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A Journey Through Terrain and Weather: Multi-scale Influences on Potential Concentrations at Monitoring Sites

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1. Introduction

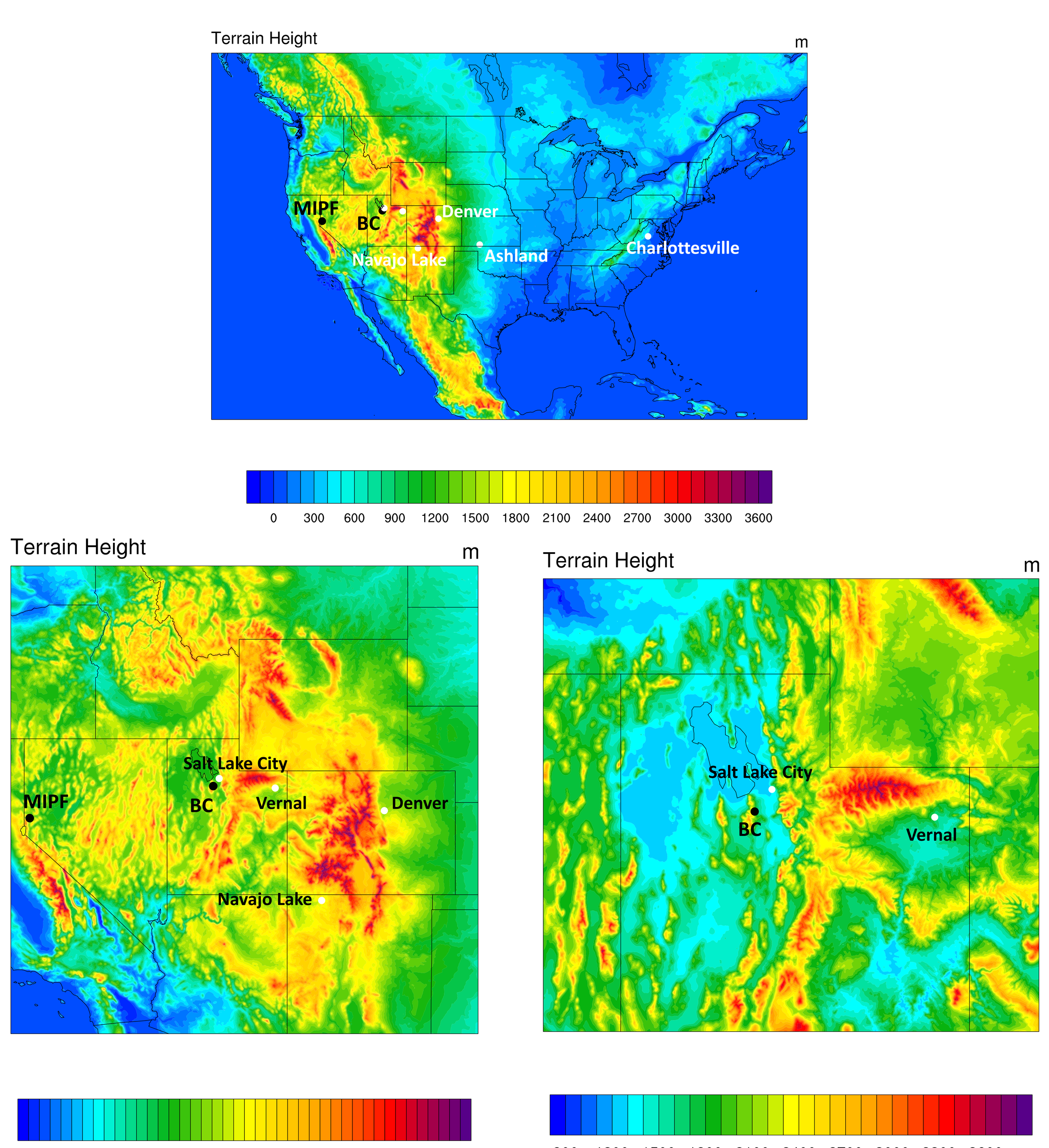
For many emissions monitoring applications, networks of measurement sites are used to detect and potentially attribute the source of the emissions. For example, atmospheric measurements of radionuclides (RN) can contribute to nuclear test monitoring. However, quantifying the effects of physical processes that affect the transport and dispersion of radionuclides between the source and measurement locations is an ongoing area of research. Other RN sources, such as medical isotope production facilities (MIPF), can also potentially contribute to RN concentrations at measurement sites, complicating the interpretation of the measurements.

In an effort to better understand the behavior of releases to the atmosphere, we performed numerical simulations with the Weather Research and Forecasting Model coupled to Chemistry (WRF-Chem). Two hypothetical, non-buoyant tracer point sources are modeled, over the continental U.S., during the two-week simulations that are initiated and nudged by synoptic weather from January 2011.

This study investigates the hypothesis that complex topography near emissions sources can influence plume concentrations at measurement sites at local to continental distances from the source.

2. Model

- The Weather Research and Forecasting with Chemistry (WRF-Chem) model (Grell et al., 2005) is used to simulate the atmospheric state and the transport and dispersion of the emissions.
  - WRF model dynamics plus in-line chemistry
  - Eulerian framework
- Simulated time period from 0000 UTC 06 January 2011 to 0000 UTC 20 January 2011.
- Global Forecast System (GFS) model analyses (NOAA, 2018) were used for initial and boundary conditions.
- Simulations with varied grid resolutions
  - Single 9 km grid
  - Three nested grids - 9 km, 3 km, and 1 km horizontal grid spacing



Topography heights (m) on the three model grids of the nested grid simulation. Top plot is domain 1, left plot is domain 2, and the right plot is domain 3. Black dots represent the locations of the MIPF and BC sources. White dots show the locations of the simulated measurements.

3. Emissions

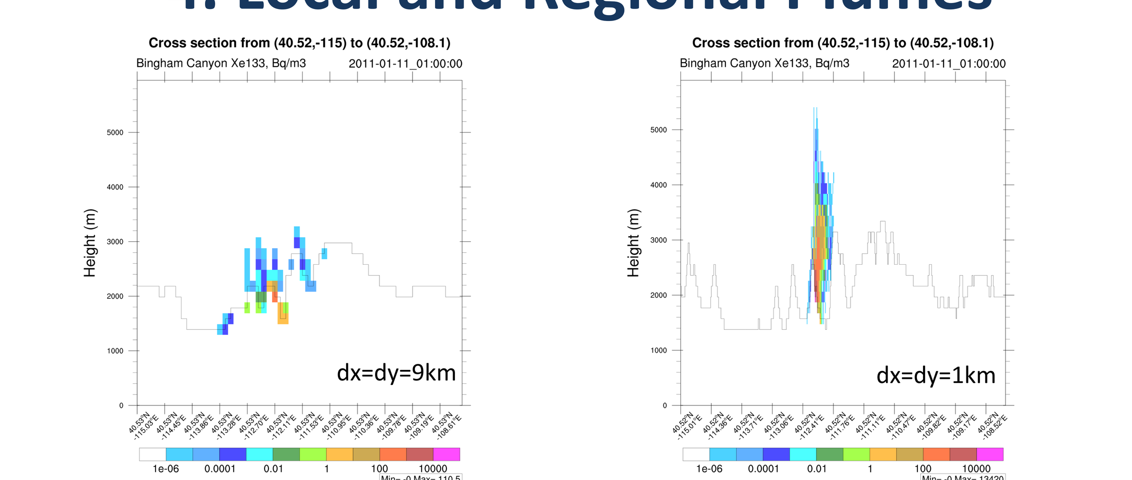
Emissions sources:

1. Single, short-term (one hour) atmospheric emissions from the Bingham Canyon copper mine (BC) were modeled, for this event.
   a) 2300 UTC 10 January 2011– 0000 UTC 11 January 2011
   b) Hypothetical large Xe133 release rate
2. A hypothetical MIPF source was arbitrarily placed at the Reno, NV airport, which is climatologically upwind of the Bingham Canyon mine.
   a) Hourly varying emission rates
   b) Time series of representative MIPF emissions
   c) Track Xe133, Xe135, Kr 85m, and Kr88
2. All emissions converted from GBq hr^{-1} to moles km^{-2} hr^{-1} for input into WRF-Chem.

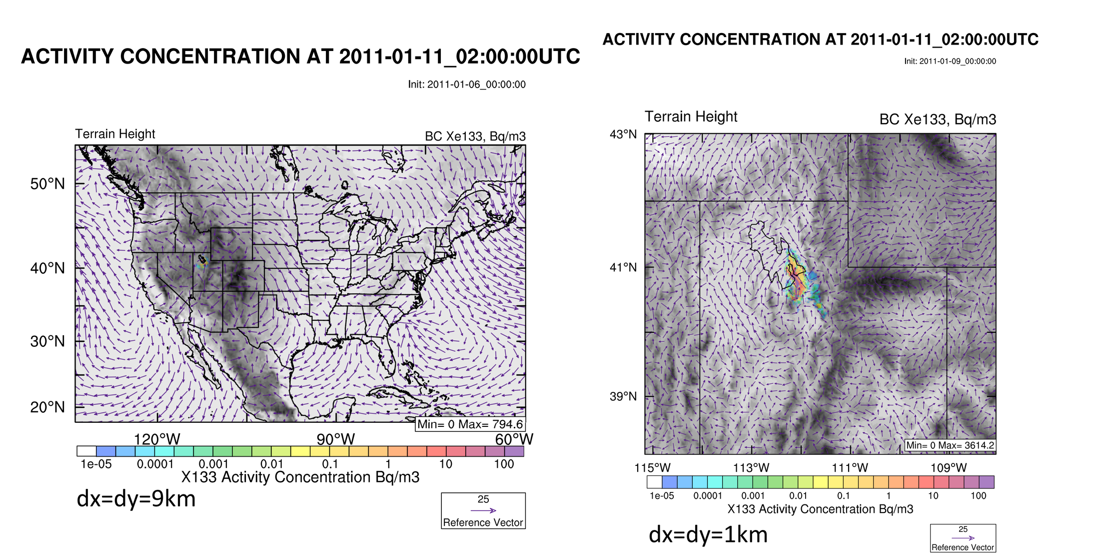
Simplifications:

- The emissions are assumed non-buoyant and within the lowest model grid cell.
- The emission rates are assumed to be constant over each hour.
- All species are treated as passive tracers, with no decay, daughter products, dry deposition, or wet deposition included, focusing on the transport and dispersion.

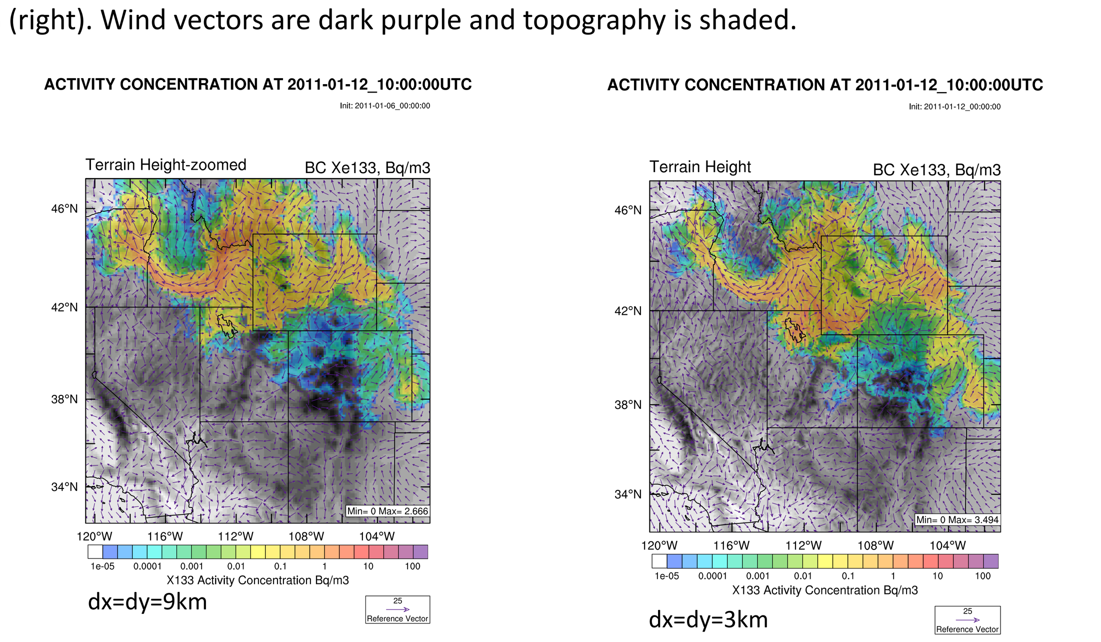
4. Local and Regional Plumes



East-West vertical cross sections of BC Xe-133 concentration above background, through BC site, one hour after the BC release. Zoomed-in from the single grid run is on the left and the nested grid simulation domain 3 is on the right. Topography is shown by the black line.

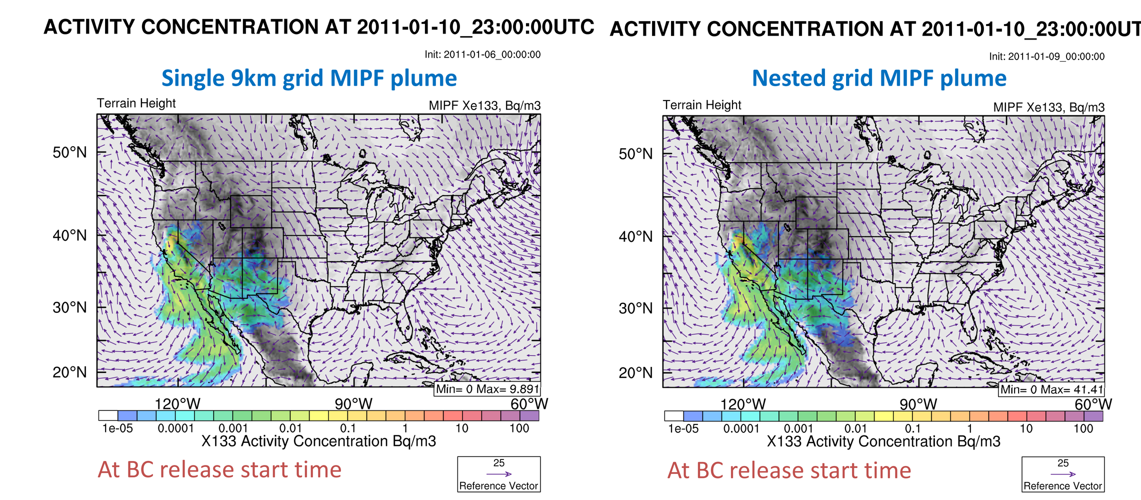


BC Xe-133 activity concentration above background in the lowest model grid cell, at 0200 UTC 11 Jan 2011, on the coarse grid simulation (left) and on nested grid simulation domain 3 (right). Wind vectors are dark purple and topography is shaded.

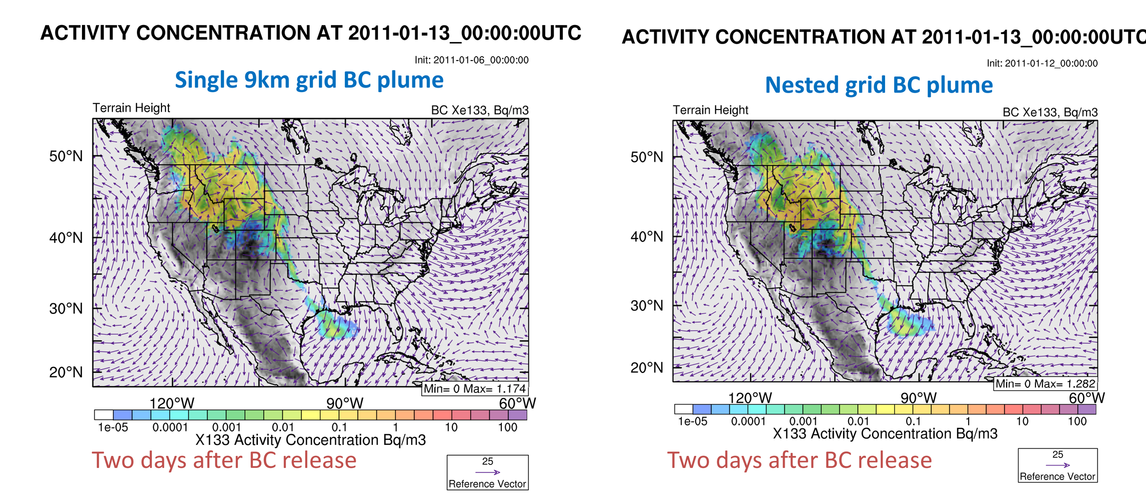


BC Xe-133 activity concentration above background in the lowest model grid cell, at 1000 UTC 12 Jan 2011, zoomed in from the coarse grid simulation (left) and on nested grid simulation domain 2 (right). Wind vectors are dark purple and topography is shaded.

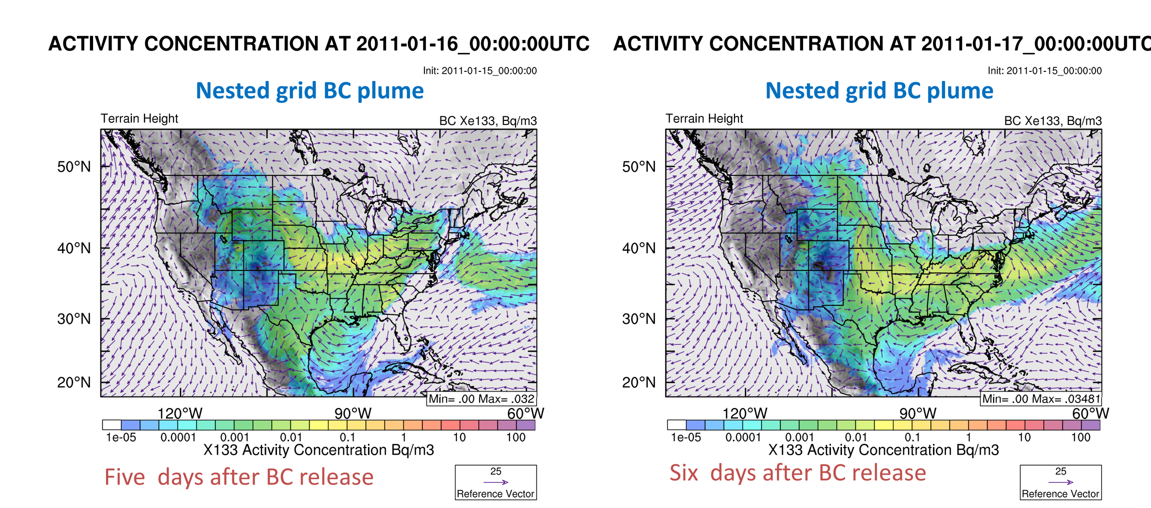
5. Continental Plumes



MIPF Xe-133 activity concentration above background in the lowest model grid cell, at 2300 UTC 10 Jan 2011, on the coarse grid simulation (left) and on nested grid simulation domain 1 (right). Wind vectors are dark purple and topography is shaded.

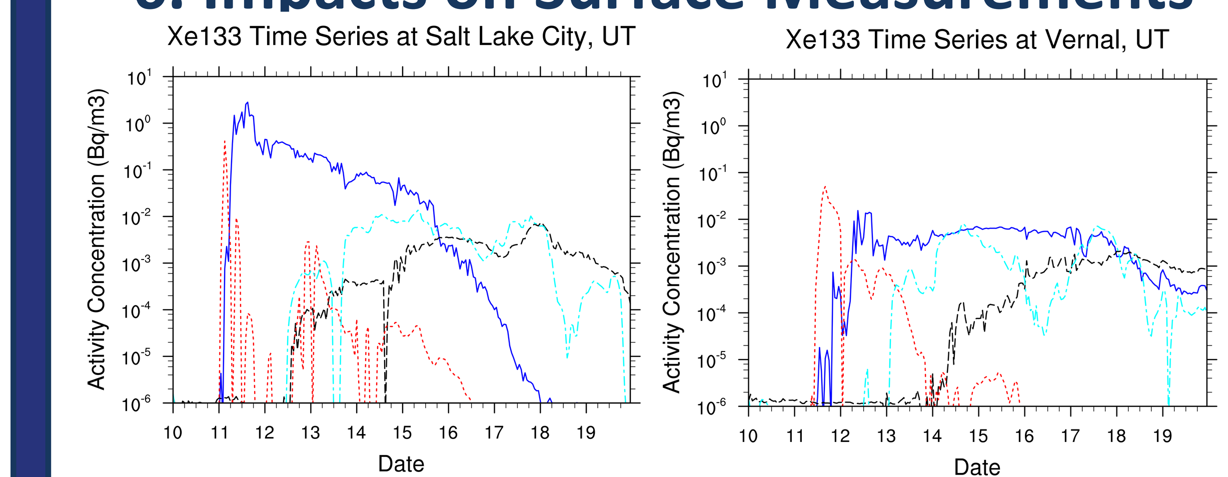


BC Xe-133 activity concentration above background in the lowest model grid cell, at 0000 UTC 13 Jan 2011, on the coarse grid simulation (left) and on nested grid simulation domain 1 (right). Wind vectors are dark purple and topography is shaded.

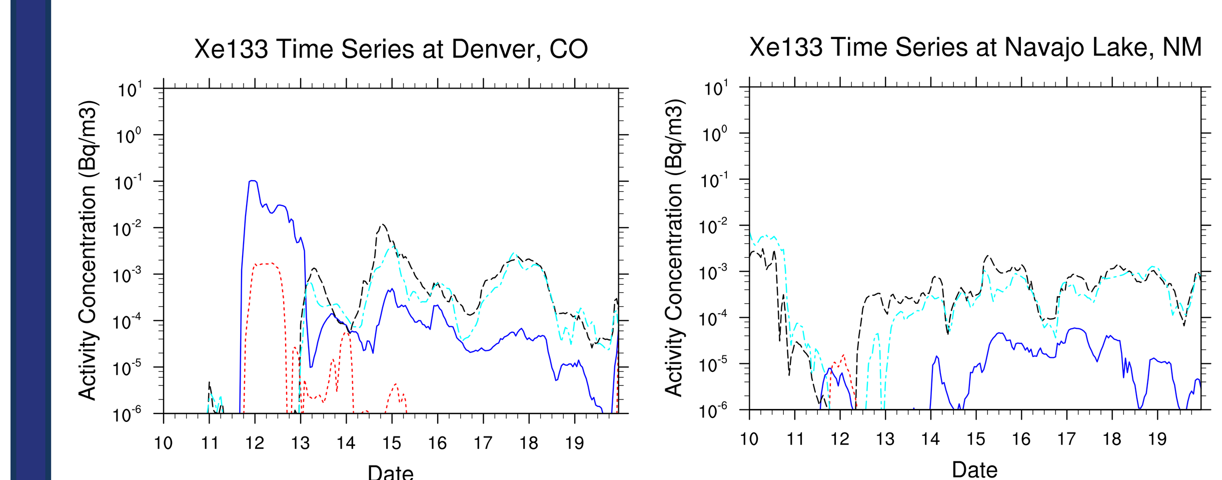


BC Xe-133 activity concentration above background in the lowest model grid cell, on nested grid simulation domain 1, at 0000 UTC 16 Jan 2011 (left) and 0000 UTC 17 Jan 2011 (right). Wind vectors are dark purple and topography is shaded.

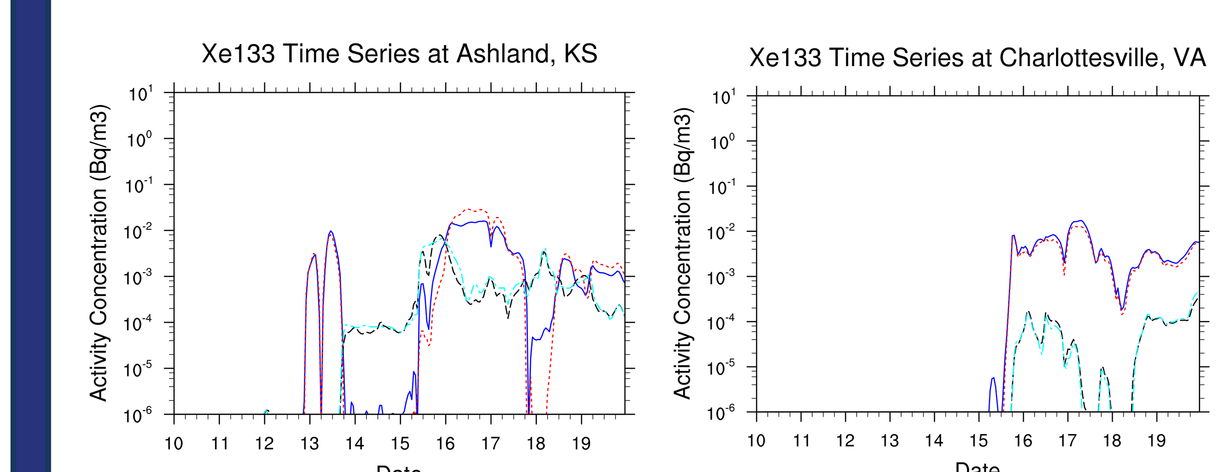
6. Impacts on Surface Measurements



Time series of Xe-133 concentrations above background at two local sites relative to BC. Lines represent the BC plume from the nested grid run (blue solid), the BC plume from the single 9km grid simulation (red dot), the MIPF plume from the nested grid simulation (black dash), and the MIPF plume from the single 9km simulation (cyan dot dash).



Time series of Xe-133 concentrations above background at two regional sites relative to BC. Lines represent the BC plume from the nested grid run (blue solid), the BC plume from the single 9km grid simulation (red dot), the MIPF plume from the nested grid simulation (black dash), and the MIPF plume from the single 9km simulation (cyan dot dash).



Time series of Xe-133 concentrations above background at two continental sites relative to BC. Lines represent the BC plume from the nested grid run (blue solid), the BC plume from the single 9km grid simulation (red dot), the MIPF plume from the nested grid simulation (black dash), and the MIPF plume from the single 9km simulation (cyan dot dash).

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- Grell, G.A., S.E. Peckham, R. Schmitz, S.A. McKeen, G. Frost, W.C. Skamarock and B. Eder, 2005: Fully coupled online chemistry within the WRF model. *Atmos. Environ*., 39, 6957-6975.
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Disclaimer

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7. Conclusions

- In the simulation results, the plumes respond to the complex terrain near the emission sources
  - Plumes generally follow the valleys as paths through the topography, especially under stable conditions
  - Higher grid resolution that allows for better representation of the topography leads to a BC plume that lingers in valleys
  - Elevation of the plume aloft allows some of the plume to cross mountain ranges
- The impact of the complex topography is greatest at locations closest to the sources
  - Influenced by slope flows and valley circulations
  - At farther distances, plumes are represented at coarse resolution in both simulations and there is more time for mixing
- Transient synoptic scale weather systems also guide plume transport
  - Stability suppresses vertical lofting early in the simulation
  - Synoptic scale winds over the Great Plains detain the plume
- The potential for a MIPF to complicate monitoring depends on the measurement location
  - Relative to the sources
  - Dependent on topography between source and sensor
  - Influenced by the track and timing of weather systems