Ensemble-based analysis of factors leading to the development of a multi-day warm-season heavy rain event

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Introduction

• In late June and early July of 2007, persistent heavy rains fell across the Great Plains of the United States (Fig. 1a). Rainfall amounts exceeded 300 mm in southeastern Kansas and caused deadly (4 fatalities) and destructive ($350M in damage) flooding

• The synoptic-scale atmospheric pattern consisted of an anomalous ridge over most of the country, with a slow-moving warm-core vortex over the Plains

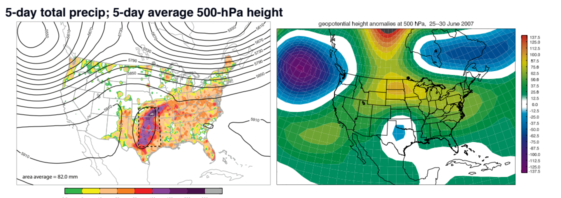

Fig. 1*: (a) Climate Prediction Center (CPC) unified gauge-based precipitation analysis (mm) for the 120-h period 1200 UTC 25 June–1200 UTC 30 June 2007, and average 500-hPa geopotential height (contoured every 30 m) from European Centre for Medium Range Weather Forecasts (ECMWF) deterministic model initializations over the same time period. The dashed black rectangle indicates the location for areal averaging of precipitation and other fields. (b) NCEP/NCAR Reanalysis 500-hPa geopotential height anomaly for 25–30 June 2007.*

• Compared with other rainfall events of similar temporal and spatial scale, medium-range forecasts of this event had low skill and large uncertainty (Schumacher and Davis 2010, *WAF*; Fig. 2)

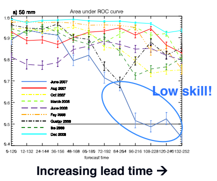

Fig. 2*: Area under the Relative Operating Characteristic (ROC) curve for the ECMWF ensemble for nine widespread 5-day rain events. Shown is the 120-h precipitation accumulation threshold of 50 mm. A perfect forecast has a ROC area of 1; a random reference forecast has an area of 0.5. Adapted from Schumacher and Davis (2010, WAF).*

• **Question to address: What were the key factors that were favorable for, or detrimental to, the development of widespread, multiple-day rainfall?**

Data and Methods

• To answer this question, global ensemble forecasts from ECMWF are used (51 members; T399); forecast data were obtained from the TIGGE portal at http://tigge.ecmwf.int

• Focus on the forecast initialized 0000 UTC 24 June (36—156-h forecast in Fig. 2) because it had members with very accurate forecasts of the vortex and rainfall as well as members with very poor forecasts (Fig. 3). All members underpredicted the maximum rainfall, however.

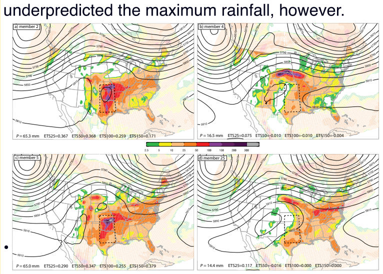

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Fig. 3*: As in Fig. 1a, except for examples of ECMWF ensemble members with "good" (left column) and "bad" (right column) 36—156-h precipitation forecasts. Precipitation outside the US has been masked out for visual comparison with Fig. 1a.*

Data and Methods, continued

• Two primary analysis techniques:

• Analysis of linear correlation and covariance between atmospheric variables and the area-averaged 36--156-h forecast rainfall over the southern Plains (abbreviated *P*), following the approach of Hakim and Torn (2008), Hawblitzel et al. (2007), Sippel and Zhang (2008, 2010) and others

• Composite analysis of "wet" and "dry" ensemble members to further elucidate physical processes in the model

Correlations/covariance

• There is a strong inverse relationship (r < -0.5) between the strength of the midlevel anticyclone in the southwestern US and *P*, with a weaker anticyclone at early times corresponding to more rainfall at later times (Fig. 4).

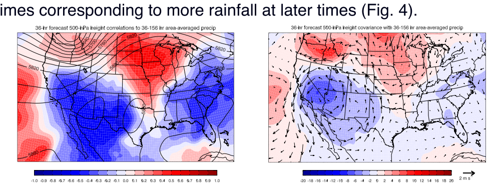


Fig. 4*: (a) Correlation of 36-h forecast 500-hPa height (valid 1200 UTC 25 June) with P (shaded), and ensemble-mean 500-hPa height (contoured every 30 m). (b) Covariance of 36-h forecast 500-hPa height (m, shaded) and wind (vectors) with P, normalized by the standard deviation of P .*

• A similar relationship exists between the strength of vertical wind shear over the incipient vortex and the development of heavy rainfall later, with weaker shear corresponding to the development of the vortex, and more rainfall (Fig. 5).

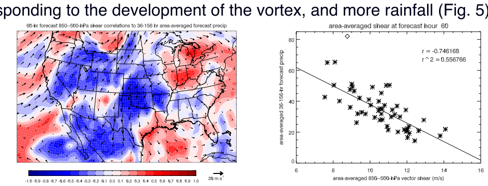


Fig. 5*: (a) Correlation of 60-h forecast 850--500-hPa shear magnitude (valid 1200 UTC 26 June) with P (shaded), and ensemble-mean shear vectors. (b) Scatter plot of the 51 ensemble members, with 60-h forecast 850–500-hPa vector shear magnitude, averaged over the area shown in Fig. 1, along the abscissa and P along the ordinate. The observed values are shown by the diamond.*

• Prior to t=60 h, correlations between convective variables (e.g., PW, CAPE) and P are much weaker than those for kinematic variables (not shown)

Composite analysis

• Construct composites of six members with the highest, and lowest, values of P

• Similar to the correlation/covariance analysis, "wet" members have a slightly weaker anticyclone in southwest, stronger ridge in Midwest (Fig. 6)

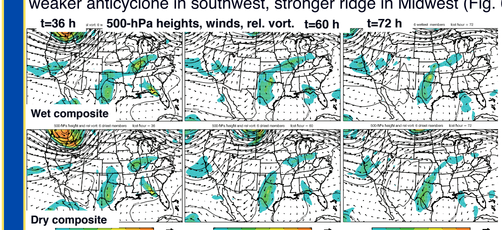


Fig. 6*: 500-hPa height, relative vorticity, and winds. (top row) Composite of six members with the highest values of P (middle row) Composite of six members with the lowest values of P Columns show forecast hours 36 (12 UTC 25 June), 60 (12 UTC 26 June), and 72 (00 UTC 27 June)*

Composite analysis, continued

• The weaker upstream anticyclone is associated with weaker shear over the incipient vortex (Fig. 7). Furthermore, convection develops near the vortex, rather than downshear, allowing it to intensify and remain over the Plains

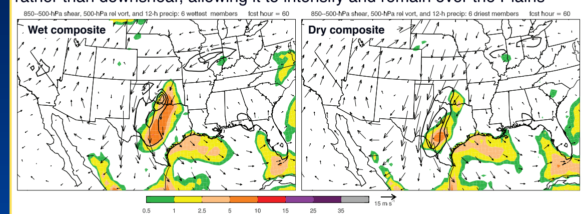
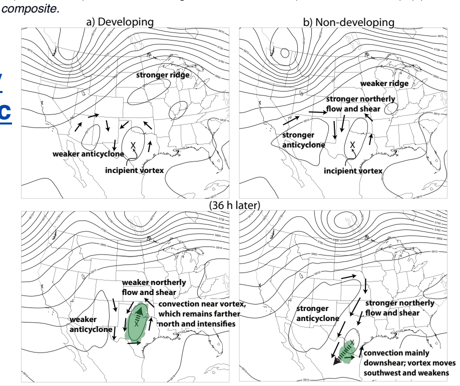


Fig. 7*: 500-hPa relative vorticity (contoured every 2 ×10–5 s–1 starting at 4), 850–500-hPa shear vectors, and precipitation (mm, shaded) in the 12 h ending at forecast hour 60 (1200 UTC 26 June). (a) Wet composite. (b) Dry composite.*

Summary schematic diagram:



Conclusions

• **Data from the TIGGE archive are useful both for forecast evaluation and diagnosis of weather systems.**

• **The strength of an anticyclone in the southwestern US was closely tied to the development of the warm-core vortex and associated precipitation. A weaker anticyclone early in the forecast was associated with less shear, which allowed the incipient vortex to intensify (connection to "tropical transition" mechanism for TC genesis of Davis and Bosart 2004?)**

• **The apparently low predictability of this case emphasizes the need for probabilistic forecasts. But it also raises questions about how to communicate such forecasts with high potential impact and high uncertainty (future work!)**

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