# Are there clouds in the sky?

## Reproducing the MODIS cloudmask using MODIS level 1 Radiance Data

**EOSC 582 Final Project**

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Clouds are generally cooler and more reflective than the earth's surface. The MODIS cloud mask uses this principle to test for cloud presence based on reflectances and brightness temperatures measured at different wavelengths of light by the Moderate Resolution Imaging Spectroradiometer, which orbits Earth on the Terra and Aqua Satellites (both built by NASA). This project aims to compare several bits of the MODIS 48-bit cloudmask with cloud determining tests performed on raw MODIS level 1 data. These tests were written using the Modis Algorithm Theoretical Basis Document as a guide (Ackerman et al, 2010), as well as Ackerman 1997, with the aim to examine how closely they reproduce the output of the final mask product. The tests of the MODIS mask are grouped into five functional groups, each using a combination of brightness temperature and reflectance ratio tests: Group 1. Detection of thick high clouds ( using brightness temperature threshold tests) Group 2. Detection of thin clouds (brightness temperature difference tests) Group 3. detecting low clouds (reflectance thresholds and reflectance ratio tests) Group 4. detecting upper tropospheric thin clouds (reflectance threshold at 1.38 microns) Group 5. detecting cirrus clouds ( brighness temperature difference tests)

I wrote tests for four bits of the mask (Bit 13 - Group 1, Bit 19 - Group 2, Bit 21 - Group 3, and Bit 24 - Group 2) and tested them on the skies over Great Britain using raw data from four different days. Bits 13, 19, and 24 use brightness temperature or brightness temperature difference, while Bit 21 uses a reflectance ratio. In analyzing the results, it is important to remember that each test is designed to look for different clouds under different conditions, and that a "clear sky" flag for a particular test means simply that a cloud was not found by that particular test (low clouds may not be detected by high cloud flags and vice versa). This is particularly important in the case of Group 1 and Group 3 tests, which complement each other - Group 1 tests are good at detecting high, thick clouds that exhibit a high thermal contrast with the surrounding area, while Group 3 tests can detect clouds that have a low thermal contrast using differences in reflectance ratios due to water vapour presence.

The final cloudmask is based on an amalgamation of the individual tests and is cloud-conservative - this is to say, in the case of borderline conditions it is more likely to assume cloud than clear sky.

# The study area

I ran the tests on similar satellite passes on four separate days:

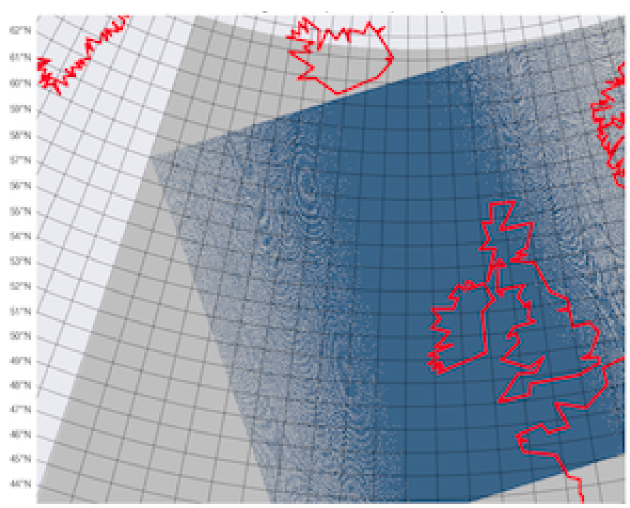
**January 4, 2014 at 13:25**

**February 10, 2014 at 13:15**

**June 6, 2014, at 13:20**

**March 5, 2015, at 13:20**

Though the passes differ slightly in spatial extent (according to time of satellite passing), all four cover Great Britain. The image below represents the spatial extent of one of the passes. For the cloudmask tests, I focused on analyzing the area around Great Britain, so I set the extent of the maps between 49 - 59 ° latitude and -11 - 3° longitude.



*The spatial extent of the pass on June 6, 2014, at 13:20*

# Data products used

In this analysis, I used 3 different types of NASA data products. All 3 can be downloaded at https://ladsweb.nascom.nasa.gov/data/search.html (https://ladsweb.nascom.nasa.gov/data/search.html), under the Aqua MODIS Satellite heading. The products are as follows:

-Level 1B calibrated radiances (MYD021KM, Aqua Level 1 Product) - contains radiance data at different bands of the MODIS for a given pass (denoted by date and time recorded in filename). A reference table of band number correspondences to wavelength can be found here: (https://en.wikipedia.org/wiki/Moderate-Resolution_Imaging_Spectroradiometer (https://en.wikipedia.org/wiki/Moderate-Resolution_Imaging_Spectroradiometer))

-Geolocation (MYD03, Aqua Level 1 Product) - Contains georeferencing information for a given pass (denoted by date and time recorded in filename, which can be matched with other products for the same pass).

-MYD35_L2 (MODIS Level 2 Cloud Mask and Spectral Test Results, Aqua Atmosphere Level 2 Product) - Contains the results of the MODIS cloudmask.

My aim in this analysis was to compare the MYD35_L2 cloudmask with the results of tests run on MYD021KM data. The visual comparison of both products (the MODIS cloudmask and my recreation of it) is enabled by plotting both using the same geolocation file.

# ##The principle of brightness temperature

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Many of the tests in the MODIS mask rely on calculations of the
brightness temperature of observed surfaces. An object's
brightness temperature at a given wavelength is a quantity related
to its radiance at that wavelength by the Planck function. The
Planck function gives radiance emitted by a body at a certain
wavelength and temperature. The version used in this analysis is
below:
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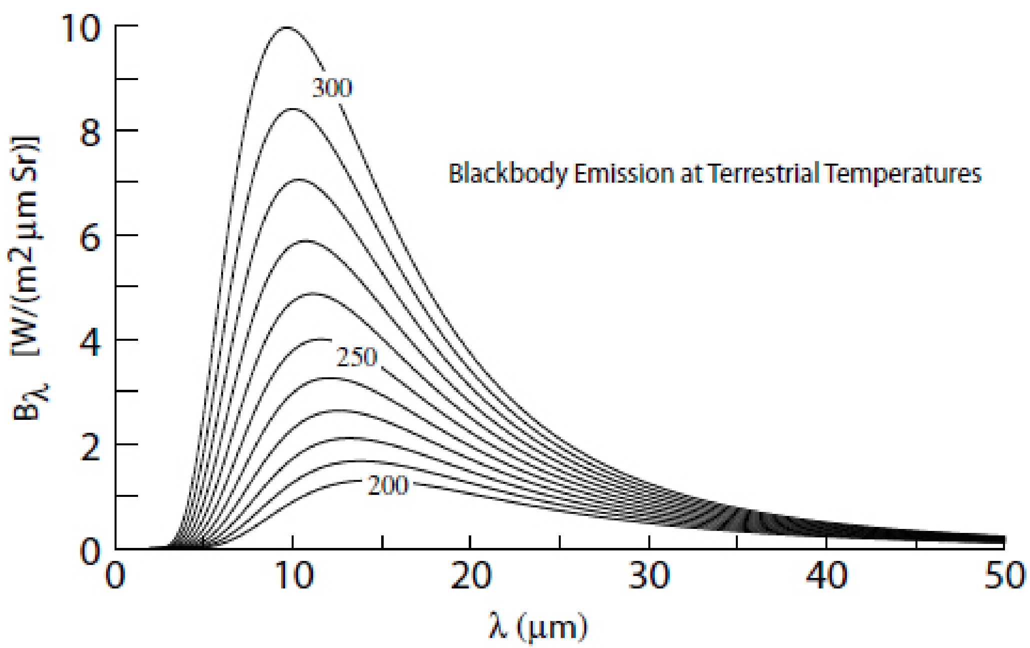
$$\boxed{B_\lambda(T) = \frac{2hc^2}{\lambda^5\left(e^{hc/k_B\lambda T} - 1\right)}\ ,}$$

In this version of  formula, λ is wavelength, c = 2.998 × 108 m s −1 is the speed of light, h = 6.626 × 10−34J s is Planck’s constant, kB = 1.381 × 10−23 J/K is Boltzmann’s constant, and T is temperature. The formula gives radiance in units of “power per unit area per unit solid angle per unit wavelength” (W m−2μm−1sr −1). This formula describes how a body's emitted radiance (B(T) at a given λ) changes with wavelength at a given temperature. The following graph of B(T) vs λ for different temperatures , taken from Petty 2011, was helpful to me in understanding this principle:



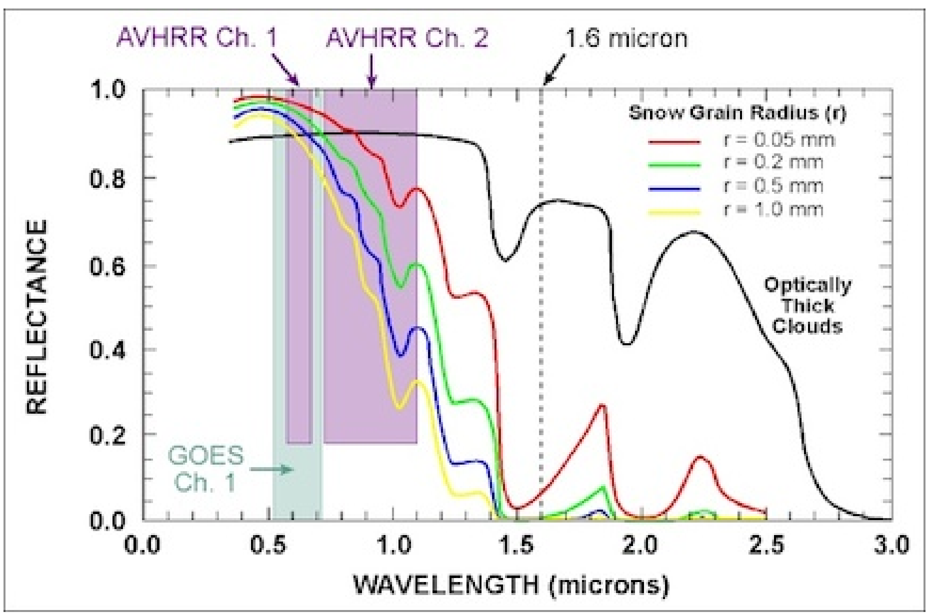

The MODIS sensor senses radiance at multiple wavelengths. If the radiance at a given wavelength is known, from the above function, a body's observed temperature at that wavelength can be found by inverting the Planck function and solving for temperature, as shown below (B -1 is the inverse of the Planck function, I(λ) is observed intensity).

$$\boxed{T_B \equiv B_\lambda^{-1}(I_\lambda),}$$

In the cloudmask, the MODIS sensor exploits the fact that different surfaces emit different intensities of radiations across wavelengths to distinguish between them. In some of the most simple tests, for example the test stored in Bit 13, it simply uses brightness temperature derived from radiation intensity at a given wavelength to discriminate between cold surfaces (which it designates as cloud) and warm ones (non-cloud). These tests are not applicable in all conditions - for example, it is difficult to distinguish between cloud and snow. More complex tests (eg Bits 19 and 24) utilize the idea that the presence of water vapour (cloud), changes radiation emitted differently at different wavelengths, and so use the difference between brightness temperatures at different wavelengths to predict the presence of clouds.

## The principle of reflectance

When energy hits a surface, only three things can happen to it: It can be absorbed, it can be transmitted, or it can be reflected. Reflectance is the proportion of incident flux at a given wavelength which is reflected (as opposed to transmitted or absorbed) by a given surface. (Reflectance ranges from 0 to 1 and has no units.) Different surfaces have different reflectaces at different wavelengths, and if we have reflectance data for multiple waveleghts at our disposal, these differences can be used to identify corresponding surfaces. The following figure (produced by NOAA, see References for source) illustrates the difference between reflectances for various types of snow and thick cloud at different wavelengths:




*Satellite channel wavelengths in microns and typical reflectance spectra for snow and clouds.*

Several bits of the MODIS cloudmask exploit the different reflectances by different surface types at different wavelengths to distinguish between them. Of these, I attempted to recreate Bit 21, which uses the ratio of reflectance at .87 microns to the reflectance at .66 microns for cloud detection.

# Bit 13: Brightness temperature at 11 microns

Bit 13 in the MODIS mask is a Group 1 test that uses brightness temperature at 11 microns (MODIS band 31, emissive channel 10) to determine the presence of thick high clouds (the colder the brightness temperature, the higher the chance of cloud presence). The test is difficult to use over land because surface emissivity varies considerably with soil and vegetation type, making it hard to discriminate colder background temperatures (eg. snow) from cloud. (According to Ackerman 1997, the test is most effective over ocean at night.) Ackerman uses the following thresholds: 267 K, 270 K and 273 K, with 270 K being the threshold value below which the pixel fails the clear-sky condition.

I recreated this test using a script that extracts radiance (W/m^2/micron/sr) at a wavelength of 11 microns for all pixels in a given MODIS level 1 file (filename designation MYD021), then finds brightness temperature from this radiance by solving the Planck function for brightness temperature using this radiance. (The Planck inversion functon was written by Phil Austin).

This script returns an array of brightness temperatures, which can be plotted using the MYD03 geolocation file. It is then possible to write a script that takes an array of brightness temperatures as an input and returns a probability of cloudiness based on the Ackerman thresholds as follows (BT = Brightness Temperature). There are 4 categories of probabilities, with 0 representing cloudy sky and 3 representing a 99% probability clear sky, as listed below:

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BT < 267..................... 0 - cloud (white on the map)
267 <= BT < 270 ..............1 - 66% probability clear
270 <= BT < 273 ..............2 - 95% probability clear
BT > 273......................3 - 99% probability clear (dar
k blue on the map)
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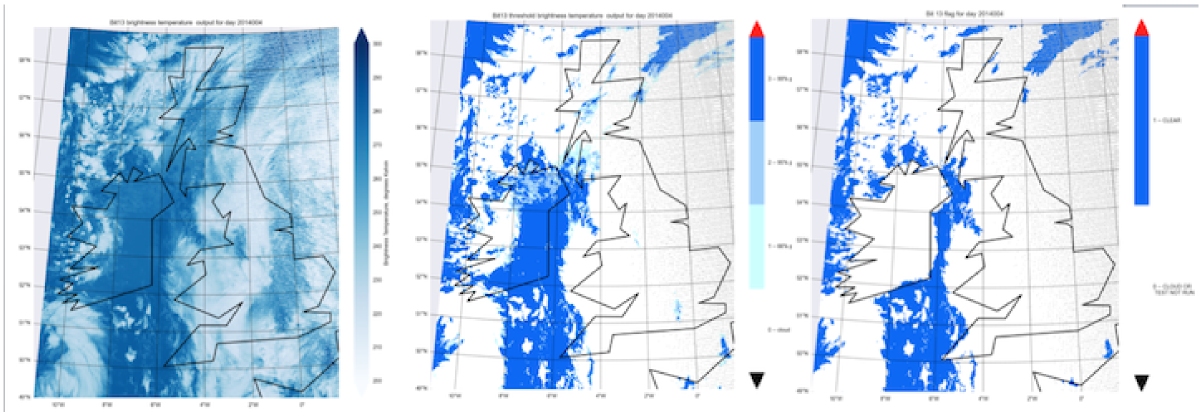
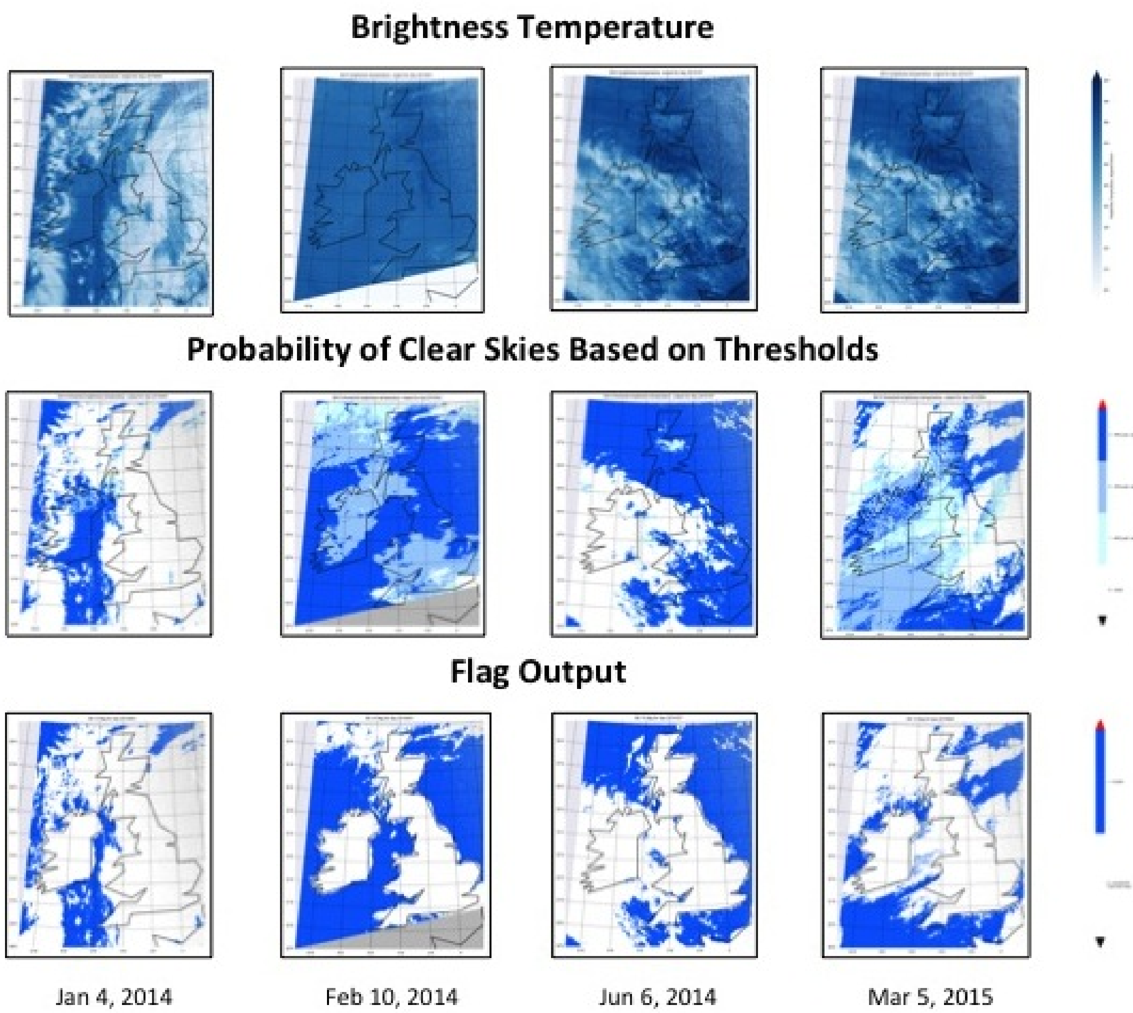
I then compared the output of the threshold categorization with the bit 13 flag in the MODIS cloudmask. The MODIS cloudmask flag is binary, with 1 representing a clear sky and 0 representing the presence of cloud (in some cases, a 0 may indicate that the test was not run).
After this, all files (brightness temperature array, threshold array, and cloudmask array) can be reprojected (using P. Austin's reproject_numba code) and plotted with the help of the geolocation array) The following image represents a comparison of the scene January 4, 2014 at 13:25 with its threshold categorization and cloudmask.



*A comparison of brightness temperatures, categorization results, and flag output for the January 4 scene*

An overview of the same comparison for all 4 days can be seen below:




*A comparison of brightness temperatures, categorization results, and flag output for all four scenes*

In [ ]:

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