4^{th} *URSI AT-RASC, Gran Canaria, 19 – 24 May 2024*

Tropospheric Ducting Effects on AIS Signals in the Canary Islands

L. Y. Wolinsky-Mancini[(1)], F. Cabrera-Almeida[(1)], N. Molina-Padrón[(1)] and V. Araña-Pulido[(1)]
(1) Institute for Technological Development and Innovation in Communications (IDeTIC), University of Las Palmas de Gran Canaria, Las Palmas, Spain

Abstract

For decades, it has been proven that communication signals experience anomalies in their propagation through the troposphere. One of the main anomalies causes these signals to exceed the radio horizon, enabling very long-distance communications. This phenomenon is known as tropospheric ducting and is due to the confinement of the signals caused by anomalous variations in temperature, pressure, and humidity. Due to their location near the equator, the Canary Islands are prone to the formation of atmospheric ducting. This study combines atmospheric information with AIS (*Automatic Identification System*) signals from vessels to investigate the formation of ducts between the Canary Islands and the Iberian Peninsula. The results obtained correspond to the year 2017, where two significant months are selected to characterise the ducts: February to represent cold months, and August for warm months. It has been demonstrated that the probability of the occurrence of ducts in warm months is significantly higher than in cold months.

1 Introduction

The oceans play a crucial role in many natural processes and commercial activities worldwide. Therefore, their importance has driven the application of technologies to enhance maritime situational awareness [1], which provides a comprehensive understanding of sea events. Among these technologies, maritime communications have played a significant role that extends across various domains, such as maritime navigation and transportation. Although numerous maritime communication systems exist, some as important as AIS (*Automatic Identification System*) or DSC (*Digital Selective Call*) are found in the VHF band (30 MHz - 300 MHz) [2].

VHF signals propagate as space waves, which are characterised by the influence of the troposphere on them. Thus, atmospheric variables such as temperature, pressure or relative humidity cause different phenomena in the propagation of RF signals. These phenomena include *tropospheric ducting*, which enables communication over much greater distances than under normal conditions due to the changes that occur in the troposphere [3].

This article presents a study on the propagation of tropospheric ducting for the maritime region between the Canary Islands and the Iberian Peninsula. After describing the motivation for this article in section 1, section 2 outlines the theoretical foundations of tropospheric propagation, focusing on the occurrence of tropospheric ducting. Section 3 describes the methodology employed in the study, which has led to the results presented in section 4. Finally, section 5 presents the conclusions of this study.

2 Tropospheric propagation

The troposphere is the layer of the atmosphere that extends from the Earth's surface up to a height of 9 to 18 km, depending on the region of the planet. This layer is not uniform and is affected by temporal and spatial variations in environmental parameters such as temperature, pressure, and humidity. As a result, the phenomenon of refraction plays a role in signal propagation, causing an apparent curvature of the rays in relation to the surface. Therefore, the refractive index, n, undergoes variations during signal propagation and it is commonly expressed in terms of the refractivity, $N = (n-1) \cdot 10^6$, or the modified refractivity, $M = N + 0.157 \cdot h$, where h is the height above the Earth's surface expressed in metres [4].

Generally, the refractivity of the atmosphere decreases with height, thus its vertical gradient allows for the analysis of atmospheric conditions. These conditions dictate the modes of signal propagation, which can be classified as *standard* and *normal*, *sub-refractive*, *super-refractive*, and *conductive* conditions (figure 1). Each condition is defined by a specific value or range of values for N and M. In the case of conductive conditions, $N < -157$ and $M < 0$. When these conditions are met, extreme super-refraction occurs in the lower regions of the troposphere, which is known as *tropospheric ducting*. This phenomenon is caused by sharp variations in the refractive index with respect to height, which confines the rays between two horizontal surfaces. As a result, signals propagating through a duct can travel long distances, often exceeding those limited by the radio horizon [5].

Various atmospheric conditions result in the formation of

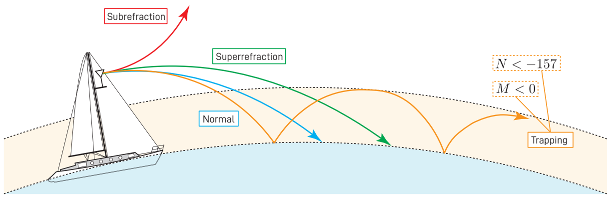


Figure 1. Relative bending for each atmospheric condition.

different types of ducts, such as *surface ducts*, *evaporation ducts*, and *elevated ducts*. On the one hand, surface ducts are formed by the overlaying of a hot, dry air mass on a colder air mass from the surface, resulting in a *thermal inversion*. If the trapping zone is located on the Earth's surface, it is referred to as a *simple surface duct*, however, if this layer is elevated and uses the Earth's surface as the base of the duct, it is called an *elevated surface duct*. Additionally, at very low altitudes evaporation ducts can be formed. On the other hand, elevated ducts are formed at a certain height under atmospheric conditions similar to those of surface ducts. This phenomenon is most common in tropical latitudes, where cold air masses descend from the upper and middle layers of the atmosphere to lower layers, causing a thermal inversion as a warm and dry air mass overlies a colder and wet one. Under favourable conditions, elevated ducts can become surface ducts, or vice versa [6].

Finally, tropospheric ducts are characterised by their *intensity*, M_d, which is the difference between the maximum and minimum M values, and by their thickness, D, defined as the difference between the maximum and minimum heights (figure 2) [4]. These factors determine the ability of ducts to confine waves of different frequencies. Thicker ducts are capable of confining waves of lower frequencies.

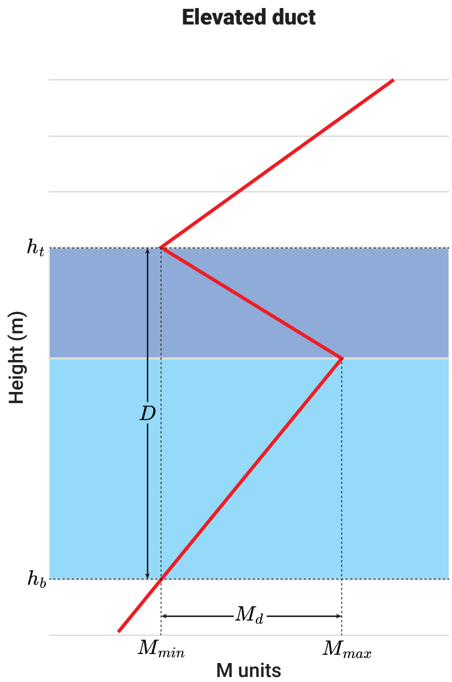


Figure 2. Theoretical M profile for an elevated duct.

3 Methodology

This study investigates the formation of tropospheric ducts in the Canary Islands in 2017 by correlating atmospheric and maritime traffic data. The study area encompasses the eastern region of the Canary Islands and the southern zone of the Iberian Peninsula, where atmospheric conditions are conducive to the formation of tropospheric ducting throughout the year [7, 8].

On the one hand, atmospheric data has been obtained from a radiosonde located in Güímar (Tenerife) at an altitude of approximately 115 metres above sea level at coordinates 28.3184°(latitude) and -16.3822°(longitude). This radiosonde belongs to the Regional Basic Synoptic Network of the WMO (*World Meteorological Organization*) Association I. It conducts two daily soundings, one at 00:00 and another at 12:00. The University of Wyoming's database was used to access these data. On the other hand, AIS data was obtained through the AIS receiving station BMT-IDeTIC (ID: 1609), which belongs to the MarineTraffic network and is managed by the University of Las Palmas de Gran Canaria. The station is located on the rooftop of the Edificio Polivalente II of the Tafira Campus (Gran Canaria), at coordinates 28.0794°(latitude) and -15.4519°(longitude), at an altitude of 375 metres above sea level. The AIS receiver is connected to a VHF antenna, and it stores the messages received on a server through an Ethernet connection.

An algorithm has been developed in MATLAB to carry out the analysis of the ducts using the atmospheric and AIS data. Figure 3 illustrates the flowchart associated with this algorithm.

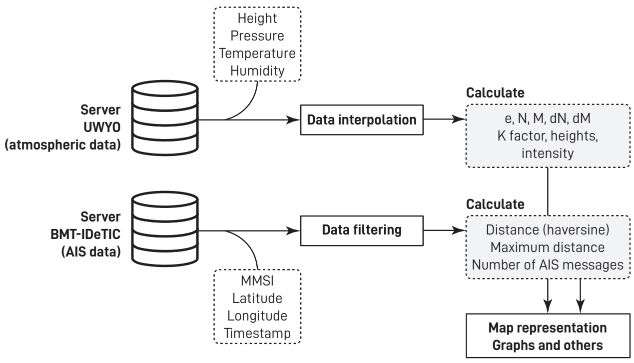


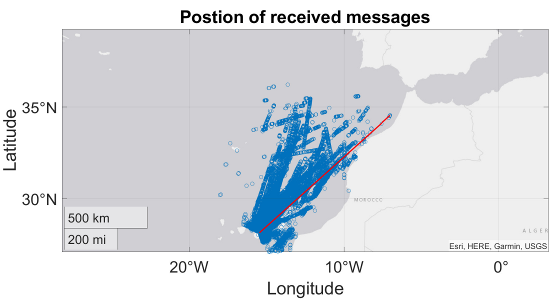
Figure 3. Flowchart illustrating the duct analysis algorithm using atmospheric and AIS data in MATLAB.

The amount of information extracted from the data is dependent on the length of the observation periods. For atmospheric data, the data is stored in a structure that contains parameters based on heights, collected for each daily sounding. The most relevant parameters for this study, namely, altitude, temperature, pressure, and relative humidity, are extracted. The data is verified to ensure correctness and ordered by height. Subsequently, the atmospheric data is interpolated to a common height vector to facilitate analysis. Refractivity and modified refractivity values, along with their variation with height, are then calculated from the interpolated data to identify the presence of ducts. From the profiles of modified refractivity, the values of maximum and minimum duct height, as well as the maximum and minimum *M* values, are calculated to estimate the duct thickness and intensity.

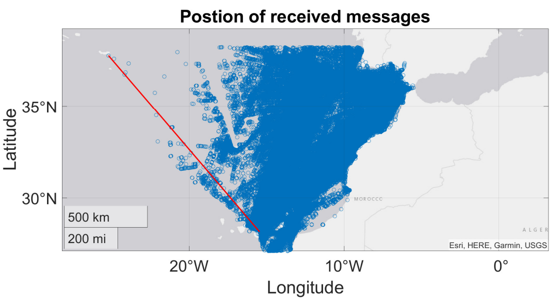
The AIS messages are decoded and classified based on their reception timestamp. For each observation period, information such as MMSI, latitude, and longitude of the vessels is extracted. The distance of the AIS emissions from the BMT-IDeTIC receiving station is calculated using the latitude and longitude. Additionally, the data is filtered to remove any erroneous information [9].

4 Results

After processing the atmospheric and AIS data, tropospheric ducts are studied and analysed for different periods. Various statistics are extracted corresponding to the months of February and August 2017. Since the atmospheric data obtained by the radiosonde correspond to two daily samples, this information is limited in time. In contrast, the AIS data is obtained continuously throughout the entire period, which may result in discrepancies in the analysis due to variations in the size of the atmospheric and maritime traffic information.



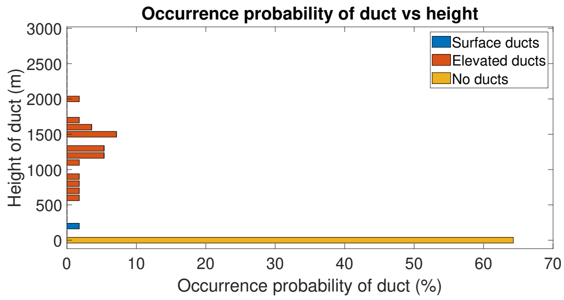
(a) February 2017.



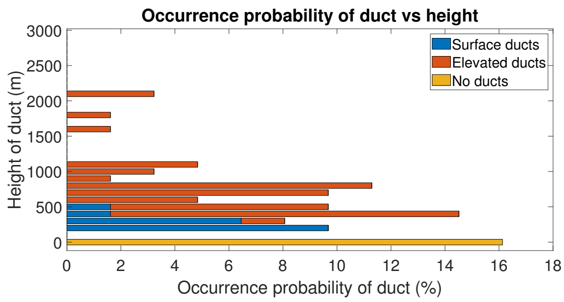
(b) August 2017.

Figure 4. Position of AIS received messages at BMT-IDeTIC station for each month.

The maps depicted in figure 4 correspond to the positions of AIS received messages during February and August 2017. It is observed that the density of points corresponding to AIS emissions is higher in August than in February, which is consistent with the more frequent occurrence of ducts in the warmer months. Furthermore, figure 5 shows the probability of the formation of different types of ducts at different heights in the two indicated months, showing a low probability of no duct occurrence in August compared to February. Additionally, the occurrence of elevated ducts is more prevalent than surface ducts in both moths, indicating the altitude at which ducts form in the Canary Islands region.

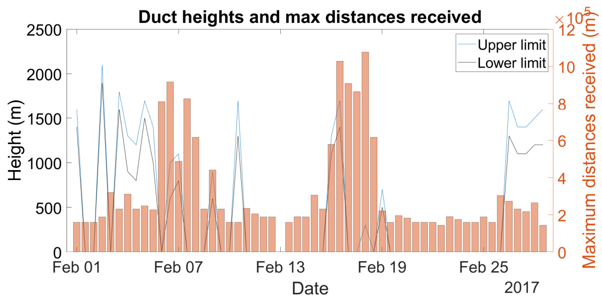


(a) February 2017.

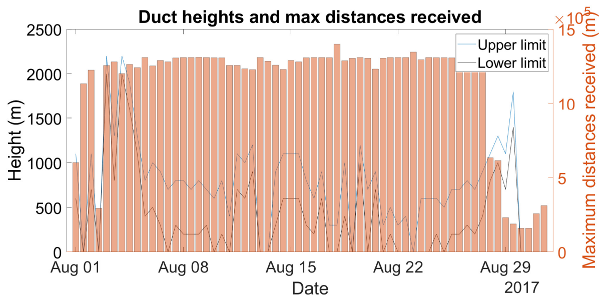


(b) August 2017.

Figure 5. Occurrence probability of each duct type at different heights.



(a) February 2017.



(b) August 2017.

Figure 6. Variation of duct maximum and minimum heights, and maximum AIS reception distance for each month.

Finally, figure 6 shows the relationship between the duct heights and the maximum reception distances for each month. It is observed that in August, the ducts are more consistent, and the maximum reception distances are greater compared to February. The graph indicates that for duct heights below approximately 1300 meters, signal propagation over very long distances is achieved, however, for higher heights, signal propagation is limited by the radio horizon.

5 Conclusions

This study presents some interesting results on the occurrence of tropospheric ducts in the maritime area between the Canary Islands and the Iberian Peninsula. The study area exhibits favourable conditions for duct formation, enabling the reception of AIS signals from vessels located at distances of up to over 2000 km. In warmer months (August), ducts are more likely to form with increased probability, intensity, and stability compared to colder months (February). In this region, elevated duct formation is more prevalent than surface ducts. For ducts formed at very high altitudes, exceeding 1300 meters, AIS signals cannot be confined and, therefore, do not propagate over very long distances.

6 Acknowledgements

This work was supported by the projects Grant TED2021-130318A-I00, funded by Spanish Ministry of Science and Innovation, and IDEA 2.37, funded by Spanish Port Authority through IDEAS program.

References

[1] M. W. Wenlong Tang, Hao Cha and B. Tian, "The effect of atmospheric ducts on the propagation of AIS signals," *Australian Journal of Electrical and Electronics Engineering*, vol. 16, no. 2, pp. 111–116, 2019. [Online]. Available: https://doi.org/10.1080/1448837X.2019.1622491

[2] F. S. Alqurashi, A. Trichili, N. Saeed, B. S. Ooi, and M.-S. Alouini, "Maritime communications: A survey on enabling technologies, opportunities, and challenges," *IEEE Internet of Things Journal*, vol. 10, no. 4, pp. 3525–3547, 2023.

[3] F. Liu, "Atmospheric ducting effect in wireless communications: Challenges and opportunities," *Journal of Communications and Information Networks*, vol. 6, no. 2, pp. 101–109, 2021. [Online]. Available: https://www.infocomm-journal.com/jcin/EN/10.23919/JCIN.2021.9475120

[4] International Telecommunications Union, "The radio refractive index: Its formula and refractivity data," International Telecommunications Union, Tech. Rep. Recommendation ITU-R P.453-14, 08 2019.

[5] H. Hitney, J. Richter, R. Pappert, K. Anderson, and G. Baumgartner, "Tropospheric radio propagation assessment," *Proceedings of the IEEE*, vol. 73, no. 2, pp. 265–283, 1985.

[6] W. L. Patterson, "Advanced refractive effects prediction system (AREPS), version 1.0 user's manual," 1998. [Online]. Available: https://api.semanticscholar.org/CorpusID:53884052

[7] R. Belón, A. González, V. Araña, and E. Jiménez, "Transhorizon tropospheric propagation in the saharian fishing bank," in *International Symposium on Recent Advances in Microwave Technology Proceedings (ISRAMT)*, 1999.

[8] M. Grabner, V. Kvicera, P. Pechac, M. Kvicera, P. Valtr, and A. Martellucci, "World maps of atmospheric refractivity statistics," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 7, pp. 3714–3722, 2014.

[9] F. Heymann, T. Noack, and P. Banys, "Plausibility analysis of navigation related AIS parameter based on time series," 2013. [Online]. Available: https://api.semanticscholar.org/CorpusID:4247740