Behavior of Stable Surface Layer in the NCEP Global Forecast System

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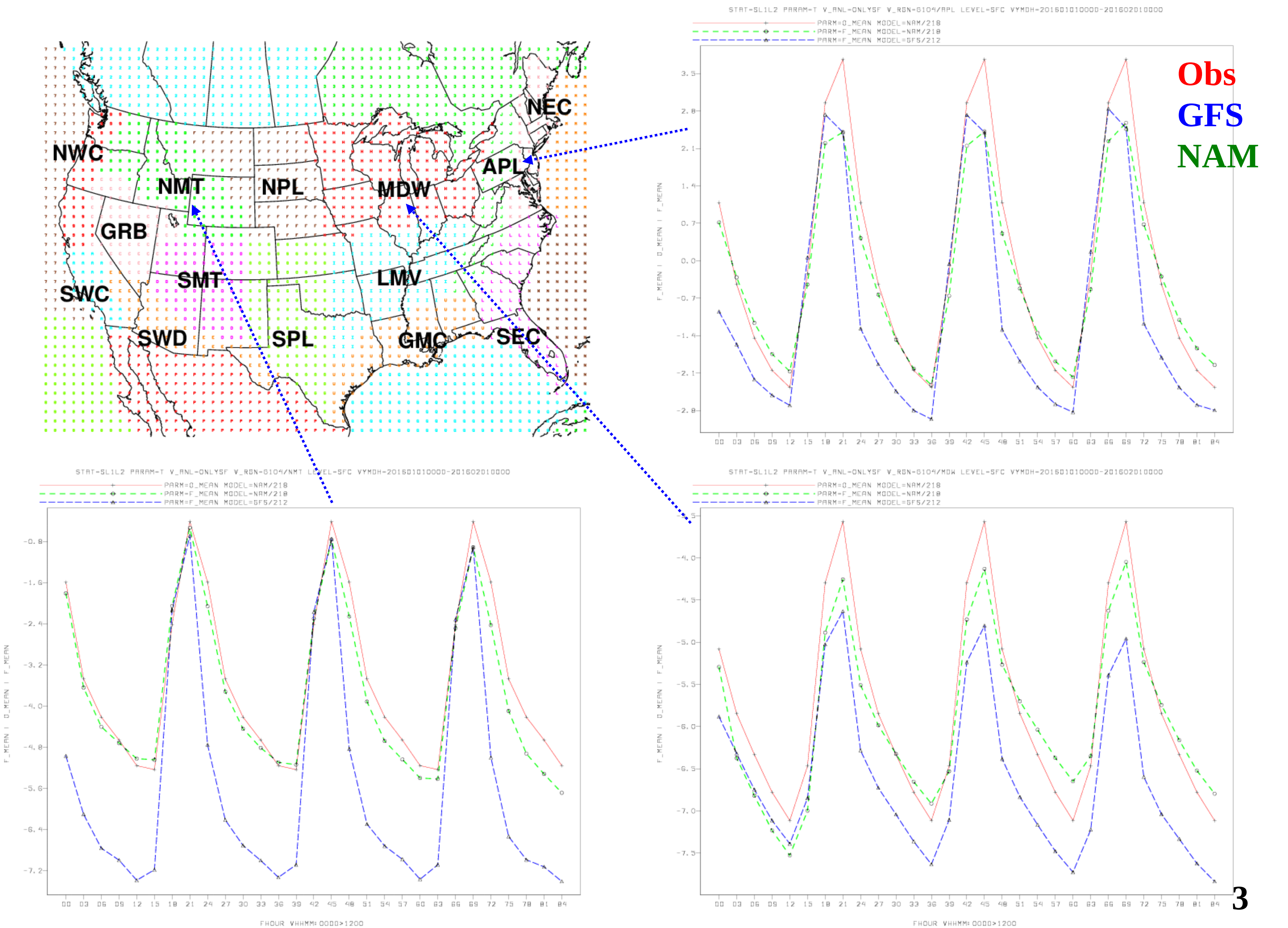
Motivations:

- **What is the problem about GFS surface temperature forecast?**
  - ***One of Top 10 problems in the GFS***
    NWS Field Office, NCEP/EMC Model Evaluation Group (MEG)

- **What causes this kind of problem?**
  - ***Understanding of stable boundary layer (SBL) processes***

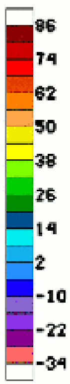
- **How to solve the problem?**
  - ***An approach to fix the problem***

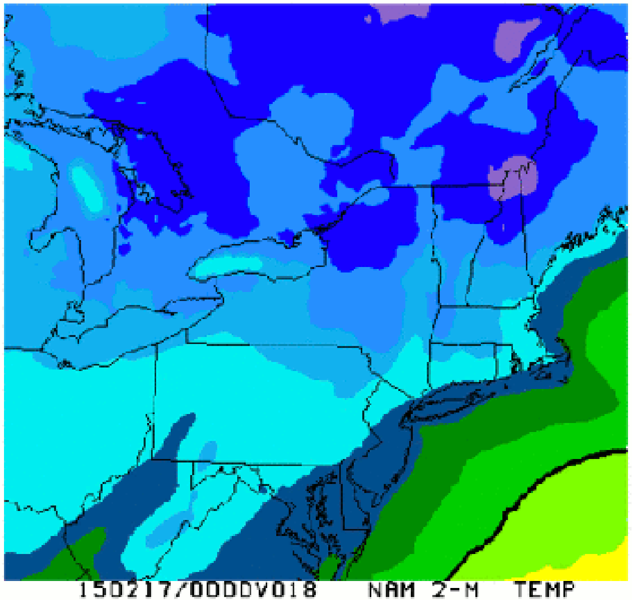
Ops GFS: T2m Forecast Verification Statistics for Jan 2016



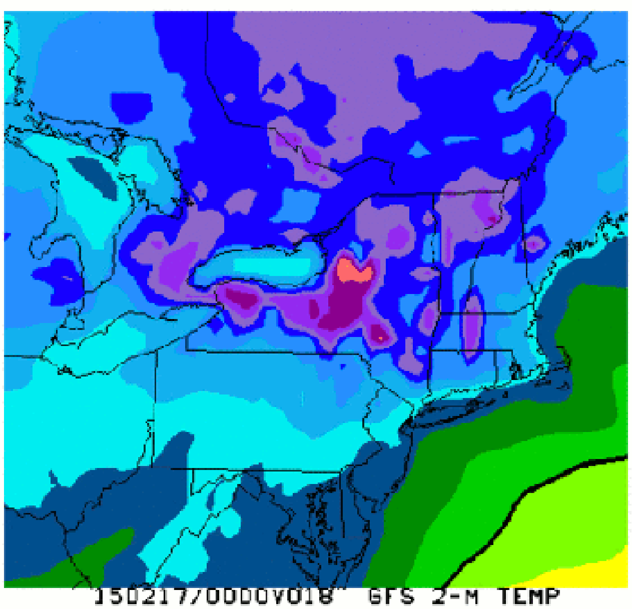
Comparison of T_{2m} (F): NAM, GFS and Obs, 00UTC, 2015-02-17

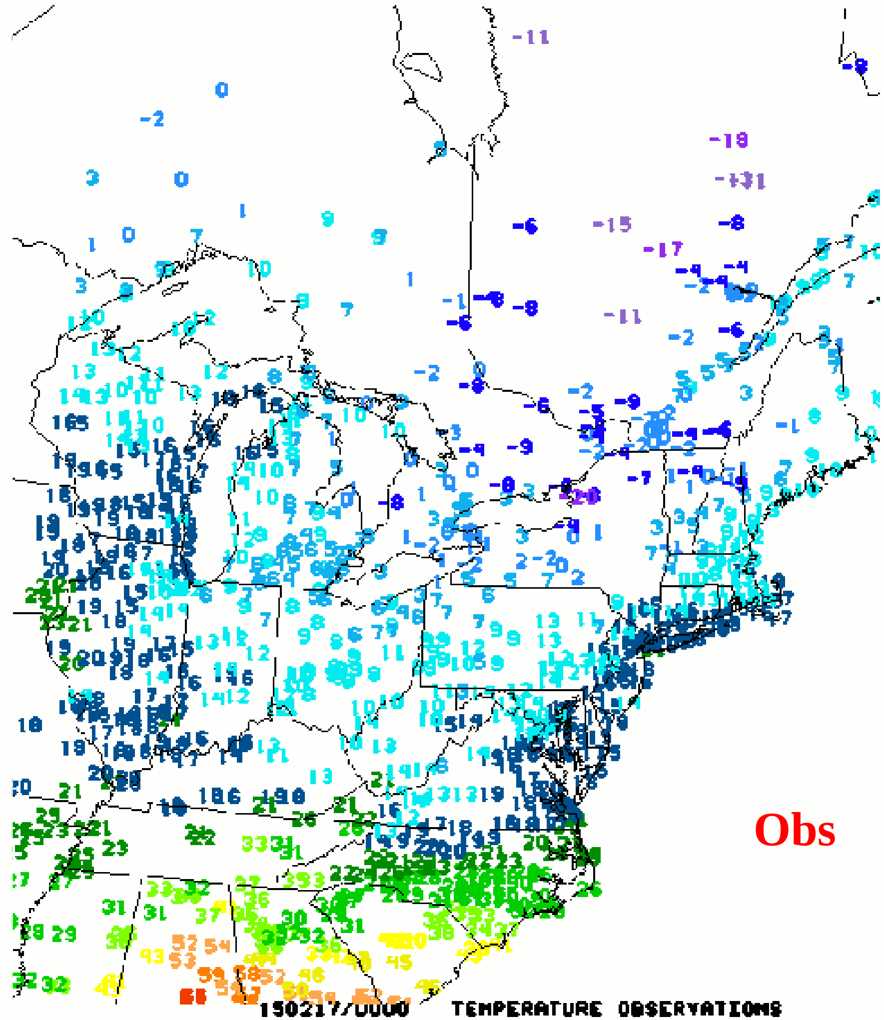
NAM





GFS



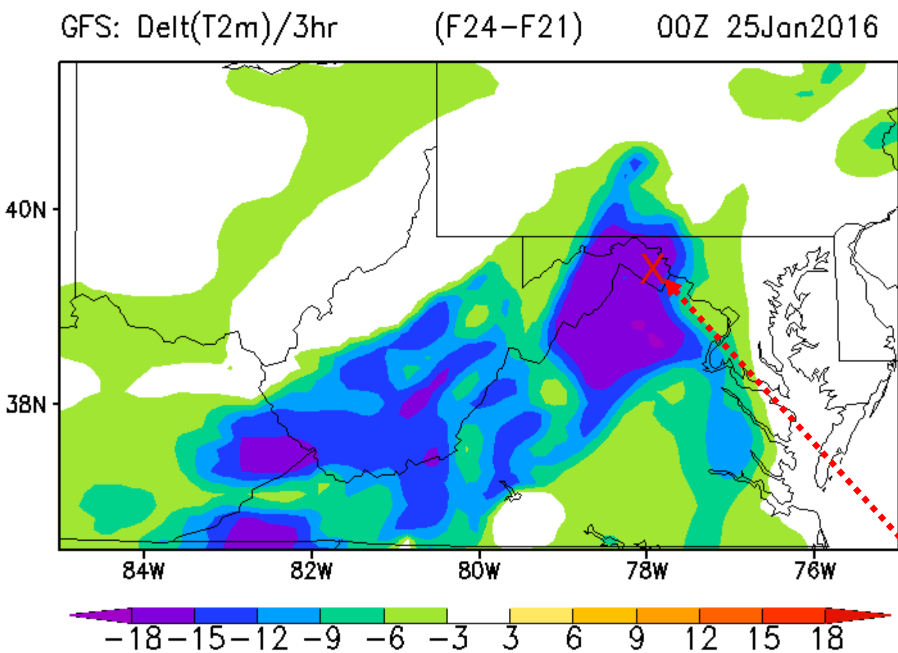


Obs

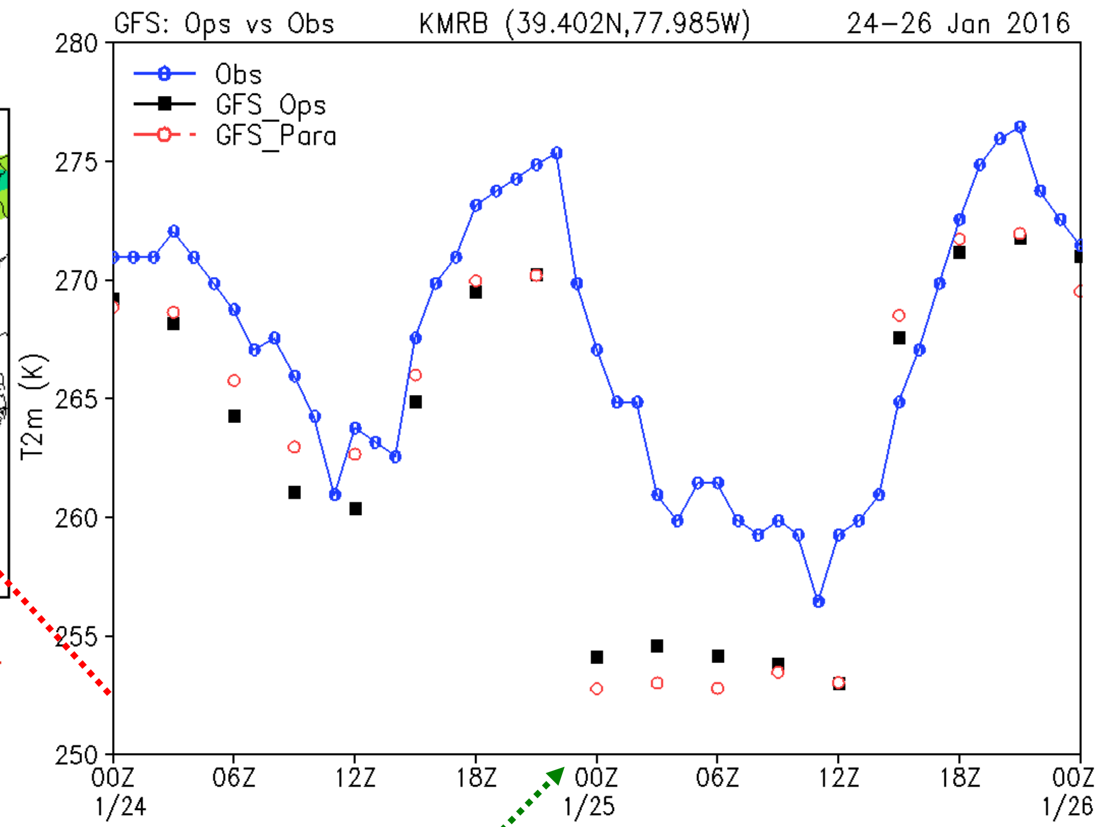
Courtesy Geoffrey Manikin, MEG- 02/19/15

GFS/GFSX T2m @ MRB Matinsburg RGNL, WV

00Z 01/24/2016 Cycle

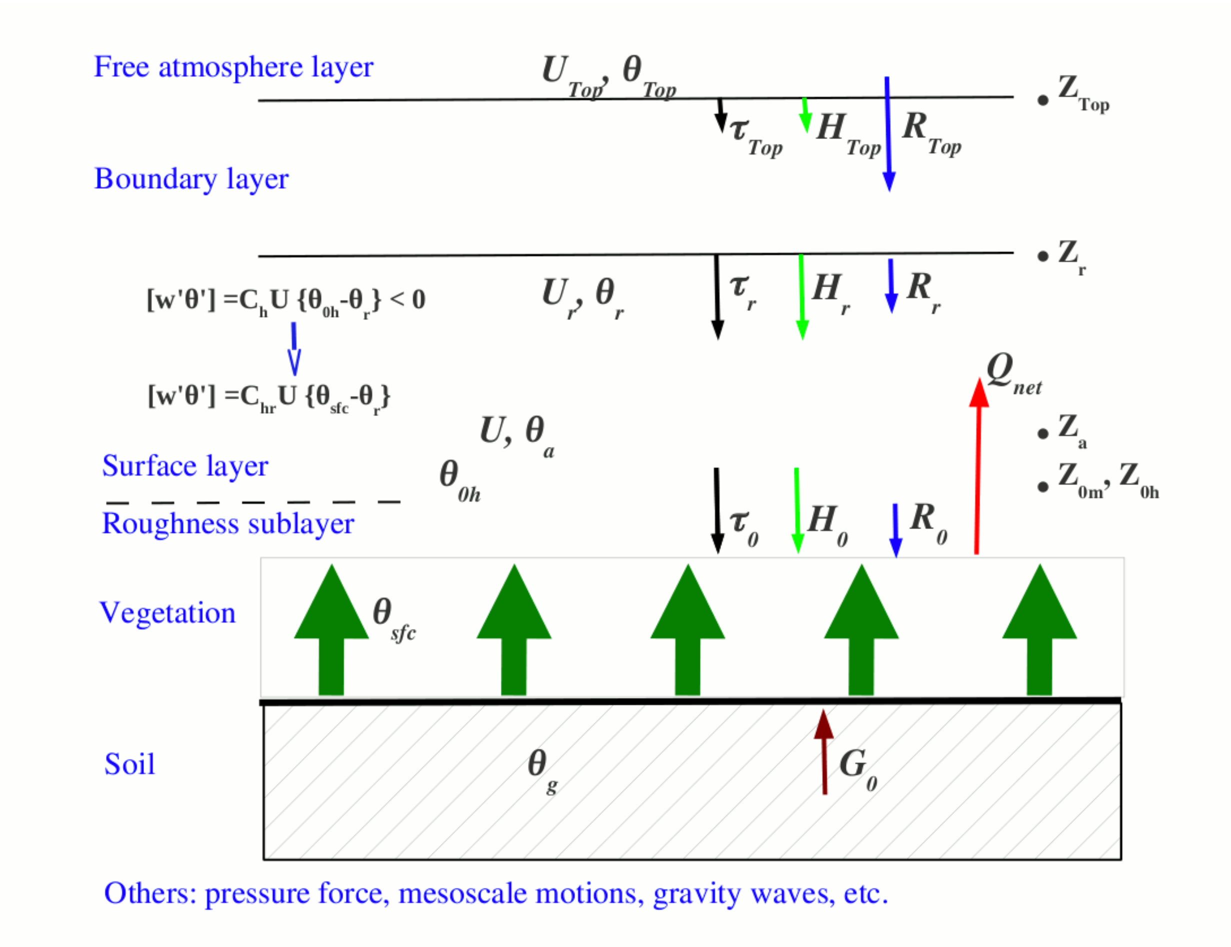


T2m @ KMRB



Ops GFS or GFSX: Rapidly cooling up to 15 °C during 3hr;
About 13 degrees of cold bias at 00Z, 25 Jan.
GFSX: Became current operational version on May 11, 2016.

Schematic view of land-atmosphere stable boundary layer



Night-time surface energy budget (LHF is small so neglected):

(A) Under turbulence: $H+R+G_0 \sim Q_{net}$ ===> ***quasi-steady state***

(B) Under cessation of turbulence: $R+G_0 \sim Q_{net}$ + (others) ===> ***new state***

The system may reach different equilibrium states !

Monin-Obukov Similarity Theory in GFS (SBL)

$$C_M = k^2/F_M^2$$

$$C_H = k^2/F_M F_H$$

$$\varphi_M = \varphi_H = \frac{1}{2}(1 + \sqrt{1 + 4\alpha\xi}).$$ $\xi = z/L$ $L = \frac{\theta}{kg}\frac{u_*^2}{\theta *}$

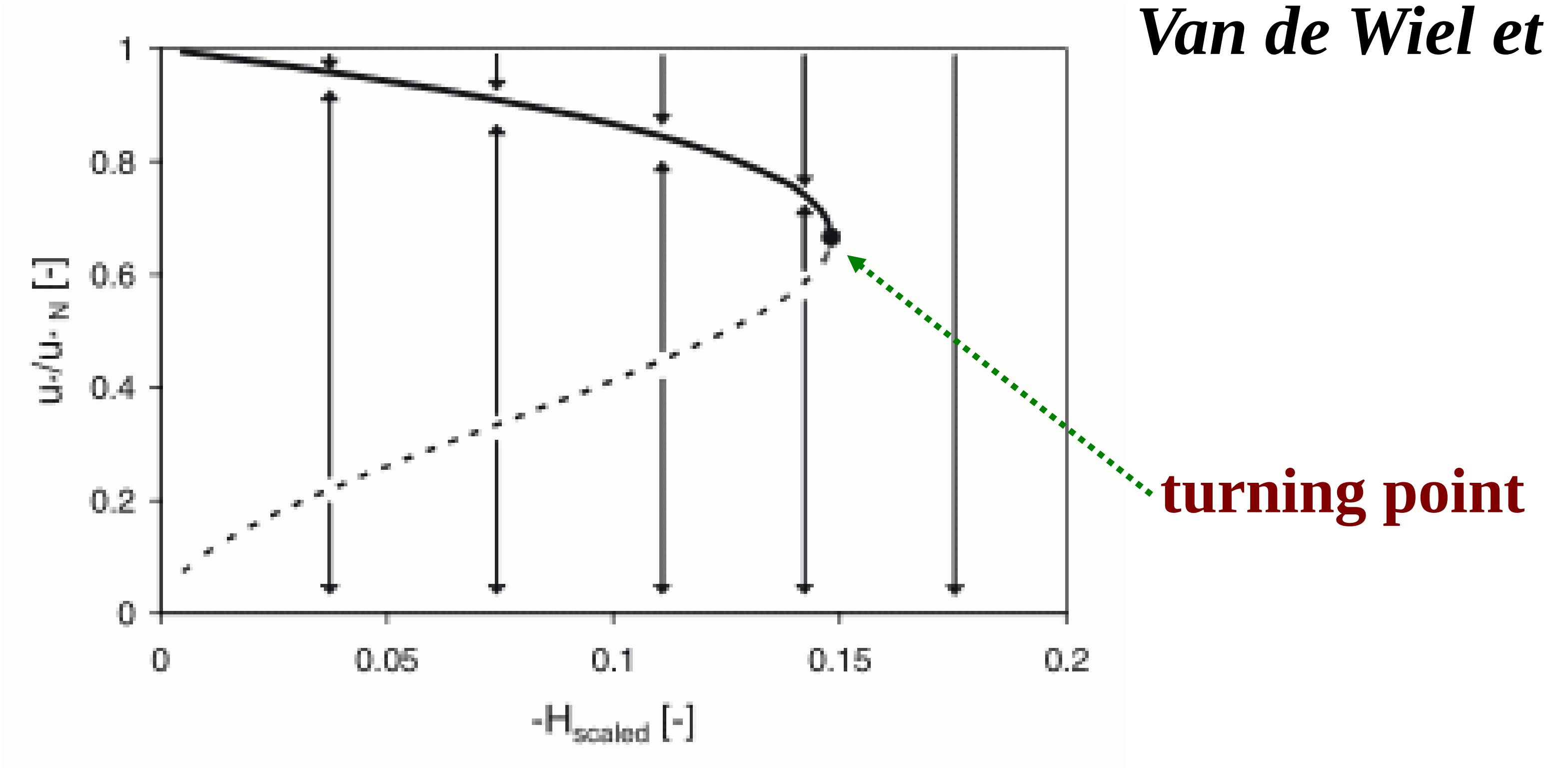
$$F_{M,H} = \int_{z_0}^{z} \frac{dz'}{z'} \varphi_{M,H}(z'/L)$$

$$F_{M,H} = ln\frac{z}{z_0} - [\sqrt{1 + 4\alpha\xi_0} - \sqrt{1 + 4\alpha\xi} + ln\frac{\sqrt{1 + 4\alpha\xi} + 1}{\sqrt{1 + 4\alpha\xi_0} - 1}]$$

The flux-profile has no limitation of a finite critical bulk Richardson number throughout a continuous range of the stable regime.

Negative feedback / positive feedback in SBL

Van de Wiel et al.



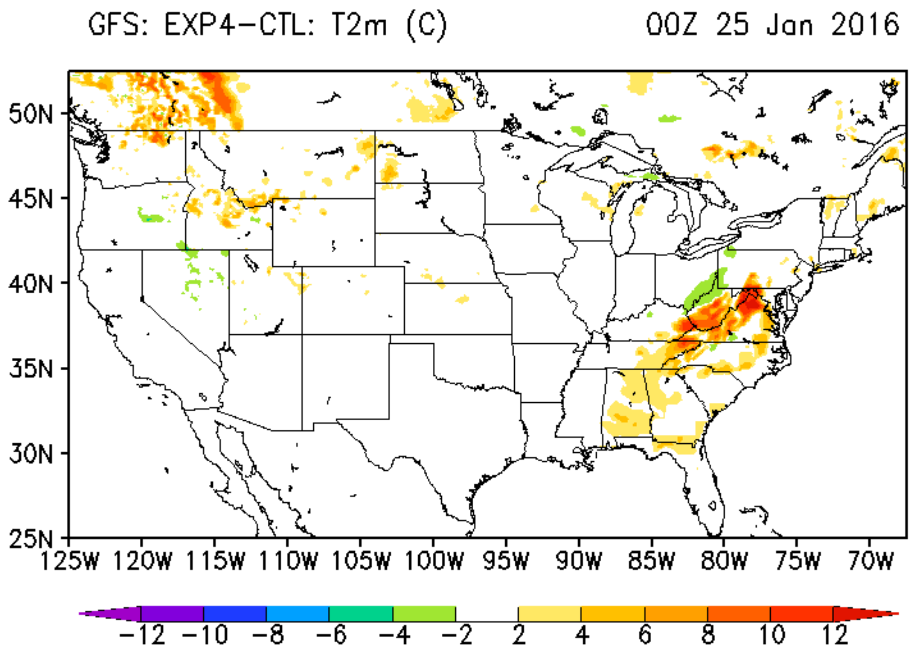
Bifurcation diagram: Turbulence vs cooling rates.

Linear stability analysis: Stable/unstable equilibrium states

$$z/L < z/L|_M = \ln(z/z_0)/[2*\alpha*(1-z_0/z)]$$

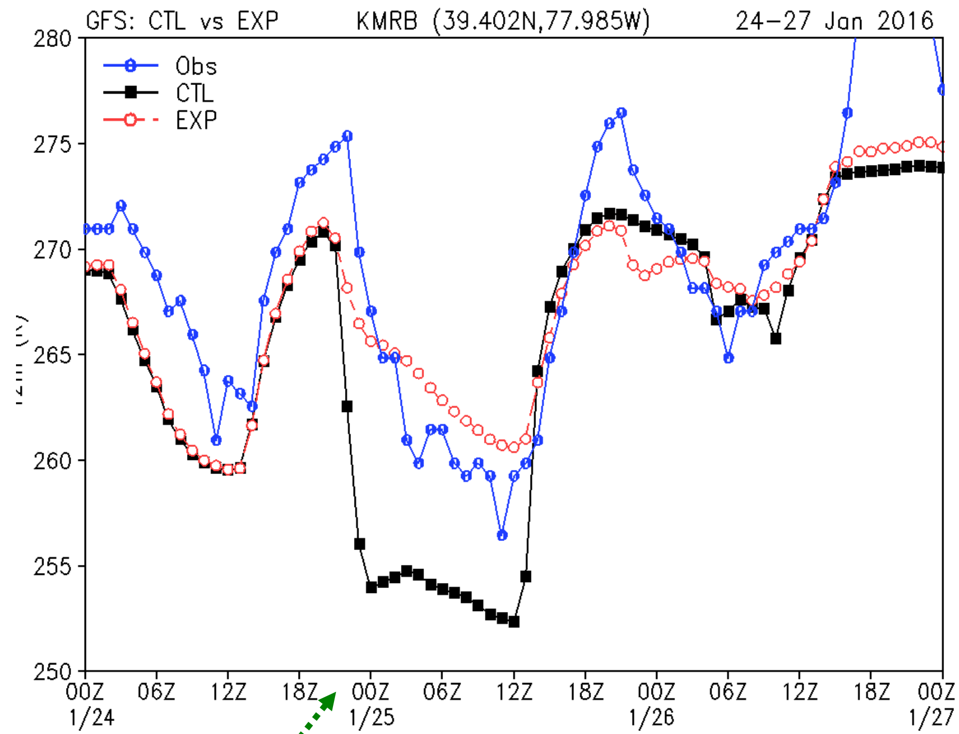
Here z0 is the momentum roughness length, and α=5.

GFS Test: T2m 00Z, 2016-01-24 Cycle



GFS Test: Increase T_{2m} and reduce cold bias

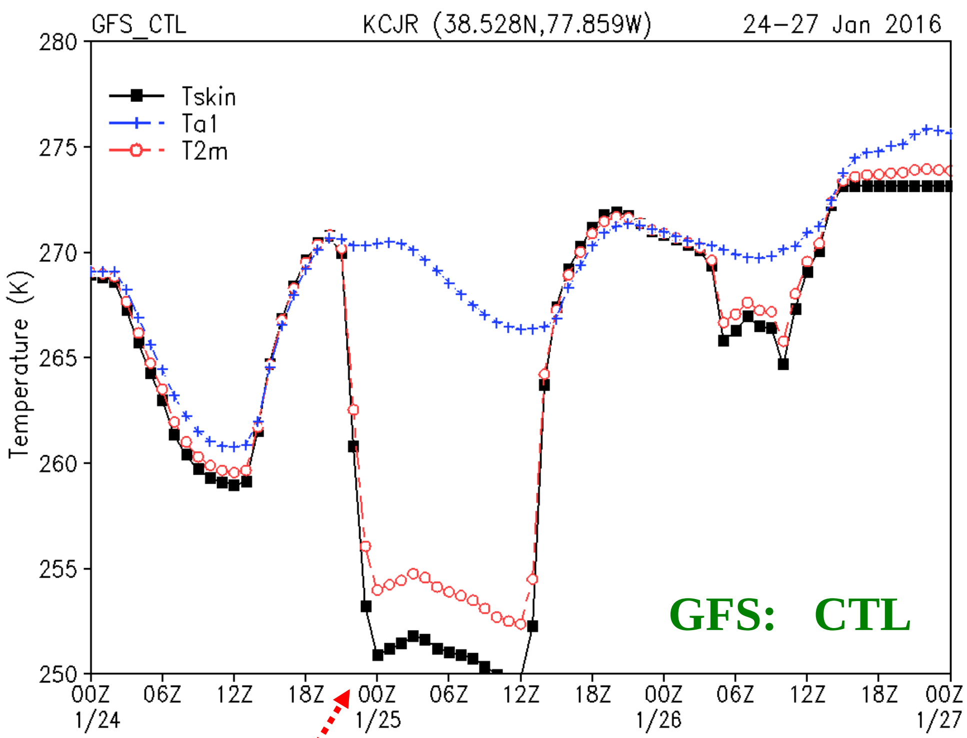
T2m @ MRB Matinsburg RGNL, WV

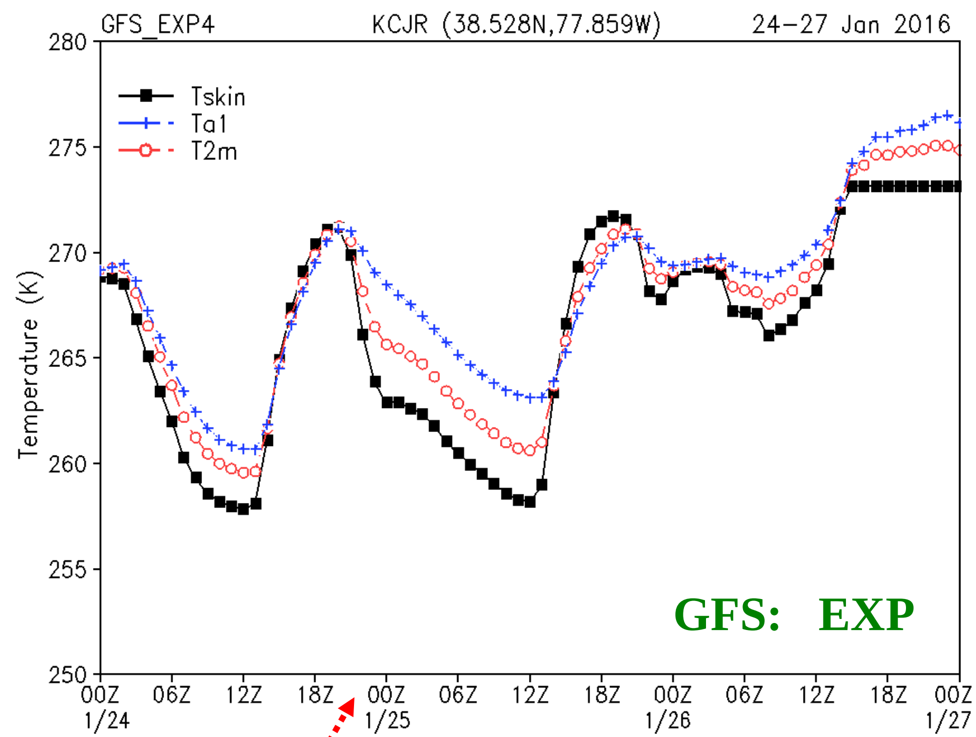


CTL: Rapidly cooling more than 15 °C during 3hr;
EXP: Substantially improved

GFS Test: T1, T2m and Tskin @ MRB

T1: Temperature at the lowest model level (Blue); T2m: Red; Tskin: Black





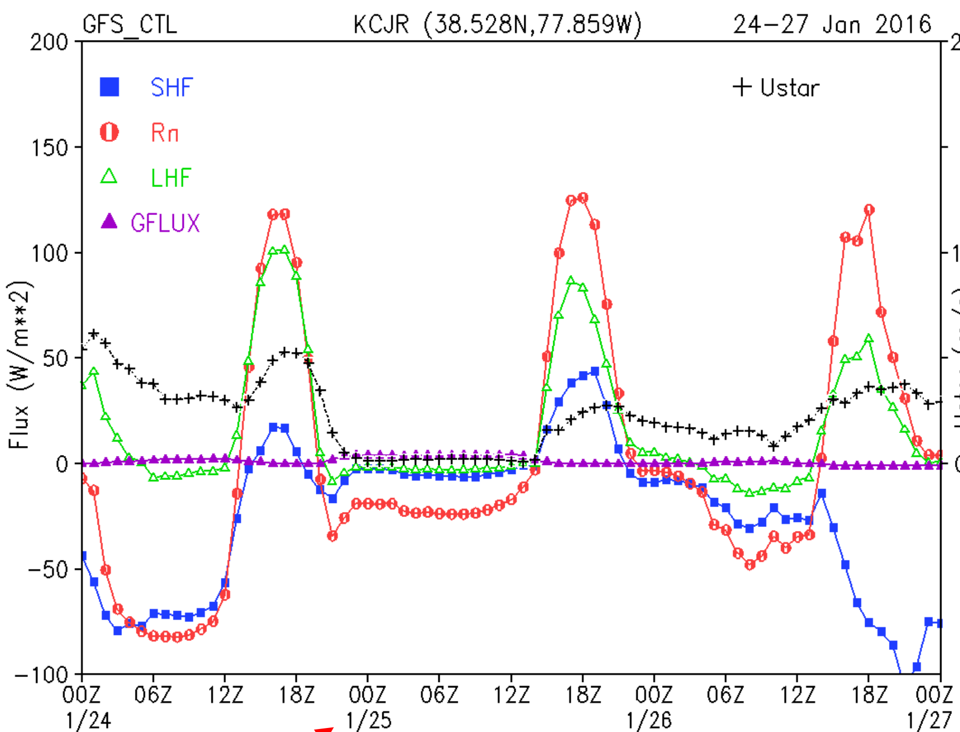
Rapidly cooling: Decoupled

Improvement

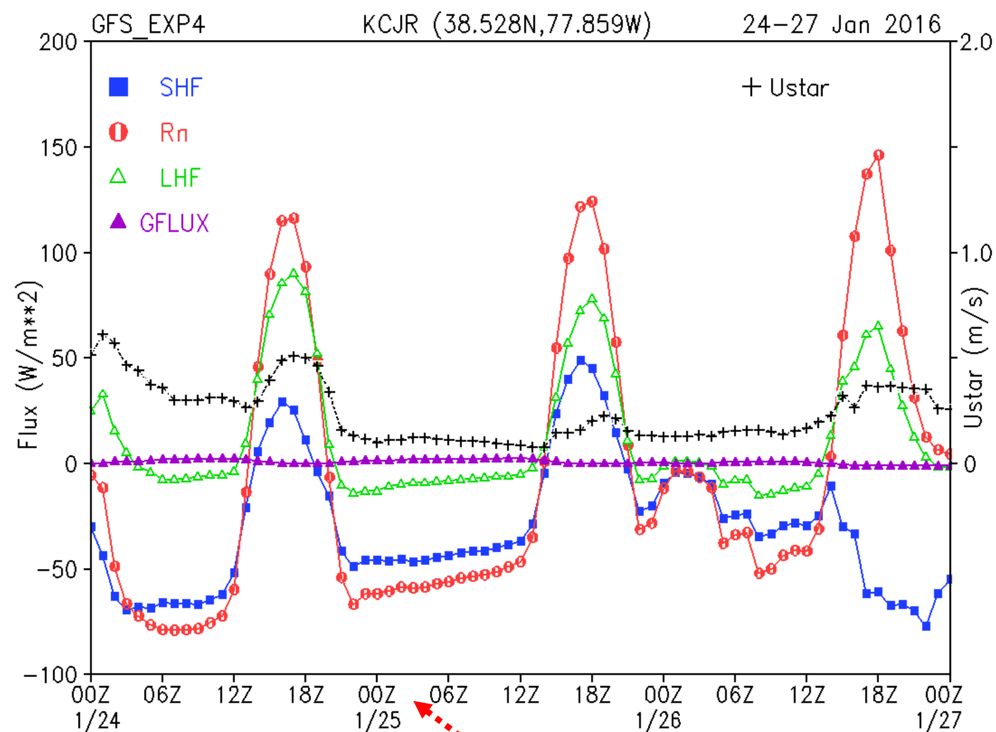
CTL: ***Large difference between T1 and T2m (or Tskin) during a period of nighttime on 1/25.***
EXP: ***Substantially improved not only T2m, but also Tskin and T1.***

GFS Test: Surface Fluxes and Ustar @ MRB

GFS: CTL



GFS: Test



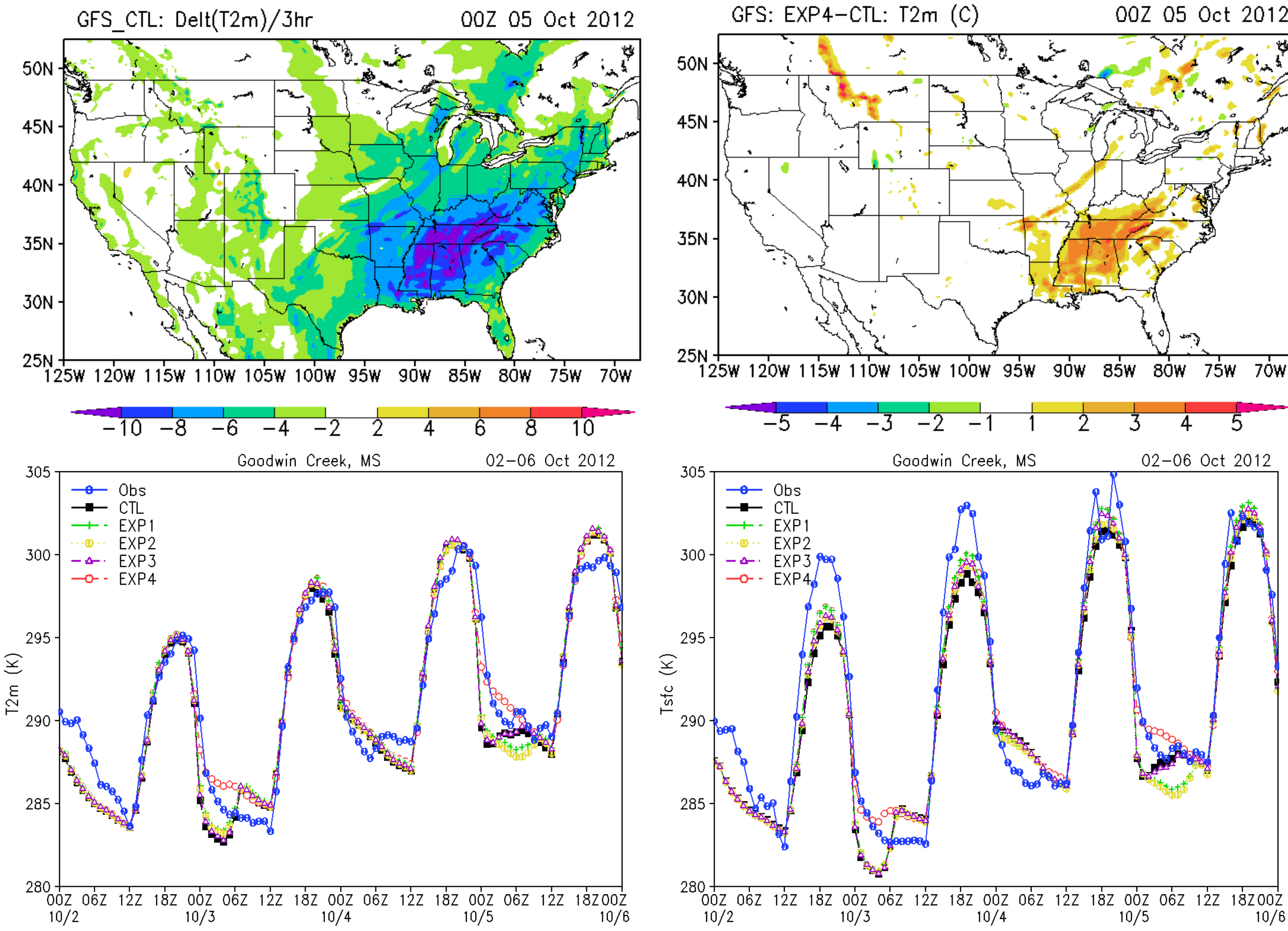
Under weak turbulence

Cessation of turbulence: SHF, Ustar → 0

SHF: Sensible heat flux; Rn: Net downward radiation;

LHF: Latent heat flux; GFLUX: Soil heat flux; Ustar: Friction velocity

GFS Test: T2m 00Z, 2012-10-05 Cycle



Summary/Discussion

- The GFS T2m excessive cold bias is closely related to the positive/negative feedback between the land and the atmosphere under stable conditions.

- The modifications were proposed to fix the T2m cold bias, which prevented the coupling system from decoupling.

- The case study for snow-free or snow pack indicates the modifications can remove the large cold biases of T2m and Tskin, and temperature at the first model level was also improved.

- We plan to include these modifications in next upgrade operational GFS model in 2017.

- In the future, new land data sets (e.g. veg/soil types, new GVF, albedo, etc.) will be updated in the model and expect to further reduction of T2m bias.

Thank You !

Any questions/comments?