EGU22-8411
https://doi.org/10.5194/egusphere-egu22-8411
EGU General Assembly 2022
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Reconstructing the Atlantic Meridional Overturning Circulation in Earth System Model simulations from density information using explainable machine learning

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Despite the importance of the Atlantic Meridional Overturning Circulation (AMOC) to the climate on decadal and multidecadal timescales, Earth System Models (ESM) exhibit large differences in their estimation of the amplitude and spectrum of its variability. In addition, observational data is sparse and before the onset of the current century, many reconstructions of the AMOC rely on linear relationships to the more readily observed surface properties of the Atlantic rather than the less explored deeper ocean. Yet, it is conceptually well established that the density distribution is dynamically closely related to the AMOC, and in this contribution, we investigate this connection in model simulations to identify which density information is necessary to reconstruct the AMOC. We chose to establish these links in a data-driven approach.

We use simulations from a historically forced large ensemble as well as abruptly forced long term simulations with varying strength of forcing and therefore comprising vastly different states of the AMOC. In a first step, we train uncertainty-aware neural networks to infer the state of the AMOC from the density information at different layers in the North Atlantic. In a second step, we compare the performance of the trained neural networks across depth and with their linear counterparts in simulations that were not part of the training process. Finally, we investigate how the networks arrived at their specific prediction using Layer-Wise-Relevance Propagation (LRP), a recently developed technique that propagates relevance backwards through the network to the input density field, effectively filtering out important from unimportant information and identifying regions of high relevance for the reconstruction of the AMOC.

Our preliminary results show that in general, the information provided by only one density layer between the surface and 1100 m is sufficient to reconstruct the AMOC with high precision, and neural networks are capable of generalizing to unseen simulations. From the set of these neural networks trained on different layers, we choose the surface layer as well as one subsurface layer close to 1000 m for further investigation of their decision-making process using LRP. Our

preliminary investigation reveals that the LRP in the subsurface layer identifies regions of potentially high physical relevance for the AMOC. By contrast, the regions identified in the surface layer show little physical relevance for the AMOC.