Synergistic Cloud Clearing Using Aqua Sounding and Imaging Infrared Measurements

H-L Allen Huang, et al.
CIMSS/SSEC Univ. of Wisconsin-Madison
and William L. Smith, LaRC, NASA

- 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

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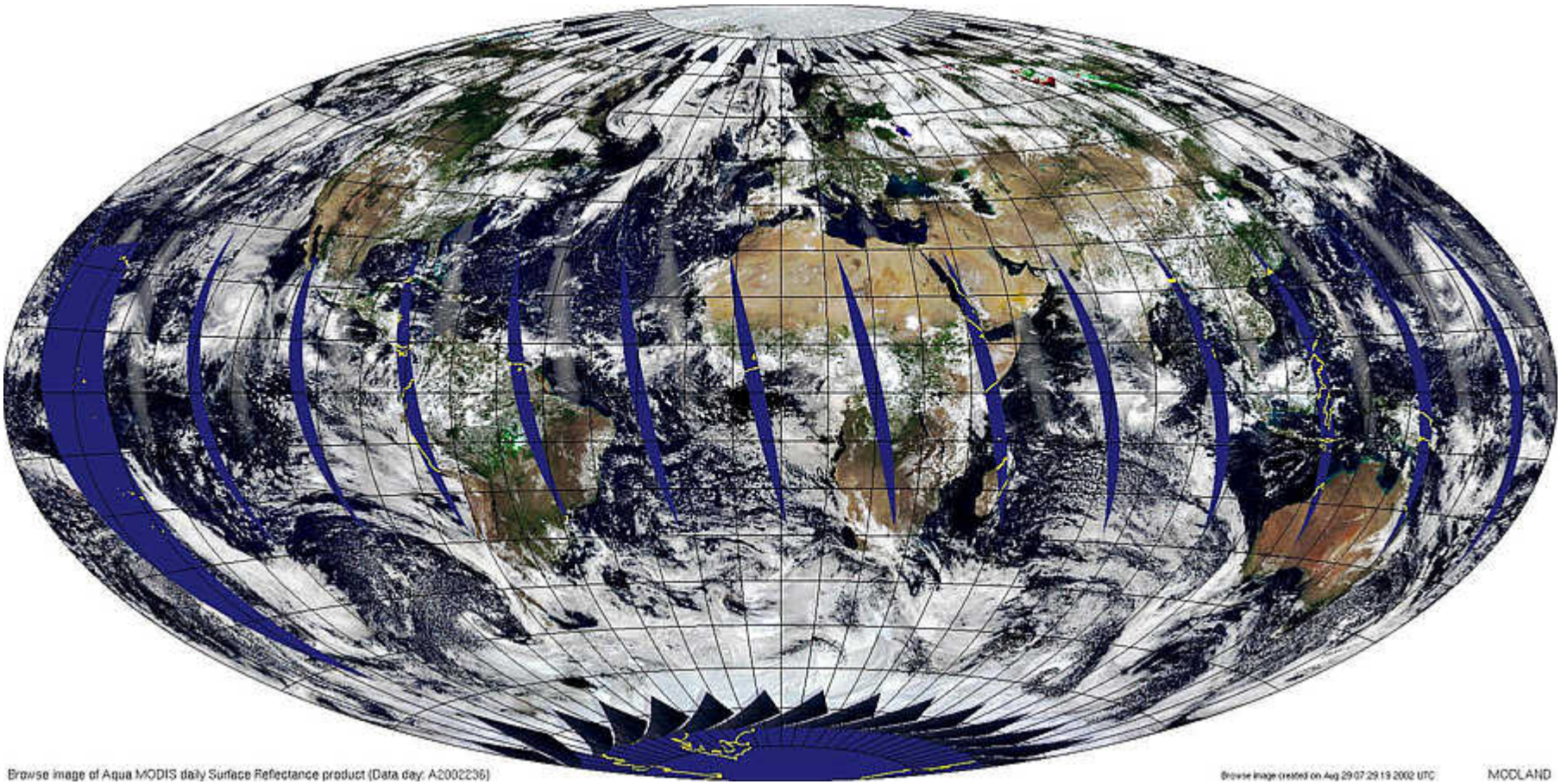
MODIS True Color Image – 24 August, 2002



Clouds are almost everywhere

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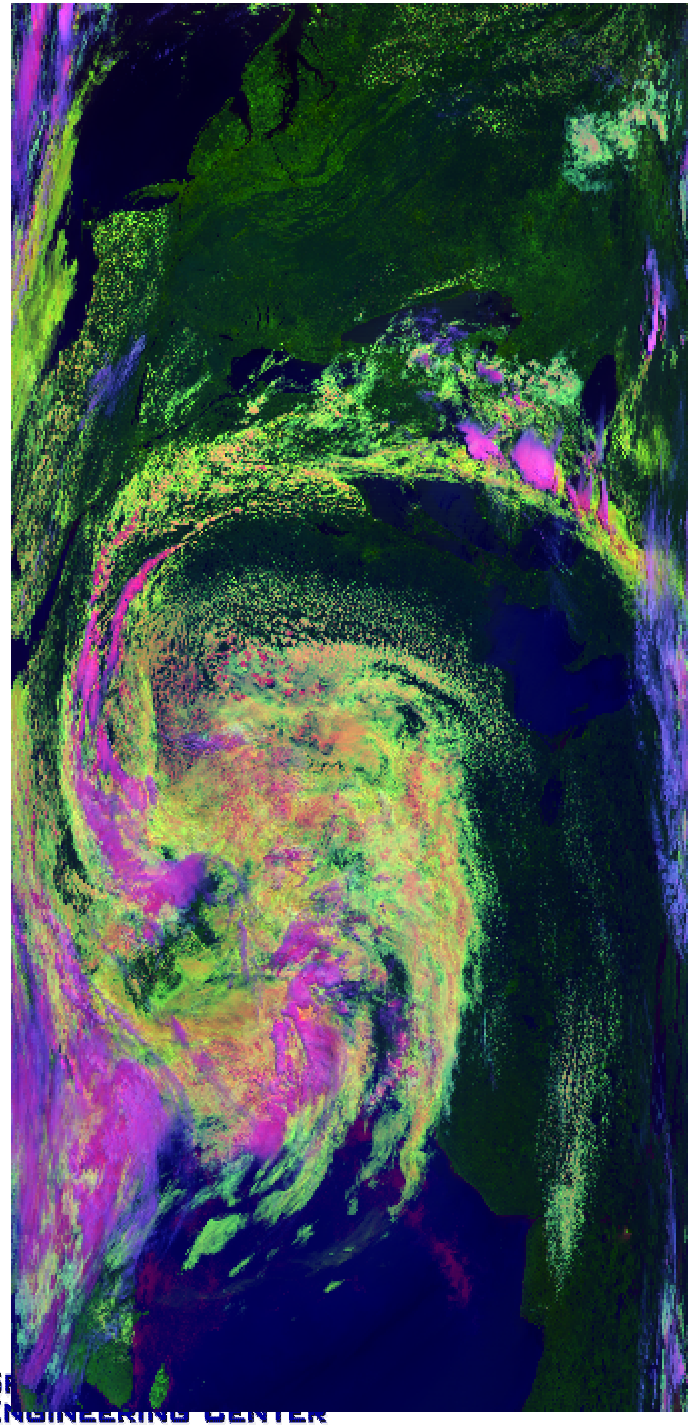
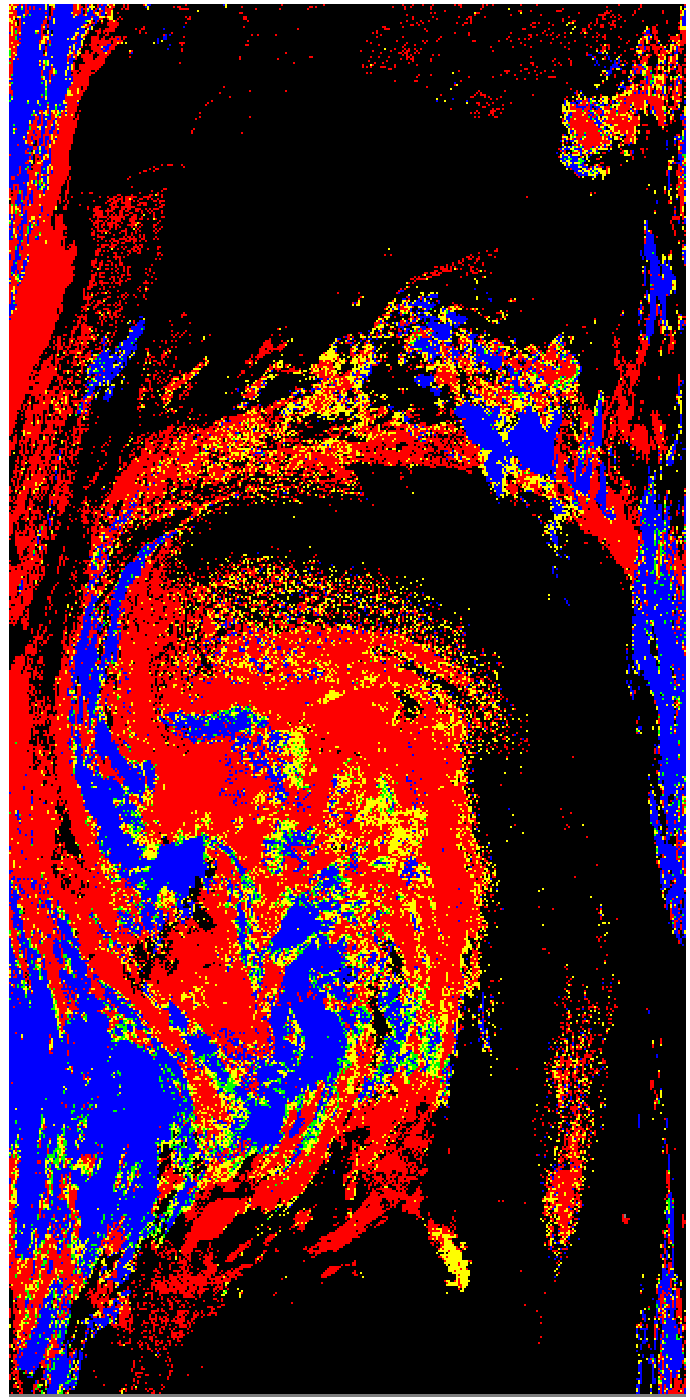


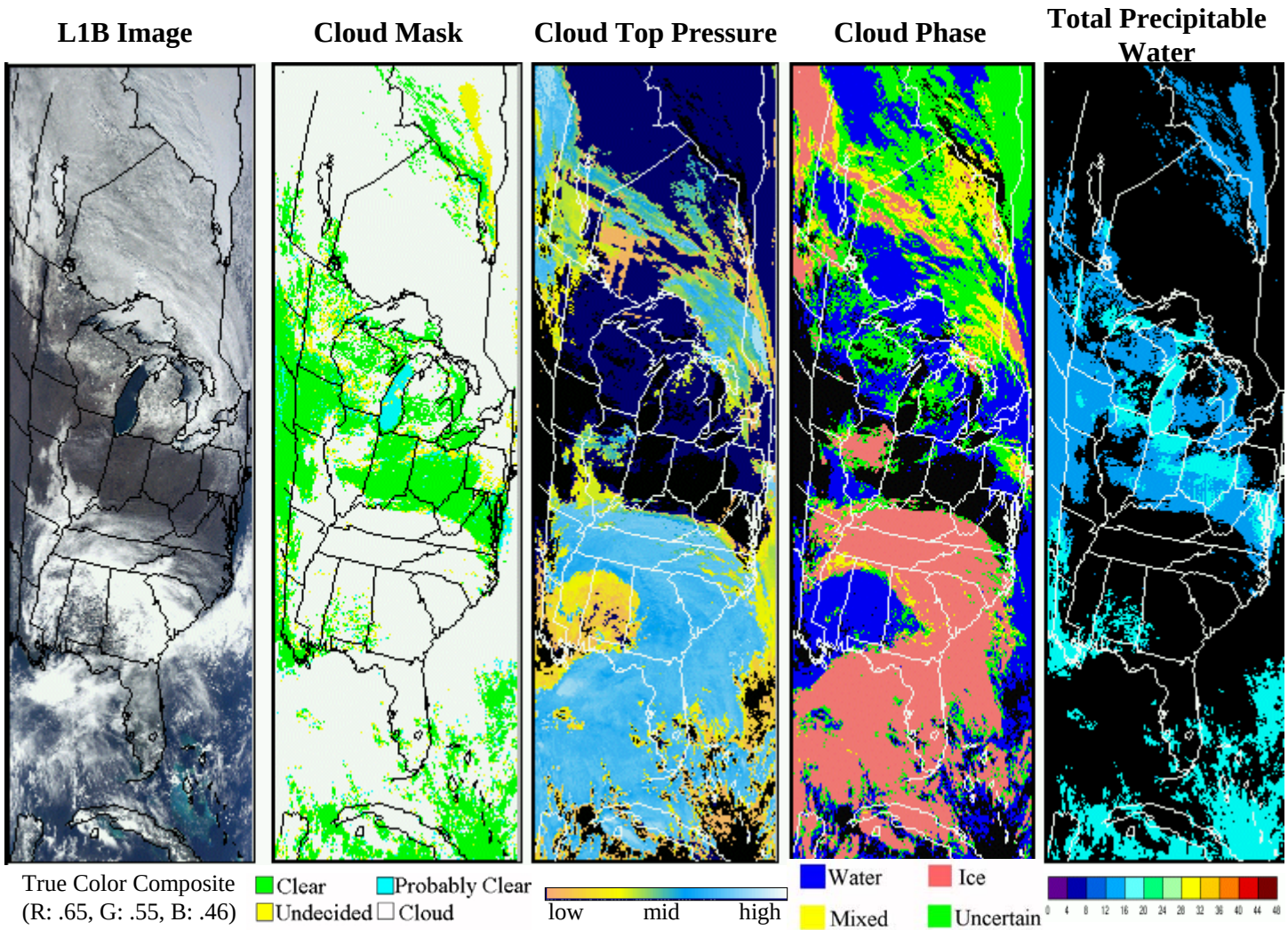
Aqua
← Color
Composite
Red: B1 (.645)
Green: B6 (1.64)
Blue: B31 (11.)

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

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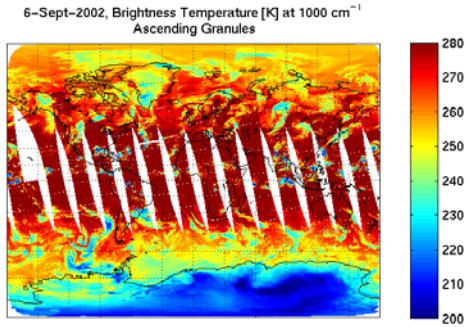
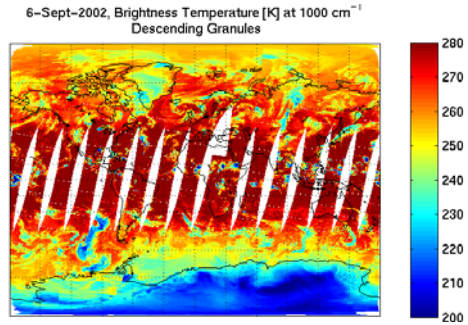
Global Aqua AIRS

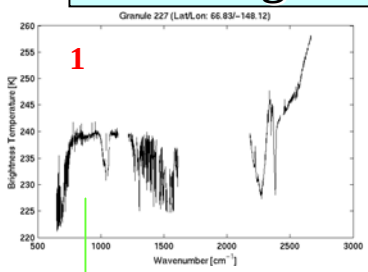
6 September, 2002

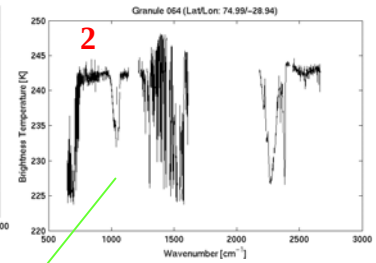
High-spectral Resolution

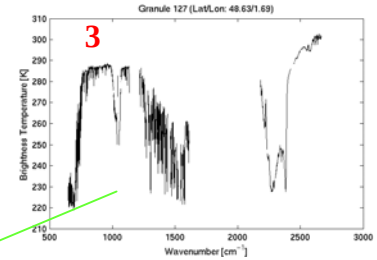
Brightness temperature Images and Spectra

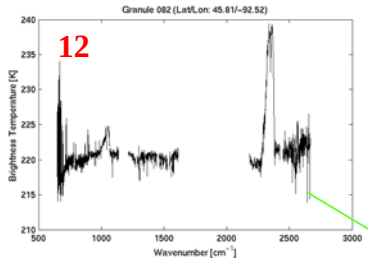


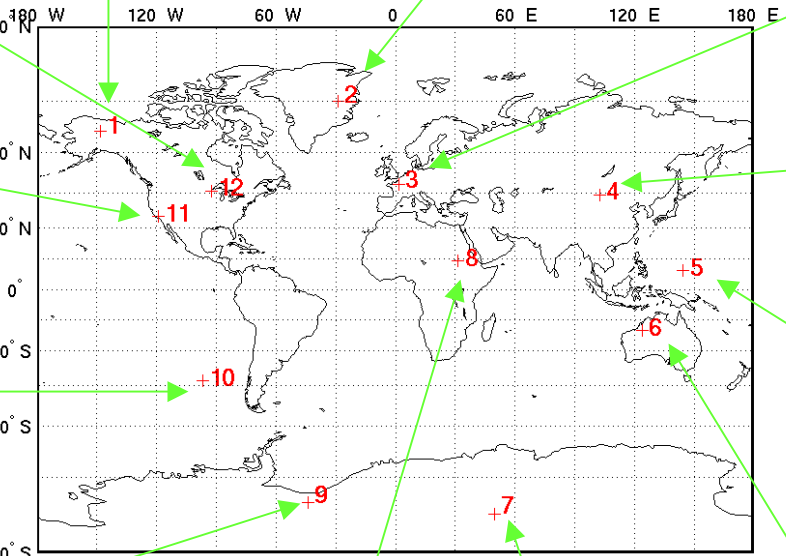


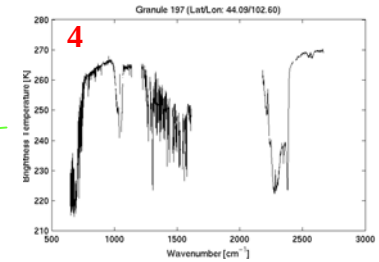


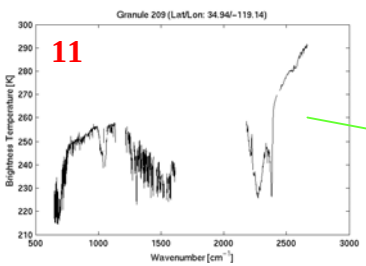


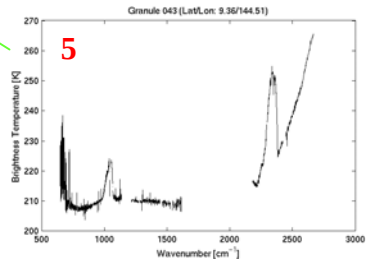


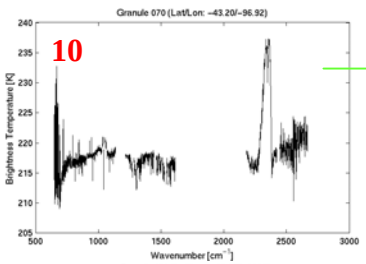


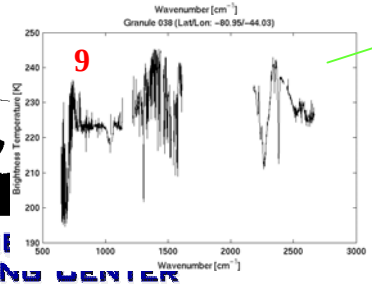


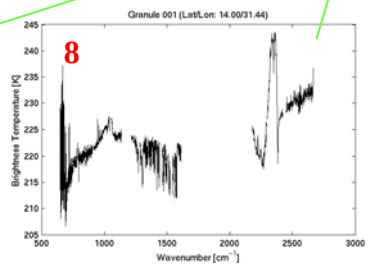


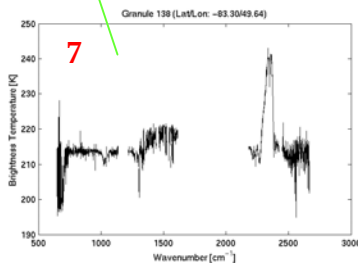


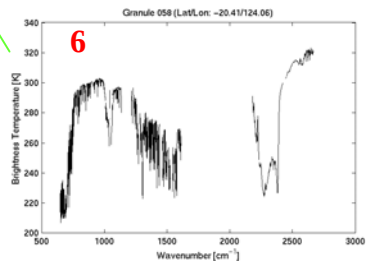












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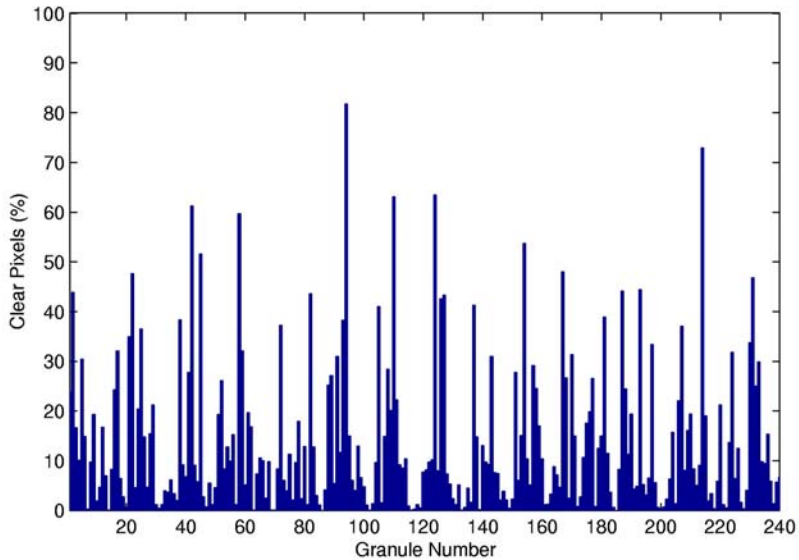
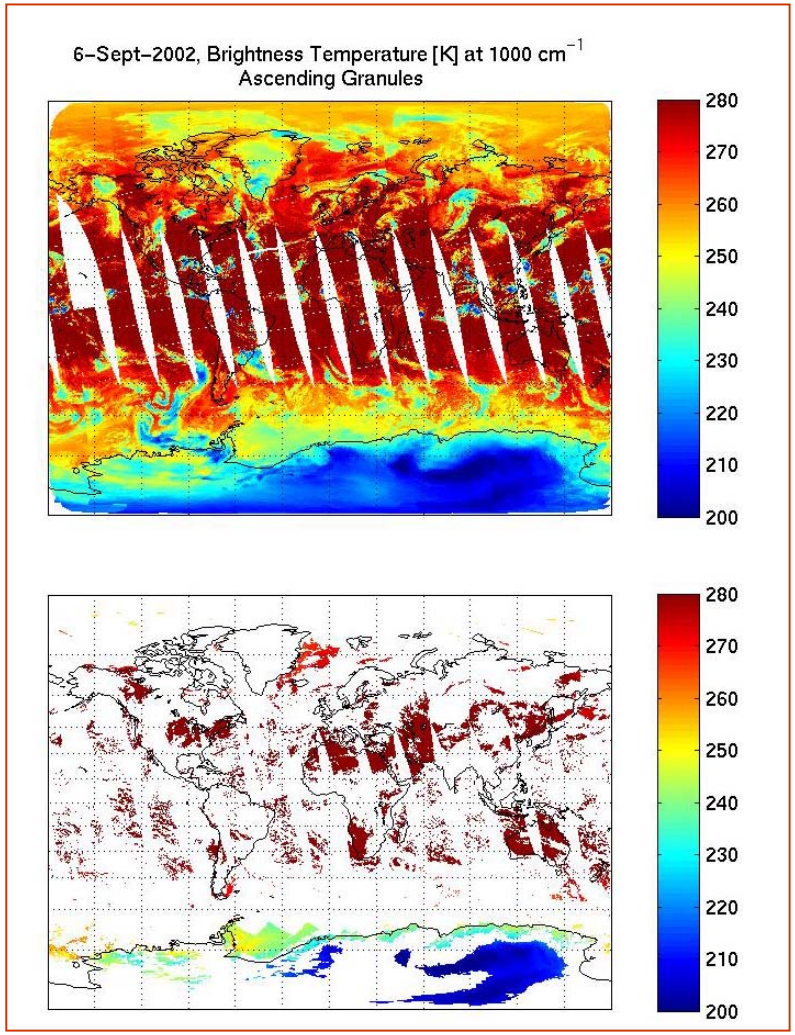
AIRS Clear FOV Determination Using MODIS 1 km Cloud Mask

- 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%





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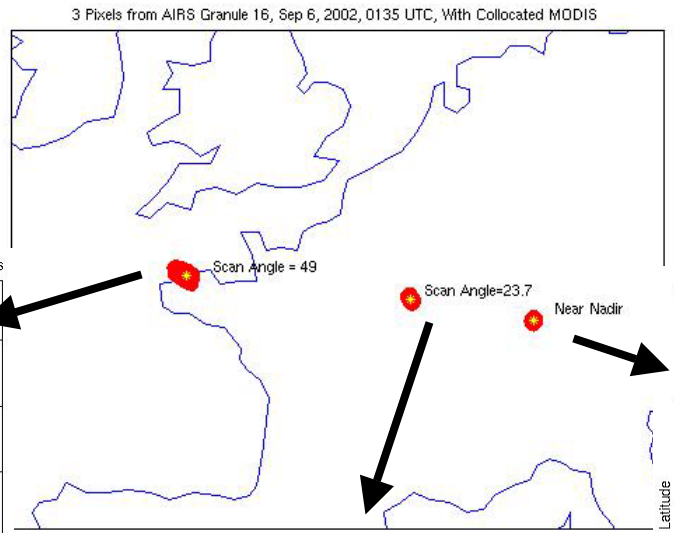
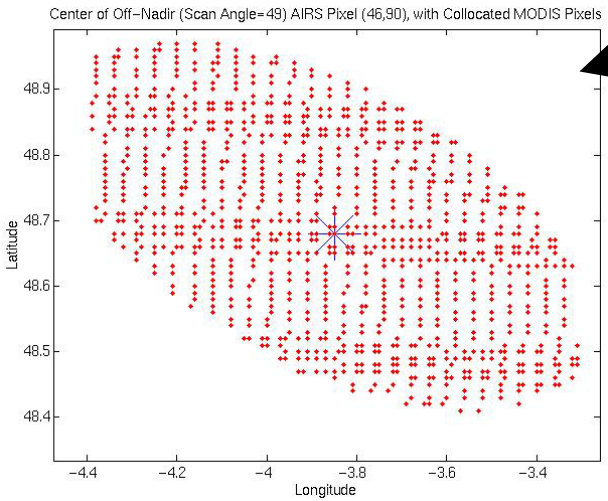
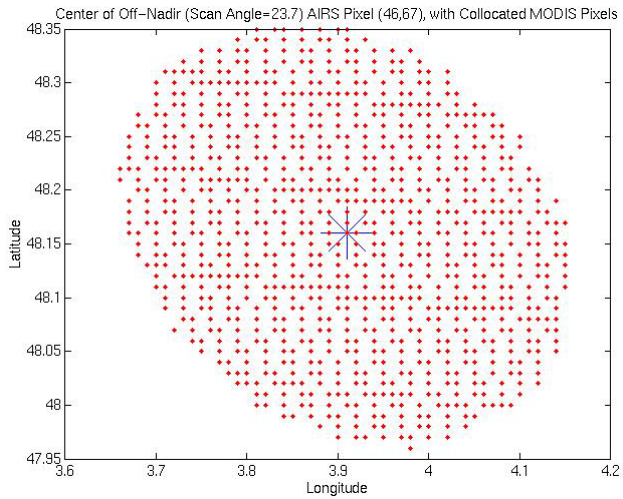
AIRS/MODIS Co-location Example

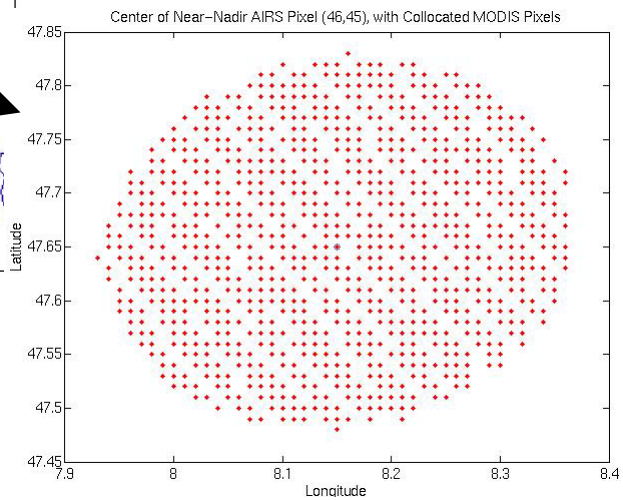




Scan Angle = 49



Scan Angle = 23.7



Nadir

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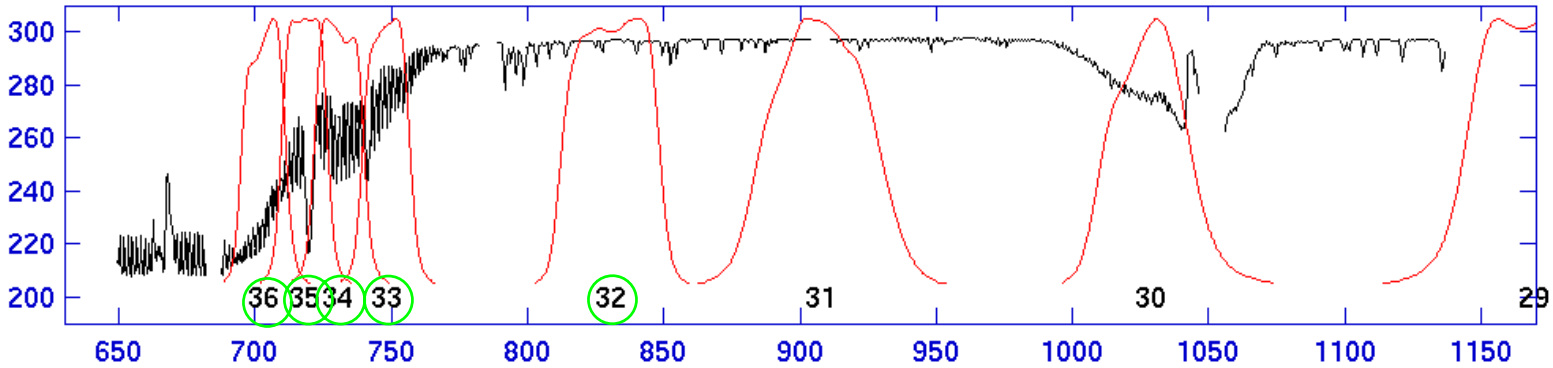
Convolving AIRS with MODIS SRFs



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

Band	1/cm	microns	"convError" = conv1-conv2 (K)
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
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MODIS Vs. AIRS
Good Co-located/Spectral agreement – can be used Synergistically

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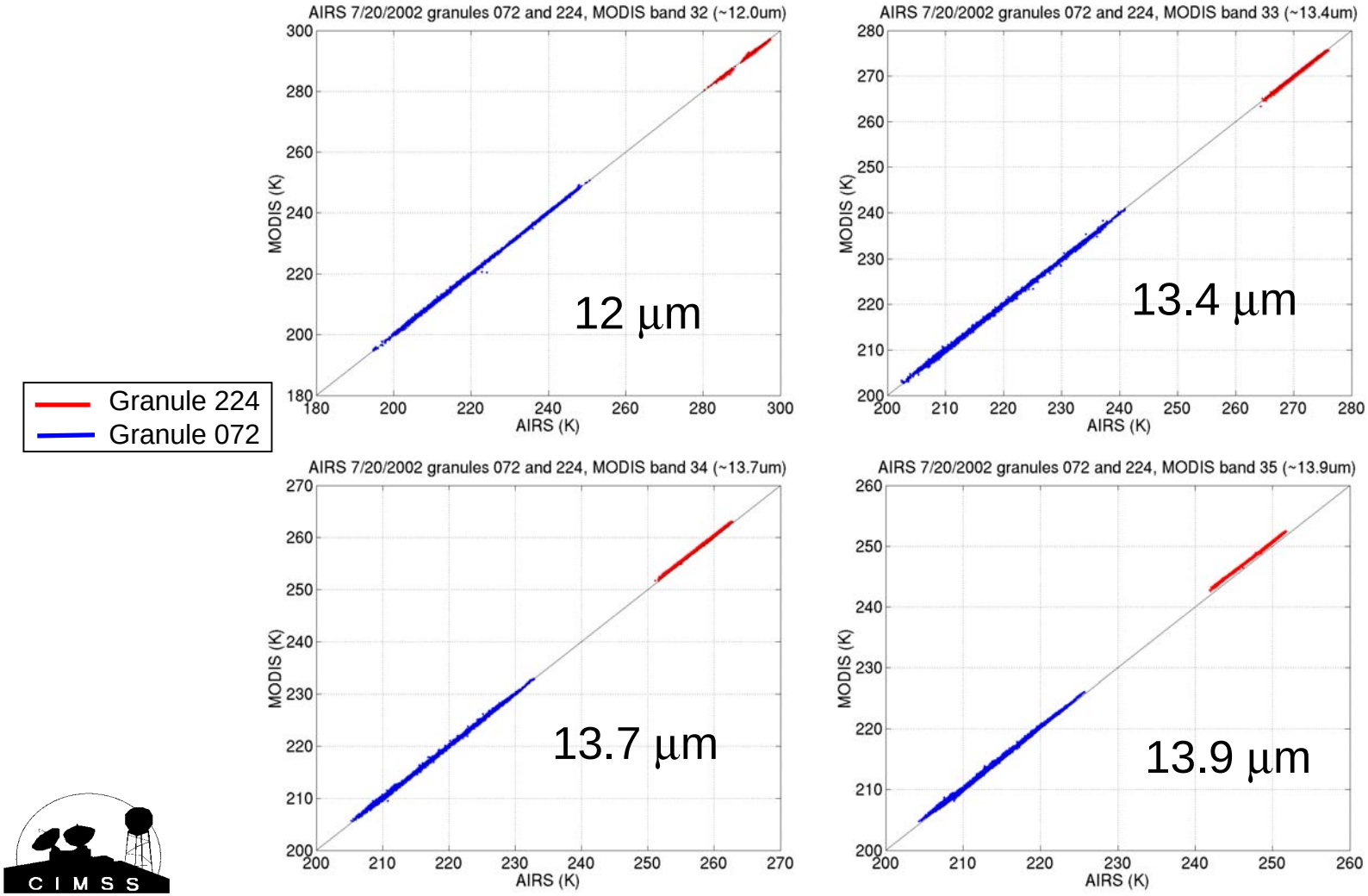

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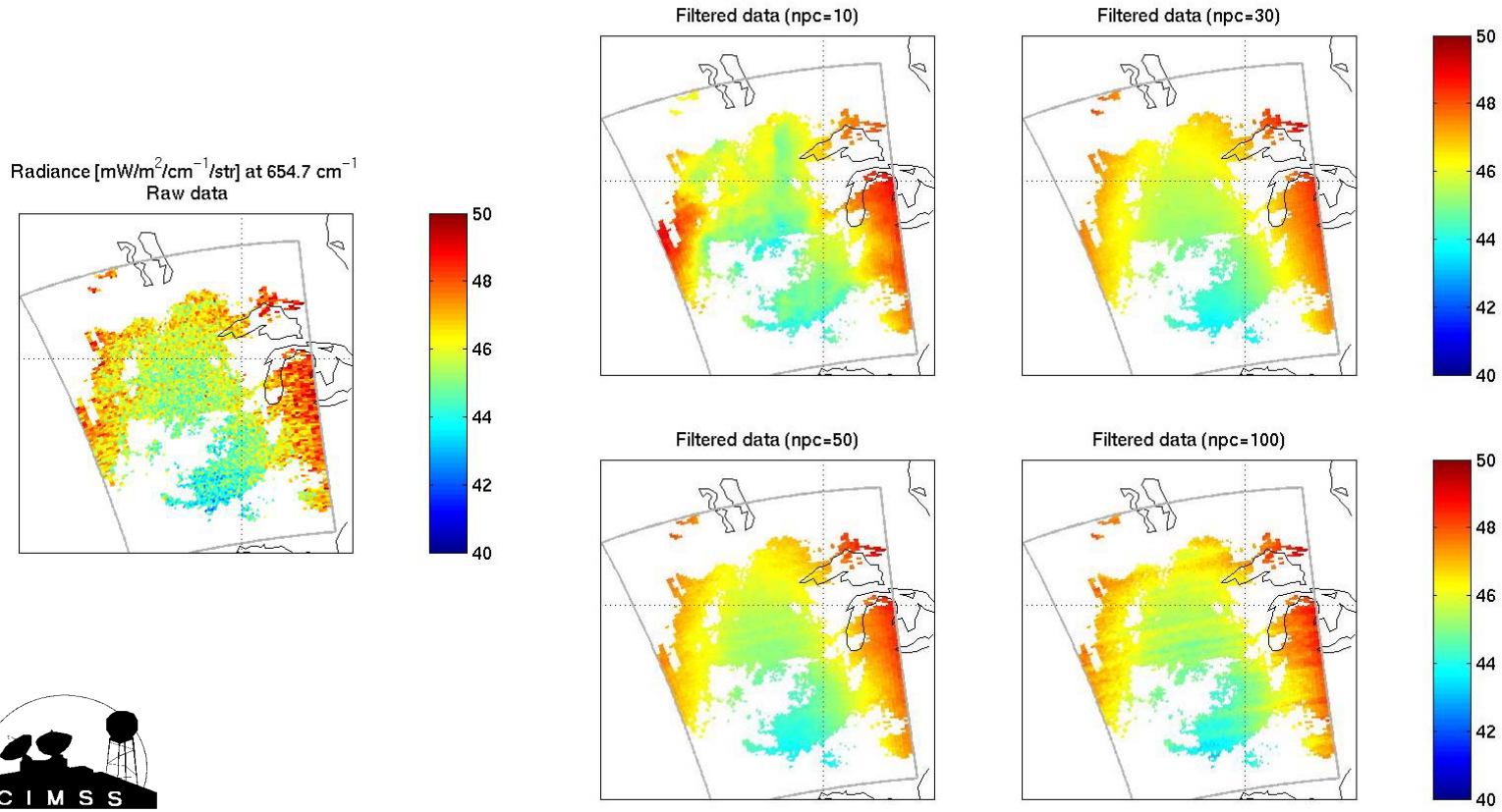
AIRS Measurement Noise Filtering

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



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Cloud Clearing Noise Amplification Factor

$$R_{clear} = R' + \eta_1 (R'-R_1) + \eta_2 (R'-R_2) + \ldots + \eta_K (R'-R_K)$$

Need guess of clear radiances to solve the ηs iteratively

(K+1) FOVs are required to solve for R_{clear} with K cloud formations.

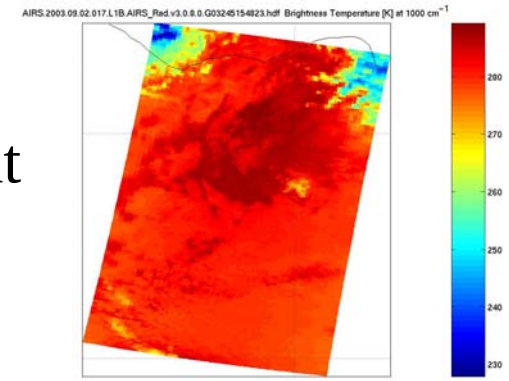
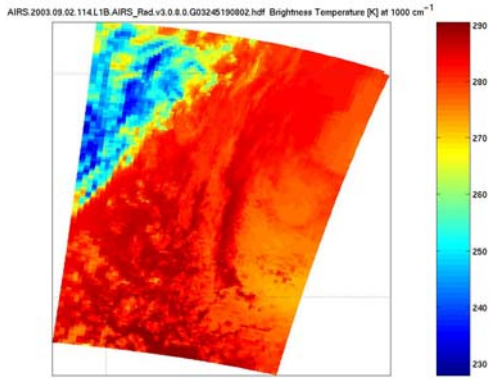
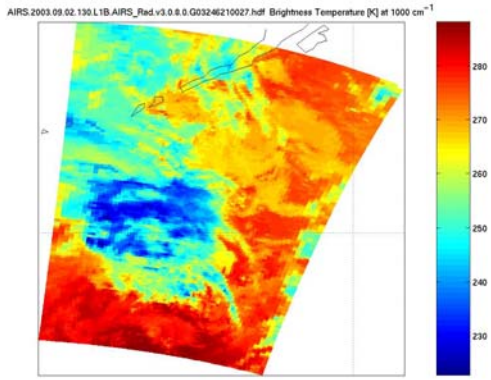
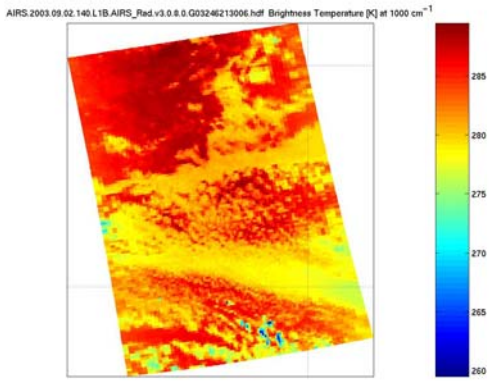
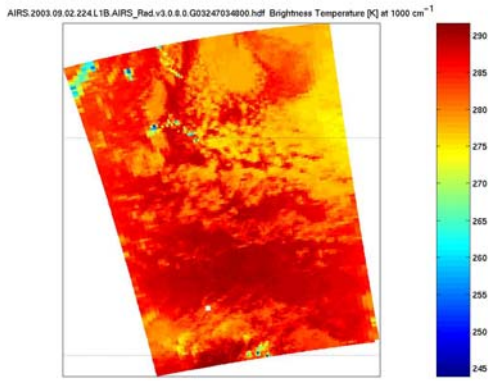
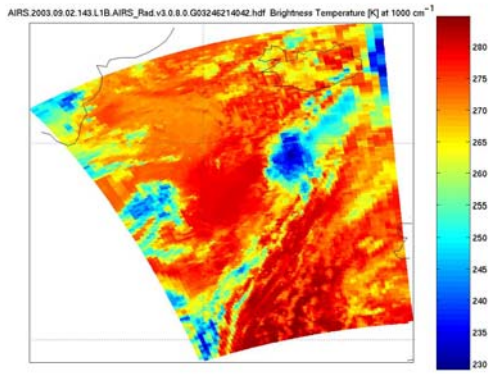
Reconstructed radiance **R_{clear} contains an amplified random (measurement) noise σ':**

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

σ: random (measurement) noise of radiances $R_1, R_2, \ldots, R_{K+1}$

Operational AIRS/AMSU Cloud Clearing Error Estimates

Good Performance Over Ocean Most of Time

	Tropic	Mid-Latitude	Sub-Polar
Night			
Day			

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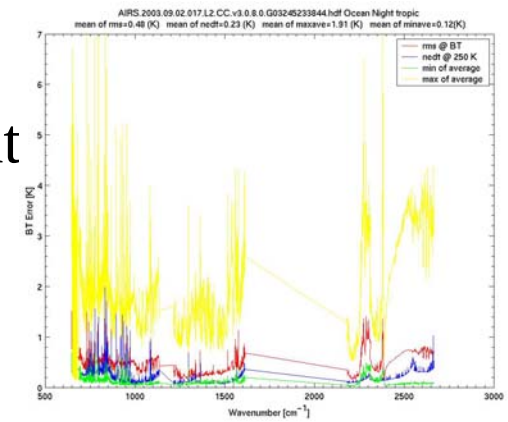
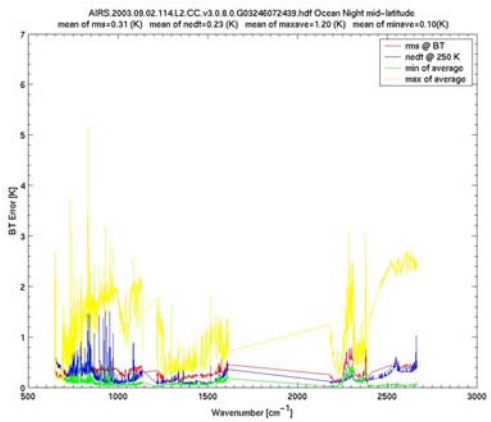
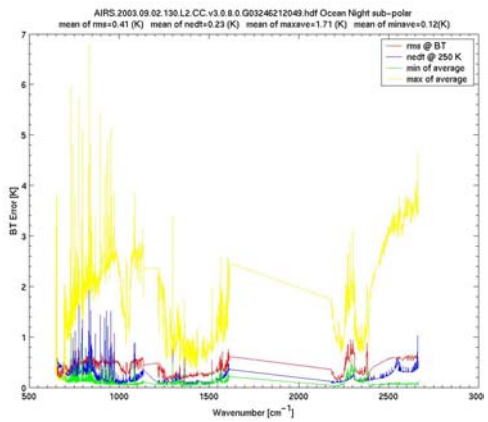
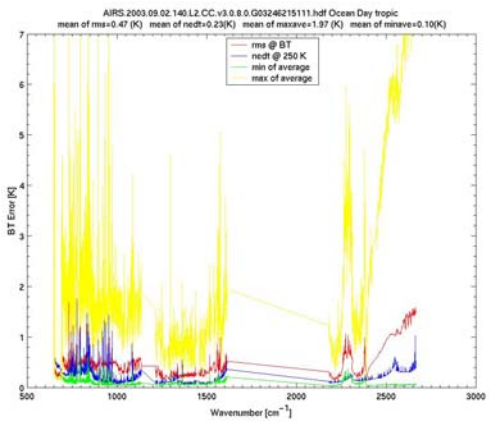
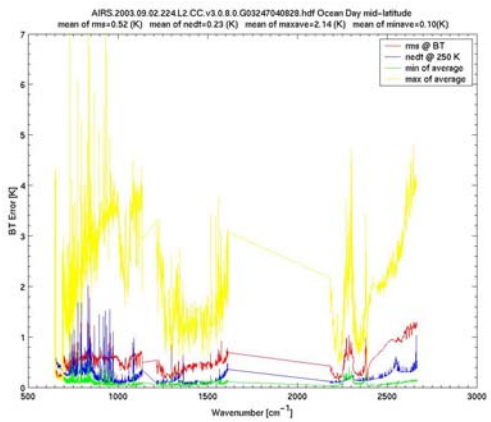
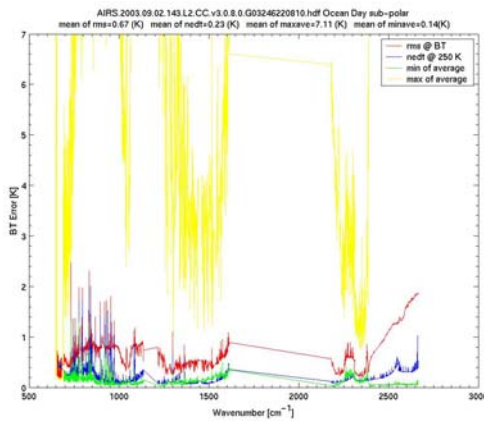
Operational AIRS/AMSU Cloud Clearing Error Estimates

Good Performance Over Ocean Most of Time

	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

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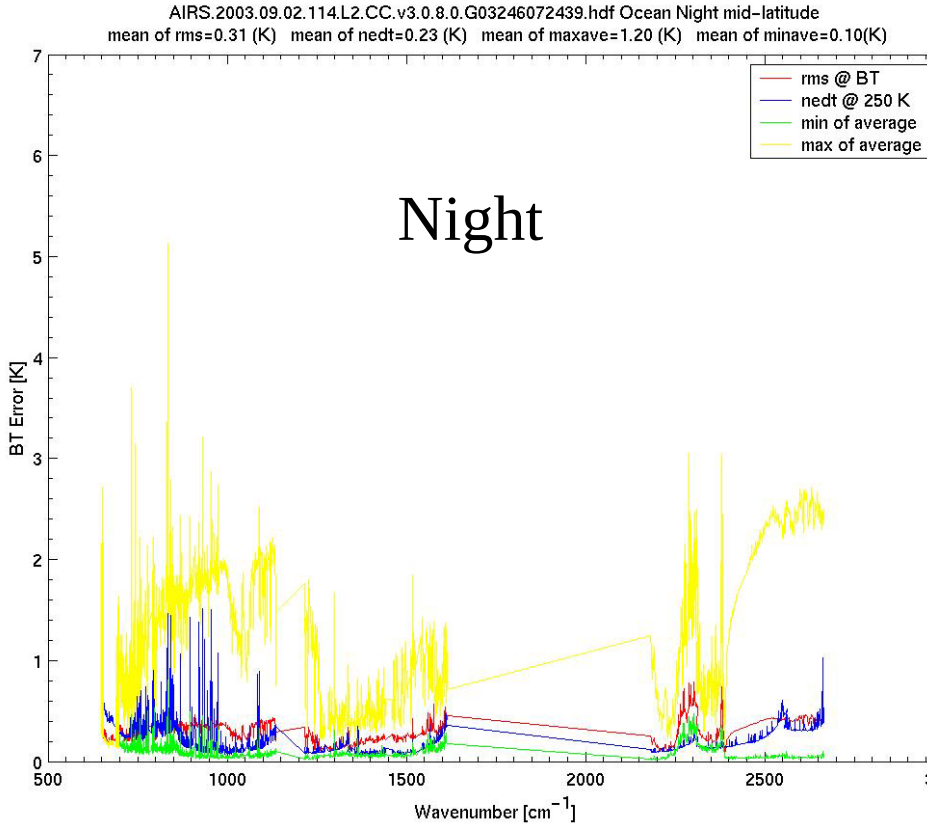
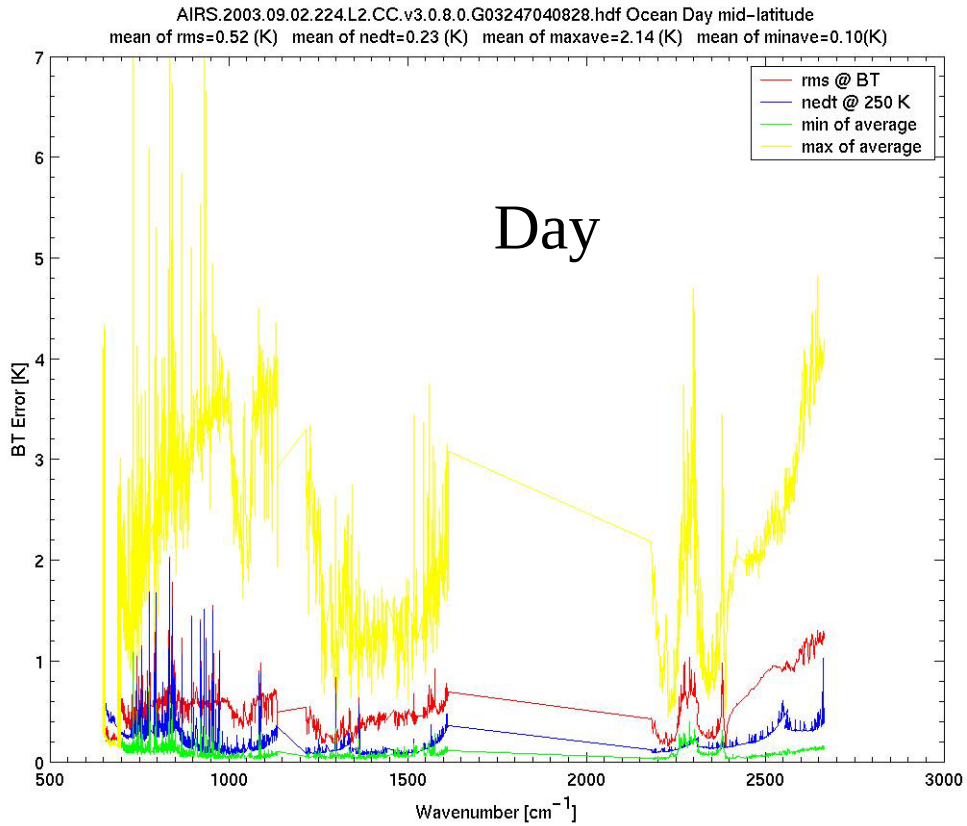
Operational AIRS/AMSU Cloud Clearing Error Estimates

Good Performance Over Ocean Most of Time

Mid-Latitude





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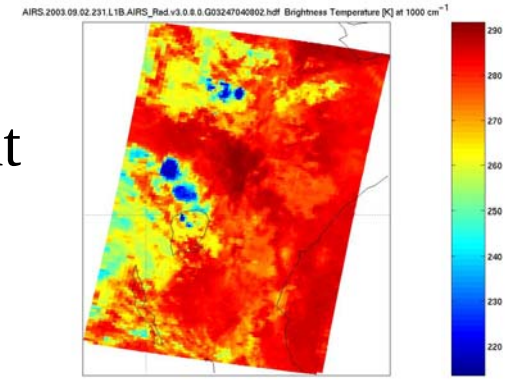
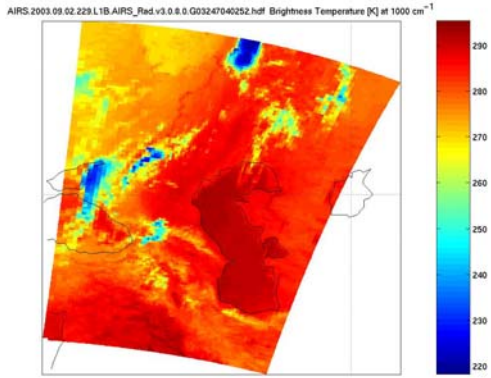
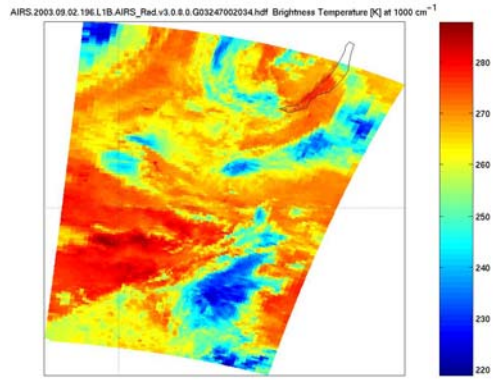
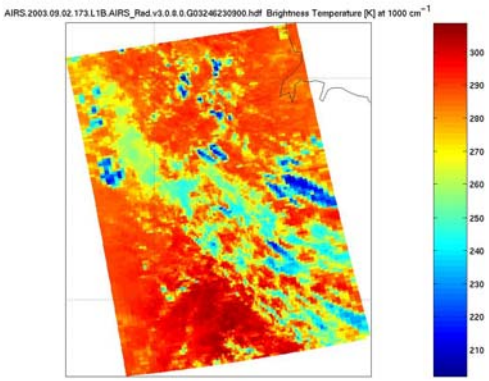
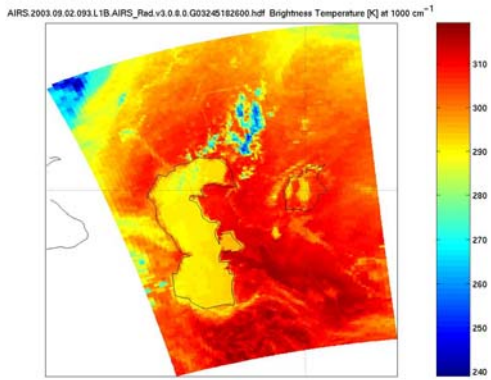
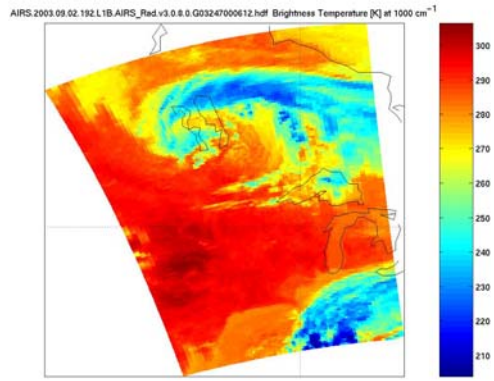
Operational AIRS/AMSU Cloud Clearing Error Estimates

Problematic Over Some Land Cases

	Tropic	Mid-Latitude	Sub-Polar
Night			
Day			

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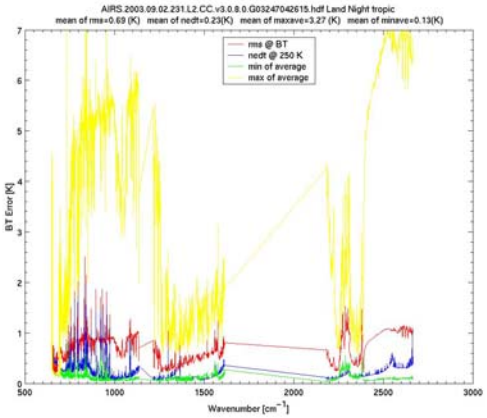
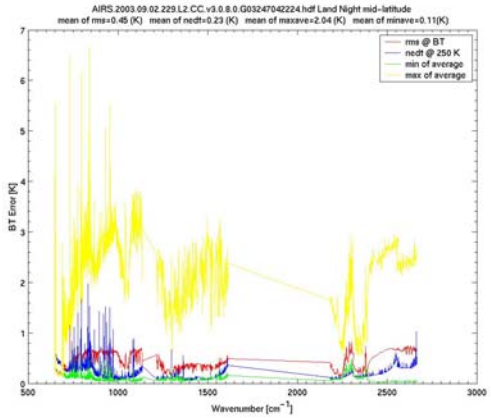
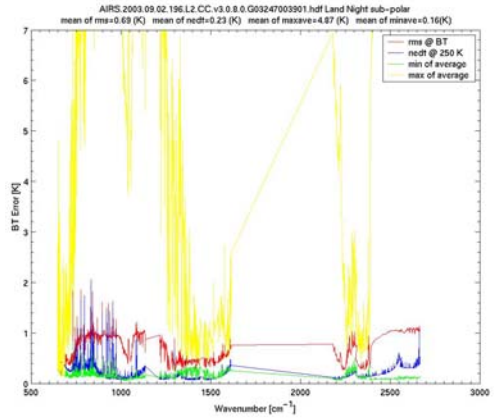
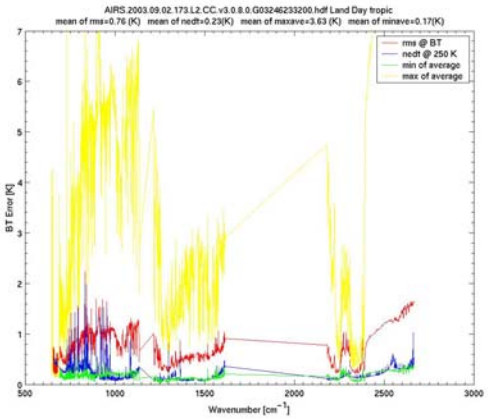
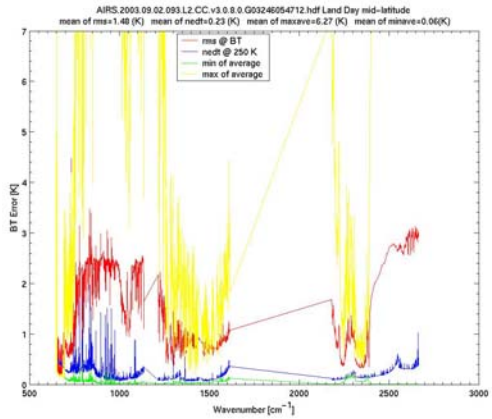
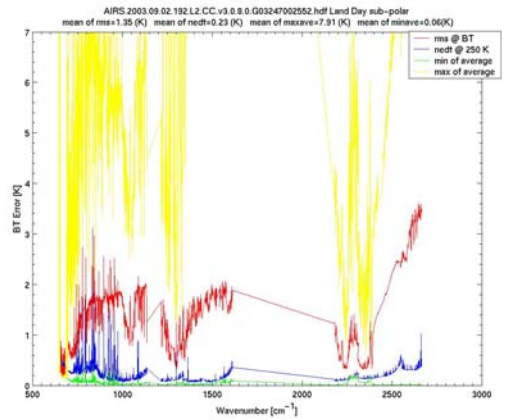
Operational AIRS/AMSU Cloud Clearing Error Estimates

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

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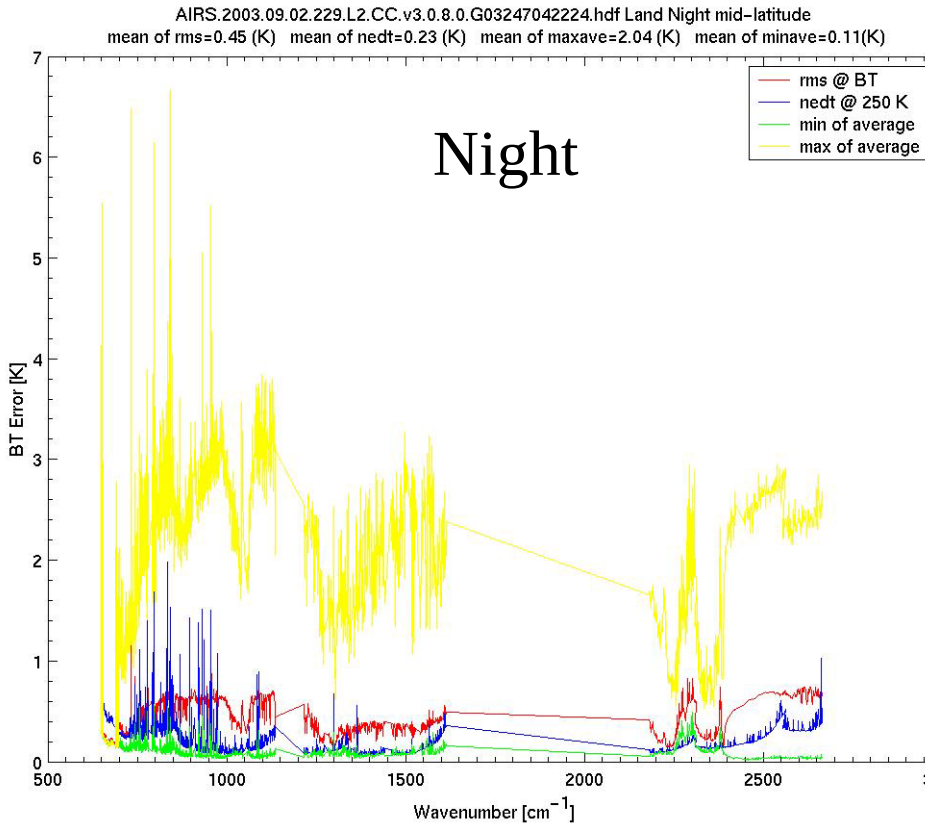
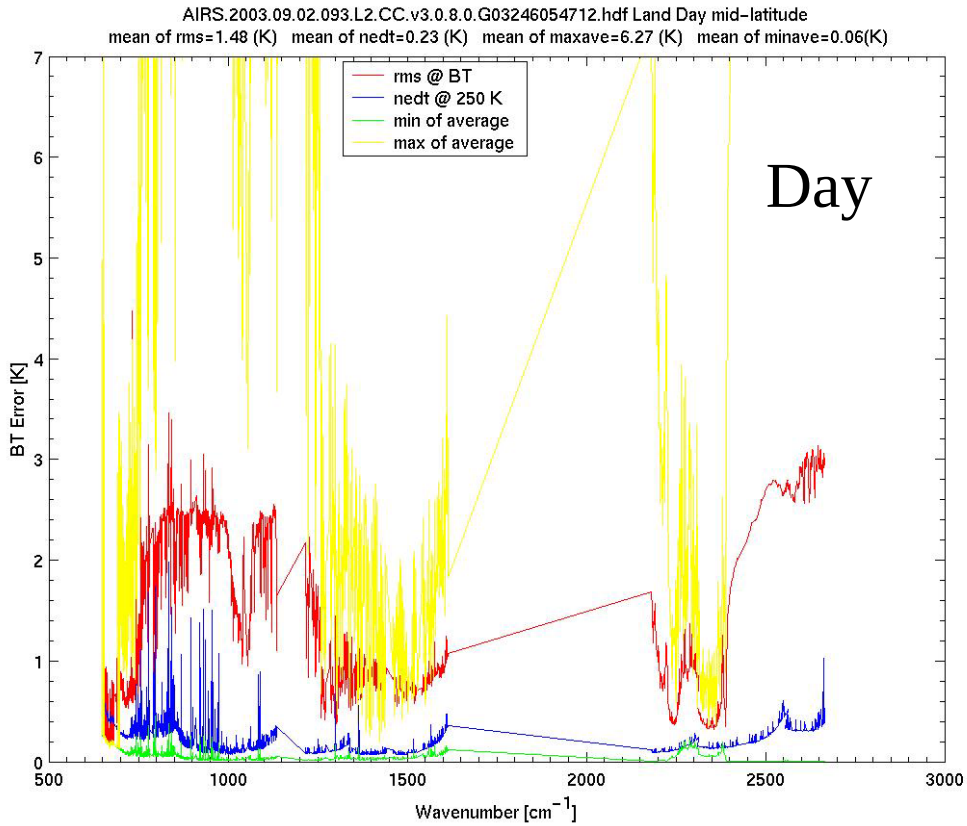
Operational AIRS/AMSU Cloud Clearing Error Estimates

Problematic Over Some Land Cases

Mid-Latitude





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

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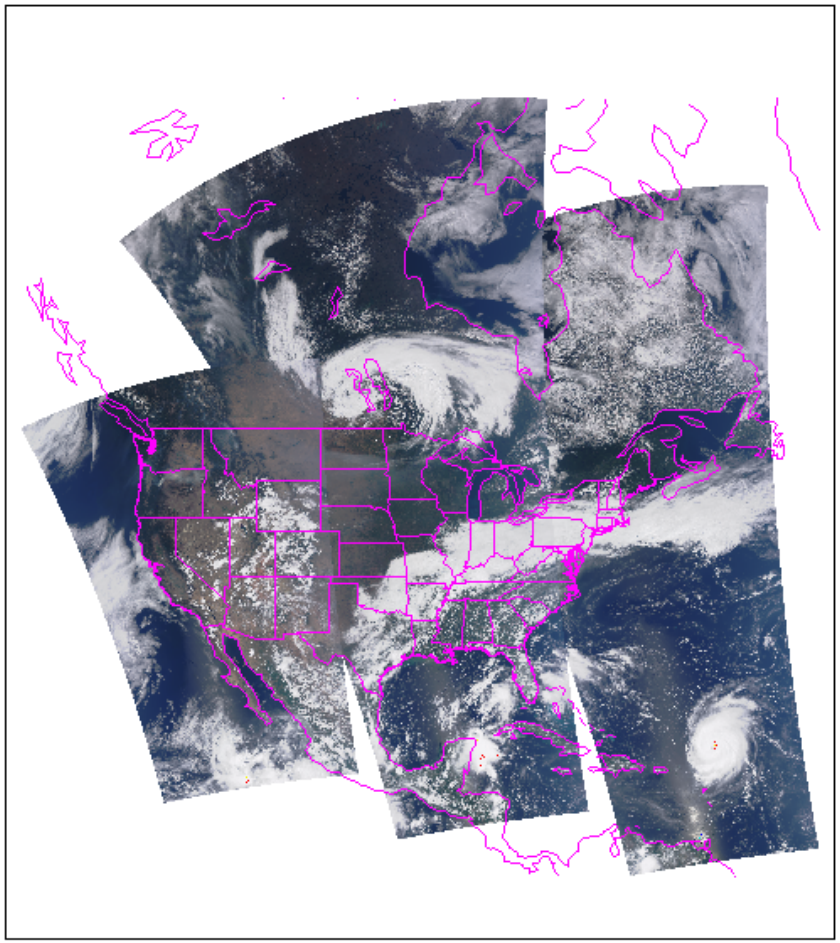
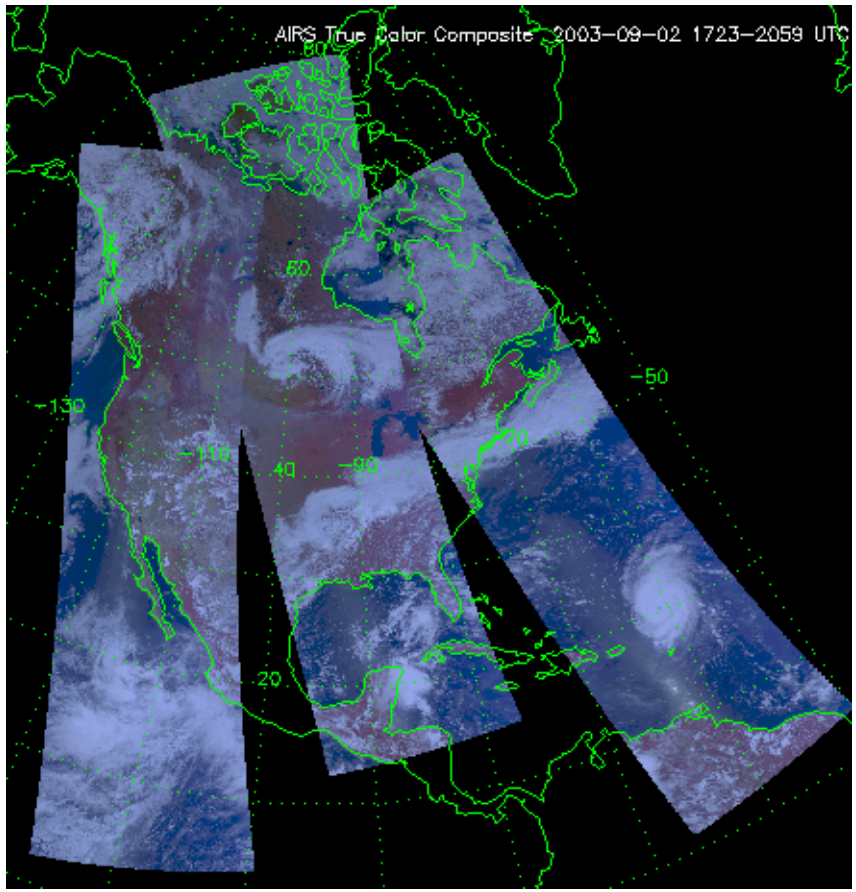
MODIS and AIRS Color Composite Images

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

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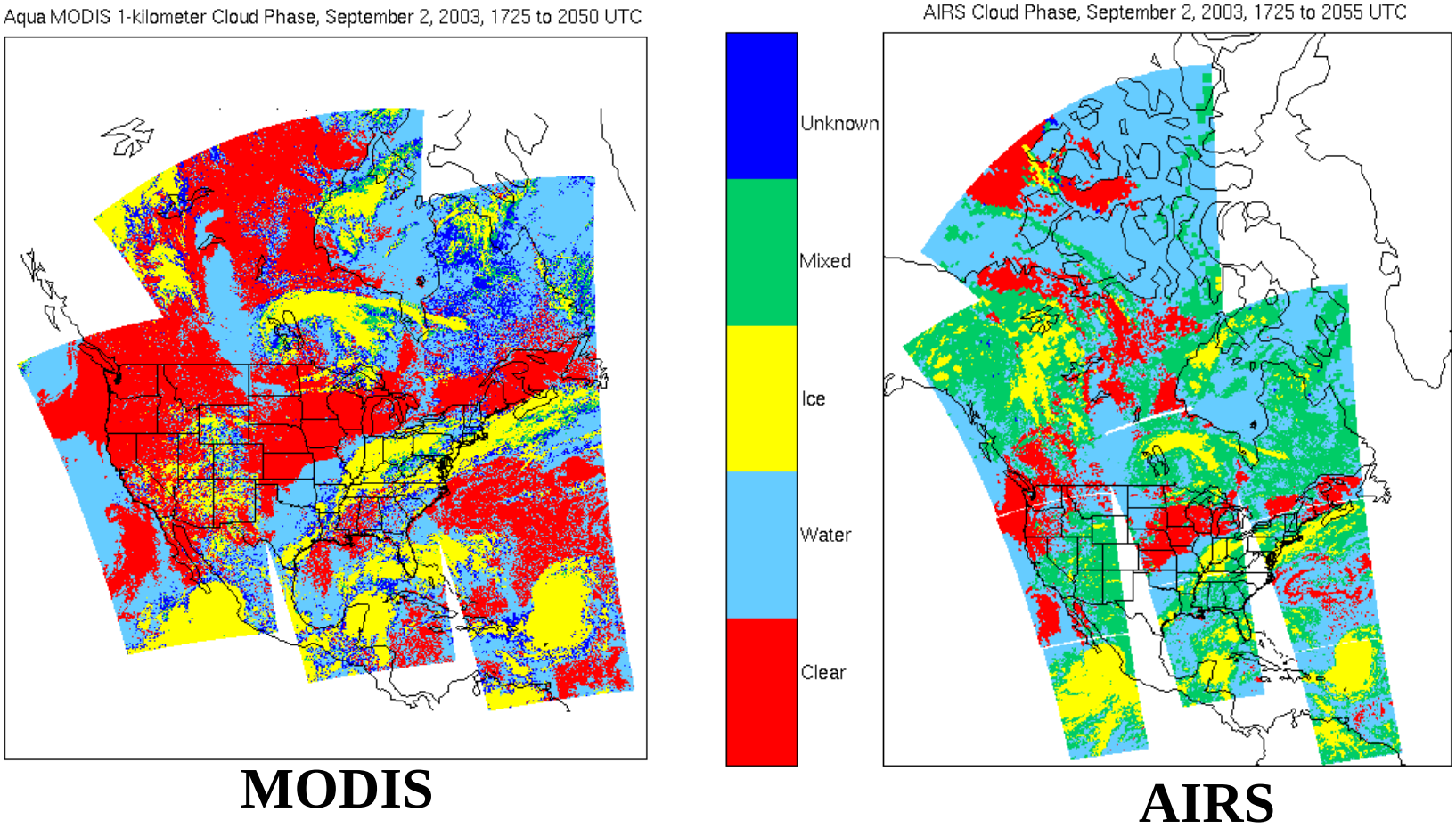
MODIS (1 km*) and AIRS (~14 km*) Cloud Phase Images



MODIS **AIRS**

More mixed phase clouds occur in AIRS FOV/FOR

*Resolution is specified as nadir view only

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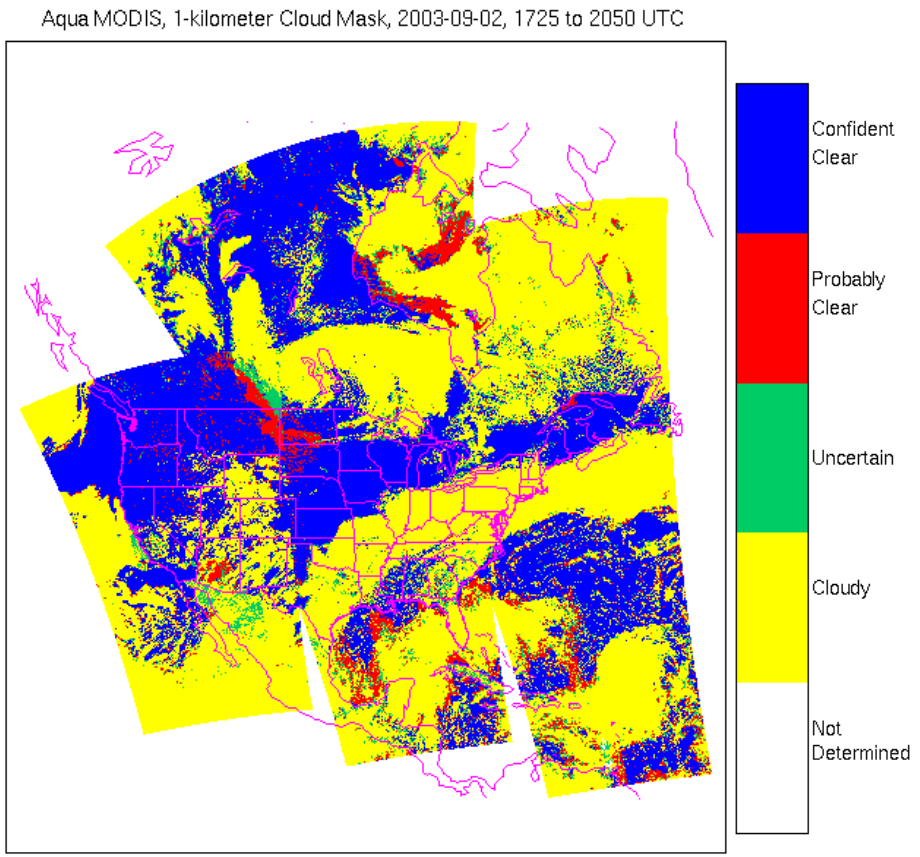
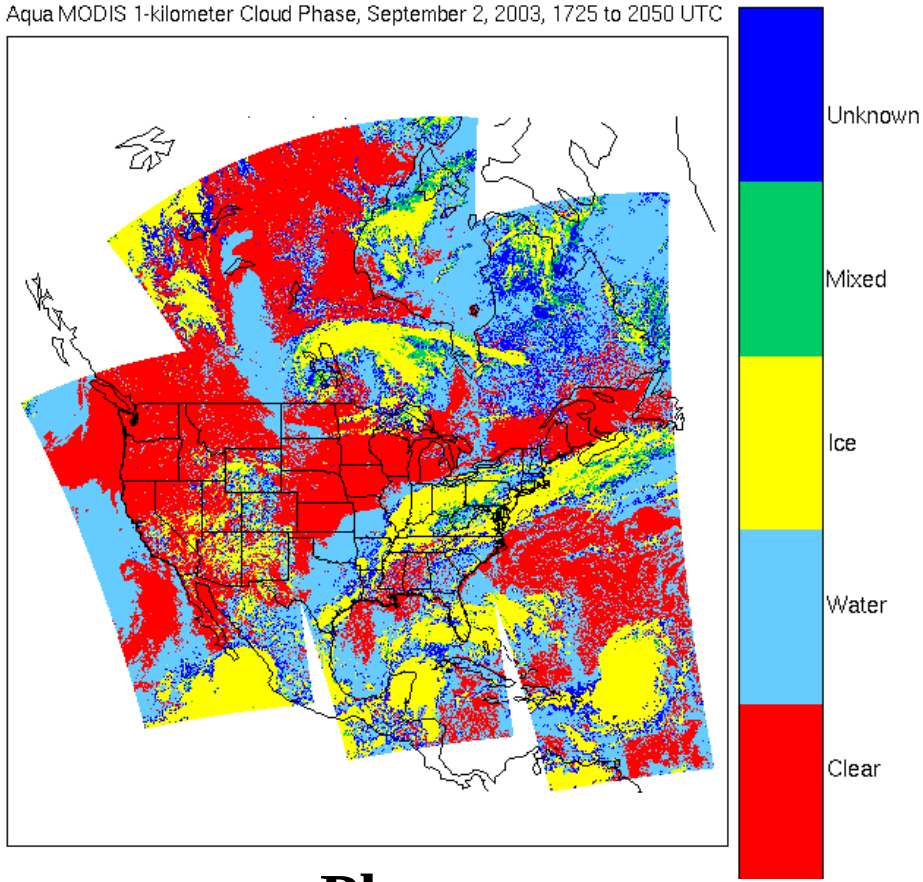
MODIS 1 km Cloud Mask & Phase Images



Mask



Phase

@ 1 km Nadir Resolution

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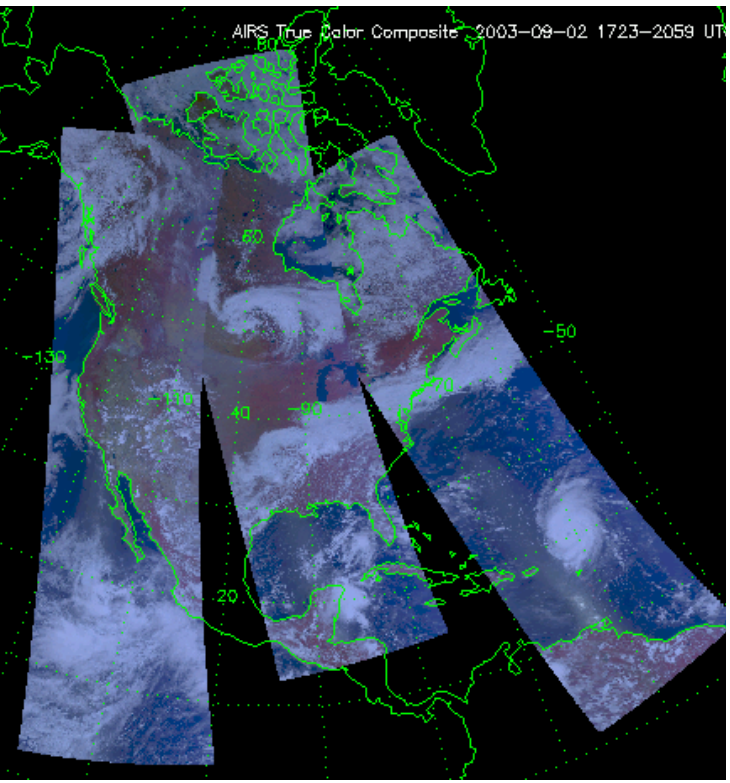
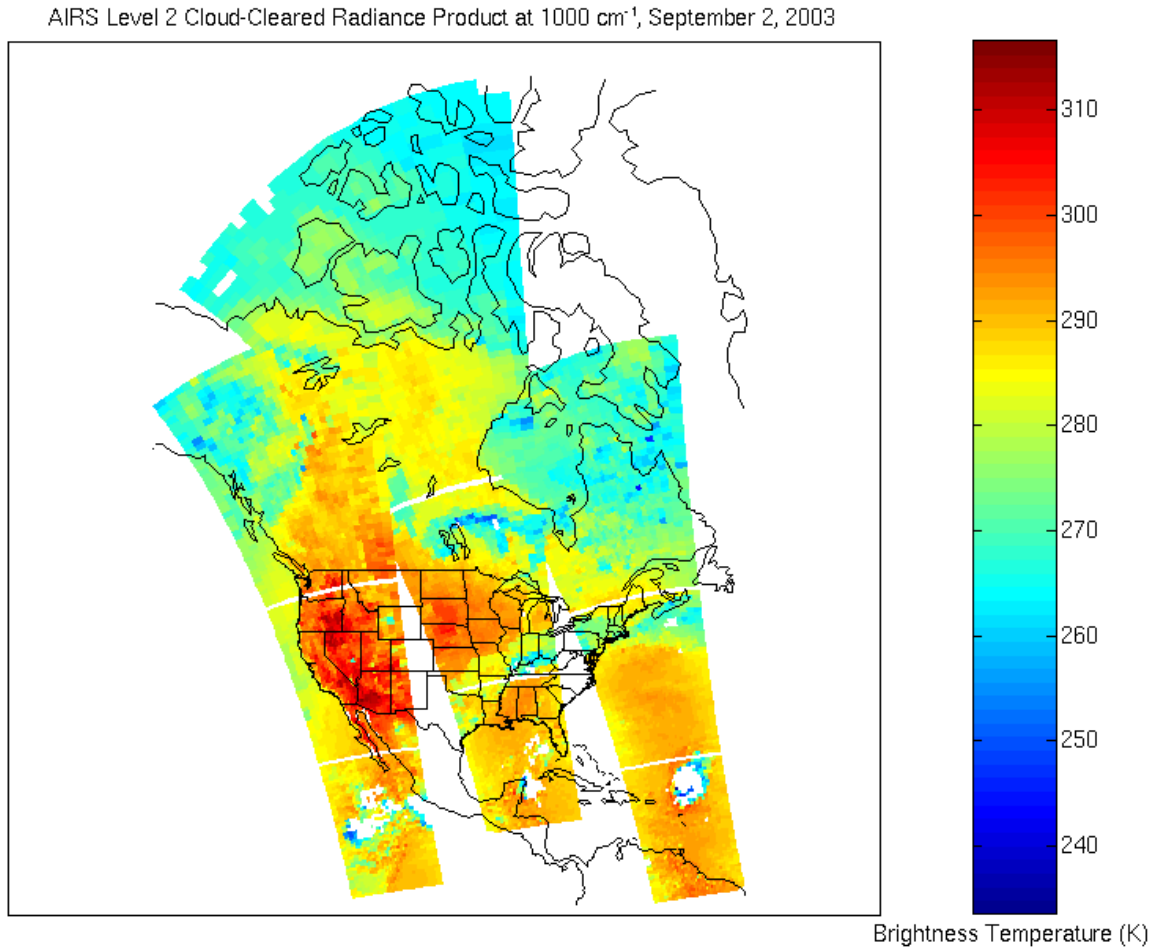
AIRS Color Composite and Cloud Cleared Window Channel Images





Operational AIRS Cloud Cleared Tb Image

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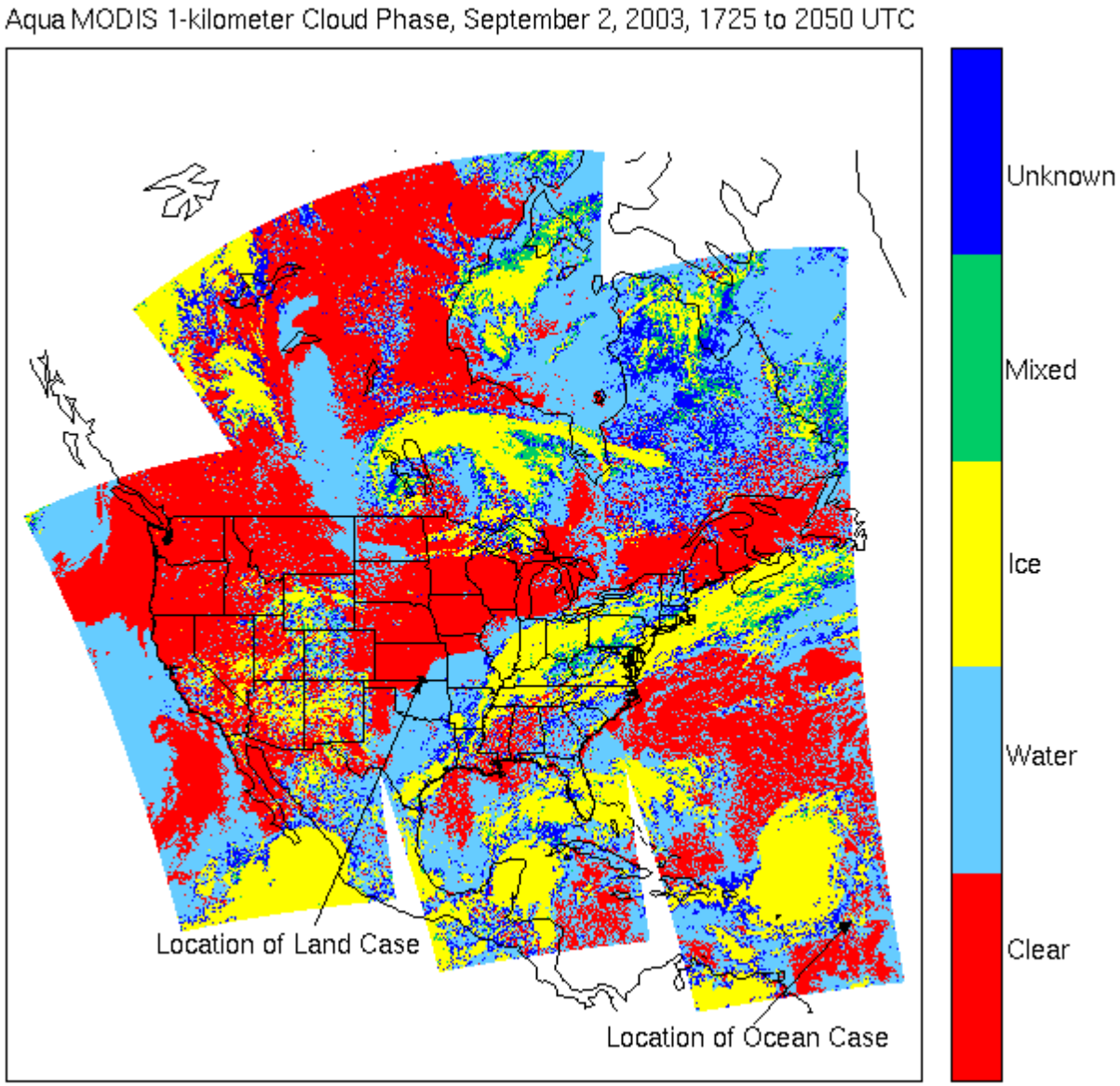
MODIS/AIRS Synergistic Cloud Clearing Examples



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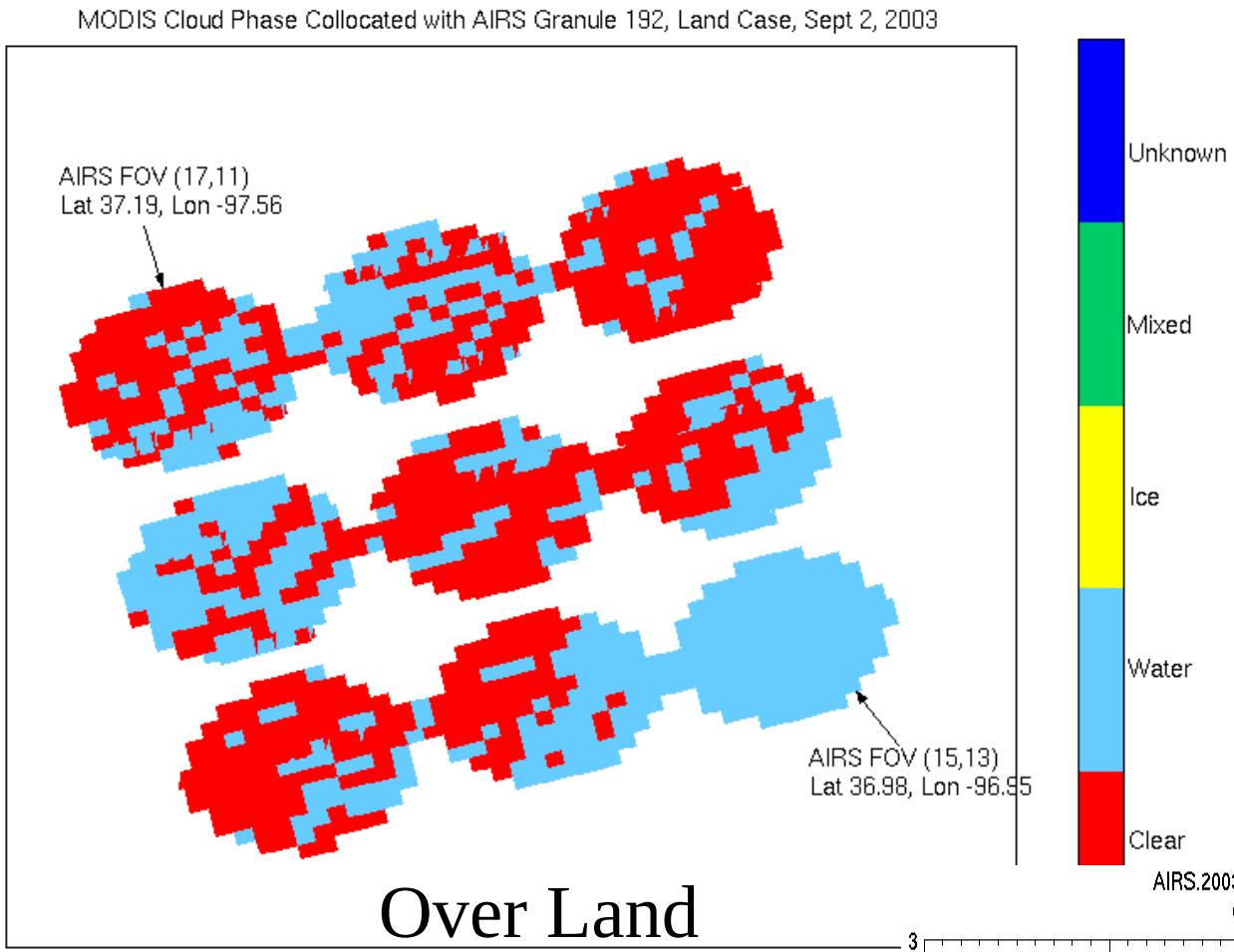
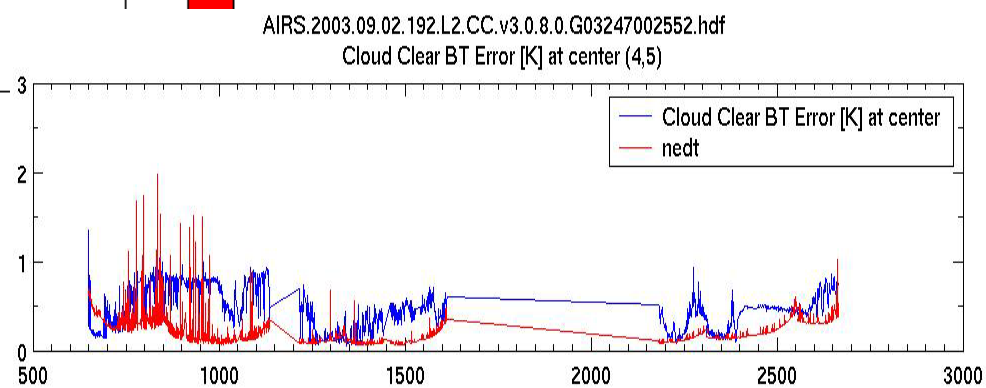
MODIS/AIRS Co-located Cloud Phase Image



Over Land



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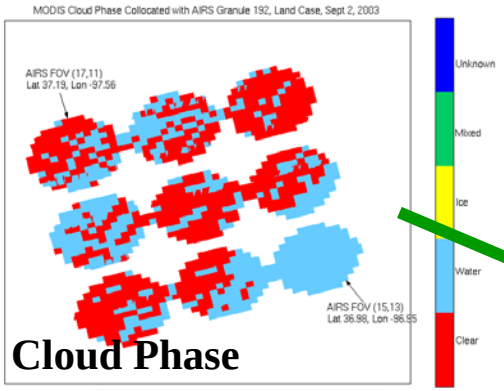
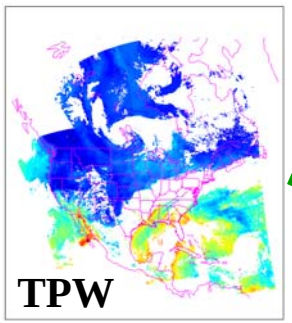
MODIS/AIRS Co-located TWP & Skin Temperature



Cloud Phase



TPW

Skin Tem.

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

Mean TPW = 1.68 cm
Mean Skin Temp = 295.84 K

Mean TPW = 1.81 cm
Mean Skin Temp = 295.37 K

Mean TPW = 1.83 cm
Mean Skin Temp = 295.24 K

Mean TPW = 1.92 cm
Mean Skin Temp = 295.33 K

Mean TPW = 1.68 cm
Mean Skin Temp = 295.16 K

Mean TPW = 1.61 cm
Mean Skin Temp = 295.24 K

Mean TPW Not Available
Mean Skin Temp Not Available

Mean TPW = 2.11 cm
Mean Skin Temp = 295.54 K

Mean TPW = 1.86 cm
Mean Skin Temp = 295.34 K

$\delta TPW = 0.5$ cm
$\delta Tskin = 0.68K$

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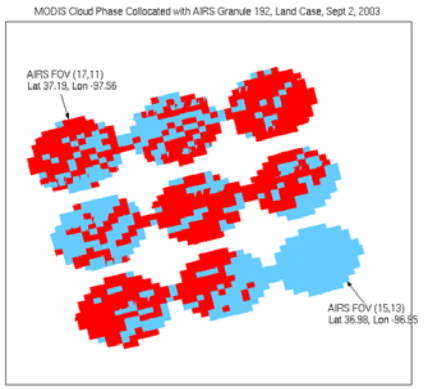
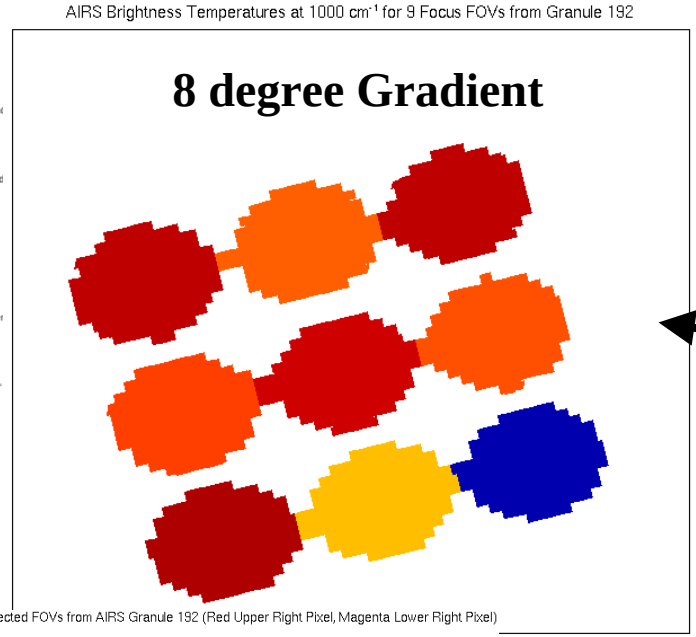
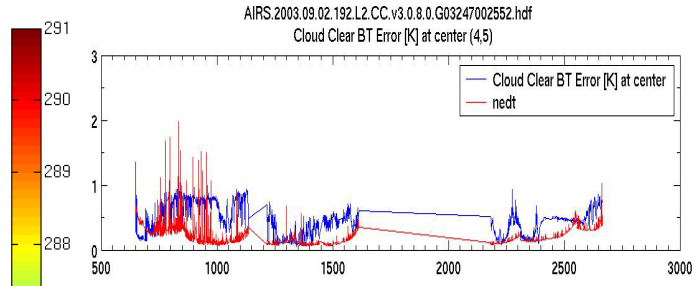
AIRS Single FOV Window Channel Brightness Temperature Variations

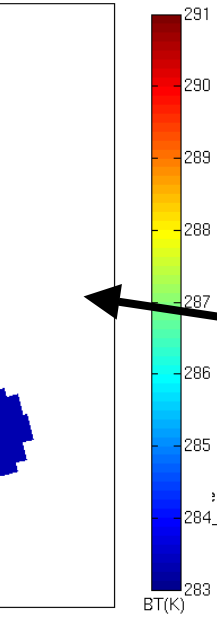


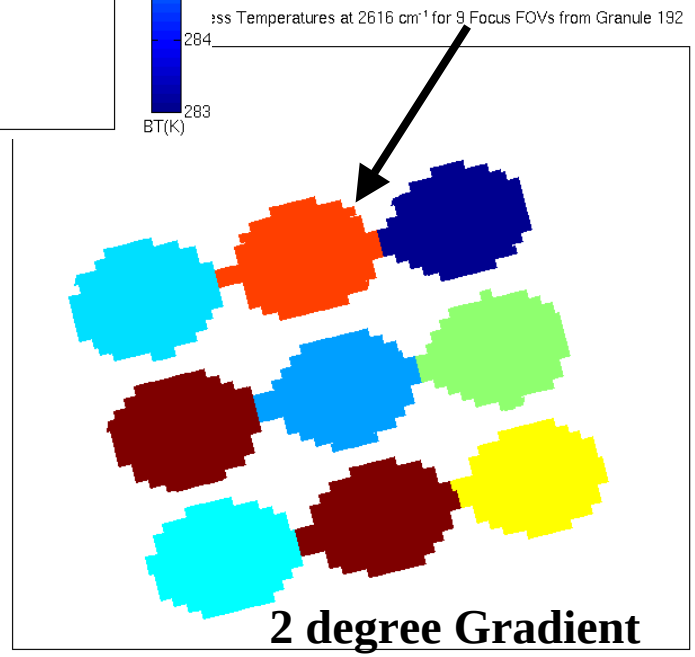
Cloud Phase

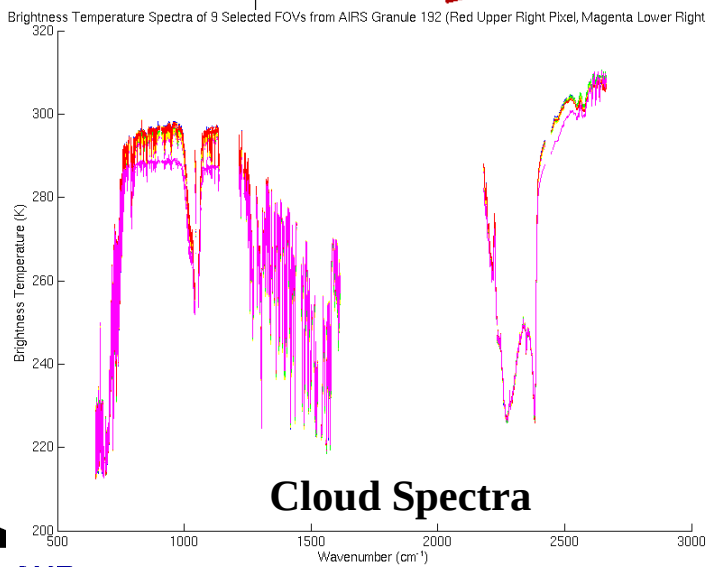




Window BT
1000 cm^{-1}
&
2616 cm^{-1}







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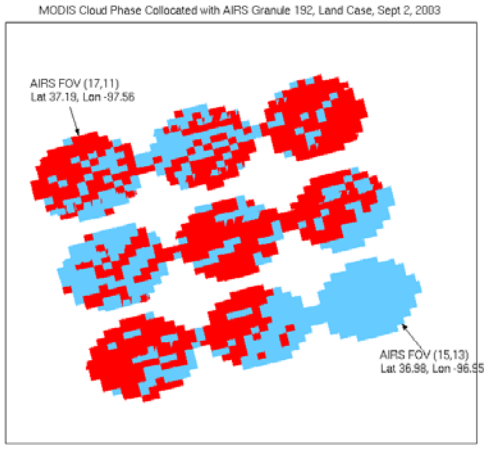
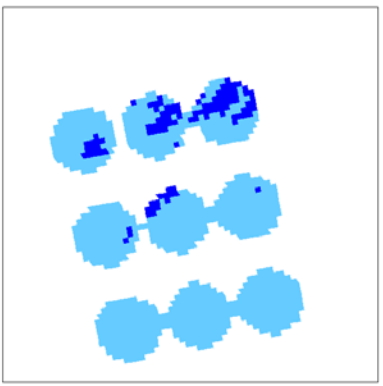
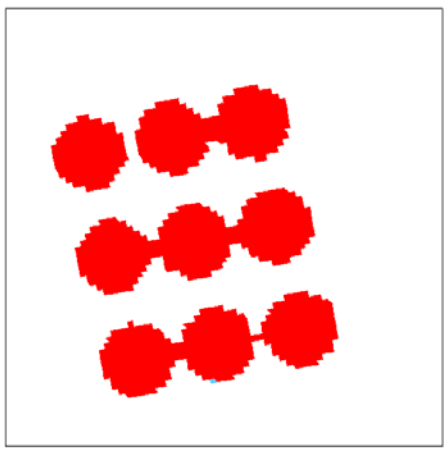
AIRS FOR (3 by 3) Cloud Clearing Error Examples

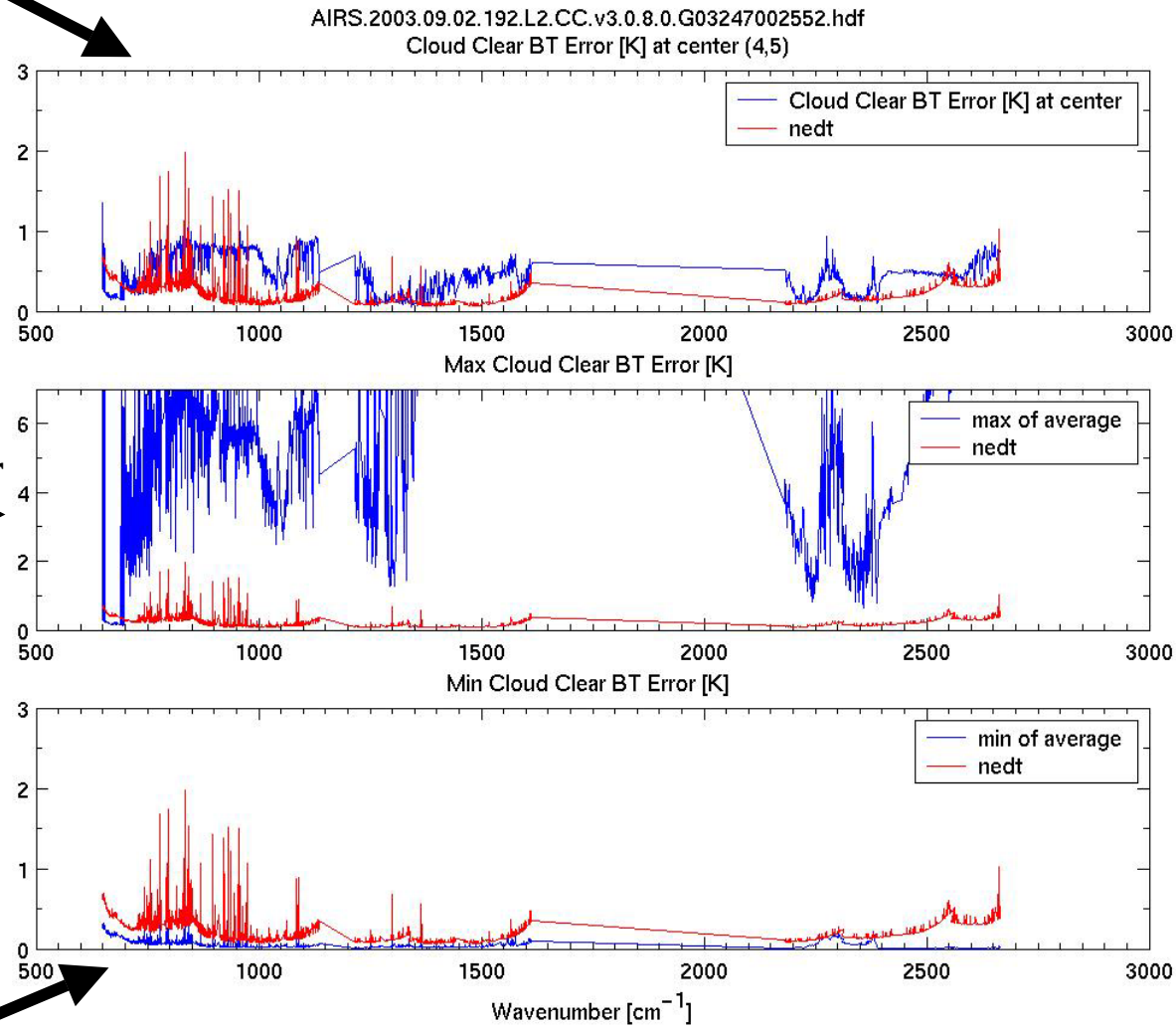




Max. C.C. Error

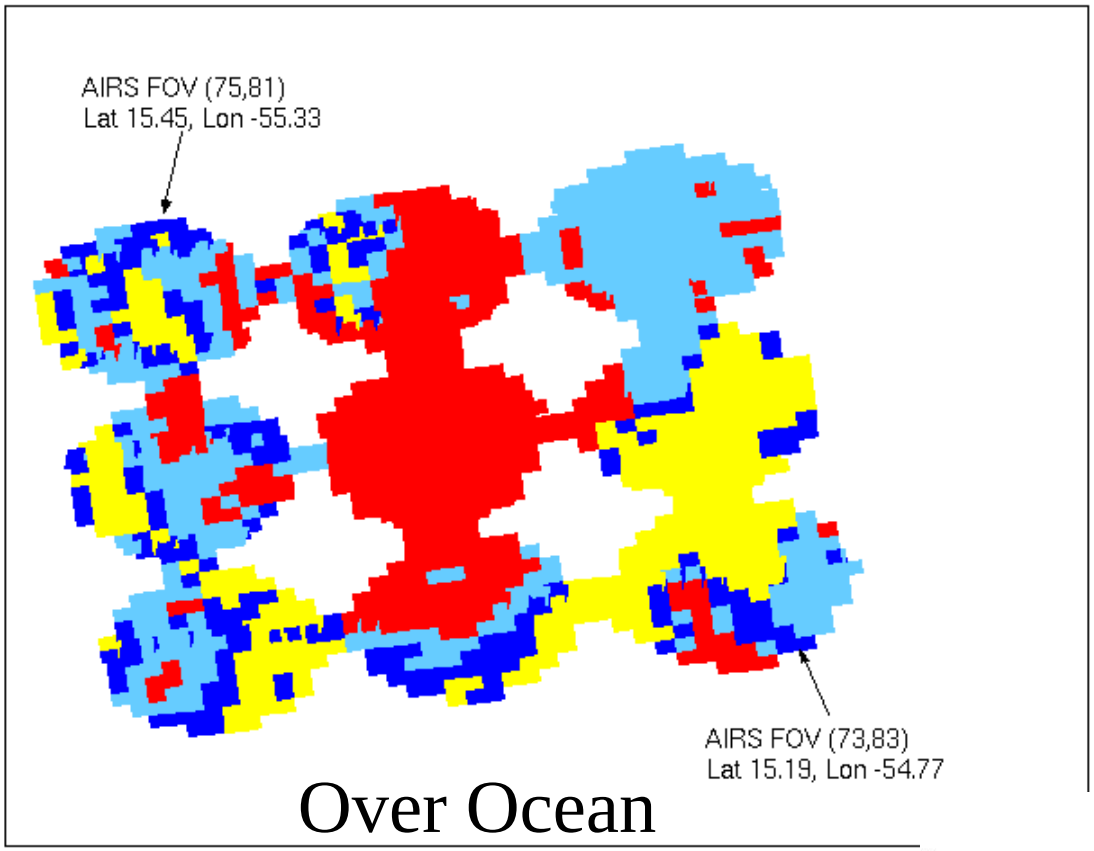


Min. C.C. Error

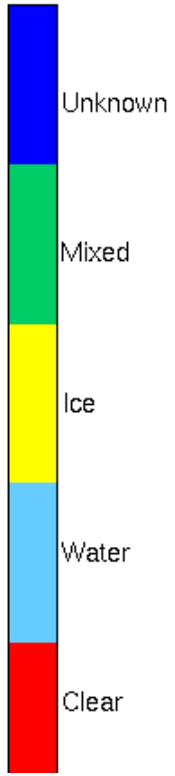


MODIS/AIRS Co-located Cloud Phase Image

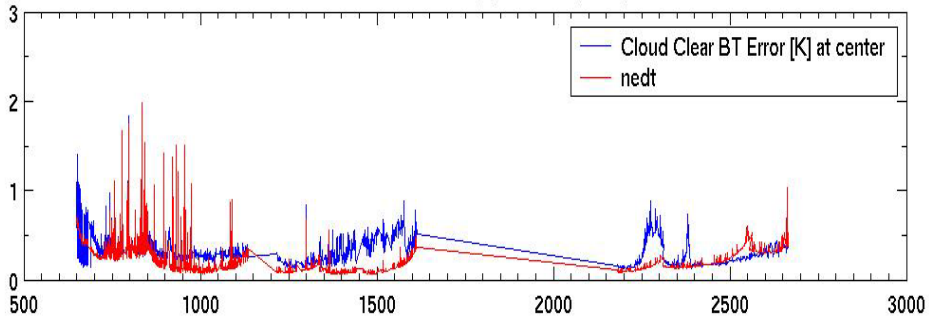
MODIS Cloud Phase Collocated with AIRS Granule 174 FOVs, Ocean Case, Sept 2, 2003



Over Ocean



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



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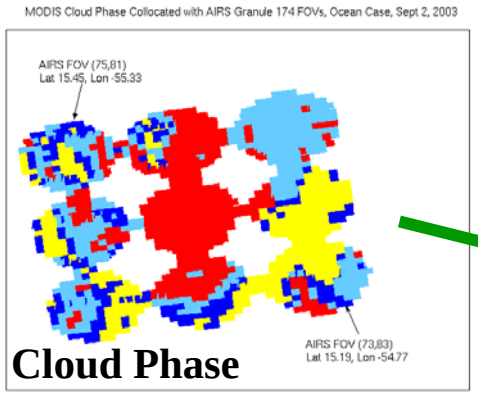
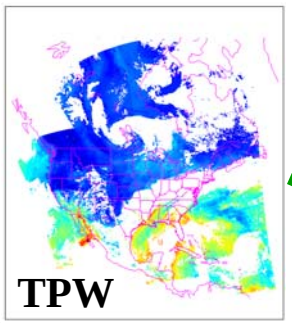
MODIS/AIRS Co-located TWP & Skin Temperature



Cloud Phase



TPW

Skin Tem.

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

Mean TPW = 2.70 cm
Mean Skin Temp =293.39 K

Mean TPW = 2.89 cm
Mean Skin Temp = 295.44 K

Mean TPW = 3.01 cm
Mean Skin Temp = 295.32 K

Mean TPW = 2.57 cm
Mean Skin Temp = 292.89 K

Mean TPW = 2.86 cm
Mean Skin Temp = 296.34 K

Mean TPW = 3.02 cm
Mean Skin Temp = 296.01 K

Mean TPW = 2.75 cm
Mean Skin Temp = 294.61 K

Mean TPW = 2.79 cm
Mean Skin Temp = 295.21 K

Mean TPW = 2.92 cm
Mean Skin Temp = 295.34 K

$\delta TPW = 0.45$ cm
$\delta Tskin = 3.12K$

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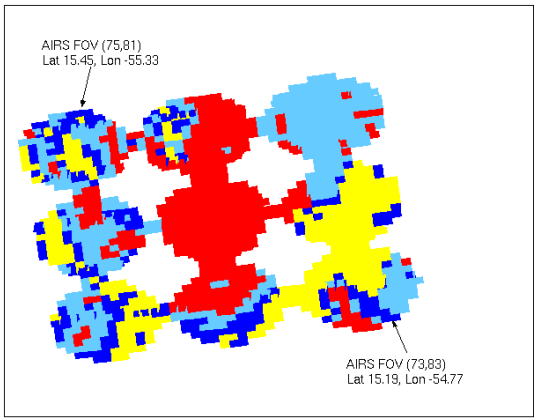
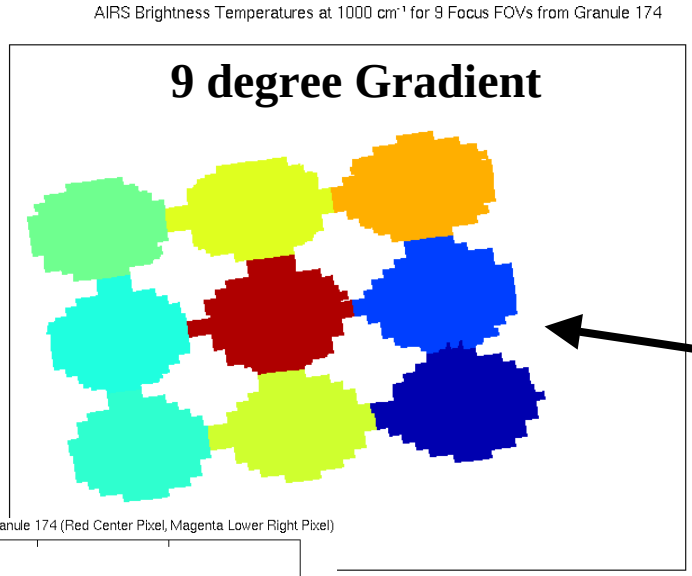
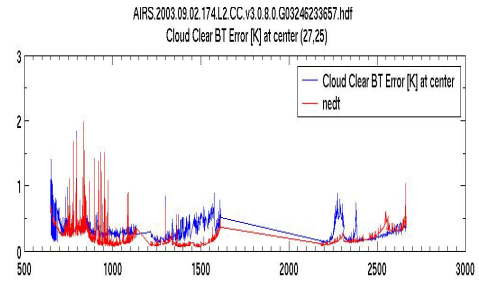
AIRS FOR (3 by 3) Single FOV Window Channel Brightness Temperature Variations

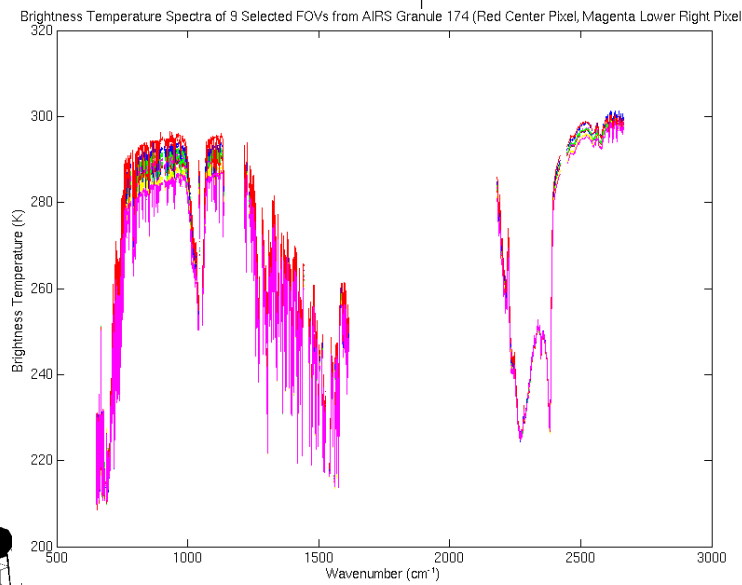


Cloud Phase

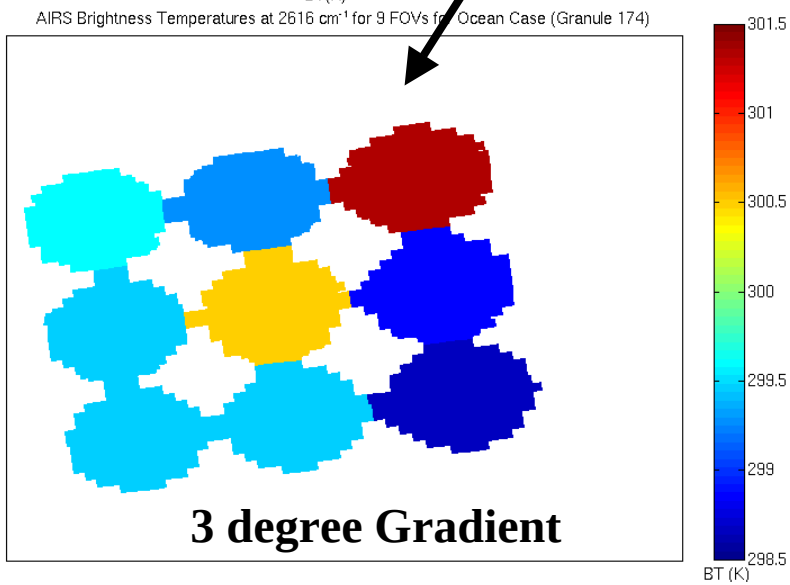




Window BT
1000 cm^{-1}
&
2616 cm^{-1}



Cloud Spectra



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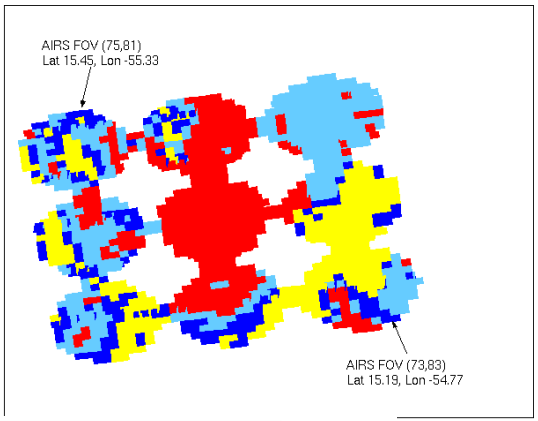
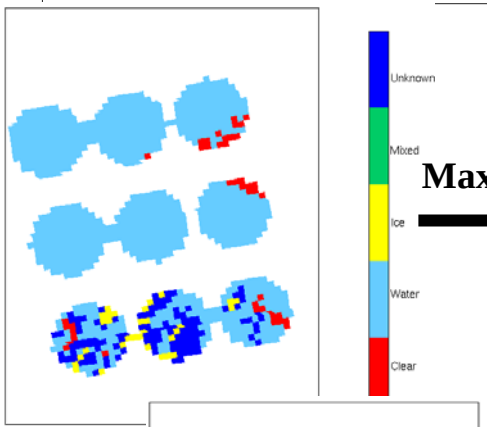
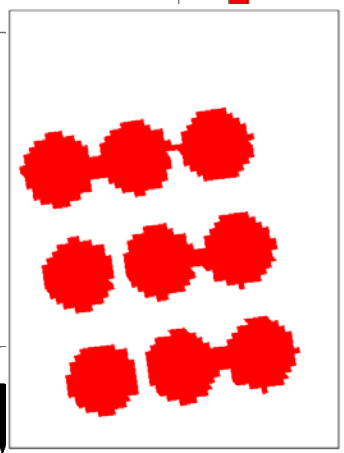
AIRS FOR (3 by 3) Cloud Clearing Error Examples

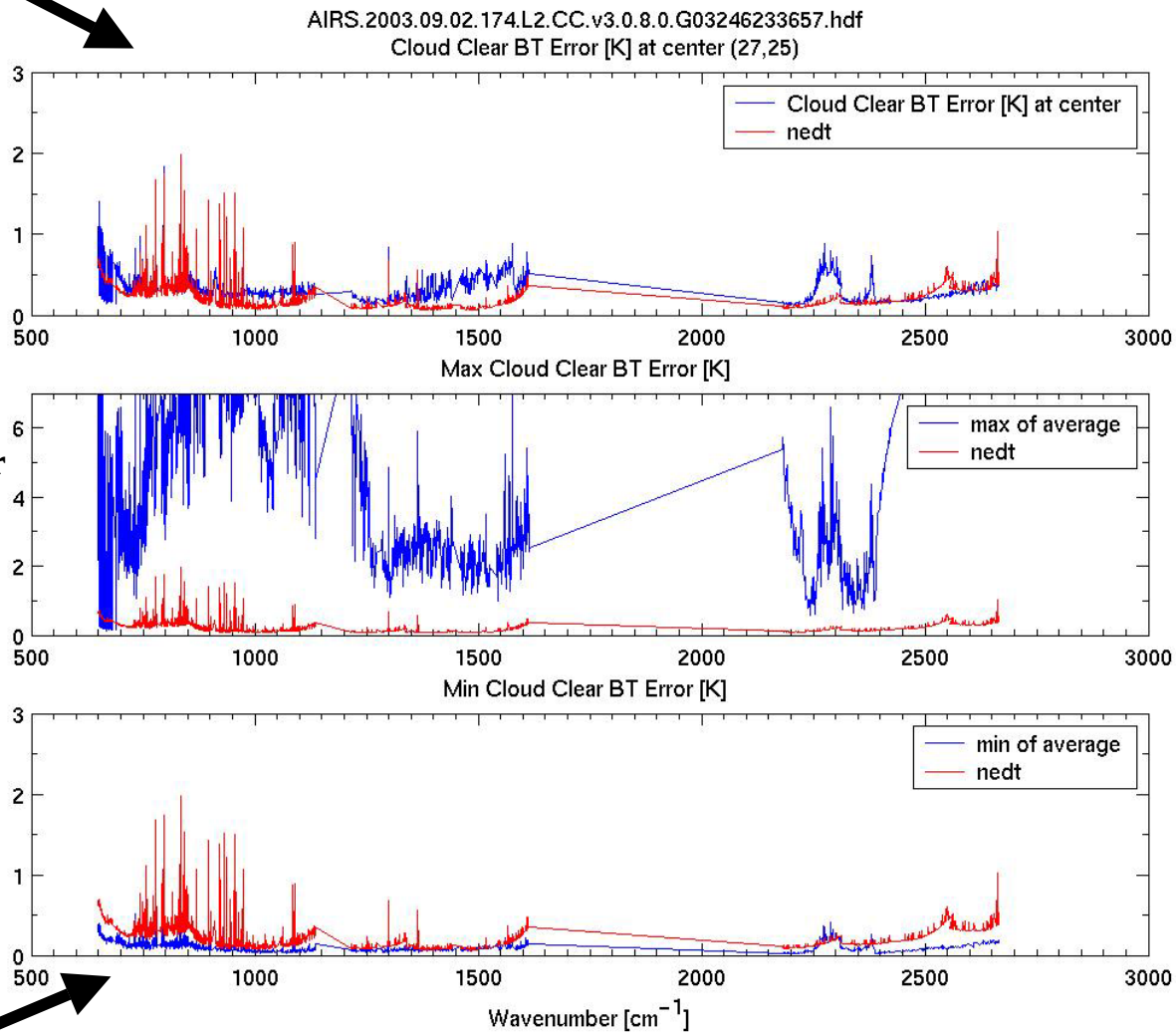




Max. C.C. Error



Min. C.C. Error



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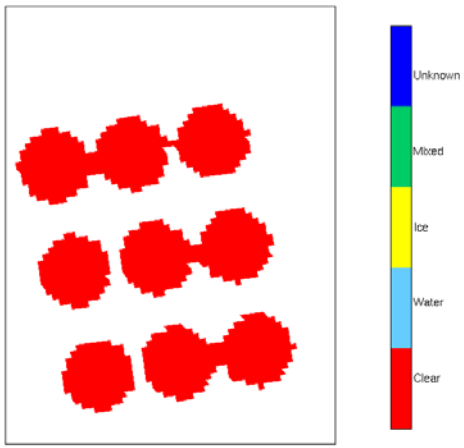
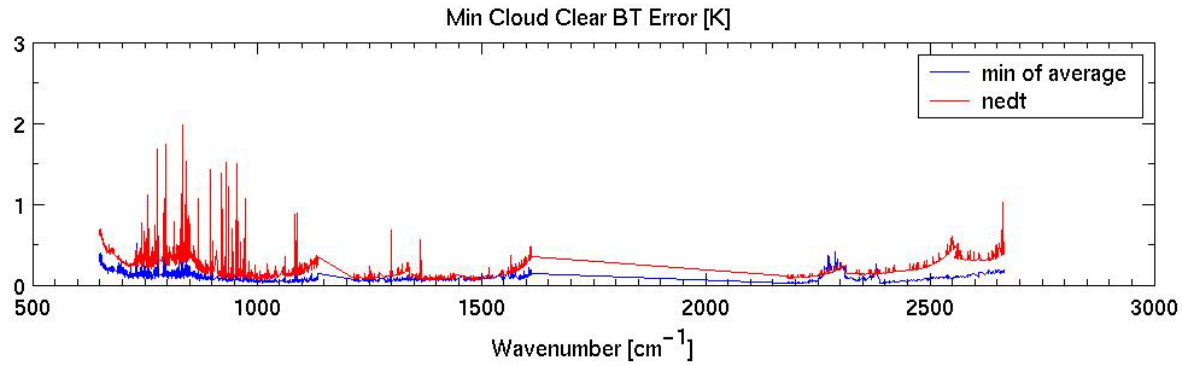
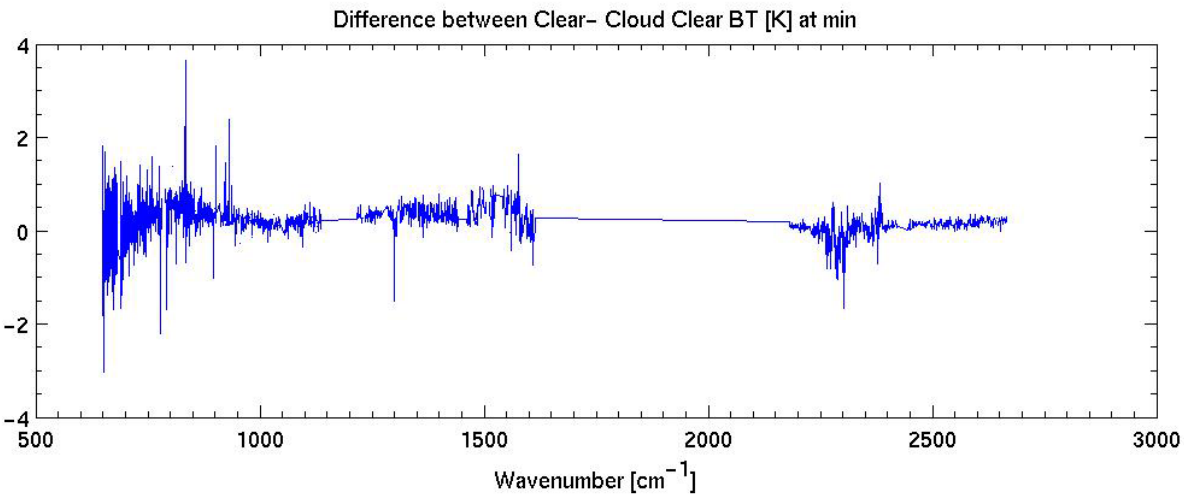
AIRS FOR (3 by 3) Cloud Clearing Error Examples

Minimum C.C. Error Case





Cloud Clear Error Estimate



Difference between Averaged Clear and Cloud Cleared

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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

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International TOVS Study Conference, 13th, TOVS-13, Sainte Adele, Quebec, Canada, 29 October-4 November 2003. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2003.