Sensitivity analysis of the WRF-HAILCAST model to estimate hail size

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Background

The simulated dynamical evolution of hailstorms remains a challenge due to a number of factors such as physical parameterization and initial and boundary conditions. The research questions that we are addressing are *(1) Does the selection of a microphysics scheme have an impact on the production of hail?, (2) Which combination will produce the largest hail size/amount/area extent? and (3) How do the vertical profiles of the temperature, vertical motion and hydrometeor variables vary with microphysics schemes?* To address these questions, a mesoscale convective event that produced a significant hail over Minnesota on 11 June 2017, is examined.

Methodology

The Weather Research Forecast (WRF) version 4.1 coupled with HAILCAST (**Figure 1**) which is a one-dimensional model is used in this study to estimate hail size forecast at fine spatial scale. The aim of this work is to test different microphysics parameterization (MP) to estimate hail size using WRF-HAILCAST. The MP tested were *Kessler, Thompson, WSM 6-class, WSM 7-class and Goddard*. Each combination was tested using the stochastic kinetic energy backscatter (SKEB) and Stochastic perturbed parametrization tendency (SPPT) schemes to skillfully predict the potential for hail. The experiments were conducted on the parent domain of 9-km resolution with 630 x 432 points with an inner domain centered over Minnesota of 3-km resolution with 475 x 475 points (**Figure 2**). The domains have 33 vertical levels and were run for 48 h, initialized at 1800 UTC 10 June 2017.

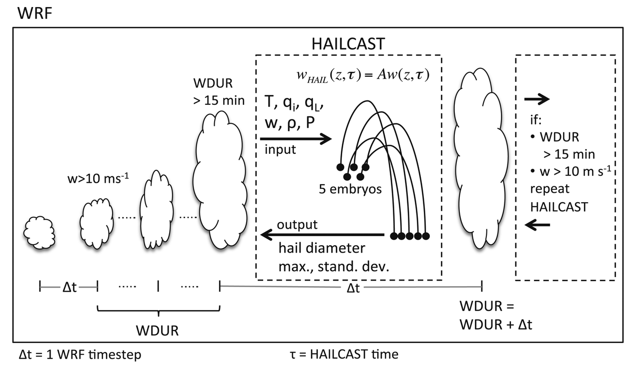


Figure 1. Conceptual model of WRF-HAILCAST processing. (Adams, 2016).

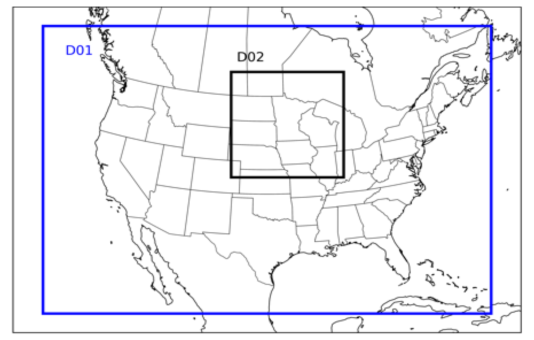


Figure 2. Parent and inner domain of 9 km and 3 km respectively for the event that occurred over Minnesota.

Results

Experiment 1: Maximum Hail Forecast

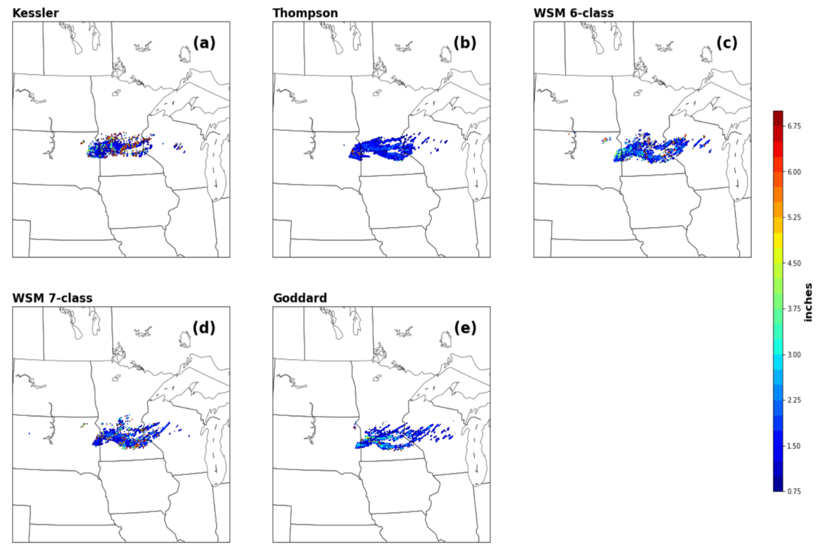


Figure 3 WRF-HAILCAST forecast maximum hail size (in) at each grid point displayed from 1100 UTC to 1500 UTC 11 June 2017: (a) Kessler, (b) Thompson, (c) WSM 6-class, (d) WSM 7-class, and (e) Goddard.

Experiment 1: WRF reflectivity dBZ

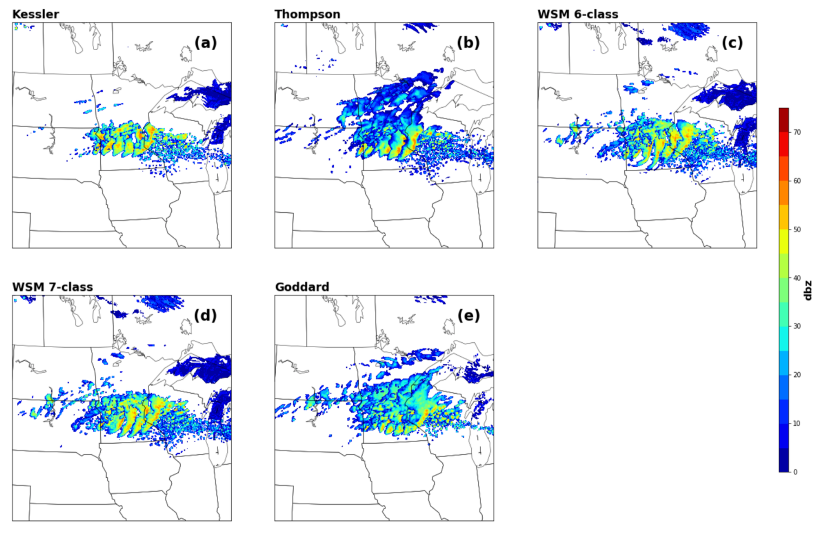


Figure 4 WRF reflectivity dBZ at lower level at each grid point displayed from 1100 UTC to 1500 UTC 11 June 2017: (a) Kessler, (b) Thompson, (c) WSM 6-class, (d) WSM 7-class, and (e) Goddard.

Number of grid points

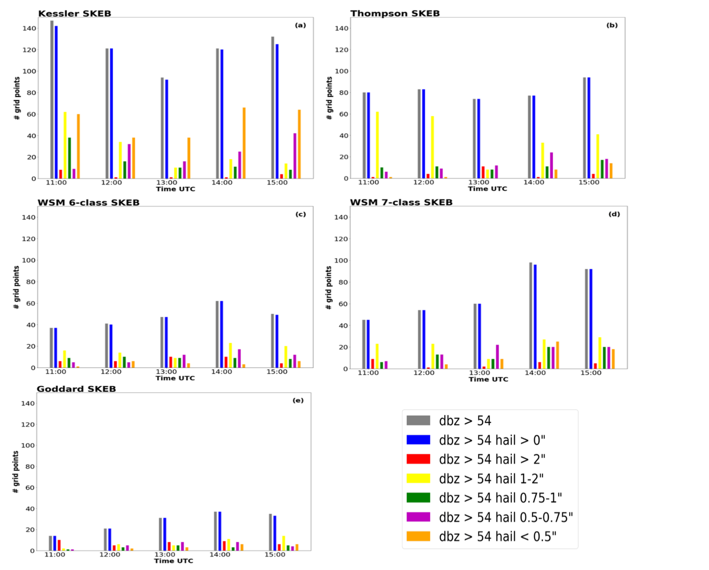
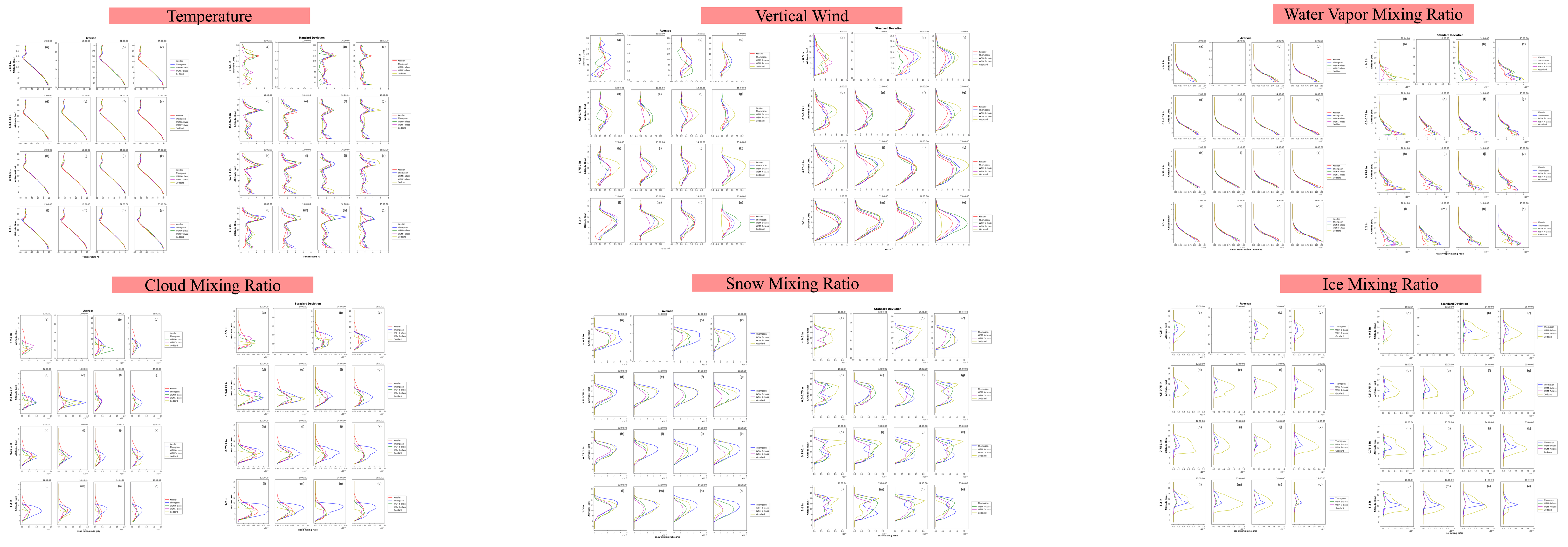


Figure 5 Number of grid points that contains certain hail sizes for each Microphysics scheme tested: from 1100 UTC to 1500 UTC 11 June 2017: (a) Kessler, (b) Thompson, (c) WSM 6-class, (d) WSM 7-class, and (e) Goddard.

Vertical Profiles



Thompson Scheme

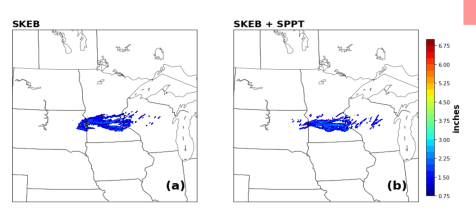


Figure 6 Maximum diameter at each grid point displayed from 1100 UTC to 1500 UTC 11 June 20

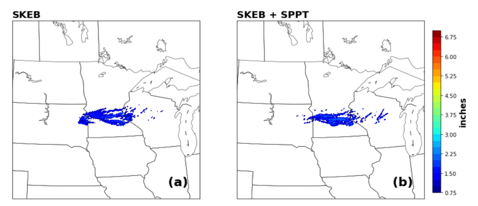


Figure 7 Mean diameter at each grid point displayed from 1100 UTC to 1500 UTC 11 June 20

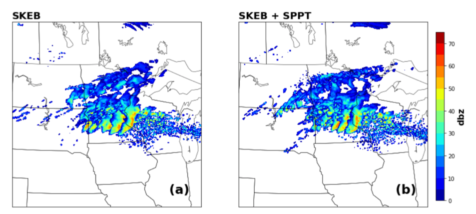


Figure 8 WRF reflectivity dBZ at lower level for each grid point displayed from 1100 UTC to 1500 UTC 11 June 20

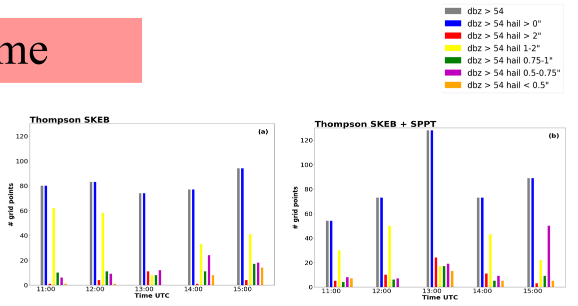


Figure 9 Number of grid points that contains certain hail sizes using the WRF-HAILCAST maximum diameter from 1100 UTC to 1500 UTC 11 June 2017

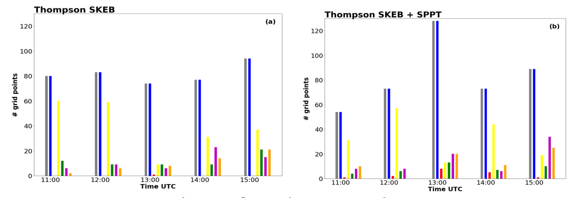


Figure 10 Number of grid points that contains certain hail sizes using the WRF-HAILCAST mean diameter from 1100 UTC to 1500 UTC 11 June 2017

Goddard Scheme

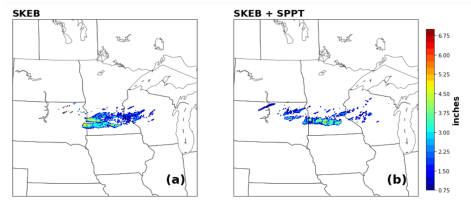


Figure 11 Maximum diameter at each grid point displayed from 1100 UTC to 1500 UTC 11 June 20

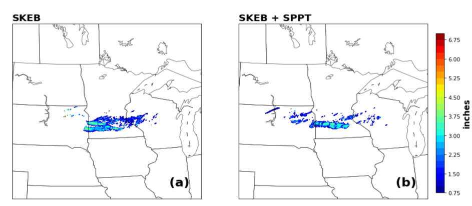


Figure 12 Mean diameter at each grid point displayed from 1100 UTC to 1500 UTC 11 June 20

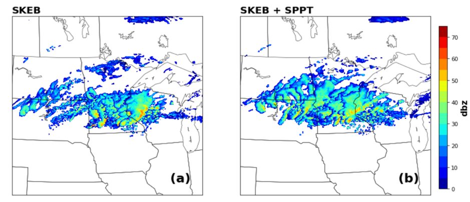


Figure 13 WRF reflectivity dBZ at lower level for each grid point displayed from 1100 UTC to 1500 UTC 11 June 20

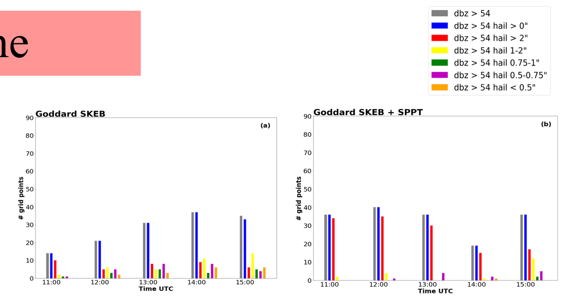


Figure 14 Number of grid points that contains certain hail sizes using the WRF-HAILCAST maximum diameter from 1100 UTC to 1500 UTC 11 June 2017

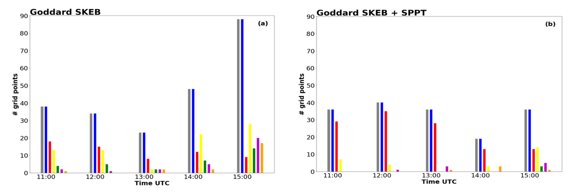


Figure 15 Number of grid points that contains certain hail sizes using the WRF-HAILCAST mean diameter from 1100 UTC to 1500 UTC 11 June 2017

Summary

- Although there is not a direct impact on forecast skill, it still recommended to use **SKEB** for proper physical representation of upscale energy transfer.
- **Thompson or Goddard** scheme are recommended to be used, although further testing needs to be done, to determine which microphysics parameterization options are the most skillful.
- Results suggest that vertical wind at mid-level may have impacted the hail size forecast.
- Based on the vertical profile for **Thompson** and **Goddard,** it seems that an increase in cloud, snow, ice mixing ratio at mid levels it may have an impact in the hail size production and size.
- The influence of **SPPT** on the forecast skill among the schemes it's not clear, further analysis need to be addressed to determined the impact of the representation of the possible sources of model error.

Future work

- Adjoint sensitivities will be used to create initial conditions perturbations to intentionally change the hail forecast.
- The use of a singular vector technique to create an ensemble forecasting system for hail size distribution.

Acknowledgments

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Selected Bibliography

Adams-Selin, R. D., and C. L. Ziegler, 2016: Forecasting hail using a one-dimensional hail growth model within WRF. *Mon. Wea. Rev.*, 144, 4919–4939.

Bae, S.Y.; Hong, S.Y.; Tao, W.K., 2019: Development of a Single-Moment Cloud Microphysics Scheme with Prognostic Hail for the Weather Research and Forecasting (WRF) Model. *Asia-Pac. J. Atmos. Sci.*, *55*, 233–245.