Incorporating the Wind Erosion Prediction System (WEPS) into a Regional Air Quality Modeling System for the Pacific Northwest

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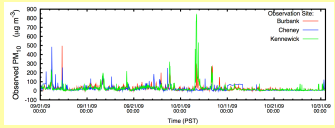
Motivation

- In the Pacific Northwest, wind storms intermittently cause massive dust events that produce extremely high levels of PM_{10}.
- Reduced visibility from windblown dust poses a hazard to motorists and can lead to road closures, accidents, and fatalities.
- High levels of windblown dust pose direct health threats related to inhalation.
- In eastern Washington, windblown dust contributes to exceedances of the US EPA National Ambient Air Quality Standard for PM_{10} with $PM_{2.5}$ constituting 4 to 7% of PM_{10} during high wind events (Sharratt and Lauer, 2006).



Observed PM_{10} concentrations for three sites in the Columbia Plateau region of eastern Washington for Fall 2009. Data are from https://fortress.wa.gov/ecy/enviwa.

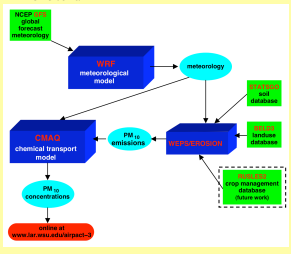
Wind Prediction Erosion System (WEPS)

- WEPS is a process-based, continuous, daily time-step model that simulates field conditions and erosion, including PM_{10} generation, for specific fields.
- WEPS simulates not only the basic wind erosion processes, but also the processes that modify a soil's susceptibility to wind erosion (Hagen, 2008).
- The entire WEPS model allows for an integrative way of modeling soil erosion on agricultural land to account for crop growth, crop management practices, and soil conditions and surface cover. It includes six submodels to account for processes that impact soil conditions and govern soil erosion:

HYDROLOGY:
models soil temperature and water content
DECOMPOSITION:
models crop decomposition
CROP:
models growth of crop plants
SOIL:
models changes in soil properties between management events
MANAGEMENT:
models effects of management activities (e.g., tillage)
EROSION:
models soil erosion processes and calculates PM_{10} emissions

Objectives

- The overall objective is to integrate the entire WEPS modeling system into the AIRPACT-3 regional air quality forecasting system for the Pacific Northwest.
- The first step to achieve the overall goal is to incorporate WEPS' EROSION submodel into the WRF-CMAQ modeling framework for the AIRPACT-3 domain.

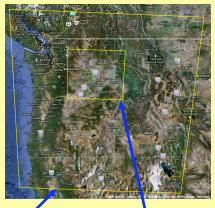


- Evaluate the model by testing sensitivity of model-predicted windblown PM_{10} emissions and concentrations to treatment of soil properties, simulation resolutions, and other input parameters.
- Evaluate model performance using observational data.

Acknowledgment

This work is supported by the United States Department of Agriculture.

AIRPACT-3 Air Quality Forecasting System

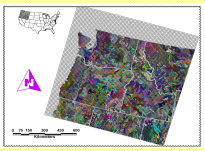


Simulation domain for daily AIRPACT-3 operation at 12-km resolution.

Simulation domain covering the Columbia Plateau region at 4-km resolution.

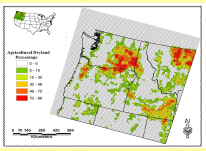
- The goal of the AIRPACT (Air Indicator Report for Public Awareness and Community Tracking) project is to provide timely air quality information to people in the Pacific Northwest region.
- The simulation domain covers the Pacific Northwest region at 12-km resolution.
- Uses WRF-MCIP-CMAQ modeling framework.
- AIRPACT-3 runs a 64-hour forecast once a day, starting at midnight Pacific Standard Time (08:00:00 UTC) and using meteorological results of 72-hour 00Z forecast by WRF.
- The model accounts for major sources of anthropogenic, biogenic, and fire emissions.
- Results are updated daily online at http://www.lar.wsu.edu/airpact-3
- The overall goal of this project is to include windblown dust in the daily forecast for the entire Pacific Northwest region and with a focus on the Columbia Plateau region.

Model Input: Soil, Land Use, and Cop Management Databases



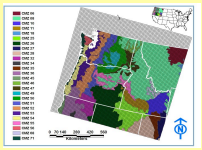
Mosaic of STATSGO soil map units overlaid with 1-km cells across the AIRPACT-3 domain

3910 soil map units in the Natural Resources Conservation STATSGO database are gridded to 1-km and 12-km grid cells of the AIRPACT-3 domain. Each map unit is defined by 10 soil layers and each layer is characterized by 31 soil physical, chemical, and hydraulic properties. (Feng et al., 2009).



Distribution of dry and irrigated agricultural land as derived from the BELD3 landcover database

To determine the percent area in each grid cell that is erodible land surfaces, the Biogenic Emissions Landcover Database version 3 (BELD3) is used to determine the percentage of dry and irrigated agricultural land in each 1-km and 12-km grid cells of the AIRPACT-3 domain.

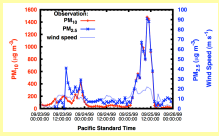


Gridded crop management zones derived from the USDA-NRCS RUSLE2 Crop Management database

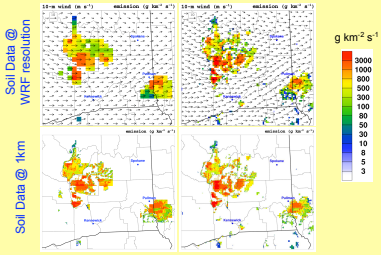
For future work, the RUSLE2 crop management database will be incorporated into the forecasting system and used by WEPS to simulate standing and residue biomass covers and surface soil properties. Currently, these surface properties are user-input parameters.

Retrospective Simulations: September 23-25, 1999 Dust Storm Event

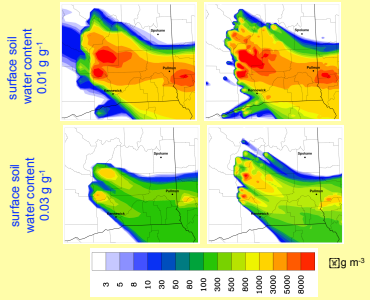
A large dust storm occurred over a three-day period during September 23-25, 1999. During the event, observed wind speeds exceeded 20 m s^{-1}. Observed hourly PM_{10} concentrations in Spokane, WA exceeded 1000 μg m^{-3} while $PM_{2.5}$ reached 90 μg m^{-3}. (Sundram et al., 2004). WRF-MCIP-WEPS/EROSION simulated the onset of the dust plume for 09/25/2009, but not for the smaller plume on 09/23/2009.



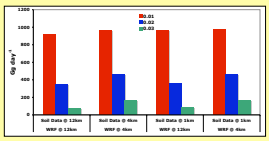
Sensitivity of Modeled PM_{10} Emissions to WRF and Soil Data Resolutions



Sensitivity of Modeled PM_{10} Concentrations to Simulation Resolution and Surface Soil Moisture



Sensitivity of Modeled PM_{10} Emissions to Surface Soil Moisture

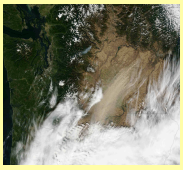


- Each 12-km and 4-km grid cells in the AIRPACT-3 domain can contain more than ten STATSGO soil map units. Simulations were carried out using different resolutions for the soil-property data and wind speed from WRF. The figures above show model results assuming bare soil and very dry surfaces (surface water content = 0.01 g g^{-1}). The results are averaged for September 25, 1999. The figures above show that modeled PM_{10} emissions are relatively insensitive to the resolution of soil-property data.
- The figure to the left shows the total modeled PM_{10} emissions for the Columbia Plateau simulation region for September 25, 1999, assuming bare soil. The results are much more sensitive to surface soil moisture than to the grid resolution of WRF simulations and soil-property data.

The figures above show averaged model-predicted PM_{10} concentrations for September 25, 1999 under assumption of bare soil. These figures again show that the model is most sensitive to surface soil moisture. Note that the modeled dust plume does not pass through Spokane, where elevated PM_{10} concentrations were observed. Comparison to a previous study suggests errors in modeled wind direction is the cause (Sundram et al., 2004).

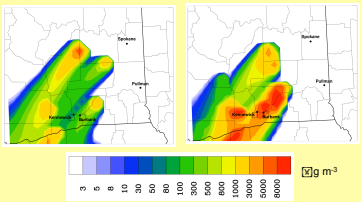
Forecast of October 4, 2009 Dust Storm

A large dust storm occurred in parts of eastern Washington on October 4, 2009. The image on the right was captured by the Moderate Resolution Imaging Spectroradiometer on NASA's Terra satellite shortly after noon Pacific Daylight Time. The onset of the storm was correctly predicted twice by AIRPACT-3's operational 48-hour forecast, which assumes bare soil and very dry soil surfaces (surface soil moisture of 0.01 g g^{-1}). The forecast was performed at 12-km resolution for the whole AIRPACT-3 domain. Results shown here are for the Columbia Plateau region only.

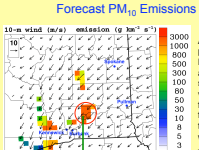


Courtesy Jeff Schmaltz, MODIS Rapid Response Team.
http://earthobservatory.nasa.gov/IOTD/view.php?id=40590

Forecast PM_{10} Concentrations for 10/04/2009

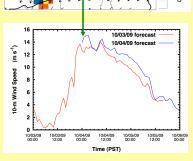


Forecast PM_{10} Emissions for 10/04/2009

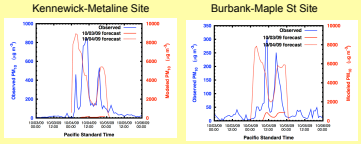


A 48-hr forecast for PM_{10} was produced daily starting at midnight PST each day (with WRF start-up at at 4PM PST). The figure on the top shows the model-predicted wind vectors and PM_{10} emissions averaged for 10/04/2009 from the 10/04/2009 forecast. This storm was unusual in that it was driven by northeasterly winds.

The red circle indicates an area in which the 10/03/2009 forecast predicted much lower emission rates than those of the 10/04/2009 forecast. The difference in emission rate is driven by < 2 m s^{-1} difference in forecast wind speeds by WRF (bottom figure). Other than wind peed and direction, the same input parameters to WEPS' EROSION module are used in both forecasts.



Model-Observation Comparison



Elevated PM_{10} concentrations were observed at the Kennewick and Burbank sites, which are ~12km apart. Observed PM_{10} concentrations differ by a factor of 3 between the two sites. Model forecast qualitatively captures the onset of the dust storm. Results from the 24-hour and 48-hour forecasts differ significantly because modeled friction velocity is around the modeled threshold friction velocity for erosion. The predicted PM_{10} concentrations differ by 2 orders of magnitude. Retrospective analysis also indicates that model results are very sensitive to assumption of surface soil moisture content (results not shown).

Conclusions and Future Work

- The WEPS EROSION submodel has been incorporated into a WRF-MCIP-CMAQ regional air quality modeling framework for windblown dust for the Pacific Northwest.
- Model simulated PM_{10} emissions and concentrations are very sensitive to assumptions for surface soil water content and modeled wind speed. Currently, the operational forecasting system assumes bare, dry soil.
- Model results are relatively insensitive to resolution of the soil and land use data; however, model results are still sensitive to model resolution because they are very sensitive to modeled wind speed.
- The model successfully forecast the onset of a dust storm in eastern Washington on October 4, 2009; however, model results vary by 2 orders of magnitude depending on assumptions used for soil surface properties and modeled wind speed.
- To model standing biomass and soil moisture properly, other submodels of WEPS will be incorporated into the modeling framework with the use of the USDA-NRCS RUSLE2 crop management database. Satellite soil moisture data from AMSR-E may be utilized.
- Model performance with assimilated weather data will be evaluated against measurements from historical, current, and future dust storms.

References

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