Doppler radar to monitor ash of Popocatepetl volcano

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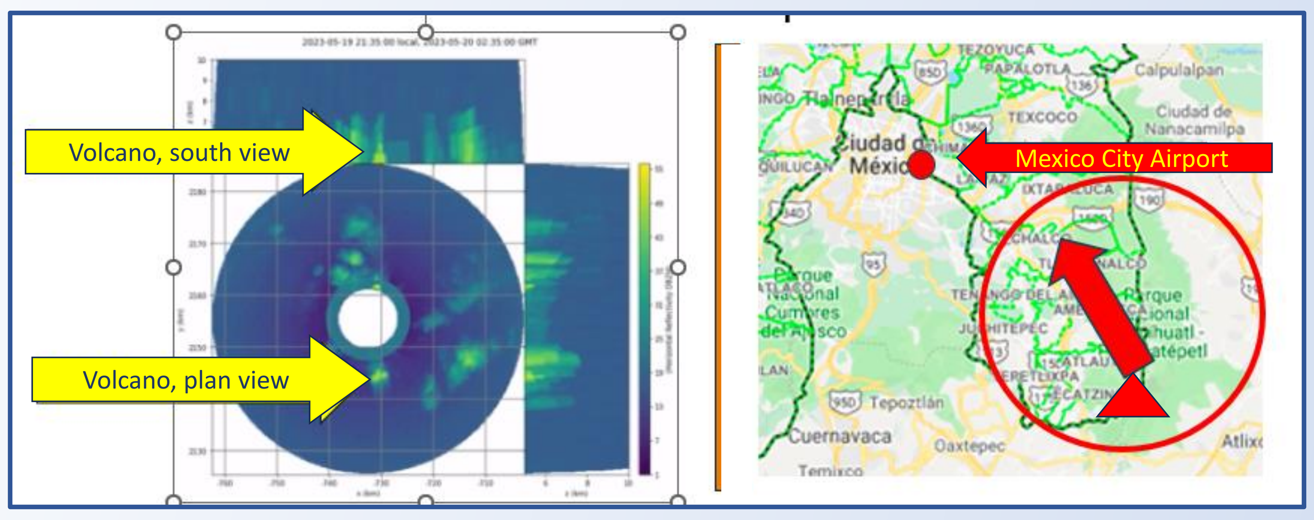
Radar placed 11 km North of the crater of the volcano at 4000 masl.

Popocatepetl volcano is one of the most important threads to the security of the population of Mexico City and some other cities in the center of Mexico. Monitoring this volcano aims to provide civil protection authorities with tools to mitigate the risks associated with its activity. The National Autonomous University of Mexico (UNAM) conducts surveillance to reduce most of the risks associated with it, particularly, one of the tools used to monitoring ash emissions in real-time is a Doppler radar. This radar is placed 11 km North to the volcano at 4000 masl inside the Iztaccihuatl-Popocatepetl National Park. For the past few years, we have collected data of the ash emissions and we already have 8 Tb of raw data that will be publicly available in the following months. This tool have allowed us to detect activity that otherwise is difficult or even impossible to detect due to meteorological conditions with a delay of less than 5 minutes. Efforts have been made to obtain ash mass and concentration with the Marzano method, but first we must clean the signal, take out the terrain and also the clouds.

SCAN ME

To check out videos of the explosions with radar data.

Successful example of monitoring without visibility



During May 2023, the use of the radar was crucial to alert the National Centre for Disaster Prevention (Cenapred) about the ash emissions direction during a small crisis of the volcano and eventually this centre recommended to close Mexico City's main airport. In the night of the Friday 19th of May, 2023, Popocatépetl started an episode of intense activity that lasted about three weeks. That night was a heavy storm over the volcano, that ultimate lasted all the weekend, so we couldn't confirm the activity with webcams (we just had the seismic activity). At 20:00 the wind changed to the Northwest, almost exactly in the direction of the main airport of Mexico City. Radar data was sent over the National Centre for Disaster Prevention and the authorities decided to close the airport on Saturday 20th of May for about 4 hours. Image in the far left shows the Vol-Cappi projection of the data in almost real-time with the help of the Python library wradlib; image on the left is a map of Mexico City with Benito Juarez Airport and the direction of the ashes. Image to the right, Popocatépetl with full visibility from Paso de Cortés, on Tuesday 23th of May 2023 still during this activity period.

Ground clutter removal

Why is important? Before we get the ash mass and concentration of each emission, we have to clean out the signal, take out the terrain, the mountains, and also the clouds. This noise in the signal is called ground clutter, so this procedure is called ground clutter removal.

1. Problem: take out the signal of the terrain and, if posible, also the clouds
2. Limitations: the algorithms are designed for meteorological applications
3. First approach solutions: use of this algorithms and try to improve them
4. First results: we get a clean signal but we are missing some of the useful data

7th of September 2022, 02:19 UTC

Altzomoni webcam image surveying the volcano. This event registered the greatest reflectivity in our database of explosions so far. The explosion occurred during the night and with almost zero visibility. This particular camera is the closest webcam to the radar.

To clean the signal of this explosion first we have to gather clear sky data over the course of several months. All the data was taken in the morning between 4 am and 9 am, because in these hours we have almost no clouds, and during the driests months of the year (February, March and April). From these data we created a static clutter map which is an average of all these measurements. Then a trapezoidal function is needed to get a quality map Q that is subjectively generated by combining several polarimetric variables. In the function d(Xj), Xj represents 5 different polarimetric variables: static-clutter map (CMAP), radial velocity V, texture of Zdr (TxZdr), texture of rho (TxRho) and texture of phidp (TxPhi). And $X_{i,j}$ represents the weight of the function in each interval. This weight is taken from Vulpiani and Crisologo.

$$d(Xj) = d(X_j) = \begin{cases} 0 & if\ X_j < X_{1,j}\ or\ X_j > X_{4,j} \\ \dfrac{X_j - X_{1,j}}{X_{2,j} - X_{1,j}} & if\ X_{1,j} < X_j < X_{2,j} \\ \dfrac{X_{4,j} - X_j}{X_{4,j} - X_{3,j}} & if\ X_{3,j} < X_j < X_{4,j} \\ 1 & if\ X_{2,j} < X_j < X_{3,j} \end{cases}$$

where Xi,j is the ith vertex of the trapezoid relative to the jth quality indicator. Last, the overall quality Q is obtained through a weighted sum of the relative quality indices:

$$Q = \frac{\sum_{j=1}^{N} W_j q_j}{\sum_{j=1}^{N} W_j}$$

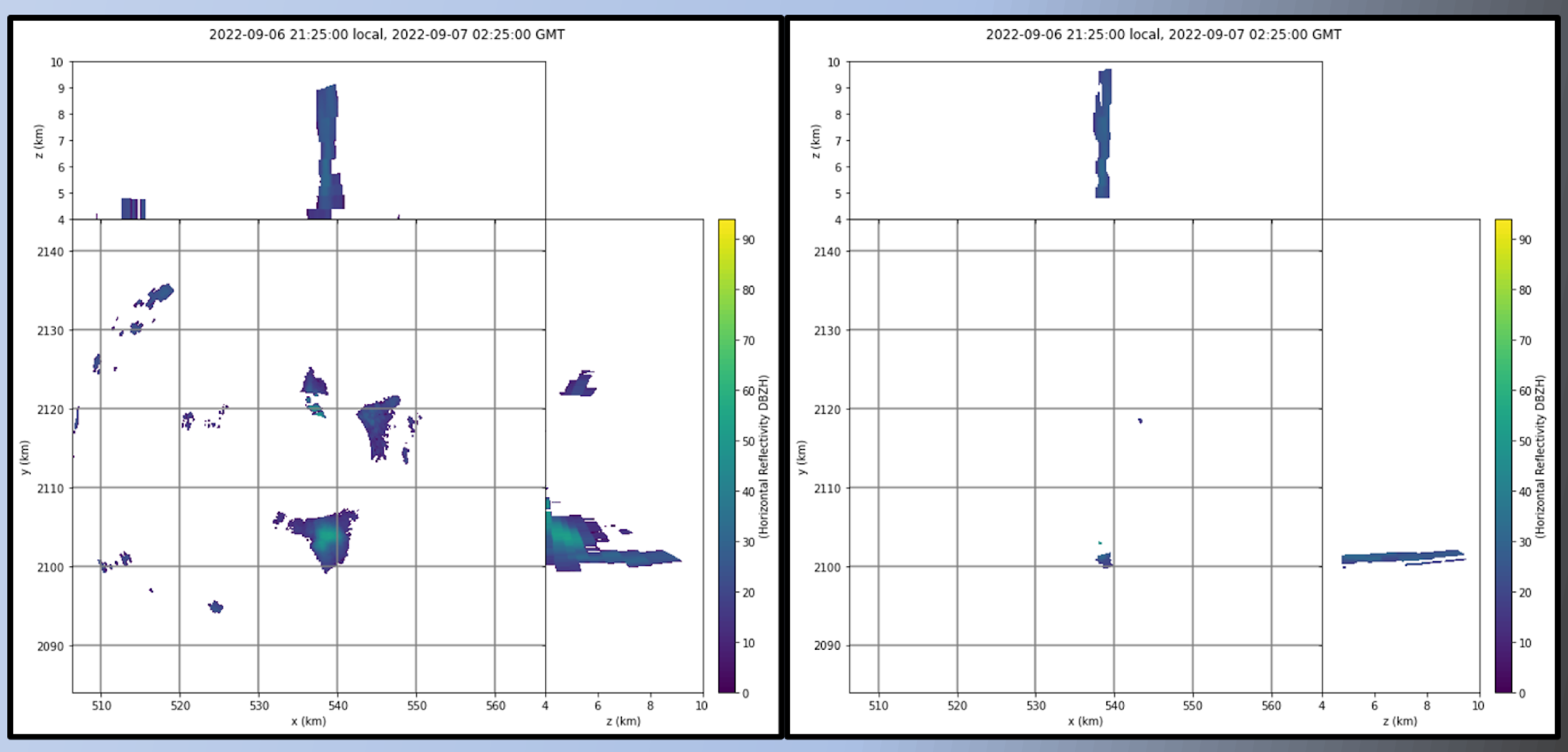
The next table contains the weights for each section of the function.

X	Weight	X1,j	X2,j	X3,j	X4,j
CMAP	0.5	10	30	70	∞
V	0.1	-0.2	-0.1	0.1	0.2
TxZdr	0.4	0.7	1.0	∞	∞
TxRho	0.4	0.1	0.15	∞	∞
TxPhi	0.1	15	20	∞	∞
Rho	0.4	-∞	-∞	0.9	0.95

Computationally, in order to get faster results for real-time monitoring, not useful data was converted to NaN before enter the calculations and before plotting.

Results: Vol-Cappi of explosion of 7th of September 2022

In the left side is the graph of raw data as obtained by the radar. The scale color represents the reflectivity in dBZH. Almost at the center of the graph is the volcano. The panels of the side are the vertical profile of the data, on the top is the south view and on the right is the East view. The graph on the right is the image after the ground clutter removal with this procedure. We can see only the explosión but this procedure is not definitive since it takes out much of the useful signal. In the raw data, we can appreciate the ash almost half an hour after the explosion and with the ground clutter removal the ashes are only visible for about 15 minutes maximum. No statistical method to quantify the loss of information has been implemented yet.



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https://github.com/erictellez/radar_popocatepetl
https://radarcenizas.geofisica.unam.mx/