Cloud Identification

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In this lecture:

- Spectral features of clouds in the visible and infrared
- Algorithms to identify clouds in polar-orbiting satellites imagery
- Cloud identification with geostationary satellites

Cloud Identification: Facts

- Clouds are mostly opaque in visible and IR, but can also be semitransparent
- For land surface and ocean studies with satellite data clouds in the satellite imagery should be properly identified and masked out
- Missed clouds cause errors when land/ocean properties are derived

Cloud detection and mapping techniques

- For occasional image analysis: Interactive, supervised
- For routine satellite monitoring: Automated (unsupervised) algorithms

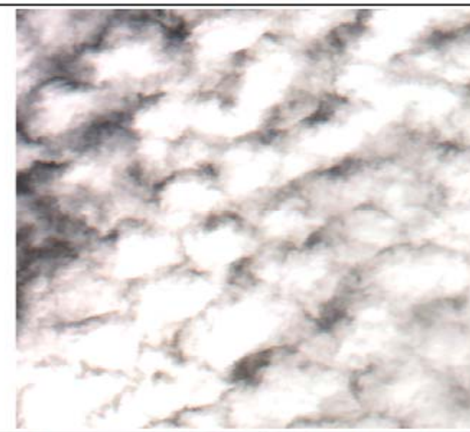
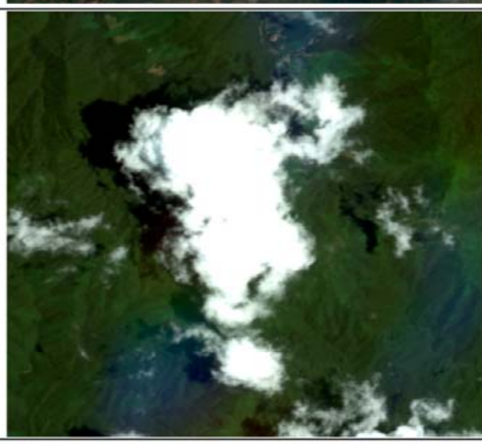
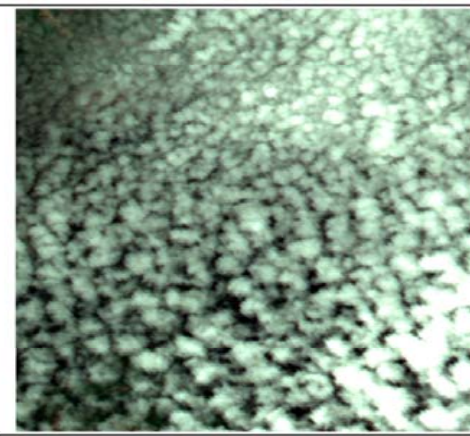
Interactive vs Automative Cloud Identification

Interactive : Clouds are identified by specific spatial patterns seen in the visible and infrared imagery and by associated brightness contrasts. 3-band false color images can be used .

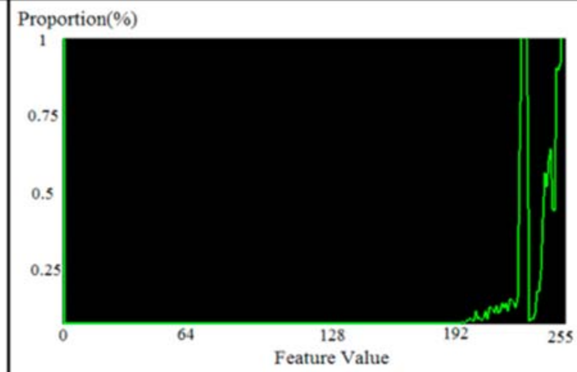
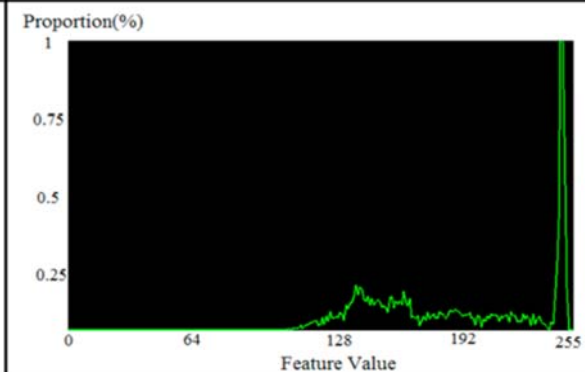
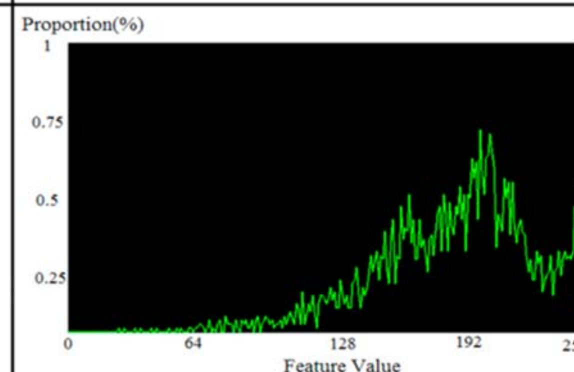
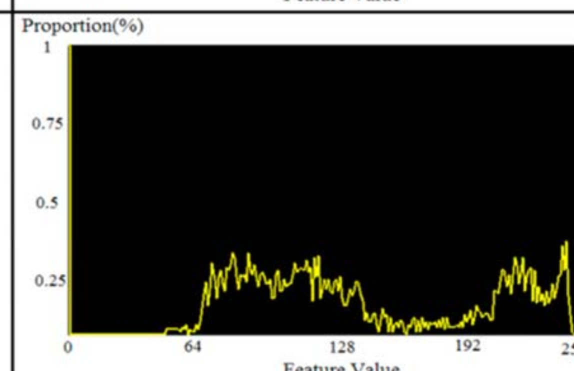
Automated:

- Typically process imagery pixel-by-pixel
- Identify clouds based on pixel temperature or reflectance
- May involve data in several spectral bands
- May examine small-scale spatial variability (2x2, 3x3, 5x5 pixel blocks)
- May examine temporal variability of pixel response (geostationary)
- May utilize auxiliary data to improve cloud identification
  - Background reflectance of land surface (from previous obs.)
  - Land or ocean surface temperature (from models)

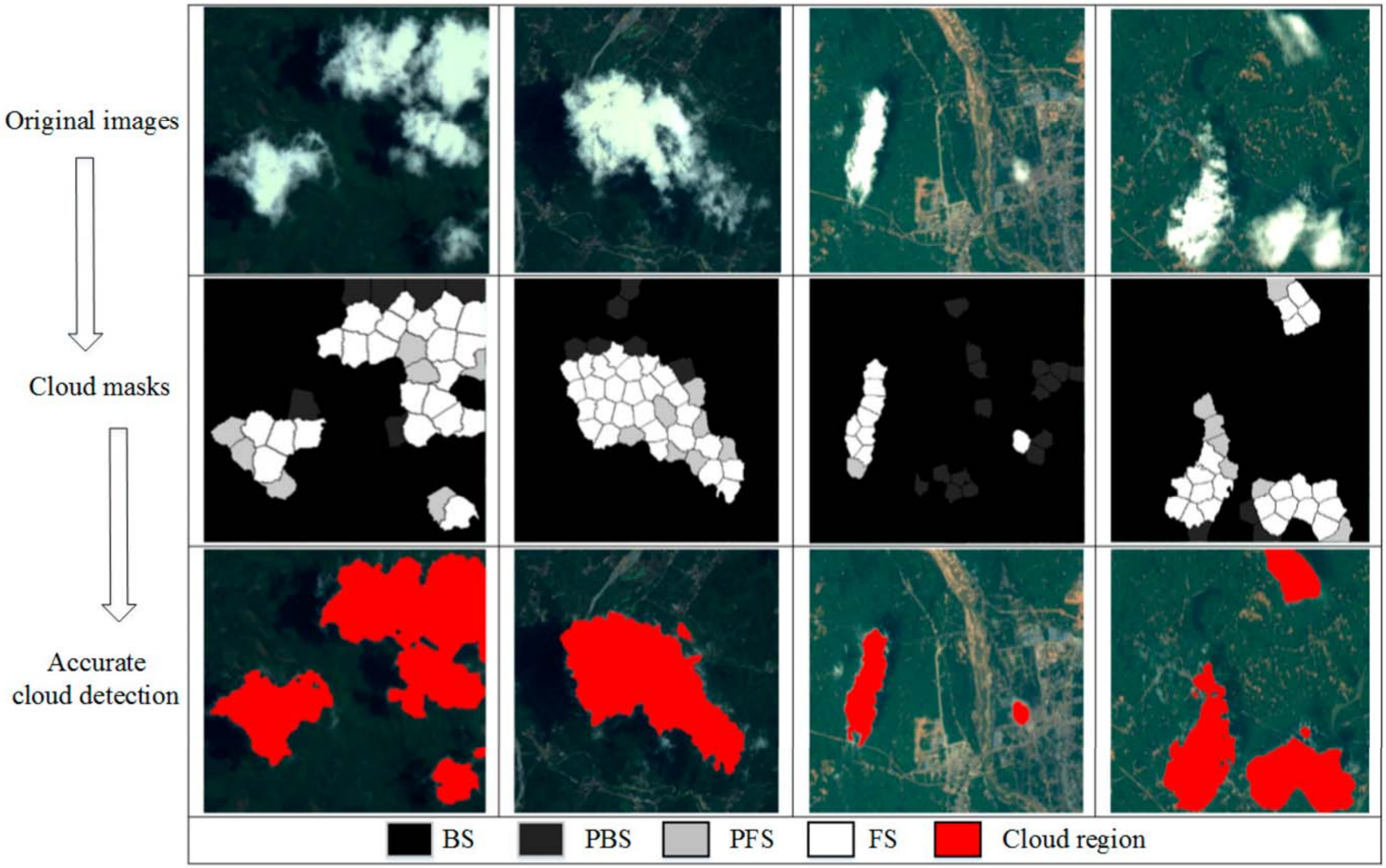
Graphic examples of the three types of clouds visually recognizable from remotely sensed data: thick cloud, thin cloud, Cirrus cloud.

Thick cloud	Thin cloud	Cirrus cloud
		
		
✧ Brightest ✧ Irregular ✧ Has little details	✧ Semitransparent ✧ Has little details ✧ Brighter	✧ Has more details ✧ Dark or bright ✧ Cluster

Four categories of superpixels and their feature histogram

Category Name	Sample	Feature Histogram
Thick cloud		
Thin cloud		
Cirrus cloud		
Others (red houses)		

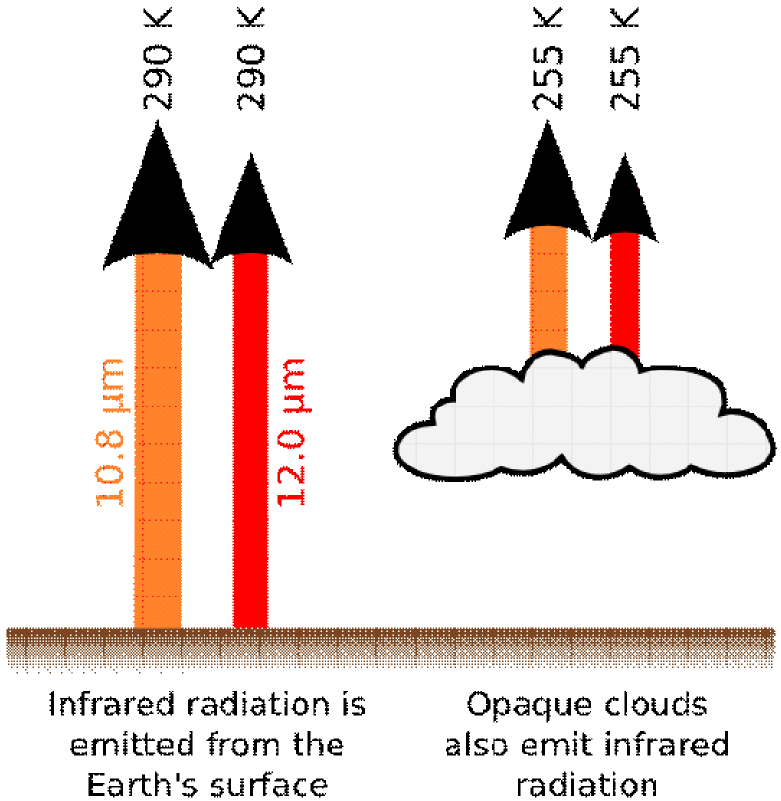
Could mask and detection



Automated Cloud Identification Algorithms:

Cloud features used to identify clouds in satellite imagery

Clouds are "Cold" in Thermal Infrared…



Clouds are usually colder than the land or ocean surface

Brightness temperature of clouds in thermal infrared is smaller than of the land surface

To decide whether cloud is within the sensor field of view <u>need to know (or estimate) the surface temperature</u>

Surface temperature can be estimated from

Numerical Weather Prediction (NWP) Models

- Climatology (statistics of past observations)
- General physics (e.g. water temperature is above 0C)
- From the same image
  - Warmest pixel within certain area adjacent to the pixel
  - Through the analysis of brightness temperature frequency histogram analysis
  - Area should not be large and should not be completely covered with clouds.

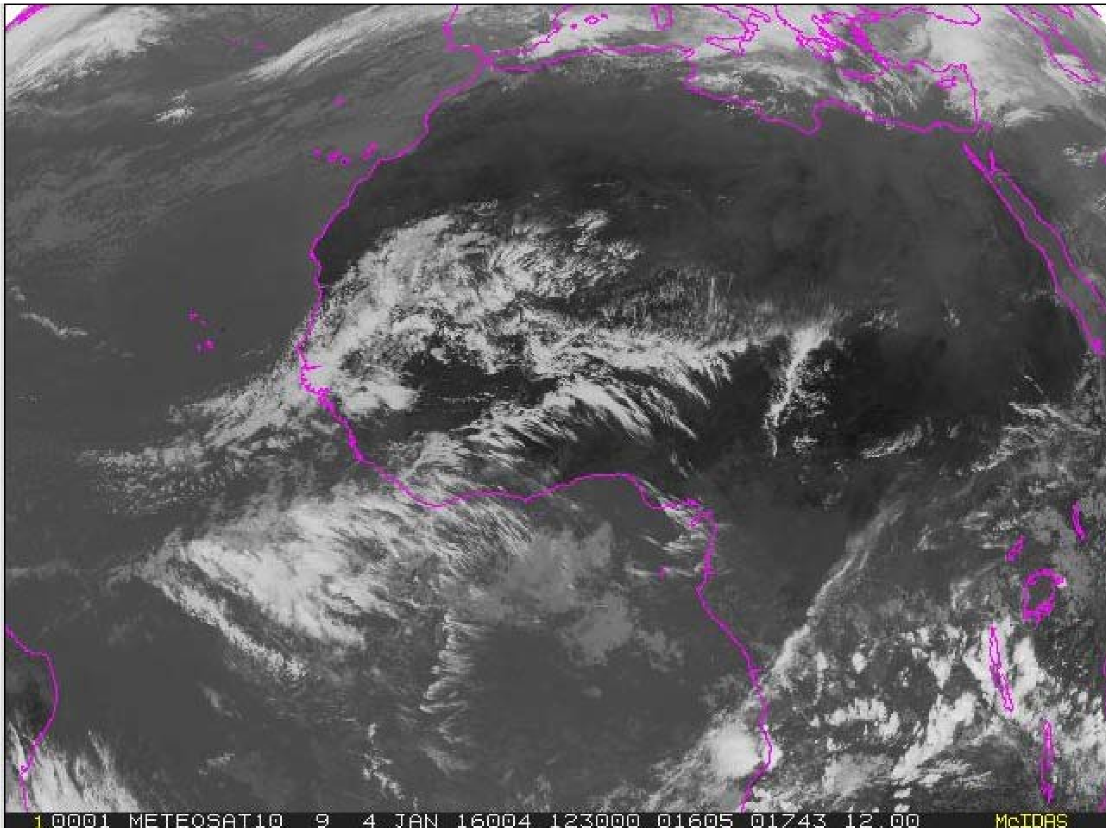
Typical thermal threshold test employed:

If ***Tb_land*** - ***Tb_observed*** > 20 K then cloud

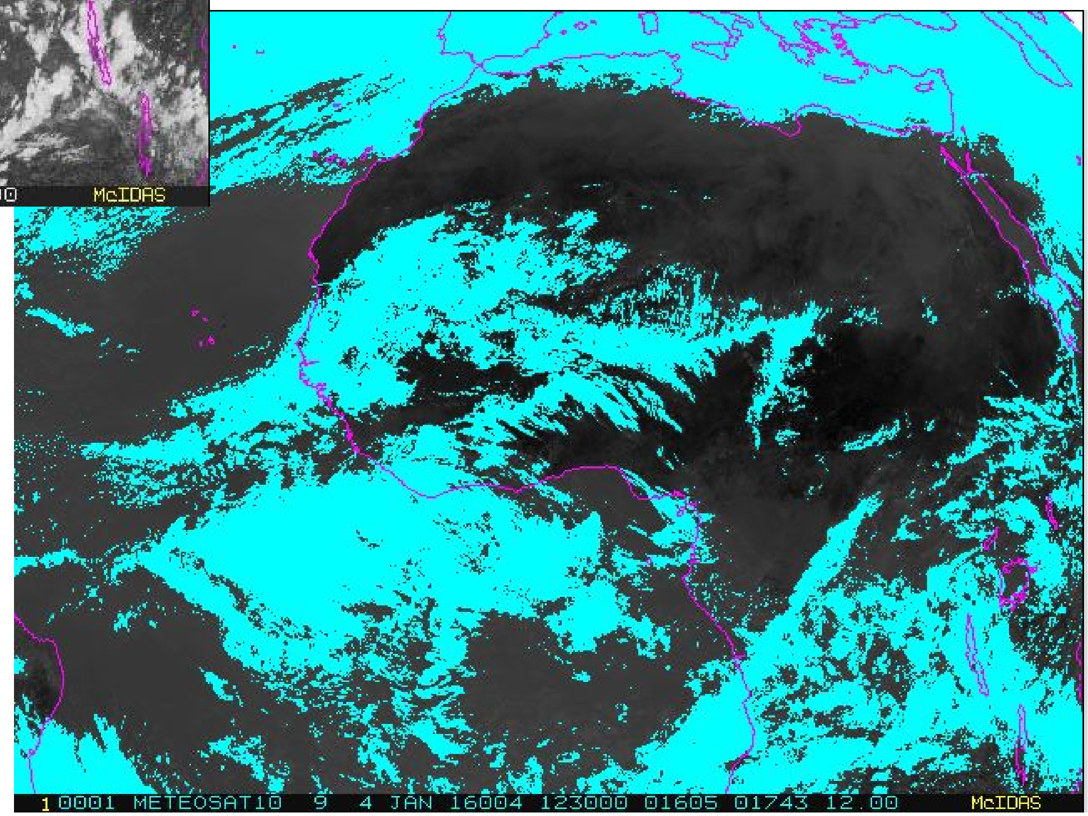
Where

Tb_land is estimated infrared brightness temperature of the land or water surface and

Tb_observed is the observed brightness temperature in the thermal infrared

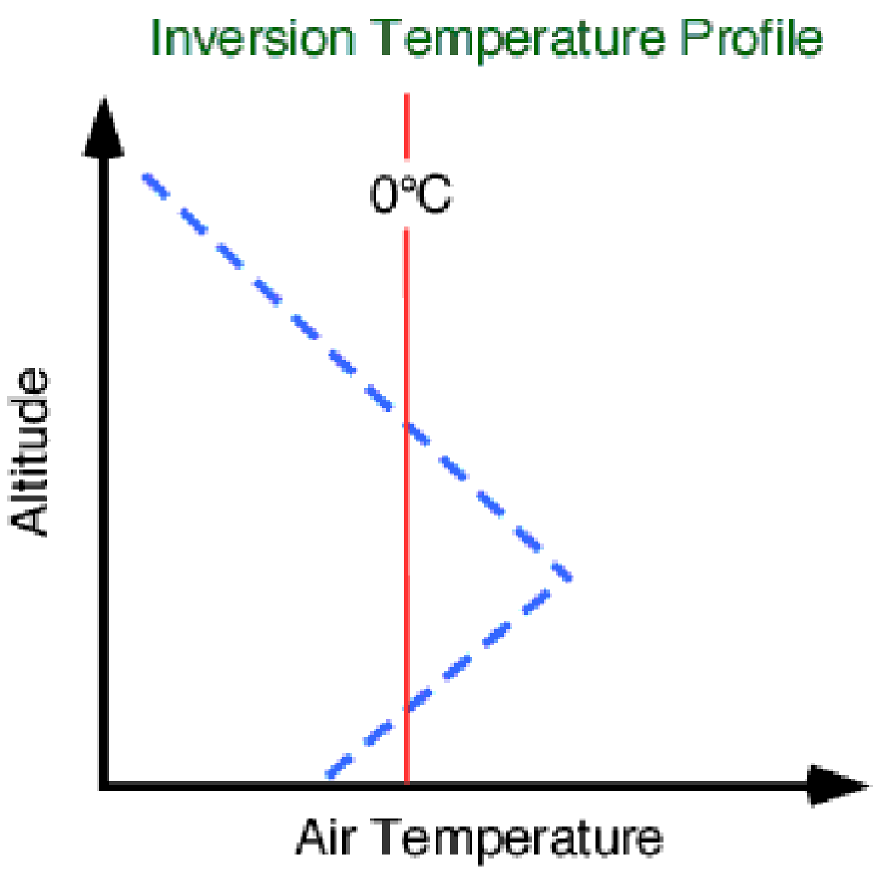


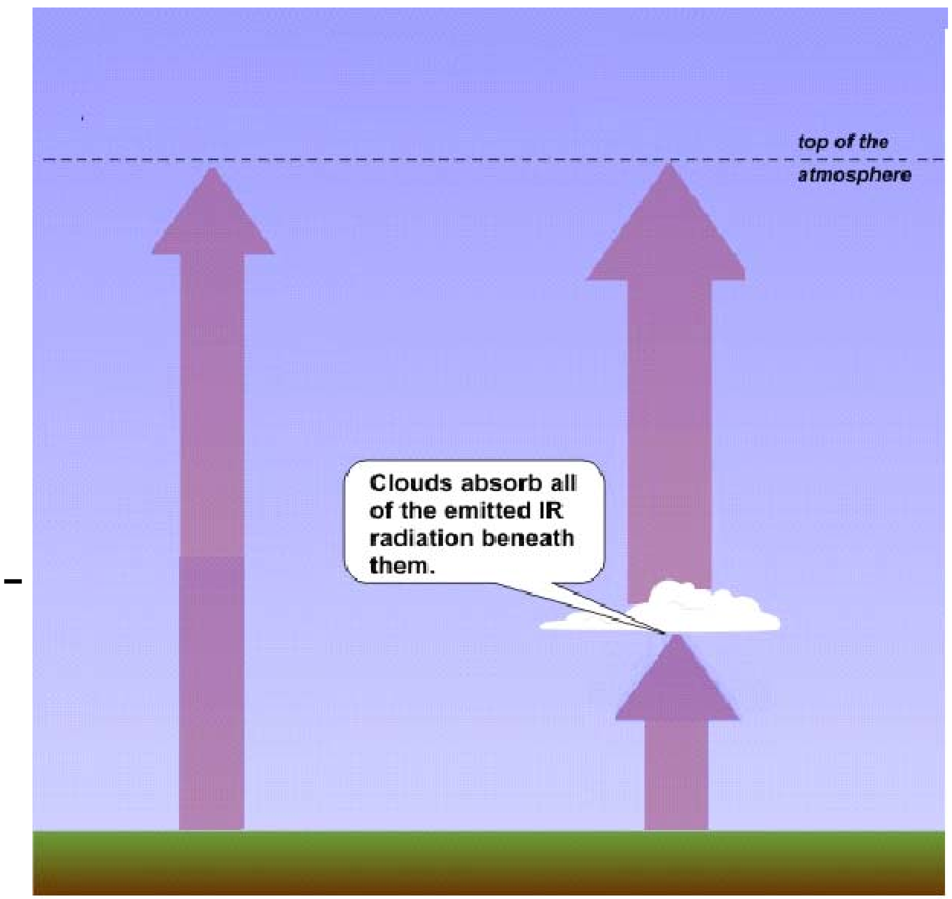
Meteosat SEVIRI InfraRed image over Africa



Temperature-based cloud mask overlaid thermal image. Threshold was set at 288K: Surfaces with temperature below 288K are masked. This threshold works for this particular cases but is too high for global application

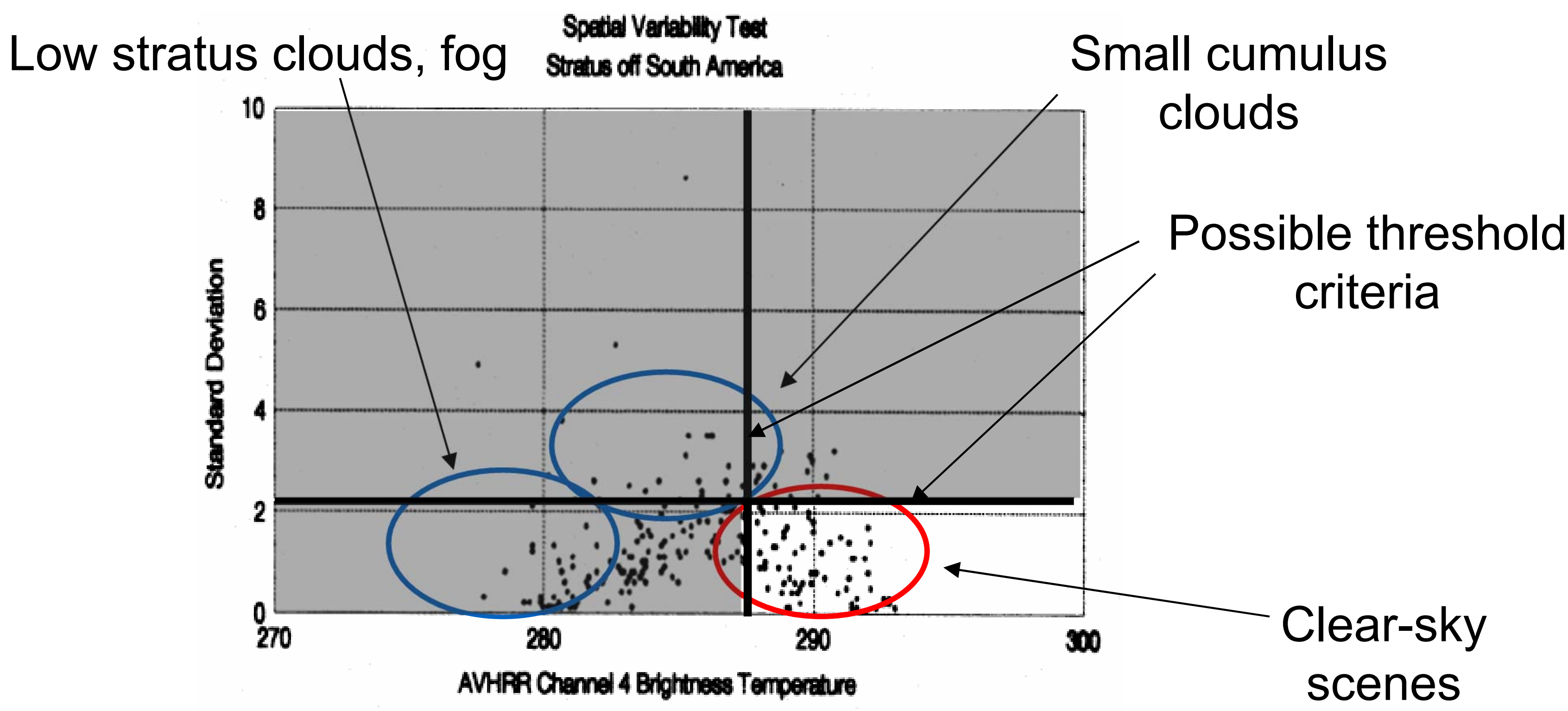
- Sometimes atmospheric temperature inversions occur so that clouds may look "warmer" than cloud-clear land or ocean surface
- This often occurs over oceans at night
- In this case the thermal criteria for cloud identification will fail





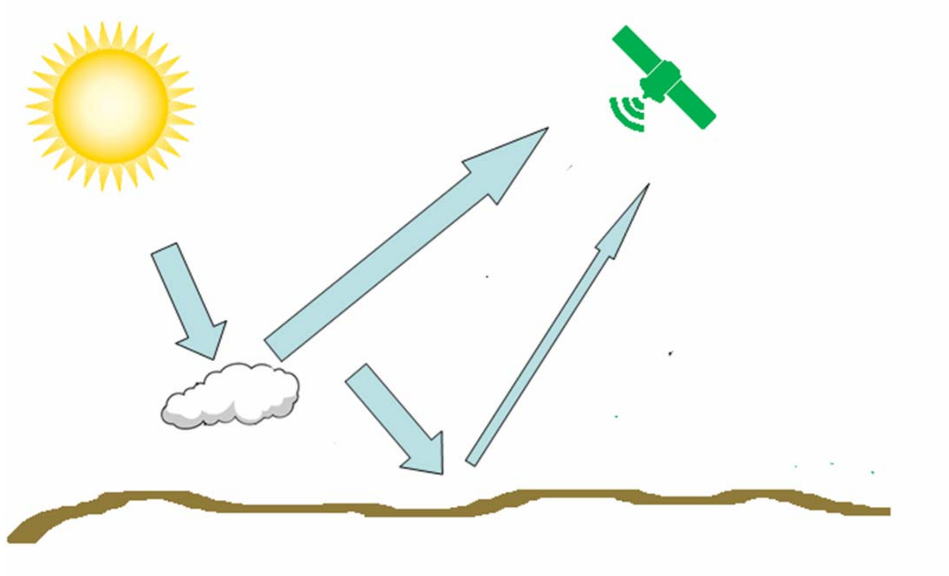
Cloud Temperature is Less Spatially Uniform…

- Land and ocean surface temperature is more spatially uniform than temperature of clouds. Small boxes of 3x3 or 5x5 pixels are used to estimate temperature variability
- Large variability of IR brightness temperature is indicative of clouds



Cloud are Bright in the Visible Bands

- Clouds reflect solar radiation better than most land cover types
- Large reflectance in shortwave spectral bands is indicative of clouds



Typical reflectance threshold test

If $R_{observed} > R_{threshold}$, then cloud

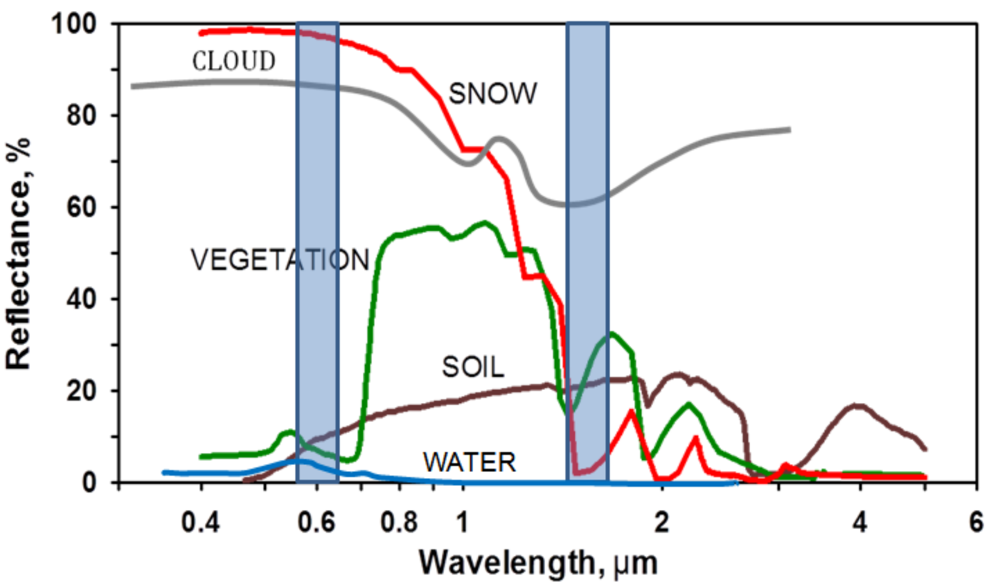
$R_{threshold}$=0.11 (visible)

$R_{threshold}$=0.06 (near infrared)

Threshold values may be established dynamically

Spatial Uniformity Test for Reflectance (similar to the one for IR bands) may be added to improve cloud detection.

Clouds are Spectrally "Neutral"



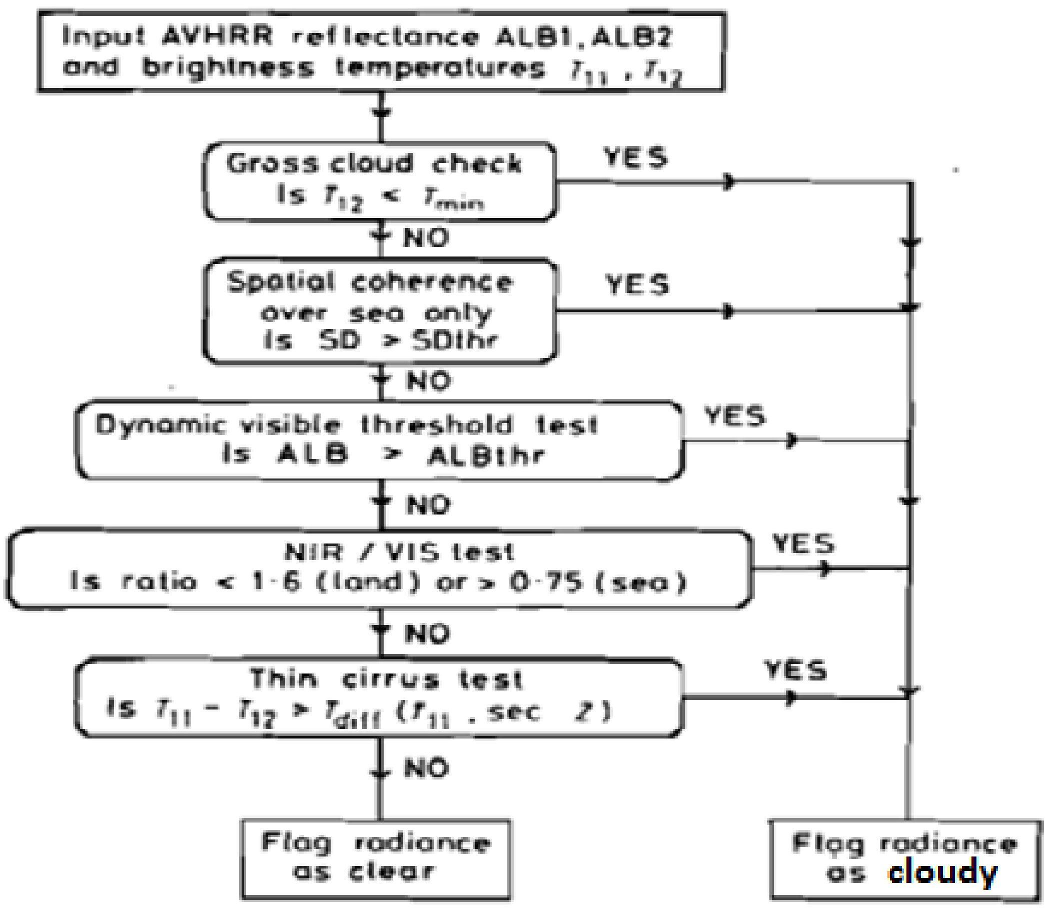
- Reflectance of clouds does not change much within the visible and near infrared spectral range.
- Small difference between visible and near infrared reflectance may be used as another indication of clouds within the sensor field of view.

Clouds: Cause Larger Temporal Variations of Temperature and Reflectance

- Passing clouds cause large temporal change in the pixel reflectance and temperature observed from satellite
- Large short-term temporal variability in the pixel’s reflectance and temperature during the day is indicative of clouds
- This feature may be used to identify clouds with geostationary satellite data which are available at 30 min-1h time interval

Saunders and Kriebel Algorithm (1988)

A “classical” cloud detection algorithm for AVHRR



Daytime algorithm

Applied pixel-by-pixel

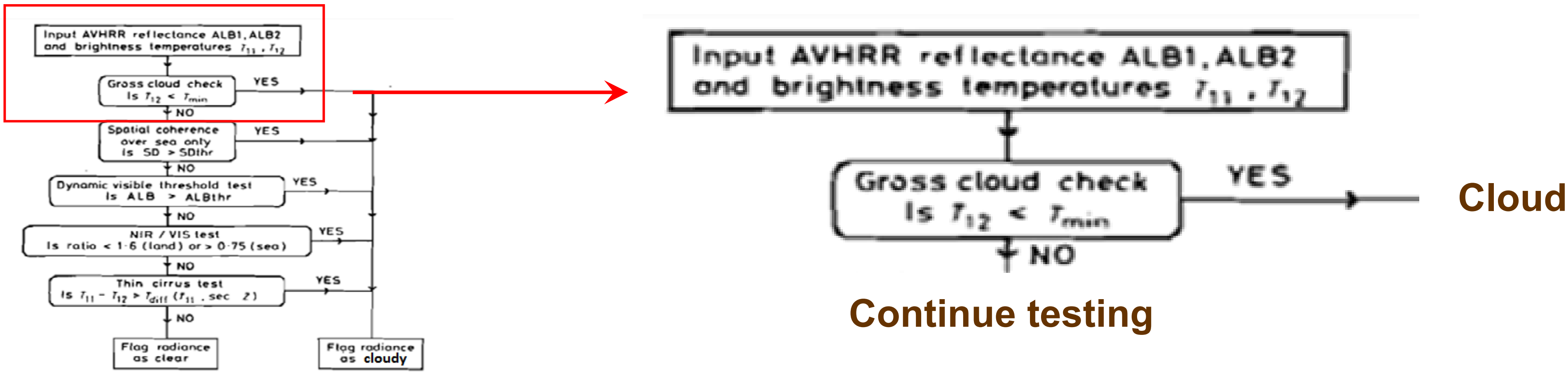
Utilizes threshold-based decision-tree image classification technique

Uses

- Reflectance at 0.6 μm (ALB1),
- Reflectance at 0.8 μm (ALB2),
- Br. Temperature at 11 μm (T_{11})
- Br. Temperature at 12 μm (T_{12})

Employs 5 tests

Saunders and Kriebel Algorithm (1988): Test 1: Thermal Infrared



Daytime algorithm

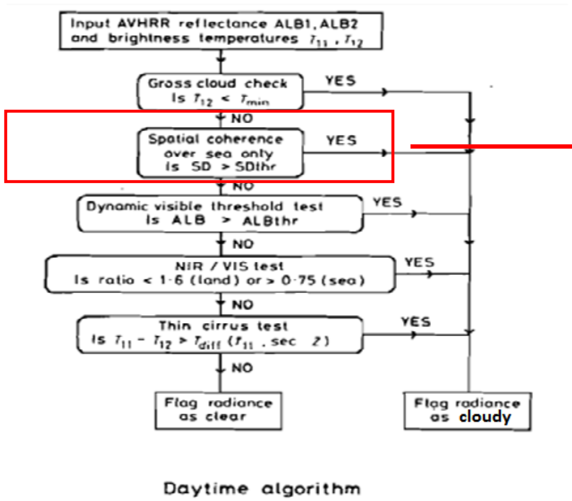
Thermal infrared test

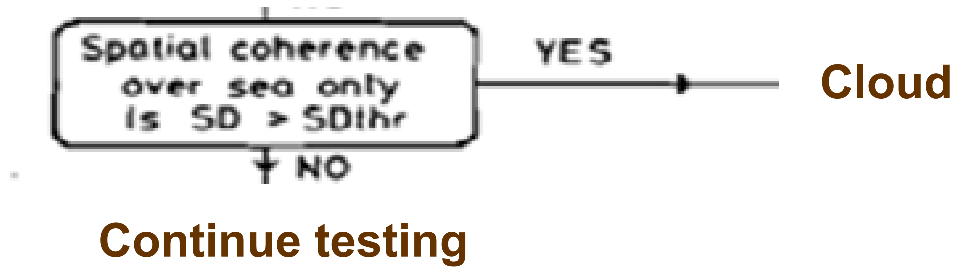
Tests whether the observed infrared brightness temperature at 12μm (T_{12}) is not below the certain threshold (T_{min})..

If temperature is below the threshold, pixel is labeled as “cloudy” and the code moves to the next pixel. If temperature is above the threshold, testing continues.

Threshold value is set depending on the geographical area, region of application, season, etc.

Saunders and Kriebel Algorithm (1988): Test 2: Spatial coherence





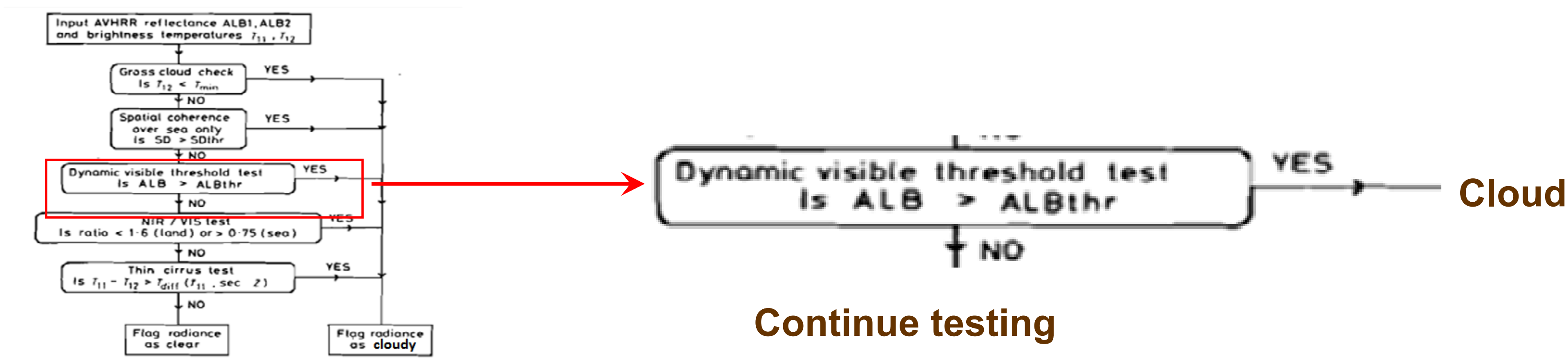
Spatial coherence test

Tests whether the scatter in the observed infrared brightness temperature within certain distance from the pixel is not above certain threshold (SD_{thr})

If the scatter is above the threshold, pixel is labeled as "cloudy" and the algorithm moves to the next pixel. Otherwise it continues testing the pixel

Test is applied only over the ocean

Saunders and Kriebel Algorithm (1988): Test 3: Visible



Daytime algorithm

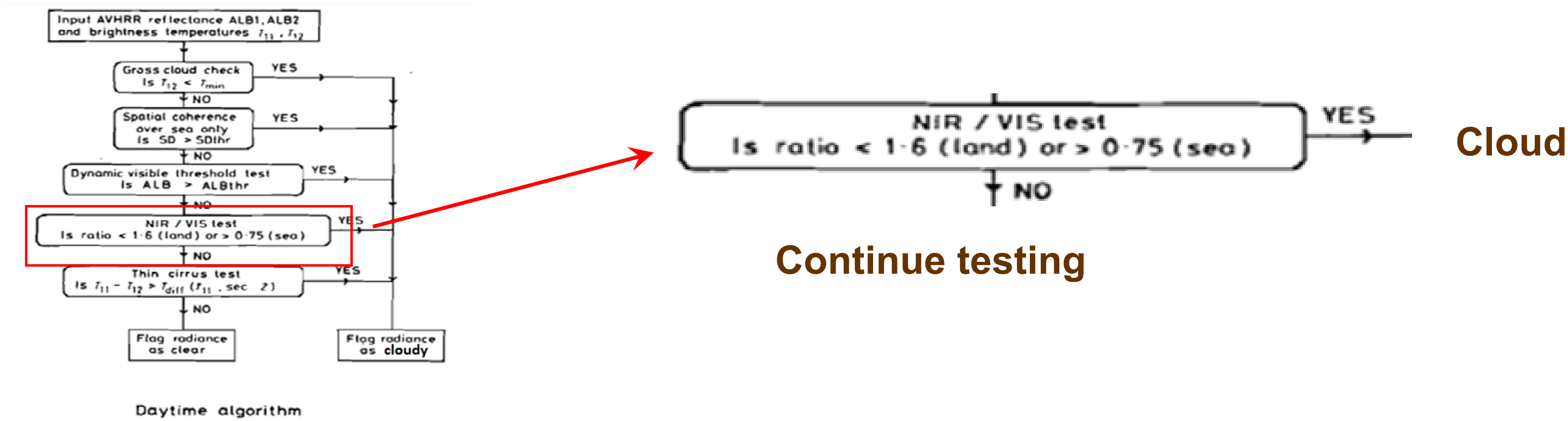
Visible reflectance test

Tests whether the visible reflectance of the pixel (ALB_1) is above the threshold set for cloudy pixels (ALB_{thr})

Uses the fact that clouds are typically brighter than the land surface or the sea surface

If the reflectance is above the threshold, pixel is labeled as “cloudy” and the algorithm moves to the next pixel. Otherwise it continues testing the pixel

Saunders and Kriebel Algorithm (1988): Test 4: Visible and Near-IR



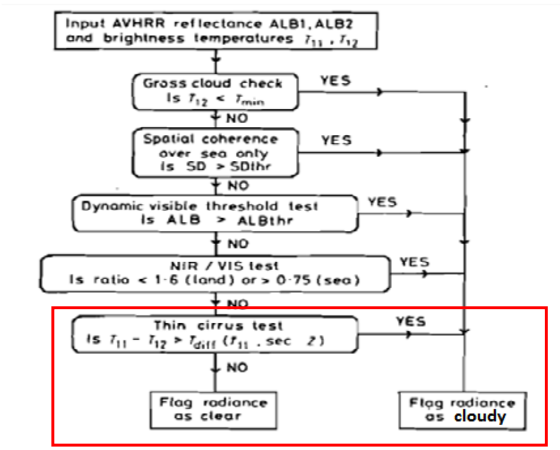
Visible and near-infrared reflectance test

Tests if the visible to near-infrared reflectance ratio (**ALB_1 / ALB_2**) is not much different from 1.

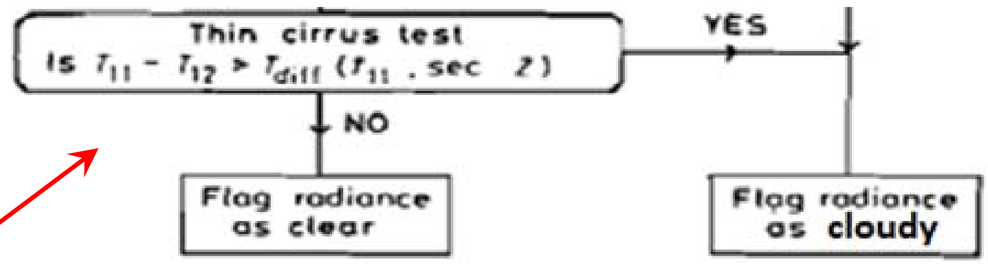
Uses the fact that clouds are more spectrally “neutral” than land surface and sea surface.

If the ratio is close to 1 (spectral reflectance doesn’t change much from visible to near-infrared), the pixel is labeled as “cloud” and the algorithm moves to the next pixel. Otherwise it continues testing the pixel.

Saunders and Kriebel Algorithm (1988): Test 5: Cirrus Clouds Test



Daytime algorithm



Thin cirrus test

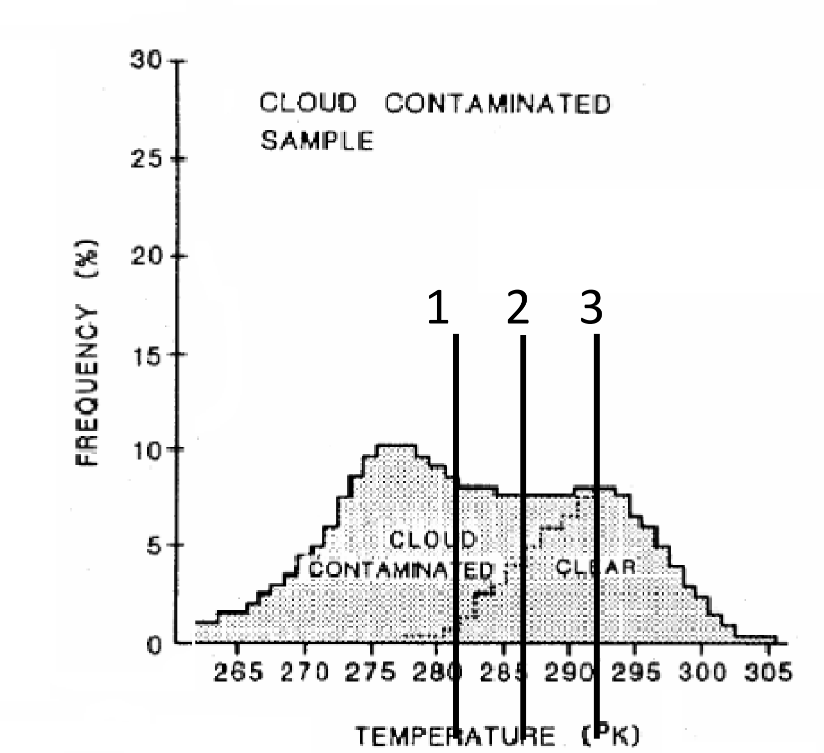
Tests the difference between brightness temperatures observed at 11 μm and 12 μm.

Uses the fact that with no clouds the difference between brightness temperature observed at 11 and 12 μm should be small (within 3-4 K)

Large difference is indicative of cirrus clouds in the instrument field of view. If the difference is large, the pixel is labeled as “cloudy”, otherwise it is labeled as “clear”.

Factors complicating cloud detection

In any image containing clouds and cloud-clear views there is a lot of “mixed” pixels which are partially covered by clouds. The approach to where to set the threshold separating cloudy and cloud-clear pixels varies.



Threshold to separate cloudy and clear pixels may be set equal to any of the values (1,2,3) depending on the further application of the classified image. In particular, if the objective is to study properties of the land surface, it is desirable to exclude all potentially “mixed” pixels and set the threshold at 3.

Factors complicating cloud detection

- Cloud detection at night is less accurate because of unavailable observations in reflective spectral bands
- Clouds look similar to snow
- Optical and thermal properties of clouds are highly variable
    - Temperature from 190K to 280K+
    - Reflectance from 0.20 to 1.0
- Reflection from clouds and land/ocean surface is anisotropic: it depends on a particular observations' geometry
    - Solar illumination angle
    - View zenith angle
    - Azimuth between directions to the sun and satellite

There is no “ideal” cloud algorithm

Algorithm developed for one sensor may not be applicable to another

- Different spectral bands (spectral position, width)
- Different observation geometry (e.g.,solar illumination angle)

Algorithm developed for one geographical region/surface type may not perform well over another

- Statistical properties of clouds, e.g., prevailing cloud types, vary with location, season, surface type, topography.
- Reflective/emissive properties of various surface types are different (land, snow, water)

Algorithm developed for the global application may not be optimal for a particular region, whereas algorithm developed for a specific region may not perform well over the globe.

Other VIS/IR Cloud Detection Techniques

A number of different approaches to satellite image analysis and cloud masking have been developed proposed:

- Cluster analysis
- Neural Networks
- Max probability

However most often decision-tree threshold-based algorithms are used. They are

- Easy to implement
- Easy to modify, tune
- Easy to understand
- Easy to incorporate ancillary information on the surface properties

SUMMARY

- Cloud identification is usually the first (and a very important) step in quantitative interpretation of satellite images in the visible and infrared
- Cloud detection algorithms utilize observations in the reflective and in the emissive bands. They rely on both spectral differences of clouds from the land surface and different spatial variability of reflectance and temperature
- Cloud identification at night is more complicated due to the lack of reflective bands
- Most often simple threshold-based decision-tree techniques are employed to identify and mask clouds in satellite imagery
- There is no "best" cloud detection algorithm. All algorithms are specific for a particular satellite, sensor and geographical region. Best performance is achieved when the algorithms is tailored for a specific application (e.g., cloud detection over open water for sea surface temperature retrievals)

Reading

- **Remote Sensing Applications with Meteorological Satellites** by W. Paul Menzel, https://cimss.ssec.wisc.edu/rss/benevento/source/AppMetSat06.pdf, Chapter 6.