Examining the Impact of Microphysics Parameters in Simulations of a January 2019 Vermont Winter Storm

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Using the Weather Research and Forecasting (WRF) model, we conduct simulations of a major winter storm that produced up to 50 centimeters of snow to parts of Vermont on 20-21 January 2019. In WRF simulations, different microphysics schemes yield different model outputs. We employ a sensitivity test using the Thompson (THOM), Morrison 2-moment (M2M), WRF Double Moment 6-class (WDM6), Goddard (GODD), and Milbrandt–Yau Double Moment (MILL) schemes to analyze snowfall during the Vermont storm at a near sea level location in Middlebury, VT and at a mountain location in Rochester, VT. We analyze radar reflectivities produced by WRF, mixing ratios of the hydrometeor species, and accumulated snowfall totals. We find that the THOM and GODD microphysics parameterization predicts snowfall totals that fall most in line with observed snowfall from the storm, while WDM6 and M2M schemes slightly overpredict snowfall, and the MILL simulation grossly underpredicts snowfall.

Date Accepted: ________________________

I Introduction

In this section I will provide an overview of my report.

I.1 The snowstorm context

In this first section of my introduction, I will explain the Vermont snowstorm that struck from Jan 20-21 in 2019. I will discuss the timing of the storm, the unusually high snow density given the extremely cold temperatures, storm impacts, and my personal memory (skiing). I will also provide some details on the numbers of the storm. Which places saw greatest snowfall totals, etc? (Possibly an NWS observed snow total figure could be useful here).

I.2 Cloud microphysics

This next section of my introduction will discuss cloud microphysics and how it gets modeled. I will discuss cloud condensation nuclei and the coalescence of particles in the atmosphere to form cloud droplets, which ultimately form rain and snow. (I envision a figure here to show the development

I will then cover the modeling of microphysics. I will discuss the differences between bin and bulk microphysics modeling, and I will discuss what different moments mean. Helpful equations in this section will show particle size distributions and other aspects. I will also discuss how different microphysics schemes predict different aspects of the hydrometeor species.

I will discuss the specific microphysics schemes that I use in my simulations, and I will talk about the intricacies of each one. (A table could be helpful here.

II Data and Methods

I will provide a main overview of WRF, my main research tool here.

In this section, I will disucss all the methods that I use, and the data I intend to find. I will explain how I use WRF with 5 different microphysics schemes for the Jan 2019 snowstorm. And I will discuss the data that I seek to find. (That includes mixing ratios for different parts of the hydrometeor species, temperature data, and reflectivity data, and accumulated snowfall).

III Results

This section will be my longest section, and it will contain information about each of the simulations that I run. Rather than separating my presentation of the results by simulation, I plan to discuss different pieces of my analysis in each section.

III.1 Accumulated snowfall

Statistical data as well as my plots of accumulation and maps for each mp scheme will be helpful here.

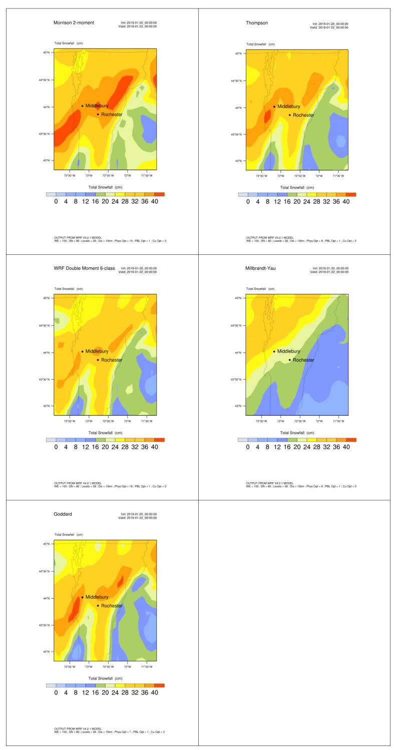

Fig. 1. A figure like this will absolutely go in the subsection for accumulated snowfall.

III.2 Simulated radar reflectively

Here my plot will be good. It will be neat to see if I can get real radar data to compare to. I can probably show radar plots for a few times during the storm.

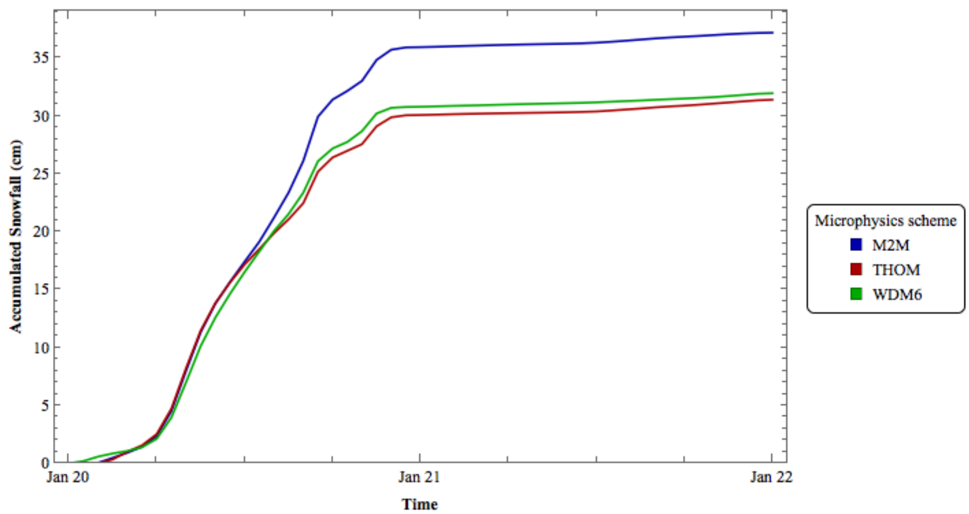

Fig. 2. Another figure in the subsection for accumulated snowfall.

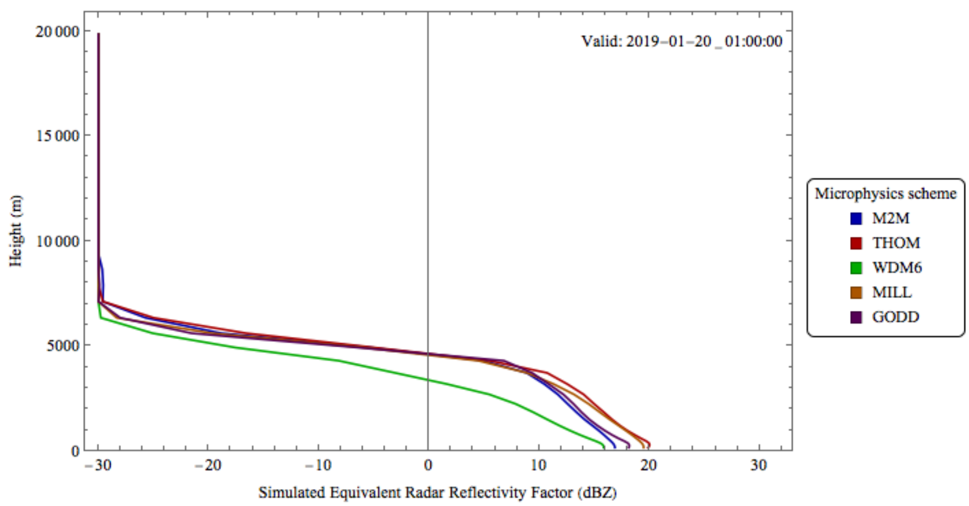

Fig. 3. Some figures like this will go in the radar reflectivity section, and it would be cool if I could find real data as well.

III.3 mixing ratios

Here I will display both my mixing ratio plots and my vertical snow cross sections, as well as some statistical data.

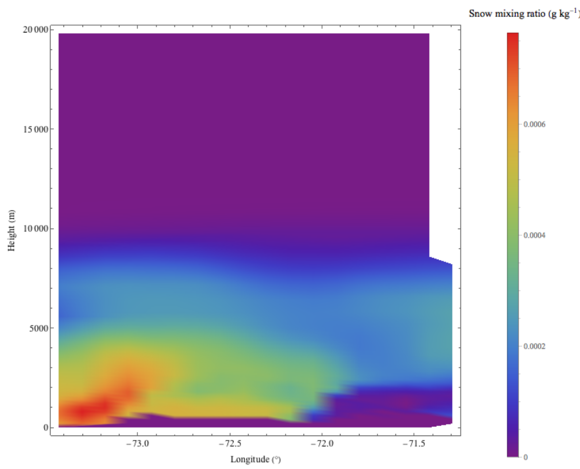

Fig. 4. this figure will go in the mixing ratio section and I can demonstrate different times.

IV Discussion

In this section, I will discuss the results of each simulation of the storm and the characteristics of each microphysics scheme that best predict snowfall for this case study. (I need to do more reading on each microphysics scheme to be able to effectively execute this section).

V Conclusion

Here, I will sumarize my simulations and results, and I can discuss future directions for the project. I can also discuss the characteristics of microphysics best utilized in WRF - though I have to assert that this was only one case study.

PHYS 0704 - Annotated Bibliography

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October 29, 2020

References

[1] S. Y. Bae, S.-Y. Hong, and W.-K. Tao, "Development of a Single-Moment Cloud Microphysics Scheme with Prognostic Hail for the Weather Research and Forecasting (WRF) Model," *Asia-Pacific Journal of Atmospheric Sciences*, vol. 55, no. 2, pp. 233–245, May 2019.

This paper gives an overview of the very new WSM7 microphysics scheme, which I don't intend to use in my simulations, but it is something that I can consider looking at.

[2] J.-W. Bao, S. A. Michelson, and E. D. Grell, "Microphysical Process Comparison of Three Microphysics Parameterization Schemes in the WRF Model for an Idealized Squall-Line Case Study," *Monthly Weather Review*, vol. 147, no. 9, pp. 3093–3120, Sept. 2019, publisher: American Meteorological Society.

Although it tests microphysics for an idealized WRF run and for one parametrization that I did not use, I think this paper has some great analysis that I can model some of my work off of.

[3] V. S. Galligani, D. Wang, M. Alvarez Imaz, P. Salio, and C. Prigent, "Analysis and evaluation of WRF microphysical schemes for deep moist convection over south-eastern South America (SESA) using microwave satellite observations and radiative transfer simulations," *Atmospheric Measurement Techniques*, vol. 10, no. 10, pp. 3627–3649, Oct. 2017.

This is another paper that can serve as a good example for the types of analysis and writing that I am trying to do.

[4] I. Jankov, L. D. Grasso, M. Sengupta, P. J. Neiman, D. Zupanski, M. Zupanski, D. Lindsey, D. W. Hillger, D. L. Birkenheuer, R. Brummer, and H. Yuan, "An Evaluation of Five ARW-WRF Microphysics Schemes Using Synthetic GOES Imagery for an Atmospheric River Event Affecting the California Coast," *Journal of Hydrometeorology*, vol. 12, no. 4, pp. 618–633, Aug. 2011, publisher: American Meteorological Society.

Similar to the McMillen and Steenburgh reference, this one provides a sample of a similar analysis to what I hope to conduct. This one uses the WSM6, Thompson, Schultz, Morrison 2 moment, and Lin schemes, and it is particularly interesting because it compares results to satellite data for atmospheric rivers. I plan to only compare my data to observed snowfall totals, but this is an interesting approach.

[5] K.-S. S. Lim and S.-Y. Hong, "Development of an Effective Double-Moment Cloud Microphysics Scheme with Prognostic Cloud Condensation Nuclei (CCN) for Weather and Climate Models," *Monthly Weather Review*, vol. 138, no. 5, pp. 1587–1612, May 2010, publisher: American Meteorological Society.

This reference gives a good overview of the WDM6 microphysics scheme. I have not yet read it, but it will give me a good sense of the changes in the physics that I will be making when I use this scheme.

[6] J. D. McMillen and W. J. Steenburgh, "Impact of Microphysics Parameterizations on Simulations of the 27 October 2010 Great Salt Lake–Effect Snowstorm," *Weather and Forecasting*, vol. 30, no. 1, pp. 136–152, Feb. 2015, publisher: American Meteorological Society.

This reference serves as a good example for the type of analysis that I hope to conduct in my research. Essentially, McMillen and Steenburgh conduct a similar microphysics analysis of a lake effect storm in Utah using 4 different microphysics schemes. This set a god example for my report, and it gives me a good idea of the microphysics schemes that I should choose and the controls that I can use.

[7] J. A. Milbrandt and M. K. Yau, "A Multimoment Bulk Microphysics Parameterization. Part II: A Proposed Three-Moment Closure and Scheme Description," *Journal of the Atmospheric Sciences*, vol. 62, no. 9, pp. 3065–3081, Sept. 2005, publisher: American Meteorological Society.

This paper gives me a good overview of the Millbrandt-Yau microphysics scheme.

[8] H. Morrison, G. Thompson, and V. Tatarskii, "Impact of Cloud Microphysics on the Development of Trailing Stratiform Precipitation in a Simulated Squall Line: Comparison of One- and Two-Moment Schemes," *Monthly Weather Review*, vol. 137, no. 3, pp. 991–1007, Mar. 2009, publisher: American Meteorological Society.

This reference was the introduction of the Morrison microphysics scheme for WRF. It gives me a good idea of the differences between double moment and single moment MP schemes. In this reference, I learned that 2 moment schemes predict mixing ratios of the hydrometeor species in addition to number concentration.

[9] J. J. Shi, W.-K. Tao, T. Matsui, R. Cifelli, A. Hou, S. Lang, A. Tokay, N.-Y. Wang, C. Peters-Lidard, G. Skofronick-Jackson, S. Rutledge, and W. Petersen, "WRF Simulations of the 20–22 January 2007 Snow Events over Eastern Canada: Comparison with In Situ and Satellite Observations," *Journal of Applied Meteorology and Climatology*, vol. 49, no. 11, pp. 2246–2266, Nov. 2010, publisher: American Meteorological Society.

This paper is another great example that is similar to the type of research that I'm doing.

[10] C. Skamarock, B. Klemp, J. Dudhia, O. Gill, Z. Liu, J. Berner, W. Wang, G. Powers, G. Duda, D. Barker, and X.-y. Huang, "A Description of the Advanced Research WRF Model Version 4," 2019.

This reference, highly cited in any of the papers that I have read that use WRF, provides an overview of the model. It tells me the equations that serve as the basis for WRF, gives some insight into the physics of the model, and talks about setting domains, among other topics.

[11] W.-K. Tao, D. Anderson, J. Chern, J. Entin, A. Hou, P. Houser, R. Kakar, S. Lang, W. Lau, C. Peters-Lidard, X. Li, T. Matsui, M. Rienecker, M. R. Schoeberl, B.-W. Shen, J. J. Shi, and X. Zeng, "The Goddard multi-scale modeling system with unified physics," *Annales Geophysicae*, vol. 27, no. 8, pp. 3055–3064, Aug. 2009.

This paper explains the Goddard microphysics scheme, and it will be very helpful when I analyze why certain microphysics yield certain snowfall outputs.

[12] W.-K. Tao, D. Wu, S. Lang, J.-D. Chern, C. Peters-Lidard, A. Fridlind, and T. Matsui, "High-resolution NU-WRF simulations of a deep convective-precipitation system during MC3E: Further improvements and comparisons between Goddard microphysics schemes and observations," *Journal of Geophysical Research: Atmospheres*, vol. 121, no. 3, pp. 1278–1305, 2016.

This paper gives an overview of the Goddard microphysics scheme, which I may decide to use for some simulations, though I'm not certain.

[13] G. Thompson, P. R. Field, R. M. Rasmussen, and W. D. Hall, "Explicit Forecasts of Winter Precipitation Using an Improved Bulk Microphysics Scheme. Part II: Implementation of a New Snow Parameterization," *Monthly Weather Review*, vol. 136, no. 12, pp. 5095–5115, Dec. 2008, publisher: American Meteorological Society.

This reference is the introduction of the Thompson microphysics scheme in WRF. In reading this paper, I learned that in the Thompson scheme better predicts the shape of snow because it does not assume that snow is spherical. While spherical snow can be assumed for certain densities, at higher snow densities, the shape must be changed.

[14] N. US Department of Commerce, “The January 20-21, 2019 Winter Storm,” publisher: NOAA’s National Weather Service. [Online]. Available: https://www.weather.gov/btv/The-January-20-21-2019-Winter-Storm

This National Weather Service (NWS) report on the January 2019 snowstorm that I’ll be analyzing provides a fantastic overview of the storm. It gives a good idea of the synoptic and mesoscale environments, the impacts of the storm, and some basic data. It gives me a good idea of what actually happened in January 2019.