Earth Observation Data Analysis - Homework 02 - 2018

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1. Install SNAP

To download SNAP, go to the link http://step.esa.int/main/download/.

2. Follow LearnEO-Lesson13 (http://www.learn-eo.org/lessons/l13), step by step as in the following, by using SNAP instead of Bilko tool

The guide LeainEO-Lesson13 was followed to write the results for the homework. Other materials have been used to provide a clearer explanation of the behavior of the elements composing an ash cloud. The material is listed in the bibliography at the end of the homework.

3. Download the SEVIRI/METEOSAT and MODIS/AQUA imagery on the case study of the 2010 Icelandic eruption of 2010, following LearnEO-Lesson13 instructions or download data provided by the professor.

The images used for the homework are the following:

- MSG_201005081200, SEVIRI 12:00 UTC on 8th May 2010 (Iceland)
- MSG_201101122300, SEVIRI 23:00 UTC on 12th Jan 2011 (Etna)
- MOD02HKM.A2010129.1225.005, MODIS 12:25 UTC on 9th May 2010

The first 2 observations are made by SEVIRI/METEOSAT while the second one is made by MODIS/AQUA.

METEOSAT is a geostationary satellite and the instrument SEVIRI has the capacity of observe Earth in 12 spectral channels with 3 km of resolution, except the HRV channel that has 1 km resolution. [2]

AQUA is a LEO satellite and the instrument MODIS is a 36-band spectroradiometer. [3]

4. Perform data quality check

In the file MSG_201005081200 all the images are usable to perform the tasks asked in the homework.

In the file MSG_201101122300 the usable images are:

- IR_039, WV_062, WV_073, IR_087, IR_097, IR_108, IR_120, IR_134.

The images VIS006, VIS008, IR_016 are non-usable.

In the file MOD02HKM.A2010129.1225.005 all the images are usable to perform the tasks asked in the homework.

5. Perform and display “visible” RGB (Red-Green-Blue) composite with MODIS data

To display the RGB image with the MODIS data I used the **645nm Band 1** for the red color, the **469 nm Band 3** for the blue color and the **555 nm Band 4** for the green color.

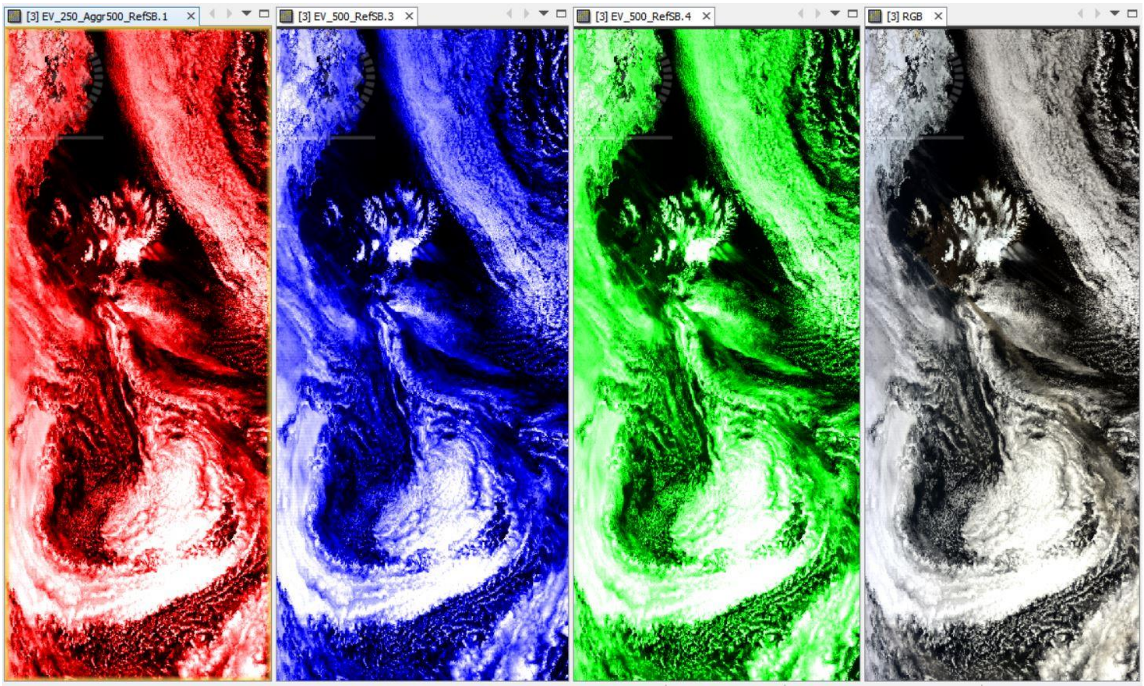

Figure 1 - Red, blue, green and RGB images using MODIS data

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

I cannot perform the standard RGB image using the proper frequencies for the red, green and blue color, because that information is not provided by the SEVIRI data. The approach used is chosen to detect the volcanic ash clouds by a visual inspection of the product using **IR_087** as red, **IR_108** as green and **IR_120** as blue.

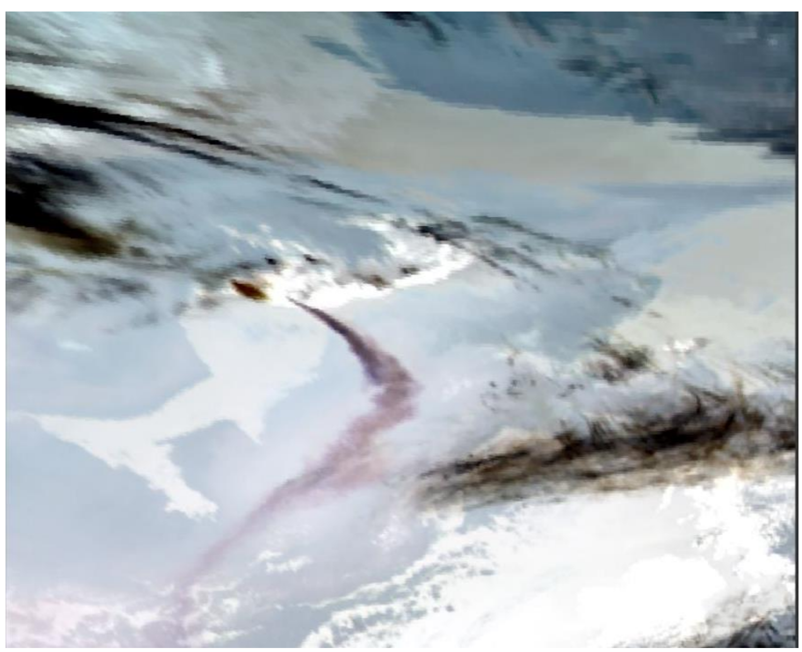

Figure 2 – virtual RGB images using SEVIRI channels (Iceland)

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

In the next image I performed an analysis of stacked imaged (the RGB product of 3 different frequencies) using the transects to study the **ash-cloud signature**. To perform this analysis, I traced a line over the detected ash plume and I displayed the profile plot to quantify the temperature measured by SEVIRI. Following the line, the behavior is stable.

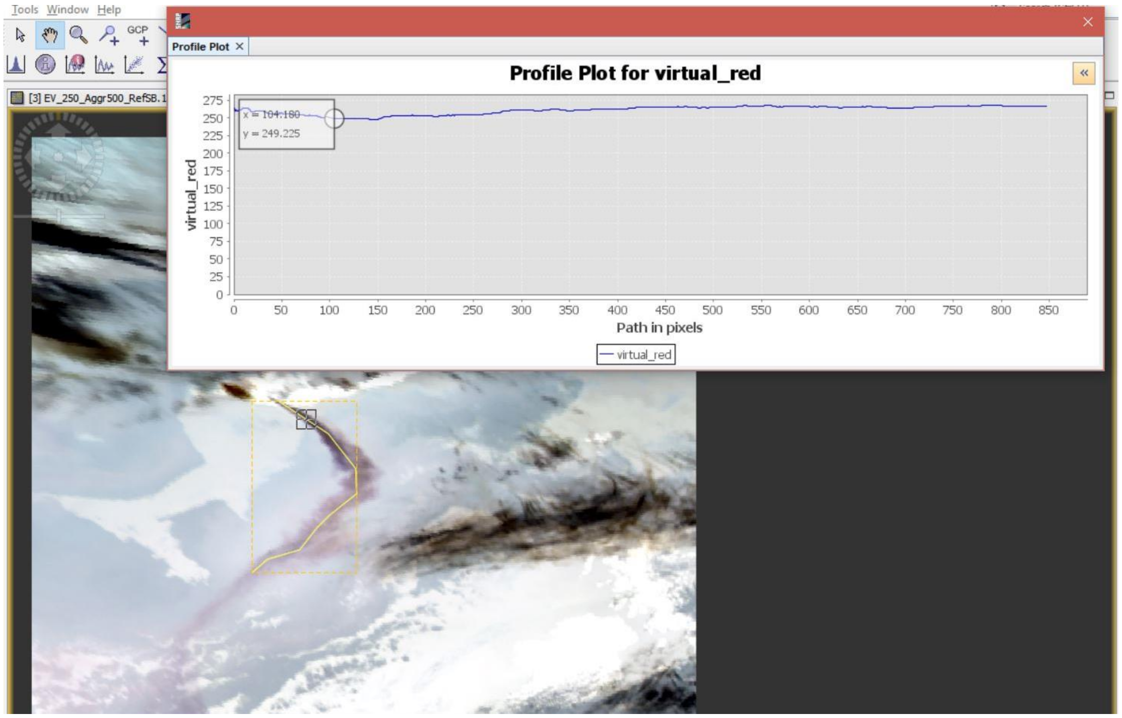

Figure 3 - Profile plot of the ash plume

All the three channels listed in the previous point exhibit a similar trend in the region of the ash plume. This can be clearly seen in the next image where the three profiles are compared.

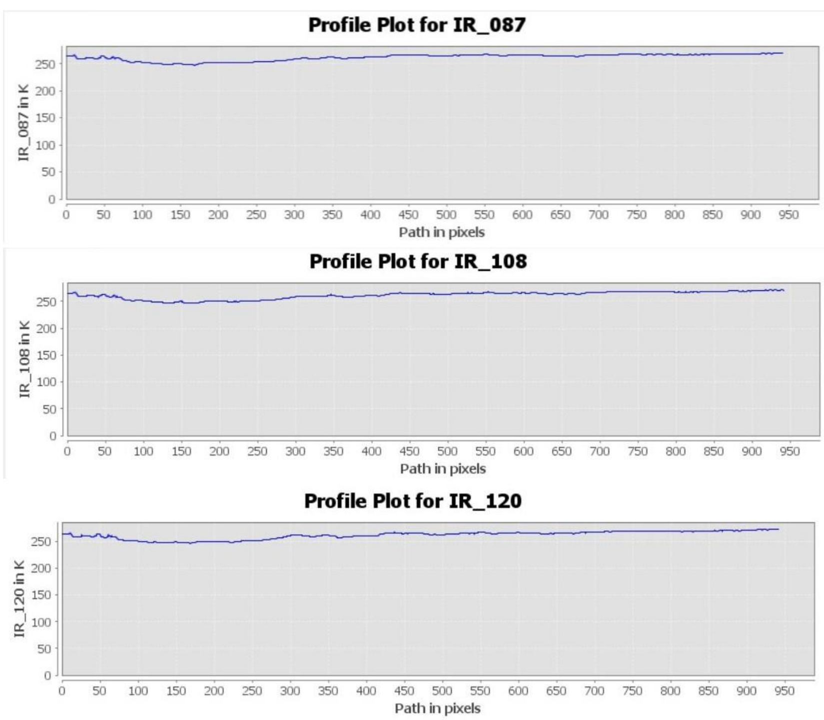

Figure 4 - Profile plot of the 3 channels over the ash plume

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

In the next imaged the result of the BTD using SEVIRI data is showed. Volcanic ash clouds consist of silicate particles, aluminium dioxide, ferrous sulphates and other elements. Furthermore, it's known that after the eruption of Eyjafjallajökull the analysis of the components of the ash cloud showed a **high concentration of silicate** particles (58%) [1].

The main idea of the analysis that we are performing is discerning the most common constituents of meteorological clouds (water droplets, water vapor and ice particles) from ash clouds.

The silicate particles have a **lower emissivity at 10.8 µm** than at 12.0 µm, so the difference between IR_120 and IR_108 would be positive with respect to the ash clouds. In the case of the ice clouds the brightness temperature difference will be negative due to a lower emissivity ad 12.0 µm with respect to 10.8 µm. In the next image the positive values are, in increasing order, the red and black ones. The negative values are, in decreasing order, the yellow, green, light blue and blue ones. In the end the **black pixels** should represent **the ash cloud** and the blue pixels should represent the ice clouds.

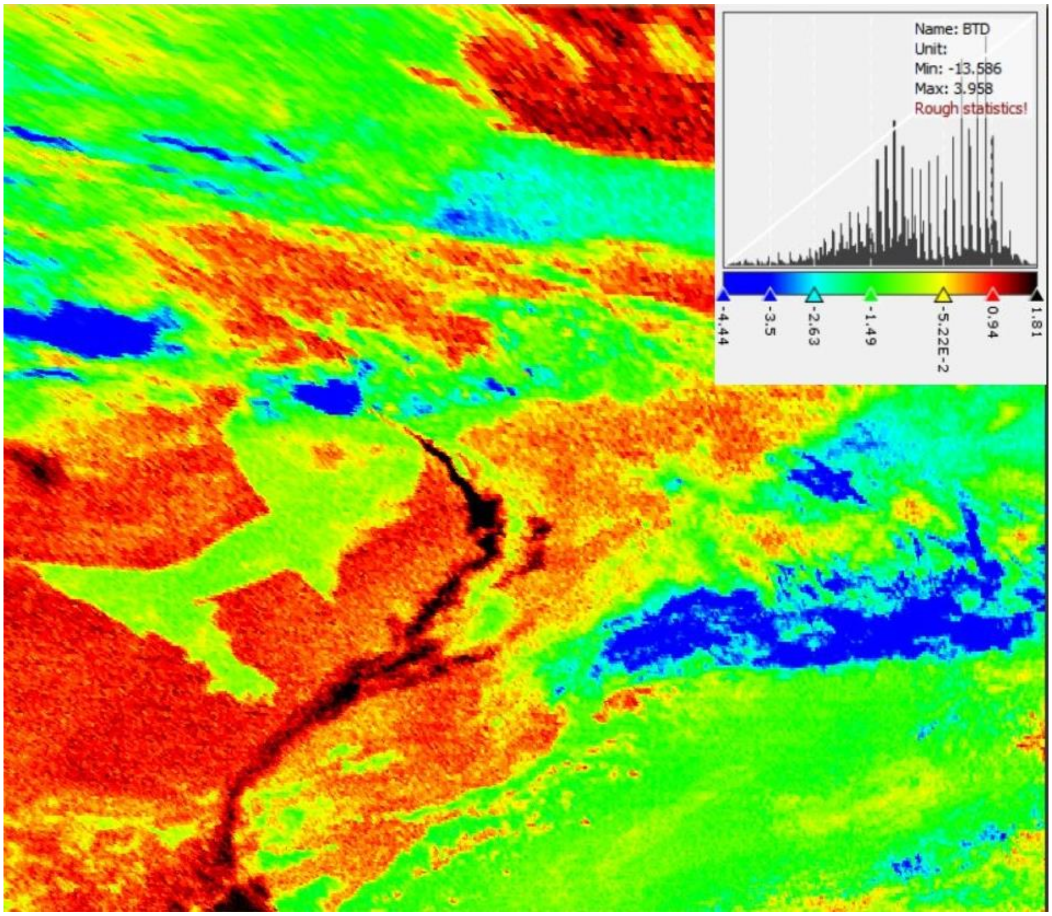

Figure 5 - BTD between IR_120 and IR_108

The method used in the previous picture allows a discrimination among ice clouds and volcanic ash clouds, but further analysis can be accomplished considering the behavior of other elements. As a matter of fact, using only this computation it's not possible to identify correctly the ash plume because there are clearly **false positive** pixels (top and left).

Using the 8.7 µm band it's possible to detect the concentration of sulfur dioxide, which can be present in volcanic plumes. SO2 molecule has a **higher absorption at 8.7 µm** with respect to 10.8 µm, thus computing the brightness temperature difference between IR_087 and IR_108 it's possible to find SO2 clouds looking for positive values.

In contrast ice clouds are more transparent at IR_087 than IR_108 so it's possible to detect them looking for negative pixels values. This is the generic theoretical analysis, but as it can be seen in the next image the ash cloud cannot be discriminate.

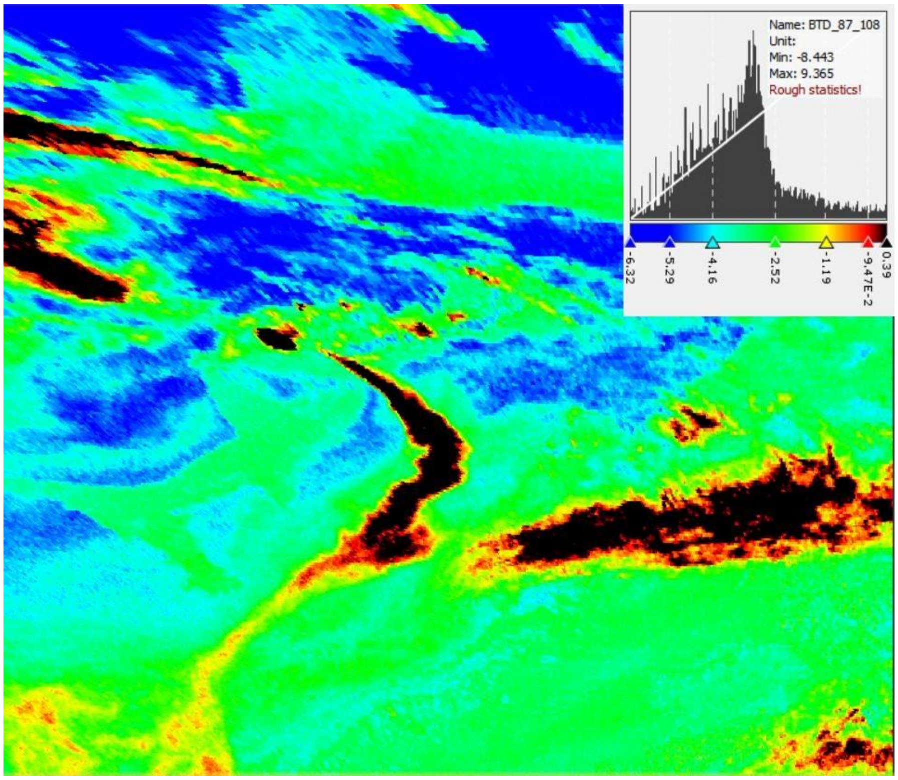

Figure 6 - BTD between IR_087 and IR_108

Even the brightness temperature difference between IR_039 and IR_120 can't allow the discrimination between the ash clouds and the ice clouds, because there are a lot of false positive as it can be seen in the next image.

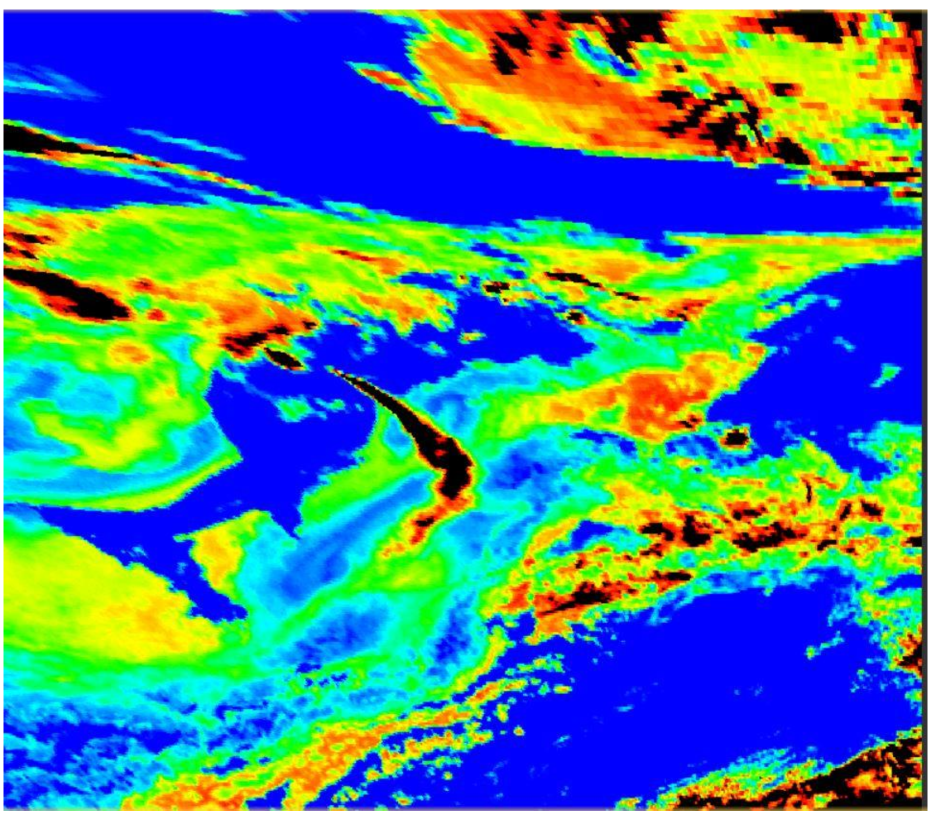

Figure 7 - BTD between IR_039 and IR_108

9. Implement Volcanic Ash Detection Algorithm (VASD) using SNAP processing tools

The implementation of the VASD is a combination of the ideas seen in the BTD analysis and basically uses the three BTD implemented in the previous point to detect ash clouds obtaining less ambiguity with respect to the single BTD.

The main idea is in the physical nature of silicate particle that absorb infrared waves more strongly at longer wavelengths, while water particles tend to absorb more strongly at shorter infrared wavelengths.

As it can easily be seen looking at the previous images, the **ash plume** has always **positive values**: this means that to detect the ash clouds the each BTD must be greater than zero.

To apply all the previous formulas, I create a Band Math using the logical operator AND to guarantee that the three BTD must greater than zero.

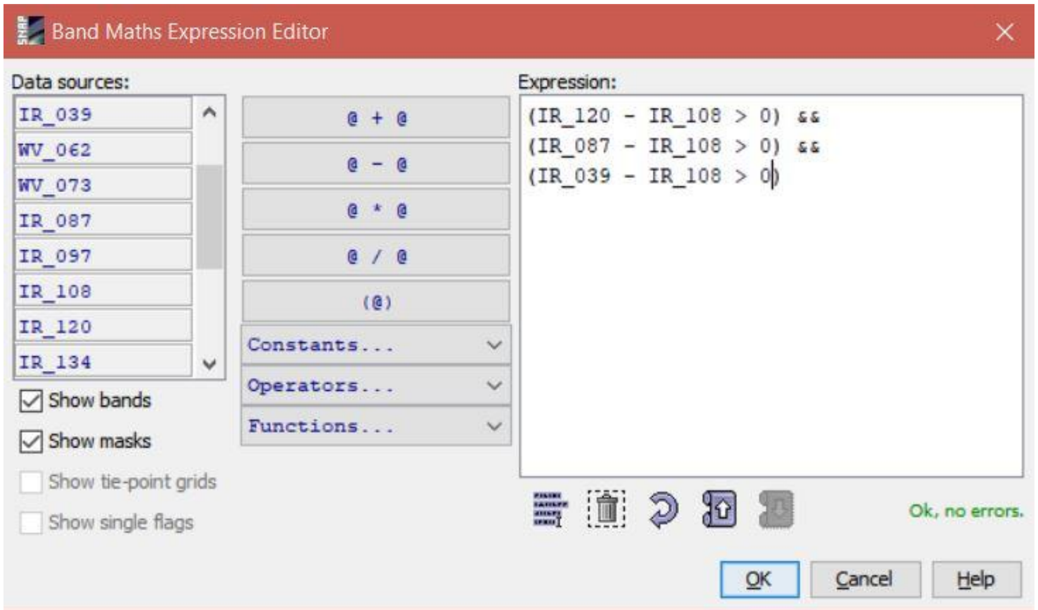

Figure 8 - VASD formula

Another approach to detect ash clouds is to apply the variant VASD formula shown in the next image.

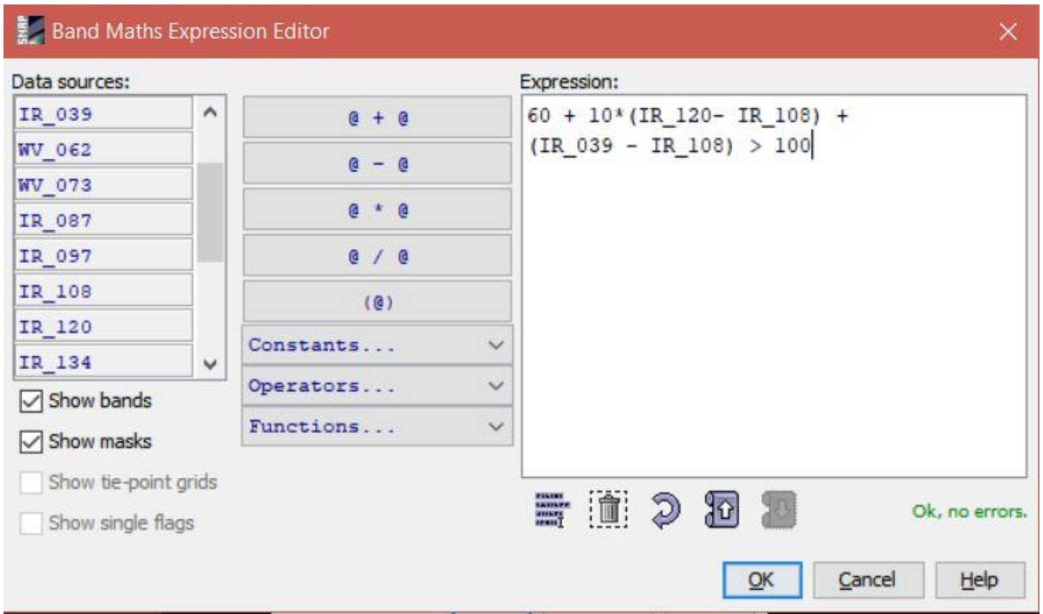

Figure 9 - Variant VASD formula

10. Apply VASD (algorithm 1 and 2) and interpret their output results and differences

The next images are the result of the formulas shown in the previous point: on the left the result of the VASD formula can be seen, while and **variant VASD formula** is on the right.

Figure 10 - VASD (on the left) and variant VASD (on the right)

The results of the VASD formula are quite reasonable, knowing where the Eyjafjallajökull volcano is and considering the **pattern visible** in the RGB image (Figure 11). There are other white pixels in the top left pixels that can be considered false positives, but the overall quality of this analysis is indeed high.

The image retrieved with the variant VASD approach isn't reliable as the previous one: only the initial part of the ash plume is detected and there are also some **false positive** on the top right of the image. It's clear that there are a lot of ash clouds **pixels not detected** (false negative).

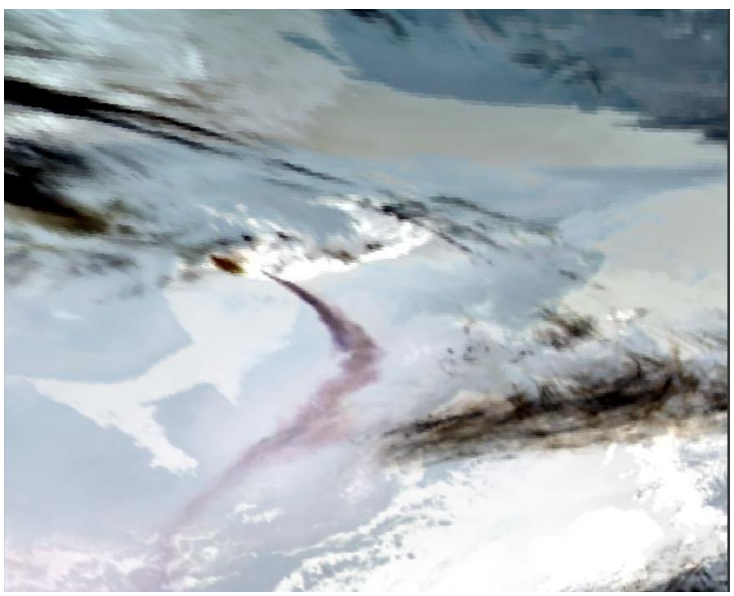

Figure 11 - virtual RGB of SEVIRI data

11. Develop and implement a TIR optical thickness retrieval algorithm by applying the no-scattering radiative transfer theory for a thermal homogeneous ash cloud layer noting that TB≤T0 (you can use SNAP, Python/Matlab or R-language environment to implement the algorithm depending on its complexity).

To retrieve the optical thickness an approximation of the spectral radiative transfer equation is needed in order to retrieve an estimator. Assuming a fully opaque atmosphere at TIR over the ash cloud all the equation can be simplified in this form:

$$I_{\lambda sat}(\lambda) = I_{\lambda eupw}(\lambda) = I_{\lambda BB}(1 - e^{-\tau})$$

Where τ is the needed optical thickness. Inverting the equation, I can explicit τ:

$$\tau = -\ln\left(1 - \frac{I_{\lambda sat}}{I_{\lambda BB}}\right)$$

Using the **Rayleigh-Jeans** approximation, the spectral radiance can be replaced with the spectral brightness temperature, (simplifying all the other constants):

$$\tau = -\ln\left(1 - \frac{T_{\lambda sat}}{T_{\lambda BB}}\right)$$

The optical thickness is the unknown variable to retrieve, $T_{\lambda sat}$ is the temperature measured by SEVIRI and $T_{\lambda BB}$ is the black body temperature. I don't have this information so I assume as black body temperature the **"hottest" pixel** in the image, pretending that can represent the equivalent temperature of a black body.

First, I computer the VASD formula to identify the ash cloud. As shown in the previous point, I obtain a mask where the ash plume ha pixel values equal to 1 and 0 elsewhere. To obtain the values of temperature of the ash cloud I multiply every single pixel by the value of the 10.8 µm image (later I'll do the same operation for the 12 µm image).

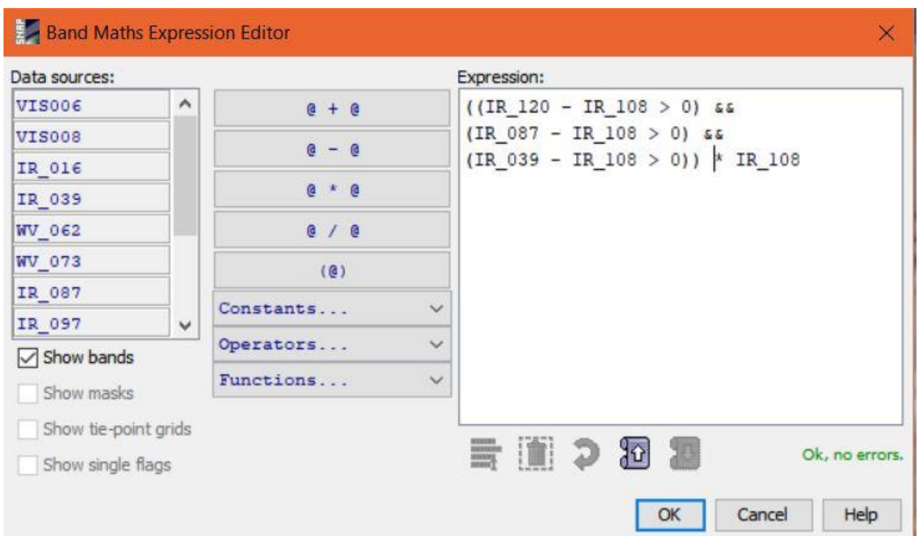

Figure 12 - VASD formula multiplied by the IR_108 image

The result is the ash cloud with pixels having the same value as the IR_108 image. To obtain the maximum value of the ash plume I simply inspect the histogram that shows **268.358 K** as maximum intensity.

This value will be the $T_{\lambda BB}$ spectral brightness temperature of the black body and will be used to retrieve the optical thickness.

The next image shows the implementation of the TIR optical thickness retrieval algorithm, where VASD_108 is the result of the previous computation showed in figure 12.

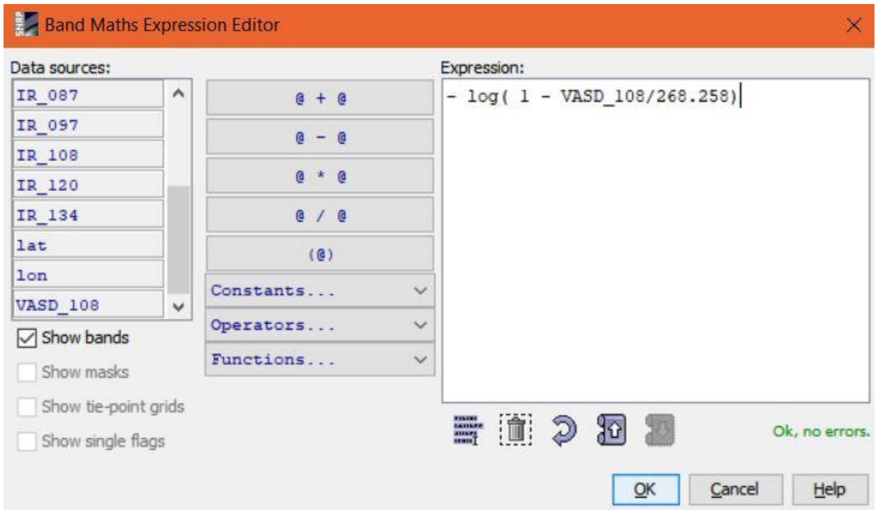

Figure 13 - TIR optical thickness retrieval algorithm for IR_108

The exact same procedure can be performed in the case of IR_120. The only difference is in the maximum value of the ash cloud, which is 270.31 K.

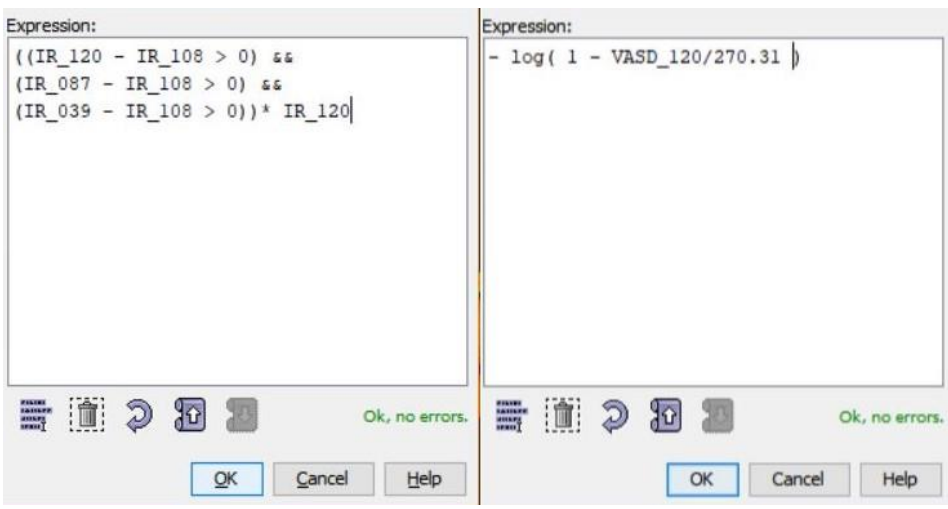

Figure 14 - TIR optical thickness retrieval algorithm for IR_120

In the last figure VASD_120 is the result obtained in the first step (left part) where I multiplied the ash cloud by the values of the IR_120 image. Those values are used to obtain the optical thickness τ (right part of the image).

12. Apply the TIR retrieval algorithm at 10.8 μm and at 12.0 μm to ash-cloud mask using SEVIRI data and interpret the output results (you can use SNAP, Python/Matlab or R-language environment to implement the algorithm depending on its complexity). Note that thermodynamical data (useful to compute the Planck law) can be retrieved from http://weather.uwyo.edu/upperair/sounding.html

Now I can apply all the formulas explained in the previous point to obtain numerical result of the optical thickness for each pixel of the IR_108 and the IR_120. In the next image there's the temperature brightness value of IR_108, where reddish colors have higher values and green/blue colors have lower values.

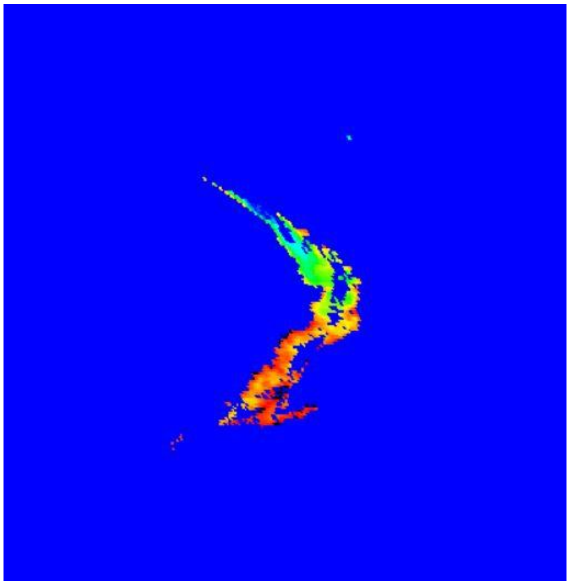

Figure 15 - temperature brightness of IR_108

Applying the formula of the optical thickness showed in the previous point, assuming $T_{\lambda BB}$ as the maximum values assumed by the ash cloud, I obtain the results showed in the next image.

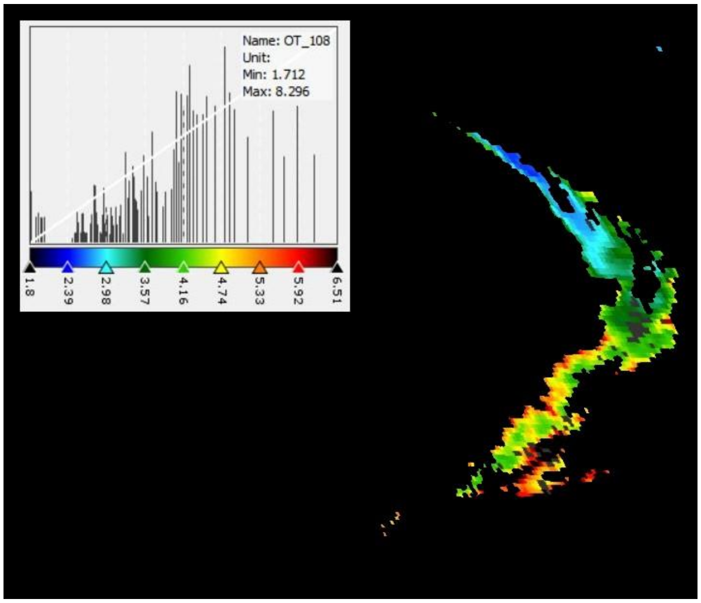

Figure 16 - optical thickness for IR_108

As shown in the next image that contains all the statistics of the optical thickness, the values are in a range from 1.71 to 8.3, with mean value 4.13, median 4.11 and standard deviation 1.2. While the first part of the ash cloud (top left) is less optically thick, the middle part has pixels with value around 4.

In the last part (bottom) of the plume the values near the edges are more than 5, and maybe this is due to the proximity of the cloud with other clouds excluded with the VASD formula.

OT_108

#Pixels total:	46393
Minimum:	1.7122
Maximum:	8.2961
Mean:	4.1340
Sigma:	1.2099
Median:	4.1185
Coef Variation:	0.6018
ENL:	2.7612
P75 threshold:	4.7727
P80 threshold:	4.9270
P85 threshold:	5.2356
P90 threshold:	5.5185
Max error:	0.0129

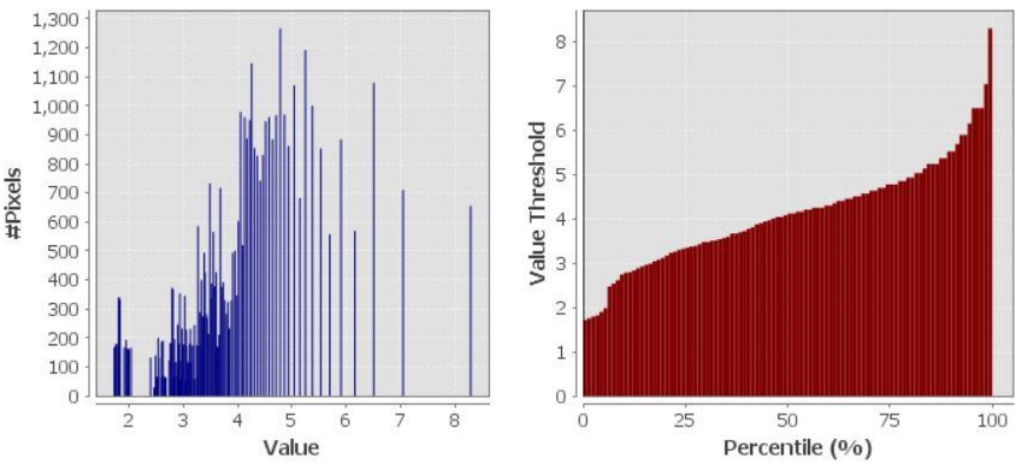

Figure 17 - statistics for the results of the optical thickness of IR_108

The same procedure can be done in the case of IR_120. As the previous case, in the next image there's the temperature brightness value of IR_120, where reddish colors have higher values and green/blue colors have lower values. The values seem to be similar with respect to IR_108, with less extreme case: in fact the red is less intense in the last part of the ash cloud.

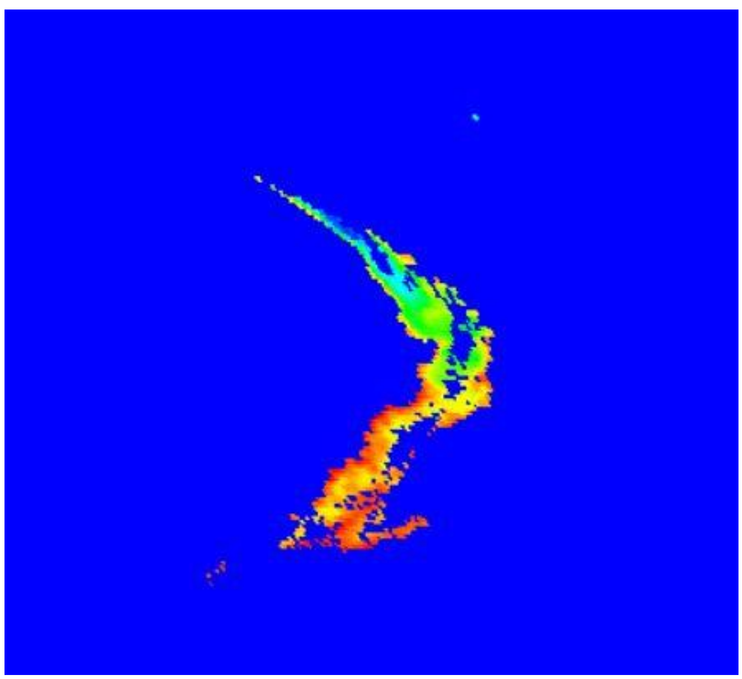

Figure 18 - temperature brightness of IR_120

Applying the formula of the optical thickness showed in the previous point I obtain the results showed in the next image.

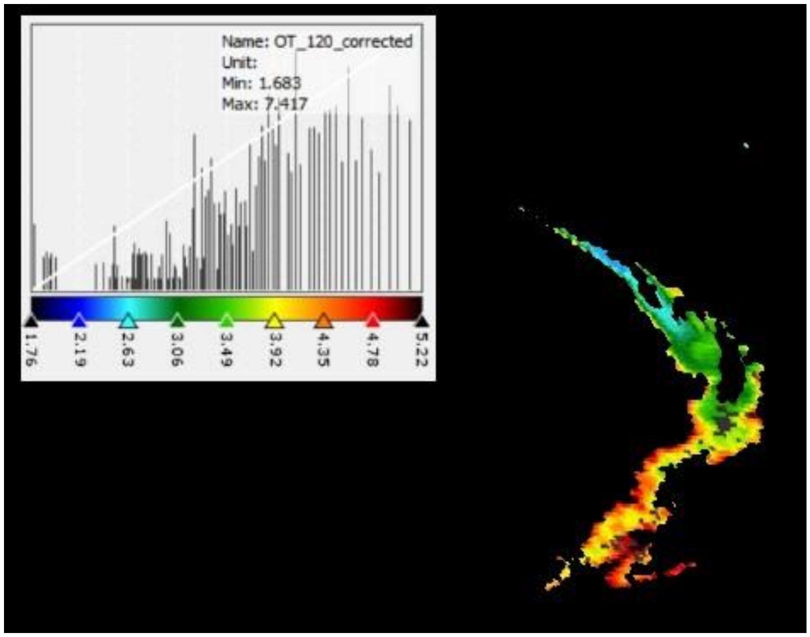

Figure 19 - optical thickness for IR_120

As shown in the next image that contains all the statistics of the optical thickness, the values are in a range from 1.68 to 7.41, with mean value 3.86, median 3.84 and standard deviation 0.95. While the first part of the ash cloud (top left) is less optically thick, the middle part has pixels with value around 3.8. In the last part (bottom) of the plume the values near the edges are more than 4.5, and maybe this is due to the proximity of the cloud with other clouds excluded with the VASD formula.

OT_120_corrected

#Pixels total:	47858
Minimum:	1.6830
Maximum:	7.4173
Mean:	3.8553
Sigma:	0.9502
Median:	3.8446
Coef Variation:	0.4864
ENL:	4.2273
P75 threshold:	4.3934
P80 threshold:	4.5614
P85 threshold:	4.7630
P90 threshold:	4.9982
Max error:	0.0112

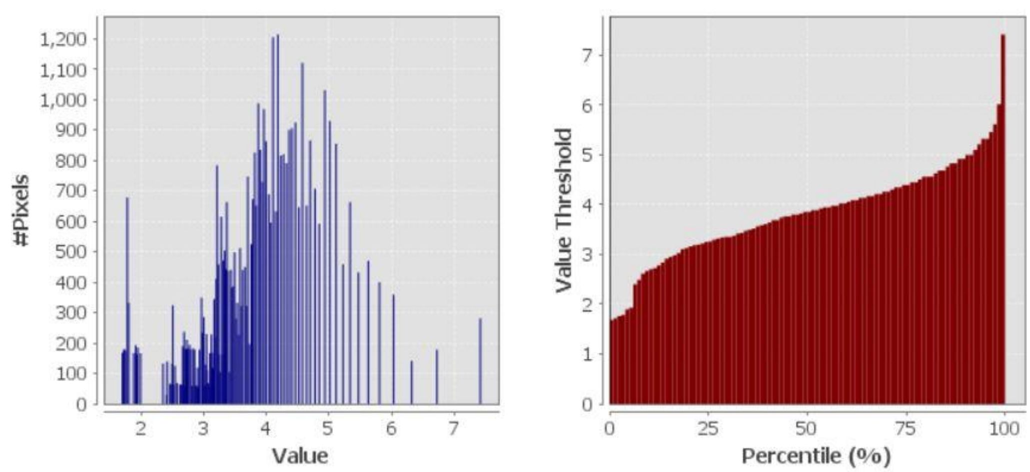

Figure 20 - statistics for the results of the optical thickness of IR_120

Silicate particles have a higher emissivity at 12 μm with respect to 10.8 μm, so ideally the results of the optical thickness are more reliable. Confronting the two histograms I noticed that the optical thickness values at 12 μm are **less sparse** (lower standard deviation) and more concentrated around the mean, while the optical thickness at 10.8 μm have more sparse values: this can be seen in the histogram looking at values greater than 5.

Maybe this is because at 10.8 μm there is a higher influence of the ice clouds with respect to 12 μm. In the latter case the results seem to be more consistent, even if the difference between the two cases is not so evident.

Bibliography

[1] http://eumetrain.org/data/1/144/navmenu.php?page=3.2.0
[2] https://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Meteosat/MeteosatDesign/index.html
[3] https://aqua.nasa.gov/modis