An overview of cloud masking and other research for Landsat and LDCM

- ✓LTAP-related work
- ✓Cloud masking (with and without TIRS thermal and OLI cirrus band)
- ✓Cloud number vs. size of marine trade cumulus (if time permits)

Lazaros Oreopoulos (NASA-GSFC)
and
Mike Wilson (UMBC-GEST)

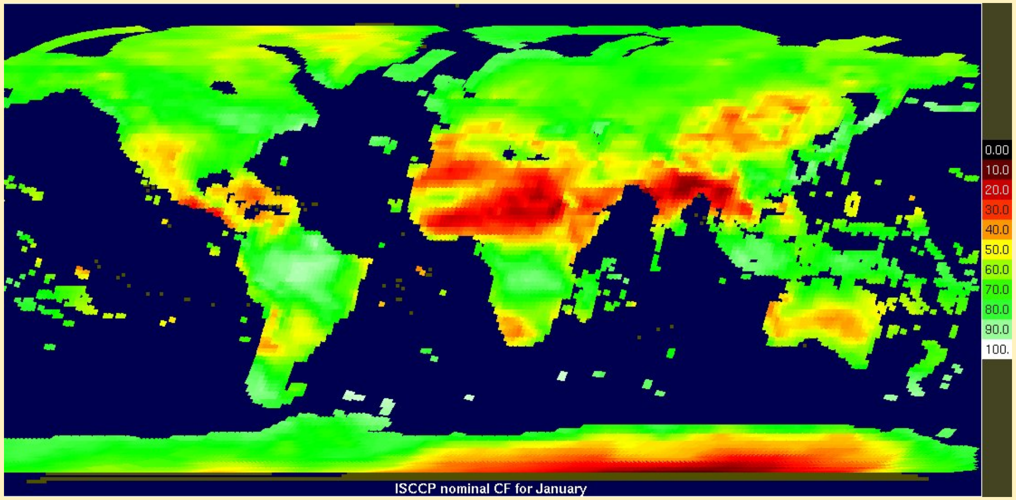
with contributions by
Tamás Várnai, John Gasch, Dongmin Lee, Ilan Koren, and Graham Feingold

LTAP-related work

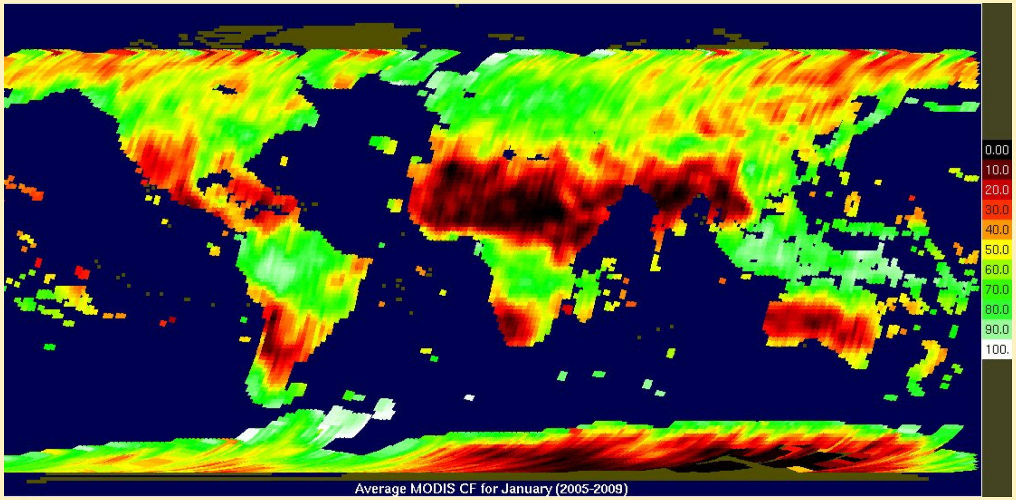
(with John Gasch & Dongmin Lee)

Cloud Fraction climatology comparison: ISCCP vs. MODIS

ISCCP D2 Nominal CF-
(January 1983 – 1997)
Land CF = 56



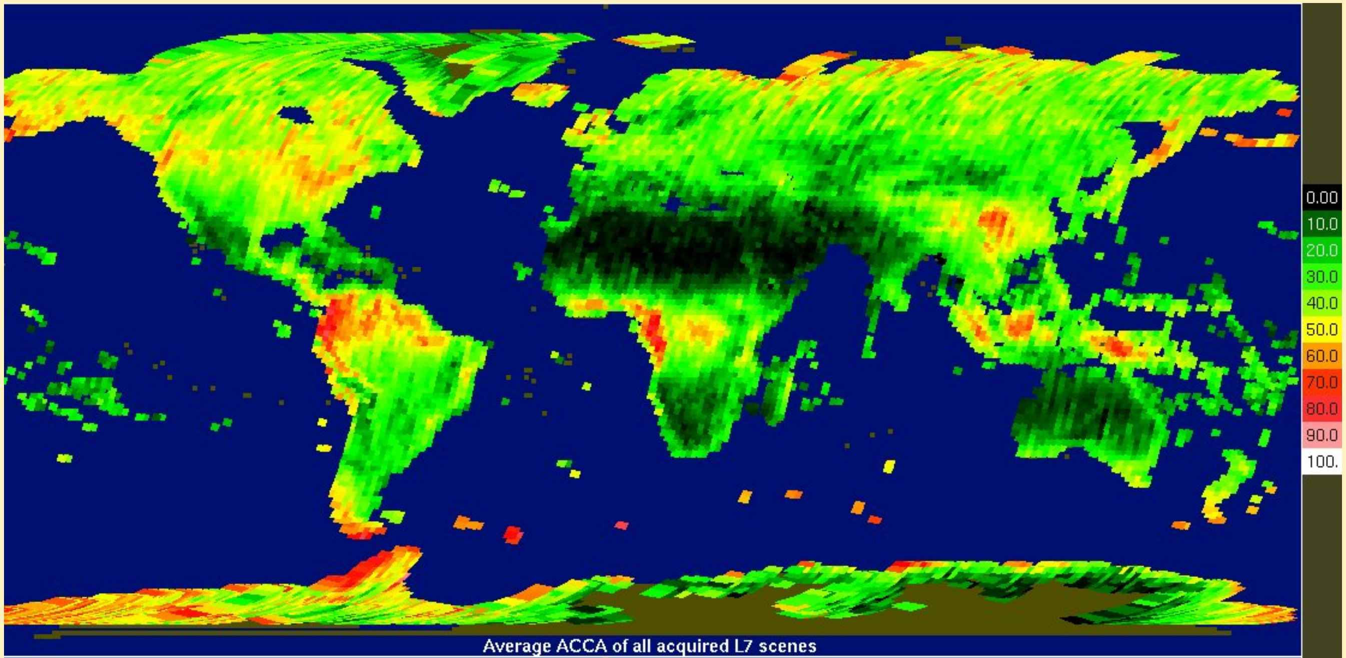
Average MODIS L2 CF –
(January 2005-2009)
Land CF = 45



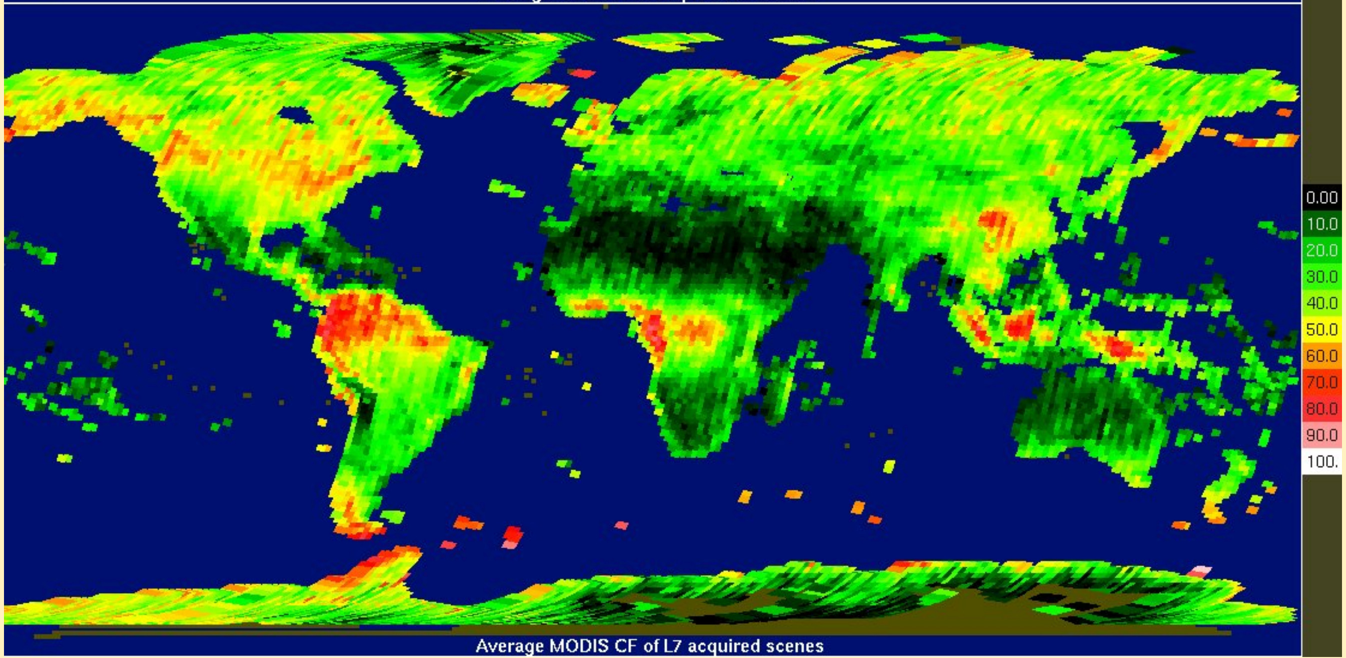
In LTAP, cloud fraction predictions are compared to climatology

Average Cloud Fraction 2005 – 2009

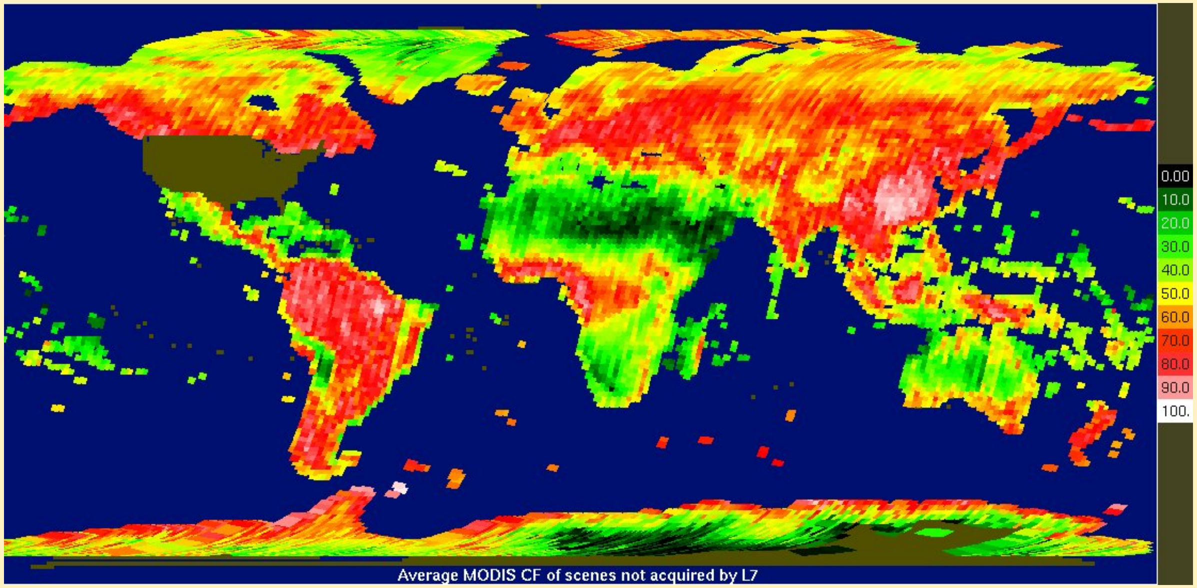
Average **ACCA**
= **31.0**



Average **MODIS CF**
of all acquired
ETM+ scenes
= **32.7**

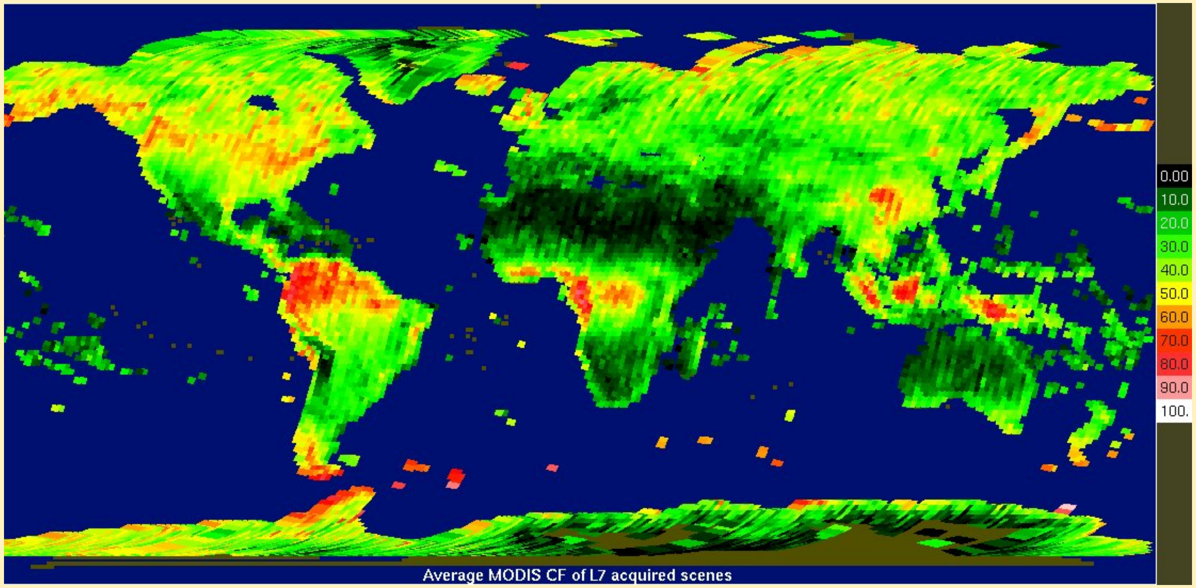


Average MODIS CF of scenes *not acquired* by L7



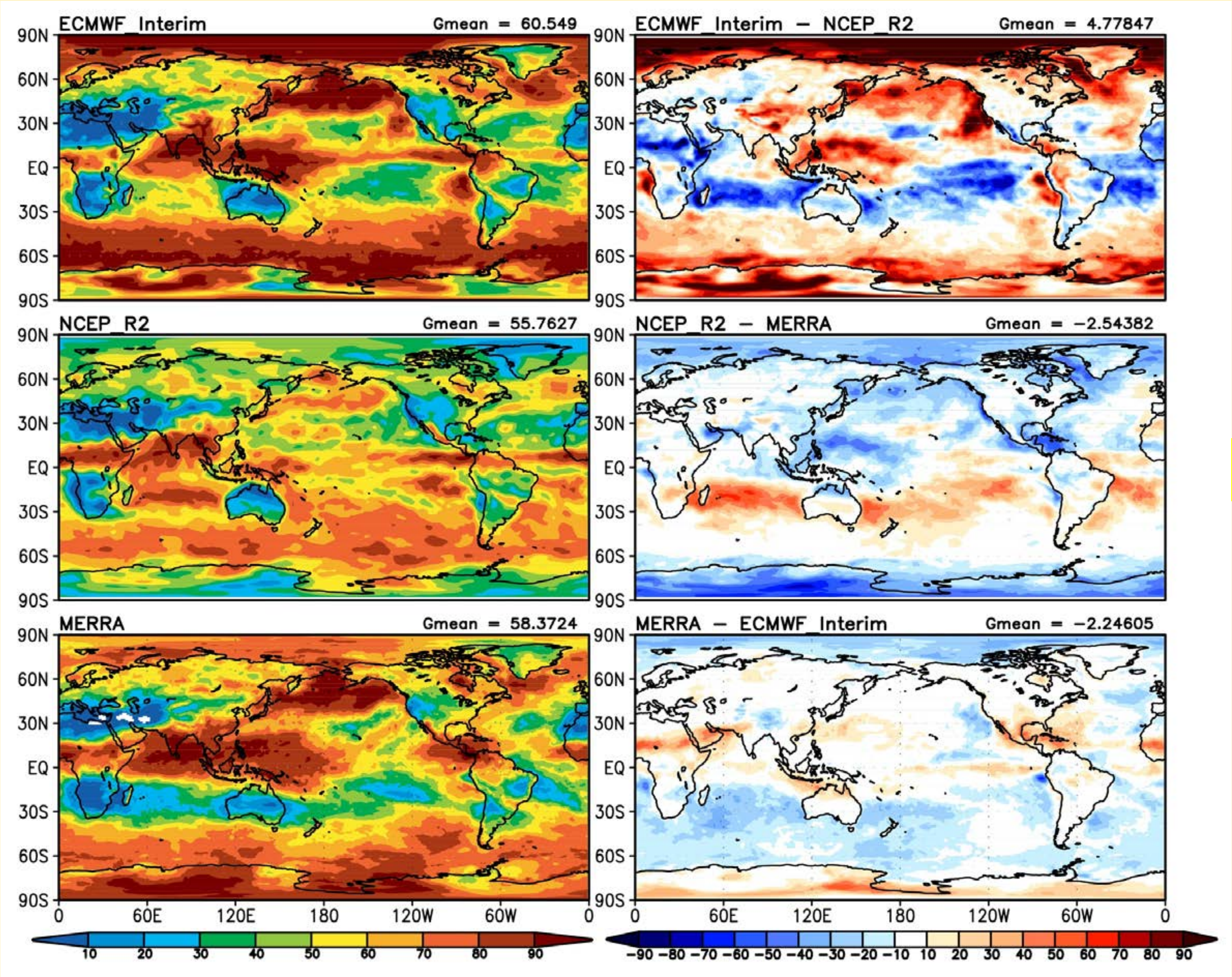
Black and Dark-Green are regions where consistently clear candidate scenes were routinely skipped by L7

(Note that CONUS is always acquired)



Contrast above with this map of average MODIS CF of scenes acquired by L7
These depict the advantage of the cloud avoidance approach.

Model cloud fractions: NCEP vs. ECMWF vs. NASA

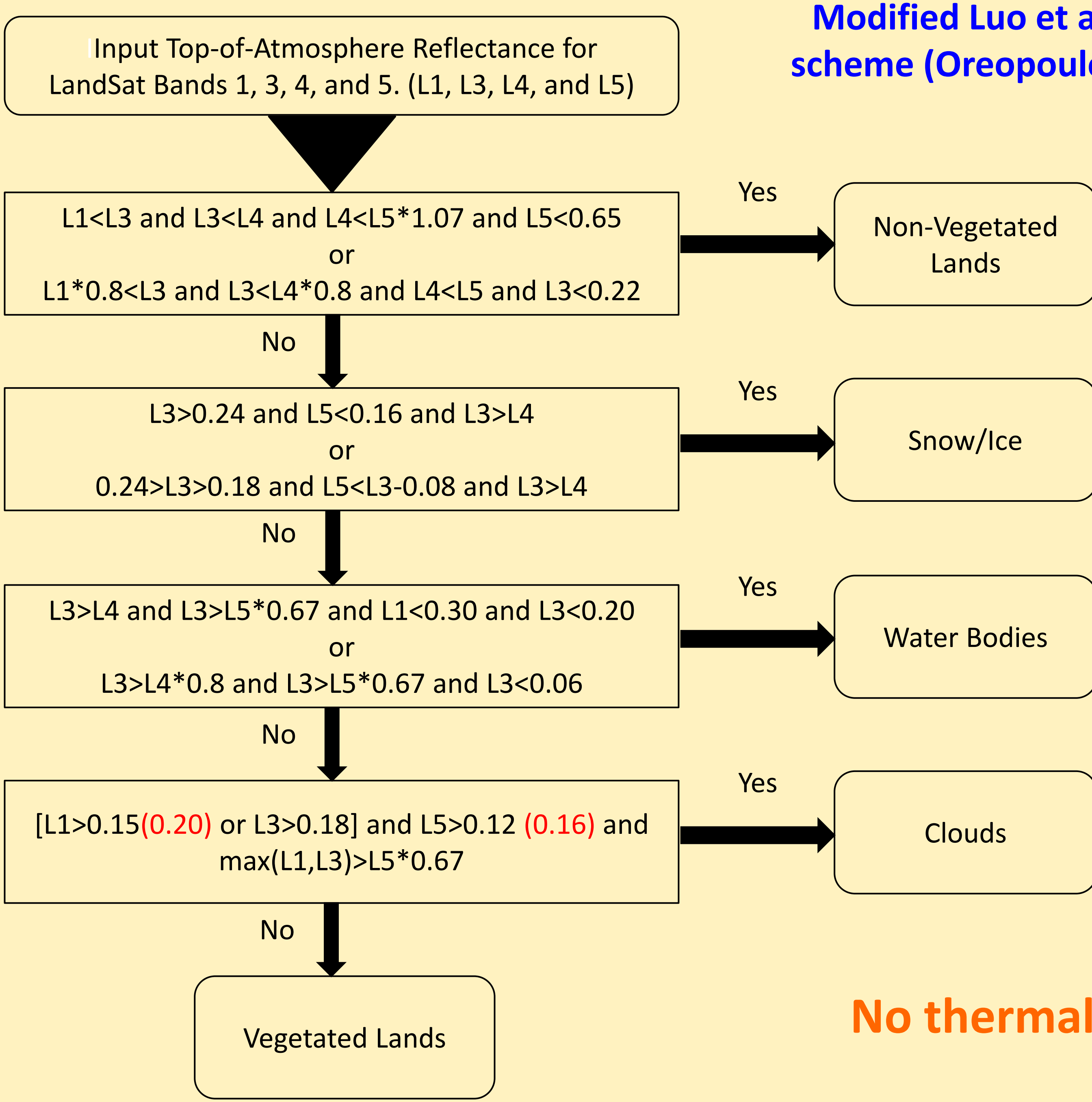


July 2009

Cloud masking, historic Landsat

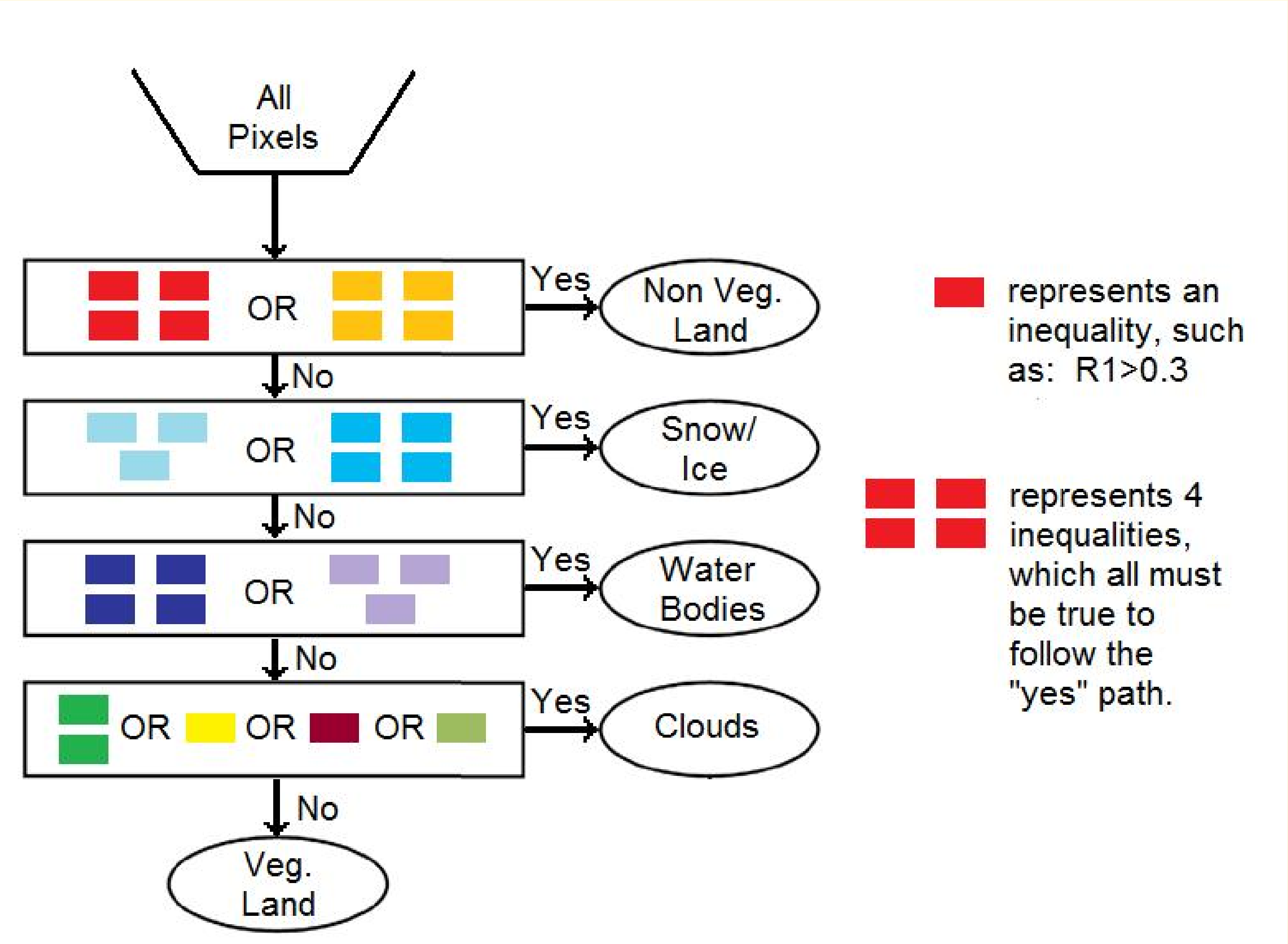
(with Mike Wilson & Tamás Várnai)

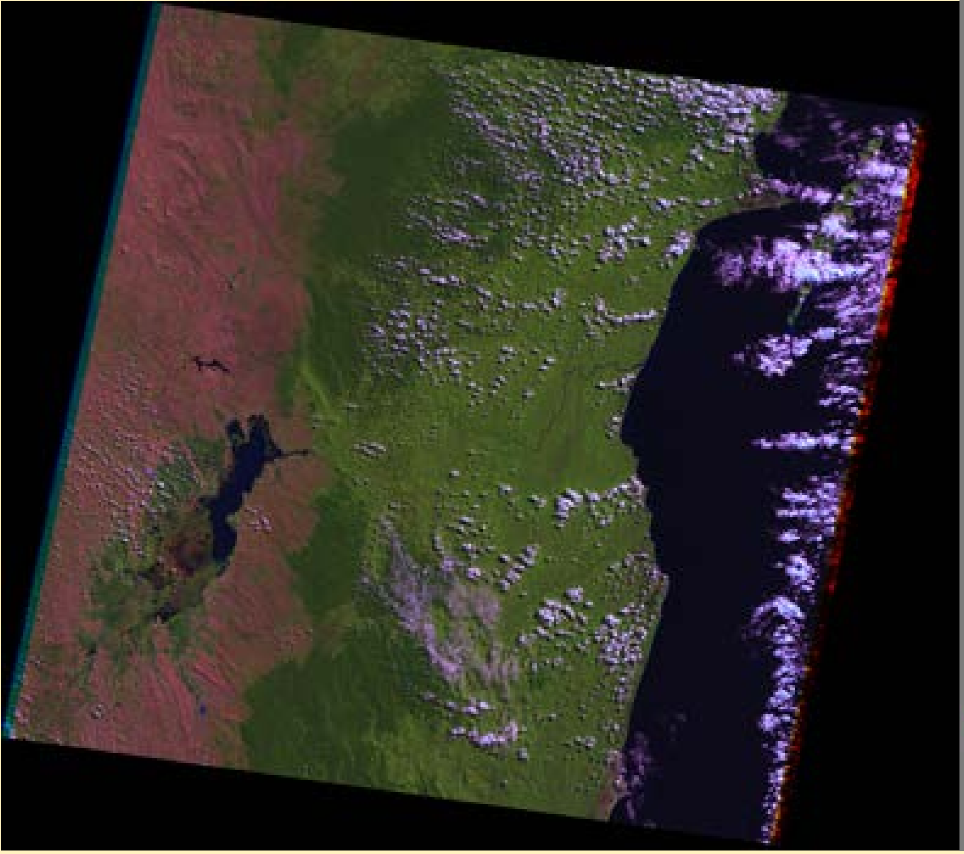
Modified Luo et al. (2008) LTK scheme (Oreopoulos et al. 2011)

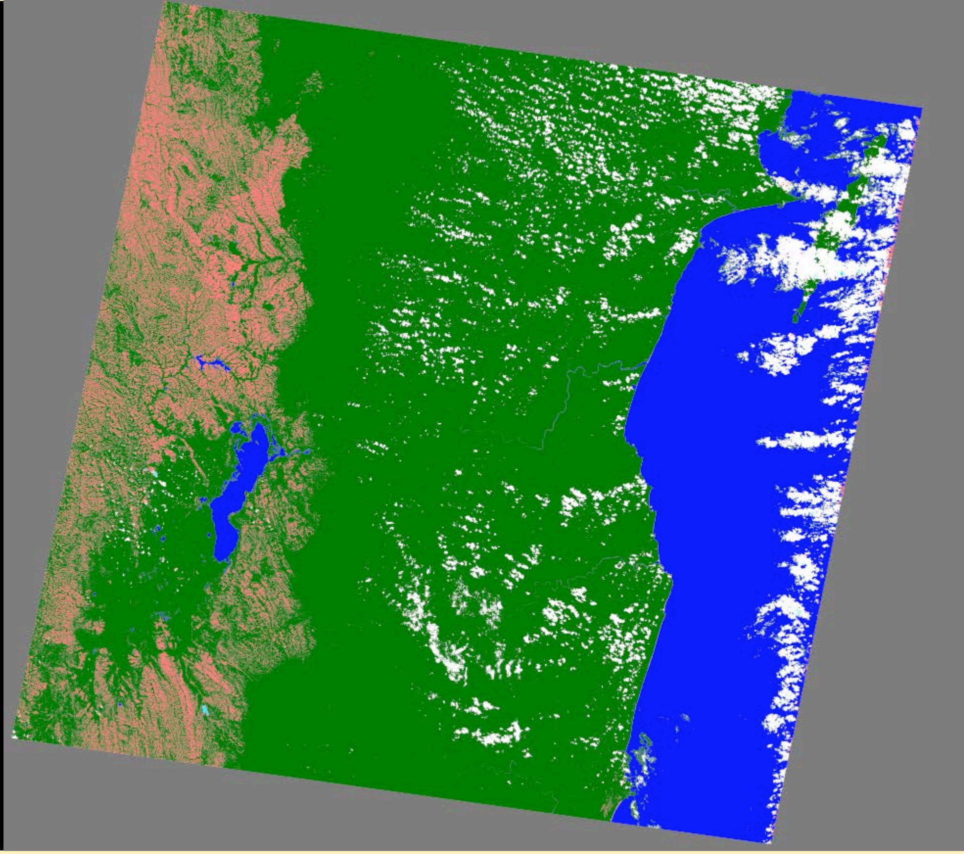


No thermal!

Simplified view of the LTK scheme

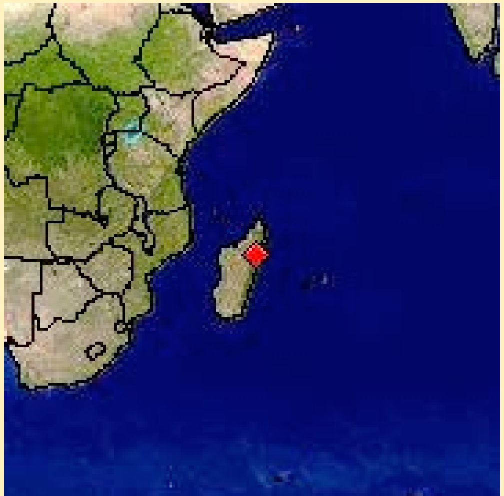






Subtropical South
P158_r72_4

ACCA agreement 96.7%
LTK agreement 95.7%



Non-Vegetated Lands

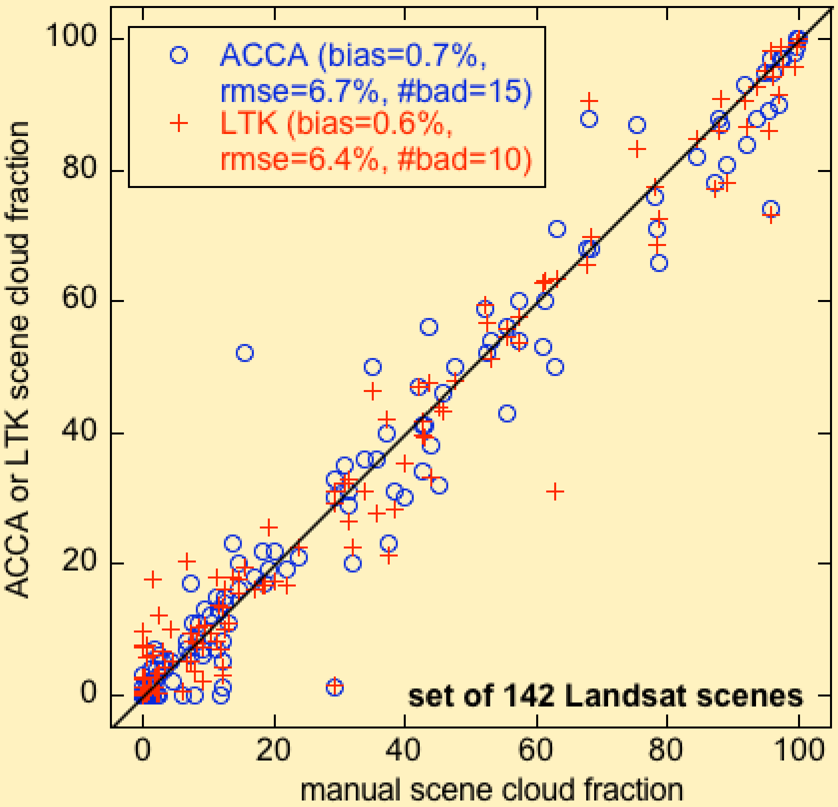
Snow/Ice

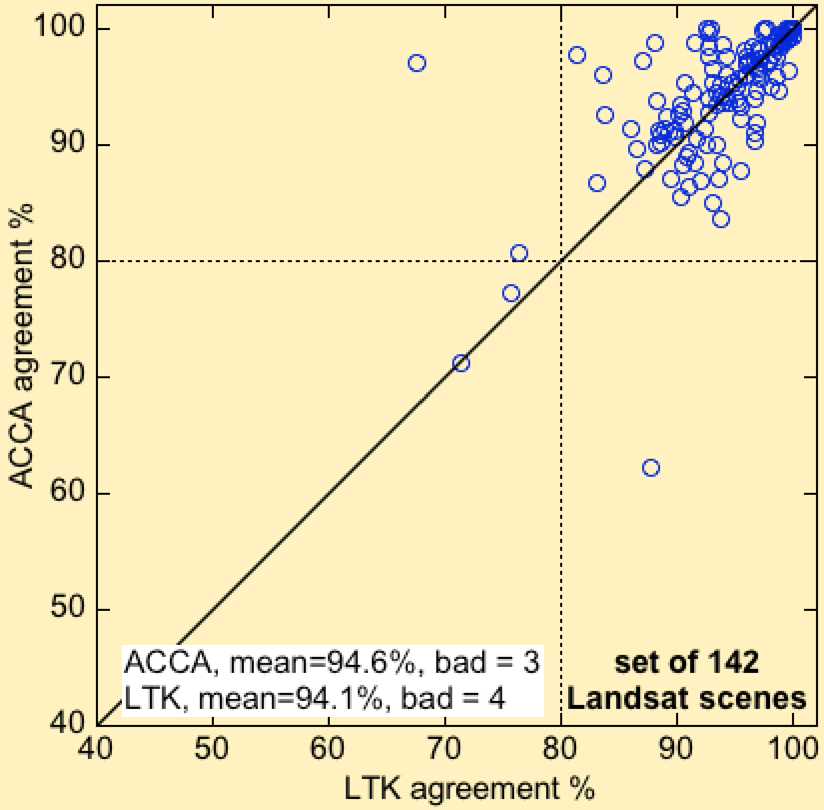
Water Bodies

Vegetated Lands

Cloud

Cloud "score" and mask performance: LTK vs. ACCA

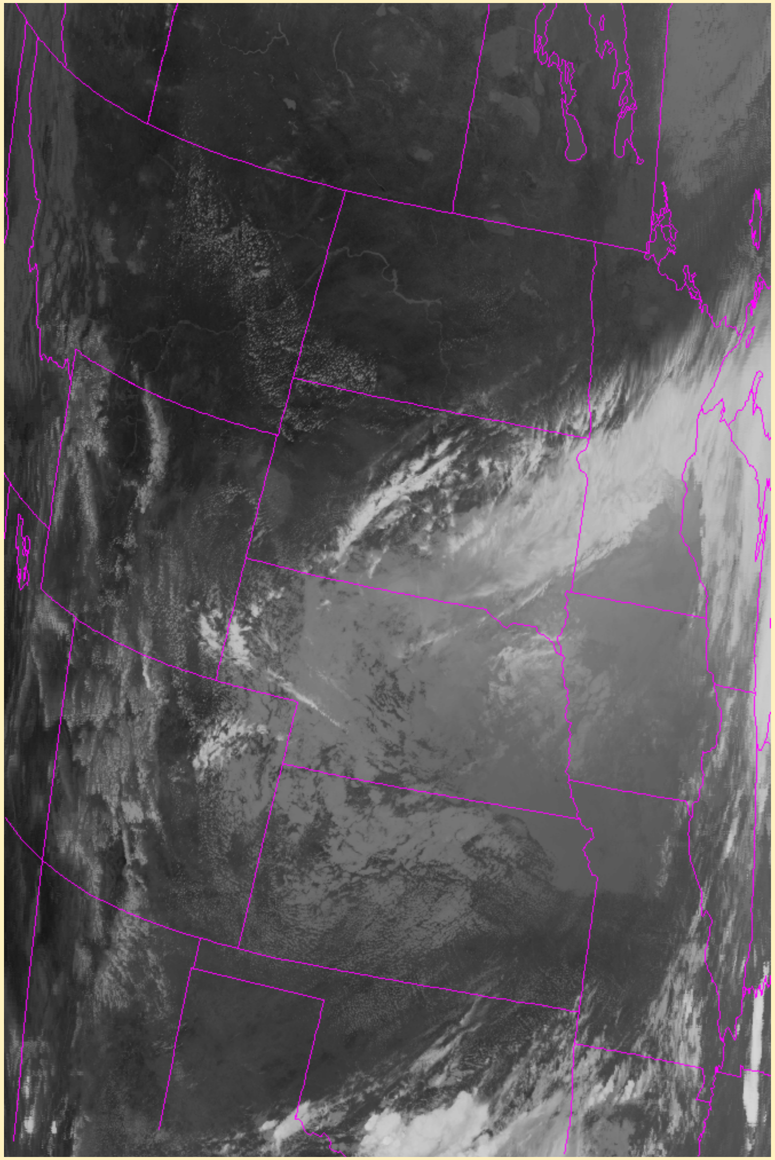




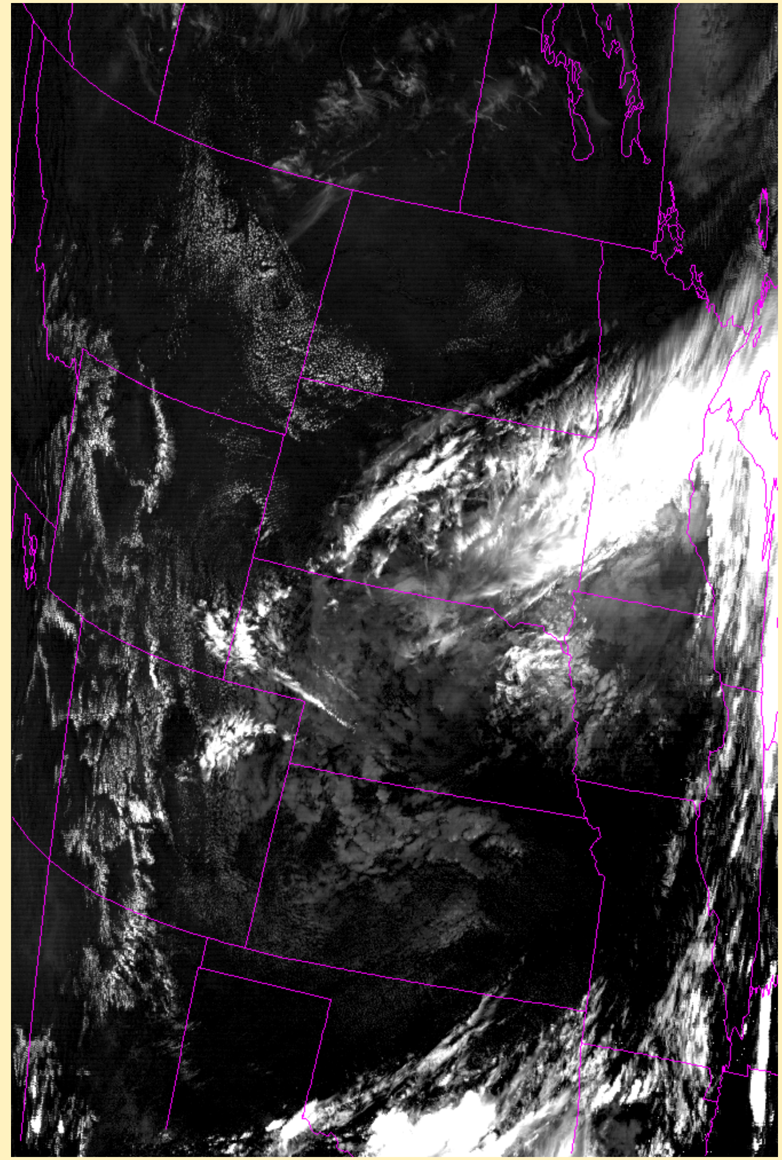
Cloud masking for LDCM: adding split window (BT11-BT12) and the cirrus (1.38 μm) band

(with Mike Wilson)

MODIS 2006240 19:45 UTC (courtesy of R. Frey)

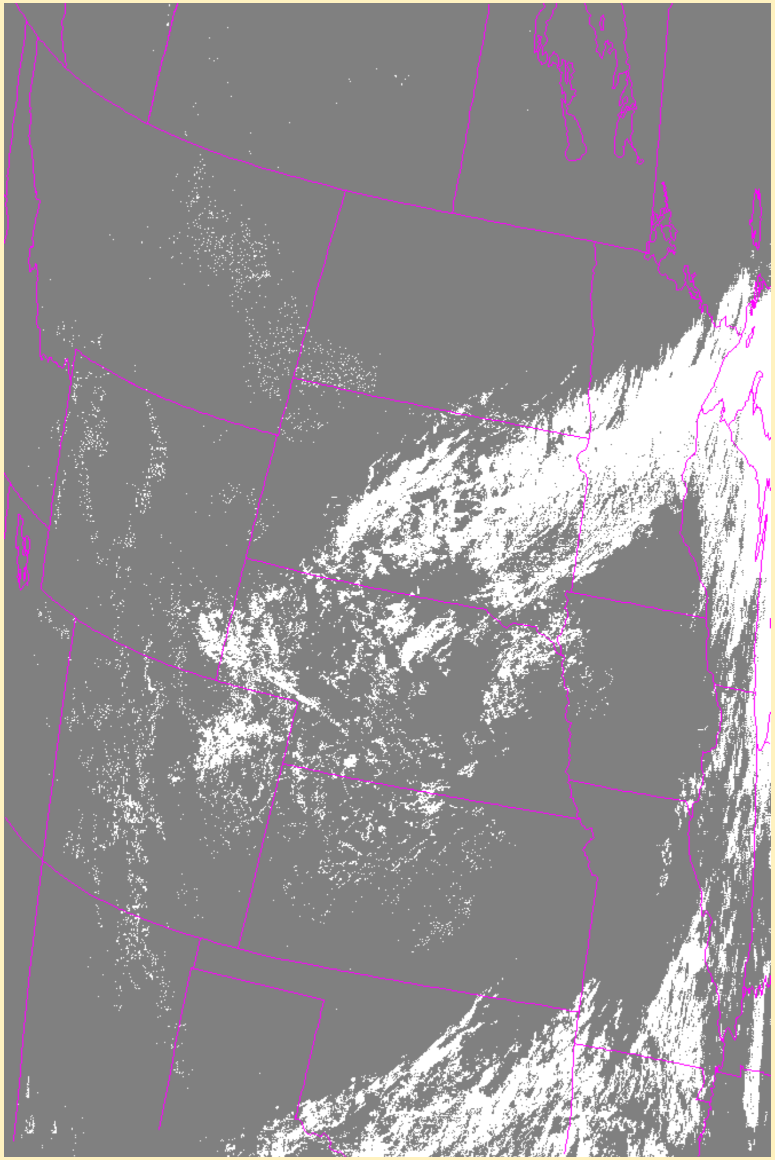


Band 31 (11.1μm)

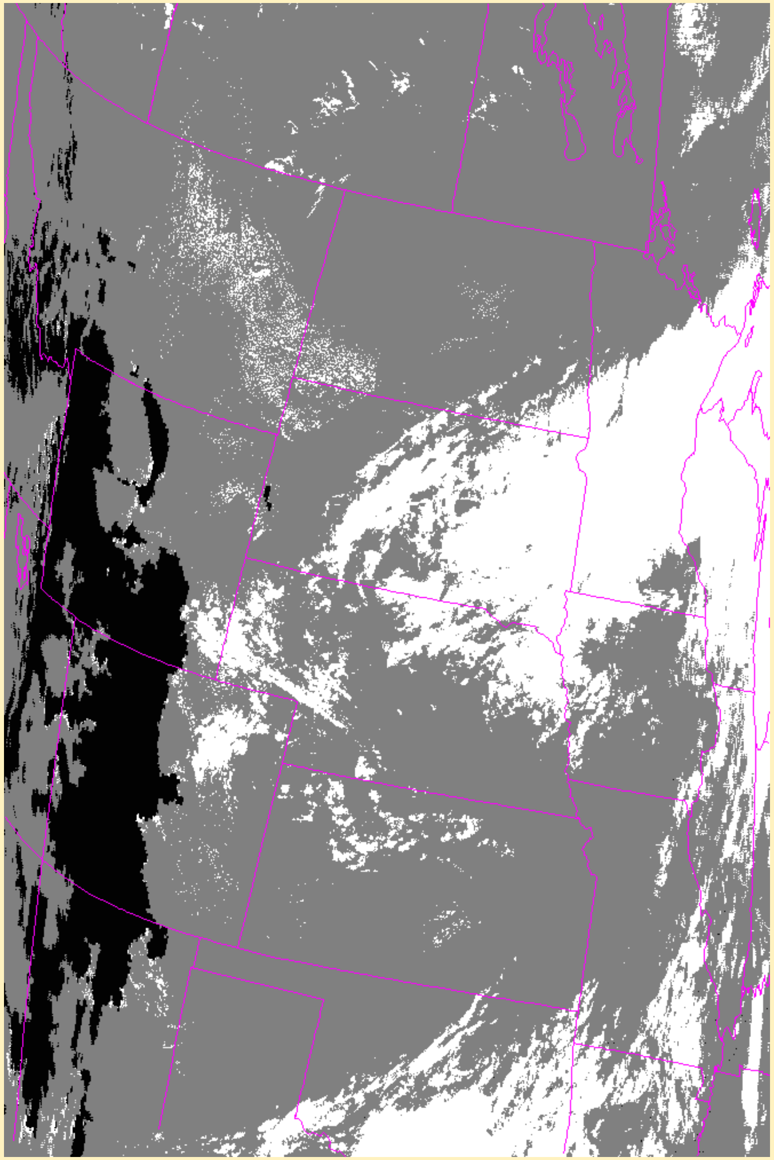


Band 26 (1.38μm)

MODIS 2006240 19:45 UTC (courtesy of R. Frey)



Split-window Test



1.38 µm Ref. Test
(black means test not performed)

Simulations by others (what MODIS applies)

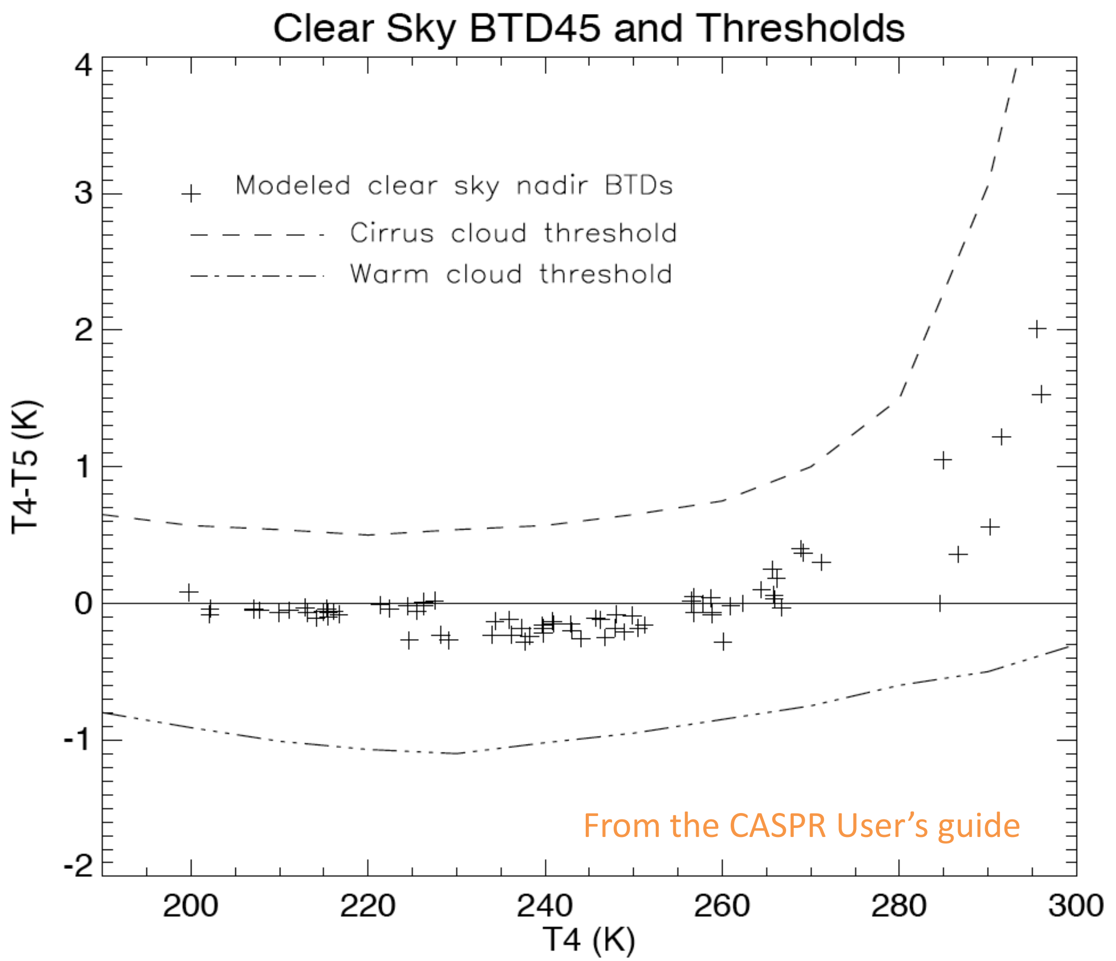
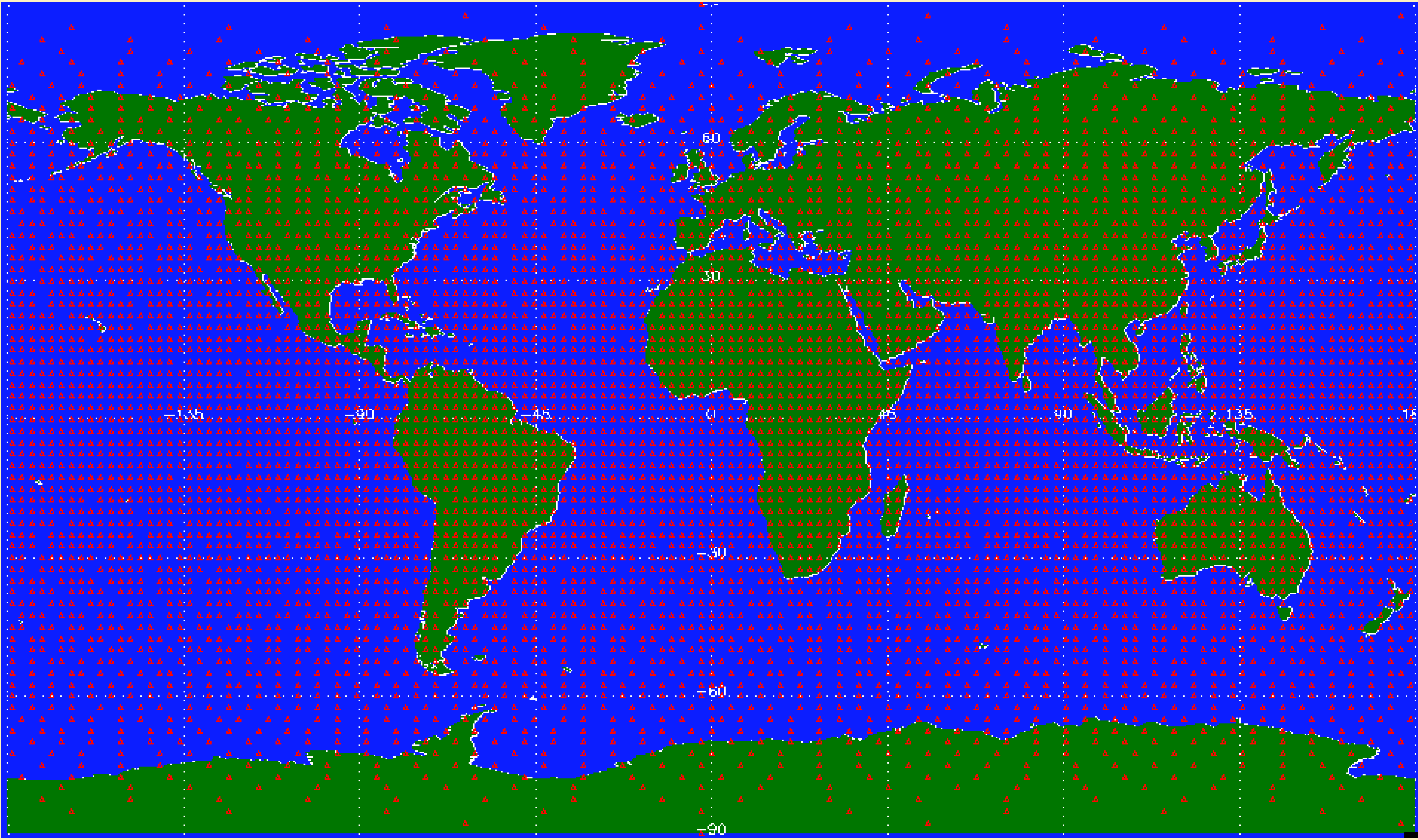


Figure 6. Modeled (*Streamer*) clear sky brightness temperature differences (plus signs) the the cirrus and warm cloud test thresholds (dashed and solid lines, respectively).

Finding thresholds for the Split Window

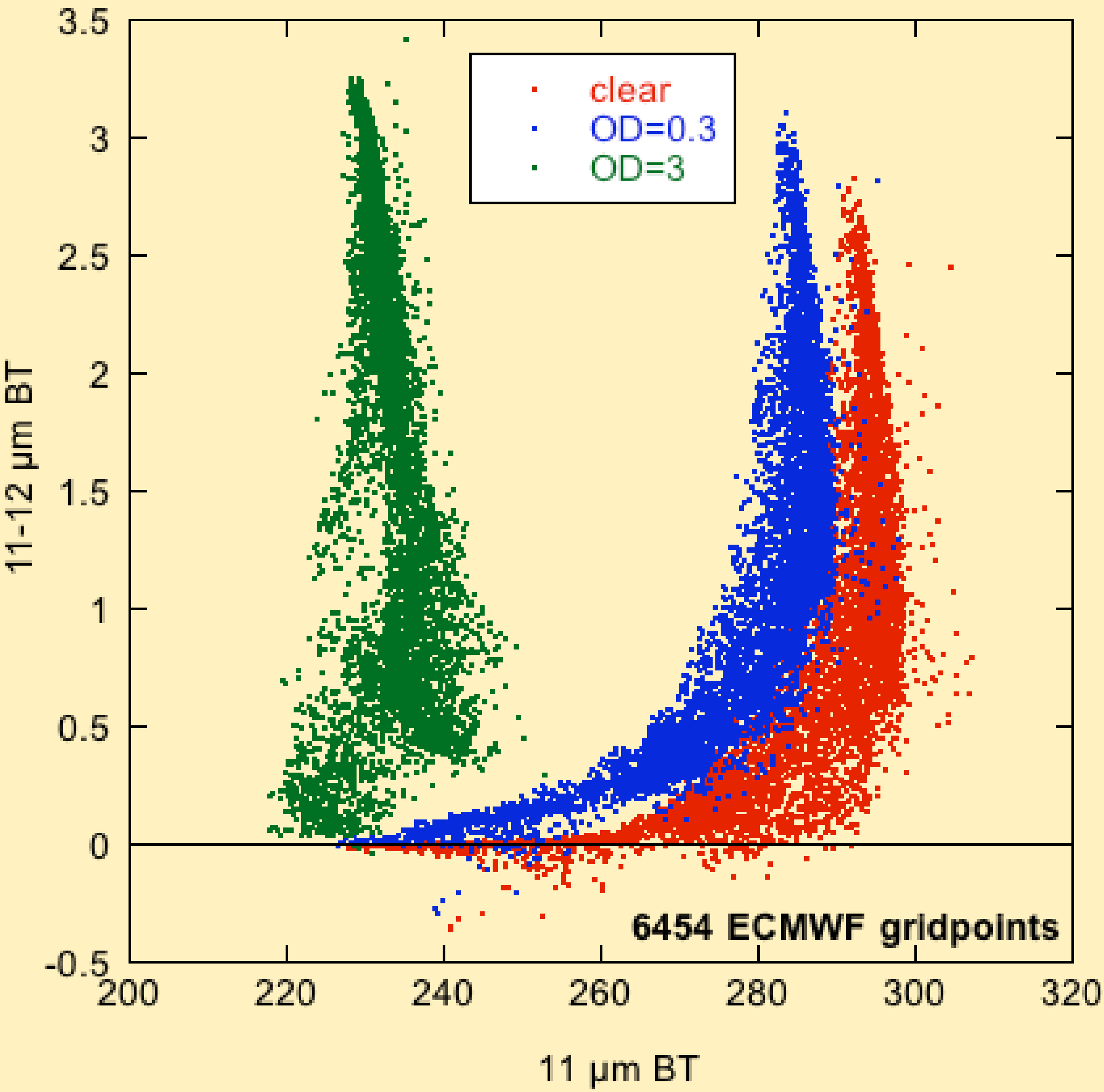
- The difference in Brightness Temperature between 11 µm and 12 µm is calculated with a radiative transfer code for gridded ECMWF data.
  - ECMWF is on 2.5 degree longitude by 2.5 degree latitude grid.
  - All data taken at 00 Z on January 15, 2002.
  - Total of 10512 different profiles, each with information on pressure, height, temperature, ozone, and water vapor.
  - Converted to an equal area grid, so that polar regions are not unfairly emphasized; 6454 profiles remained for analysis.
  - (Thin) Clouds also included in the simulations (various heights, ODs, ice particle sizes)

Selected profiles shown by triangles

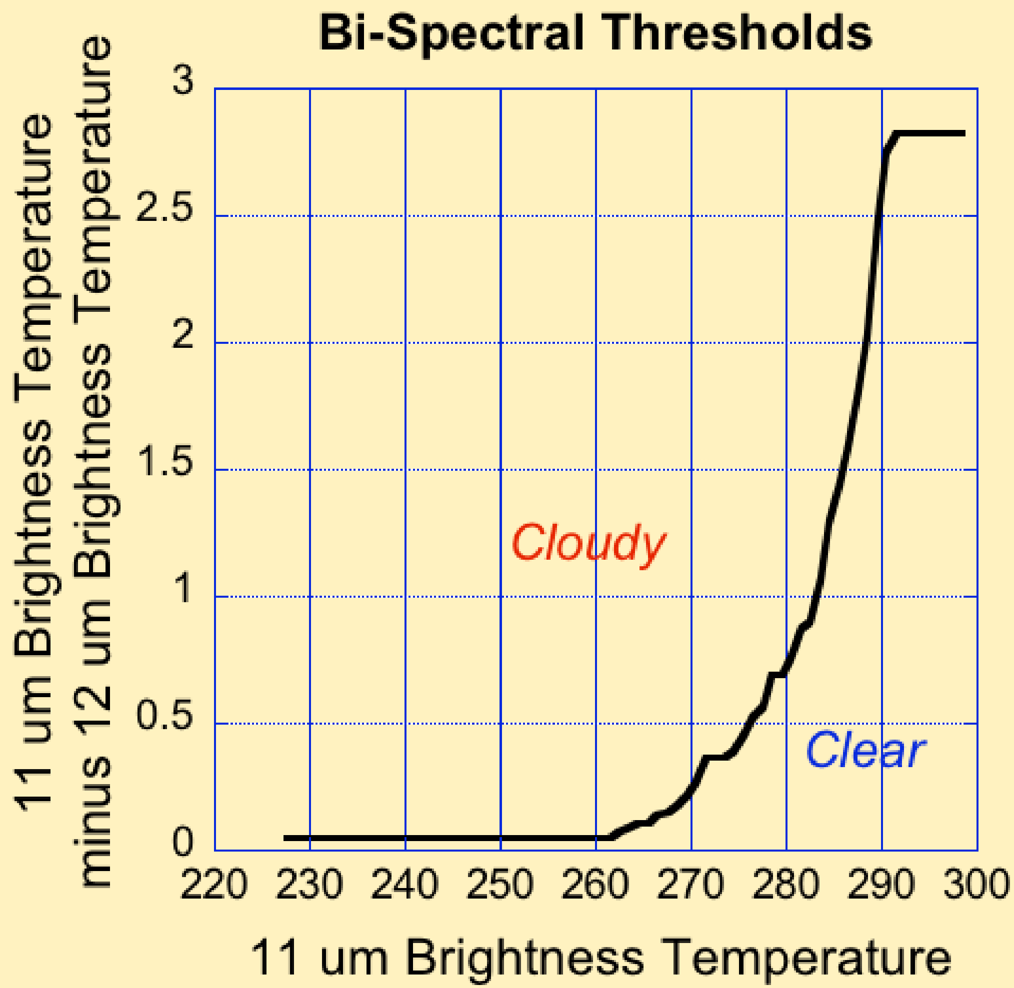


Fewer Triangles occur near the poles

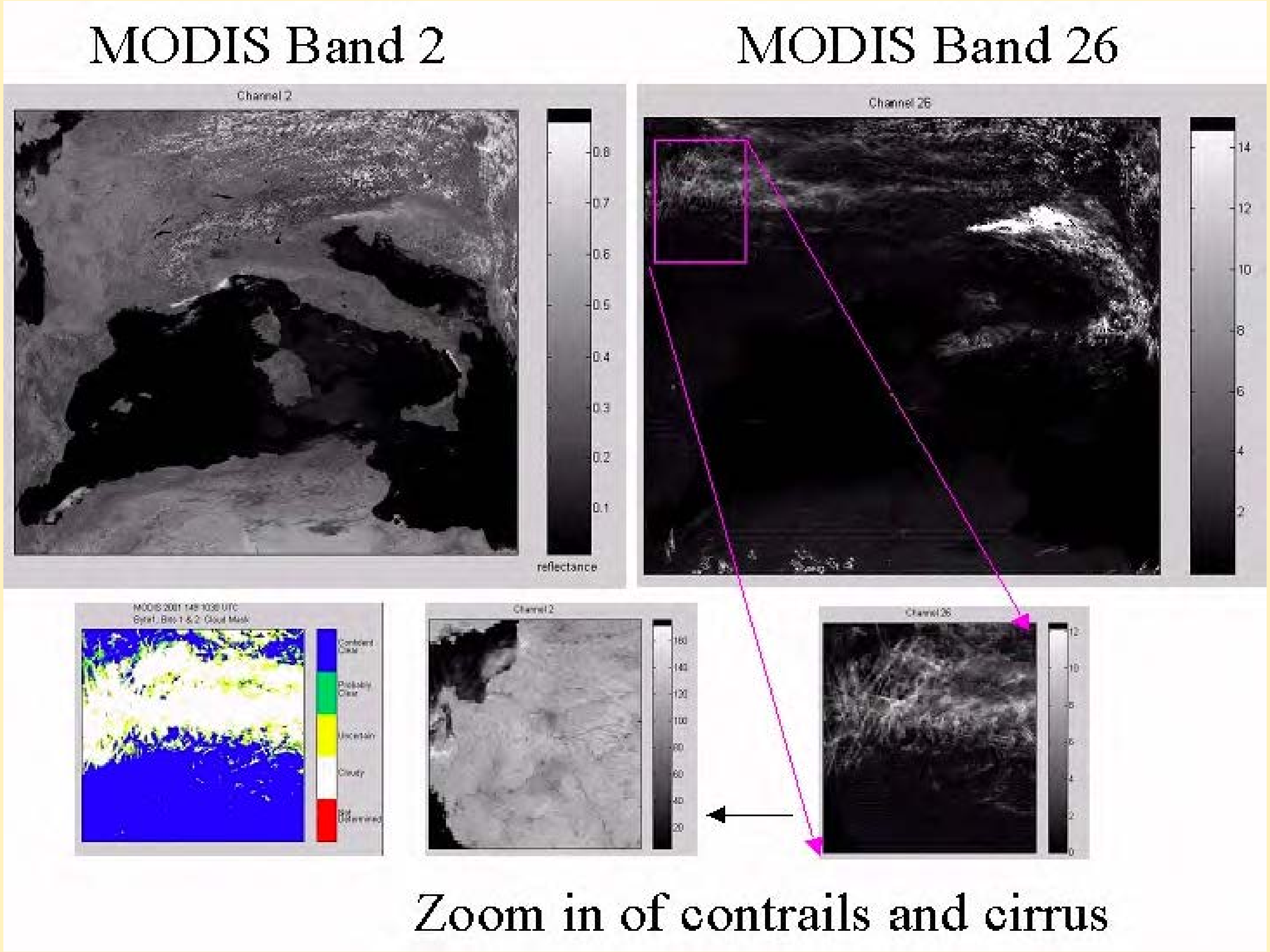
Clouds separate from clear in a bispectral plot



Upper envelope of red points=our thresholds



1.38 µm vs. visible images



(from MODIS cloud mask ATBD)

Derivation of 1.38 μm Threshold (1)

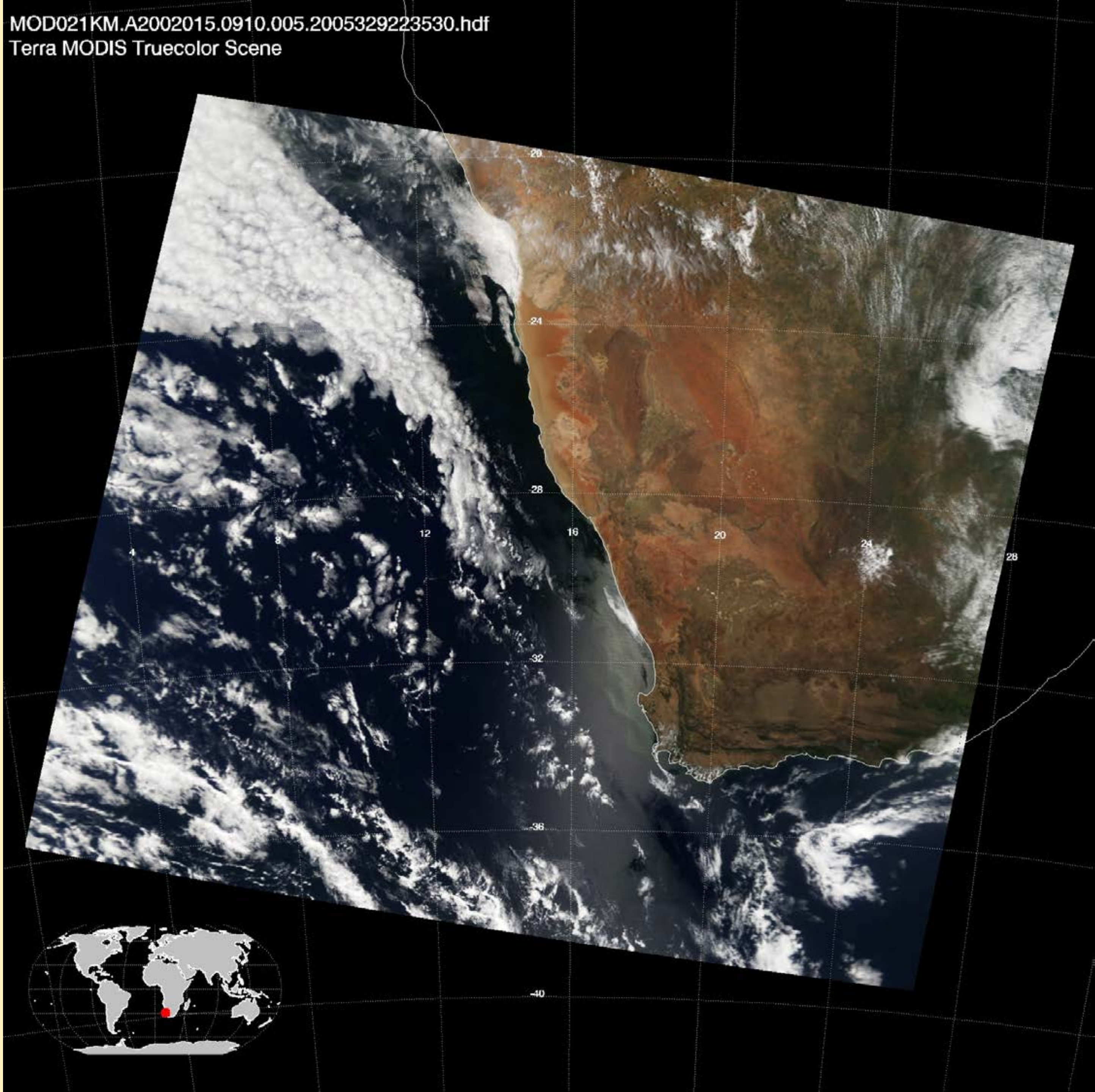
- 6454 ECMWF gridboxes from January 15, 2002.
- Constant values for all cases:
  - Solar Zenith Angle = 30 degrees
  - Surface Albedo = 0.25
- All combinations of the following:
  - Cloud Optical Depths of 1, 2, 3, 4.
  - Cloud Top Heights of 100,150,200,250,300,400 mb
  - Effective Ice Diameters of 40, 70, 100 μm.

Derivation of 1.38 µm Threshold (2)

- Threshold set to reflectance at which 99% of cloudy cases were brighter than that reflectance.
- Threshold value: **0.01126**.

- For this value:
  - 99% of cloudy simulations were correctly thresholded
  - 93.7% of clear simulations were correctly thresholded.

Example:
0910 Z



Example: 0910 Z

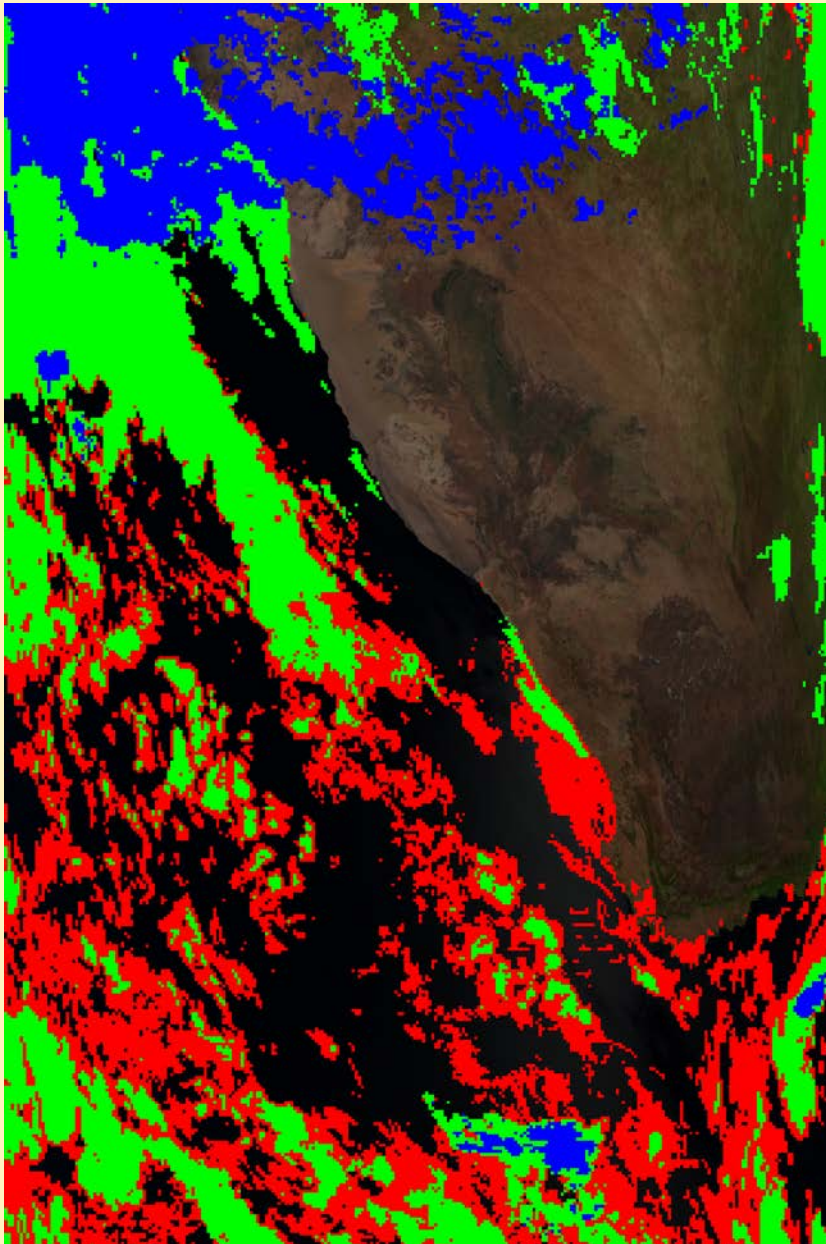
High Clouds

Mid-Level Clouds

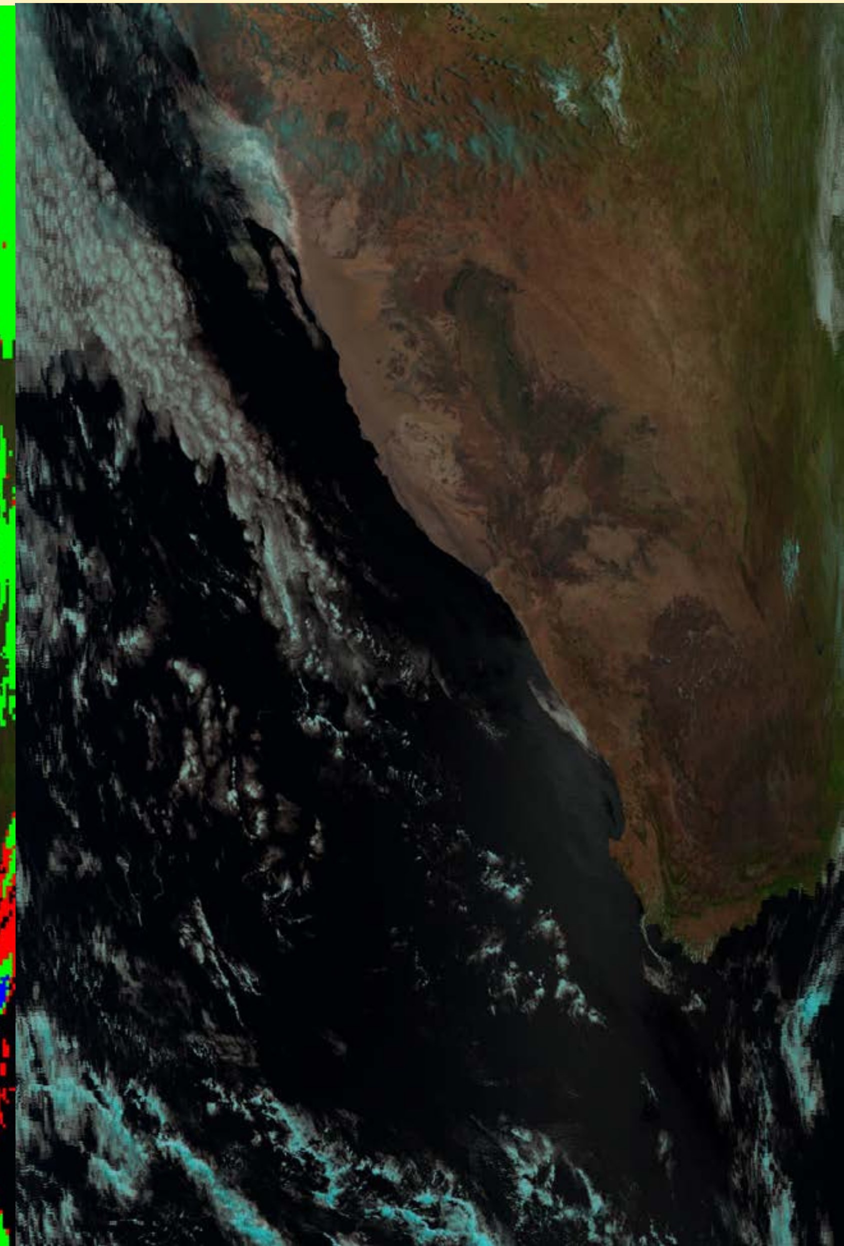
Low Clouds

Clear

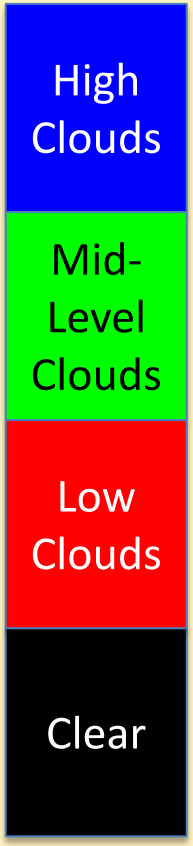
Cloud Height



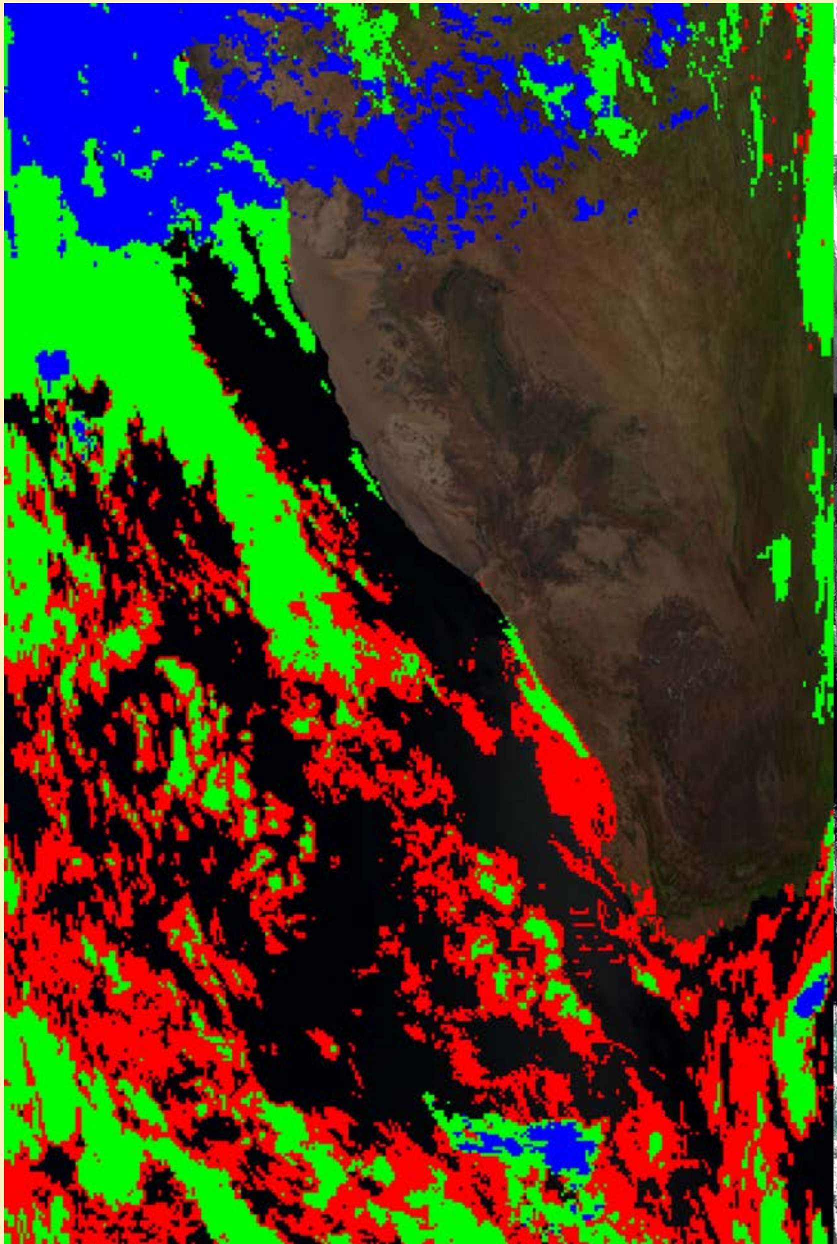
False-Color RGB (6-2-1)



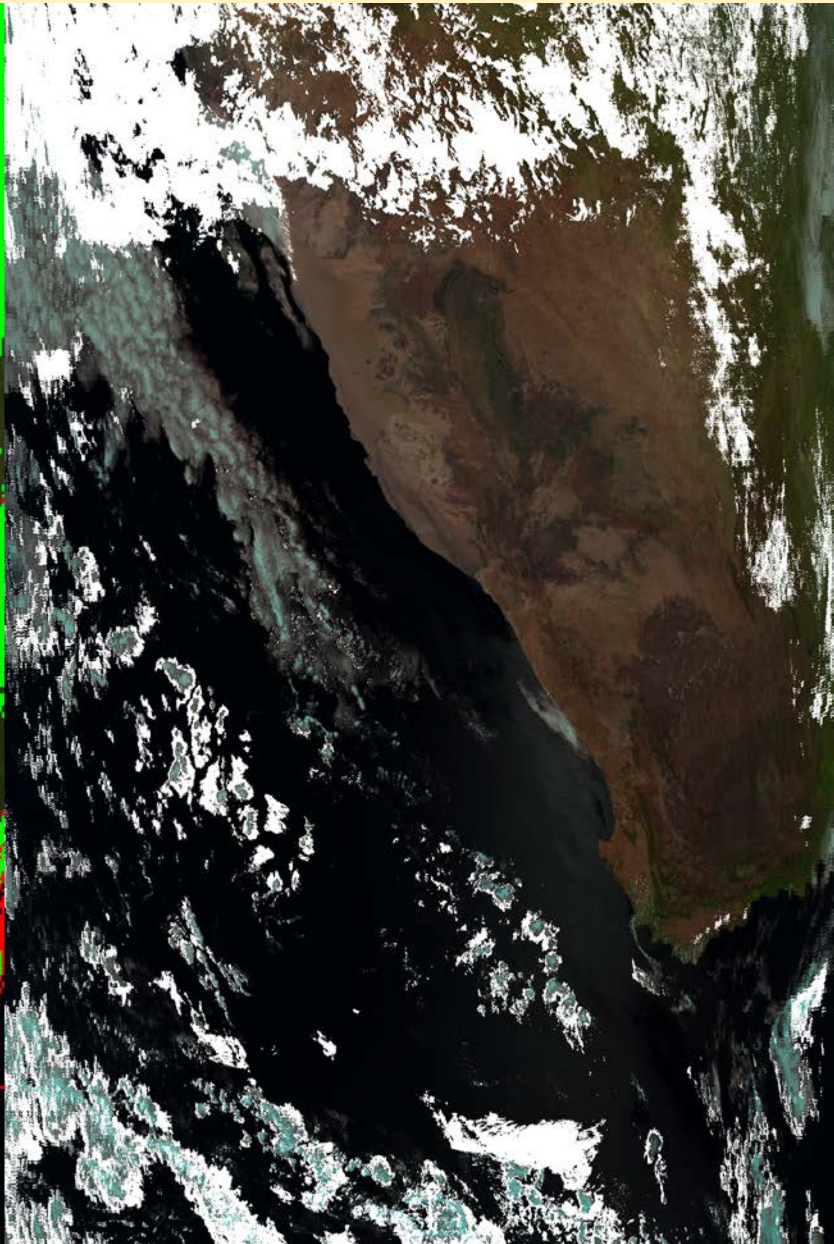
Example: 0910 Z



Cloud Height



Split-Window Cloud Mask



Example: 0910 Z

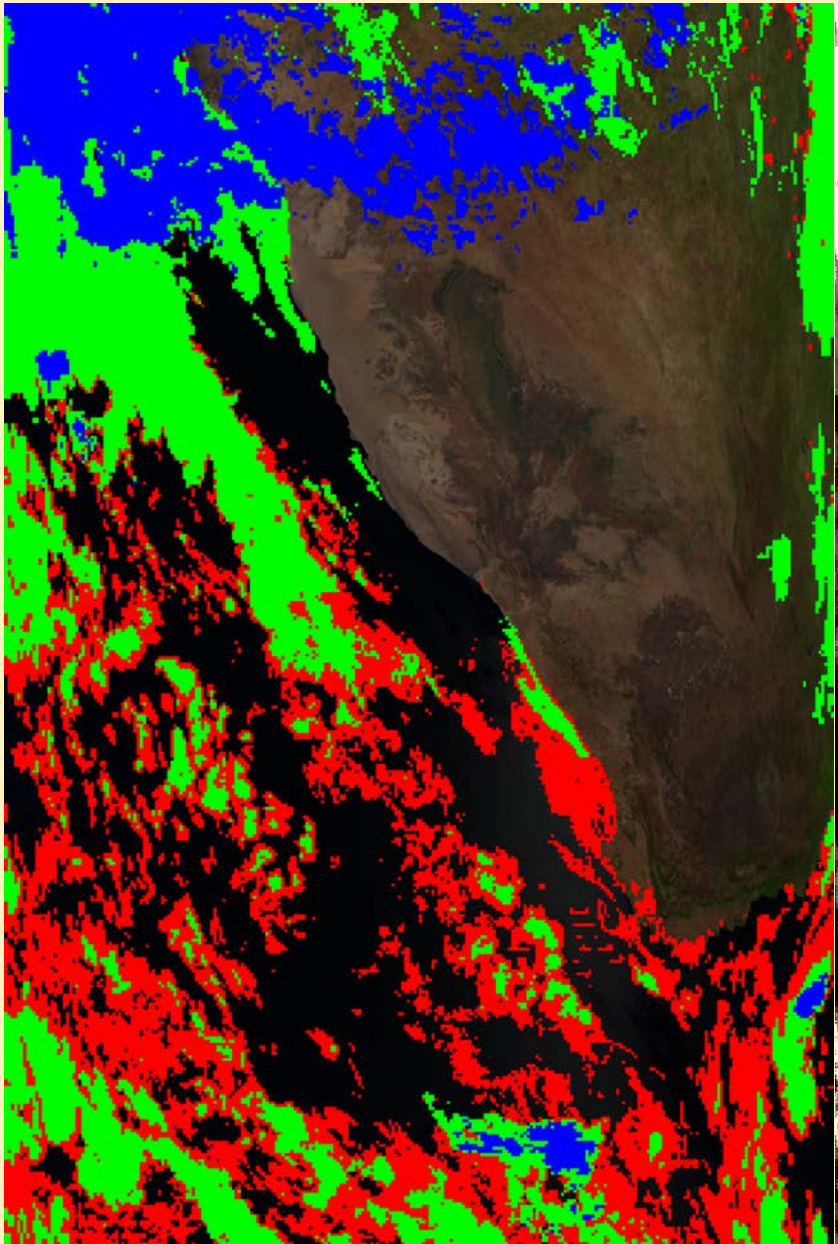
High Clouds

Mid-Level Clouds

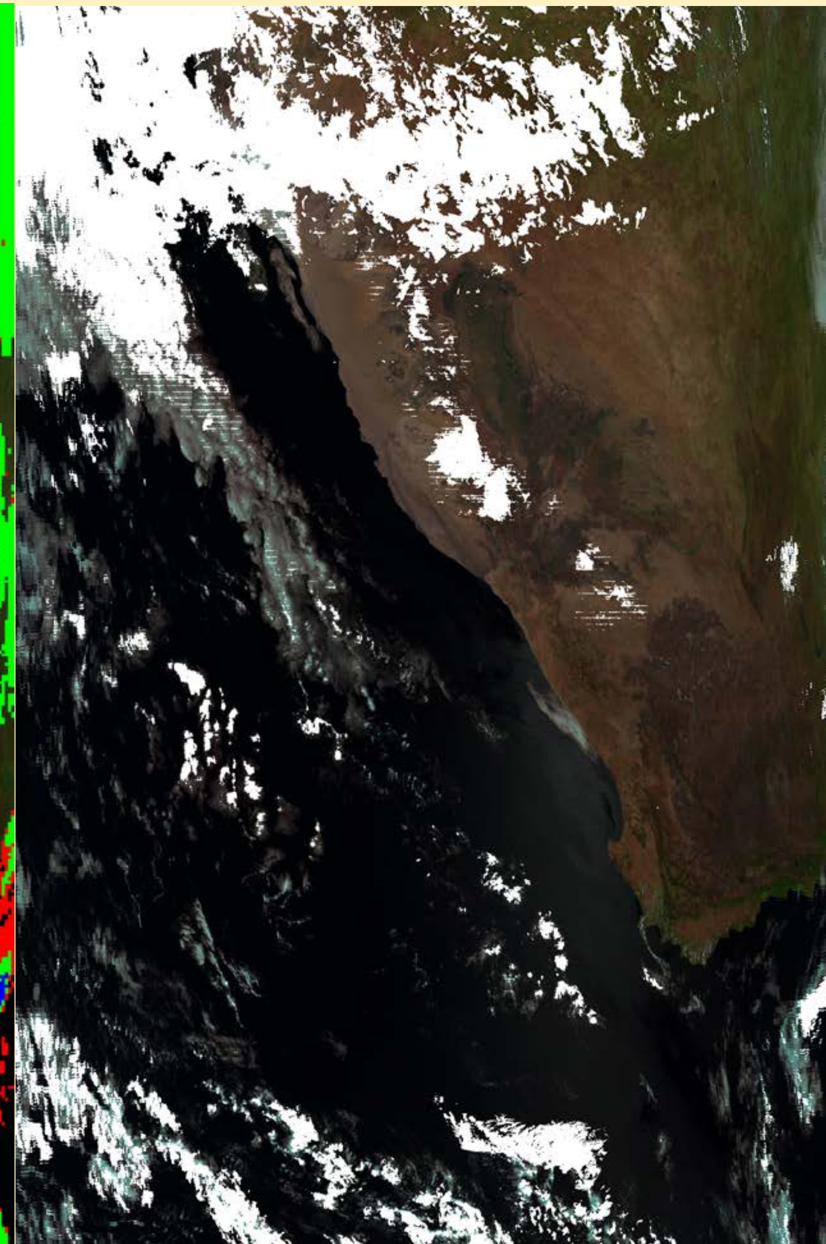
Low Clouds

Clear

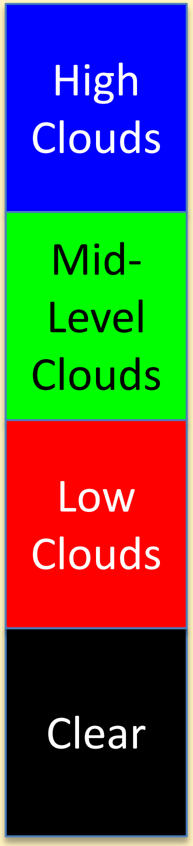
Cloud Height



1.38 µm Cloud Mask

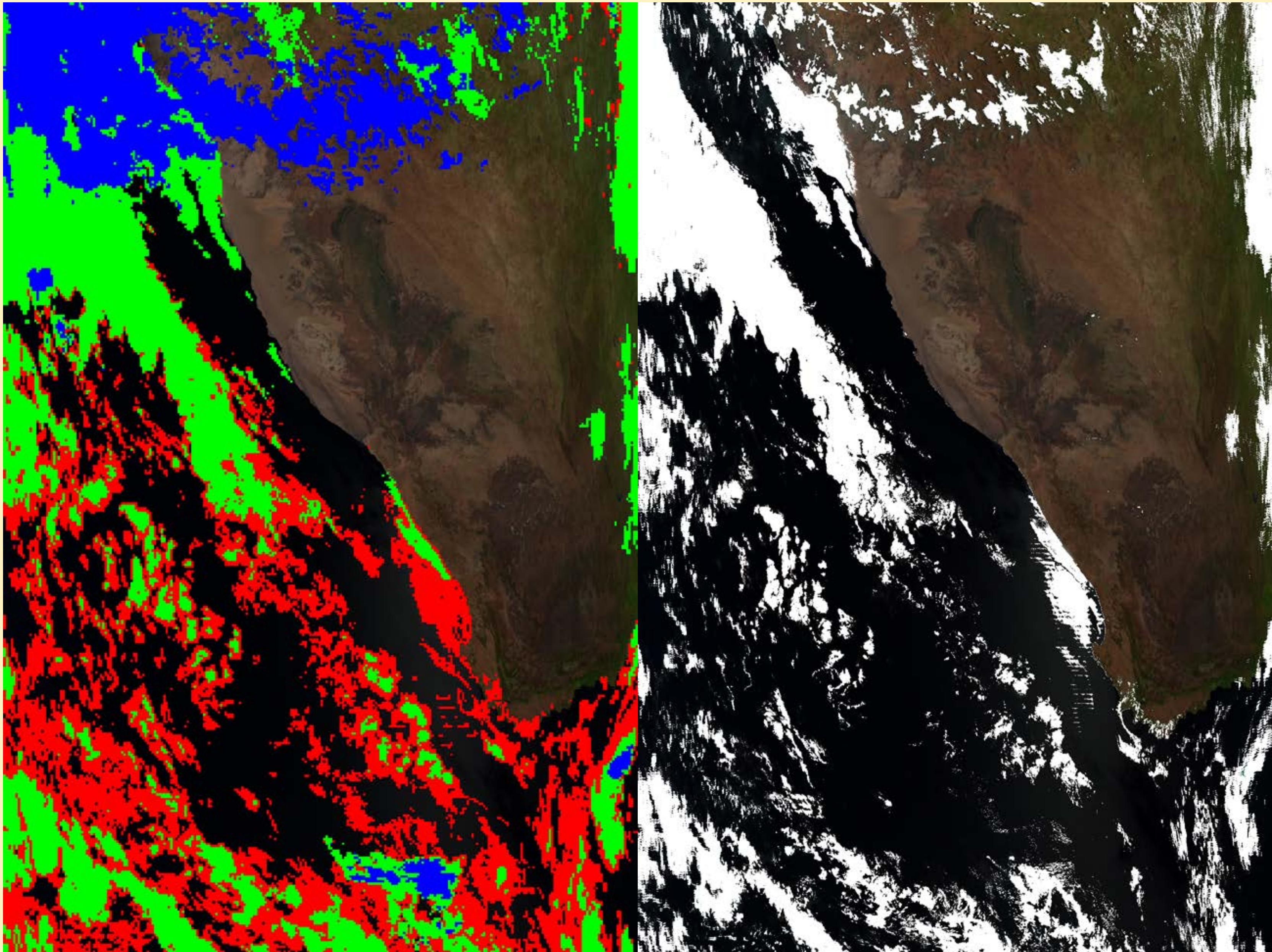


Example: 0910 Z



Cloud Height

LTK Cloud Mask



Example: 0910 Z

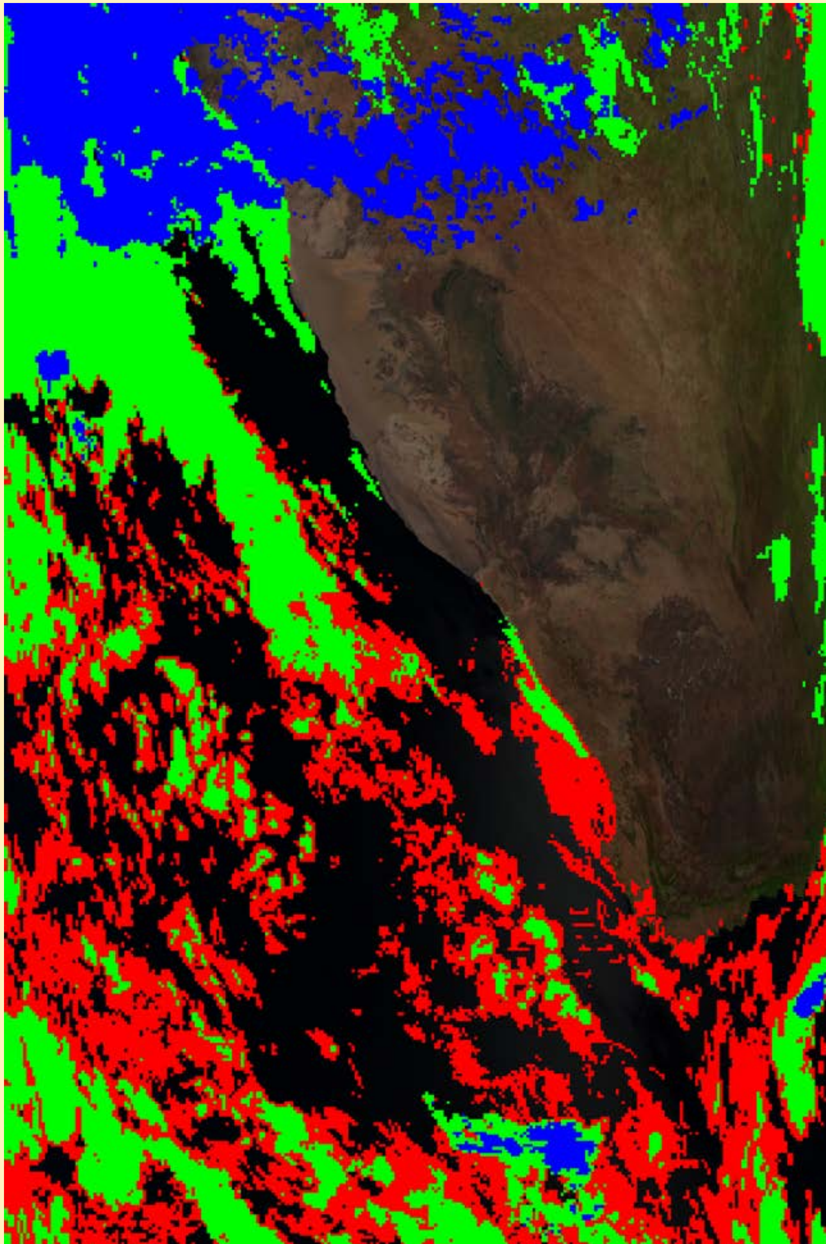
High Clouds

Mid-Level Clouds

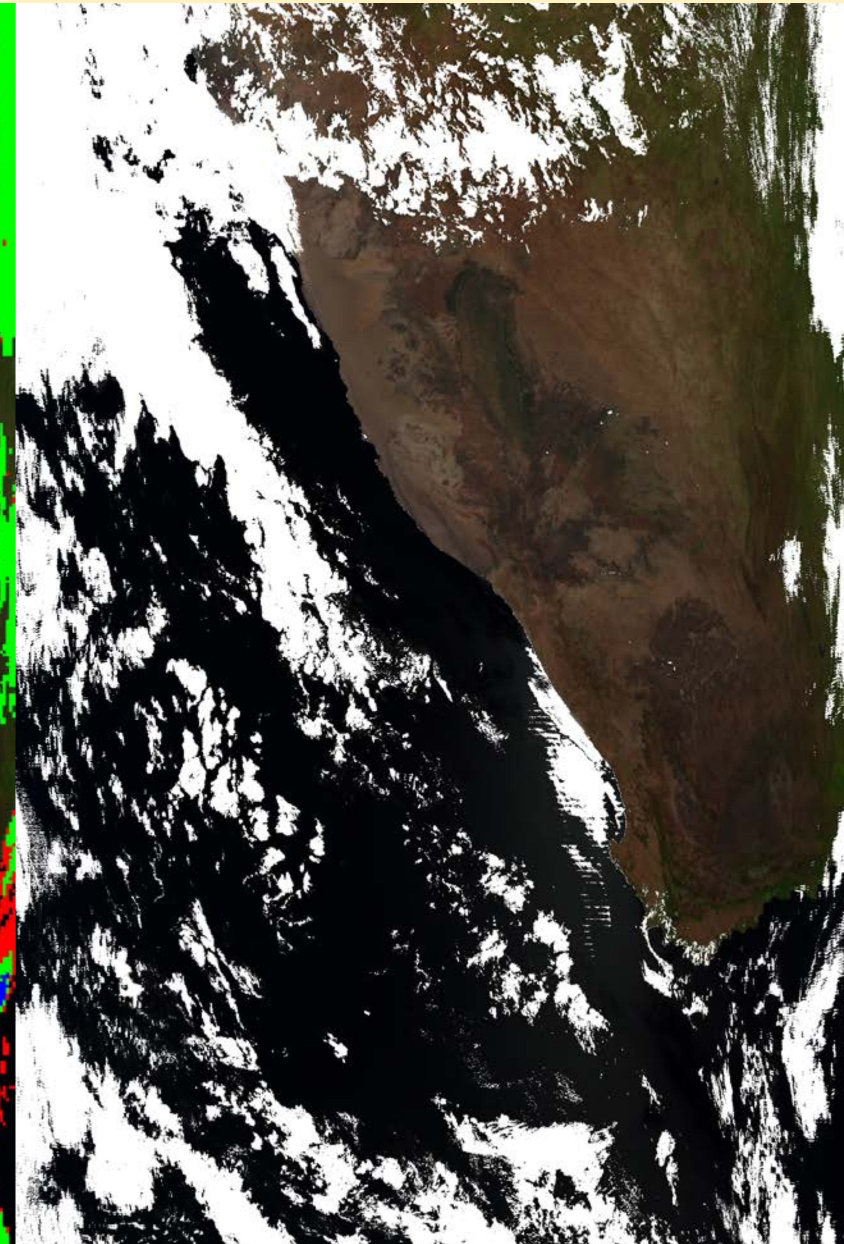
Low Clouds

Clear

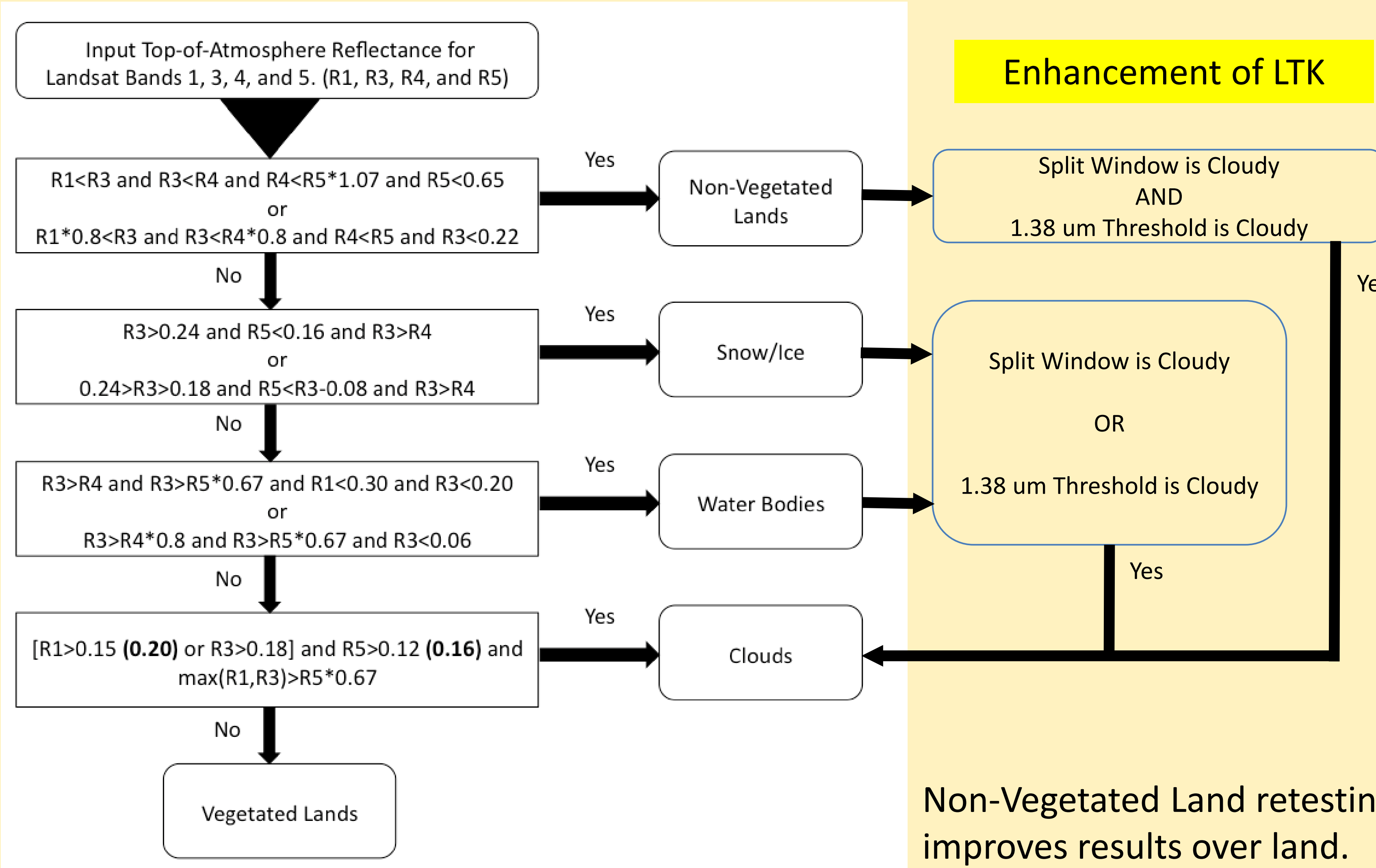
Cloud Height



Enhanced LTK Cloud Mask



Enhanced LTK scheme



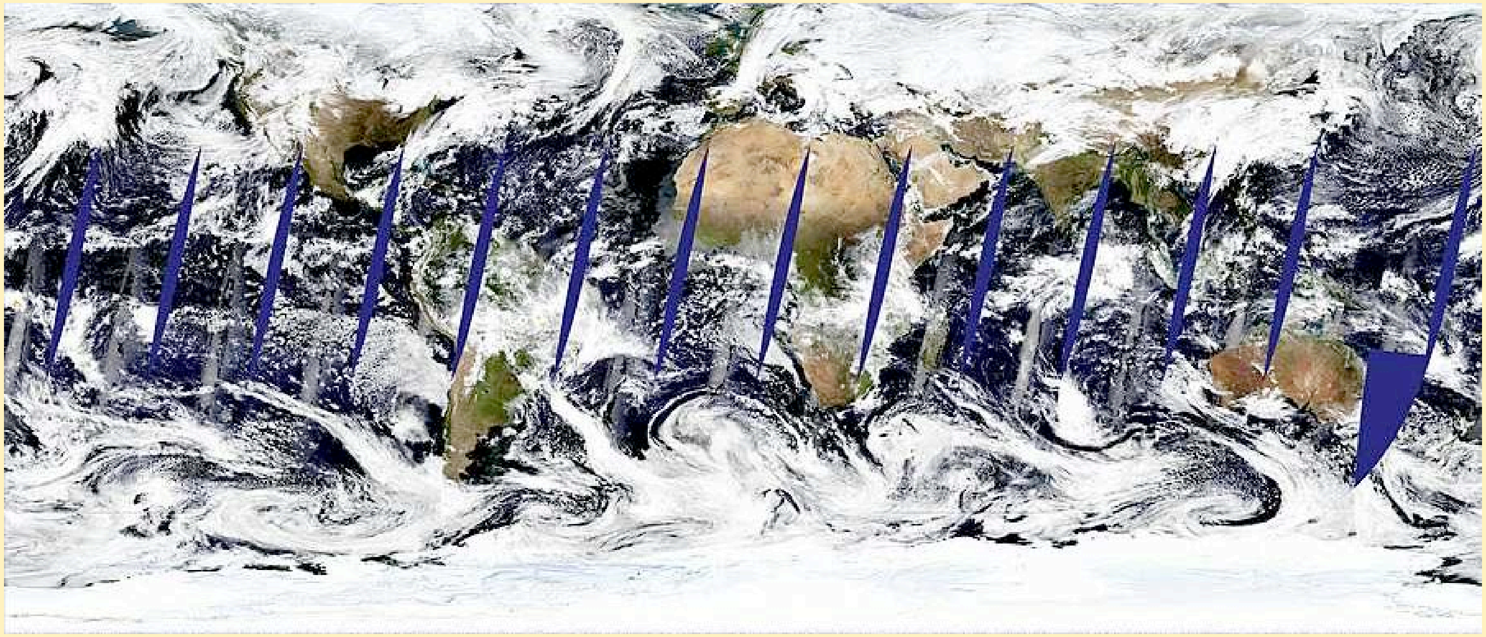
No Enhancement for Vegetated Land

Non-Vegetated Land retesting improves results over land.

Snow/Ice and Water retesting improves results over water.

MODIS Global Analysis (1)

- One day's worth of MODIS data used for analysis.
  - January 15, 2002: same day as ECMWF data runs.
  - Daytime granules between 60°N and 60°S latitude (108 granules total)



MODIS Global Analysis (2)

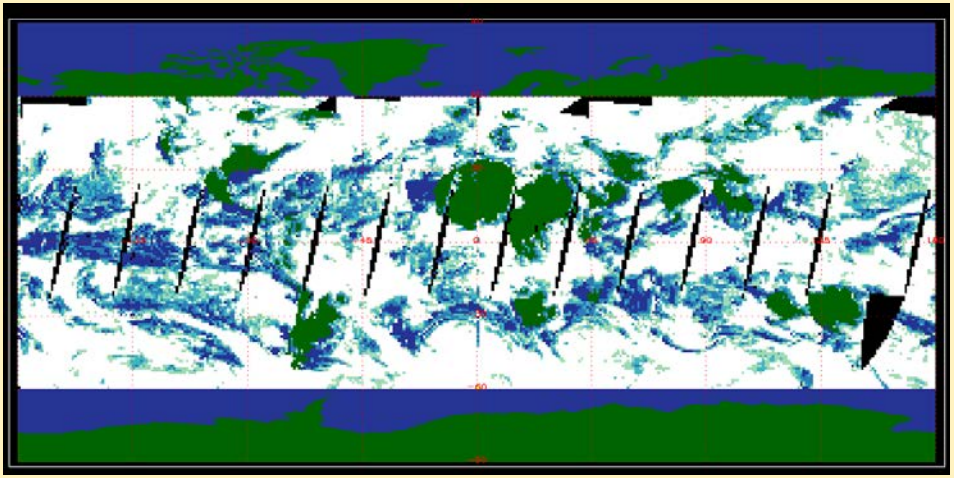
- MOD35 (MODIS cloud mask) was assumed to be "cloudy" if pixel was either "confident cloudy" or "probably cloudy."
- Several algorithms were tested against the MOD35 Cloud Mask:
  - LTK Cloud Mask a la Oreopoulos et al. (2011)
  - Split window
  - 1.38 μm Reflectance Threshold
  - Enhanced LTK cloud mask with split window and 1.38 μm

MODIS Global Analysis (3)

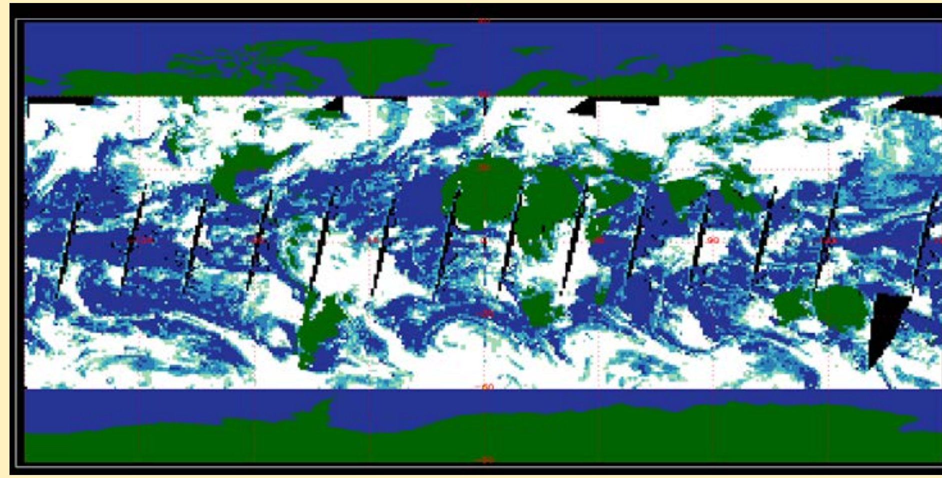
- A pressure cloud mask (MOD06) was used to divide clouds into high (<400 mb), mid-level (400-850 mb) and low clouds (>=850 mb).
- Each algorithm's agreement to these categories was measured.
  - 100% means the algorithm completely agreed with the cloudy/clear results of MOD35.
  - 0% means the algorithm completely disagreed.
  - Scene (granule) cloud fractions were also compared.
- Results for land only (according to MOD35 flags) were also derived.

Cloud Fraction Comparison

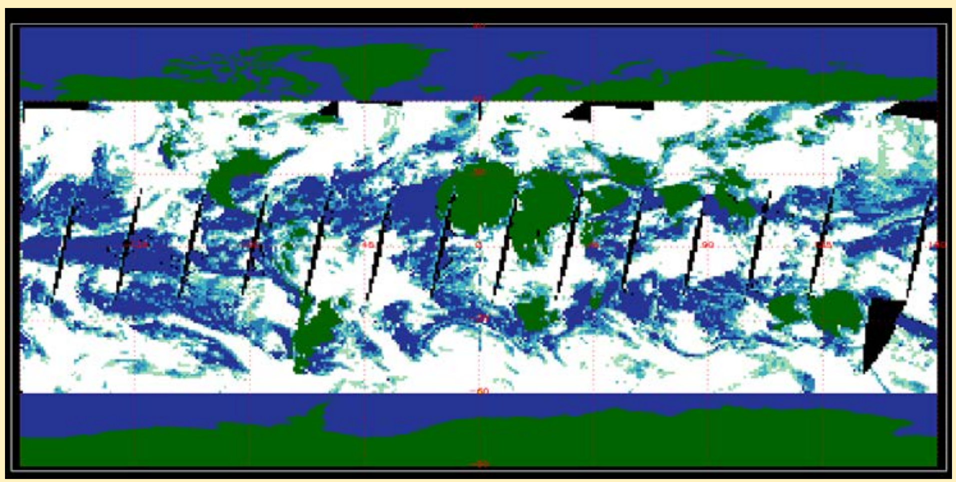
MODIS (MOD35) Cloud Mask



LTK Cloud Mask



Enhanced LTK Cloud Mask

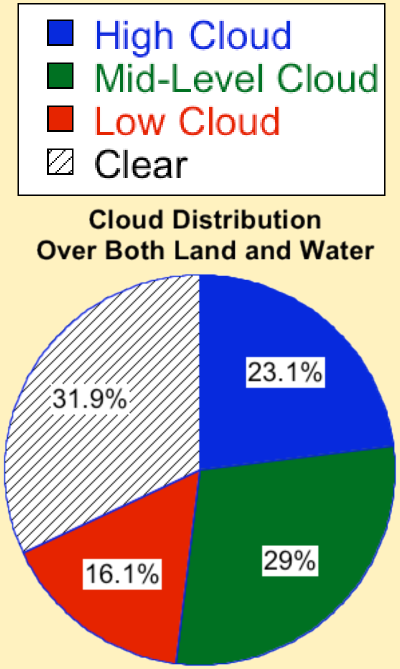


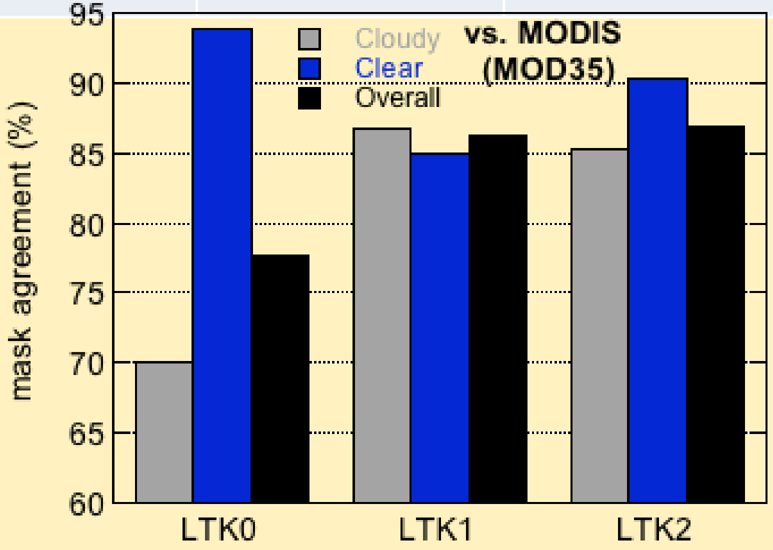
Cloud Fraction:	No Retrieval	0%-20% Land	0%-20% Water	20%-40%	40%-60%	60%-80%	80%-100%

Cloud Fraction of 1 deg gridboxes

Enhanced LTK scheme mask performance

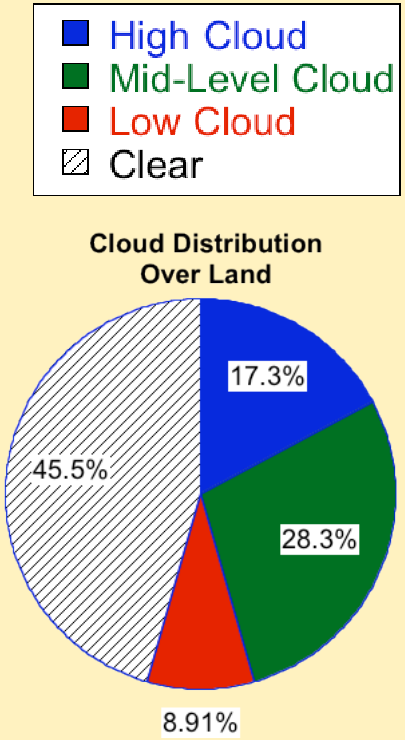
	LTK0 by Oreopoulos et al. (2011)	At least one algorithm cloudy (LTK1)	LTK with selective reclassification (LTK2)
All Clouds	70.01%	86.75%	85.21%
High Clouds	71.36%	97.21%	96.08%
Mid Clouds	86.83%	95.73%	94.37%
Low Clouds	40.01%	58.10%	55.83%
Clear	93.88%	84.96%	90.35%
Overall Performanc e	**77.62%**	**86.18%**	**86.85%**

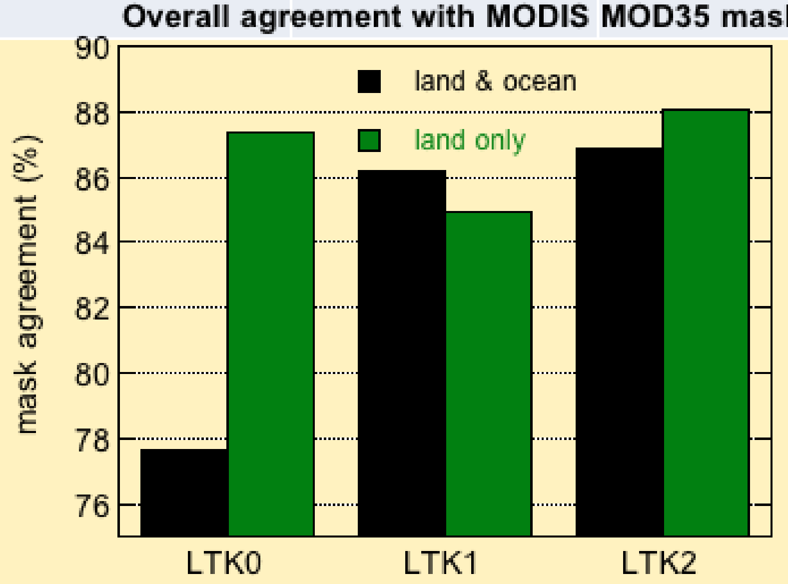




Enhanced LTK mask performance (land)

	LTK0 by Oreopoulos et al. (2011)	At least one algorithm cloudy (LTK1)	LTK with selective reclassification (LTK2)
All Clouds	88.52%	96.17%	90.42%
High Clouds	90.93%	99.15%	93.85%
Mid Clouds	93.20%	99.04%	94.60%
Low Clouds	68.95%	81.28%	70.42%
Clear	85.99%	71.43%	85.24%
Overall Performance	**87.37%**	**84.91%**	**88.06%**

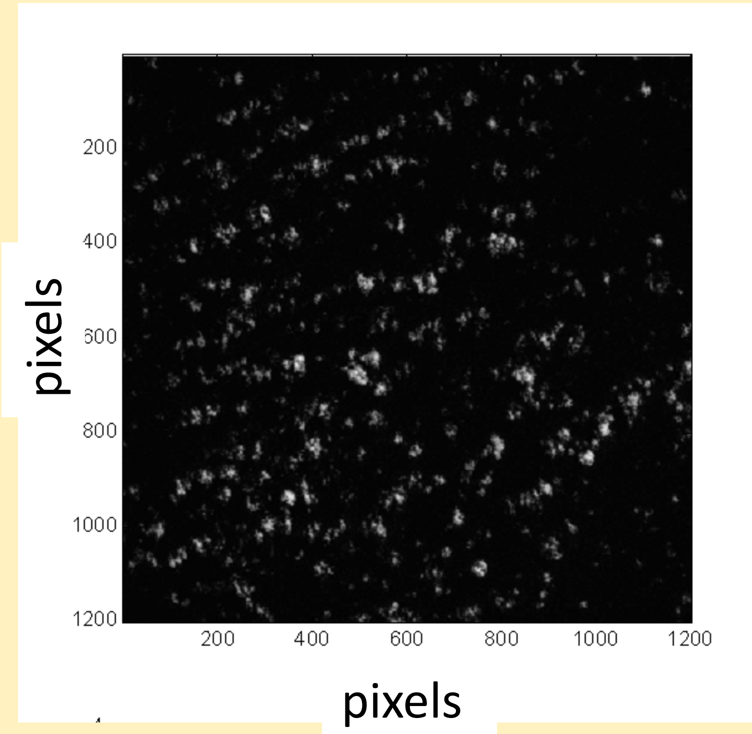


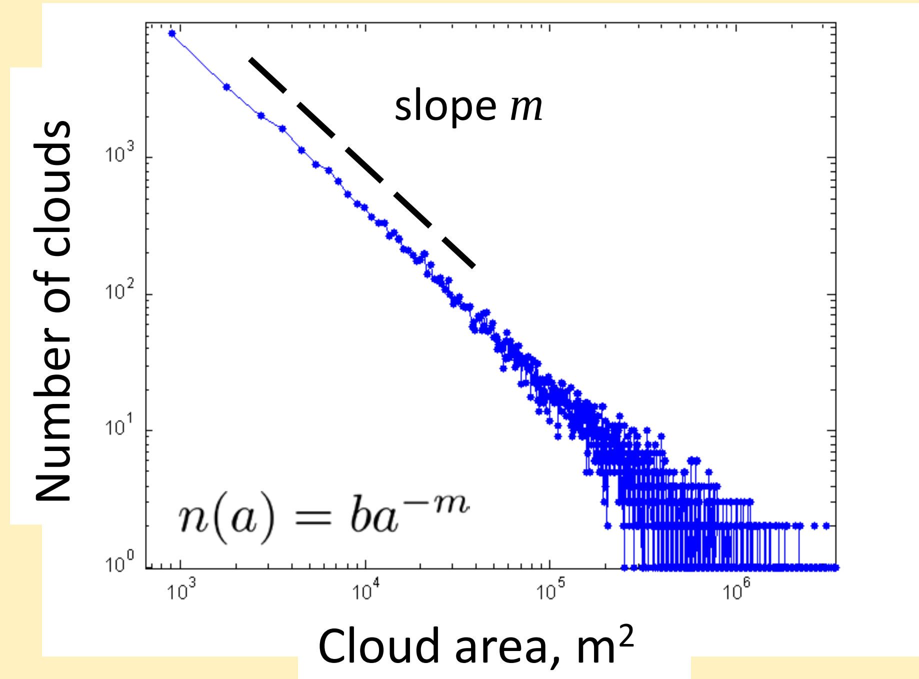


Small cumulus size distribution analysis

(with Ilan Koren and Graham Feingold)

Sparse marine cumulus from Landsat-7





Cloud fraction = $f\,(A)$

Reflectance = $f\,(A,\ \tau_c)$

$$A(a) = ba^{-m+1}$$

a = area of individual cloud

A = total area of clouds

τ_c = cloud optical depth

Koren, Oreopoulos, Feingold, Remer, Altaratz, ACP, 2008

What is the value of m and why does it matter so much?

$$n(a) = ba^{-m}$$
$$A(a) = ba^{-m+1}$$

A = total cloud area
a = area of individual cloud
m = slope on log-log plot

- 5 cloud scenes: Bahamas, Barbados, Hawaii, Polynesia, Ascension Island
- Various trade cumulus regimes
- 30 m resolution

m = 1.3 +/- 0.1

Because $m > 1$:

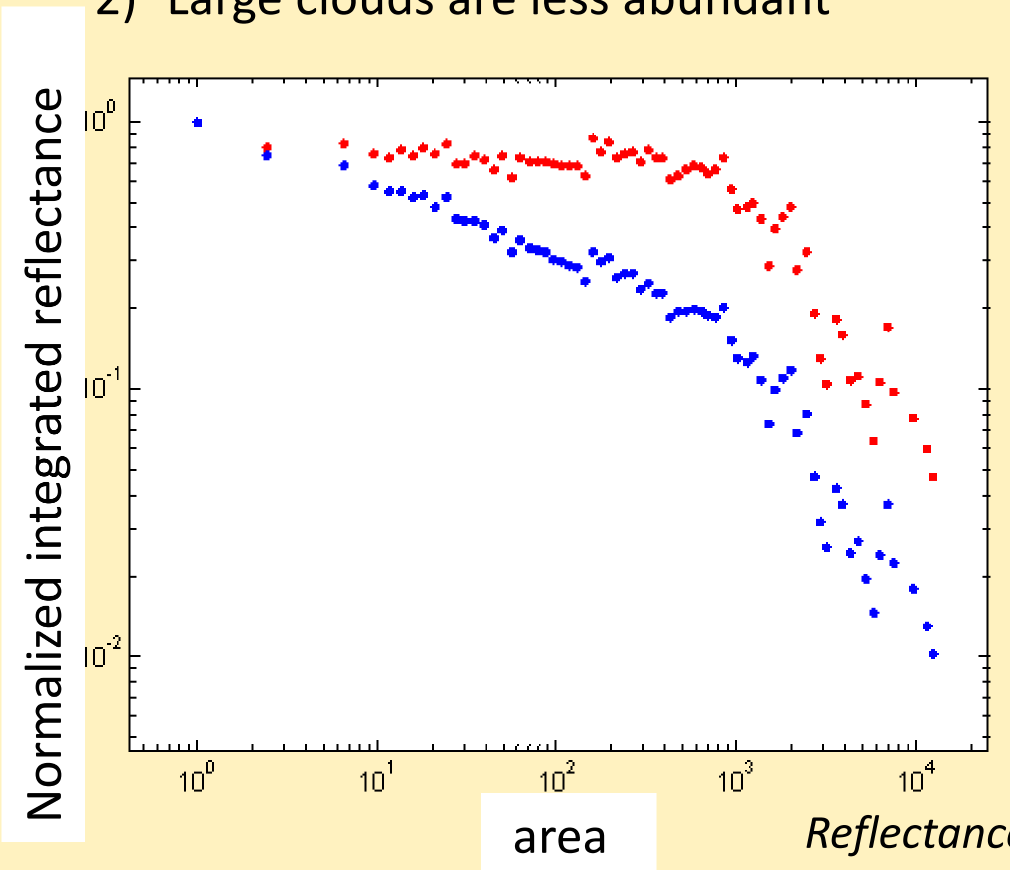
1) cloud number increases monotonically with decreasing size
2) cloud area increases monotonically with decreasing size

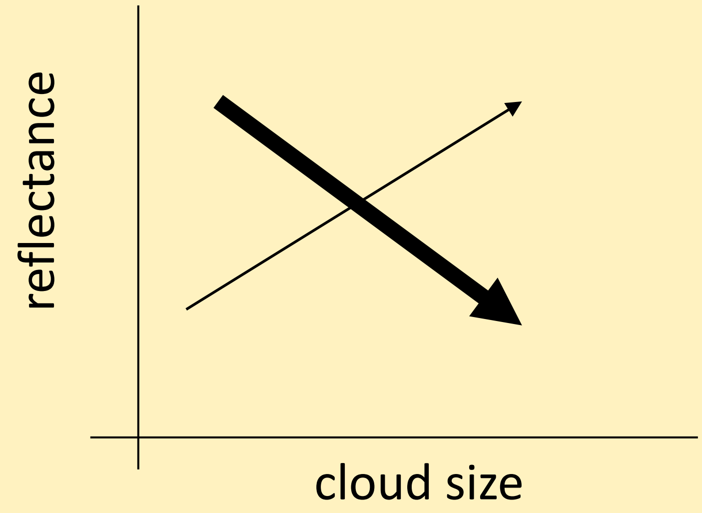
Small clouds contribute more to number and cloud fraction

What about reflectance?

Two opposing forces:

1) Large clouds are optically thicker and reflect more
2) Large clouds are less abundant



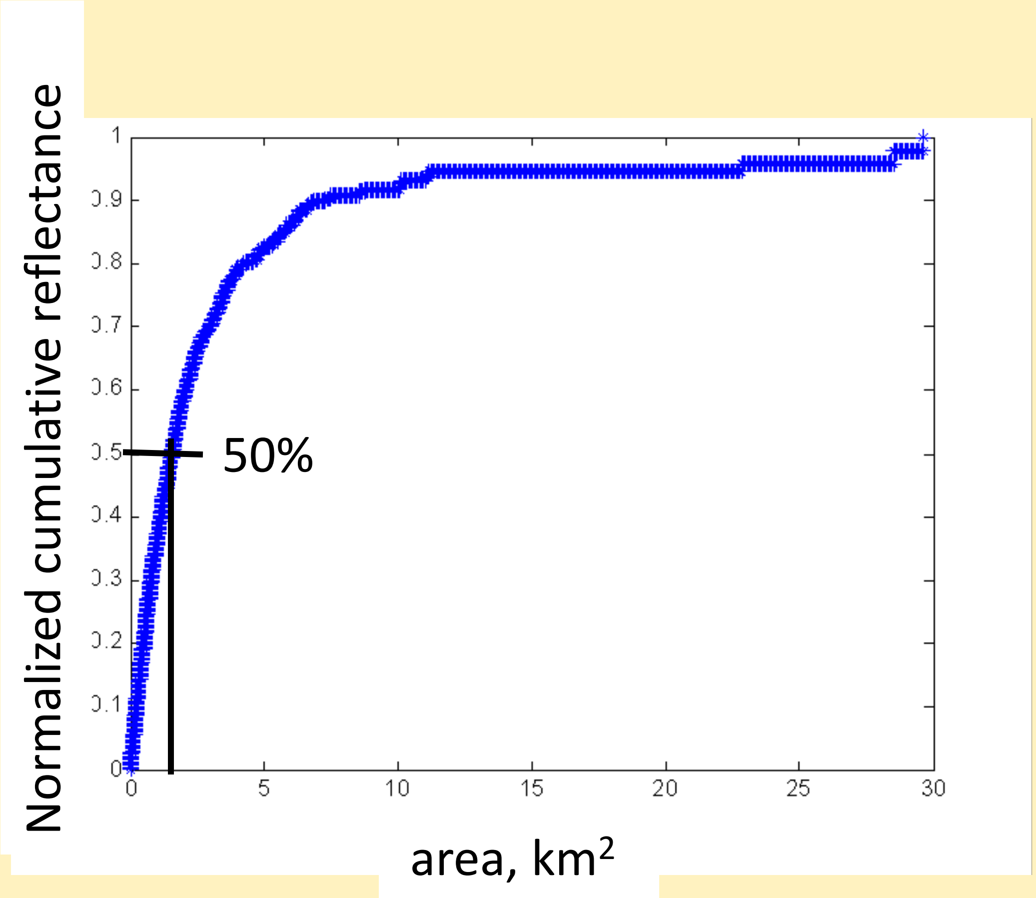


Reflectance decreases with increasing size provided

m>1.269 (1600 nm)

m>1.125 (470 nm)

The end result



50% of the reflectance
derives from clouds with areas <1 km^2

Thoughts on Landsat, LDCM and the future

- It’s been a great learning experience to be part of an excellent Landsat STM
- Free Landsat data will lead to increase of even cloud-related research
- The acquisition strategy needs to be simplified: always acquire over land should be the way of the future
  - If something like LTAP continues to exist try to use the best cloud climatologies and forecasts
- Fight for thermal capabilities in future missions
- Cloud masking will never be perfect (85-90% accuracy probably the best we can do with limited number of bands), but a product should be provided.
- Shadow detection is much harder (especially to automate), but its importance should not be overemphasized

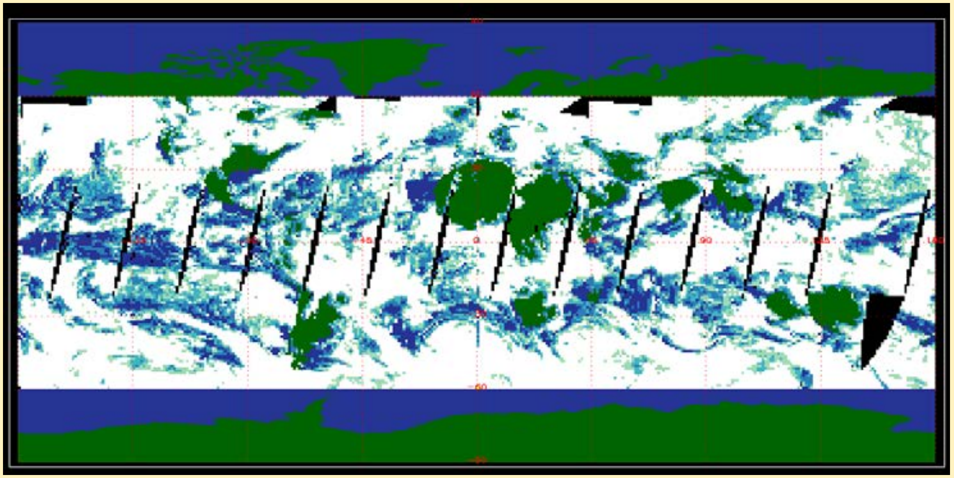
Acknowledgements

- Financial support by NASA's LPSO (Irons/Masek)

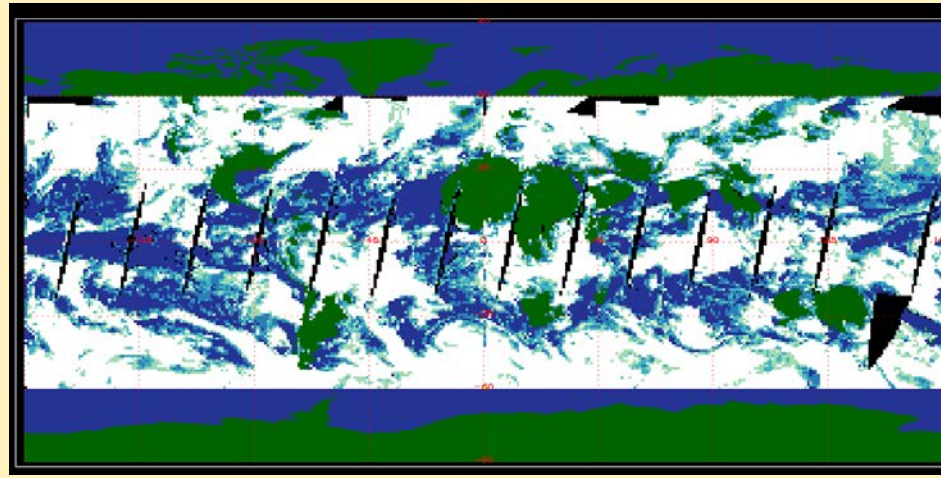
Additional slides

Cloud Fraction Comparison

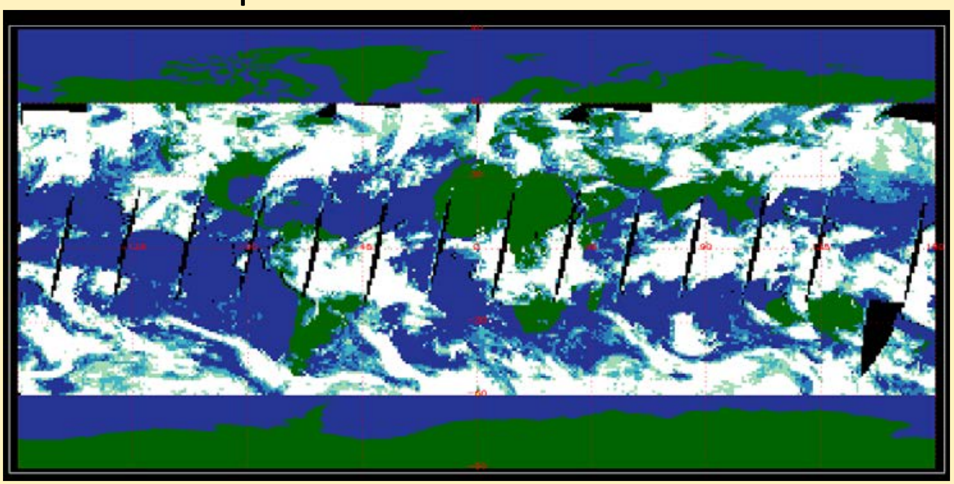
MODIS (MOD35) Cloud Mask



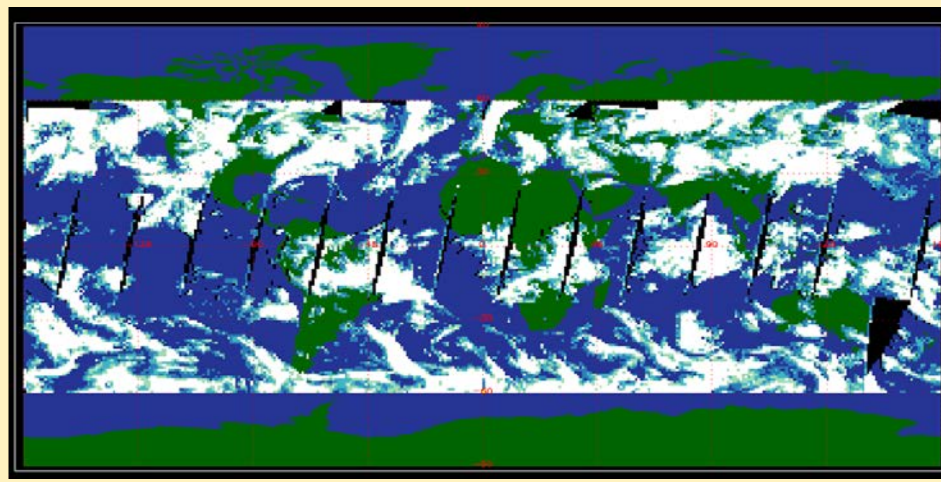
Enhanced LTK Cloud Mask



Split Window Cloud Mask



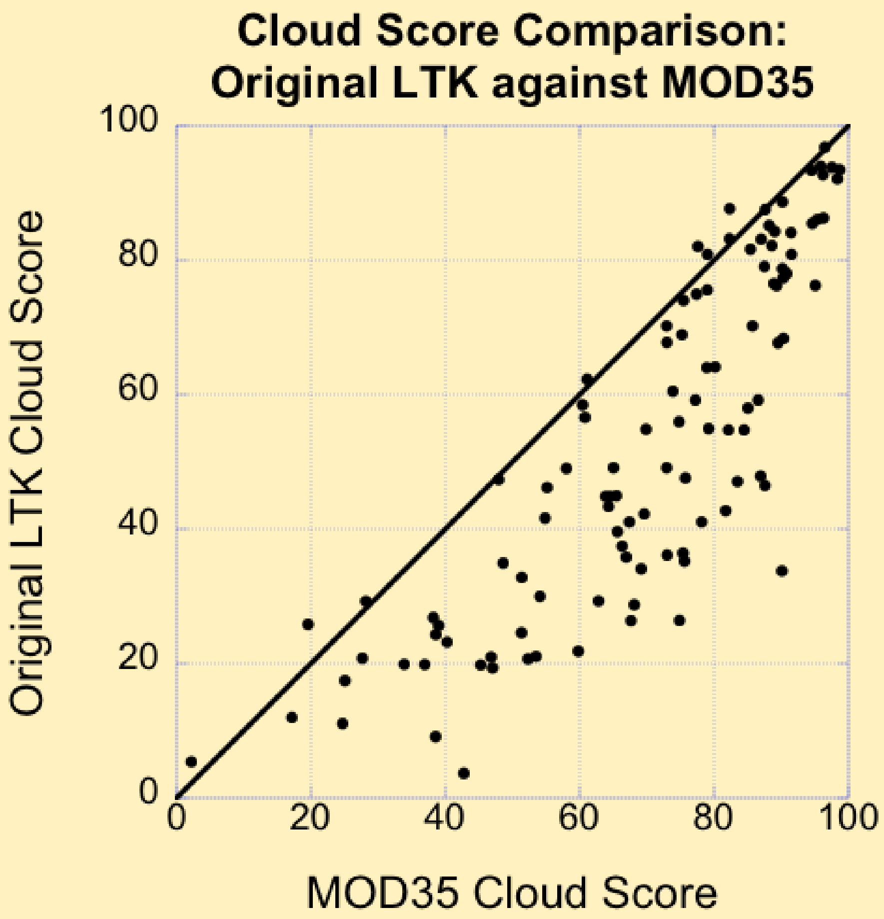
1.38 µm Cloud Mask



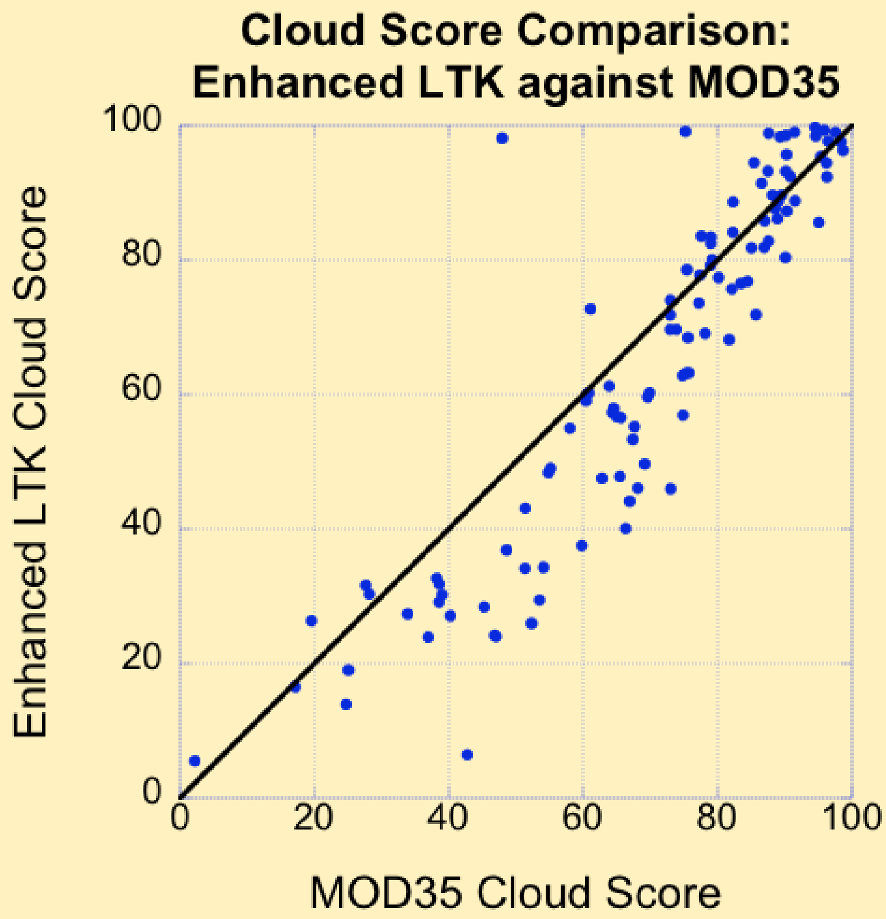
Cloud Fraction:	No Retrieval	0%-20% Land	0%-20% Water	20%-40%	40%-60%	60%-80%	80%-100%

Cloud Fraction of 1 deg gridboxes

Cloud score performance: 108 MODIS granules



Original LTK



Enhanced LTK

Cloud mask performance: 108 MODIS granules