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

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

Courtesy Geoffrey Manikin, MEG-02/19/15
GFS/GFSX T2m @ MRB Matinsburg RGNL, WV

00Z 01/24/2016 Cycle

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: \( H + R + G_0 \sim Q_{\text{net}} \quad \Rightarrow \quad \text{quasi-steady state} \)

(B) Under cessation of turbulence: \( R + G_0 \sim Q_{\text{net}} + (\text{others}) \quad \Rightarrow \quad \text{new state} \)

The system may reach different equilibrium states!
Monin-Obukov Similarity Theory in GFS (SBL)

\[ C_M = \frac{k^2}{F_M^2} \]

\[ C_H = \frac{k^2}{F_M F_H} \]

\[ \varphi_M = \varphi_H = \frac{1}{2} (1 + \sqrt{1 + 4\alpha \xi}). \quad \xi = \frac{z}{L} \quad L = \frac{\theta}{k_g} \frac{u_*^2}{\theta^*} \]

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

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

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

Bifurcation diagram: Turbulence vs cooling rates.
Linear stability analysis: Stable/unstable equilibrium states

$$z/L < z/L\big|_M = \frac{\ln(z/z_0)}{2\alpha(1-z_0/z)}$$

Here $z_0$ is the momentum roughness length, and $\alpha=5$. 

Van de Wiel et al.
GFS Test: Increase $T_{2m}$ and reduce cold bias

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

**GFS Test:** T1, T2m and Tskin @ MRB

**GFS:** CTL GFS: EXP

**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

Cessation of turbulence: SHF, Ustar → 0

SHF: Sensible heat flux; Rn: Net downward radiation;
LHF: Latent heat flux; GFLUX: Soil heat flux;

Under weak turbulence

Ustar: Friction velocity
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?