Analysis of Mt. Etna's Eruptions: 2024 vs 2025

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Outline

1. Introduction
2. Data Gathering
3. Data Output
4. Data Analysis
   - Difference Vegetation Index (DVI)
   - SO_2 Analysis: Statistics
   - SO_2 Analysis: Concentration
5. Conclusions

Introduction

- **Focus:** Comparison of Mt. Etna's eruptions in August 2024 and June 2025.

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- **Parameters:** NDVI, Sulfur Dioxide Emissions.
- **Data gathering sites:** Google Earth, Earth Observatory, Copernicus.

Outline

R script for dowloading images

R packages used:

```
library(terra)
library(imageRy)
library(viridis)
library(patchwork)
library(ggplot2)
```

Image processing function:

```
flot <- function(x, y){
  x = rast(y)
  x = flip(x)
  plot(x)
  return(x)
}
```

Setting Working Directory for Importing Data

- **Image examples:** Italy base map, true and false color eruption imagery.

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- **Image examples:** Italy base map, true and false color eruption imagery.
- **Data:** Sentinel-2, Sentinel-5P, NASA.
- **Comparison:** Images compared side-by-side to highlight differences.

Setting Working Directory for Importing Data

All images are imported with the same procedure as the second line of code:

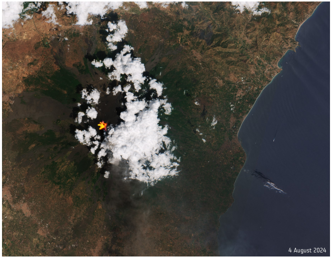
```
setwd("C:/Users/fsaiu/UNI/MAGISTRALE/TELERILEVAMENTO")
 gview = flot(gview, "Italy.jpg")
```

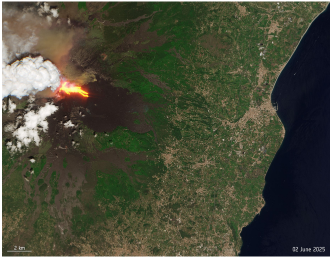
Image Example

The images will looks like this one, it shows Italy in a typical setting:

Mt.Etna Eruptions

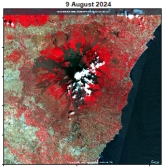
During the eruptions Mt. Etna looks like these two images in true colors, respectively in 2024 and 2025:



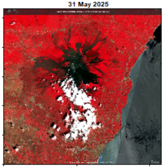


Images Analysed

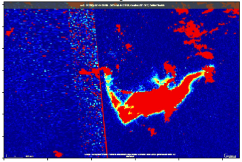
9 August 2024



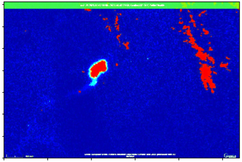
31 May 2025



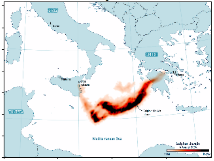
4 August 2024



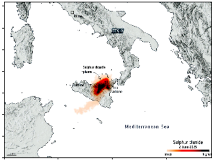
2 June 2025



4 August 2024



2 June 2025



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Output Collage Creation

All following outcome images are made by generating a png file:

```
png("images.png", width=1000, height=800)
im.multiframe(3,2)
im.plotRGB(fc24, r=1, g=2, b=3, title="9␣August␣2024")
im.plotRGB(fc25, r=1, g=2, b=3, title="31␣May␣2025")
im.plotRGB(so2.24, r=1, g=2, b=3, title="4␣August␣2024")
im.plotRGB(so2.25, r=1, g=2, b=3, title="2␣June␣2025")
...
dev.off()
```

This script, for example, produced the previous picture.

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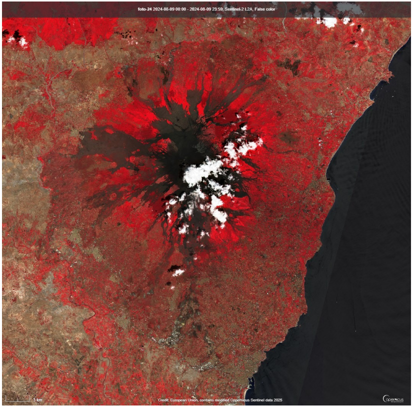
NDVI Analysis

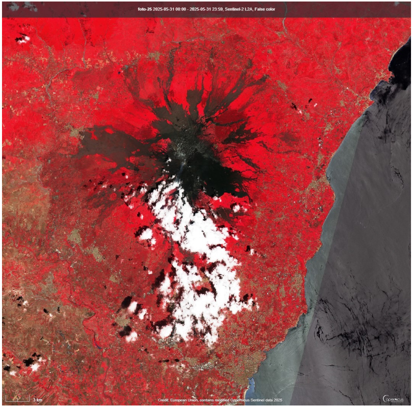
- DVI = NIR - Red
- NDVI = (NIR - Red) / (NIR + Red)
- NDVI$\in$ [-1;+1]
- Clear difference between spring (2025) and summer (2024).

Analysed Images

2024 Eruption



2025 Eruption

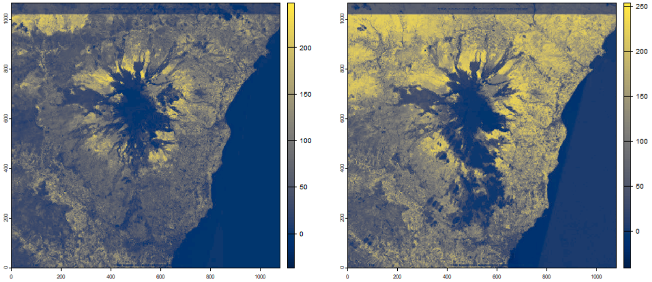


DVI R Code

With false color images it is possible to calculate the DVI:

```
dvi24 = fc24[[1]] - fc24[[2]]
dvi25 = fc25[[1]] - fc25[[2]]
```

The result is:



NDVI R Code and Graph

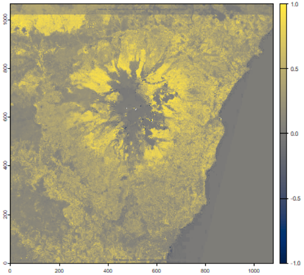
With false color images it is possible to calculate the NDVI:

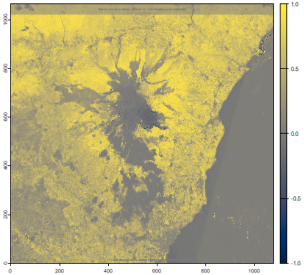
```
ndvi24 = dvi24 / (fc24[[1]] + fc24[[2]])
ndvi25 = dvi25 / (fc25[[1]] + fc25[[2]])
```

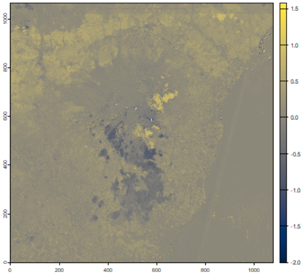
To analitically compare NDVI values between the two dates, results are plotted in a cartesian graph and it is added a bisector for reference:

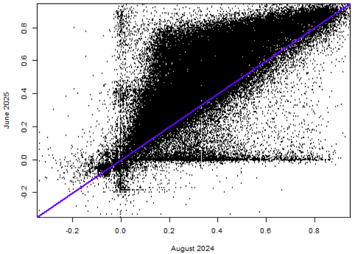
```
ndvidiff = ndvi25 - ndvi24
plot(ndvi24, ndvi25, xlim=c(-0.3,0.9), ylim=c(-0.3, 0.9), ylab="June
    ␣2025", xlab="August␣2024")
abline(0, 1, col="#6600ff", lwd=2)
dev.off()
```

NDVI Comparison Images









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Sulfur Dioxide Analysis

- **Importance:**
  - Monitoring, helps with predictions of new eruptions;
  - Health, irritation eyes and mucous membranes and cause damage to the respiratory system;
  - Climate, reaction with the water in the atmosphere and generation of sulfuric acid that contributes to acid rain, vegetation damage and soil contamination;

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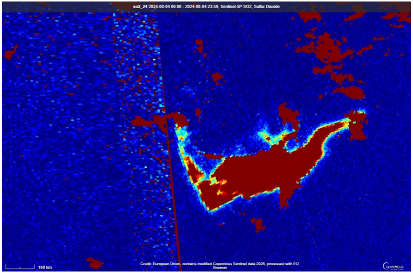
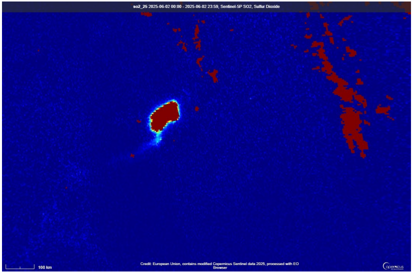
  - Monitoring, helps with predictions of new eruptions;
  - Health, irritation eyes and mucous membranes and cause damage to the respiratory system;
  - Climate, reaction with the water in the atmosphere and generation of sulfuric acid that contributes to acid rain, vegetation damage and soil contamination;
- **Analysis:** Emission extent, standard deviation, variance.

Analysed Images

2024 Eruption



2025 Eruption



SO_2 Standard Deviation

Taking a look at the images it is possible to see that the sulfur dioxide plume of year 2024 was spreading much more than this year's plume.The difference is calculated like this:

```
so2d = so2.25[[1]] + so2.24[[1]]
```

Then, the extent to which the values deviate from their average can be extrapolated using the latter variable:

```
sd = focal(so2d, w=c(3,3), fun="sd")
sd24 = focal(so2.24[[1]], w=c(3,3), fun="sd")
sd25 = focal(so2.25[[1]], w=c(3,3), fun="sd")
```

SO_2 Variance and Comparison Plots Code

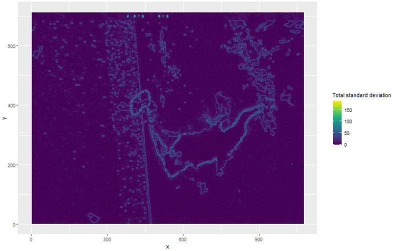
From total standard deviation can be evaluated the variance index:

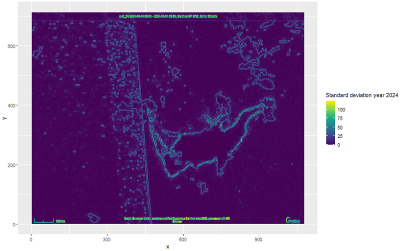
```
var = sd^2
```

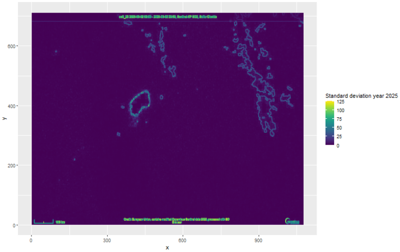
Plotting ggplot graphics:

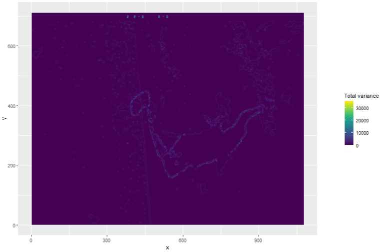
```
# Changing names to distinguish the graphics
names(sd)="Total standard deviation"
names(sd24)="Standard deviation year 2024"
names(sd25)="Standard deviation year 2025"
names(var)="Total variance"

p0 = im.ggplot(sd)
p1 = im.ggplot(sd24)
p2 = im.ggplot(sd25)
p3 = im.ggplot(var)

p0+p1+p2+p3
```

Graphic Outcome









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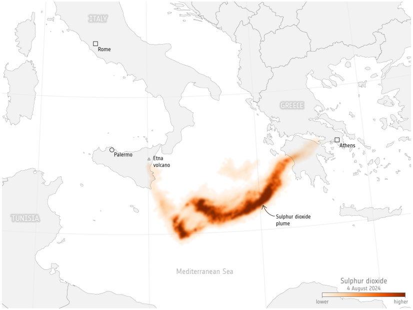
Analysed Images

2024 Eruption



2025 Eruption

SO_2 Classification

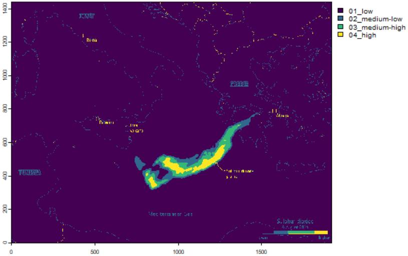
As last analysis, the previous pictures are employed for sulfur dioxide concentration calculation through a function taken from package imageRy that permits an unsupervised (automatic) classification:

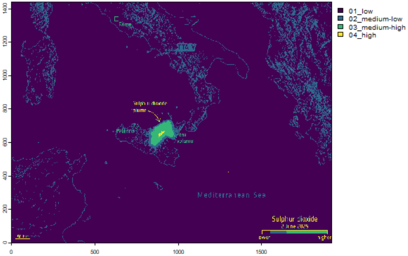
```
so2d24c = im.classify(so2d24, num_clusters=4)
so2d25c = im.classify(so2d25, num_clusters=4)
```

Making a correct legend:

```
so2d24cs = subst(so2d24c, c(3,2,4,1), c("01_low","02_medium-low","03
    _medium-high", "04_high"))
so2d25cs = subst(so2d25c, c(2,1,3,4), c("01_low","02_medium-low","03
    _medium-high", "04_high"))
```

Resulting Images





Determining SO_2 Concentration Percentages Classes

Calculating the percentages of both years:

```
perc24 = freq(so2d24cs)$count*100/ncell(so2d24cs)
perc25 = freq(so2d25cs)$count*100/ncell(so2d25cs)
```

And put in a dataframe:

```
class = c("01_low","02_medium-low","03_medium-high", "04_high")
perc_24 = c(95.33,2.71,1.04,0.91)
perc_25 = c(92.20,6.74,0.74,0.32)
tabso2 = data.frame(class, perc_24, perc_25)
```

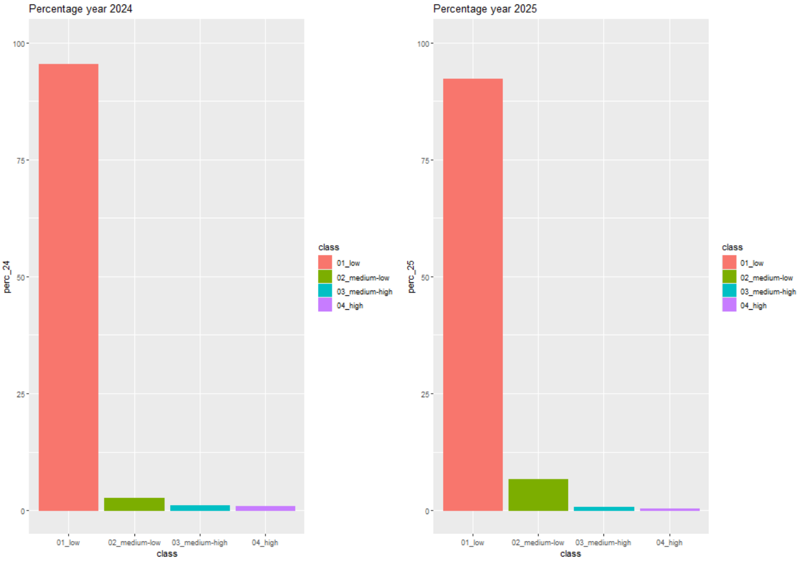
It is a table 3x4, where the rows correspond to the names stored in the variable called "class", while the columns contain percentage values.

Histogram of SO_2 Concentration Classes

The last outputs are two ggplot graphics that show the percentages of variuos classes in the form of histograms:

```
gso24 = ggplot(tabso2, aes(x=class, y=perc_24, fill=class)) +
        geom_bar(stat="identity") + ggtitle("2024") + ylim(c(0,100))
gso25 = ggplot(tabso2, aes(x=class, y=perc_25, fill=class)) +
        geom_bar(stat="identity") + ggtitle("2025") + ylim(c(0,100))
gso24 + gso25
```

Histogram Comparison



Outline

Conclusions

- NDVI increased in 2025 — healthier vegetation.
- SO_2 plume smaller in 2025 — weather likely influenced spread.
- Classified results confirm more concentrated SO_2 in 2025.

Conclusions

Thanks for the attention!