Characterizing the Role of Latent and Sensible Heat in Antarctic Atmospheric River Impacts on the AIS and Synoptic Dynamics

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Abstract

Traditionally, Atmospheric Rivers (ARs) have been defined as elongated, intense corridors of atmospheric moisture transport. Antarctic ARs were identified in Wille et al. (2019) as objects extending at least 20◦ meridionally, detected either dynamically as intense meridional integrated vapor transport (vIVT) or statically as intense integrated water vapor (IWV), both exceeding their respective 98th monthly percentiles. However, moisture represents only one component of atmospheric energy, as it is equivalent to latent heat, to a constant. While latent heat serves as a major mechanism for energy redistribution from lower to higher latitudes, the other primary form of atmospheric energy, sensible heat, has received comparatively less attention.
This study develops a polar energy-atmospheric river (enAR) detection algorithm, analogous to that of Wille et al. (2019), but based on meridional energy rather than moisture, incorporating both latent (LH) and sensible heat (SH). enARs are identified using the meridional transport and static reservoirs of these components, defining four enAR types in the Southern Hemisphere: vLHT enARs (intense southward latent heat transport), vSHT enARs (intense southward sensible heat transport), ILH enARs (high integrated latent heat), and ISH enARs (high integrated sensible heat). Since water vapor is directly proportional to latent heat, vIVT (IWV) ARs are inherently equivalent to vLHT (ILH) enARs. This framework provides a finer decomposition of AR-related processes by distinguishing dynamic (transport) from static (reservoir) components and latent from sensible heat contributions. Furthermore, because vIVT and IWV ARs, as defined by Wille et al. (2019), correspond directly to vLHT and ILH enARs, respectively, this framework allows for a more detailed assessment of AR impacts on the Antarctic Ice Sheet by disentangling the contributions of different energy types and distinguishing between dynamic (transport) and static (reservoir) processes.

The results confirm that ARs play a dominant role in driving extreme precipitation (P) and temperature (T) events over the AIS. While the strong relationship between vLHT, ILH, and extreme P is expected due to their direct connection to water vapor, their dominant influence on extreme T events is less intuitive. Surprisingly, vSHT enARs, which directly represent warm air advection, are less efficient than vLHT enARs in producing extreme T

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anomalies. Beyond confirming the critical role of ARs in extreme events, this study provides a more detailed analysis of their impacts. It reveals that ARs associated with the strongest P and T anomalies most often coincide with co-occurring vSHT enARs and vLHT enARs, highlighting the combined role of both sensible heat transport and latent heat transport.

Furthermore, these co-occurring vSHT and vLHT enARs not only produce the most significant impacts but also exhibit an enhanced synoptic circulation. Specifically, they are associated with stronger and more persistent anticyclonic anomalies, which remain stationary for longer durations compared to other enAR types. This suggests a potential feedback mechanism in which the release of latent heat and heat-induced potential vorticity anomalies amplify the ridge, further enhancing synoptic winds and prolonging AR activity. This study underscores the complex interplay of different energy components in AR impacts on the AIS, and their associated synoptic scale dynamics, emphasizing the role of combined latent and sensible heat transport in shaping extreme events and synoptic patterns.