On the effectiveness of surface assimilation in probabilistic nowcasts of planetary boundary layer profiles.

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Motivation: Forecast/nowcast in the Planetary Boundary Layer (PBL)

Importance: Successful forecast/nowcast of the PBL is important is valuable for a broad spectrum of practical forecasting applications:

- Convective initiation and forecasted precipitation (e.g. Crook 1996; McCaul and Cohen 2002; Martin and Xue 2006).
- Air quality and plume dispersion (e.g. Kumar and Russell 1996; Shafran et al. 2000).
- Wind-resource siting and real time wind-power operations (e.g. Wagner et al. 2009)
- Forecast of local thermally-driven circulations such as sea-land and mountain breezes (e.g. Leidner et al. 2001).

Challenges:

- Short scale dynamics: need to be parameterized in mesoscale NWP models.
- Model error in the PBL as severe as other sources of error.
- Real-time mesoscale ensemble systems capable of providing skillful high-resolution [O(1) km] probabilistic nowcasts and short-range forecasts of the PBL are beyond the capacity of present computational resources.

Motivation: Surface observations

- They are often the most reliable and easiest to set up observations we have in the PBL

- They are generally under-utilized in NWP and data assimilation (DA):
  - Difficult to determine the vertical influence of the observations.
  - Error of representativeness (coarse resolution of the model).
  - Dynamic balances exploited in large-scale DA inappropriate.

- Potential for information transfer from the surface to the atmosphere aloft:
  - Hacker and Snyder (2005) showed strong surface-atmosphere correlation, that is intermittent, anisotropic and nonstationary.
  - Hacker and Rostkier-Edelstein (2007) showed that surface observations can be an important source of information with an single column model and an ensemble filter.

Goal:

Find an efficient system for probabilistic nowcasting of PBL profiles wherever surface observations are present.

Question:

What is the needed degree of sophistication of the surface assimilation method to be used?

Approaches:

1. A Single Column Model (SCM) of the PBL and Ensemble Filter (EF) Data Assimilation (DA) of surface observations

2. Correct a 3D-mesoscale prediction of the profile and dress it to provide uncertainty, using surface-forecast errors and climatological surface-atmosphere covariances.

Both methods computationally cheap!

Thousands of realizations possible with a quick turn around.

1. SCM/EF

SCM:

- Original model developed by Mariusz Pagowski, NOAA/ESRL.
- Various (WRF) land-surface and PBL parameterizations.
- Prognostic equations for T, Q_v, U, V.
- Externally-imposed horizontal advection (optional).
- Parameterized radiation calculations (optional).
- Fast, so many vertical levels are possible (here 81, top at 16 km).

- A variety of initialization and forcing options: Here use WRF 3D forecast at the column location.

- Several possible levels of complexity: factor-separation study to assess the impact of several model components.

EF DA:

- NCAR DART system
- Typically 100-member ensemble of SCM→ ***flow-dependent covariances***
- Assimilation of surface observations (T, Q_v, U, V) every 30 minutes.
- Mean and uncertainty forecasts directly derived from the ensemble of SCM.

2. "Climatological dressing" (CD)

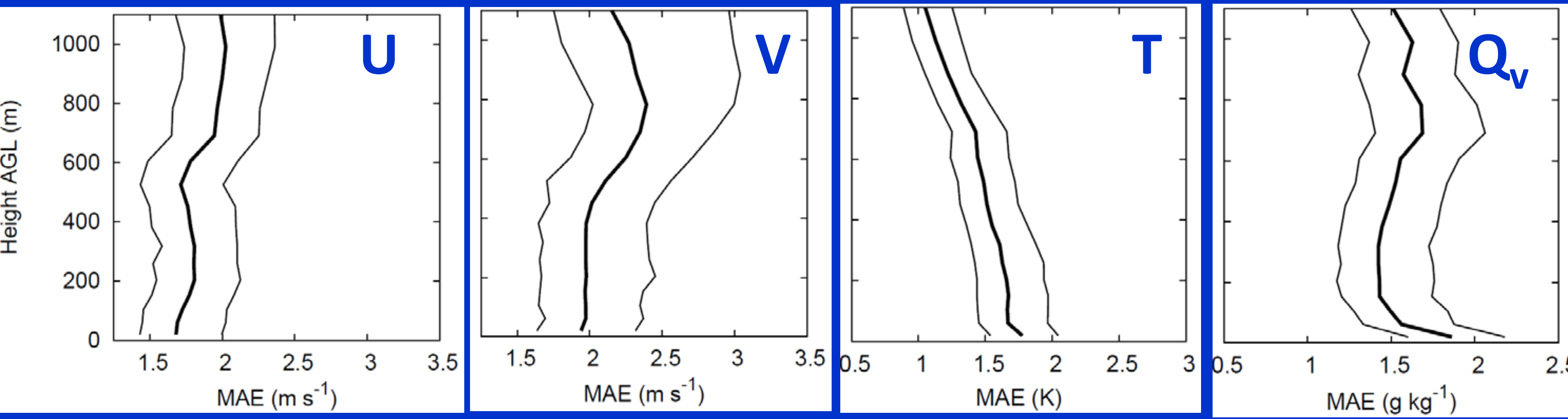
- Simpler and faster than SCM/EF.
- Corrects a 3D-mesoscale prediction in the column, and dresses it to provide uncertainty.
- Uses surface observations (*T*, Q_v, *U*, *V*) to assess surface-forecast errors.
- Assumes error in the surface is persistent over 30 min.
- Mean 30-min profile forecast: May be viewed as an optimal interpolation method.
  - Uses ***static "climatological" surface-atmosphere covariances*** (conditioned to time of day) to linearly regress the error correction at the surface onto the profile.
  - We use a sample of WRF 3D forecast profiles for the covariance calculation.
- 30-min uncertainty estimate: The climatological variance of a profile variable scaled by the climatological error variance at the surface (scaling acts to contract).

Can these simple models improve WRF forecasts?

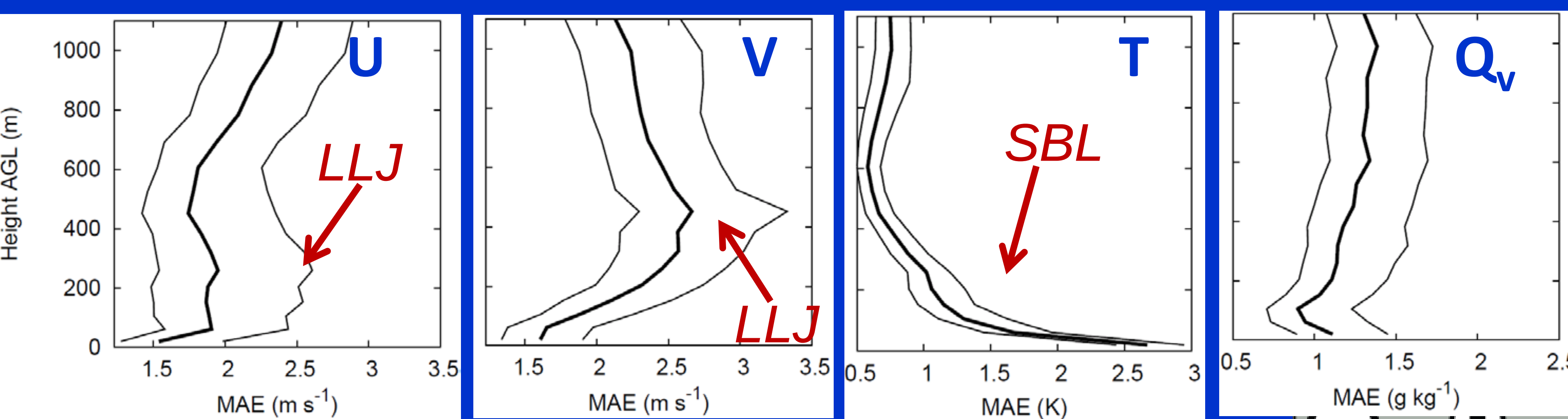
<u>WRF, 4km grid,</u> cold starts at 19 LT, ARM site (Oklahoma, USA), May 3 –July 14, 2003.

Mean absolute error, MAE (against soundings)

12:30 LT



00:30 LT



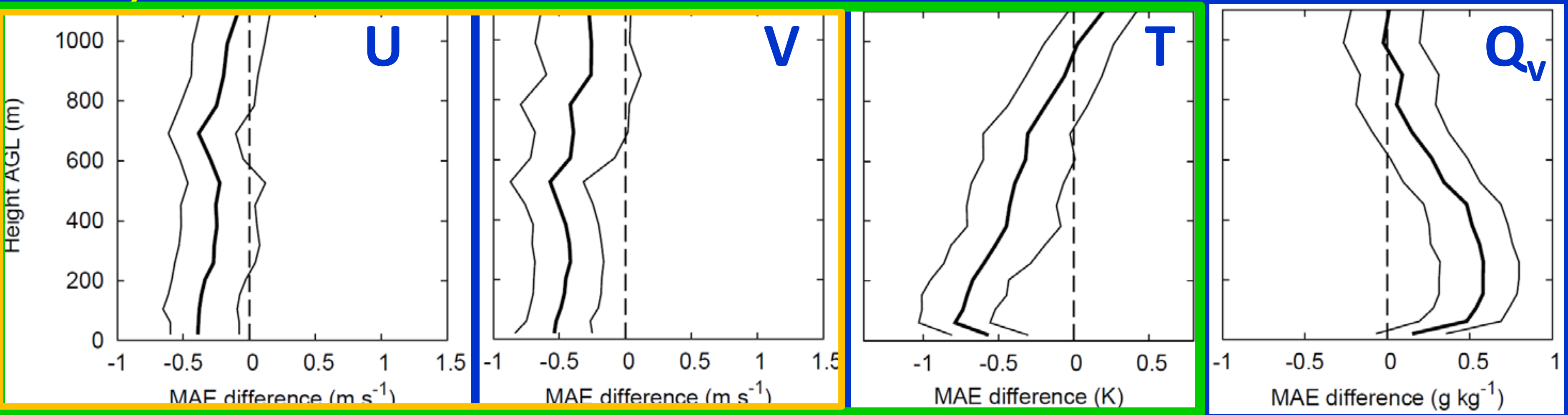
(bold lines: WRF experiments; thin lines: 90% confidence intervals, by bootstrapping)

Can these simple models improve WRF forecasts?

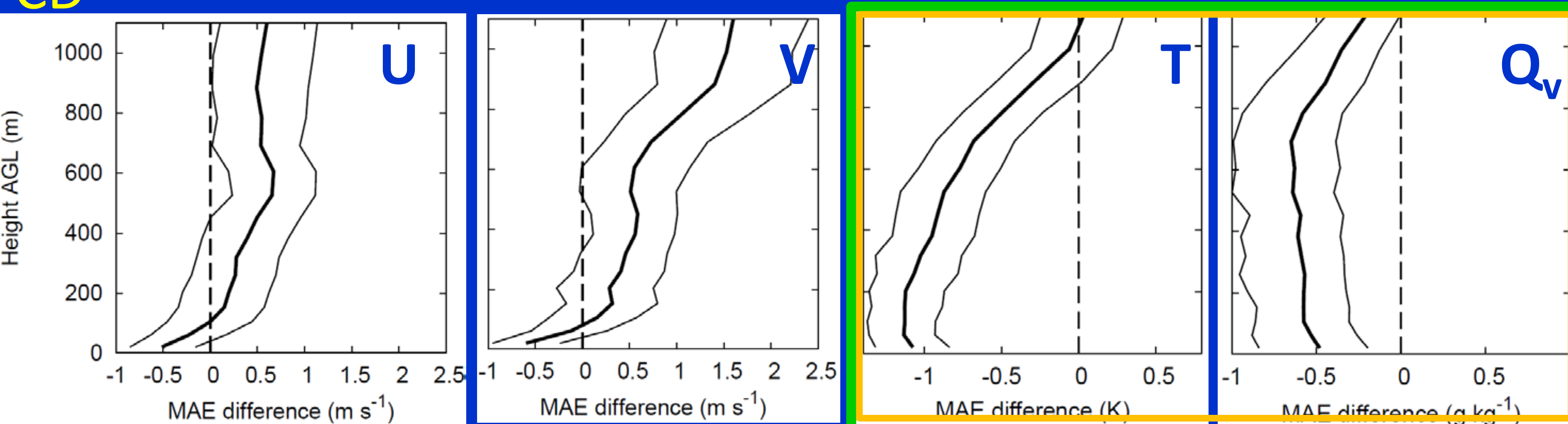
MAE differences: simple model 30-min nowcasts *minus* WRF forecasts

12:30 LT

SCM/EF



CD



A negative MAE difference indicates improvement over WRF

SCM/EF and CD w.r.t. WRF at 12:30 LT

- Both methods are capable of improving WRF forecasts.

- Further analysis (not shown here) show the reasons for the differences between the methods:
  - Superior skill from SCM/EF for wind components:

    Flow-dependent covariances are more accurate than climatological covariances.

  - CD is more skillful for temperature and moisture:

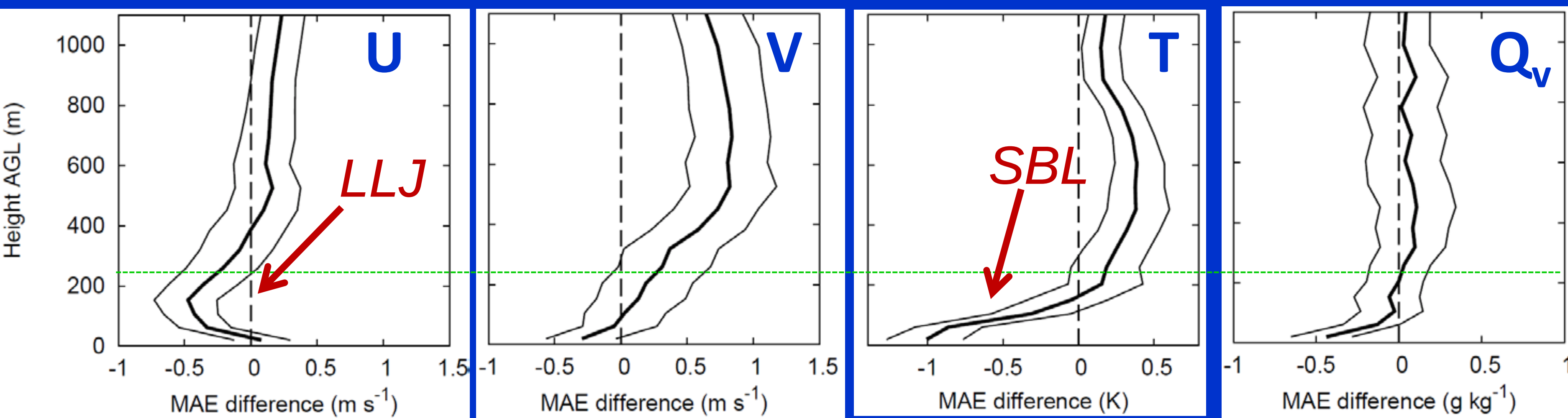
    SCM/PBL parameterization yields biased flow-dependent covariances (**model error a limitation** in the EF)

    Climatological covariances are not biased.

Can these simple models improve WRF forecasts?

MAE differences: simple model 30-min nowcasts *minus* WRF forecasts

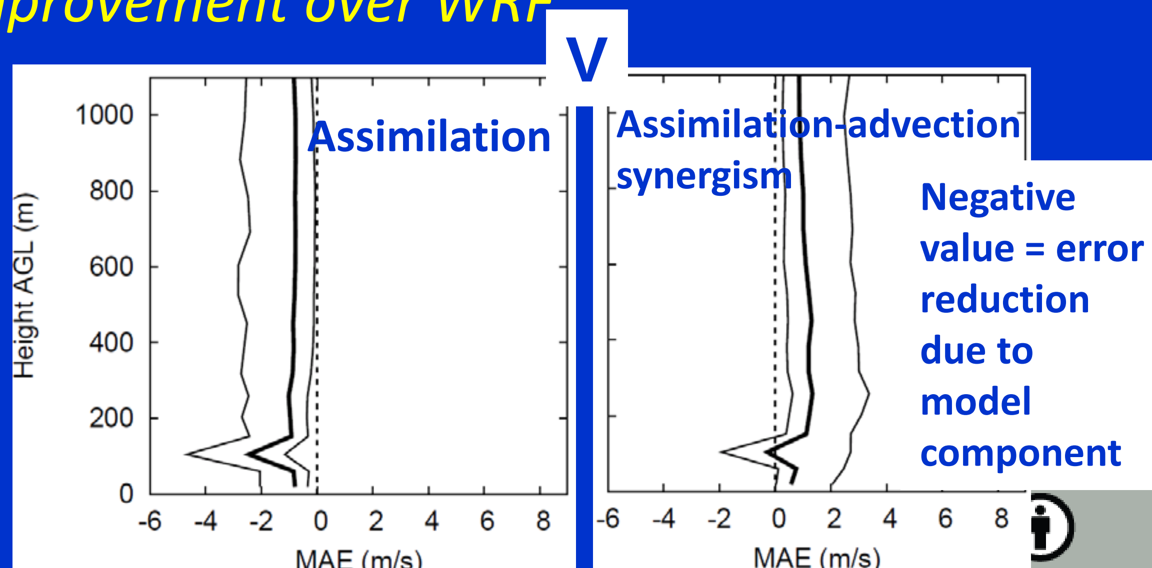
Only SCM/EF improves WRF   00:30 LT



A negative value indicates improvement over WRF

Factor separation analysis, **V:**

- Assimilation reduces error, in particular at levels where LLJ develops.
- Assimilation-advection synergism erases this improvement.



SCM/EF and CD w.r.t. WRF at 00:30 LT

Further analysis (not shown here) show the reasons for the differences between the methods:

- CD fails to improve WRF at night because either:
  - The 30-min surface-error persistence assumption fails.
  - Failure of WRF-sample climatological covariances to represent error covariances.

- SCM/EF improves WRF at night because:

  It handles seasonal flow variability not accounted for in static CD covariances.

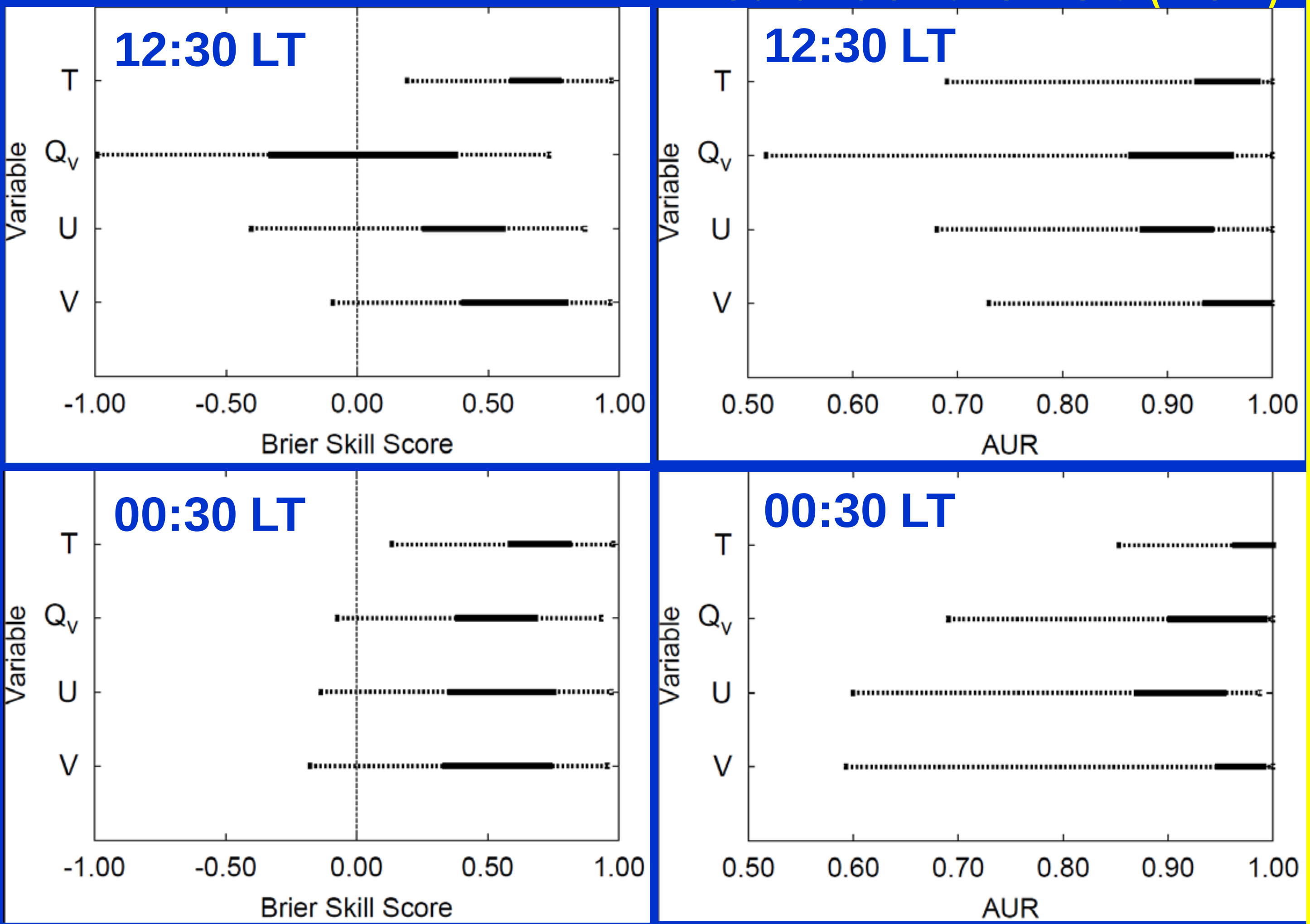
- SCM/EF shows poorer skill than the 3DWRF above approximately 200 m AGL because:

  Surface-atmosphere covariances decrease steeply with height leading to spurious covariances (need for better locatization or larger ensemble).

Probabilistic verification: SCM/EF

Verifying: Probability of exceeding the 75th quantile of the observed climatology relative to in-sample climatological forecast

Brier Skill Score — Area under the ROC (AUR)



- Useful probabilistic information with respect to observed climatology both at 1230 and 0030 LDT **(BSS > 0, AUR > 0.5)**
- Scores show similar ranges of values for all variables along the profile, except for Q_v at 1230 LDT.
- The reliability score indicates bias for Q_v at 1230 LDT, consistent with the deterministic verification (not shown here).

(Ranges of values between 0-1km AGL, full lines: experiments; dotted lines: 90% confidence intervals)

Summary

- Both methods improve 3D-WRF forecasts under several flow conditions.
- Assimilating surface observations improves predictions in the lowest hundred meters AGL where surface-atmospheric covariances are significant.
- The SCM/EF improves forecasts under a wider variety of flow scenarios than does the CD.
- **The CD method is less sensitive to bias, suggesting that some of its features could be used in a simple bias-correction scheme for the SCM/EF (on-going)**
- Both the CD and SCM/EF provide an estimate of the nowcast uncertainty **not available in the 3D-WRF deterministic forecasts.**
- On-going work uses WRF-SCM and DART EF.

References:

Rostkier-Edelstein, D. and J. P. Hacker, 2010. *Wea. Forecasting, 25, 1670–1690, doi:10.1175/2010WAF2222435.1.*800

Rostkier-Edelstein, D. and J. P. Hacker, 2013. *Wea. Forecasting*, **28**, 29–54. doi: 10.1175/WAF-D-12-00043.1

Thanks