Earth Observation Data Analysis: Homework #2

Due on May 2016

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Contents

1. 2. 3. Download and install SNAP (if needed, use ESA Cloud ToolBox facility), SEVIRI/METEOSAT and MODIS/AQUA imagery on the casestudy of the 2010 Icelandic eruption of 2010 and follow LearnEO-Lesson13 instructions

The 2010 eruptions of the Eyjafjallajkull (a smaller ice cap located in Iceland that covers a stratovolcano) lasted several weeks, sustaining an average magma discharge of several hundred tonnes per second and producing large quantities of lapilli, coarse, fine and very fine ash particles which were advected towards south and south-east along the major European air traffic routes, causing an unprecedented flight crisis.

Figure 1: Eyjafjallajokull volcano

Data from SEVIRI (Spinning Enhanced Visible and InfraRed Imager) and MODIS (MODerate-resolution Imaging Spectroradiometer) radiometers are used to analyze the features of volcanic plumes from Eyjafjallajkull, which the prevailing northerly winds stretched across the Atlantic Ocean toward mainland Europe.

For this HW we're going to use the ESA RSS Cloudtoolbox facility to process the images in SNAP, courtesy of ESA/ESRIN team.

4. Perform data quality check

1. SEVIRI: file name "MSG_201101122300", platform "METEOSAT".

   The start date is: "09-MAY-2010 10:25:00.000000"
   The stop date is: "09-MAY-2010 10:30:00.000000"

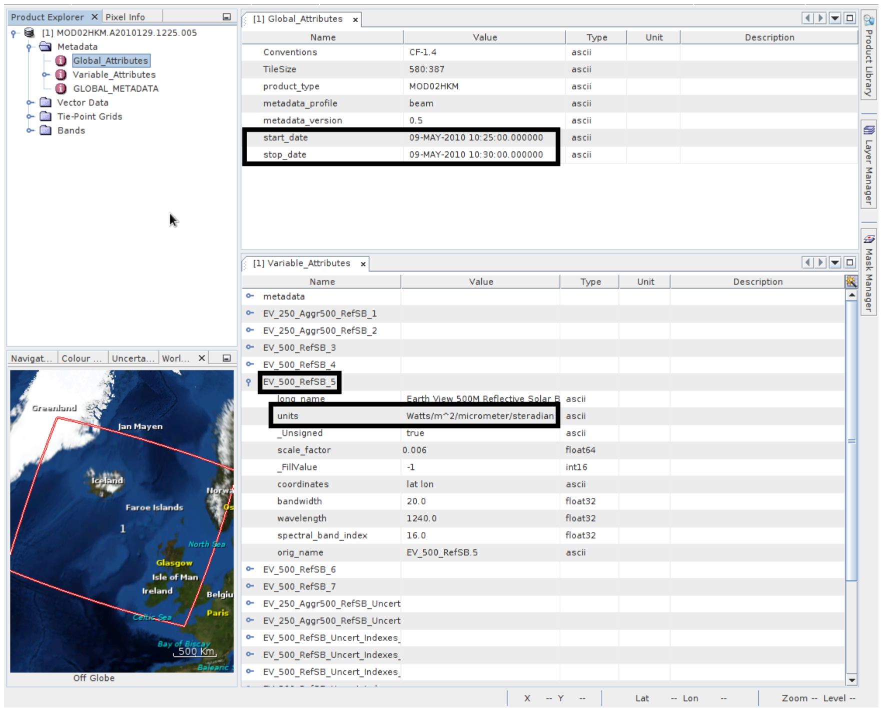


Figure 2: SEVIRI file

As we can see in "Variable_Attributes", an important data to consider is the unit of the bands in infrared (IR) that are set in *Kelvin*

2. MODIS: file name "MOD02HKM.A2010129.1225.005", platform "AQUA".

   The first line time is: "09-MAY-2010 10:25:00.000000"
   The last line time is: "09-MAY-2010 10:30:00.000000"

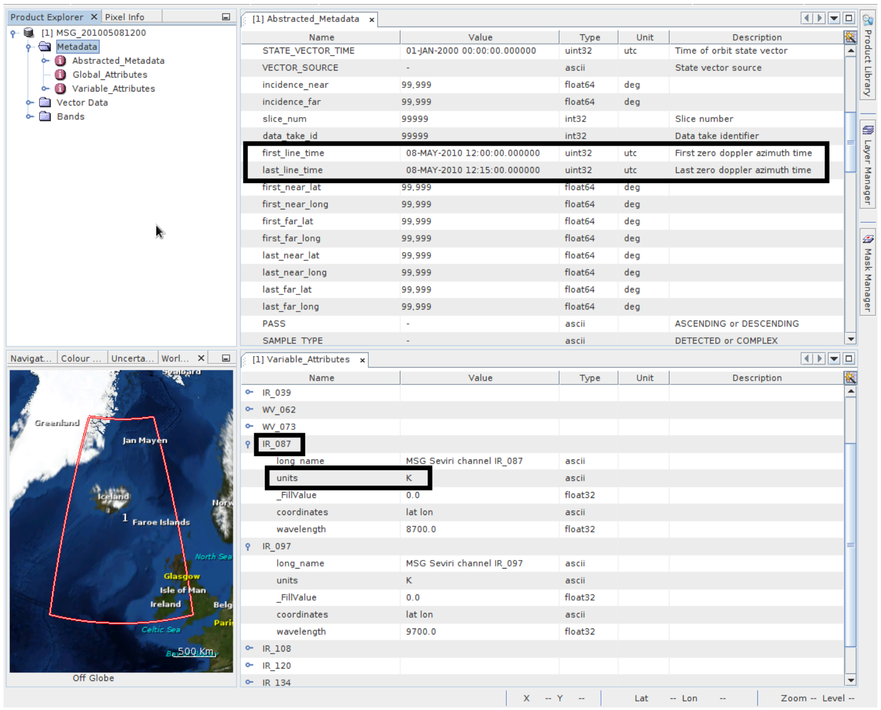


Figure 3: MODIS file

In this case, the units for the bands are mostly set in "Watts/m^2/micrometer/steradian"

5. Perform and display visible RGB (RedGreenBlue) composite with MODIS data

The sum of specifics bands in RED, BLUE and GREEN bands

Band 1 - 0.620 nm - 0.670 nm (Red - R);
Band 4 - 0.545 nm - 0.565 nm (Green - G);
Band 3 - 0.459 nm - 0.479 nm (Blue - B).

allows to create an RGB composite image of the MODIS stack using, in our case, the bands:

Channel 1 EV_250_Aggr500_RefSB_1 (645 nm)
Channel 4 EV_500_RefSB_4 (555 nm)
Channel 3 EV_500_RefSB_3 (469 nm)

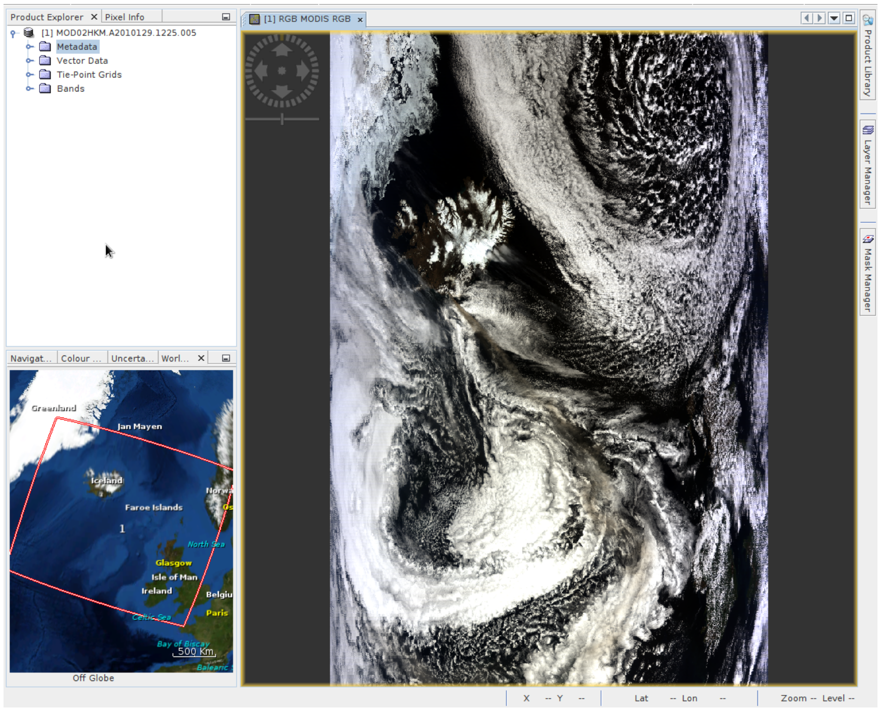


Figure 4: MODIS composite RGB image

We can distinguish the volcanic ash plume from the white clouds that cover the northern part of the Atlantic Ocean: clouds and ice are bright white whereas volcanic ash look shiny brown or in copper color.

6. Perform and display virtual RGB composite using SEVIRI data channels

For the SEVIRI data, we're going to use the bands:

Band 7 IR_087 (8700 nm)
Band 9 IR_108 (10800 nm)
Band 11 IR_120 (12000 nm)

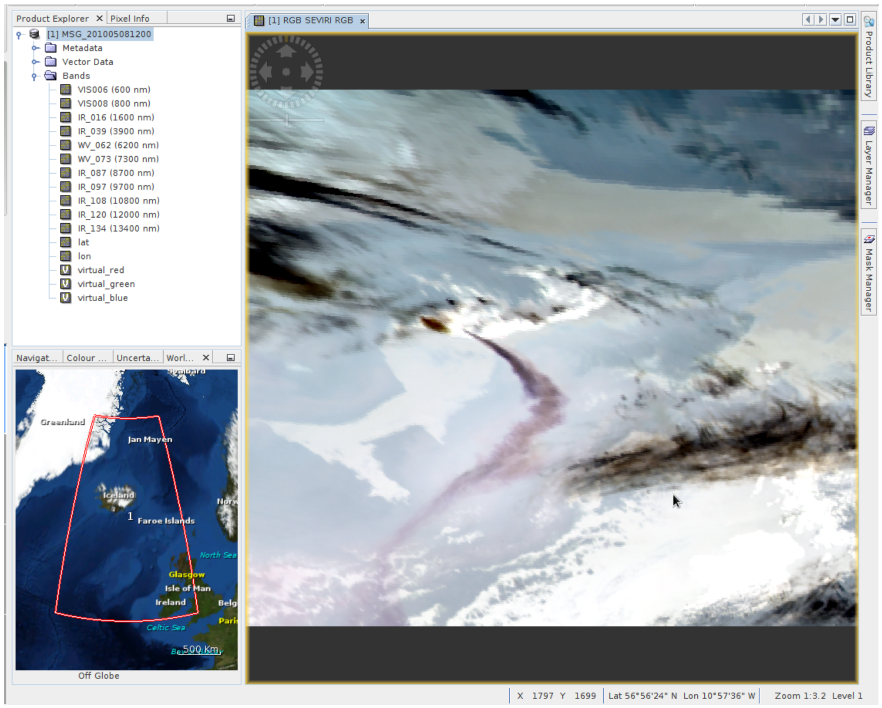


Figure 5: SEVIRI composite RGB image

In the SEVIRI case, the major focus is on ash and sulphur dioxide (SO_2). Volcanic ash clouds tend to be colored in light purple where the plume stretching from Eyjafjallajkull towards mainland Europe across Atlantic Ocean is clearly visible.

7. Perform and display ash-cloud transects on SEVIRI RGB composite data

The profile plot shows the intensities along its path of the polyline, chosen on the volcanic plume. The band used is IR_087.

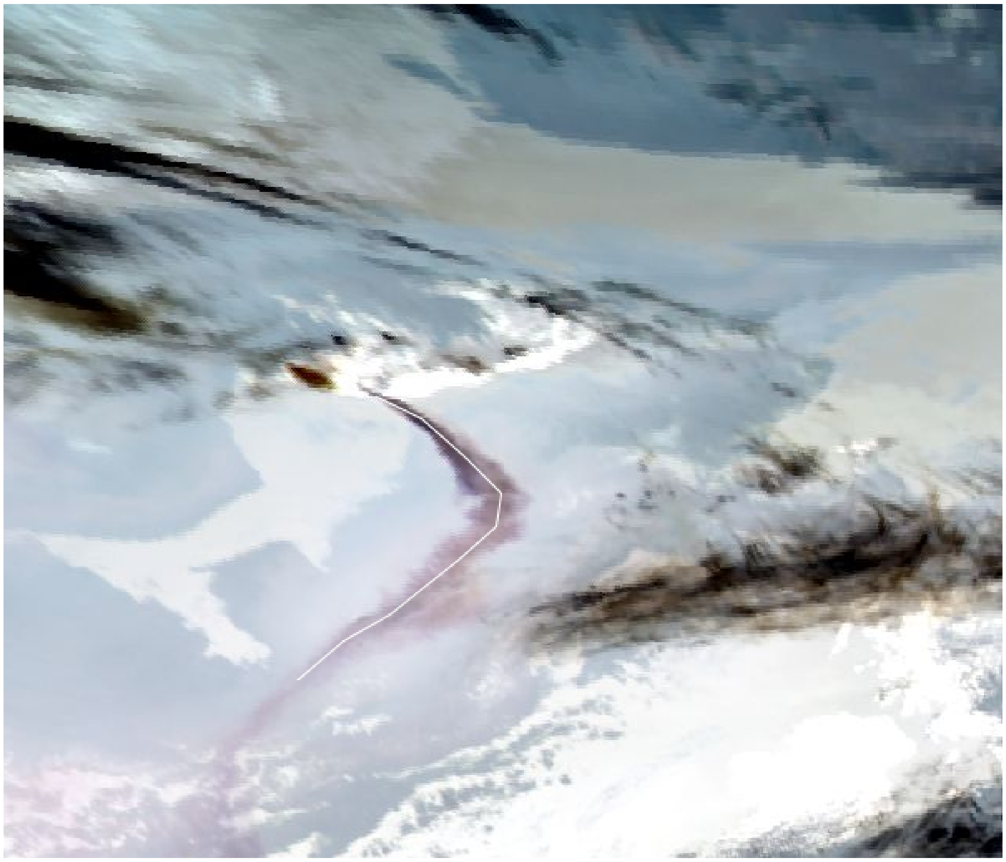


Figure 6: SEVIRI polyline on ash plume

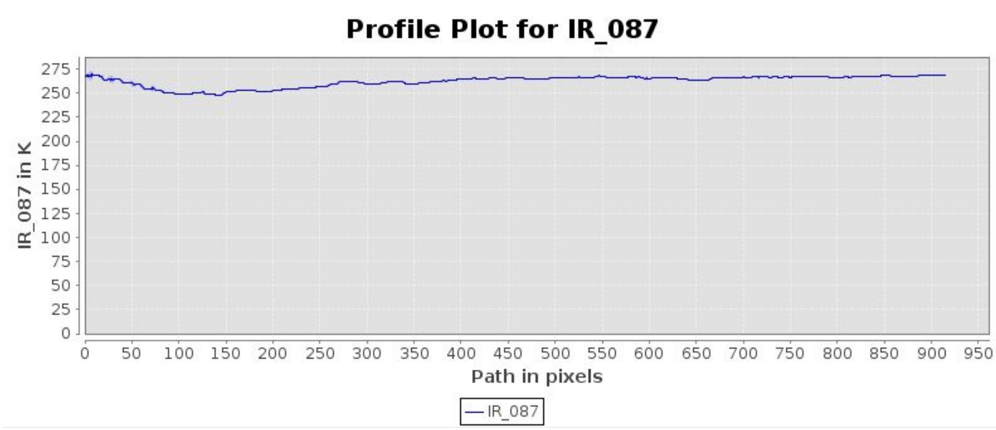


Figure 7: SEVIRI profile plot

8. Perform and display Brightness Temperature Difference (BTD) using SEVIRI data

BTD stands for Brightness Temperature Difference and is a basic detection technique exploiting the different behavior of ash plumes in different spectral channels.

The resulting images are obtained making the math difference between couples of bands and then applying a colour manipulation.

For every band math we'll choose a particular color palette in which we'll modify the colors and values to obtain the best results.

1. BTD between **IR_120 and IR_108 channels**

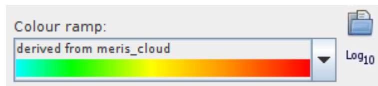
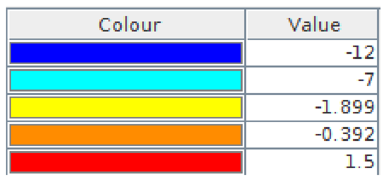


Figure 8: Original Color Palette



Colour	Value
	-12
	-7
	-1.899
	-0.392
	1.5

Figure 9: Modified Color Palette

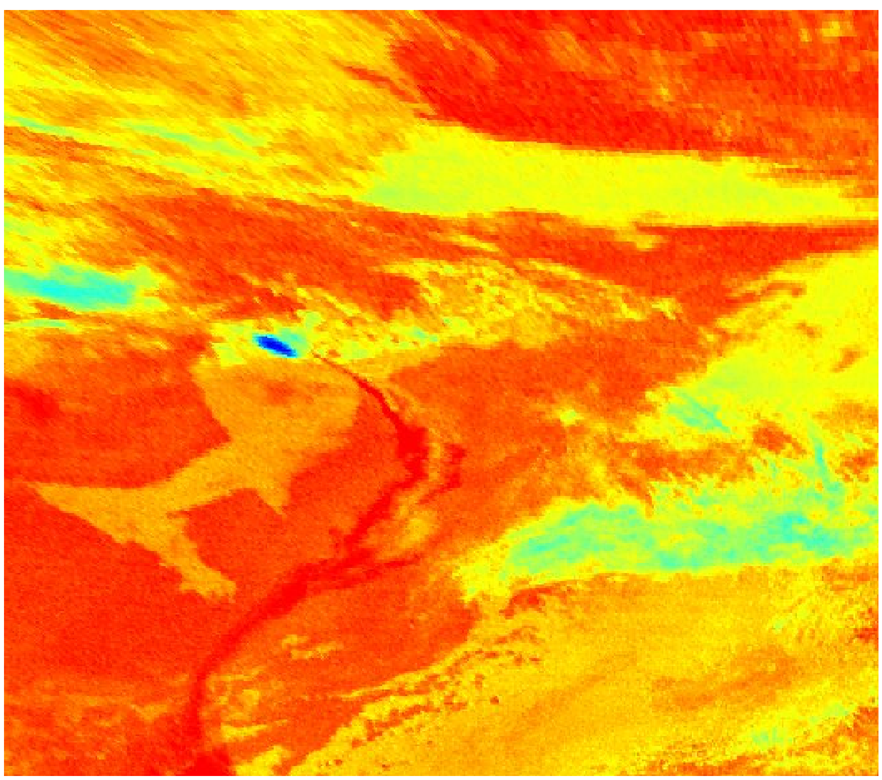


Figure 10: Color Palette on IR_120 - IR_108

The pixels containing ash will be shown in red or darker red. The emissivity of silicate particles (which are one of the main component of ash clouds) is lower at 10.8 m than at 12.0 m, whereas it has an opposite behavior for water and ice particles.

2. BTD between **IR_039 - IR_108 channels**

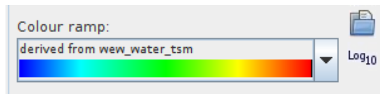


Figure 11: Original Color Palette

Colour	Value
	-4.356
	-4.195
	3.022
	13
	25
	30
	42

Figure 12: Modified Color Palette

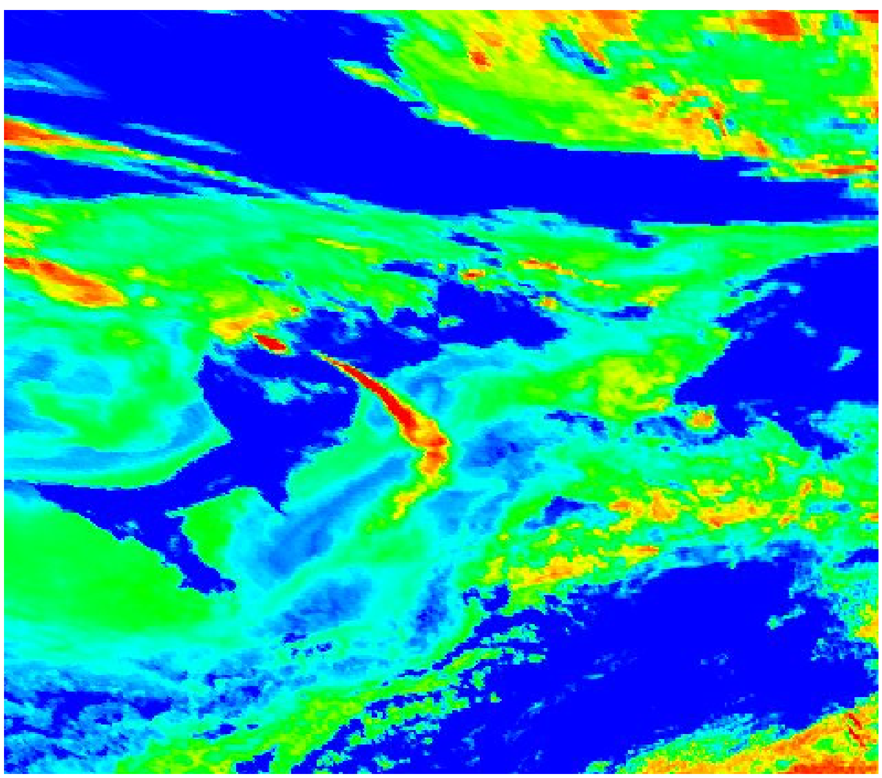


Figure 13: Color Palette on IR_039 - IR_108

The ash plume stretching from Iceland over the Atlantic Ocean is clearly visible but there is an evident example of false alarms.

This BTD tends to be positive for ash clouds with a high concentration of sulfure dioxide and sulfate, but does not allow to discern between ice and ash clouds.

3. BTD between **IR_087 - IR_108 channels**

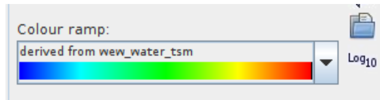
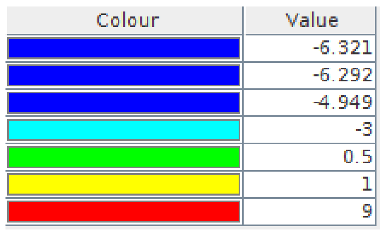


Figure 14: Original Color Palette



Colour	Value
	-6.321
	-6.292
	-4.949
	-3
	0.5
	1
	9

Figure 15: Modified Color Palette

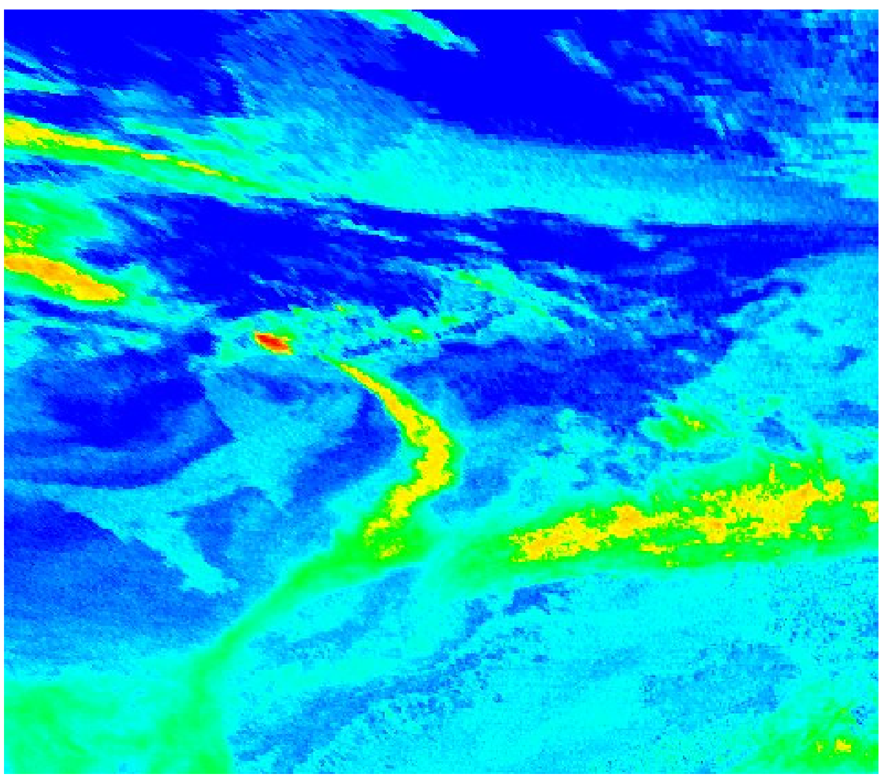


Figure 16: Color Palette on IR_087 - IR_108

The ash plume from Iceland over the Atlantic Ocean is clearly visible but there are also similar signatures in other areas of the image.

The main difference is that in the BTD test between IR_039 and IR_108 the ash-containing pixels tend to be red, whereas the same pixels are in light yellow in the BTD test between IR_087 and IR_108.

Basically, it means that the BTD test between IR_039 and IR_108 gives higher values for ash than the BTD test between IR_087 and IR_108, where there is slight difference between the tested spectral channels.

The BTD test between IR_087 and IR_108 tends to be positive for volcanic plumes with a high concentration of sulfure dioxide and silicate, because of sulfure dioxide absorption band at 8.7 m, whereas ice clouds, given their lower transparence at 10.8 m, behave opposite.

9. 10. Implement Volcanic Ash Detection Algorithm (VASD) using SNAP processing tools and apply (algorithm 1 and 2) and interpret their output results and differences

Volcanic Ash Detection Algorithm (VASD) are built using multi-channel data and combining the BTDs. At wavelengths between 8 and 14 m, silicate particles absorb infrared radiation more strongly at longer wavelengths, while water droplets, water vapor and ice particles (the most common constituents of meteorological clouds) absorb more strongly at shorter (infrared) wavelengths. The basic version of VASD consists in a binary algorithm, where there is a flag for ash cloud containing pixels and no flag for all the other classes of pixels (clear sky over land, clear sky over water, meteorological cloud). VASD uses a combination of the previously described tests, implementing the following conditions, that we'll call VASD_1, to detect an ash cloud:

$$\begin{cases} IR\_120 - IR\_108 > 0 \\ IR\_039 - IR\_108 > 0 \\ IR\_087 - IR\_108 > 0 \end{cases}$$

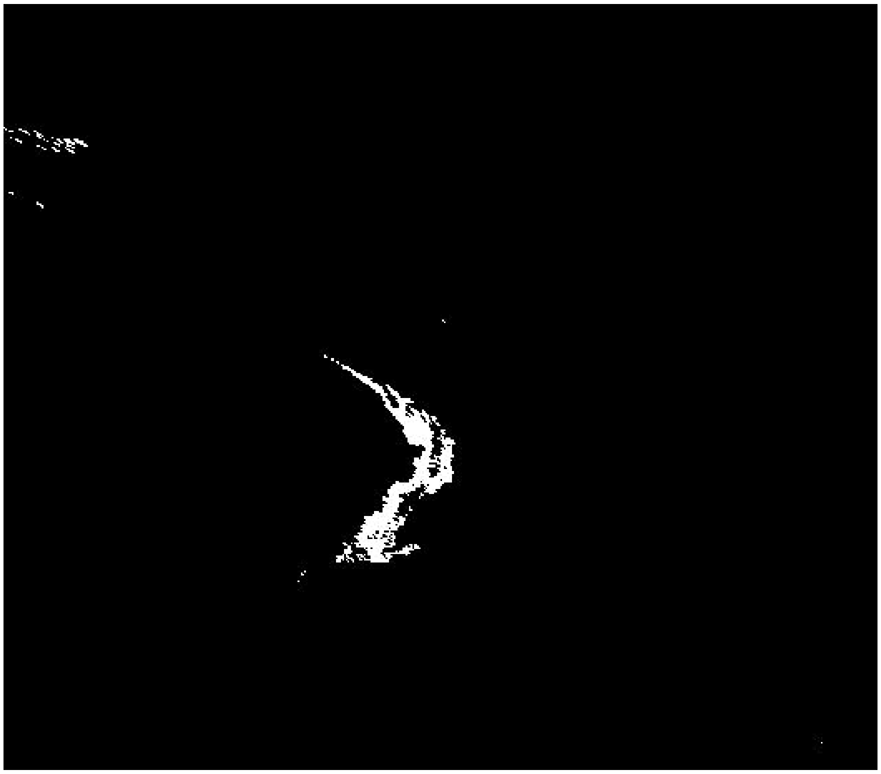


Figure 17: VASD_1 Algorithm

Consider now the formula:

$$60 + 10 * (IR\_120IR\_108) + (IR\_039IR\_108) > 100 \tag{1}$$

The algorithm, VASD_2, is less sensitive (i.e. higher number of false negatives or missed detection of ash pixels) with respect to the VASD, but in turn this results in a lower occurrence of false positives.
It is quite glaring the detection performances of this technique: more ash pixels are found, but there are many false alarms too.

Figure 18: VASD_2 Algorithm

We neglect now the BTD between IR_120 and IR_108 channels (VASD_3):

$$\begin{cases} IR\_039 - IR\_108 > 0 \\ IR\_087 - IR\_108 > 0 \end{cases}$$

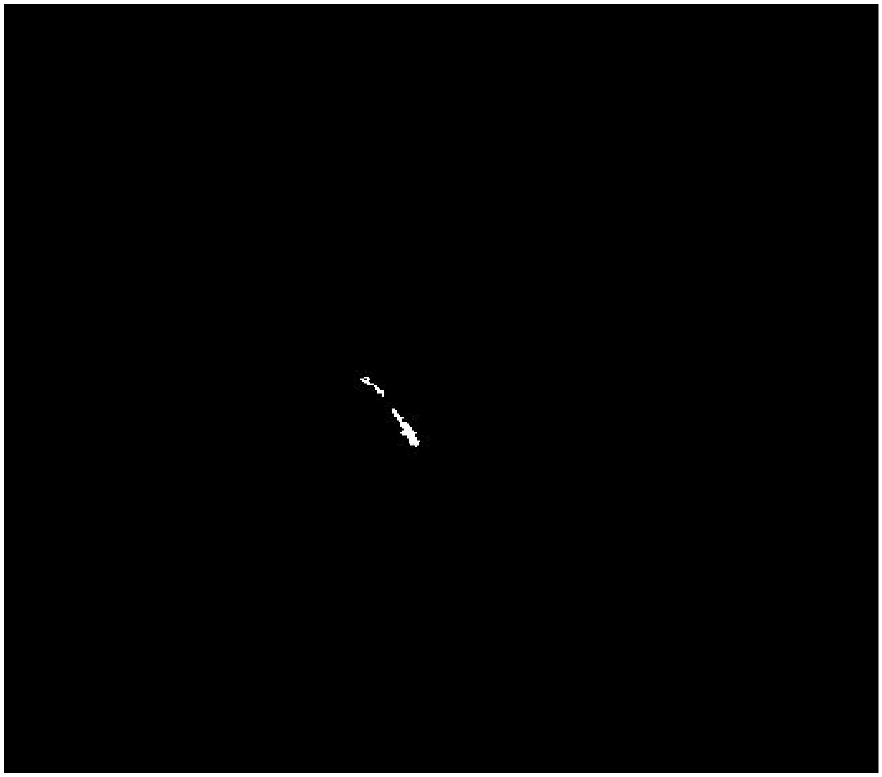


Figure 19: VASD_3 Algorithm

Choosing an adequate value of the detection threshold is the key to have a good trade-off between false positives (i.e. false alarms: ash-free pixels marked as if they include ash) and false-negatives (i.e. missed detections: pixels containing ash marked as if they are ash-free). The expected behavior is the following: the higher conservative (i.e. low threshold) the approach, the higher the false alarms; vice versa, the higher the value of the threshold, the lower the sensitivity of the algorithm.

11. 12. Develop and implement a TIR optical thickness retrieval algorithm by applying the no-scattering radiative transfer theory for a thermal homogeneous ash cloud layer and apply the TIR retrieval algorithm at 10.800 nm and at 11.000 nm to ash-cloud mask using SEVIRI data and interpret the output results

The observed radiation is the result of a series of interactions with the surface and the atmosphere with an external radiation source.

$$I_{sat}(\theta, H) = t(\theta)[e(\theta)I_{BB}(T_s) + wE_i/\pi] + I_{UPW} \tag{2}$$

Where:

I_{sat}: radiance observed by the satellite sensor
I_{UPW}: upward atmospheric radiance (haze)
$t(\%)$: atmospheric transmittance
T_s: surface temperature
E_i: upward atmospheric radiance (haze) irradiance incident upon the surface

We assume a homogeneous isothermal (constant temperature and interaction parameters) non-scattering layer of thickness H, neglect phenomena reflection / refraction at the interfaces.
The first term will be neglegible so that we have only I_{UPW} that, with the Rayleigh-Jeans approximation, can be written as:

$$T_B(r) = T_0[1 - t(0, L)] = e^{-k_{e0}L} \tag{3}$$

That becomes:

$$\tau = -ln(1 - T_B/T_0) \tag{4}$$

Where:

τ: optical thickness of the layer
T_0: temperature of the layer/ash cloud

We could extract T_0 from metereological data over Iceland (`http://weather.uwyo.edu/upperair/sounding.html`) but the argument of the logarithm would be negative ($T_0 < T_B$) so we could also consider to take the ash pixel with the highest optical tickness (black body).

So we mask the ash cloud with the first VASD algorithm (VASD_1) on the band IR_108 with the formula:

if VASD_1 == 1 $then$ IR_108 $else$ NaN

In the "Analysis" section in SNAP we look for "Statistics" and we see the pixel with the max value that is max(T$_B$) = 269.35

#Pixels to...	48089
Minimum:	219.8472
Maximum:	269.3503
Mean:	260.5950
Sigma:	9.7692
Median:	264.0538
Coef Varia...	0.0713
ENL:	196.6822
P75 thres...	266.1326
P80 thres...	266.6771
P85 thres...	266.9741
P90 thres...	267.5187
Max error:	0.0495

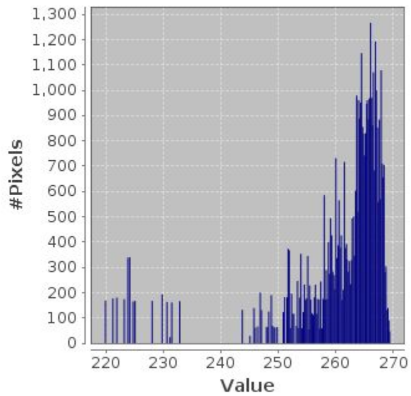


Figure 20: VASD mask statistics

Approximating T_0=max(T_B), we calculate the optical thickness with:

if (VASD_1 == 1) *then* -log(1 - IR_108/269.35) *else* NaN

In the following figure we can see a color palette showing pixel values from red, the highest values, to green, the lowest ones.

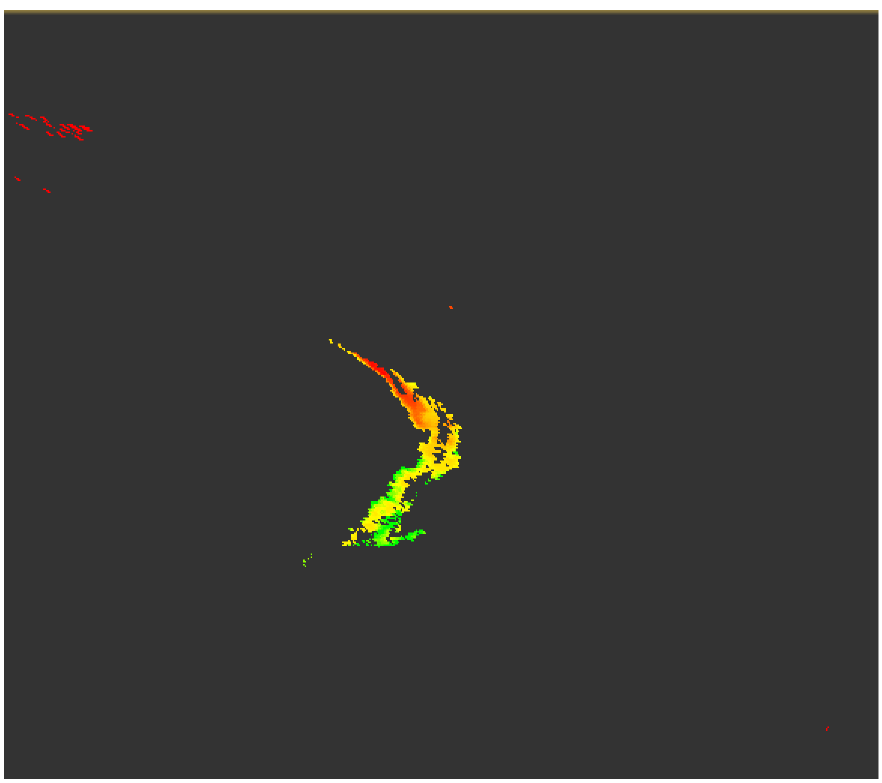


Figure 21: TIR (on the VASD_1) in the IR_108 band

In the IR_120 instead:

if VASD_1 == 1 *then* IR_108 *else* NaN

$\max(T_B) = 270.63$

So the optical thickness in the IR_120 will be:

if (VASD_1 == 1) *then* -log(1 - IR_120/270.63) *else* NaN

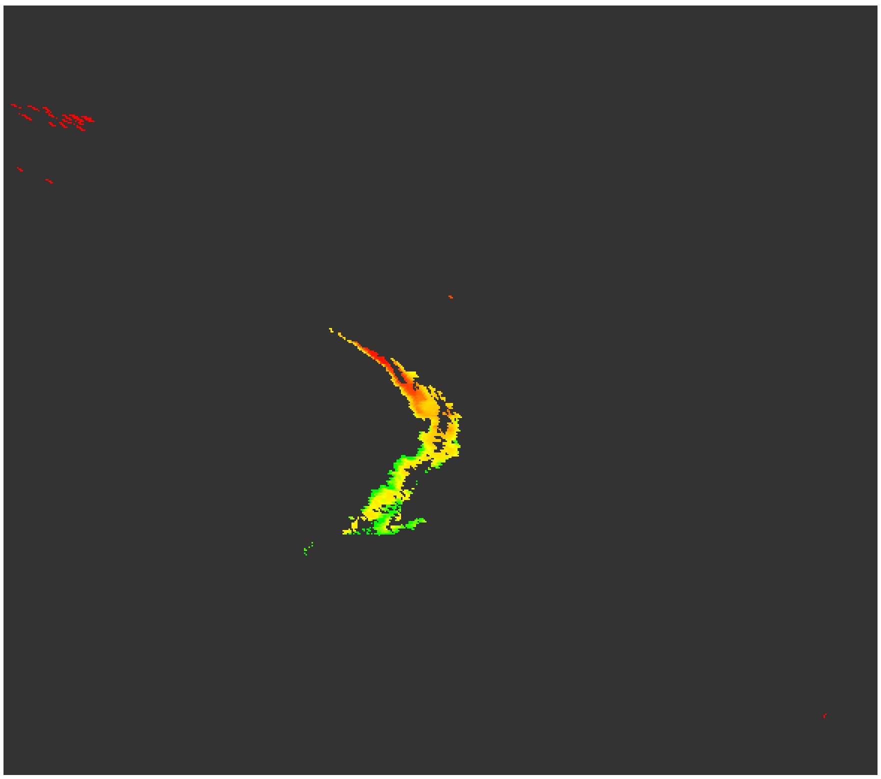


Figure 22: TIR (on the VASD_1) in the IR_120 band