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TAT.py: Tropospheric Analysis Tools in Python

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Statement of need

Propagation beyond the horizon is a well known field of research which has been used to establish long communication links since WW II. Oftentimes people have experienced abnormal reception of FM radio channels or TV broadcasts, especially in the summer. Nowadays, with the exponential growth of Internet of Things (IoT) networks, many users have documented very long links on the ISM bands (868 MHz in Europe) used by such devices. It is worth noting that beyond the horizon transmission is also a source of interference to other users, which might be unaware of the origin of the spurious signals (Imam et al., 2009). Shedding light on the anomalous propagation mechanism is a first and important step in the mitigation efforts.

In a previous study (Zennaro et al., 2020), we focussed on the use of the crowd sourced initiative TheThingsNetwork (TTN), since it allowed leveraging the openness of that system and the great number of TTN gateways deployed globally, to check the reach of a simple IoT node that we have installed on the roof of our institute.

Presently, we generalyze the analysis to cover any wireless link for which the transmitter and receiver sites are specified, as well as the date on which the very long distance link was observed.

Anomalous tropospheric propagation is defined (ITU-R, 1990) as a transmission that extends beyond the geographical horizon. Normally, in those areas, signals start to rapidly reduce in strength. Viewers living in such a "deep fringe" reception area will notice that during certain conditions, weak signals, normally masked by noise, increase its strength to the point of allowing normal reception. Furthermore, in special conditions related to the state of the troposphere at a given time along the trajectory, the signals can reach very long distances [ko1983anomalous]. Tropospheric propagated waves travel in the part of the atmosphere adjacent to the surface and extending to some 12000 m. Such signals are thus directly affected by weather conditions extending over hundreds of kilometers.

Even if the maximum transmitted power of 14 dBm in LPWAN networks in Europe is much lower than that of FM transmissions, the advantage in terms of receiver sensitivity of both LoRa (thanks to the processing gain offered by spread spectrum modulation) and Sigfox (thanks to the ultra narrowband employed), explains why such long distance paths can be spanned, if the anomalous propagation conditions exist.

In this paper we present a set of software tools that allow the analysis of any radio link making use of the publicly available IGRA (Integrated Global Radiosonde Archive) database (NOAA, n.d.) of metereological radiosondes that are periodically launched all over the globe.

These tools facilitate the analysis of beyond the horizon propagation by automating the process of identifying the nearest radiosonde launch site to any pair of points at a specific date.

The data from the identified radiosonde are then used to graph the refractivity gradient versus height, the information needed to assess the possible presence of the conditions for the existence of super-refraction (which can extend the propagation moderately beyond the line

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of sight) or tropospheric ducts, which can explain transmissions over distances of thousands of kilometers. section depicts the latter case, which is more frequent in paths over seawater, since it is a very good reflector.

Tropspheric duct propagation: Wave reflection on the surafce (water or ground) is sharp, while in the tropospheric layer it is a succession of gradual bends. Happens more frequently in pathts over water, where the evaporation favors the formation of inversion layers

Python tools

We built a series of software tools to analyze anomalous tropospheric propagation links. They are available on Github under an MIT License and also as a Jupyter Notebook hosted by Google Colab as shown in Figure 1. Sharing the code using Google Colab facilitates the usage of these tools for researchers, practitioners, or anyone interested, by removing the installation requirements (Colab runs in a browser). While the complete set of tools include more than 20 separate pieces of code (to parse data from online databases and find long links, to gather data from TTN, etc), in this paper we will focus on the tools that are part of the workflow shown in Figure 2. All the code is compatible with Python 3 and runs on Windows, OSX and Linux devices.

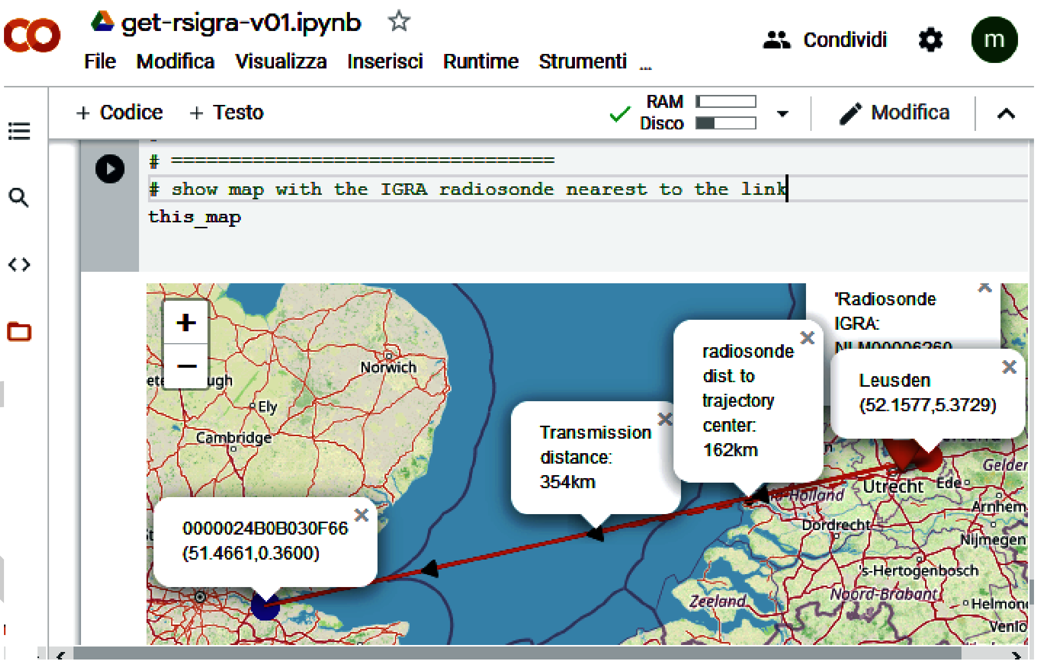

Figure 1: Jupyter Notebook hosted by Google Colab.

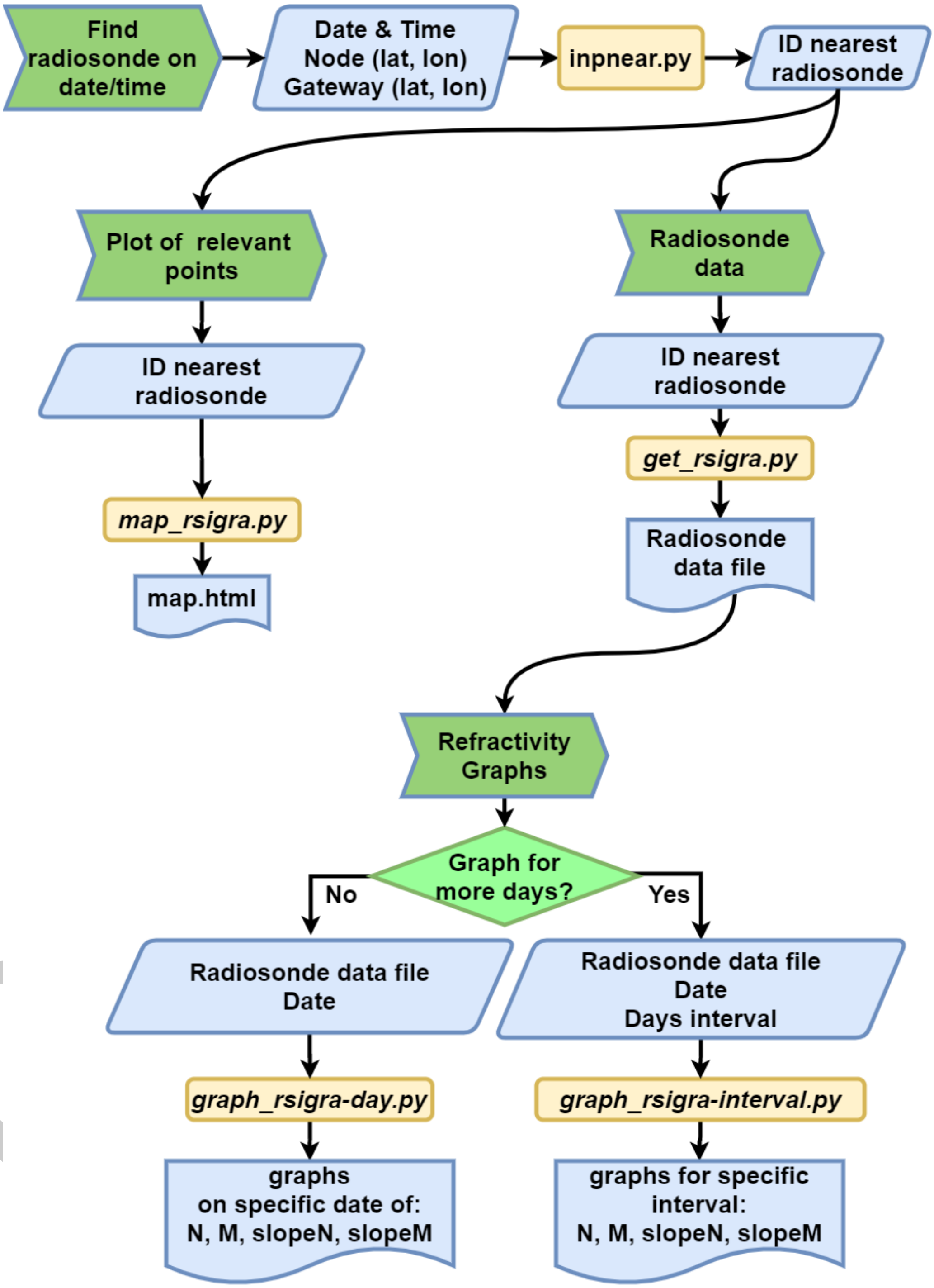

Figure 2: Workflow using the Python tools developed.

Following is a description of the workflow to analyze a specific link.

1. the user launches the *ipnear.py* script. Then enters the geographical coordinates of the two extremes of the link, the transmitter and the receiver, or the node and the gateway using LPWAN's naming convention. Next the date and time when the link has been documented must be supplied. The output is the name of the radiosonde closest to the mid point between the two ends which has measurements available for the specific

date. To determine its location we use the IGRA database, which contains radiosonde and pilot balloon observations from over 2700 globally distributed stations.

2. to visualize the location of the radiosonde, launch the script called *map-rsigra.py*. This will produce a map similar to the one shown in Figure 4. This is not a mandatory step in the workflow, but gives an idea of where the nearest radiosonde is located.

3. now that the closest radiosonde has been determined, data for the specific date and time has to be downloaded from IGRA. This is done using the *get-rsigra.py* script. No further input is needed as the necessary information has already been inserted. As output, the file from the nearest radiosonde for the specific date and time is downloaded in idx format. From this file the refractivity index N, the refractivity module M, and their respective slopes or gradient DeltaN/Deltah and DeltaM/Deltah, are obtained at each measurement height h. They will be used to check if the condition for a tropospheric duct are met (some publications use the refractivity lapse-rate instead of the slope, which has the same value but opposite sign).

4. it is now possible to generate the graph of the refractivity gradient DeltaN/Deltah in N units per km by calling the *graph-rsigra-day.py* script. Whenever the gradient is between -79 and -157 the conditions for super-refractivity are in place, meaning that the curvature of the wave is much greater than that of the earth, and the radio horizon will be considerably greater than the geographical horizon. If the gradient falls below the -157 threshold, the possibility of the existence of a tropospheric duct is present [ko1983anomalous]. If the duct is confirmed, the wave will encounter a heavily perturbed layer that will reflect it back to the surface (either ground or water), where it undergoes another reflection upward. This process can repeat itself a number of times, depending on the reflectivity of the surface, which is very high in the case of seawater. So in essence, between the surface and the perturbed layer a sort of waveguide will be formed that can extend the transmission to very long distances. The trapping of the wave in the vertical plane accounts for the fact that the attenuation increases linearly with the distance, instead of quadratically as is the case in normal propagation conditions, so the received signal level could be higher than that of free space propgation. Figure 5 is an example of the output of the script showing the threshold for ducting conditions.

   There is also the option to gather data for multiple dates, and this is done via the *graph-rsigra-interval.py* script. Figure 6 shows an interesting case in which only one of the launches from this site surpassed the -157 threshold that indicates the condition for the possibility of a tropospheric duct. These launches were made at the Rivolto site in Italy, which is the closest to the beyond the horizon links reported in (Zennaro et al., 2020).

Use cases

LoRaWAN link in Germany

Using TTNMapper, a popular application to check LoRaWAN coverage using TTN, we identified a 280 km long link crossing over Munich in Germany. Leveraging our BotRf tool (Zennaro et al., 2016), we obtained the corresponding terrain profile shown in Figure 3, evidencing that the line of sight is completely blocked and therefore the transmission must be attributed to anomalouus tropospheric propagation. Launching the previous scripts produced Figure 4 and Figure 5. Figure 4 shows that the radiosonde in the IGRA database which is closest to the center of the link lies at a distance of 25 km. Data collected by this radiosonde on the same day in which the anomalous propagation was reported, processed by the *graph-rsigra-day.py* script produced Figure 5. The -157 DeltaN/Deltah gradient in N units per km is shown to be crossed at an altitude of 1800 m, confirming the probable presence of a tropospheric duct.

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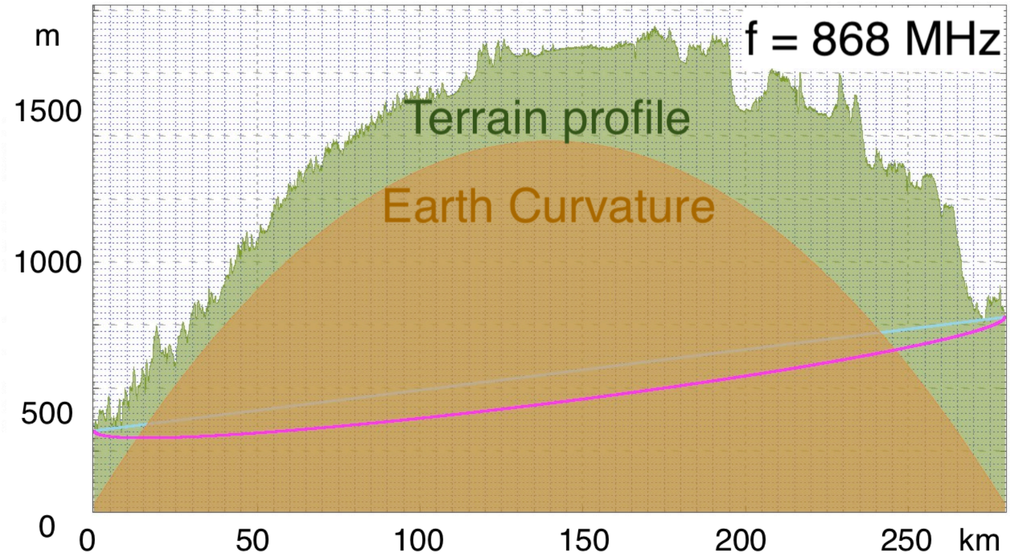

Figure 3: Terrain profile obtained with the BotRf tool of the 280 km link in Germany, showing a completely blocked line of sight.

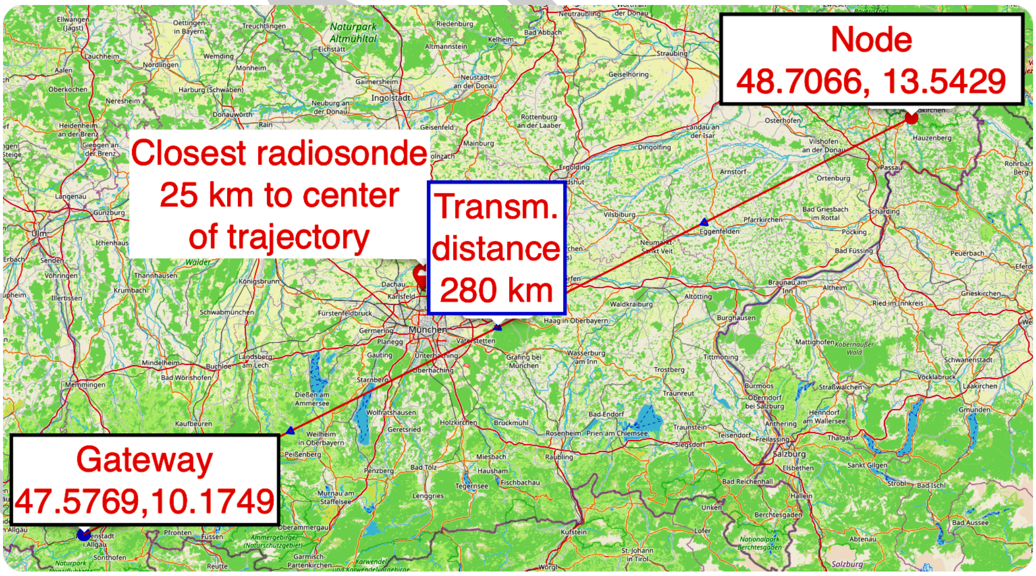

Figure 4: Map of a 280 km tropospheric duct link in Germany showing the positions of the node, gateway and the closest radiosonde launch site.

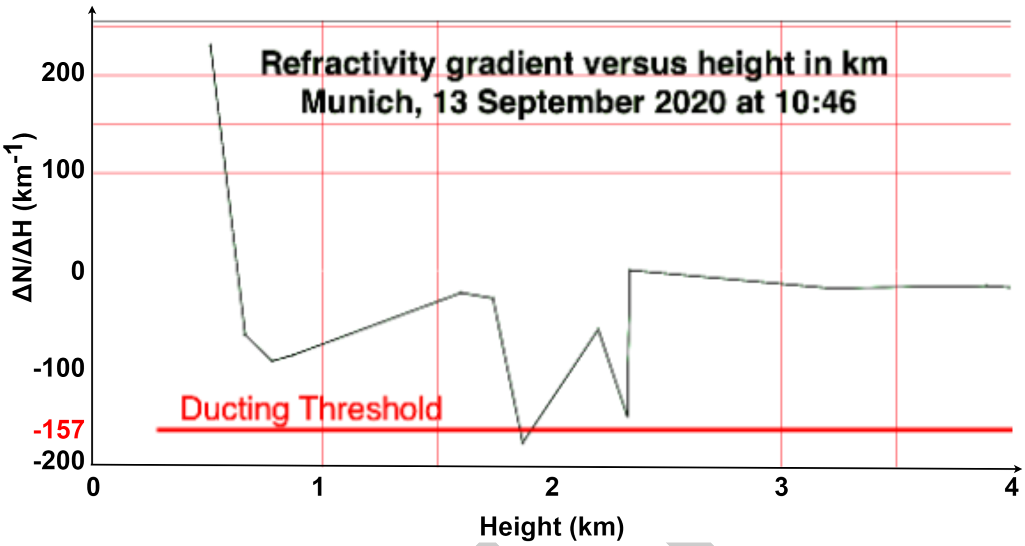

Figure 5: Refractivity gradient Delta/Deltah versus height in Munich. The -157 threshold is crossed at the height of 1800 m denoting a tropospheric duct.

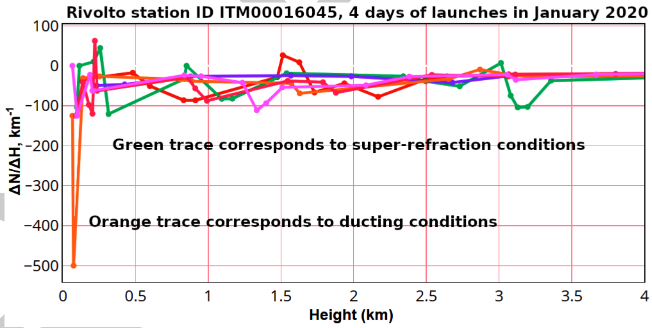

Figure 6: Refractivity gradient Delta/Deltah versus height corresponding to 4 days launches from the ITM 00016045 station in Italy. Conditions for tropospheric duct were present at a height of 100 m on 12 January 2020.

Sigfox link between Portugal and Grand Canary Island

On social media some extremely long links have been documented using Sigfox (HidnSeek, n.d.). As this is an LPWAN technology using a much narrower band than that of LoRaWAN, it is understandable that longer links can be established. Thanks to the collaboration with the Sigfox operator we were able to get the exact positions and time of such long links. One of them spanned 1204 km, with the node in Portugal and the gateway (base station) on Grand Canary Island, Spain. Given the extremely long distance, only tropospheric ducting propagation can explain this link, entirely over sea water, which is a strong reflecting medium.

Launching the scripts we obtained subsection and Figure 7.

Map of the node in Albufeira PT, the gateawy in Grand Canary ES and the launching site of the closest radiosonde in Casablanca, Morocco.

subsection

shows that the nearest radiosonde is in Casablanca, Morocco. In Figure 7 we see that the DeltaN/Deltah value drops below the threshold value of -157, so a tropospheric duct is clearly the propagation mechanism since the earth curvature is blocking the line of sight.

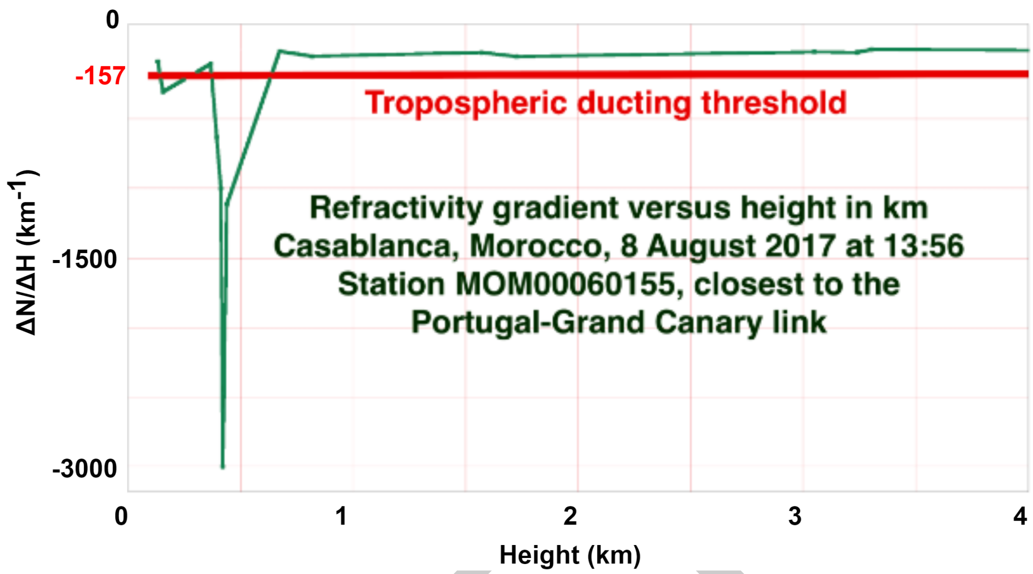

Figure 7: Refractivity gradient DeltaN/Deltah. The -157 N units per km threshold is crossed very close to the surface in this link between Portugal and Spain, as revealed by the tropspheric data gathered by the radiosonde in Morocco.

Conclusions and future work

We have presented a series of Python open source tools that can be used in an automated fashion to analyze wireless links that extend well beyond the geographical horizon. They were applied to explain the propagation mechanism in two representative examples. As an exercise of citizen science, they can be used by anyone to assess the existing tropospheric conditions in many places, in order to determine the type of anomalous radio propagation at a given date, leveraging publicly available radiosonde derived data. The Google Colab notebook can be used by any interested person, in particular by students, to acquire knowledge about propagation issues by leveraging open data and tools. Further details about the profile of the terrain and the radiofrequency power over distance can be obtained by means of the RfBot tool mentioned. Anomalous propagation is essentially independent of the signal's bandwidth, over a wide range of frequencies that extend from VHF to microwaves. Since there is the possibility that the identified radiosonde does not evidence the presence of a duct, due to the fact that even being the closest to the center of the trajectory it might miss local anomalies, future work will address extending the tool to examine several radiosondes data in the proximity of the path of interest.

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