North American Weather Regimes and Their Influence on Western U.S. Fire-Weather Conditions

Guanyuan (Andrew) Zheng[1] (gz2414@columbia.edu), Muhammad Azhar Ehsan[2,3]

[1]Department of Applied Physics and Applied Mathematics, Columbia University, New York, NY 10027, USA, [2]Center for Climate Systems Research, Columbia Climate School, Columbia University, New York, NY 10968, USA, [3]NASA Goddard Institute for Space Studies, New York, NY, USA

Wildfire activity across North America has increased markedly during the past four decades, while damaging events increasingly occur outside the traditional fire season. This study examines how recurrent large-scale circulation patterns modulate the surface conditions that govern fire-weather risk. Using ECMWF ERA5 reanalysis for 1979-2025, we identify four active year-round weather regimes over the North American sector from 500-hPa geopotential height (Z500) anomalies, together with a near-climatological No Regime state. After deseasonalization, 10-day low-pass filtering, detrending, and normalization by seasonal variance, empirical orthogonal function (EOF) analysis is applied; the first 12 principal components, which explain 81% of Z500 anomaly variance, are retained for k-means clustering. Because 66% of reported U.S. wildfire disasters occur between June and October, fire-weather composites focus on JJASO. We characterize the seasonal cycle and long-term trends in regime occurrence and analyze near-surface temperature, precipitation, vapor pressure deficit (VPD), and the Canadian Fire Weather Index (FWI). The Pacific Trough is the most frequent regime overall but decreases significantly by 5.9 days per decade ($p = 0.02$), with its strongest seasonal decline in MAM, while Greenland High occurrence increases significantly in JJA. Over the southwestern United States, the background trends are consistently fire-favorable: warming, drying, increasing VPD, and rising FWI. Regime composites show distinct regional signatures, with the Alaska Ridge producing the strongest positive VPD and FWI anomalies along the West Coast and the Pacific Trough shifting elevated fire-weather potential toward the north-central United States and south-central Canada. These results demonstrate that weather regimes provide a physically interpretable framework for diagnosing sub-seasonal variations in North American fire weather.

Keywords: weather regimes; fire weather index; vapor pressure deficit; ERA5 reanalysis; k-means clustering; wildfire; North America