Supplemental Material

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The role of circulation and its changes in present and future Atmospheric Rivers over western North America

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Supplemental Material
**Figure S1.** Annual AR frequency bias (days; x axis) vs IVT threshold bias (kg m⁻¹ s⁻¹; y axis) in CMIP5 models relative to the ERA-Interim reanalysis.
Figure S2. (a) Time series of 1980-2004 (Dec-Jan-Feb) AR frequency over the coastline of western North America in the ERA-I reanalysis (black line) and in the 5 runs of the CanESM2 ensemble (color lines). (b) Ensemble mean ratio of climatological 1980-2004 winter (Dec-Jan-Feb) AR activity probability over the coastline of western North America in the 5 CanESM2 runs to that in the ERA-I reanalysis. Red points indicate positive bias and blue points indicate negative bias relative to ERA-I. Consistent with most models, CanESM2 under-simulates AR activity over Vancouver Island, between ~48°N and ~52°N latitude.
Figure S3. Climatological IVT differences (kg m\(^{-1}\) s\(^{-1}\)) between models and ERA-Interim reanalysis in DJF from 1980 to 2004.
Figure S4. Climatological IWV differences (mm) between models and ERA-Interim reanalysis in DJF from 1980 to 2004.
Figure S5. As in FIG 7, but for the southern AR type in CanESM2, based on the 5-member CanESM2 ensemble.
Figure S6. As in FIG 8, but for the northern AR type in CanESM2, based on the 5-member CanESM2 ensemble.
Figure S7. As in FIG 9, but for the middle AR type in CanESM2, based on the 5-member CanESM2 ensemble.
Figure S8. Differences of anomalous circulation patterns associated with three types of AR between 5-member CanESM2 and ERA-I from 1980 to 2004. Differences of wind field anomaly (ms$^{-1}$) at 250 hPa (vectors in a-c) and 850 hPa (vectors in d-f), geopotential height anomaly (m) at 500 hPa (shading in a-c). Shading in d-f indicates the differences between 2-meter air temperature anomaly (°C) in ERA-I and surface air temperature anomaly (°C) in CanESM2. The top three rows correspond to the southern, northern and middle AR types respectively. The areas enclosed by red contours in (a-c) and (d-f) denote the regions where the geopotential height and air temperature differences are significantly different from zero at the 10% significance.
level, respectively. The thick vectors indicate where the wind speed differences are significantly different from zero at the 10% significance levels. The black shading indicates the topography that extends above the corresponding pressure levels.
Figure S9. Temperature dependent thresholds for IVT and IWV from CanESM2 in the future period.
Figure S10. Differences of AR activity probability (%) influenced by total changes (a) and dynamical changes (b) between future and historical periods based on the 5-member CanESM2 simulations with historical and RCP8.5 forcings.
Figure S11. As Figure 10, but for 2075-2099 rather than 1980-2004.
**Figure S12.** Annual AR frequency biases in CMIP5 models relative to the ERA-Interim reanalysis (days; x axis) vs the annual AR frequency changes influenced by the total changes in future period 2075-2099 relative to those in the historical period 1980-2004 in CMIP5 models (days; y axis).
Figure S13. AR frequency biases of different types in CMIP5 models relative to the ERA-Interim reanalysis in the historical period 1980-2004 (days; x axis) vs AR frequency changes for the different AR types in the future period 2075-2099 relative to those in the historical period 1980-2004 in CMIP5 models (days; y axis). Results influenced by the total changes and the dynamical changes are showed in (a-c) and (d-f), respectively. Southern types are displayed in (a) and (d), the northern types in (b) and (e), and the middle types in (c) and (f).