Applying Ensemble-Based Sensitivity Analysis to WRF Convection Forecasts in the Northern Great Plains

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State College, PA

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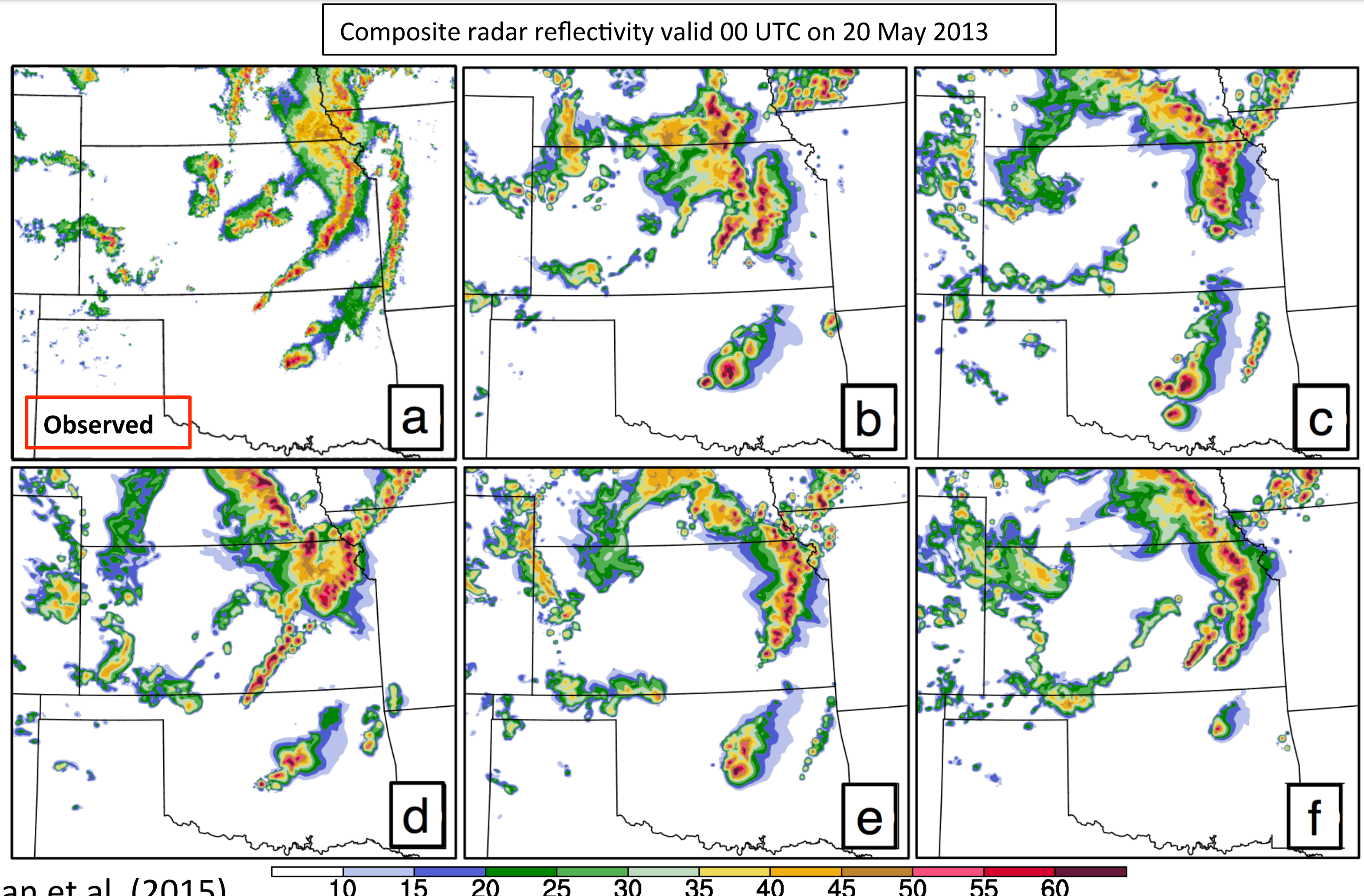
Motivation

- Numerical Weather Prediction model forecasts of severe convection are often characterized by varied degrees of predictability depending on the particular case.

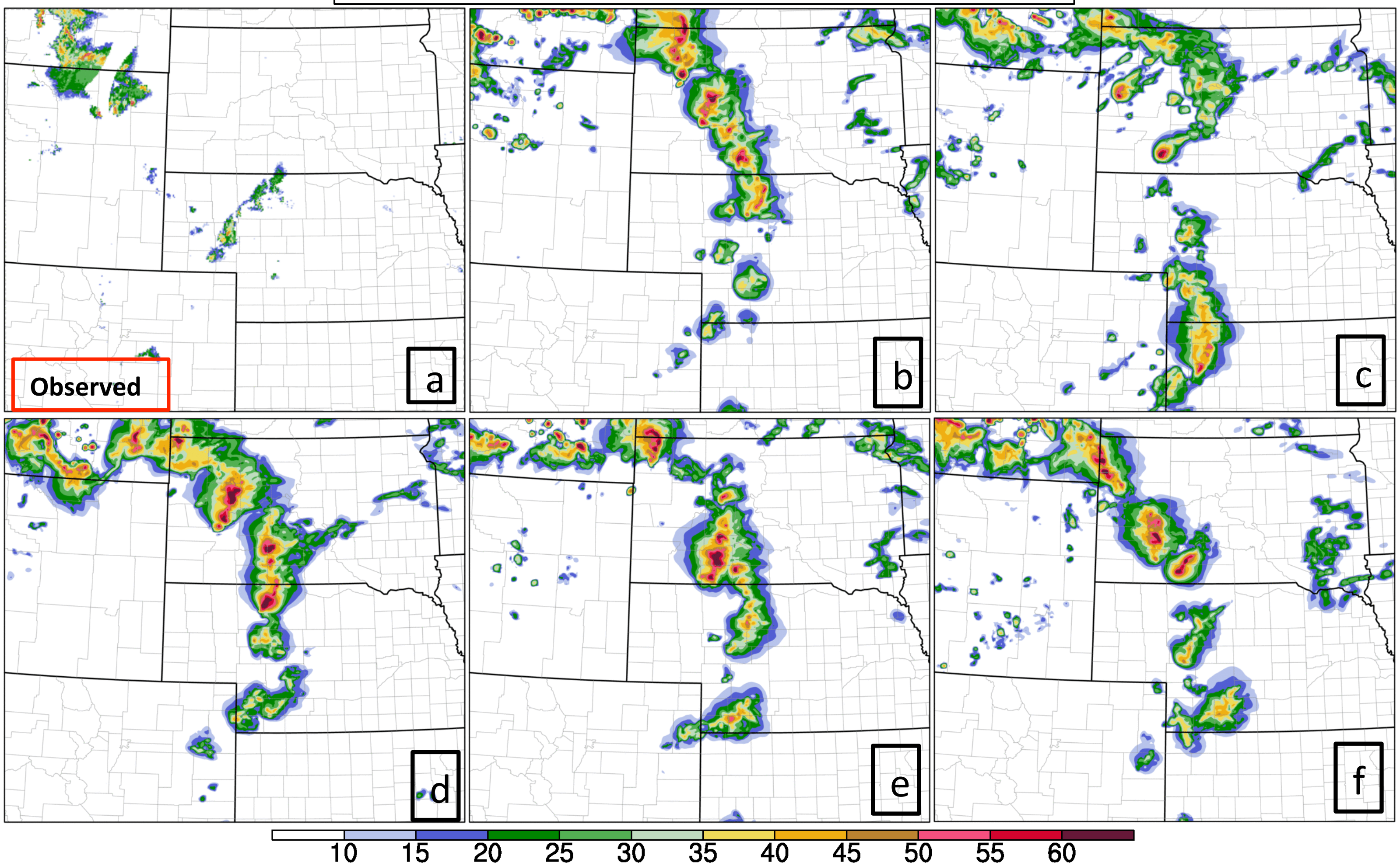
Model Forecast: The Good



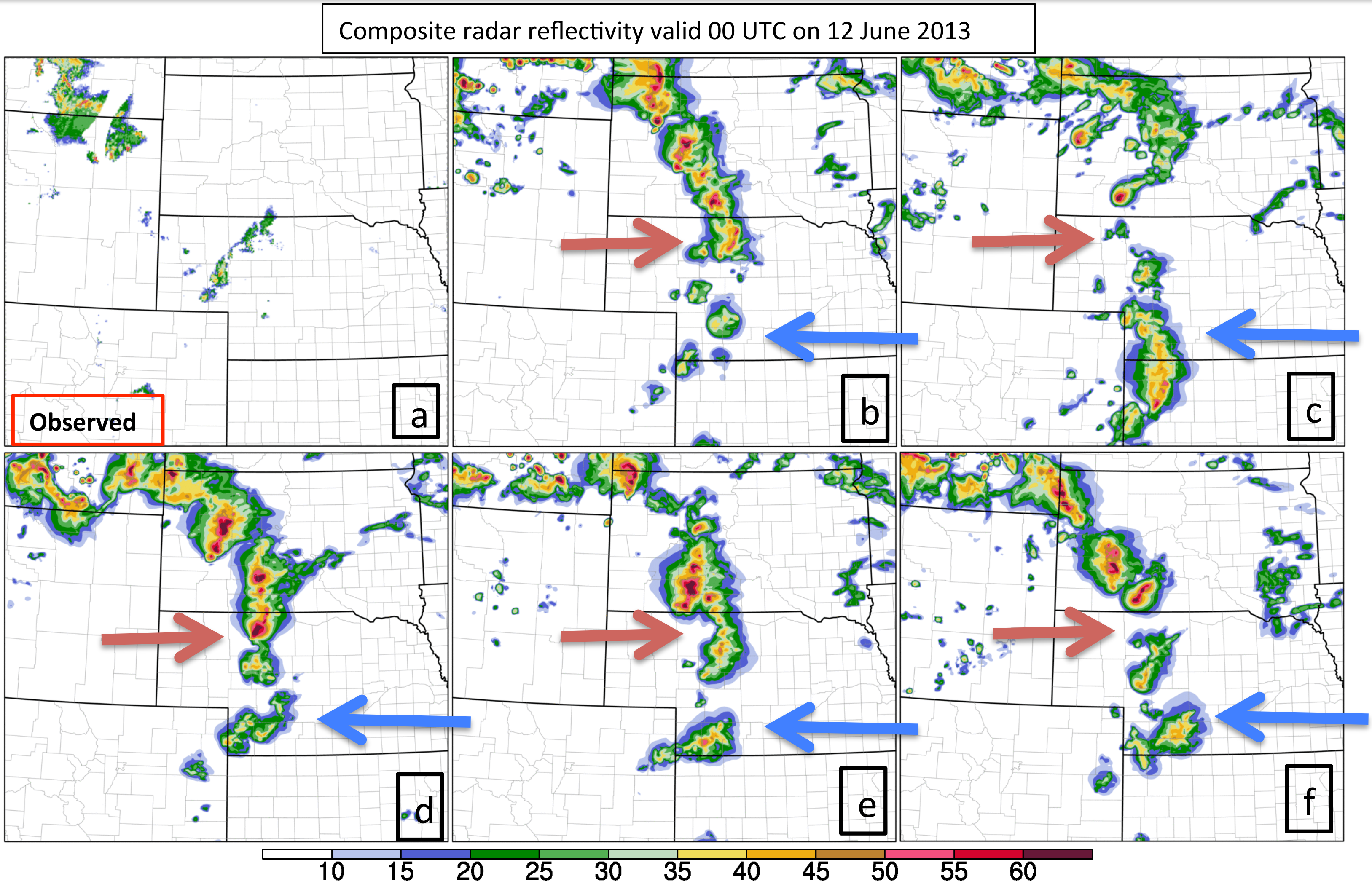
Weisman et al. (2015)

Model Forecast: The Bad

Composite radar reflectivity valid 00 UTC on 12 June 2013



Model Forecast: The Bad



Motivation

- Numerical Weather Prediction model forecasts of severe convection are often characterized by varied degrees of predictability depending on the particular case.
- One hypothesis for larger errors in some cases is that the model's initial conditions are characterized by errors in upstream sub-synoptic features before convective initiation takes place.
  - (e.g., Weisman et al., 2008; Clark et al., 2010ab)

MPEX: Observations

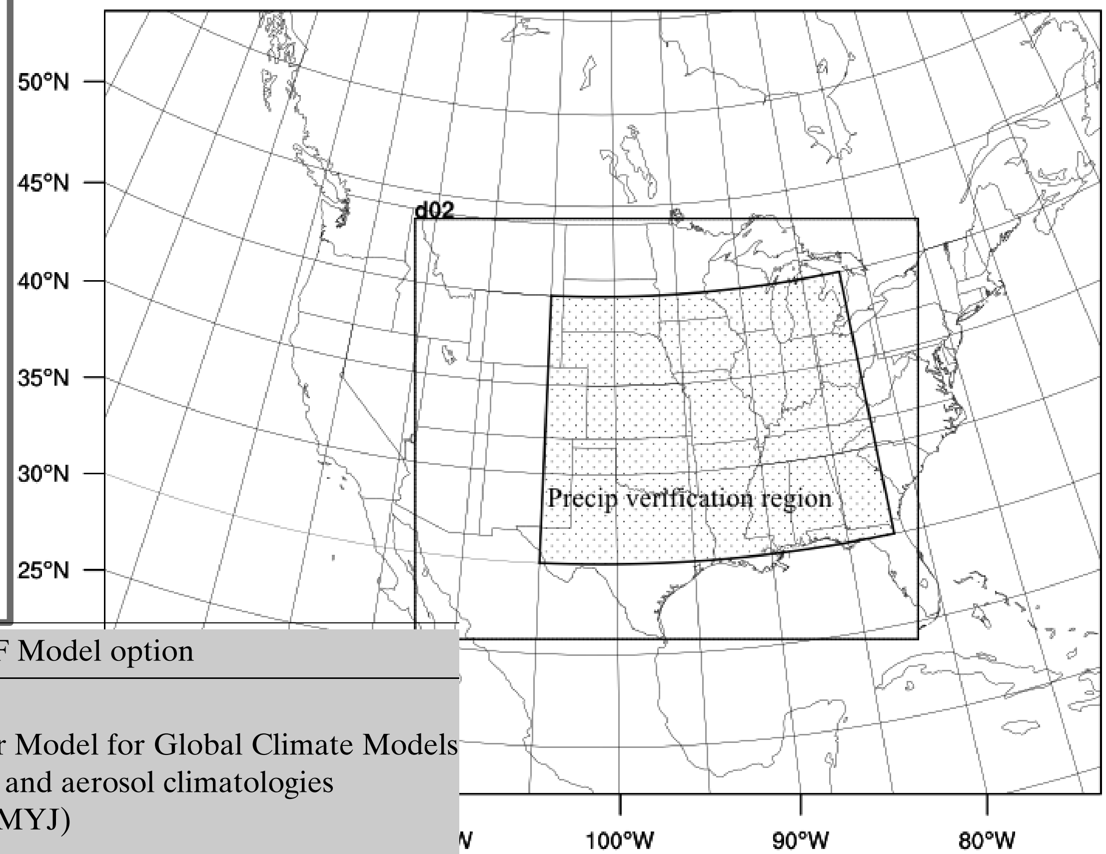
- 15 May – 15 June 2013
- Two missions a day:
  - early morning mission (~3:00 am - 10:00 am) primarily over the intermountain region
  - afternoon and early evening mission to the lee of the mountains
- Ensemble sensitivity analysis for dropsonde locations
- WRF ensemble forecasts produced twice daily (00 and 12 UTC)

NCAR GV and mini-dropsonde

WRF Model and Domain

- WRF V3.3.1
- CONUS 15 [3] km grid spacing, 40 vertical levels
- 50 member EAKF (Anderson 2001) with DART software (Anderson 2009) used to initialize forecasts.
- EnKF data assimilation system using 6-hr cycling, adaptive inflation & localization, sampling error correction

WRF Domain



Romine et al. (2013)

Physical parameterization	WRF Model option
Microphysics	Thompson
Long- and shortwave radiation	Rapid Radiative Transfer Model for Global Climate Models (RRTMG) with ozone and aerosol climatologies
Planetary boundary layer	Mellor–Yamada–Janjić (MYJ)
Land surface model	Noah
Cumulus parameterization	Tiedtke

Parameter	
Localization function	Gaspari–Cohn
Horizontal localization half-width	635 km
Vertical localization half-width	8 km

Tables adapted from Schwartz et al. (2015)

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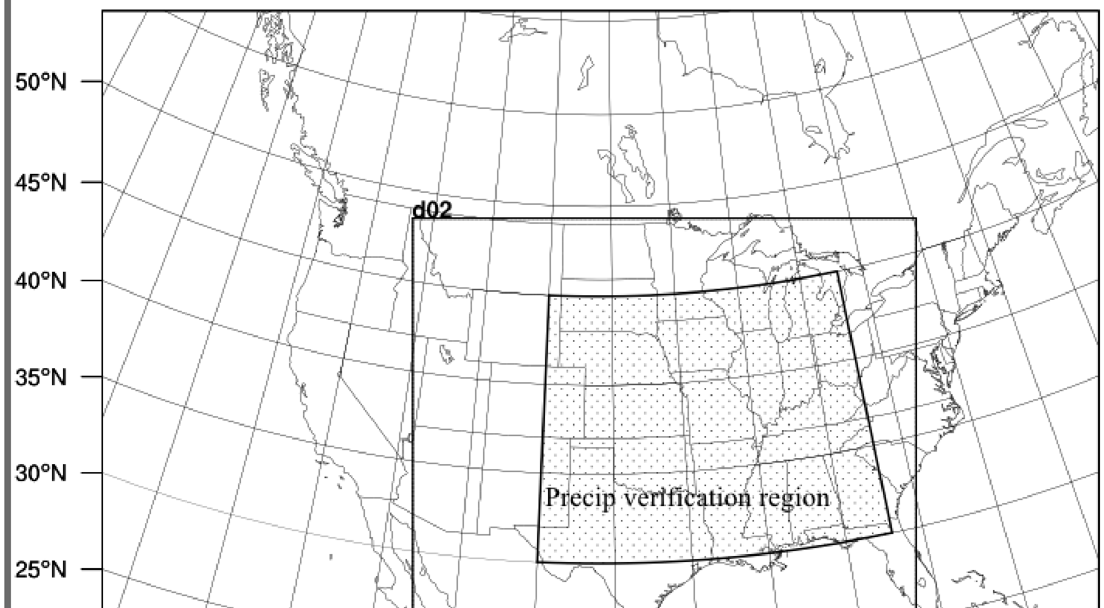

50-member WRF-DART Forecasts for MPEX Case Study of Severe Convection: 11-12 June 2013

Parameter	
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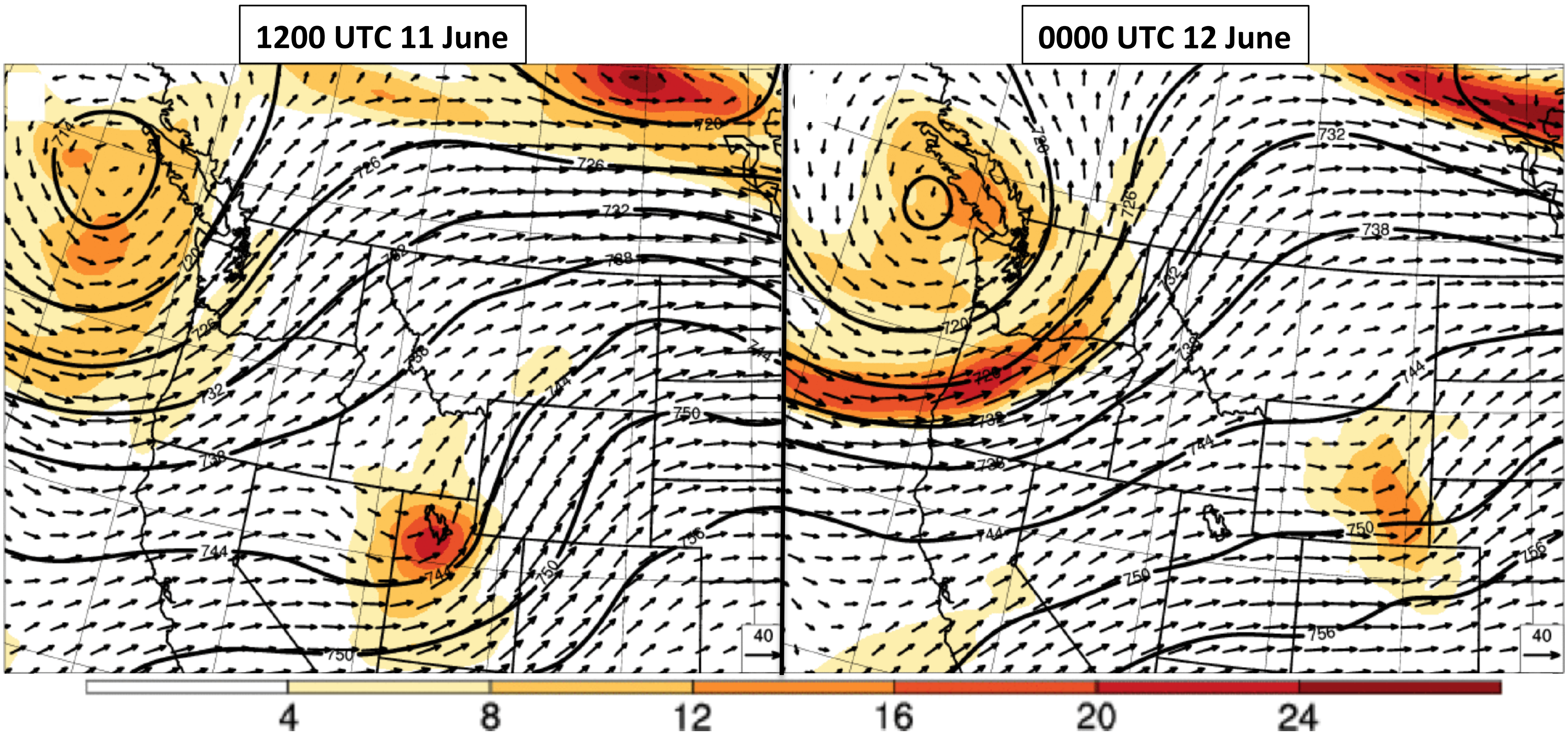
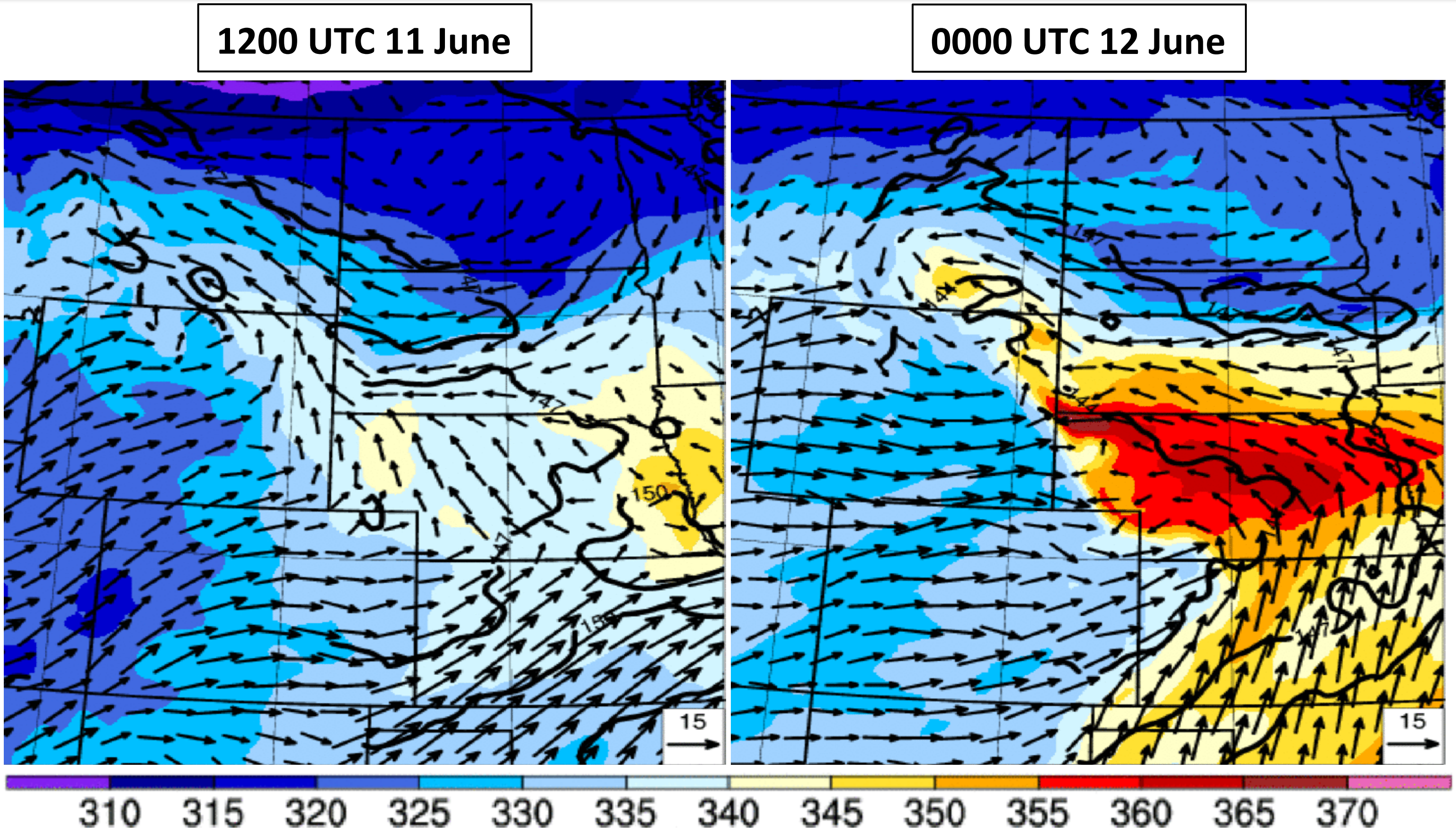
Tables adapted from Schwartz et al. (2015)

Case Overview: Mid-level Short-wave Trough



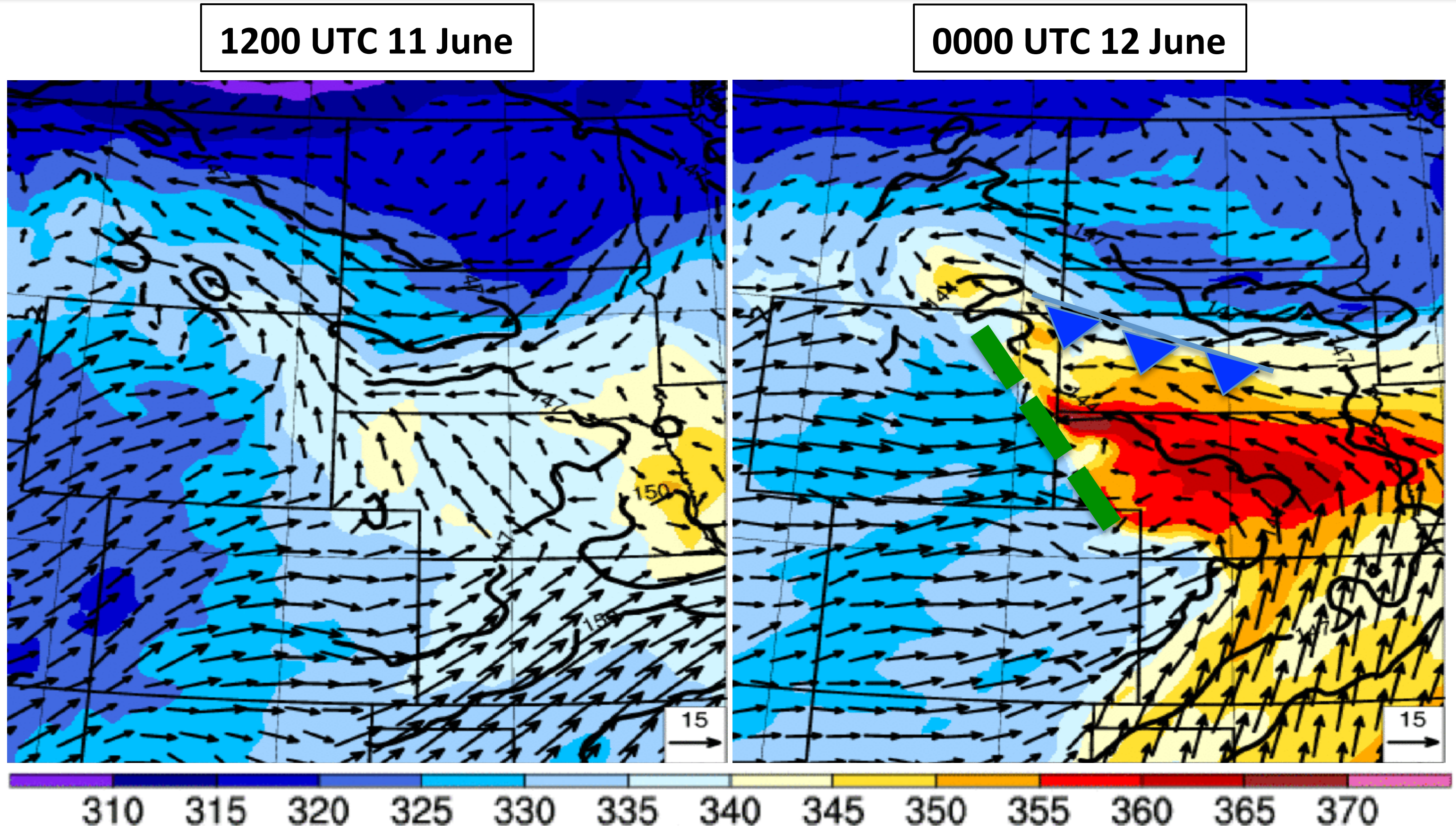
WRF-DART analyses of 400 hPa vorticity (shading, 10^{-5} s^{-1}), heights (contours, dm), and winds (vectors, m s^{-1}).

Case Overview:
Lower-level thermodynamic boundaries



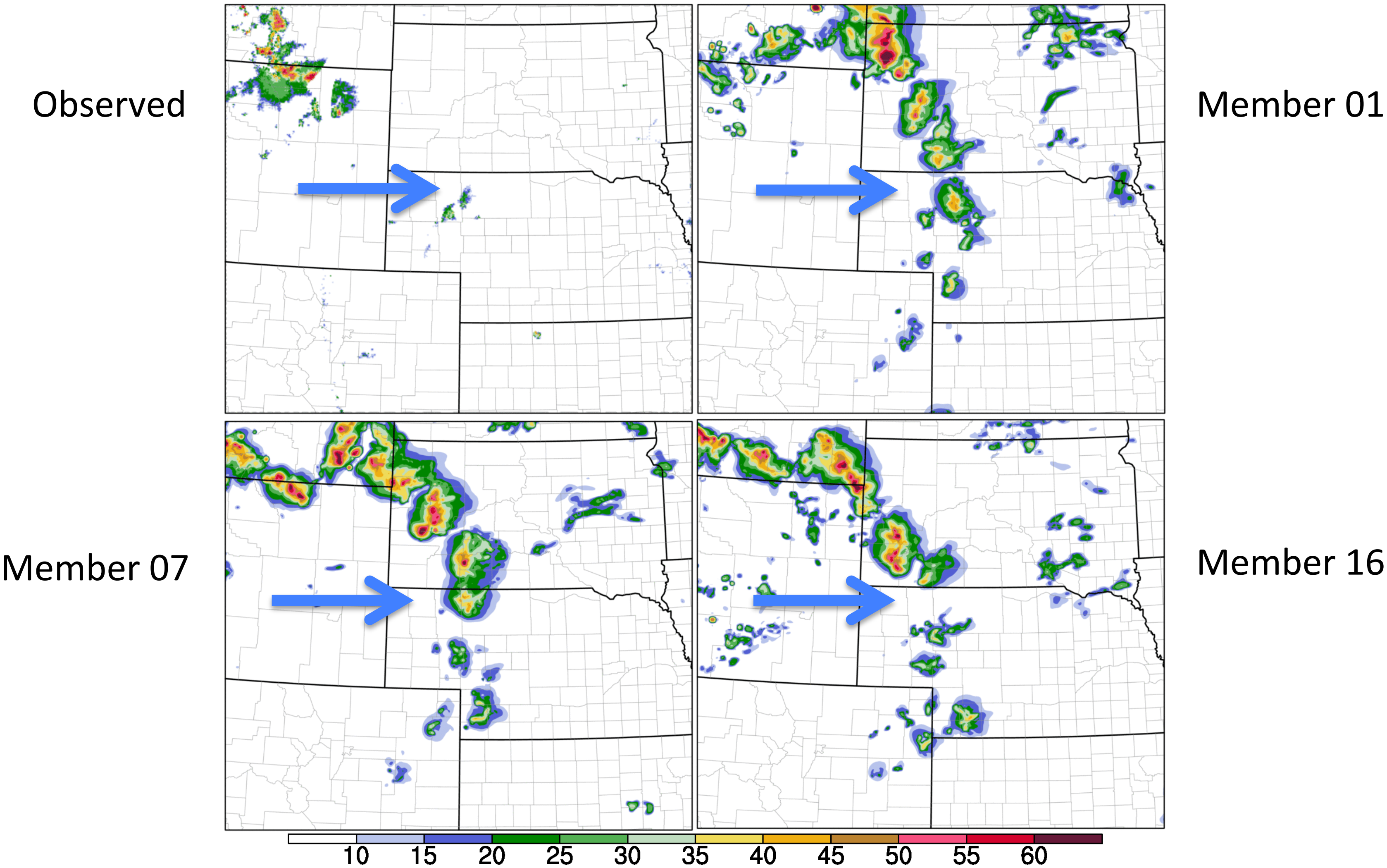
WRF-DART analyses of 0-1 km equivalent potential temperature (shading, K), 850 hPa heights (contours, dm), and 0-1 km winds (vectors, m s^{-1}).

Case Overview:
Lower-level thermodynamic boundaries



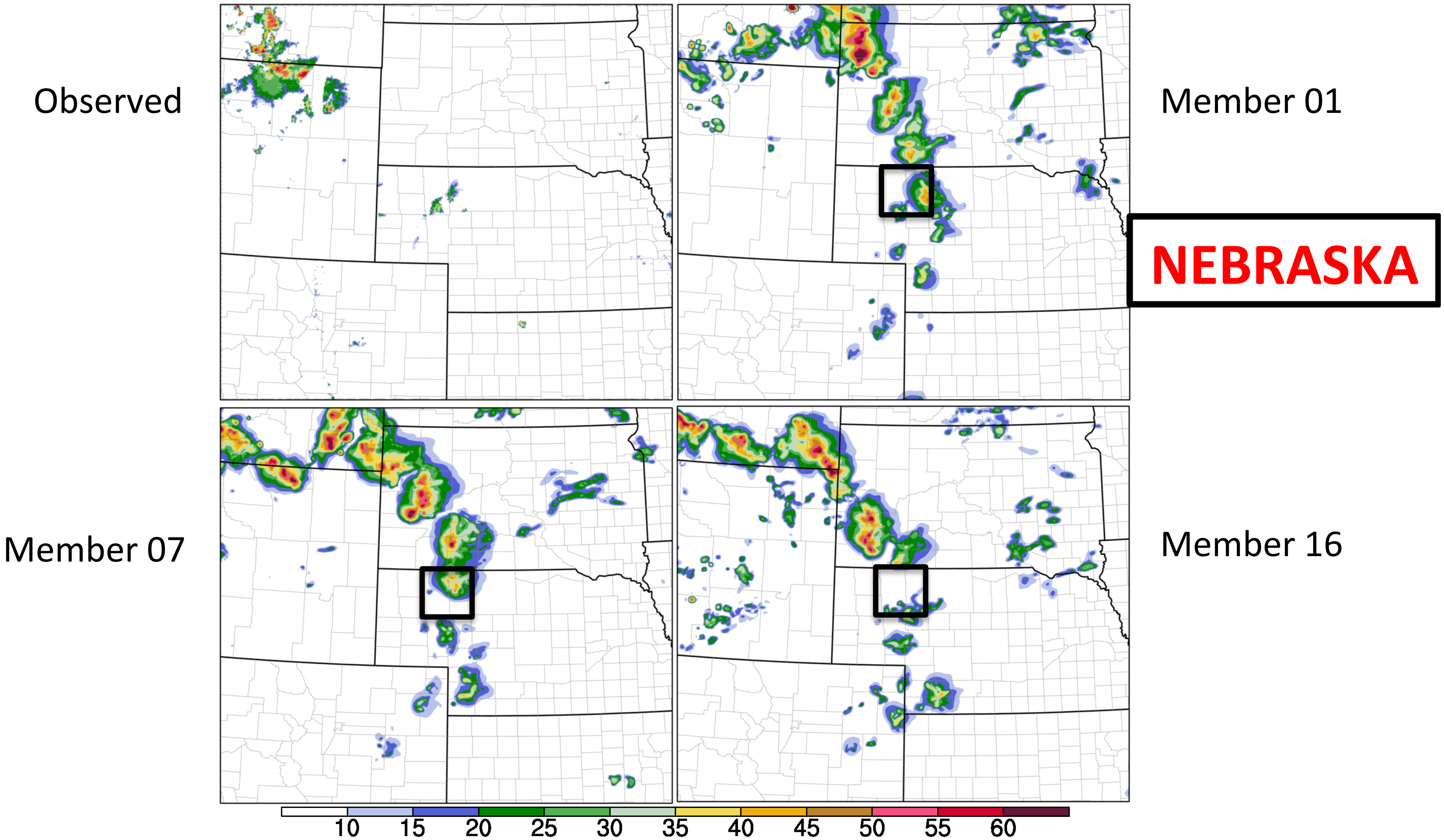
WRF-DART analyses of 0-1 km equivalent potential temperature (shading, K), 850 hPa heights (contours, dm), and 0-1 km winds (vectors, m s^{-1}).

Model Reflectivity and Observation: 2300 UTC 11 June 2013



Initialized: 1200 UTC 10 June 2013

Model Reflectivity and Observation: 2300 UTC 11 June 2013



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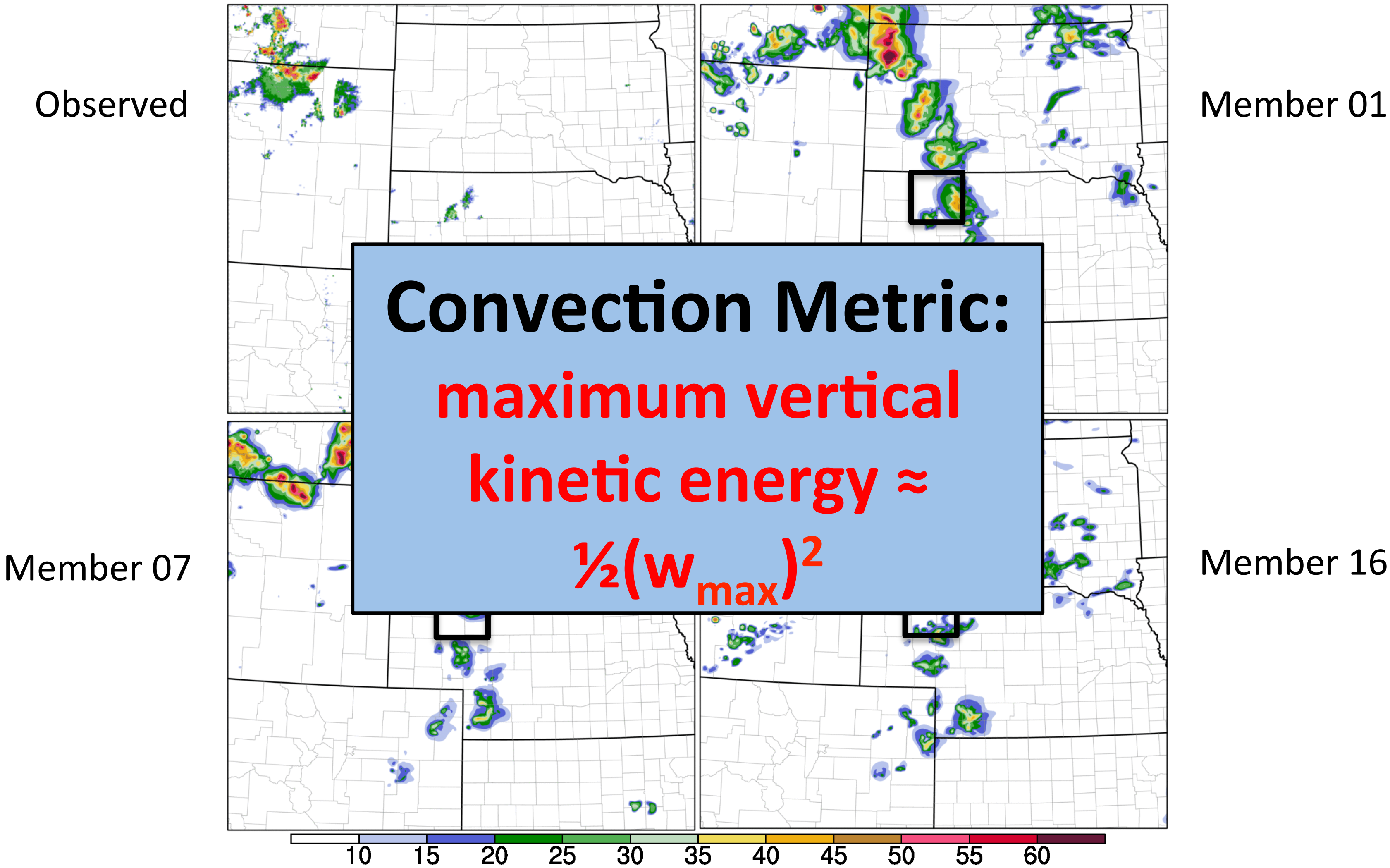
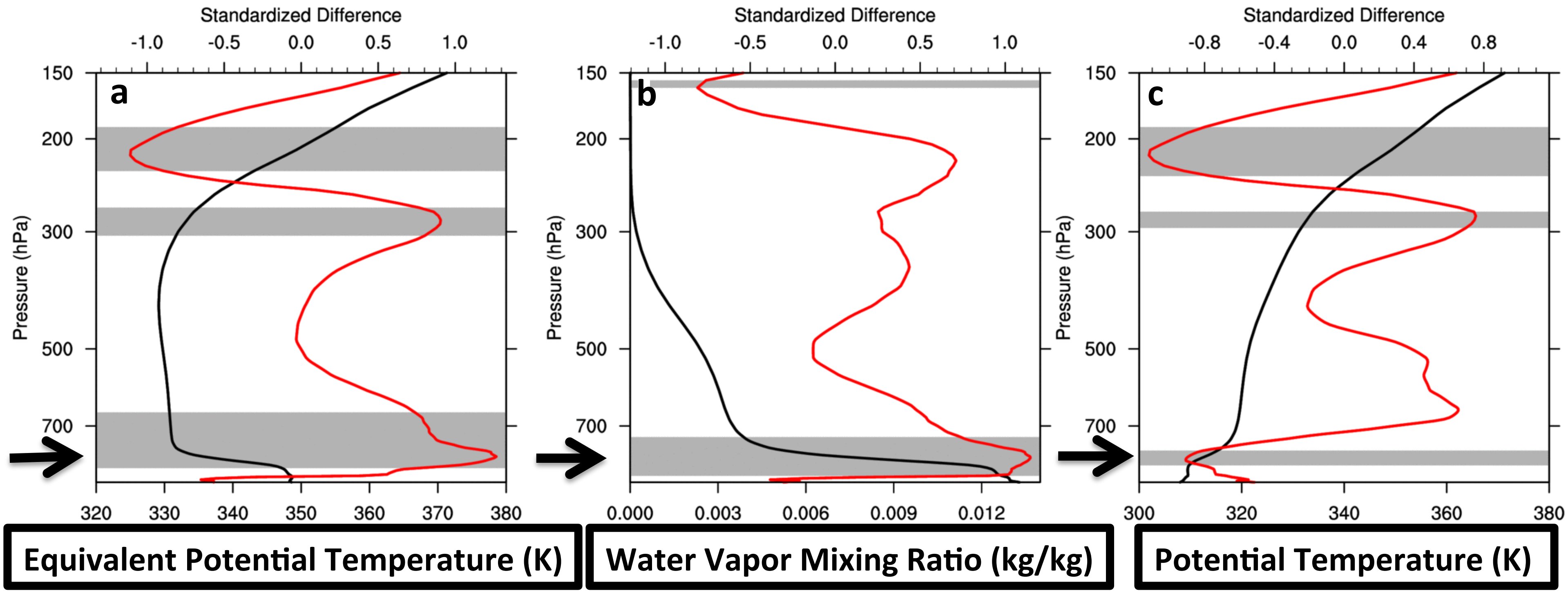


Convection Metric:
maximum vertical kinetic energy ≈ $\frac{1}{2}(w_{max})^2$

Initialized: 1200 UTC 10 June 2013

Pre-convective Profile Differences: 1800 UTC 11 June

$$\Delta x_i = \frac{\bar{x}_i^{strong} - \bar{x}_i^{weak}}{\sigma_{x_i}}$$

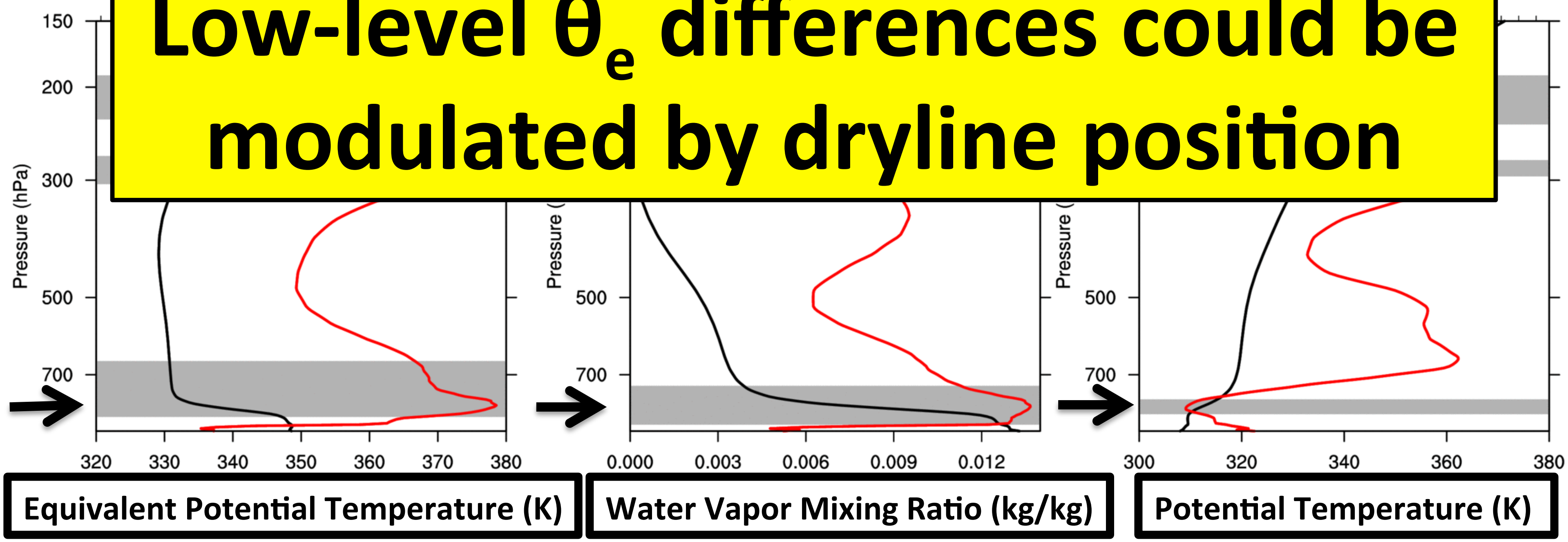


Profile standardized difference (red line) and ensemble-mean (black line) profile. Statistical significance at the 95% confidence level (gray shading).

Pre-convective Profile Differences: 1800 UTC 11 June

$$\Delta x_i = \frac{\bar{x}_i^{strong} - \bar{x}_i^{weak}}{\sigma_{x_i}}$$

Low-level θ_e differences could be modulated by dryline position



Profile standardized difference (red line) and ensemble-mean (black line) profile. Statistical significance at the 95% confidence level (gray shading).

Ensemble-Sensitivity Analysis

- Linear regression between ensemble model grid point and forecast metric

$$\frac{\partial J}{\partial x} = \frac{\mathrm{cov}(\mathbf{J}, \mathbf{x})}{\mathrm{var}(\mathbf{x})}$$

Ancell and Hakim (2007); Hakim and Torn (2008)

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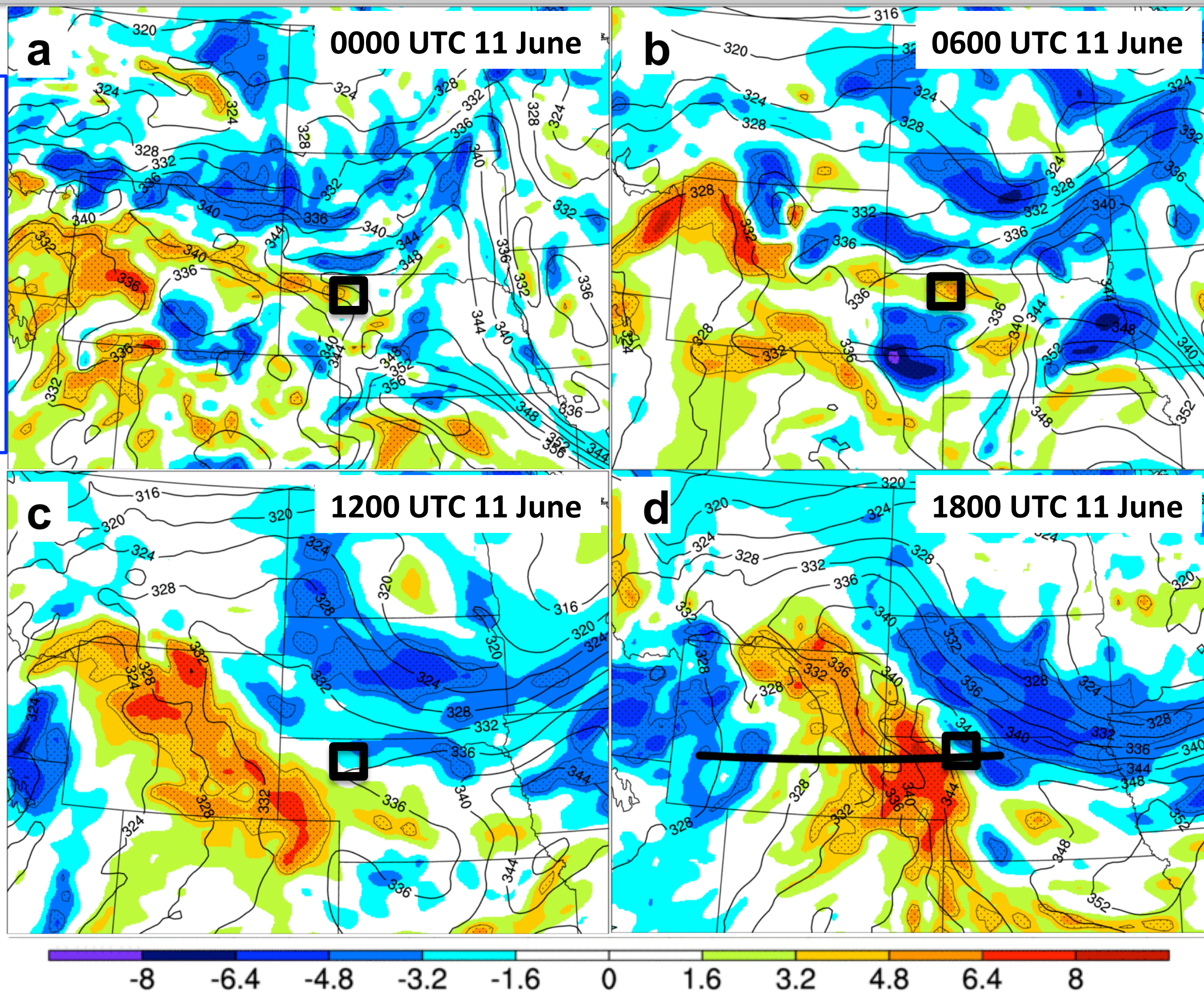
Ancell and Hakim (2007); Hakim and Torn (2008)

- Sensitivity of J (vertical KE) to earlier forecast time state variable x (near-surface $\boldsymbol{\theta}_e$)

Sensitivity Analysis: Near-surface θ_e

<u>Contours</u>: Ensemble-mean (K)

<u>Shading</u>: Sensitivity = $\dfrac{\Delta KE}{\Delta\sigma_{0\text{-}1\,km}\theta_e}$



Sensitivity Analysis: Near-surface θ_e

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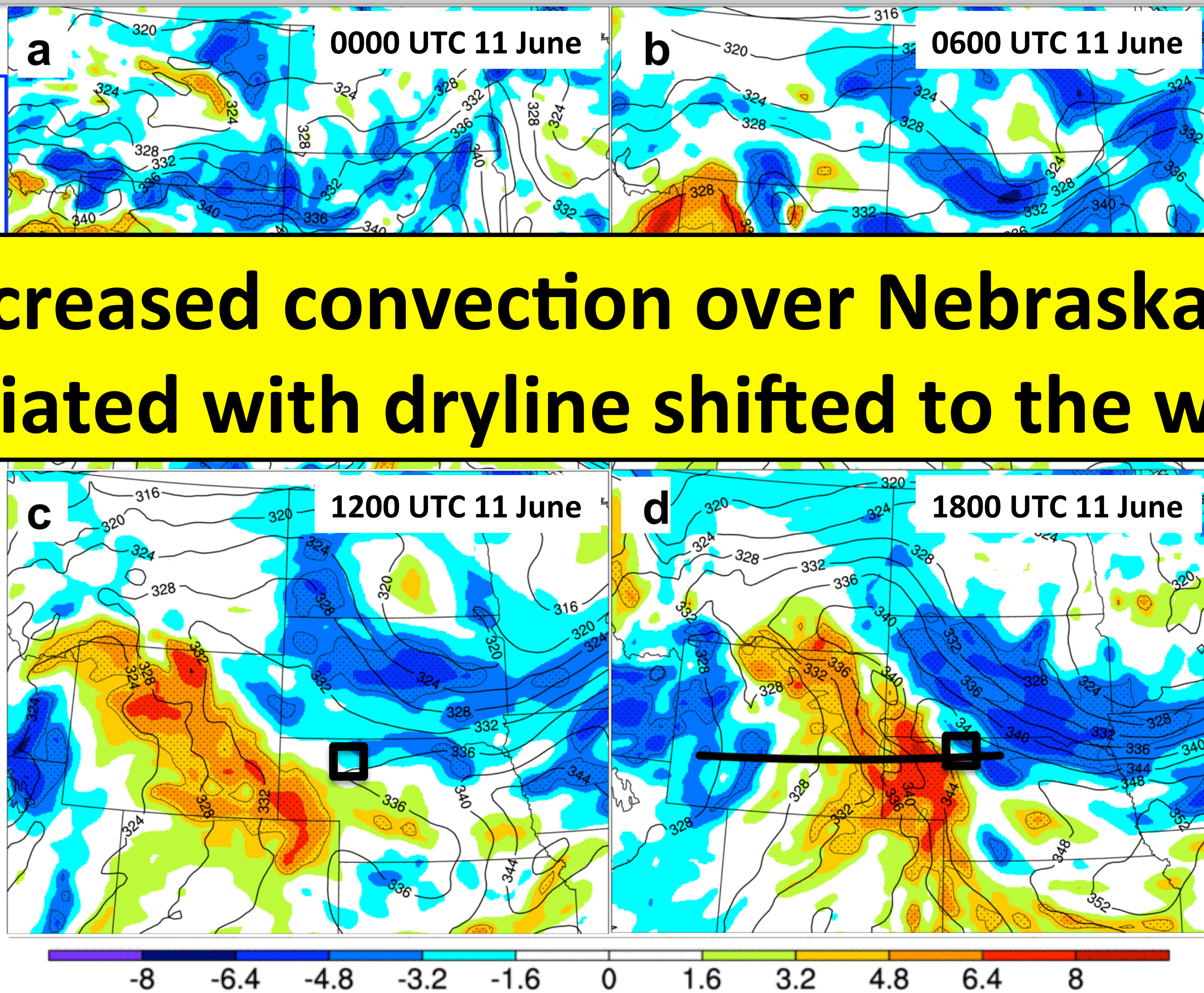
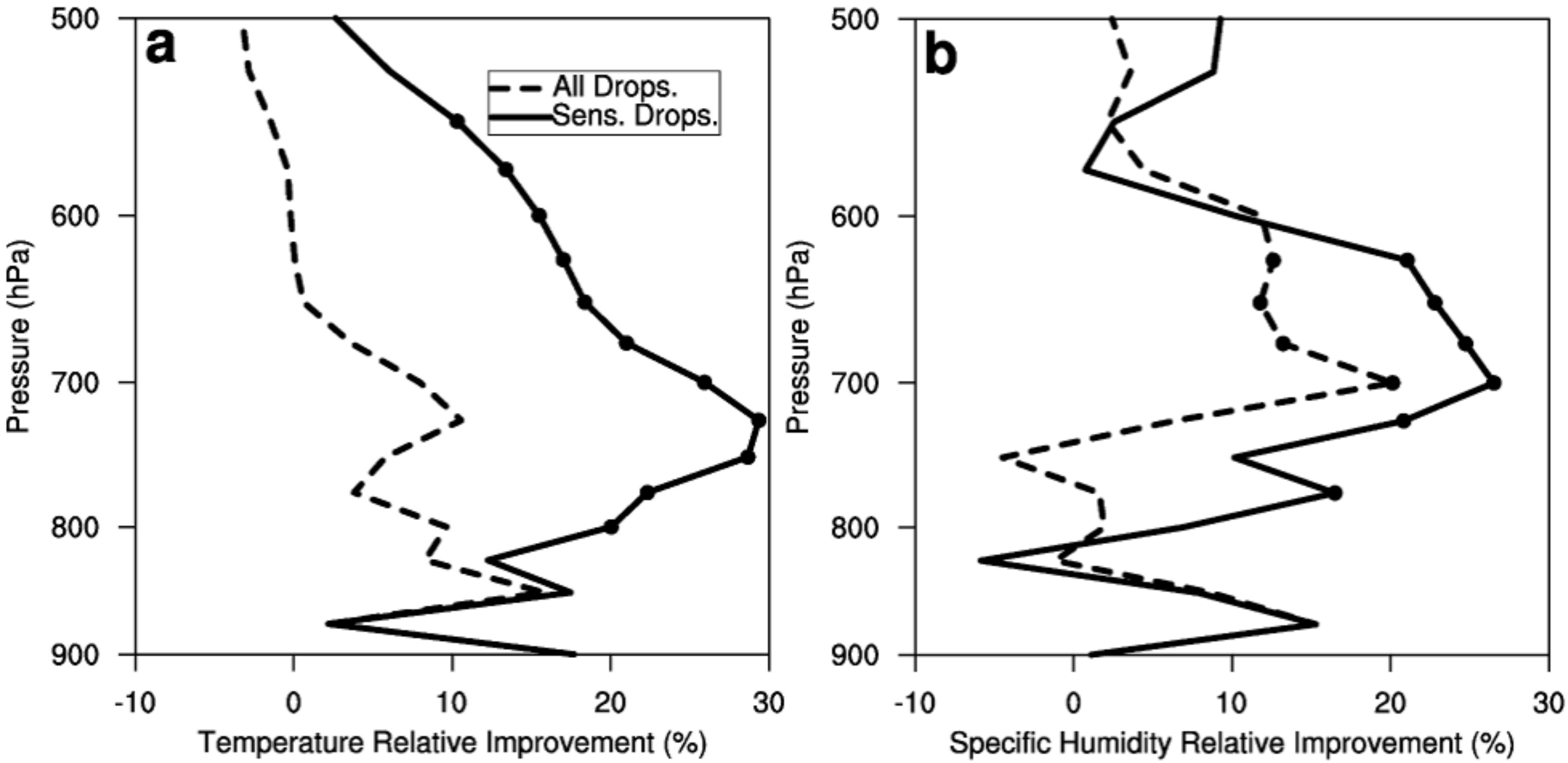


Increased convection over Nebraska associated with dryline shifted to the west

Dropsonde Impact on Dryline: 1200 UTC 11 June



Relative improvement in (a) temperature and (b) specific humidity mean-absolute error between the weak and strong members with respect to the sensitive profiles (black) and all dropsondes (dashed) initialized 24-h prior. Levels with a dot denote where the difference is statistically significant at the 95% confidence level.

Summary and Conclusions

- Forecast variability in the timing and location of convection over Nebraska.

- Convection forecasts sensitive to position of upstream dryline, which modulates the pre-convective moisture.

- Sensitivity analysis can suggest regions for targeting to improve convective forecasts.
  - Dropsondes near sensitive area show a more accurate forecast of the pre-convective thermodynamic environment.
  - Future work to assimilate these dropsondes.

Berman, J. D., R. D. Torn, G. S. Romine, M. L. Weisman: *MWR*, soon to be submitted

Extra Slides

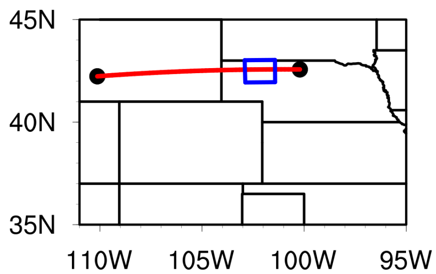


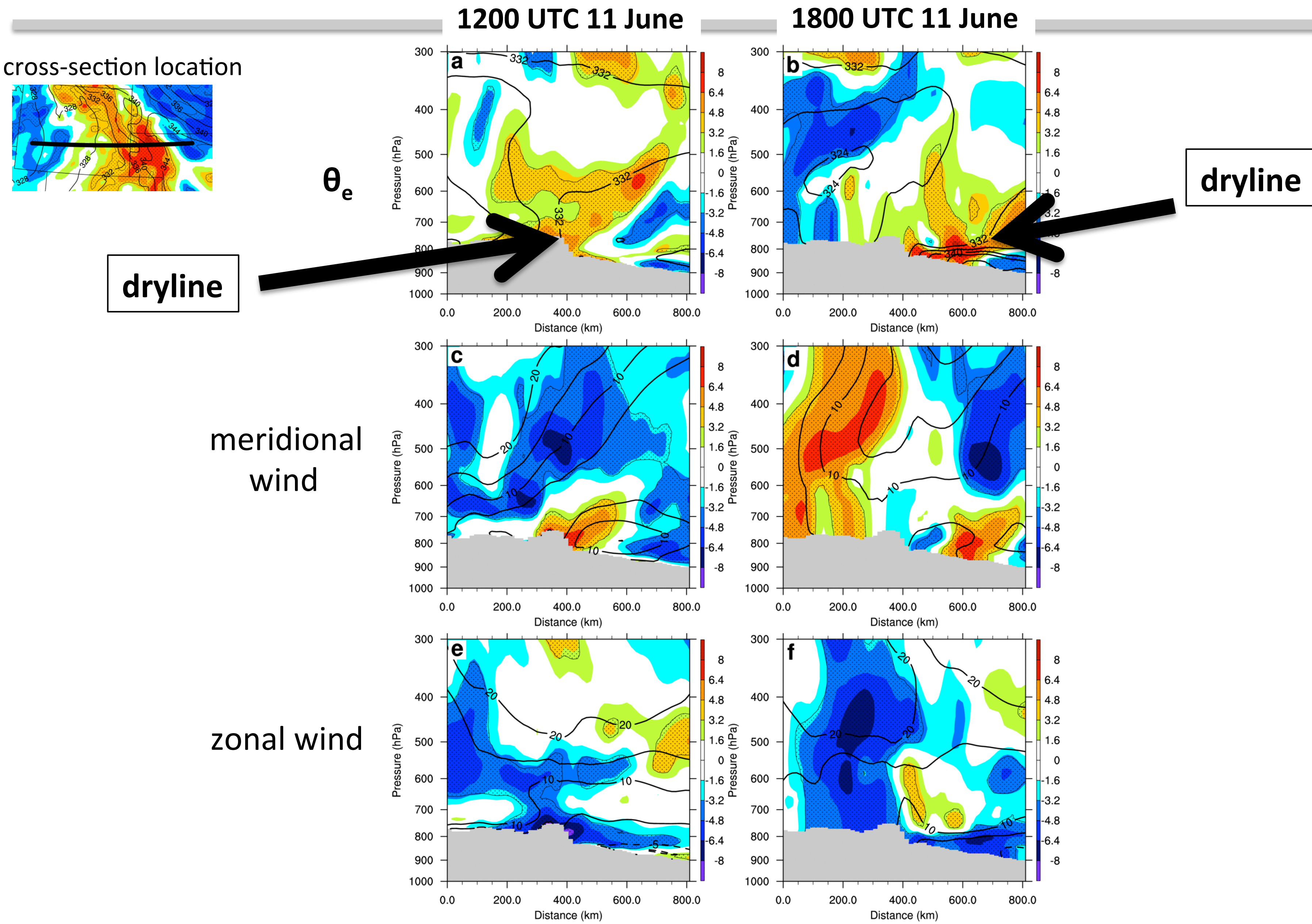
TABLE 1. Physical parameterizations used in all WRF Model forecasts. Cumulus parameterization was not used on the convection-allowing 3-km grid.

Physical parameterization	WRF Model option	References
Microphysics	Thompson	Thompson et al. (2008)
Long- and shortwave radiation	Rapid Radiative Transfer Model for Global Climate Models (RRTMG) with ozone and aerosol climatologies	Mlawer et al. (1997); Iacono et al. (2008); Tegen et al. (1997)
Planetary boundary layer	Mellor–Yamada–Janjić (MYJ)	Mellor and Yamada (1982); Janjić (1994, 2002)
Land surface model	Noah	Chen and Dudhia (2001)
Cumulus parameterization	Tiedtke	Tiedtke (1989); Zhang et al. (2011)

TABLE 2. Localization settings and analysis variables in the EAKF system, as well as the observations that were assimilated.

Parameter	Value
ocalization function	Gaspari–Cohn
orizontal localization half-width	635 km
ertical localization half-width	8 km
nalysis variables	Zonal and meridional wind components; perturbation potential temperature and geopotential height; water vapor, cloud water, rainwater, ice, graupel, and snow mixing ratios; rainwater and ice number concentrations; diabatic heating
ssimilated observations	Radiosonde, aircraft, METAR, surface synoptic observation (SYNOP), buoy, ship, atmospheric motion vectors, global positioning system refractivity

Sensitivity Analysis: Cross-section



Sensitivity Analysis: 330-340 K PV