

# Synergistic Cloud Clearing Using Aqua Sounding and Imaging Infrared Measurements

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- Cloud Clearing/Cloud Detection
- MODIS/AIRS Variable FOV Rtv.
- AIRS Cloud Clearing Assessment
- IMAPP (see Presentation/Poster for details)
- Co-location/Comparison
- Synergistic C.C. Approach
- Summary, Future Work & Goal

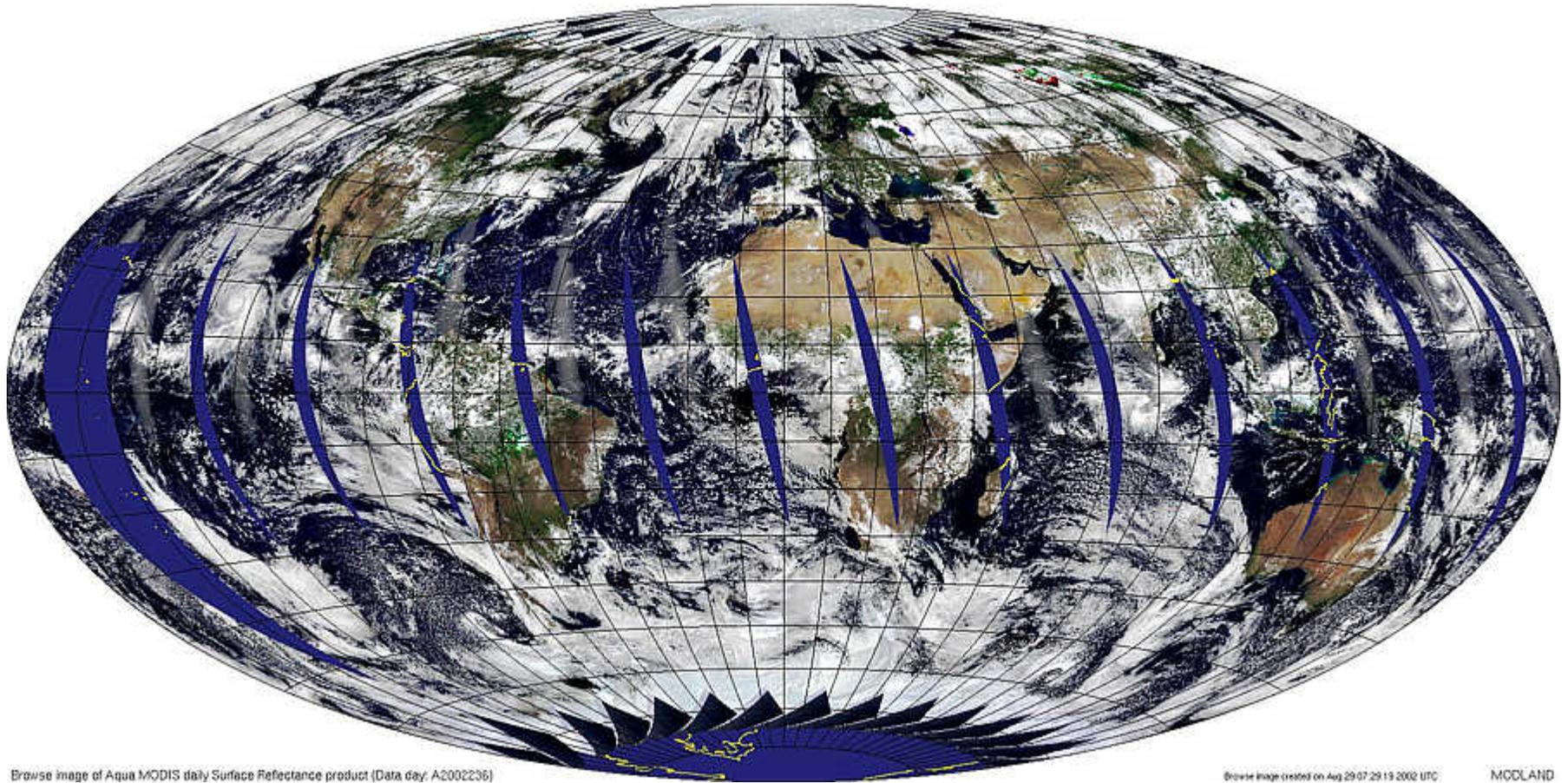


Sainte Adele, Canada

29 October 2003 - 4 November 2003



# MODIS True Color Image – 24 August, 2002



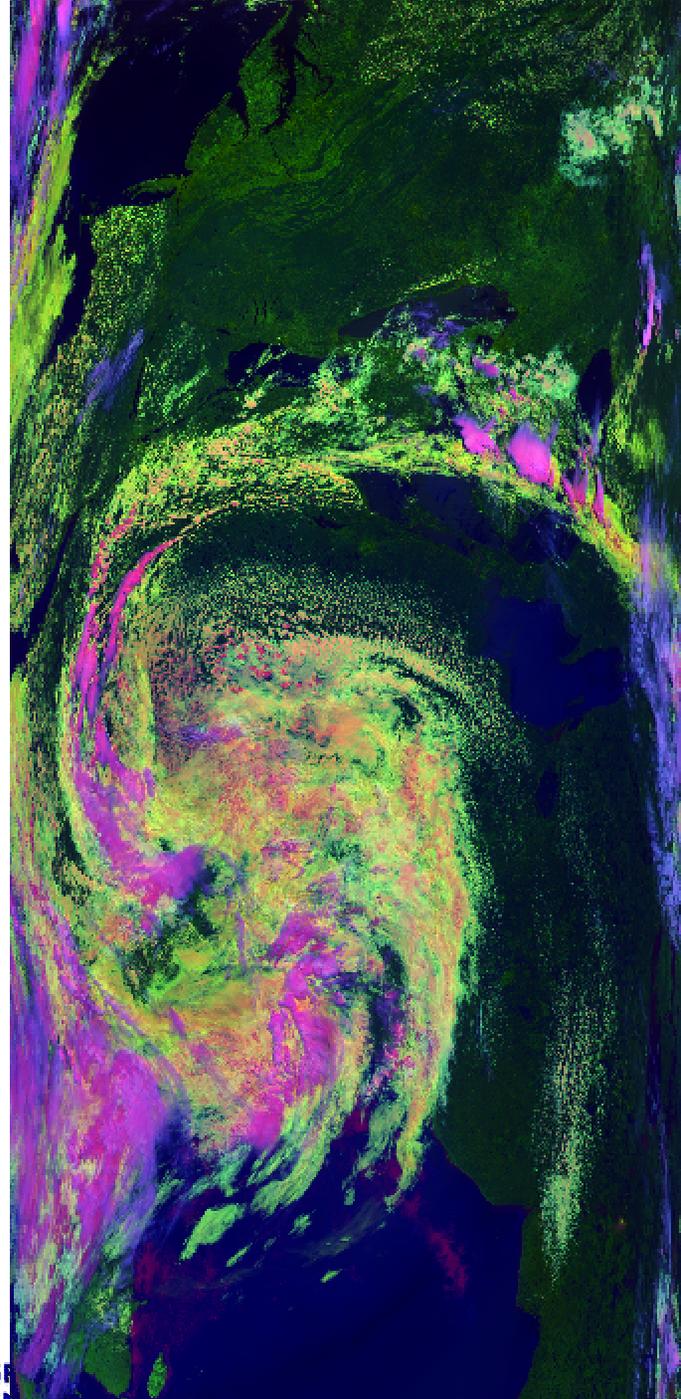
Browse image of Aqua MODIS daily Surface Reflectance product (Data day: A2002236)

Browse image (retrieved on Aug 29 07:29:19 2002 UTC)

MCDLAND

**Clouds are almost everywhere**

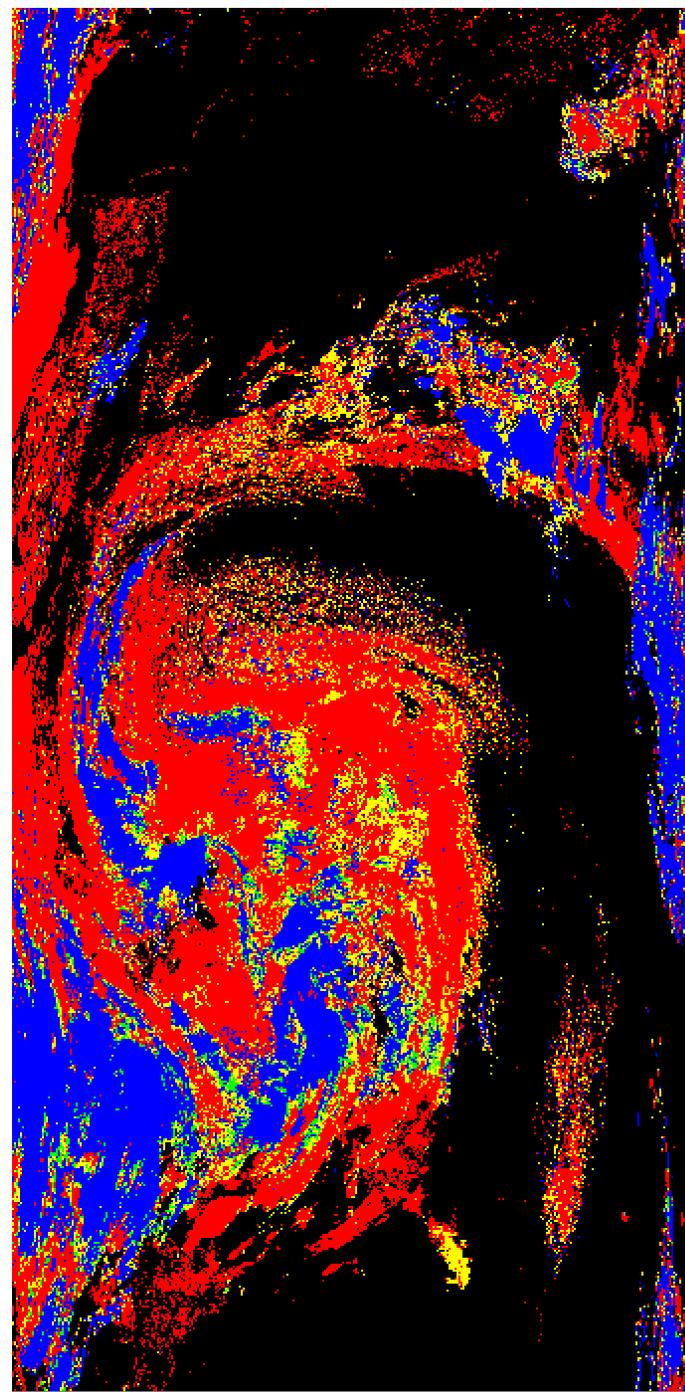




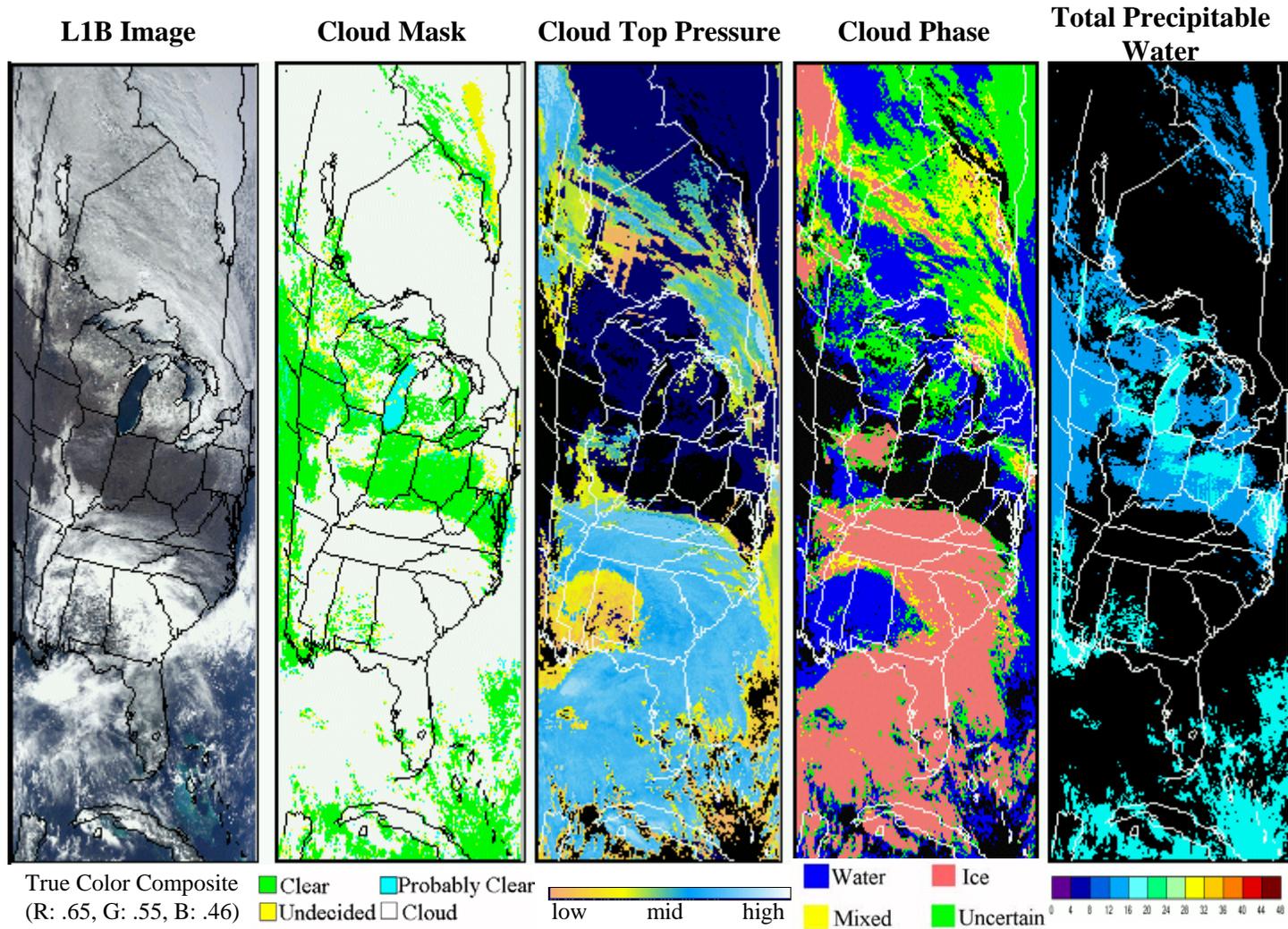
Aqua  
← Color  
Composite  
Red: B1 (.645)  
Green: B6 (1.64)  
Blue: B31 (11.)

Cloud Phase →  
(Day time Alog.)

-  *Ice*
-  *Water*
-  *Mixed*
-  *Uncertain*
-  *Clear*
-  *No Retrieval*



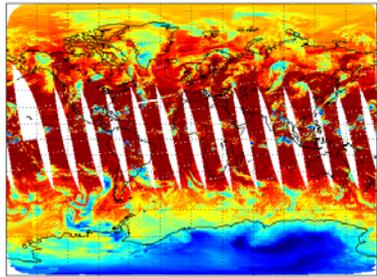
# MODIS IMAPP Direct Broadcast Suite of Products - 14 March 2003 18:41 UTC



**See IMAPP Poster for Details**



6-Sept-2002, Brightness Temperature [K] at 1000 cm<sup>-1</sup>  
Ascending Granules

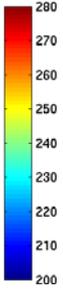
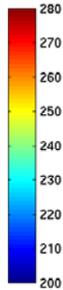
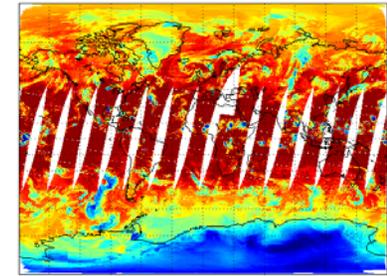


# Global Aqua AIRS

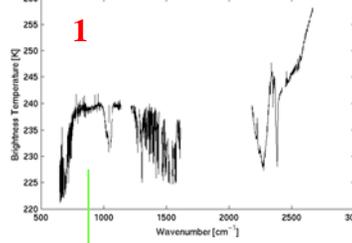
6 September, 2002

## High-spectral Resolution Brightness temperature Images and Spectra

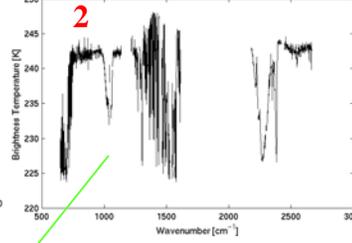
6-Sept-2002, Brightness Temperature [K] at 1000 cm<sup>-1</sup>  
Descending Granules



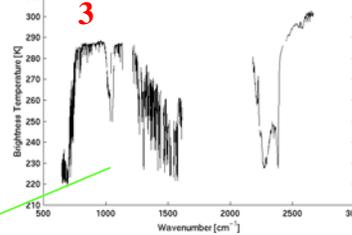
Granule 227 (Lat/Lon: 66.83/-148.12)



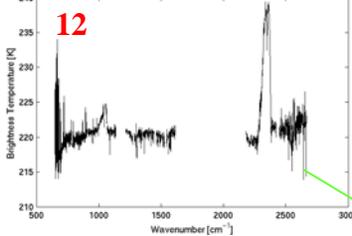
Granule 064 (Lat/Lon: 74.99/-28.94)



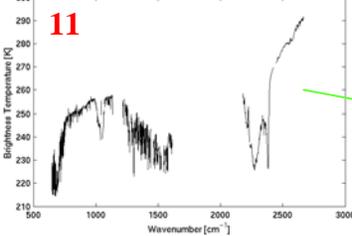
Granule 127 (Lat/Lon: 48.63/1.69)



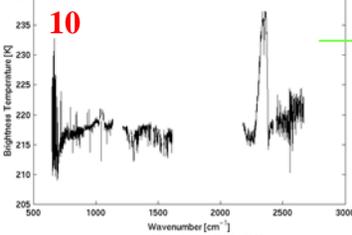
Granule 082 (Lat/Lon: 45.81/-92.52)



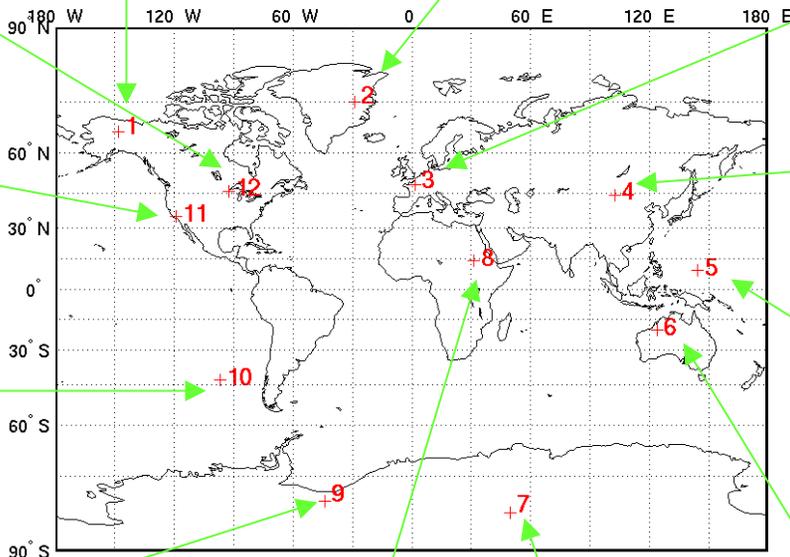
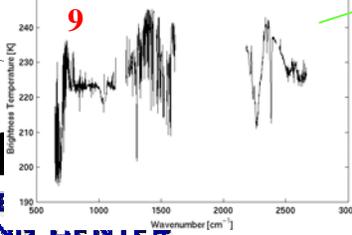
Granule 209 (Lat/Lon: 34.94/-119.14)



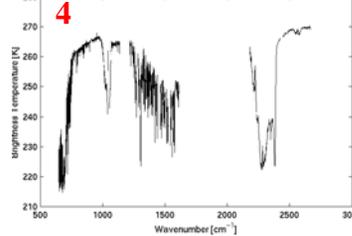
Granule 070 (Lat/Lon: -43.20/-96.92)



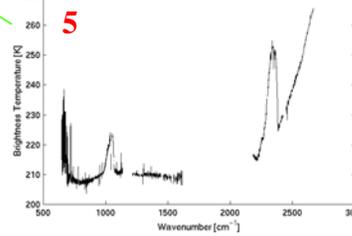
Granule 038 (Lat/Lon: -80.95/-44.03)



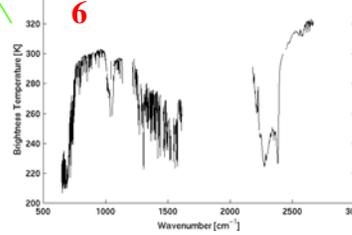
Granule 197 (Lat/Lon: 44.09/102.60)



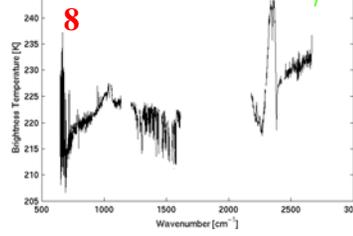
Granule 043 (Lat/Lon: 9.36/144.51)



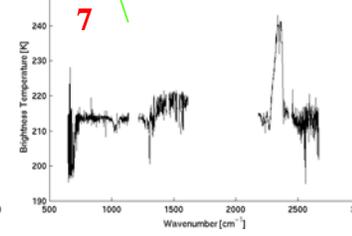
Granule 058 (Lat/Lon: -20.41/124.06)



Granule 001 (Lat/Lon: 14.00/31.44)

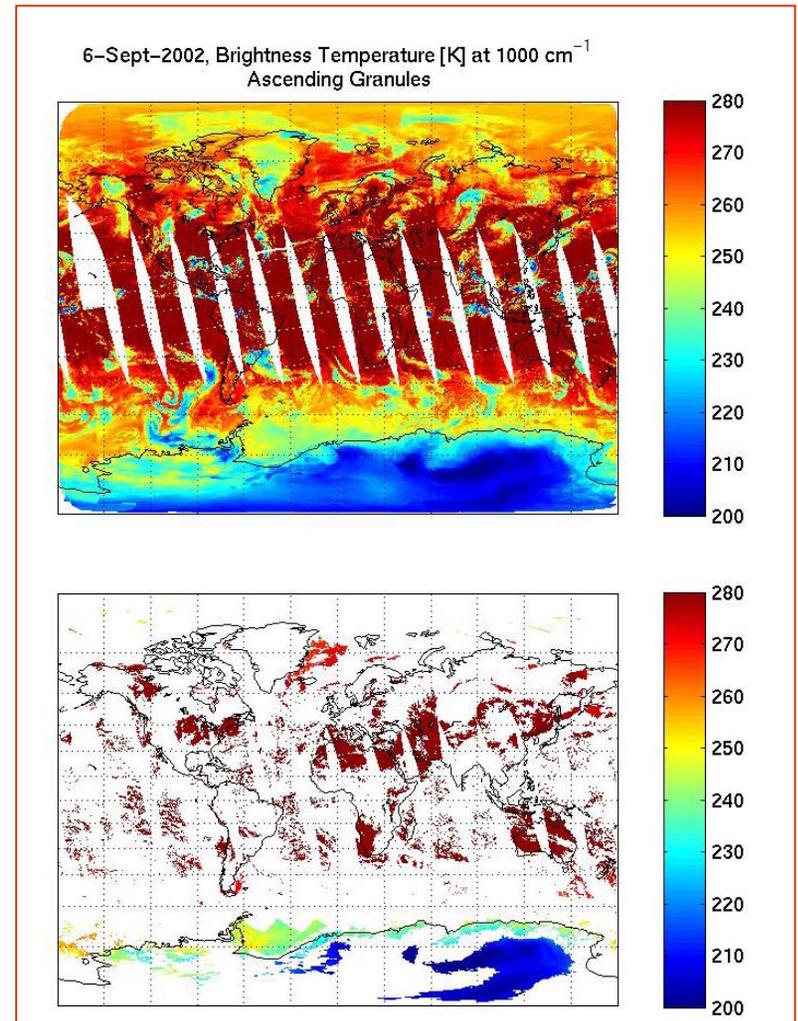
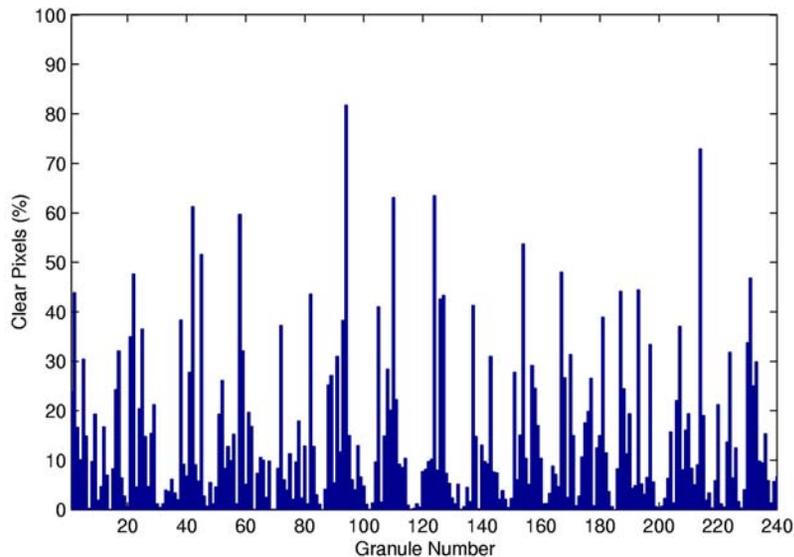


Granule 138 (Lat/Lon: -83.30/49.64)



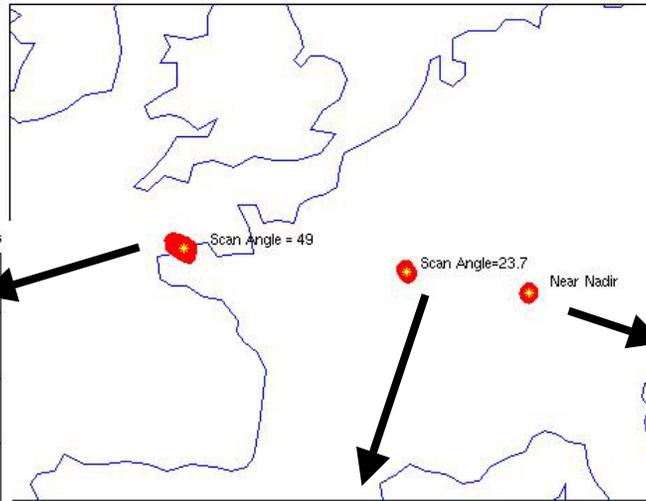
# AIRS Clear FOV Determination Using MODIS 1 km Cloud Mask

- Cloudy Scenes identified by MODIS cloudmask (adapted for AIRS FOVs)
- Clear if  $[n99\%+n95\%/nTot > 0.95]$
- **Clear Percentage: 13.5%**  
Clear&Land: 6.1 %, Clear&Ocean:7.4%

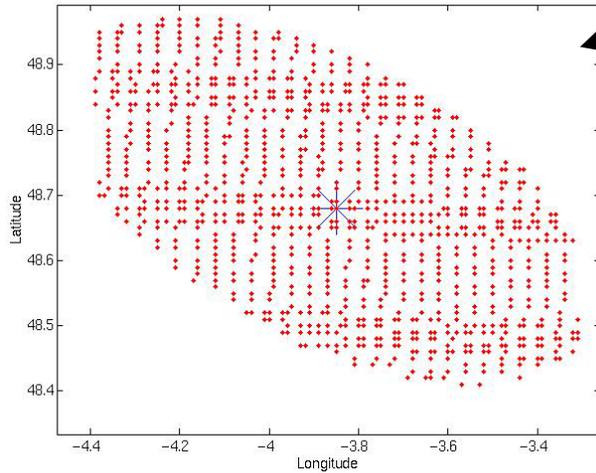


# AIRS/MODIS Co-location Example

3 Pixels from AIRS Granule 16, Sep 6, 2002, 0135 UTC, With Collocated MODIS

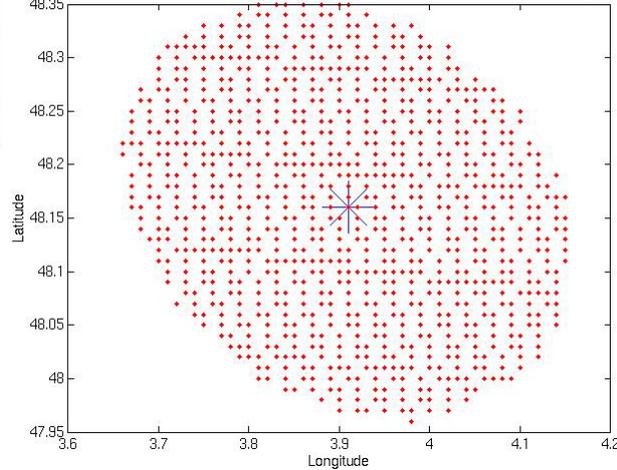


Center of Off-Nadir (Scan Angle=49) AIRS Pixel (46,90), with Collocated MODIS Pixels



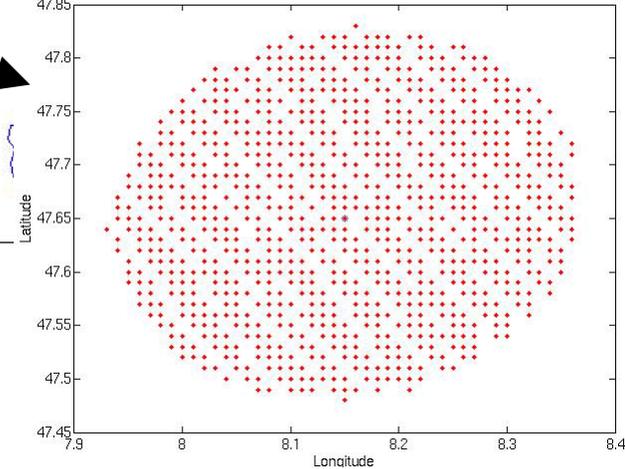
Scan Angle = 49

Center of Off-Nadir (Scan Angle=23.7) AIRS Pixel (46,67), with Collocated MODIS Pixels



Scan Angle = 23.7

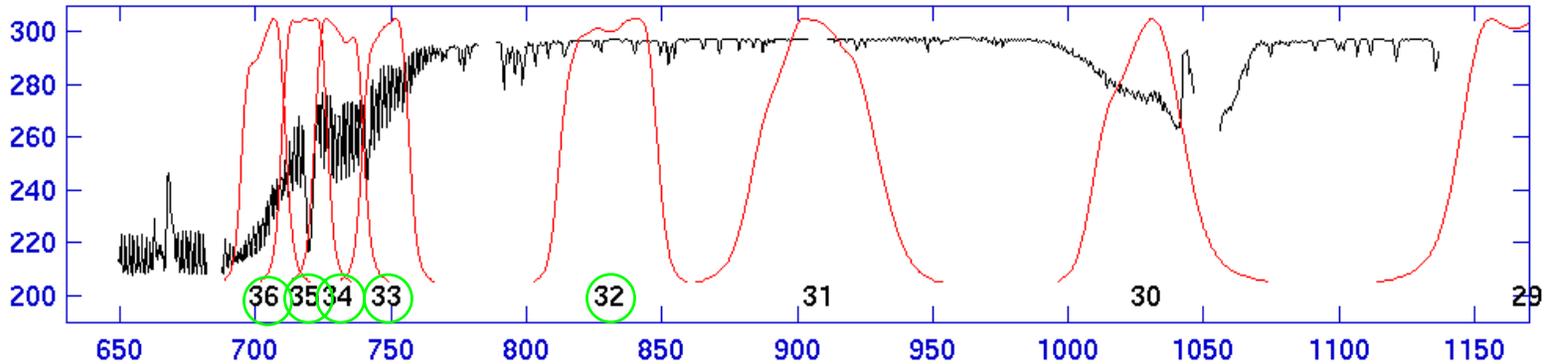
Center of Near-Nadir AIRS Pixel (46,45), with Collocated MODIS Pixels



Nadir



# Convoluting AIRS with MODIS SRFs



conv1 = *continuous* kcarta monochromatic calculation based on ECMWF profile coincident w/ 20 July granule 224 convolved w/ GOES10 SRFs

conv2 = *continuous* kcarta monochromatic calculation based on ECMWF profile coincident w/ 20 July granule 224 convolved w/ AIRS SRFs and then with GOES10 SRFs

\* using channels w/ Bad\_Flag == 0

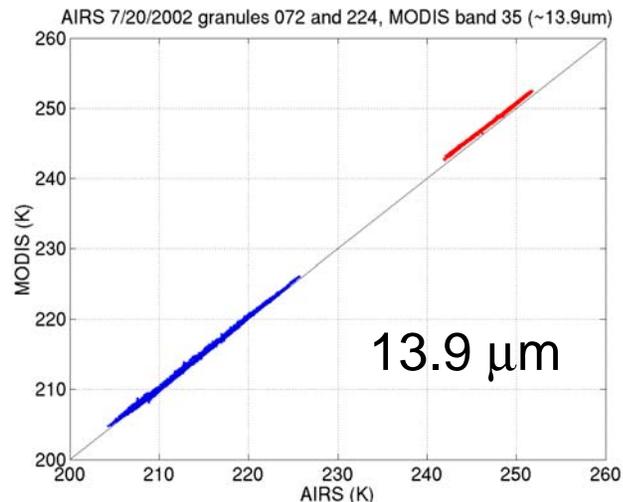
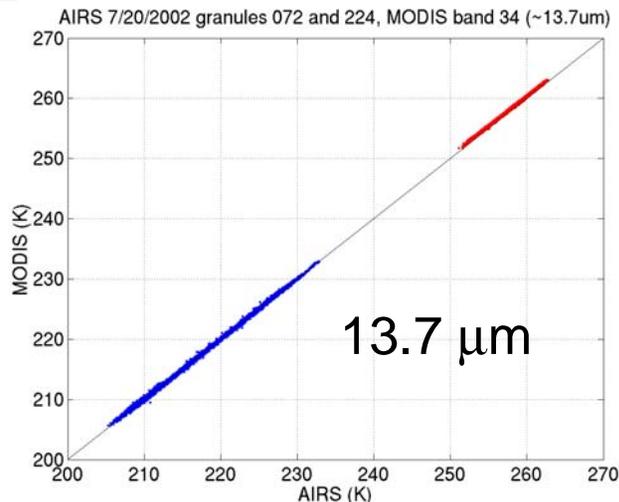
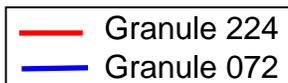
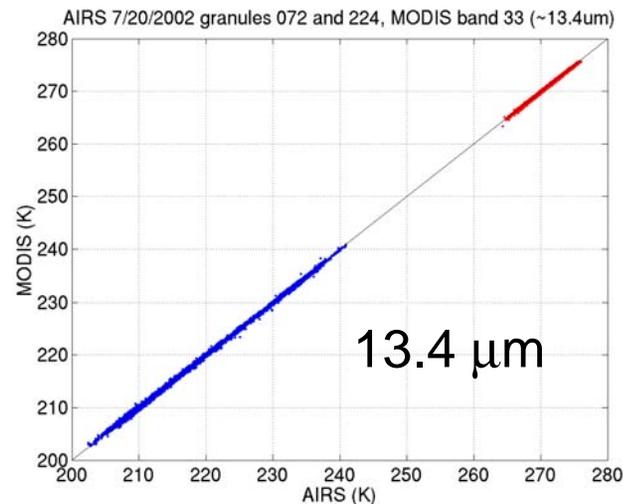
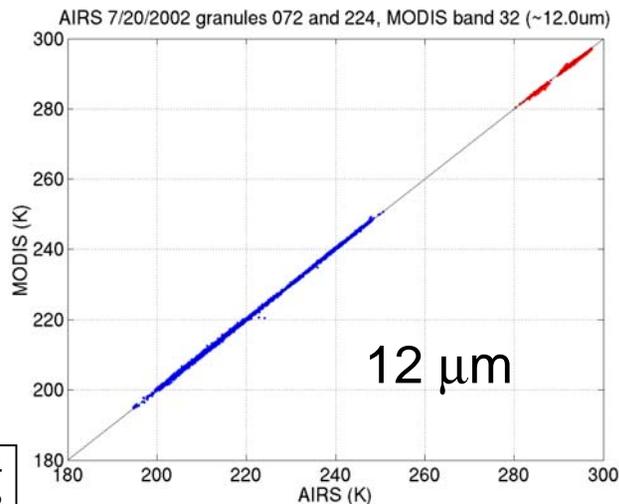
<u>Band</u>	<u>1/cm</u>	<u>microns</u>	<u>"convError" = conv1-conv2 (K)</u>
32	830.8	12.03	-0.00
33	748.3	13.36	0.20
34	730.8	13.68	0.05
35	718.2	13.92	0.21
36	703.5	14.21	0.16

After  
Dave Tobin  
CIMSS  
UW-Madison



# MODIS Vs. AIRS

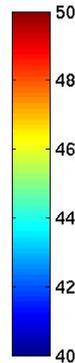
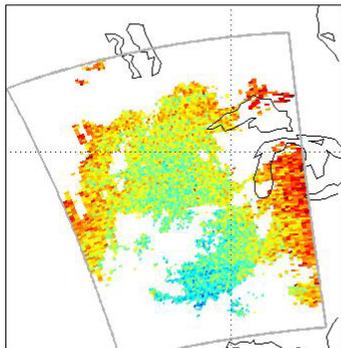
## Good Co-located/Spectral agreement – can be used Synergistically



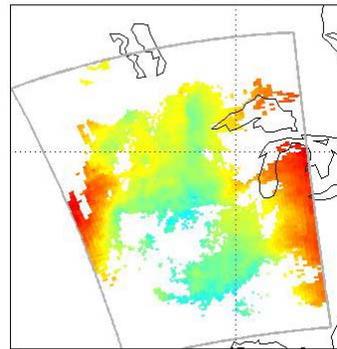
# AIRS Measurement Noise Filtering

- Calculate eigenvectors of observation covariance matrix
- Reconstruct observations using first eigenvectors
- Filter out random component of noise

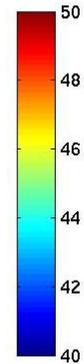
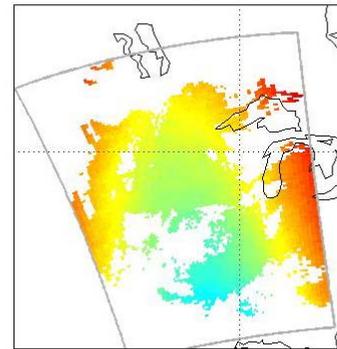
Radiance [ $\text{mW/m}^2/\text{cm}^{-1}/\text{str}$ ] at  $654.7 \text{ cm}^{-1}$   
Raw data



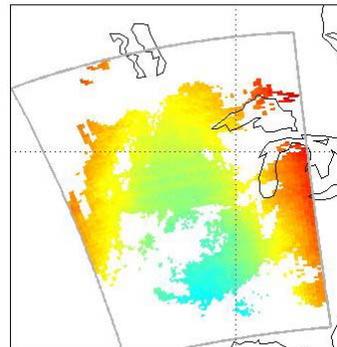
Filtered data (npc=10)



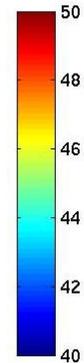
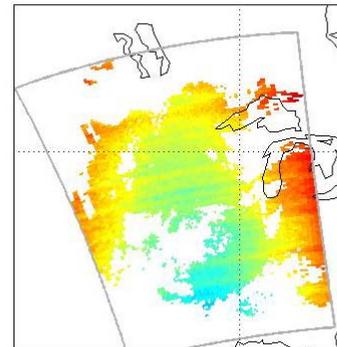
Filtered data (npc=30)



Filtered data (npc=50)



Filtered data (npc=100)



# Cloud Clearing Noise Amplification Factor

$$\mathbf{R}_{\text{clear}} = \mathbf{R}' + \eta_1 (\mathbf{R}' - \mathbf{R}_1) + \eta_2 (\mathbf{R}' - \mathbf{R}_2) + \dots + \eta_K (\mathbf{R}' - \mathbf{R}_K)$$

Need guess of clear radiances to solve the  $\eta$ s iteratively

(K+1) FOVs are required to solve for  $\mathbf{R}_{\text{clear}}$  with K cloud formations.

Reconstructed radiance  $\mathbf{R}_{\text{clear}}$  **contains an amplified random (measurement) noise  $\sigma'$ :**

$$\sigma'^2 = [ (1 + \eta_1 + \eta_2 + \dots + \eta_K)^2 + \eta_1^2 + \eta_2^2 + \dots + \eta_K^2 ] \sigma^2$$

$\sigma$ : random (measurement) noise of radiances  $\mathbf{R}_1, \mathbf{R}_2, \dots, \mathbf{R}_{K+1}$



# Operational AIRS/AMSU Cloud Clearing Error Estimates

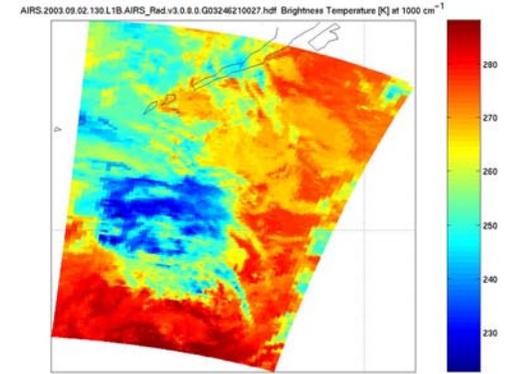
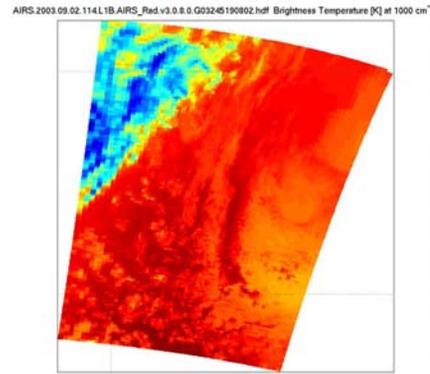
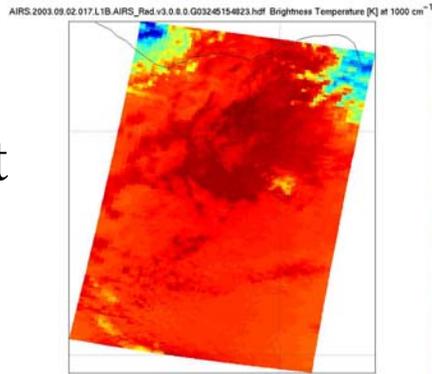
## Good Performance Over Ocean Most of Time

Tropic

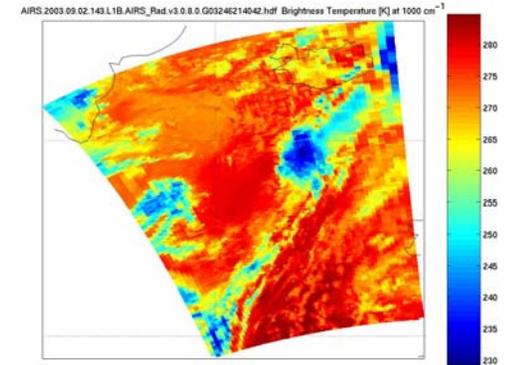
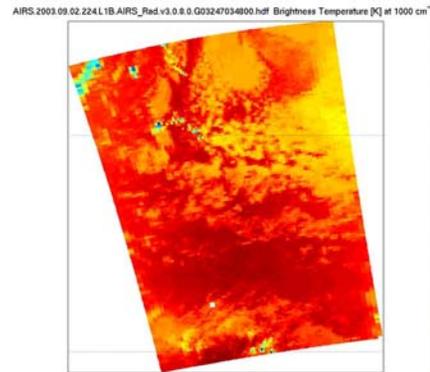
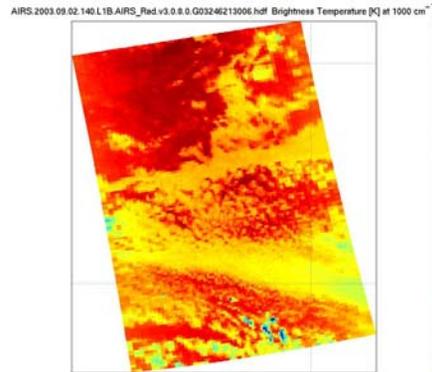
Mid-Latitude

Sub-Polar

Night



Day



# Operational AIRS/AMSU Cloud Clearing Error Estimates

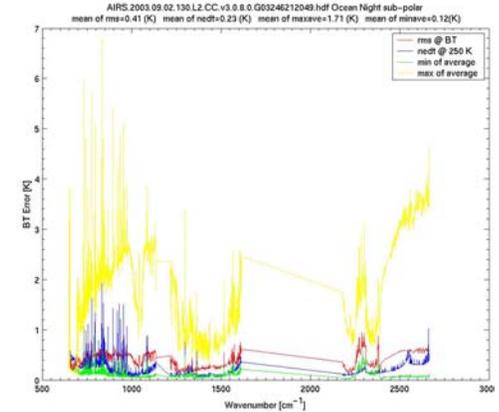
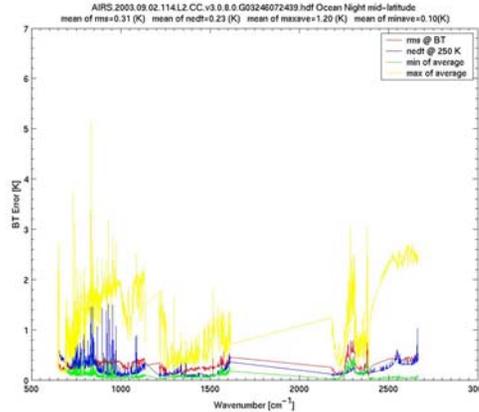
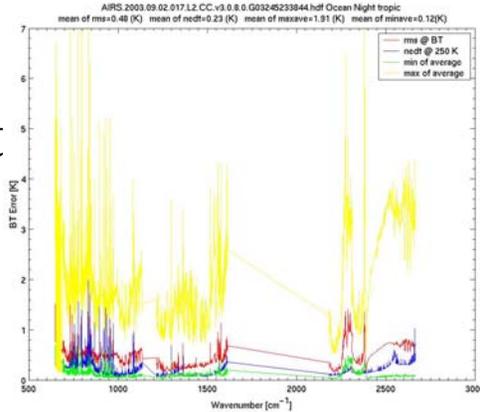
## Good Performance Over Ocean Most of Time

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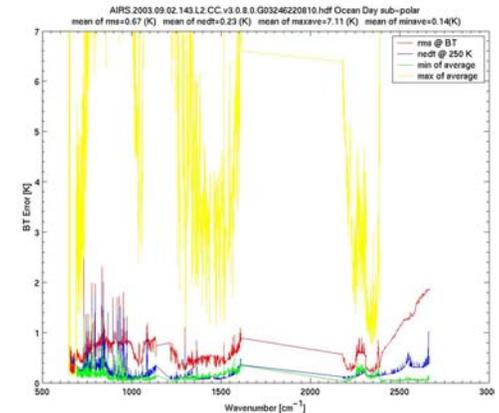
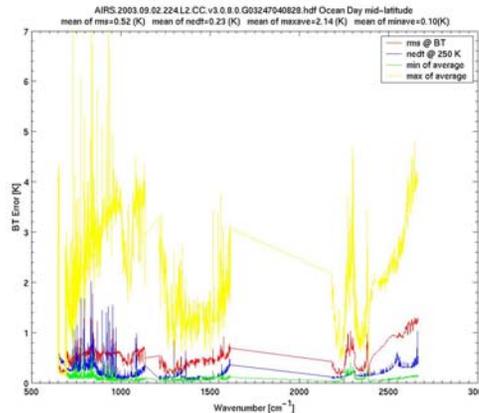
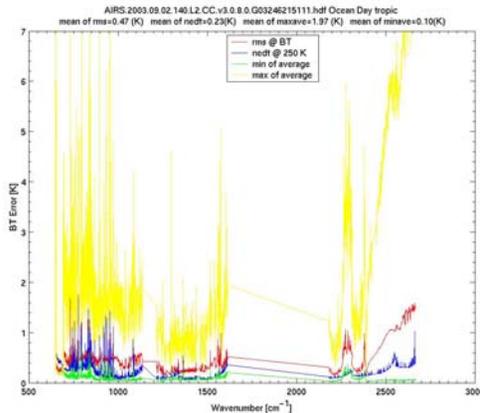
Mid-Latitude

Sub-Polar

Night



Day



Yellow – Max. C.C. Err.; Green – Min. C.C. Err.  
 Red – C.C. RMS Err.; Blue – AIRS FOV Noise

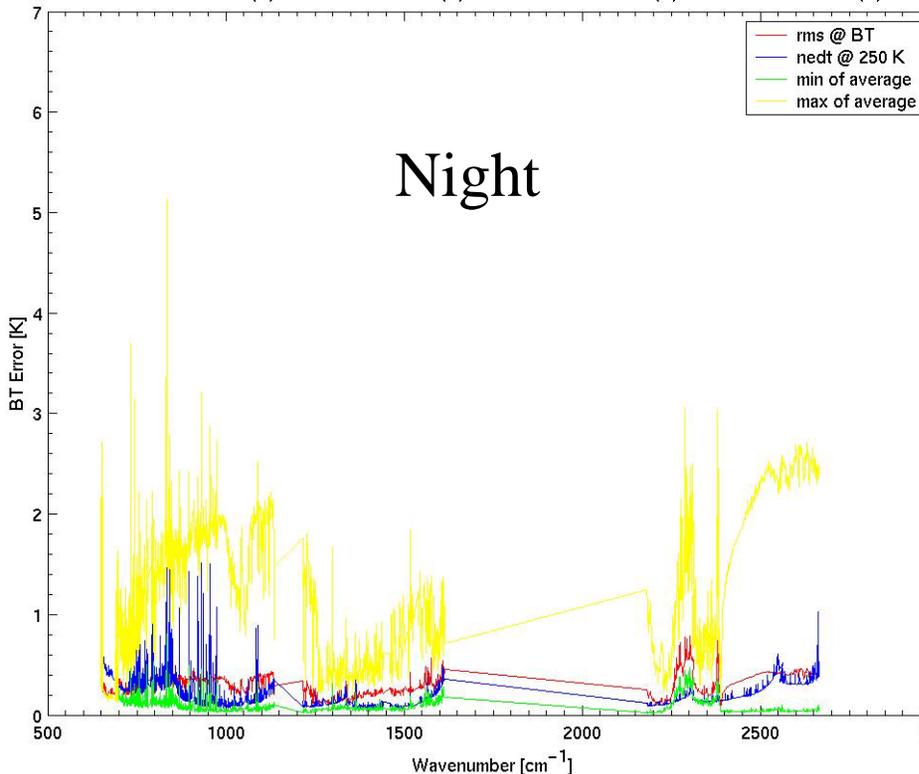


# Operational AIRS/AMSU Cloud Clearing Error Estimates

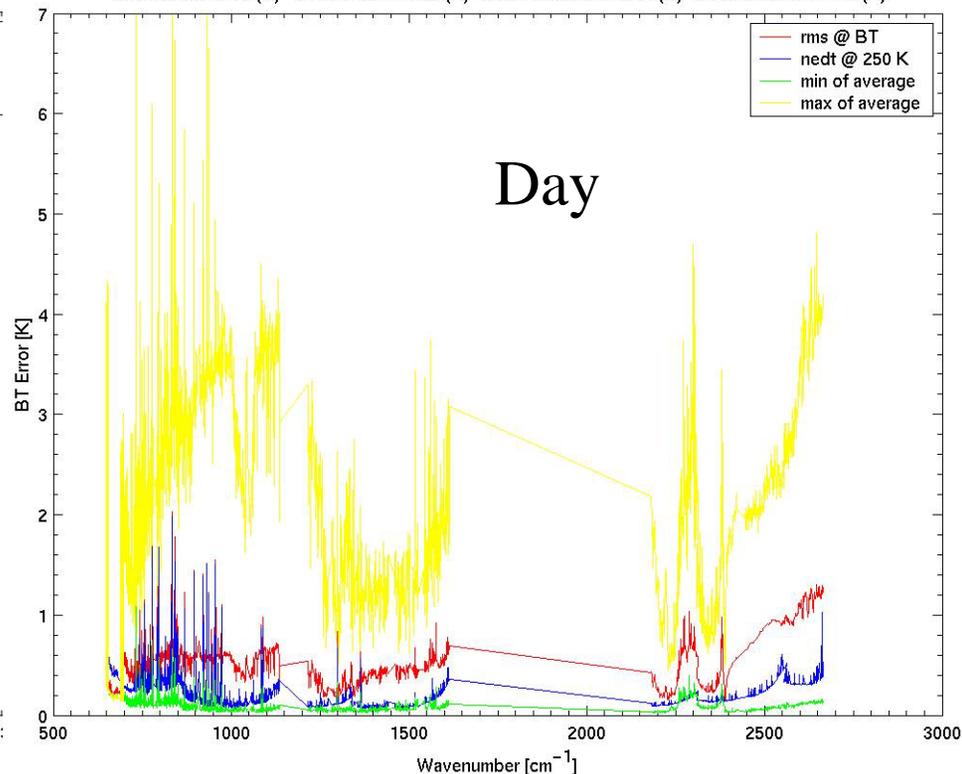
## Good Performance Over Ocean Most of Time

### Mid-Latitude

AIRS.2003.09.02.114.L2.CC.v3.0.8.0.G03246072439.hdf Ocean Night mid-latitude  
mean of rms=0.31 (K) mean of nedt=0.23 (K) mean of maxave=1.20 (K) mean of minave=0.10(K)



AIRS.2003.09.02.224.L2.CC.v3.0.8.0.G03247040828.hdf Ocean Day mid-latitude  
mean of rms=0.52 (K) mean of nedt=0.23 (K) mean of maxave=2.14 (K) mean of minave=0.10(K)



Yellow – Max. C.C. Err.; Green – Min. C.C. Err.  
Red – C.C. RMS Err.; Blue – AIRS FOV Noise



# Operational AIRS/AMSU Cloud Clearing Error Estimates

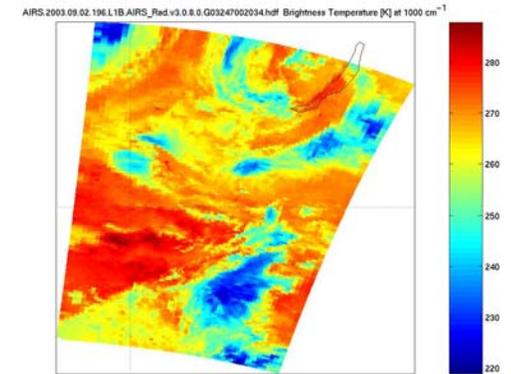
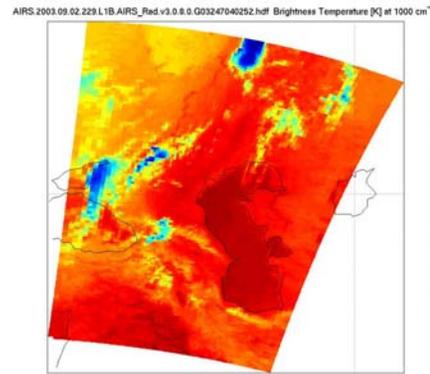
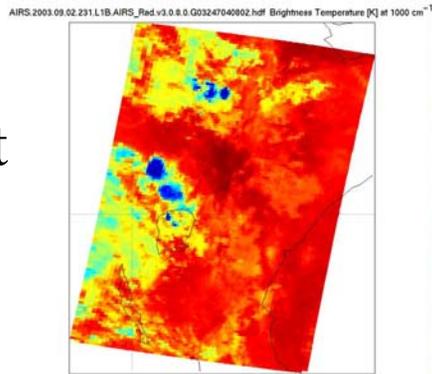
## Problematic Over Some Land Cases

Tropic

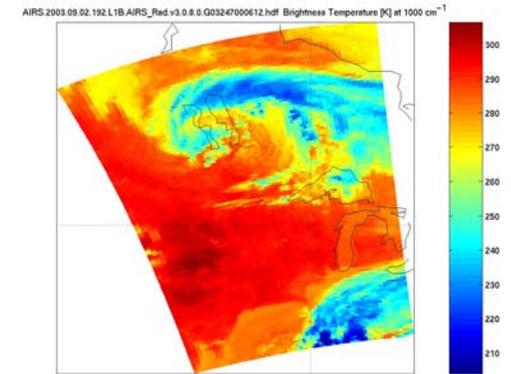
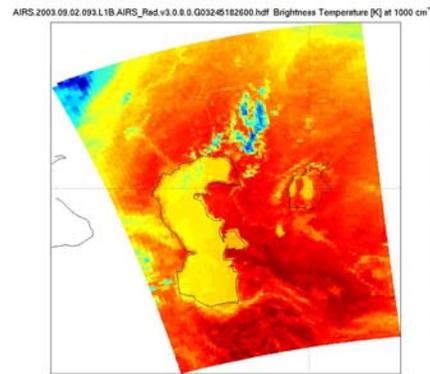
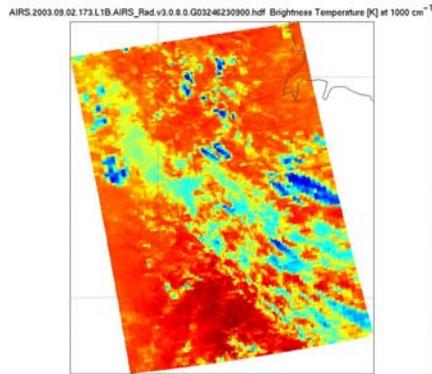
Mid-Latitude

Sub-Polar

Night



Day



# Operational AIRS/AMSU Cloud Clearing Error Estimates

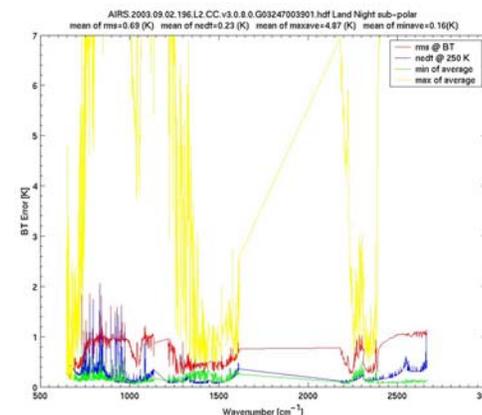
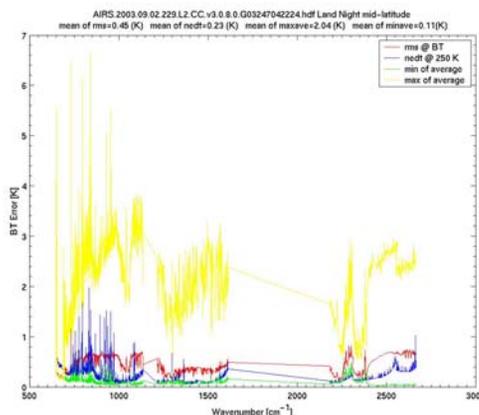
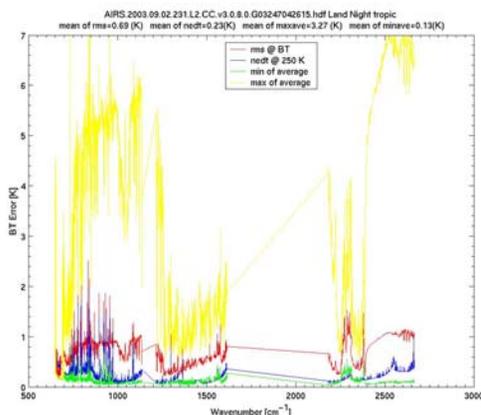
## Problematic Over Some Land Cases

Tropic

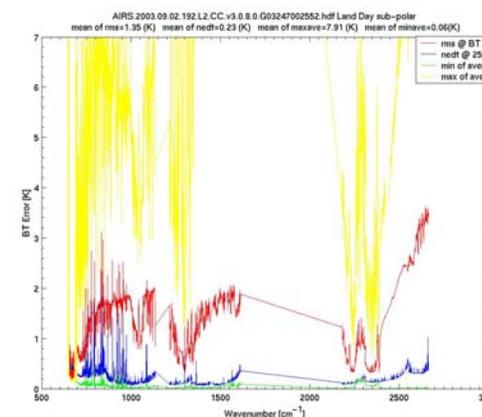
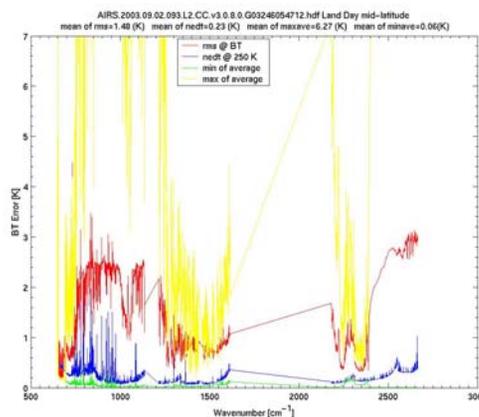
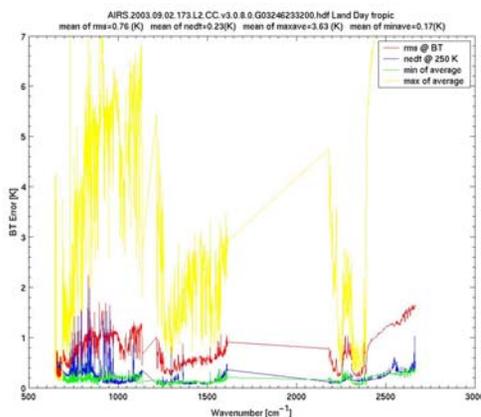
Mid-Latitude

Sub-Polar

Night



Day



Yellow – Max. C.C. Err.; Green – Min. C.C. Err.  
 Red – C.C. RMS Err.; Blue – AIRS FOV Noise

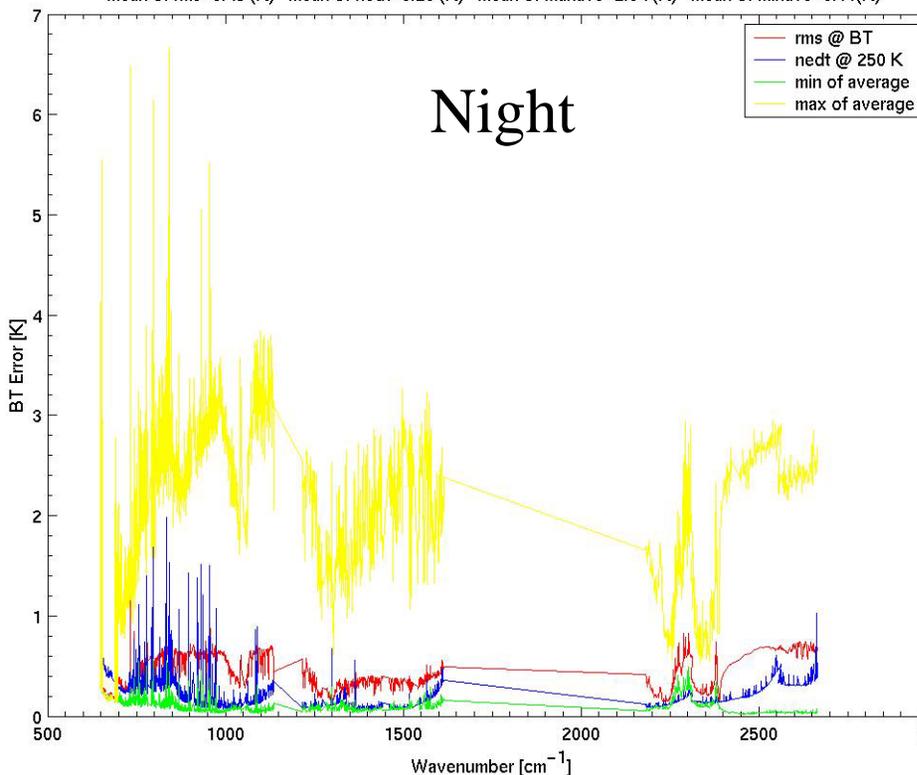


# Operational AIRS/AMSU Cloud Clearing Error Estimates

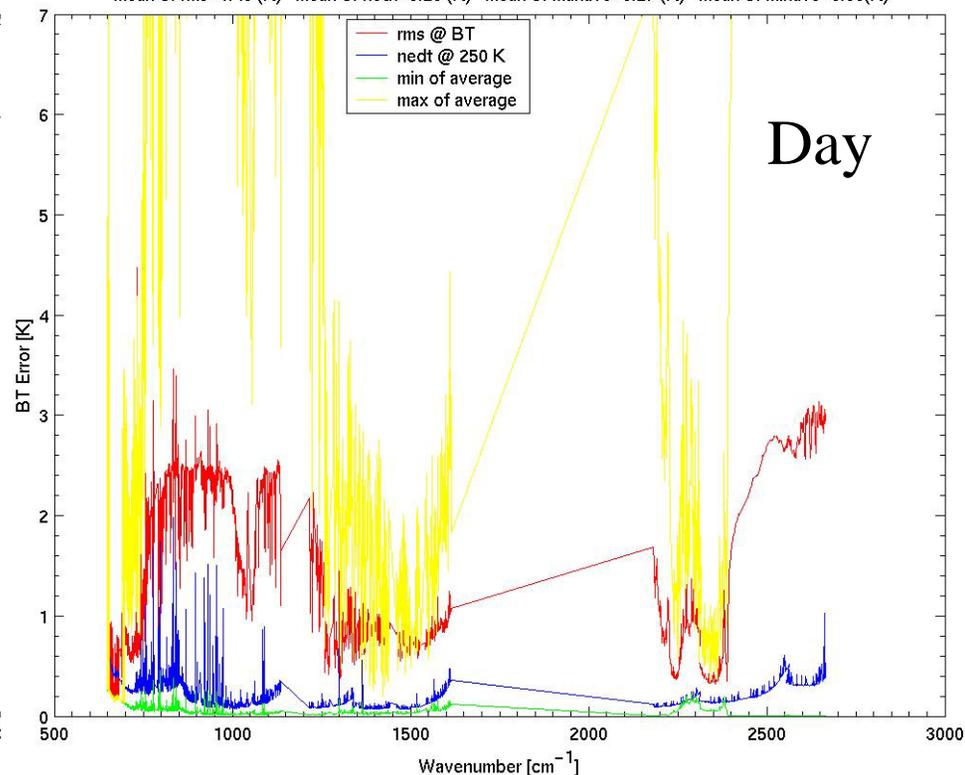
## Problematic Over Some Land Cases

### Mid-Latitude

AIRS.2003.09.02.229.L2.CC.v3.0.8.0.G03247042224.hdf Land Night mid-latitude  
 mean of rms=0.45 (K) mean of nedt=0.23 (K) mean of maxave=2.04 (K) mean of minave=0.11(K)



AIRS.2003.09.02.093.L2.CC.v3.0.8.0.G03246054712.hdf Land Day mid-latitude  
 mean of rms=1.48 (K) mean of nedt=0.23 (K) mean of maxave=6.27 (K) mean of minave=0.06(K)

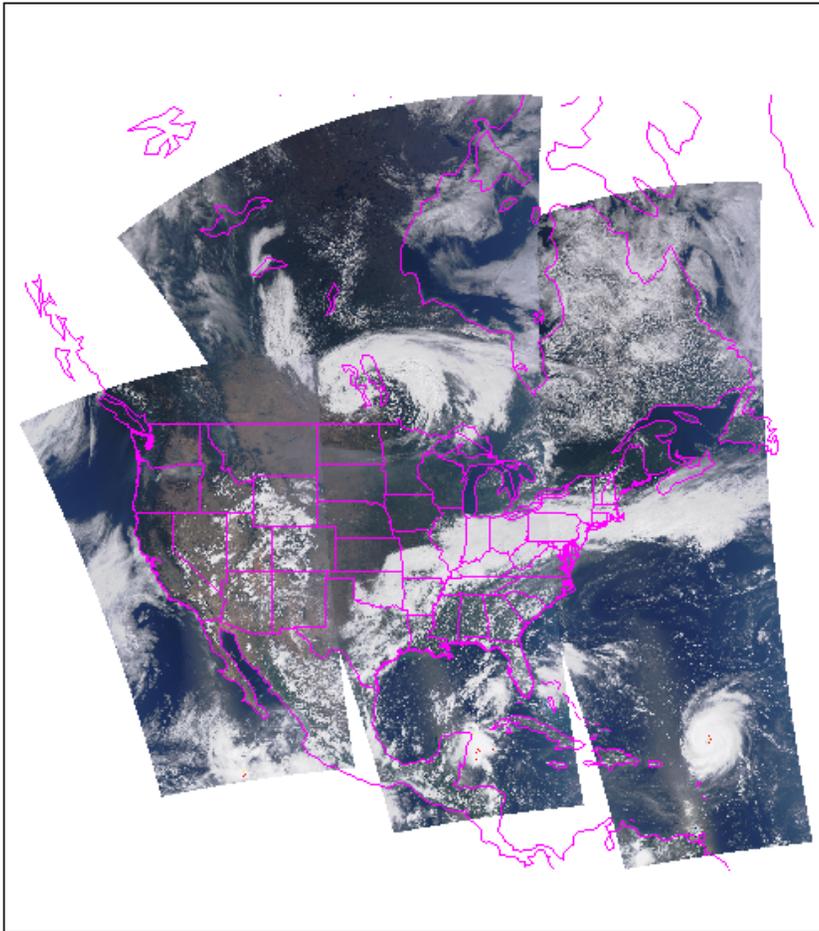


Yellow – Max. C.C. Err.; Green – Min. C.C. Err.  
 Red – C.C. RMS Err.; Blue – AIRS FOV Noise

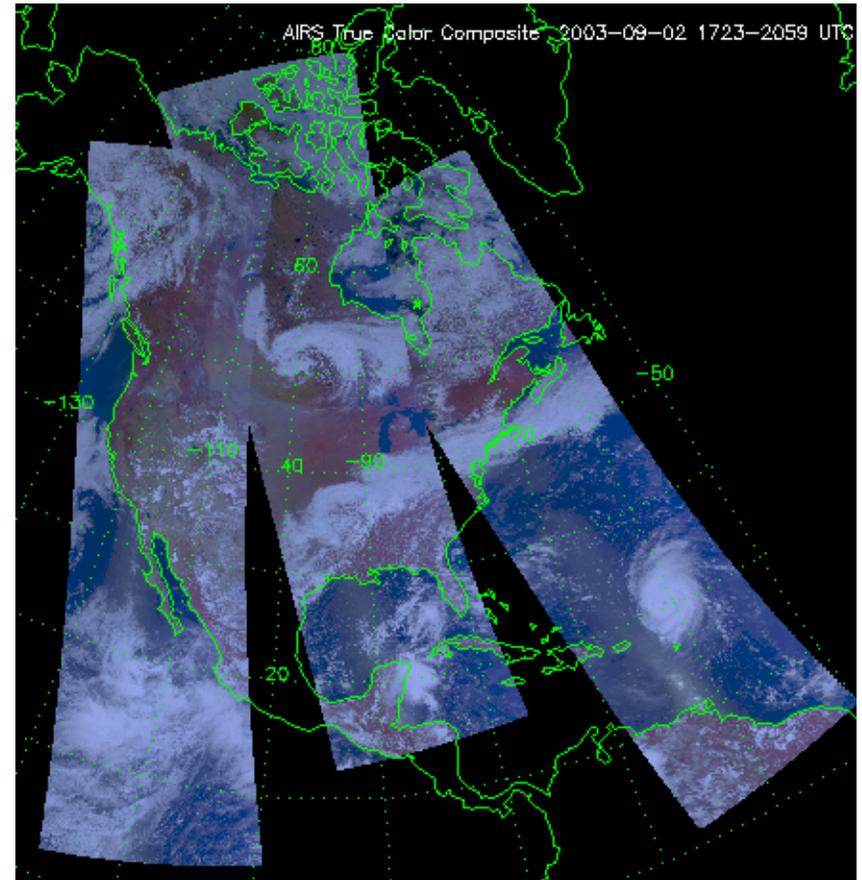


# MODIS and AIRS Color Composite Images

MODIS True Color Composite Image, 1725 to 2050 UTC, September 2, 2003



**MODIS (~1 km\*)**



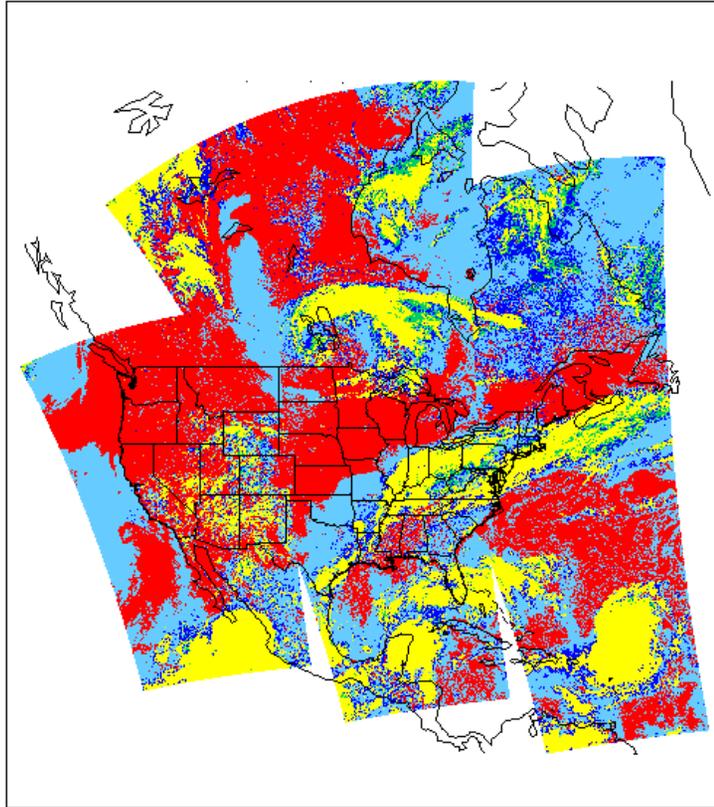
**AIRS (~14 km\*)**

\*Resolution is specified as nadir view only



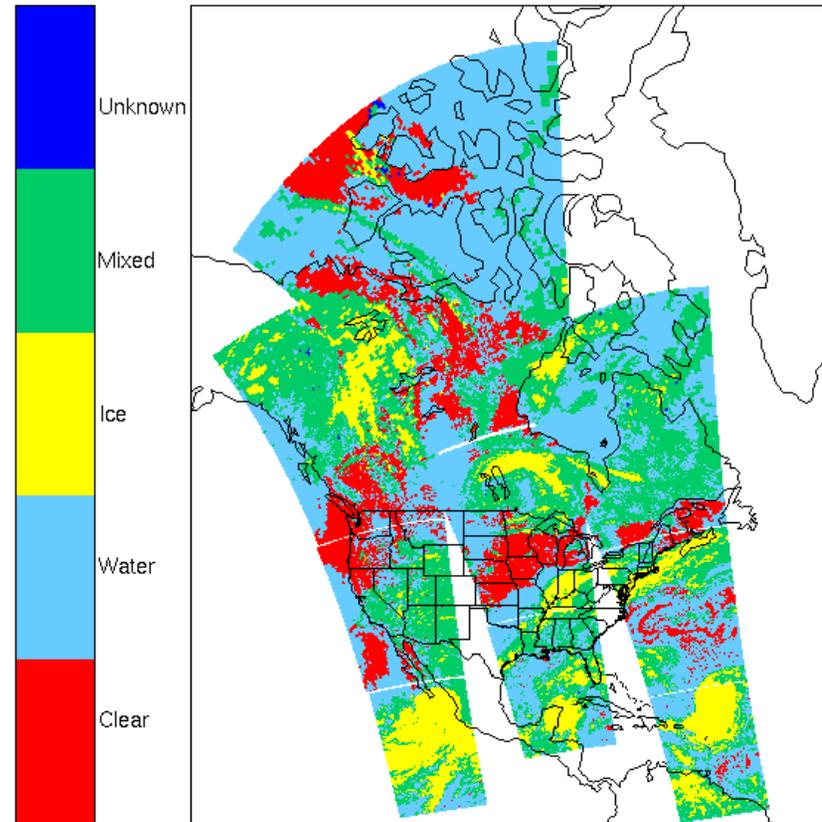
# MODIS (1 km\*) and AIRS (~14 km\*) Cloud Phase Images

Aqua MODIS 1-kilometer Cloud Phase, September 2, 2003, 1725 to 2050 UTC



**MODIS**

AIRS Cloud Phase, September 2, 2003, 1725 to 2055 UTC



**AIRS**

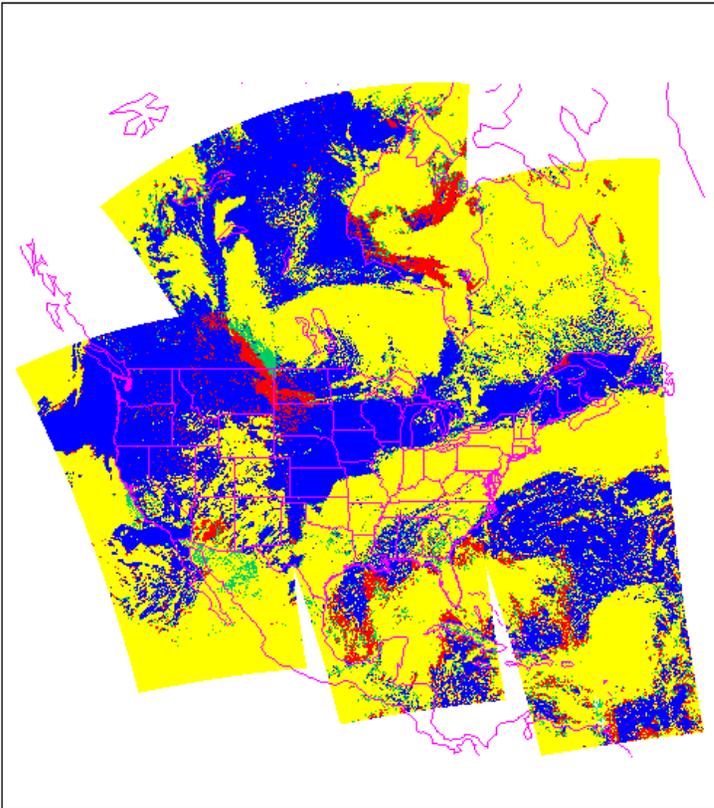
**More mixed phase clouds  
occur in AIRS FOV/FOR**

\*Resolution is specified as nadir view only



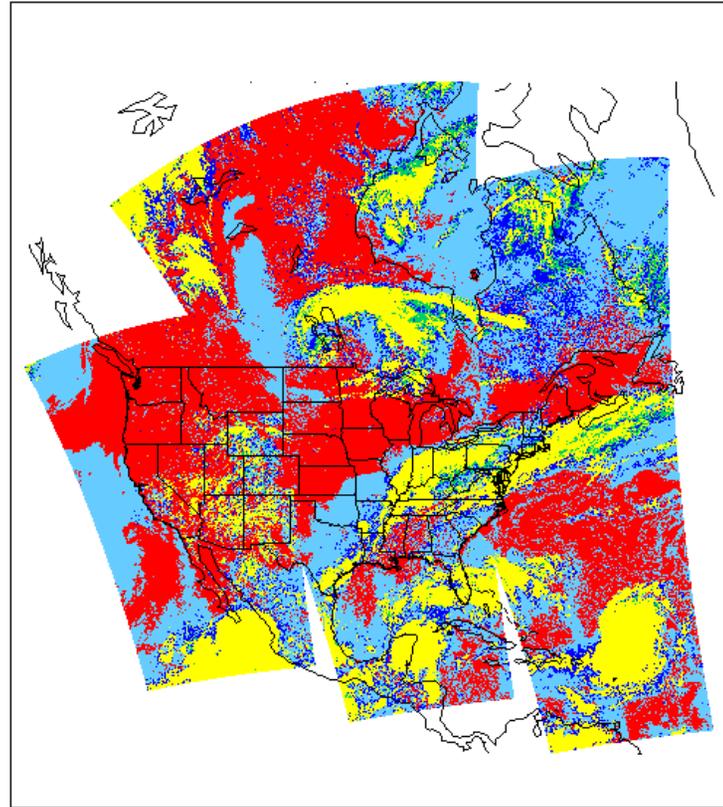
# MODIS 1 km Cloud Mask & Phase Images

Aqua MODIS, 1-kilometer Cloud Mask, 2003-09-02, 1725 to 2050 UTC



**Mask**

Aqua MODIS 1-kilometer Cloud Phase, September 2, 2003, 1725 to 2050 UTC



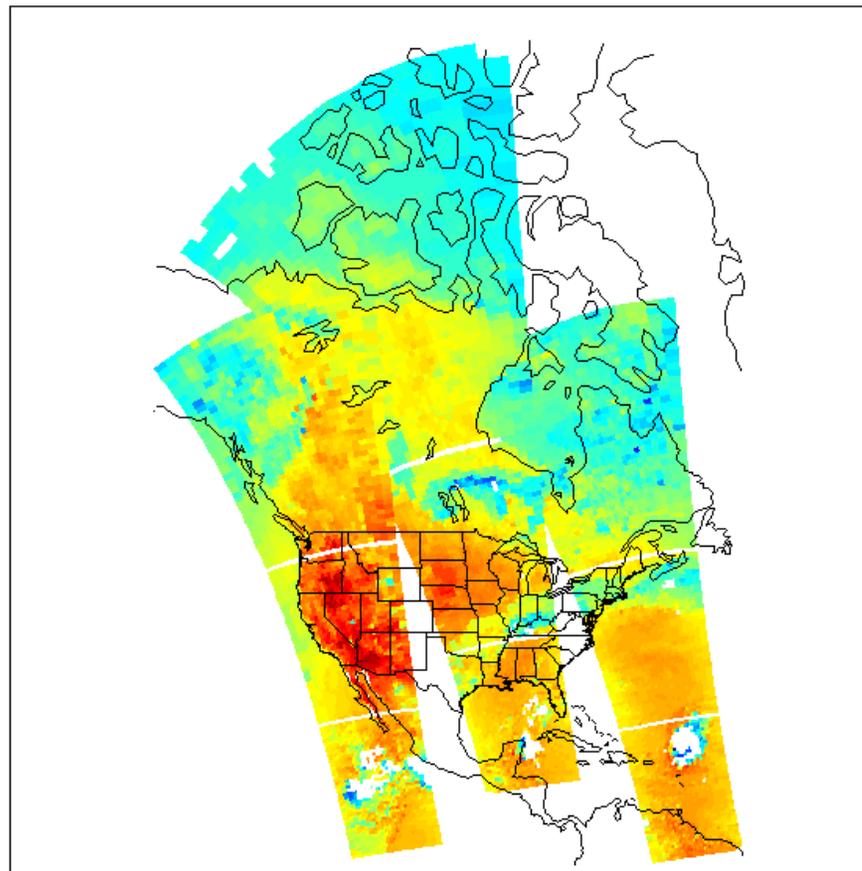
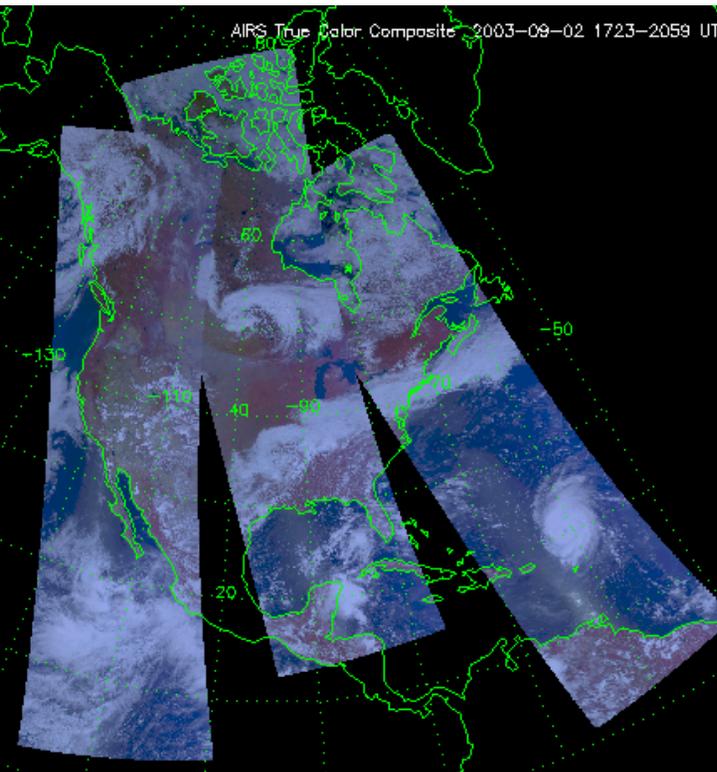
**Phase**

@ 1 km Nadir Resolution



# AIRS Color Composite and Cloud Cleared Window Channel Images

AIRS Level 2 Cloud-Cleared Radiance Product at  $1000\text{ cm}^{-1}$ , September 2, 2003



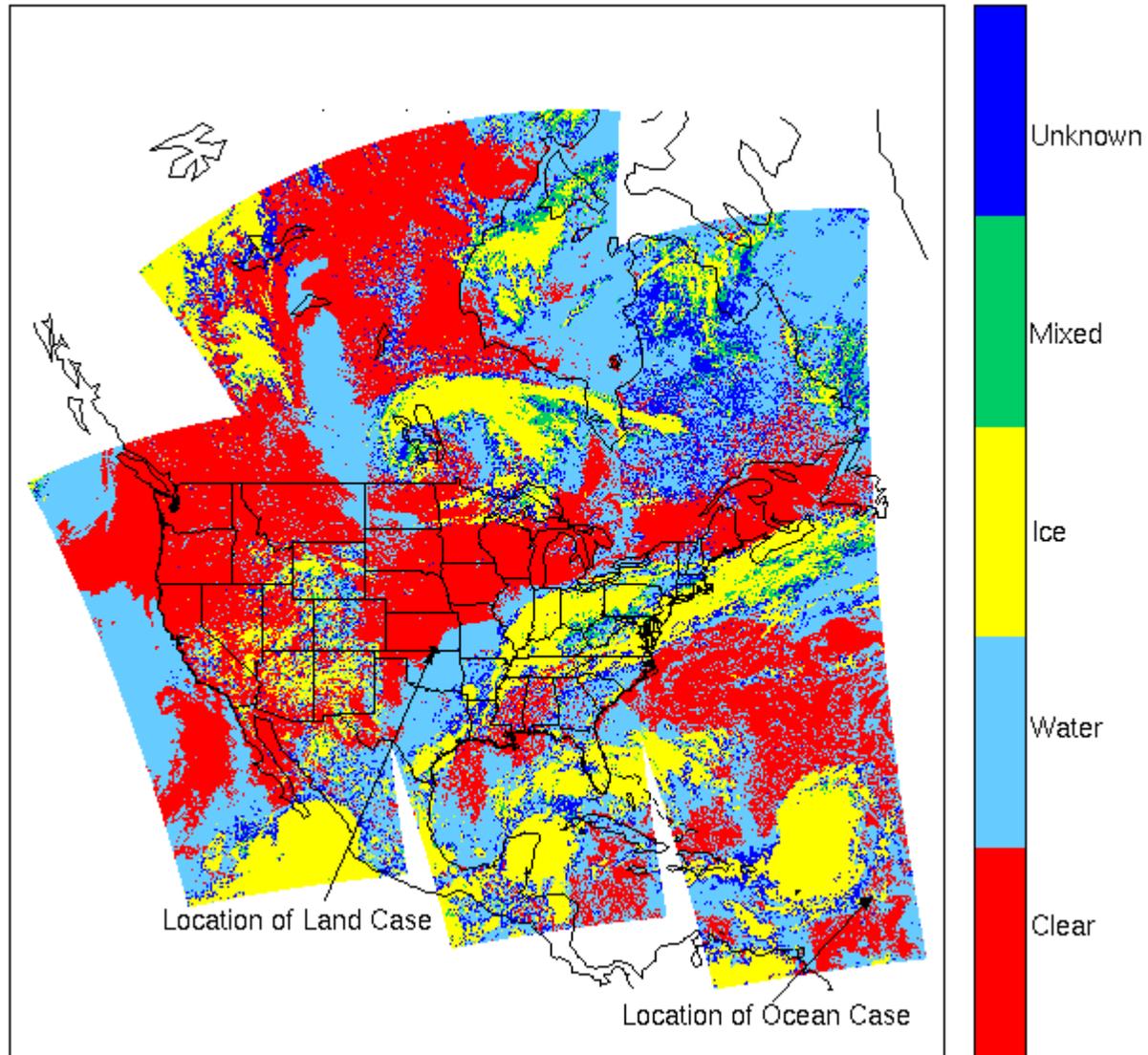
Brightness Temperature (K)

## Operational AIRS Cloud Cleared Tb Image



# MODIS/AIRS Synergistic Cloud Clearing Examples

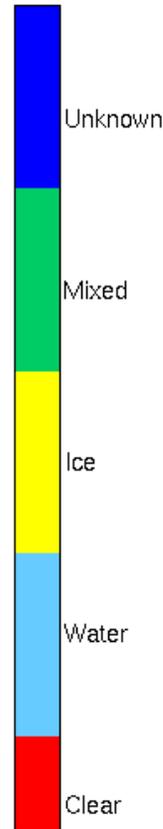
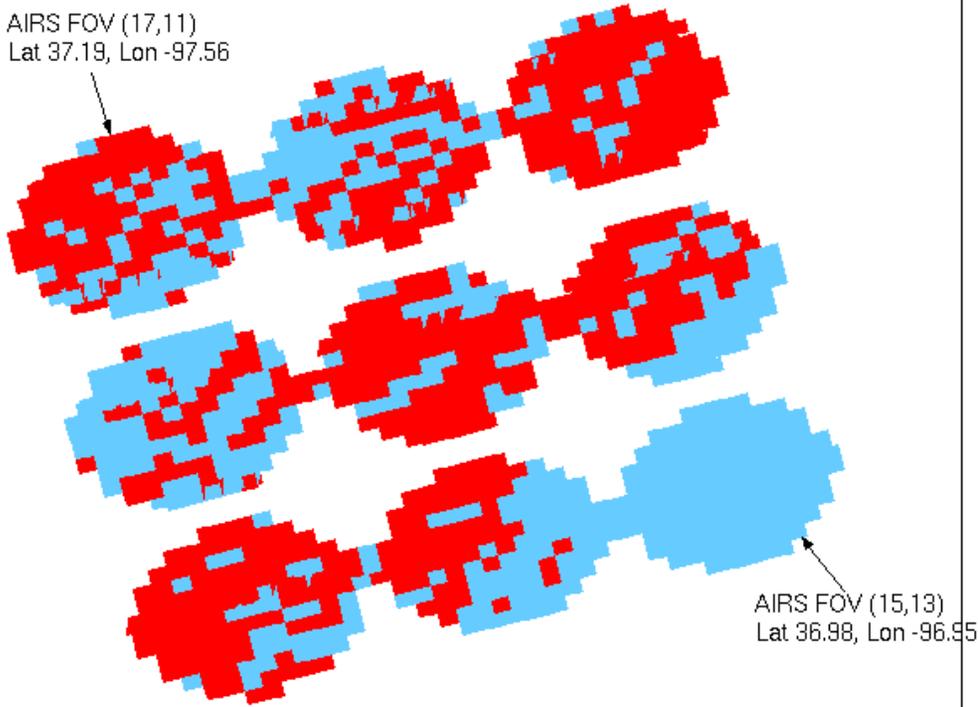
Aqua MODIS 1-kilometer Cloud Phase, September 2, 2003, 1725 to 2050 UTC



# MODIS/AIRS Co-located Cloud Phase Image

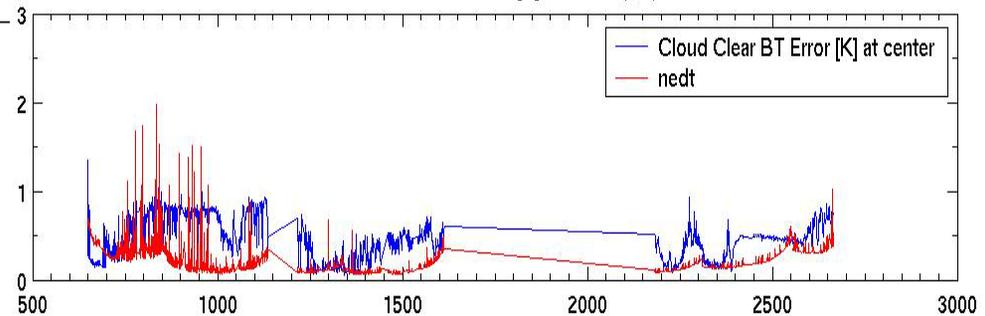
MODIS Cloud Phase Collocated with AIRS Granule 192, Land Case, Sept 2, 2003

AIRS FOV (17,11)  
Lat 37.19, Lon -97.56

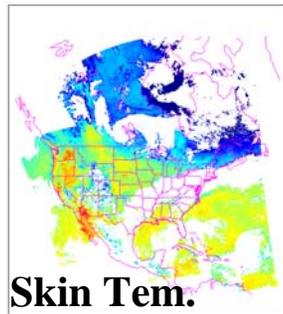
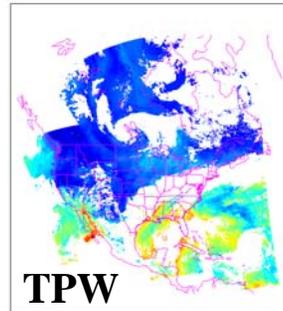
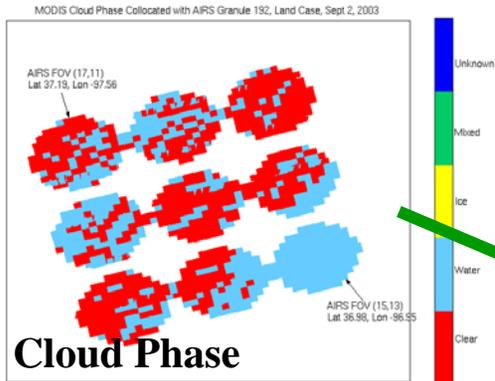


Over Land

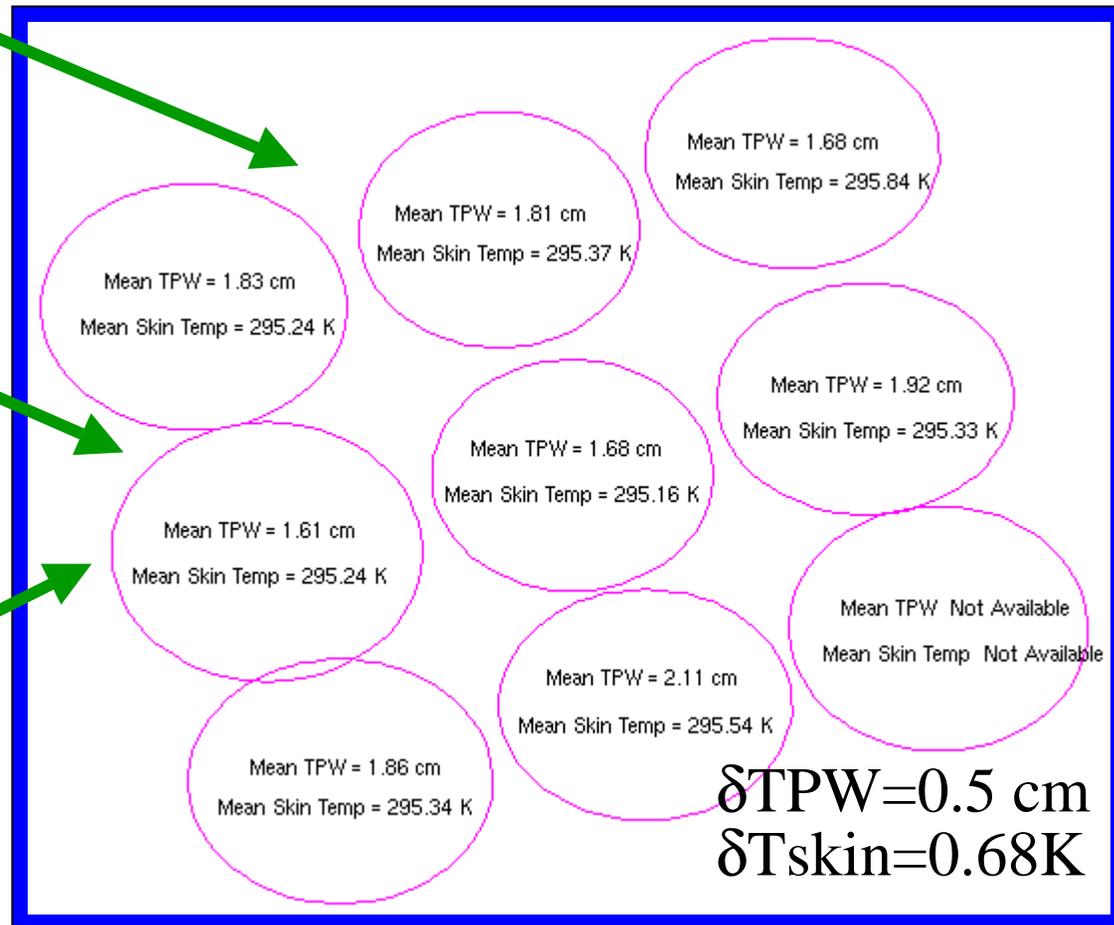
AIRS.2003.09.02.192.L2.CC.v3.0.8.0.G03247002552.hdf  
Cloud Clear BT Error [K] at center (4,5)



# MODIS/AIRS Co-located TWP & Skin Temperature



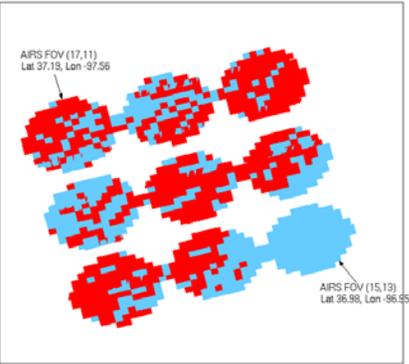
## Mean Values of TPW and Skin Temperature for clear MODIS pixels within AIRS FOVs, Land Case



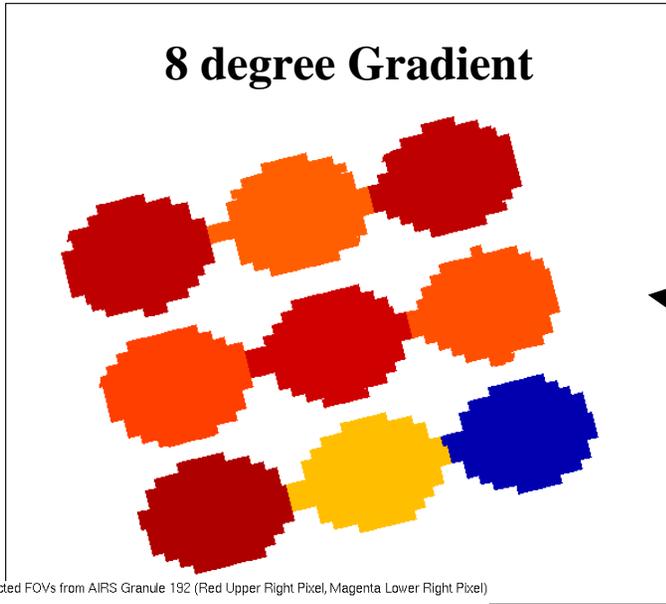
# AIRS Single FOV Window Channel Brightness Temperature Variations

AIRS Brightness Temperatures at 1000 cm<sup>-1</sup> for 9 Focus FOVs from Granule 192

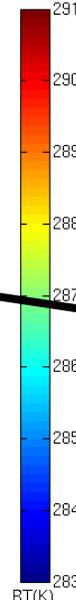
MODIS Cloud Phase Collocated with AIRS Granule 192, Land Case, Sept 2, 2003



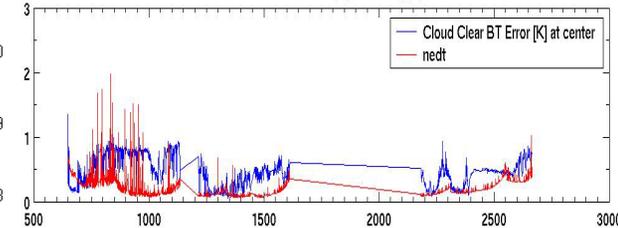
Cloud Phase



8 degree Gradient

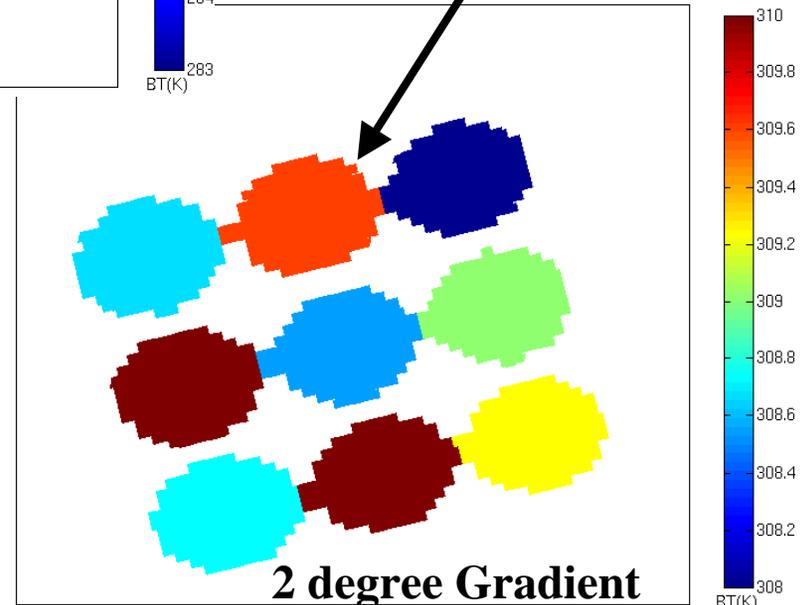


AIRS.2003.09.02.192.L2.CC.v3.0.8.0.G03247002552.hdf  
Cloud Clear BT Error [K] at center (4,5)

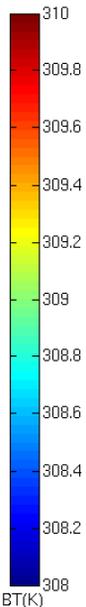


Window BT  
1000 cm<sup>-1</sup>  
&  
2616 cm<sup>-1</sup>

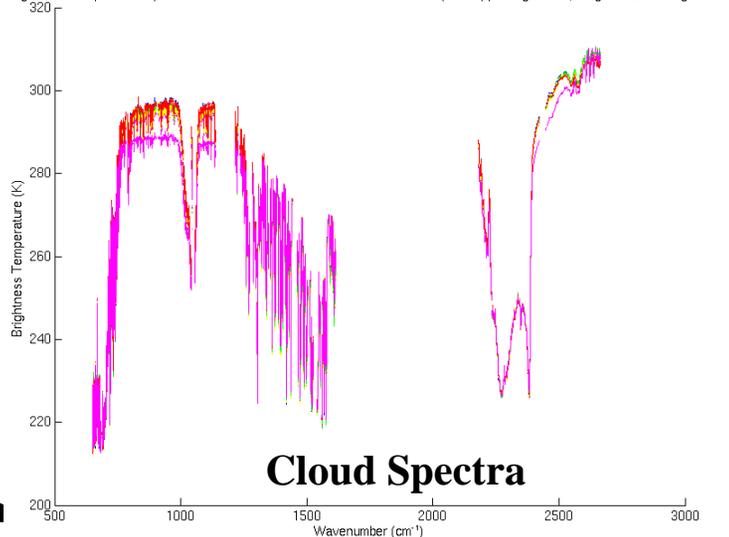
Brightness Temperatures at 2616 cm<sup>-1</sup> for 9 Focus FOVs from Granule 192



2 degree Gradient



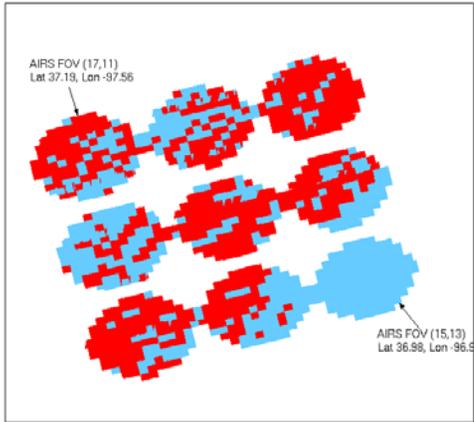
Brightness Temperature Spectra of 9 Selected FOVs from AIRS Granule 192 (Red Upper Right Pixel, Magenta Lower Right Pixel)



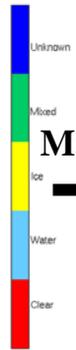
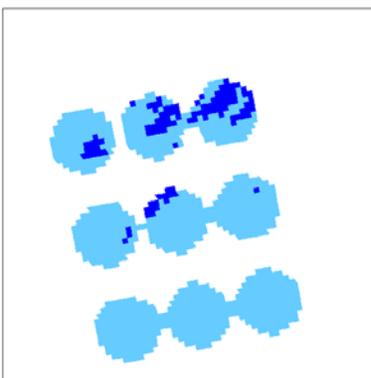
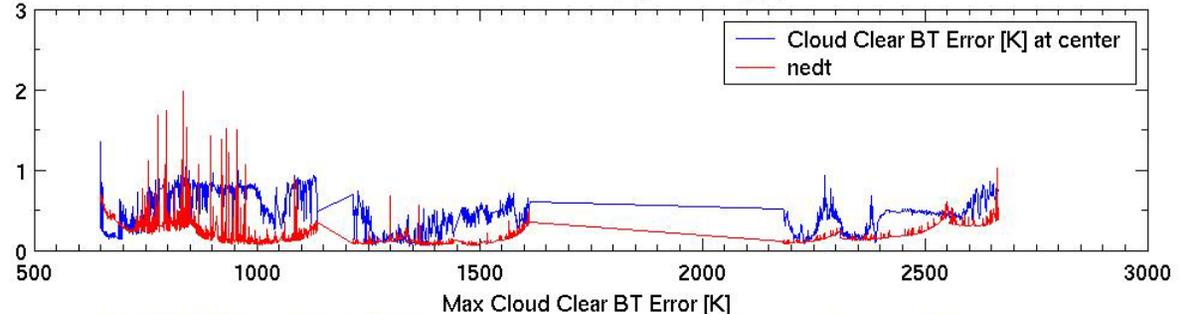
Cloud Spectra



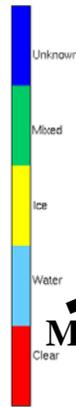
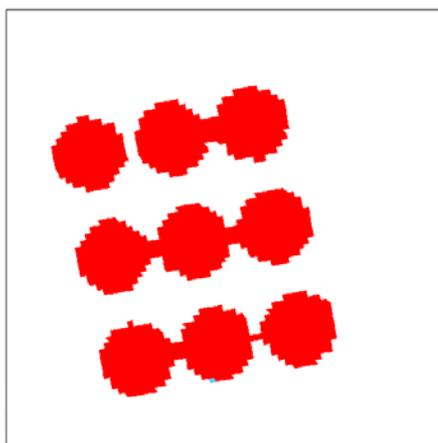
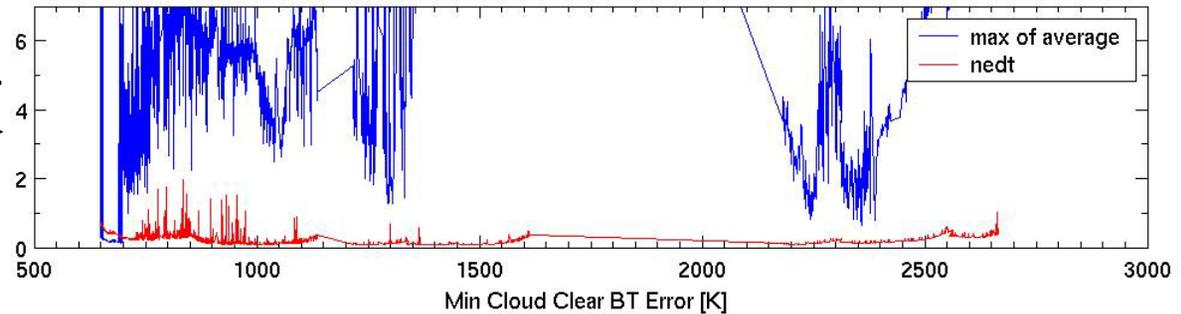
# AIRS FOR ( 3 by 3 ) Cloud Clearing Error Examples



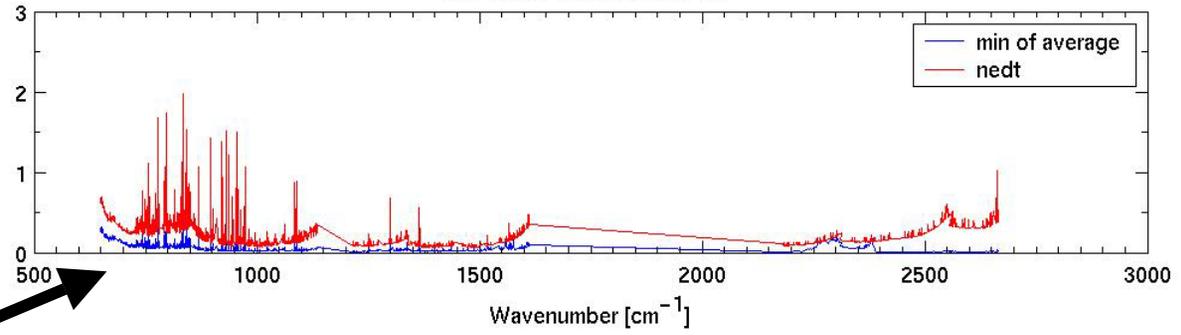
AIRS.2003.09.02.192.L2.CC.v3.0.8.0.G03247002552.hdf  
Cloud Clear BT Error [K] at center (4,5)



**Max. C.C. Error**

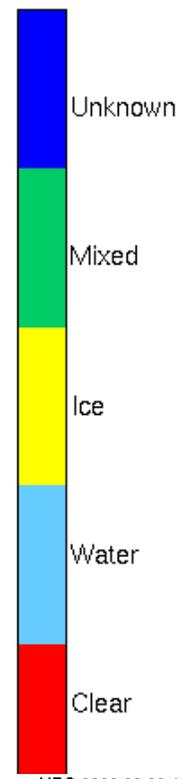
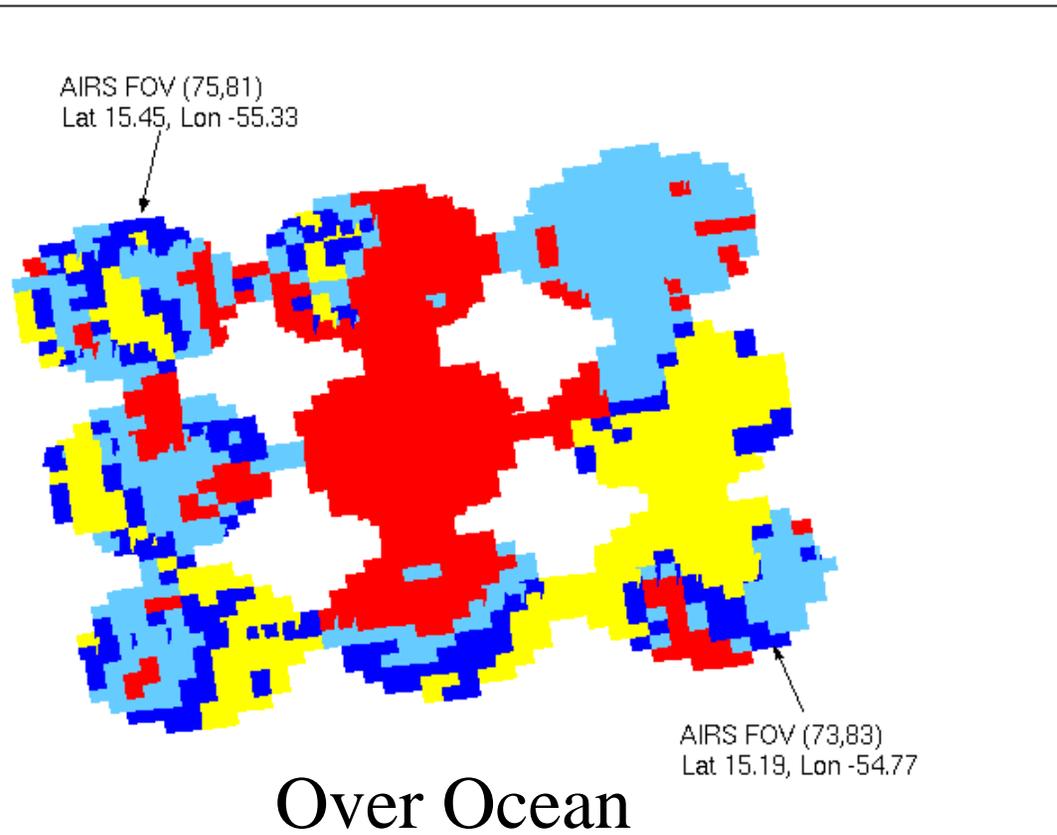


**Min. C.C. Error**

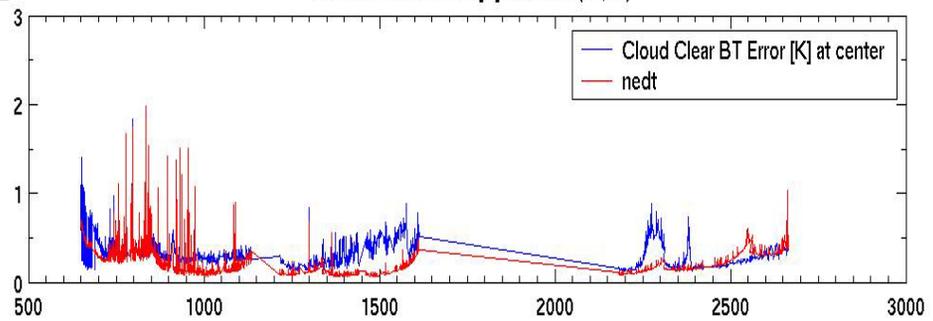


# MODIS/AIRS Co-located Cloud Phase Image

MODIS Cloud Phase Collocated with AIRS Granule 174 FOVs, Ocean Case, Sept 2, 2003

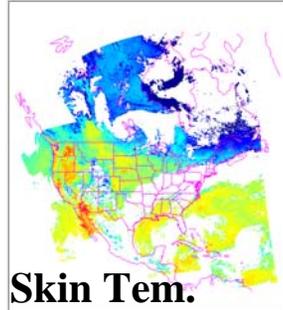
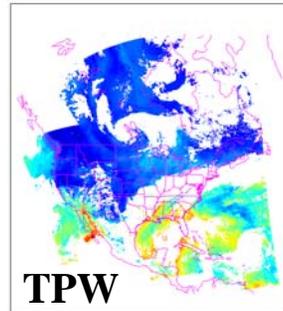
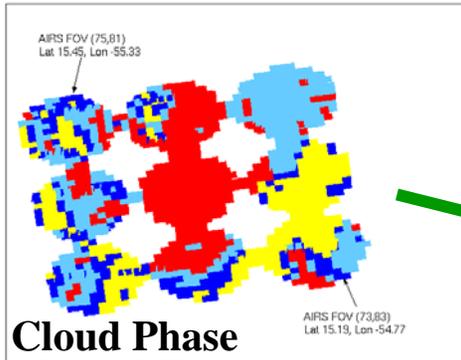


AIRS.2003.09.02.174.L2.CC.v3.0.8.0.G03246233657.hdf  
Cloud Clear BT Error [K] at center (27,25)

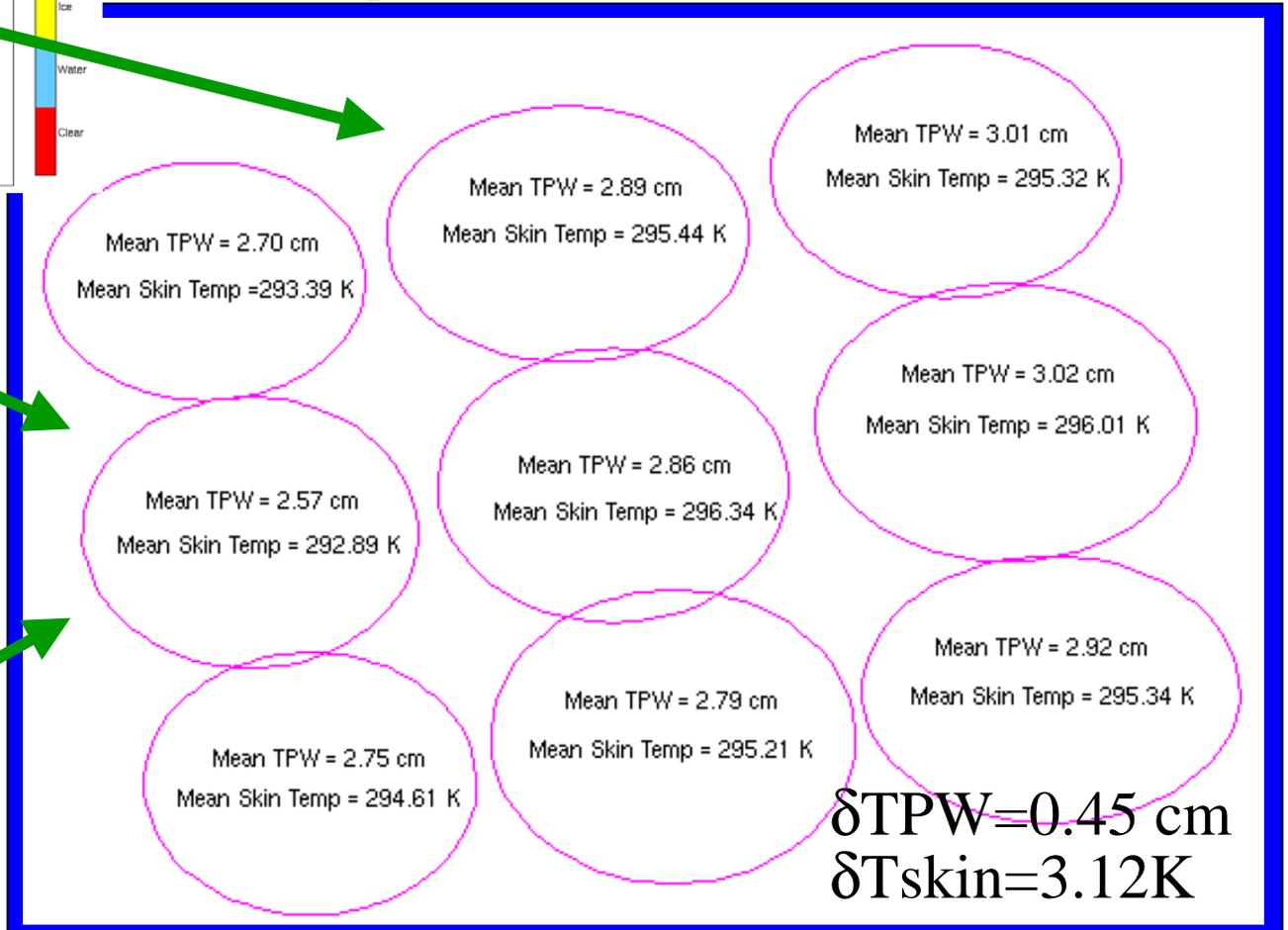


# MODIS/AIRS Co-located TWP & Skin Temperature

MODIS Cloud Phase Collocated with AIRS Granule 174 FOVs, Ocean Case, Sept 2, 2003



## Mean Values of TPW and Skin Temperature for clear MODIS pixels within AIRS FOVs, Ocean Case

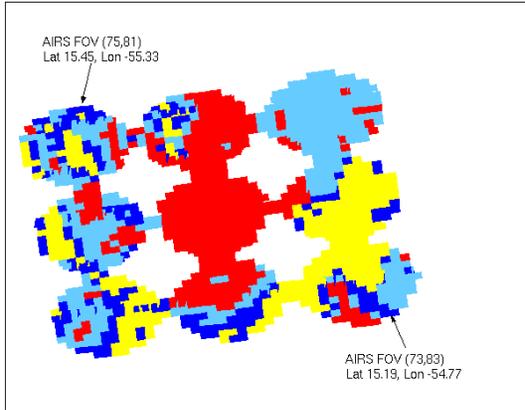


# AIRS FOR ( 3 by 3) Single FOV Window Channel Brightness Temperature Variations

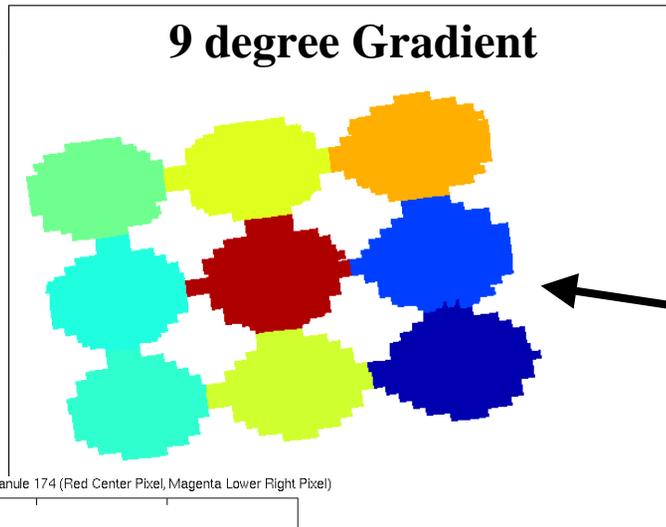
MODIS Cloud Phase Collocated with AIRS Granule 174 FOVs, Ocean Case, Sept 2, 2003

AIRS Brightness Temperatures at 1000 cm<sup>-1</sup> for 9 Focus FOVs from Granule 174

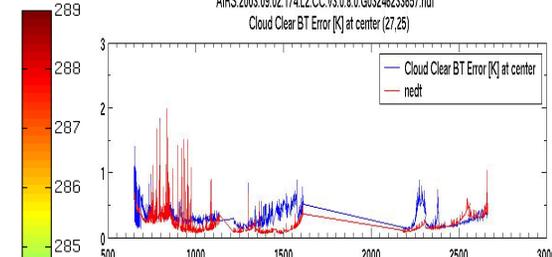
AIRS.2003.09.02.174.L2.CC.v3.0.0.G03246238657.hdf  
Cloud Clear BT Error [K] at center (27.25)



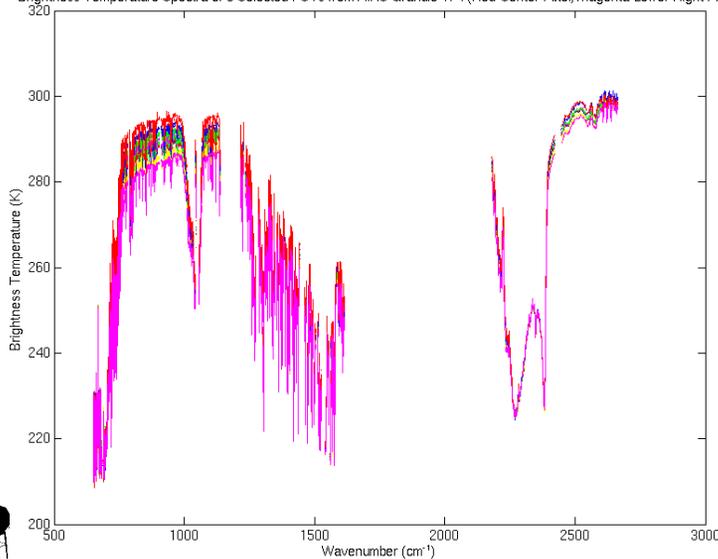
Cloud Phase



Window BT  
1000 cm<sup>-1</sup>  
&  
2616 cm<sup>-1</sup>

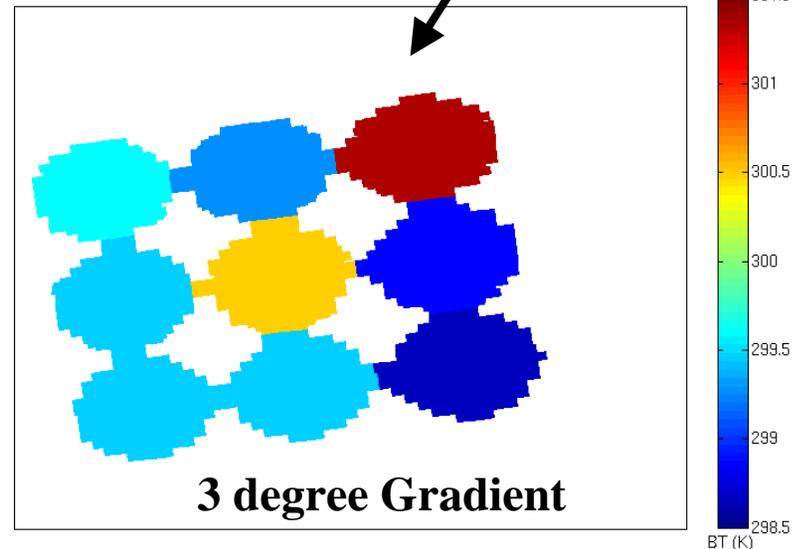


Brightness Temperature Spectra of 9 Selected FOVs from AIRS Granule 174 (Red Center Pixel, Magenta Lower Right Pixel)

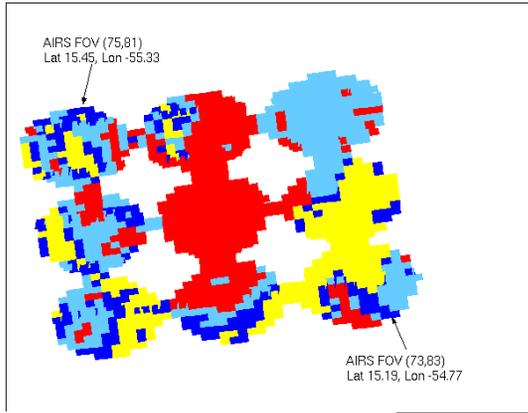


Cloud Spectra

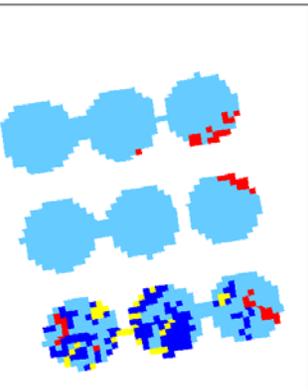
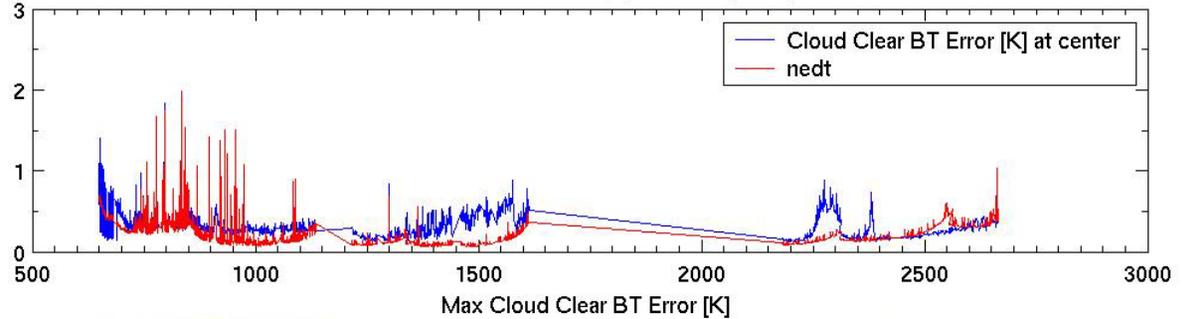
AIRS Brightness Temperatures at 2616 cm<sup>-1</sup> for 9 FOVs from Ocean Case (Granule 174)



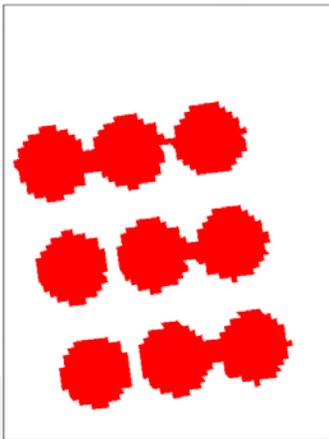
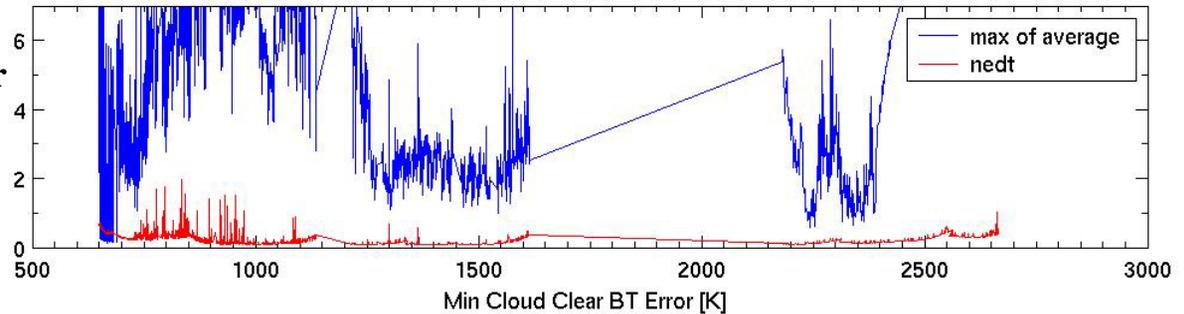
# AIRS FOR ( 3 by 3 ) Cloud Clearing Error Examples



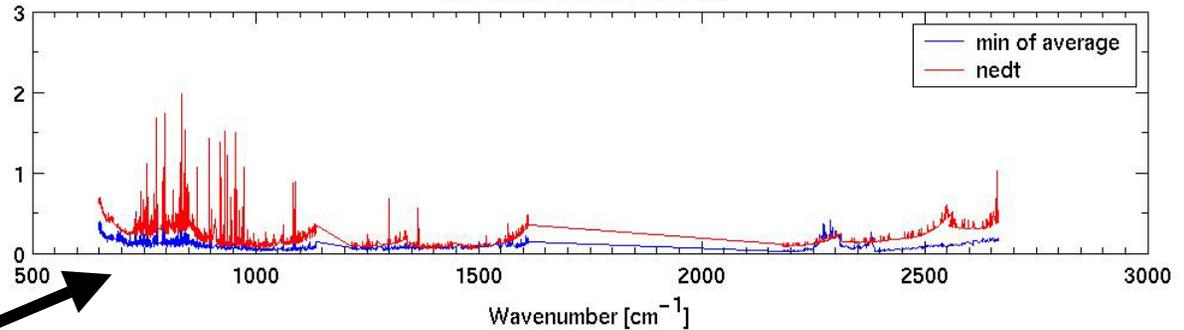
AIRS.2003.09.02.174.L2.CC.v3.0.8.0.G03246233657.hdf  
Cloud Clear BT Error [K] at center (27,25)



Max. C.C. Error

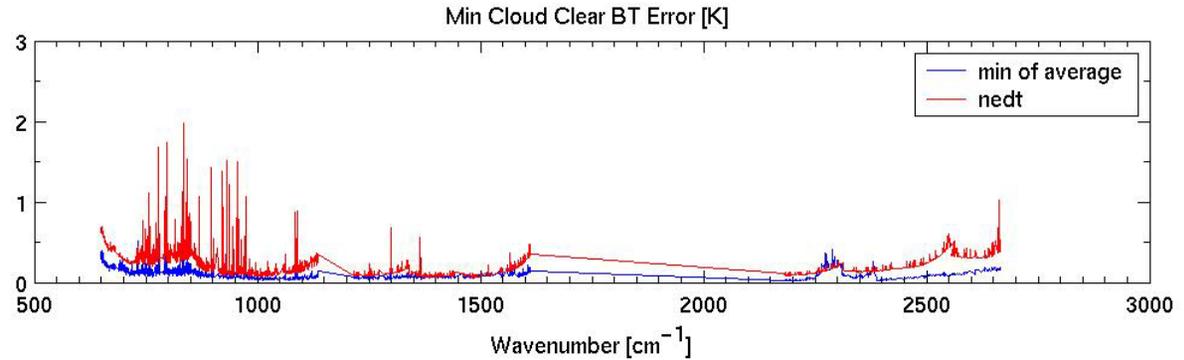
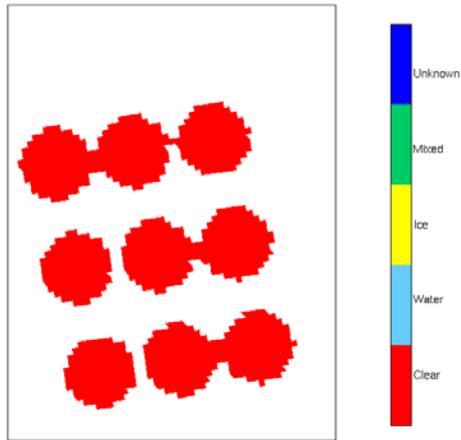


Min. C.C. Error

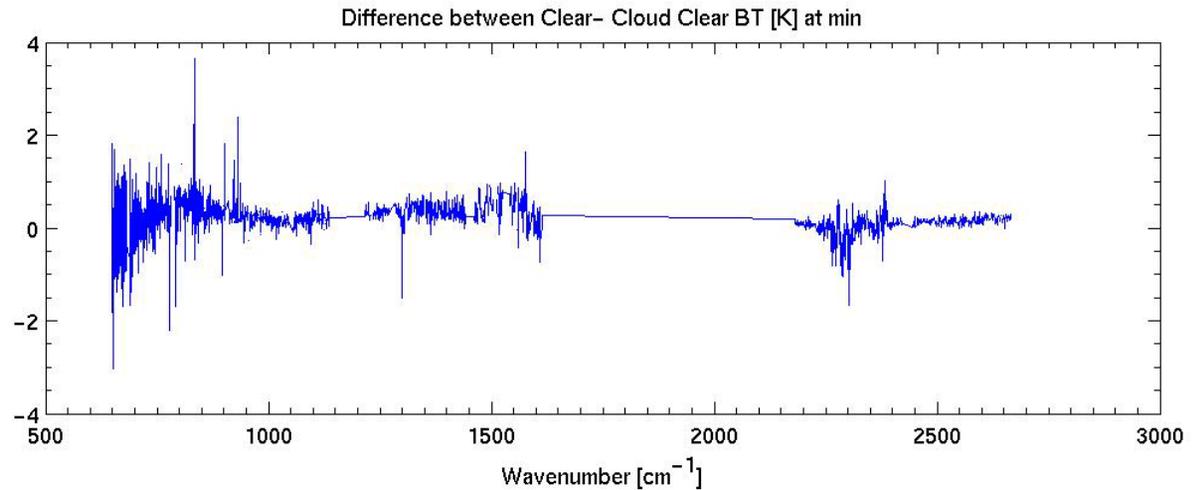


# AIRS FOR ( 3 by 3) Cloud Clearing Error Examples

## Minimum C.C. Error Case



## Cloud Clear Error Estimate



## Difference between Averaged Clear and Cloud Cleared



# Alternative Stand-Along IMAPP AIRS Cloud Clearing Approaches - Without Performing Profile Retrieval

- **Noise filtering AIRS cloudy radiances prior to C.C. to minimize noise amplification**
  - **Use of minimum resources and ancillary data (besides available Direct Broadcast measurements)**

- **Synergistic AIRS/MODIS C.C.:**
  - Use of MODIS clear radiance estimates
  - Use of MODIS for surface type/emissivity estimates
  - Use of MODIS level 2 (single pixel) TPW, Sfc-Tskin ..for Q.C.
- **Variable C.C. Area (1 by 3; 2 by 2 FOVs; superobs or customized ....)**
- **Evaluation of AIRS/AMSU Cloud Clearing Performance**
- **Optimal use of Cloud Cleared Radiances**

## Goal

**Demonstrate Imaging/Sounding Synergy to improve yields of IR Data utilization**

