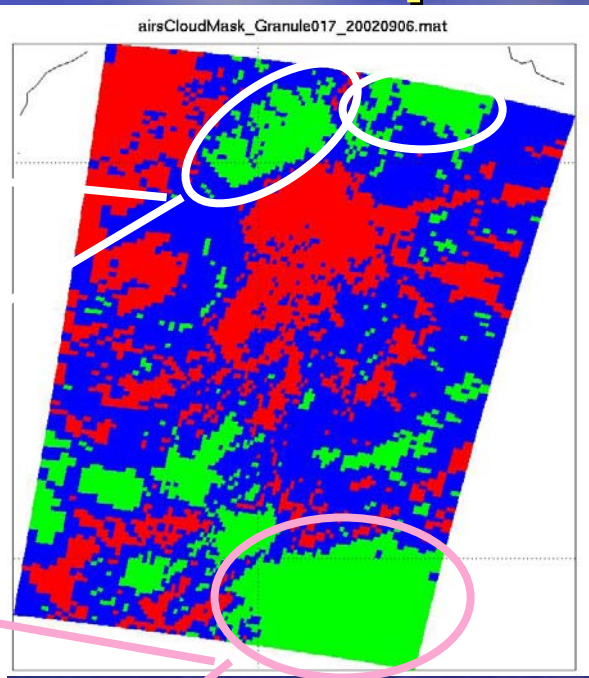
1400
1200
1000
800
600
400
200

CIMSS UW-Madison

AIRS Cloudy Channel Determination - Example

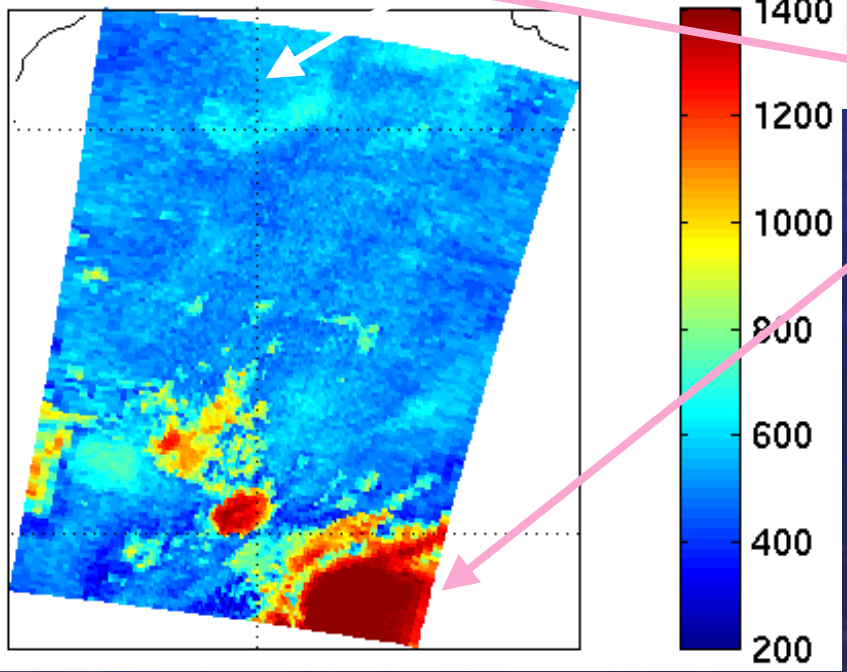


Preliminary



Number of cloudy channels G017

Window Channel Brightness Temp.



AIRS Cloud Mask

Number of Cloudy Channel per AIRS FOV

Current* AIRS Cloudy Cloud Clearing Characteristic – Characterization Approach

1. Find at least one neighboring AIRS single FOVs (S-FOV) within or surrounding the AIRS golf ball that is clear (according to MODIS cloud mask for which that within this FOV at least 99% is clear). In other words, from 25 candidates (fig. 1 below) find one clear AIRS FOV as the " clear ground truth" to estimate cloud clearing (CC) error.

2. Compute bias (mean of differences), RMSE, and RMSD spectra from all AIRS/AMSU golf ball CC that has found the corresponding clear S-FOV (defined as above) radiances.

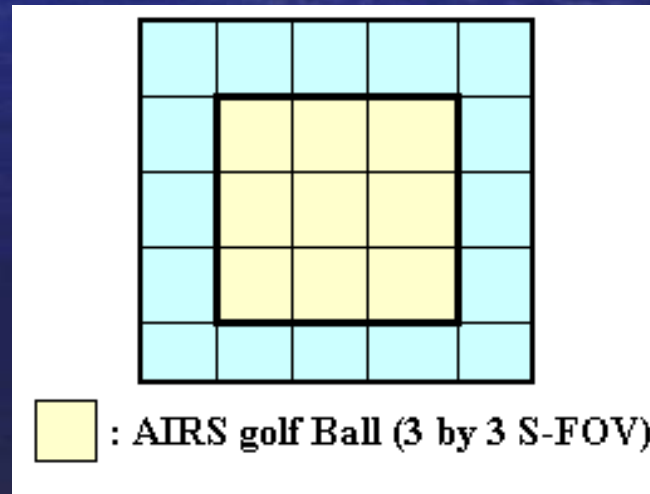


Fig. 1, AIRS golf ball and its neighboring Single FOVs

*AIRS cloud clearing Version 3.5.0.0

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Data Set

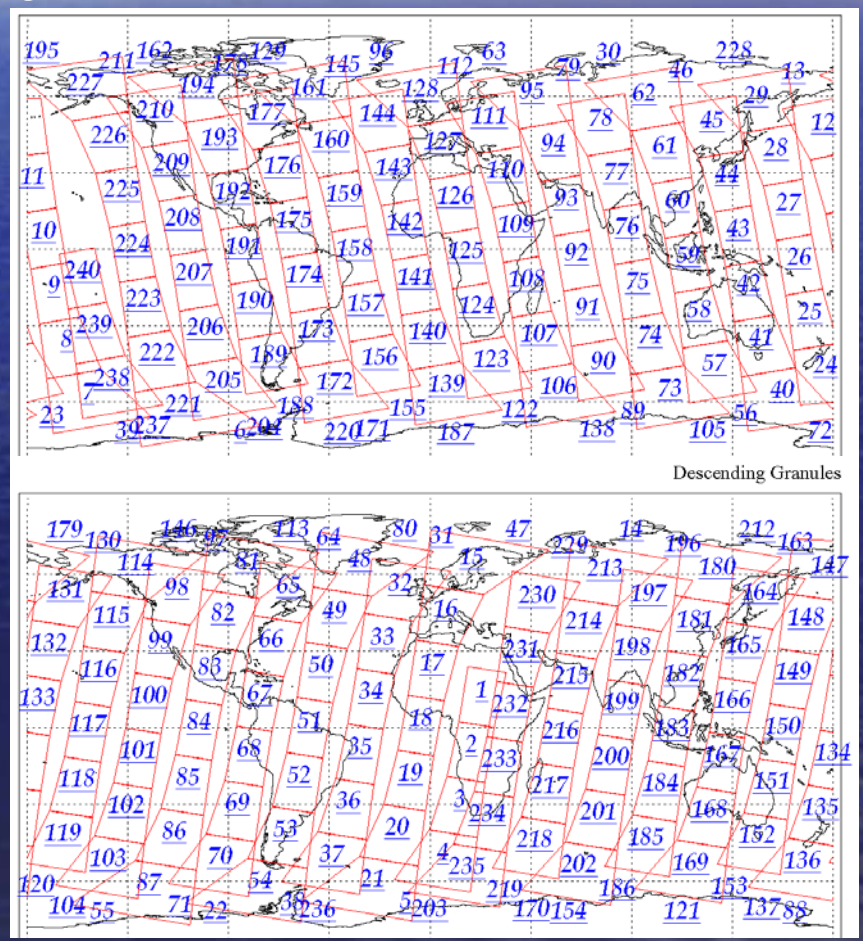
The selected granules of focus day of 6 September 2002 (so far cloud clearing Ver. 3.5.0 data are available for AIRS focus days only) are used for the error estimate. 24 -day and 24 –night granules over ocean and land are:

Day

G025, G027, G058, G060, G061, G075, G078, G092, G094, G108, G111, G126, G141, G144, G157, G159, G174, G192, G193, G207, G209, G224, G226, G239

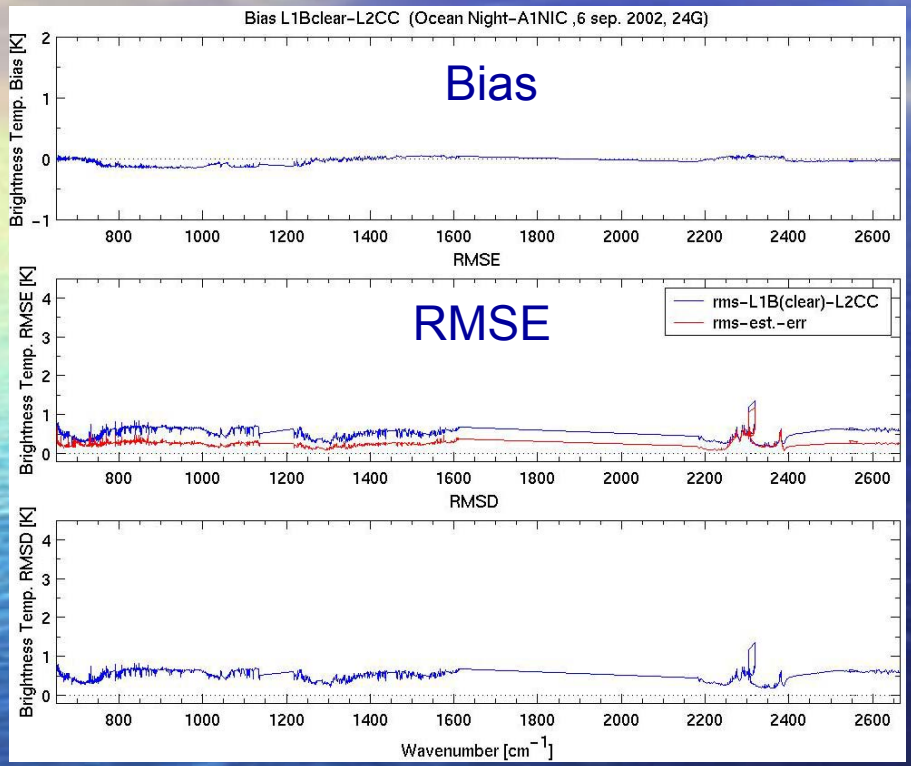
Night

G115, G117, G100, G082, G083, G085 G065, G049, G052, G034, G036, G016 G017, G019, G001, G230, G214, G216 G197, G200, G182, G184, G148, G151

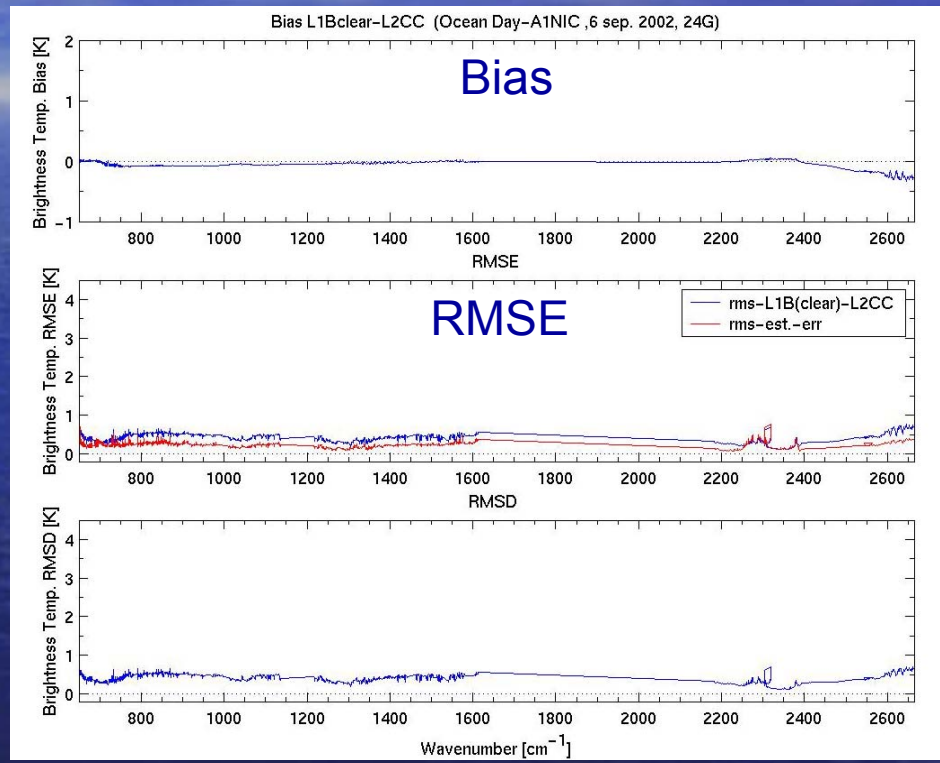


***AIRS cloud clearing Version 3.5.0.0**

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Ocean)



Nighttime – 1550/24 Sample Size/Granule

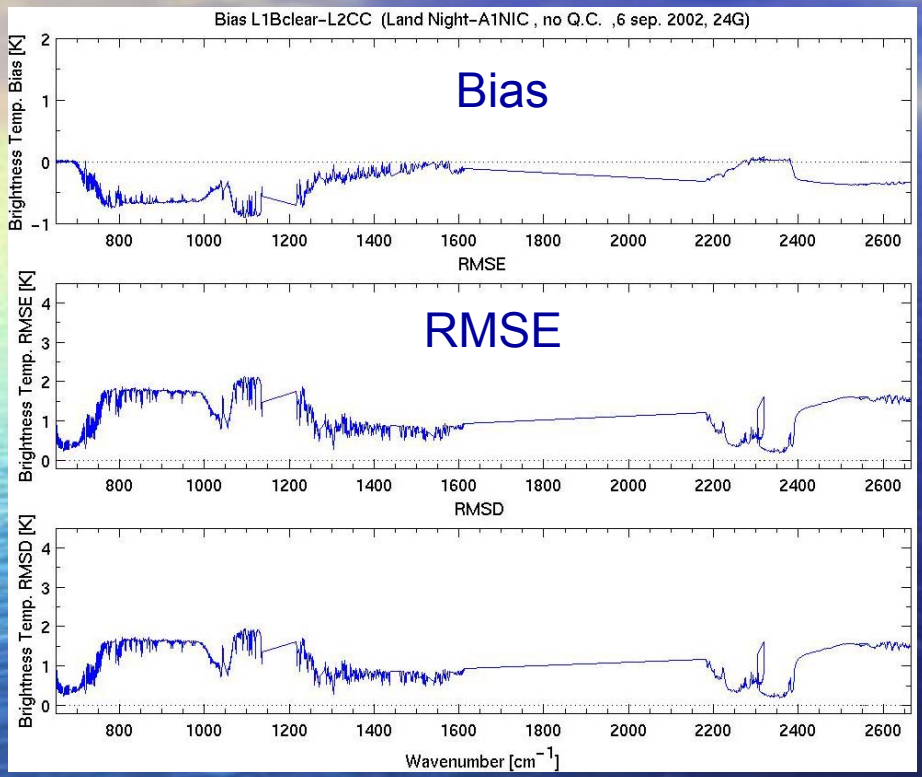


Daytime – 5071/24 Sample Size/Granule

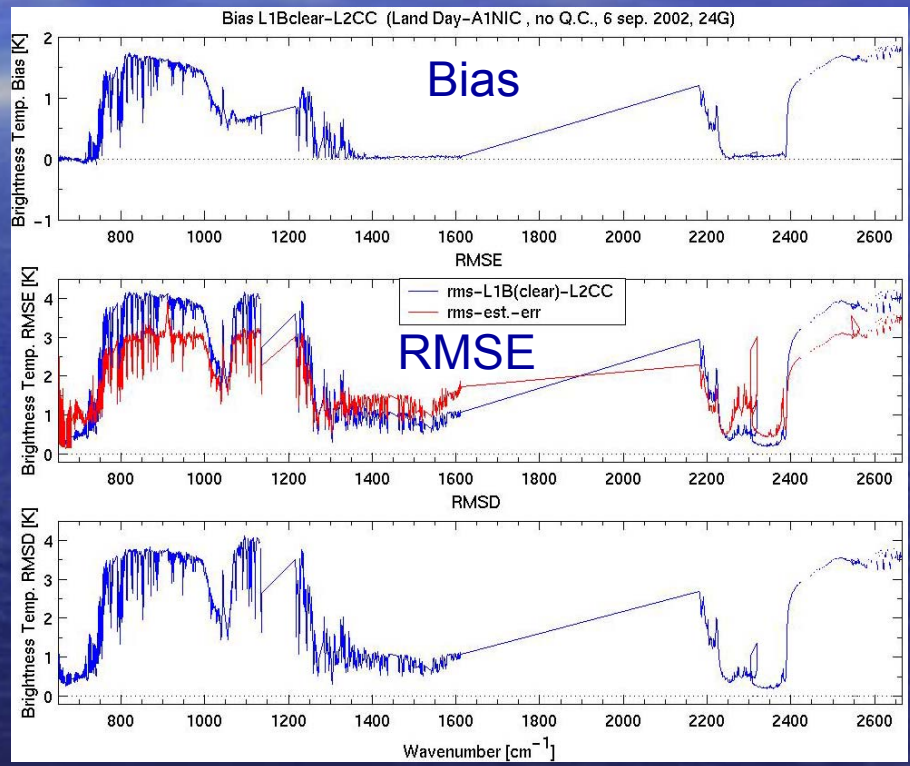
Red curves are AIRS C.C. theoretical error estimate for comparison

***AIRS cloud clearing Version 3.5.0.0**

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)



Nighttime – 2612/24 Sample Size/Granule



Daytime – 1745/24 Sample Size/Granule

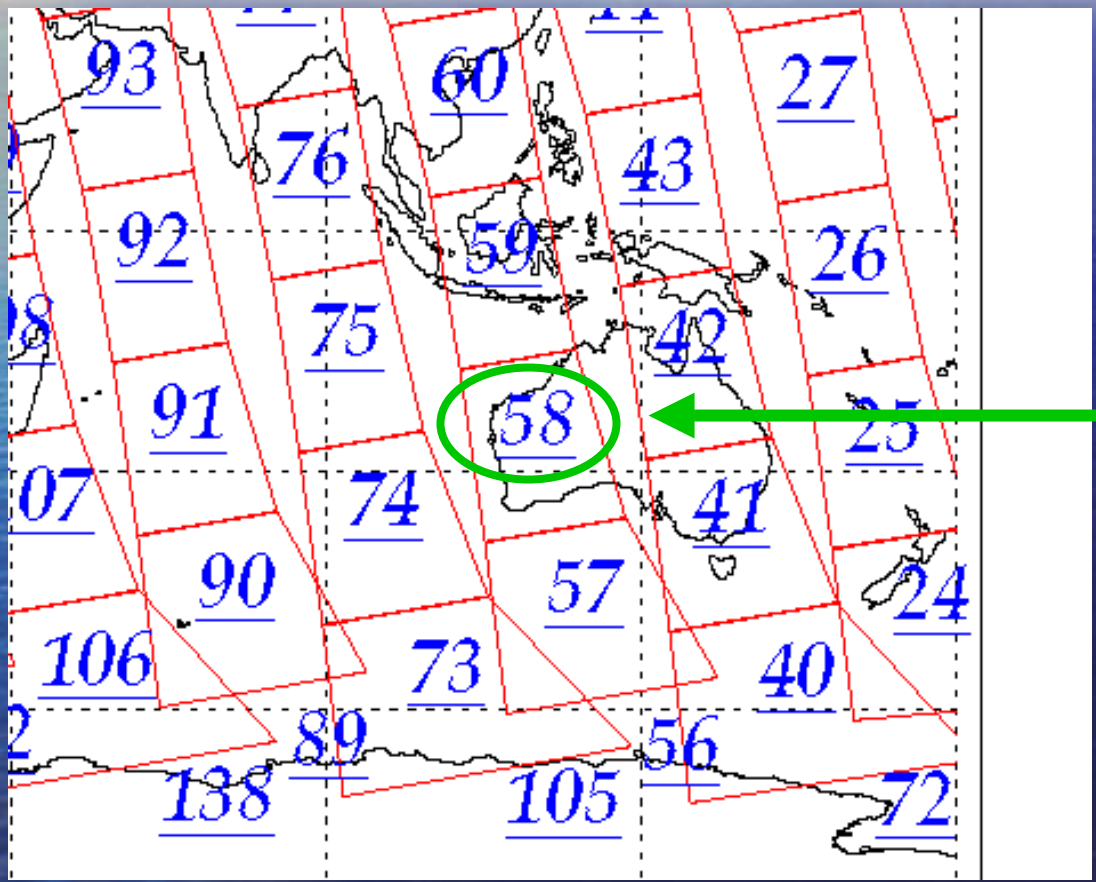
Red curves are AIRS C.C. theoretical error estimate for comparison

***AIRS cloud clearing Version 3.5.0.0**

%With failed quality control data

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)
Level 1B Brightness Temperature



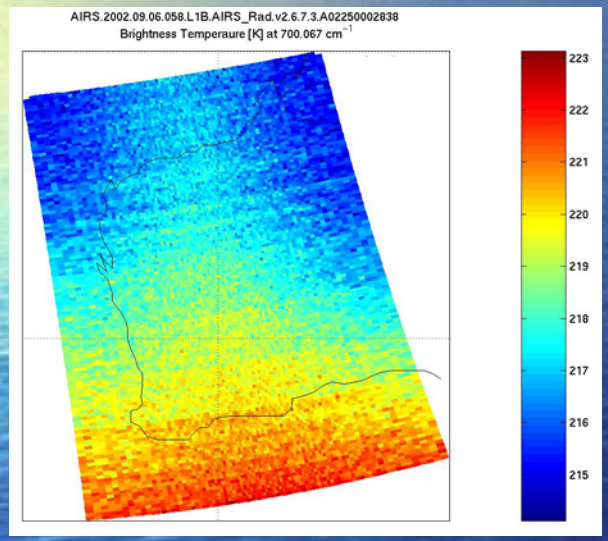
Case Granule 58 Partial Land Daytime (Desert & Ocean)

%With failed quality control data

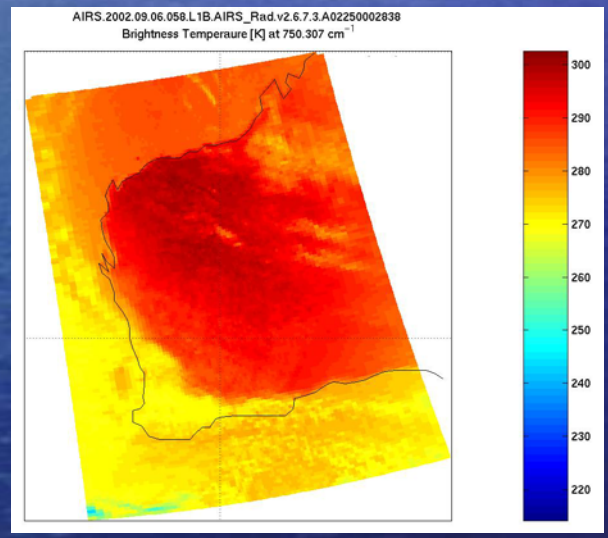
*AIRS cloud clearing Version 3.5.0.0

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

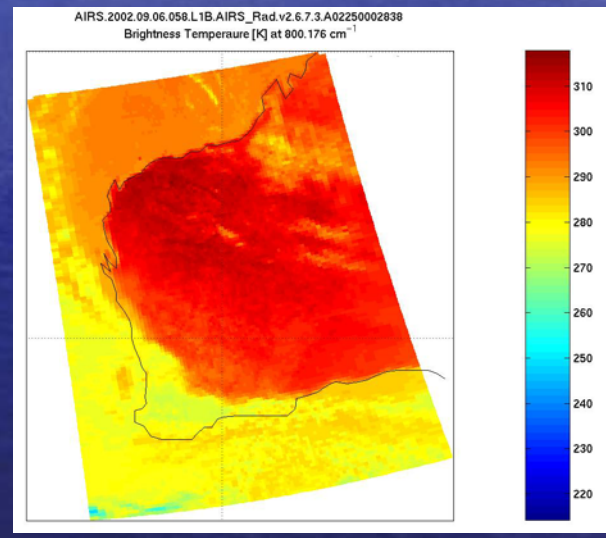
6 Sep 2002 focus day Granule 58 (Partial Land Day)
Level 1B Brightness Temperature



700 cm^{-1}



750 cm^{-1}



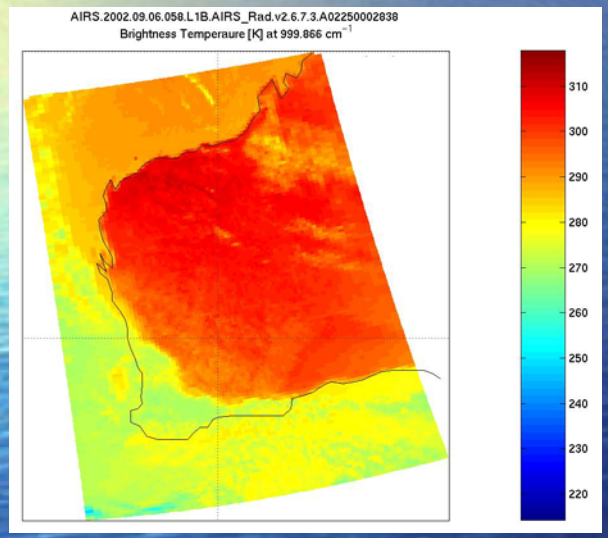
800 cm^{-1}

*AIRS cloud clearing Version 3.5.0.0

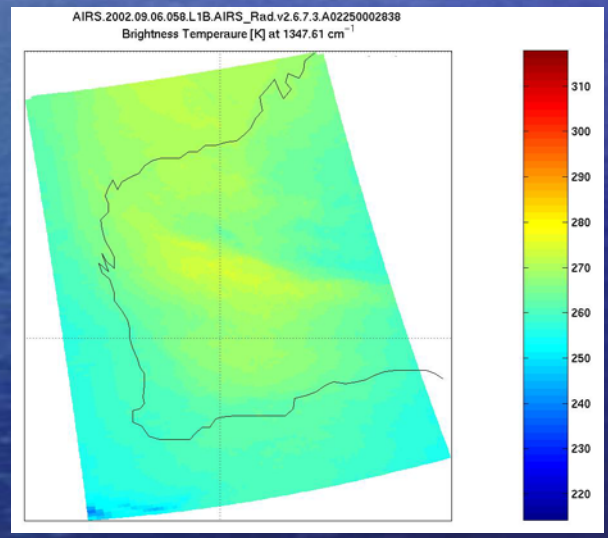
%With failed quality control data

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

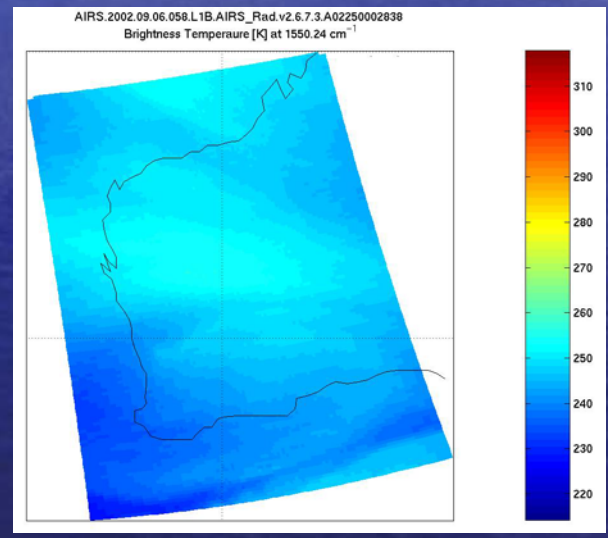
6 Sep 2002 focus day Granule 58 (Partial Land Day)
Level 1B Brightness emperature



1000 cm^{-1}



1350 cm^{-1}



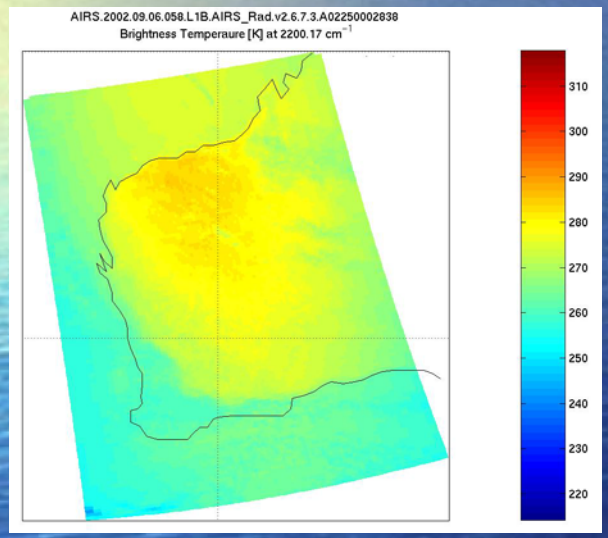
1550 cm^{-1}

*AIRS cloud clearing Version 3.5.0.0

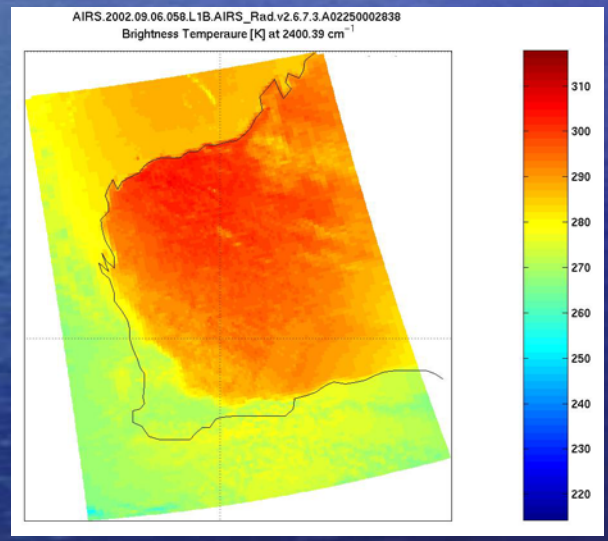
%With failed quality control data

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

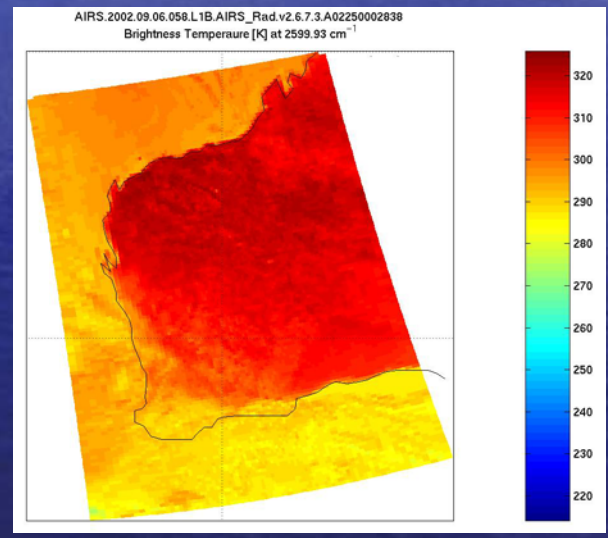
6 Sep 2002 focus day Granule 58 (Partial Land Day)
Level 1B Brightness emperature



2200 cm^{-1}



2400 cm^{-1}



2600 cm^{-1}

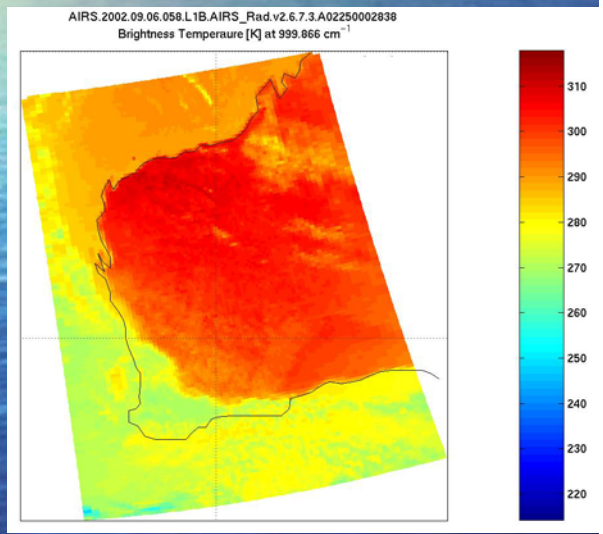
*AIRS cloud clearing Version 3.5.0.0

%With failed quality control data

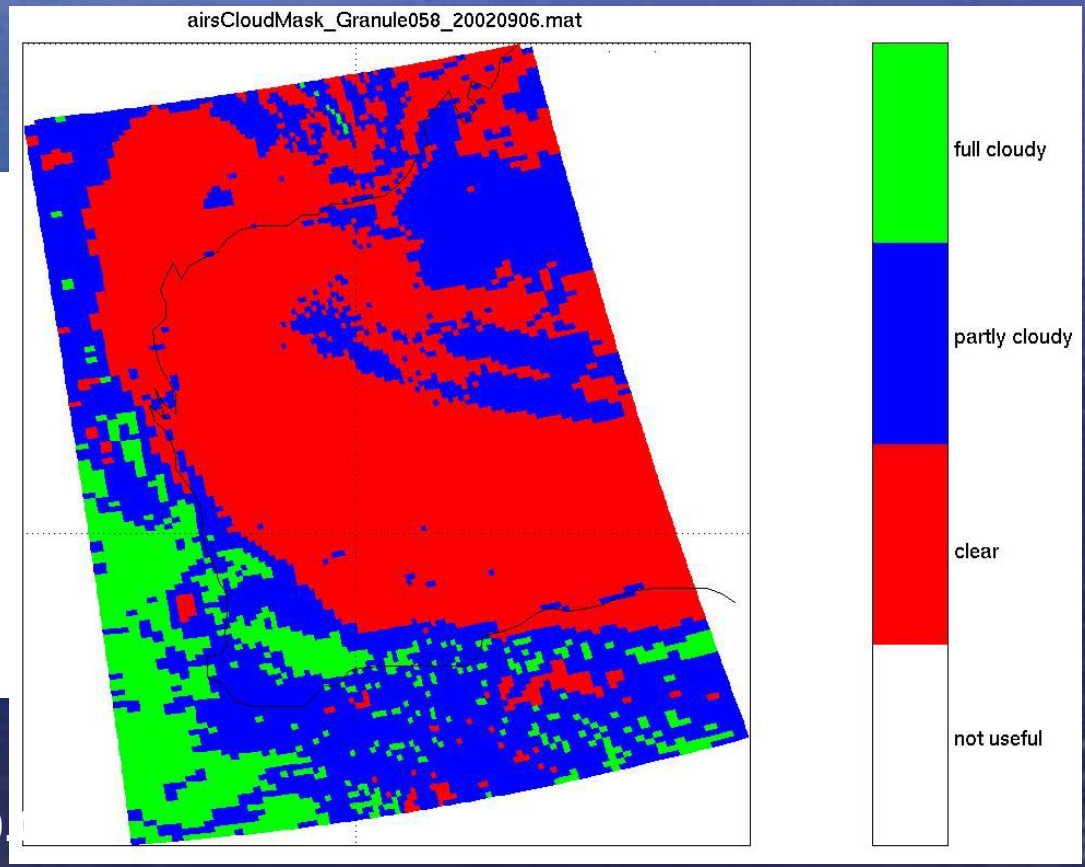
Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)
AIRS Cloud Mask (derived from co-located MODIS cloud mask)

West Coast of Australia



Brightness Temp.



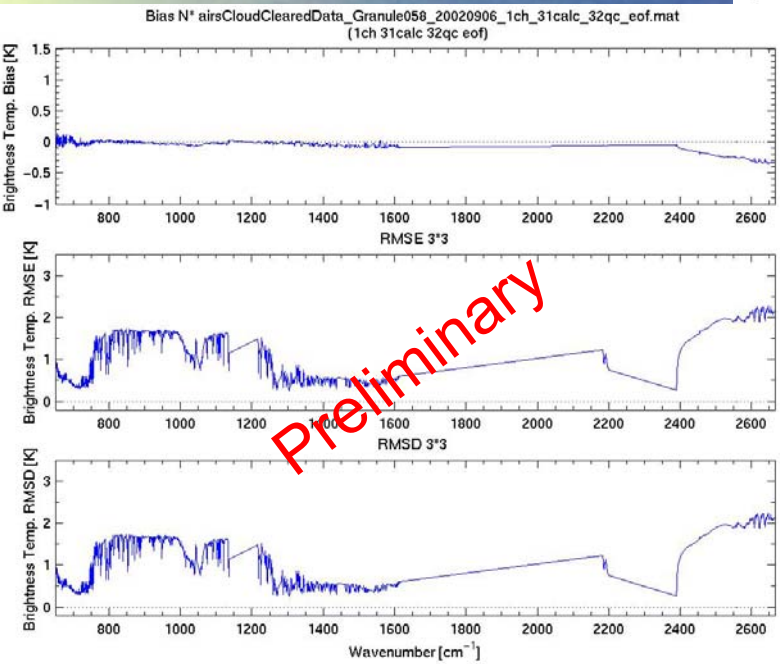
***AIRS cloud clearing Version 3.5.0**

%With failed quality control data

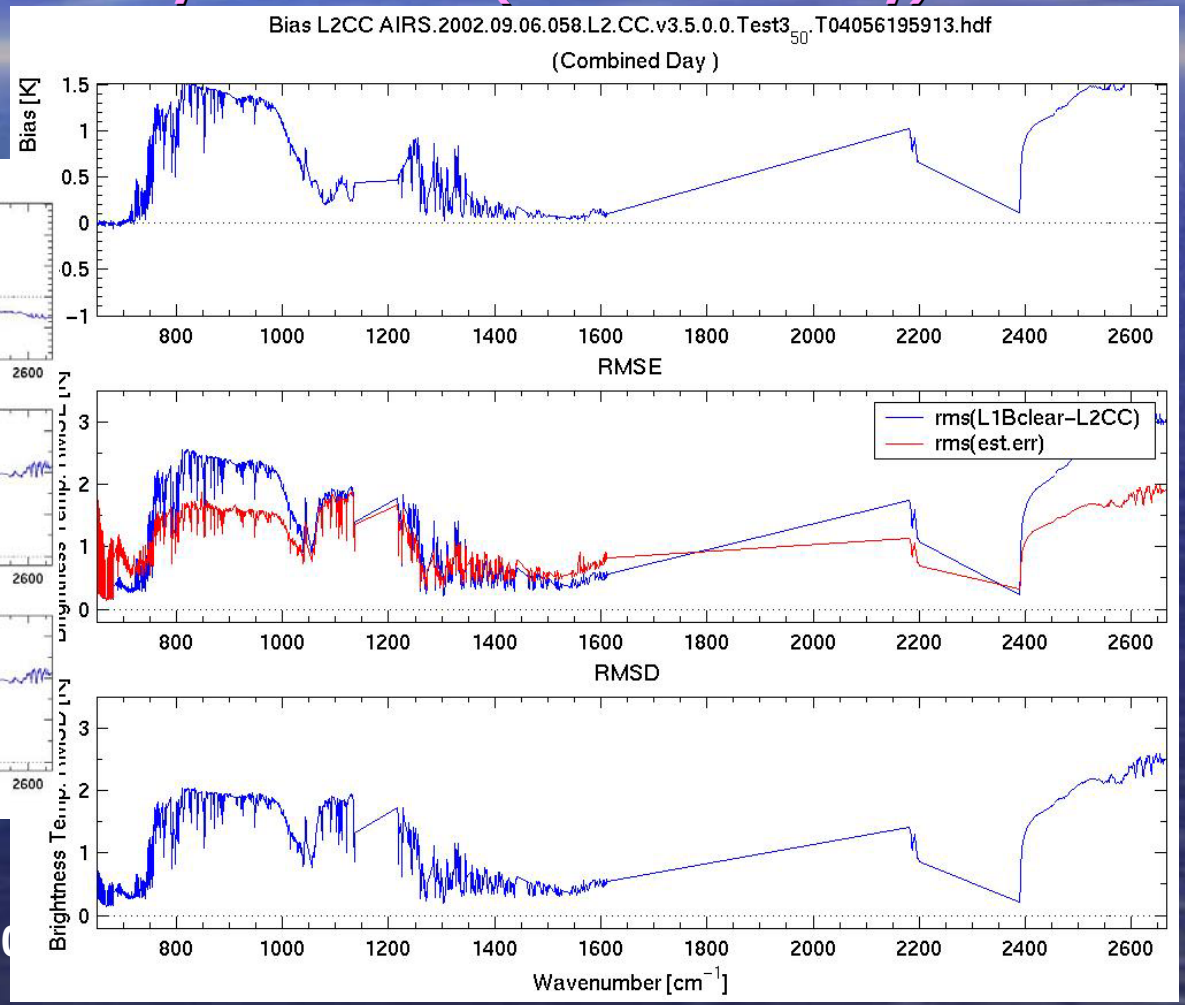
Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)

AIRS Operational% →



Preliminary

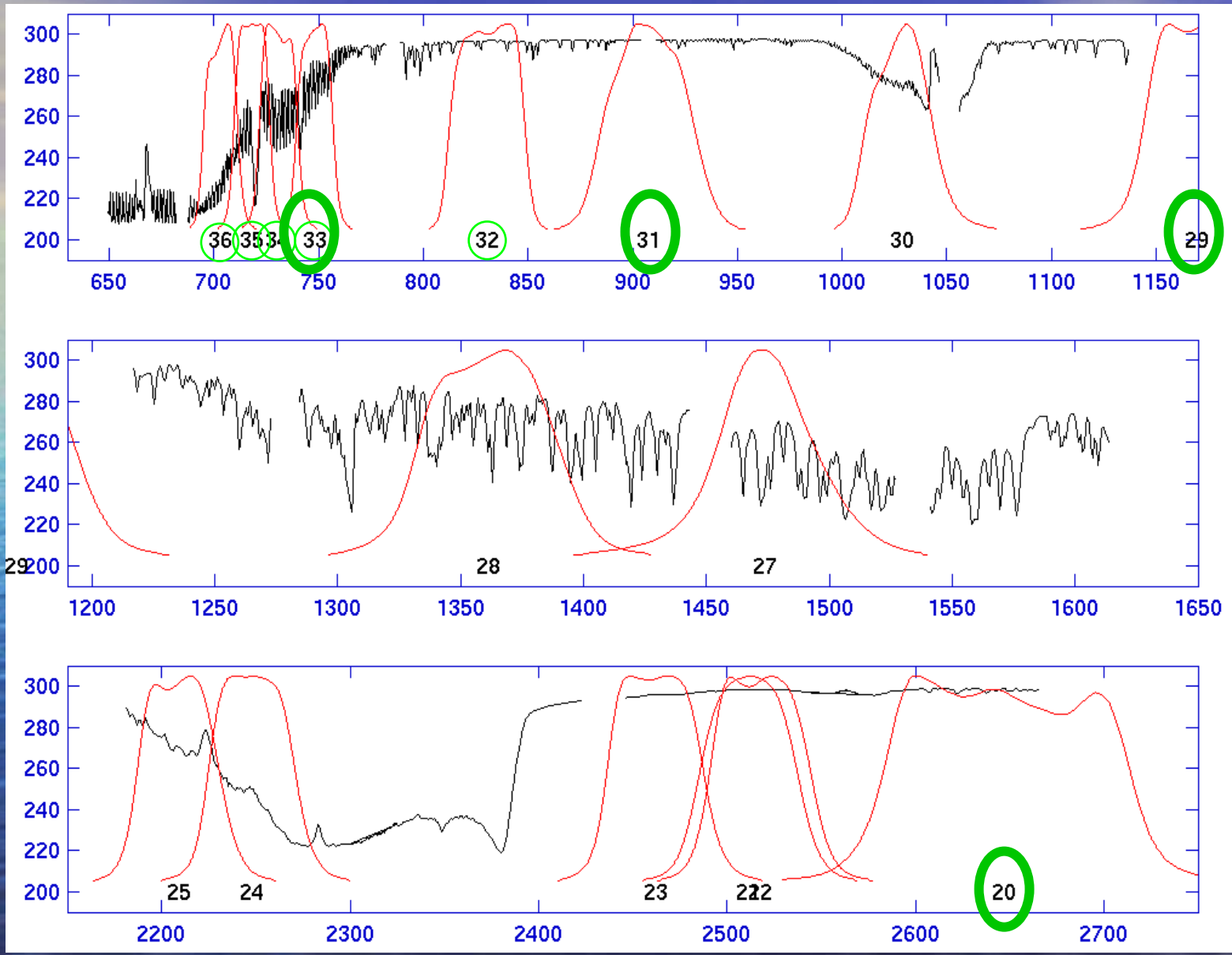


MODIS/AIRS N* Preliminary

*AIRS cloud clearing Version 3.5.0.

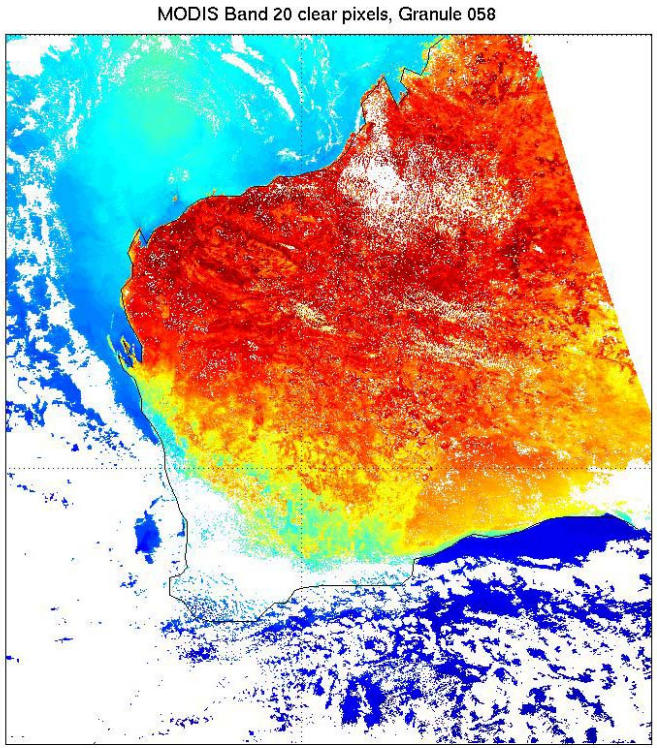
%With failed quality control data

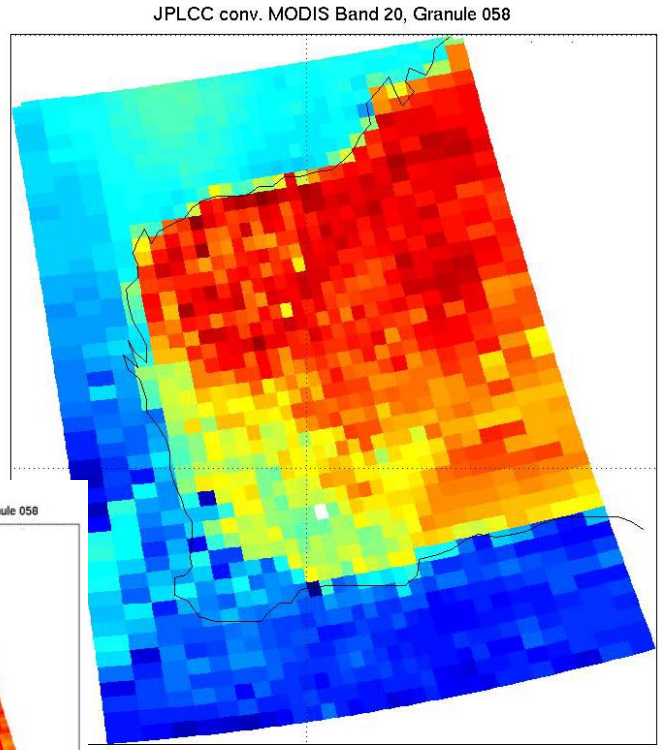
Aqua MODIS SRF Overlay on AIRS Spectrum

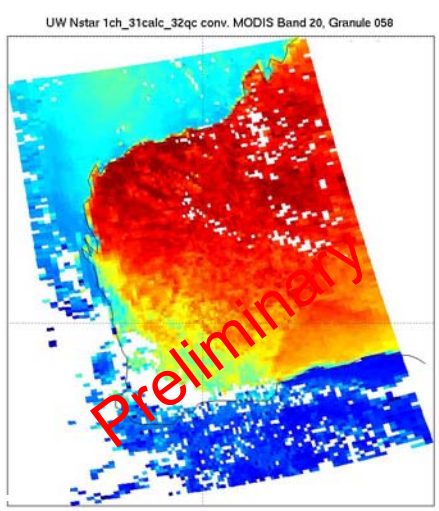


Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)







MODIS Clear Pixel only BT

AIRS Cloud Cleared BT

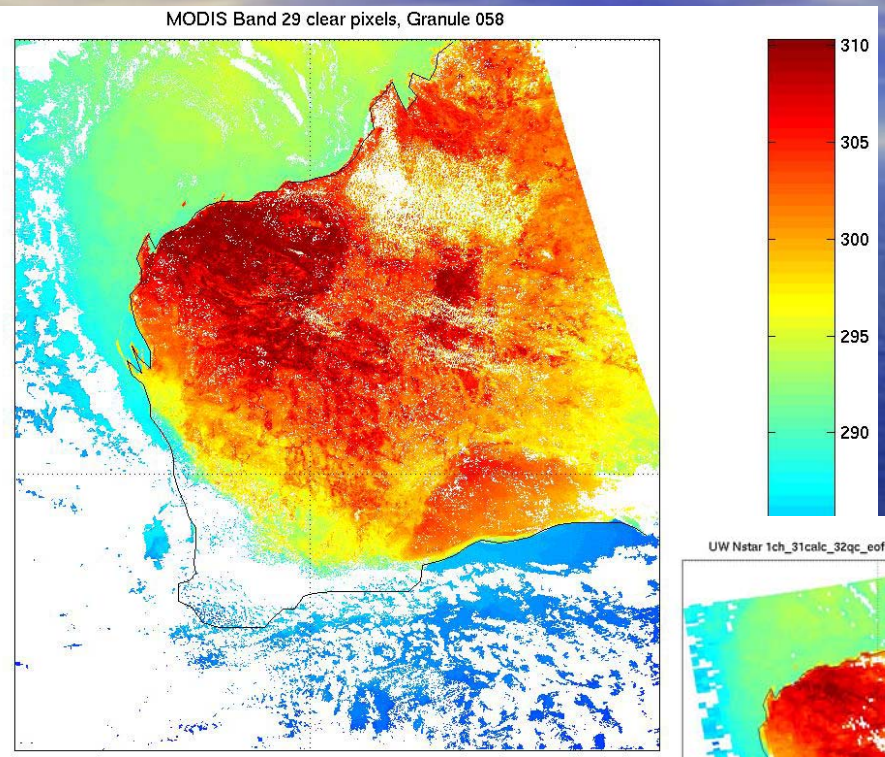
*AIRS cloud clearing Version 3.5

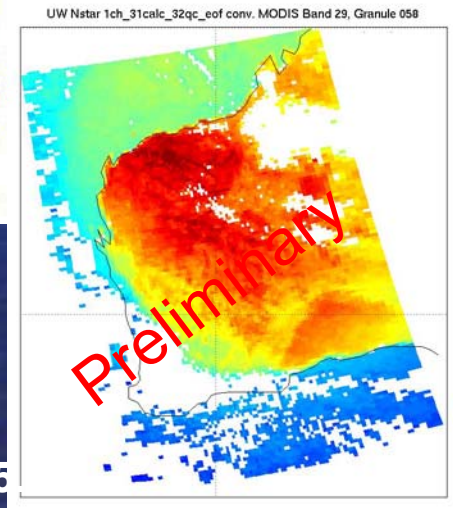
%With failed quality control data

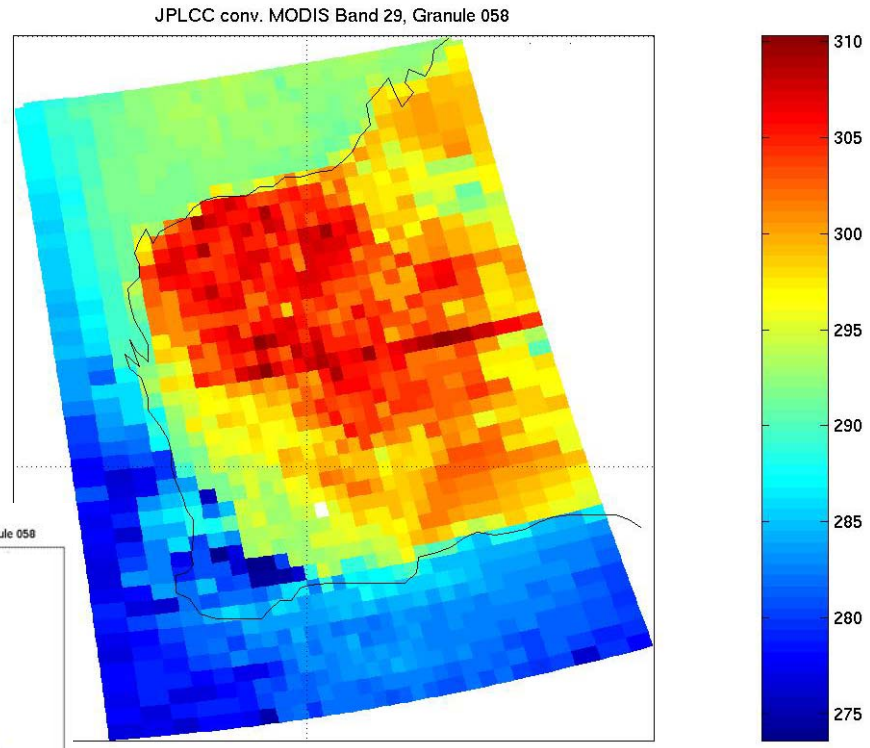
Band 20

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)







MODIS Clear Pixel only BT

AIRS Cloud Cleared BT

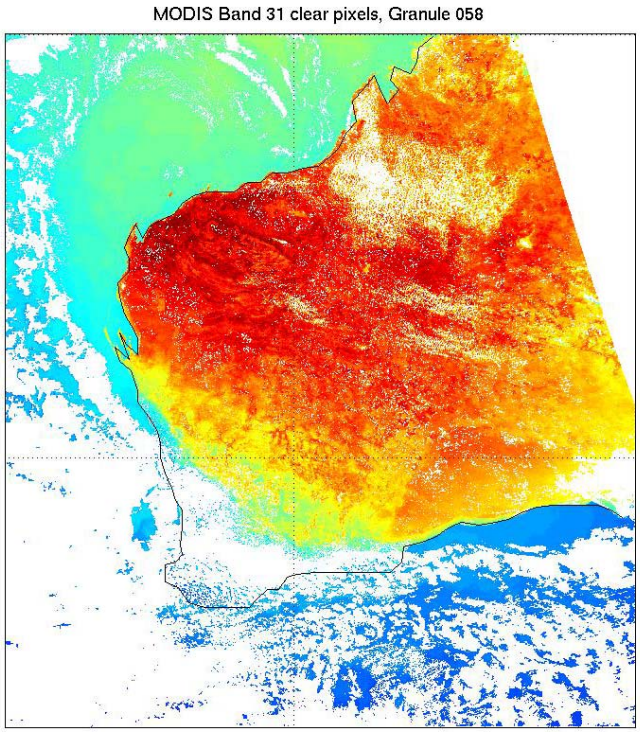
*AIRS cloud clearing Version 3.5

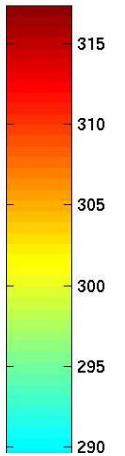
%With failed quality control data

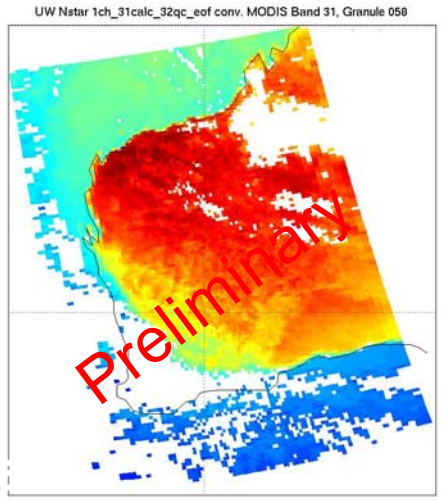
Band 29

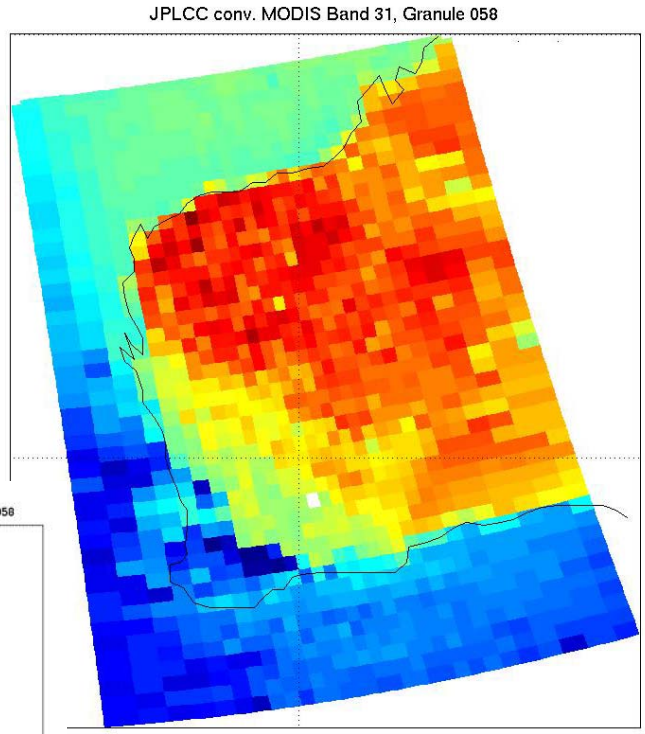
Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

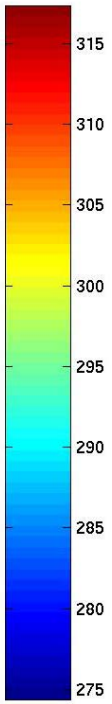
6 Sep 2002 focus day Granule 58 (Partial Land Day)











MODIS Clear Pixel only BT

AIRS Cloud Cleared BT

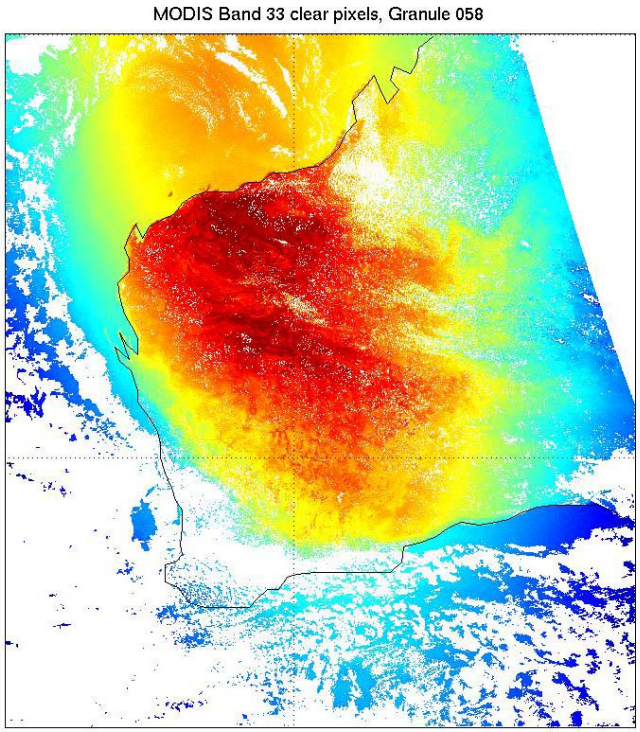
*AIRS cloud clearing Version 3.

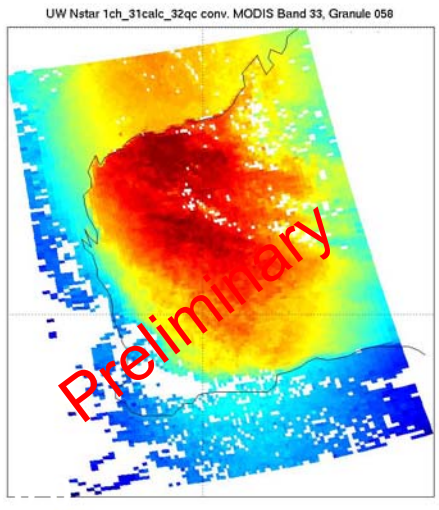
%With failed quality control data

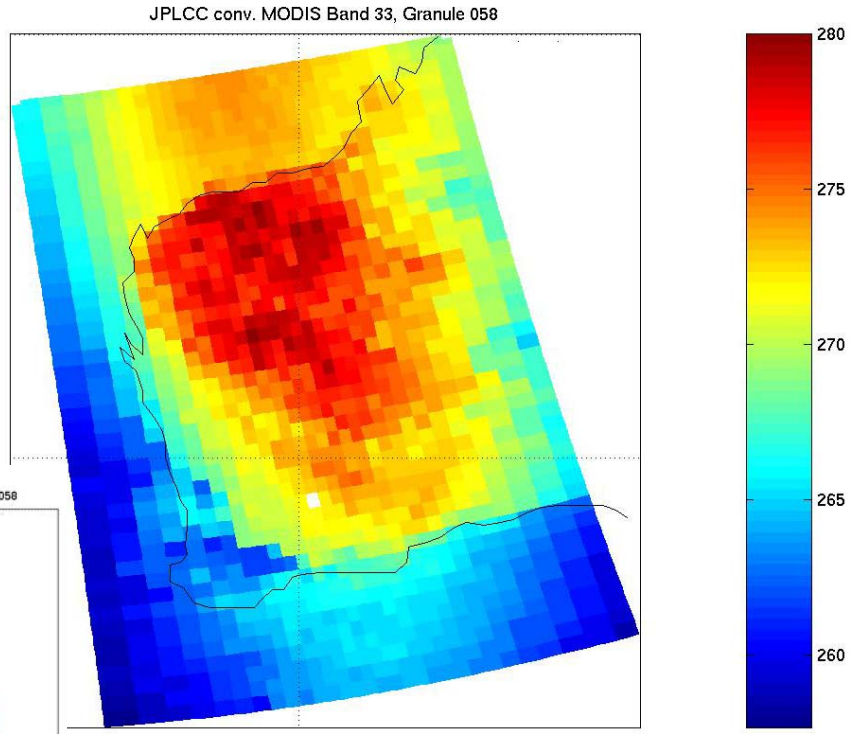
Band 31

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)







MODIS Clear Pixel only BT

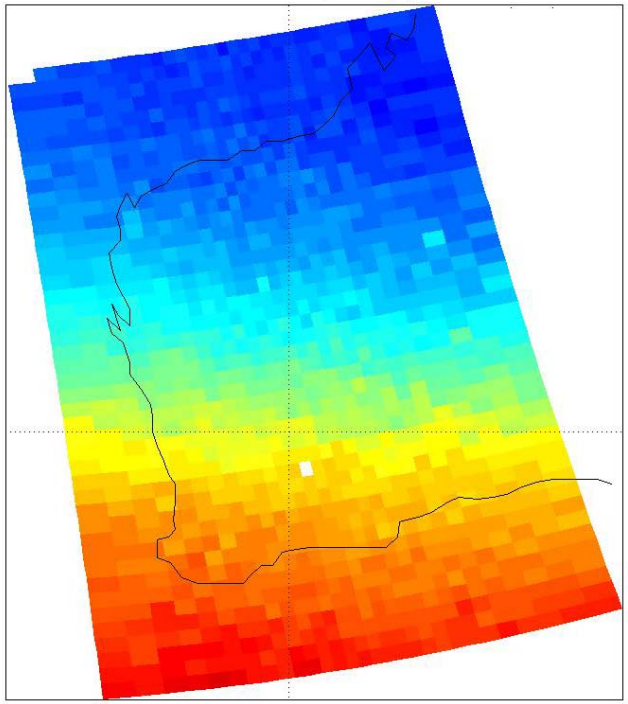
AIRS Cloud Cleared BT

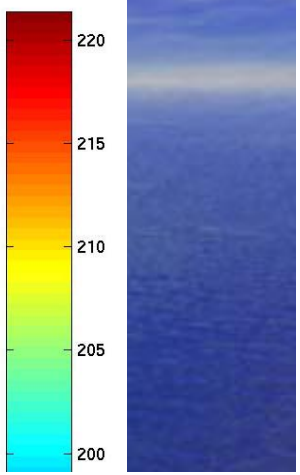
*AIRS cloud clearing Version 3.5

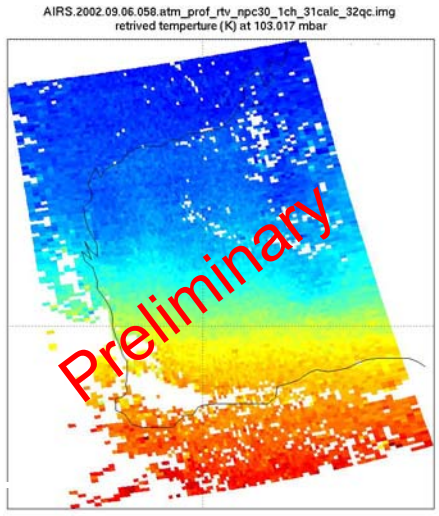
%With failed quality control data

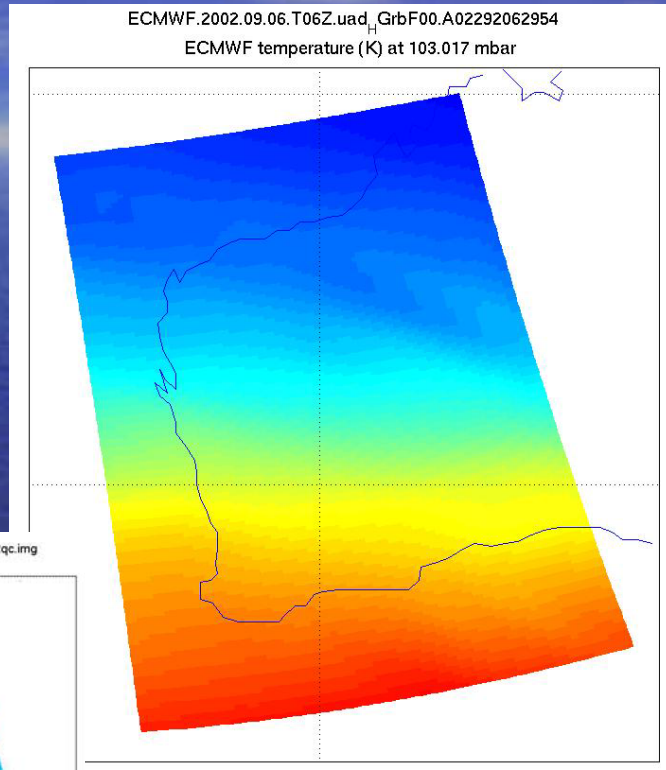
Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

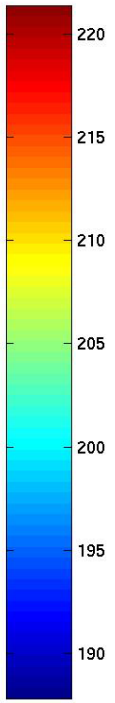
6 Sep 2002 focus day Granule 58 (Partial Land Day)











AIRS Cloud Cleared Rtv

ECMWF Analysis

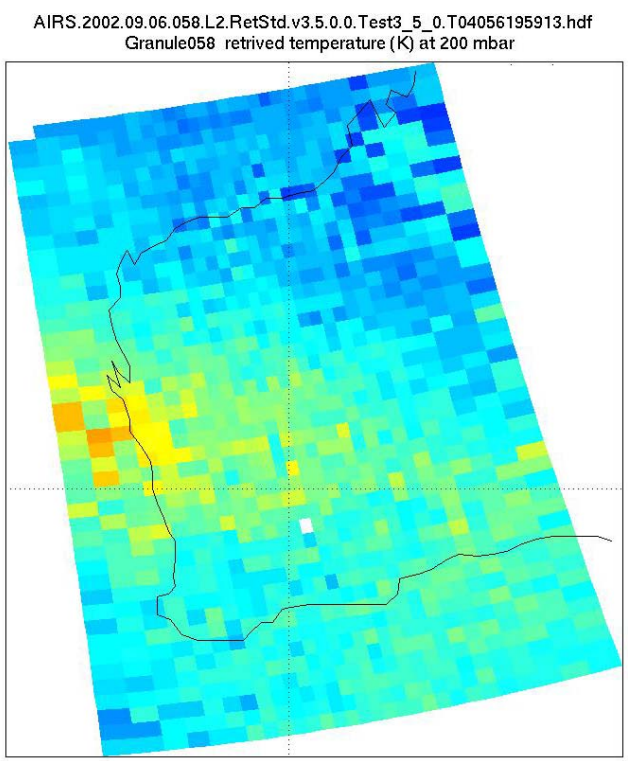
*AIRS cloud clearing Version 3.5

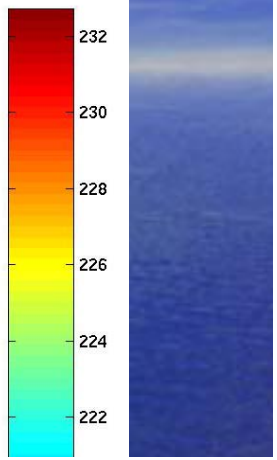
%With failed quality control data

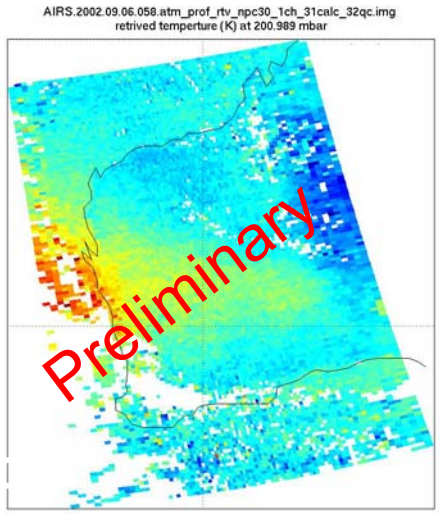
100 mb Temperature

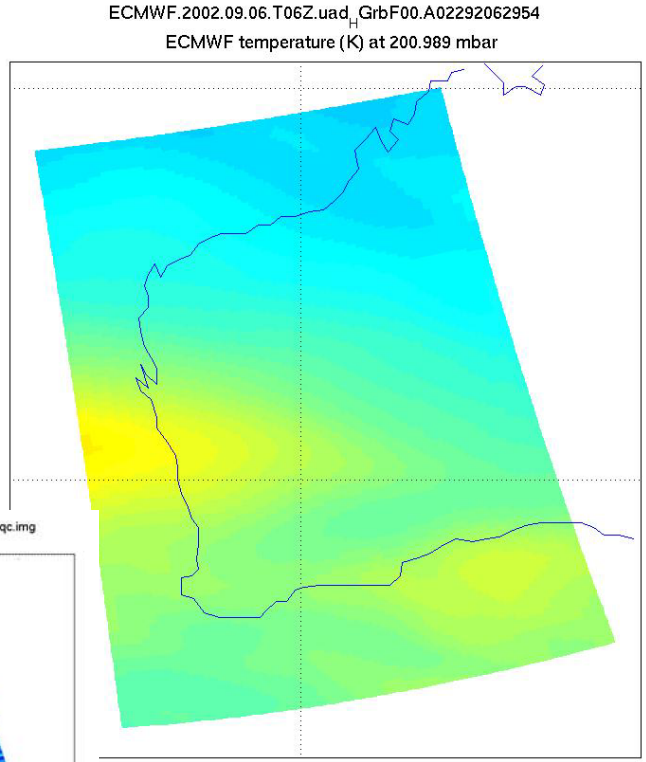
Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

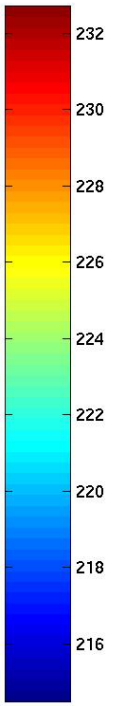
6 Sep 2002 focus day Granule 58 (Partial Land Day)











AIRS Cloud Cleared Rtv

ECMWF Analysis

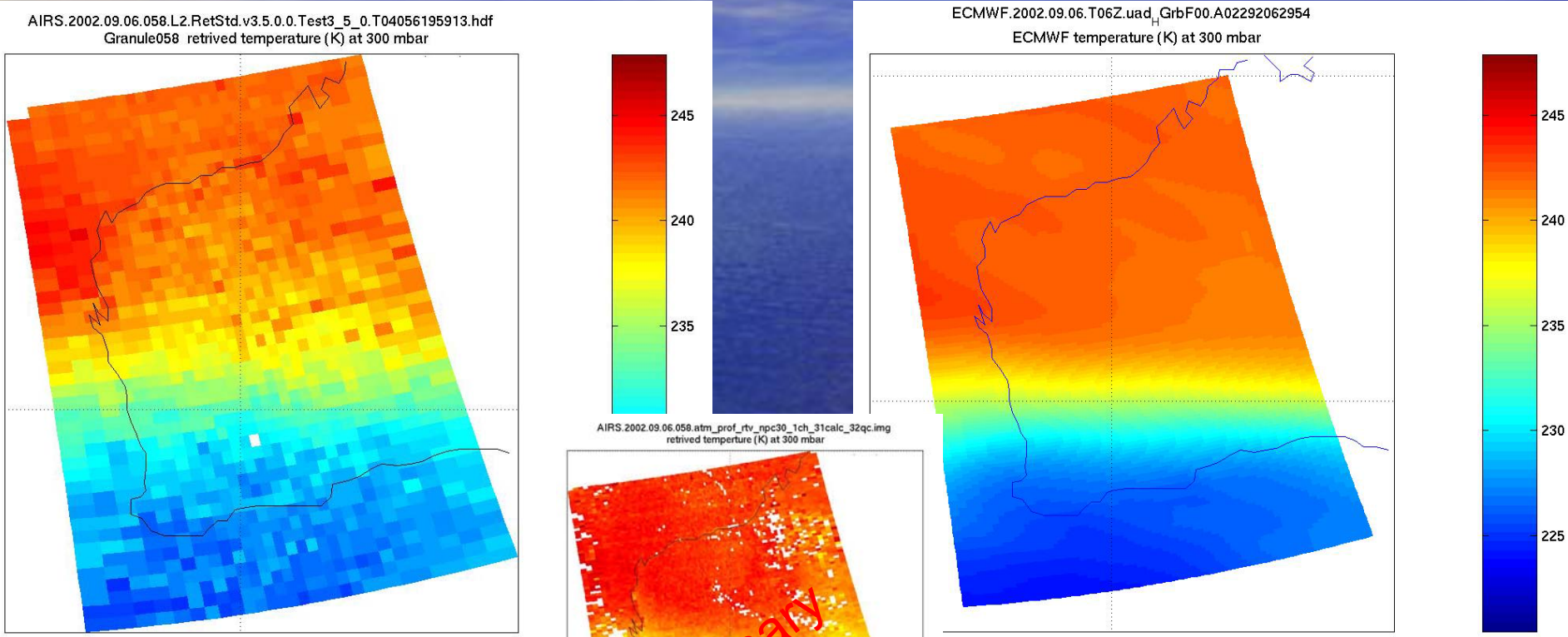
*AIRS cloud clearing Version 3.5.

%With failed quality control data

200 mb Temperature

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)



AIRS Cloud Cleared Rtv

ECMWF Analysis

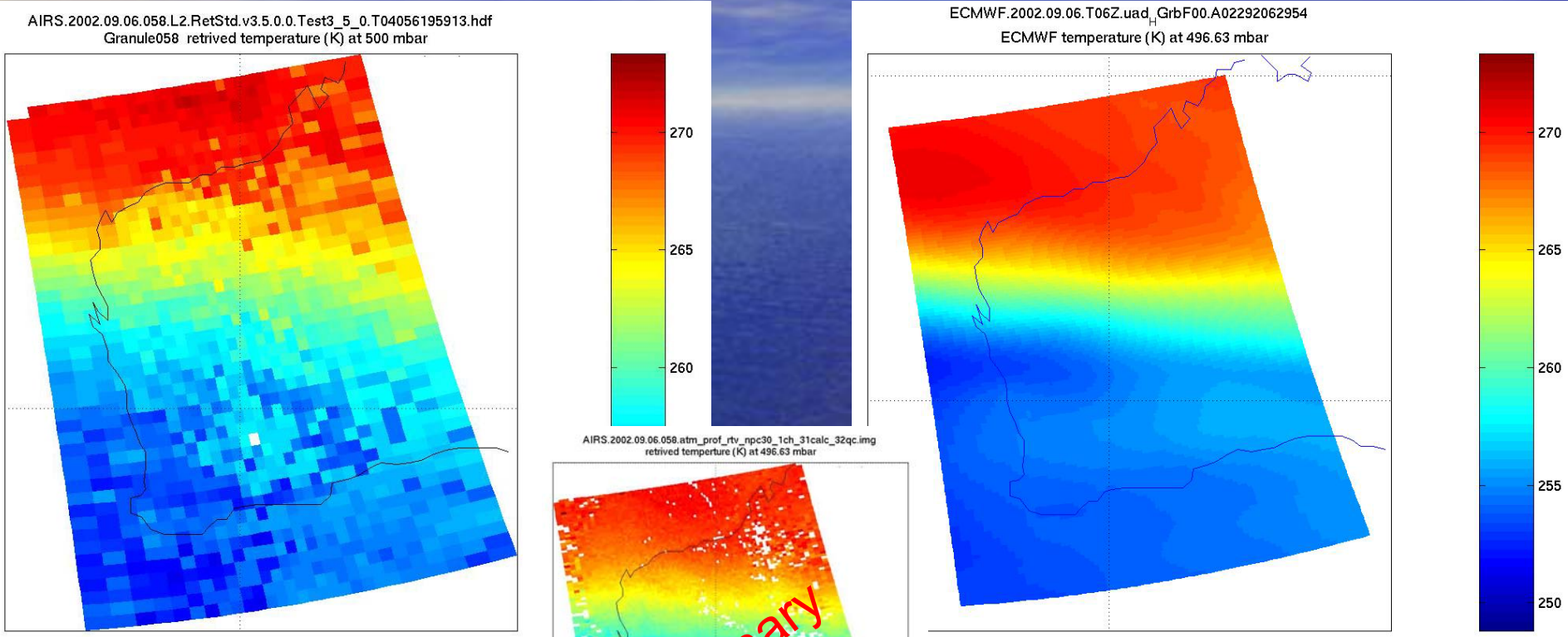
*AIRS cloud clearing Version 3.5.

%With failed quality control data

300 mb Temperature

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)



AIRS Cloud Cleared Rtv

ECMWF Analysis

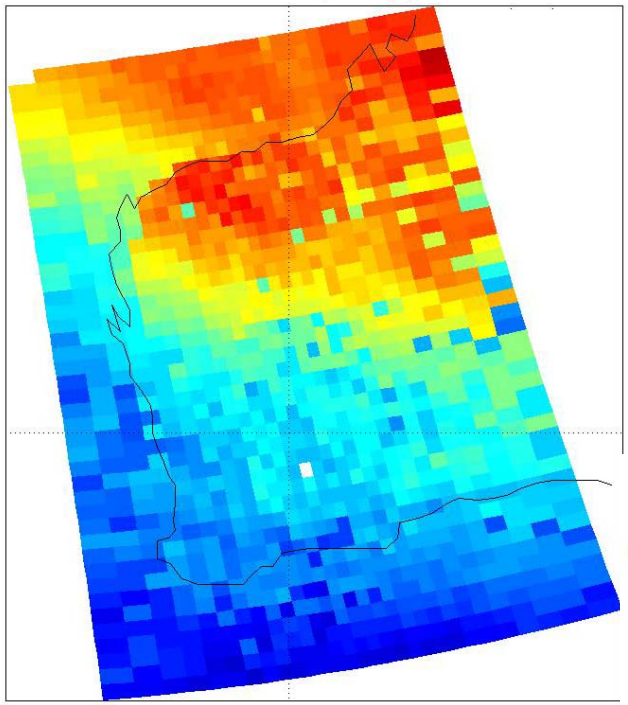
*AIRS cloud clearing Version 3.5

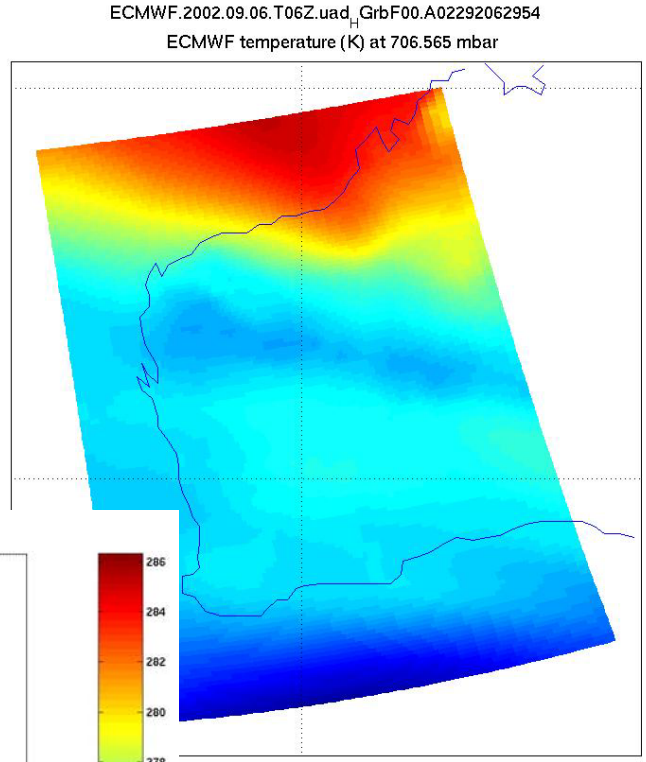
%With failed quality control data

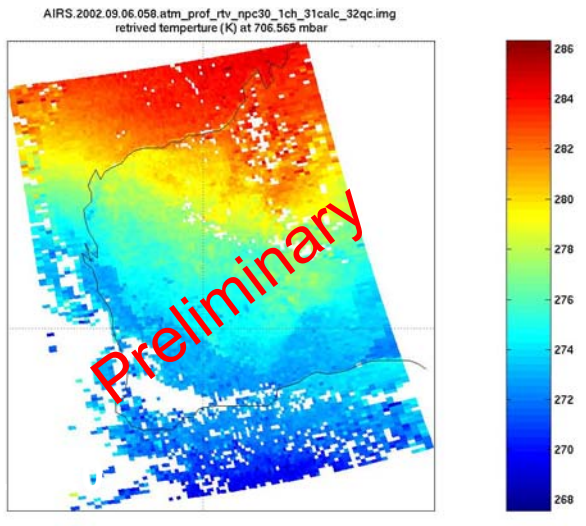
500 mb Temperature

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)







AIRS Cloud Cleared Rtv

ECMWF Analysis

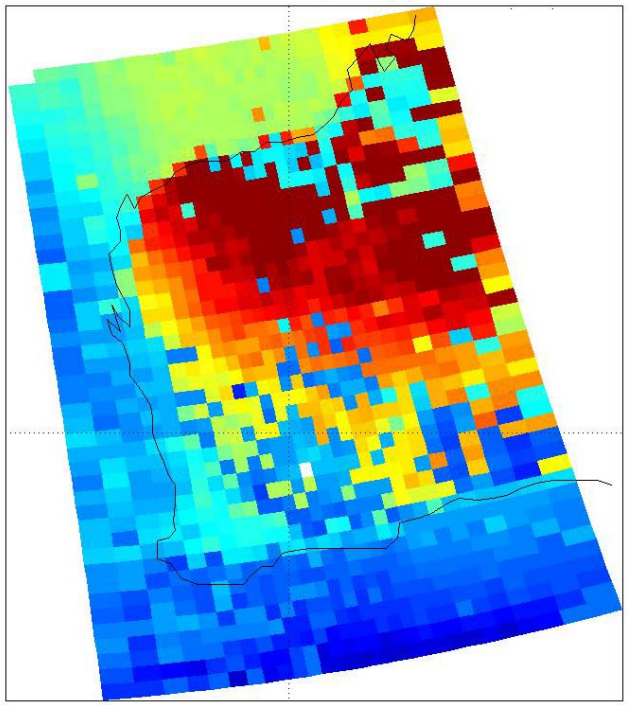
***AIRS cloud clearing Version 3**

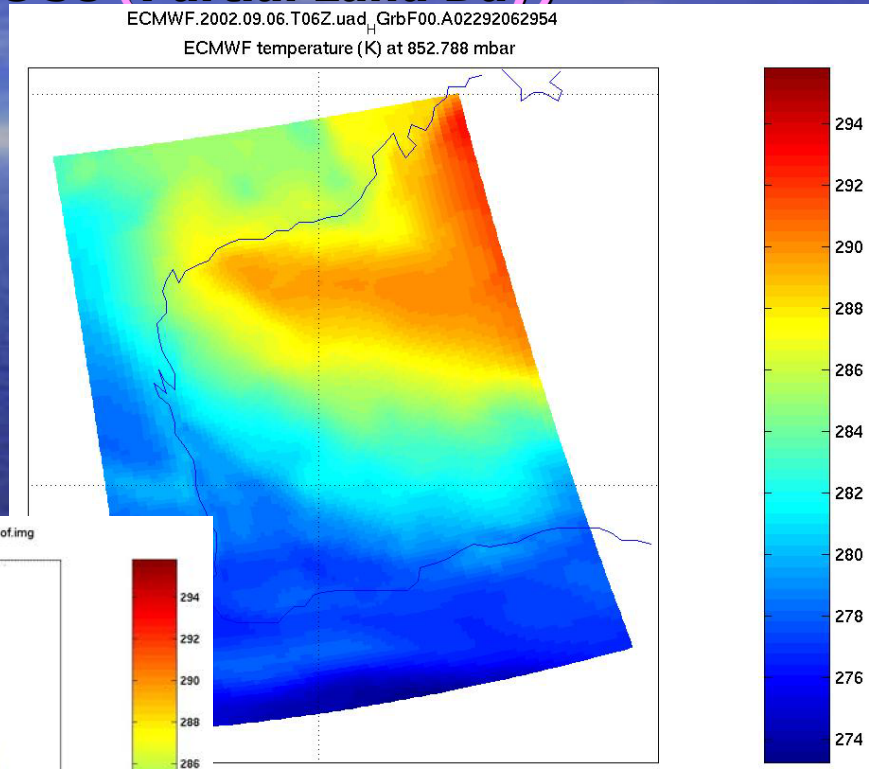
%With failed quality control data

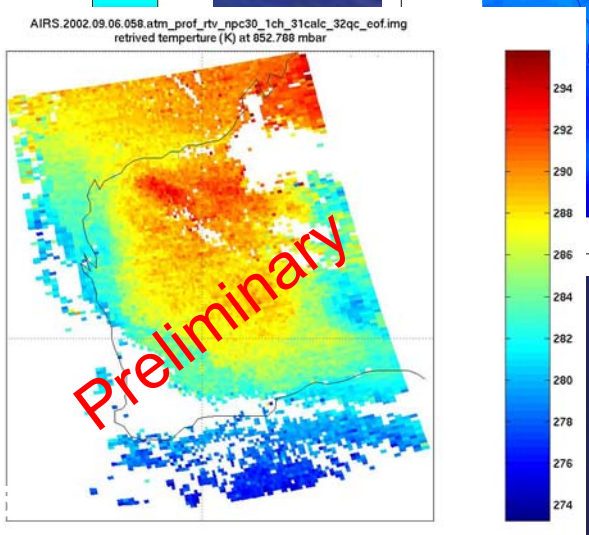
700 mb Temperature

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)







AIRS Cloud Cleared Rtv

ECMWF Analysis

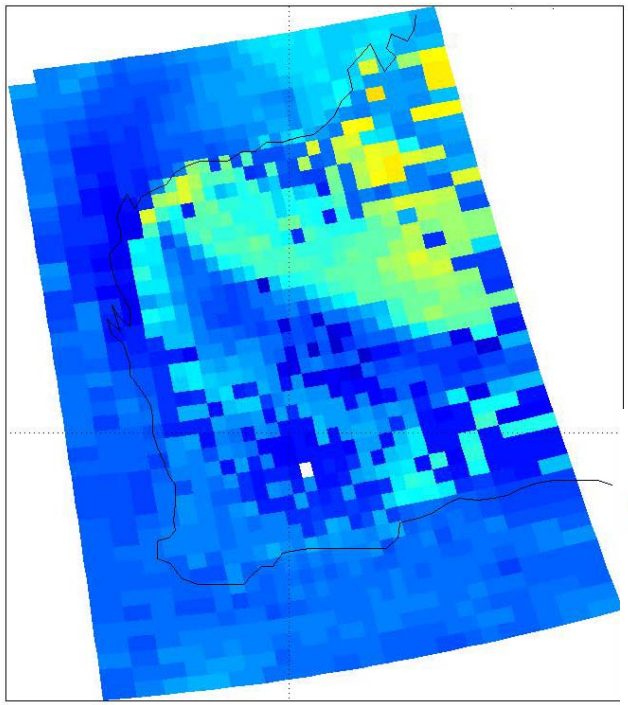
***AIRS cloud clearing Version 3.**

%With failed quality control data

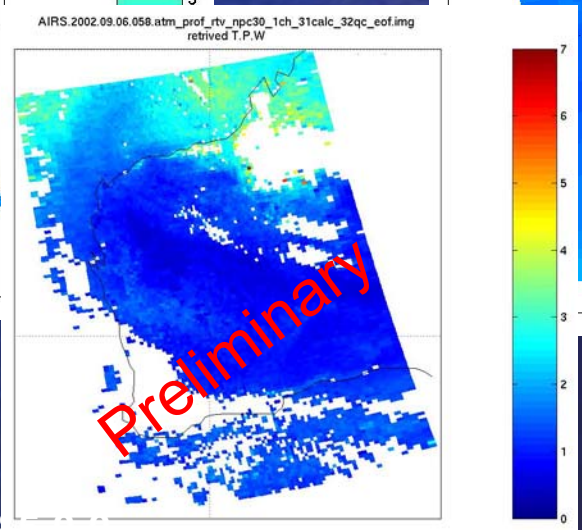
850 mb Temperature

Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

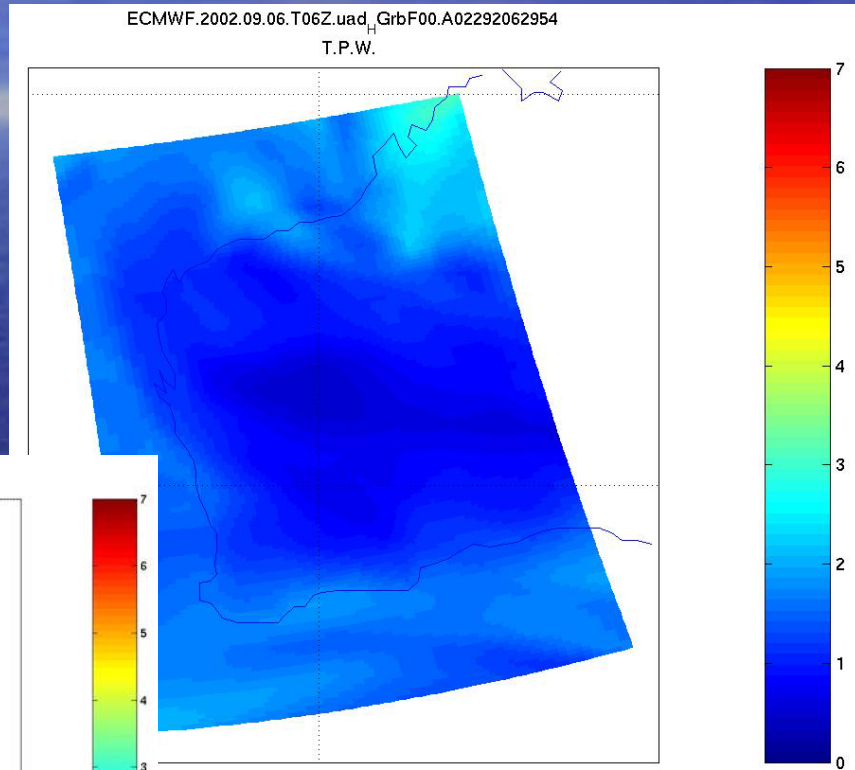
6 Sep 2002 focus day Granule 58 (Partial Land Day)



AIRS Cloud Cleared Rtv



Total Precipitable Water



ECMWF Analysis

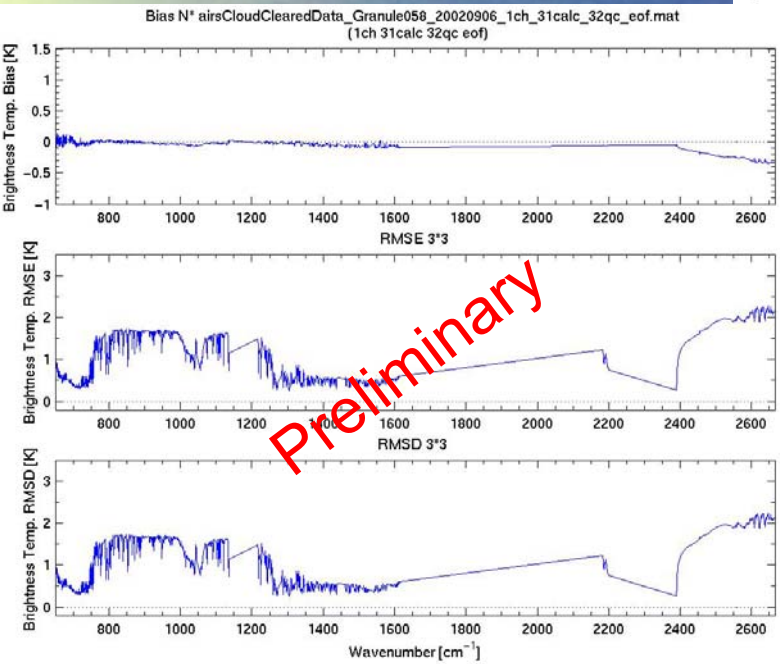
*AIRS cloud clearing Version 3.5.0.0

%With failed quality control data

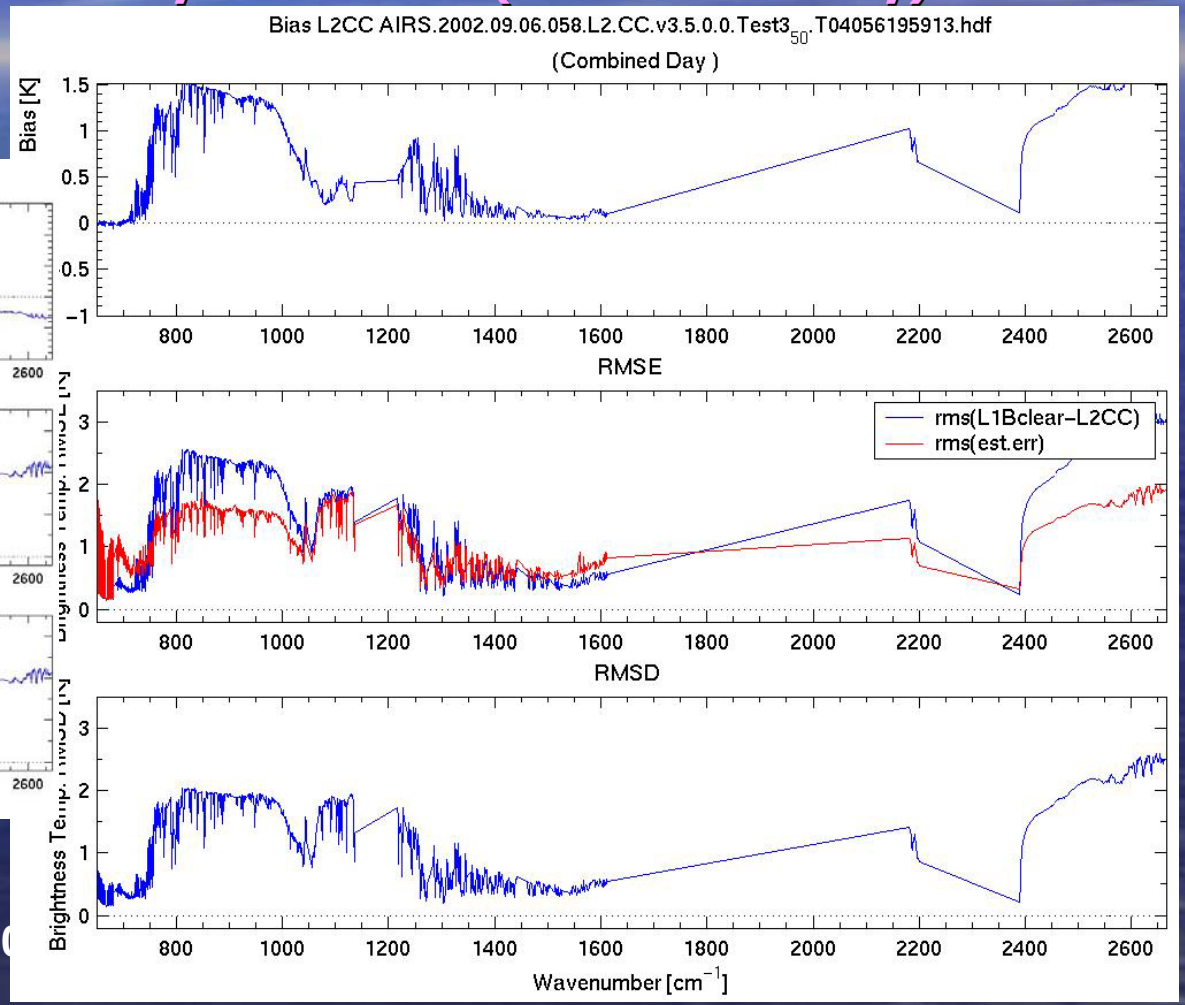
Current* AIRS Cloudy Cloud Clearing Characteristic – Case Study Result (Over Land%)

6 Sep 2002 focus day Granule 58 (Partial Land Day)

AIRS Operational% →



Preliminary



MODIS/AIRS N* Preliminary

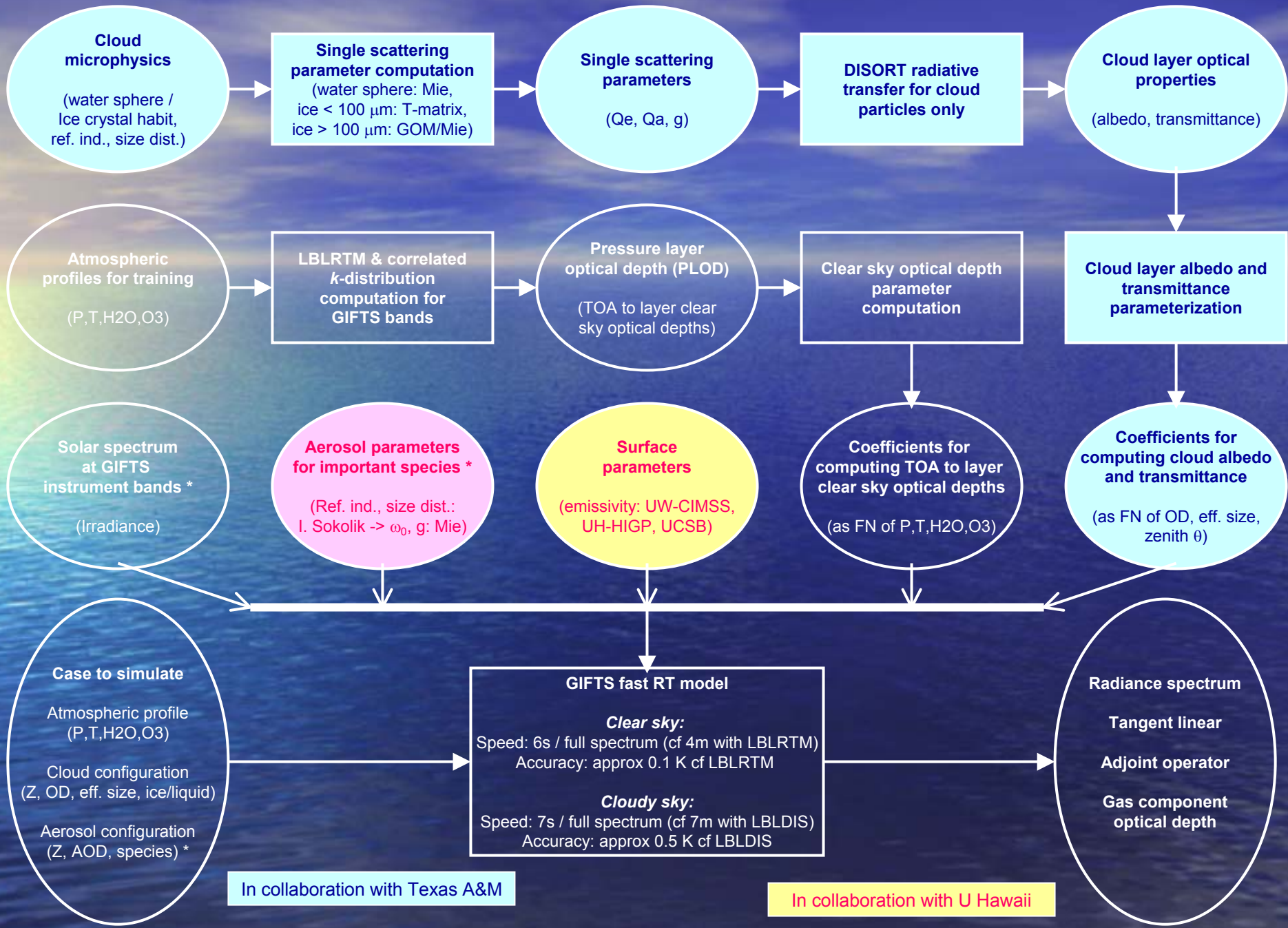
*AIRS cloud clearing Version 3.5.0.(

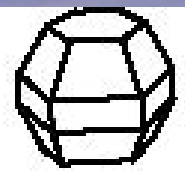
%With failed quality control data

Apperception* of Clouds in AIRS Data

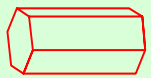
Presentation Outline

- Clouds in AIRS Data – Almost Everywhere in Anytime
- AIRS Spectral Signature
  - Spatial, Noise, Spectral, Optical, and Clouds feature
- Cloud Clearing Issue
  - Current Operational C.C. Characteristic
  - Clear vs. Cloud Cleared vs. Cloudy Sounding
- Hyperspectral IR Cloud Forward Modeling (if time permit)
- Summary

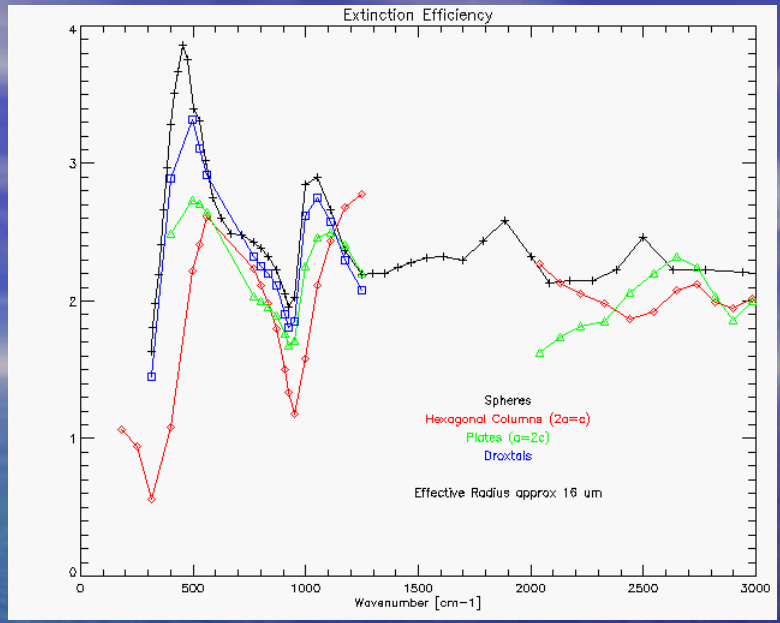

Cloud microphysics
(water sphere / Ice crystal habit, ref. ind., size dist.)
Single scattering parameter computation
(water sphere: Mie, ice < 100 μm: T-matrix, ice > 100 μm: GOM/Mie)
Single scattering parameters
(Qe, Qa, g)
DISORT radiative transfer for cloud particles only
Cloud layer optical properties
(albedo, transmittance)
Atmospheric profiles for training
(P,T,H2O,O3)
LBLRTM & correlated k-distribution computation for GIFTS bands
Pressure layer optical depth (PLOD)
(TOA to layer clear sky optical depths)
Clear sky optical depth parameter computation
Cloud layer albedo and transmittance parameterization
Solar spectrum at GIFTS instrument bands *
(Irradiance)
Aerosol parameters for important species *
(Ref. ind., size dist.: I. Sokolik -> ω0, g: Mie)
Surface parameters
(emissivity: UW-CIMSS, UH-HIGP, UCSB)
Coefficients for computing TOA to layer clear sky optical depths
(as FN of P,T,H2O,O3)
Coefficients for computing cloud albedo and transmittance
(as FN of OD, eff. size, zenith θ)
Case to simulate
Atmospheric profile (P,T,H2O,O3)
Cloud configuration (Z, OD, eff. size, ice/liquid)
Aerosol configuration (Z, AOD, species) *
GIFTS fast RT model
Clear sky:
Speed: 6s / full spectrum (cf 4m with LBLRTM)
Accuracy: approx 0.1 K cf LBLRTM
Cloudy sky:
Speed: 7s / full spectrum (cf 7m with LBLDIS)
Accuracy: approx 0.5 K cf LBLDIS
Radiance spectrum
Tangent linear
Adjoint operator
Gas component optical depth
In collaboration with Texas A&M
In collaboration with I. Sokolik
In collaboration with U Hawaii
* Not implemented
June/2004
CIMSS UW-Madison
60/Allen H



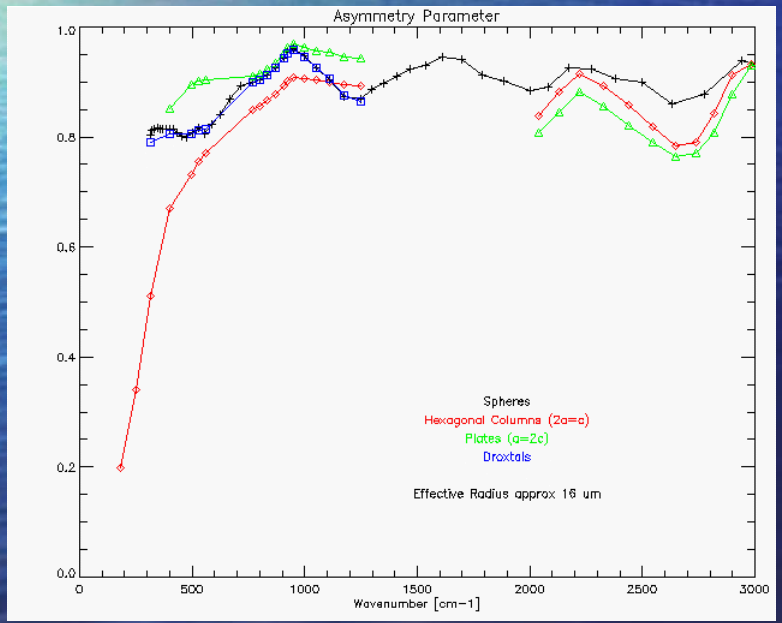
Droxtal

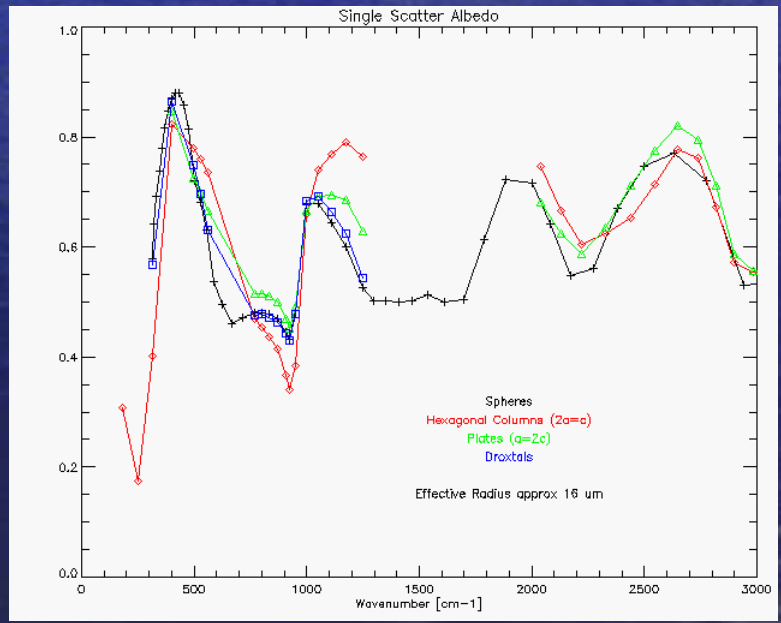


Hexagonal Column



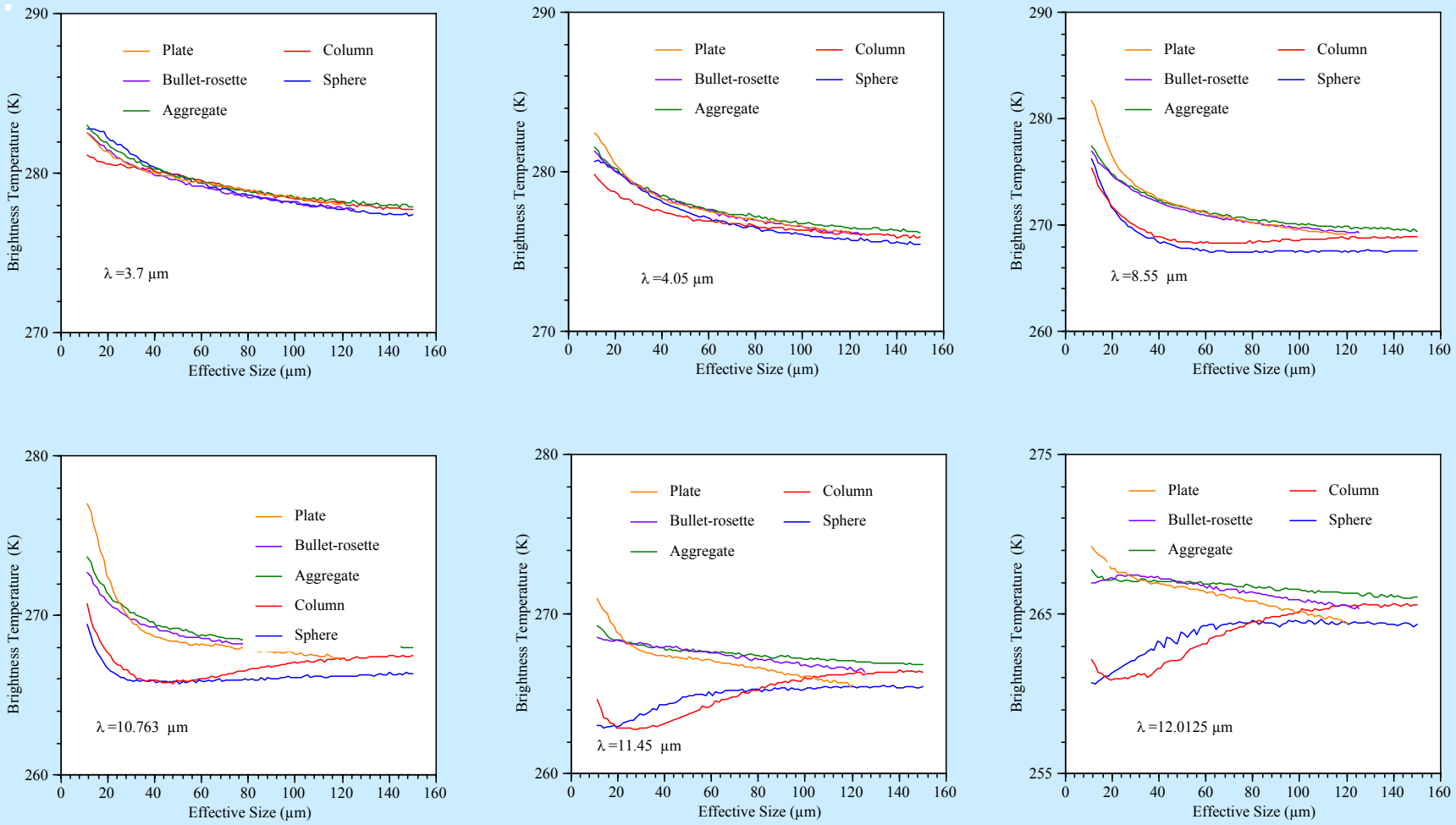
plate





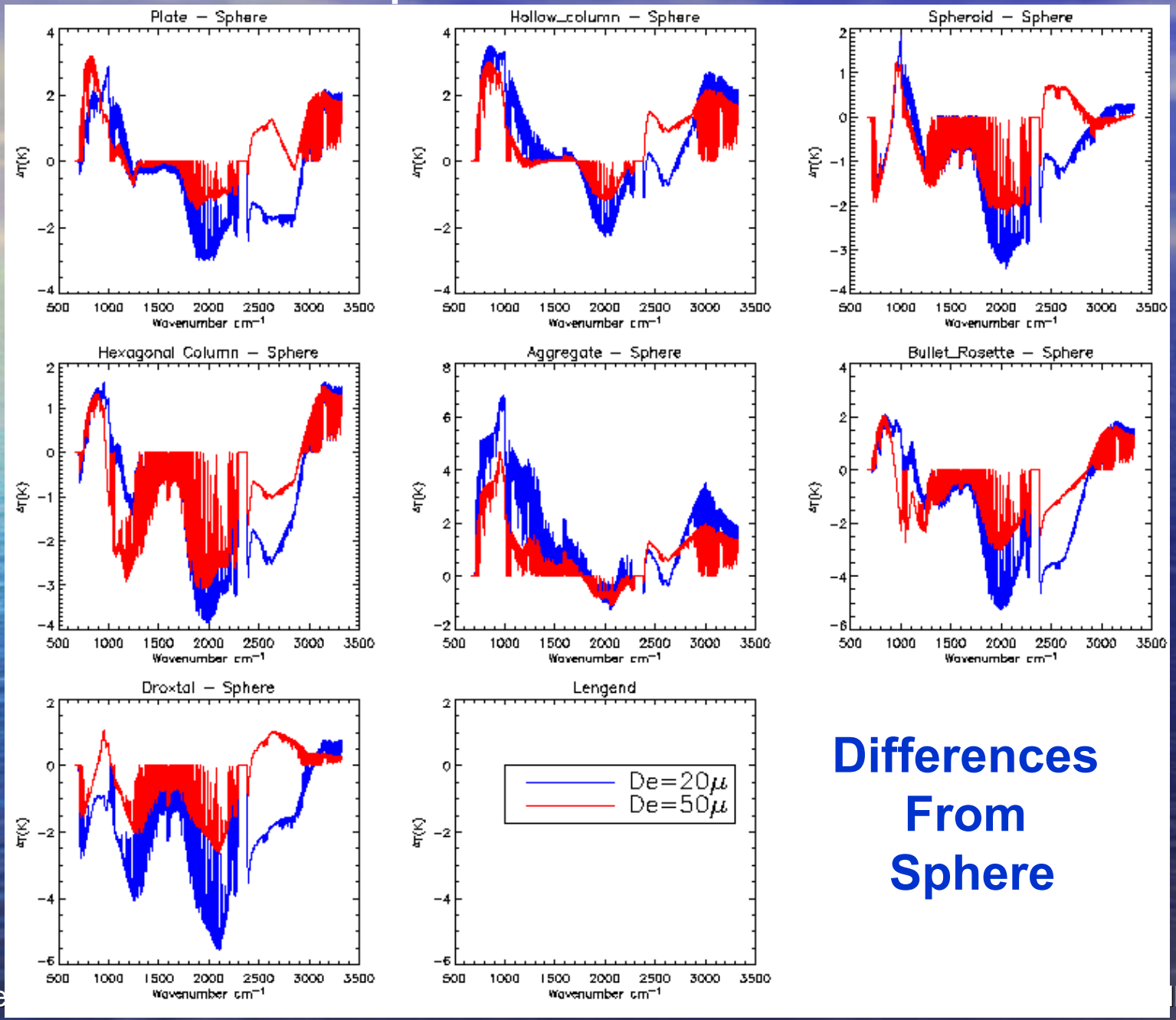
From Turner et, al.

Cloud Shape & Size Effects on IR Measurements



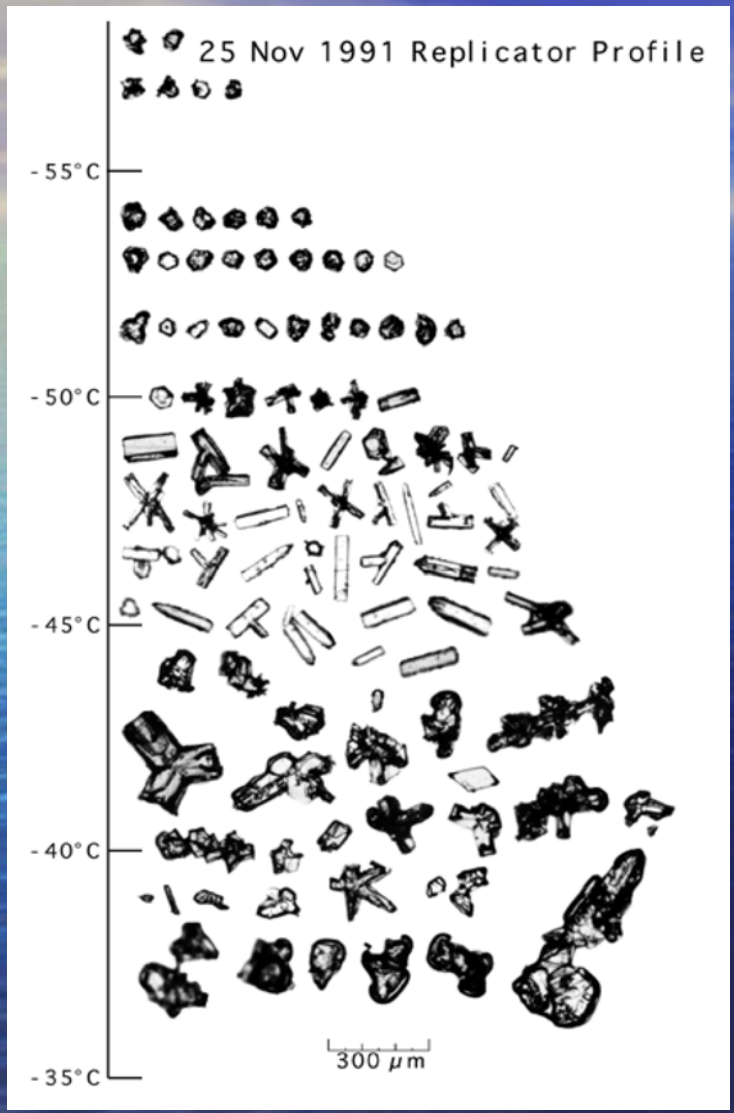
Comparisons of brightness temperatures of ice clouds for aggregate, hexagonal column, hexagonal plate, bullet-rosette,and sphere at 6 wavelengths by assuming the U.S. stand atmosphere. Clouds are located at 10 km altitude, and optical thickness is 1. These results are for a nadir view case.

Cloud Shape Effects on IR Measurements

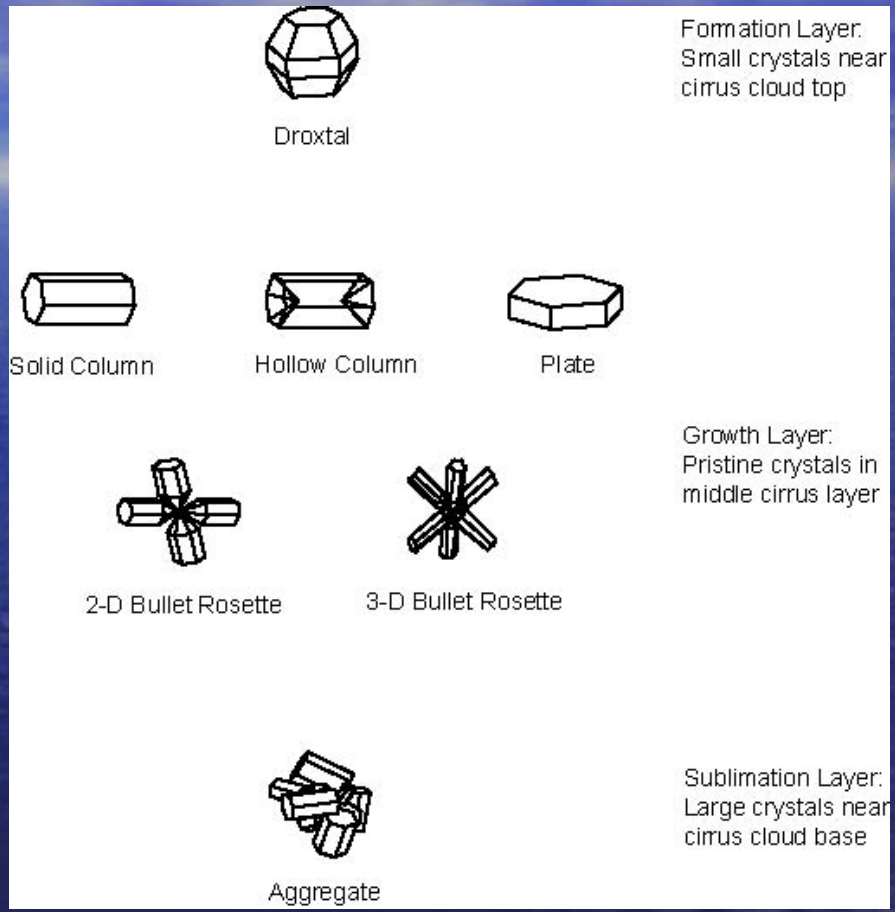


Differences From Sphere

Replicator Particle Habits



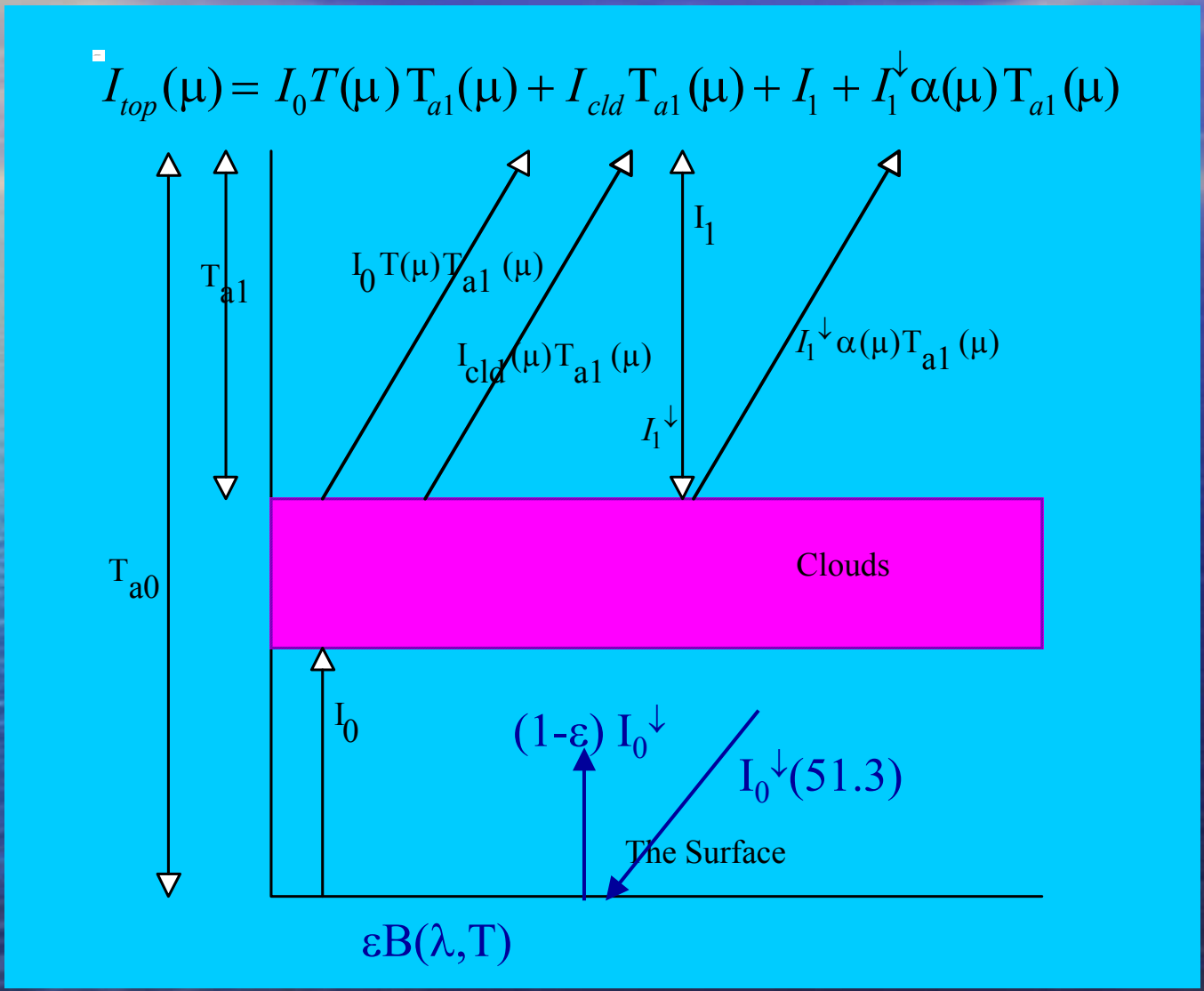
Simulated Particle Habits



From Ping Yang

Radiative Transfer Approx.

$$I_{top}(\mu) = I_0 T(\mu) T_{a1}(\mu) + I_{cld} T_{a1}(\mu) + I_1 + I_1^{\downarrow} \alpha(\mu) T_{a1}(\mu)$$



Radiative Transfer Approx.

$$I_{top}(\mu) = I_0 T(\mu) \mathrm{T}_{a1}(\mu) + I_{cld}\, \mathrm{T}_{a1}(\mu) + I_1 + I_1^{\downarrow} \alpha(\mu) \mathrm{T}_{a1}(\mu)$$

Where:

$$I_0 = B(t_s)\mathrm{T}_{a0} + \int_{\mathrm{T}_{a0}}^{\mathrm{T}_{a1}} B(t)\, d\mathrm{T}_a$$

$$I_1 = \int_{\mathrm{T}_{a1}}^{1} B(t)\, d\mathrm{T}_a$$

$$I_{cld}(\mu) = [1 - R(\mu) - T(\mu)] * B(t_c)$$

$$I_1^{\downarrow} = \int_{\mathrm{T}_{a1}}^{1} B(t) \frac{\mathrm{T}_{a1}}{\mathrm{T}_a^{\,2}}\, d\mathrm{T}_a$$

T_{a0} and T_{a1} are clear sky atmospheric transmission from the space to the surface and to cloud top, respectively.

Cloud Database - albedo & tansmissivity function

For ice clouds:

- ✓ Optical thickness: 0.04-50
- ✓ Effective size: 10-157µm
- ✓ Effective Shape: Aggregates, solid hexagonal columns, Spheres, Bullet-rosettes, Droxtals, Hollow columns, Plates, and Spheroids (8)
- ✓ Zenith angle: (0-80^{o})
- ✓ Wavenumber:(500-2500cm^{-1})

For water clouds:

- ✓ Optical thickness: 0.06-150
- ✓ Effective size: 2-20 µm
- ✓ Zenith angle: (0-80^{o})
- ✓ Wavenumber:(500-2500cm^{-1})

Ice Crystal Single-Scattering Property Database

- Shapes of ice crystals

  Aggregates, solid hexagonal columns, Spheres, Bullet-rosettes, Droxtals, Hollow columns, Plates, and Spheroids

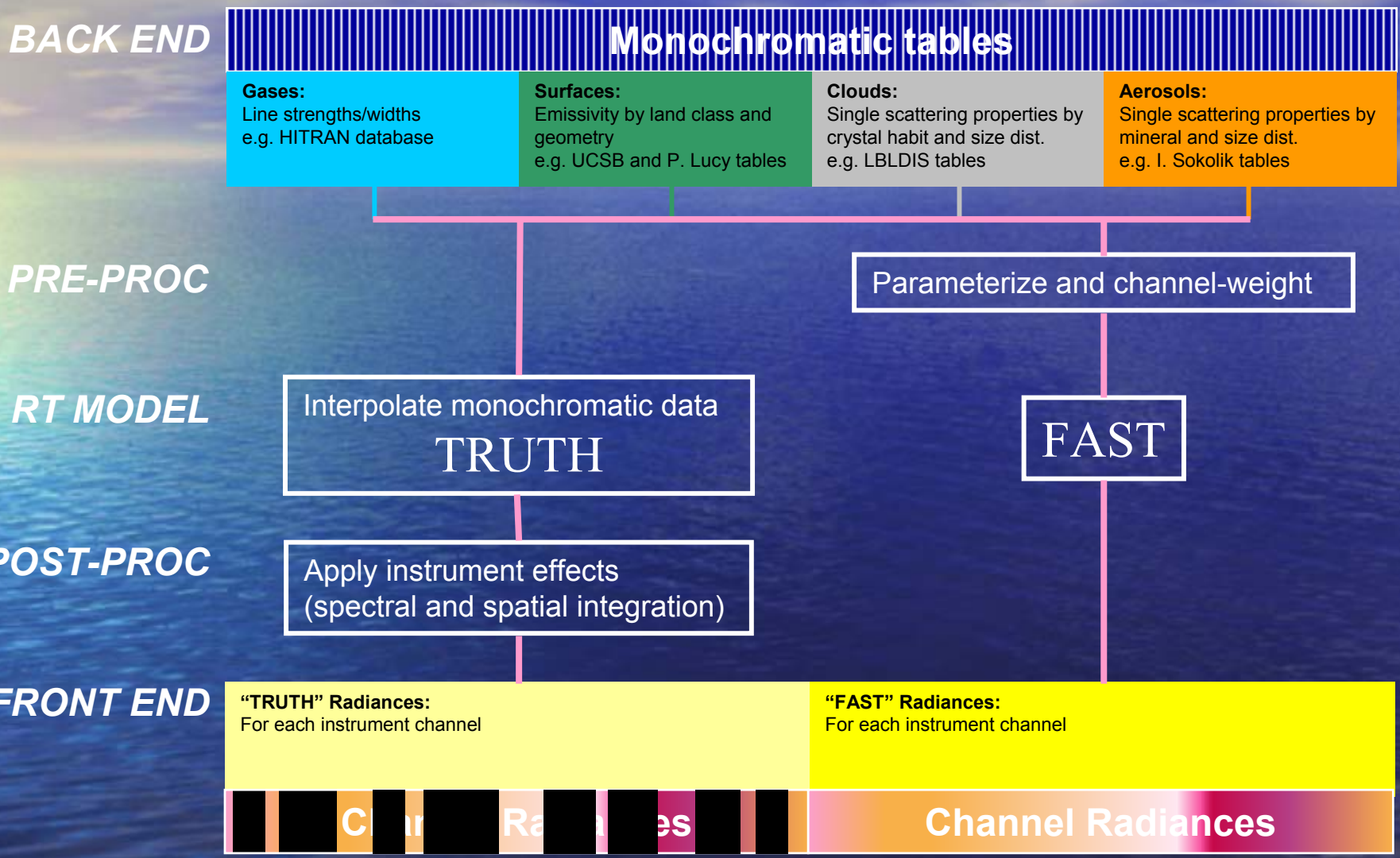
- Wavelengths:

  49 Wavelengths from 3.08 μm to 100 μm

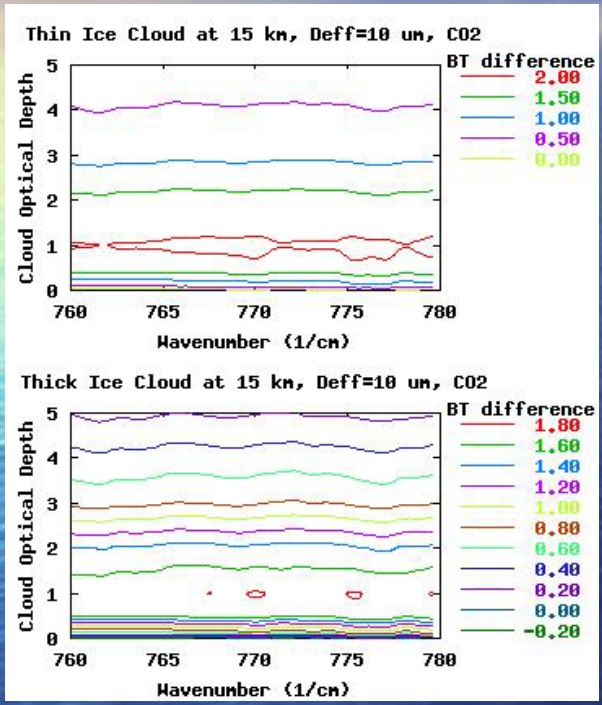
- Size bins:

  38 Size bins from 2 μm to 3100 μm in terms of particle maximum dimension

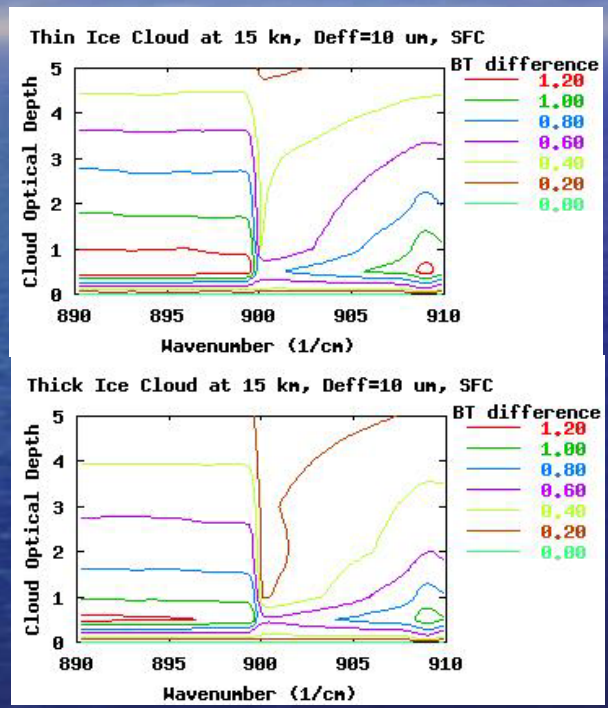
TRUTH (LBLRTM/DISORT) and FAST models



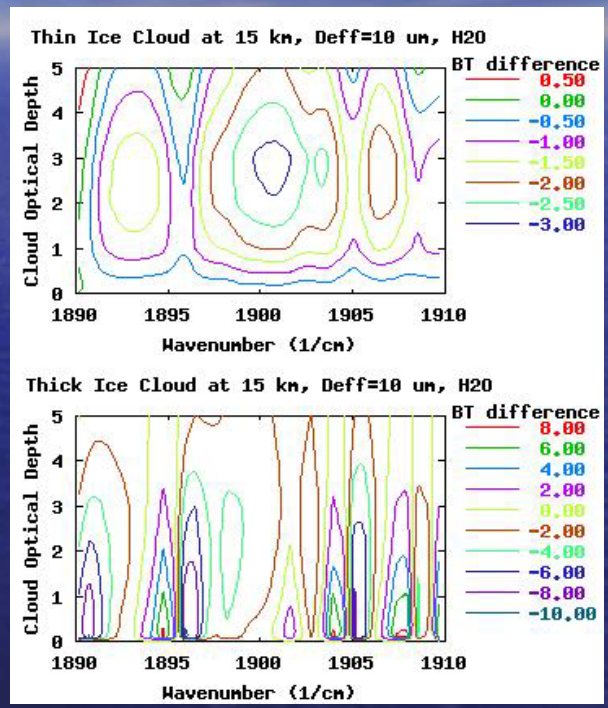
Fast IR Forward Model Error Estimate



CO_2 Channels



Surface Channels



H_2O Channels

Apperception* of Clouds in AIRS Data

Presentation Outline

- Clouds in AIRS Data – Almost Everywhere in Anytime
- AIRS Cloud Signature
  - Spatial, Noise, Spectral and Optical feature
- Cloud Clearing Issue
  - Current Operational C.C. Characteristic
  - Clear Vs. Cloudy Sounding
- Hyperspectral IR Cloud Forward Modeling
- **Summary**

Apperception* of Clouds in AIRS Data

Summary

- **Knowing that clouds are dominating the IR measurements, can spectral dependent clear/cloudy index (0 or 1, or 0 to 1) can be useful and reliable enough for NWP, cloud clearing, sounding retrieval and cloud property applications?**

Apperception* of Clouds in AIRS Data

Summary - continue

- Cloud cleared radiances/soundings represent clouds nearby clear sky condition only and should be assimilated with caution:
  - Could introducing potential clear sky bias, however,
  - Cloud cleared radiances could be a useful intermediate product for cloud study

Apperception* of Clouds in AIRS Data

Summary - continue

- Microphysical property of clouds should be characterized to allow any future accurate modeling and assimilation of cloudy radiances

Apperception* of Clouds in AIRS Data

Summary - Continue

- Fast cloudy forward modeling development (limited effort so far) is underway, however, many challenges remain, and much more efforts are required

Apperception* of Clouds in AIRS Data

Summary - Continue

- Preliminary synergistic imager/sounder (MODIS/AIRS) cloud clearing analysis showing it can provide
  - Consistent quality control, and
  - Stable cloud cleared radiances for both over ocean and land% (need further verification)

%So far AIRS has not demonstrated successful cloud clearing over land

Apperception* of Clouds in AIRS Data

Summary - Continue

- ***Apperception of clouds in AIRS data could provide useful information for the optimization of planned MTG and GOES-R Imaging and Sounding instruments***