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Quantifying the global impact of atmospheric rivers on the recurrence of flood events

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Abstract: Atmospheric rivers (ARs) are long, narrow corridors of enhanced water vapour transport that transfer moisture from the subtropics to the mid-latitudes. These systems are already recognised as a major driver of extreme precipitation and flood events in many regions of the world. However, the extent to which ARs alter the frequency of flooding at a global scale has remained poorly quantified. In this study, we assess the global influence of ARs on extreme precipitation and streamflow events by analysing 2,686 largely unregulated catchments across all continents.

We used daily precipitation and streamflow data from the Caravan catchment dataset (Kratzert et al., 2023) covering the period 1980 to 2019, combined with hourly AR data from the Atmospheric River Tracking Method Intercomparison Project (ARTMIP) (Collow et al., 2022). Here we used two global AR detection methods for: The Reid500 and the Mundhenk methods. These algorithms were selected for their effectiveness in identifying the interaction between ARs and precipitation (Pradhan et al., 2024). AR data were processed into a daily format to match hydrological records. To analyse the impact of ARs, we identified extreme events using a peaks-over-threshold approach and applied the Generalized Pareto Distribution (GPD) (Pickands, 1975) to model the tail behaviour of precipitation and streamflow under both AR and non-AR conditions. We then calculated and compared return periods for each condition to determine the change in event likelihood associated with AR presence.

Our results show that ARs are responsible for more than 70% of the highest precipitation and streamflow events recorded across the study catchments over the last four decades. Globally, we found that ARs significantly reduce the recurrence intervals of extreme hydrological events. In many cases, the likelihood of extreme events increases by a factor of 2 to 4 when an AR is present. In key AR-affected regions, including parts of North America, western Europe and southeastern Australia, we observed that rare flood events can become up to 12 times more likely during AR conditions compared to non-AR days. This shift in recurrence interval implies that conventional flood frequency analysis, which often assumes a single population of flood drivers, may underestimate risk in AR-dominated regions if the presence of ARs is not considered explicitly.

The findings underline that ARs are not only meteorological phenomena of regional concern but also have a consistent and quantifiable global influence on extreme hydrological events. Moreover, projected increases in AR frequency, intensity and duration under climate change suggest that the role of ARs in altering flood risk is likely to become even more important in the future (Zhang et al., 2024). By treating AR-driven events as a distinct class of extremes, this study provides a basis for improving the understanding of flood-generating mechanisms and supports more reliable risk assessments in affected areas.

This work highlights the importance of integrating AR-induced extreme events into flood modelling frameworks. Flood risk assessments that ignore AR-specific dynamics may misrepresent future flood frequencies, especially in a warming climate where AR activity is expected to intensify. Future hydrological models and planning strategies will need to explicitly account for AR-related processes to ensure robust adaptation and preparedness in a changing climate.

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