

Authors' response to the Editor and Referee #2 comments on the revised manuscript

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, EGU sphere [preprint], <https://doi.org/10.5194/egusphere-2025-1790>, 2025.

Editor's decision:

Publish subject to minor revisions (review by editor):

Please review your work considering the reviewer's comments. You might want to reconsider adding the regional duct maps from the met reanalysis data suggested by Referee 1.

We thank the Editor for the feedback and suggestions. We have included our current responses in dark blue, old responses in light blue cursive, old review comments in grey cursive and new review comments in black font.

Comment editor is referencing:

“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.”

Our response:

“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.”

Response to the editor:

We appreciate the suggestion. Our concern with including a regional analysis is that it requires an in-depth analysis of the reanalysis itself in addition to comparison to our study. This constitutes its own study, and there is an ongoing project working on this. To condense this analysis, we have opted to compare our mast profiles and duct strengths to those calculated from the nearest ERA5 grid (Figure 1). The ERA horizontal resolution is $0.25^\circ \times 0.25^\circ$, which corresponds to roughly a 27 km grid.

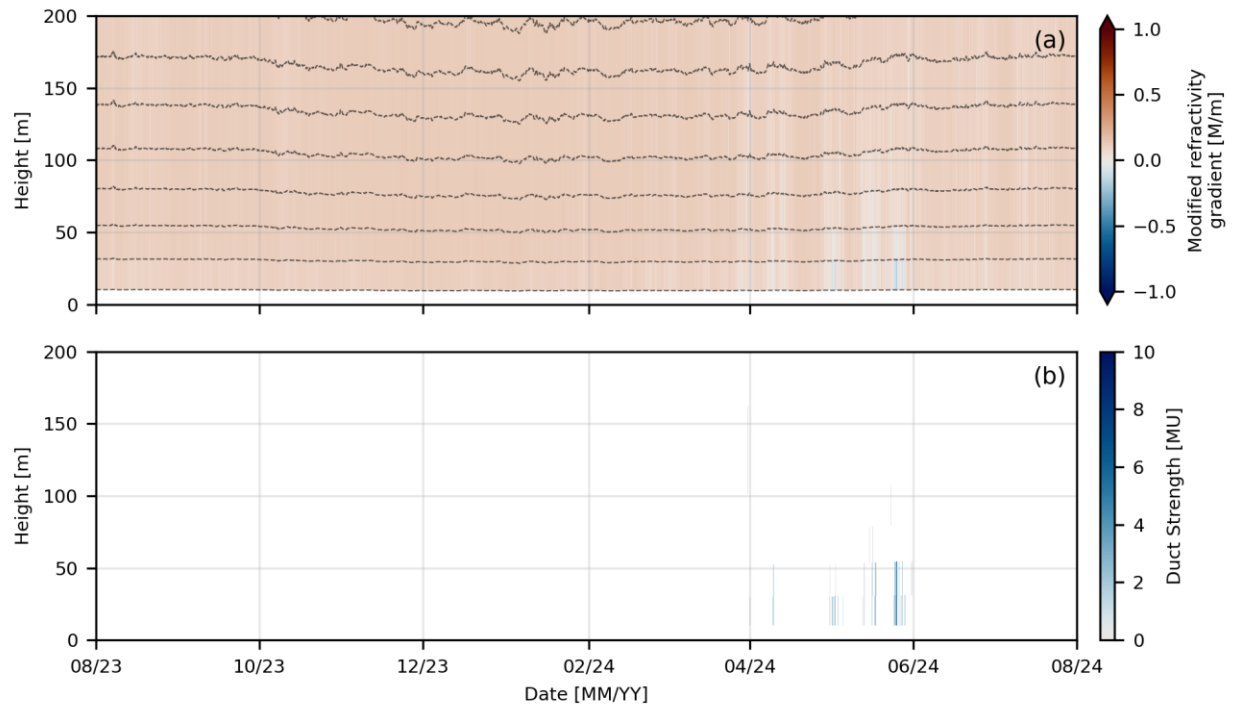


Figure 1. Time series of a) the modified refractivity gradient [M/m] and b) the trapping layer heights and duct strengths calculated for the ERA5 nearest grid to Utö.

It is worth noting that the ERA5 resolution is coarse and starts at ~ 10 m from the surface. Therefore, it is not very comparable with our mast, which is specifically aimed at identifying surface ducts with observations taken at 4, 7, 12, 22, 32 and 59 m heights above the mean sea level. While the benefit of including the reanalysis would be additional heights above 60 m, the vertical resolution of the model gets coarser with height which makes detecting elevated ducts less reliable. In the future, we plan to address this by launching weather balloons alongside acquiring drone profiles. Hence, here, we do not attempt to validate the ERA5 profiles with the mast measurements, or vice versa.

As the Referees had concerns with the length of the study, we added this comparison to the Appendix E. We brought in a new co-author, Mikael Hasu, who performed the analysis.

Referee #2 comments on revised version 1

I appreciate most of the changes and explanations by the authors. The manuscript certainly improved by the recent revision. Many of the comments of all three reviewers have been addressed properly also in the manuscript.

We thank Referee #2 for their time and effort in reviewing the revised manuscript! We hope that these new changes and further explanations address the remaining concerns. We have included our current responses in dark blue, old responses in light blue cursive, old review comments in grey cursive and new review comments in black font.

My remaining concerns and comments are:

Referee #2:

L62 "... behave in unexpected ways" means what? "... behave in unexpected ways"

Authors:

The term "unexpected" is used to describe situations where the data does not follow the guidelines expected by the user, e.g. how often the messages are transmitted should correspond to the speed of the vessel, which is not always the case.

Referee #2:

still exit - it's still not explained in the manuscript, what is meant by this phrase.

Authors:

Thank you for pointing this out, we have added the explanation to the new revised manuscript L61:

"The data can also include user errors which cause the data to behave in unexpected ways, e.g. the frequency of broadcasted messages does not correspond to the speed of the vessel."

Referee #2:

L207- I'd suppress all the data below 10km (at least!) as the local harbour spoils the statistics and as you're rather after "anomalous" propagation these distances are not useful anyway.

Authors:

The figure here is mainly included to illustrate the overall data and where from the messages are received prior to any exclusions. This justifies excluding the nearest 1 km from the analysis as the harbour on the island pollutes the data. Excluding 10 km from the data could potentially hide other forms and effects of anomalous propagation, such as subrefraction.

Referee #2:

I still don't agree. These close distances have nothing to do with tropospheric long distance ducting, what you are after in this manuscript, nor will it contribute additional knowledge or understanding of it.

Authors:

We appreciate the concern raised by the Referee #2. Excluding the nearest 1 km is justified by the directional histogram analysis where the share of the messages from the nearest 1 km is dominating the histogram. We do not see a similar issue with the nearest 1-10 km as the harbour is 700 m away from our mast (see Fig. 1 below). The distances above 1 km are the ship traffic that we wish to include in the analyses. The traffic to and from the harbour is not an issue, the issue is caused by the harboured ships. Therefore, we do not see eliminating the nearest 10 km as justified as eliminating the nearest 1 km, as the question would then arise why we chose to exclude the nearest 10 km rather than the nearest 5, 20, or 40 km.

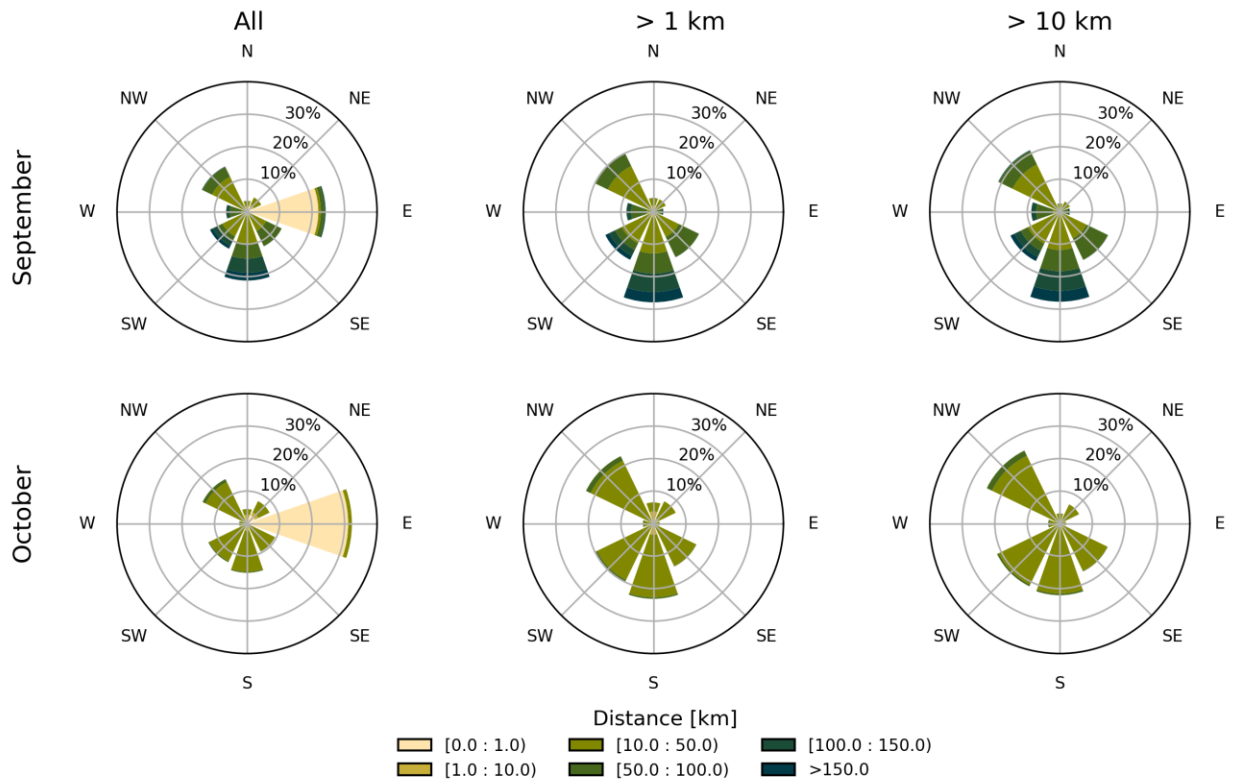


Figure 1. Directional distribution and distance from Utö [km] of AIS messages received by the 7 m antenna for two months Sept and Oct 2023 (rows). The columns show the data with all distances (left column), distances > 1 km (middle column) and distances > 10 km (right column).

Referee #2:

Sect3.6 I'm not too convinced, what has been learnt from the global AIS, this probably needs to be clarified more clearly. In that light, for the global AIS as it is comprised of spaceborne and terrestrial data during ducting, I'd bet quite some of the AIS signals are not received by the satellites, but at the same time more terrestrial detections will exist, which compensates?...

Authors:

Thank you for the comment, please see the answer to L125 comment.

The comment authors reference to:

We appreciate the comment and now see that not enough context for including the global data was provided. These two datasets, the AIS dataset and the global AIS dataset are

independent from each other. Hence, the global AIS data is used in this study as a background truth to compare the experimental set-up results to.

We have added the following context to the manuscript L125:

“The ORBCOMM global AIS data is independent from the AIS data used in this study and therefore was used as a background “truth” to establish the areal coverage of the experimental AIS set-up over two months, September-October 2023.”

Referee #2:

That's not really answering my question. I was hypothesizing that with the presence of the tropospheric duct, there might be less AIS signals detected by the satellites as the signals are refracted and not propagating to the spacecraft. On the other hand other coastal stations that are included in the global AIS(???) will add more information due to the tropospheric ducting... right? That's what I meant with "it might compensate".

Authors:

We thank the Referee #2 for the clarification; we have added the following sentence to the manuscript L118:

“As the global AIS combines satellite and terrestrial AIS data, it is used as the background truth in the analysis, assuming it shows all vessels present in the study area. However, the global dataset can also be affected by anomalous propagation which can introduce error in the analysis.”

Referee #2:

Fig15 another candidate for the appendix or to be removed as it's basically a scaled version of Fig14. What do we learn from this Fig? Again, just less observations/coverage.in the right panel, why are there distances near 0km, when it's about OH grids?

Authors:

Thank you for the suggestion on how to condense the study. We have moved Fig. 15 to the appendix.

Referee 2:

Yes, you've moved the Figure, but you did not answer or reasoned, why there are counts for extremely close grids - less than 10km - IF/AS you refer to them as "grids OH". You're

describing a radio horizon, different for each direction, due to the antenna mast, topography etc., which is then altered (enhanced!) to larger distances. So, why are distances below 10km relevant ? These distances are just confusing and adding nothing to e.g. ducting.

Authors:

We are sorry to have missed the reasoning for including the within-horizon distances. The analysis carried out includes both within-horizon and over-the-horizon data as we are looking at the correlation between two datasets, one being the 95th percentile of maximum distance and the other is the number of grids over-the-horizon where the horizon is based on the global AIS dataset. This means that while the latter begins at 0 grids, the former can be anything within the min and max of the 95th percentile. As we can see, there is often a small number of grids over-the-horizon even when the 95th percentile of maximum distance is low, while when the 95th percentile is significantly greater, the number of grids is also significantly greater.

To address the Referee #2 concern, we have approached the same analysis from a different angle, by limiting the panel c to only the over-the-horizon observations:

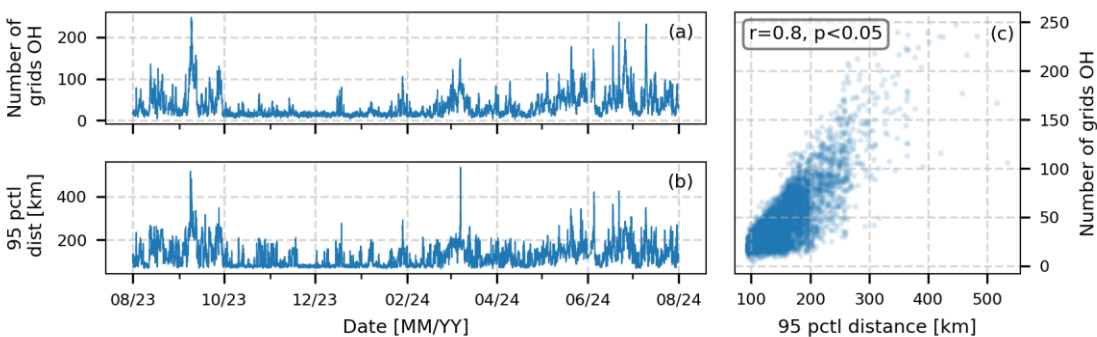


Figure 2. Based on the 30 m antenna data: (a) hourly time series of the number of grids with at least one ship outside of the horizon, (b) hourly 95th percentile of distance and (c) relationship between the two when 95th percentile is over-the-horizon.

We have edited this approach also to the manuscript for Figures 12 and C1 and updated the r-values in text.

The number of grids OH is more sensitive to individual ships than the 95th percentile, and hence changing the approach improves the analysis.

Referee #2:

L330 "However, it is unclear if the anomalous IAS" Why unclear, what else should it be?

Authors:

Thus far in the study, it has not been shown to be caused by ducting, as the OH observations could also result from other processes, e.g. troposcatter

Referee #2:

Formally true, as you want to verify ducting with the temperature profile etc. Fair enough, but I wouldn't formulate the sentence that strict. "is unclear" - perhaps you mean "unproven" !?! Btw. to my understanding we'd also need a bit larger radiated power than it is used for AIS for efficient tropo-scatter, ducting is WAY more efficient!

Authors:

We thank Referee #2 for providing further clarification on the issue. We have reworded the L302 as follows:

“However, it has not yet been demonstrated in this study, that the OH observations result from ducting.”

Referee #2:

Fig17 again, why are there distances near 0km? It's certainly not the type of ducting (over hundreds of km) you're aiming for I'd also move the 2nd panel to the appendix, if needed.

Authors:

Only the nearest 1 km is excluded from the study. The data is shown in 10 km intervals and hence there is 0-10 km interval where data is 1-10 km. We think that the 2nd panel should be included as it demonstrates the differences between heights.

Referee #2:

I still don't agree that anything below 10km is important for this study. As you want to keep the now Fig.14 with both panels - why are there no 95 percitles at distances below 60?km for the higher mounted antenna? This is not consistent, at least.

Authors:

We understand and we hope that including the 1-10 km was justified in our earlier response where we demonstrated that 1-10 km does not spoil our data.

The 95th percentile is descriptive of the horizon, which for the 30 m antenna is 94 km. The horizon for the lower antenna is 82 km but for 41% of the time the 95th percentile is from

below 60 km. While for the 30 m antenna, this is 0%. This can be seen in Figure 7 where the 95th percentile distributions are shown. In addition, as described in L226 (revised manuscript), there is a greater overlap between the two distributions (X_1 and X_2) for 7 m antenna which leads to the chosen statistical horizon under-forecasting over-the-horizon observations. The 7 m antenna is also more affected by physical blocking than the 30 m antenna.

We have added the following specification to L316:

“Note that the 95th percentile can sometimes fall significantly below the defined statistical horizon for the 7 m antenna, which could result from e.g. the signal being physically blocked by the terrain.”

Referee #2:

Fig16 somewhat hard to see details, especially in the 3rd panel

Authors:

Thank you for pointing this out; we have made the figure wider. Hopefully this helps the interpretation of the figure!

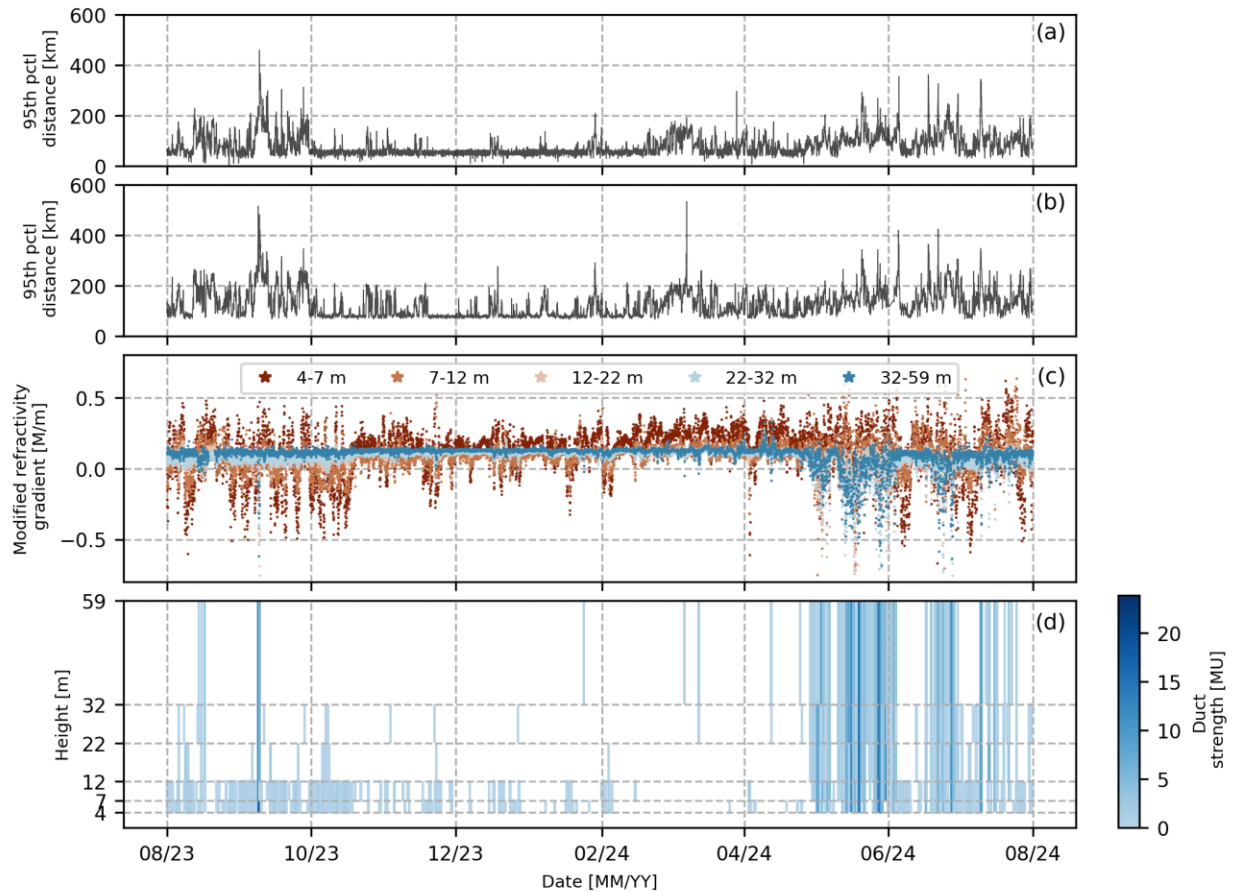
Referee #2:

Fig.13 : if it stays at full page width it's probably fine, but if it's going to be shown differently I suspect it will be hard to see details in panel (c).

Authors:

We understand the concern, this is perhaps not the best way to display the M -gradients over the 1-year long time series.

We have plotted the gradients differently to hopefully account for this:



Referee #2:

Besides that, topics like the likelihood of ducts, existence of high-pressure systems (contant pressure path), suitable temperature / humidity profiles over various terrain and land/sea should be discussed also in the perspective to other publications.

Authors:

We agree that this is a very important aspect but unfortunately out of scope for this study. We compare our observed ducts to other publications in Rautiainen et al., 2025, and we have an ongoing project that will investigate this in more detail.

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>.

Referee #2:

I had hoped that it would be less “outside the scope of this publication”, but instead I still would have liked to see a little more discussion and comparison with other studies.

Authors:

We understand the issue Referee #2 is describing.

We have compared our AIS results to C-band weather radar-based analysis by Norin (2023) and X-band radar analysis by Rautiainen et al. (2025) from the same region, the northern Baltic Sea. We have also reflected on where our study fits in the current AIS ducting research.

To refer to the original comment by Referee #2, weather data analysis (high pressure systems, suitable T and RH profiles, and so on) has not been carried out in this study. These have been consciously left out of this study as the focus is on our AIS results. As noted in the review process, this study is lengthy as it is. The topic itself is broad and comes with many different opportunities and different angles that can be taken (including modelling, for one). Unfortunately, one study cannot cover all aspects, but the research work is continuous.

We have added the following sentence to the discussion L375:

“In addition, in future studies, examining favourable weather conditions (e.g. temperature and humidity profiles and high-pressure systems) to AIS ducting would deepen our understanding of the phenomenon.”

Norin, L.: Observations of anomalous propagation over waters near Sweden, Atmos. Meas. Tech., 16, 1789–1801, <https://doi.org/10.5194/amt-16-1789-2023>, 2023.