Intercomparison of PBL Parameterizations in the WRF Model for a Day of CASES-99

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Contents

Introduction

- **Role of PBL (ABL) parameterizations** in **atmospheric models**

  : **To express impact** of the **sub-grid scale turbulent motions on grid scale properties** by means of turbulent mixing.

- **Importance of PBL parameterizations** in **numerical prediction**

  PBL schemes and Tunable parameters → BL and Precipitation forecasts (Hong and Pan 1996)

  PBL parameterizations → Hurricane prediction (Braun and Tao 2002; Li and Pu 2008)

  PBL schemes in seasonal simulations using a GCM (Holtslag and Boville 1993)

  PBL and radiation schemes → diurnal cycles and three different nights (Steeneveld et al. 2008)

  : **considerable sensitivity of numerical prediction** to the **PBL parameterizations**

  → **expressing turbulent mixing in PBL** still induces **a lot of uncertainty in numerical forecasts** → **various methods in expressing the turbulent mixing**

- **Evaluations of various PBL schemes** against in situ observations **using a 1D model**

  Holt and Raman 1988, Musson-Genon 1995, Sharan and Gopalakrishnan 1997, Svensson and Holtslag, 2006

Introduction

- **Objective** of **this study** is

PART 1: Intercomparison of PBL parameterizations

To elucidate **intrinsic characteristics of each PBL parameterization** **using the three-dimensional WRF model**.

PART 2: Sensitivity of performance of a PBL scheme to surface layer formulations

To assess the **relative contribution of surface layer formulations** **to the intercomparison characteristics of PBL parameterizations**.

Experimental Setup 2.1. Five PBL parameterizations

- **Role of PBL (ABL) parameterizations** in **atmospheric models**

To express **effects of the divergence of turbulent fluxes to prognostic mean variables** (C: u, v, θ, q) **by vertical diffusion**

The simplest formula: $$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial z}\overline{w'c'} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z}\right)\right]$$

- **Five PBL parameterizations** in the **WRF model**

PBL schemes	Order of closure	Diffusivities	Nonlocal mixing
YSU	1st order closure	$K_M = kw_s z\left(1-\frac{z}{h}\right)^2$ $K_H = \mathrm{Pr}^{-1} K_M$	Counter gradient terms for u, v, and θ
ACM2			Explicit nonlocal fluxes for u, v, θ, and q
MYJ	TKE closure (1.5 order) (One additional prognostic equation for TKE)	$K_c = l\sqrt{TKE}S_c$	-
QNSE			-
BouLac			Counter gradient term for θ

Experimental Setup 2.2. Case description and observations

- **CASES-99** (Cooperative Atmosphere-Surface Exchange Study)

(Poulos et al. 2002)

In October 1999 in Leon, Kansas, USA

Main site: 96.7°W, 37.6°N

Relatively flat

Covered by grassland

Surface moist availability **M = 0.08**

Steeneveld et al. (2008)

Roughness length **z_0 = 3 cm**

Clear sky and dry environment

Observations as reference values in this study

For Surface variables

six 10-m towers

For PBL structures

rawinsonde soundings launched at Leon

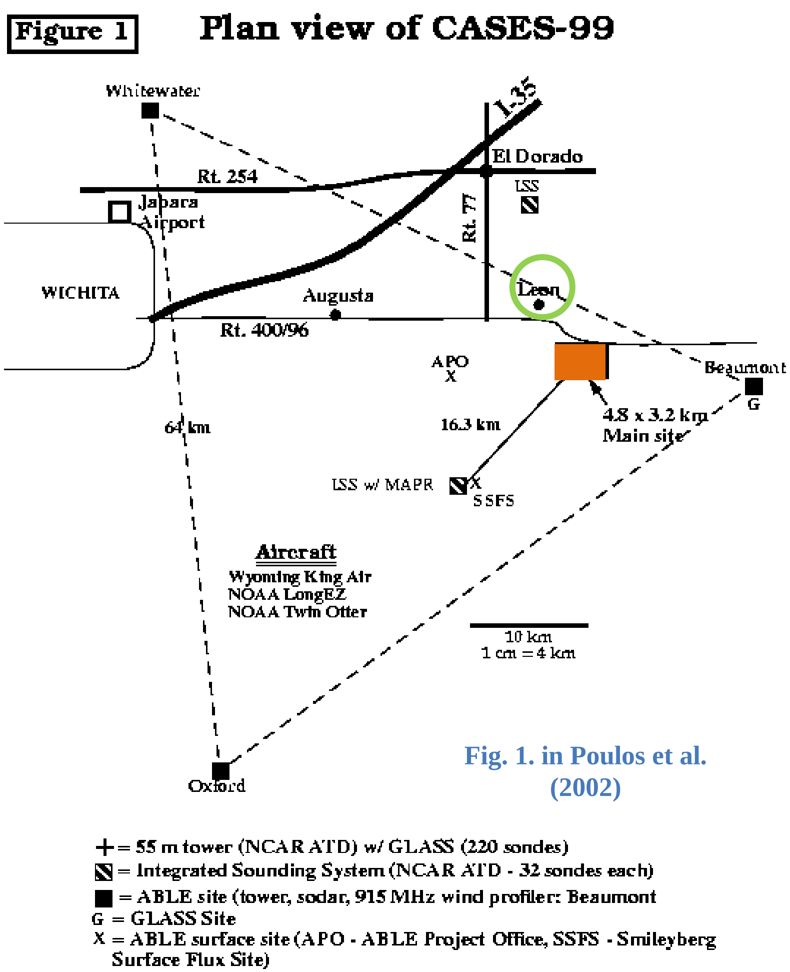


Fig. 1. in Poulos et al. (2002)

Experimental Setup <u>2.3. Experimental design</u>

Model

- The Weather Research and Forecast (WRF) model Version 3.2.

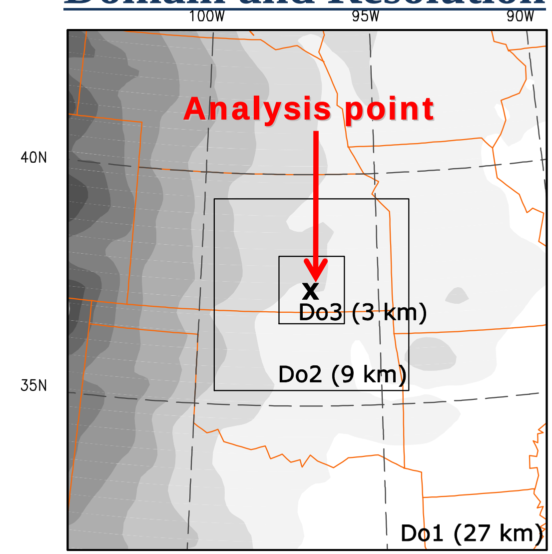
Integration time

- 1 day from 12UTC 23 to 12UTC 24 OCT 1999.
  a day of CASES-99 field experiment

Initial and Boundary Conditions

- 12-hourly NCEP Final Analysis (FNL) data

Domain and Resolution



Summary of experiments

PBL Intercomparison Experiments

	PBL	Surface Layer
SW Goddard **LW** RRTMG **LSM** NOAH **CPS** KF **MPS** WSM6	**YSU**	**MM5 Similarity**
	ACM2	**PX Similarity**
	MYJ	**Eta Similarity**
	QNSE	**Modified Eta Similarity**
	BouLac	**Eta Similarity**

Part 1: PBL intercomparison

In the current version of the WRF, Each **PBL** scheme **is tied to** a **particular surface layer option**, expect for BouLac.

<u>Results</u> <u>are presented</u> **<u>in Section 3</u>**.

Experimental Setup 2.3. Experimental design

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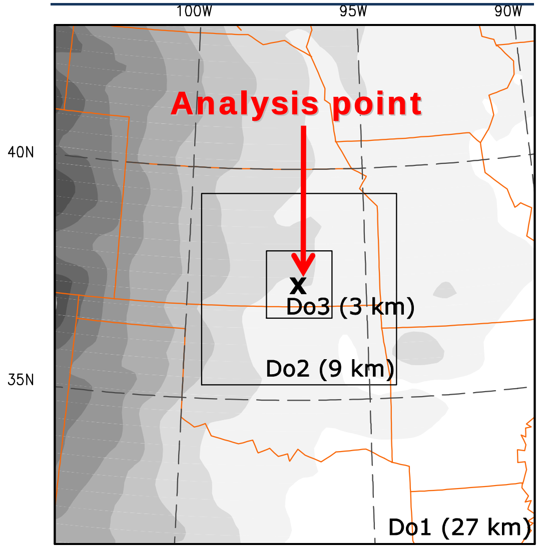


Summary of experiments

Part 2: Sensitivity to SL formulations

BouLac PBL is **flexible in selecting surface layer options**.
Four experiments **with BouLac PBL** and four SL options tied to **YSU**, **ACM2**, **MYJ**, and **QNSE**.

Results are presented **in Section 4**.

Surface-Layer Sensitivity Experiments		
	PBL	Surface Layer
BL_YSU	BouLac	MM5 Similarity (YSU)
BL_ACM2		PX Similarity (ACM2)
BL_MYJ		Eta Similarity (MYJ)
BL_QNSE		Modified Eta Similarity (QNSE)

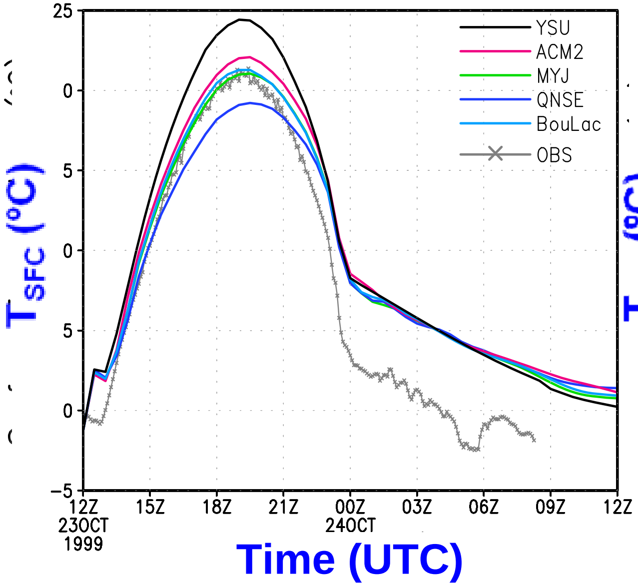
Part 1

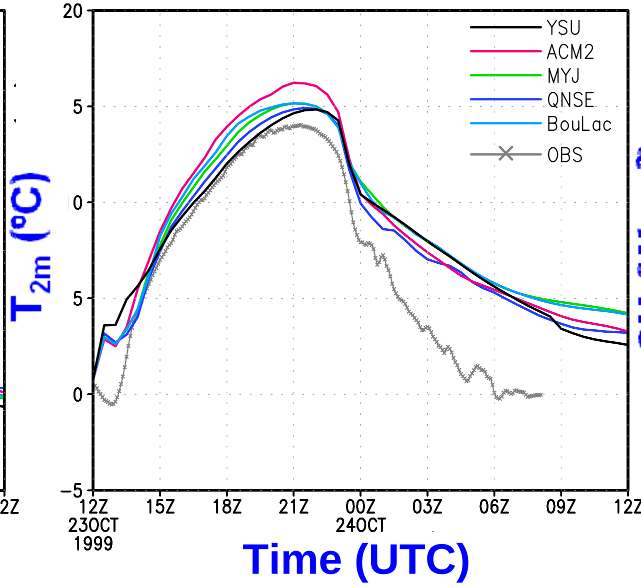
Intercomparison of Five PBL Parameterizations

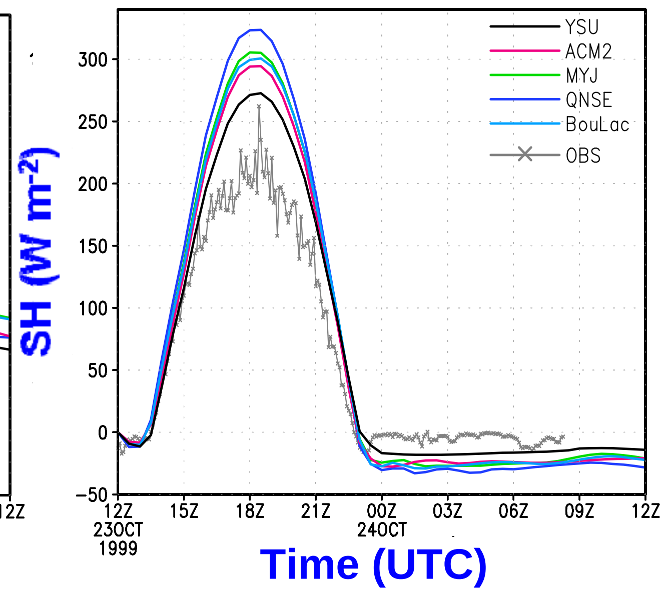
Intercomparison of PBL schemes 3.1. Surface variables

- **Thermodynamic components**

YSU **ACM2** **MYJ** **QNSE** **BouLac**







During the daytime

(T_{SFC}) YSU > ACM2 (overestimation) > MYJ ~ BouLac > QNSE (under)

(T_{2m}) ACM2 > MYJ ~ QNSE ~ BouLac > YSU (overestimation)

→ → **(ΔT) Largest in YSU, smallest in QNSE**

During the nighttime

(T_{SFC} and T_{2m}) Five schemes converge, but with warm biases

(SH) QNSE > ACM2 ~ MYJ ~ BouLac > YSU (overestimation)

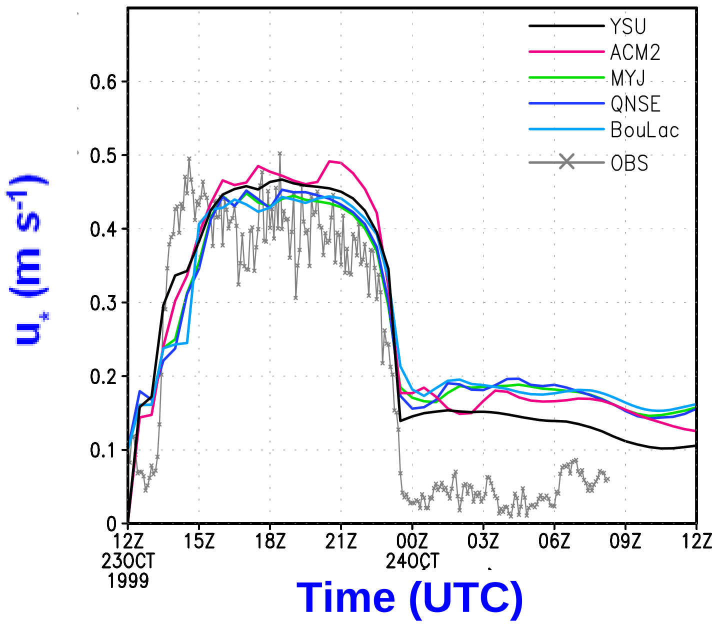
: opposite to (ΔT) $SH = \rho C_p C_H U_a (\theta_s - \theta_a)$

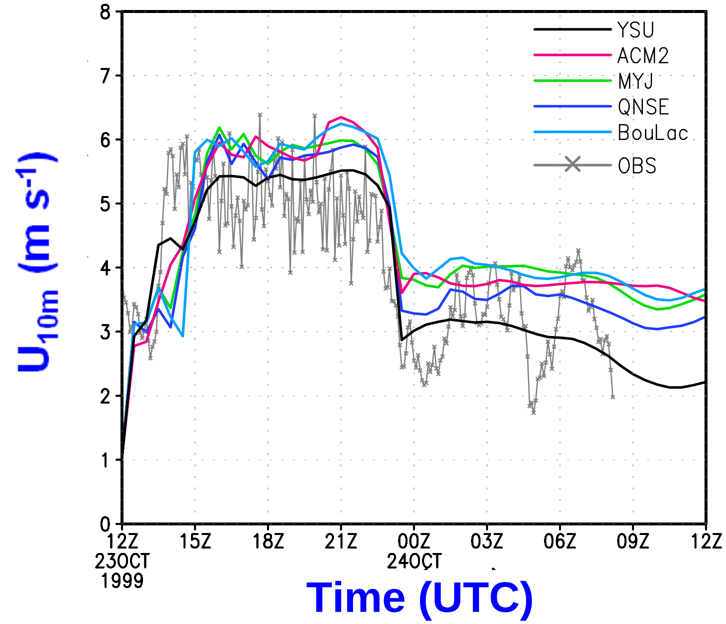
→ implies **smallest** (**largest**) C_H from the SL formulation tied to **YSU** (**QNSE**)

Intercomparison of PBL schemes 3.1. Surface variables

- **Wind components**

YSU ACM2
MYJ QNSE BouLac





<u>During the daytime</u>

(u_*) ACM2 > YSU > Three TKE schemes ~ consistent with the order of CBL mean U

→ → the **momentum flux from SFC** determines the **mean wind structure of CBL**

<u>During the nighttime</u>

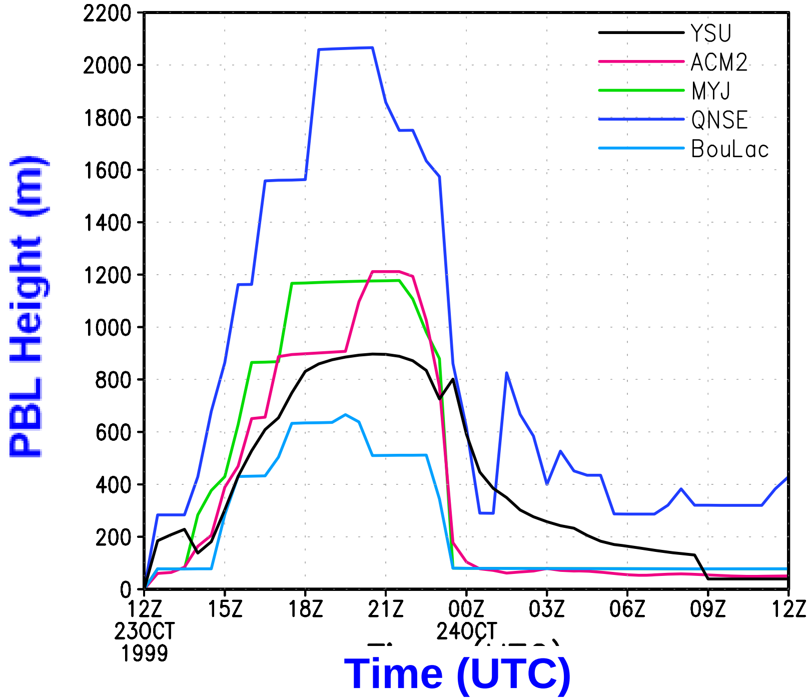
(u_*) Three TKE schemes > ACM2 > YSU ~ consistent with the near-ground wind gradient

→ → the **PBL mixing** determines the **near ground wind profile**, and then **the**

Intercomparison of PBL schemes [3.1. Surface variables]

- **PBL Height**

YSU ACM2
MYJ QNSE BouLac



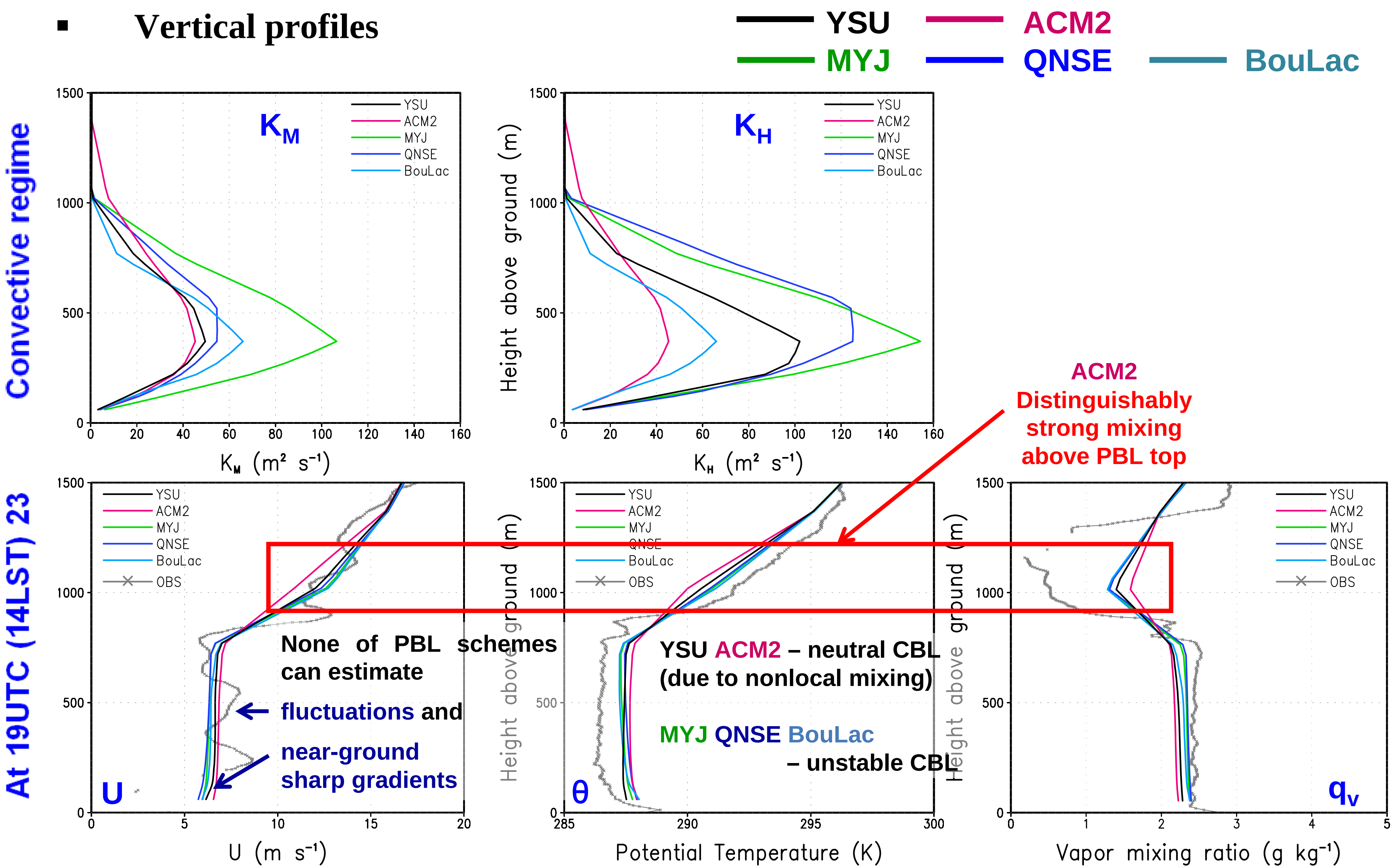
<u>**During the daytime**</u> <u>**During the nighttime**</u>

(PBLH) QNSE > ACM2 ~ MYJ > YSU > BouLac QNSE > YSU > ACM2 ~ MYJ ~ BouLac

The calculated **PBL heights from five schemes greatly diverge** .

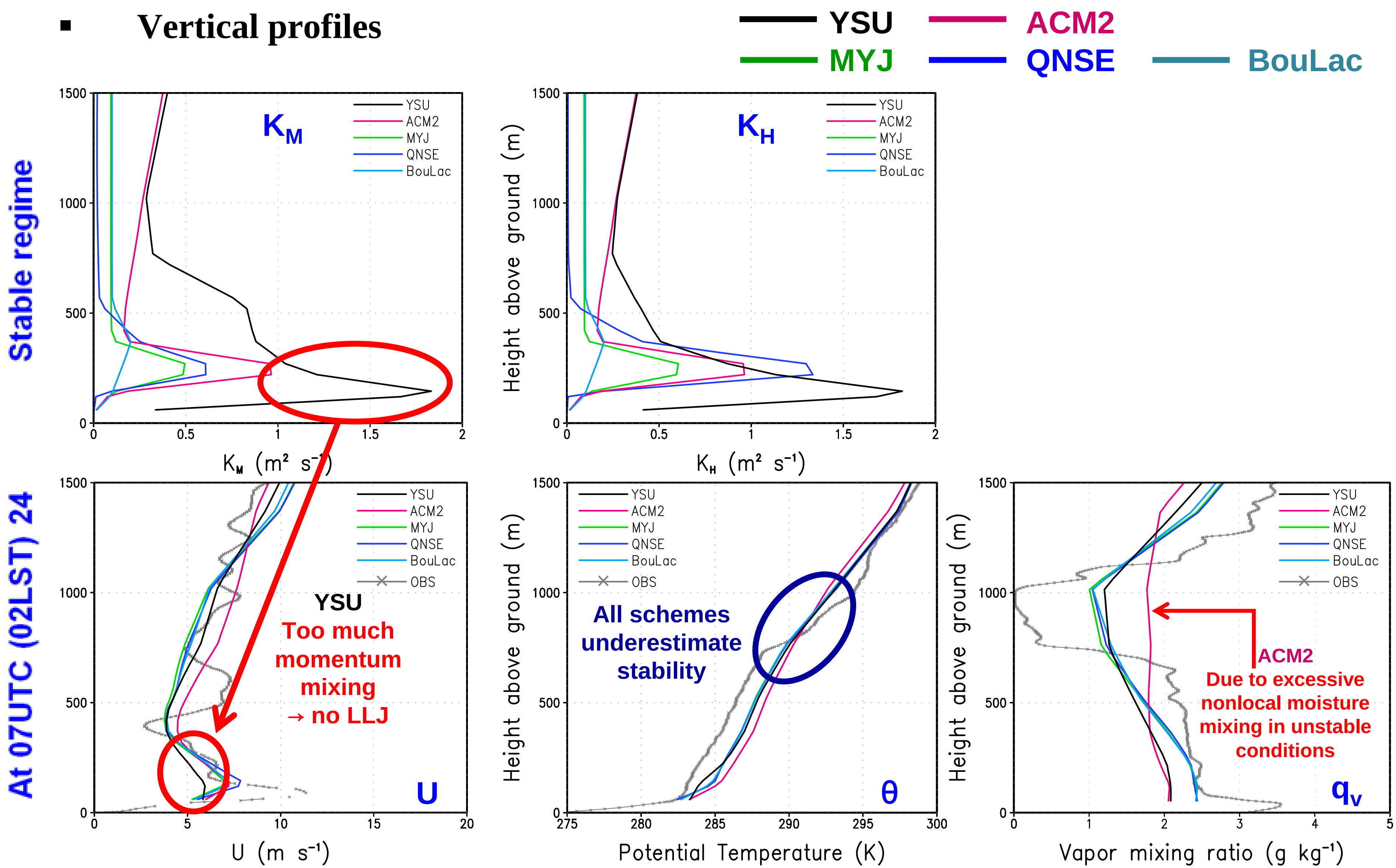
Intercomparison of PBL schemes [3.2. PBL structures]

- **Vertical profiles**



Intercomparison of PBL schemes 3.2. PBL structures

- **Vertical profiles**



Part 2
Sensitivity of a PBL Scheme to Surface Layer Formulations

*Q1) How much do **surface layer options** contribute **to the intercompared characteristics of PBL parameterizations**?*

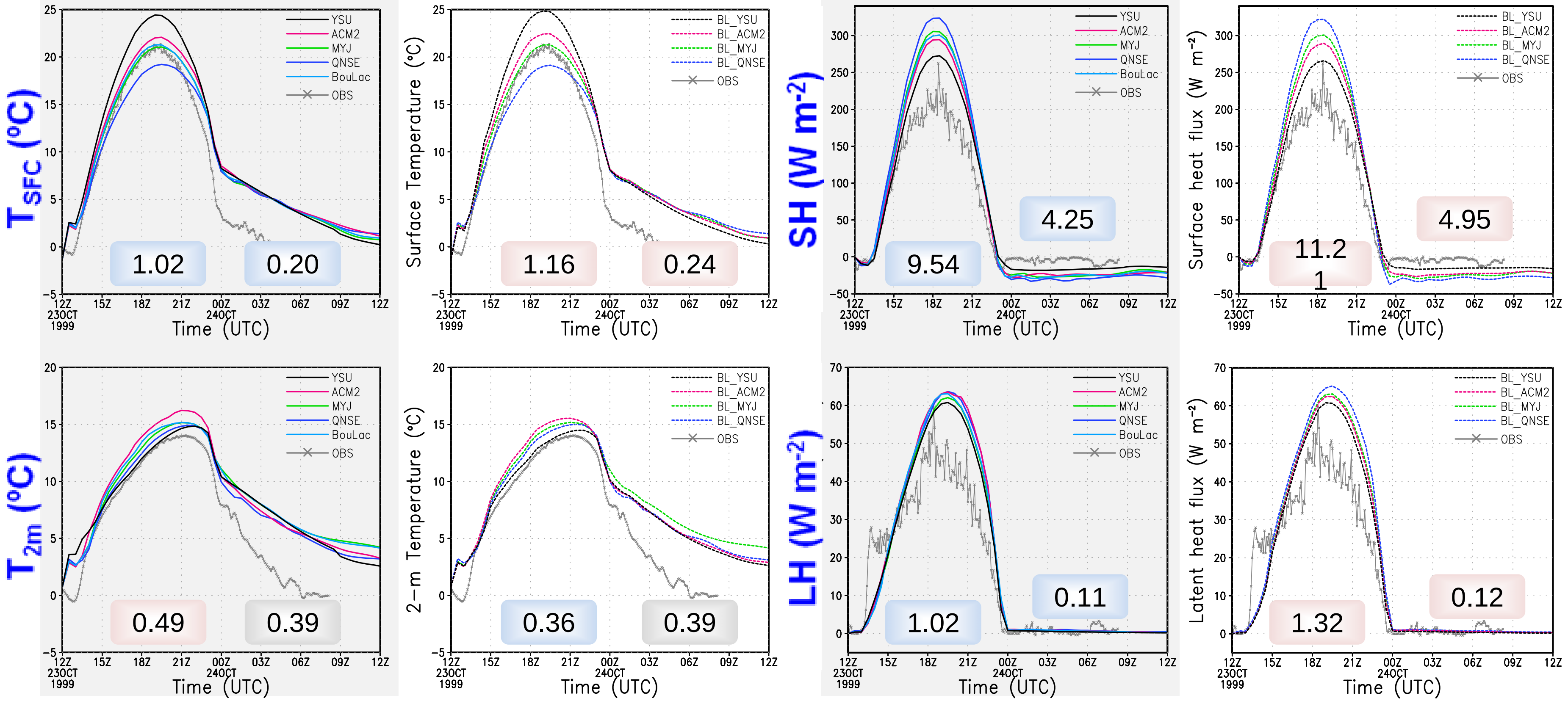
*Q2) How much is the **variability among PBL parameterizations** attributed to **surface layer formulations**?*

Sensitivity to SL formulations 4.1. Surface variables

Smaller S.D. | Larger S.D.

BL_YSU BL_ACM2 BL_MYJ BL_QNSE

PBL intercomparison experiments | SL algorithm sensitivity experiments | PBL intercomparison experiments | SL algorithm sensitivity experiments



For thermodynamic variables

Variables are **almost fully characterized by surface layer formulations** both during the daytime and nighttime.

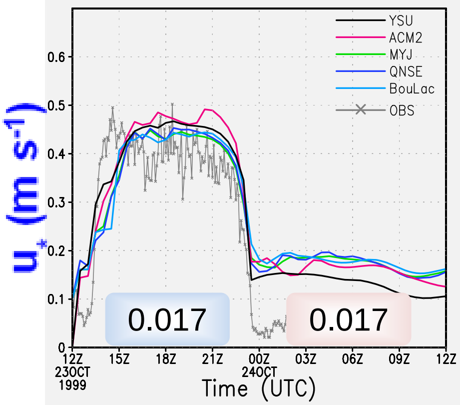
Variability among different PBL schemes is **attributed to differences in the surface layer option** than in vertical mixing formulations

Sensitivity to SL formulations [4.1. Surface variables]

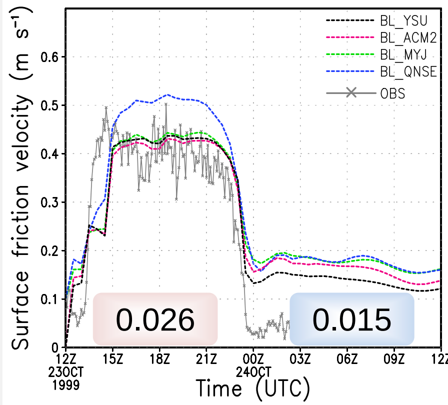
Smaller S.D. | Larger S.D.

BL_YSU　BL_ACM2　BL_MYJ　BL_QNSE

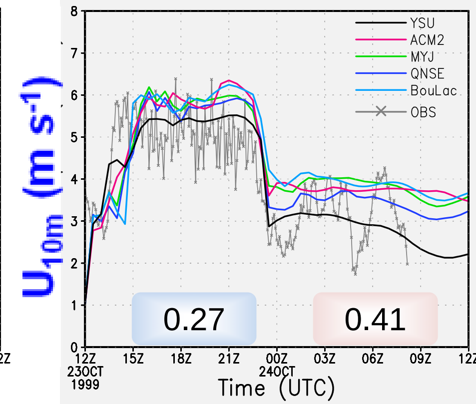
PBL intercomparison experiments



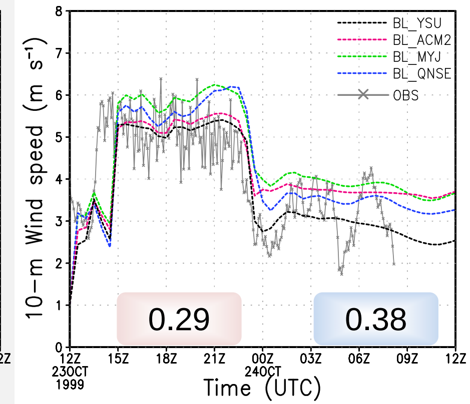
SL algorithm sensitivity experiments



PBL intercomparison experiments



SL algorithm sensitivity experiments



For wind components

During the daytime, **u* converges** when the **surface layer option is unified**.

→u* is **more dependent** on the **vertical mixing formulations**.

During the nighttime, **variability among the surface-layer experiments are smaller** than **that among the PBL intercomparison experiments**.

Sensitivity to SL formulations <u>4.2. PBL structures</u>

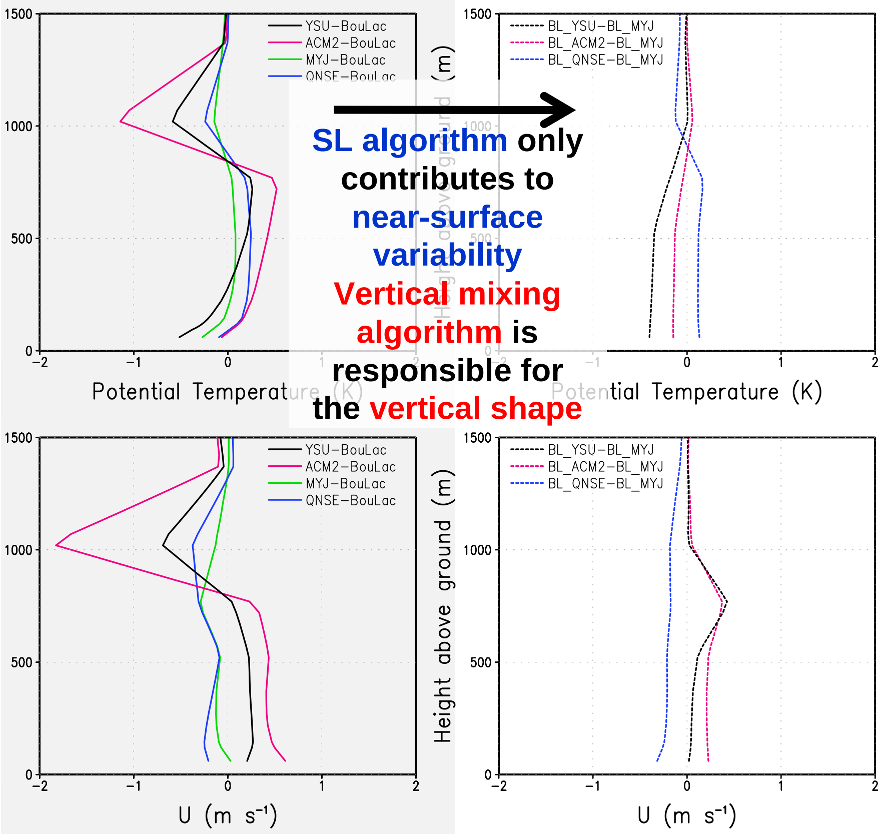
BL_YSU — BL_ACM2 — BL_MYJ — BL_QNSE

At 19UTC (14LST) 23 Oct 1999

Effects of both PBL and SL formulations | **Effects of only SL formulation**

θ

U



SL algorithm only contributes to near-surface variability

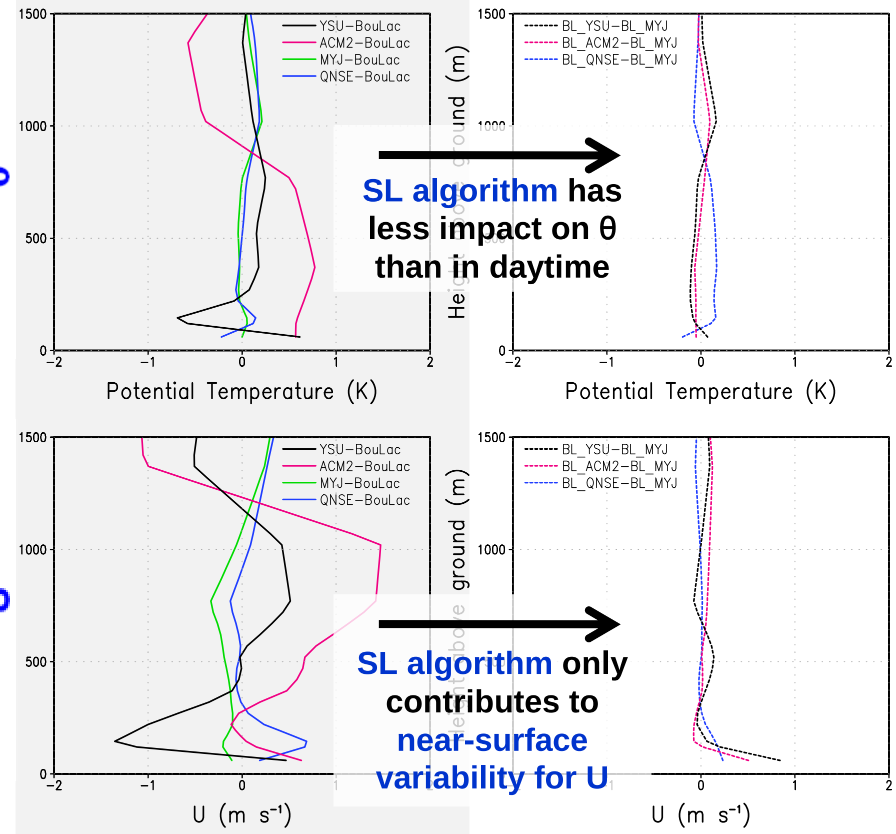
Vertical mixing algorithm is responsible for the vertical shape

At 07UTC (02LST) 24 Oct 1999

Effects of both PBL and SL formulations | **Effects of only SL formulation**

θ

U



SL algorithm has less impact on θ than in daytime

SL algorithm only contributes to near-surface variability for U

Concluding Remarks

PART 1: Intercomparison of PBL parameterizations

For surface variables

Variability of thermodynamic (wind) components among PBL schemes **is large in daytime (nighttime)**.

For vertical profiles

Under unstable (stable) conditions, **ACM2 (YSU)** PBL shows **strong mixing near the top of the PBL (near the ground)**.

PART 2: Sensitivity of performance of a PBL scheme to surface layer formulations

For surface variables

Thermodynamic (wind) components are more strongly influenced **by surface layer formulations (by vertical diffusion formulations) in both convective and stable regimes (in stable regime)**.

For vertical profiles

Surface layer formulations only contribute to **near surface variability**, whereas **the shapes of the profiles** are determined **by PBL mixing algorithms**.