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Partners or Cooperative Project:

Partners

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Variability of the Influence of Convection on Conveyor Belts: Development of Conceptual Models and Forecast Methodologies

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SECTION 1: Summary of Project Objectives

The use of potential vorticity (PV) as a diagnostic to evaluate undulation and folding of the tropopause has long been established in both the research and operational communities. More recently, the impacts of diabatically generated low- to mid-tropospheric PV on the flow field have been analyzed (e.g., Lackmann 2002, Brennan and Lackmann 2005, Baxter 2006).

The primary objectives of this research were:

A. to investigate and analyze the relevant physical processes and conveyor belt structures in three cases that feature east-to-west oriented convection and snowfall to the north in comparison to cases that feature north-to-south oriented convection to the south and snowfall to the north

B. to transfer the new knowledge gained through (A) to the current framework of operational forecasting

C. to provide a Central Michigan University undergraduate student with research experience, direct interaction with NWS personnel, and experience at preparing and presenting research results

SECTION 2: Project Accomplishments and Findings

Three cases were investigated that meet the criteria specified in (A) above: January 4-5, 2005; February 4-5, 2004; and February, 14-15, 2003. The WRF-ARW model was set up and run for the first time at Central Michigan University on the University PI's 40 processor cluster. North American Regional Reanalysis (NARR) data was used for initial and lateral boundary conditions. The accuracy of the simulations was evaluated through comparison with the NARR data, which was used as a proxy for the observed data. The University PI provided a set of programs that facilitate the easy plotting of COOP precipitation reports within GEMPAK that allowed us to determine that the NARR precipitation was acceptable to use in place of observed precipitation.

To insure our analysis of these cases was operationally relevant, we began to consider the WRF simulation to be analogous to a real-time forecast of the event. The NARR data was considered to be analogous to a real-time forecast of the event from another mesoscale model. The goal was to determine the differing impacts convection had on the evolution of the flow field and precipitation distribution in each dataset. The February 4-5, 2004 case was simulated very well, and therefore was not investigated further. There was significant divergence between the WRF simulation for the January 4-5, 2005 case, and even greater divergence for the February 14-15, 2003 case.

Next, a PV budget was computed, allowing us to determine that indeed, the low- to mid-tropospheric PV was diabatically generated in-situ by the convection, and not advected from elsewhere. Perhaps the largest challenge faced in completing this project was the use of piecewise PV inversion. Conducting a piecewise PV inversion involves the use of a rather complicated application of successive overrelaxation on a two equation set (as documented in Davis and Emanuel (1991)). Thus, rather than write our own code, we use the code written by Chris Davis of NCAR-MMM. This code only works with data in the unique format output by the MM5 model. The university PI successfully created FORTRAN code that interfaces with Chris Davis' code, but can now read in data output by any model, as long as it has been converted to GEMPAK format. As all NWS offices have free access to GEMPAK, the development of this code makes it possible for NWS offices to now conduct their own piecewise PV inversions.

In order to quantitatively specify PV anomalies, a mean state must be defined. Our use of the monthly average PV from the 30 year NARR climatology proved adequate in removing the planetary-scale waves to define the synoptic-scale PV anomalies. The results of the piecewise PV inversions allowed us to quantify the impacts of the diabatically generated PV anomalies on the flow field. In both cases, convection incorrectly simulated by the WRF model and it's associated PV led to the formation of a positive feedback between the convection and the cyclonic circulation associated with the PV. This positive feedback set up halfway through both of the 48 hour model runs. In the February 14-15, 2003 case, this positive feedback led to further divergence from reality for the remainder of the model run. In contrast, the positive feedback was short-lived in the January 4-5, 2005 case, likely because the upper dynamics associated with a strong tropopause undulation overwhelmed the mid-level diabatic effects when the longwave trough began to lift northeastward. In both cases, the low- to mid- level PV anomalies were shown to impact both the moisture advection and deformation fields, altering the distribution of precipitation to the north of the convection. Also in both cases, the influence of the tropopause level PV anomalies did not play a significant role in moisture transport or deformation in the low- to mid- levels, indicating that the interior PV anomalies alone altered the distribution of precipitation north of the convection. It was also noted that in these cases the orientation of the east-west configured interior PV anomaly impacts the N-S position of the snowfall. The more east-west oriented the interior anomaly, the stronger the gradient of snowfall to the north will be.

Our work demonstrates that piecewise PV inversion could provide otherwise inaccessible information to forecasters in situations that involve convection and snowfall further north. With education and training on this technique, forecasters can interpret the results of piecewise PV inversion and assimilate them into the forecast process. The PIs are very close to establishing a system that would make piecewise PV inversion possible using output from a locally run model. The code used is scientifically correct, and scripts have been written to automate the process of making sure the necessary grids are present in the GEMPAK file, running the inversion, saving the output grids, and plotting the data. In some instances the inversion code fails to achieve numerical convergence, which is desirable for confidence in the results. Future work is needed to further examine what aspects of the model input data are causing these failures. Preliminary investigation suggests that the use of a 36 km grid may be too high of a resolution for the use of piecewise PV inversion in an operational setting. Coarser grid spacing may allow numerical convergence to occur more reliably, and would reduce the length of time needed for the code to run.

An idea proposed in the grant was to investigate the application of approaches designed by the verification community that can identify unique areas of precipitation. These approaches have the potential to be used to automatically define areas of PV to be inverted. Upon further investigation, these approaches are only designed for use with two-dimensional fields. The three-dimensional nature of PV anomalies prevents the use of such approaches at this time. However, the verification community continues to work on extending this approach to three-dimensions, and the use of such an approach with PV inversion remains viable in the future.

SECTION 3: Benefits and Lessons Learned: Operational Partner Perspective

The goal of the study was to expand on the conceptual models presented by Brennan and Lackmann (2005) and Baxter (2006) on the impacts of convection on conveyer belts. This study added to this conceptual model by analyzing the impacts of convection oriented in a west to east orientation along a warm front, and determining how under (over) forecasts of convection along warm fronts can impact snowfall further north.

Using the knowledge gained from this study on the influence of convection on precipitation further north, forecasters will have a means to understand model differences in placement and amounts of precipitation. This new understanding will provide forecasters with an additional tool in helping to decide which of the models may be incorrect. Some of these tools include the ability to use wind and height perturbations recovered from piecewise PV inversion in an operational setting and a means to view potential forecast errors in frontal position and upper level discrepancies.

The forecaster PIs have taken an interest in setting up local area models as a result of this project, as this would be the best way for potential vorticity budgets and potential vorticity inversions to be conducted. The University PI has provided the forecaster PIs with GEMPAK scripts they can use in the analysis of future cases.

SECTION 4: Benefits and Lessons Learned: University Partner Perspective

Through collaboration with the forecaster PIs, the University PI has garnered a greater appreciation for the difficulty inherent in forecasting, as well as the time constraints involved. This has improved the University PI's ability to conceptualize the transfer of research into operations. In addition, the University PI now better understands the challenges to implementation of new forecasting techniques facing the NWS as a result of the necessity of preparing a unified QPF grid over many different office's areas of responsibility. Transfer of research into operations within the existing structure of the NWS must be implemented in combination with training for all offices expected to benefit from a new approach or technique. Failure to do so may result in increased difficulties in creating a gridded product.

The CMU undergraduate student was able to observe forecaster duties during a severe weather event, and gain a greater knowledge of procedures within the National Weather Service. The student has also acquired new skills that will benefit him in his job search. These include learning how to set up and run the WRF model, decoding WRF model data into GEMPAK format, and downloading and displaying Level-III radar data in GEMPAK. Lastly, the University PI has incorporated elements of the lectures presented to NWS forecasters and the results of these cases in lecture and lab exercises for his Synoptic Meteorology II course.

SECTION 5: Publications and Presentations

5.1 Three seminars were given by the University PI at the NWS PI's forecast offices over August 19th-23rd, 2007:

Introduction to and Applications of the Potential Vorticity Framework, National Weather Service Forecast Office, Omaha, Nebraska.

Critical Processes Attending Heavy Banded Snowfall with Illustrations from Case Study Events, National Weather Service Forecast Office, Omaha, Nebraska.

Applications of the Potential Vorticity Framework, National Weather Service Forecast Office, Sioux Falls, South Dakota

5.2 Three posters and one presentation at the National Weather Association Annual Meeting, October 13-18, 2007

The Role of Lower Mississippi Valley Elevated Convection in Snowfall Further North: 4-5 February 2005, David Anderson and Martin Baxter, Central Michigan University, Mt. Pleasant, MI, Philip Schumacher, NOAA/NWS, Sioux Falls, SD., and Joshua Boustead, NOAA/NWS, Omaha/Valley, NE.

The Influence of Elevated Convection on the Warm Moist Conveyer Belt during the 3-5 January 2005 Central Plains Winter Storm, Joshua Boustead, NOAA/NWS, Omaha/Valley, NE., Martin Baxter, Dave Anderson, Central Michigan University, Mt. Pleasant, MI., and Philip Schumacher, NOAA/NWS, Sioux Falls, SD.

A Case Study Examination of the Effect of Convection on Winter Precipitation, Philip Schumacher, NOAA/NWS, Sioux Falls, SD., Joshua Boustead, NOAA/NWS, Omaha/Valley, NE., and Martin Baxter, Central Michigan University, Mt. Pleasant, MI.

Variability of the Influence of Convection on Conveyor Belts: Development of Conceptual Models and Forecast Methodologies, Martin Baxter and David Anderson, Central Michigan University, Mt. Pleasant, MI., Phil Schumacher, NOAA/NWS, Sioux Falls, SD., and Joshua Boustead, NOAA/NWS, Omaha/Valley, NE.

5.3 Phil Schumacher included elements of the work in an invited talk entitled, **"Where are Forecasts Headed?"** at the Northern Plains Winter Storm Conference at St. Cloud State University, 24 October 2007

5.4 Josh Boustead described the approach used and the January 2005 case during two 8 hour winter weather training sessions at the Omaha, NE office in October 2007

5.5 Phil Schumacher gave a presentation describing the approach used and the February 2003 case as a webcast for NWS Central Region SOOs at five offices in December of 2007

5.6 Martin Baxter gave a presentation entitled, **"The Use of Potential Vorticity Diagnostics to Evaluate Differences Between Two Datasets: February 14-15 2003"** at the Northwest Indiana NWA Great Lakes Meteorology Conference, 5 April 2008

5.7 The February 2003 case was used by Phil Schumacher and Michael Brennan (SOO at HPC) as part of a lab at the 2008 COMET COMAP course in April 2008

5.8 Josh Boustead has submitted an abstract entitled, **"Variability of the Influence of Convection on Conveyor Belts: Development of Conceptual Models and Forecast Methodologies"**, to the AMS/NWA High Plains Conference, which will take place 4-5 September 2008

The authors have begun work on a publication. We anticipate submitting the publication in December of 2008. The paper will be submitted to Weather and Forecasting, and is currently titled: *The Use of Potential Vorticity Inversion to Evaluate Upscale Impacts of Convection.* The authors have completed an outline of the sections and figures to be included in the paper. This outline is attached as Appendix A.

In addition, Phil Schumacher will be presenting the final results of our cases as part of NWS-Sioux Falls winter weather training in October 2008. The PIs are also interested in presenting the work at the AMS Weather and Forecasting / Numerical Weather Prediction conference to take place in Omaha, NE in July 2008.

SECTION 6: Summary of University/Operational Partner Interactions and Roles

Despite the geographical distance between the three PIs, the funding from the project provided us with the means to meet face-to-face three separate times. These meetings proved invaluable in making progress on this work, and the tasks accomplished at the meetings are detailed below.

6.1 Joint

- Case selection (largely based on NWS PI personal experience)
- Development of GEMPAK scripts for data analysis and plotting
- **Meeting #1 (All PIs present)**
    - August 19th-20th, 2007: Omaha, NE
    - August 21st-23rd, 2007: Sioux Falls, SD
    - Evaluation of the WRF simulations vs the NARR data, training talks by the University PI, NWA presentation preparation
- **Meeting #2 (Martin Baxter and Phil Schumacher)**
    - March 2nd-7th, 2008: Mt. Pleasant, MI

        - Full evaluation of all relevant diagnostic quantities and PV inversion results at all times/levels, for both cases
    - **Meeting #3 (All PIs present)**
        - August 11^{th}-14^{th}, 2008: Omaha, NE
        - Final investigation of cases, final report composed, outline for paper to be submitted completed

6.2 University

- Setup of WRF model, running of WRF model, post-processing of data into GEMPAK format
- Development of code to conduct piecewise PV inversion using model data in GEMPAK format and running of the inversion code for all cases
- Dissemination of code and model results to NWS PIs via web pages and DVD
- Focal point for February 4-5, 2004 case
- Mentor for CMU undergraduate student

6.3 NWS Offices

- Phil Schumacher – Focal point for February 14-15, 2003 case
- Josh Boustead – Focal point for January 4-5, 2005 case
- Both PIs gave presentations to other NWS forecasters and SOOs to promote the utility of PV diagnostics using our work as an example
- Development of new AWIPS procedures that involve the "PV Thinking" approach

APPENDIX A: Outline for Paper to be Submitted to Weather and Forecasting

Tentative Title: The Use of Potential Vorticity Inversion to Evaluate Upscale Impacts of Convection

General Outline:

- Intro and Literature Review
    - Data and Methodology
    - Mesoscale Model
    - PV Budget
    - Piecewise PV Inversion
- Feb 2003 Case
- Jan 2005 Case
- Discussion
- Conclusions

<u>Feb 2003 Case Outline</u>

- Synoptic Scale Overview

- Standard 4 panel plot from the NARR only (12 Z 14th & 00 Z 15th)
- Snowfall / precip map for event total – COOP, WRF, and NARR

- Mesoscale Overview
  - Two 6 hr precip totals (NARR & WRF) spanning 12-18 Z 14th and 18-00 Z 15th
  - FGEN (700 mb) / EPV (700-600 mb) 4 panel at 18Z and 00Z (NARR & WRF)
  - Radar at 6 Z (Pseudo and Real)

- PV diagnostics
  - PV at 12 Z and 18 Z (NARR & WRF) at 700 mb only
  - PV 12 Z cross section (NARR & WRF)
  - PV 12 Z non-advective tendency cross section (must make this for same line as above)
  - Inverted wind field at 700 mb for 12Z and 18 Z (NARR & WRF) – must include surface fields in the inversion
  - Inverted wind field at 700 mb for 12Z and 18 Z (NARR & WRF) – inversion of upper level cyclonic PV only
  - Balanced deformation 2 panel at 700 mb from the low-level (including surface) at 12Z (NARR & WRF)
  - Balanced deformation 2 panel at 700 mb from the low-level (including surface) at 18 Z (NARR & WRF)

<u>Jan 2005 Case Outline</u>

- Synoptic Scale Overview
  - Standard 4 panel plot from the NARR only (3-9 Z 5th & 9-15 Z 5th)

- Mesoscale Overview
  - Radar at 6 Z & 12 Z (Pseudo and Real)
  - Two 6 hr precip totals (NARR & WRF) spanning 12-18 Z 14th and 18-00 Z 15th
  - FGEN (700 mb) / EPV (700-600 mb) 4 panel at 6Z and 12Z (NARR & WRF)

- PV diagnostics
  - PV at 6 Z and 12 Z (NARR & WRF) at 700 mb and tropopause map
  - PV 9 z cross section (NARR & WRF)
  - PV 9 Z non-advective tendency cross section (must make this for same line as above)
  - Inverted wind field at 700 mb for 12 Z (NARR & WRF) – must include surface fields in the inversion
  - Inverted wind field at 700 mb for 12 Z (NARR & WRF) – inversion of upper level cyclonic PV only

- Deformation 2 panel at 700 mb from the low-level (including surface) at 12 Z only (NARR & WRF)

<u>Discussion Section</u>

- What happened later?
  - 4 panel at 00Z 15th – PV field, FGEN, Balanced moisture transport, balanced deformation (NARR & WRF)

- What happened later?
  - 4 panel at 00Z 6th – PV field, FGEN, balanced deformation (NARR & WRF)

APPENDIX B: References

Baxter, M. A., 2006: *The role of warm sector convection in the development of mesoscale banded snowfall*. Ph.D. dissertation, Saint Louis University, 241 pp.

Brennan, M. J., 2005: The influence of incipient latent heat release on the precipitation distribution of the 24-25 January 2000 U.S. East Coast cyclone. *Mon. Wea. Rev.*, **133**, 1913-1937.

Davis, C. A. and K. A. Emanuel, 1991: Potential vorticity diagnostics of cyclogenesis. *Mon. Wea. Rev.*, **119**, 1929-1953.

Lackmann, G. L., 2002: Cold-frontal potential vorticity maxima, the low-level jet, and moisture transport in extratropical cyclones. *Mon. Wea. Rev.*, **130**, 59-74.