MODIS/AIRS Workshop
MODIS Level 2 Cloud Product

6 April 2006

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University of Wisconsin-Madison USA

Day 3 Lecture Outline

- Review of MODIS atmosphere products
- MODIS Level 2 product theory and algorithms
  - MODIS Cloud Top Properties Product
  - MODIS Cloud Phase Product
  - MODIS Aerosol Product
    - Example of MODIS aerosol application
  - MODIS Atmospheric Profiles Product

  MODIS Ocean Products
  - SeaDAS

MODIS Standard Products

Atmosphere

- *MOD 04 - Aerosol Product*
- *MOD 05 - Total Precipitable Water (Water Vapor)*
- ***MOD 06 - Cloud Product** * (CTP & IRPHASE only)*
- *MOD 07 - Atmospheric Profiles*
- MOD 08 - Gridded Atmospheric Product
- *MOD 35 - Cloud Mask*

Cloud Top Properties

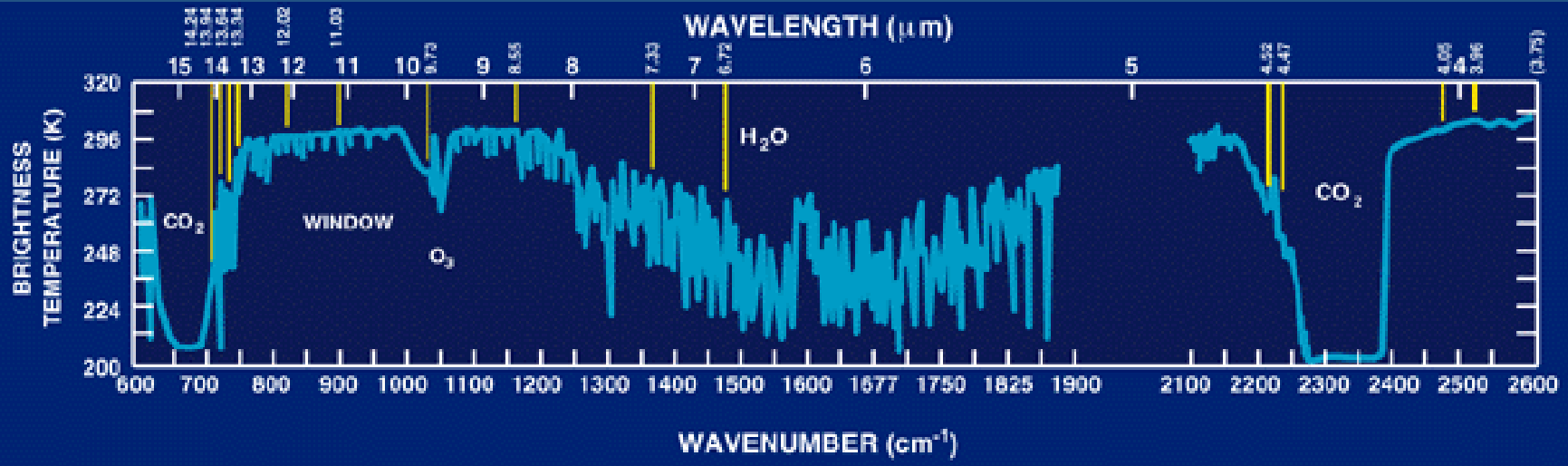
Menzel, Wylie - CIMSS

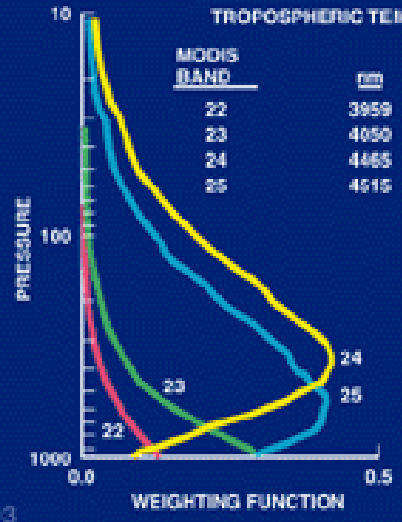
- Cloud Top Pressure, Temperature, Emissivity derived using CO_2 "slicing"
- MODIS product utilizes 4 spectral channels in the 13 – 14 μm region.
- 5x5 1 km pixel retrievals where at least 5 of the 1 km pixels are cloudy as determined by the cloud mask
- Cloud properties retrieved both day and night

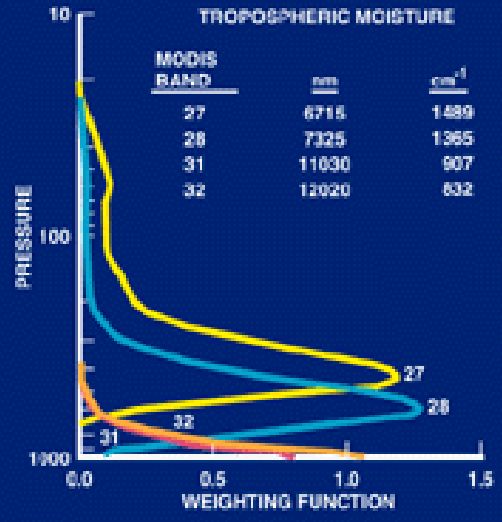
Inputs

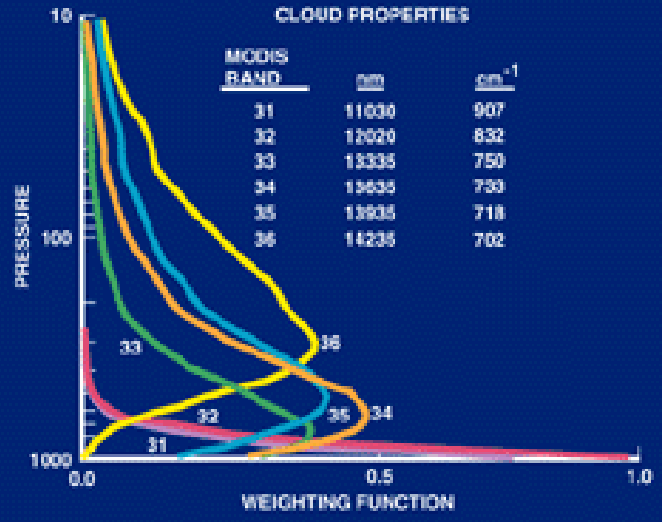
- MODIS L1B (MOD021KM) and geolocation file (MOD03)
- MODIS Cloud Mask (MOD35)
- 6 hourly Global Data Assimilation System T126 resolution analysis from NCEP (Vertical Profiles of Temperature and Moisture)
  ex: gdas1.PGrbF00.020430.00z
- Weekly Optimum Interpolation (OI) Sea Surface Temperature (SST) Analysis
  ex: oisst.20050608
- Latest 7 days ancillary data and documentation available from:
  ftp://aqua.ssec.wisc.edu/pub/terra/ancillary

ATMOSPHERE - THERMAL RADIATION









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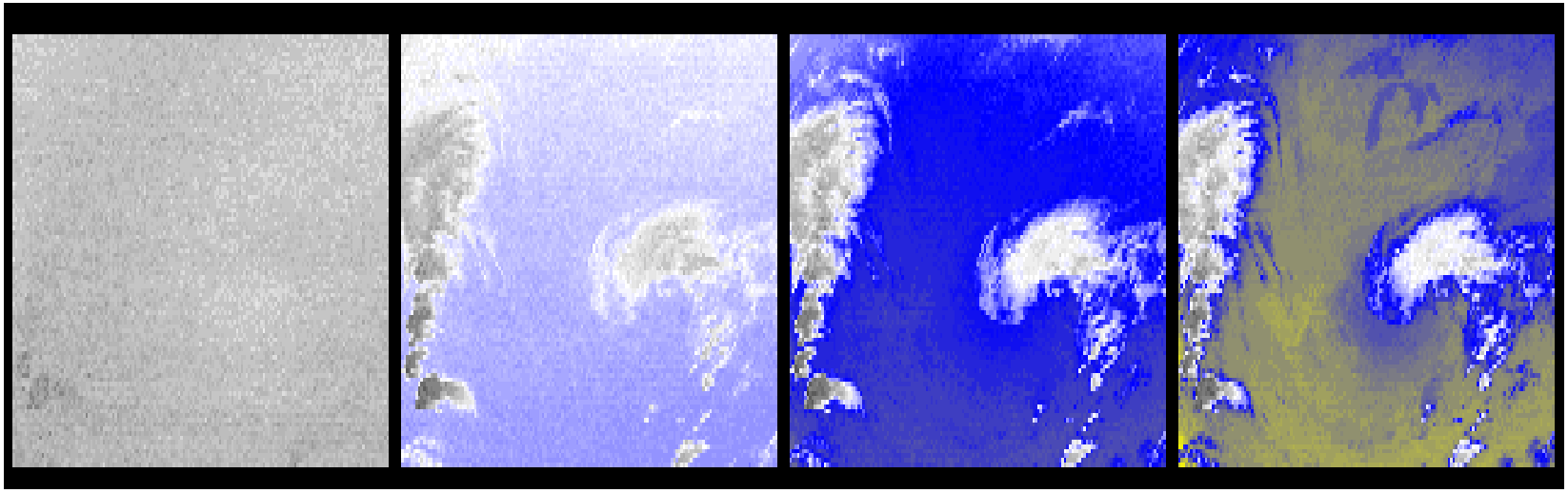
CO2 channels see to different levels in the atmosphere



14.2 um 13.9 um 13.6 um 13.3 um

Radiative Transfer Equation

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T_s)\, \tau_\lambda(p_s) + \int B_\lambda(T(p))\, [d\tau_\lambda(p)/\, dp]\, dp$$

RTE in Cloudy Conditions

$$I_\lambda = \eta\, I_\lambda^{cd} + (1 - \eta)\, I_\lambda^{clr}$$ where cd = cloud, clr = clear, η = cloud fraction

$$I_\lambda^{clr} = B_\lambda(T_s)\, \tau_\lambda(p_s) + \int_{p_s}^{o} B_\lambda(T(p))\, d\tau_\lambda \,.$$

$$I_\lambda^{cd} = (1-\varepsilon_\lambda)\, B_\lambda(T_s)\, \tau_\lambda(p_s) + (1-\varepsilon_\lambda) \int_{p_s}^{p_c} B_\lambda(T(p))\, d\tau_\lambda$$

$$+ \varepsilon_\lambda\, B_\lambda(T(p_c))\, \tau_\lambda(p_c) + \int_{p_c}^{o} B_\lambda(T(p))\, d\tau_\lambda$$

ε_λ is emittance of cloud. First two terms are from below cloud, third term is cloud contribution, and fourth term is from above cloud. After rearranging

$$I_\lambda^{cd} - I_\lambda^{clr} = \eta\varepsilon_\lambda \int_{p_s}^{p_c} \tau(p)\, \frac{dB_\lambda}{dp}\, dp \,.$$

Cloud Properties from CO2 Slicing

RTE for cloudy conditions indicates dependence of cloud forcing (observed minus clear sky radiance) on cloud amount ($\eta\varepsilon_\lambda$) and cloud top pressure (p_c)

$$(I_\lambda - I_\lambda^{clr}) = \eta\varepsilon_\lambda \int_{p_s}^{p_c} \tau_\lambda \, dB_\lambda(T) .$$

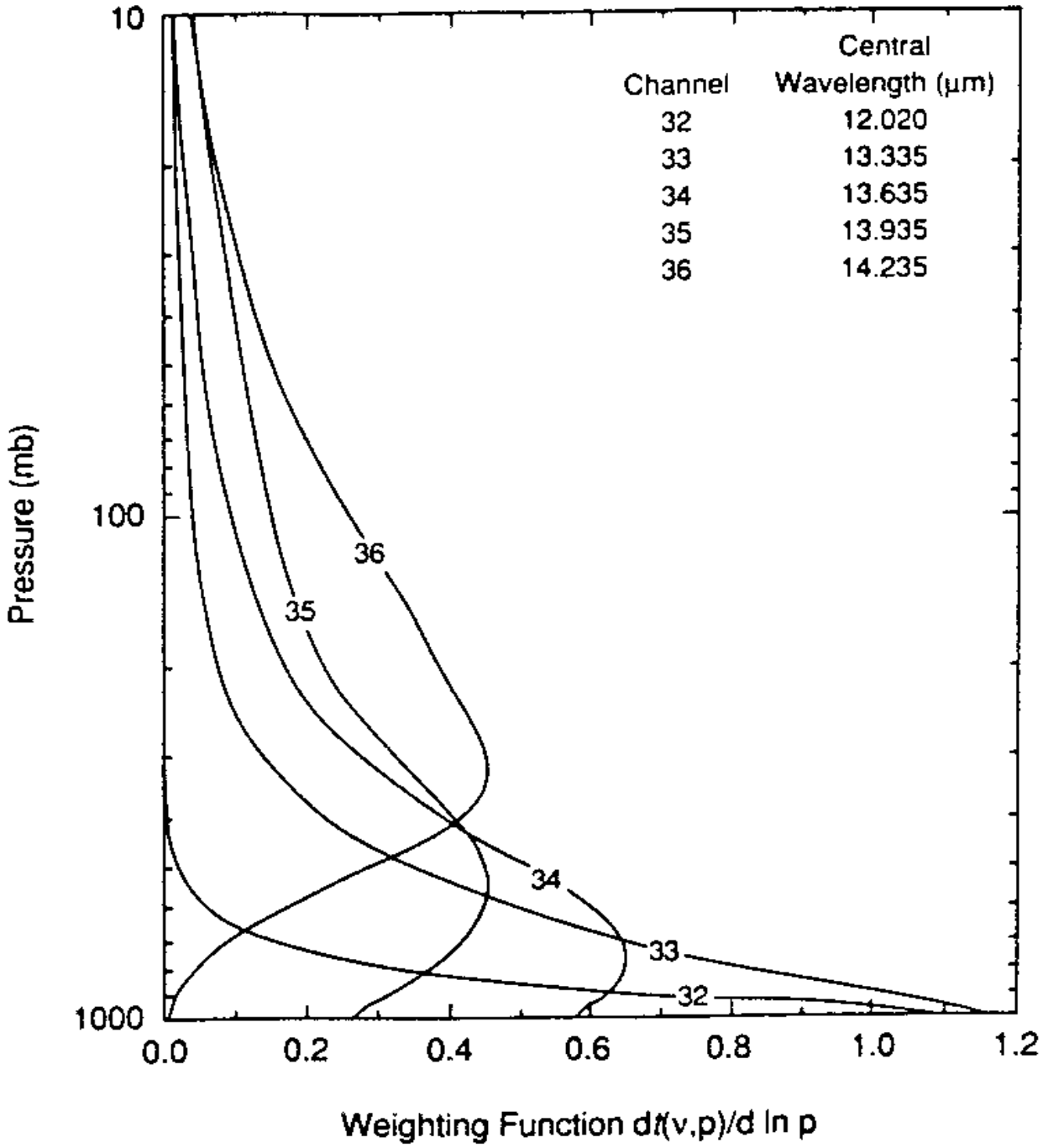
Higher colder cloud or greater cloud amount produces greater cloud forcing; dense low cloud can be confused for high thin cloud. Two unknowns require two equations.

p_c can be inferred from radiance measurements in two spectral bands where cloud emissivity is the same. $\eta\varepsilon_\lambda$ is derived from the infrared window, once p_c is known.

Different ratios reveal cloud properties at different levels

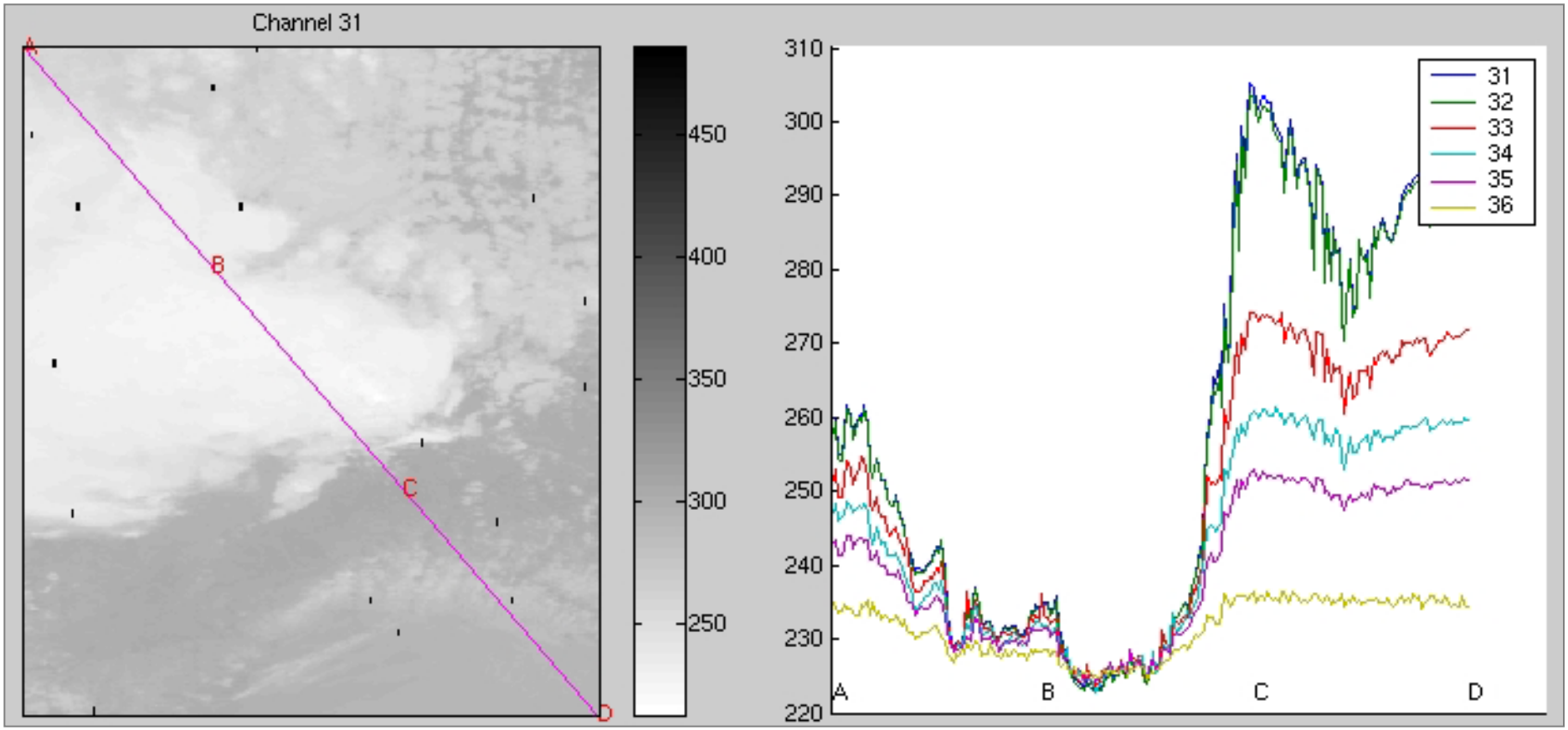
hi - 14.2/13.9
mid - 13.9/13.6
low - 13.6/13.3

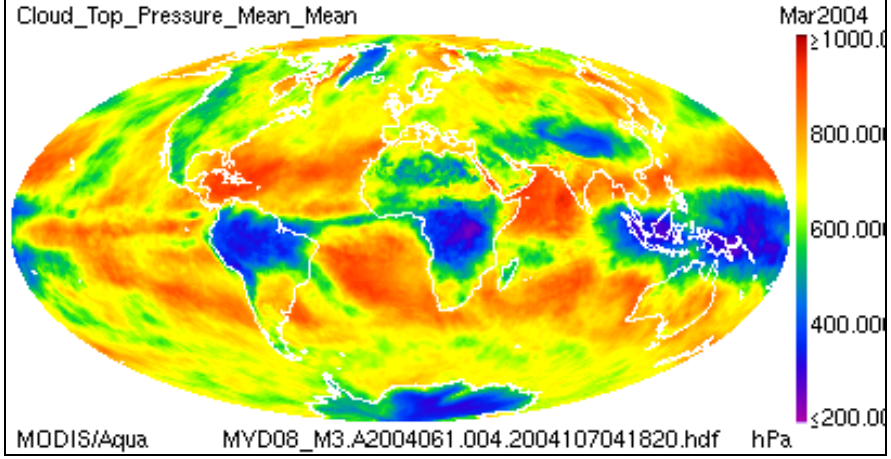
$$\frac{(I_{\lambda 1} - I_{\lambda 1}^{clr})}{(I_{\lambda 2} - I_{\lambda 2}^{clr})} \quad \text{Meas} \qquad = \qquad \frac{\eta \varepsilon_{\lambda 1} \int_{p_s}^{p_c} \tau_{\lambda 1} \, dB_{\lambda 1}}{\eta \varepsilon_{\lambda 2} \int_{p_s}^{p_c} \tau_{\lambda 2} \, dB_{\lambda 2}} \quad \text{Calc}$$

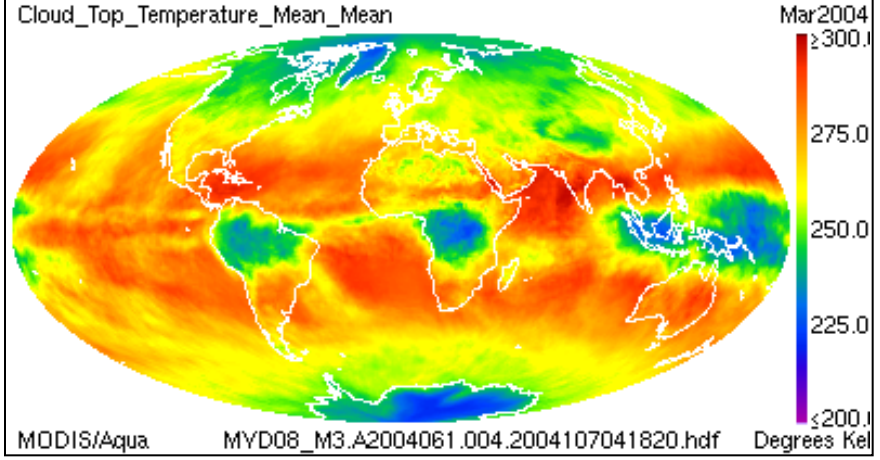


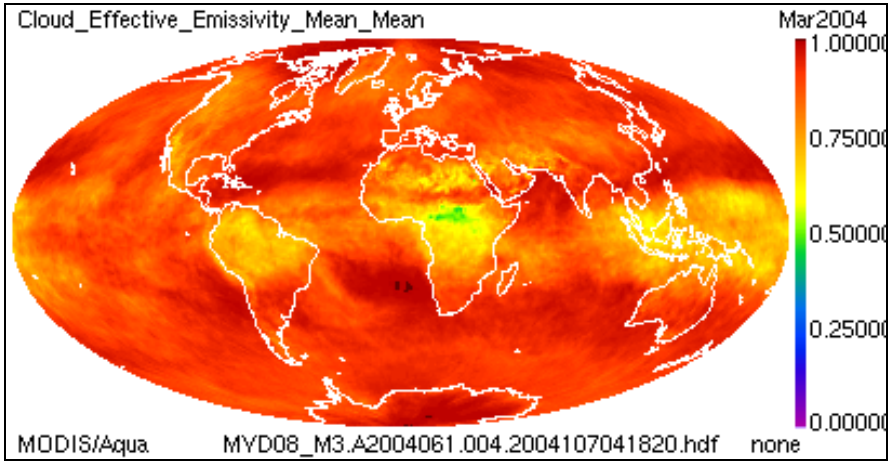
BT in and out of clouds for MODIS CO_2 bands

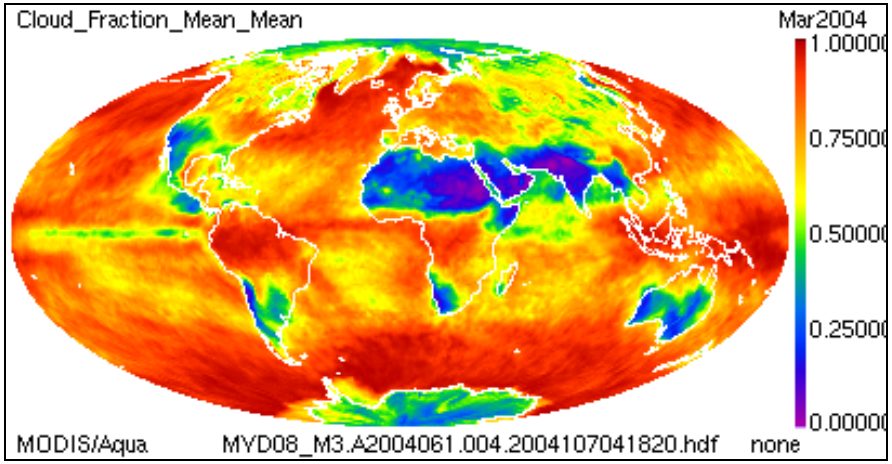
- demonstrate weighting functions and cloud top algorithm

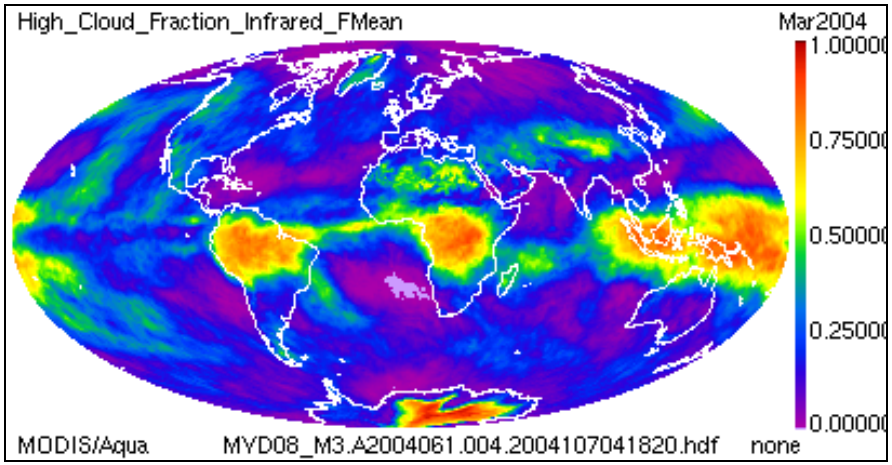




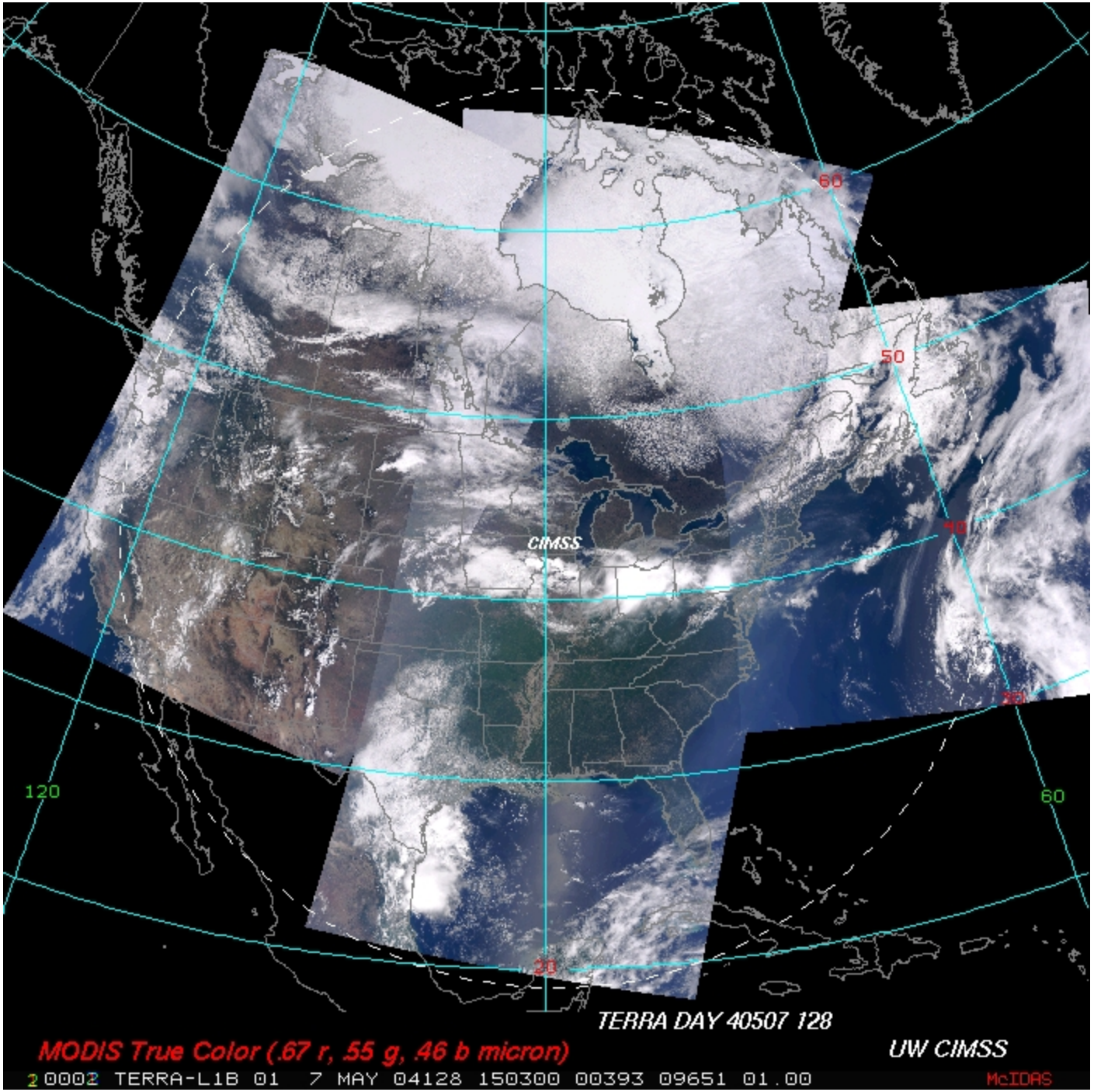








MODIS Cloud Top Properties Level 3 Products March 2004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CIMSS
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MODIS True Color (.67 r, .55 g, .46 b micron)
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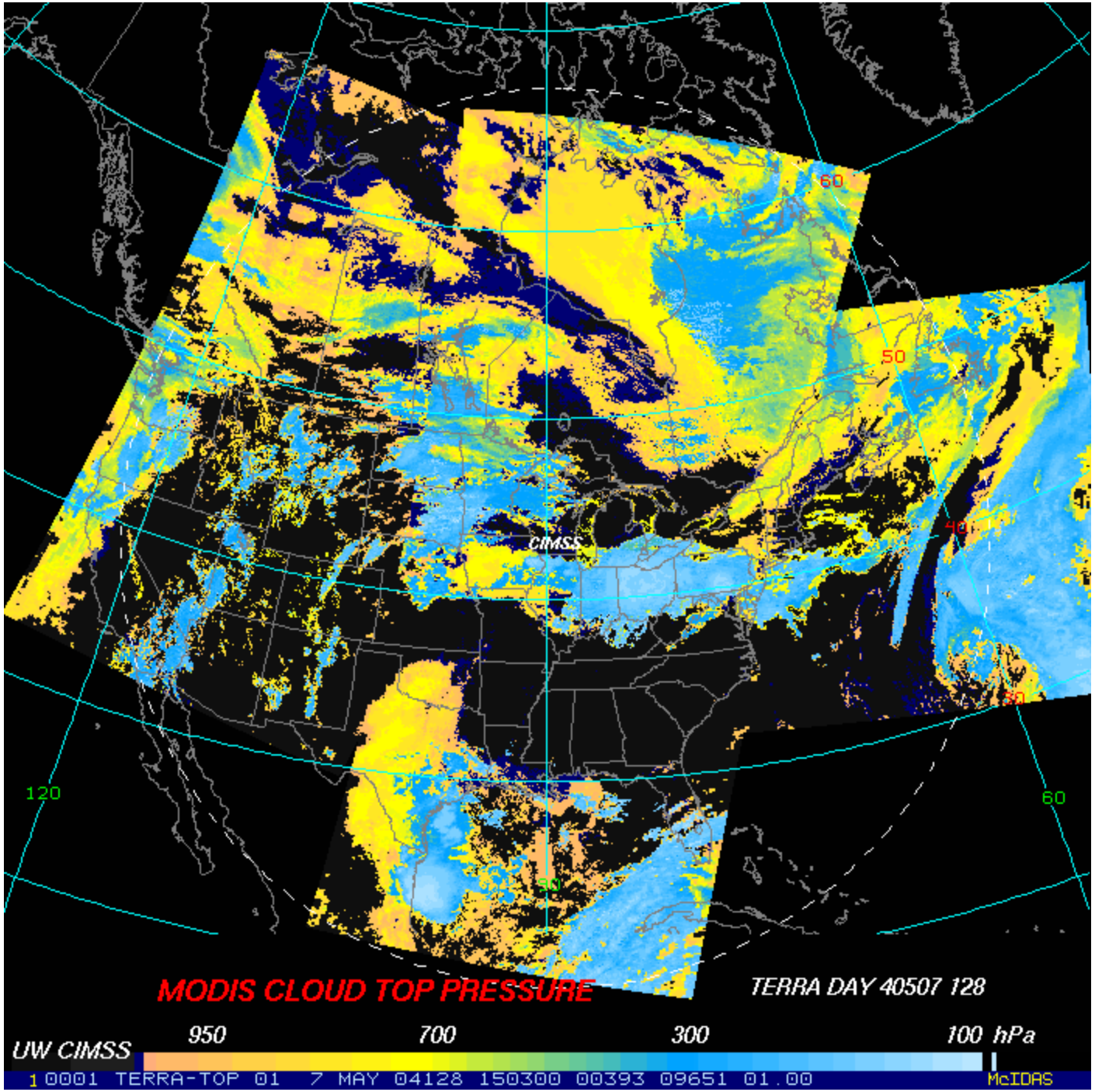
McIDAS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MODIS CLOUD TOP PRESSURE
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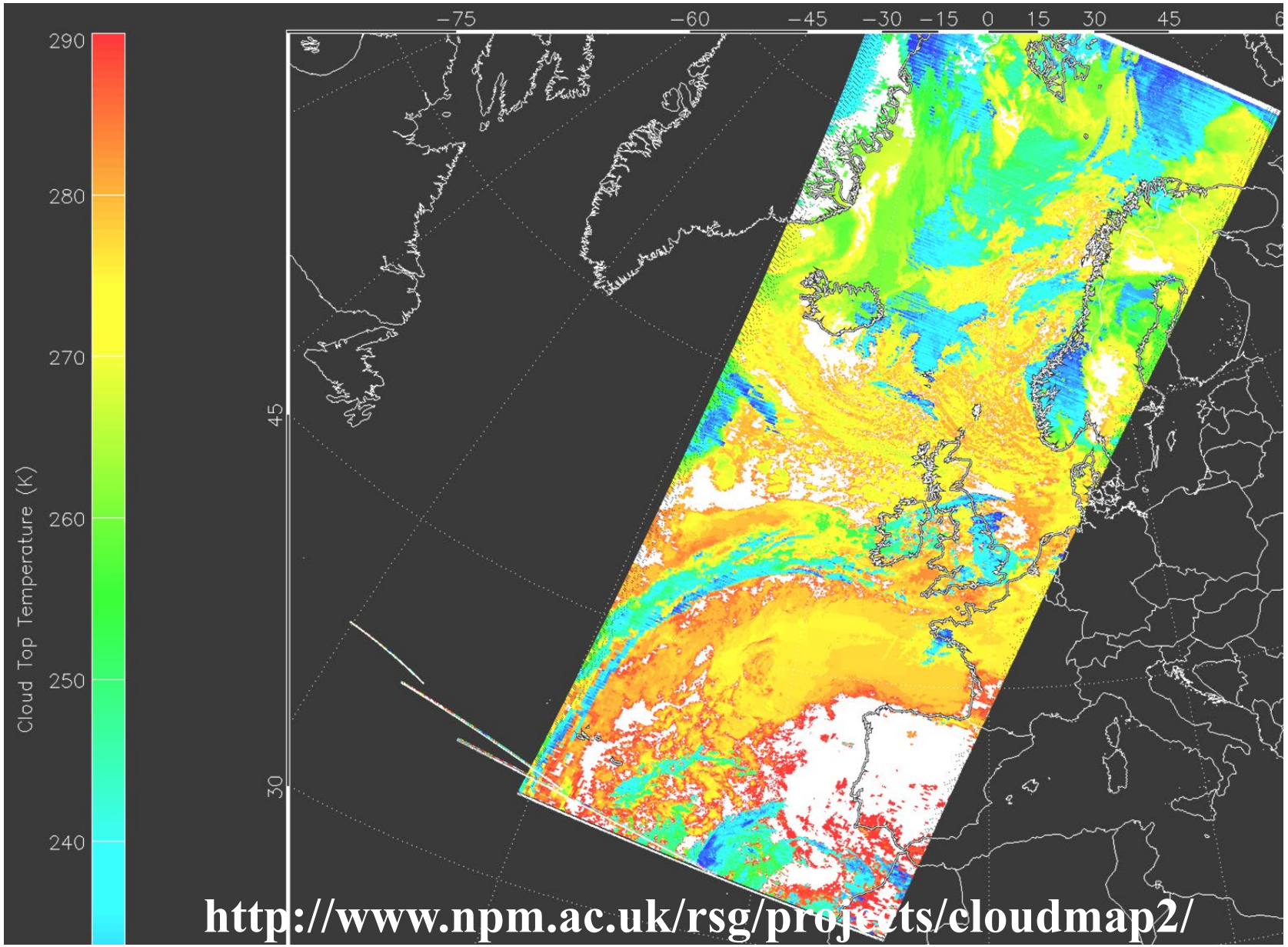
McIDAS

Cloud Top Temperature Plymouth Marine Lab, UK

10 October 2003 11:57 UTC



Output Product Description

MOD06 Key Output Parameters

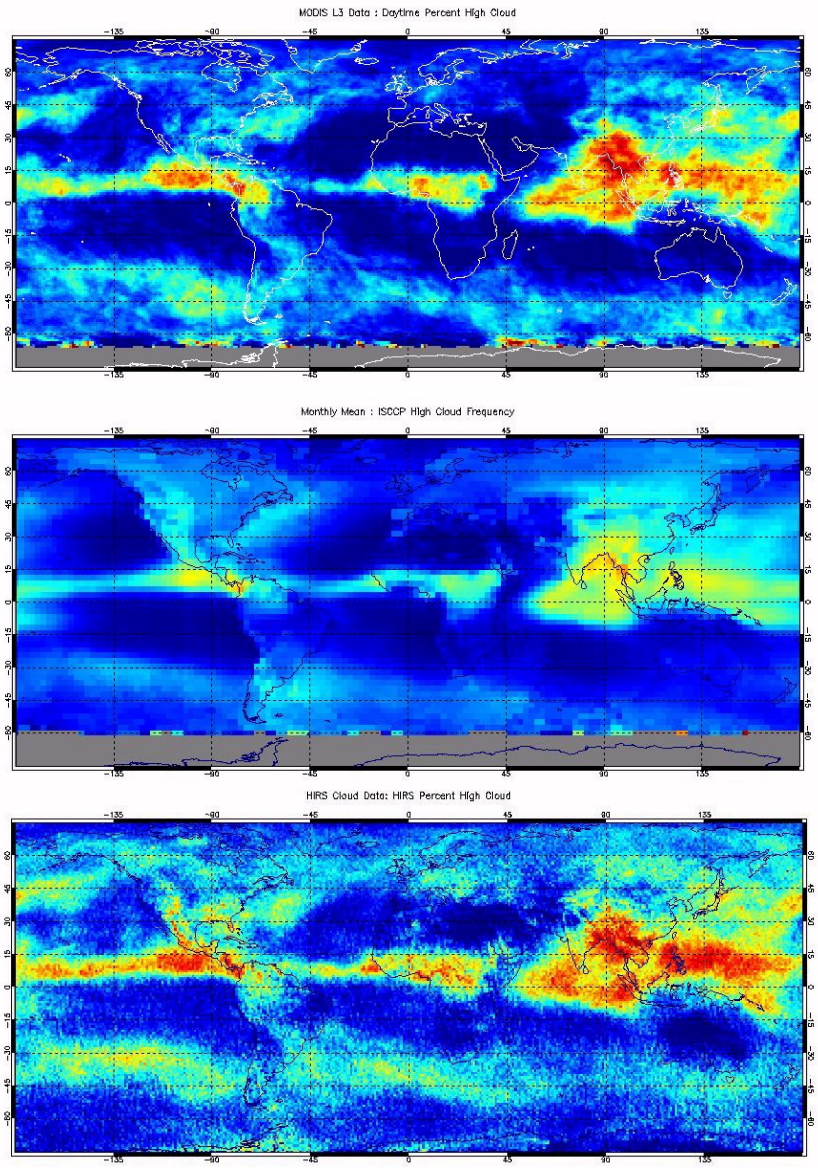
5x5 pixel (1km) resolution

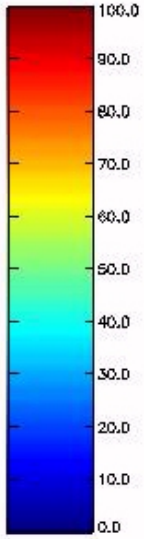
- **Surface_Temperature (GDAS input)**
- **Surface_Pressure (GDAS input)**
- **Cloud_Top_Pressure**
- **Cloud_Top_Temperature**
- **Tropopause_Height**
- **Cloud_Fraction**
- **Cloud_Effective_Emissivity**
- **Cloud_Top_Pressure_Infrared**
- Brightness_Temperature_Difference_B29-B31
- Brightness_Temperature_Difference_B31-B32
- Cloud_Phase_Infrared
- Cloud Optical Depth (daytime – 1 km product)
- Cloud Effective Radius (daytime – 1km)

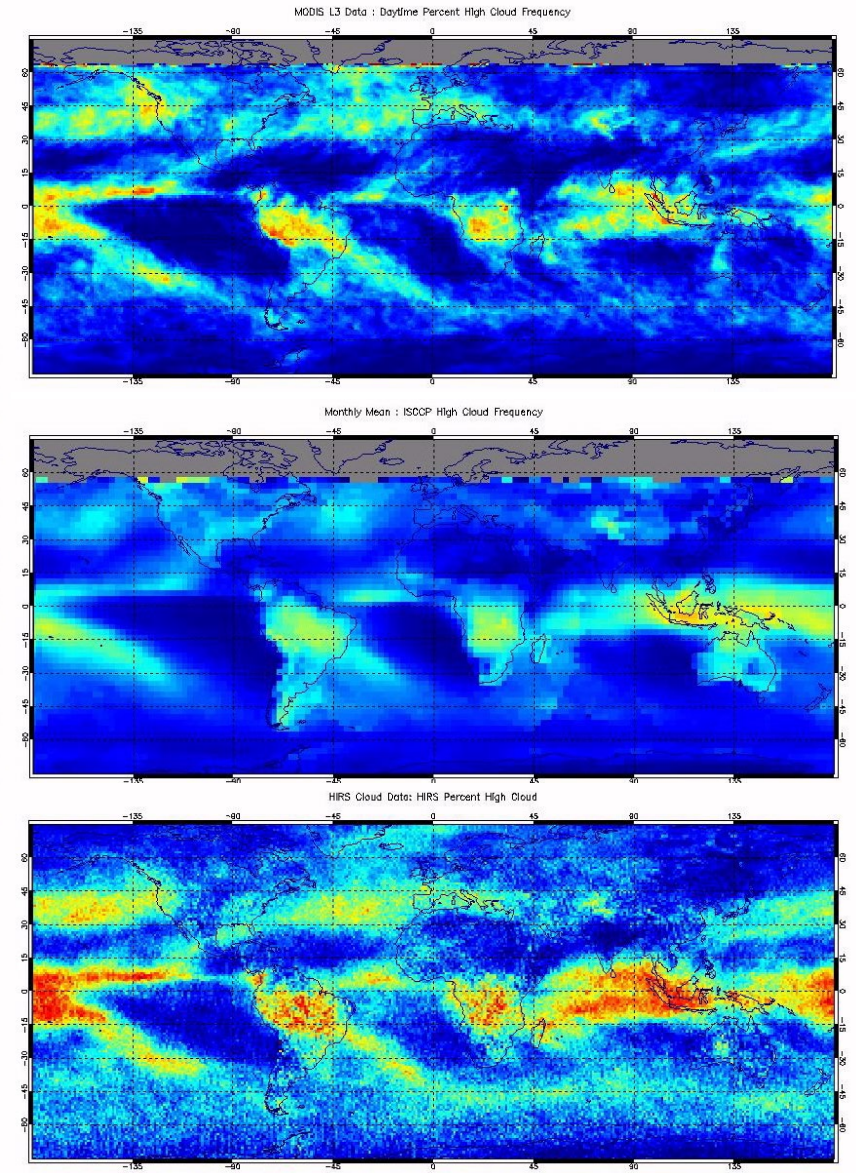
Known Problems

- Low cloud
  - Vantage point of satellite means more sensitive to high cloud than low cloud. New algorithm address this
- Solution converges on highest pressure level
  - Addressed with latest algorithm

Validation - Comparison of HIRS/ISCCP/MODIS High Cloud Frequency







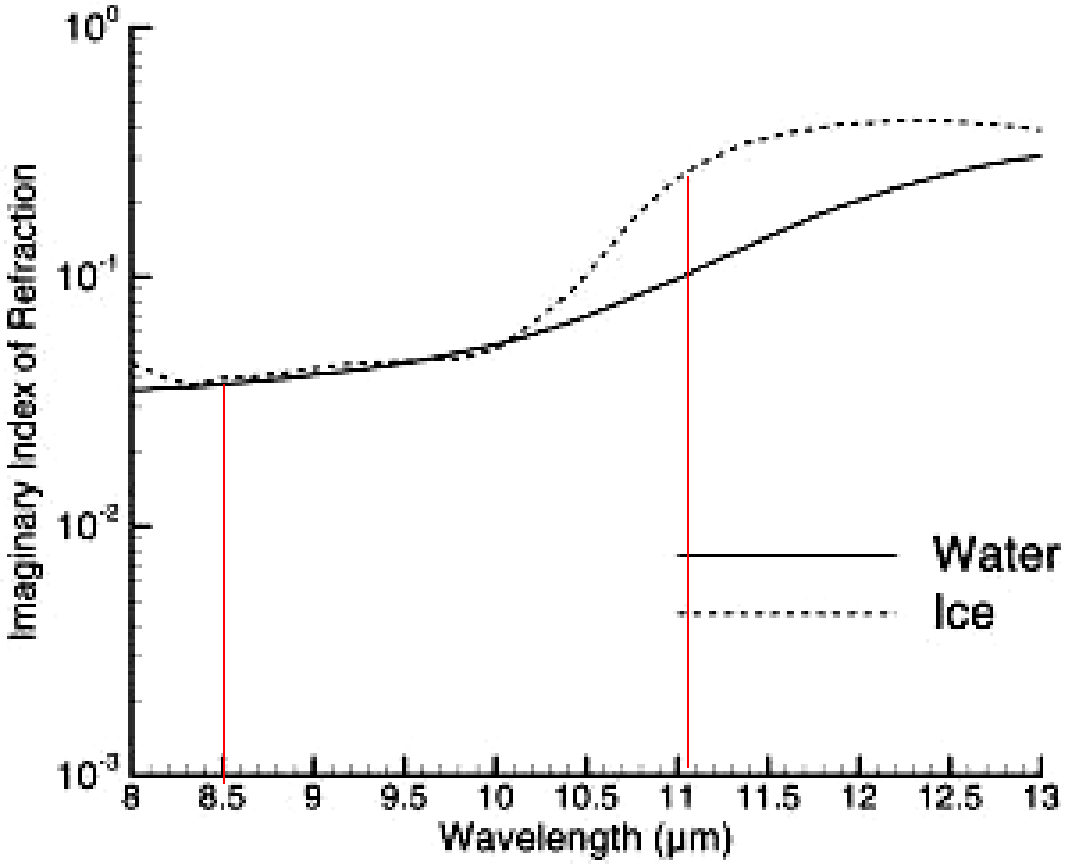
July 2002

December 2002

Cloud Phase

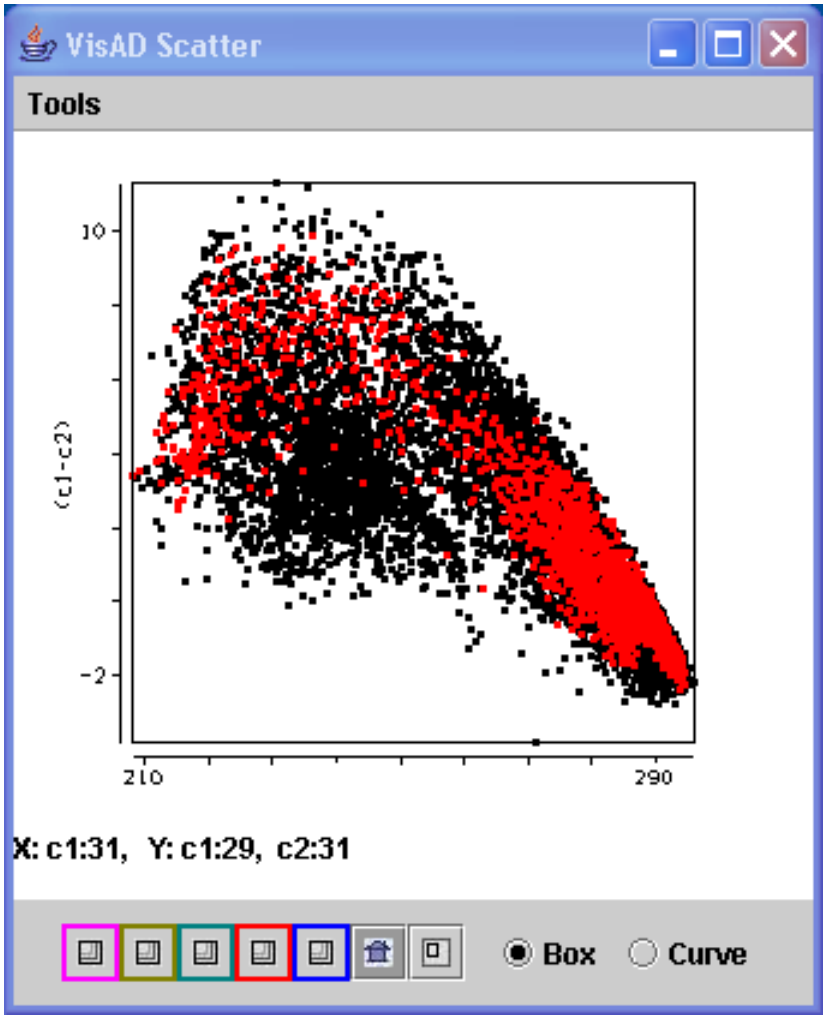
Dr. Bryan Baum CIMSS

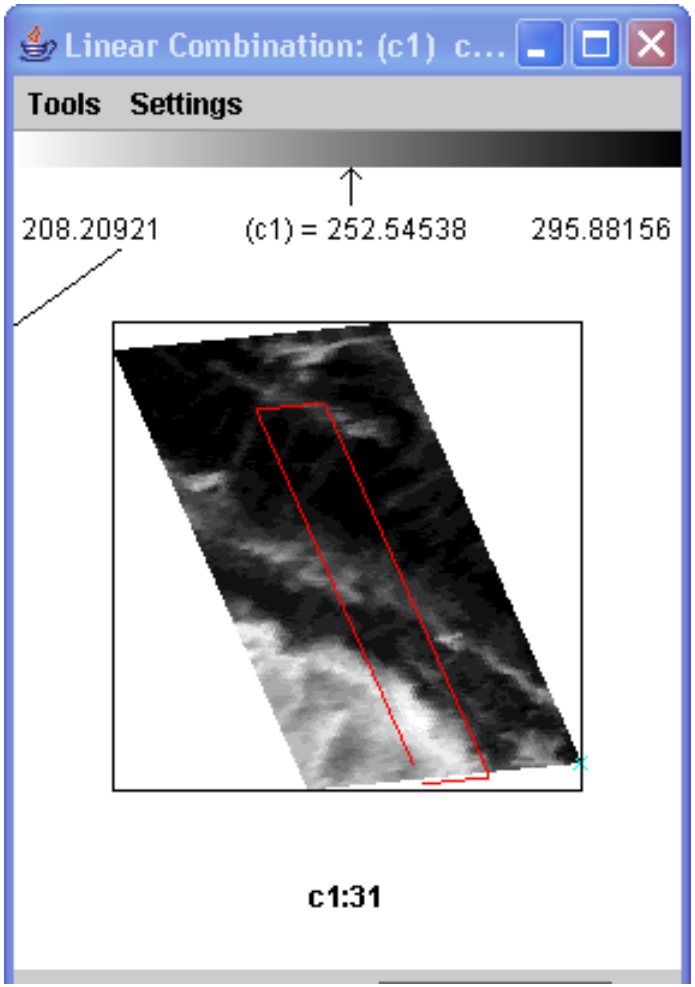
- Based upon the differential absorption of ice and water between 8 and 11 microns
- Simple brightness temperature difference (8-11 BTDIF) technique
- Included as part of the MOD06 product



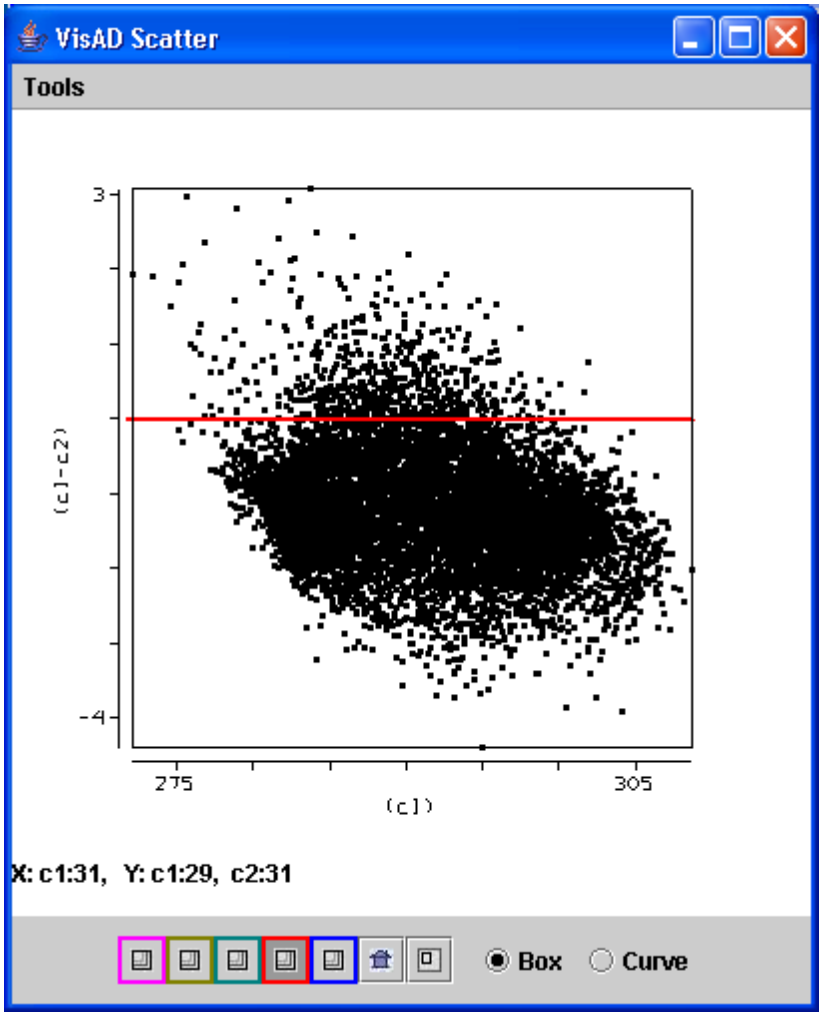
Imaginary Index of Refraction of Ice and Water
8 – 13 microns

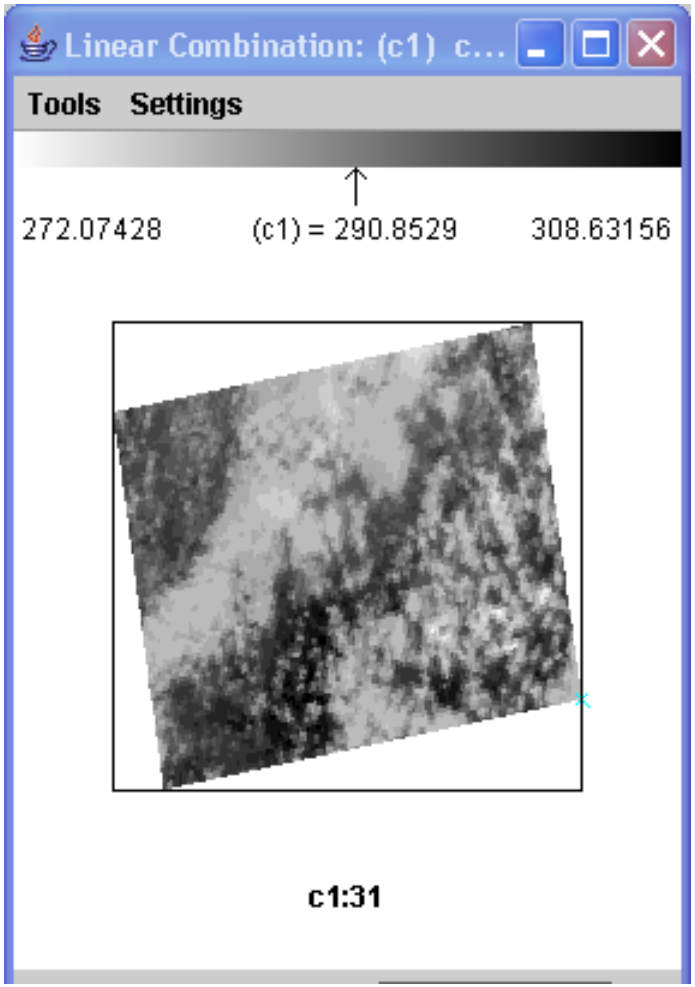
Ice Cloud Example





Water Cloud Example





IRPHASE Thresholds

- Ice Cloud
  - BT11 < 238 K or BTD8-11> 0.5 K
- Mixed Phase
  - BT11 between 238 and 268 K

    and
  - BTD8-11 between –0.25 and –1.0 K
- Water Cloud
  - BT11 > 238 K and BTD8-11 < -1.5 K

    or
  - BT11>285 and BTD8-11 < -0.5 K

Output Product Description

4 categories

1 – Water Cloud

2 – Ice Cloud

3 – Mixed Phase Cloud

6 – Undecided

MOD06 Key Output Parameters

5x5 pixel (1km) resolution

- Surface_Temperature (GDAS input)
- Surface_Pressure (GDAS input)
- Cloud_Top_Pressure
- Cloud_Top_Temperature
- Tropopause_Height
- Cloud_Fraction
- Cloud_Effective_Emissivity
- Cloud_Top_Pressure_Infrared
- **Brightness_Temperature_Difference_B29-B31**
- **Brightness_Temperature_Difference_B31-B32**
- **Cloud_Phase_Infrared**
- Cloud Optical Depth (daytime – 1 km product)
- Cloud Effective Radius (daytime – 1km)

Temperature sensitivity, or the percentage change in radiance corresponding to a percentage change in temperature, α, is defined as

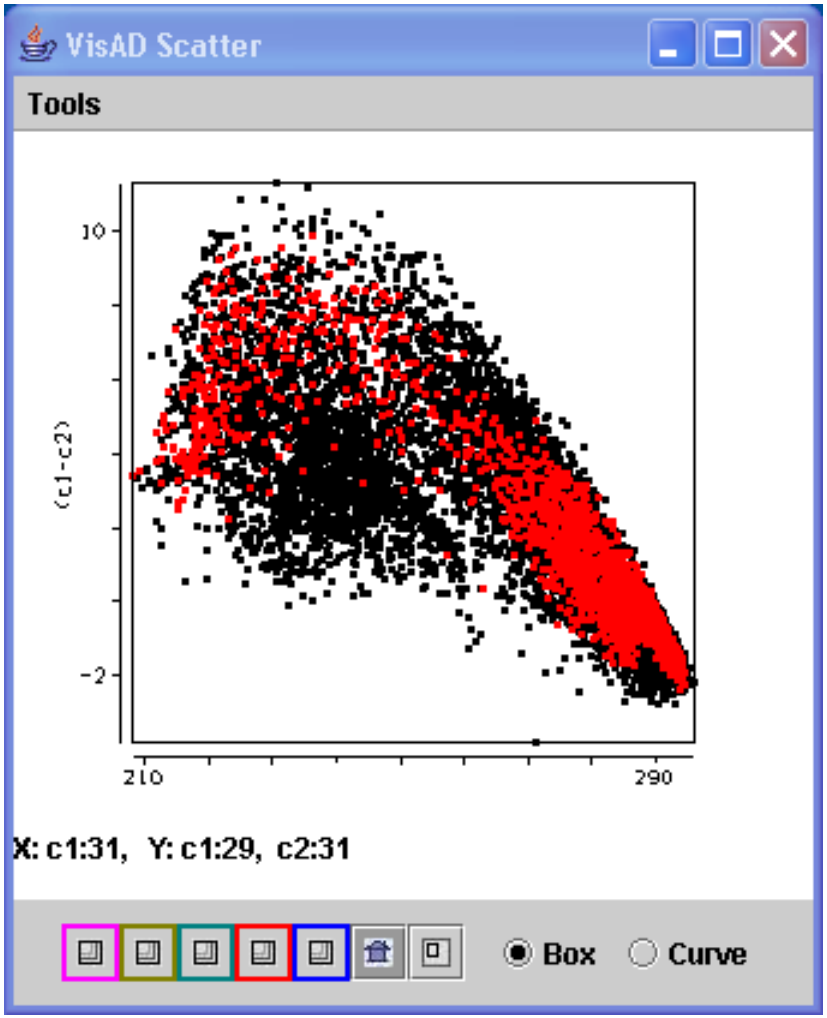
$$dB/B = \alpha\, dT/T.$$

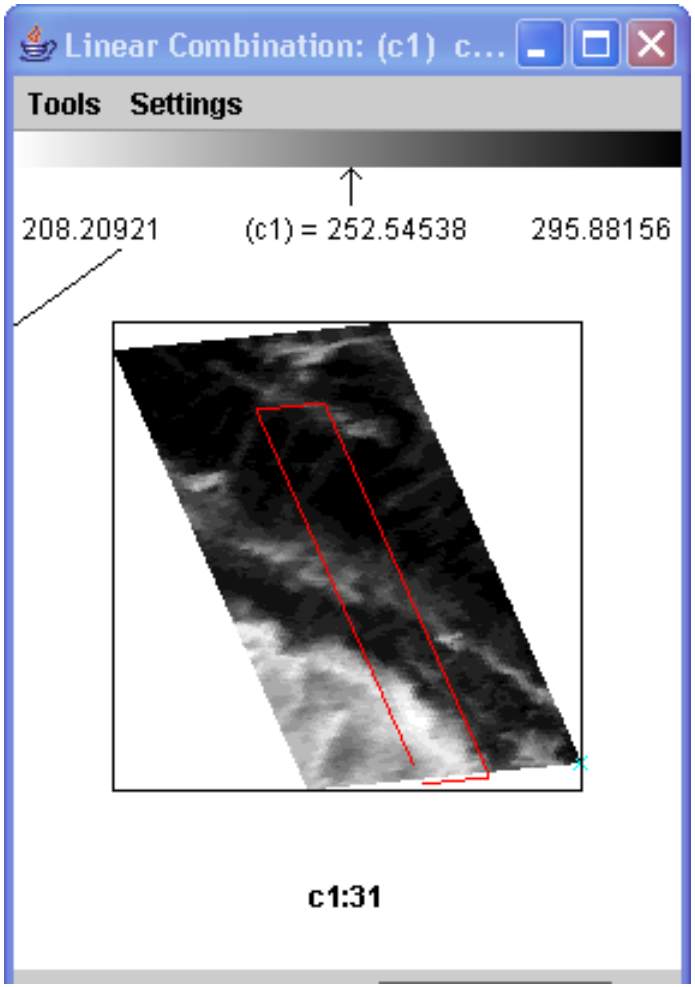
The temperature sensivity indicates the power to which the Planck radiance depends on temperature, since B proportional to T^{α} satisfies the equation. For infrared wavelengths,

$$\alpha = c_2\nu/T = c_2/\lambda T.$$

Wavenumber	Typical Scene Temperature	Temperature Sensitivity
700 (14 μm)	220	4.58
900 (11 μm)	300	4.32
1200 (8.3 μm)	300	5.76
1600 (6.5 μm)	240	9.59
2300 (4.4 μm)	220	15.04
2500 (4.0 μm)	300	11.99

Ice Cloud Example

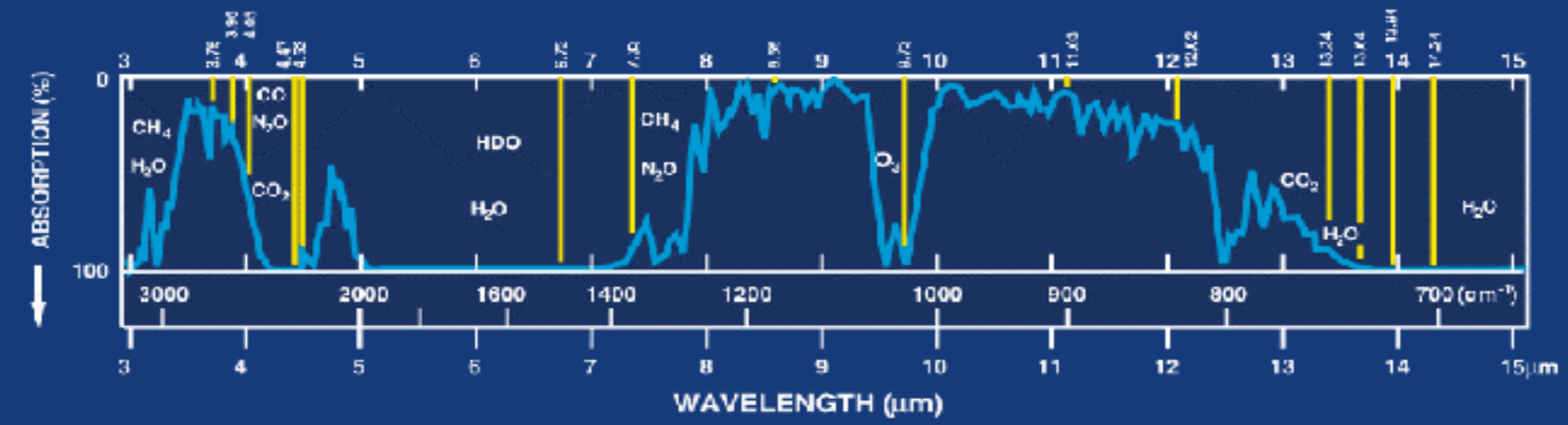


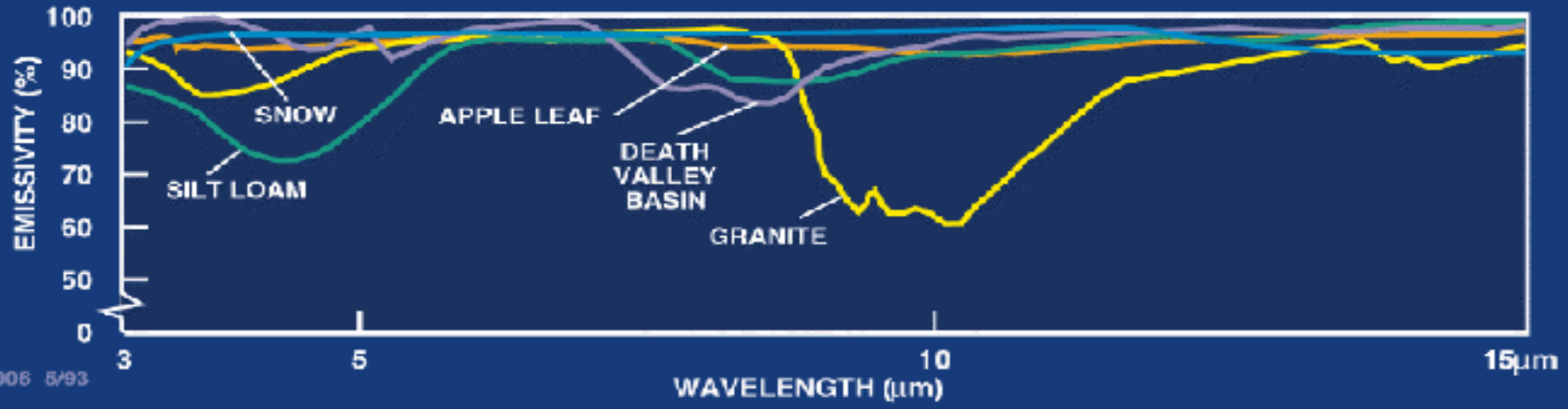


Known Problems

- Mid-level cloud (BT ~ 250 K)
  - Ambiguous solution
- Surface Emissivity Effects
  - Not always the same over the IR window (granite)
- Mixed phase cloud category
  - should be considered as undecided

LAND - THERMAL RADIATION





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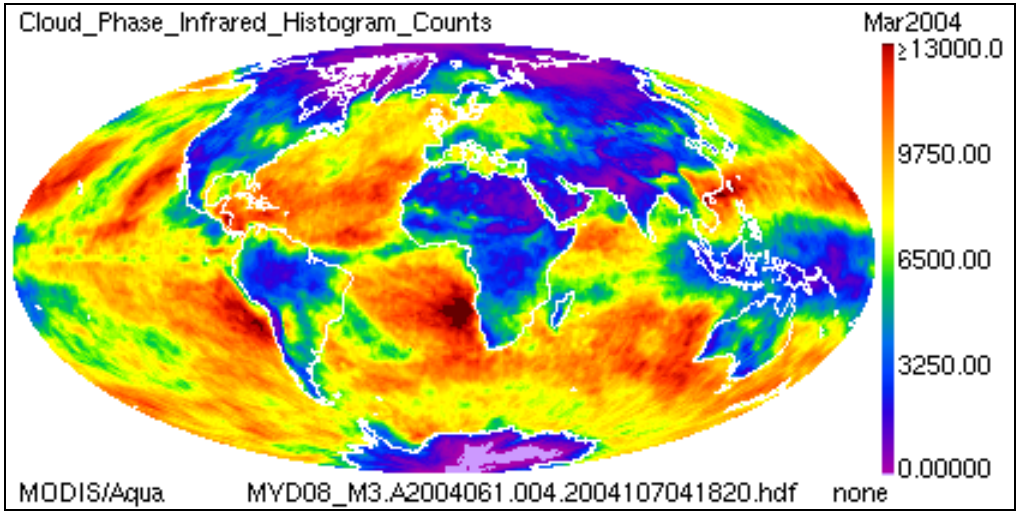
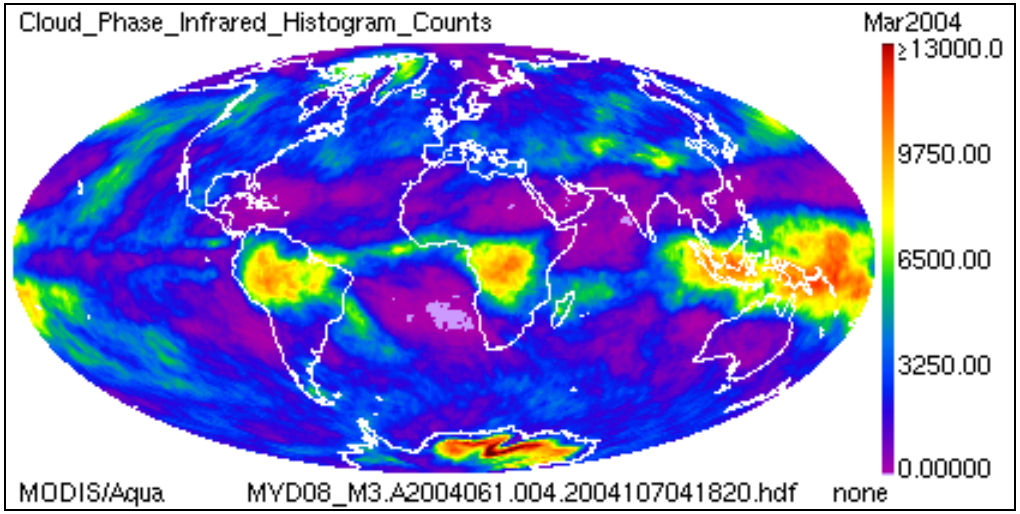
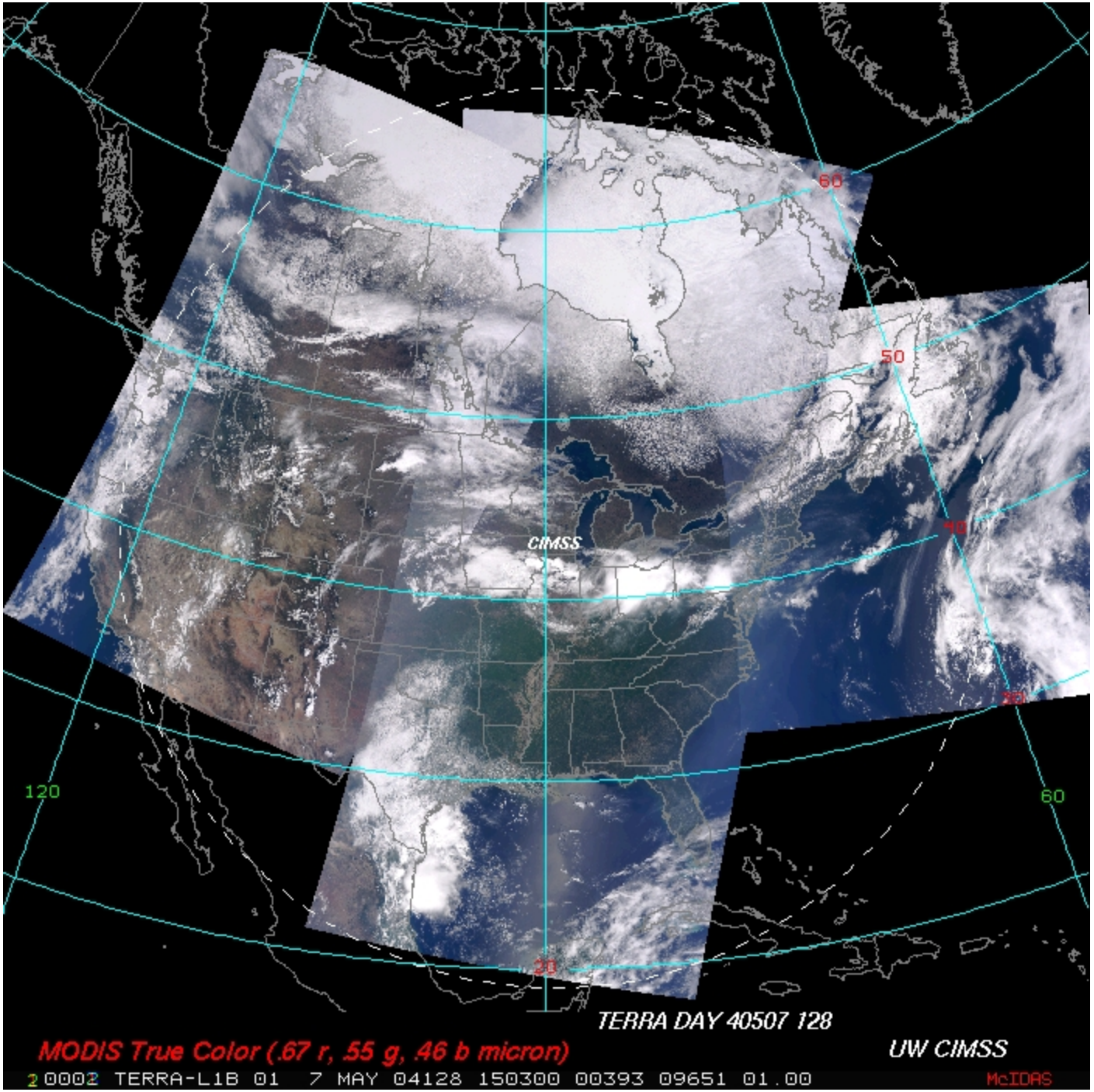
Cloud Phase Level 3 Product March 2004



Water



Ice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CIMSS
TERRA DAY 40507 128
MODIS True Color (.67 r, .55 g, .46 b micron)
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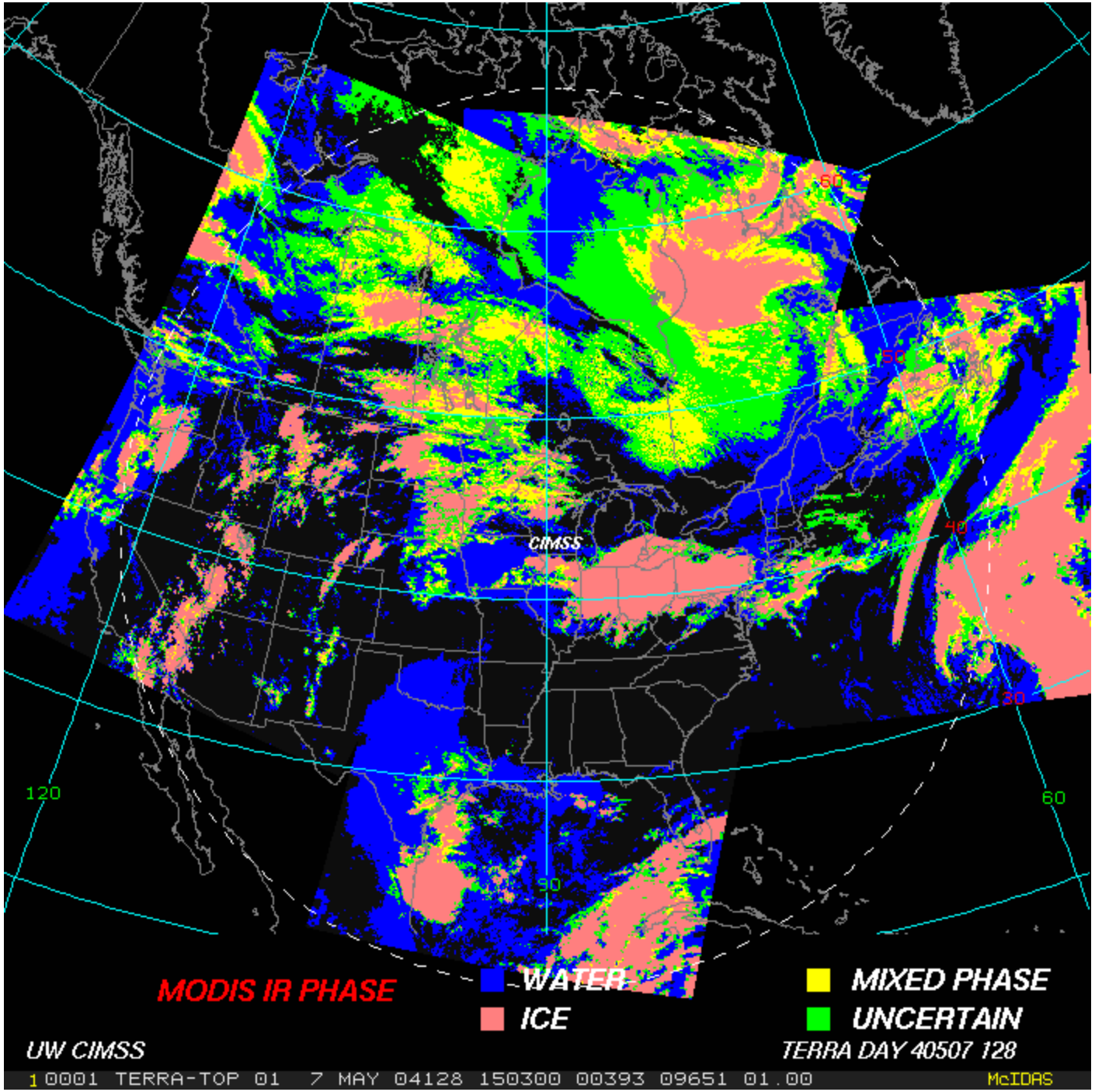
MODIS IR PHASE
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MIXED PHASE
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