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P1.18 DETERMINATION OF THE PREDICTABILITY OF AVIATION-RELEVANT CHARACTERISTICS OF CONVECTIVE WEATHER

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1. INTRODUCTION

Convective weather can exert a disruptive influence on aviation. This is true both for en-route air traffic flow and traffic around the terminal area. As future demand on the national airspace increases, the need for coherent, relevant, and up-to-date weather information will also increase. Successful and effective flight planning requires accurate weather analyses and skillful 0 – 6 h forecasts.

The focus of this study is on determining characteristics of convective weather (e.g., its spatial organization) that are most disruptive to en-route air traffic, assessing how these weather characteristics vary with spatial scale, and the extent to which numerical weather prediction (NWP) models are capable to predict such information.

2. DATA, MODELS, AND PROCEDURES

2.1 National radar mosaic

The WSI national radar reflectivity mosaic data was used as the baseline ("truth") for the presented analyses. These data are created by merging information from all available NEXRAD sites and have a resolution of 5 min in time and 2 km in space. The value at each grid point represents the maximum reflectivity anywhere within the vertical column above that location.

2.2 Real-Time Four-Dimensional Data Assimilation modeling system

The Real-Time Four-Dimensional Data Assimilation (RT-FDDA) modeling system, which has been developed under Army Test and Evaluation Command (ATEC) support, is one of two models evaluated in this study. The RT-FDDA continuously assimilates conventional and radar data, as they become available. Assimilation of radar reflectivity data is accomplished by means of a latent heating nudging scheme. We are using the RT-FDDA based on the Pennsylvania State University – NCAR Mesoscale Model Version 5 (MM5) with agrid resolution of 5 km. Forecast cycles were initialized every three hours, starting at 02 UTC.

2.3 Weather Research and Forecasting model

This study makes also use of the Weather Research and Forecasting (WRF) model, which is developed through a community effort. We are using a version that includes assimilation of conventional data only. The WRF model was initialized twice daily, at 00 and 12 UTC, and run at a 4 km resolution.

2.4 Analysis procedures

A flexible analysis tool has been developed that enables computation of various parameters and displays them in both a spatial (horizontal view) and temporal context (time series window), as shown in Fig. 1. Parameters are derived within grid boxes of a user-specifiable size. Currently, the following storm characteristics are computed: fractional echo area coverage above a selectable intensity threshold (expressed as a percentage); the number of storms, average and median storm size (km^2). The number of aircraft within a grid box is counted as well. Other relevant parameters (e.g., storm motion; gap size between storms or porosity; etc.) will be added in the future.

To compare results from the three different datasets equitably, a remapping of the WSI data was done to match the model grid resolution.

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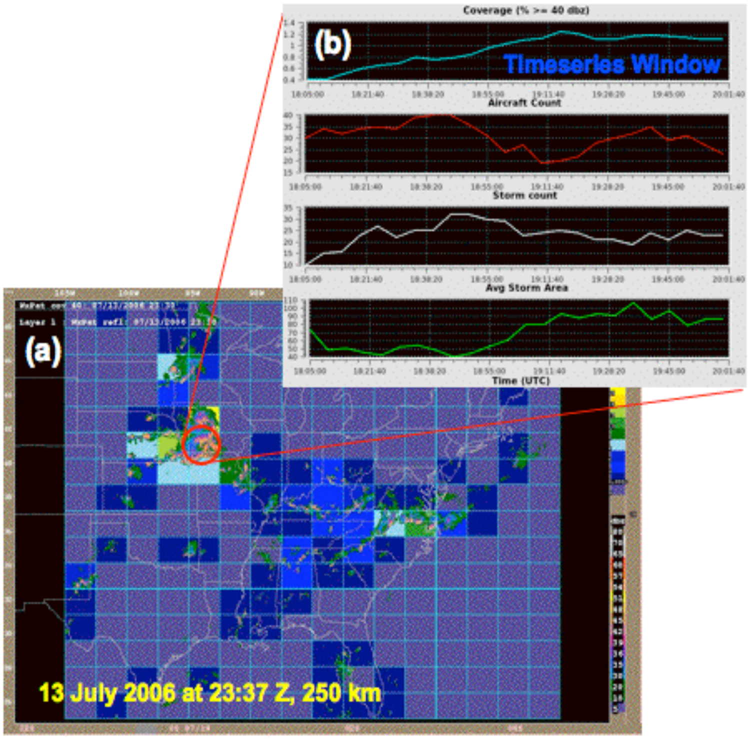

Figure 1. *Analysis tool showing a horizontal view (a) of radar reflectivity weather patterns with fractional echo area coverage within grid boxes overlaid (color coded). The time series window (b) shows various parameters as a function of time for the selected grid box.*

Storms were defined as continuous areas above an intensity threshold of 40 dBZ with a minimum size of 100 km^2.

Several analysis grid resolutions were explored, including: 1080x680 km, 540x340 km, and 270x170 km—the latter shown in Fig. 1.

The region of interest encompasses the continental United States east of 100°W. This domain includes a number of major airline hubs—Atlanta (ATL), Dallas – Ft. Worth (DFW), Chicago (ORD), and the New York airports La Guardia (LGA), John F. Kennedy (JFK), and Newark (EWR)—and associated heavy traffic routes connecting these terminal areas.

3. WEATHER CHARACTERISTICS

3.1 Temporal persistence of weather

The analysis tool presented in section 2.4 was used to compute weather characteristics within grid boxes based on data collected in July 2006. These computations were carried out for all available data and the three grid resolutions mentioned above. The auto-correlation was used as a measure of the temporal persistence of weather patterns and characteristics thereof. The auto-correlation was computed based on the time series of weather characteristics derived for a specific location (i.e., grid box). Figure 2a shows the auto-correlation with lag times from 0 – 5 hours based on the fractional echo area coverage for all grid boxes and weather encountered on 13 July 2006. A decrease in value with increasing time separation (i.e., lag) indicates a decreasing correlation between the information at those times. A value of zero indicates “no correlation”, while negative values indicate “anti-correlation”.

Figure 2a shows a wide range of behavior, with some curves dropping rather quickly toward zero correlation, while others indicate significant temporal persistence. The rate at which the correlation decreases with increasing time lag provides insight as to how much predictive skill one might expect for a particular weather situation.

Generally, weather patterns de-correlate rapidly with increasing time separation. The wide spread seen in Fig. 2a is a reflection of a variety of weather patterns within the analysis domain. Clearly, the temporal persistence depends strongly on the type of weather system encountered. These results are consistent with earlier analyses by Wilson et al. (1998) shown in Fig. 2d.

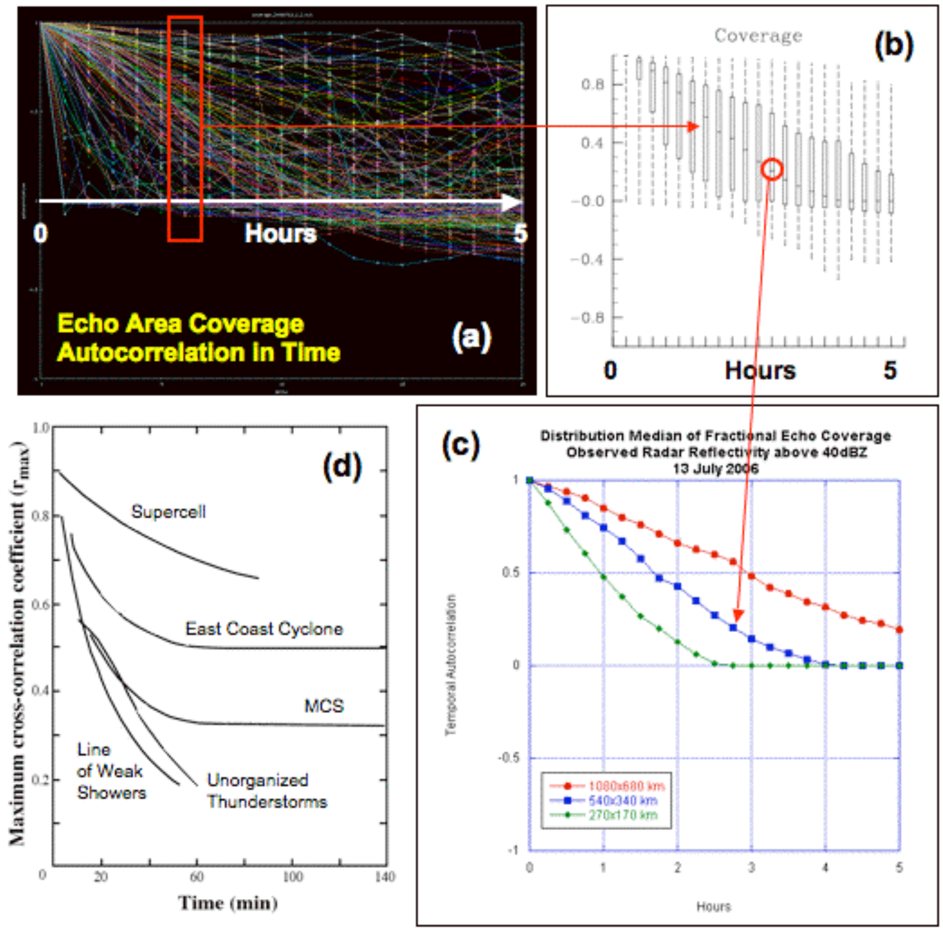

Figure 2. *Temporal persistence of weather characteristics, as measured by the auto-correlation. Shown are the results of the fractional echo area coverage for weather encountered on 13 July 2006 (a) and (b), and how that depends on the spatial scale of interest (c). Dependence on storm type is shown in (d).*

3.2 Scaling with domain size

In order to facilitate a comparison of the temporal persistence of weather characteristics for various grid resolutions (i.e., spatial scale), we rearranged the data shown in Fig. 2a into boxplots (i.e., median, center half of data boxed, full range of data dashed), as shown in Fig. 2b. This representation reveals the aggregate behavior more easily. Moreover, using the distribution median as a yardstick, we are able to visualize not only how the auto-correlation of the fractional echo area coverage decreases with increasing time lag, but also how this function depends on the spatial scale. Figure 2c demonstrates that the temporal persistence of weather characteristics tends to be larger for larger domains. Therefore, one might expect a higher prediction skill for weather characteristics by focusing on bigger areas.

Our results suggest that fractional echo area coverage and the number of storms may be reasonably predictable up to 3 hours into the future, while the median storm size appears to be de-correlated already within an hour (not shown).

4. SIMULATED CHARACTERISTICS

4.1 Weather characteristics by forecast lead time

How well do NWP models reproduce the spatial characteristics of storms as a function of forecast lead time? Figure 3a shows a comparison of the fractional echo area coverage generated by the RT-FDDA at analysis time with contemporaneous observations. At analysis time, the RT-FDDA model tends to exhibit a smaller fractional echo area coverage than observed, which may be attributed to fewer number of storms represented in the model (Fig. 4a). The median storm size appears to be reasonably well handled by the RT-FDDA analysis.

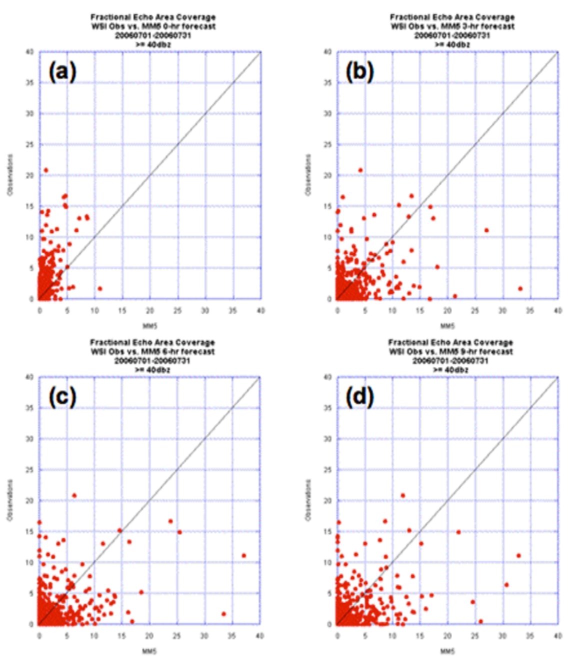

Figure 3. *Observed vs. modeled (RT-FDDA) fractional echo area coverage above 40 dBZ for July 2006. Shown are results at (a) analysis time, and forecasts with (b) 3 hour, (c) 6 hour, and (d) 9 hour lead times, respectively.*

The tendency of fewer storms persists into the forecasts (Figs. 4b, c, d), however, the RT-FDDA appears to grow these storms into larger entities than observed (Figs. 5b, c, d), which boosts the fractional echo area coverage towards the observations (Figs. 6b, c, d). More specifically, Phillips et al. (2008) find that the RT-FDDA tends to forecast approximately only one-third of the observed number of storms sized less than 500 km^2.

4.2 <u>Weather characteristics by time of day</u>

Does the RT-FDDA model performance depend on the time of day? Stratification of the fractional echo area coverage results shown in Fig. 3d (i.e., 9 hour forecasts vs. corresponding observations) by time of day—i.e., into four time periods 0-6Z (Fig. 6a), 6-12Z (Fig. 6b), 12-18Z (Fig. 6c), and 18-24Z (Fig. 6d)—reveals that the RT-FDDA model tends toward larger storm systems particularly in the late evening hours, as highlighted in Fig. 6a.

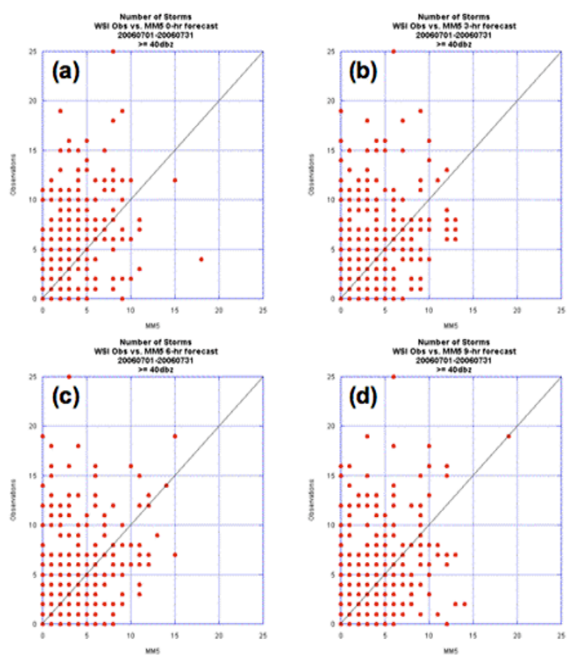

Figure 4. *Same as Fig. 3, but for number of storms.*

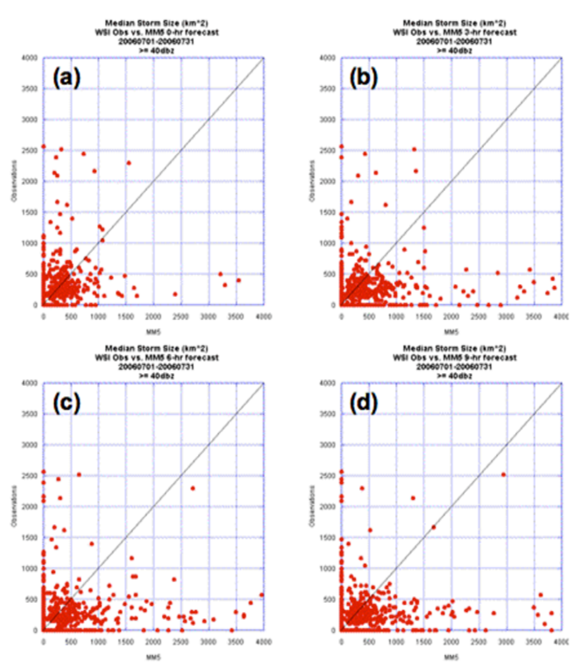

Figure 5. *Same as Fig. 3, but for median size of storms.*

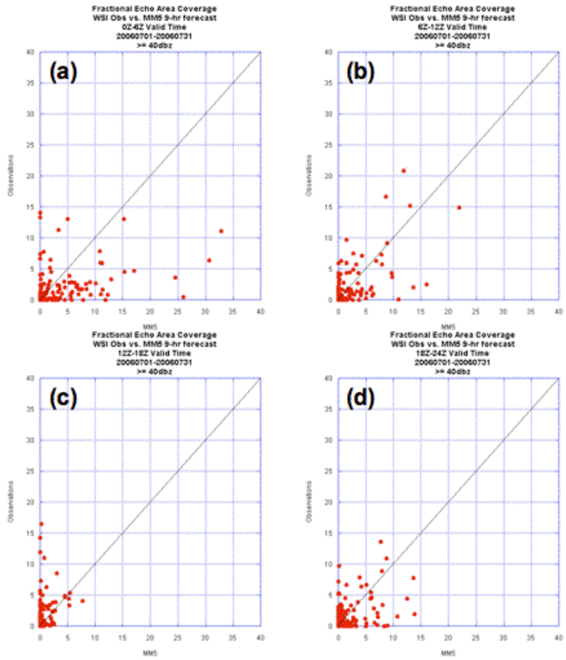

Figure 6. *Observed vs. modeled (RT-FDDA) fractional echo area coverage above 40 dBZ for July 2006. Shown are 9 hour forecasts stratified by time of day, (a) 0-6Z, (b) 6-12Z, (c) 12-18Z, and (d) 18-24Z.*

5. DIFFERENCES AMONG MODELS

5.1 Comparison of RT-FDDA and WRF results

To what extent exhibit other NWP models similar characteristics? Here we contrast the RT-FDDA results (discussed in section 4) with those obtained by the WRF model. We expect some differences, because of the different model architecture, data assimilation, and physics packages. We use root-mean-square (RMS) difference between model and observations (Table 1) and mean bias (Table 2) as measures.

As we have seen in section 4, the RT-FDDA model tends to underestimate the fractional echo area coverage at analysis time—i.e., a negative bias is shown in Table 2. This echo area coverage bias diminishes with increasing forecast lead times, in concert with an increasing positive model bias in median storm size. This increasing positive bias in median storm size is also reflected in the increasing RMS differences (Table 1). The negative bias in number of storms persists for all forecast times evaluated, and the RMS differences remain approximately level as well.

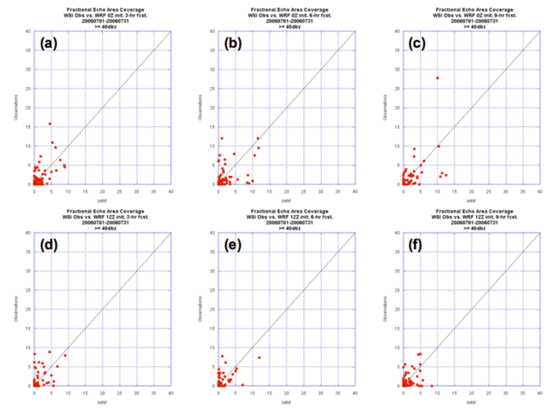

Figure 7. *Observed vs. modeled (WRF) fractional echo area coverage above 40 dBZ for July 2006. Shown are forecasts with (a) 3 hour, (b) 6 hour, and (c) 9 hour lead times from runs initiated at 0Z and (d) 3 hour, (e) 6 hour, and (f) 9 hour forecasts initiated at 12Z, respectively.*

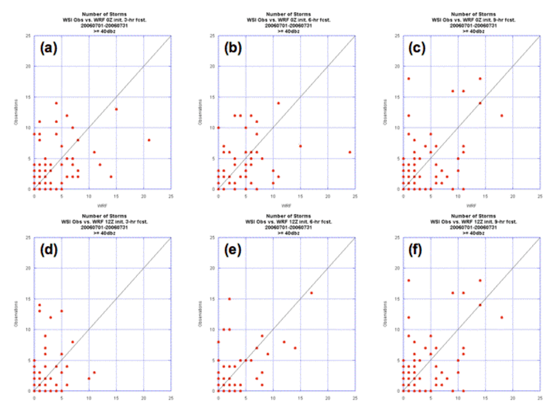

Figure 8. *Same as Fig. 6, but for number of storms.*

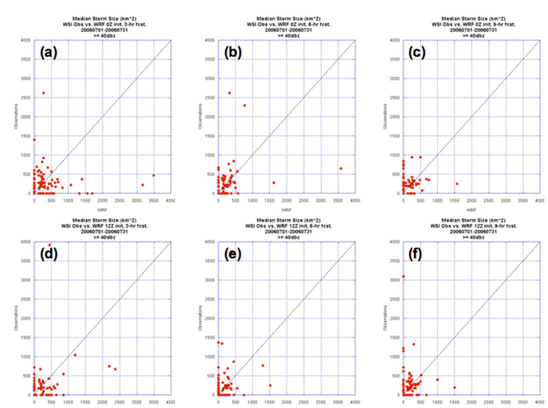

Figure 9. *Same as Fig. 6, but for median size of storms.*

The results of the WRF model runs are visualized in Figs. 7 – 9. Given only two runs initialized per day, significantly fewer samples are contained in our analyses (see Tables 1 and 2). Also, no information was available for the WRF analysis time. A visual assessment of trends based on Figs. 7, 8, and 9 is difficult, because of the limited data. For the same reason, we also have to cautiously interpret the values shown in Tables 1 and 2.

Both the 00Z and 12Z WRF runs show slightly negative biased 3 hour forecasts of the fractional echo area coverage and a minor overestimation of median storm size that reduces for longer lead time forecasts. The WRF model seems to be doing a pretty good job in terms of the number of storms produced.

6. SUMMARY & OUTLOOK

This study presented initial results of an effort geared toward assessing aviation-relevant weather characteristics in space and time, and how well NWP models may be able to reproduce those characteristics.

A flexible display and analysis tool was developed to assist with this project. This tool enables computation of a variety of parameters that characterize aspects of weather patterns contained within grid boxes of interest, and at various spatial scales. We discussed the fractional echo area coverage, number of storms, and their median size here.

Table 1. RMS differences between model and observations for the RT-FDDA and WRF.

Model	Coverage	Median Size (km^2)	Num. Storms	Sample Size
RT-FDDA 0hr	1.61%	344.30	2.3	1470
RT-FDDA 3hr	2.18%	857.93	2.5	1470
RT-FDDA 6hr	2.34%	996.62	2.5	1470
RT-FDDA 9hr	2.37%	849.39	2.4	1470
WRF-i00 3hr	1.55%	483.77	2.8	174
WRF-i00 6hr	1.94%	350.60	1.7	174
WRF-i00 9hr	2.07%	201.55	2.4	174
WRF-i12 3hr	1.34%	458.94	2.3	180
WRF-i12 6hr	1.14%	335.89	2.1	180
WRF-i12 9hr	1.31%	336.68	3.0	174

Table 2. Mean bias between model and observation for the RT-FDDA and WRF.

Model	Coverage	Median Size (km^2)	Num. Storms	Sample Size
RT-FDDA 0hr	-0.451%	-11.68	-0.61	1470
RT-FDDA 3hr	-0.002%	101.46	-0.44	1470
RT-FDDA 6hr	0.018%	132.41	-0.46	1470
RT-FDDA 9hr	0.013%	82.35	-0.42	1470
WRF-i00 3hr	-0.126%	39.54	-0.07	174
WRF-i00 6hr	0.016%	-14.04	0.06	174
WRF-i00 9hr	-0.035%	-27.51	-0.03	174
WRF-i12 3hr	-0.110%	31.16	-0.28	180
WRF-i12 6hr	-0.028%	-34.90	-0.05	180
WRF-i12 9hr	0.030%	-41.12	0.01	174

Weather patterns were found to generally de-correlate rapidly with time, although this depends strongly on the type of storms encountered. The temporal persistence of weather characteristics is also dependent on the spatial scale—the auto-correlation of aspects characterizing weather patterns tends to drop much more rapidly within smaller than larger domains. This suggests that somewhat higher predictive skills maybe achieved for forecasting weather characteristics over larger domains.

The skill of NWP models to simulate aspects of evolving weather patterns depends on the type of model. We found notable differences between the RT-FDDA and WRF model results. An interesting feature is the underestimation of the fractional echo area coverage by the RT-FDDA at analysis time, which appears to be primarily caused by an underestimation of the number of storms present. The number of storms in the forecasted weather remains low compared to observations, however, the RT-FDDA model tends to grow these storms into larger than observed entities, which ultimately yields a fractional echo area coverage that is comparable to the observations. The WRF model appeared somewhat better behaved than the RT-FDDA; however, because of a limited sample size no conclusions may be drawn.

Work in the future will include additional parameters (e.g., storm motion; gap size between storms or porosity; etc.) and evaluating ensemble model capabilities.

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