Challenges to Modeling "Cold Pool" Meteorology Associated with High Pollution Episodes

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3 AUTHORS, INCLUDING:

Heather Simon

United States Environmental Protection Age…

James T. Kelly

U. S. Environmental Protection Agency

Environmental Science & Technology

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Challenges to Modeling "Cold Pool" Meteorology Associated with High Pollution Episodes

Kirk R. Baker,* Heather Simon, and James T. Kelly

Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, United States

Although ozone pollution events are commonly associated with summertime conditions, wintertime ozone concentrations in southwest Wyoming are high enough that they frequently exceed the level of the 8-h ozone National Ambient Air Quality Standard (NAAQS). These wintertime ozone episodes typically occur when large amounts of pollutant emissions coincide with periods of prolonged temperature inversions and stagnant winds. These meteorological conditions, called "cold pools", are also associated with elevated $PM_{2.5}$ (particulate matter with aerodynamic diameter <2.5 μm) concentrations that exceed the level of the 24-h $PM_{2.5}$ NAAQS in many other parts of the western United States including Salt Lake City, central California, and the Pacific Northwest (Figure 1).[1] Cold air can be trapped in valleys and basins by the combination of terrain features and a stable vertical stratification of warm air above cold air that limits vertical ventilation. Air pollutant concentrations can build up to unhealthy levels in cold pools over multiday stagnation episodes.[1,2]

Cold pool conditions of extremely low temperatures and wind speeds are frequent during the winter months in the western United States.[2] Persistent cold pools last longer than one diurnal cycle and lead to hazardous weather conditions (fog and freezing rain) and poor air quality.[2] In many locations, these conditions can occur 10−15 times per winter and last from 1 to 14 days, with longer episodes generally leading to more severe pollution events.[1] Studies have identified many U.S. cities across the intermountain west affected by persistent cold pools spanning from California, Oregon, and Washington in the west to Colorado in the east.[2] Many western cities that are affected by these wintertime inversions have been classified as nonattainment for the $PM_{2.5}$ 2006 24-h NAAQS of 35 $\mu g/m^3$ and are not on track to attain the NAAQS based on recent design value information (2008−2010): Fairbanks, Alaska (51 $\mu g/m^3$), Klamath Falls, Oregon (45 $\mu g/m^3$), Oakridge, Oregon (38 $\mu g/m^3$), Salt Lake City, Utah (45 $\mu g/m^3$), and the San Joaquin Valley, California (65 $\mu g/m^3$).

State and local agencies that have monitors violating the 8-h ozone or 24-h $PM_{2.5}$ NAAQS may need to demonstrate the efficacy of controls on precursor emissions using photochemical air quality models. In June 2011, many state and local agencies in the western United States presented preliminary meteorological and air quality modeling work to support upcoming State Implementation Plans at the Western Meteorological, Emissions, and Air Quality Modeling Workshop in Boulder, Colorado (http://www.wrapair2.org/WesternEmissionsMetAQModelingWorkshop_June21-23Boulder2011_final_agenda.pdf). The failure to appropriately simulate wintertime multiday stagnant air mass conditions by prognostic meteorological models is hindering successful photochemical model representation of these air quality problems.[3,4] Routine application of prognostic meteorological models including the Fifth-Generation NCAR/Penn State Mesoscale Model (MM5) and Weather Research and Forecasting Model (WRF) with a variety of different physics options, initialization input, vertical and horizontal resolutions, and nudging approaches have failed to replicate the degree and persistence of stagnant meteorological condition.[5] Air quality studies based on diagnostic meteorological fields have also reported under-predictions of $PM_{2.5}$ concentrations under very stagnant meteorological conditions.

New research is needed to develop a boundary layer and land surface scheme to capture multiday wintertime inversion episodes[5] and enable more accurate simulations of wintertime air pollution episodes. Persistent cold pool meteorology is difficult to capture due to the multiple geographic and temporal scales of processes, which range from micro to synoptic scale. Wintertime solar radiation is often not strong enough to break up the stable near-surface layer of cold air. Radiation is often further weakened by stratiform clouds and fog. Synoptic scale weather patterns can strengthen the inversion by keeping warm air above

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Figure 1. Stratified layer of pollution during a “cold pool” event near Salt Lake City, Utah. Erik Crosman (photographed December 19, 2009; Erik.Crosman@utah.edu).

the cold layer at the surface.[2,5] Boundary layer and land surface models in prognostic meteorological models are not designed to capture these unique sets of conditions that lead to persistent cold pools in the complex orography of the western United States. Improved characterization of these conditions enable regulating agencies to better replicate the meteorological conditions associated with elevated ozone or $PM_{2.5}$ in the winter and design effective air pollution control strategies.

AUTHOR INFORMATION

Corresponding Author

*E-mail: baker.kirk@epa.gov.

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