Rupert Ford Award: project report

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With the generous support of the Royal Meteorological Society's Rupert Ford fund I visited the Alfred Wegener Institute (AWI) in Potsdam in early 2024 to collaborate with colleagues on a project examining the impacts and drivers of atmospheric rivers and warm air intrusions (WAIs) on the polar environment.

The objectives of the project were to evaluate the occurrence, origins and impacts of WAIs in two high-resolution (~11km) regional climate model datasets produced as part of the EU Horizon 2020 project PolarRES[1]. The German ICON model and British MetUM models were used for this purpose. My colleague Jan Landwehrs and I enhanced our own models by adapting them to output integrated water vapour transport (IVT), which is necessary to track WAIs in model data.

The aims of the project were as follows:

1. Apply the WAI detection method of Prein et al. (2023) to model simulations produced as part of PolarRES
2. Evaluate the impacts of WAIs on the polar environment, using a case study approach
3. Create a climatology of WAIs in the Arctic and Antarctic
4. Compare the frequency and impacts of WAIs between the Arctic and Antarctic
5. Develop the collaboration between researchers at BAS and AWI-Potsdam

All five of the objectives have been successfully completed or are in progress, and we continue to work on the project together.

During my visit, we agreed to examine two extreme case studies. First, for the Arctic, the period April 2020 was simulated. This month was during the MOSAiC campaign[2] and two WAIs were identified in this period that crossed the Arctic and arrived at the Polarstern, which was moored in the sea ice. This meant that there were many observations against which to validate the model simulations. Second, for the Antarctic, the period March 2022 was simulated. A record-breaking atmospheric river/WAI was recorded in this period, which resulted in enormous temperature change, melt fluxes and surface energy budget perturbations, as documented in the literature (e.g. Wille et al., 2024a; 2024b). This meant we could compare our results against an already thorough and well-documented case.

We adapted the detection algorithm of Prein et al. (2023) for use in the polar regions. The technique detects WAIs using an absolute IVT threshold and a percentile-based threshold that is computed from an IVT climatology. However, using data from global datasets in this context is not appropriate because the polar environment is much drier and colder. Hence, using mid-latitude or tropical thresholds will under-detect polar WAIs. Therefore, we used an ERA5-based climatology produced by Melanie Lauer, an AWI collaborator, and revised the threshold to 100 kg kg^{-1} s^{-1}.

We applied the algorithm firstly to the two case studies and then to the full data period (2000-2022). The algorithm had not before been applied in the Antarctic, so this is novel work. Further work is ongoing at AWI to apply the algorithm to future projections of Arctic climate made by downscaling CMIP-class models with ICON as part of PolarRES.

Figure 1 shows an example of some of the output of the Prein et al. algorithm. It returns the coordinates of WAI 'objects' which allow us to track the WAI as it moves through time and space. Figure 1 shows a specific example from the March 2022 heatwave in Antarctica. The colours show IVT transport within the footprint of the WAI, which is defined as all the gridpoints that are determined to be within the tracked WAI object at any point during its lifetime. The black dots show the mid-point 'track' of the object.

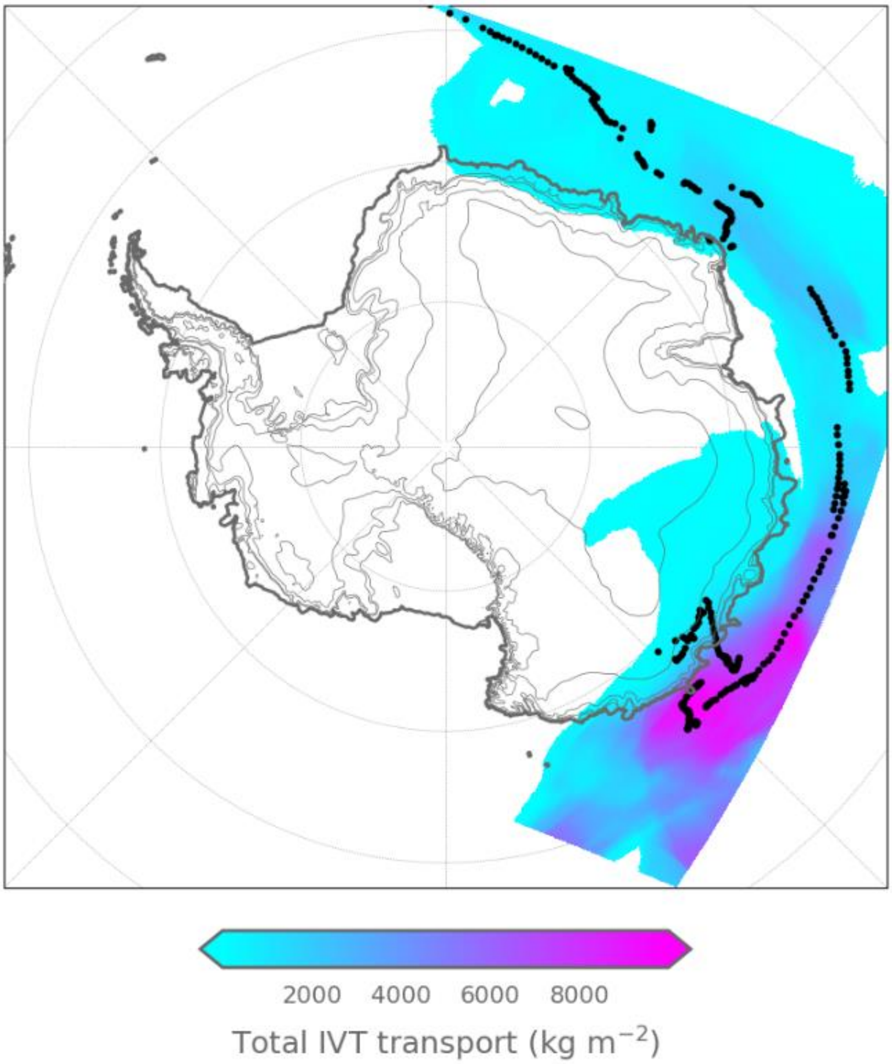

Figure 1 – WAI "footprint" for an extreme case during March 2022 over the Antarctic. Model data shown are from the MetUM model. Colours show total integrated water vapour transport (IVT) during the entire event, and the black dots show the location of the object's track – defined in the algorithm as the central coordinates of the object.

We compared the outputs of both models, and Figure 2 shows an example of the objects tracked by the Prein et al. algorithm. Objects are enclosed by coloured lines, which are tracked over space and time by the algorithm: Figure 2 shows a snapshot from April 2020 over the Arctic, with ICON on the left and MetUM on the right. Both represent WAIs similarly, and have comparable IVT amounts, which is encouraging.

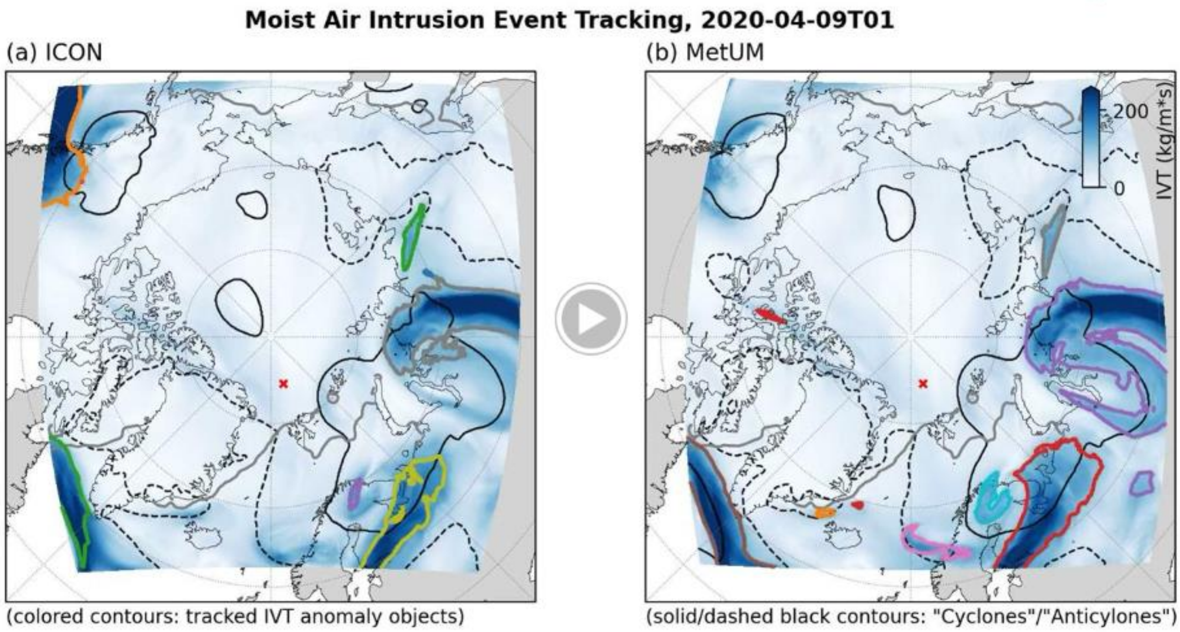

Figure 2 – A snapshot of WAI outputs from a) ICON and b) MetUM over the Arctic during April 2020. Simulated IVT is shown as blue filled contours, with the WAI objects tracked by the Prein et al. (2023) algorithm overlain as solid coloured lines. The location of the MOSAiC measurements is indicated with a red cross.

Whilst in Potsdam I explored the impact of simulated WAIs on the Greenland and Antarctic ice sheets, evaluating their effects on the surface energy balance, melting and precipitation. I compared WAI/atmospheric river periods with non-WAI/atmospheric river periods throughout the two case studies for both ice sheets. Some examples using the MetUM are given in Figure 3. They show that WAIs are warmer, moister and cloudier than non-WAI periods, and that they deliver considerable energy and precipitation to both polar regions. Further work is ongoing to explicitly and systematically understand by how much WAIs can enhance processes like melting and precipitation, and hence their contribution to societally-relevant questions like ice mass loss and sea level rise.

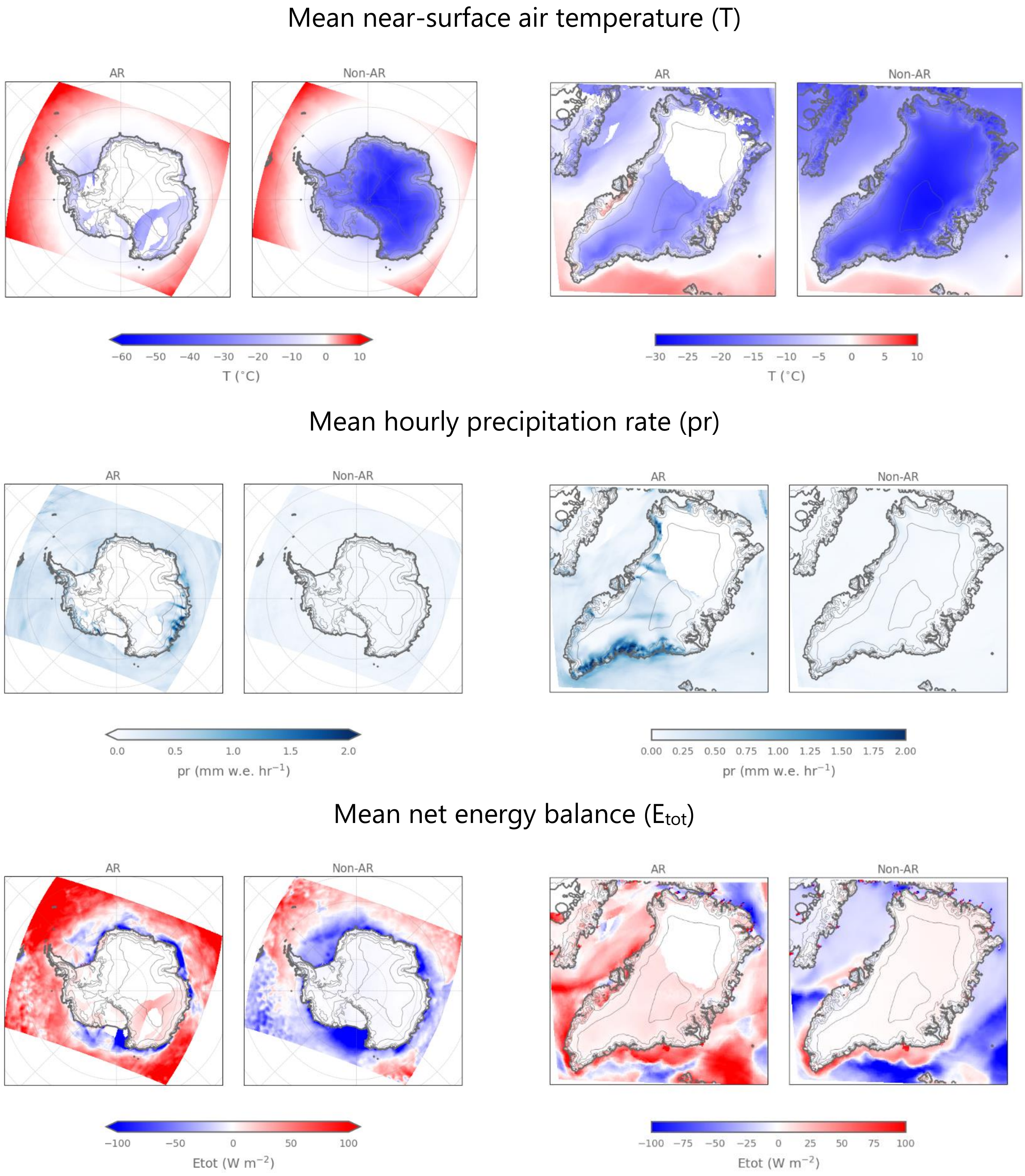

Figure 3 – Comparison of composited WAI/AR conditions vs non-WAI/AR conditions for the Antarctic (left) and Greenland (right) ice sheets, as simulated by the MetUM model. Sub-plots show mean near surface air temperature at the top, where reds and blues indicate temperatures above and below 0°C, respectively; mean precipitation rate in the middle, where darker blues indicate heavier precipitation; and mean net energy balance on the bottom, where red and blue colours indicate positive and negative energy balance, respectively.

Since my visit, I have continued to work on this project with Jan Landwehrs and Annette Rinke at AWI-Potsdam. This work was also the subject of a project at an early career bootcamp that Jan and I attended, where we collaborated with Marlen Kolbe from KIT, who provided additional simulation data using another model. I have also been invited to return to AWI in October to continue the collaboration, and we intend to submit a paper on this topic in the near future. While I was in Potsdam I was also invited to give several seminars, including one at the Potsdam Institute for Climate Impacts research, and co-supervised a bachelor's student thesis project.

I am extremely grateful to the society for the support, which has allowed me to deepen my collaborations with AWI and in Germany more broadly, and to develop my own independent research agenda and career prospects. Thank you again for the opportunity.

Best regards,

Ella Gilbert

Footnotes

[1] www.polarres.eu

[2] https://mosaic-expedition.org/

References

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