Ash Cloud detection with SEVIRI/METEOSAT data

Homework 2

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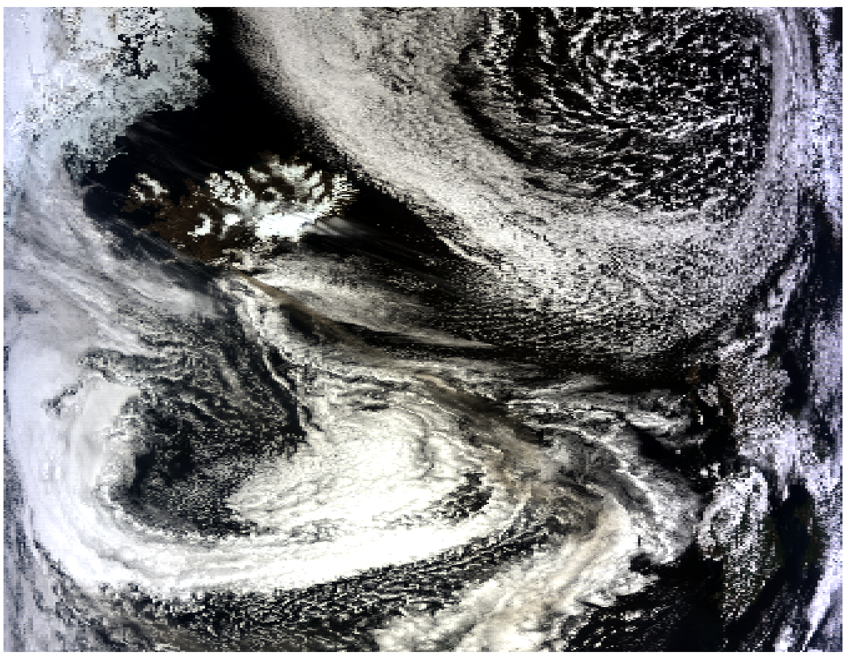
Earth Observation

INTRODUCTION

Volcanic eruptions represent a serious threat to human safety and may have a huge impact on economic activities. Prevention and mitigation of risks related to volcanic activity through the comprehension, better knowledge and continuous supervision is an imperative need. So in this work we want to deal with some methods with the aim to discriminate ash-clouds by environment remote sensing data (MODIS and SEVIRI).

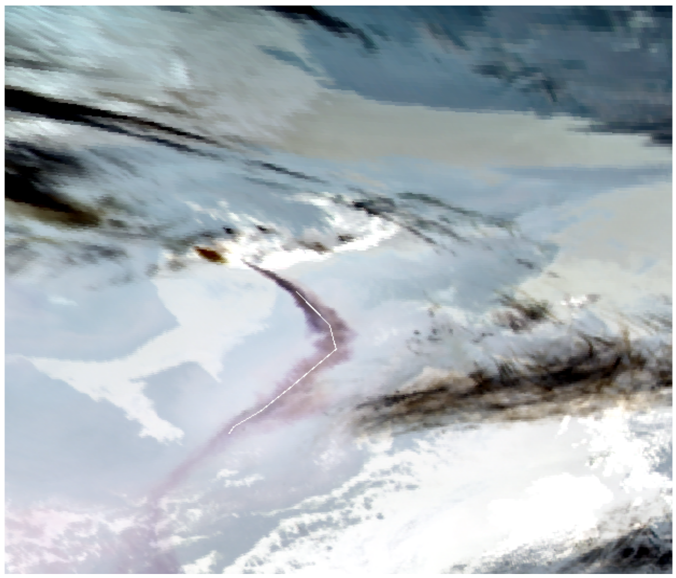
RGB visualization and Profile plot

To have a first look of what information these data gives us, I build two RGB images one using MODIS "visible" bands, that reproduce a realistic image of what our eyes can see usually.



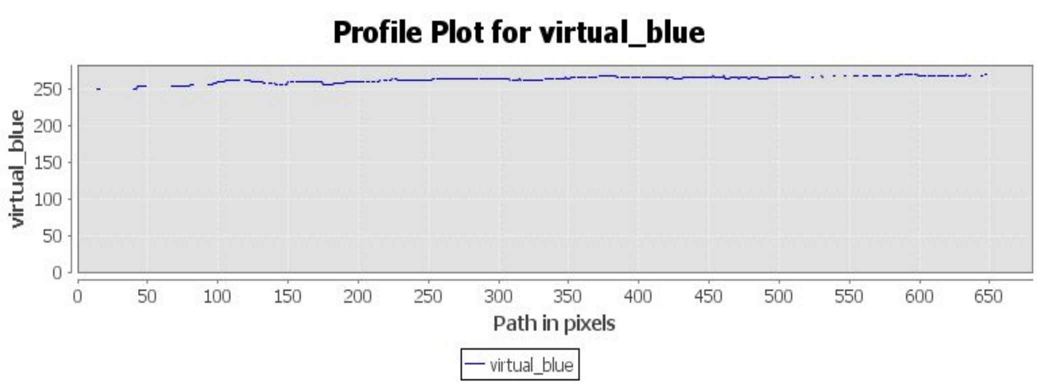
(bands selected are: red 645 nm, Green 555 nm, Blue 469 nm)

Afterwards, since from the real one is not easy to detect clearly the ash cloud, we can create a virtual RGB image that highlights on the ash cloud since sulphur dioxide (SO_2) has an higher absorption on the infrared bands and if we choose bands that are far from water vapor absorption we can clearly identify ash clouds. In this second case I used SEVIRI data, which are more interesting since SEVIRI is on a geostationary satellite and we can have images from it each 15 minutes allowing to monitoring and detecting ash cloud continuously.



(selected bands: red 8700 nm, green 10800 nm, blue 12000 nm)

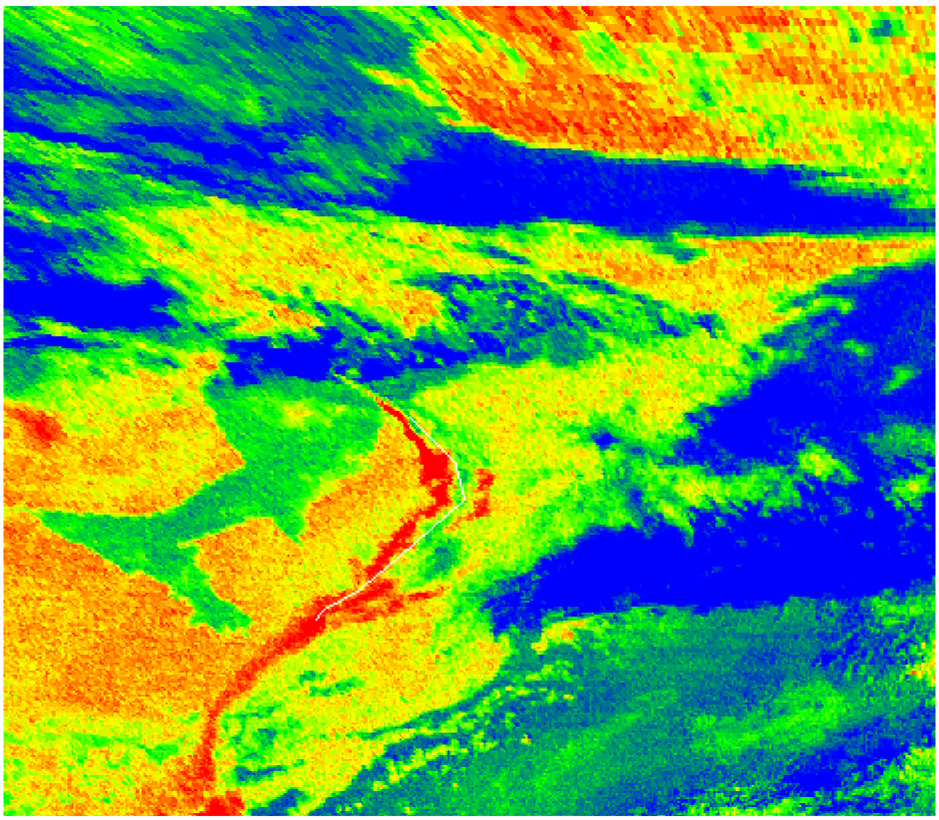
Here the ash cloud is much more clear, even if the resolution of SEVIRI is lower than the one of MODIS. Another proof of the fact that ash cloud absorption on IR is high is in the transect below.



the same behaviour we have also for virtual red and virtual green.

Brightness Temperature Difference

BTD is a basic detection technique exploiting the difference behavior of silicate particle on different spectral channels. Infact the silicate particles have a lower emissivity at 10.8 µm than at 12.0 µm, thus the difference between IR_120 and IR_108 would be positive for ash clouds, whereas ice clouds and water clouds brightness temperature difference is going to be negative due to lower emissivity at 12.0 µm with respect to 10.8 µm.



(BTD 12 µm - 10,8 µm)

To visualize better the differences between the temperature values, red ones are those with BTD above 1, the yellow ones has BTD > 0, whereas values under 0 are green and blue correspondly to them negativity, blue ones have BTD values below negative 2.

Volcanic Ash Detection Algorithm

How we notice in the previous image, BTD method is good to identify ash clouds but it gives unfortunately a lot of false positive, and to provide the lack of specificity of the previously seen methods, in literature is used a combination of several BTDs, and the algorithm originated is called VASD (Volcanic Ash Detection Algorithm).

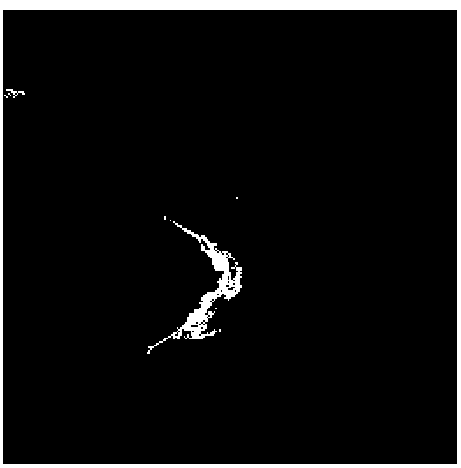
We are going to see two different VASD:

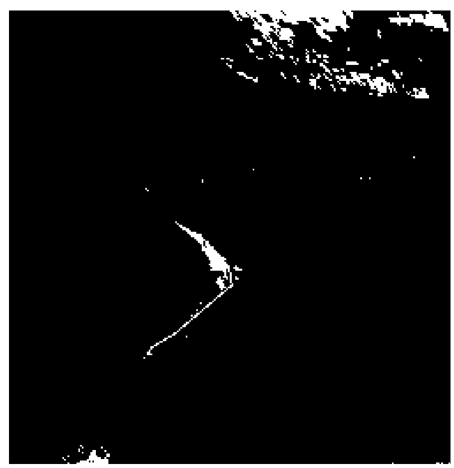
1) is builded by the join of three BTD:

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

2) is a simple linear combination of two BTD:

$$60 + 10 * (IR\_120 - IR\_108) + (IR\_039 - IR\_108) > 100$$





Now the detection method has a better specificity, but makes us think about the clouds on the top right… Are they ash clouds or not?

I can’t answer this question certainty since we need to know all the elements which have higher emissivity on 12 μm and 3.9 μm than on 10.8 μm. But still I will advice pilots flying on that direction since the behaviour on that zone is not clear.

TIR optical thickness algorithm using the no-scattering radiative transfer theory for a thermal homogeneous ash cloud layer

The specific intensity of radiation is the energy flux per unit time, unit frequency, unit solid angle and unit area normal to the direction of propagation.

The radiative transfer equation states that the specific intensity of radiation I_λ during its propagation in a medium is subject to losses due to extinction and gains due to emission

$$\frac{d I_\lambda}{d s} = - \mu_\lambda \cdot I_\lambda + \rho \cdot J_\lambda$$

where s is the coordinate along the optical path, μ_λ is the extinction coefficient, ρ is the mass density and J_λ is the emission coefficient per unit mass. With this notation the optical thickness is defined by $\tau(s) = \int_0^s \mu_\lambda(s)\, ds$, and since in our simplification the ash cloud is homogeneous we have $\tau(s) = \mu_\lambda \cdot [s - 0]$.

The extinction coefficient μ_λ includes both absorption α and scattering σ coefficients:

$$\mu_\lambda = \alpha_\lambda{}^{gas} + \alpha_\lambda{}^{aerosol} + \sigma_\lambda{}^{gas} + \sigma_\lambda{}^{aerosol}$$

but in our case the approximation to a pure gas atmosphere with no-scattering, a simpler expression is obtained: $\mu_\lambda = \alpha_\lambda{}^{gas} = \alpha_\lambda$.

In absence of scattering and for local thermodynamic equilibrium (LTE), the source function is equal to: $\rho \cdot J_\lambda = \alpha_\lambda \cdot B_\lambda(T)$. Where α_λ is the absorption coefficient (equal to the emission coefficient for the Kirchhoff's law) and $B_\lambda(T)$ is the Plank function at frequency λ and temperature T.

So for an atmosphere with no scattering and in LTE the radiative transfer equation is reduced to:

$$\frac{d I_\lambda}{d s} = - \alpha_\lambda \cdot I_\lambda + \alpha \cdot B_\lambda(T)$$

Integrating this differential equation along the path going from s_1 to s_2, we have the solution:

$$I_\lambda(s_2) = I_\lambda(s_1) \cdot e^{-\alpha_\lambda (s_2 - s_1)} + B_\lambda(T) \cdot (1 - e^{-\alpha_\lambda (s_2 - s_1)})$$

and assuming that the ash cloud is fully opaque at TIR, then the radiative transfer equation for wavelength in TIR range will be: $I_\lambda(s_2) = B_\lambda(T) \cdot (1 - e^{-\tau})$

inverting the equation we can find that the optical thickness is:

$$\tau = -ln(1 - \frac{I_\lambda(s_2)}{B_\lambda(T)})$$

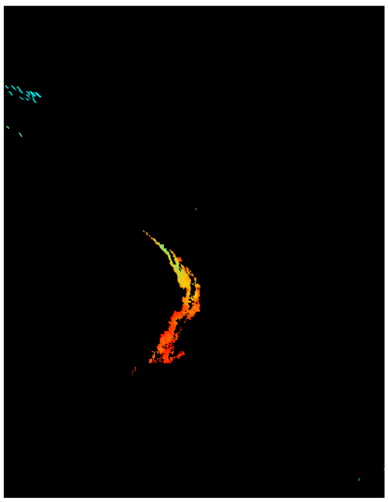
and using **Rayleigh-Jeans** approximation:

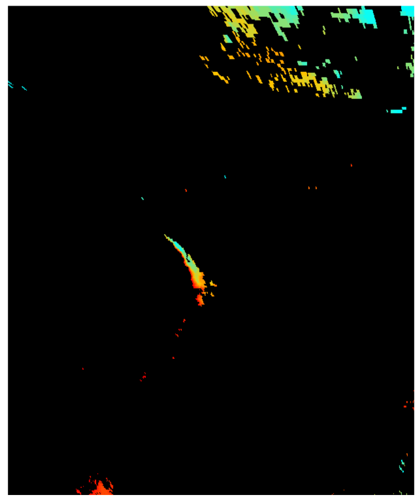
$$\tau = -ln(1 - \frac{T_\lambda(s_2)}{T_{\lambda BB}})$$

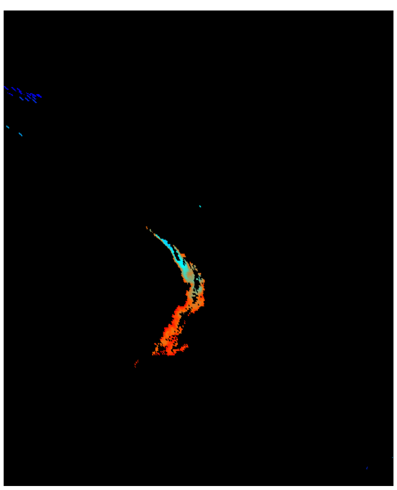
where $T_\lambda(s_2)$ is the temperature measured by thermal infrared sensors, whereas $T_{\lambda BB}$ is the temperature of the ash cloud according to the black body model.

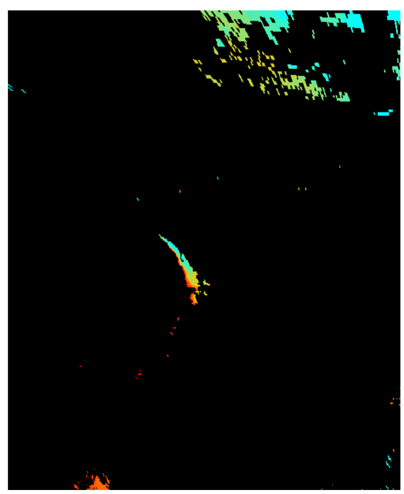
Applying the TIR retrieval algorithm at 10.8 μm and at 12.0 μm to ash-cloud mask using SEVIRI data and interpret the output results

Since the temperature of the black body is constant given the wavelength in the homogeneous simplification we can replace this number with the hottest pixel in the image, so this are the temperature for mask 1 and mask 2 at 10.8 μm and 12.0 μm.

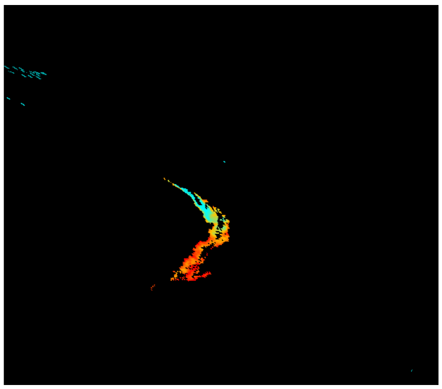
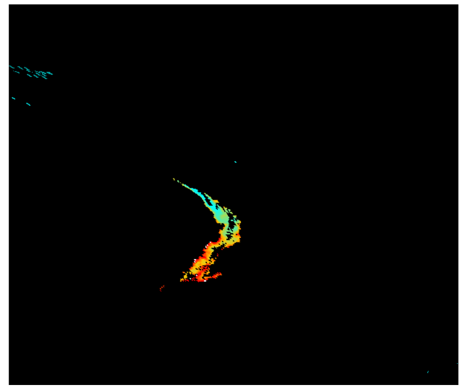
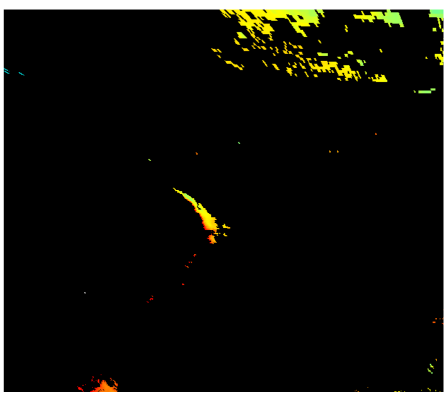
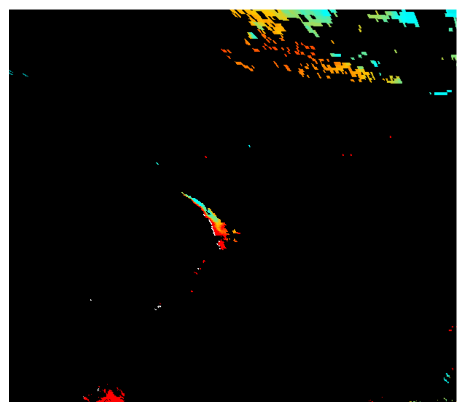








and this are the optical thickness computed with the formula seen previously.

From these images is possible to behaviour of an approximated optical thickness for mask 1 created using VASD 1 for a wavelength of 10.8 μm first and after 12.0 μm, below instead we can see for mask 2 using VASD 2.

It's interesting to note that values for optical thickness are higher at 10.8 μm wavelength than the ones at 12.0 μm these phenomena is related to the dimension of particles in the ash cloud.

More is clear to see that red central part is the one close to the eruption, while going up the thickness decrease (red is for high values, orange medium, blue for low values).

CONCLUSIONS

So in these few pages we saw how it's possible to detect ash cloud by images from geostationary satellites, and more how we can estimate also an approximation to the optical thickness of the ash cloud given a specific wavelength.

References

1. LearnEO-3rd Prize
2. Volcanic Ash
3. Thermal Remote Sensing
4. Basic about radiative transfer (ESA)
5. TIR (Thermal Remote Sensing)