The VARION approach to volcanoes: case study on 2021 Etna eruptions

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Co-Volcanic Ionospheric disturbance (CVID)

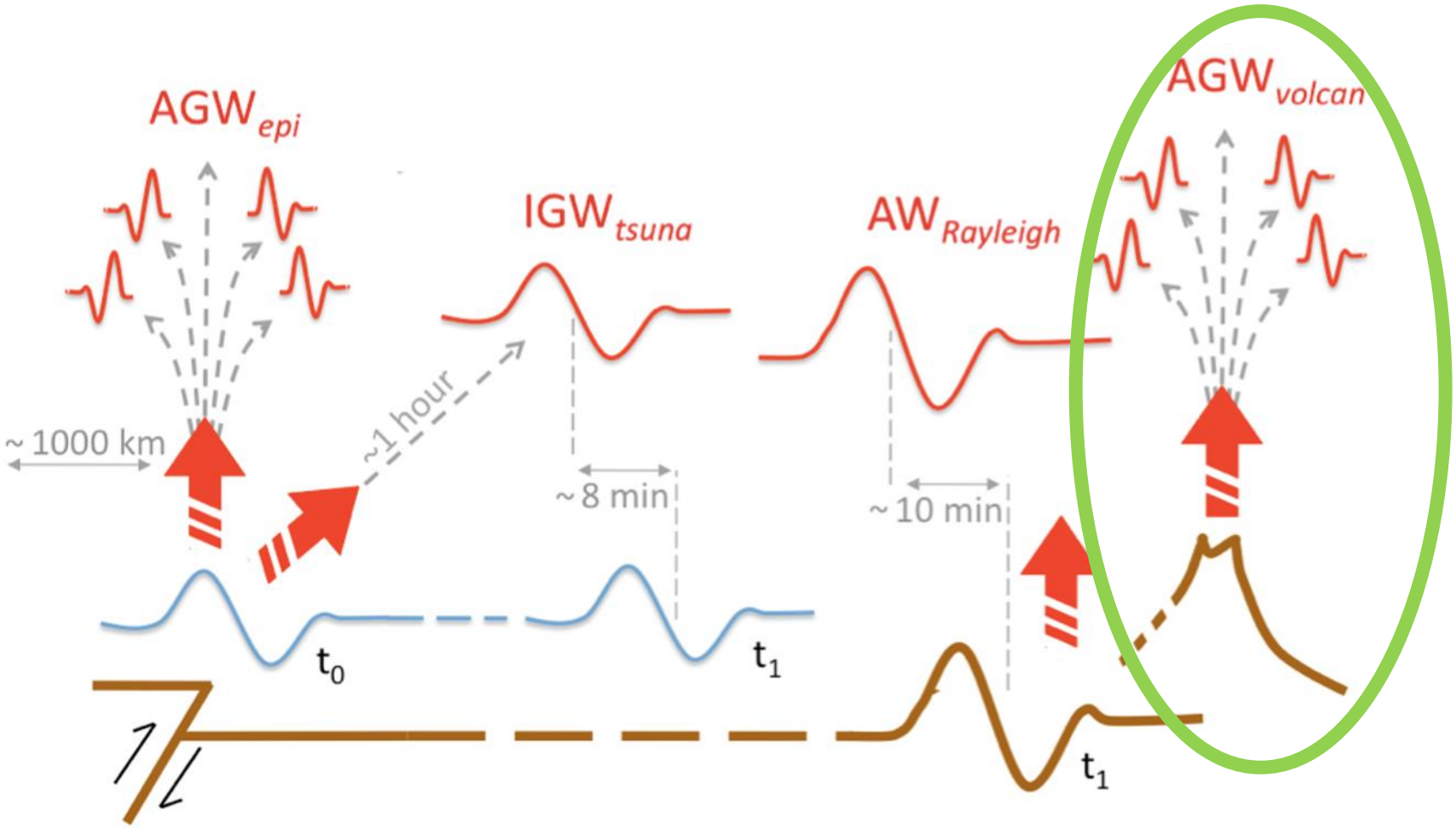


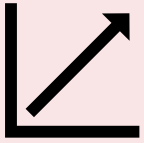
Figure adapted from Occhipinti, 2015

Co-Volcanic Ionospheric disturbance (CVID)

Main features

About **10 to 45 minutes** after the eruption onset, near the volcano and as far as 800-1000 km away from it

Quasi-periodic variations of TEC with periods of 12-30 min



The apparent velocity of propagation can vary between **550 m/s and 1.1 km/s**, which corresponds to acoustic, gravito-acoustic and shock-acoustic waves.

VARION fundamentals

Variometric
Approach for
Real-time
Ionosphere
Observatio
N

Main Features

$$\underbrace{L_{4R}^{S}(t+1) - L_{4R}^{S}(t) =}_{\text{time single difference geometry-free observations}}$$

$$\underbrace{\frac{f_1^2 - f_2^2}{f_2^2}\left[I_{1R}^{S}(t+1) - I_{1R}^{S}(t)\right]}_{\text{unknown term, sTEC variation}} +$$

$$\underbrace{\Delta m_R^S + \Delta \epsilon_R^S}_{\textit{noise}}$$

VARION fundamentals

Variometric
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Main Features

- **sTEC variation** estimation from the observations of a **stand-alone GNSS receiver** (single station approach) in **real time**
- Advantages: no infrastructure, no post-processing, no initialization needed

Etna case studies

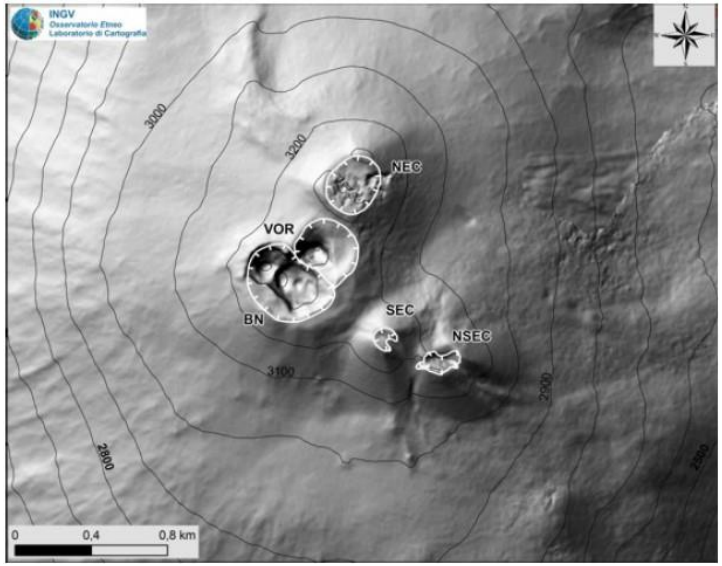
Date	*Crater*	*Duration (hours)*	*RD_{max} (cm^2)*	*Height plume (km)*
03/12/2015	VOR	9	84	11.8 – 15
04/12/2015	VOR	2.7	149	13.4 – 14.1
04/12/2015	VOR	2.3	132	10.5 – 13.3
05/12/2015	VOR	4.7	131	10.4 – 13
16/02/2021	NSEC	1.5	86	10
28/02/2021	NSEC	1.7	195	> 9
04/03/2021	NSEC	3.8	191	11
07/03/2021	NSEC	6.5	255	5
12/03/2021	NSEC	8	236	9

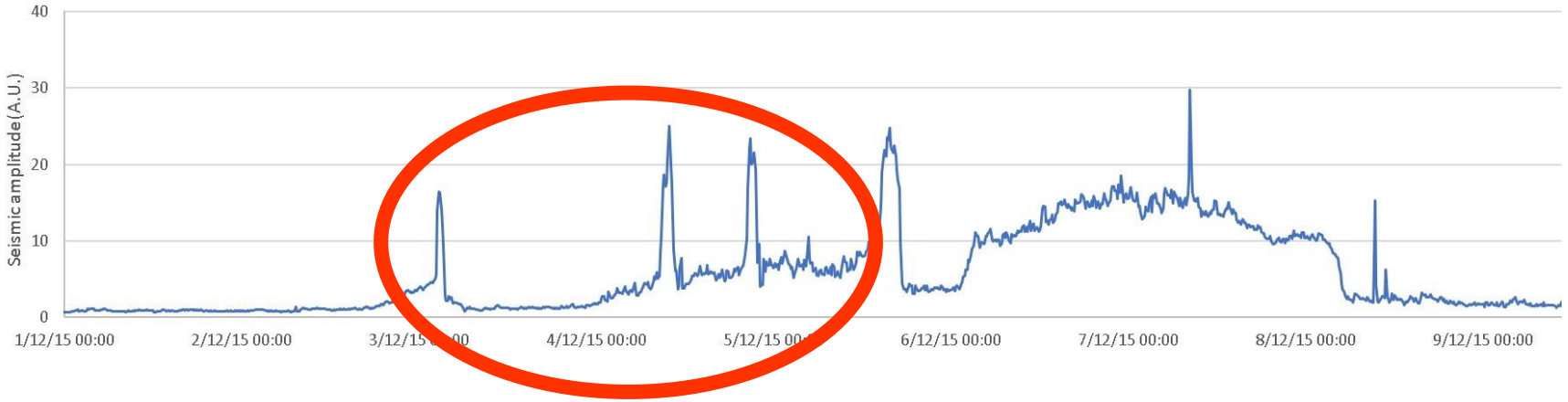
Etna case studies

2015

- Voragine
- High energy events (paroxysms)
- Strombolian activity
- High Lava fountain
- Abundant tephra emission
- Stroger explosive activity
- Low seismic activity

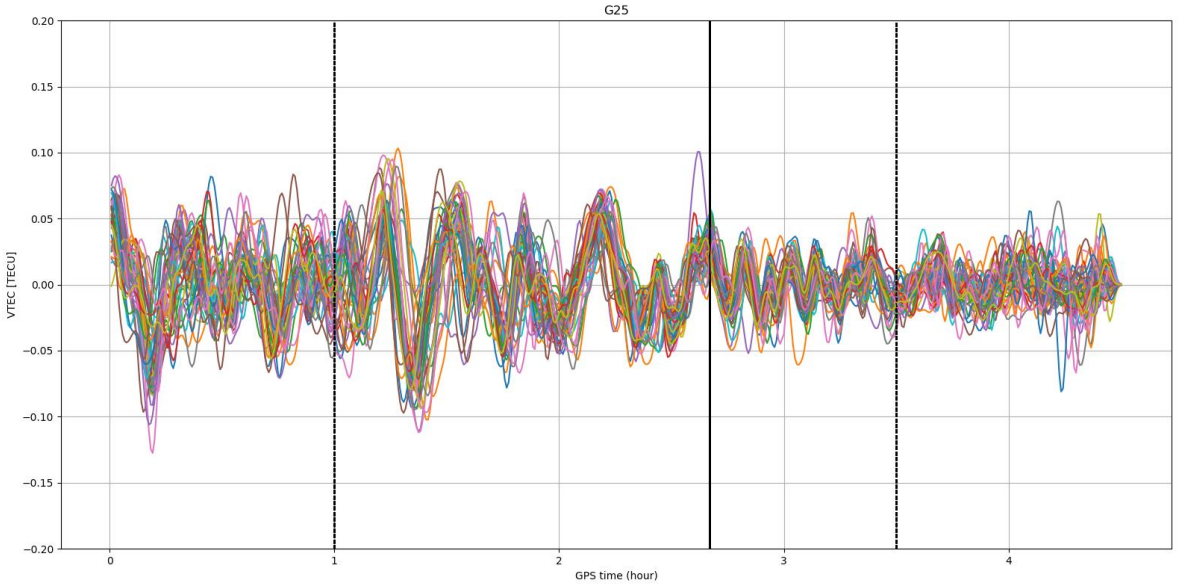
VARION processing
0.5-5 mHz bandpass filtering

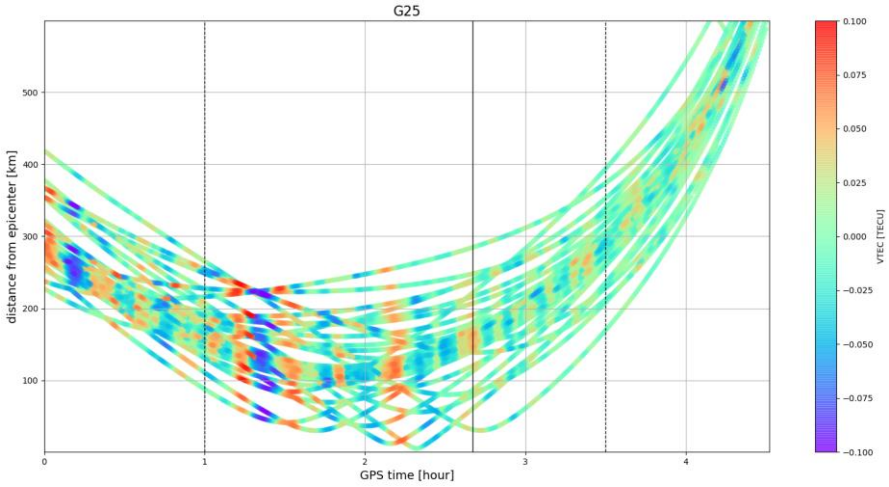


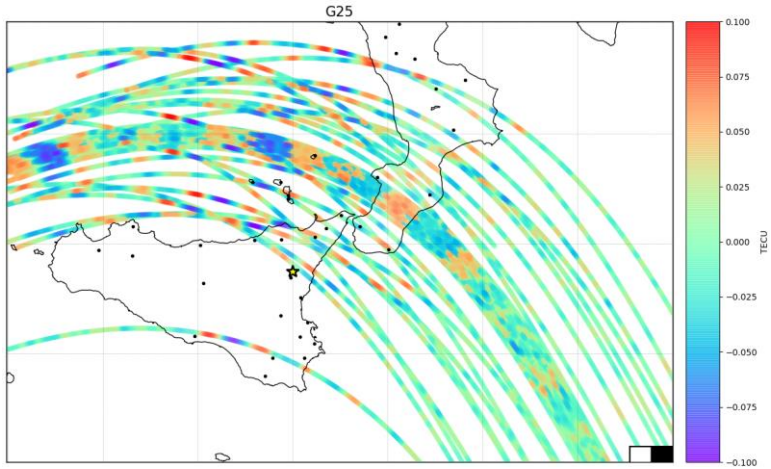


Etna case studies

2015

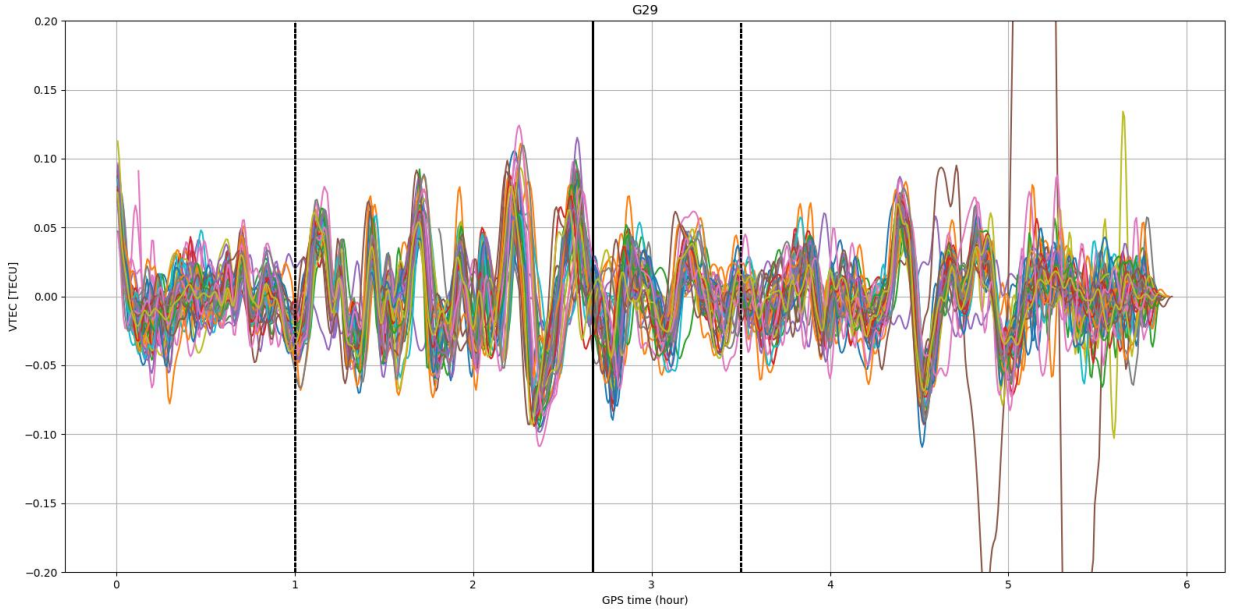


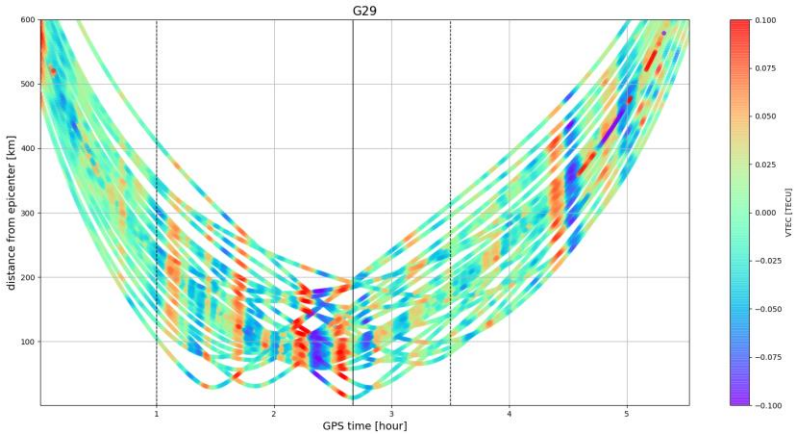


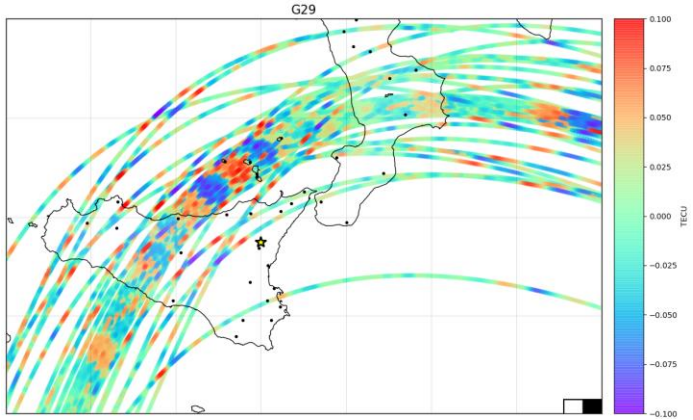


Etna case studies

2015





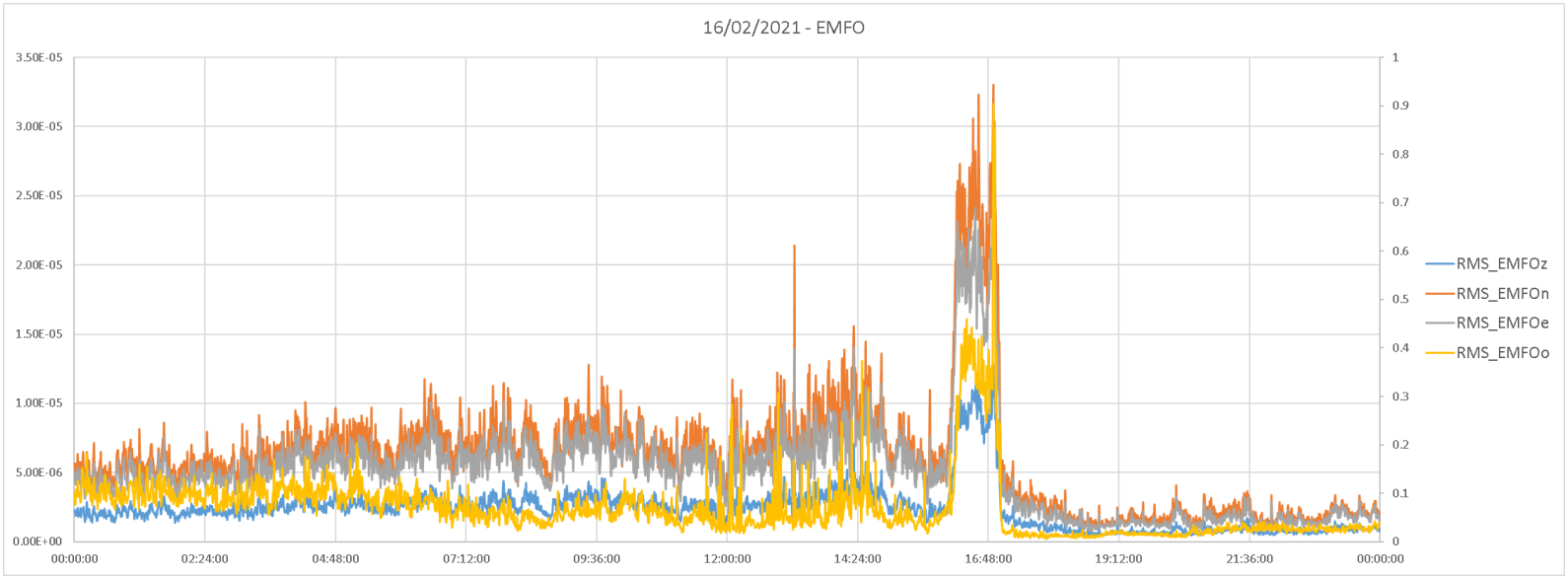


Etna case studies

2021

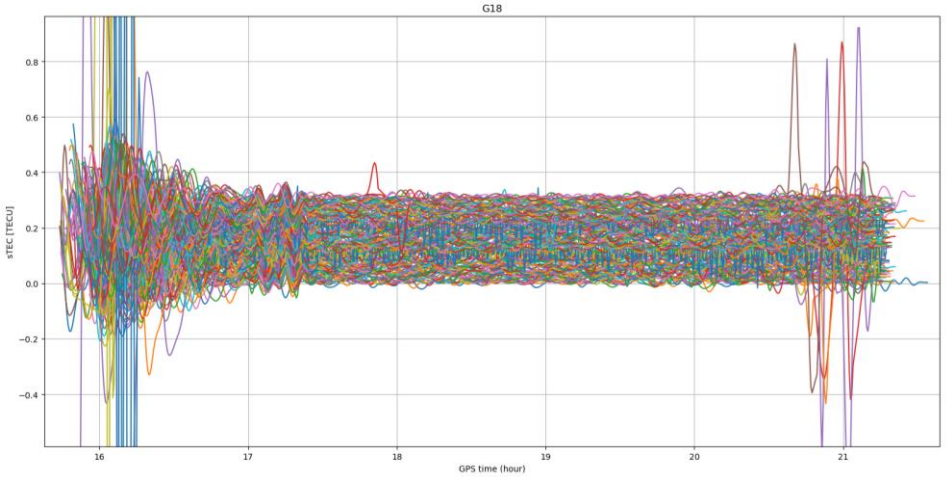
- New South-East Crater
- Lava fountain of February/March 2021
- Strombolian activity
- High seismic activity

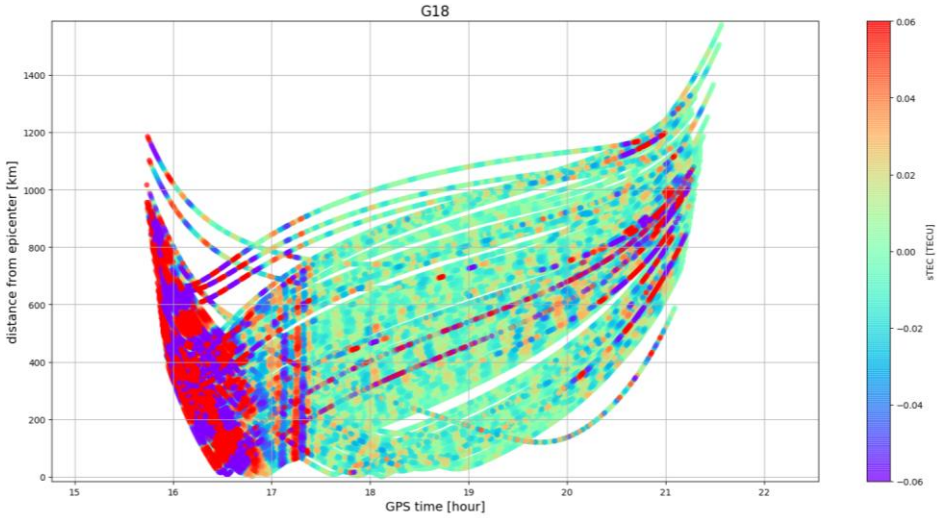
VARION processing
0.5-5 mHz bandpass filtering

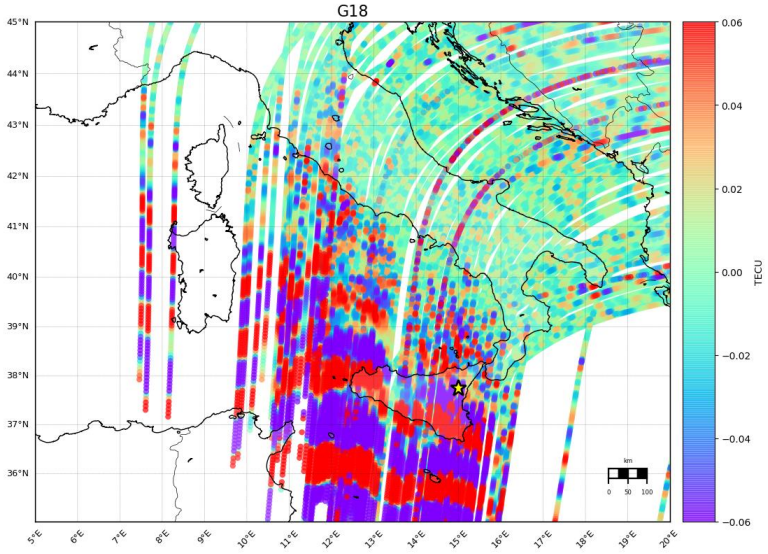


Etna case studies

2021

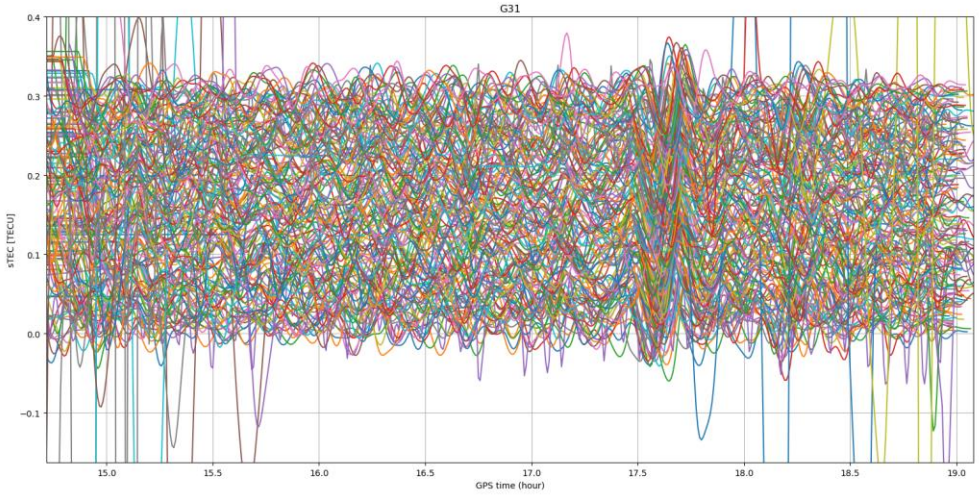


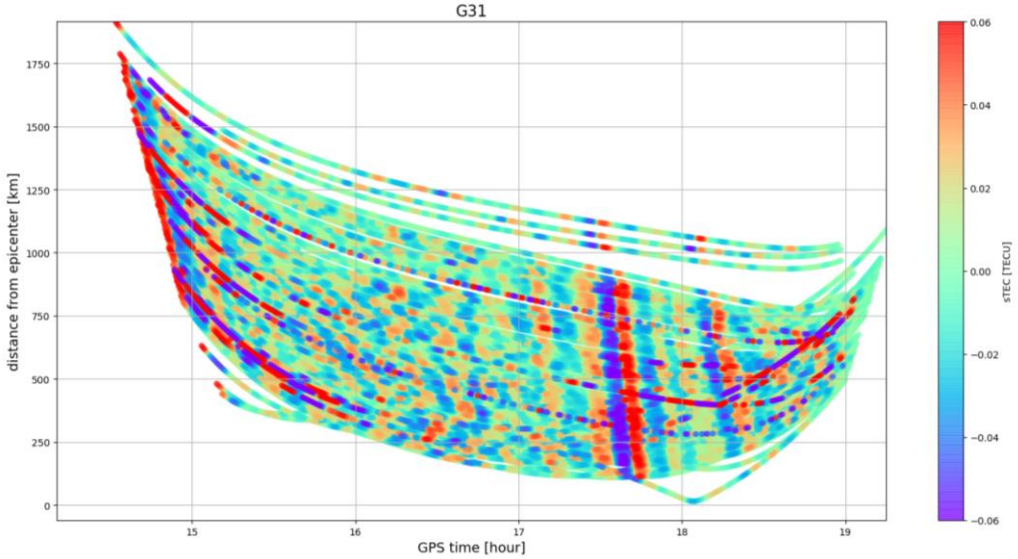


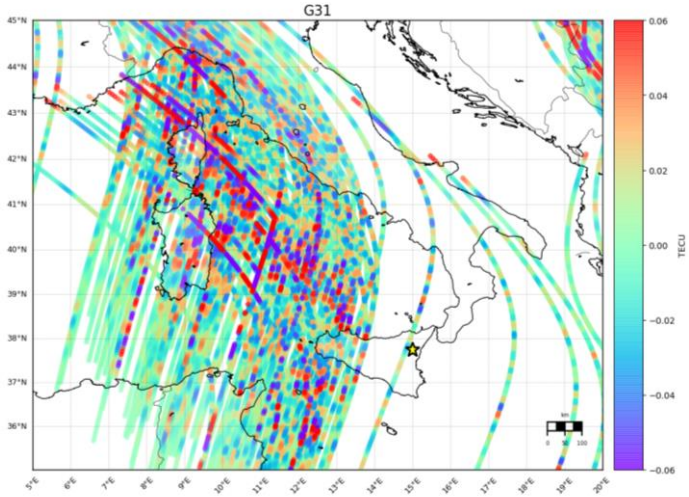


Etna case studies

2021







Conclusions and perspectives

Differences

- **Different seductive character** Vor in 2015 and Sec in 2021
- **Diameter** of the vent and of the duct presumably greater in 2015 than in 2021
- **Maximum height of the plume** in 2015 among those observed in recent years
- **Mass emitted** (the one found on the ground after the eruption) and mass eruption rate (emission rate from the crater) greater in 2015

Conclusions and perspectives

- **Preliminary studies**, need more analyses
- CVID linked more to what it is emitted than the tremors itself
- Still difficult to characterize the ionospheric response of volcanic eruptions

Conclusions and perspectives

Outlook

- Other events
- Comparison with infrasonic data
- **ML approach** on events

Thanks for your kind attention!