Investigation of surface layer parameterization in WRF model & its impact on modeled nocturnal wind biases

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Motivation

Revisiting nocturnal low level wind speed biases by WRF

- *Inaccurate placement/transport of pollutants and precursors
- *Inaccurate composition/dynamics for O_3 production, …
- ^Inaccurate rate of transfer of momentum in the vertical
- ^Inaccurate rate & magnitude of decoupling of NBL
- ^Inaccurate predictions of hub-height winds & LLJ

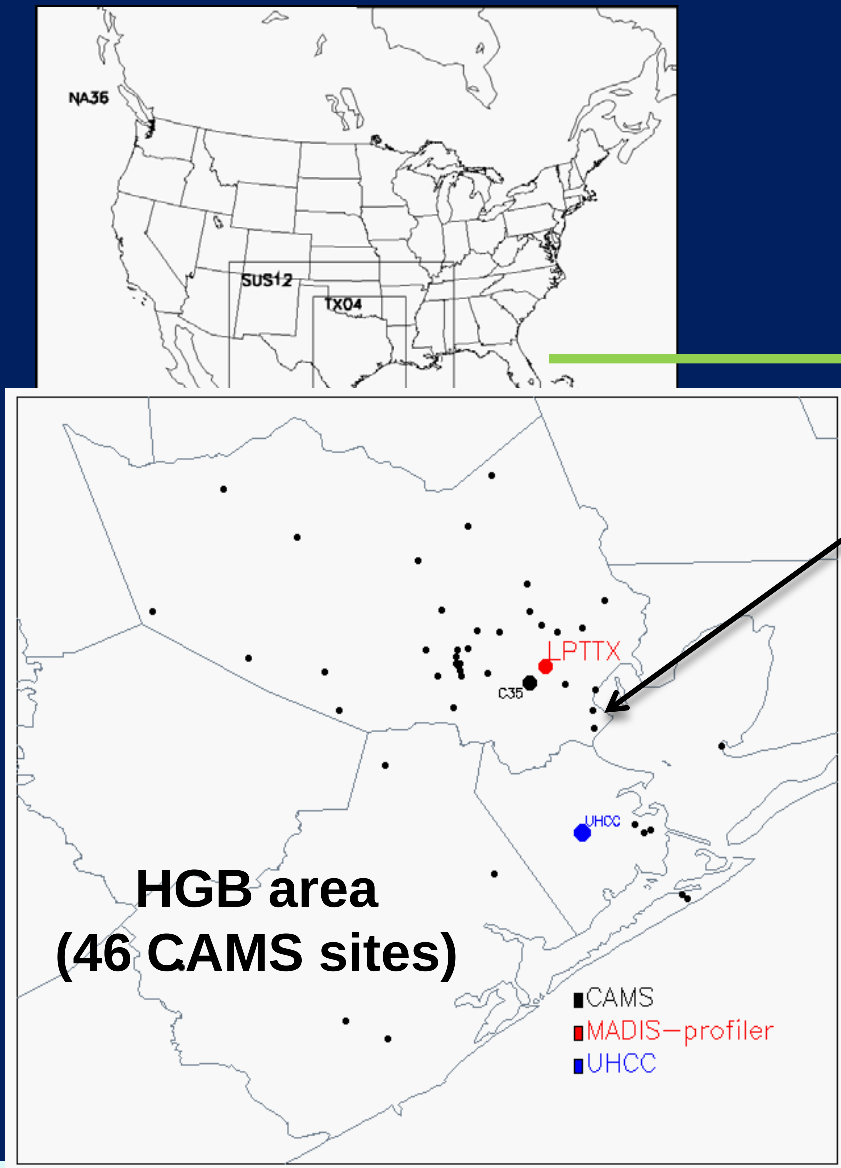
**(Byun et al., 2008; and Yerramilli, A. 2010, Lee, P. and Ngan 2011)*
*^(Zhang and Zheng 2004; Lee S. H. et al., **ACP** 2010; and Storm and Basu, **Energies** 2010)*

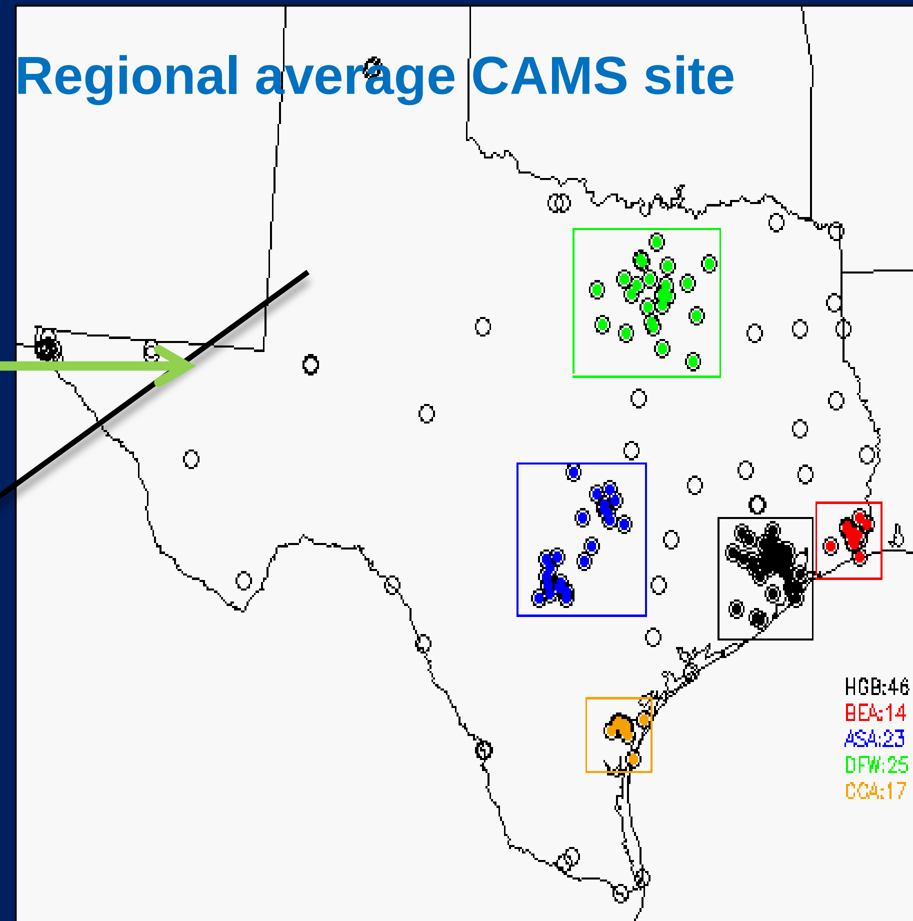
Goals of this project:

- Understand the sensitivities of the various surface layer similarity schemes in the WRF meteorological model
- Investigate the temporal and spatial characteristics of exchange coefficients
- Characterize sensible, latent heat and moisture fluxes contributing to the wind speed biases

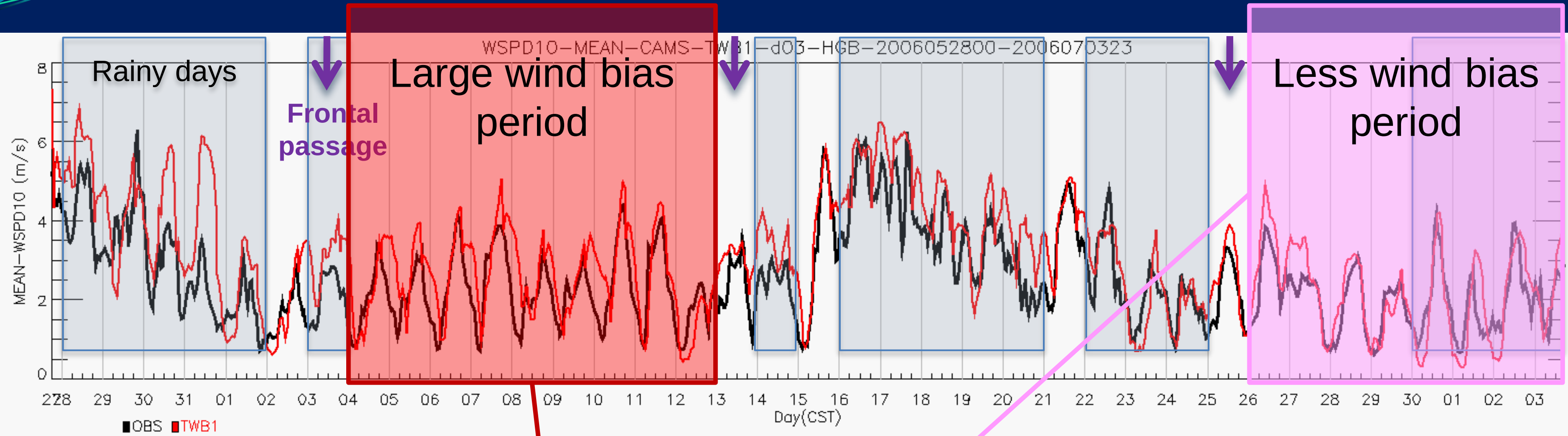
Domain Configuration: 36, 12, 4 km

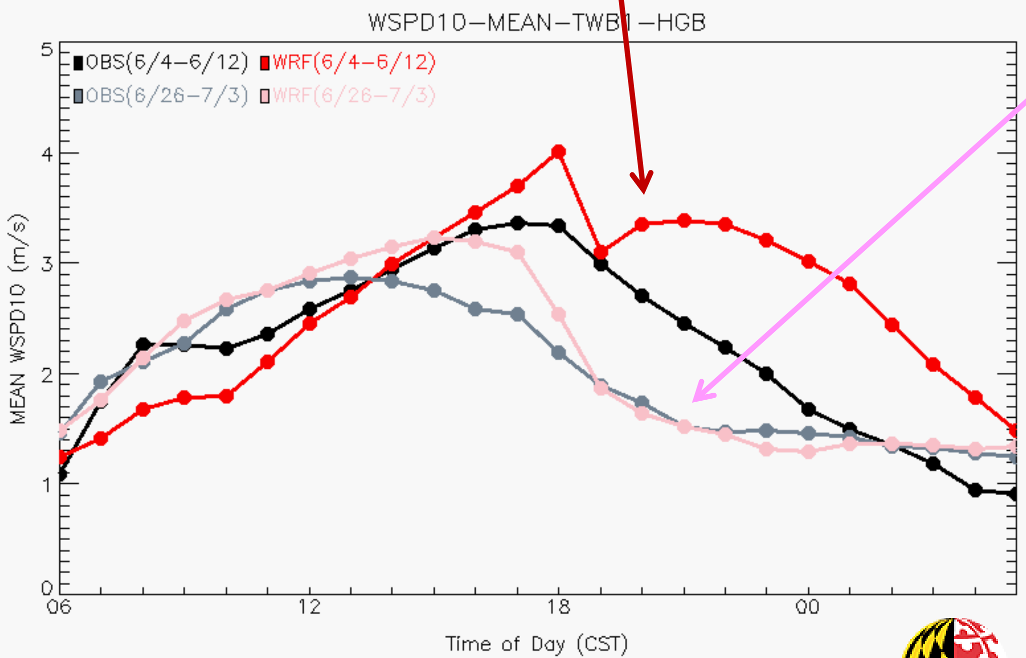
Simulation period: 2006/05/28 00 UTC – 07/04 00 UTC





Regional average wind speed for HGB area





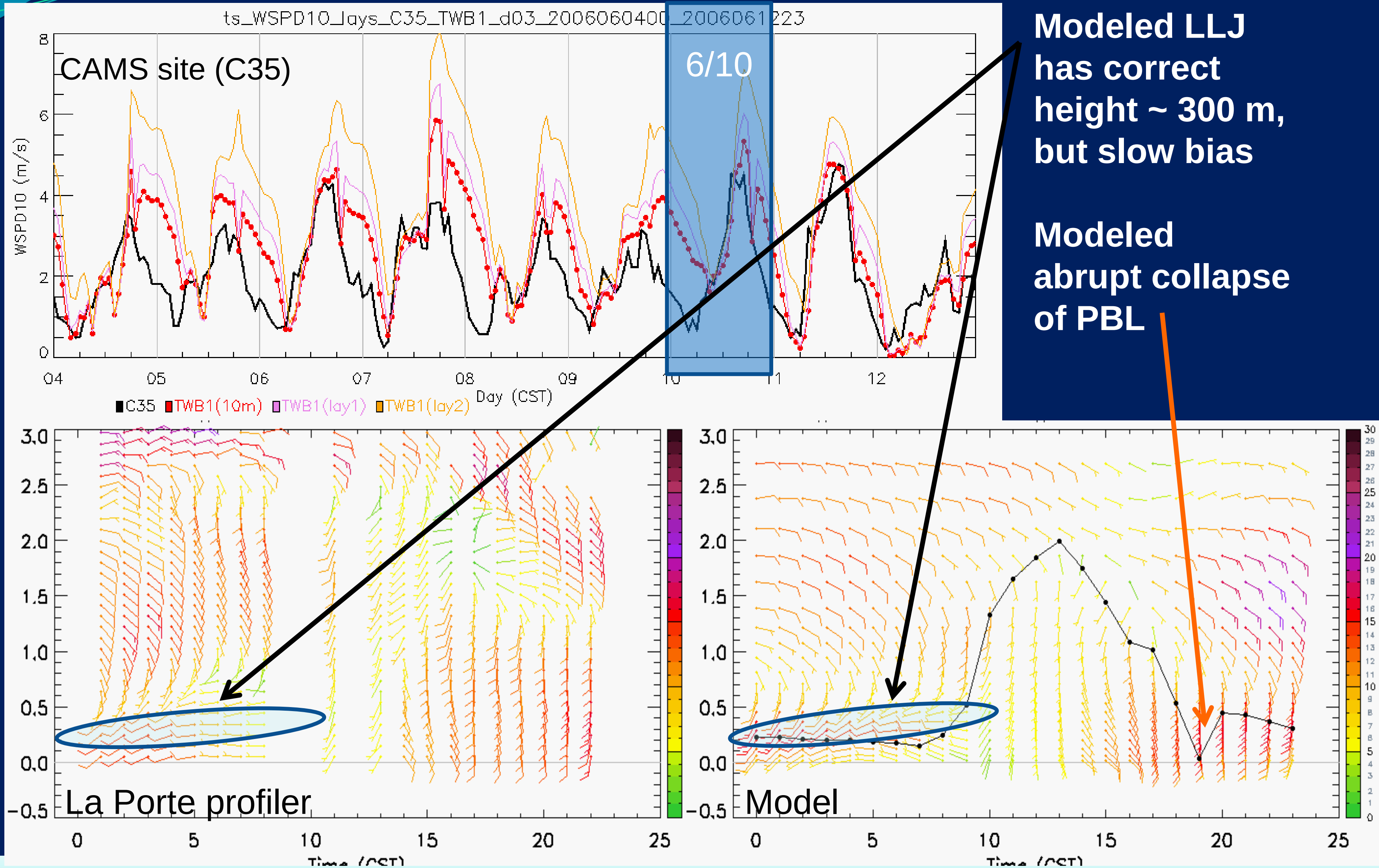
Diurnal variation of 10-m wind speed

6/4 – 6/12 (Large wind bias period)

6/26 – 7/3 (Less wind bias period)

Simulated wind speed increases in the evening hours (starting 19 CST)

La Porte (LPTTX) wind profiler (June 10, 2006)

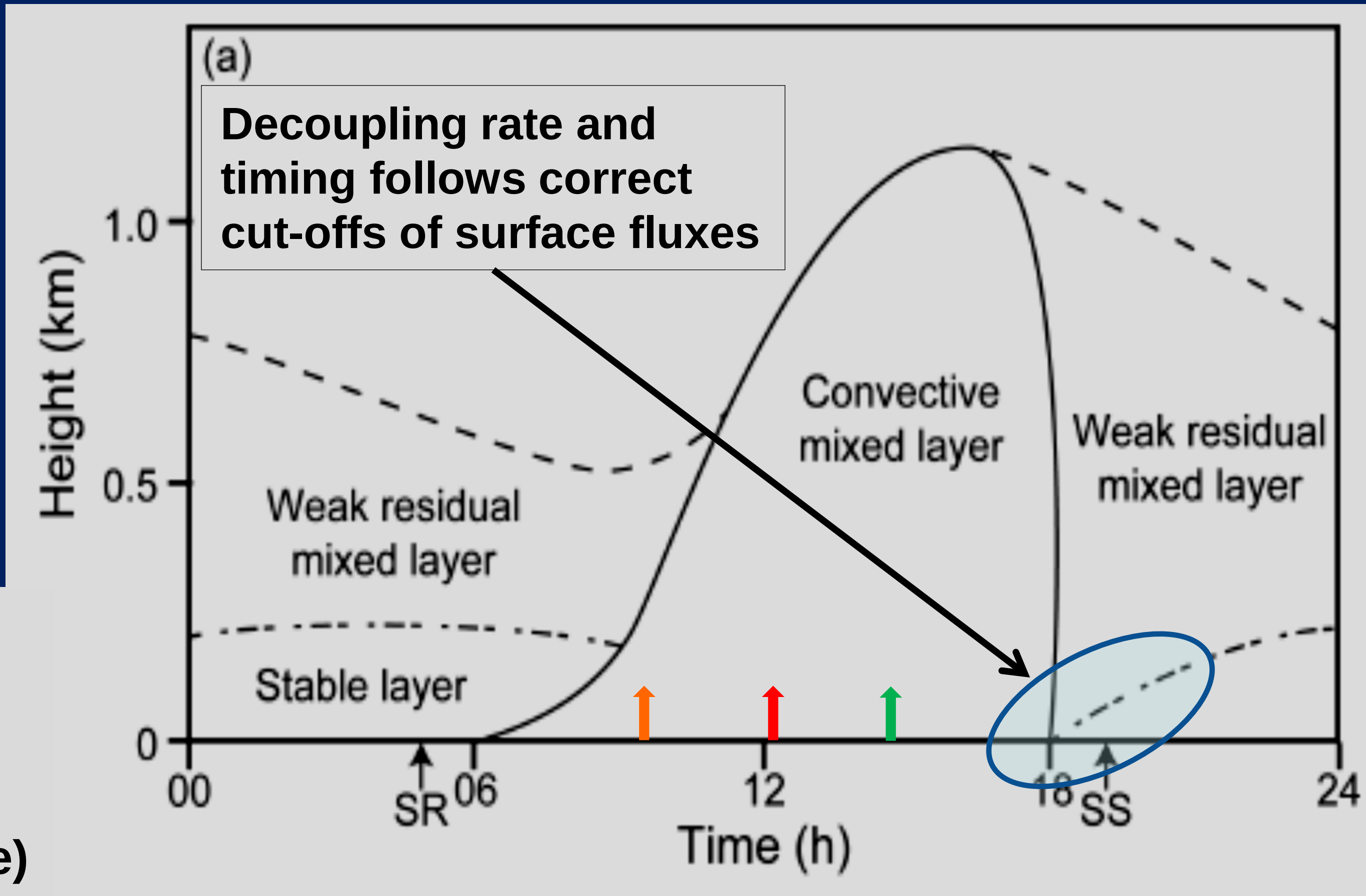


Modeled LLJ has correct height ~ 300 m, but slow bias

Modeled abrupt collapse of PBL

Surface layer scheme (SLS) determinates surface heat and moisture fluxes in LSM used as BC in PBL

SLS also provides friction velocities for PBL



- **Momentum flux**
- **Sensible & latent heat fluxes**
- **Moisture flux**

(throughout daytime)

Surface Layer Similarity schemes in WRF

Surface Layer Scheme (SLS) (Ref.)	Opt #	Remarks	Field data
MM5 (Zhang & Anthes 1982)	1	Û enhanced by convective velocity (Beljaars 1995)	Kansas (Izumi 1971)
MM5 extend (Jiménez et al., 2012)	11	Very unstable (Fairall 1996) & stable (Chen et al., 2005)	Iberian (Jiménez et al., 2010)
Eta (Janjic 2001)	2	In conjunction 2.5 PBL closure (2002)	Kerang (Swinbank 1964)
GFS (Hong and Pan 1996)	3	Miyakoda and Sirutis (1986)	TOGA COARE (Zeng et al.,1998)
QNSE (Sukoriansky et al., 2005)	4	Tested in extreme cold Sodankyla station, Finland	CASES-99 (Poulos et al. 2002)
MYNN (Nakanishi et al., 2001)	5	force restore method after soil heat flux is obtained	Wangara (Clarke et al., 1971)

Focused on YSU PBL as originally performed for 2006 campaign

***MM5 Surface Layer Scheme (sf_sfclay_physics=1)*, profile functions:**

$$\phi_m\left(\frac{z}{L}\right)=\frac{kz}{u_*}\frac{\partial U}{\partial z}$$

$$\phi_h\left(\frac{z}{L}\right)=\frac{kz}{\theta_*}\frac{\partial \theta}{\partial z}$$

Where z/L represents, L the Monin-Obukhov stability parameter, defined as

$$\frac{z}{L}=k\frac{g}{\theta_a}z\frac{\theta_*}{u_*^2}$$

With field data, empirical parameters was derived to quantify exchange coefficients that are used to determine fluxes: momentum, sensible & latent heat

$$\tau=\rho \ u_*^2=\rho C_d\hat{U}^2$$

$$H=-\rho c_p u_*\theta_*=-\rho c_p C_h\hat{U}(\theta_a-\theta_g)$$

$$LH=L_e\rho u_* q_*=L_e\rho M C_q\hat{U}(q_g-q_a)$$

Where $\hat{U}$ wind speed Enhanced by a convective velocity (Beljaars 1999)

MM5 Surface Layer Scheme (sf_sfclay_physics=11)

*Jimenez et al. (2012):

- Originally minimum friction velocity was set at 0.1 m s^{-1}. In this new option this minimum value is reset to 0.01 m s^{-1} --- such low friction velocity occurs occasionally during night time (*Shin and Hong 2011).

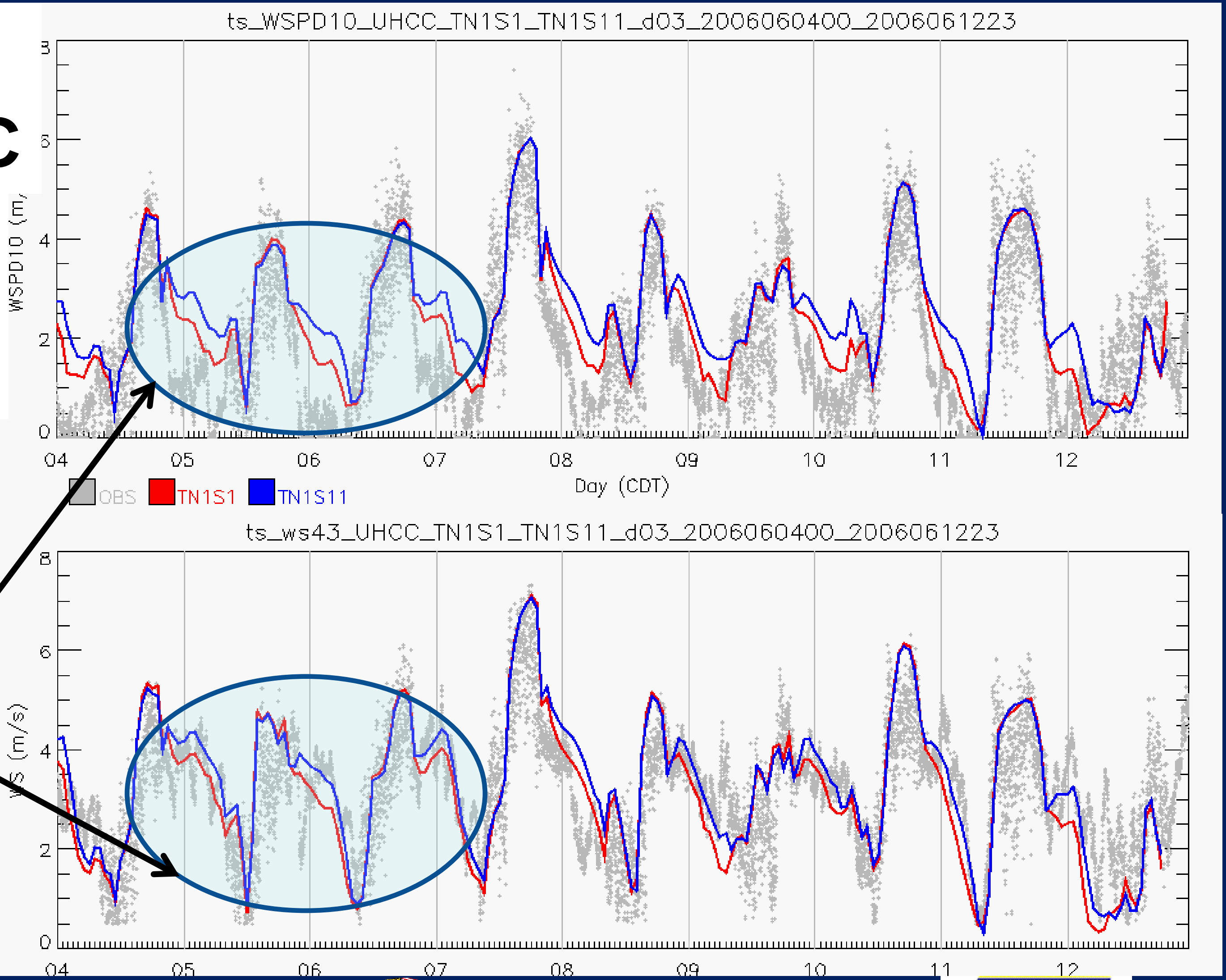
- It incorporated highly unstable atmospheric regimes after formulation suggested by *Fairall et al., (1996): For unstable regimes, the similarity function that weighs between a Monin-Obukhov type similarity profile and a profile resulted from pure convection suggested by *Fairall et al. (1996) was used.

- Similarly for highly stable regimes incorporated formulation by Cheng and Brutsaert (2005)

**(Jimenez et al., 2012; Shin, H. H.; and S. Hong, 2011; Fairall et al.,1966, Cheng et al., 2005)*

10 m wind Over UHCC

sfclay=1
sfclay=11 Jiménez et al. (2012)



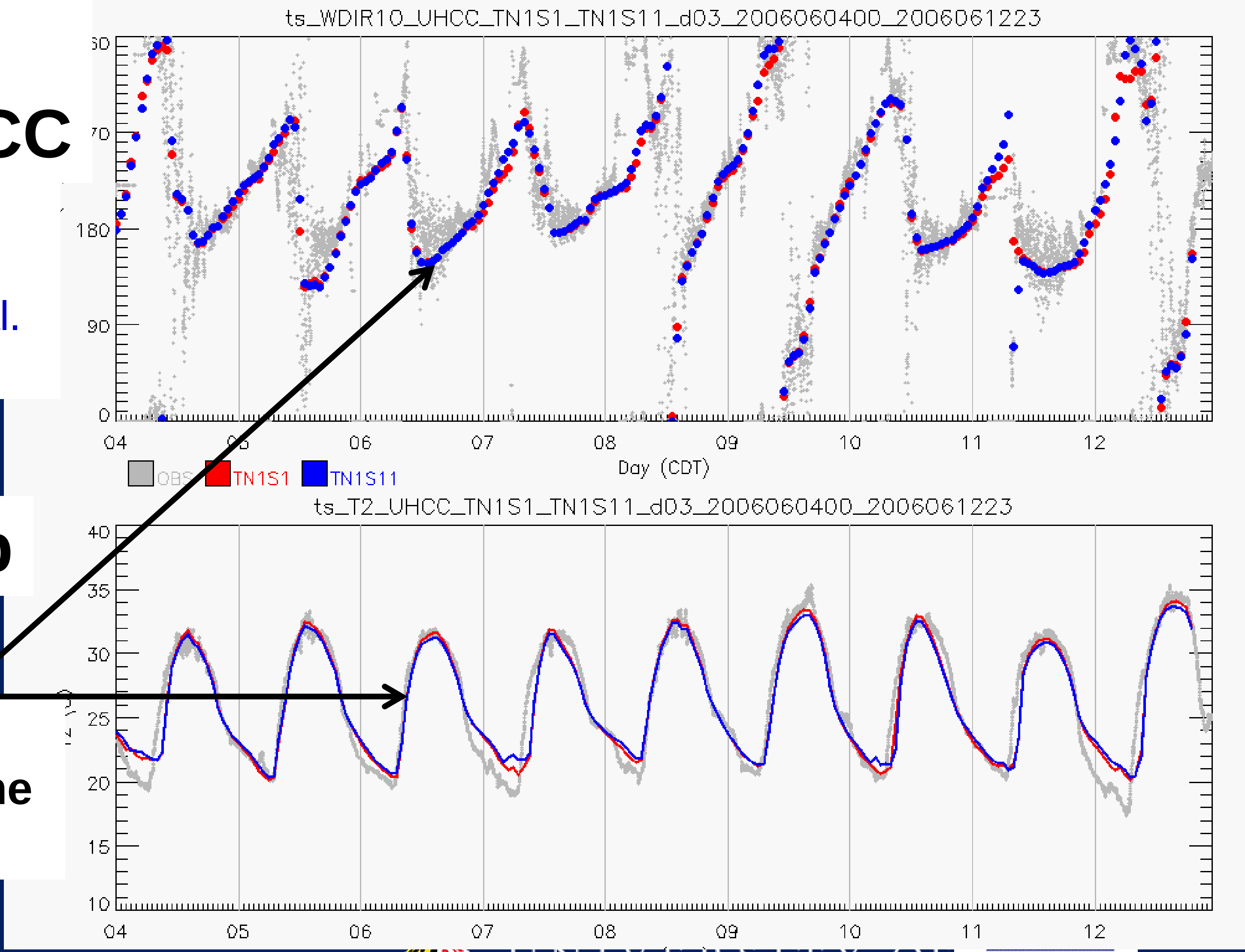
43 m wind

sfclay=1 is outperforming

10 m Dir Over UHCC

sfclay=1
sfclay=11
Jiménez et al. (2012)

2 m Temp



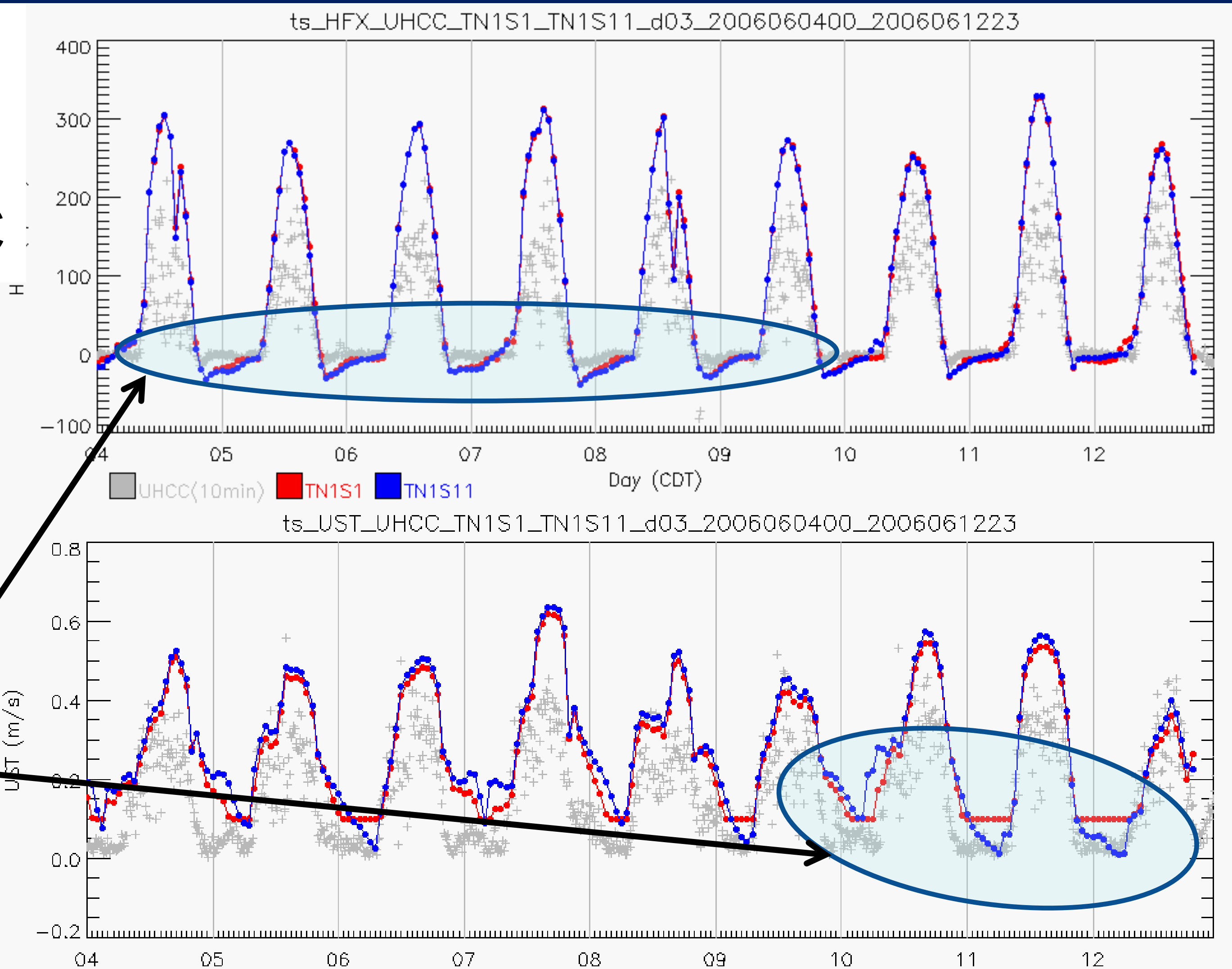
sfclay=1 & sfclay=11 same performance

Sensible heat flux Over UHCC

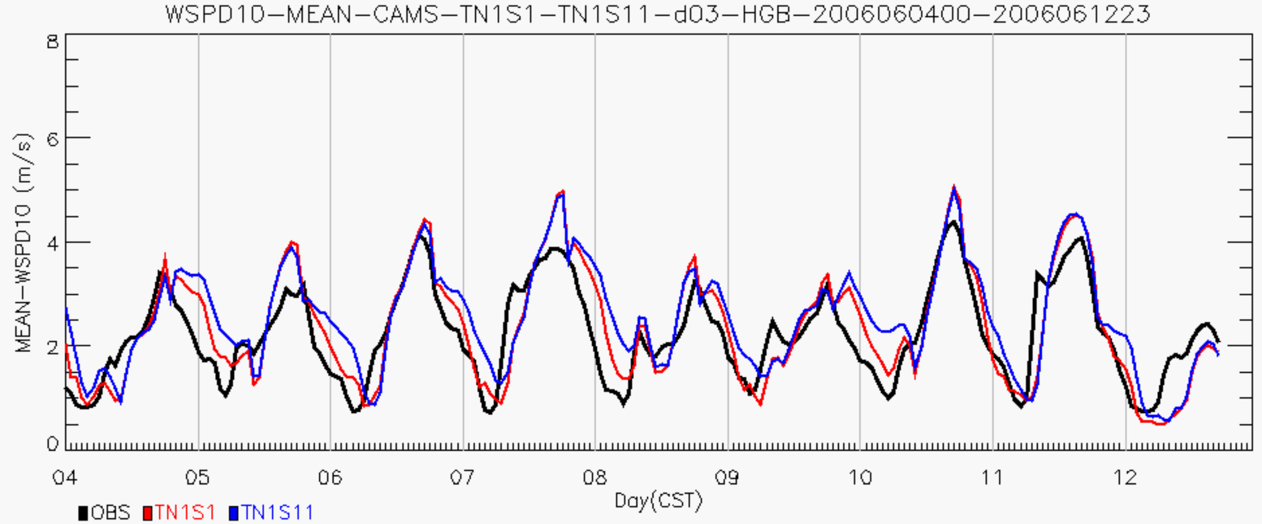
sfclay=1
sfclay=11
Jiménez et al. (2012)

Friction velocity

sfclay=1 is outperforming except too high cutoff

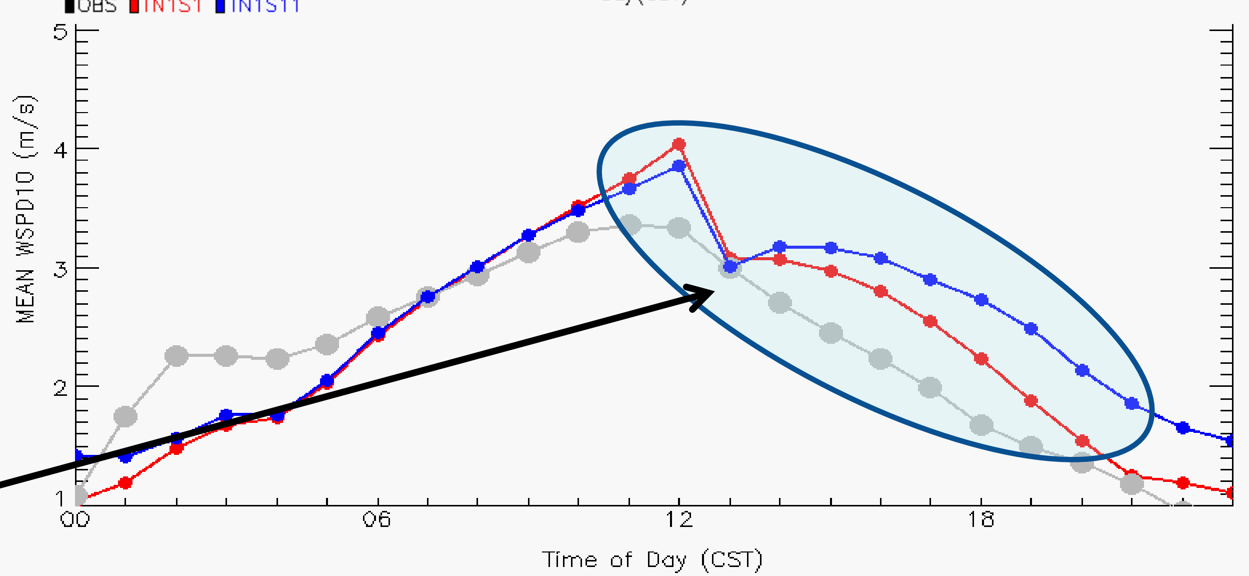


Wind speed Avg over 46 CAMS in HG



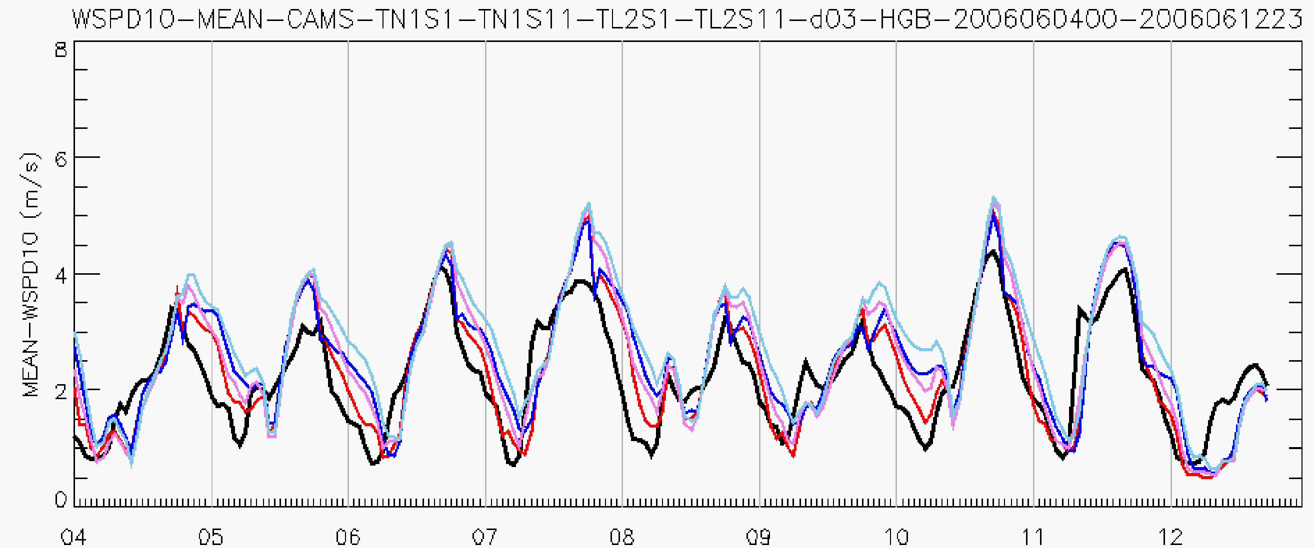
- Obs
- sfclay=1
- sfclay=11 Jiménez et al. (2012)

Diurnal Variation of the above

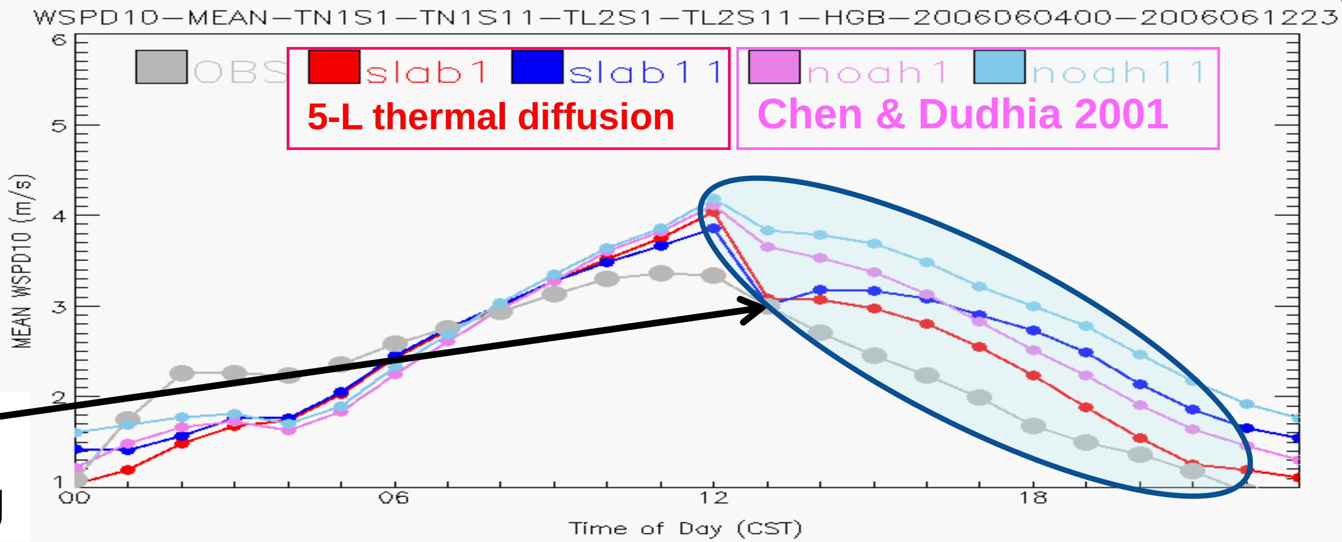


sfclay=1 is outperforming

Wind speed Avg over 46 CAMS in HGB



Diurnal Variation of the above

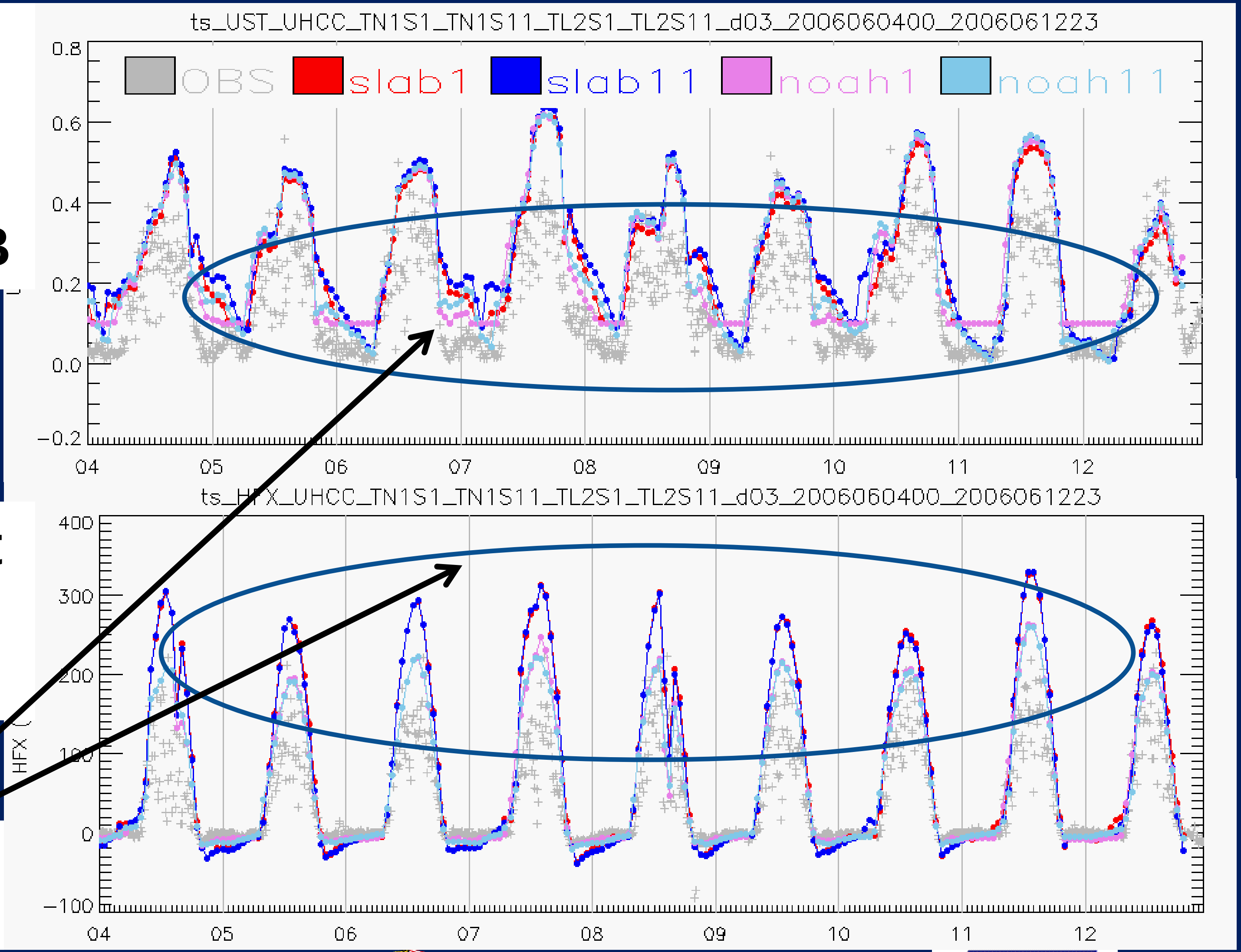


noah has no abrupt decoupling

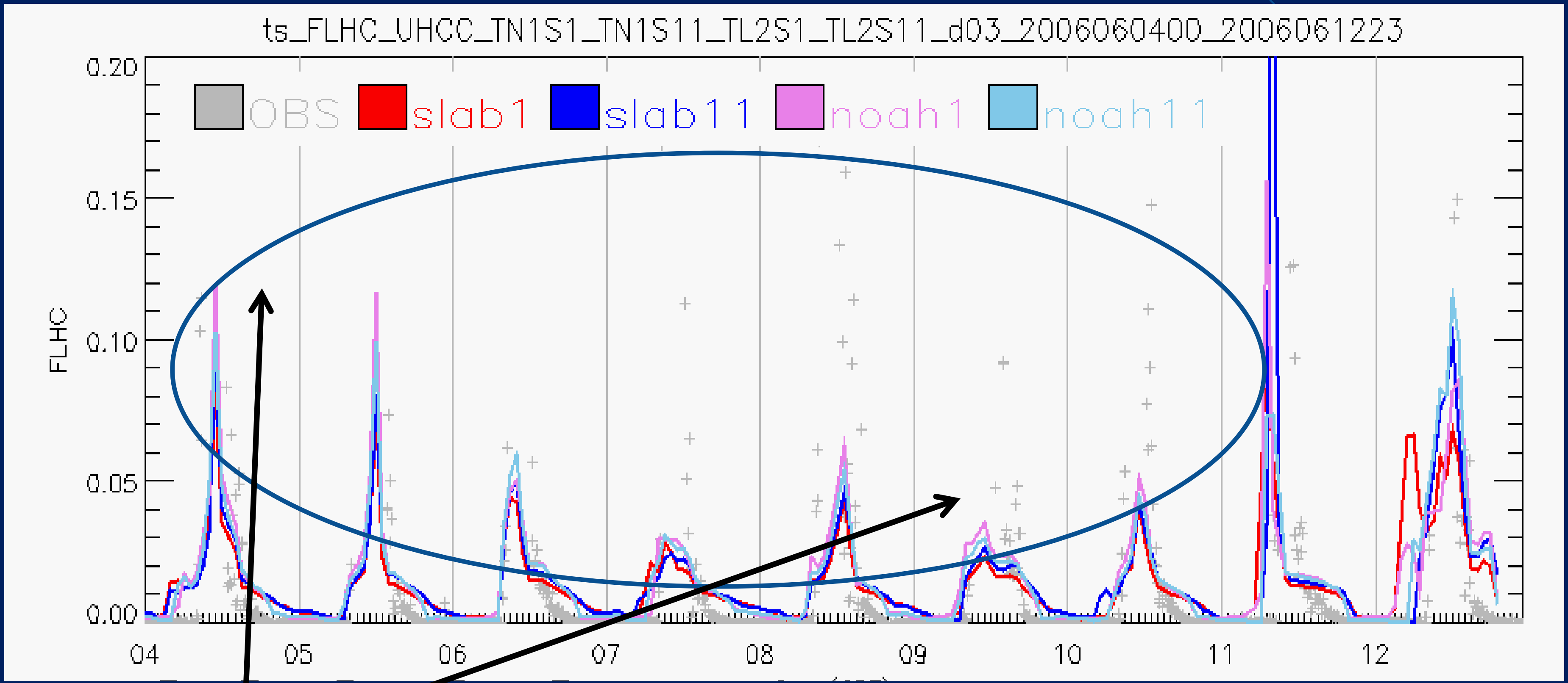
Friction velocity Avg over 46 CAMS in HGB

Sensible heat flux of the above

noah is outperforming



Surface exchanged coefficient for heat at UHCC



noah is outperforming

Indication that MM5 LSM although showed smaller bias but mismatch in surface decoupling behaviors:

- Sensible heat flux stayed too strong before sunset
- Sensible hear flux temporal gradient upon sunset

Further investigation of surface moisture flux in NOAH

- Although not showing strong superiority as is, but option to nudge soil moisture is promising to correct decoupling

- Comprehensive methodology to optimize physically based scheme (e.g. Gupta et al., 1999, Sen et al., 2001)

Investigated Surface Layer Schemes in WRF:

- Night time over-estimation of low level wind-speed
- Extremely shallow modeled boundary layer height at 19 CST:
  - Such wind biases prevails when H over Lower Middle
- Surface Layer scheme (SLS) feeds BC to PBL schemes:
  - Exchange coefficients enables LSM to calculate fluxes which PBL uses to constrain its lower boundary
  - SLS exhibits uncertainties: e.g., empirical constants
- Take advantage of CAMS and UHCC:
  - Investigate PBL growth and collapse dynamics relates low level wind & surface heat & moisture fluxes
  - Optimize a LSM, SLS and PBL option set

Possible next steps:

- Nudge soil moisture

EXTRA SLIDES

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