Sensitivity of WRF Surface Fluxes to PBL and LSM Parameterizations During Persistent Cold Air Pools

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Cold Air Pool (CAP)
Salt Lake Valley, Utah, USA

Map showing monitoring locations in Northern Utah. Time series of hourly (line) and 24 h (bar) PM concentrations during the month of February 2004 consisting of two cold air pool periods and one mix-out period. Note: Hourly data from the UDAQ Routine Monitoring Network Data.
Wintertime Air Pollution: Cold Air Pool

- Stable atmospheric boundary layers
- Decrease in boundary layer height
- Inhibited mixing
- **Leads to an increase in pollutant concentrations!**
Particulate Matter: Observations vs. Model

Holmes et al., ES&T, 2015
Objectives and Hypotheses

Objectives

• Quantify surface fluxes during wintertime CAPs

• Compare obs to numerical weather prediction (NWP) results

• *Use NWP results in chemical transport model*

Hypotheses

• Modeled will over estimate surface fluxes compared to observations during all time periods

• NWP model will not predict the decrease in atmospheric turbulence during wintertime CAPs
Approach

• Measure turbulence and surface fluxes using a fast response sonic anemometer

• Use NWP model to simulate meteorological conditions

• Sensitivity testing of planetary boundary layer (PBL) and land surface model (LSM) schemes in NWP

• Collect PM$_{2.5}$ mass concentrations form regulatory monitoring networks in northern Utah

• *Model air quality using a chemical transport model to investigate air pollution concentrations*
Numerical Weather Prediction Model

Weather Research & Forecasting (WRF) v3.7.1

- NCEP North American Regional Reanalysis: 32km
- 3 Nested Domains: 12km, 2.4km, 480m
- 30 Vertical Levels: 10 in first 1,000m AGL
- Surface and Upper Air Nudging: OBSGRID
  - Surface: T, u, v, q
  - Vertical, all levels: u, v
  - NCEP ADP surface and upper air weather data
- Land Use Classification: USGS 24-category data
WRF Physics Options

- **Cloud Microphysics**: Lin
- **Longwave Radiation**: Rapid Radiative Transfer Model
- **Shortwave Radiation**: Dudhia
- **Cumulus Parameterizations**: Kain-Fritsch
- **Cloud Fraction Option**: Xu-Randall

D01: 12km x 12km Grids

D03: 480m x 480m Grids

77.3 km

72.5 km

SLC
Planetary Boundary Layer, Surface Physics, Land Surface

1. ACM2, Pleim-Xiu, Pleim-Xiu (with soil nudging) [PLX]
2. YSU, Monin-Obukhov Similarity, Noah [YSU]
3. MYJ, Monin-Obukhov Janjic Eta Similarity, Noah [MYJ]
4. BouLac, Monin-Obukhov Similarity, Noah [BLC]

Combination based on what the PBL model developers intended the configuration to be!
Temperature and Humidity

Temperature (°C)

q (kg kg$^{-1}$)

9-Feb 11-Feb 13-Feb 15-Feb 17-Feb 19-Feb 21-Feb 23-Feb 25-Feb 27-Feb 29-Feb

PLX
YSU
MYJ
BLC
CAP
CAP

Obs
13 February 2004
- Surface based inversion
- Snow on ground
- No clouds
Vertical Profiles: Cloudy CAP

21 February 2004
• Surface mixing + elevated inversion
• No snow on ground
• Layer of stratus clouds
Particulate Matter Accumulation

Two Persistent Cold Air Pools
12-16 February (CAP1), Dry CAP [12.3 µg m$^{-3}$ day$^{-1}$]
20-24 February (CAP2), Cloudy CAP [9.6 µg m$^{-3}$ day$^{-1}$]

Holmes et al., 2015
Sensible and Latent Heat Fluxes

Sensible Heat Flux (W m$^{-2}$)

Latent Heat Flux (W m$^{-2}$)
Sensible Heat Flux
CAP versus non-CAP

OBSERVATIONS

MYJ

-50 0 50 100 150 200
11-15 Mar 11-15 Feb

Hs (W m⁻²)
0 50 100 150 200
-50 0 50 100 150 200
01:00 04:00 07:00 10:00 13:00 16:00 19:00 22:00

11-15 Mar 11-15 Feb
Latent Heat Flux
CAP versus non-CAP

OBSERVATIONS

MYJ

H_L (W m^{-2})

01:00 04:00 07:00 10:00 13:00 16:00 19:00 22:00

0 10 20 30 40 50 60

11-15 Mar 11-15 Feb

11-15 Mar 11-15 Feb
Summary

• Elevated PM during wintertime in complex terrain is due to both physical and chemical processes in the atmosphere

• WRF captures the mesoscale CAP formation, but does not capture the microscale physics

• CAP surface fluxes are over estimated in simulation results

• Sensible heat flux during non-CAP agrees better with obs

• Simulation results do not capture the cloudy CAP event, likely due to fog issues in the mesoscale model
Future Work

- Plot friction velocity data
- Investigate surface heterogeneity differences
- Sensitivity of PBL/LSM in chemical transport model
- Simulate more recent time periods (e.g., PCAPS)
- Incorporate improved land use data from MODIS

Sensible HF
13 Feb 2004
11:00 MST
PLX

Sensible HF
13 Feb 2004
11:00 MST
MYJ