

Response to Referee #1.

Rautiainen, L., Johansson, M., Lensu, M., Tyynelä, J., Jalkanen, J.-P., Stenbäck, K., Lonka, H., and Laakso, L.: Studying anomalous propagation over marine areas using an experimental AIS receiver set-up, EGUsphere [preprint], <https://doi.org/10.5194/egusphere-2025-1790>, 2025.

We thank Dr. Alex Chartier for their insightful comments which have helped us to improve and clarify the paper. Below, we have provided a reply to the comments comment-by-comment with the responses in red font.

RC1 – Alex Chartier – 11 Aug 2025

Thanks for an interesting manuscript. I have the following comments, but defer to tropospheric experts regarding the significance of the results.

1. What is the distribution of propagation distances observed? Can you show a histogram of distances to illustrate the ‘break point’ between normal and anomalous propagation? The selected criterion (95th percentile of maximum distance) seems ad-hoc and vulnerable to variations in the distribution of ships with relation to the receiver station (as noted by the authors between lines 325-30). Why not use a simple distance cutoff (e.g. at least X counts >300 km indicates anomalous propagation)?

Besides atmospheric conditions, the propagation distance is affected by the heights of transmitting and receiving stations and the power of the transmitting station. The height variation is very large as the traffic includes ships of all sizes from small tugs to large ferries for which the bridge can be more than 40 meters from the sea level. Also, the anomalous propagation conditions are seldom uniform over any larger area in the Archipelago Sea. This is clearly seen from coastal radar data where distant targets over the normal horizon flicker, disappear out of sight, and reappear during anomalous conditions.

In order to use distances to the transmitting ships unambiguously to quantify propagation, the data should be normalised by the transmitting power and the antenna height, where the latter can be assumed to have more variation. However, the antenna height data is not included in the marine radio station information databases but must be requested from the shipping companies or estimated from particulars data or images (e.g. using bridge roof height). We are aware of the

potential of such data to reveal the spatial distribution of propagation conditions and have plans to utilise it in the future. However, any definition of distance behind which the reception is interpreted as following from anomalous conditions, based on statistical distributions or other considerations, is bound to be ship specific.

We are also aware that the normal and anomalous conditions manifest as a superposition appearance in the distance histograms (See Figure 1 below). However, the distance data is not as suitable for our analysis that is targeting the identification and classification of anomalous conditions, and the percentile data that was chosen precisely to have a descriptor that is less sensitive to the variation of transmission parameters. The use of percentile data also connects our AIS based research with our earlier radar-based work (Rautiainen et al, 2023, 2025). Also for the radar data, the properties of the island and ship targets (reflectivity, height) make the distance-based measures less applicable. We also find the applicability of the same distribution superposition model for both AIS and radar data an argument in favor of our approach.

Here's an example of the distribution of propagation distances observed with the 7 m antenna over September 2023:

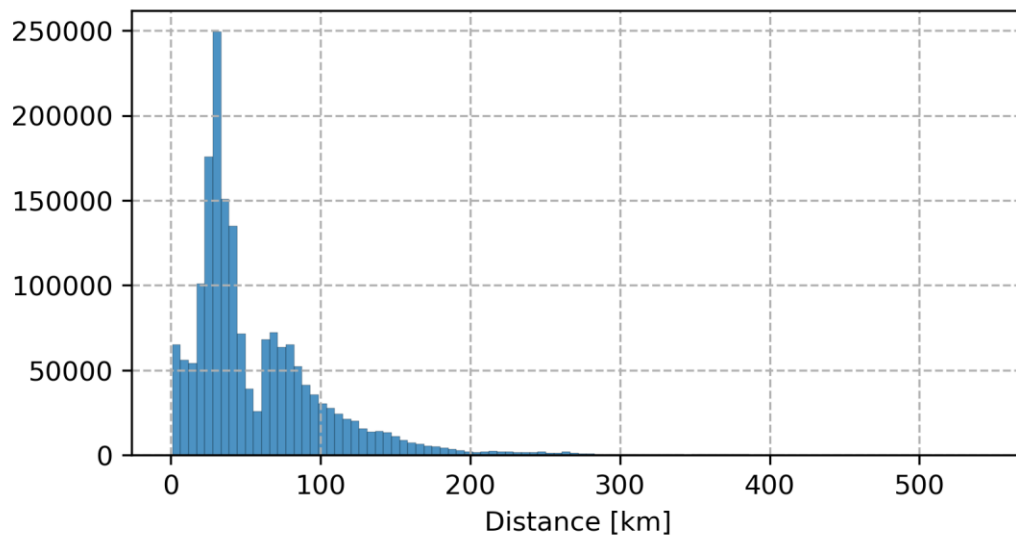


Figure 1. Histogram of distance [km] for the 7 m antenna over September 2023. The data is limited to Class A and Class B position reports from within the study area. The closest 1 km is excluded.

Additionally, the goal was to achieve a metric that limits the amount of data while being descriptive of the visibility. As the antennas receive on average 200 000-500

000 messages per day, limiting the number of data points to 24 per day before doing further analyses was desirable. The above histogram consists of 2.3 million data points alone.

Prior to submitting our paper, we tested the effect on the results by changing the 95th percentile to median, 85th percentile, and 99th percentile. The distributions for the median, 95th percentile, and 99th percentile are very similar. The 99th percentile was more sensitive to individual ships while the median was not very descriptive of the visibility, hence we decided to use the 95th percentile.

We hope this clarifies why the metric was chosen.

Rautiainen, L., Tyynelä, J., Lensu, M., Siiriä, S., Vakkari, V., O'Connor, E., Hämäläinen, K., Lonka, H., Stenbäck, K., Koistinen, J., & Laakso, L. (2023). Utö Observatory for Analysing Atmospheric Ducting Events over Baltic Coastal and Marine Waters. *Remote Sensing*, **15**(12), 2989. <https://doi.org/10.3390/rs15122989>

Rautiainen, L., M. Lensu, V. Vakkari, J. Tyynelä, H. Kanarik, and L. Laakso, 2025: Marine Atmospheric Ducting Statistics Based on 2 Years of Coastal Surveillance Radar Observations. *J. Appl. Meteor. Climatol.*, **64**, 63–76, <https://doi.org/10.1175/JAMC-D-24-0096.1>.

1. It is not obvious (at least to me) whether the results are in keeping with what is expected from current atmospheric propagation models. Additionally, the ducting analysis is restricted to local conditions at the receiver site (Utö). These two issues could be remedied by comparing the results to duct strengths calculated from meteorological reanalysis data.

Thank you for the suggestion. We agree that including modelling would allow assessing the results of this study in a more regional setting. However, it is out of scope for this study. We strongly agree that this is a very relevant comment, and there is a current, on-going project where this will be accounted for on a European scale. In addition, we are currently working on a study where the measurements done at Utö are compared to the MetCoOp model Harmonie-AROME.

1. Parts of the introduction seem to make a false dichotomy between VHF and AIS (e.g. 38-40, 52-53). Consider rephrasing.

Thank you for pointing this out. We understand the issue the referee is describing. We removed the mention of AIS frequency for 38-40 and added a specification on the line 52-53:

“..., other systems using the VHF frequency...”

Line-by-line comments as follows:

14-15: Provide some statistical metric to support the claim that “*anomalous AIS observations were also found to coincide with the stronger and higher observed ducts*”

Thank you for the comment. We have edited the sentence as follows:

“*Anomalous AIS observations were also associated with stronger and higher ducts; when the duct height was 59 m, the occurrence rates were 90% and 95% for the 7 m and 30 m antenna, respectively.*”

41: Specify ‘at distances of less than 1000 km.’

We thank the reviewer for pointing this out. It is an important specification to make. We have added it at the end of the sentence:

“However, at the AIS frequency 162 MHz, troposcatter and ducting are the most relevant factors resulting in anomalous signal propagation *at distances of less than 1000 km.*”

53: Given the separate categorization of (1) AIS and (2) VHF, Chartier et al. (2022) belongs in the first group rather than the second.

Thank you for pointing this out; it has now been fixed.

223 (and elsewhere): Consider using a different term than ‘horizon’. The manuscript makes sense if ‘horizon’ is interpreted as ‘horizon of observability’, but the most natural interpretation is ‘the line at which the earth’s surface and the sky appear to meet.’

Thank you for the suggestion. The natural interpretation does not account for the refraction by the atmosphere, while the horizon defined in the preprint is the horizon of observability under standard atmospheric conditions. We have defined the term horizon prior to using it (see L219 in the preprint).