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Low-frequency variability of and impact of climate change on Southern California's Santa Ana winds

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The low frequency variability of and impact of climate change on Southern California's Santa Ana winds are investigated within surface observational data from the last half-century and a downscaled regional climate change experiment. A dynamical framework used to diagnose the forcing causing these strong offshore surface winds is presented. This framework relates the occurrence of Santa Ana winds to two mechanisms: a synoptic scale pressure gradient and a local temperature gradient. When a large-scale pressure anomaly causes offshore geostrophic winds roughly perpendicular to the region's mountain ranges this may in turn cause surface flow as the offshore momentum is transferred to the surface. However, many days have strong Santa Ana wind conditions without proportionately large synoptic forcing, due to local thermodynamic forcing that also causes strong offshore surface flow: a large temperature gradient between the cold desert surface and the warm ocean air at the same altitude creates an offshore pressure gradient at that altitude, in turn causing katabatic-like offshore flow in a thin layer near the surface. The contribution of "synoptic" and "local thermodynamic" mechanisms can be quantified using a bivariate linear regression model. We use this bivariate regression model to investigate the low frequency variability of three groups of Santa Ana wind events - synoptically forced, locally forced, and dually-forced events - using a network of surface meteorological stations from the mid-20th century to the present. The low frequency variability of each of the three types is compared with large-scale climate indices (e.g., the Southern Oscillation Index) to determine relationships between this local phenomena and large-scale climate measures. In addition, trends in both Santa Ana occurrence and the associated meteorological conditions over the last half-century are identified and explained. Following the observational analysis, the frequency and character of Southern California's Santa Ana wind events are investigated within a 12-km-resolution downscaling of late-20th and mid-21st century time periods of the National Center for Atmospheric Research Community Climate System Model global climate change scenario run. The number of Santa Ana days per winter season is approximately 20% fewer in the mid-21st century compared to the late-20th century. Since the only systematic and sustained difference between these two periods is the level of anthropogenic forcing, this effect is anthropogenic in origin. In both time periods, Santa Ana winds are partly katabatically-driven by a temperature difference between the cold wintertime air pooling in the desert against coastal mountains and the adjacent warm air over the ocean. However, this katabatic mechanism is significantly weaker during the mid-21st century time period. This occurs because of the well-documented differential warming associated with transient climate change, with more warming in the desert interior than over the ocean. Thus the mechanism responsible for the decrease in Santa Ana frequency originates from a well-known aspect of the climate response to increasing greenhouse gases, but cannot be understood or simulated without mesoscale atmospheric dynamics. In addition to the change in Santa Ana frequency, we investigate changes during Santa Anas in two other meteorological variables known to be relevant to fire weather conditions -- relative humidity and temperature. We find a decrease in the relative humidity and an increase in temperature. Both these changes would favor fire. A fire behavior model accounting for changes in wind, temperature, and relative humidity simultaneously is necessary to draw firm conclusions about future fire risk and growth associated with Santa Ana events.