Assimilation of Fixed Screen-Height Observations in a Parameterized PBL

Joshua Hacker and Chris Snyder

hacker@ucar.edu

National Center for Atmospheric Research

Outline

- Lessons from predictability studies
- Major challenges for DA in the PBL
- Experiments with a column model
- Parameter estimation experiments

The Brutal Facts

- Initial condition error is guaranteed but unknown
- Model error is guaranteed but unknown
- Observation error is guaranteed but unknown
- The atmosphere is nonlinear and chaotic

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History shows the situation is not hopeless, but we need to recognize limitations and account for what we cannot know.

Predictability Lessons

- The forecast problem, particularly at small scales, is inherently probabilistic.
- We are obligated to include estimates of uncertainty in observations, analyses, and forecasts and how they relate to the "flow of the day."
- The only way we know how to do this is to combine ensemble forecasts with a data assimilation system, using our best dynamic models.

Challenges for ensemble DA in the PBL

- Model error
- Forward operator error
- Covariance localization shape and length

Model error in the PBL (a short list)

- Choice of “constants” in parameterization schemes
- Structural error in parameterizations
- Static land-surface descriptions
- Biases from misrepresentation of orography

Operator (H) error in the PBL

- Representativeness
- Deterministic error from model formulation
- Lack of error growth in forecast

Approaches to These Problems

The name of the game...

$$
\begin{aligned}
\mathbf{x}^{\mathsf{a}} &= \mathbf{x}^{\mathsf{b}} + \mathbf{P}^{\mathsf{b}}\mathbf{H}^{\mathsf{T}} \left(\mathbf{H}\mathbf{P}^{\mathsf{b}}\mathbf{H}^{\mathsf{T}} + \mathbf{R}\right)^{-1} \left(\mathbf{y}^{\mathsf{o}} - \mathbf{H}\mathbf{x}^{\mathsf{b}}\right) \\
\mathbf{P}^{\mathsf{b}} &= \mathbf{M}\mathbf{P}^{\mathsf{a}}\mathbf{M}^{\mathsf{T}} + \mathbf{Q}
\end{aligned}
$$

$\mathbf{M}$ is the model propagator. $\mathbf{Q}$ is the model error covariance matrix.

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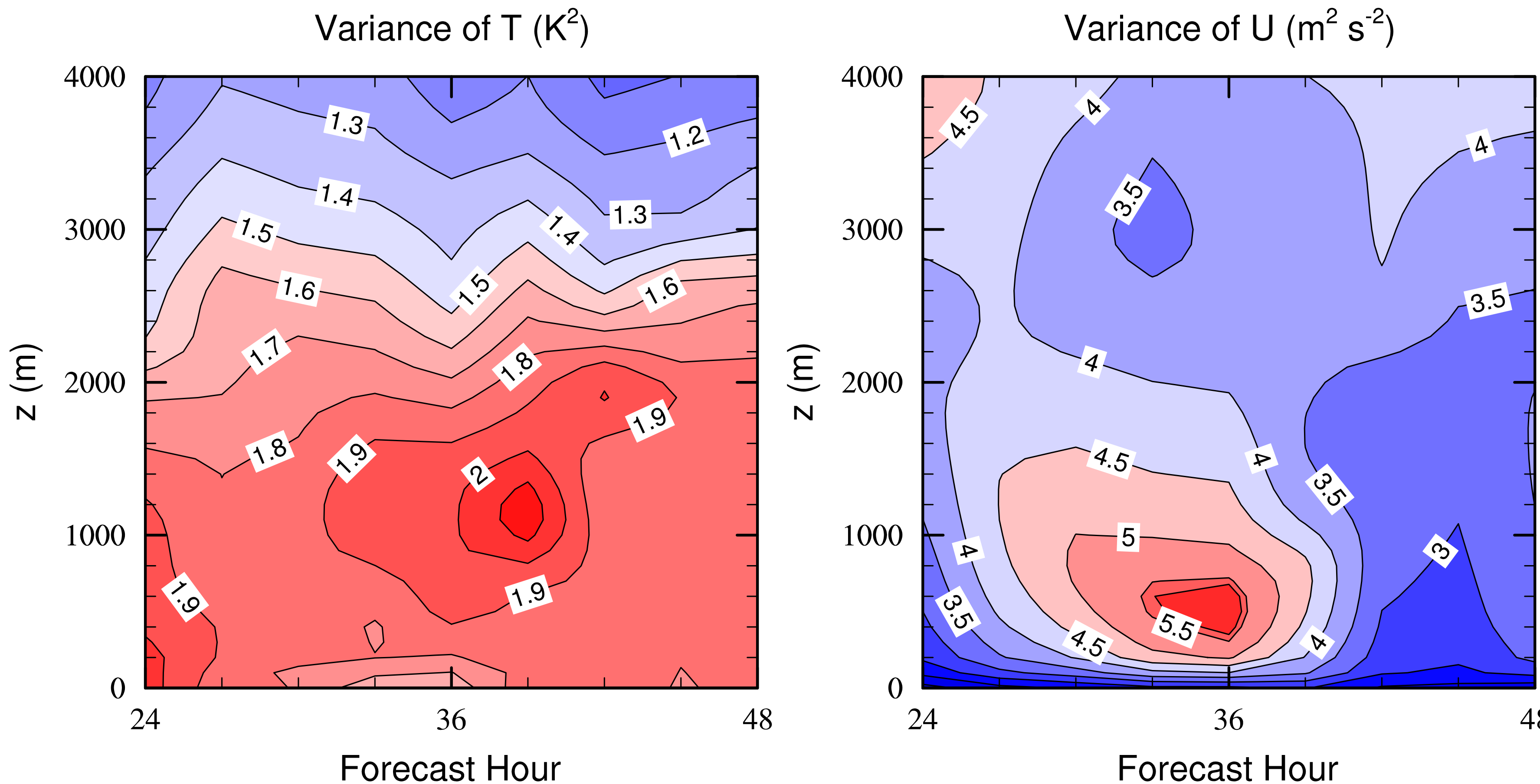
- Ensemble Kalman Filter (EnKF) data assimilation in the PBL (estimate $\mathbf{P}^{\mathsf{b}}$).
- Augment $\mathbf{x}$ with model parameters and estimate them from the observations.

Experiment

- Analyze summer WRF climatology of PBL forecasts.
- Design off-line single-column model (MRF PBL parameterization).
- Large-scales forced by WRF climatology.
- Perform assimilation experiments on 500 cases ("truth" randomly chosen) with 100-member ensembles.
- Perform parameter estimation experiments with moisture availability parameter.

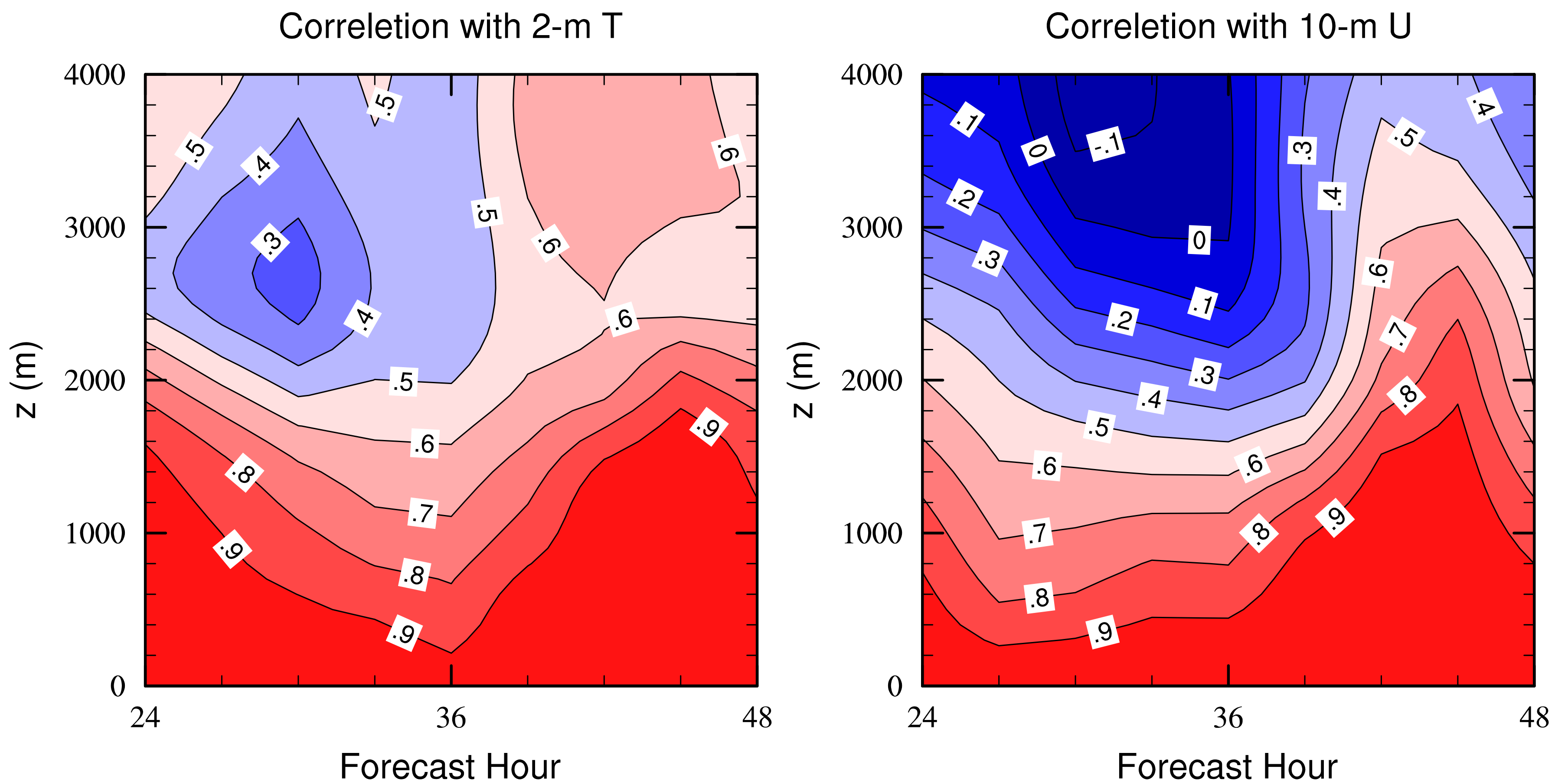
WRF Climatology

Summer southern great plains variance in the column

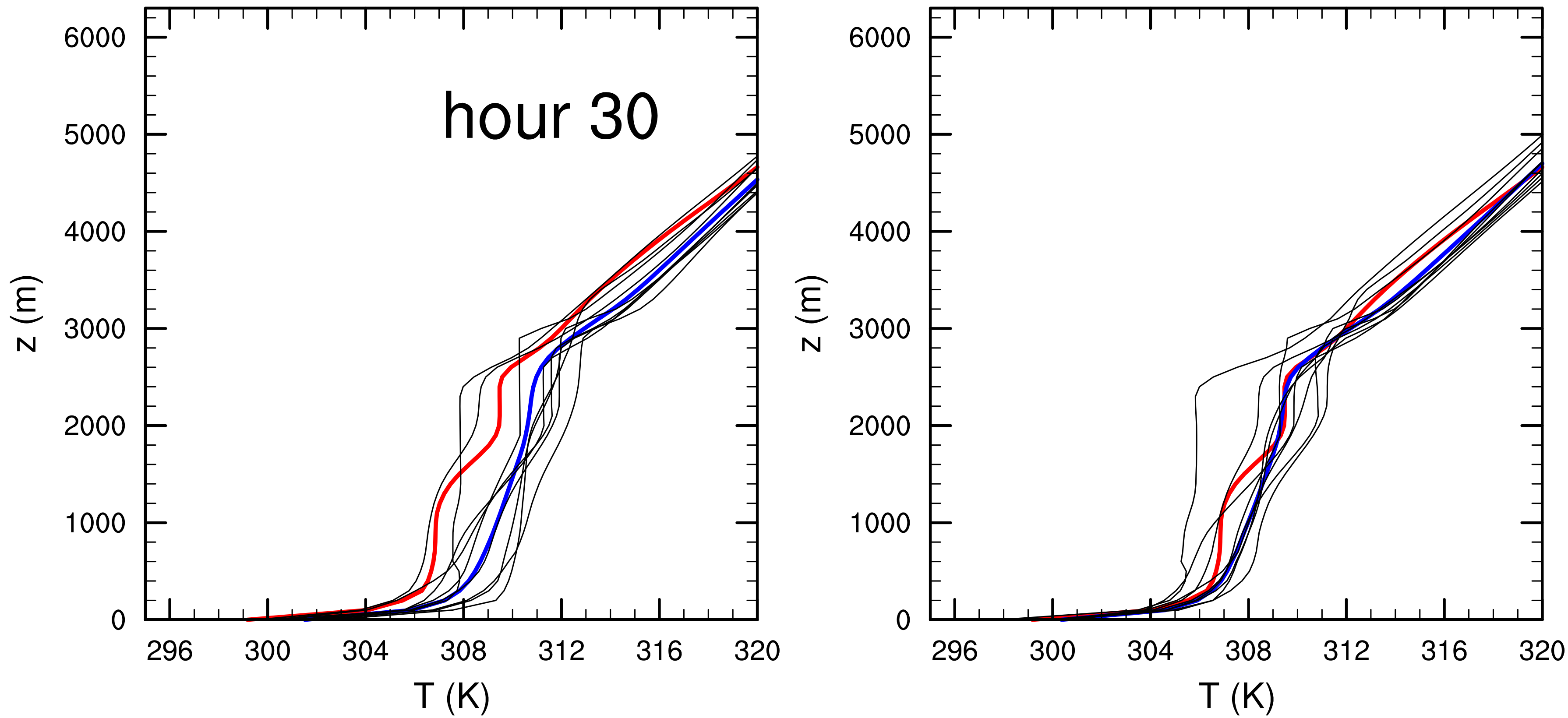


WRF Climatology

Summer southern great plains correlation with screen-height state.



Assimilation Example: Nighttime



TRUTH and ENSEMBLE MEAN

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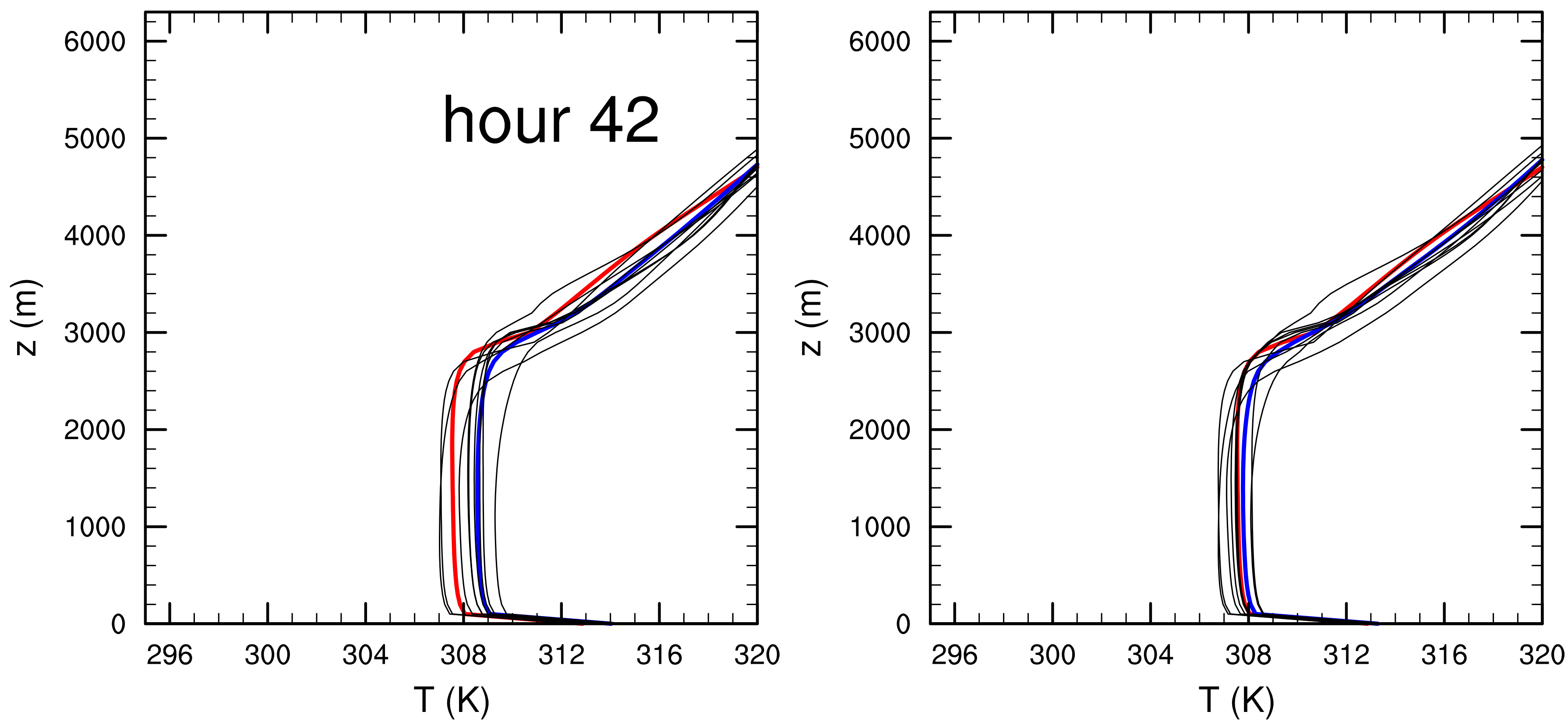
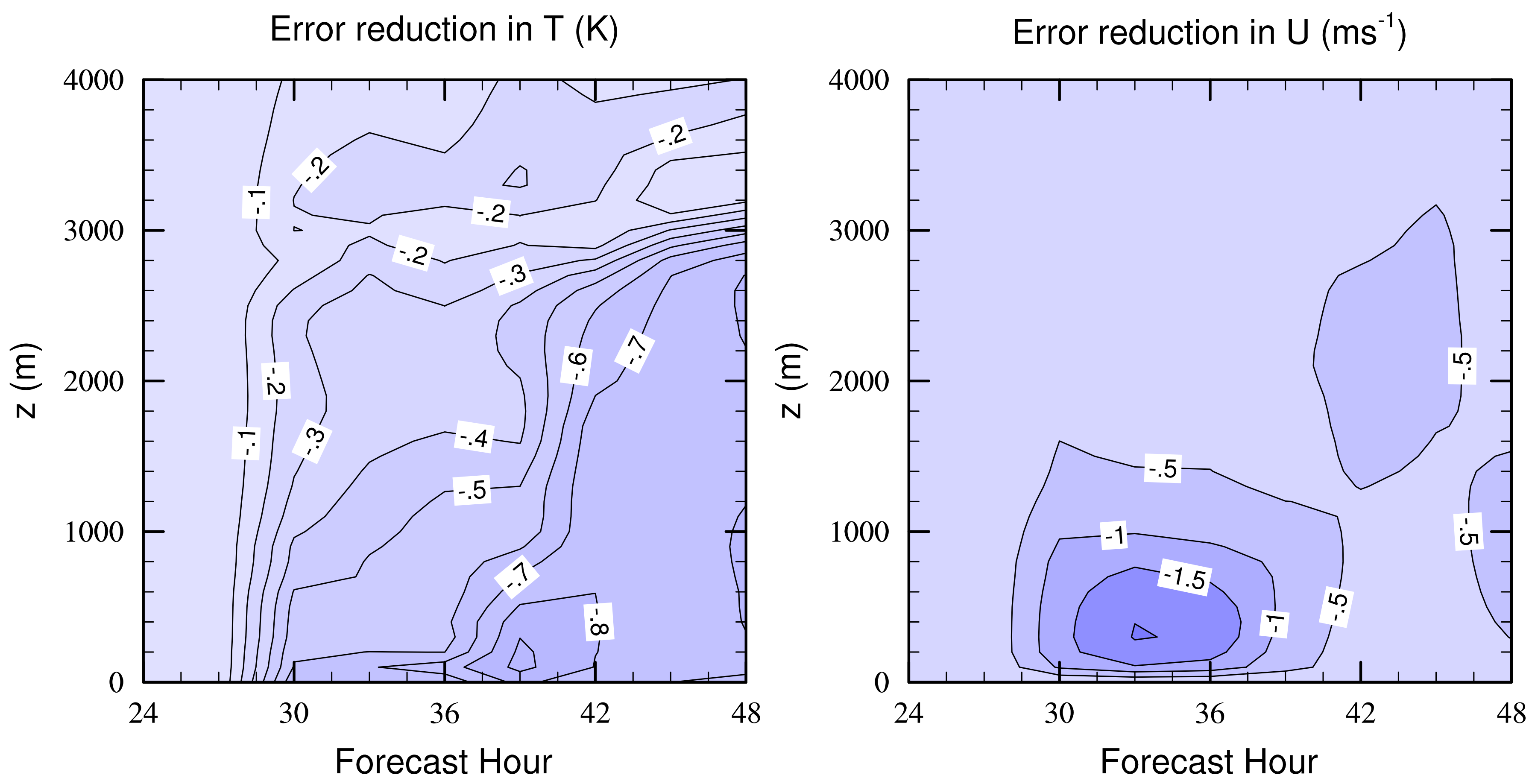


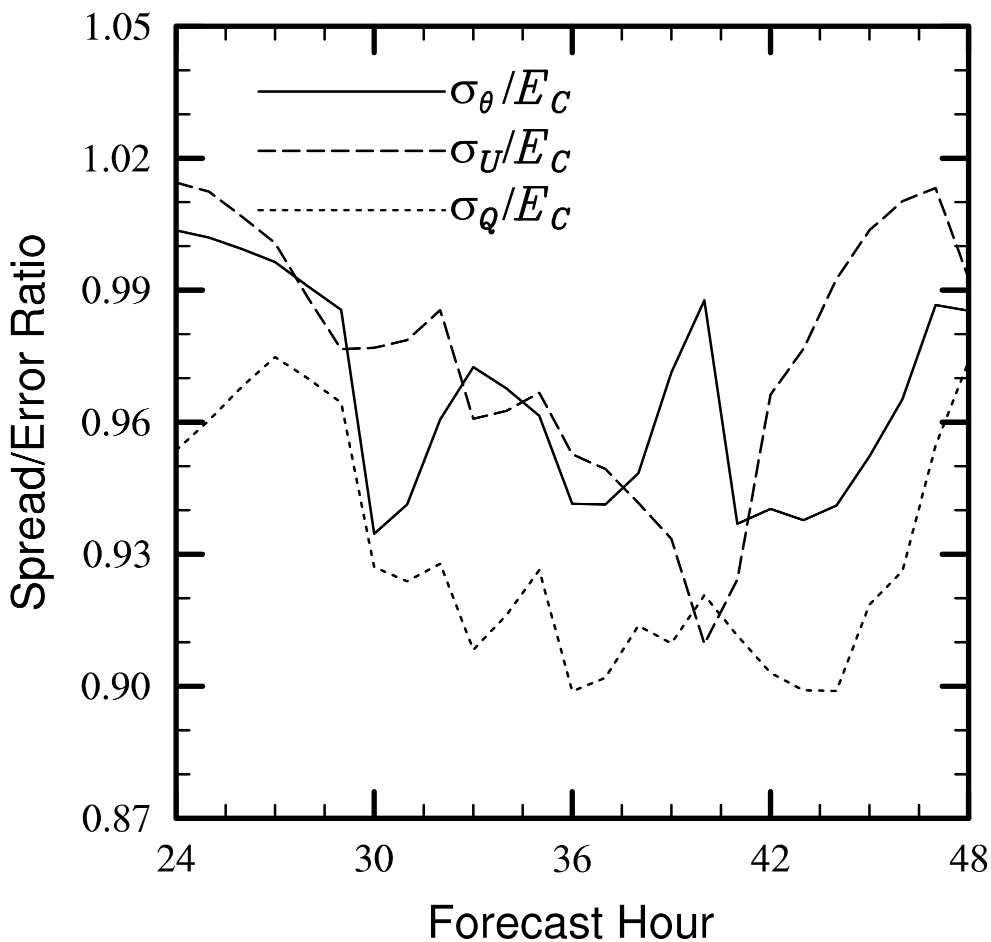
TRUTH and ENSEMBLE MEAN

Average Error Reduction for Assimilation



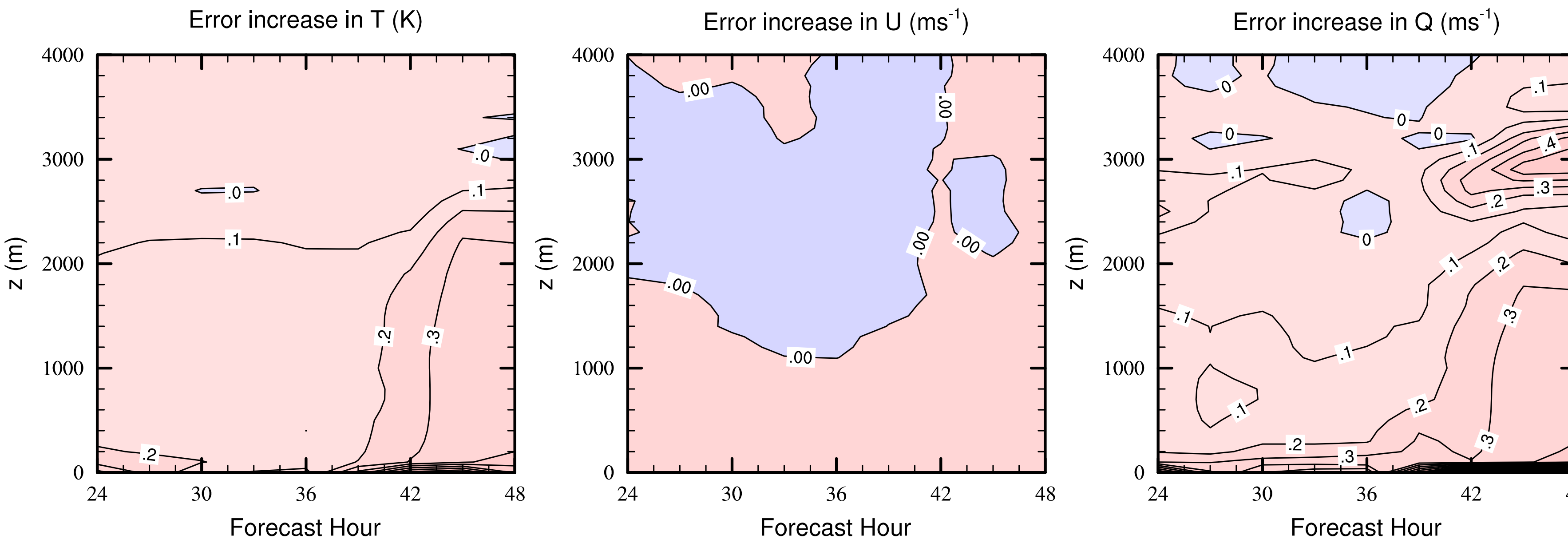
Is the Assimilation Working?

- Compare spread and error for $0 < z < 1000$ m



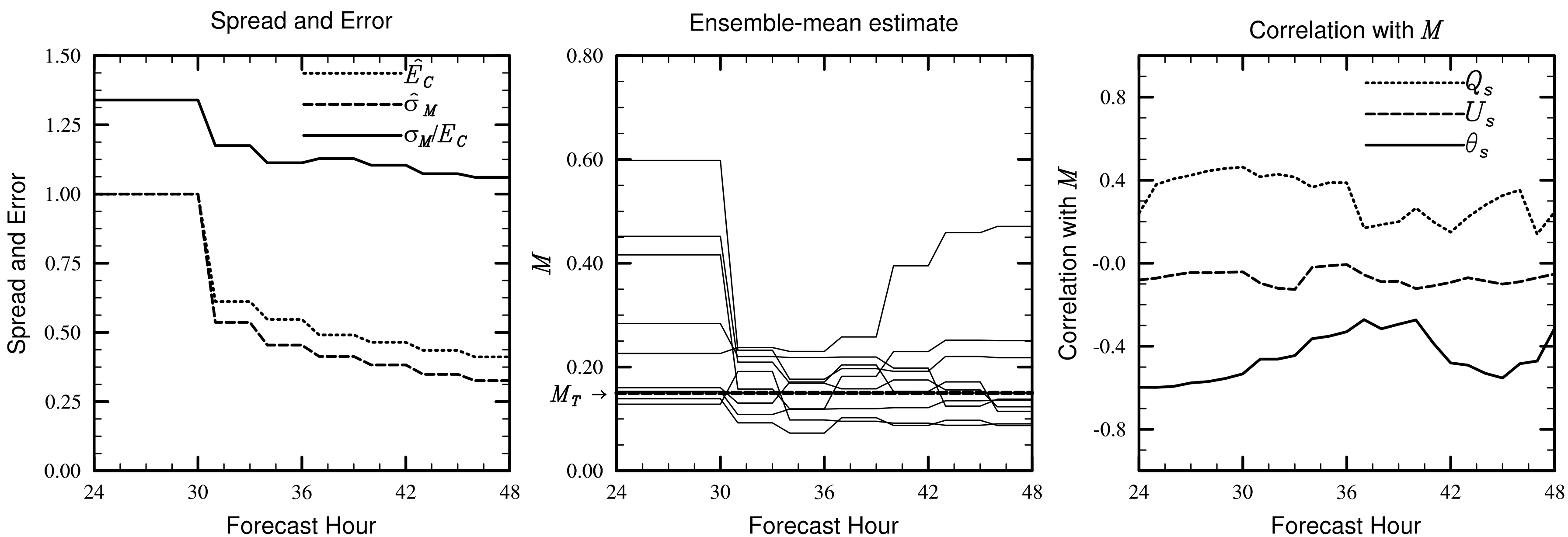
Add Some Model Error

Random log-normal error in moisture availability parameter M ($\sigma_M = 0.1M$).



Estimate M

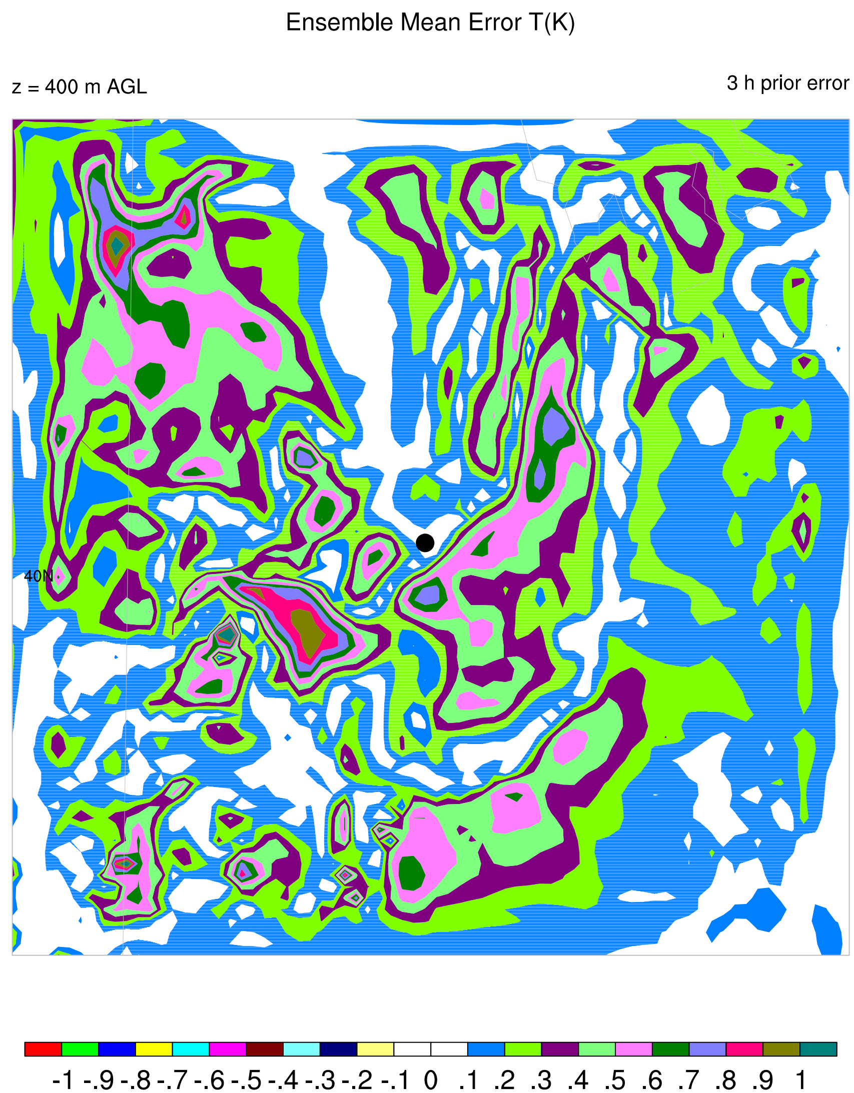
- Augment the state vector with M and allow the observations to modify the distribution.



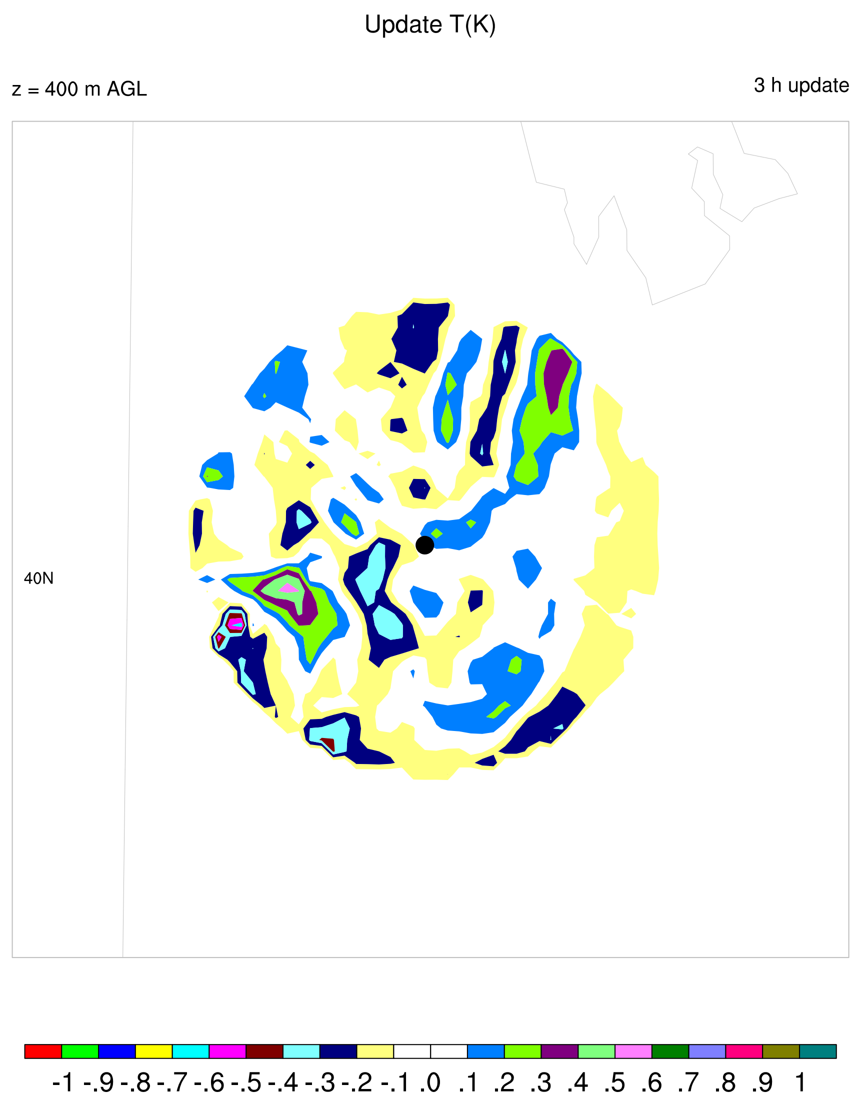
WRF experiments

- Weather Research and Forecast model
- Domain over northern Utah
- $\Delta X =$ 3 km
- 40-member ensembles
- Assimilation of single profile
- Perfect U, V, T obs with noise

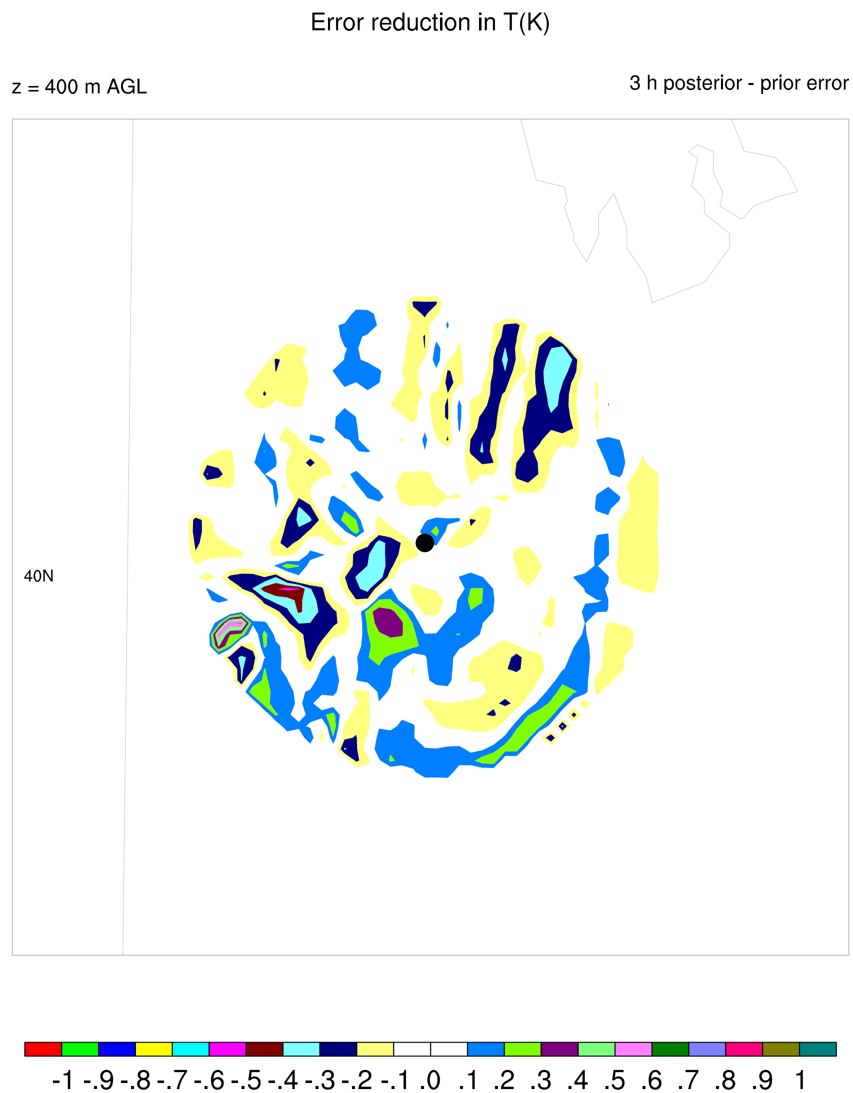
Prior error at 3 h



Update from a single profile



Error reduction at 3 h



Conclusions

- In a current-generation mesoscale model, the state at screen height is strongly coupled to the PBL through most of the diurnal cycle.
- Off-line modeling experiments show that these strong covariances can be exploited to determine the structure of the PBL with surface observations.
- Model error can be mitigated by augmenting the state vector with model parameters, and estimating their distributions.

To do:

- Continue 3D investigations — boundary conditions, nesting, cost

An Analysis of Record for the PBL

- Model error: uncertainty in $\mathbf{H}$, structural and parameter errors
- In situ observation platforms: what are the responses?