Multi-instrument detection in Europe of ionospheric disturbances caused by the 15 January 2022 eruption of the Hunga volcano

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Solar-Terrestrial Centre of Excellence

Outline

Introduction

Two circumstances of the eruption are to be considered:

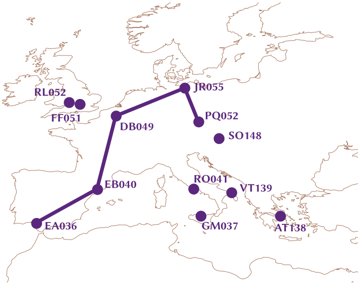
1. The location of the Hunga eruption was at 20.5°S 175.4°W, putting the antipode in northern Africa.
2. The timing of the eruption coincided with moderate geomagnetic storms.

This leads us to two questions:

1. To what extend, and through which mechanisms, do TIDs propagate to Europe?
2. Can the TIDs from this eruption be distinguished from those caused by the geomagnetic disturbances?

We use data from ionosondes and GNSS receivers from west and central Europe, as well as *in situ* measurements from Swarm C passing over the region.

Ionosondes

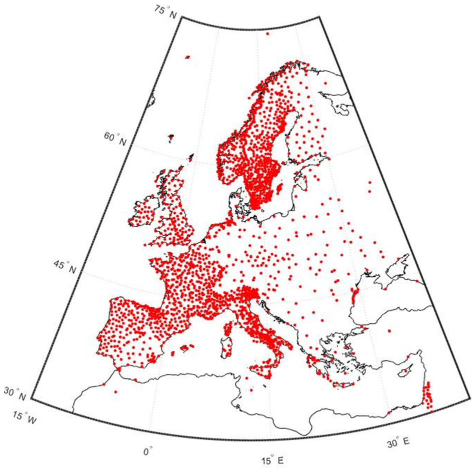


- We use vertical incidence ionograms from 12 ionosondes, plus oblique ionograms from 4 pairs.
- Sounding cadences vary between five and fifteen minutes.
- All data manually scaled (will be available through GIRO).
- We use *MUF* as well as detrended iso-density contours.
- For some ionosonde we also use plasma drift data.

Problem

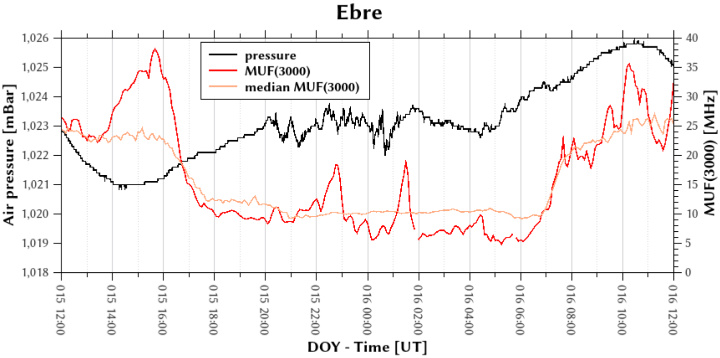
At the more northern station, ionisation is very low during winter nights, resulting in some unusable data.

GNSS receivers and Swarm



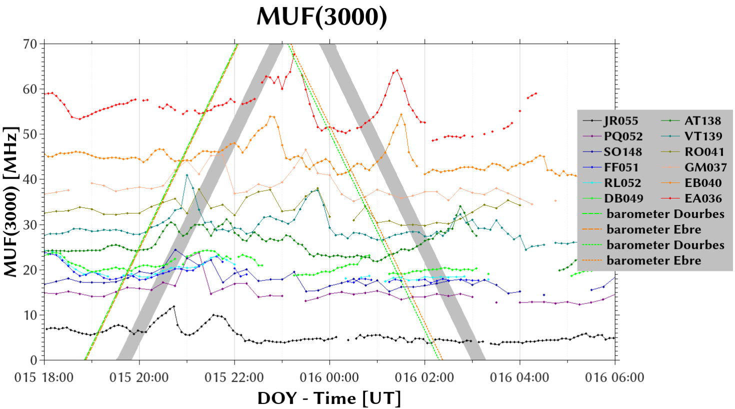
- A large number of GNSS receivers are used to obtain *TEC* data, covering latitudes between 30° and 70°N.
- Data is detrended using the Varion procedure, with a tenth-order polynomial.
- Large number of data points allows for detailed reconstruction of TID movement.
- Swarm C passed over the region twice.

Observations: *MUF* and pressure



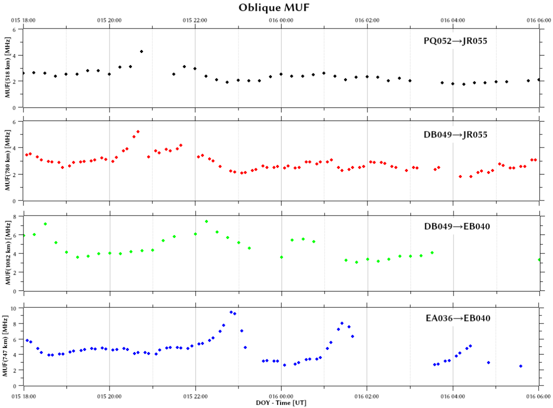
Major disturbances in *MUF* are seen on January 15 in the afternoon: geomagnetic activity. During the night, two main peaks corresponding to great-circle velocities of 300 m/s and 304 m/s from the eruption. These appear 45 – 60 minutes after the barometer signals arrival of tropospheric disturbances. The period indicate medium scale TIDs.

Observations: *MUF* throughout Europe



The *MUF* obtained from vertical and oblique ionogram traces at various locations shows the waves travelling to and from the eruption antipode. The results are consistent throughout the region (wherever data are available).

Observations: *MUF* throughout Europe

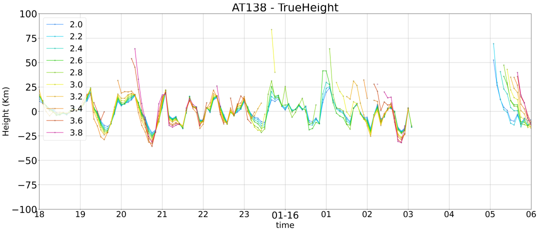


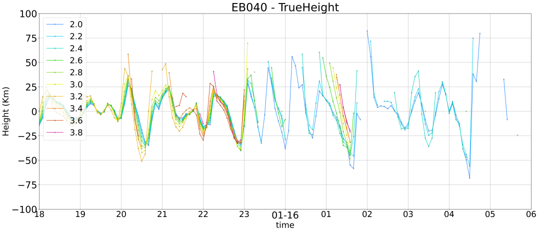
The *MUF* obtained from vertical and oblique ionogram traces at various locations shows the waves travelling to and from the eruption antipode. The results are consistent throughout the region (wherever data are available).

Observations: iso-density contours

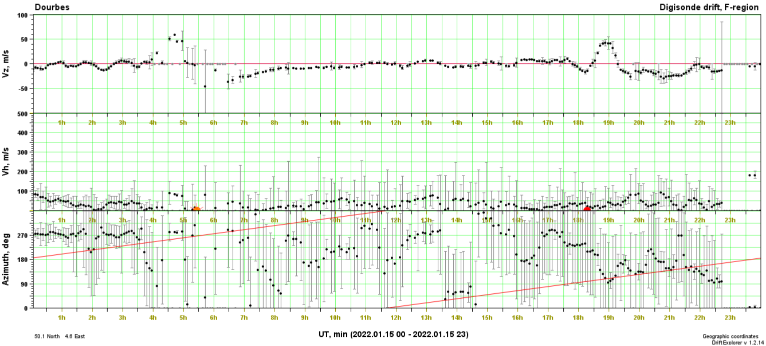
Reconstructed detrended true-height plots for densities from 2.0 to 3.8 MHz.
This looks very different from the *MUF* signature:

1. a train of oscillations instead of single peaks,
2. the disturbance starts around the moment of arrival of the pressure wave.



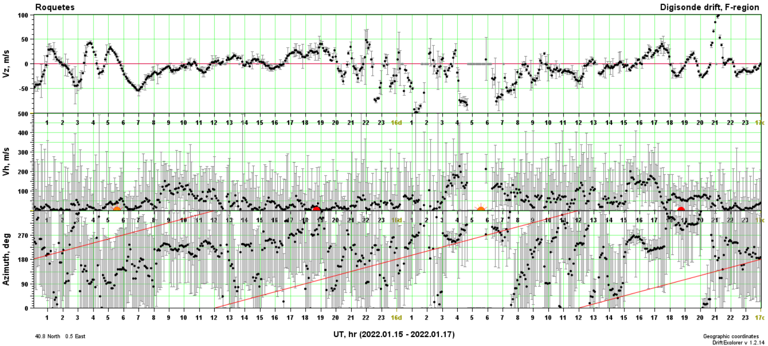


Observations: plasma drift measurements



Ionosondes detected vertical plasma drift oscillations following the arrival of tropospheric disturbances (30-minute smoothed data).

Observations: plasma drift measurements



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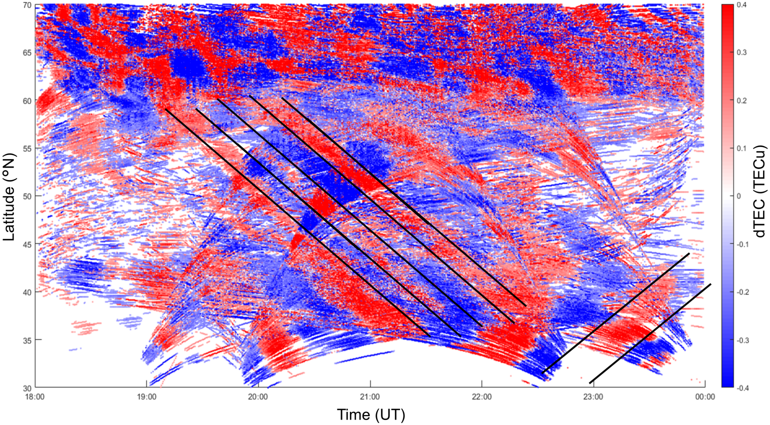
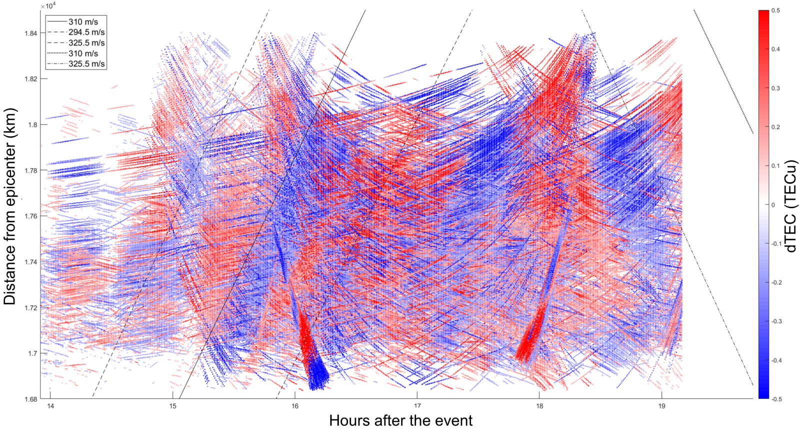
Observations: GNSS derived *TEC*



dTEC at the ionospheric pierce points, for longitudes between 12.5° and 17.5°E. Waves travelling southward between 19 and 22 UTC, followed by northward travelling waves. Wave fronts travelling at 310 m/s are indicated.

Observations: GNSS derived *TEC*

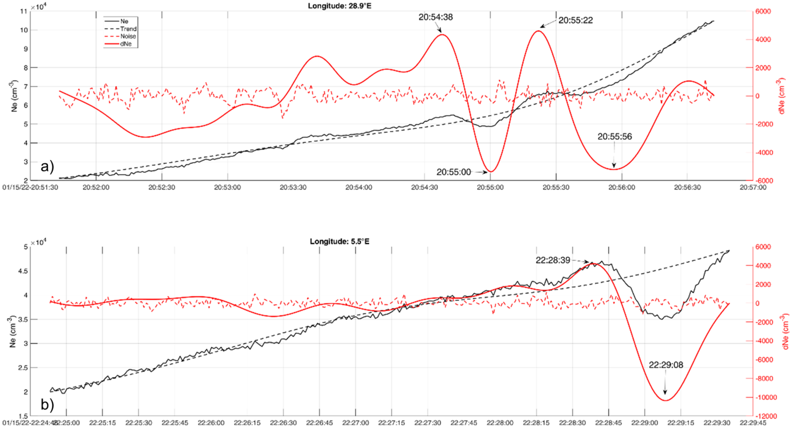


dTEC at the ionospheric pierce points for all Italian receivers. Waves travelling southward between 19 and 22 UTC, followed by northward travelling waves. Wave fronts travelling at 310 m/s($\pm 5\%$) are indicated.

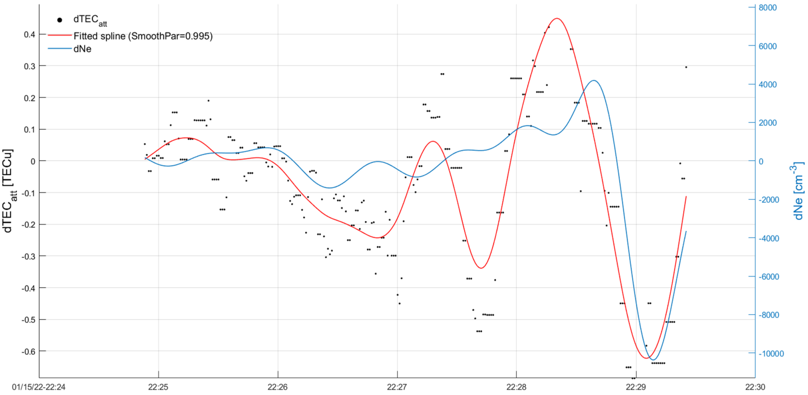
In situ electron density

The Swarm C satellite passed the area twice, flying at 435 km

1. a pass at 28.9°E between 20:51 and 20:57 UTC,
2. a pass at 5.5°E between 22:24 and 22:30 UTC.

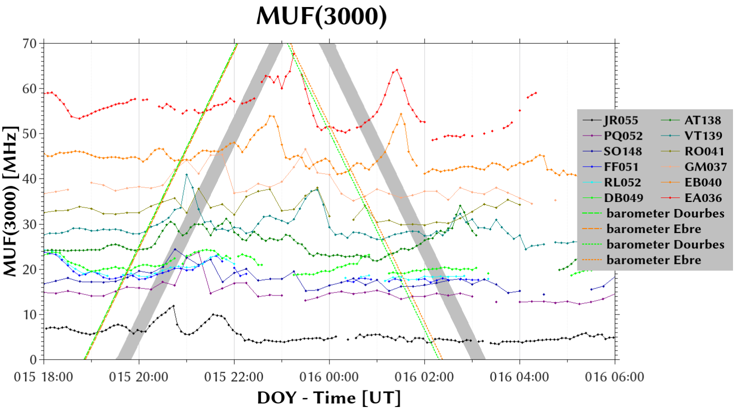


Swarm-C pass compared to *TEC*



The (negative) peak seen in the *in situ* data from the 5.5°E pass is clearly visible in the GNSS *TEC* as well.

Propagation of disturbances



TIDs caused by the eruption can be distinguished from those of geomagnetic origin by their travel direction and timing by combining data from multiple ionosondes at various distances and in different directions from the source.

Propagation of disturbances

Name	URSI code	Latitude	Longitude	Distance	Azimuth
Juliusruh	JR055	54.6°N	13.4°E	15,931 km	29.0°
Fairford	FF051	51.7°N	−1.5°E	16,536 km	5.6°
Chilton	RL052	51.5°N	−0.6°E	16,551 km	7.3°
Dourbes	DB049	50.1°N	4.6°E	16,626 km	17.2°
Pruhonice	PQ052	50.0°N	14.6°E	16,326 km	34.3°
Sopron	SO148	47.6°N	16.7°E	16,443 km	39.9°
Rome	RO041	41.9°N	12.5°E	17,148 km	39.3°
Roquetes	EB040	40.8°N	0.5°E	17,707 km	13.7°
San Vito	VT139	40.6°N	17.8°E	16,940 km	50.3°
Athens	AT138	38.0°N	23.5°E	16,694 km	62.3°
Gibilmanna	GM037	37.9°N	14.0°E	17,384 km	48.1°
El Arenosillo	EA036	37.1°N	−6.7°E	18,158 km	353.19°

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Timing of the TIDs

The travel times for the onset of the TIDs are consistent between 300 m/s and 310 m/s, seen in both ionosonde observations and *TEC* data.

This is consistent with TIDs produced locally from disturbances travelling through the troposphere.

However, the *MUF* and iso-density contours obtained from ionograms disagree in the delay between the tropospheric pressure wave and the start of the ionospheric disturbance. Also, *MUF* shows a single larger peak while the density contours and *TEC* shows multiple periods of similar amplitude.

Based on the timing, this is probably due to respectively acoustic and gravity waves arriving in the ionosphere with different delays.

Conclusions

1. TIDs caused by the eruption can be distinguished from those of geomagnetic origin by their size and travel direction.
2. Ionospheric effects seen in Europe are probably produced by disturbances propagating through the troposphere.
3. For the most part, different data sets are in good agreement.
4. *MUF* time series show something different from *TEC* and electron density, possibly detecting different types of waves.

The end, thank you!

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