Cloud Masking and Cloud Products

MODIS Operational Algorithm MOD35

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MODIS Cloud Masking

- Often done with thresholds (APOLLO, CLAVR, etc.)
- Based on expected differences from clear sky in various situations (day, night, land, water, desert, vegetation)
- Particularly difficult areas include clouds at night:
  - night time over land
  - polar regions in winter
- MODIS algorithm combines the results of many spectral tests.

Approach

Provide a flag indicating confidence that each 1 km pixel is clear.

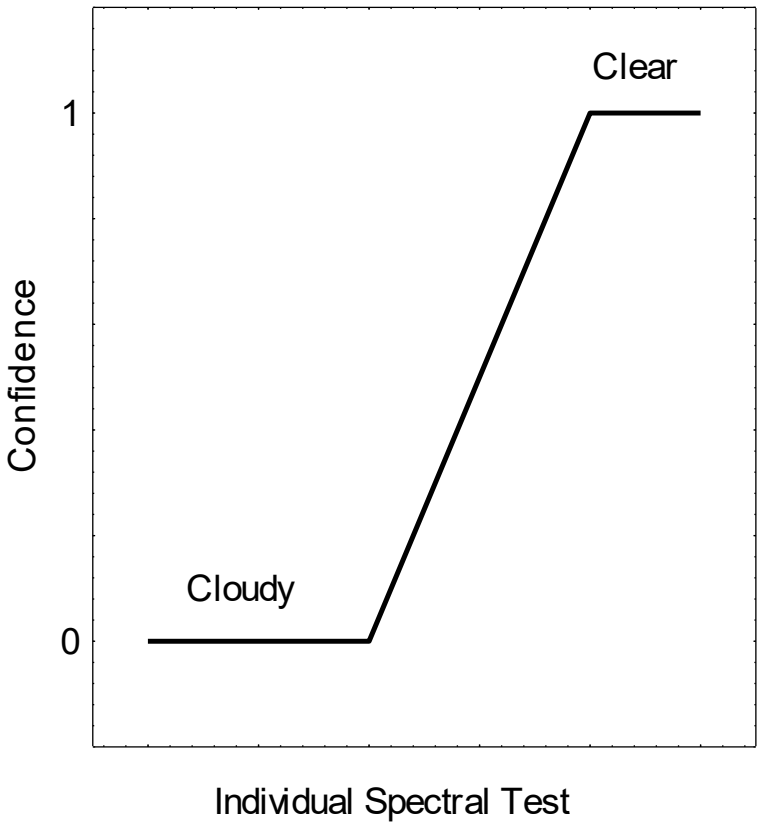
Restrictions

- Real time execution (it must be efficient)
- Must allow user to diagnose problems in the data
- Computer storage
- Ease of understanding

MODIS Cloud mask

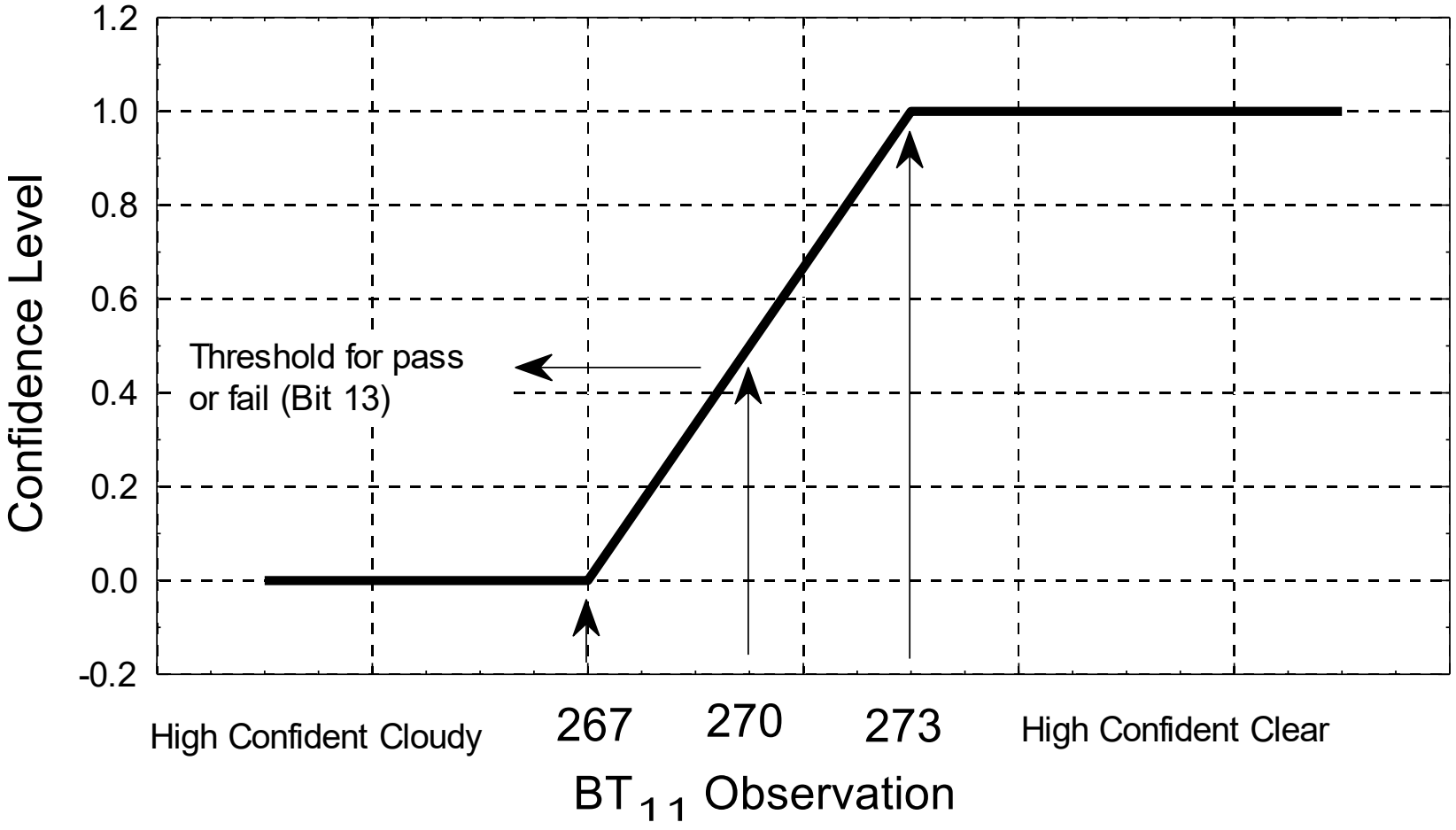
- **1 km** nadir spatial resolution **day & night**, (250 m day)
  - **17 spectral bands (0.55-13.93 µm, incl. 1.38 µm)**
    11 spectral tests (function of 5 ecosystems) with ”fuzzy” thresholds
  - temporal consistency test over ocean, desert (nighttime); spatial variability test over ocean
- **48 bits per pixel** including individual test results and processing path; generation of clear sky maps
- **bits 1,2** give combined test results as: *confident clear*, *probably clear*, *probably cloudy*, *obstructed/cloudy* (clear sky conservative)

Cloud Mask Confidence



- Confidence intervals are based on *closeness* to a threshold
- Confidence tests are combined to arrive at a **Quality Flag** (2 bits)

Confidence Level of Clear



Example thresholds for the simple IR window cold cloud test.

Combining tests

Each of the tests above returns a confidence level ranging from 1 (high confidence that the pixel is clear) to 0 (high confidence that the pixel is cloudy). The individual confidence levels must be combined to determine a final decision on clear or cloudy. We shall denote the confidence level of an individual test as F_i and the final quality flag as Q.

$$Q = \sqrt[N]{\prod_{i=1}^{N} F_i}$$

Detecting Clouds (IR)

IR Window Brightness Temperature Threshold and Difference Tests

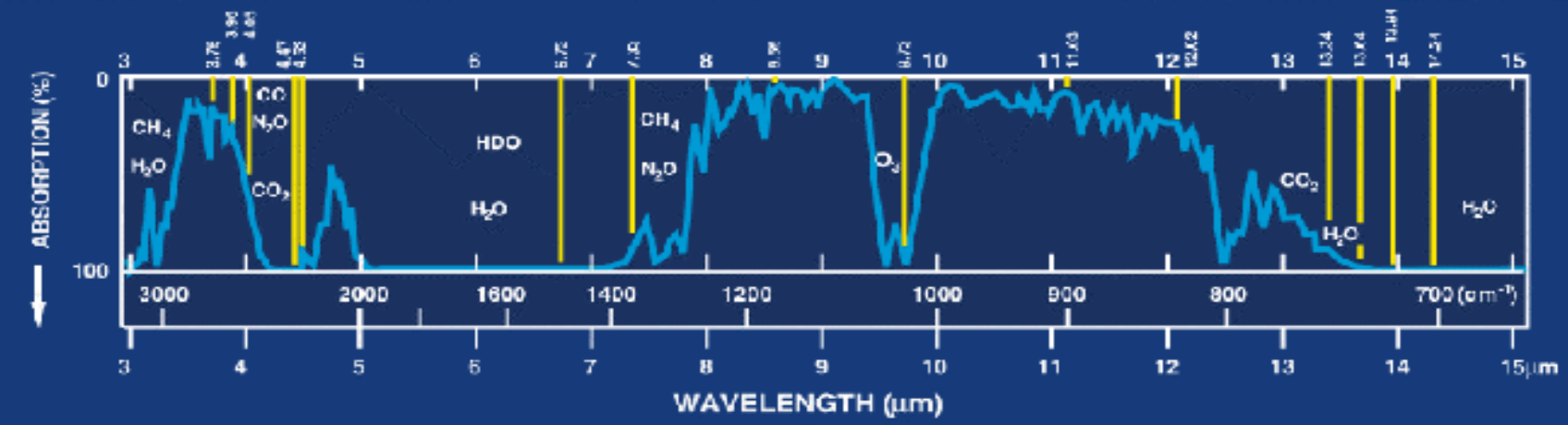
IR tests sensitive to sfc emissivity and atm PW, dust, and aerosols

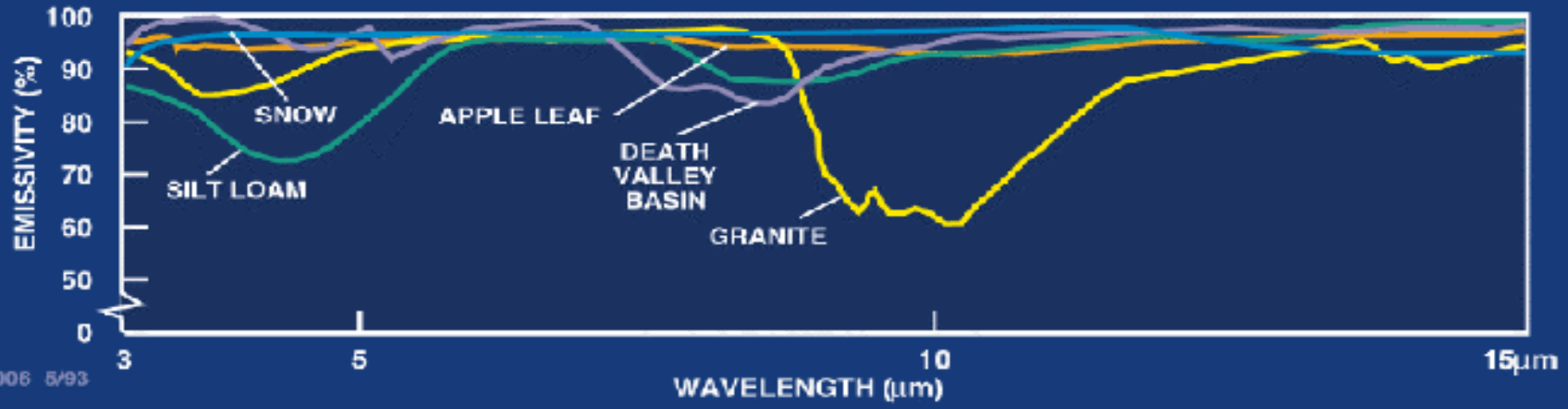
BT11 < 270
BT11 + aPW * (BT11 - BT12) < SST
BT11 + bPW * (BT11 - BT8.6) < SST
    aPW and bPW determined from lookup table as a function of PW
BT3.9 - BT11 > 12 indicates daytime low cloud cover
BT11 - BT12 < 2 (rel for scene temp) indicates high cloud
BT11 - BT6.7 large neg diff for clr sky over Antarctic Plateau winter

CO_2 Channel Test for High Clouds

BT13.9 < threshold (problems at high scan angle or high terrain)

LAND - THERMAL RADIATION





C351.006 5/93

Detecting Clouds (vis)

Reflectance Threshold Test

r.87 > 5.5% over ocean indicates cloud
r.66 > 18% over vegetated land indicates cloud

Near IR Thin Cirrus Test

r1.38 > threshold indicates presence of thin cirrus cloud
ambiguity of high thin versus low thick cloud (resolved with BT13.9)
problems in high terrain

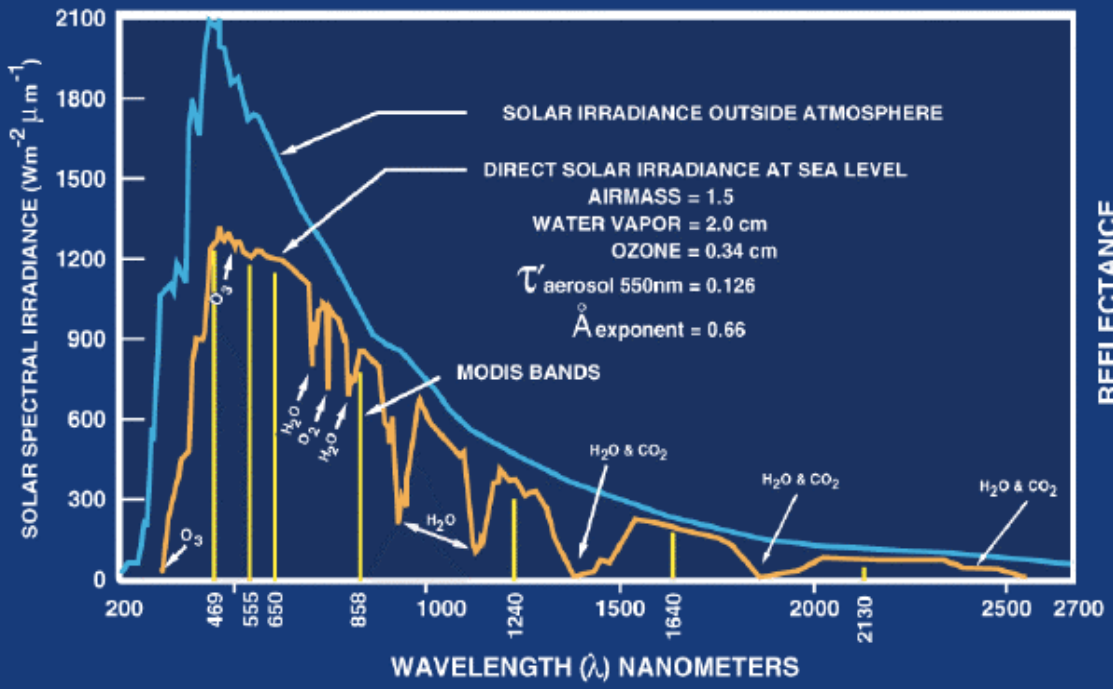
Reflectance Ratio Test

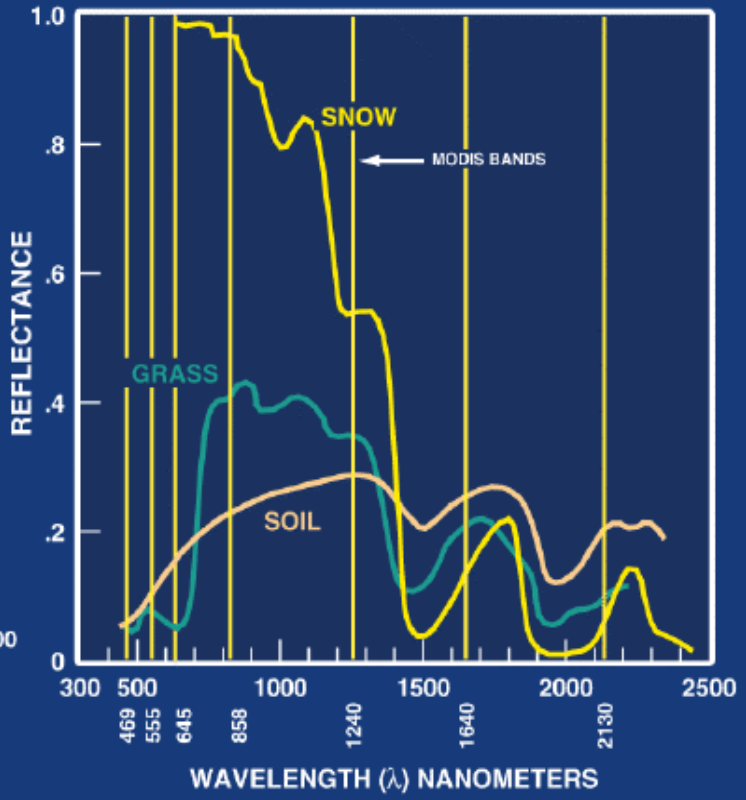
r.87/r.66 between 0.9 and 1.1 for cloudy regions
must be ecosystem specific

Snow Test

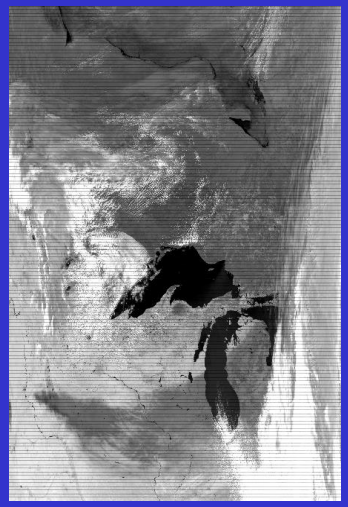
NDSI = [r.55-r1.6]/ [r.55+r1.6] > 0.4 and r.87 > 0.1 then snow

LAND-SOLAR RADIATION



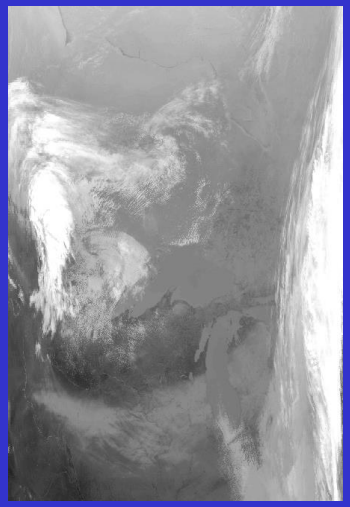


1.6 μm image

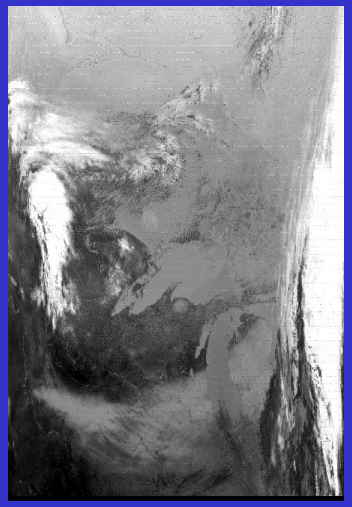


0.86 μm image

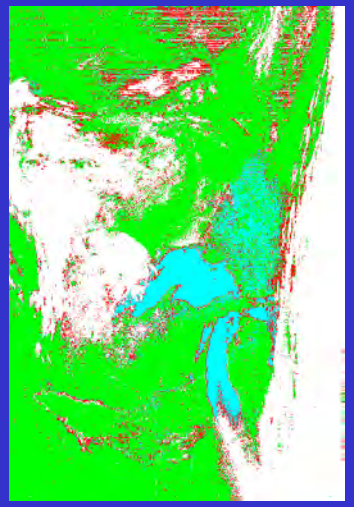
11 μm image



3.9 μm image

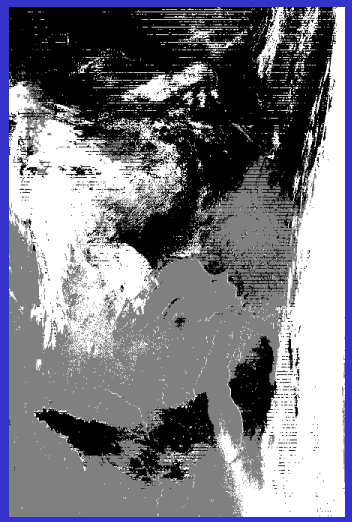


cloud mask

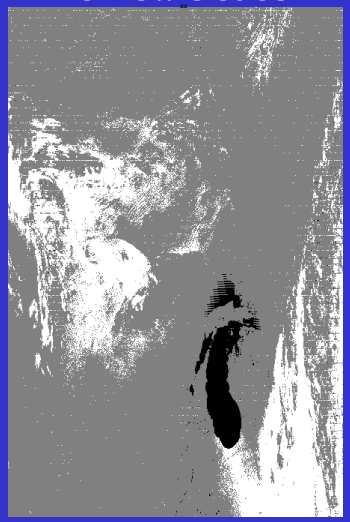


Snow test (impacts choice of tests/thresholds)

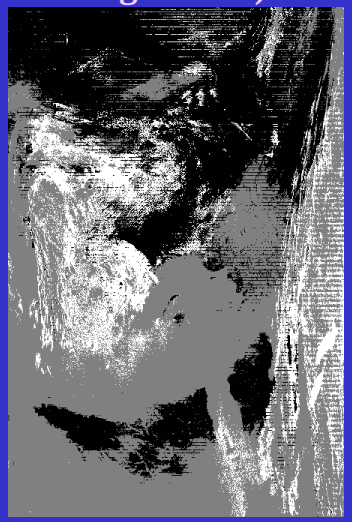
VIS test (over non-snow covered areas)



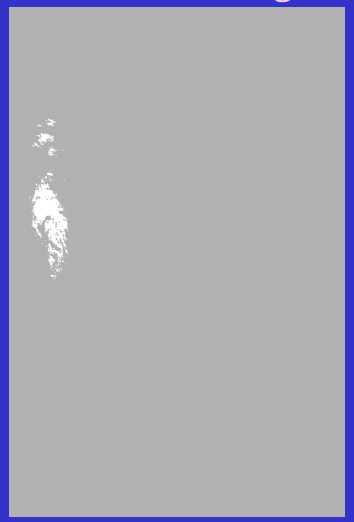
3.9 - 11 BT test for low clouds



11 - 12 BT test (primarily for high cloud)

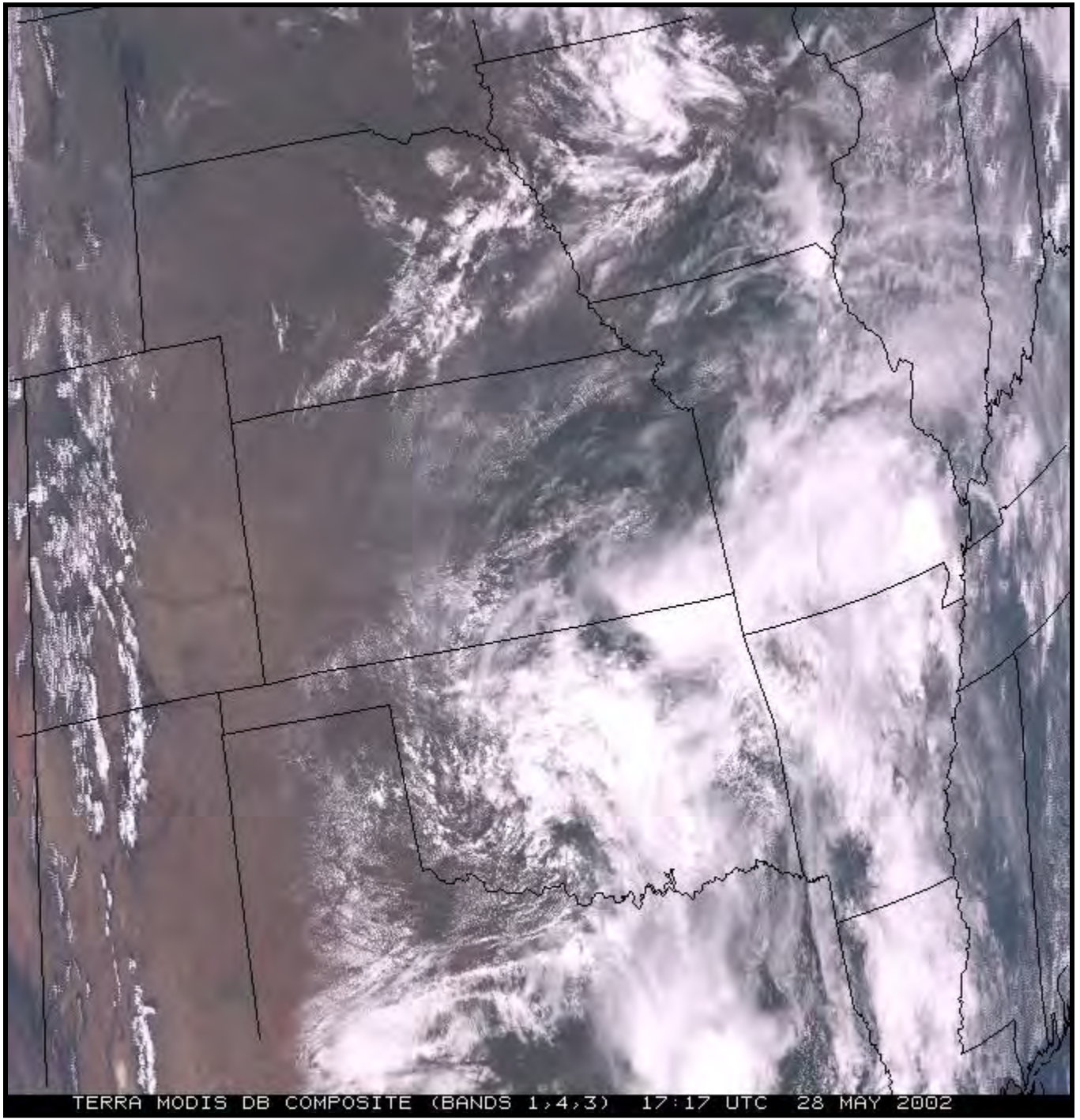


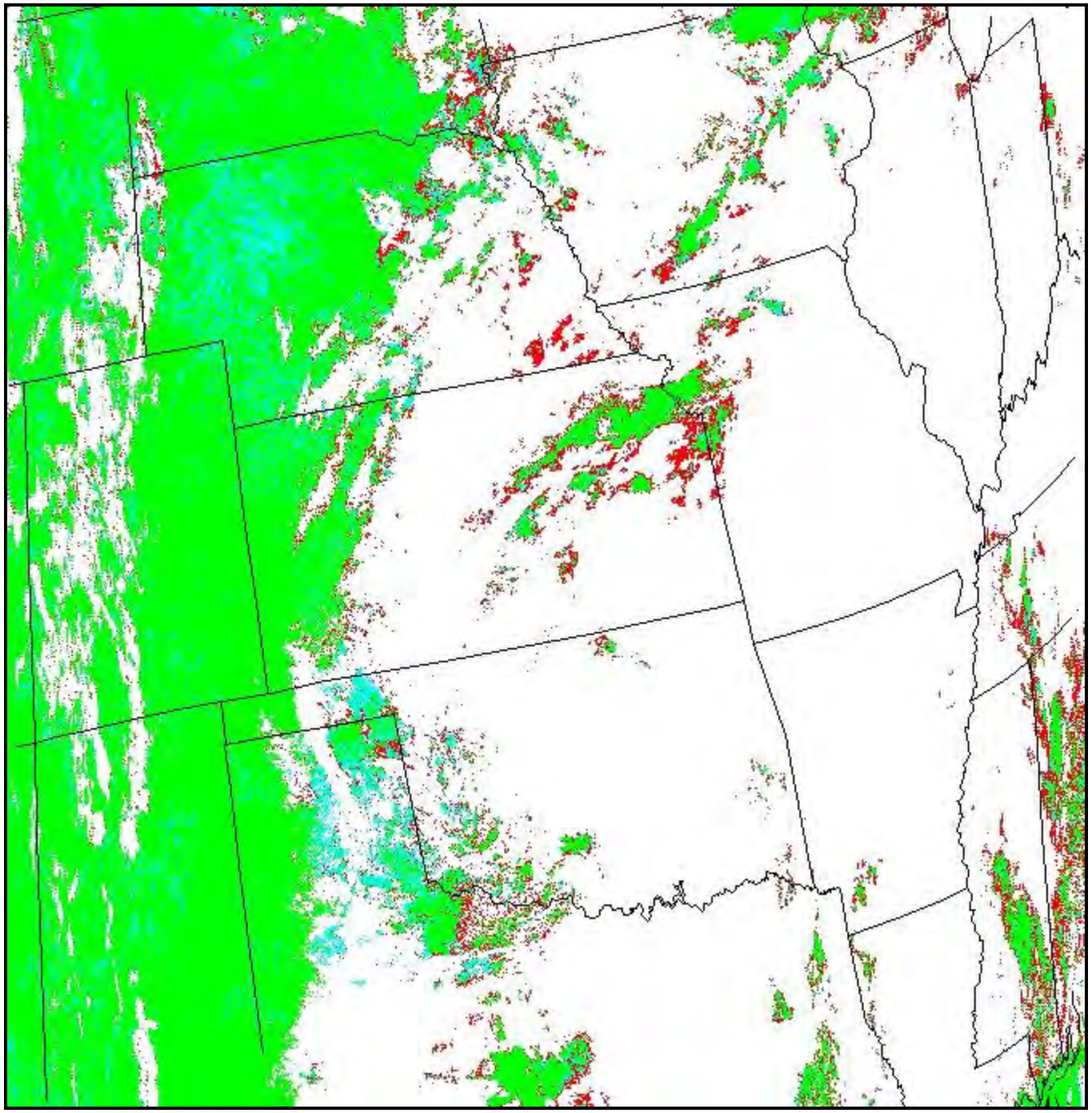
13.9 μm high cloud test (sensitive in cold regions)



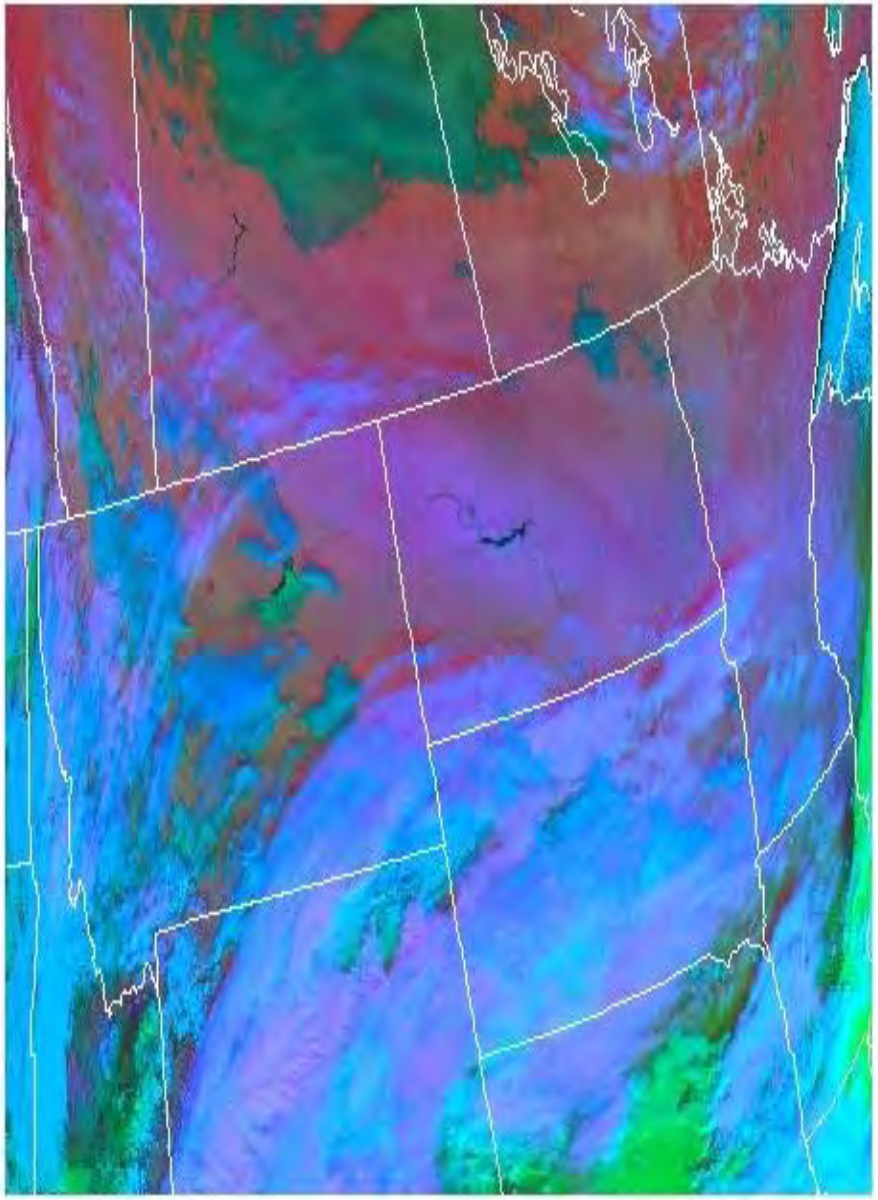
MODIS cloud mask example

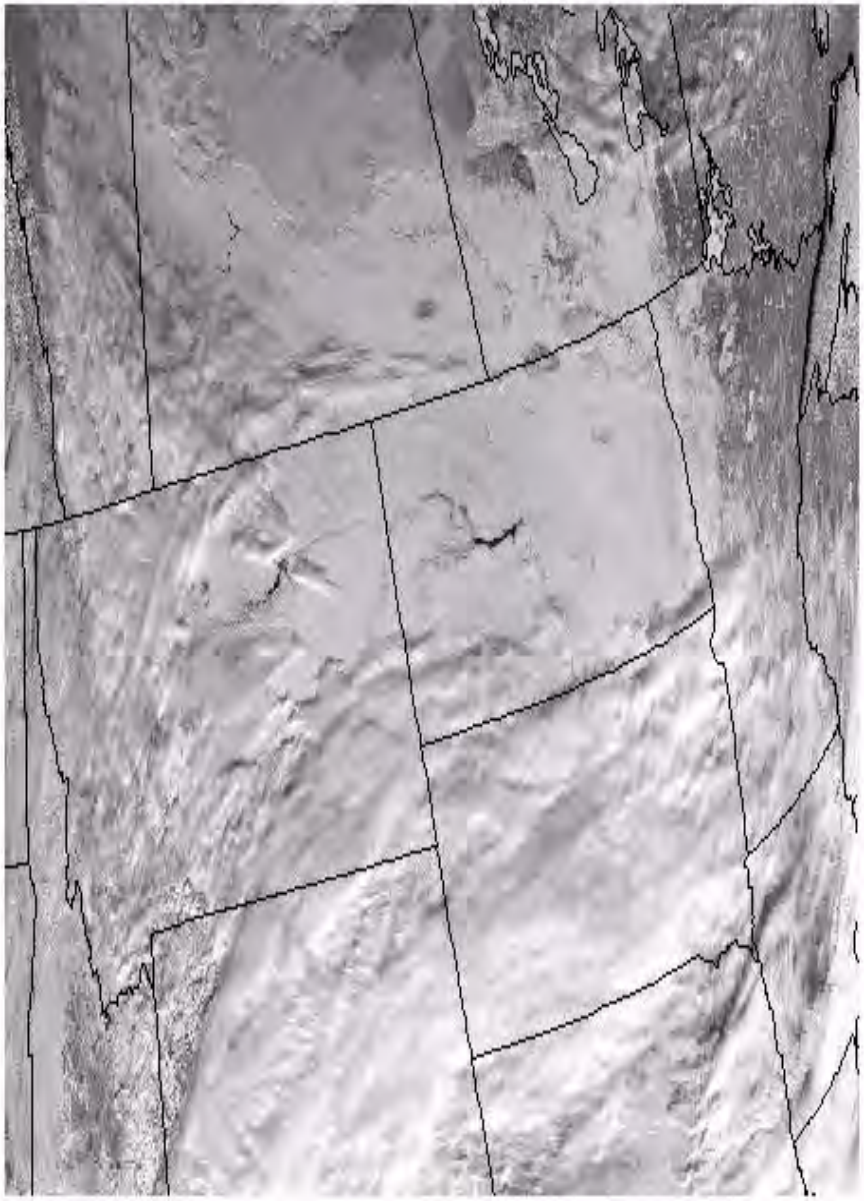
(**confident clear** is green, **probably clear** is blue, **uncertain** is red, **cloud** is white)

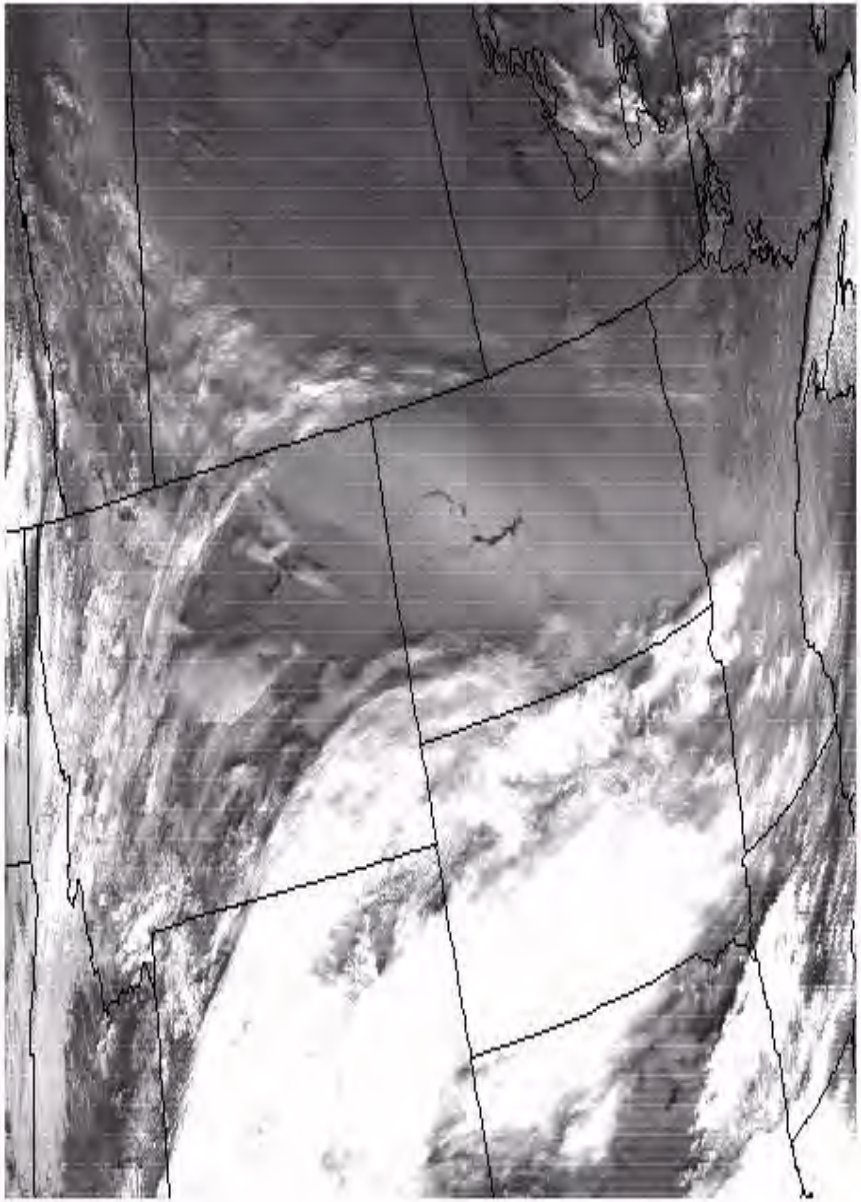

TERRA MODIS DB COMPOSITE (BANDS 1,4,3) 17:17 UTC 28 MAY 2002

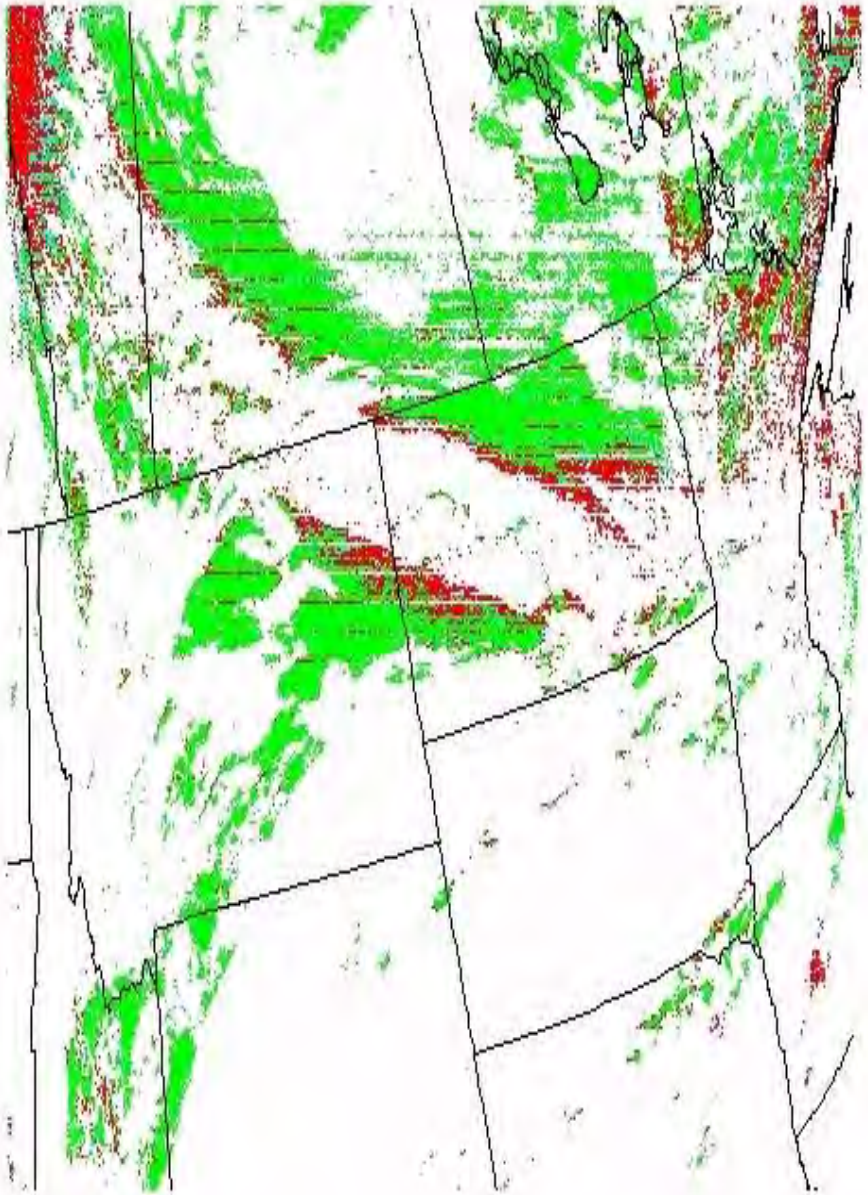


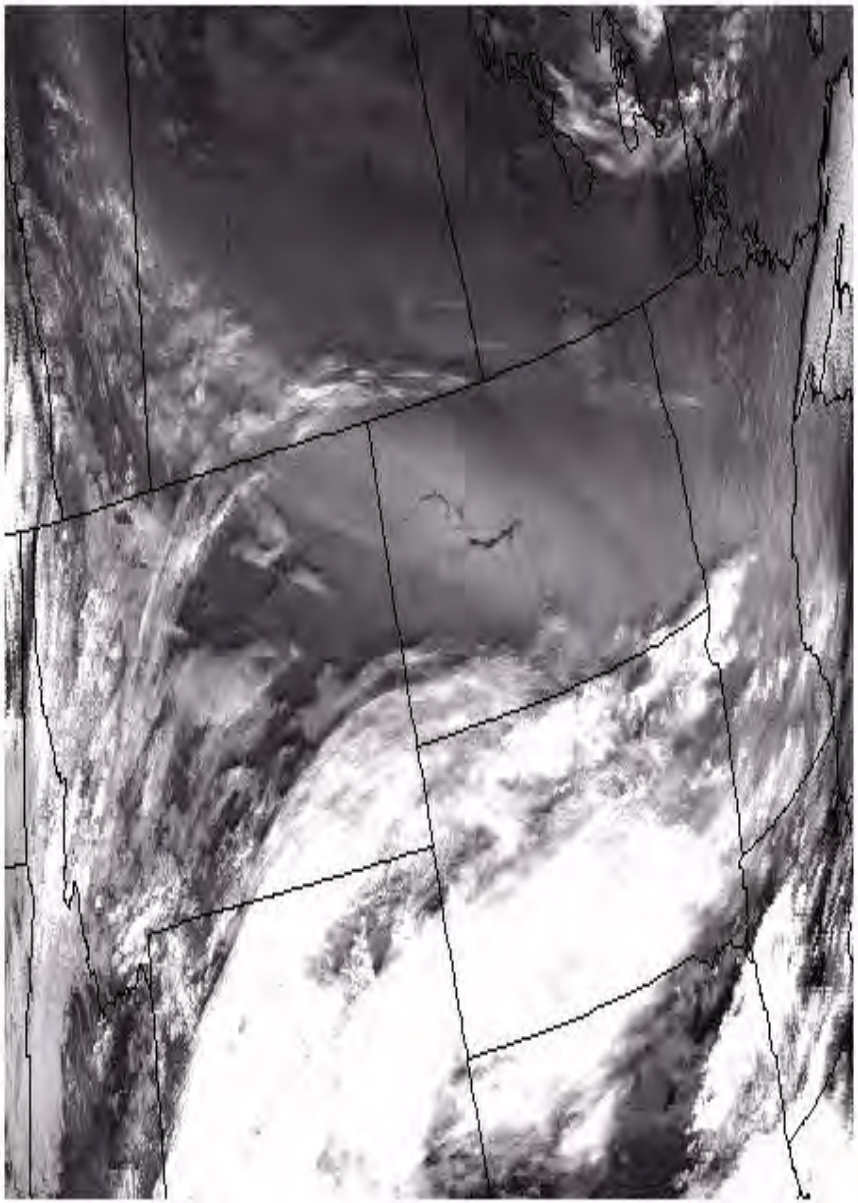
Cloud

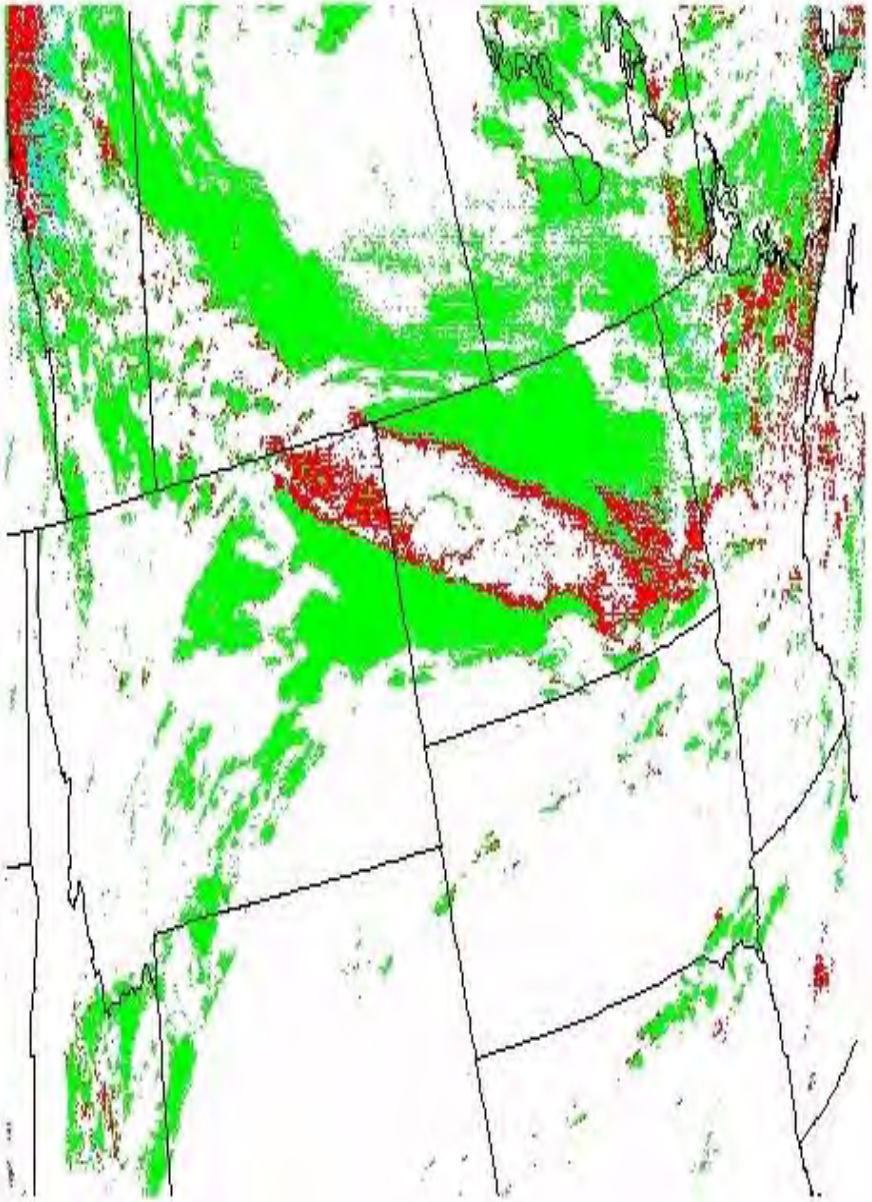


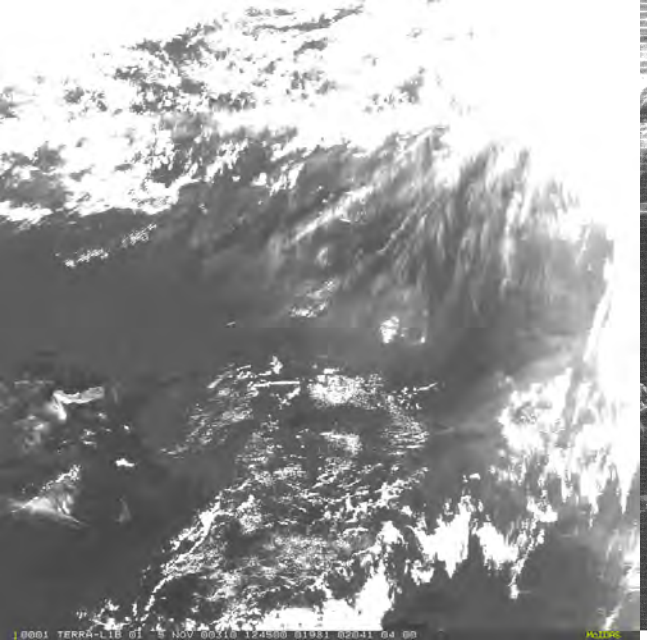




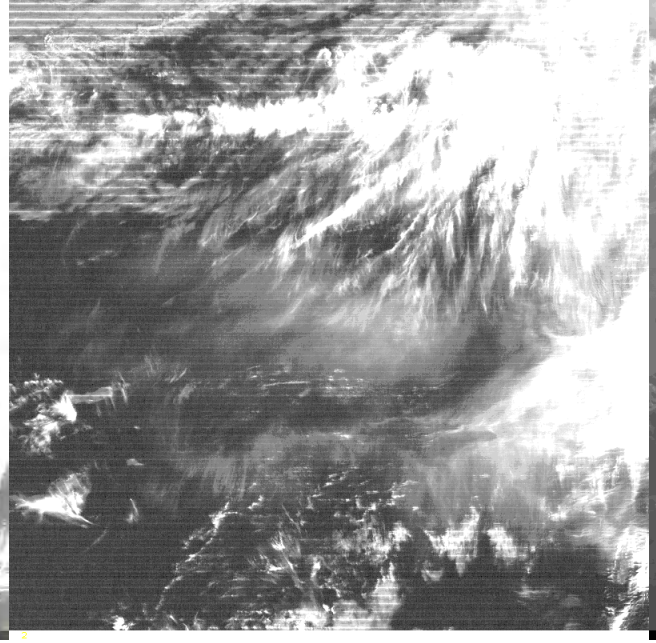




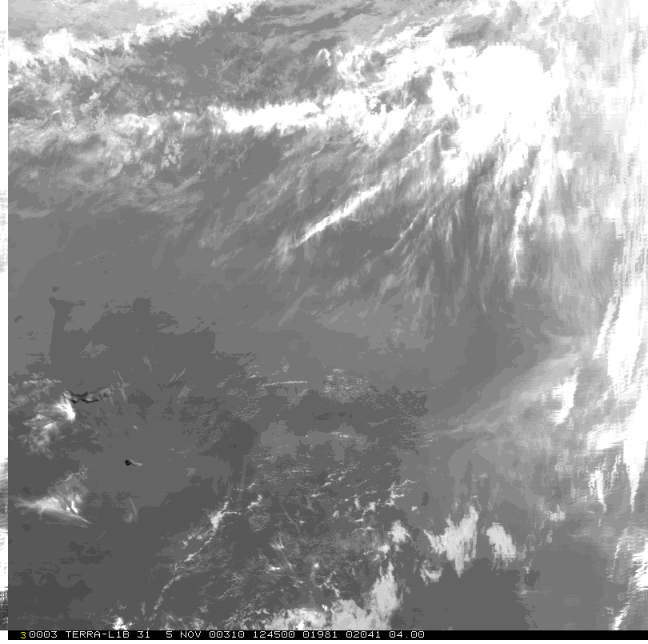




VIS

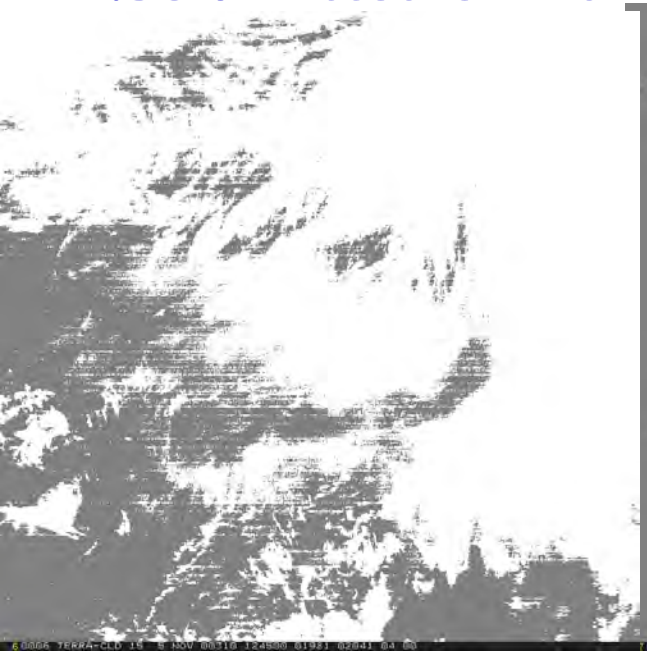


1.38

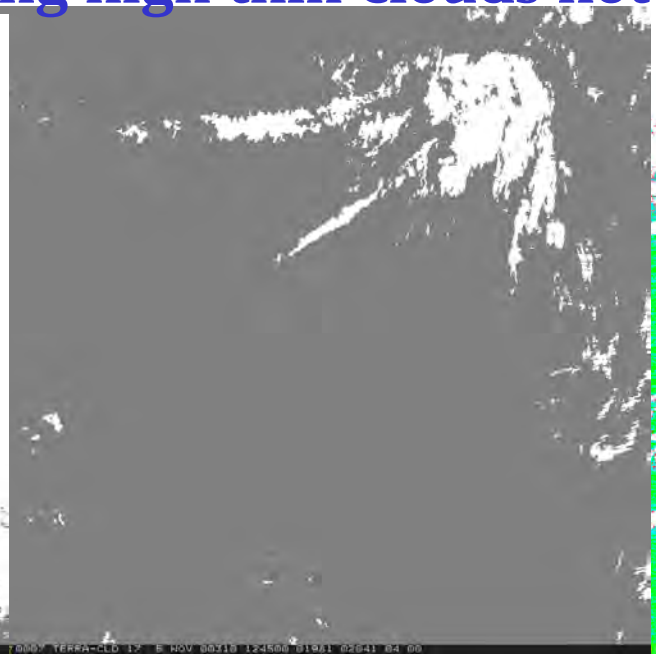


IRW

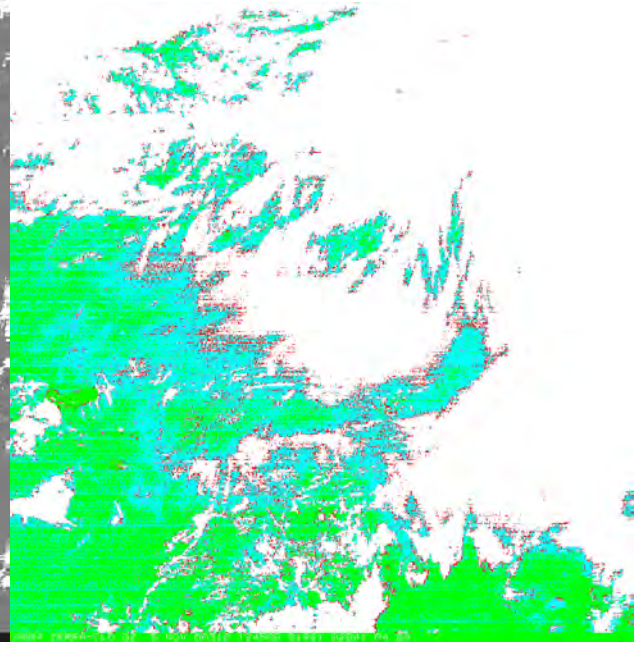
1.38 um test is finding high thin clouds not found in other tests



1.38 cld msk

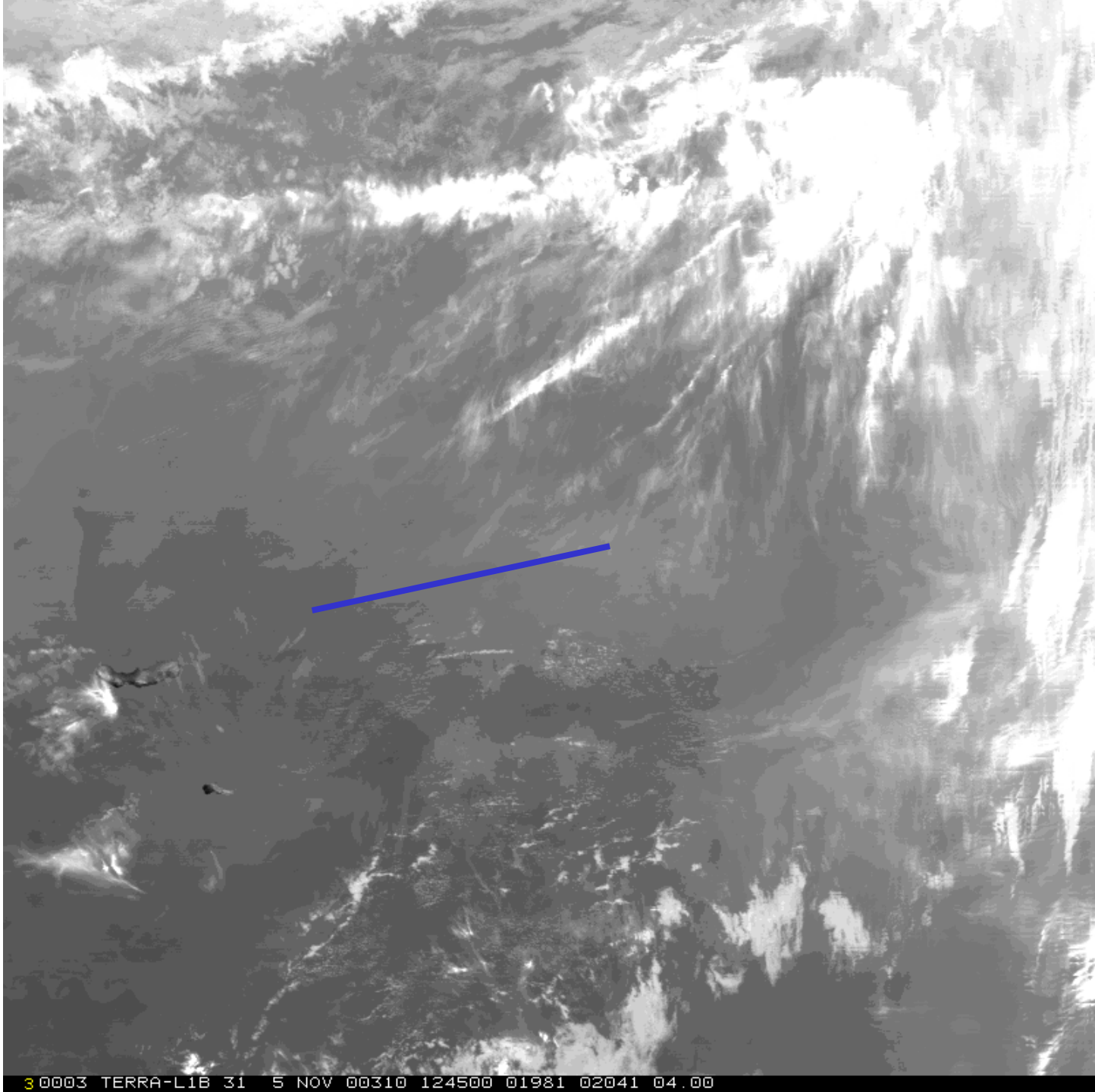


tri-spectral cld msk

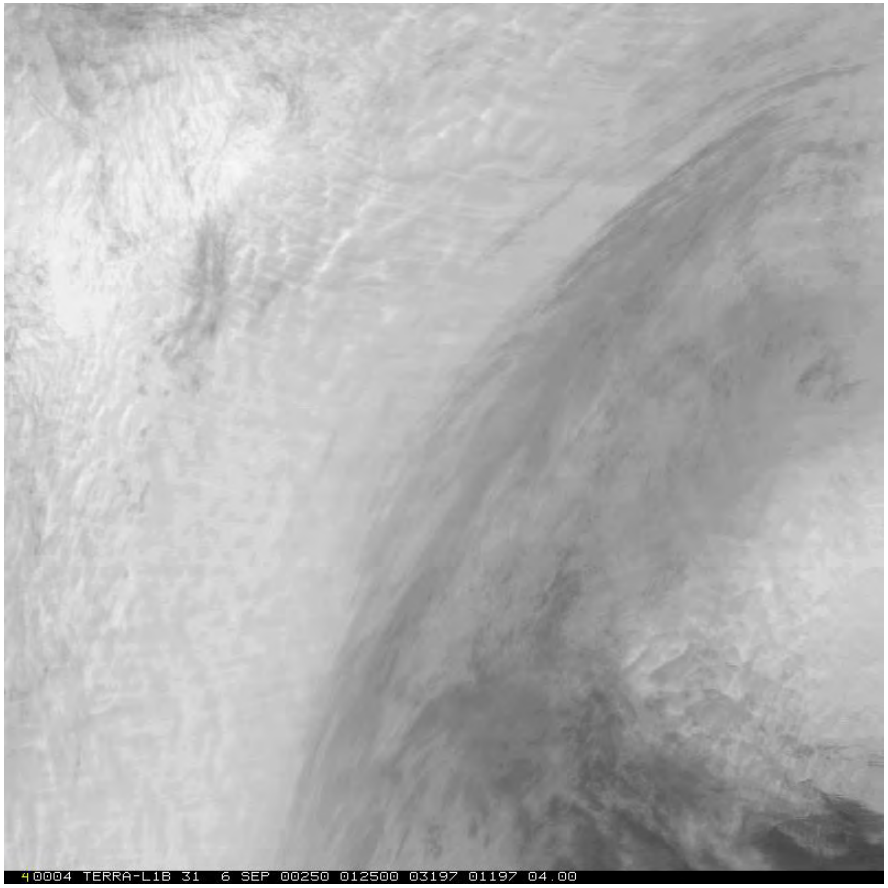


cld msk

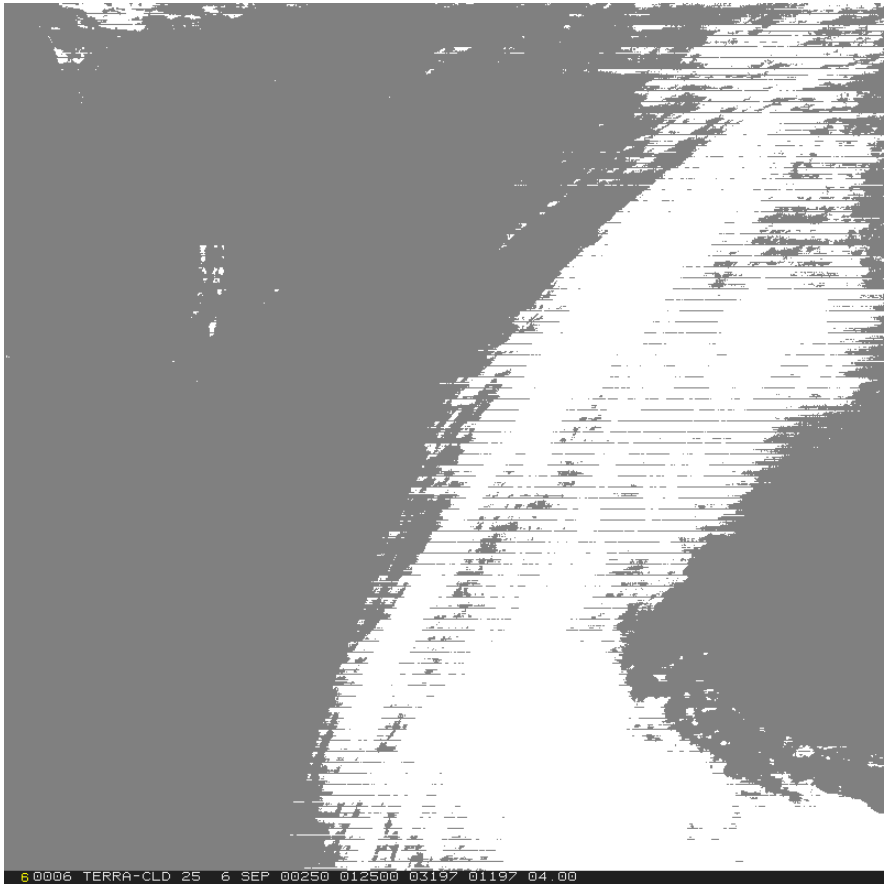
Is
3 K
gradient
SST
or
clouds?



6.7-11 µm BTD Test helping Cloud Mask in Polar Regions



MODIS 11 µm image of Antarctic near the South Pole. Warmer temperatures are darker. Brightness temperatures vary from approximately 190K to 245K. Clear areas are lighter (colder).

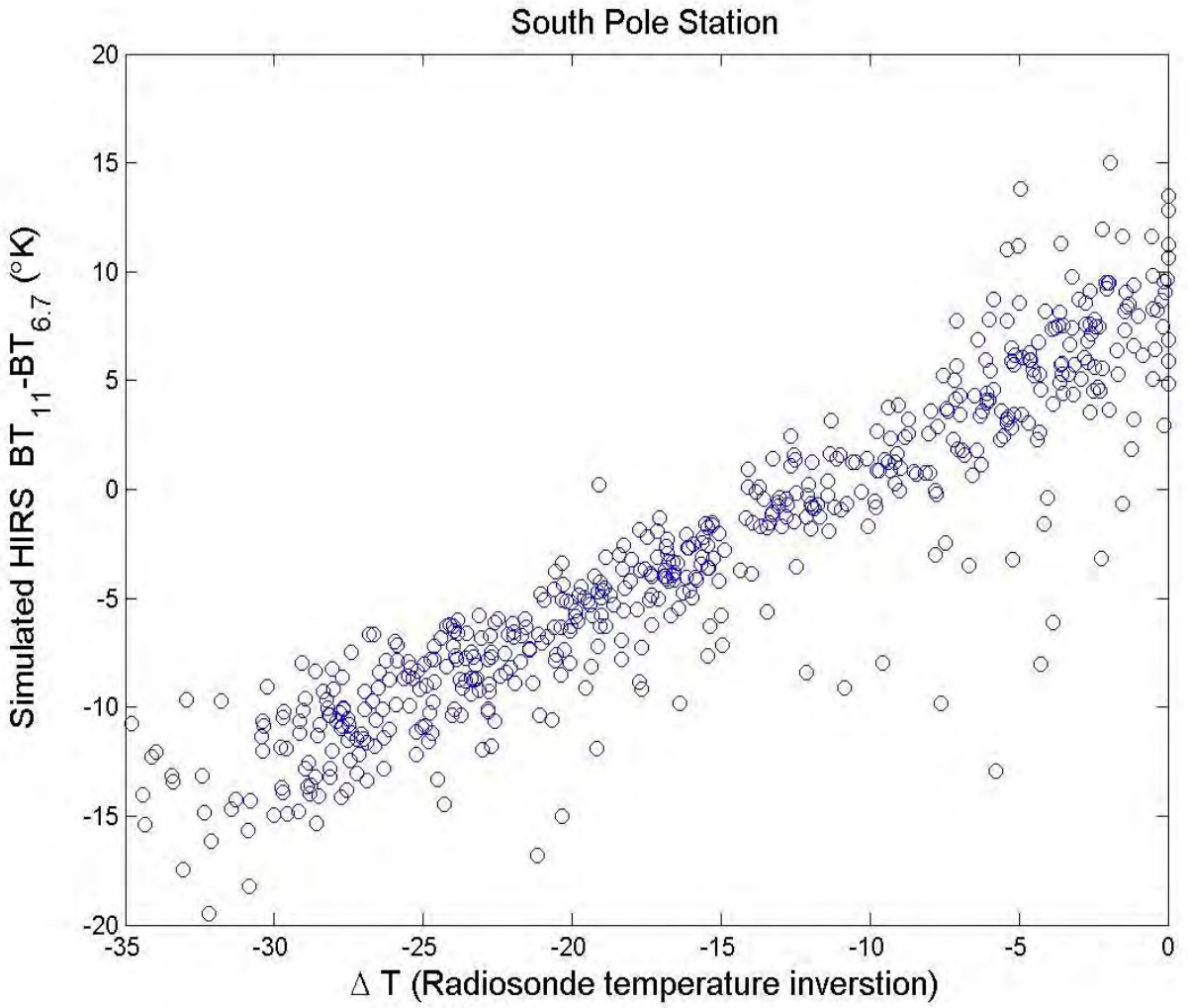


Operational MODIS cloud mask image. Clouds are indicated in white..

IRW-WV channels combine to detect polar inversions

BT6.7 (sees mid-trop) is warmer than BT11 (sees sfc)

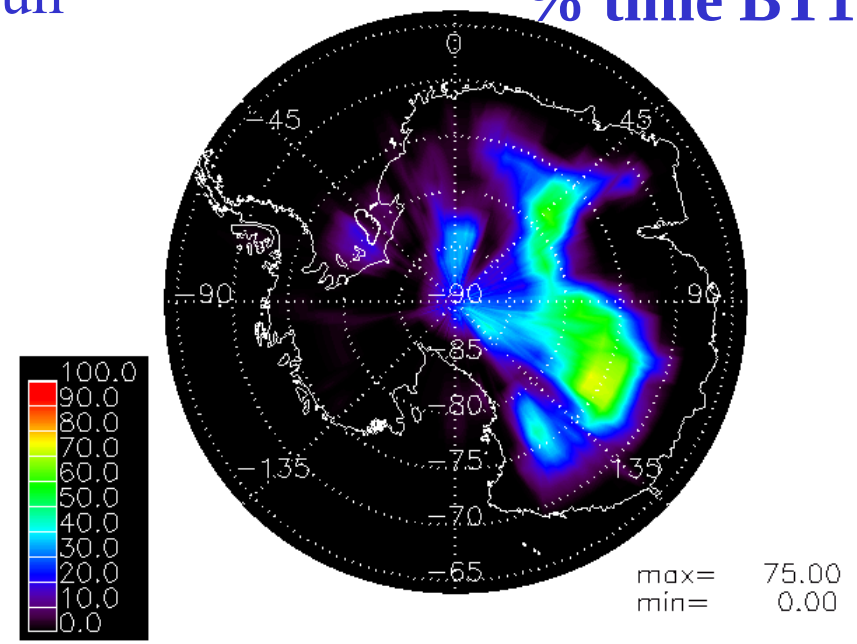
BT11-BT6.7 (from HIRS) versus strength of temperature inversion (from raobs)



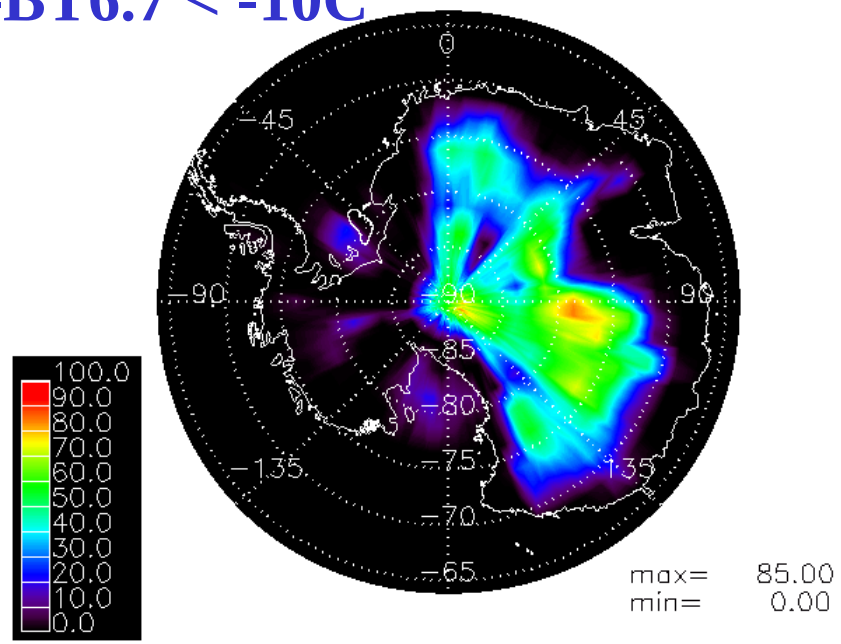
Ackerman, 1996: Global satellite observations of negative brightness temperature differences between 11 and 6.7 um. JAM, **53**, 2803-2812.

% time BT11-BT6.7 < -10C

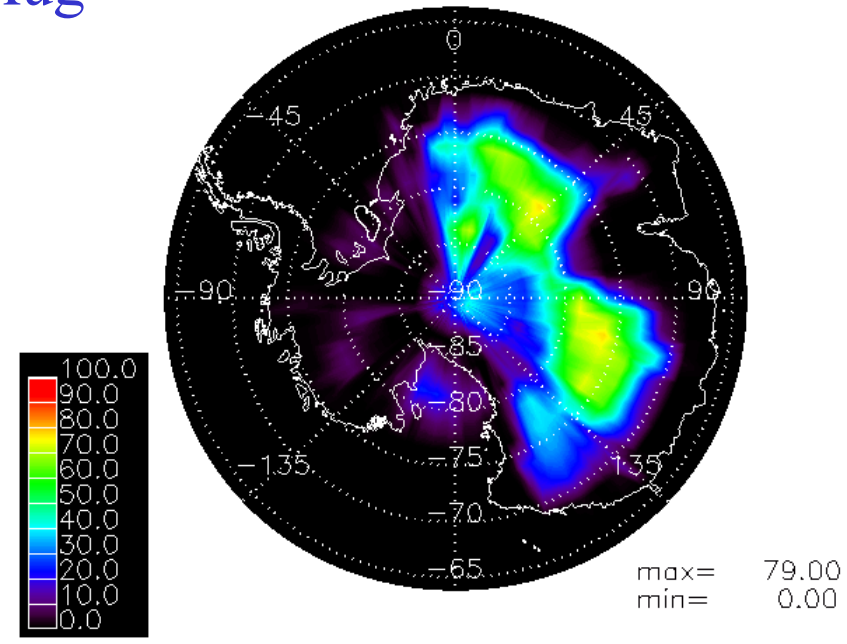
Jun



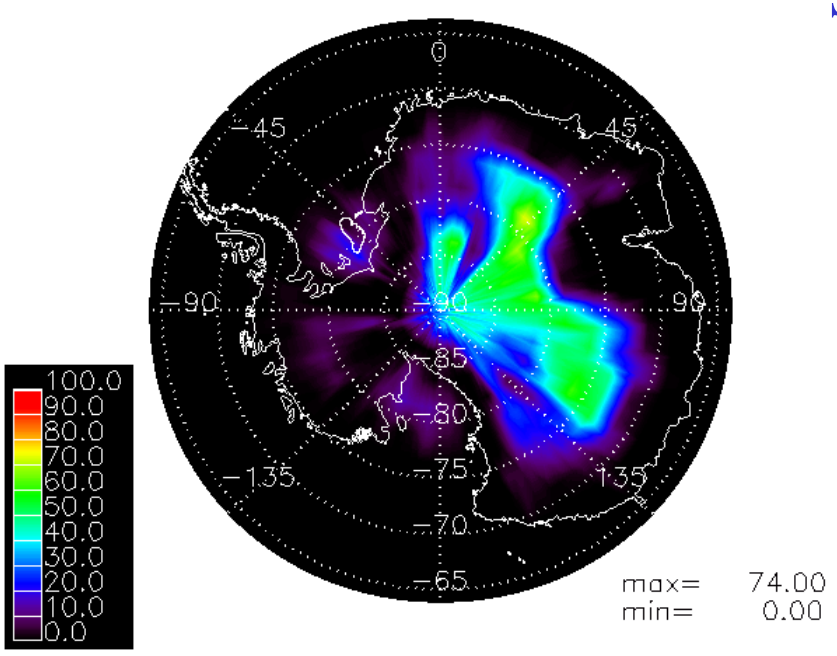
Jul



Aug

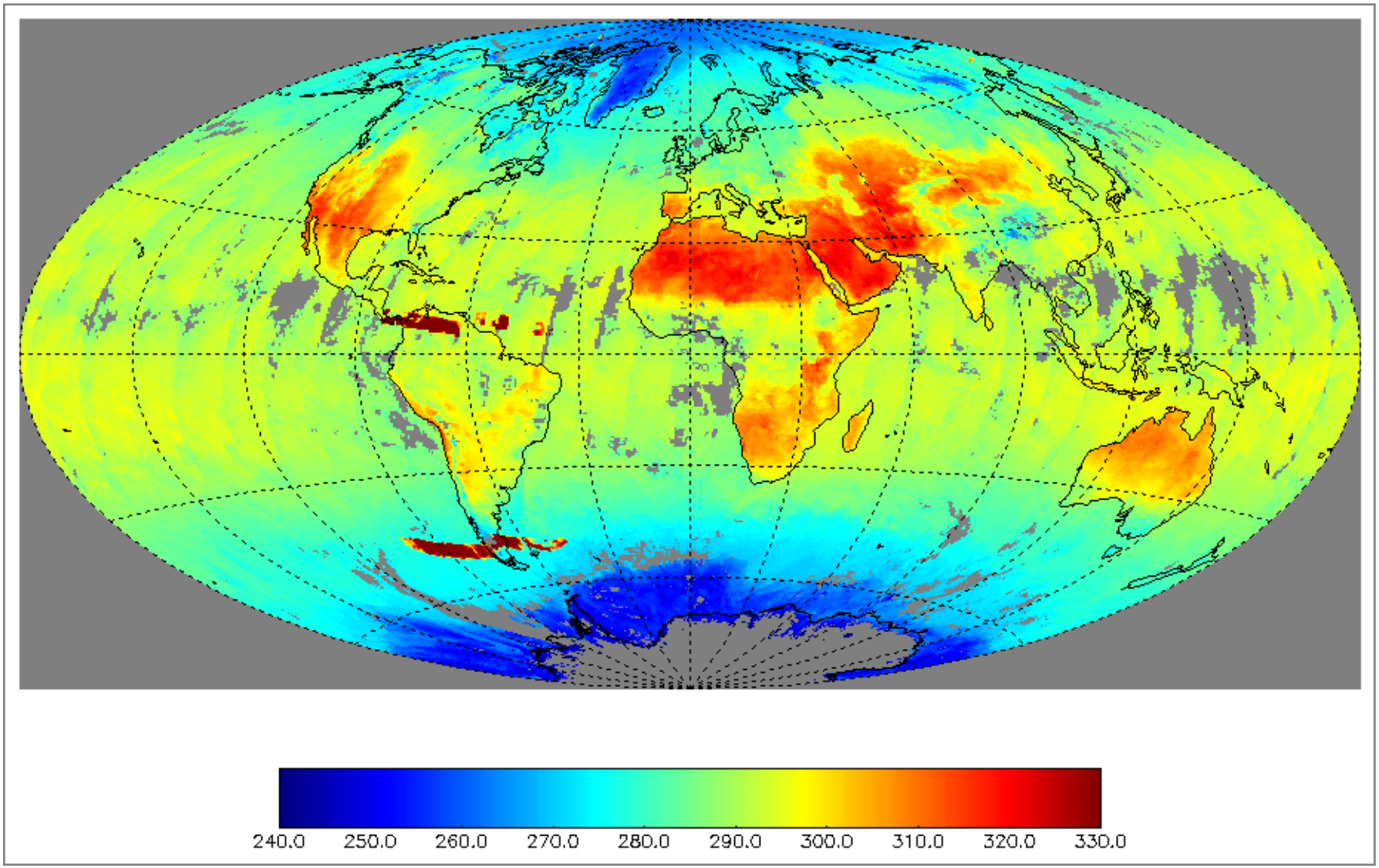


Sep



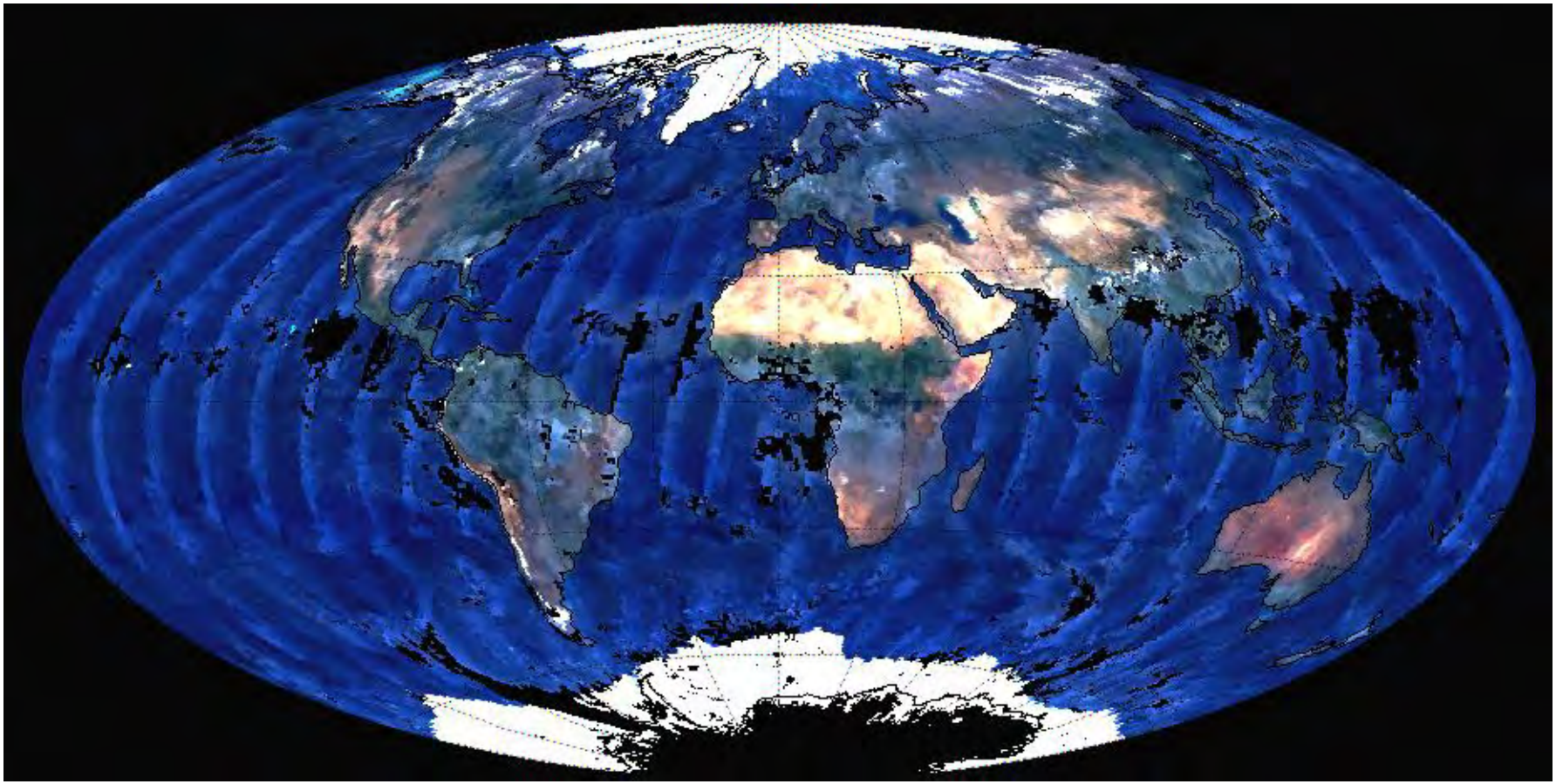
MODIS 5-8 September 2000

Band 31 (11.0 μm) Daytime Clear sky Brightness Temperature



MODIS 5-8 September 2000

Band 1, 4, 3 (R/G/B) Daytime Clear sky Reflectance Composite



Cloud Shadow Detection

Bryan Baum , Denis Grlujsich, Paul Menzel,
Steve Ackerman

Goal:

To use clear-sky reflectance maps to help filter clear-sky pixels that contain cloud shadows

Note: Not trying to detect cloud shadows on clouds

Approach:

Comparison of measured to clear-sky weekly composite reflectances at 1.6 μm

Data required:

- MOD021km and MOD03

- MOD35 - Cloud mask

- clear-sky weekly composite (25 km resolution, 8 bands, includes 1.6 μm)

Approach

From Level1B data:

- filter out water pixels (land-water mask in MOD03)
- filter out cloud pixels (cloud mask MOD35)

Clear-Sky Weekly Composite:

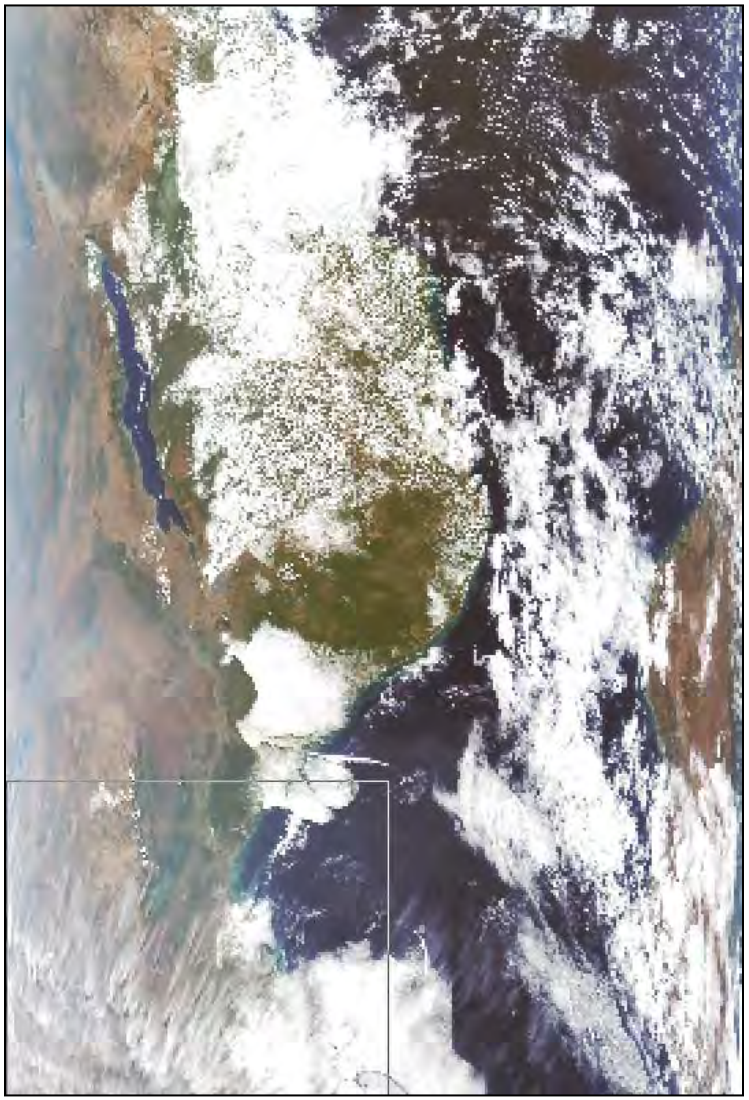
- creating subset of global 1.6 μm-daytime-reflectance composite map

Algorithm:

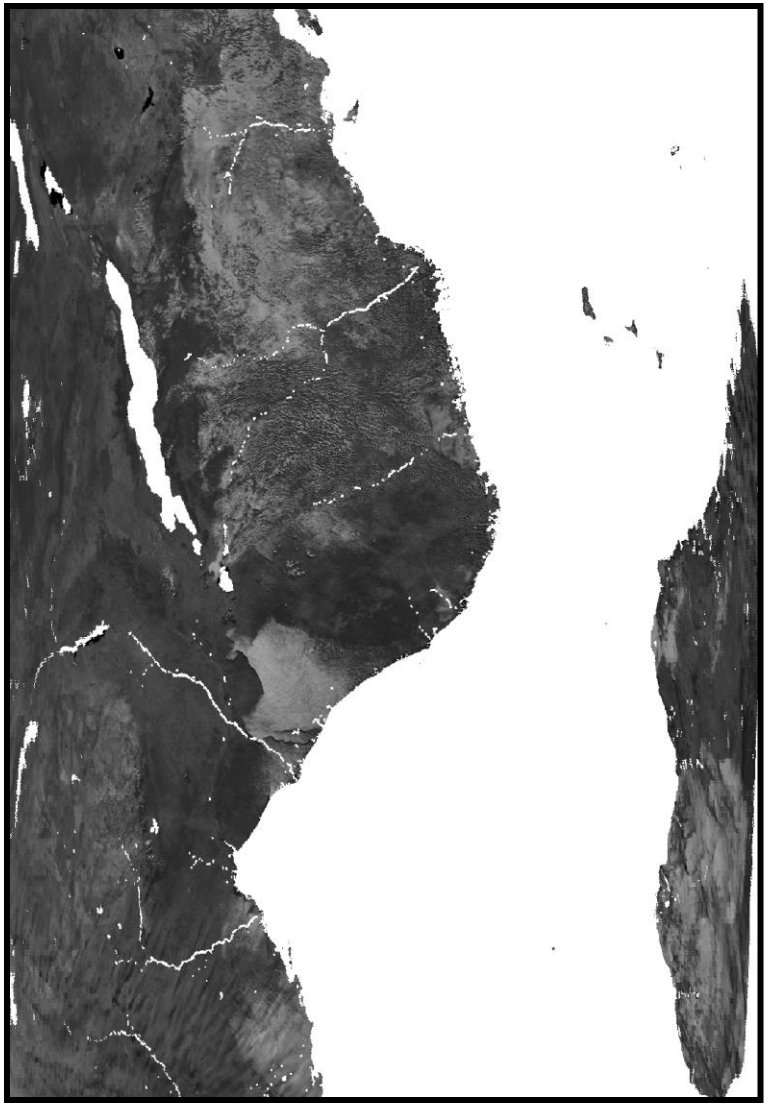
compare reflectance of clear-sky image and level1B image

set threshold as percentage of clear-sky value (e.g. 80%)

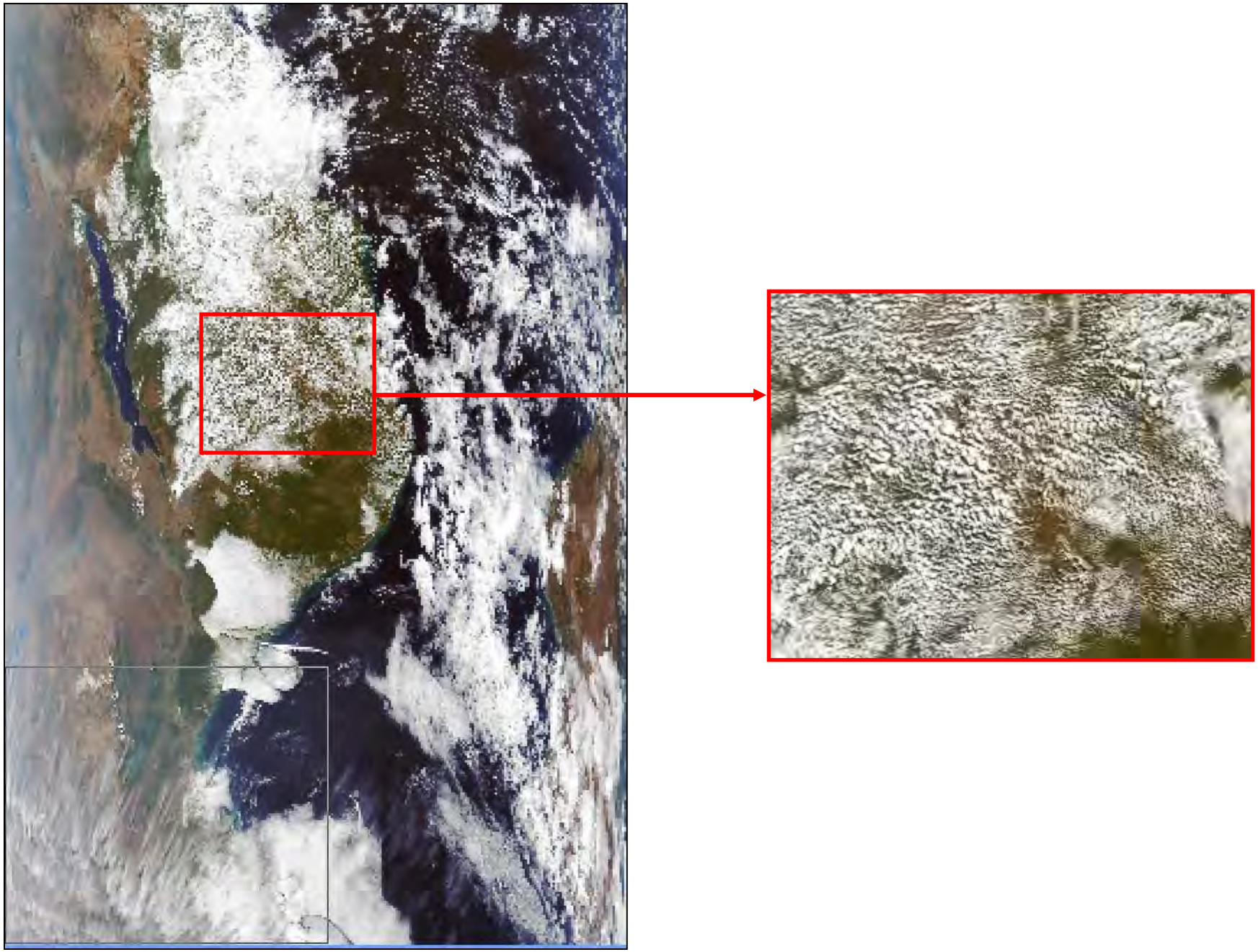
pixels with values lower than the threshold are flagged as shadow pixels

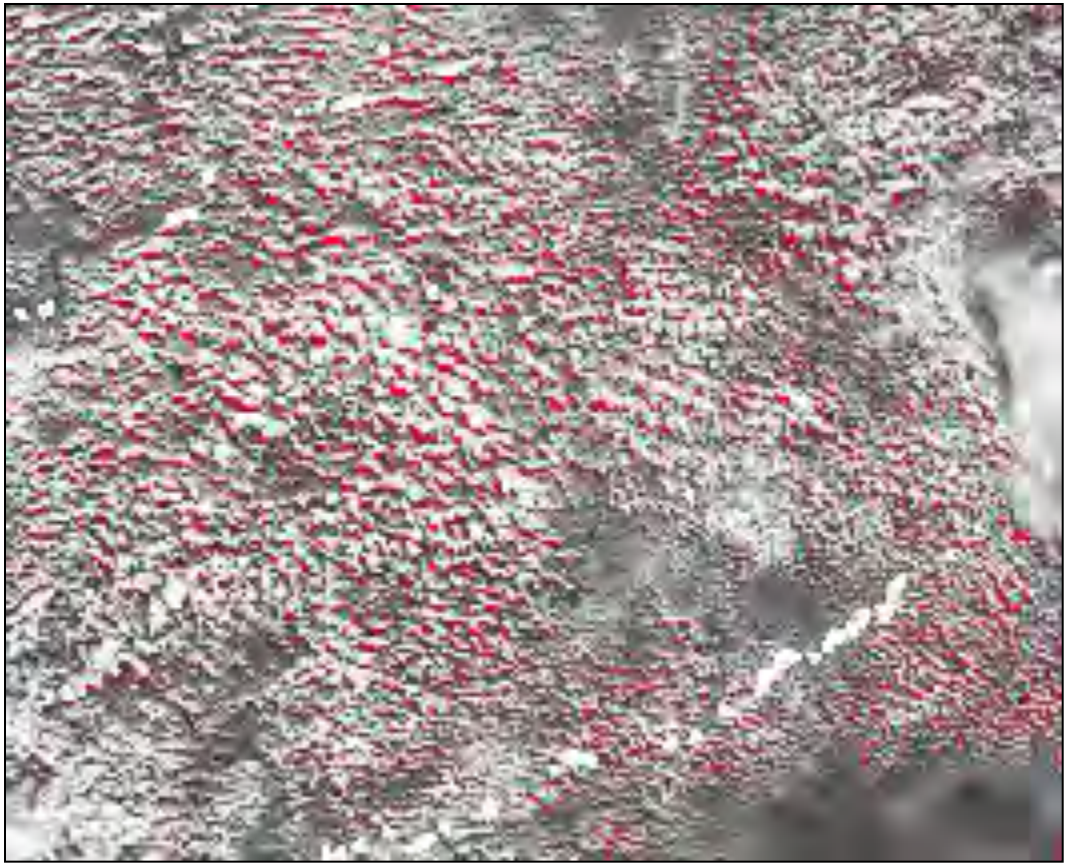


MODIS-RGB-Composite of Eastern Africa
(29 June2002, 07:45 UTC)

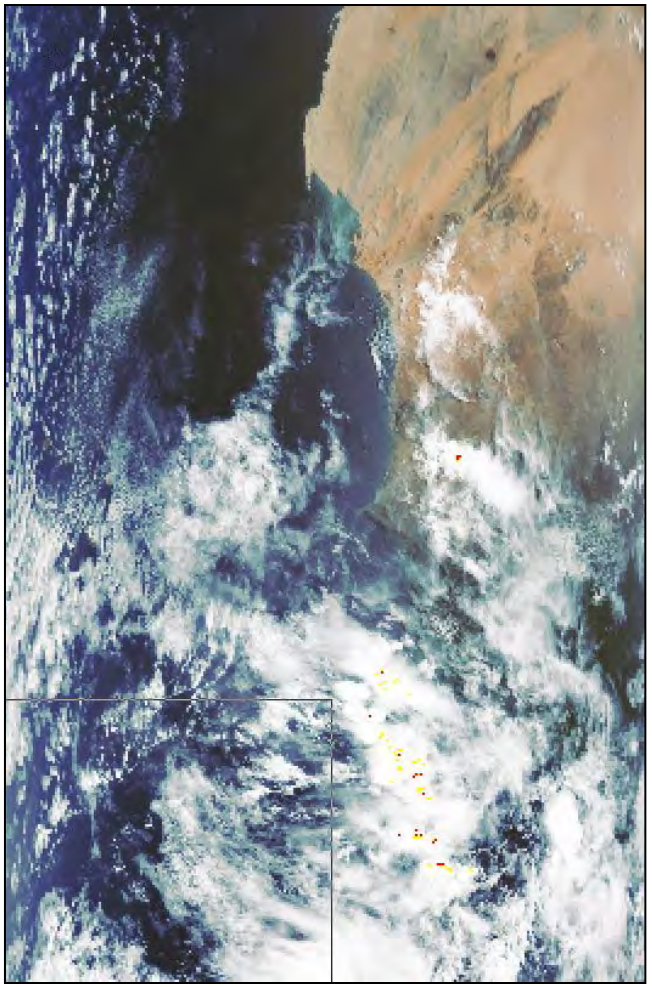


1.6-μm reflectance with water pixels filtered out of image

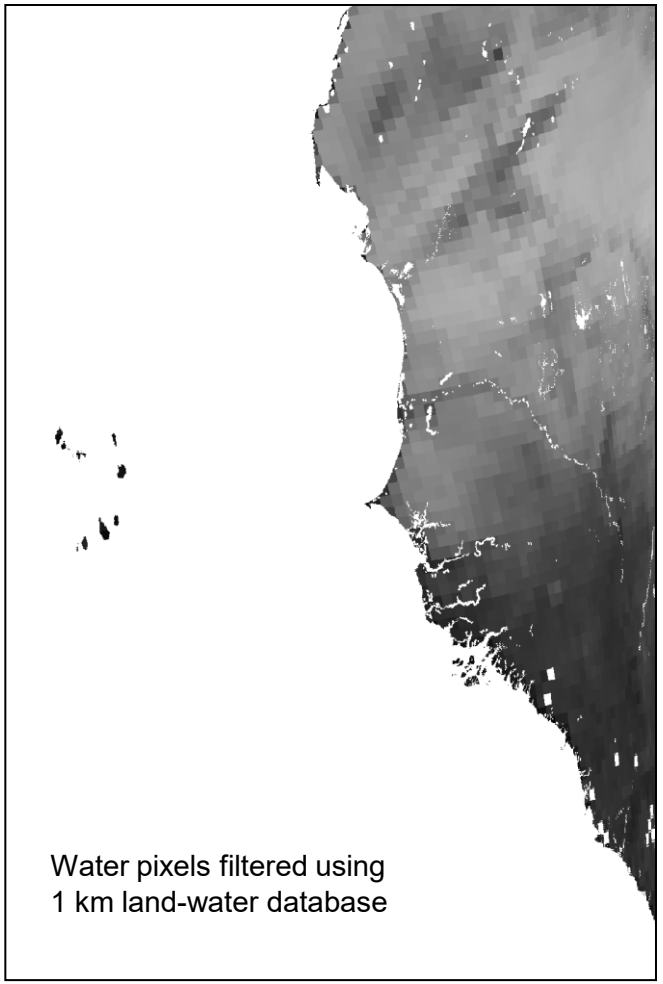




Study area: West Africa

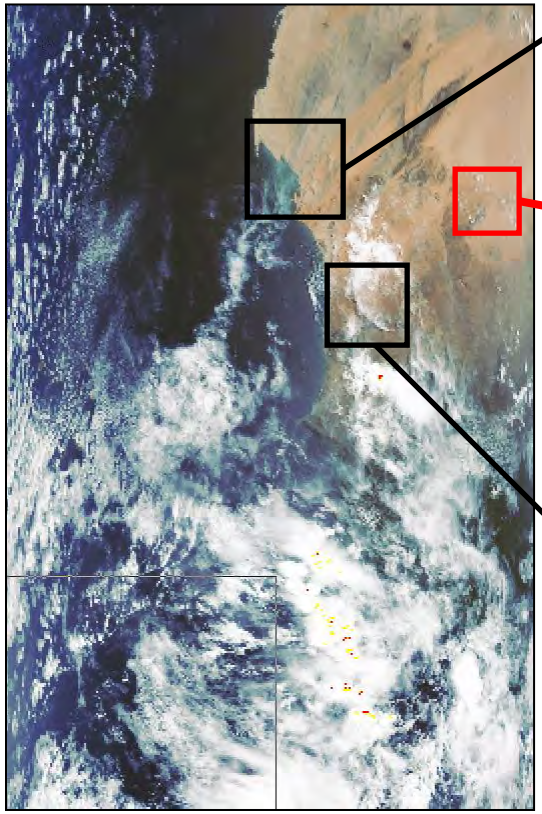


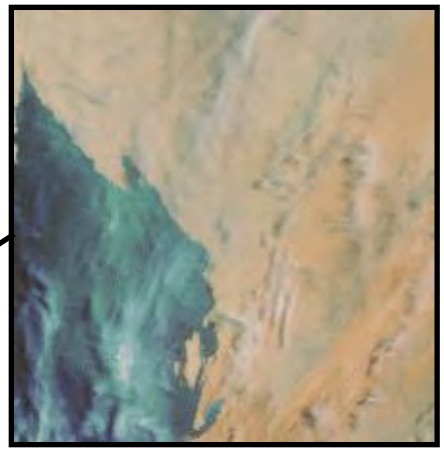
MODIS-RGB-Composite of Western Africa
(28 June2002, 11:50 UTC)

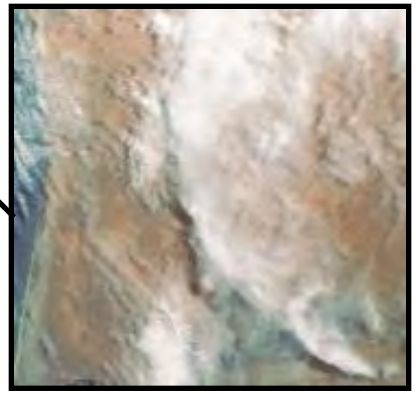


Clear-Sky Weekly Composite
(25 km resolution)

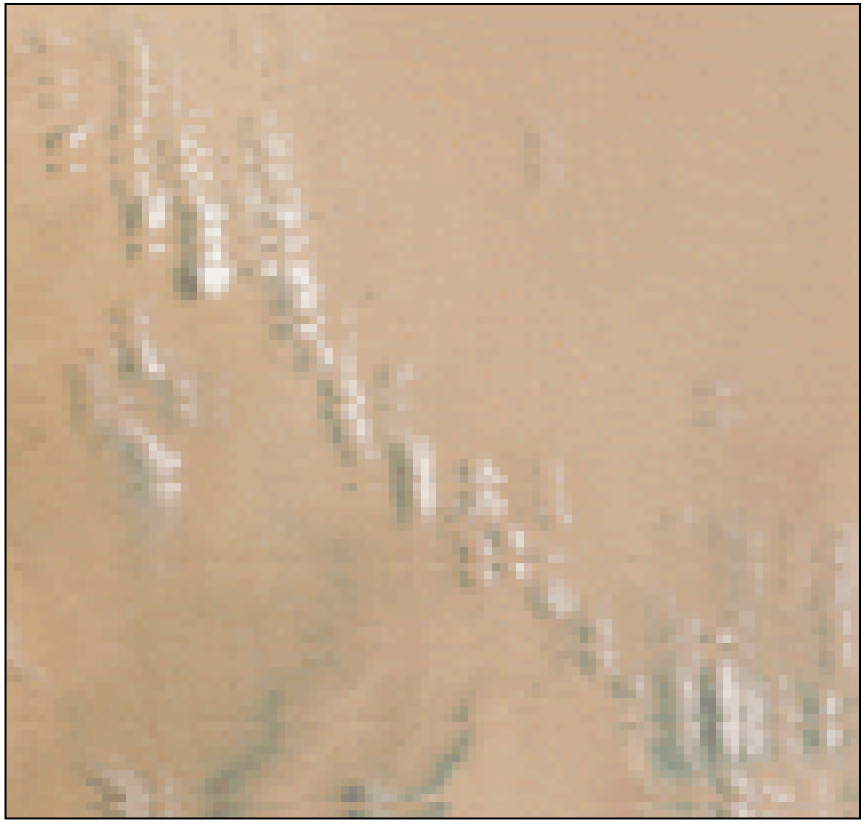
Location of example areas





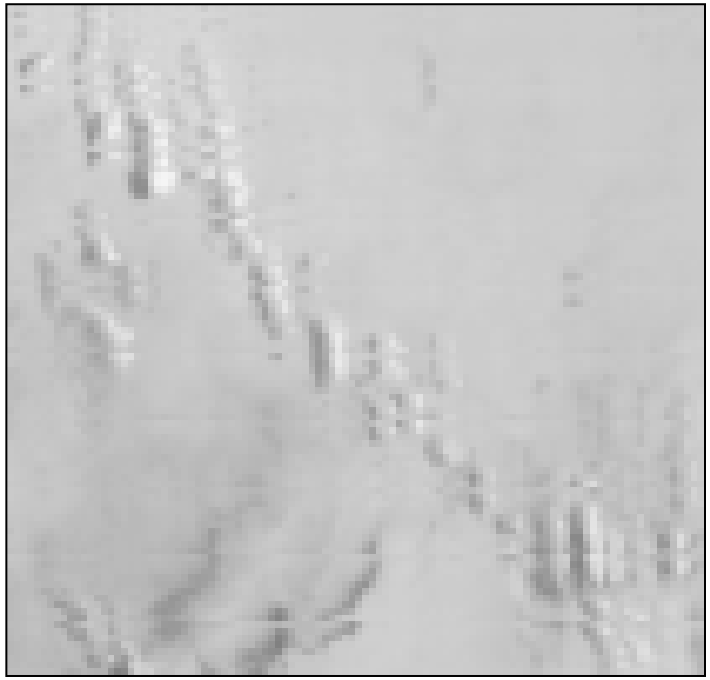


RGB-composite of area 1



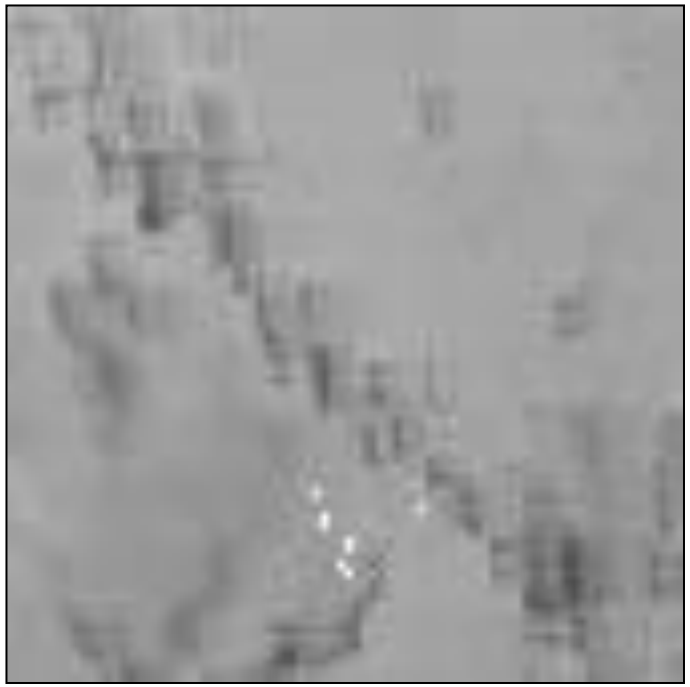
- Mauritania
- water clouds over desert
- surface has a very high reflectance
- little if any vegetation

0.65 μm-Reflectance



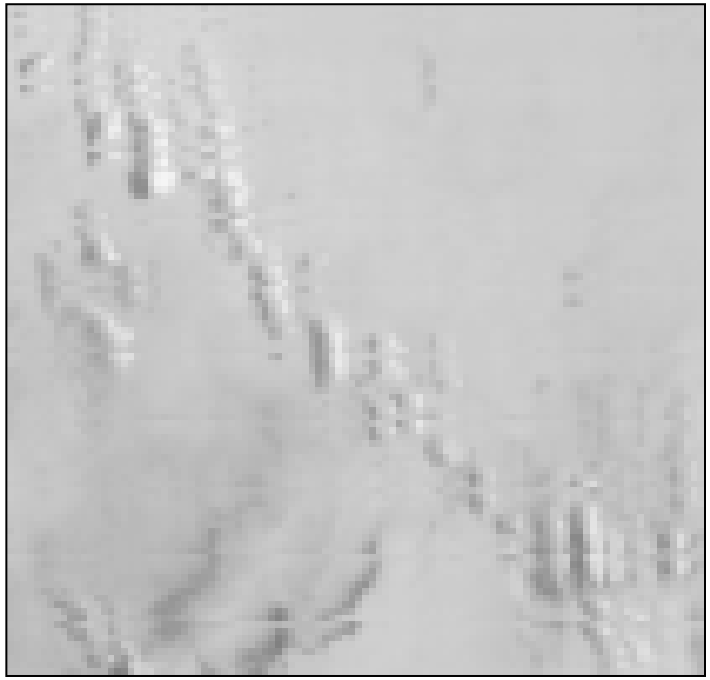
Clouds brighter than surface

1.6 μm-Reflectance

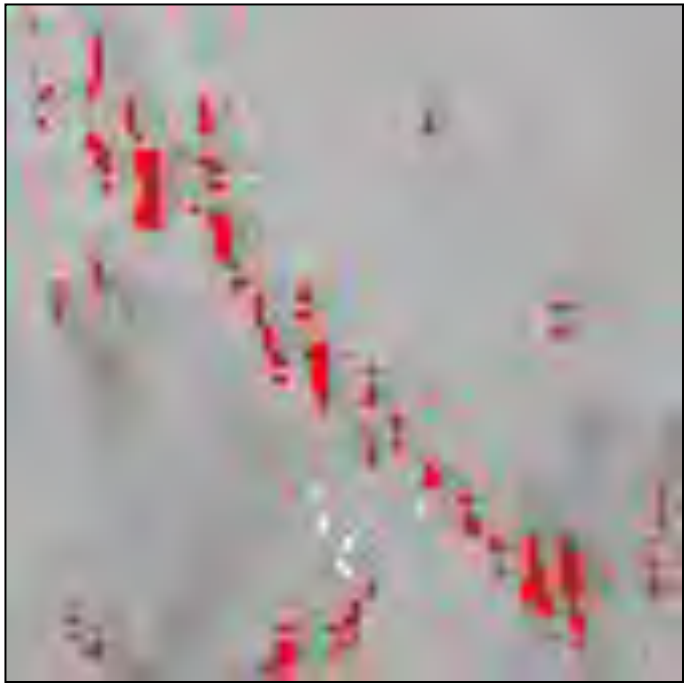


Surface brighter than clouds

0.65 μm-Reflectance

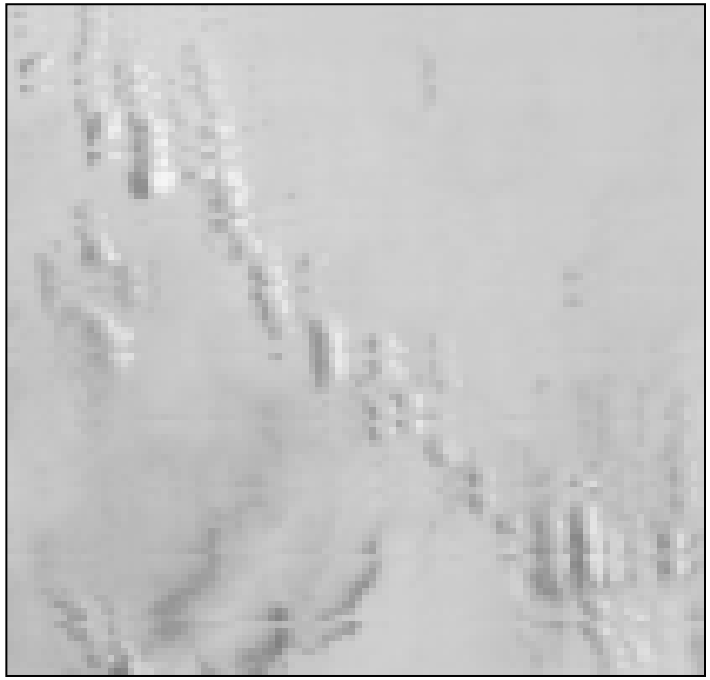


Shadow detection

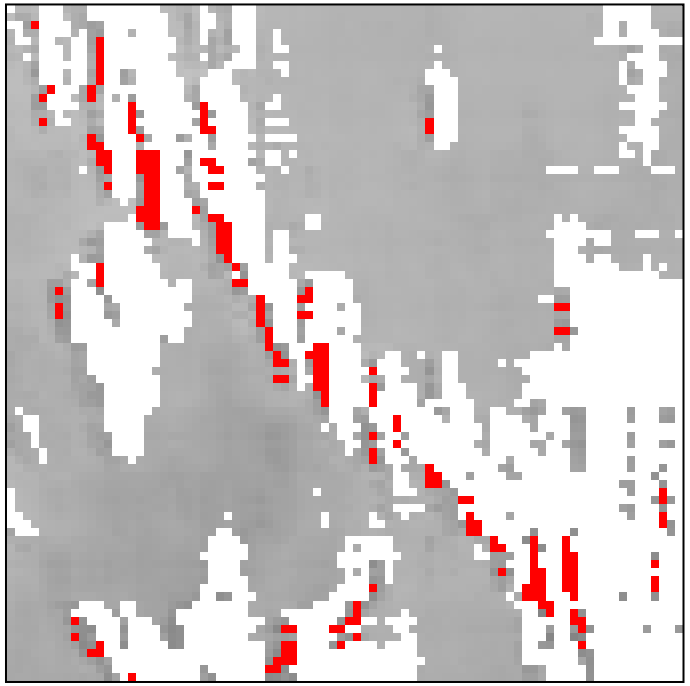


Shadows are red

0.65 μm-Reflectance

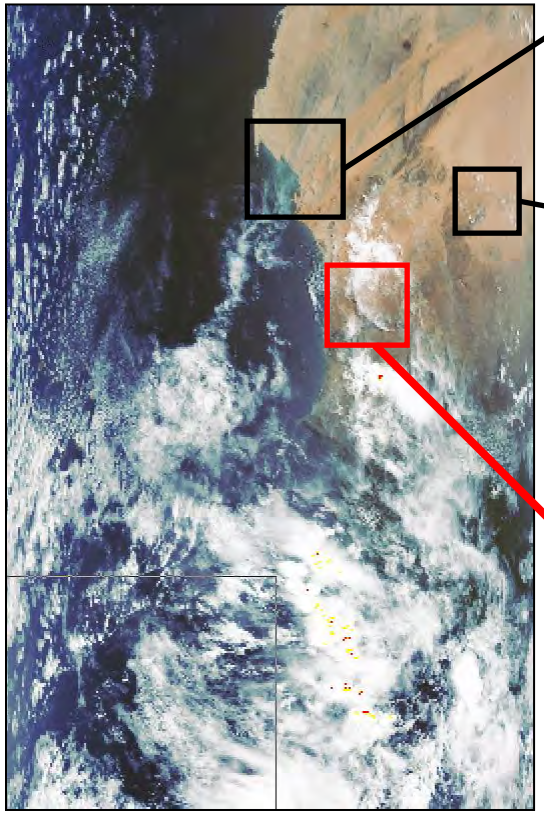


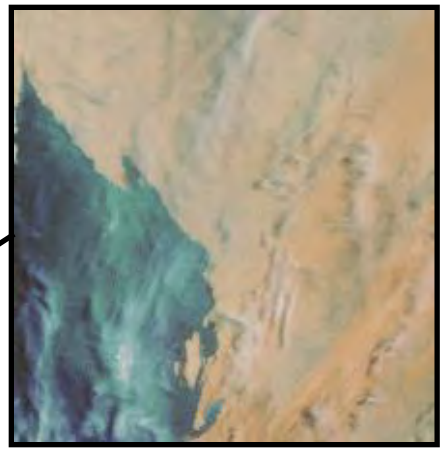
Shadow detection
(combined with cloud mask)

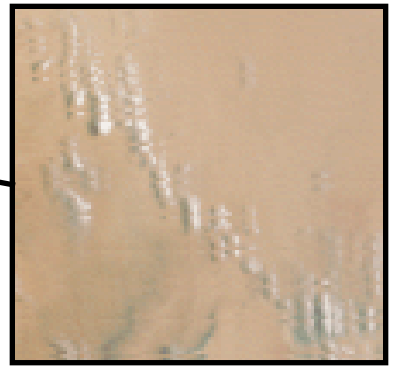


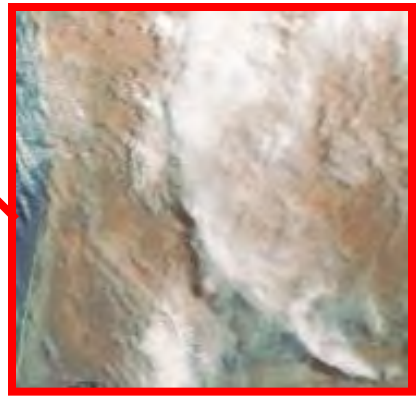
Shadows adjacent to clouds

Location of example areas

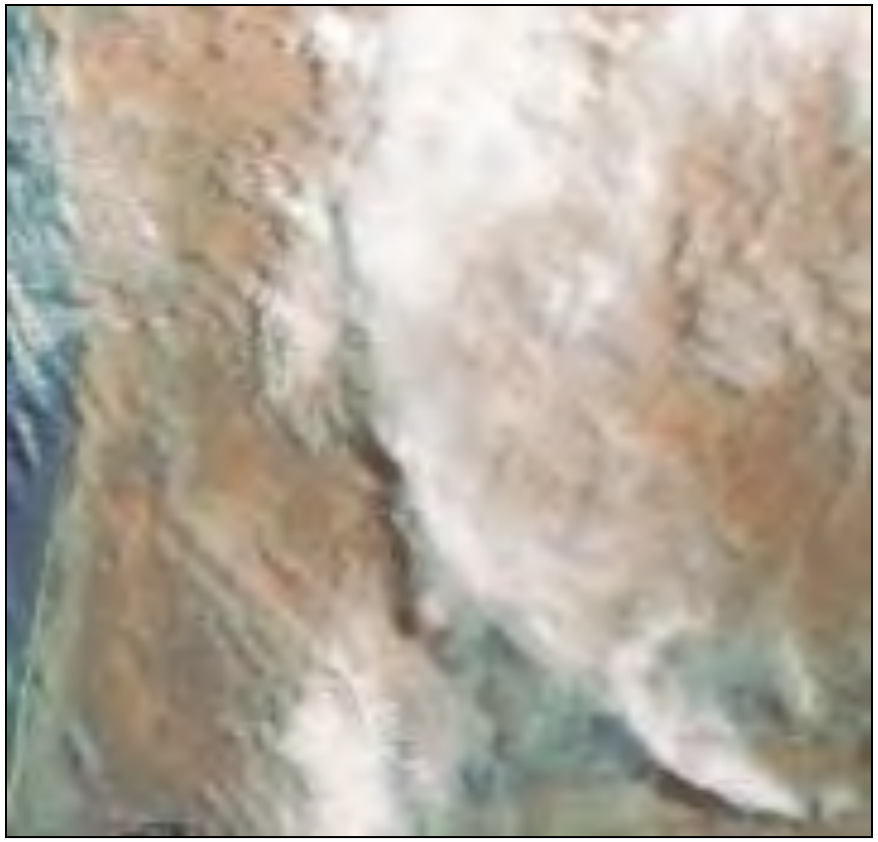






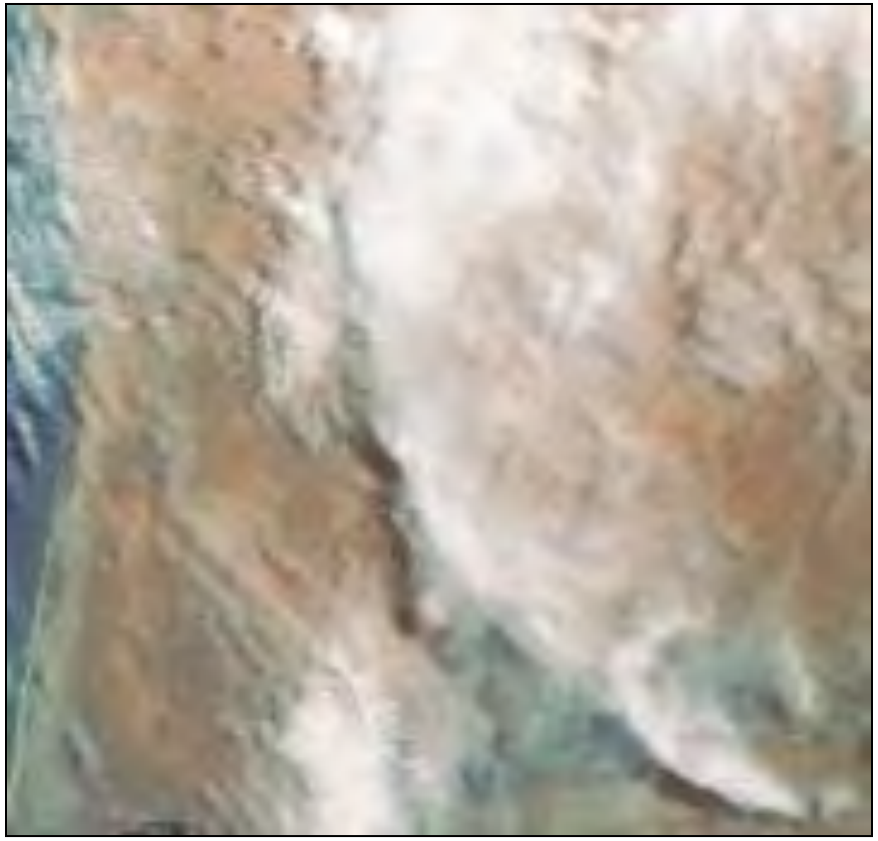


RGB-composite of area 2

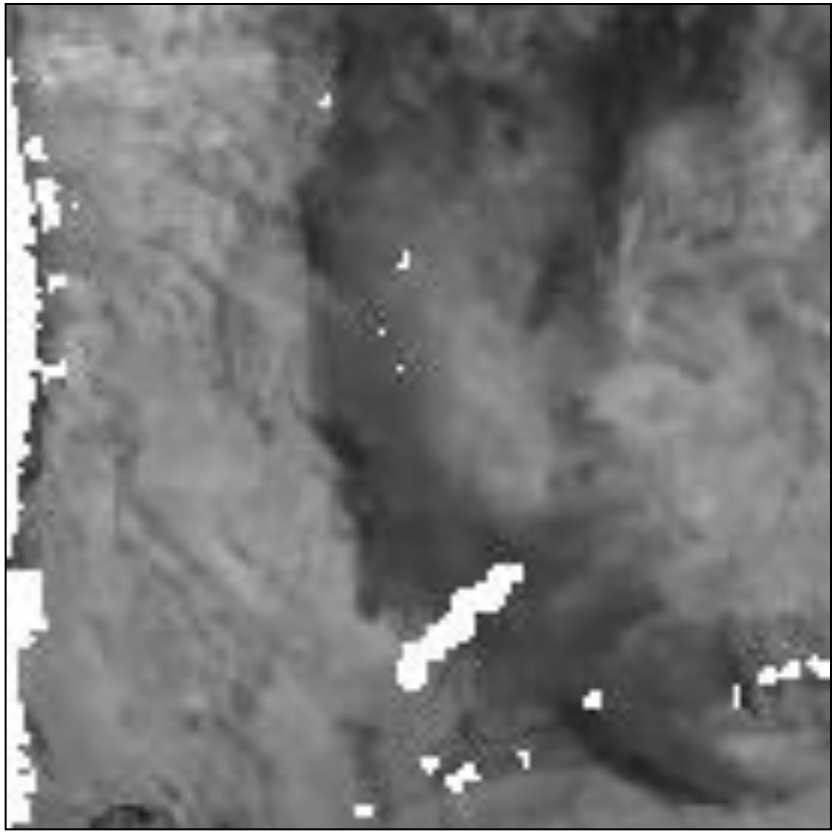


- Mauritania - Senegal
- desert-like area
- crossed by Senegal river
- mainly ice clouds

RGB - Composite

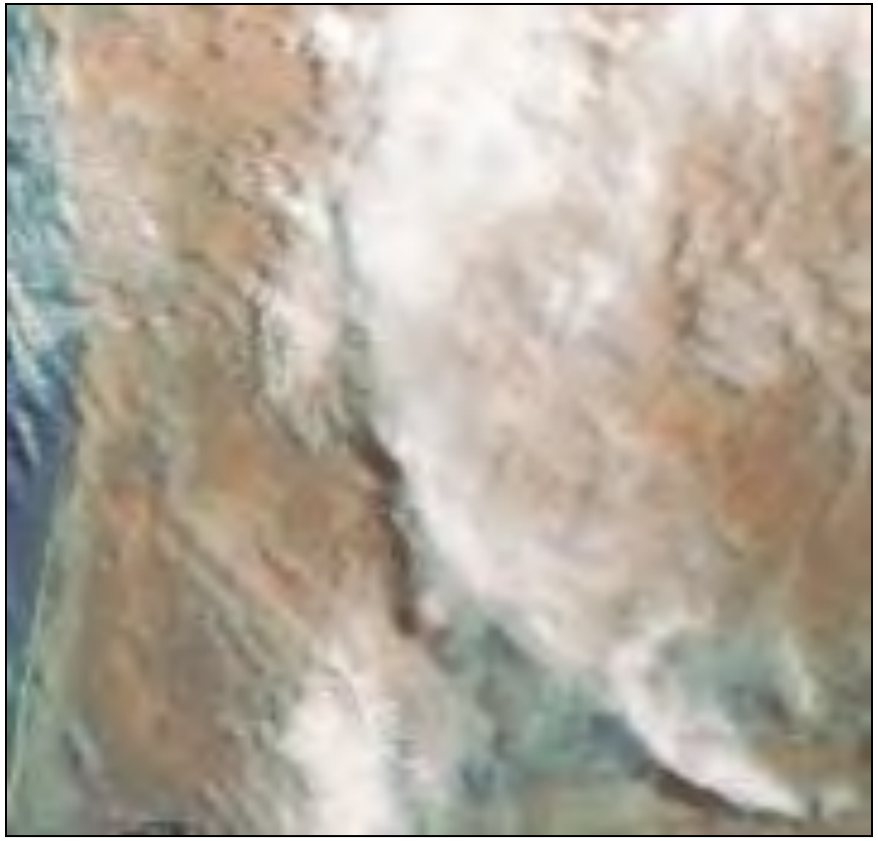


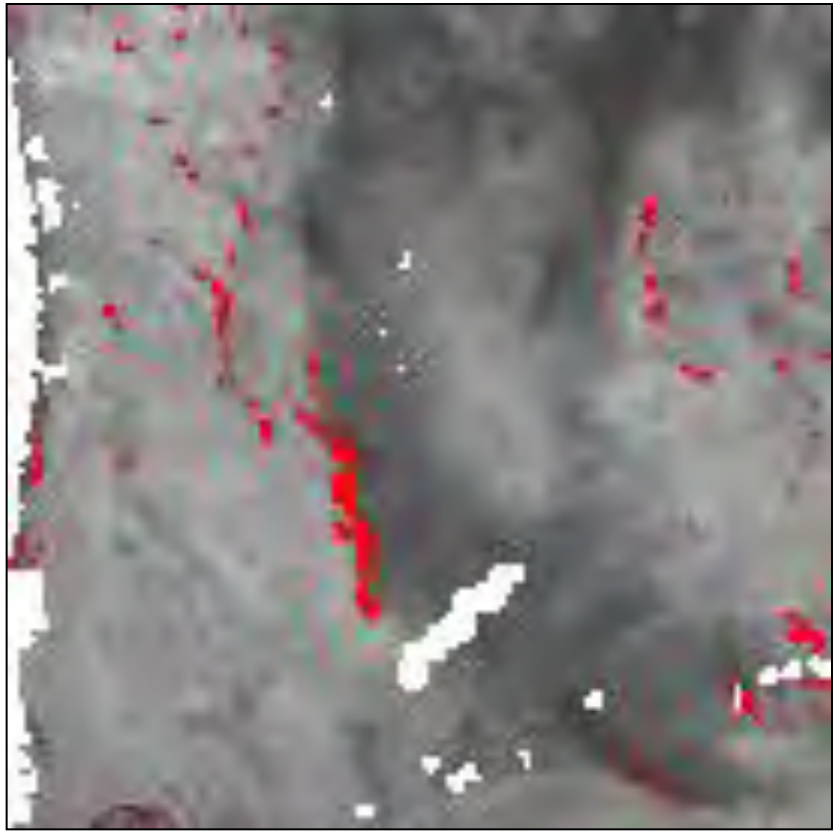
1.6 μm-Reflectance



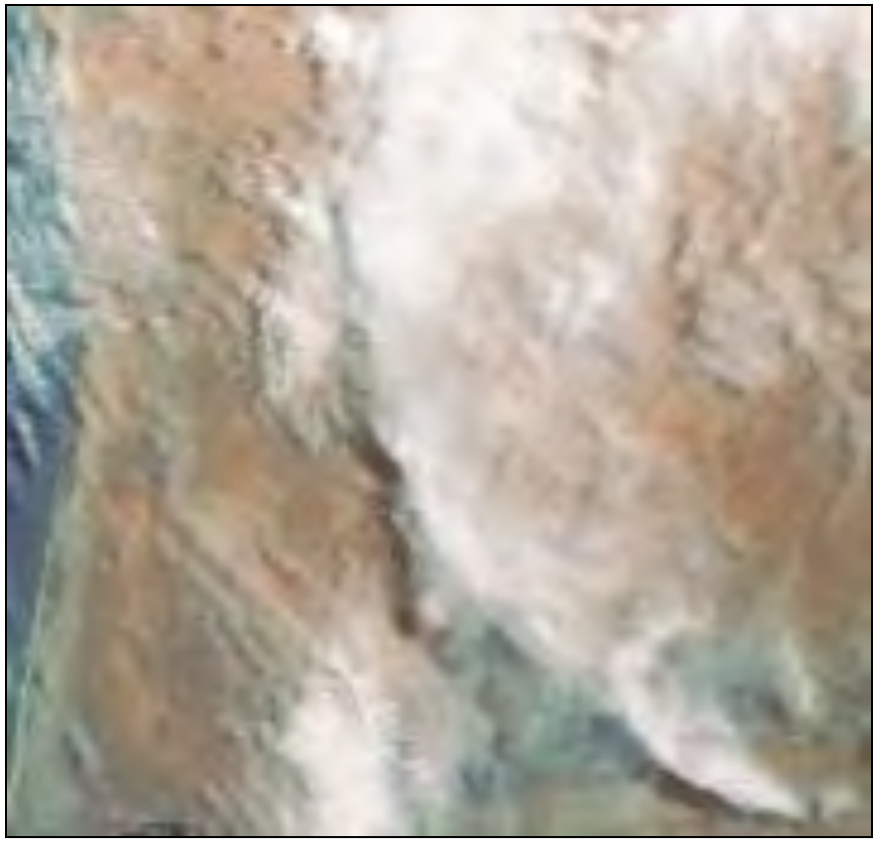
- shadows on eastern edge
- Senegal river not well detected by land-water mask

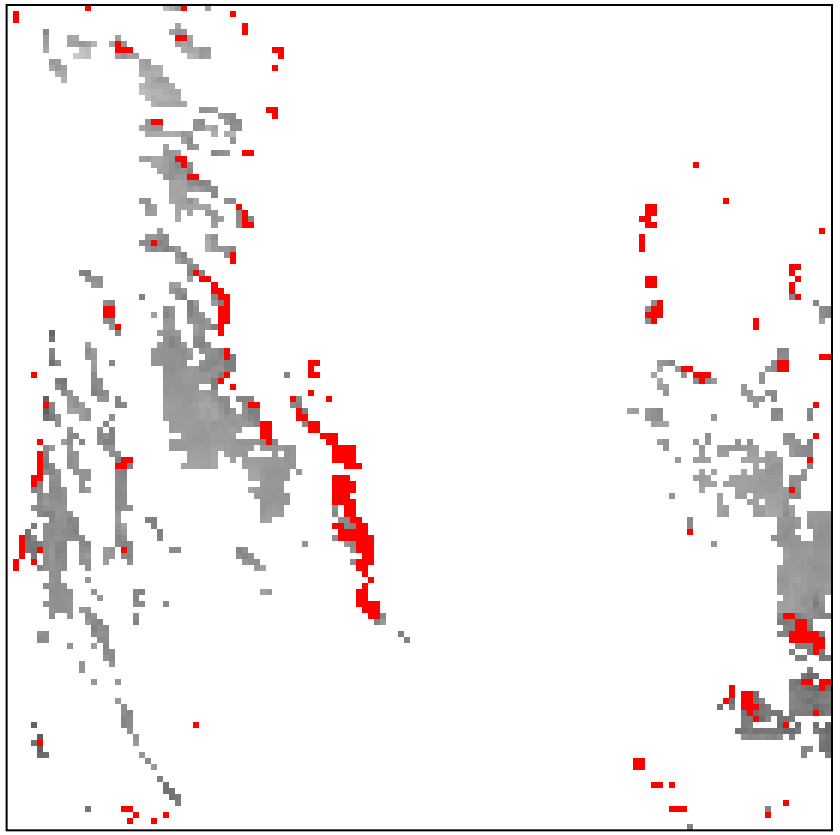
Shadow detection





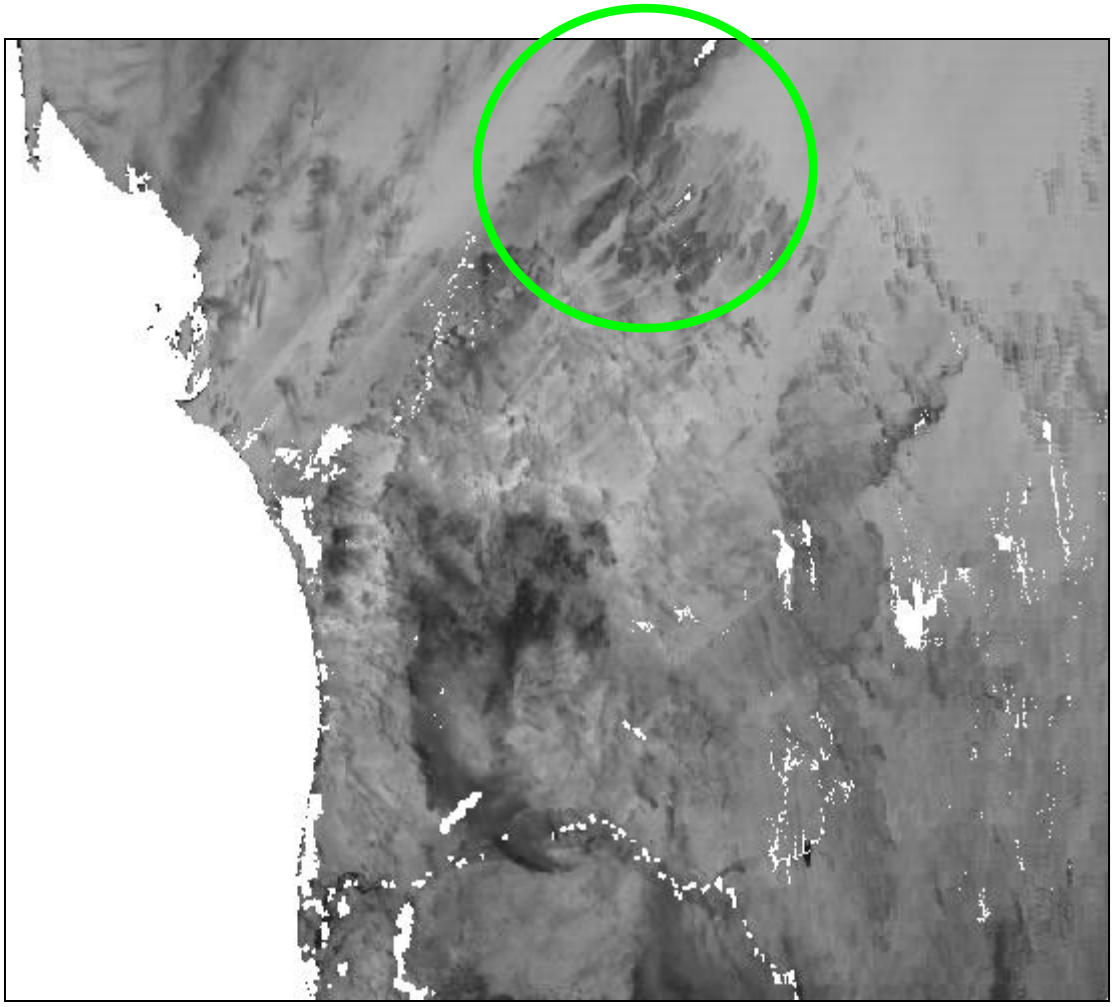
Shadow detection
(combined with cloud mask)





not detected shadows are often
already detected as cloud

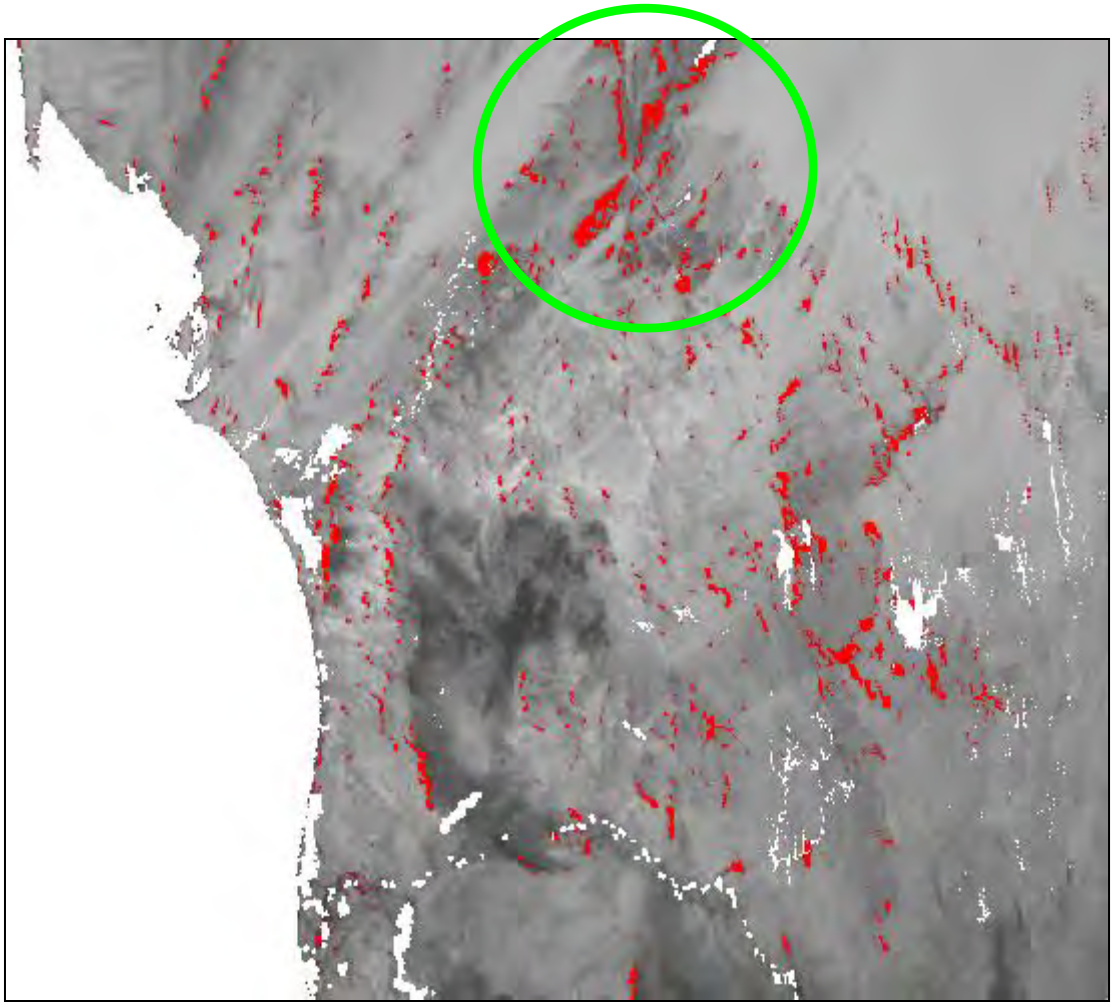
1.6 μm-Reflectance overview



high diversity of soil types in the north (diverse reflectance)

1.6 μm-Reflectance overview

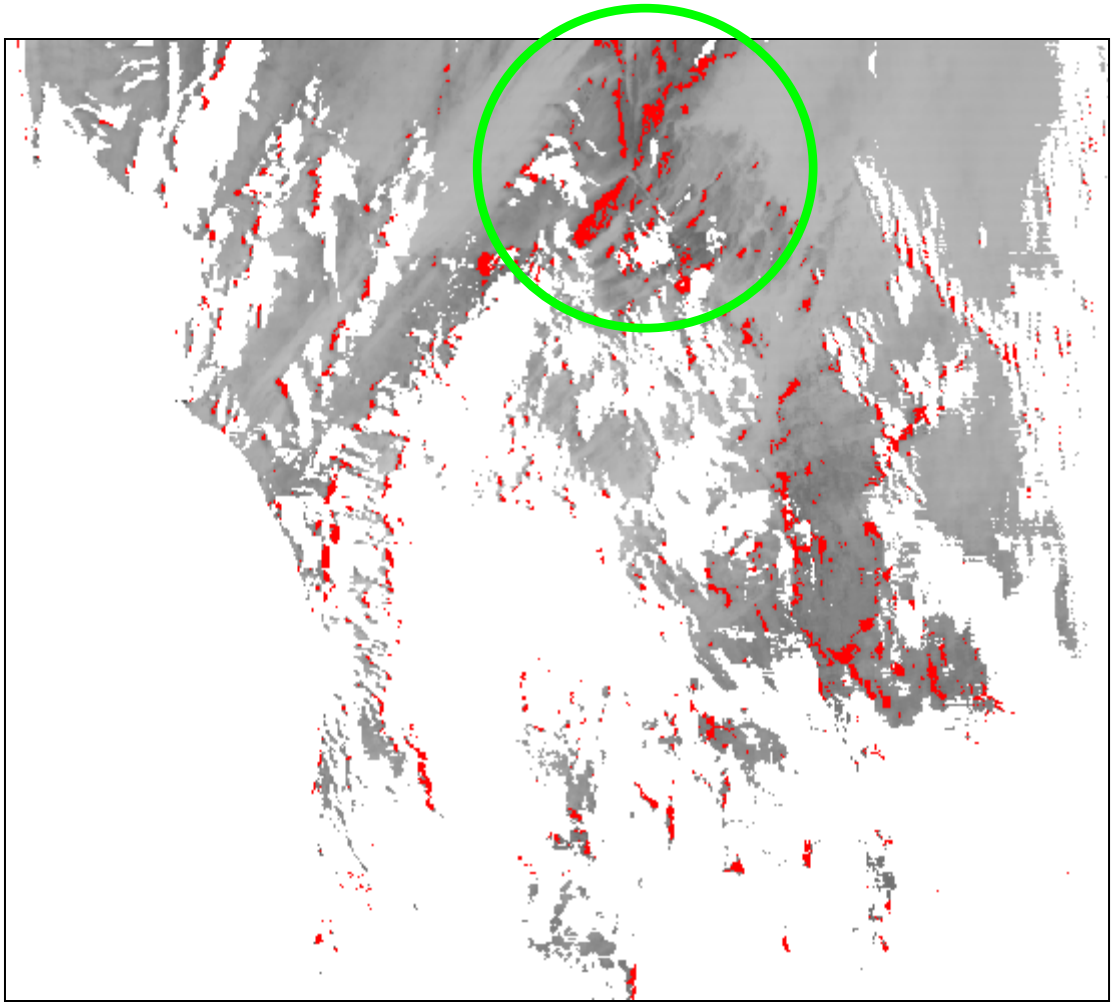
including detected “cloud shadows”



darker parts detected as shadows

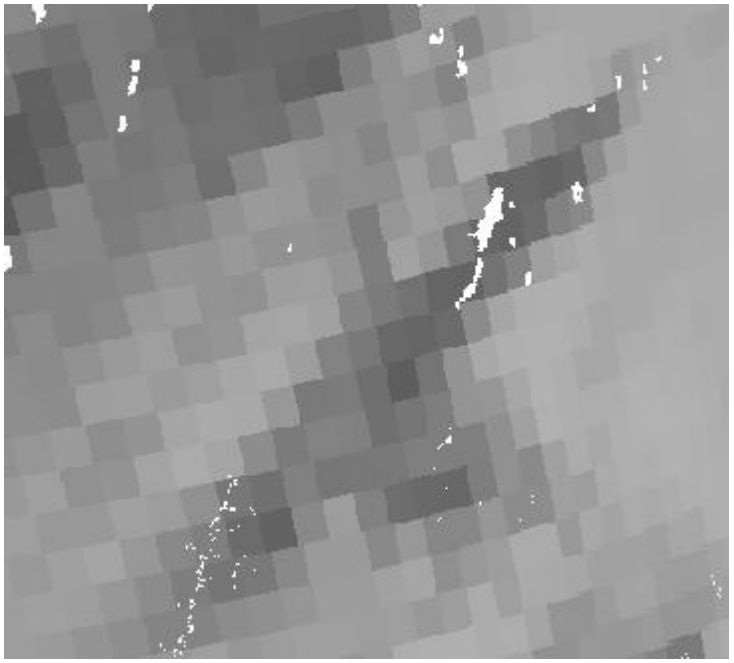
1.6 μm-Reflectance overview

including falsely detected cloud shadows and cloud mask

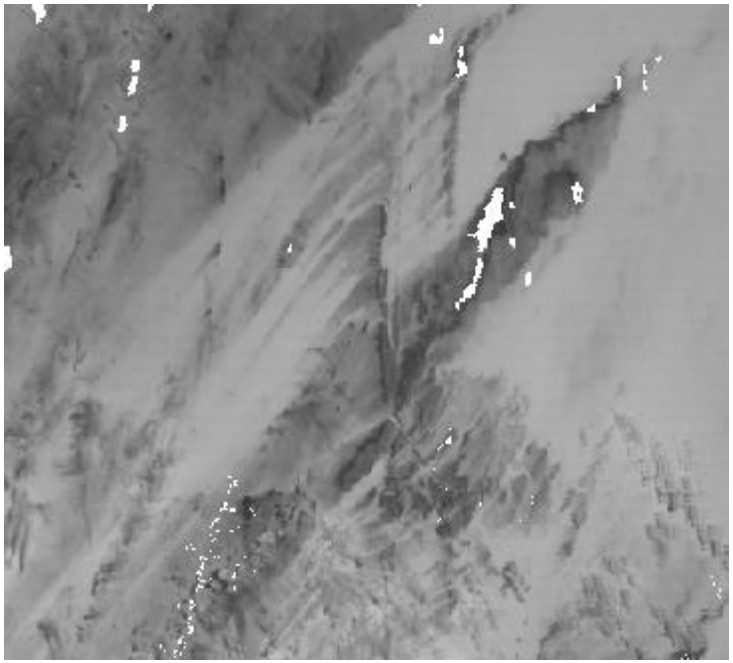


Cloud mask indicates that shadows are falsely detected
(possibly because of coarse resolution of clear-sky reflectance map)

Spatial resolution problem

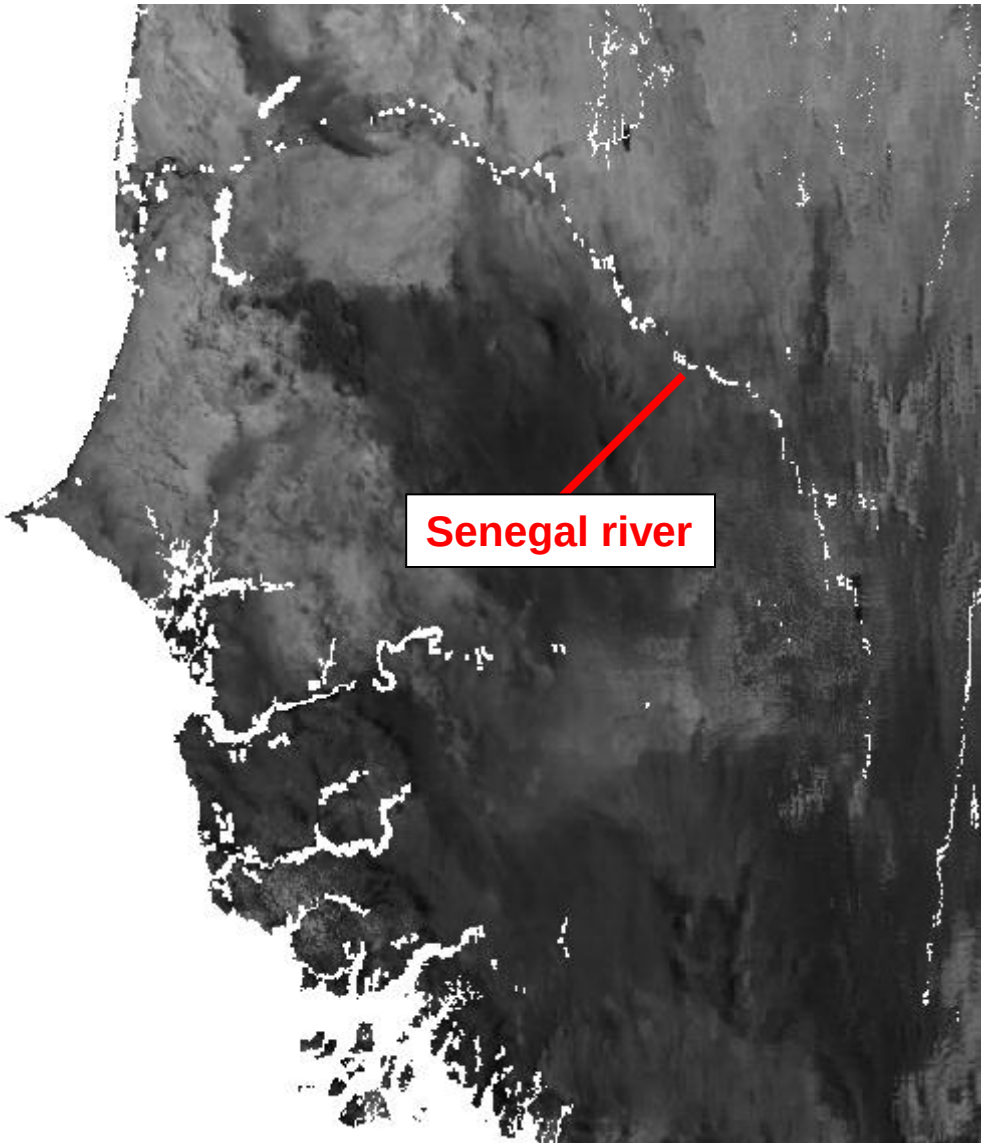


25 km - resolution
Clear-sky map



1 km - resolution
MOD021km (1.6 μm)

Land-water mask



Conclusion

Initial attempt to detect cloud shadows by comparing images with clear-sky composites is encouraging

Suggested improvements

- shadows should be next to clouds
- improve spatial resolution of clear-sky reflectance map
- can we find a higher resolution land/water mask?
- might improve detection of nondetected cloud shadows by checking nearest-neighbor pixels and relaxing threshold criteria

Problems:

- spatial resolution of clear-sky map
- setting threshold
- land-water mask
- cloud mask

Suggested improvements

- shadows should be next to clouds
- finding missing cloud shadows by pixel walking

Preliminary indications

- seems that threshold could be set by use of histograms
- in this example it could be set higher than 0.8
- but... the share of false shadows might be higher
- would help to have a clear-sky map with higher spatial resolution