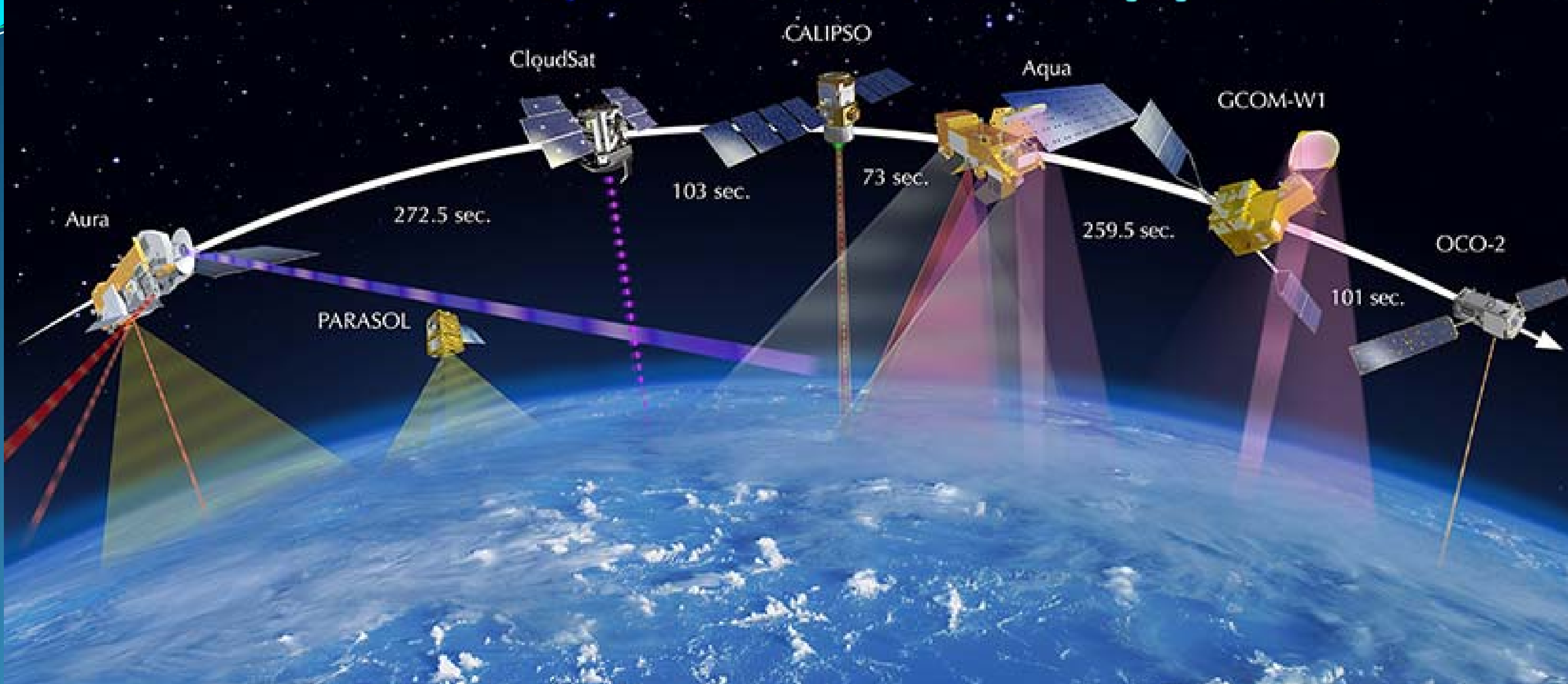
MET 611 – Satellite Data Applications

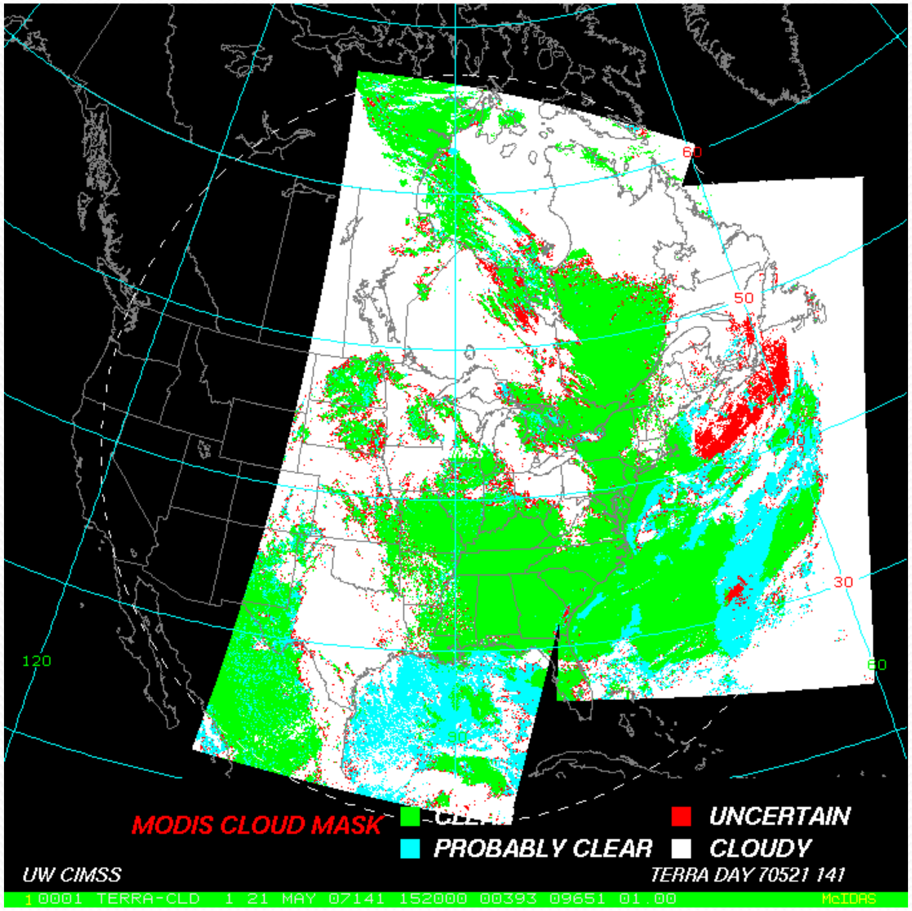


MODIS Cloud Products

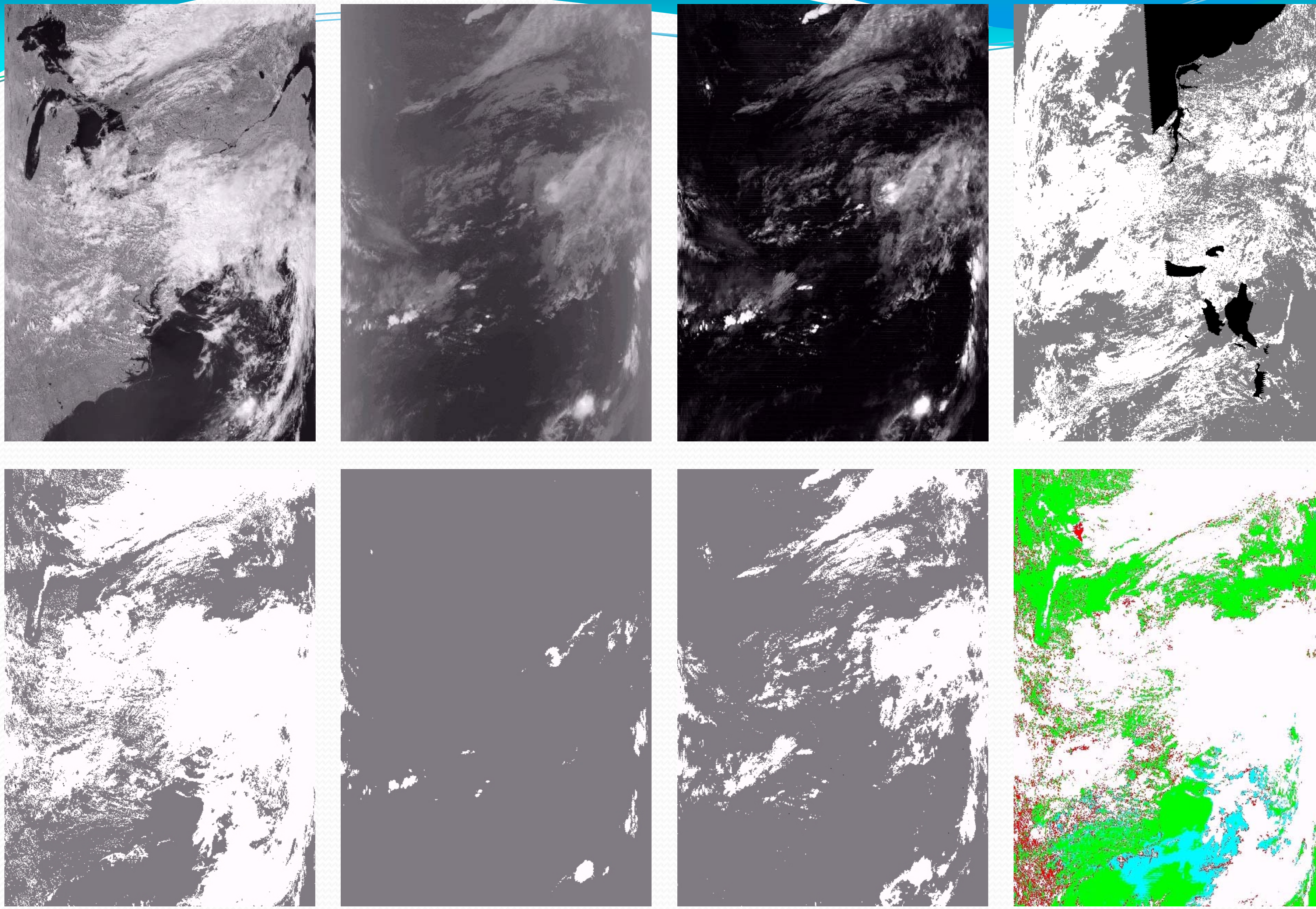
Jennifer D. S. Griswold

Cloud Mask

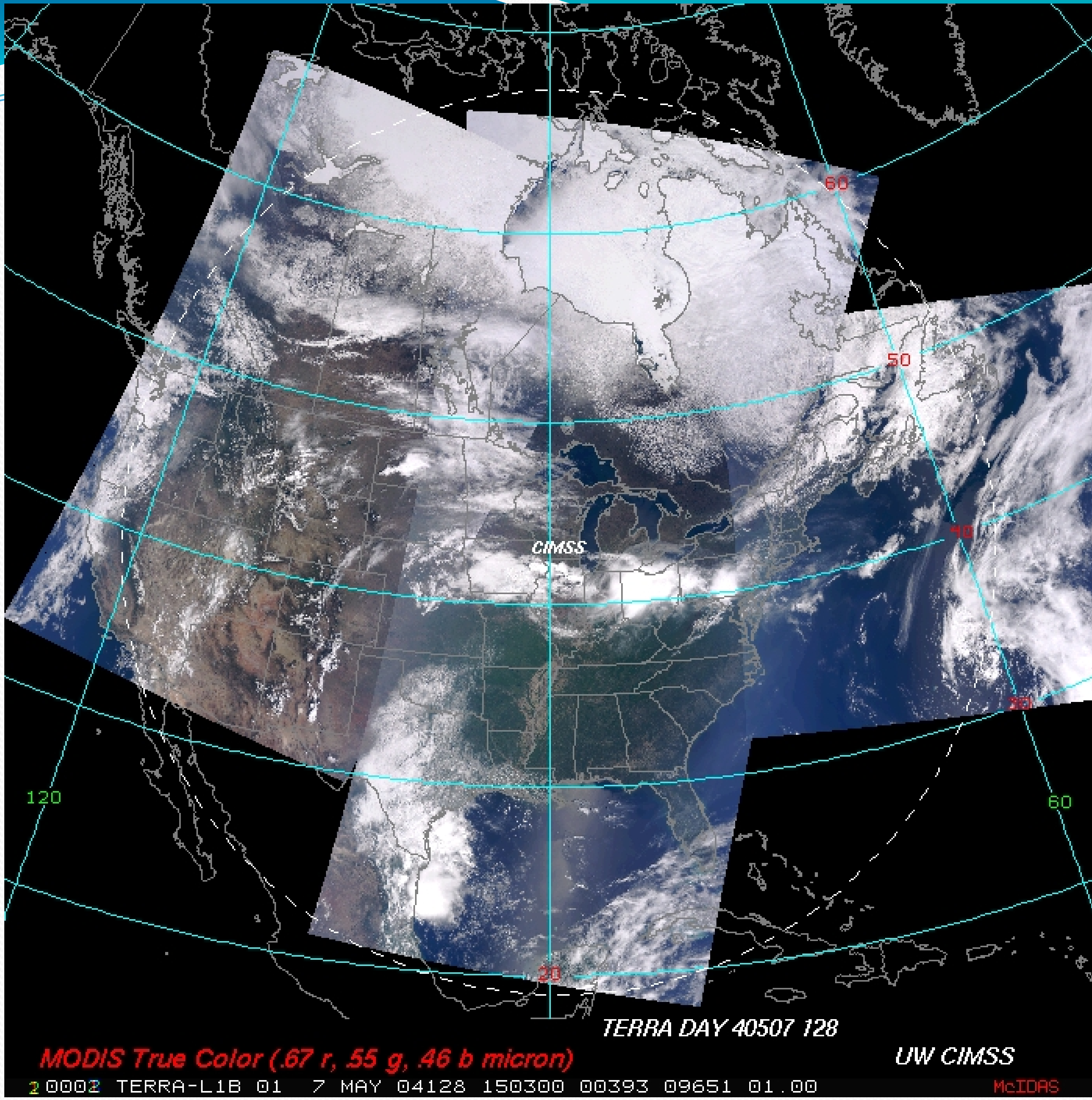
- **48 bits of output per pixel**
- **Individual cloud test results**
- **Processing path**
- **Land/Sea Tag**
- **Classification of Cloud Contamination**
  - Confident Clear
  - Probably Clear
  - Uncertain/Probably Cloudy
  - Cloudy



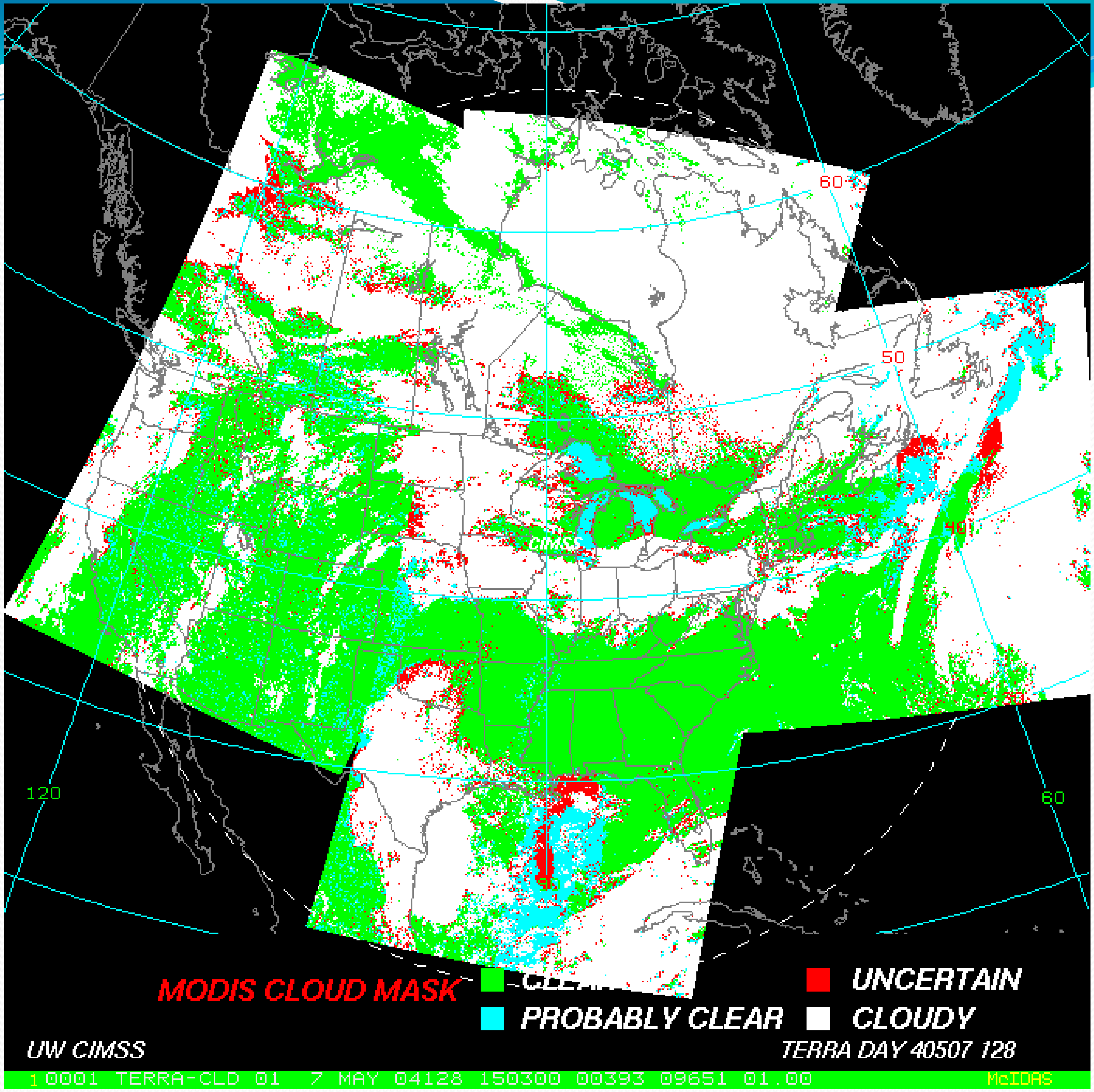
MODIS 0.86 μm | MODIS 13.9 μm | MODIS 1.38 μm | Cloud Mask 3.9-11 μm Test



Cloud Mask Visible Test | Cloud Mask 13.9 μm Test | Cloud Mask 1.38 μm Test | Final Cloud Mask



60
50
40
30
20
120
60
CIMSS
TERRA DAY 40507 128
MODIS True Color (.67 r, .55 g, .46 b micron)
UW CIMSS
2 00002 TERRA-L1B 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS

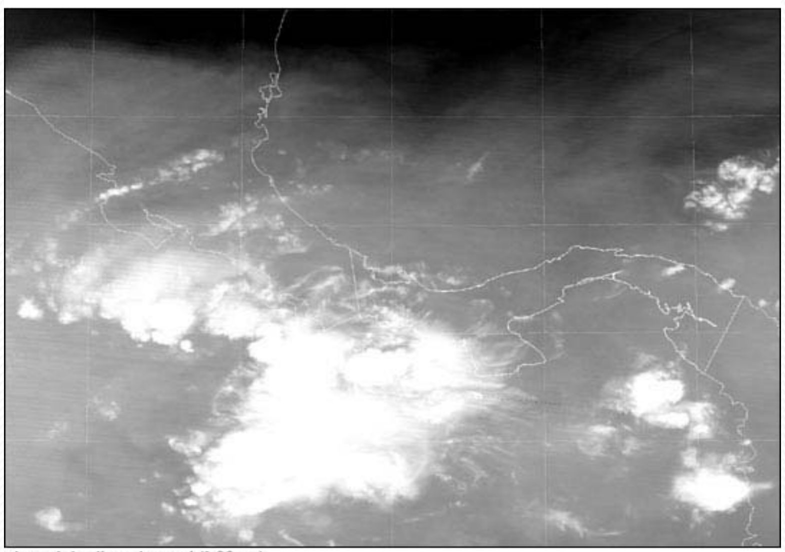


MODIS CLOUD MASK
CLEAR
UNCERTAIN
PROBABLY CLEAR
CLOUDY
UW CIMSS
TERRA DAY 40507 128
1 0001 TERRA-CLD 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS

Cloud Mask Issues

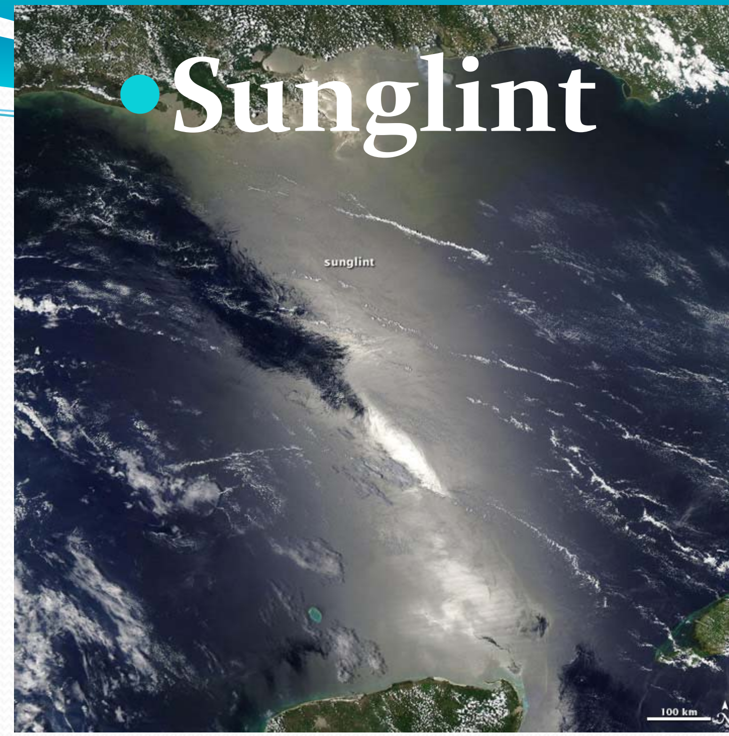
- Sub-Visible Cirrus

true color



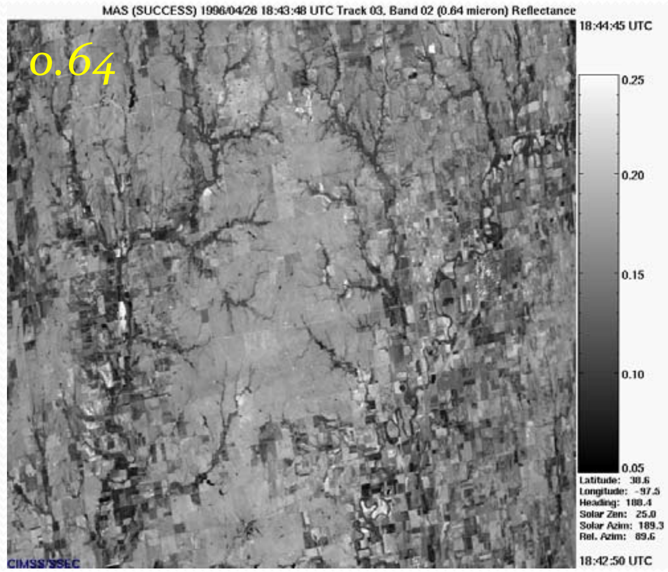
cirrus detection channel (1.38μm)

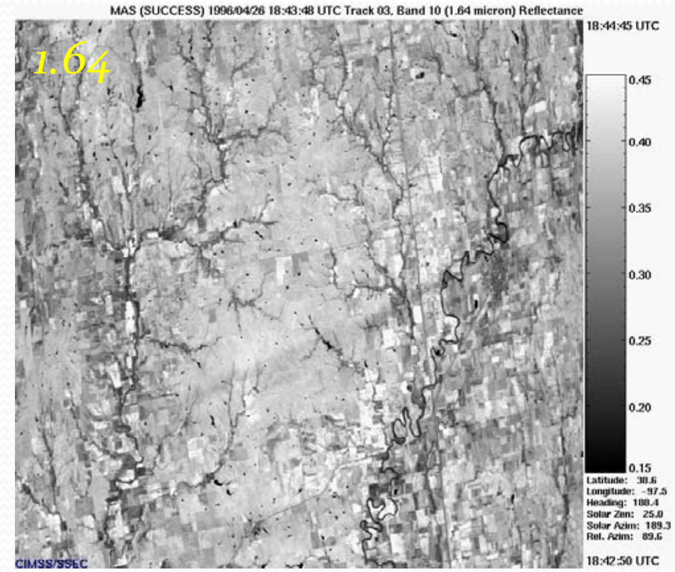
- Sunglint

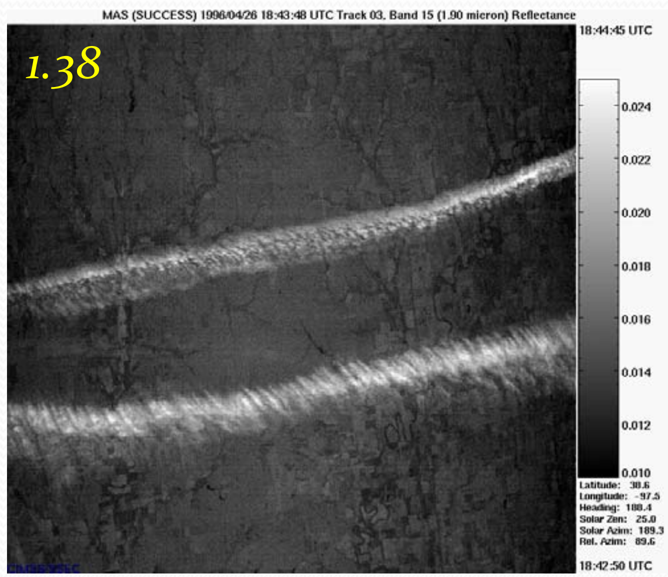


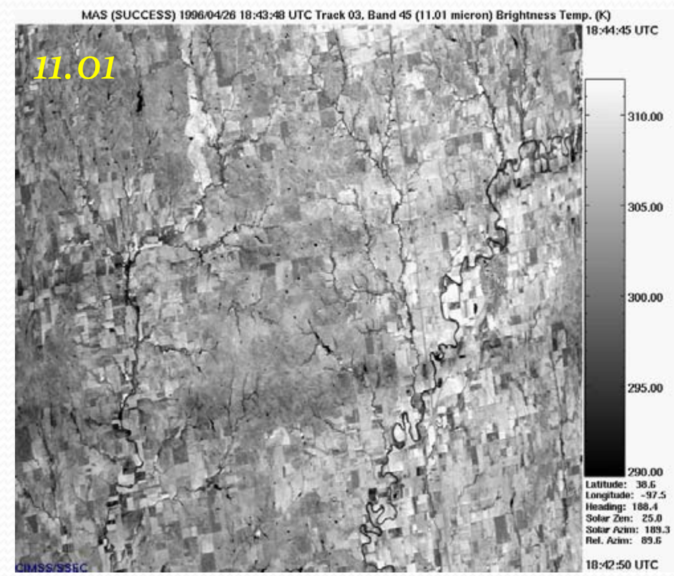
- Non-Cloud Issues

Cirrus Issues

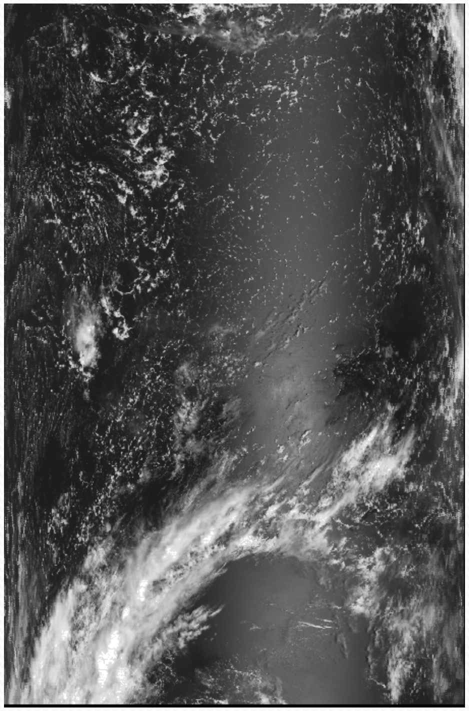




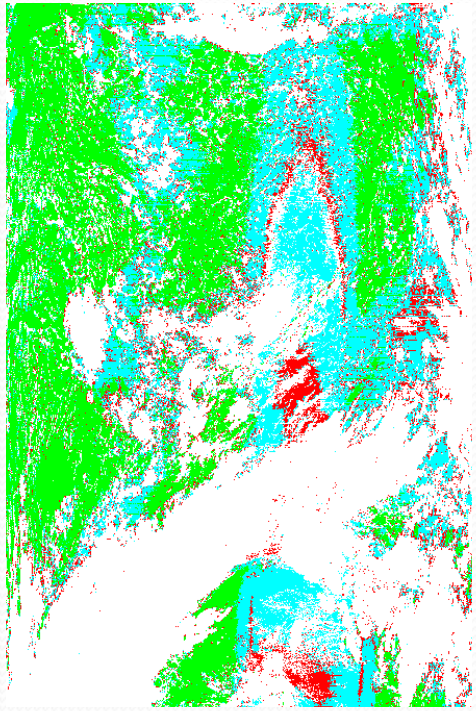




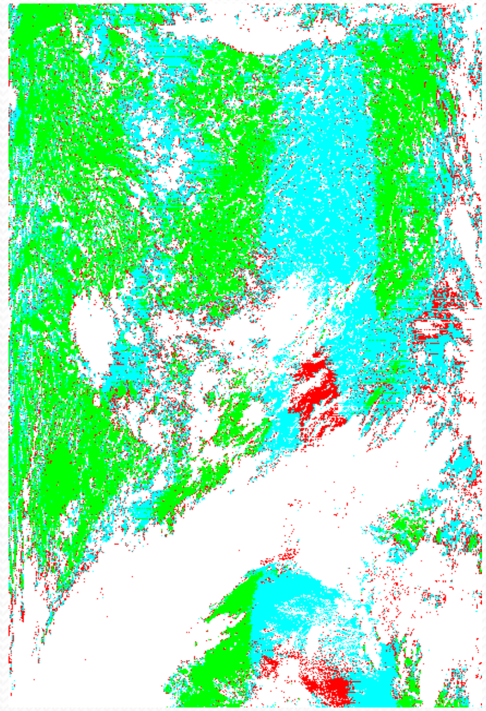
Sunglint Issues



MODIS Band 2 Image



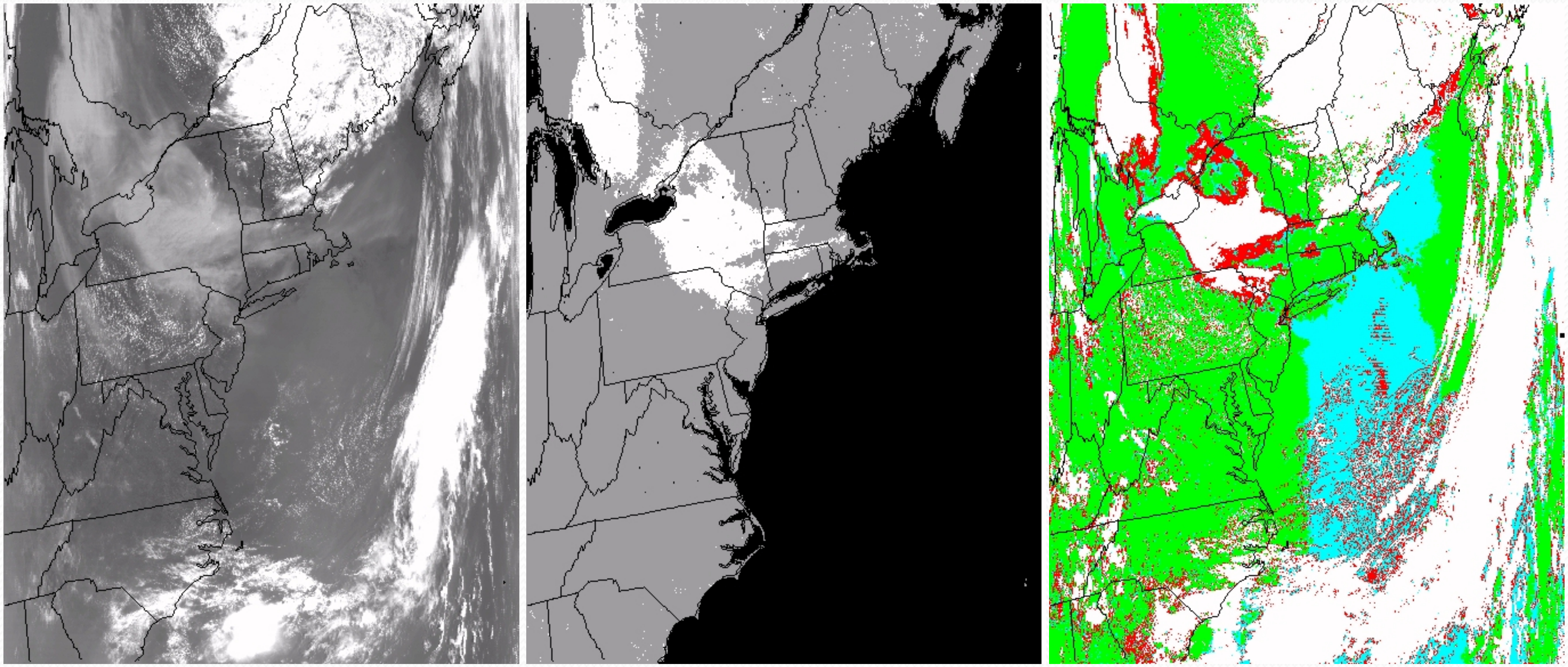
Collection 4



Collection 5

- A threshold change was made to minimize the occurrence of uncertain and cloudy “rings” around the perimeter of sun-glint regions.

Non-Cloud Issues - “Smoke Mask”



- Terra MODIS band 3, “smoke mask”, and cloud mask for 6 July, 2002, 15:50 UTC.

CO_2 Slicing Method

- See papers (Menzel et al. 1983, Wylie and Menzel 1999).
- **Used to infer**
  - cloud-top pressure
  - effective cloud amount
  - Or emissivity (product of cloud fraction and cloud emissivity at 11 μm)

1. **Ratio of deviations in cloud produced radiances and clear air radiances**
2. **Optimum Cloud Top Pressure**
3. **Effective Cloud Amount**
4. **Ratios of three CO_2 spectral channels – Derive most representative cloud height**

CO_2 Slicing Method

1. **Ratio of deviations in cloud produced radiances and clear air radiances**

$$\frac{I(\nu_1) - I_{c1}(\nu_1)}{I(\nu_2) - I_{c1}(\nu)} = \frac{\epsilon_1 \int_{P_s}^{P_c} \tau(\nu_1, p) \frac{dB[\nu_1, T(p)]}{dp} dp}{\epsilon_2 \int_{P_s}^{P_c} \tau(\nu_2, p) \frac{dB[\nu_2, T(p)]}{dp} dp} . \quad (1)$$

- From observed radiances and clear air radiances calculated from a temperature and moisture profile

- From a temperature profile and the profiles of atmospheric transmittance for the spectral channels as a function for Pc, the cloud to pressure.

- ***I(ν)*** = cloud radiances
- ***I_{cl}(ν)*** = clear air radiances
- ***ν_1*** = spectral channel frequency one
- ***ν_2*** = spectral channel frequency two
- ***Є*** = cloud emittance
- ***P_s*** = surface pressure
- ***τ(ν,p)*** = fractional transmittance of radiation of frequency *ν* emitted from the atmospheric pressure level (*p*) arriving at the top of the atmosphere (*p*=0).
- ***B_ν*****[ν, T(p)]** = the Planck radiance of frequency *ν* for temperature *T*(*p*).

CO_2 Slicing Method

2. **Optimum Cloud Top Pressure**

$$|\text{right}(\nu_1, \nu_2) - \text{left}(\nu_1, \nu_2, P_c)|$$

- When the absolute difference is a minimum.

- **Assumptions**
  - The cloud has infinitesimal thickness (Error ½ cloud thickness)
  - The cloud emittance is the same for the two spectral channels

3. **Effective Cloud Amount**

$$N\epsilon = \frac{I(w) - I_{c1}(w)}{B[w, T(P_c)] - I_{c1}(w)}$$

- Evaluated from the IR window channel using the equ to right:

- ***N*** = fractional cloud cover in FOV
- N_ϵ = effective cloud amount
- ***w*** = window channel frequency
- $B[w, T(P_c)]$ = opaque cloud radiance

CO_2 Slicing Method

4. **Ratios of three CO2 spectral channels – Derive most representative cloud height**

$$\left[(I - I_{c1})_i - N\epsilon_k \int_{P_s}^{P_{ck}} \tau_i dB_i\right] = M_{ik}$$

- Two Cloud to Pressures derived from the ratios of:
  - 14.2/14.0 (band 3/band 4)
  - 14.2/13.3 (band 3/band 5)
- The algorithm checks the differences between (I-Icl) and those calculated from the radiative transfer equation.
- P_{ck} is chosen when $\sum_{i=1}^{3} M_{ik}^2$ is a minimum and the sum is over the three CO2 channels used to derive the cloud top pressure values.

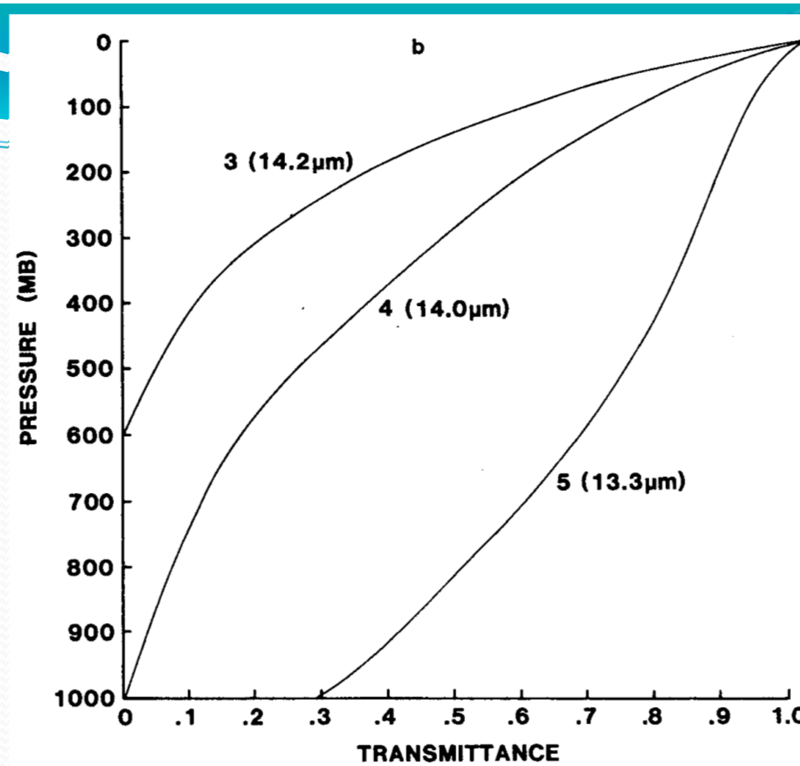


FIG. 1b. The atmospheric transmission of radiance to space as a function of emitting level for the VAS CO_2 spectral bands centered at 14.2, 14.0 and 13.3 μm.

- I = cloud radiance
- I_{cl} = clear sky radiance
- $N\epsilon_k$ = effective cloud amount
- P_S = surface pressure
- P_{ck} = most representative cloud height
- τ_i = fractional transmittance
- B_i = Planck radiance

MODIS CO_2 Slicing Method

- **Takes advantage of differing partial absorption in several of the MODIS infrared bands**
  - Each band is sensitive to a different level in the atmosphere
  - Clouds appear in the CO2-band images according to their level in the atmosphere
    - Low clouds will not appear at all in the high-absorption bands
    - High clouds will appear in all bands

- Has the ability to retrieve cloud pressure and effective cloud amount for:
  - Opaque
  - Non-opaque

  } Mid-High Level Clouds

Cloud Top Pressure and Temp

- **MODIS Cloud-Top Pressures are calculated for (µm/µm):**
  - 14.2/13.9 139/13.6 13.6/13.3 13.9/13.3 13.3/11 ← ICE CLOUD ONLY
- CO_2 Slicing gives you pressure and emissivity at 5x5 km
- GDAS met profile
- NCEP blended SST
- Pressure → Temperature
- Algorithm run for both day and night

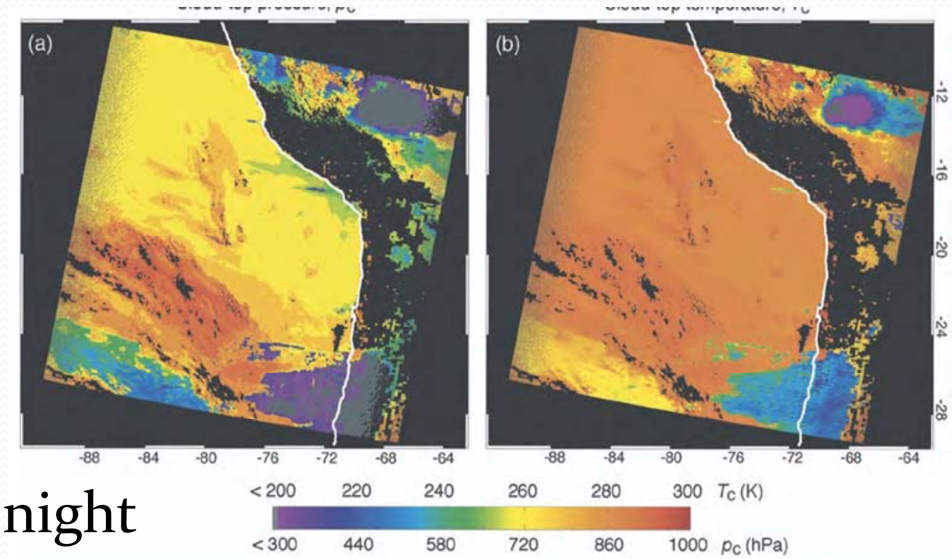


Fig. 3. (a) Cloud-top pressure and (b) temperature retrievals for the image of Fig. 1.

- Uses cloud mask (4 out of 25 pixels have to be probably cloudy or cloudy)

Thermodynamic Phase

- **Inferences**
  - Bispectral IR algorithm uses the inherent difference in water and ice optical constants
  - Optical constant differences between water and ice in selected SWIR (1.6, 2.1 μm)
  - Logic based "decision tree" using cloud mask results, IR, SWIR, and CTT

- **Brightness Temperature Differences (BTD) between 8.5 and 11 μm**
  - Difference in the optical and microphysical properties between water drops and ice crystals
  - Positive for ice clouds (visible optical thickness > 1)
  - Negative for water clouds (high optical thickness)
  - Lower clouds are negative (with increased water vapor)
  - Can be used for both day and night

- **Multilayer clouds are difficult**

Thermodynamic phase example

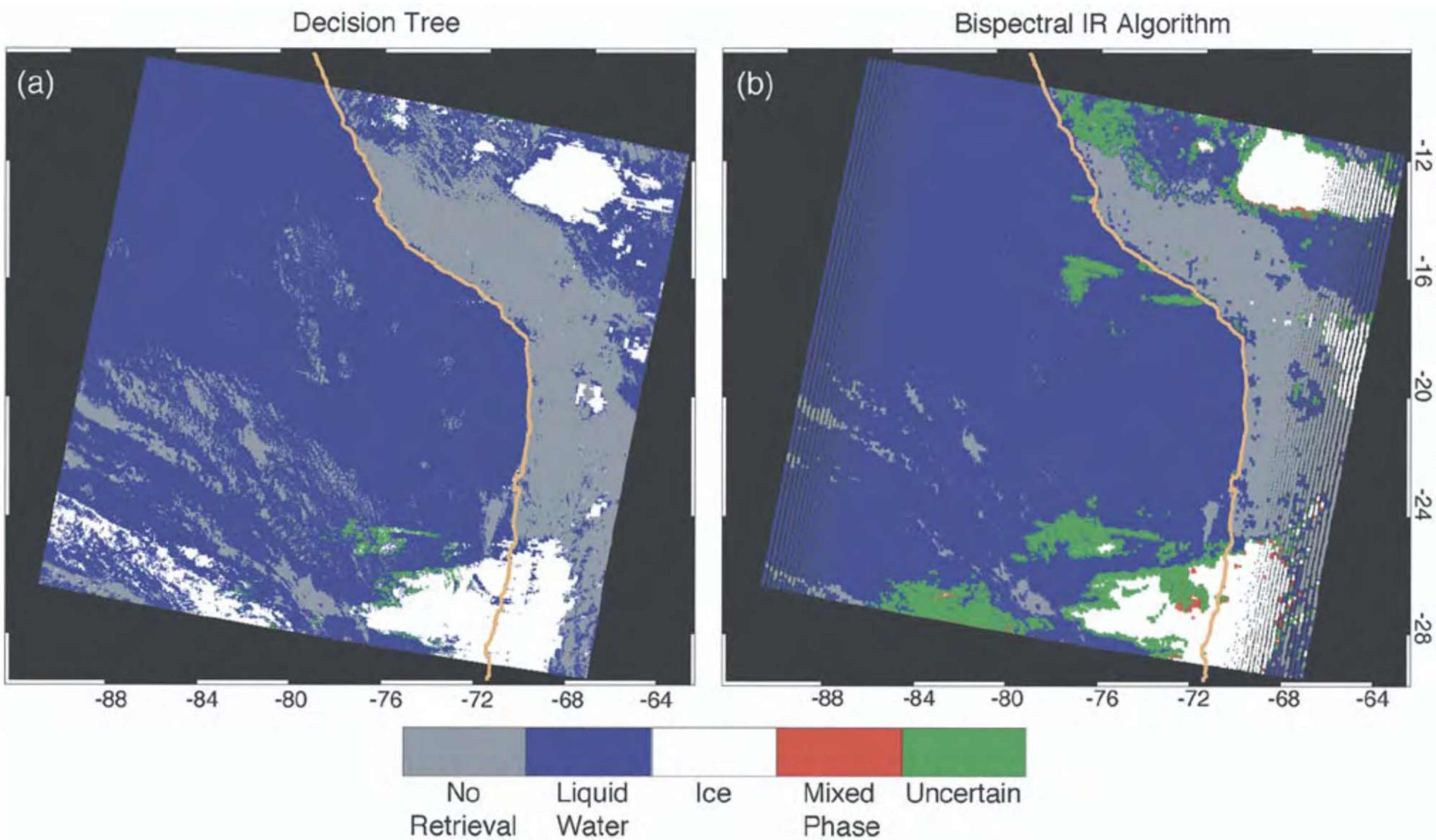
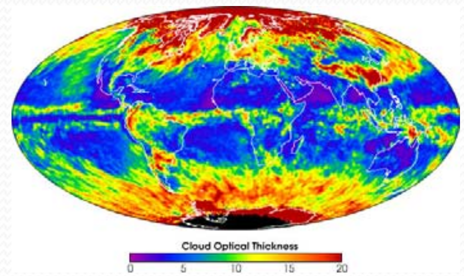


Fig. 4. Two methods for inferring cloud thermodynamic phase. (b) Results from the bispectral IR algorithm (8.5- and 11-μm MODIS bands). The logic of the "decision tree" in (a) is based on results from individual cloud mask tests, the IR and SWIR phase algorithms, and cloud-top temperature retrievals. The decision tree inference is on a 1-km scale while the IR retrieval is at 5 km. The speckled appearance near the scan edge of the IR retrieval image is an artifact of insufficient interpolation to 1-km scales.

Cloud Optical Thickness & Microphysical Properties

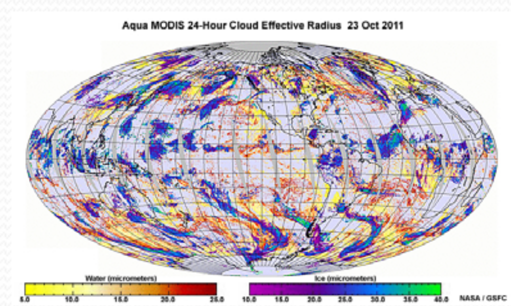
- **COT** = Vertical integration of extinction over cloud thickness



- **Effective Radius (R_e)** = ratio of the third moment of the size distribution to the second moment

$$r_e = \frac{\int_0^\infty \pi \cdot r^3 \cdot n(r)\, dr}{\int_0^\infty \pi \cdot r^2 \cdot n(r)\, dr}$$

- **Useful bands include**
  - Visible
  - IR
  - SWIR (1.6 and 2.1 um)
  - MWIR



- **Retrieved at 1 km resolution**
  - "library calculations"
  - Plane-parallel homogenous clouds overlying a black surface with no atmosphere

COT and R_e Examples

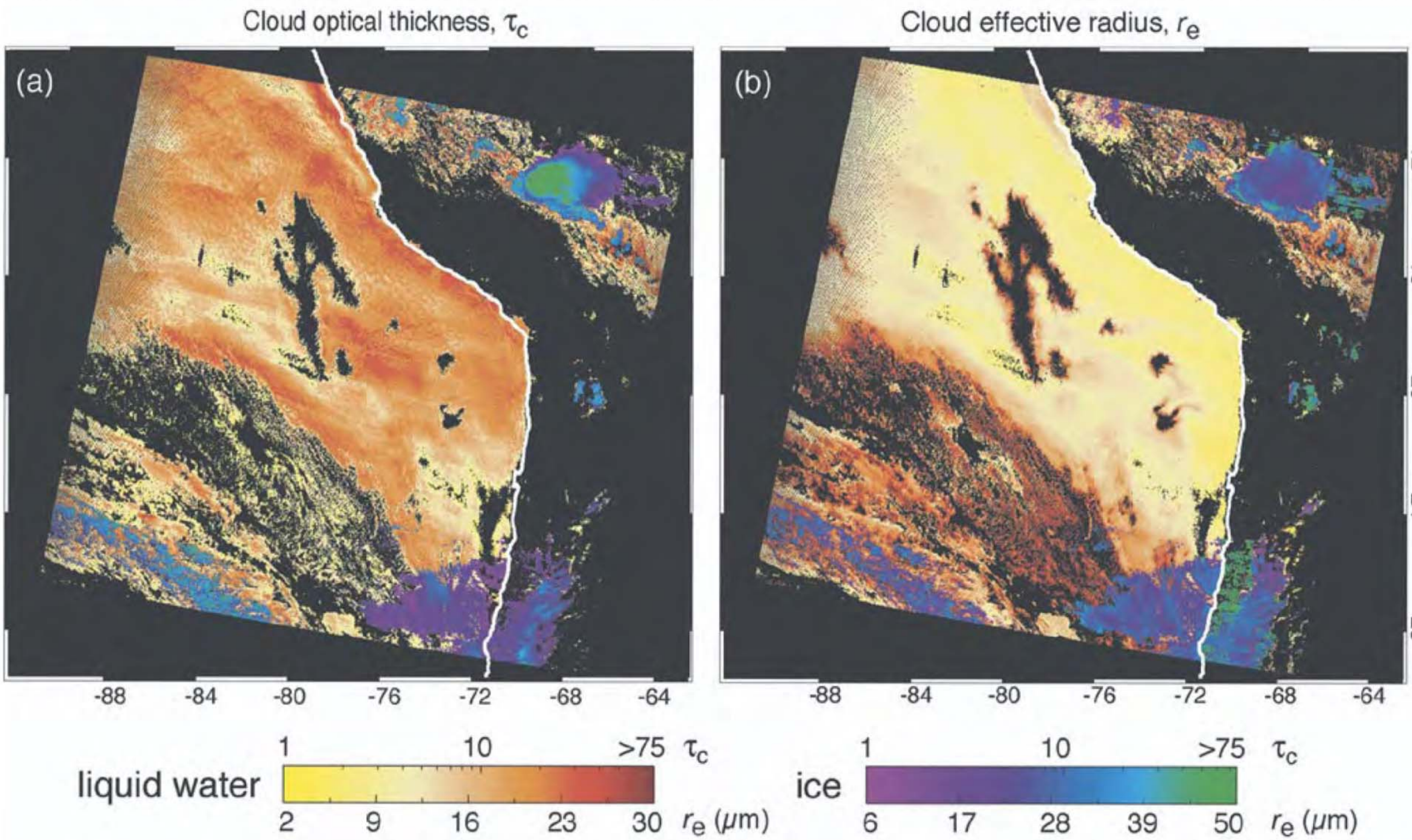
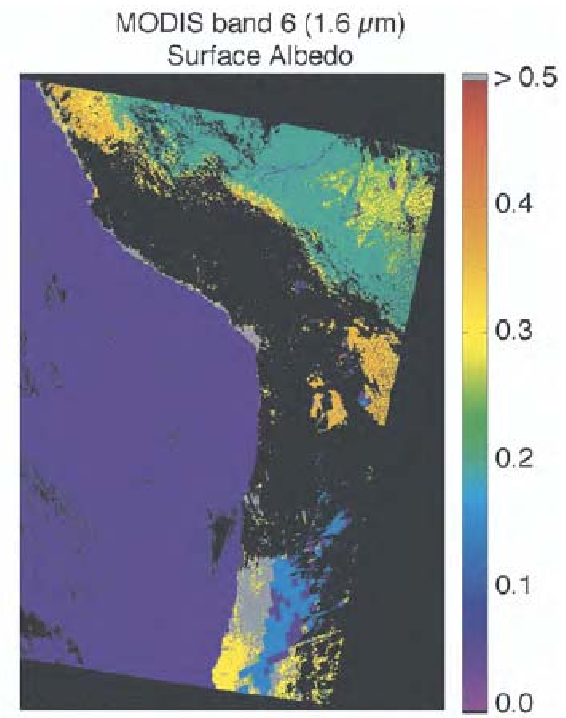


Fig. 7. (a) Cloud optical thickness and (b) effective particle radius retrievals for the image of Fig. 1, with separate color bars for liquid water and ice clouds. Retrievals use the MODIS 2.1-μm band in conjunction with the 0.65-μm band (over land) and the 0.86-μm band (over water).

Cloud Optical Thickness & Microphysical Properties- ISSUES

- **When to retrieve?**
  - Clear vs. cloudy – "not clear" does not mean it's suitable for retrieval of COT and Re
- **Surface Albedo and Ecosystem ID**
  - Cloud reflectance over land may be significantly affected by the underlying surface albedo!



Cloud Optical Thickness & Microphysical Property- ISSUES

- **Atmospheric Correction**
  - In-cloud gaseous absorption decreases the apparent cloud particle single scattering albedo
  - Above cloud water vapor
  - Absorption by trace gases above cloud
- **Retrievals**
  - Derived from water absorbing bands (1.6, 2.1, 3.7 µm) and
  - Nonabsorbing bands (0.65, 0.86, 1.2 µm) to minimize surface reflectance
  - 0.65 and 0.86 µm for land, 1.2 µm for ocean

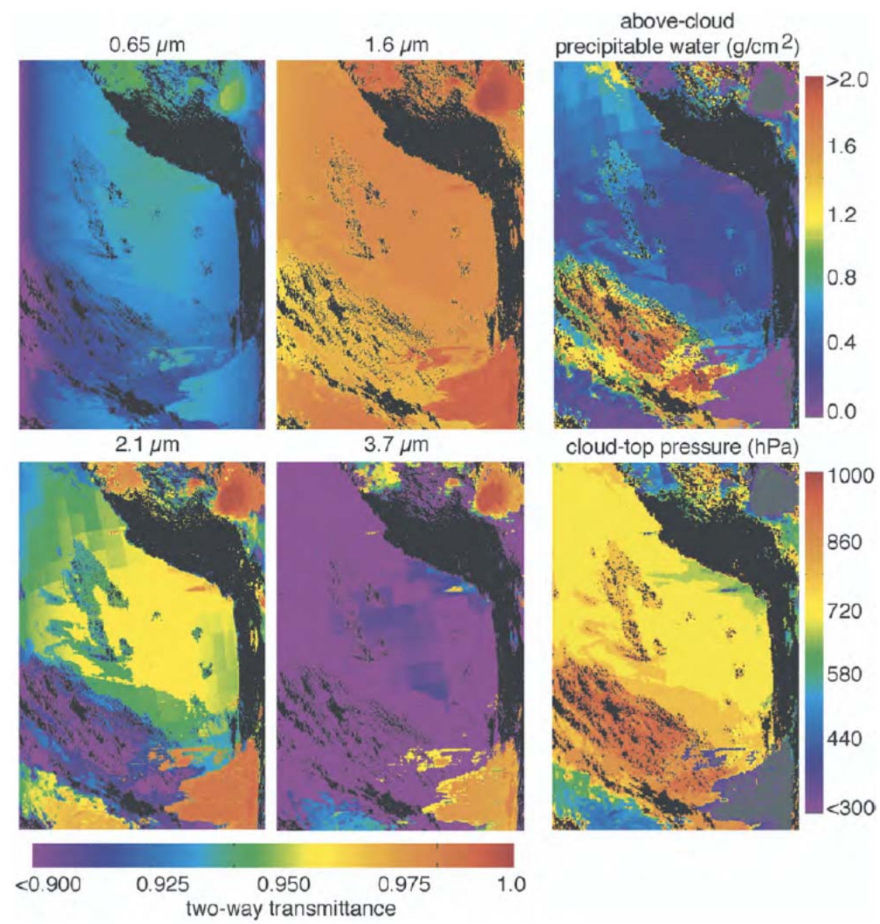
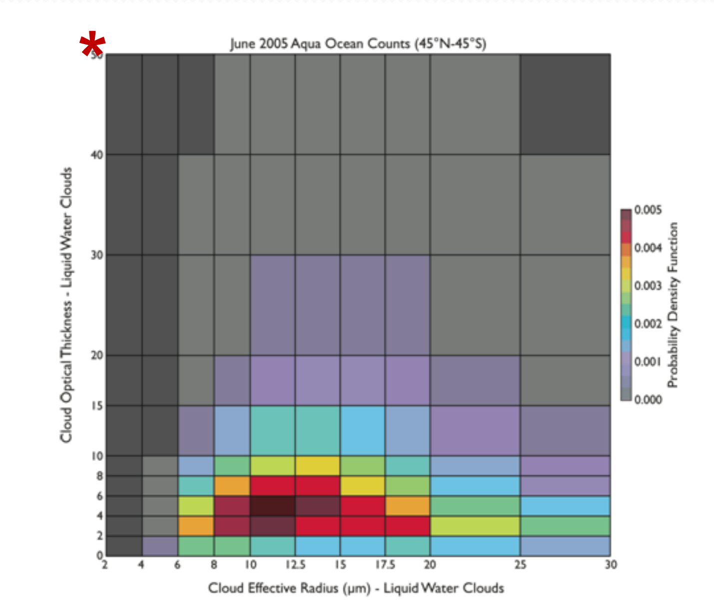
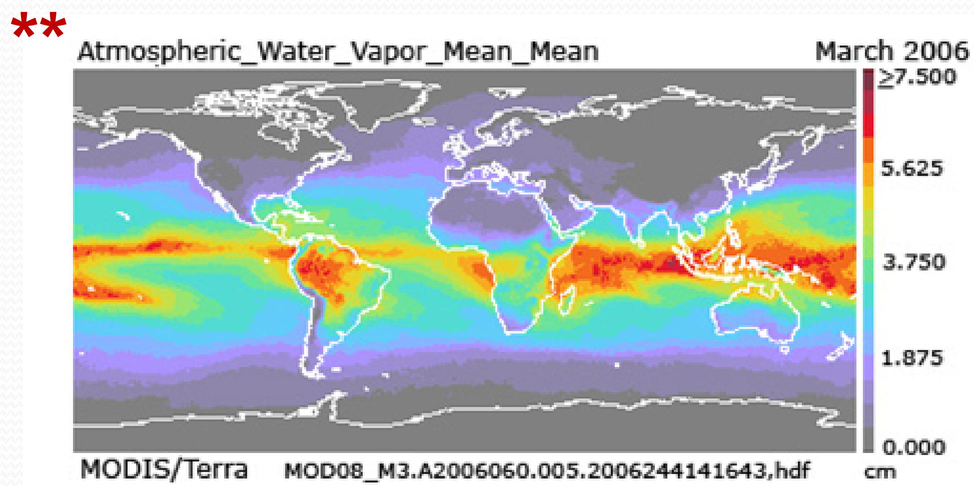


Fig. 6. Two-way band-averaged transmittance for four MODIS bands used in the optical/microphysical retrievals of Figs. 7 and 8 (set of four panels to the left). The transmittance routine requires the integrated above-cloud water amount (upper right panel), which is, in turn, derived from model moisture profile data and the cloud-top pressure field [lower right, cf. Fig. 3(a)].

Some Strengths of Standard Level -3

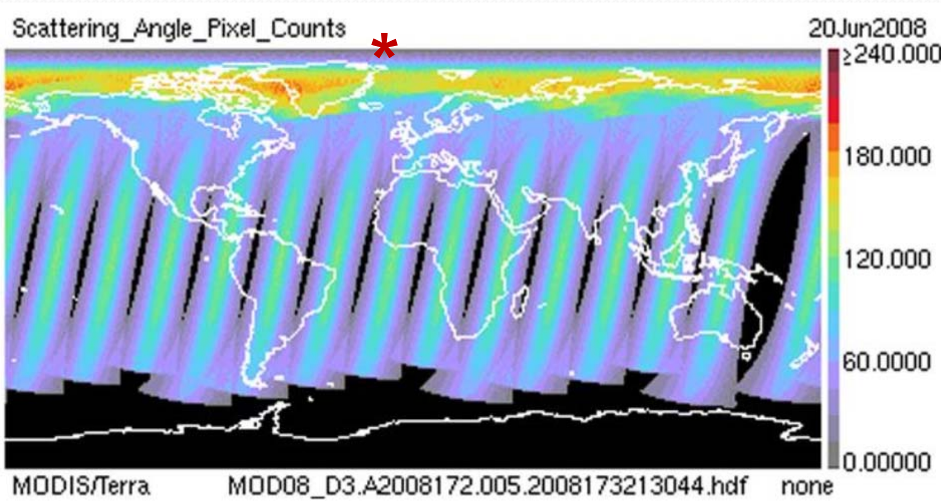
- Many different parameters (over 100)
- Many different statistics (over 20)
- Multiday files fill orbit gaps (full global coverage)
- Efficient study of global statistics & longer term trends
- Joint histograms show cross-parameter relationships *
- Useful in quality and debug efforts of L2 inputs ** (L3 browse)

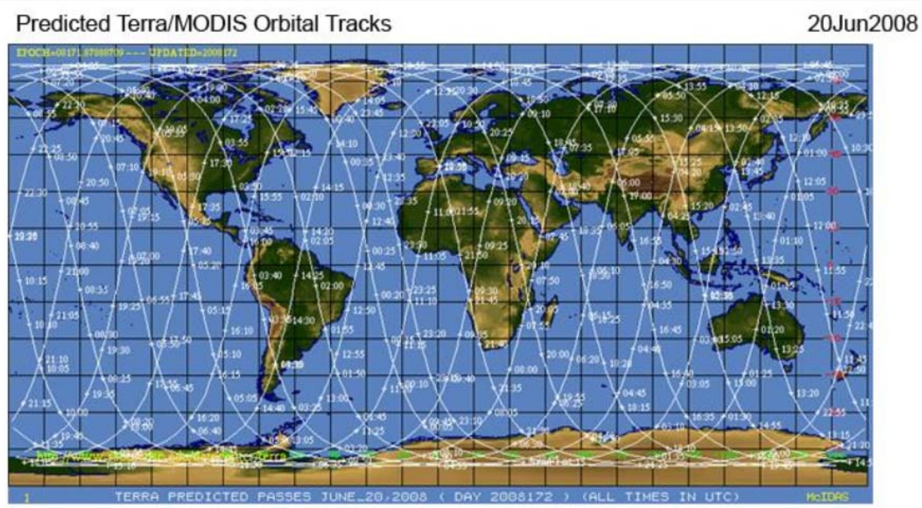




Some Limitations of Standard Level -3

- **Fixed map projection (Lat-Lon)**
- **Fixed relatively coarse resolution (1°)**
- **Fixed parameter set (per Collection)**
- **Limited set of joint histograms (per Collection)**
- **Preset histogram bin boundaries (per Collection)**
- **Overlapping orbits are averaged * (Daily)**
- The marked increase in pixel counts towards the pole is due to overlapping orbits causing the L3 data to become a multiple orbit average, over mid-latitudes the pattern of pixel counts is typical for a single orbit snapshot that can be assigned a single (approximate) local solar time.

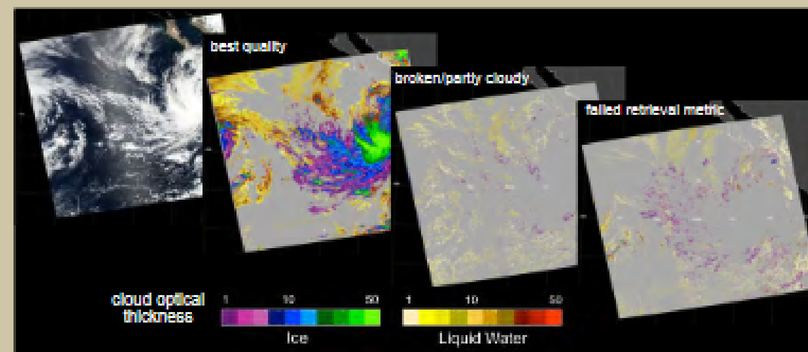




MODIS Cloud Optical Properties Guide

- 145 pages
- Everything you ever wanted to know… and more about how the new Collection 6 L2 and L3 Cloud Data

MODIS Cloud Optical Properties:
User Guide for the Collection 6 Level-2
MOD06/MYD06 Product and
Associated Level-3 Datasets



Version 1.0
October 2015

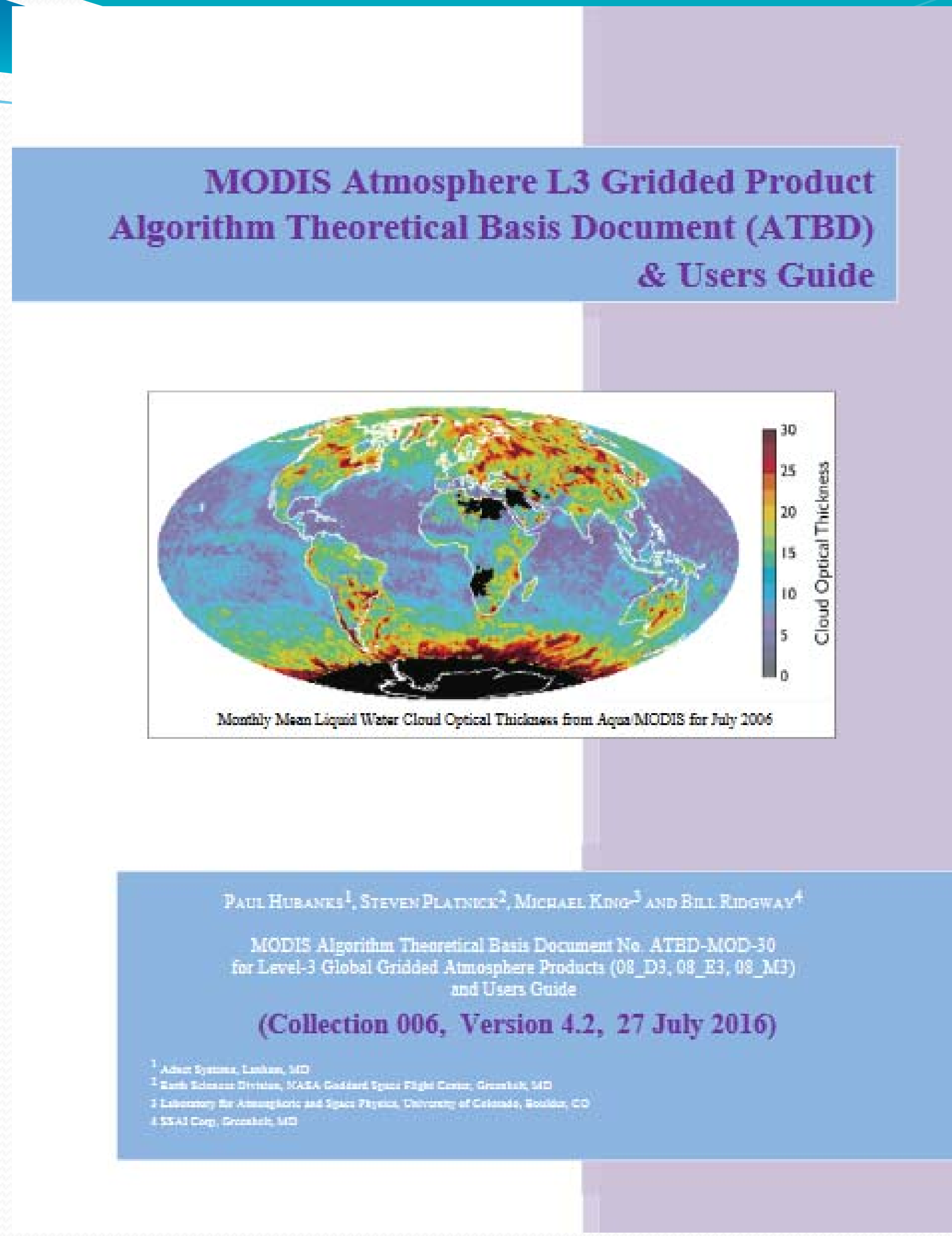
STEVEN PLATNICK [1], MICHAEL D. KING [2], KERRY G. MEYER [3,1], GALA WIND [4,1], NANDANA AMARASINGHE [4,1], BENJAMIN MARCHANT [3,1], G. THOMAS ARNOLD [4,1], ZHIBO ZHANG [5], PAUL A. HUBANKS [6,1], BILL RIDGWAY [4,1], JÉRÔME RIEDI [7]

[1] Earth Sciences Division, NASA Goddard Space Flight Center, Greenbelt, MD
[2] Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO
[3] Universities Space Research Association (USRA), Columbia, MD
[4] Science Systems and Applications, Inc., Lanham, MD
[5] University of Maryland Baltimore County, Baltimore, MD
[6] ADNET Systems, Inc., Lanham, MD
[7] Laboratoire d'Optique Atmosphérique, Université des Sciences et Technologies de Lille/CNRS, Villeneuve d'Ascq, France

https://modis-atmos.gsfc.nasa.gov/sites/default/files/ModAtmo/C6MOD06OPUserGuide_1.pdf

Level 3 ATBD

- 127 pages
- Everything you ever wanted to know about Level 3 data!
  - Gridding
  - Sampling
  - Statistics
  - Computation
  - Differences between C5 and C6



MODIS Atmosphere L3 Gridded Product
Algorithm Theoretical Basis Document (ATBD)
& Users Guide

Monthly Mean Liquid Water Cloud Optical Thickness from Aqua/MODIS for July 2006

Paul Hubanks[1], Steven Platnick[2], Michael King[3] and Bill Ridgway[4]

MODIS Algorithm Theoretical Basis Document No. ATBD-MOD-30
for Level-3 Global Gridded Atmosphere Products (08_D3, 08_E3, 08_M3)
and Users Guide

(Collection 006, Version 4.2, 27 July 2016)

1 Adnet Systems, Lanham, MD
2 Earth Sciences Division, NASA Goddard Space Flight Center, Greenbelt, MD
3 Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO
4 SSAI Corp, Greenbelt, MD

https://modis-atmosphere.gsfc.nasa.gov/sites/default/files/ModAtmo/L3_ATBD_C6.pdf

Gridding Options

- Lat-Lon (sparse) but the one that is easiest to create in Matlab.
- Hammer-Aitoff (equal area)
- Different types of distortion for each

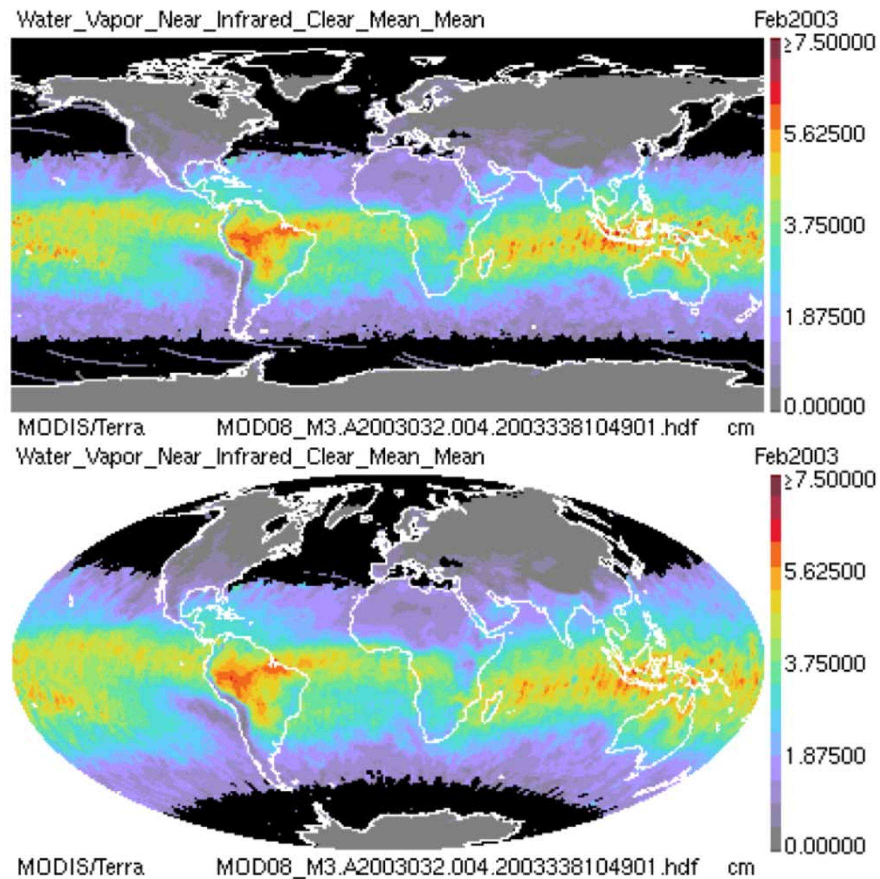


Figure 14. Identical Collection 004 data mapped on the native Latitude-Longitude grid (top) and remapped on the Hammer-Aitoff grid bottom. Note the distortion in sparse data regions especially at high latitudes on the Hammer grid (e.g., the disappearance of the bad data scans (purple streaks) in the southern Ocean); however in solid data regions (30°N to 30°S) the Hammer remapping shows little distortion.

Joint Histograms

- Two variables (x- and y-axes) with the height, or color indicated the number of “counts” in each bin that satisfy the combination of variables.

- Examples below show Joint Histograms where the y-axis is cloud Optical Thickness and x-axis Effective Radius

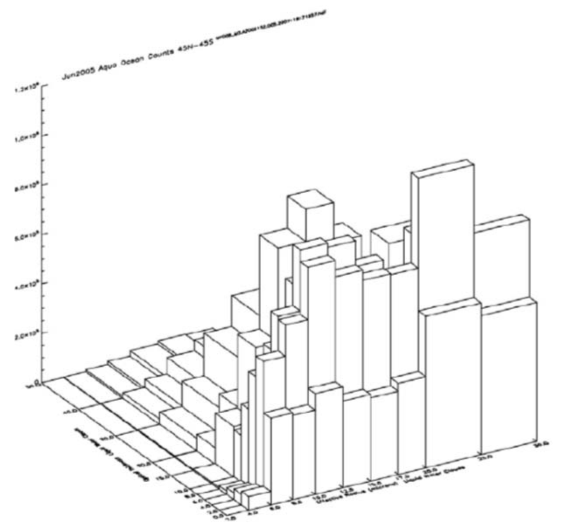


Figure 20. A June 2005 MYD08_M3 Counts Joint Histogram of cloud optical thickness (y-axis) vs. cloud effective radius (x-axis) for liquid water clouds displayed as a “3D lego plot” with post-processing to limit the data to ocean-only L3 grid cells that range from 45°N to 45°S. The top bin of cloud optical thickness from 50 to 100 was chopped off. The height of each Lego bar represents the number of counts in each bin. It is often difficult to impossible to orient lego plots to make all bins visible.

ntour plots, and (iii) color-coded histogram bin plots.

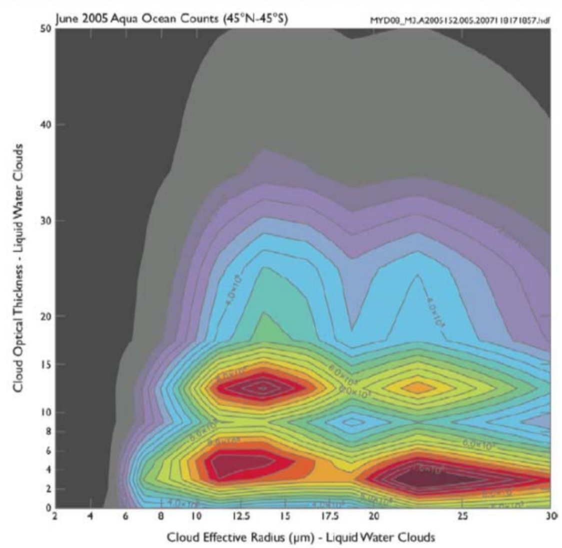


Figure 21. A June 2005 MYD08_M3 Counts Joint Histogram of cloud optical thickness (y-axis) vs. cloud effective radius (x-axis) for liquid water clouds displayed as a “colored contour plot” with post-processing to limit the data to ocean-only L3 grid cells that range from 45°N to 45°S. The top bin of cloud optical thickness from 50 to 100 was chopped off. The contour colors represent the number of counts in each bin (low is grey, high is red). Contour plots show a distorted (smoothed) view of the data stored in the joint histogram.

Day or Night Availability?

Table 7. Availability of daytime only, nighttime only, or combined daytime and nighttime parameters in L3 organized by the "derived from" product group.

Derived from Product	Daytime Only SDSs? DAYTIME	Combined Day & Night SDSs? DAYTIME NIGHTTIME	Nighttime Only SDSs? NIGHTTIME
Aerosol 04_L2	Yes	No	No
Water Vapor 05_L2	Yes	Yes*	No
Cirrus Detection 06_L2 (CD)	Yes	No	No
Cloud Top Properties 06_L2 (CT)	Yes	Yes	Yes
Cloud Optical Prop. 06_L2 (OD)	Yes	No	No
Atmosphere Profile 07_L2	No	Yes	No

* All Combined Day & Night Water Vapor (05_L2) SDSs are copied from Atmosphere Profile (07_L2)

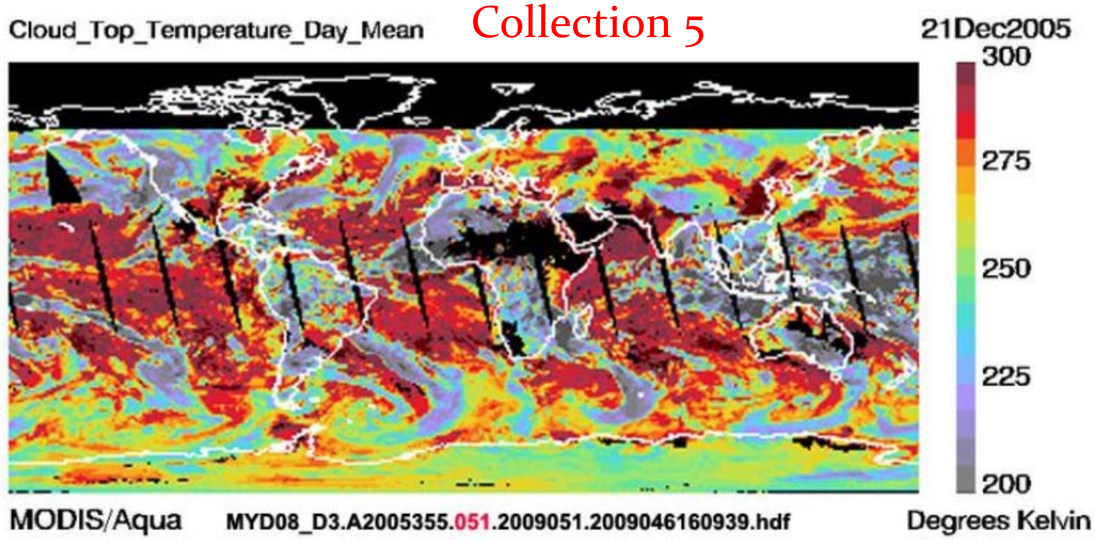
Improvements between C5 and C6

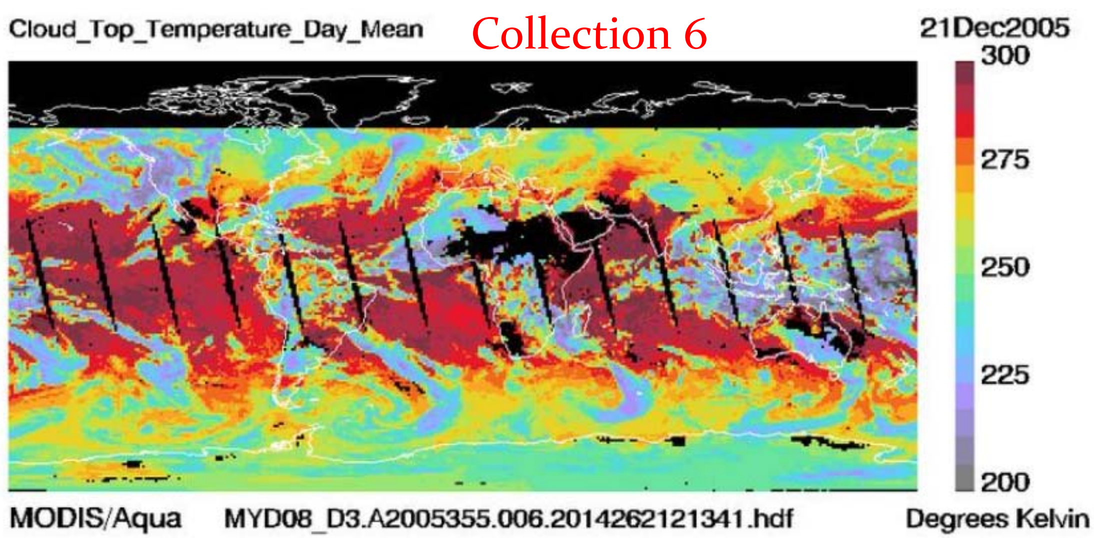
- **Cloud Top Properties (DONE!)**
  - Added Near Nadir versions of CTP, CTT, CEE, CF, and CTH (all aggregated by Day only, Night only, and Combined Day and Night). (15 parameters added)
  - Added Low (>680mb), Middle(-440mb), & High Cloud (<440mb) separation of CTP, CTT, CEE, CF, and CTH through finely binned Histograms (for CTP) and Joint Histograms vs. CTP (for remaining 4 parameters). Note that this was done for both the near nadir aggregation as well as the heritage (full view angle) parameters. Also, all were aggregated by Day only, Night only, and Combined Day and Night. (24 joint histograms added & 6 marginal histograms added)
  - Added eleven new Surface Type Fractions and Pixel Counts in the Cloud Top Property retrieval space. (11 parameters added)
  - Added Joint Histogram of Cloud Phase (Baum) vs. CTP Near Nadir for Day and Night. (2 joint histograms added)
  - Added Joint Histogram of Near Nadir CTP (5km avg) vs. CTP (1km sampled) for Day and Night. (2 joint histograms added)
  - Added Joint Histogram of Cloud Phase vs. CTT (to D3 only, due to lack of space in the E3/M3)

Improvements between C5 and C6

- **Cloud Optical Properties: (DONE!)**
  - Delete all QA Confidence Flag related statistics from all Cloud Optical Property parameters. (many SDS's deleted)
  - Add Partly Cloudy (PCL) versions of COT, CER, CWP, CF (for primary 2.1 retrieval) for Liquid, Ice, Undetermined, and Combined. (14 parameters added)
  - Delete all Combined Effective Radius and Combined Water Path parameters. (2 parameters deleted)
  - Change all "Cloud_Fraction_(Phase)" parameters to "Cloud_Retrieval_Fraction_(Phase)" (10 parameters modified)
  - Add Partly Cloudy (PCL) versions of COT, CER, CWP, CF (for 1.6/2.1 retrieval) for Liquid & Ice only. (8 parameters added)
  - Add Standard and Partly Cloudy (PCL) versions of COT, CER, CWP, CF (for 1.6 retrieval) for Liquid & Ice only. (16 parameters added)
  - Add Standard and Partly Cloudy (PCL) versions of COT, CER, CWP, CF (for 3.7 retrieval) for Liquid & Ice only. (16 parameters added)

Improvements between C5 and C6 Cloud Top Temperature

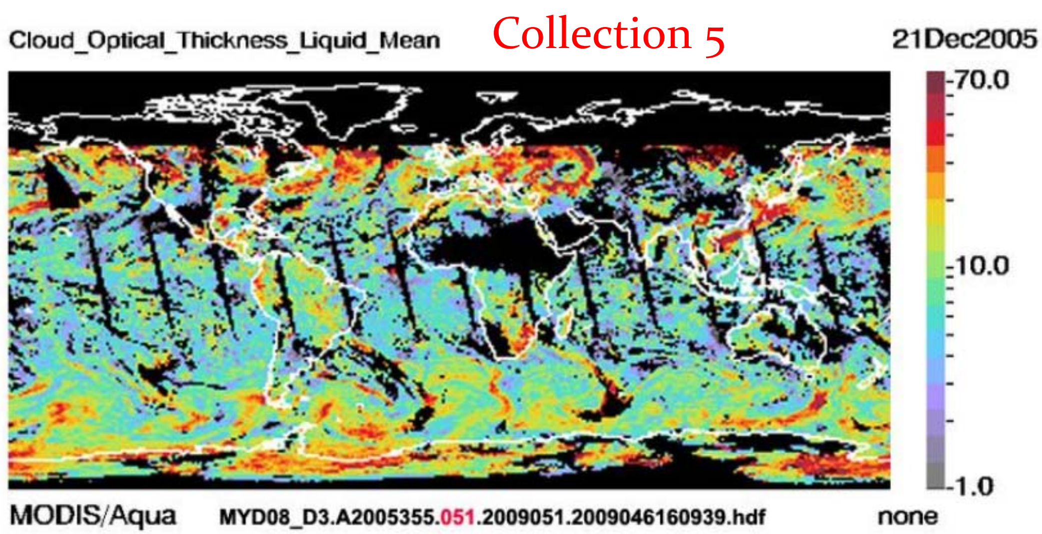


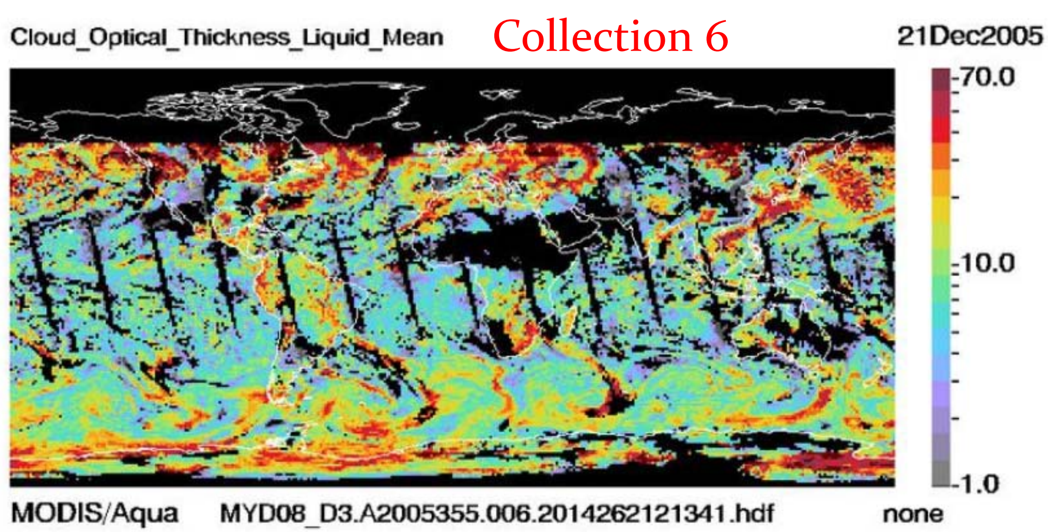


- One of the more interesting changes in C6 was a sub setting of some of the Cloud Top Property Parameters into "Near Nadir" SDSs. Near Nadir is defined as Senor Zenith Angle ≤ 32° so it's roughly the "inner half" of the scan).

- Reducing the scan angles improves the certainty and reduces errors in the algorithm providing better estimates of the various Cloud Top Property parameters computed.

Improvements between C5 and C6
Cloud Optical Thickness





- Improved coverage
- 4 different retrieval algorithms
  - **2.1 um primary**
  - 3.7 um
  - 1,6 um
  - 1.6/2.1 um

- All things being equal, MODIS data users should start out with the Primary 2.1 um retrieval.

Time to work on Lab 1 or Lab 2