EGU24-5909, updated on 14 Jul 2024
https://doi.org/10.5194/egusphere-egu24-5909
EGU General Assembly 2024

Impact of Spatial Density of Automatic Weather Station Data on Assimilation Effectiveness in WRF-3DVar Model

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Implementing the 3-Dimensional Variational (3DVar) data assimilation technique using high-density automatic weather station (AWS) observations substantially improves the precipitation simulation and forecast capabilities in the Weather Research and Forecasting (WRF) model. Given the impact of spatial distribution and quantity of observation data on assimilation effectiveness, there is a growing need to assimilate the most efficient amount of observation data to improve the precipitation forecast accuracy, especially in the context of the proliferation of data from diverse sources. This study investigates the impacts of spatial density of assimilated data on enhancing model predictions, focusing on a squall line event in Beijing on 2 August 2017 which has approximately 2400 AWSs in the simulation domain. Seven experiment groups assimilating varying proportions of AWS data (3.125, 6.25, 12.5, 25, 50, 75, and 100 percent of total AWSs) were conducted, comprising 10 experiments per group. The results were then compared with the experiment without data assimilation (CTRL) and the observations. Results show that while the WRF model roughly captured the evolution of this event, it overestimated the precipitation amount with significant deviations in precipitation locations. A general positive correlation was observed between the spatial density of assimilated data and the enhancement in model performance. However, there is a notable threshold beyond which additional data ceases to enhance forecast accuracy. The model performs best when the ratio of the number of assimilated AWSs to the model simulated area reaches 1/40 km^{-2}. Moreover, significant variations in improvement effects across experiments within the same group indicate the substantial impact of spatial distribution of assimilated AWSs on forecast outcomes. This study provides a reference for devising more efficient and cost-effective data assimilation strategies in numerical weather prediction.