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Joint influences of background RN sources and topography on plume characteristics at monitoring sites using WRF-Chem

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Motivation

- Many atmospheric monitoring applications, including the International Monitoring System (IMS), rely on sparse station networks
- Unknown source location, fluctuating concentrations from background sources such as medical isotope production facilities – MIPFs – and nuclear power plants complicate inference of emissions characteristics
- Complex topography near emissions sources can further influence plume concentrations at measurement sites at local to continental distances from the source.

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- Many atmospheric monitoring applications, including the International Monitoring System (IMS), rely on sparse station networks
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- Complex topography near emissions sources can further influence plume concentrations at measurement sites at local to continental distances from the source.

We use WRF-Chem simulations to evaluate the impact of complex topography near the source of an RN emission as well as upwind MIPF emissions on measurements at monitoring sites

Simulation approach

- WRF-Chem* simulation domains covering the continental US
- Time period: January 6, 2011 until January 20, 2011
- Two domain set-ups to study impact of topography resolution:
  - Single grid with 9 km horizontal grid spacing
  - Three nested grids with 9 km, 3 km, and 1 km grid spacing
- 60 vertical levels on hybrid terrain-following vertical coordinate
- Initial fields, lateral boundary conditions, and nudging data from Global Forecast System (GFS) 0.5-degree gridded analyses at 6-hour intervals
- Nudging applied above the planetary boundary layer on the outer-most domain (D01) to preserve large-scale flow consistent with observed synoptic weather

*** Peckham, S.E., 2012. WRF/Chem version 3.3 user's guide. https://ruc.noaa.gov/wrf/wrf-chem/**

WRF-Chem and Simplifying Assumptions

- WRF-Chem chemistry calculations performed on the same Eulerian grid as WRF dynamics and physics, in-line with each model timestep
- Here, emissions are assumed non-buoyant and released within the lowest model grid cell
- Emission rates are assumed to be constant over each hour
- Focus on transport and dispersion → all species are treated as passive tracers:
  - No decay
  - No daughter products
  - No dry or wet deposition

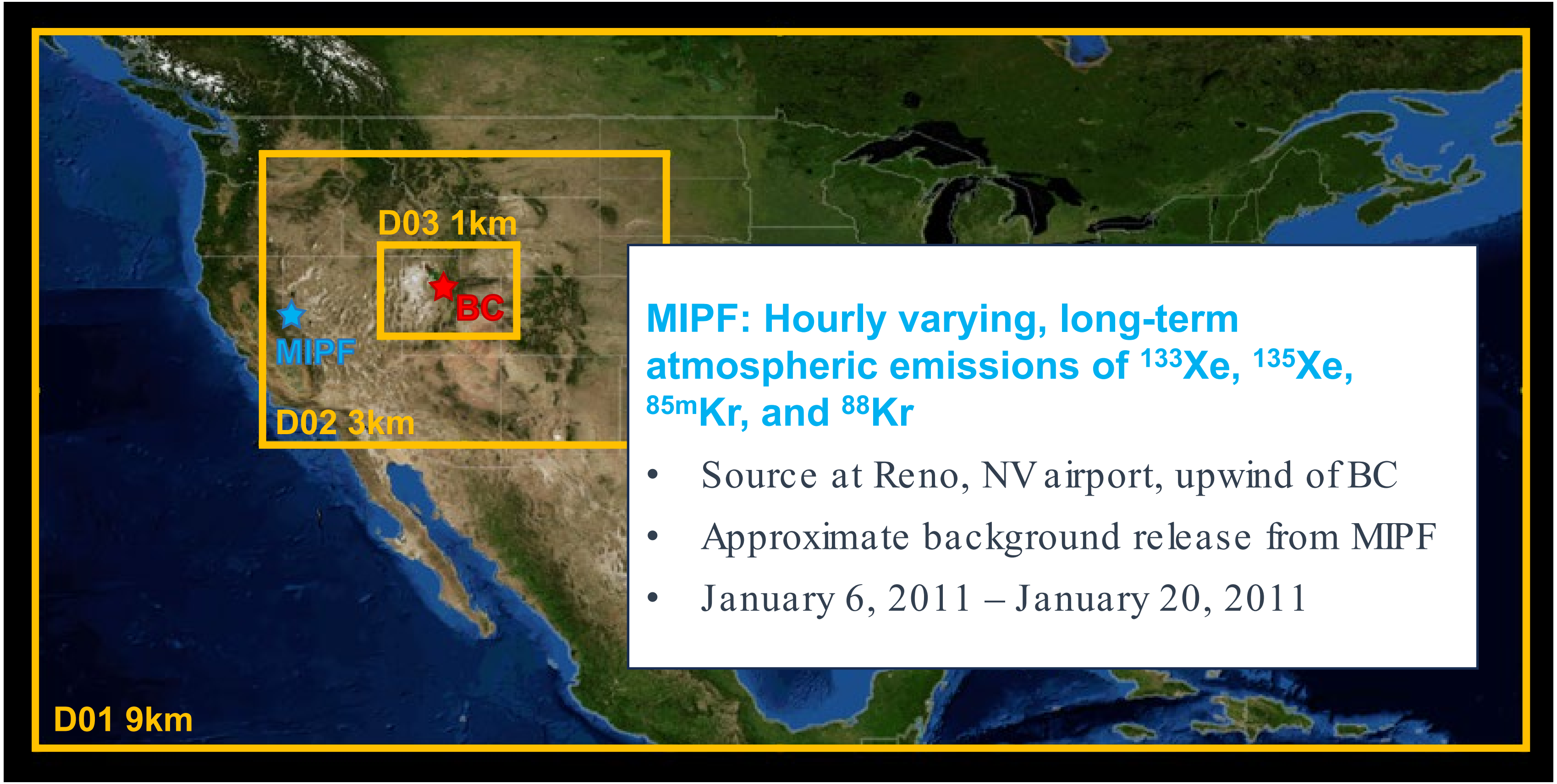
Simulation Domain Setup

Emission Sources

BC: Large, short-term (one hour) atmospheric emission of 6e13 Bq of ^{133}Xe

- Source at Bingham Canyon copper min in Utah (BC)
- Emulate explosive release
- January 10, 2011 (2300 UTC; Constant flux rate over the hour)

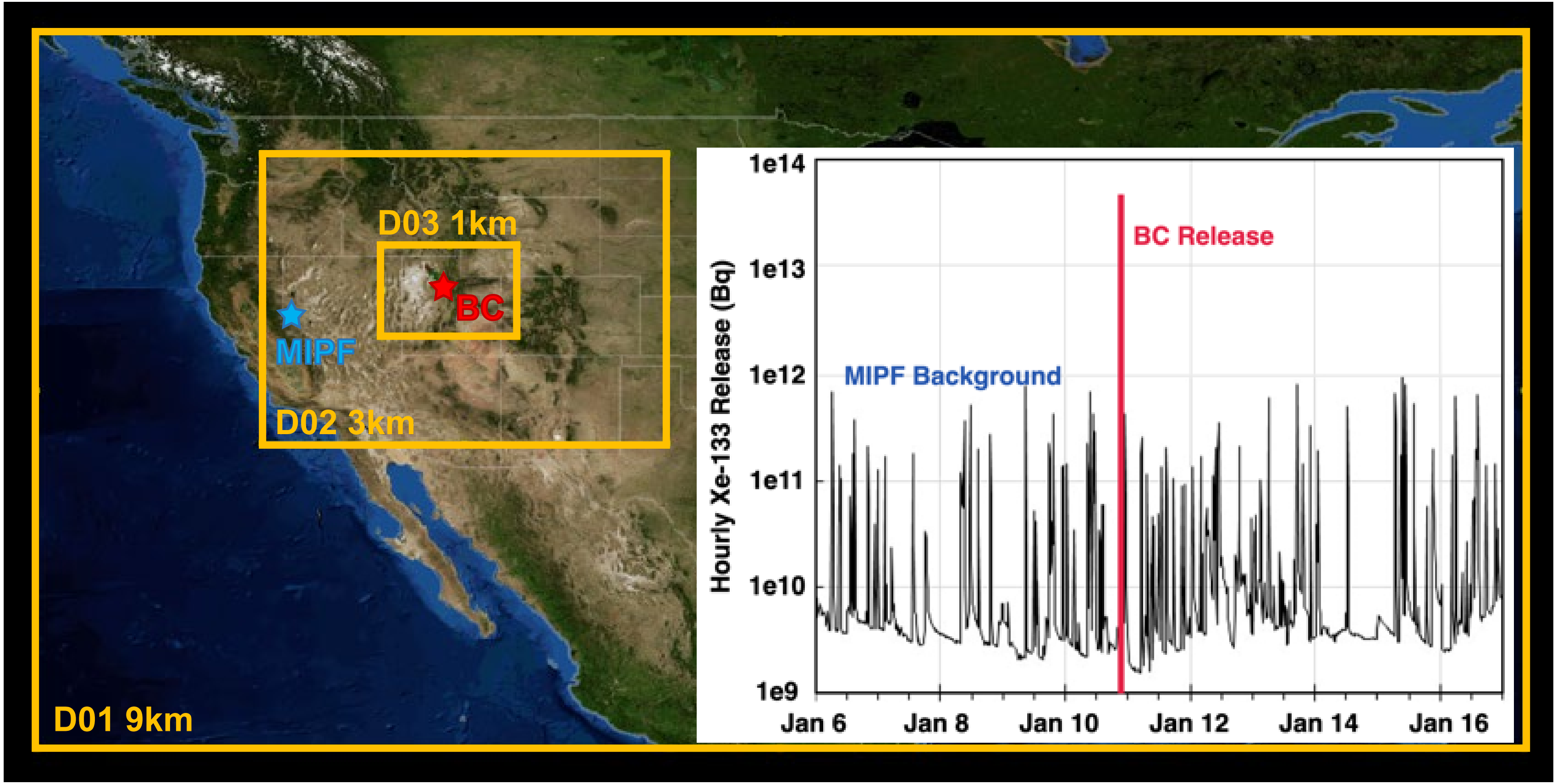
Emission Sources



MIPF: Hourly varying, long-term atmospheric emissions of ^{133}Xe, ^{135}Xe, ^{85m}Kr, and ^{88}Kr

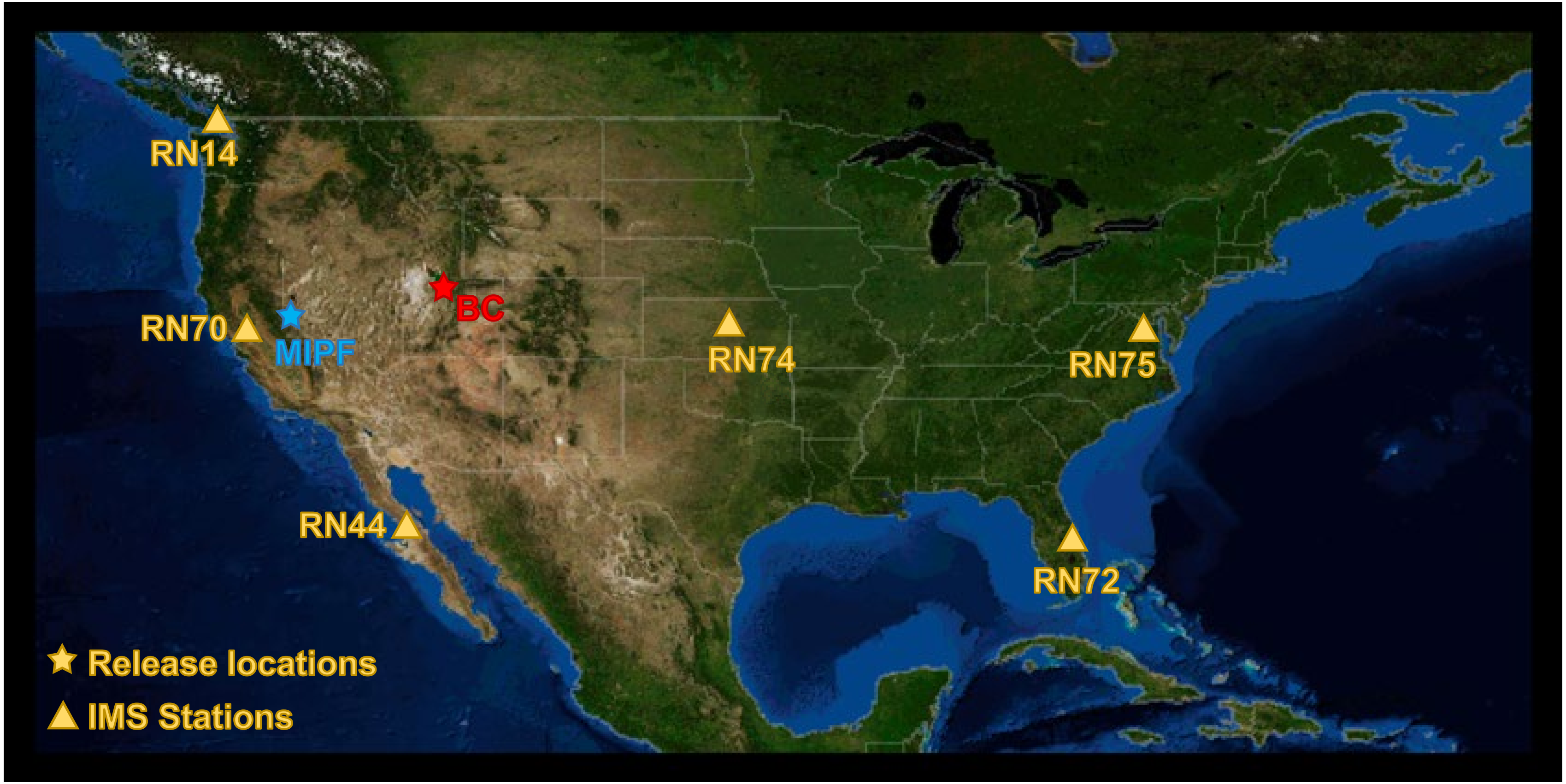
- Source at Reno, NV airport, upwind of BC
- Approximate background release from MIPF
- January 6, 2011 – January 20, 2011

Emission Sources



^{133}Xe release time series from Eslinger et al. (2019)

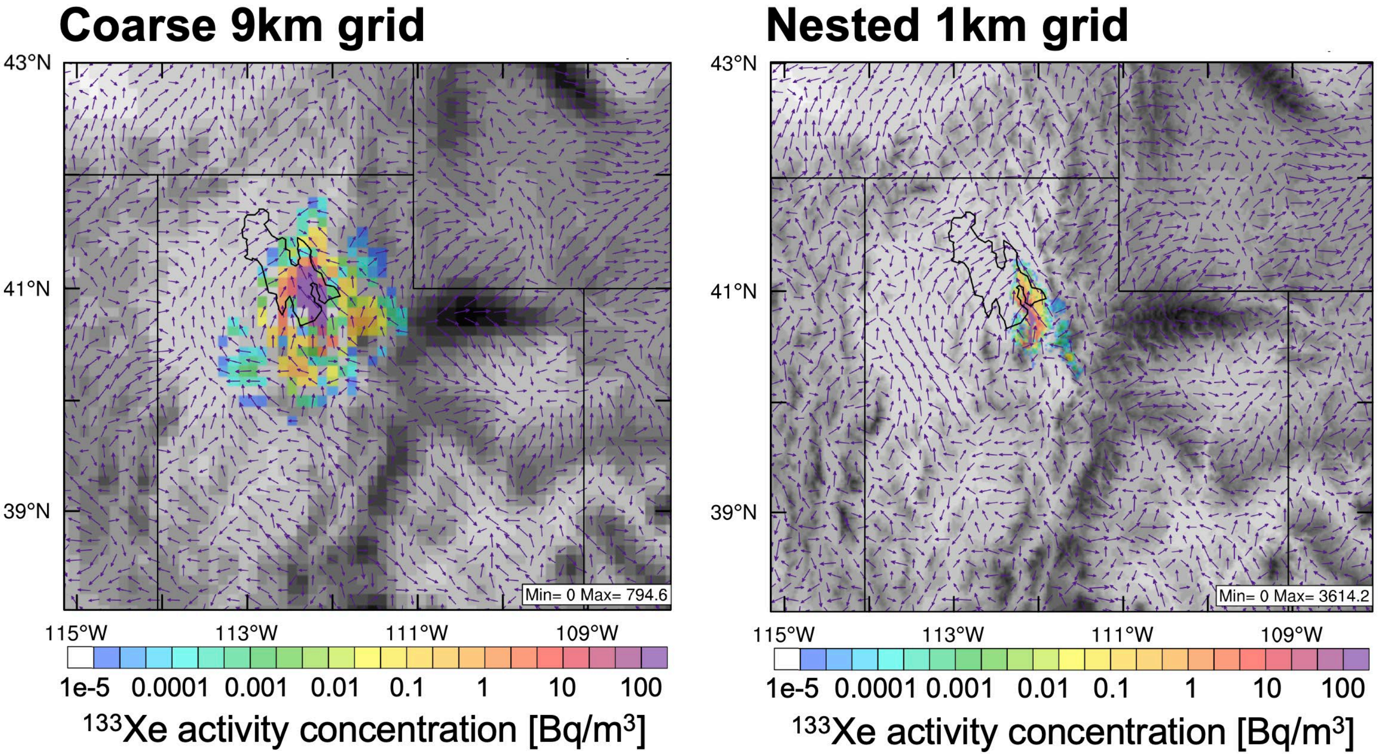
Emission Sources and Station Locations



Impact of Topography on early BC Plume

^{133}Xe activity concentrations [Bq/m³] 2 hours after release

- Two hours after the BC release, most of the BC plume in the nested grid run (right) tends to stay in the Salt Lake Valley.
- However, in the coarser resolution run (left) the BC plume expands more, especially to the south and west.
- High pressure centered east of the area suppresses vertical mixing and contributes to southerly winds.



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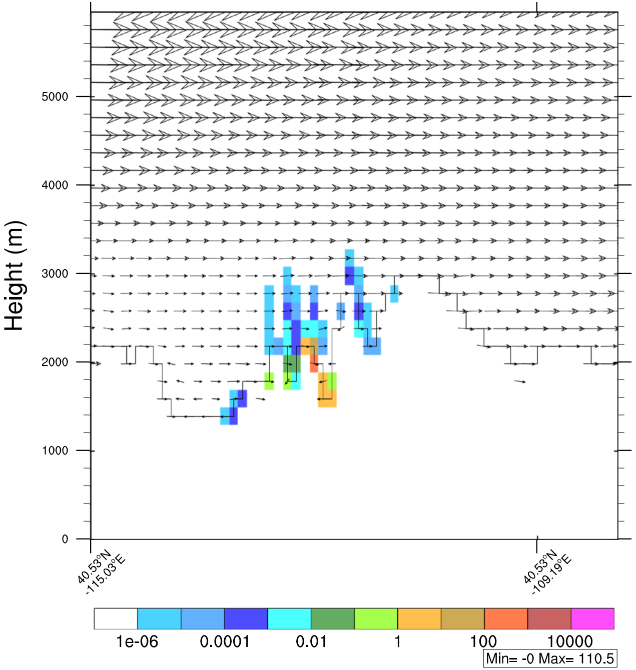
Impact of Topography on early BC Plume

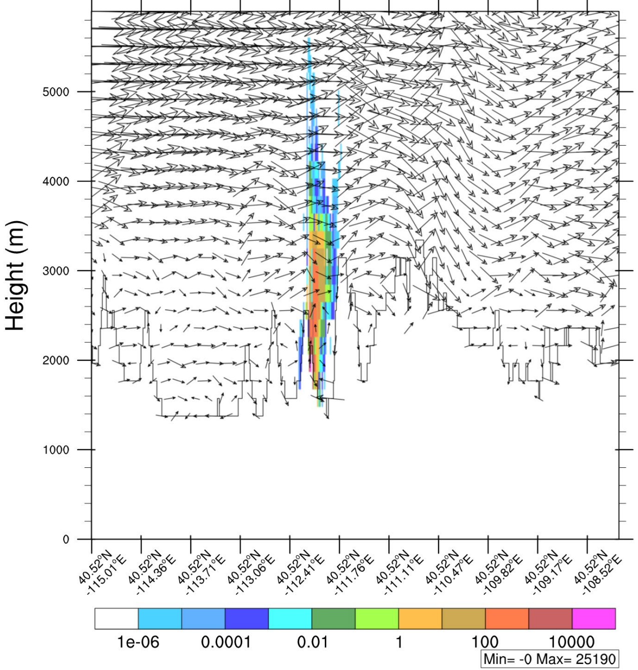
^{133}Xe activity concentrations [Bq/m^3] 2 hours after release

Vertical slice through the domain in the area of the BC release highlights differences in topography resolution and their impact on winds and ^{133}Xe concentrations

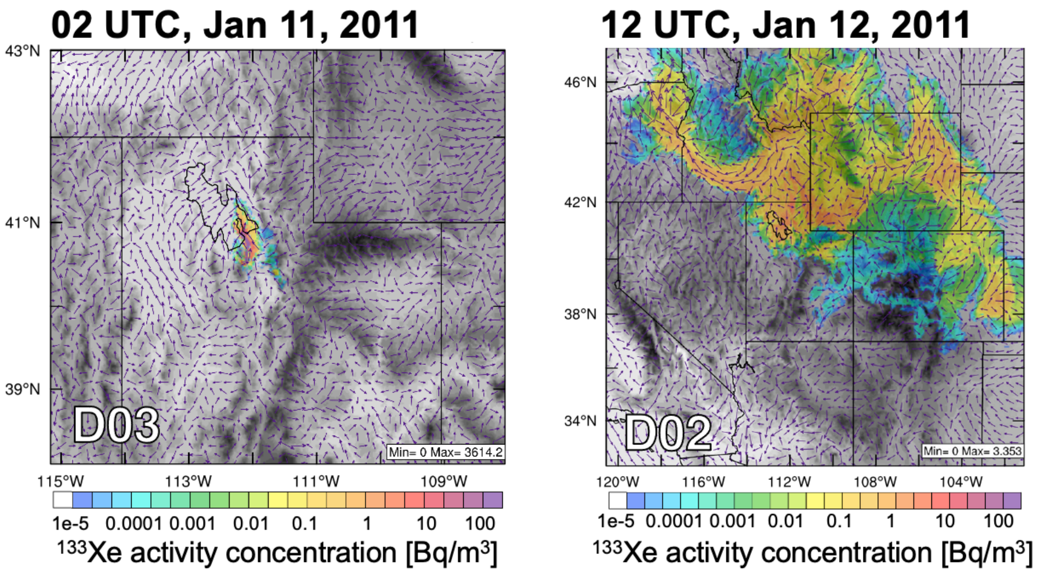
Coarse 9km grid

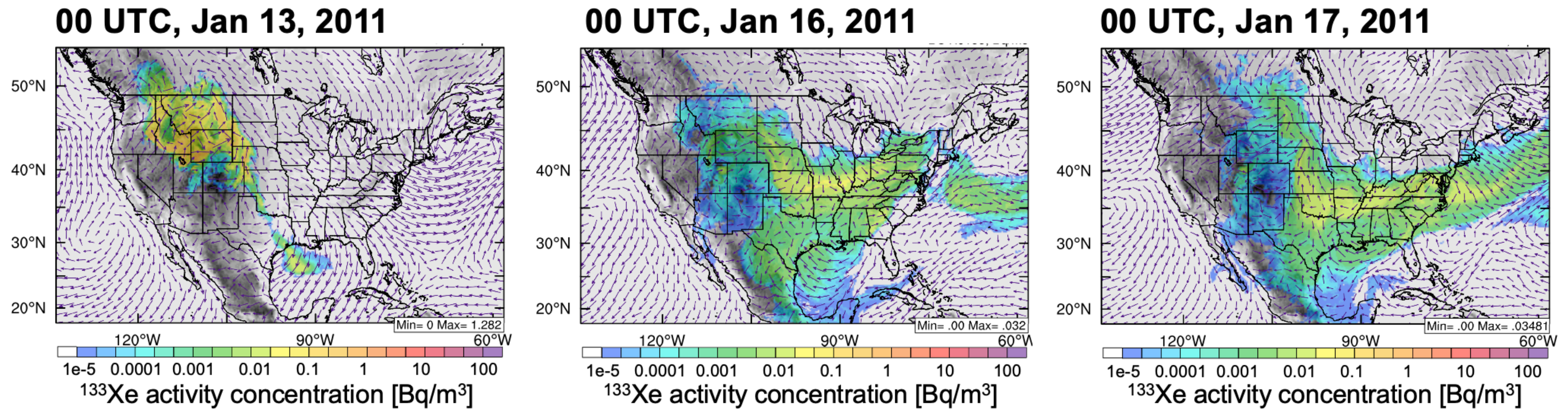


Nested 1km grid



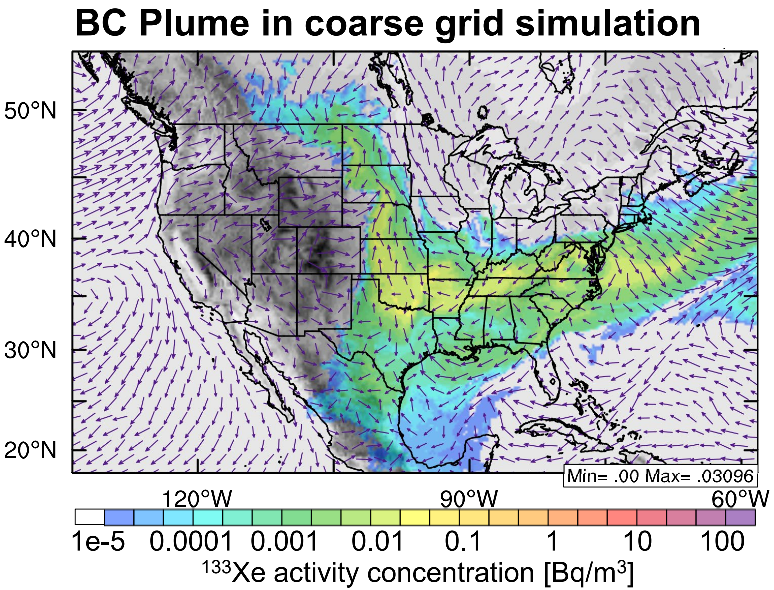
Progression of the BC Plume in nested simulation

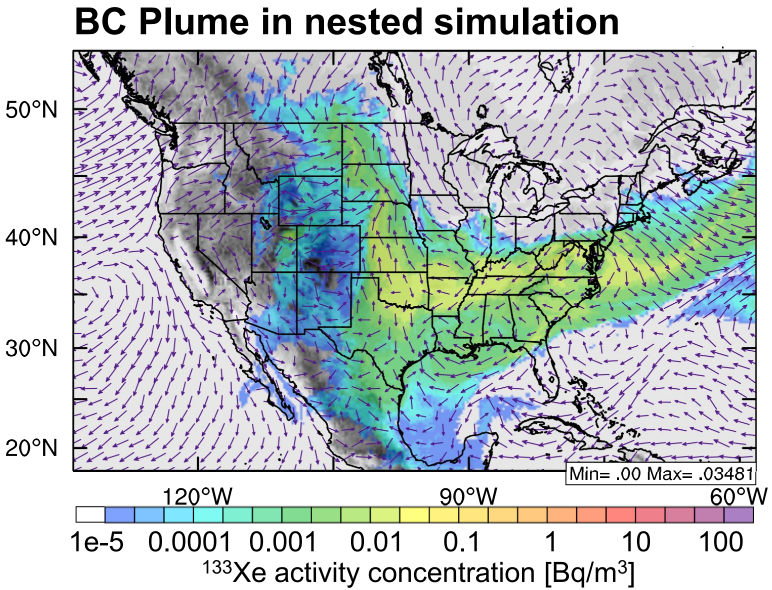




Compare BC plume in coarse vs nested simulations

6 days after BC release, January 17, 2011 00 UTC



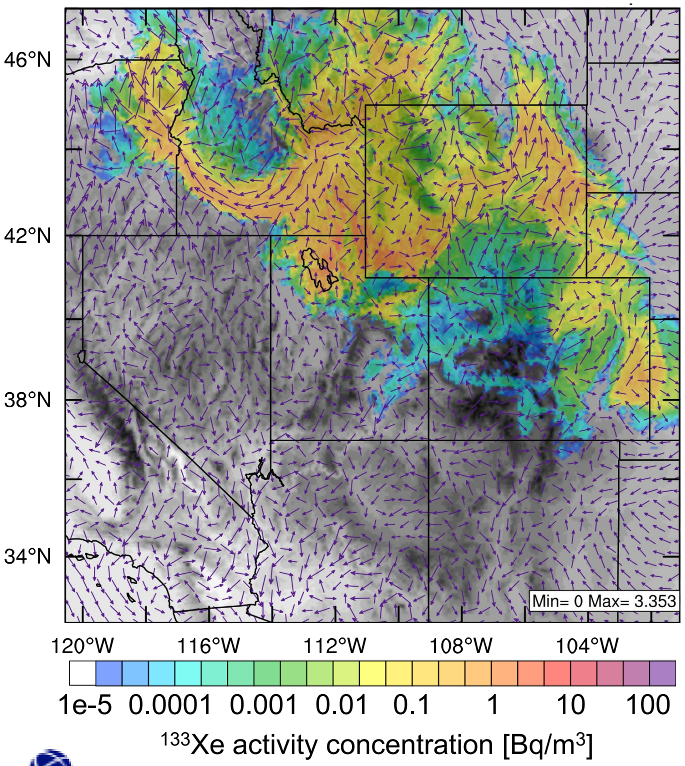


- In nested simulation, concentrations remain over the area of release and immediate downwind areas, as flow is channeled by topography
- In the coarse simulation, where topography is smoothed, flow moves over the topography more quickly, moving the plume past the area of release

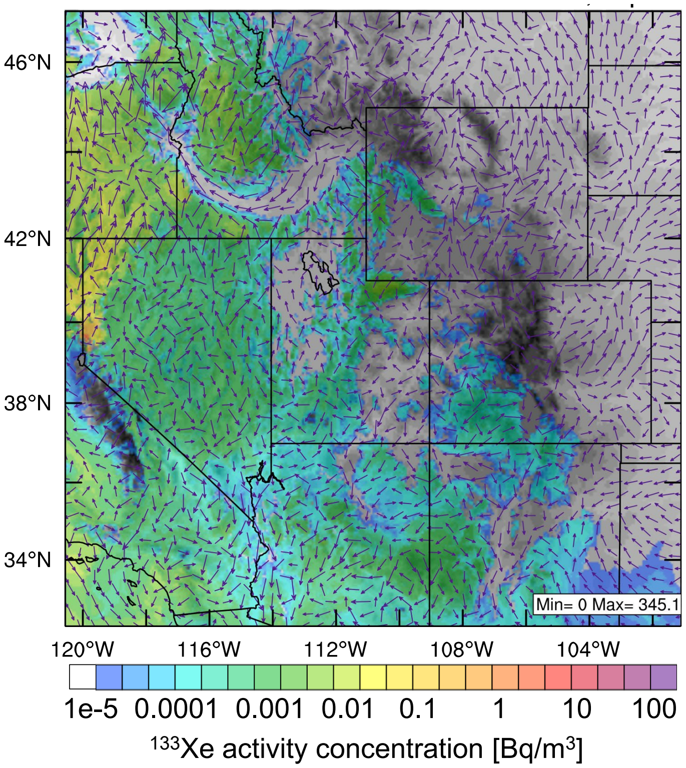
Regional progression of the BC and MIPF plumes

36 hours after BC release

BC Plume in nested simulation



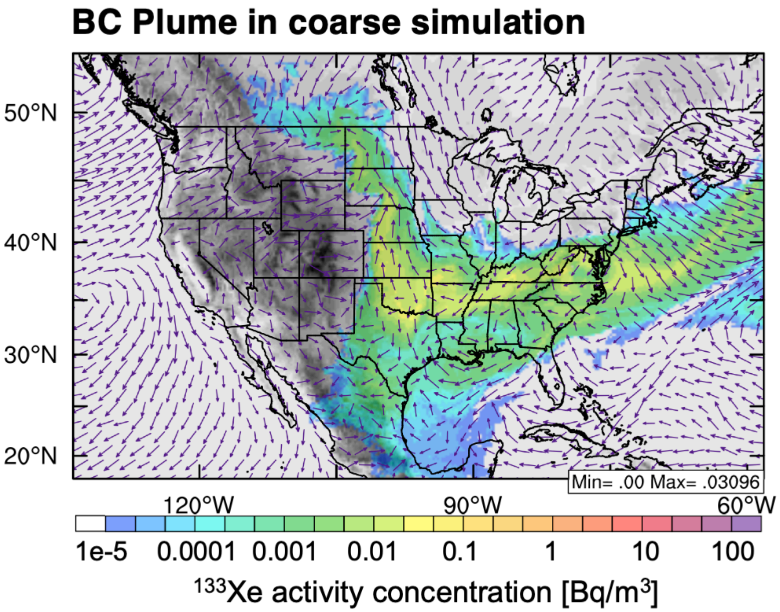
MIPF Plume in nested simulation

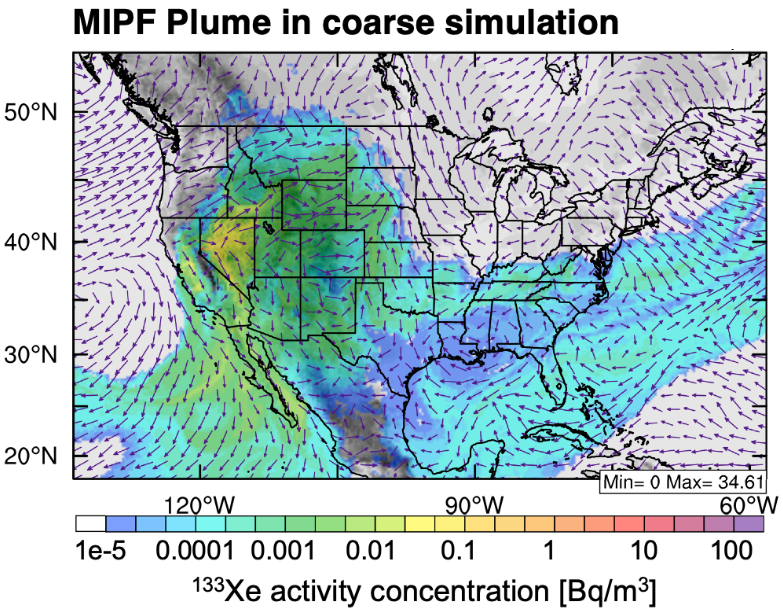


- A day and a half after the BC release, both the MIPF and BC plumes are drifting northward.
- The BC plume has moved into the Snake River Valley.
- The MIPF plume concentrations are greater in the higher terrain between the MIPF and the valley.

Continental-scale transport of the BC and MIPF plumes

6 days after BC release, January 17, 2011 00 UTC



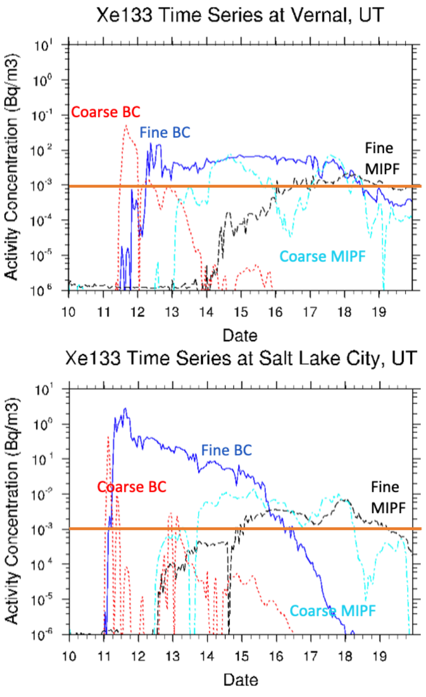


- Both plumes travel eastward with prevailing winds / passing weather systems
- MIPF plume has also traveled west over the CA Coast, Baja California, into the Pacific
- Concentrations over eastern US lower than for BC plume, below detection limits in many areas

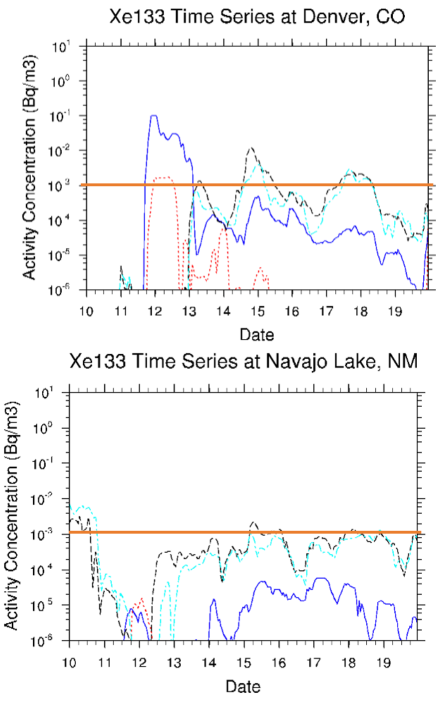
Activity concentrations over time at station locations

- Higher grid resolution, which allows for better representation of the topography and winds, leads to BC plume lingering in valleys
- The impacts of grid resolution and the complex topography are greatest at locations closest to the sources
- Days after the BC release, MIPF concentrations are comparable or greater than BC concentrations at several local and regional sites

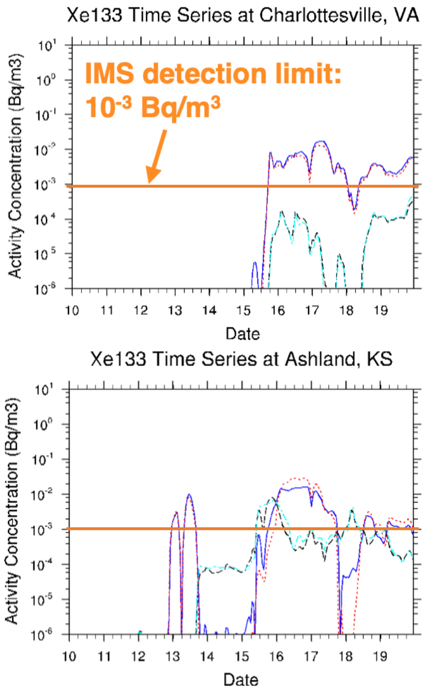
Hypothetical monitoring local to BC



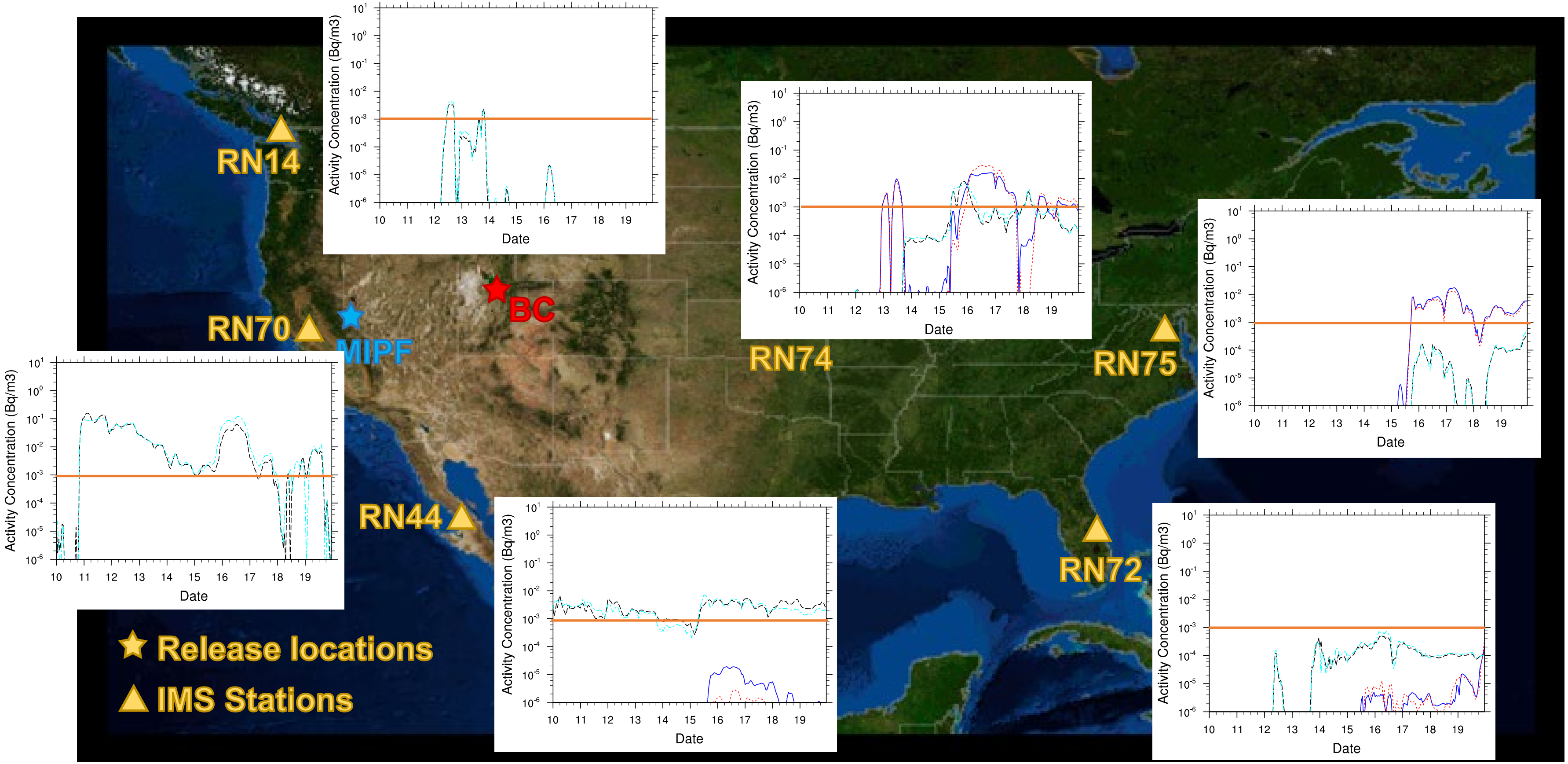
Hypothetical regional monitoring



IMS Stations



Signals at North American IMS Stations



Conclusions

Simulation results show strong sensitivity of plumes to terrain resolution near the emission sources, particularly early in the simulation

- Plumes follow valleys, especially under stable conditions
- Higher grid resolution allows for better representation of topography, and leads to a BC plume that lingers in valleys

The impact of topography doesn't persist once plume transitions into coarse resolution domain in nested simulation

At farther distances there is also more time for mixing to occur

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