Numerical Modeling of Wintertime Cold Air Pools in the Uintah and Salt Lake Basins

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Introduction

- Utah residents in basins susceptible to cold air pools (CAPs) often affected by: (1) high wintertime ozone concentrations due to oil and gas development; (2) high particulate concentrations in urban areas
- CAPs are difficult to simulate correctly
- Research underway at the University of Utah and Utah Division of Air Quality to improve modeling capabilities
- Observations from the Persistent Cold Air Pool Study (PCAPS) used to validate model performance
- PCAPS IOP5, 1-10 Jan 2011

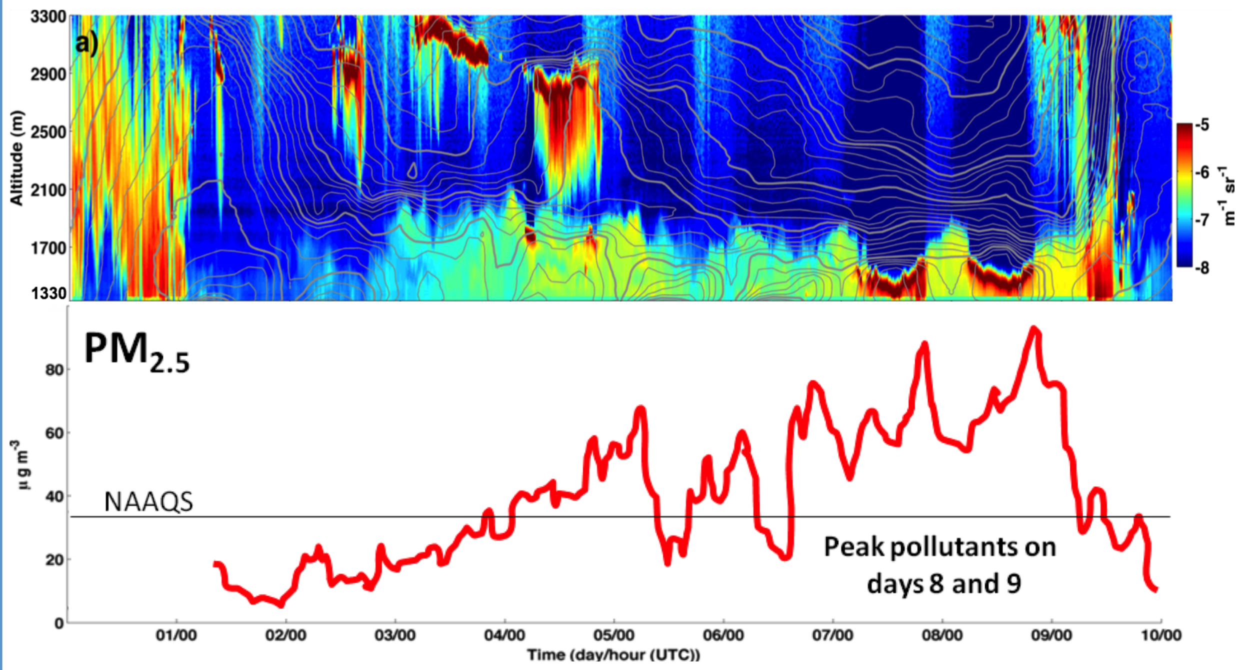


Figure 1. Panel 1: Ceilometer back scatter during PCAPS IOP5, 1-10 Jan 2011. Panel 2: PM 2.5 concentration at Hawthorne Elementary; data courtesy of DAQ (Lareau et al. 2013; Young & Whiteman 2015).

WRF Model Setup

- 3 nested domains (12, 4 and 1.33 km)
- Sensitivity studies focus on innermost domain
- 40 eta (terrain following) vertical levels
- YSU PBL scheme
- No nudging
- Thompson bulk or WRF Single Moment (WSM) microphysics schemes
- USGS, MODIS, or NLCD 2006 land use

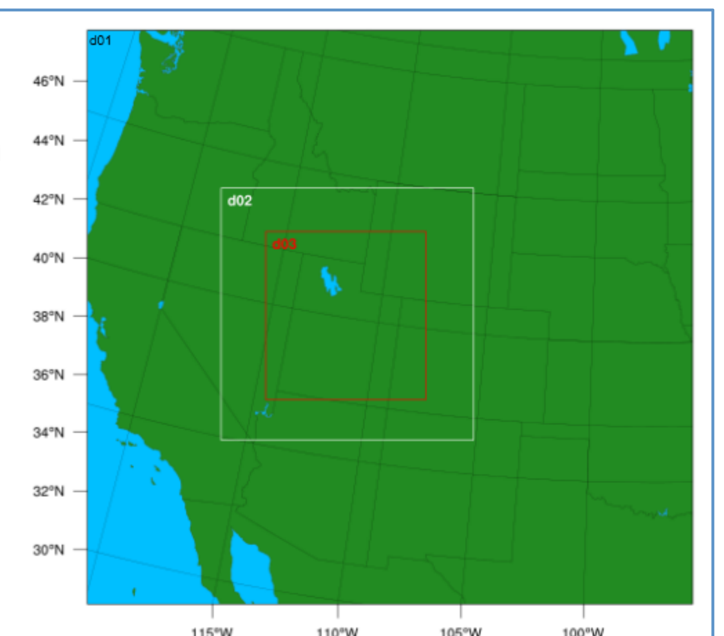
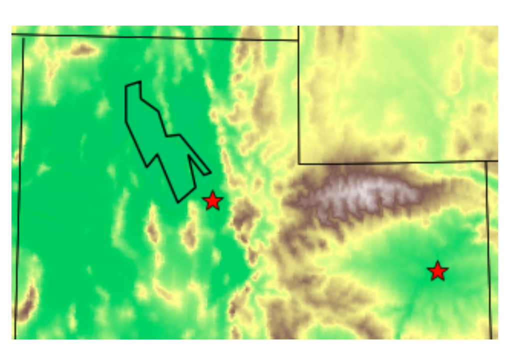


Figure 2. Map of three WRF domains.

IOP5 Simulation Period:
- 00 UTC 1 Jan 2011 to 00 UTC 10 Jan 2011



Locations of time height diagrams (central Salt Lake Basin and Central Uintah Basin)

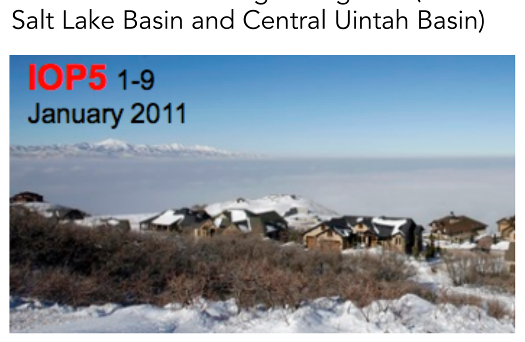


Photo courtesy of Dave Whiteman

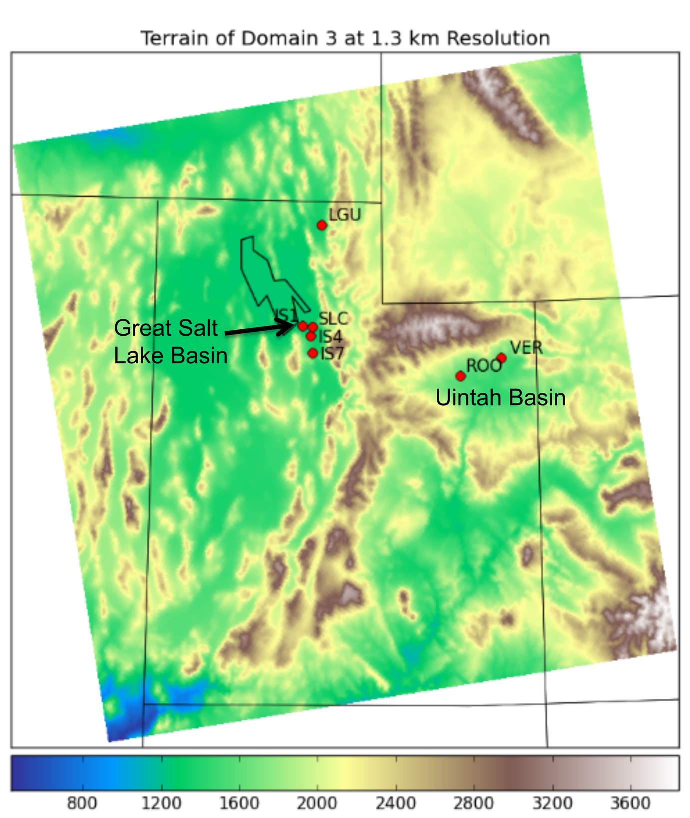


Figure 3. Map of terrain height (m) in WRF domain 3 plotted with location of station sites used for validation.

WRF Model Runs:
- USGS Run: Base model state with USGS land use
- MODIS Run: Base model state with MODIS land use
- NLCD Run: Base model state with NLCD 2006 land use.
- Early Initialization Run: Initialize WRF model at 00 UTC 31 Dec 2010, otherwise base model state with USGS land use
- WSM Run: Initialize WRF model at 00 UTC 31 Dec 2010, and use WSM3 microphysics scheme, otherwise base model state with USGS land use

Land Use Sensitivity

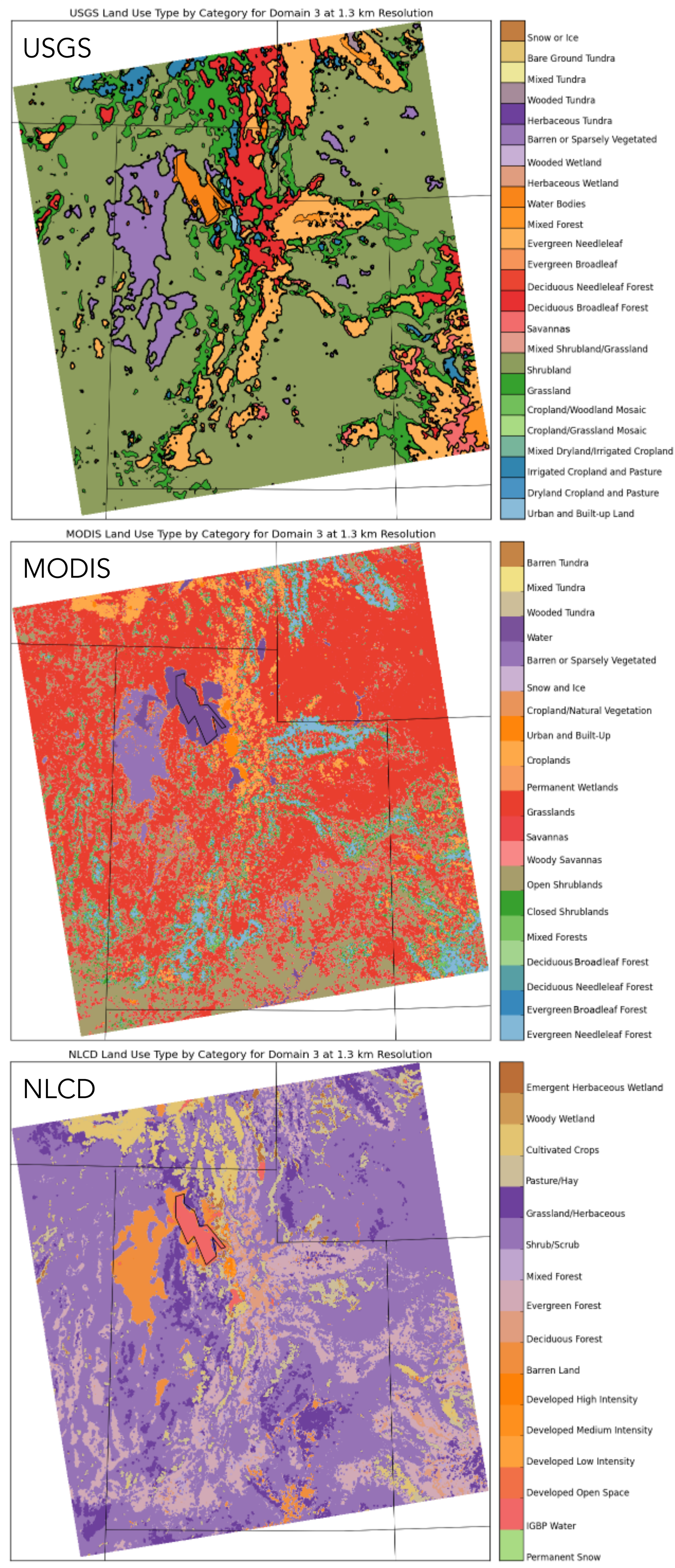


Figure 4. Maps of land use type by category for WRF model domain 3. Pictured are those of USGS, MODIS, and NLCD land use respectively.

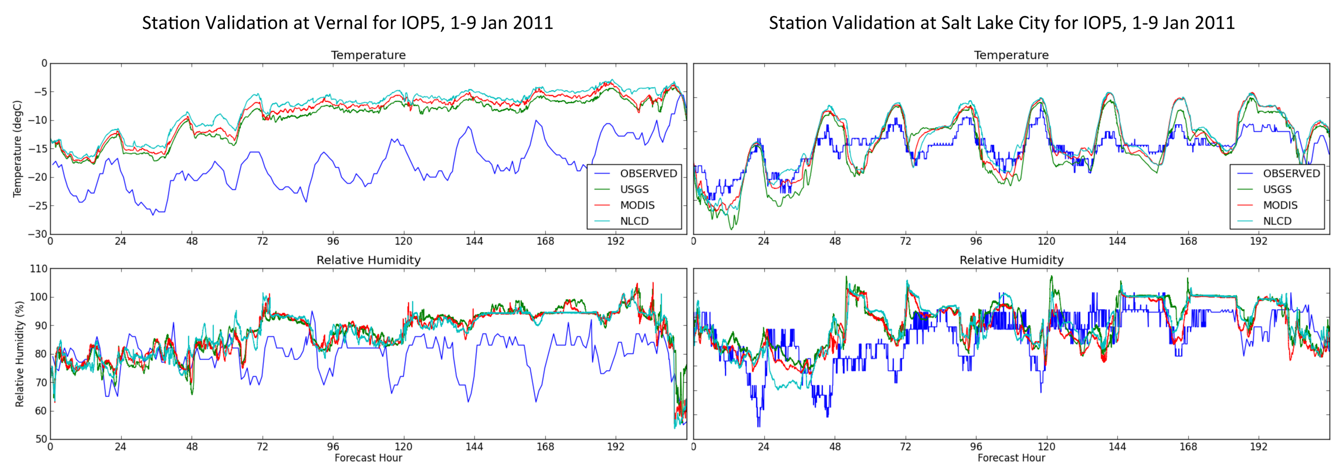


Figure 5. Time series of temperature and relative humidity at Vernal (VER), left, and Salt Lake City (SLC), right, from observations and USGS, MODIS, and NLCD WRF model runs.

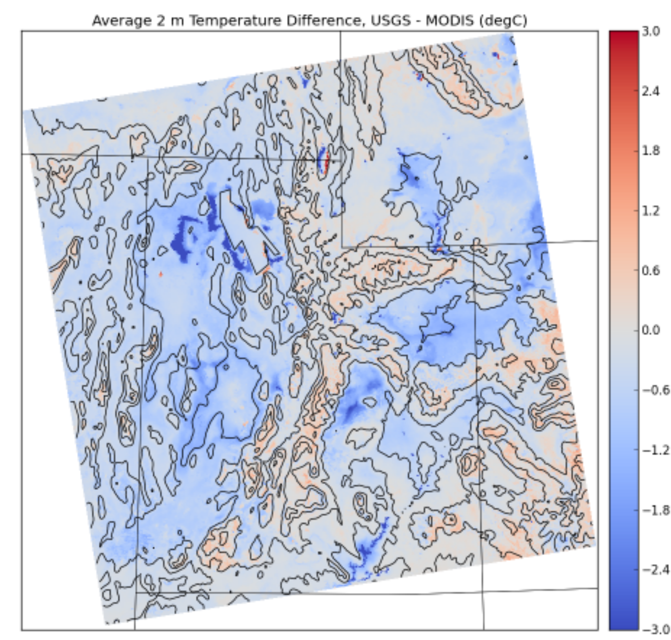


Figure 6. Average 2 m temperature of domain 3 from 1-9 Jan 2011, USGS run minus MODIS run.

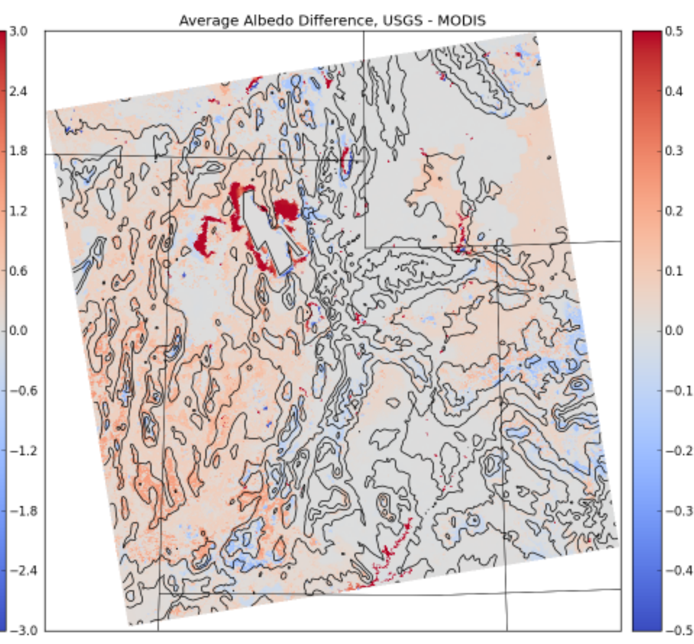


Figure 7. Average albedo of domain 3 from 1-9 Jan 2011, USGS run minus MODIS run.

- Differences in Great Salt Lake size cause the largest differences between runs, but so do differences in land use categorization.

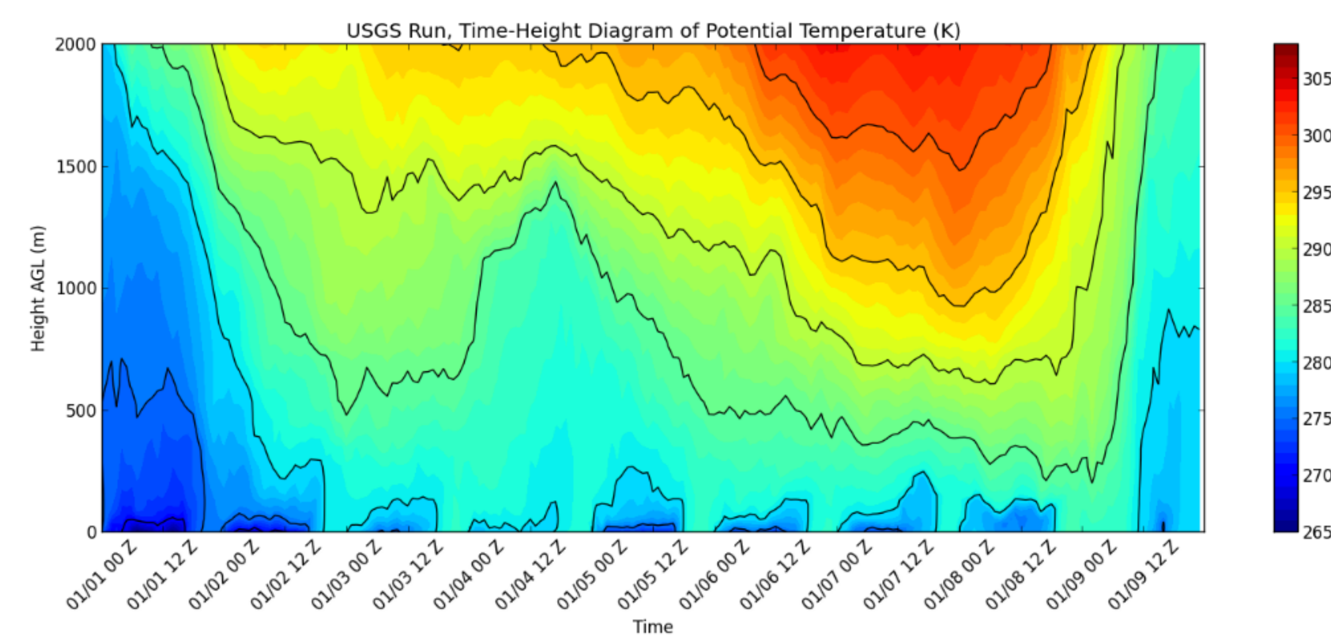


Figure 8. Time-height diagram of potential temperature in the Salt Lake basin for the USGS run from 1-9 Jan 2011. Pictured are the first 20 vertical levels from the WRF model run. Black contours plotted every 5 K.

Initialization Sensitivity

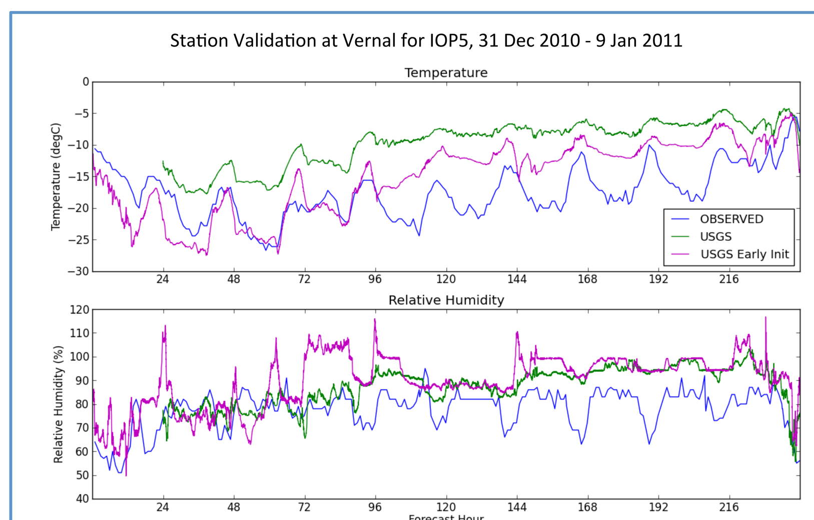


Figure 9. Time series of temperature and relative humidity at Vernal (VER) from observations and USGS and early initialization WRF model runs.

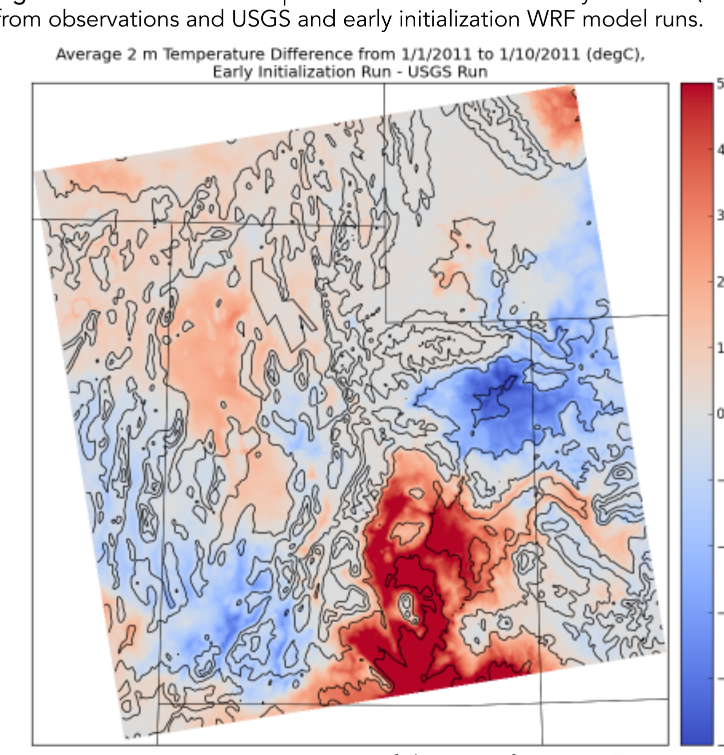


Figure 10. Average 2 m temperature of domain 3 from 00 UTC 1 Jan to 00 UTC 9 Jan 2011, early initialization run minus USGS run.

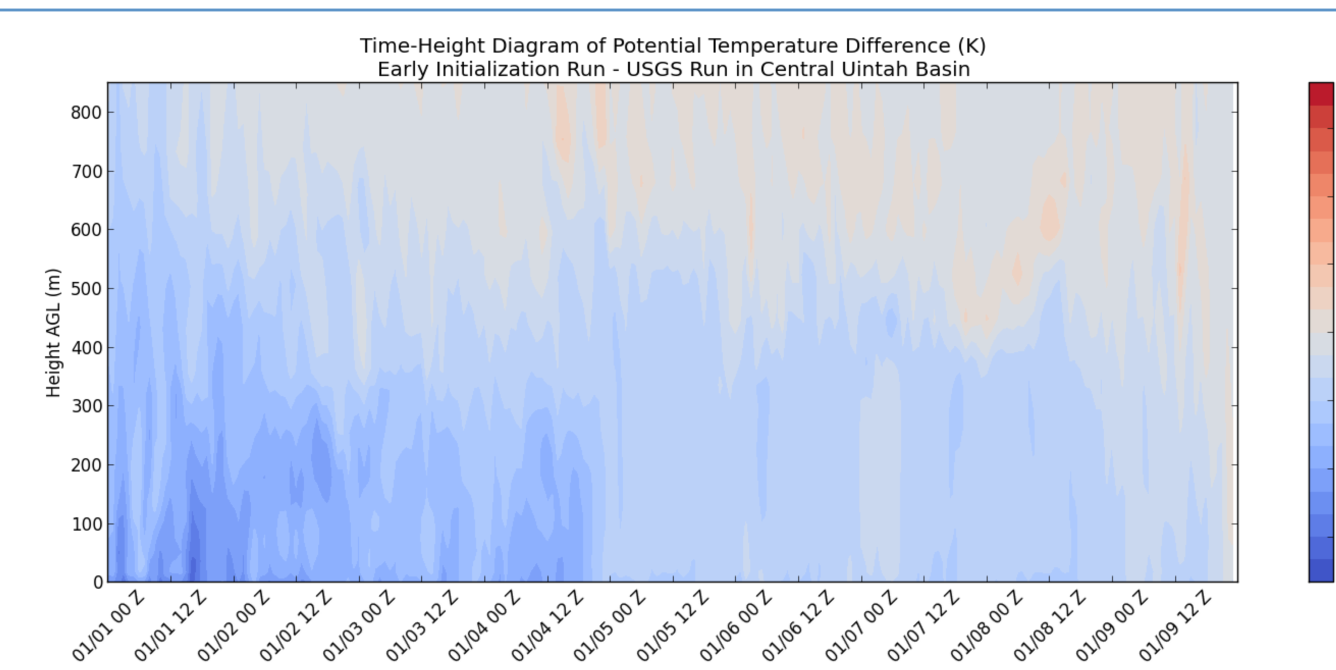


Figure 11. Time-height diagram of difference in temperature between early initialization and USGS runs in central Uintah Basin.

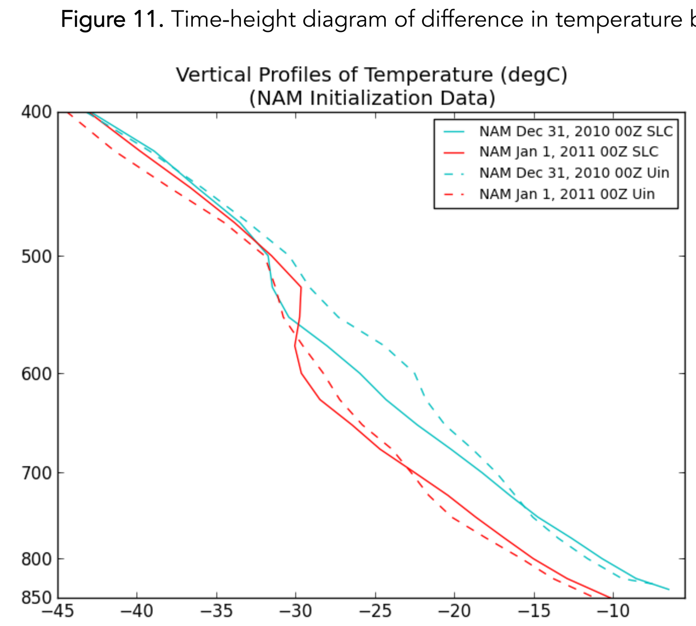


Figure 12. Vertical profiles comparing NAM initialization data from 00 UTC 31 Dec 2010 and 00 UTC 1 Jan 2011.

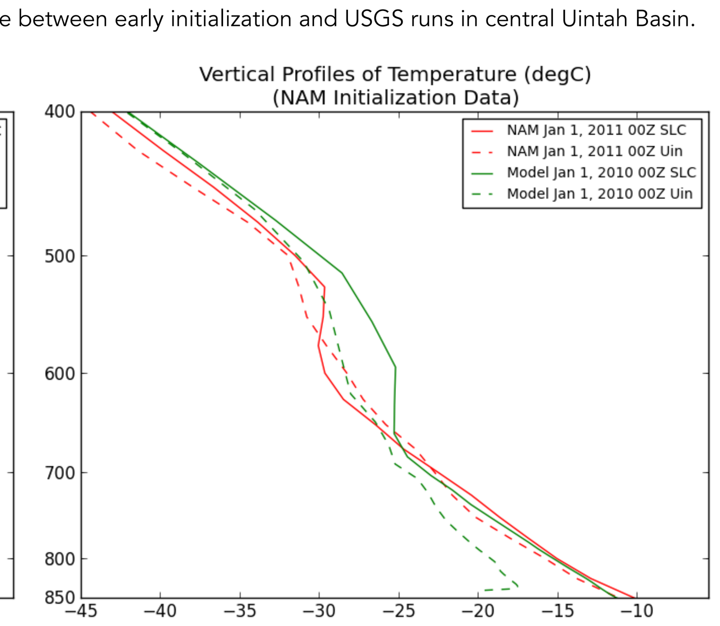


Figure 13. Vertical profiles comparing NAM initialization data from 00 UTC 1 Jan 2011 and early init. run output from 1 Jan 2011.

Microphysics Sensitivity

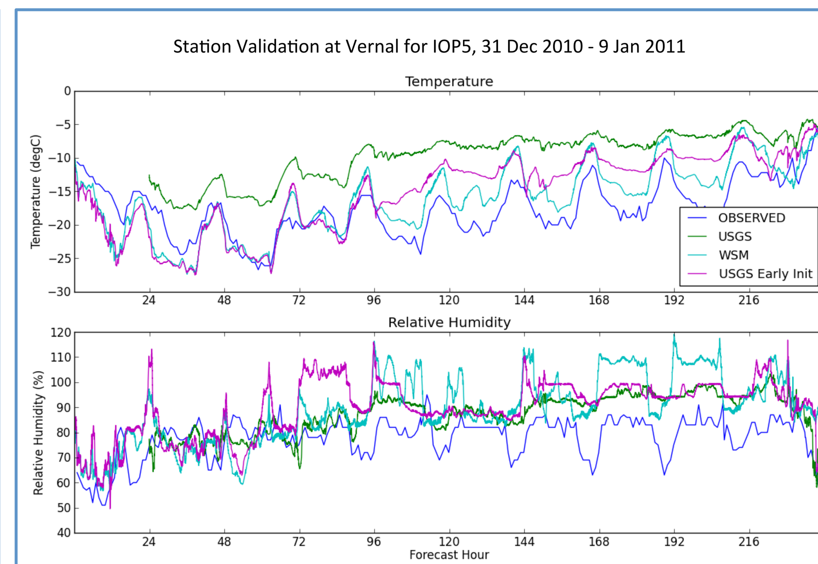


Figure 14. Time series of temperature and relative humidity at Vernal (VER) from observations and WSM and early initialization runs.

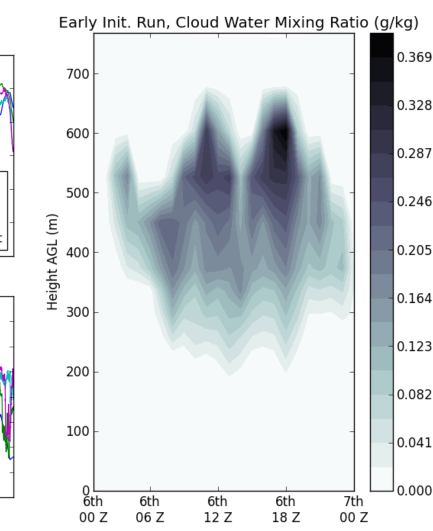


Figure 16. Time-height of cloud water mixing ratio (g/kg) in central Uintah basin, early initialization run.

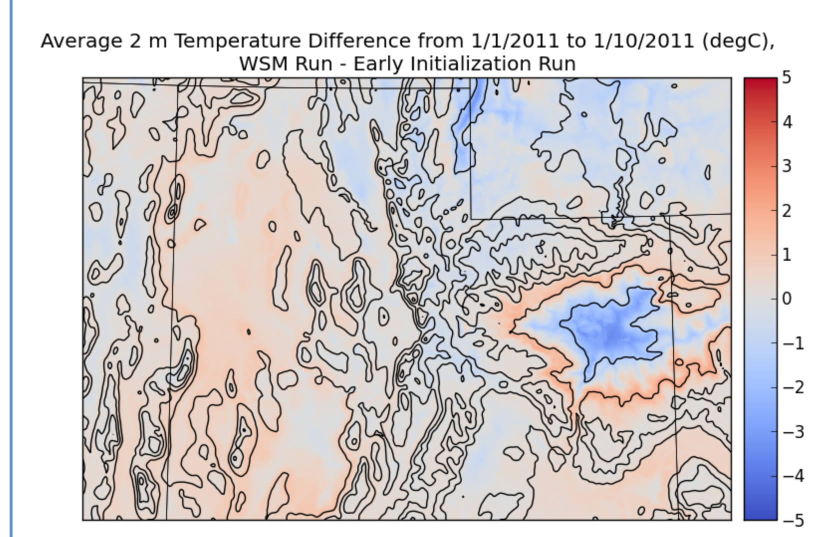


Figure 15. Average 2 m temperature of domain 3 (zoomed in) from 00 UTC 1 Jan to 00 UTC 10 Jan 2011, WSM run minus early initialization run.

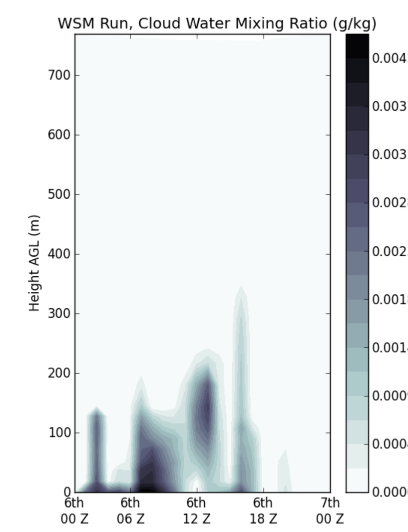


Figure 17. Time-height of cloud water mixing ratio (g/kg) in central Uintah basin, WSM run.

Summary

- WRF model runs are sensitive to land use and issues arise from the following:
  - Land use categories (different snow heights cover certain vegetation vs different land use)
  - Year of data set (varying Great Salt Lake size and outdated representation)
- Modeling of cold air pools is highly sensitive to initialization time
  - Initialize before the cold air pool onset in order to let the model simulate the CAP build-up
  - NAM meteorological input fields poor first guess
- Microphysics scheme and cloud cover
  - Less spurious cloud cover when WSM3 scheme used compared to Thompson, but that is not a general solution (see also Neemann et al. 2014)
  - Enhanced nighttime cooling with less clouds

Future Work

- Simulating partial CAP mix-outs
- Testing ice fog and aerosol-aware Thompson micro-physics schemes to improve modeled clouds (Kim et al. 2014; Thompson & Eidhammer 2014)
- Targeted large-eddy simulations
- More research regarding albedo snow interaction w/ vegetation, land use, and initialization

References

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Young, J.S., and C.D. Whiteman, 2015: Laser ceilometer investigation of persistent wintertime cold-air pools in Utah's Salt Lake Valley, submitted to Journal of Applied Meteorology and Climatology