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Atmospheric Rivers and Compound Inland Flooding under Climate Change

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Compound Inland Flooding (CIF) arises from the interactions between multiple hydrometeorological drivers, often magnified by landfalling Atmospheric Rivers (ARs) along the Pacific Northwest coast and interior basins of North America. This study investigates the mechanisms behind two primary CIF types, Rain-on-Snow (ROS) and Saturation Excess Flooding (SEF), using the CanRCM4 large ensemble under global warming levels of +1.5°C, +2°C, and +4°C. By examining the joint occurrence of ARs with ROS and SEF across key sub-regions, including the Cascade Range, Sierra Nevada, and the Great Lakes Basin, we assess the probabilities, seasonal shifts, and hydrological impacts of CIFs in the 21st century. Results show distinct regional patterns, with ROS events projected to decrease in frequency across the Pacific Northwest and Great Lakes Basin but remain significant in high-elevation regions prone to seasonal snowmelt, such as the Canadian Rockies. Conversely, SEF events are projected to increase substantially, particularly in the eastern U.S. and southern Great Lakes, driven by intensified precipitation and persistently saturated soils. The findings indicate that under higher warming levels, the contribution of ROS to extreme runoff can decrease, while SEF-driven flood events become dominant. Signal-to-noise ratio analysis shows that internal climate variability contributes considerable uncertainty to CIF projections in transitional climate zones but is overshadowed by external climate forcing at higher warming levels, particularly in coastal regions. By capturing the compounded effects of precipitation extremes, snowmelt dynamics, and soil moisture conditions, this study underscores the necessity of integrating AR-driven compound events into regional flood risk management strategies.