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Numerical Simulations of Cold Fronts over the Appalachian Piedmont during MU-PAST

Rhiannon Fleming and Kyle Johnson

Abstract
MU-Piedmont-area Arctic Storm Tracking (MU-PAST) is a research project involving over 35 undergraduate meteorology majors designed to study the structure and evolution of winter season Arctic fronts as they progress across the Appalachian piedmont region. The project takes a 3-pronged approach: 1) a climatological study of cold fronts affecting the region; 2) a field campaign where three teams conducted balloon-borne upper-air profiles; and 3) a numerical simulation initialized with observational data. Data from the observational study are assimilated to initialize high-resolution (2 km grid spacing) simulations using the Weather Research and Forecasting (WRF) System. Results of these simulations are used to diagnose the salient features of the frontal system and will be reported.

The passage of fronts is a key factor influencing the weather conditions over the midlatitudes, from 35° to 55° North. A front can be defined as the interface between air masses of differing density and origin, featuring a strong horizontal temperature gradient (Markowski and Richardson 2010). Consequently, frontal passage over a given area is marked by a change in temperature, humidity, pressure, and wind direction. In some cases, these differences between adjacent air masses can induce disturbed weather conditions, such as rain, snow, or sleet. The arctic front, a semi-permanent and semi-continuous boundary between a mass of arctic air and a mass of polar air, often pushes south into the midlatitudes during the wintertime. This type of front breeds winter weather events affecting the Appalachian Piedmont region, a plateau region between the Appalachian Mountains Atlantic coastal plain.

MU-Piedmont-area Arctic Storm Tracking (MU-PAST) is a research project designed to study the structure and evolution of winter season Arctic fronts as they progress across the Appalachian Piedmont region. The project takes a 3-pronged approach: 1) a climatological study of cold fronts affecting the region; 2) a field campaign where three teams conducted balloon-borne upper-air profiles; and 3) a numerical simulation initialized with observational data. The component of the study presented here uses the Weather Research and Forecasting System (WRF) at a high resolution of 2 km horizontal grid spacing, a small-scale model, to diagnose the

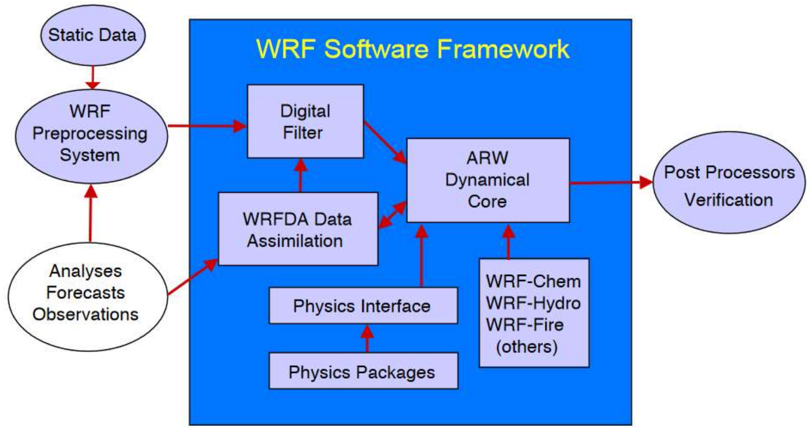

Figure 1.1: Advanced Research WRF system components.

Figure 1: Schematic of the WRF processing system and workflow. (Skamarock et. al., 2019)

salient features of the Arctic frontal system, such as temperature and wind shifts.

Method

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications. It features two dynamical cores, a data assimilation system, and a software architecture supporting parallel computation and system extensibility (Fig.1). The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometers. For researchers, WRF can produce simulations based on actual atmospheric conditions (i.e., from observations and analyses) or idealized conditions. WRF offers operational forecasting a flexible and computationally efficient platform, while reflecting recent advances in physics, numerics, and data assimilation contributed by developers from the expansive research community (National Center for Atmospheric Research [NCAR], 2021).

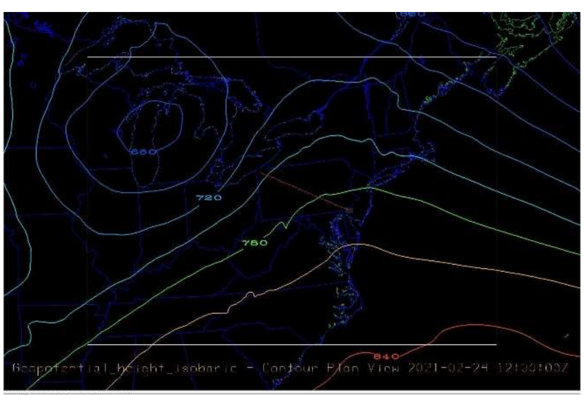

Figure : Plan View showing the Geopotential Heights along the 925 hPa isobaric surface for 12 UTC, 24 Feb 2021. Higher to lower values of Geopotential height run from lower right to upper left. The transect indicating the location of the cross-section is represented by the line diagonally crossing Pennsylvania.

As part of the analysis for MU-PAST the WRF model will be initialized with output from the Global Forecasting System (GFS) model, a large-scale model, upper-air profiles obtained at the fixed and mobile radiosonde sites, and the National Weather Service (NWS) 00 UTC and 12 UTC upper-data profiles assimilated into the WRF initialization field. The GFS and NWS are public domain resources. The fixed and mobile radiosonde sites where Millersville Meteorology students launching weather balloons, two small, mobile units and a large, fixed unit. These units were designed for different distances and are outlined in "Observations of Cold Fronts over the

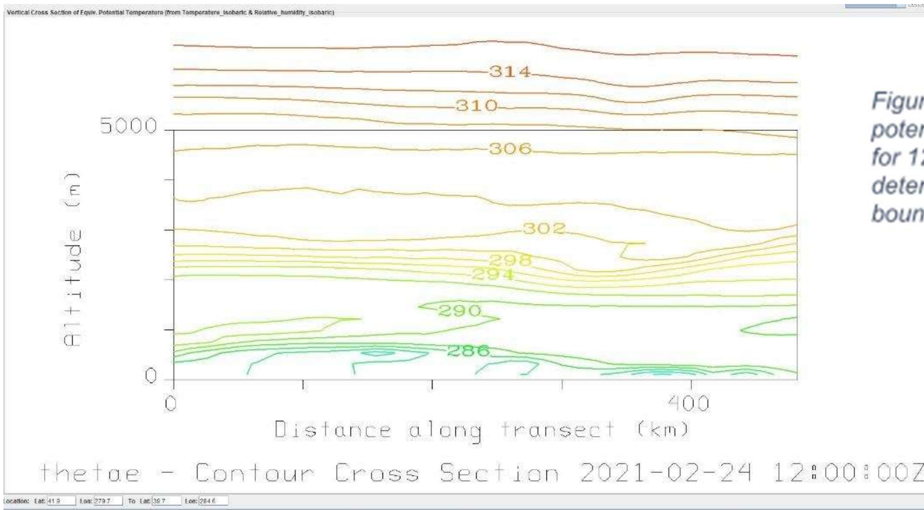

Figure : Cross-section of equivalent potential temperature from 0-5000 m AGL for 12 UTC 24 FEB 2021 can be used to determine the location of the frontal boundary.

Appalachian Piedmont during MU-PAST" (Gant et. al., 2021). The model can then be used to supplement the profile observations in between the launch times and diagnose the atmospheric variables and features pertinent to each case study. Examples of model-generated field variables are shown in the figures below. The model output also allows for detail cross-sections of variables that help in the determination of the propagation of the frontal boundary (Fig. 2). In meteorology, geopotential heights are used to determine the movement of fronts and large-scale pressure systems. Then, equivalent potential temperature, an important variable for determining the progression of a frontal boundary and the propagation of the air masses, and wind direction are excellent for the identification of frontal passage (Fig. 3). With both geopotential height and potential temperature, fronts are easier to distinguish on the larger scale models (GFS) and will be able to be located on the WRF model with the same techniques, but with more precision in timing. Timing remains to be an issue with most modern models, becoming more accurate as the models are developed. Additionally, the modelling that occurred is reminiscent of Lamraoui et. al.'s work on studying the accuracy of the WRF modelling of extratropical cold fronts (2018 & 2019). The modelling will be compared to other runs of the WRF model not originating from the case study.

Results and Conclusion

Results and conclusion await the time when we can again access the servers on which the WRF model resides. The WRF is run on a new computer cluster funded through a National Science Foundation Major Research Infrastructure grant to improve numerical modeling capabilities at Millersville.

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