Impacts of the Lowest Model Layer Height on Performance of PBL Parameterizations in Numerical Prediction

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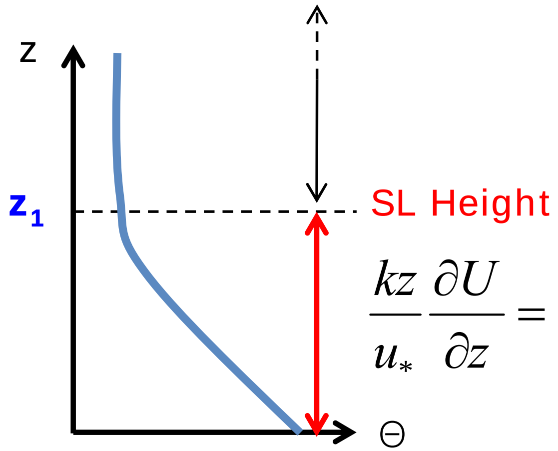
Introduction

- **Role of the lowest model layer height** on **performance of PBL schemes**

Z_1 → **Surface layer similarity** → **PBL scheme**

Z_1 ~ Surface layer depth



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

Surface layer formulation → PBL scheme

: **Surface layer formulation** provides **boundary conditions** to the **PBL schemes**.

$$\overline{u'w'}_0,\ \overline{\theta'w'}_0,\ \overline{q'w'}_0$$

:**Surface fluxes at z_1**

Introduction

- Importance of z_1 **determinations** in **numerical weather prediction**
  - Wei et al. (2001) – thermal fluxes of a strong warm-advection snowmelt event

Under thermally stable conditions of a **strong warm-advection snowmelt event**
* **z_1=40 m > SL** : **outside** the range of applicability of the **surface-layer similarity**
→ Model calculated **turbulent thermal flux** is **smaller** than fluxes with **z_1=3 or 10 m**.

  - Zängl et al. (2008) – simulations of Alpine foehn

Influence of **PBL scheme** and **z_1** on simulations of an **Alpine foehn**
* Five PBL schemes & **z_1 = 7, 22, and 36 m**
→ The **dependence of the model skill on z_1** tends to be **larger and more systematic**.

  - Aligo et al. (2009) – QPF (quantitative precipitation forecasts) over Midwest

Impact of model **vertical grid resolution** on **Midwest summer rainfall forecasts**
* **z_1** is **lowered from 54 m to 10 m** and higher resolution in the surface layer
→ **Improved precipitation forecasts** due to alternations in the convective initiation.

: These researches were **targeted to the stable SL**: **z_1** of 30-50m **> real SL** depth

→ **Improvement** of numerical simulations **by lowering the z_1**.

Introduction

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

To investigate **impacts of z_1 determinations** **on performance of PBL parameterizations** in numerical prediction models **for a diurnal cycle** using three PBL schemes.

Experimental Setup

Experimental Setup 2.1. Model configuration and Physics package

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 (Poulos et al. 2002)

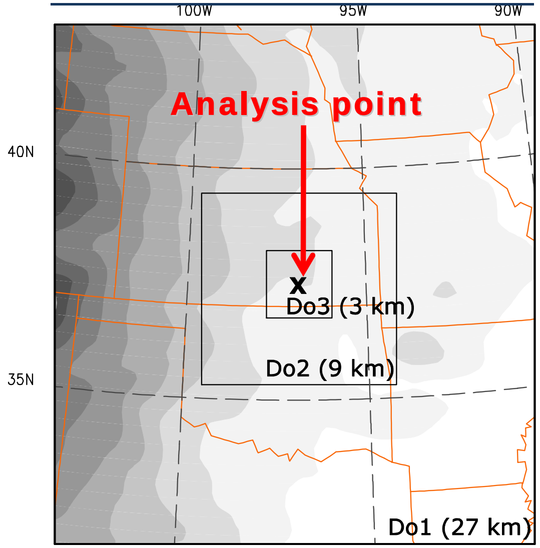
Initial and Boundary Conditions

- 12-hourly NCEP Final Analysis (FNL) data

Observation data for reference values

- Surface data and sounding data are provided by
  http://www.eol.ucar.edu/isf/projects/cases99/asciiDownload.jsp
  http://www.eol.ucar.edu/projects/cases99

Domain and Resolution



Summary of experiments

Impacts of z_1 for three PBL schemes

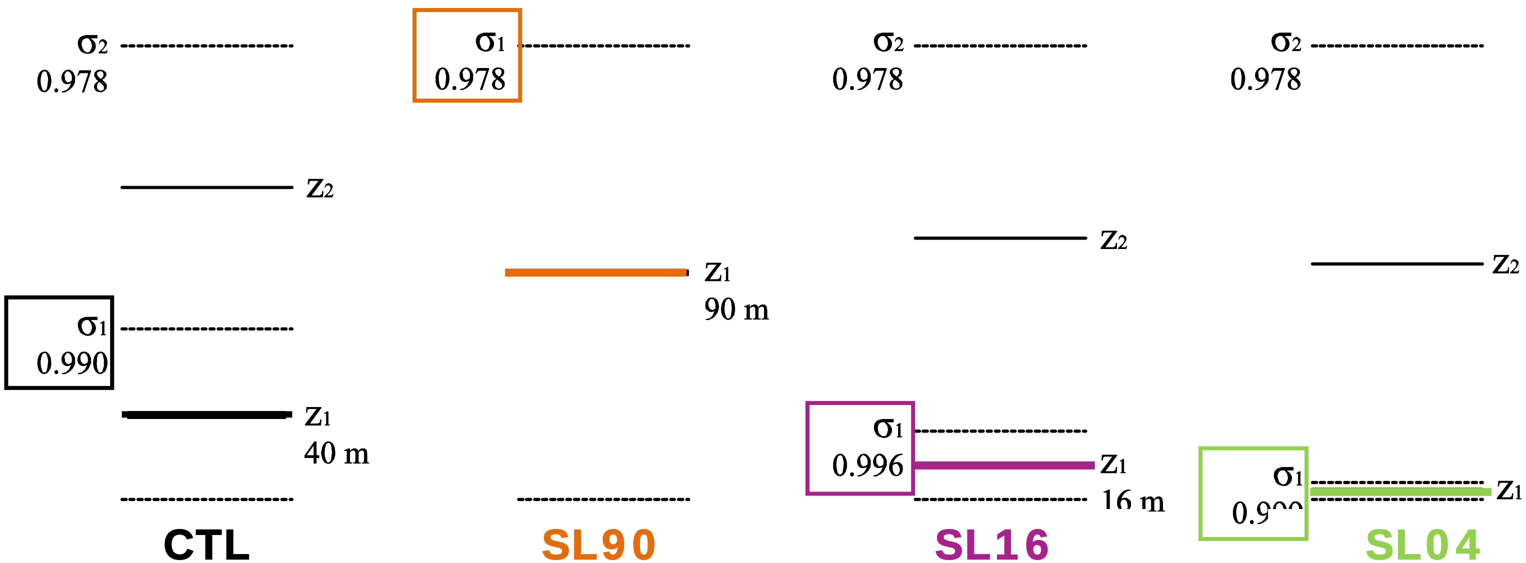
	PBL	Surface Layer	Order of closure	Diffusivities	Nonlocal mixing
YSU	**YSU**	**(MM5 Similarity)**	**1st order closure**	$K_M = k w_s z \left(1 - \frac{z}{h}\right)^2$	**Counter gradient terms for u, v, and θ**
ACM2	**ACM2**	**(PX Similarity)**		$K_H = \mathrm{Pr}^{-1} K_M$	**Nonlocal fluxes for u, v, θ, and q**
MYJ	**MYJ**	**(Eta Similarity)**	**TKE closure**	$K_c = l \sqrt{TKE} S_c$	**-**

Experimental Setup 2.2. Vertical grid system

Vertical grid system

- 28 full-sigma levels (i.e., 27 half-sigma levels or 27 layers) with model top at 50 hPa.
- In the WRF model: at the **half-σ levels** ← u, v, Θ, q_v

  at the **full-σ levels** ← w, <w'c'>, K_C for any scalar C (C: u, v, Θ, q_v)



z_1 is **40 m** (**frequently used**)	z_1 is **90 m** (**Deep SL** case)	z_1 is **16 m** (**Shallow SL** case)	z_1 is **4 m** (**Shallow SL** case)

- **Each PBL scheme**, **4 experiments** are conducted with different z_1.

Results

Impacts of z_1 on performance of PBL parameterizations

*Q1) Are the **three PBL parameterizations** sensitive to the **changes of the lowest model layer height**?*

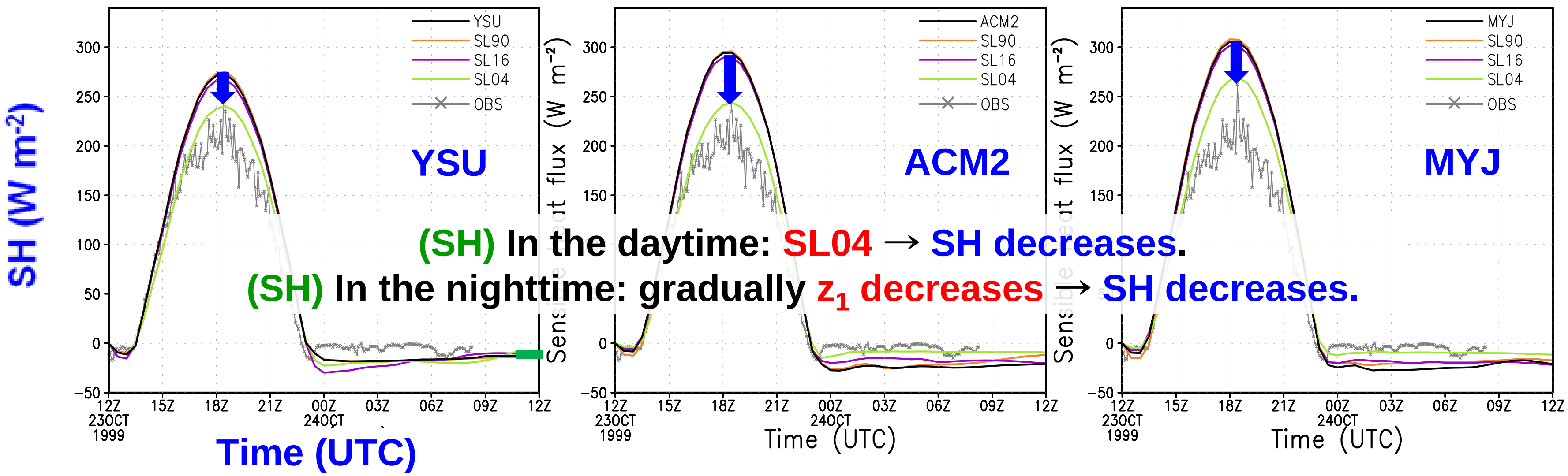
*If they are so, do **the three schemes react to the height changes in the same way**?*

*Q2) How does the **sensitivity differ according to environmental regime changes**?*

Impacts of z_1 3.1. Surface variables

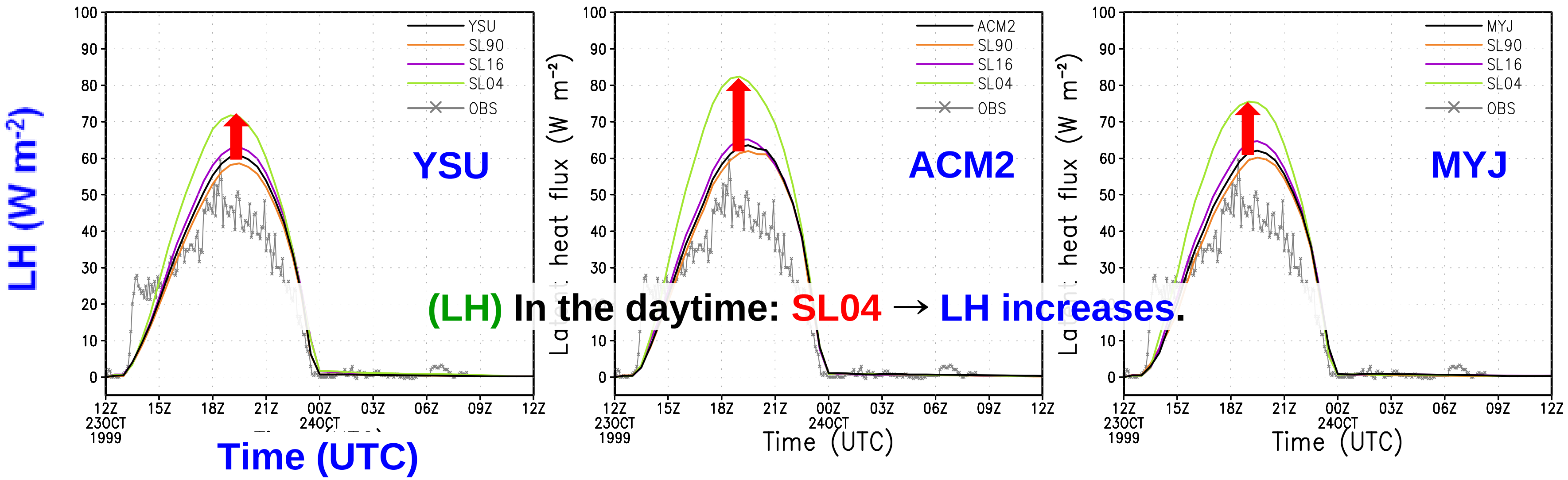
- SH and LH (W m^{-2})

CTL Z_1 ~ 40 m | SL90 Z_1 ~ 90 m | SL16 Z_1 ~ 16 m | SL04 Z_1 ~ 4 m



(SH) In the daytime: SL04 → SH decreases.

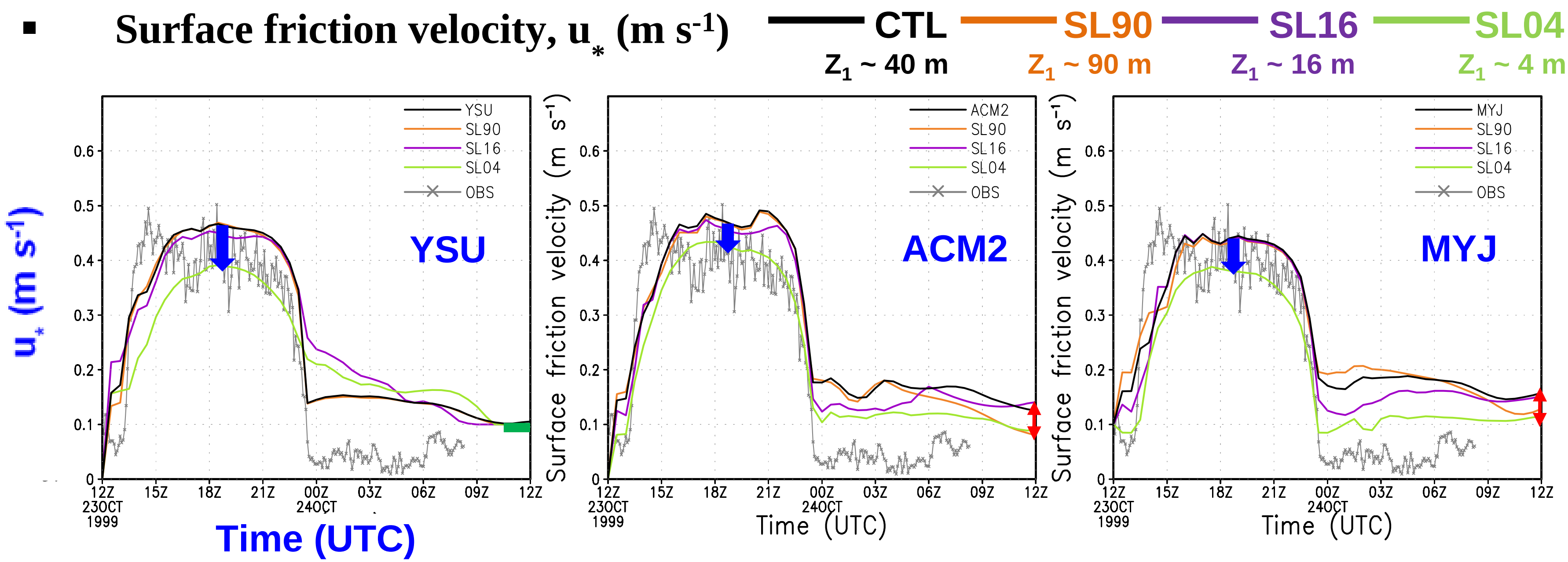
(SH) In the nighttime: gradually z_1 decreases → SH decreases.



(LH) In the daytime: SL04 → LH increases.

Impacts of z_1 3.1. Surface variables

- **Surface friction velocity, u_* ($m\ s^{-1}$)**

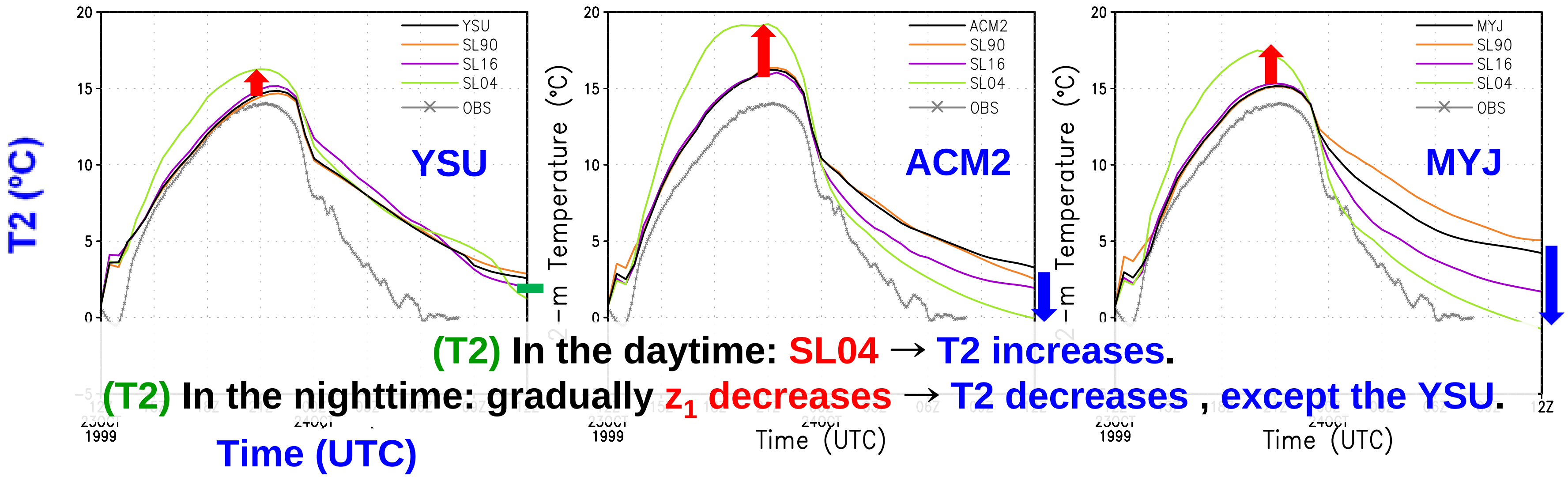


(u_*) In the daytime: SL04 → ustar decreases.
(u_*) In the nighttime: gradually z_1 decreases → ustar decreases, except the YSU.

Impacts of z_1 3.1. Surface variables

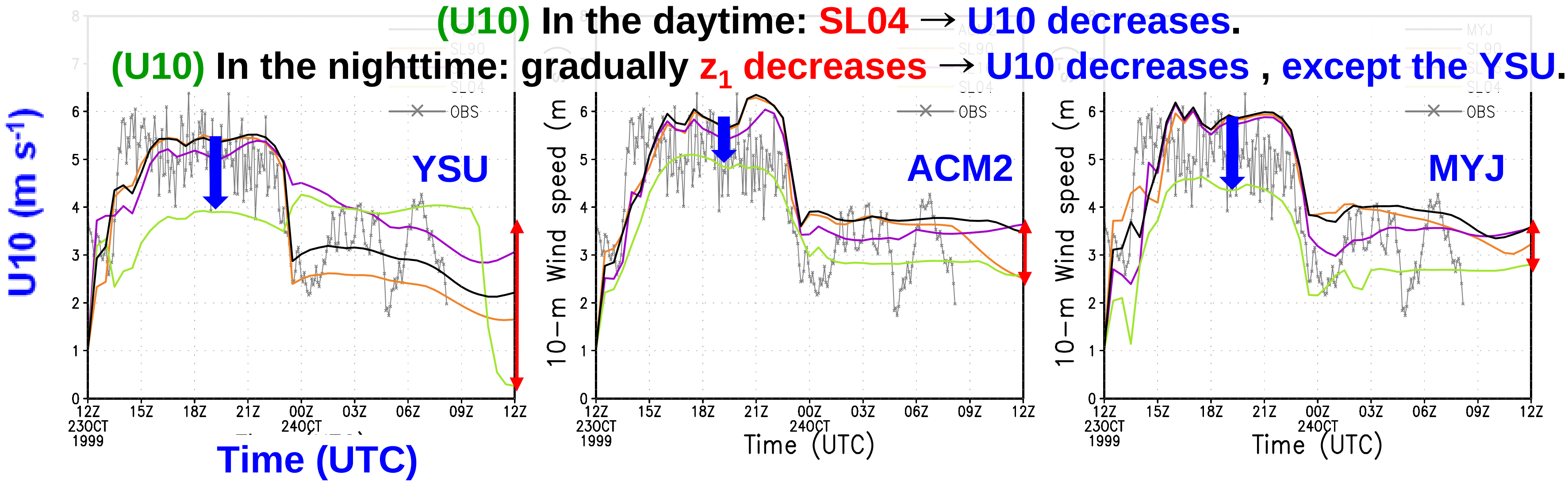
- T2 (ºC) and U10 (m s⁻¹)

CTL Z_1 ~ 40 m | SL90 Z_1 ~ 90 m | SL16 Z_1 ~ 16 m | SL04 Z_1 ~ 4 m



(T2) In the daytime: SL04 → T2 increases.

(T2) In the nighttime: gradually z_1 decreases → T2 decreases , except the YSU.



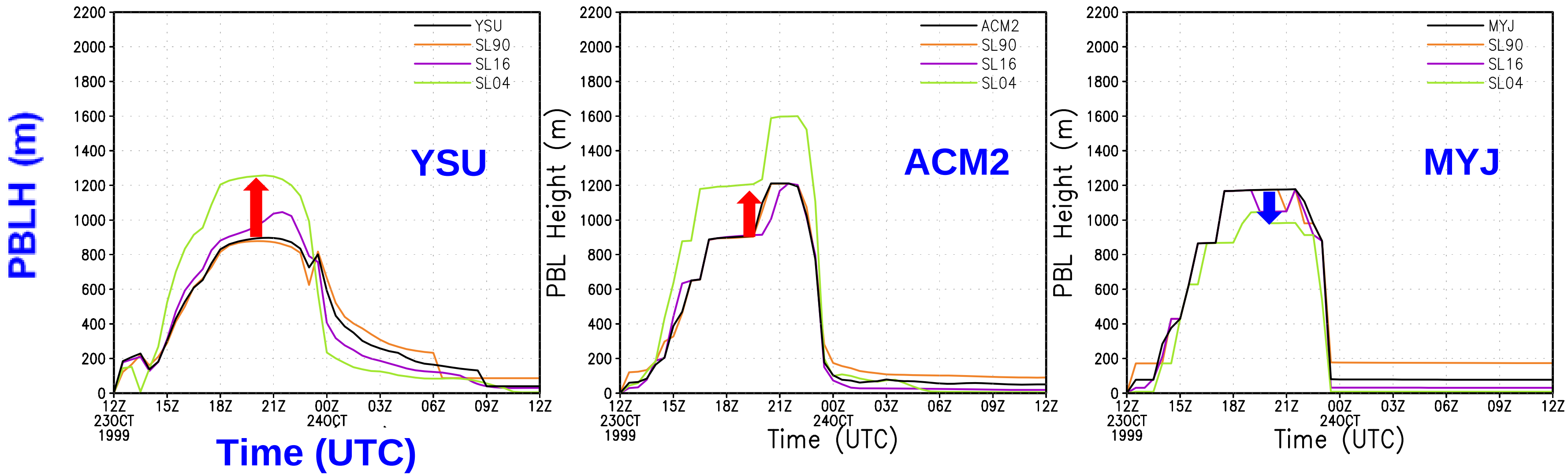
(U10) In the daytime: SL04 → U10 decreases.

(U10) In the nighttime: gradually z_1 decreases → U10 decreases , except the YSU.

Impacts of z_1 3.1. Surface variables

- **PBL height (m)**

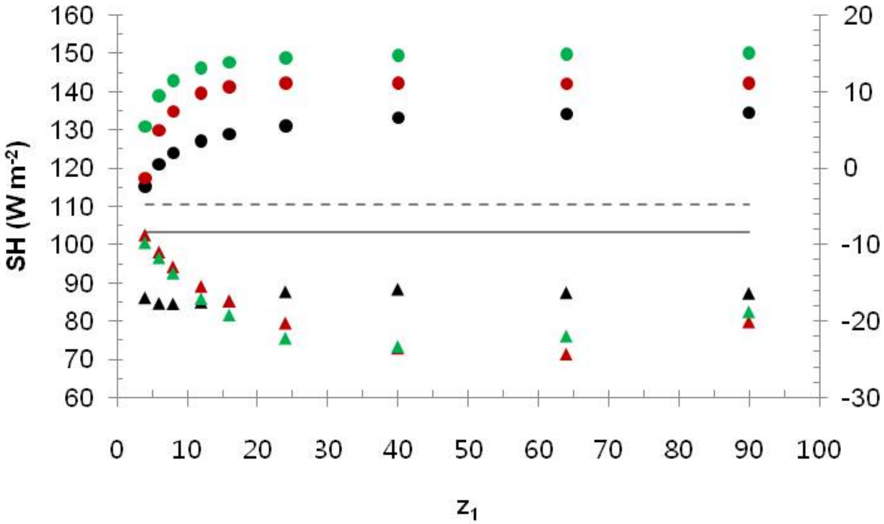
CTL Z_1 ~ 40 m SL90 Z_1 ~ 90 m SL16 Z_1 ~ 16 m SL04 Z_1 ~ 4 m

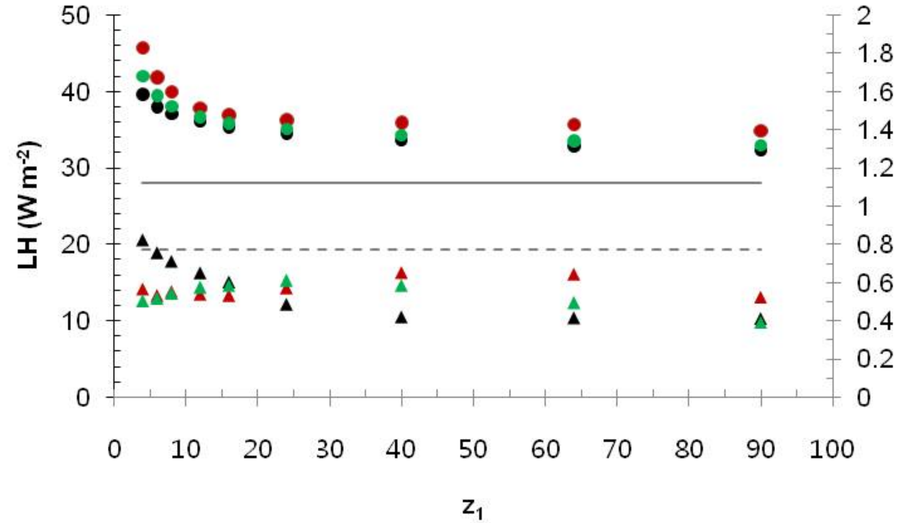


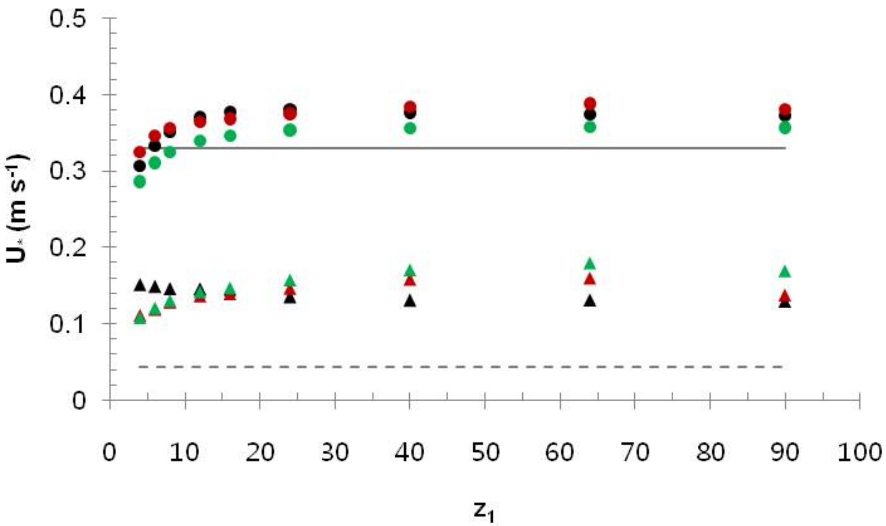
(PBLH) In the daytime: SL04 → Deeper PBL with YSU and ACM2, Shallower PBL with MYJ.

Impacts of z_1 3.1. Surface variables

- **Summary of surface variables**







(CBL)

From z_1 of **12 ~ 16 m**

→ Simulations are **insensitive**.

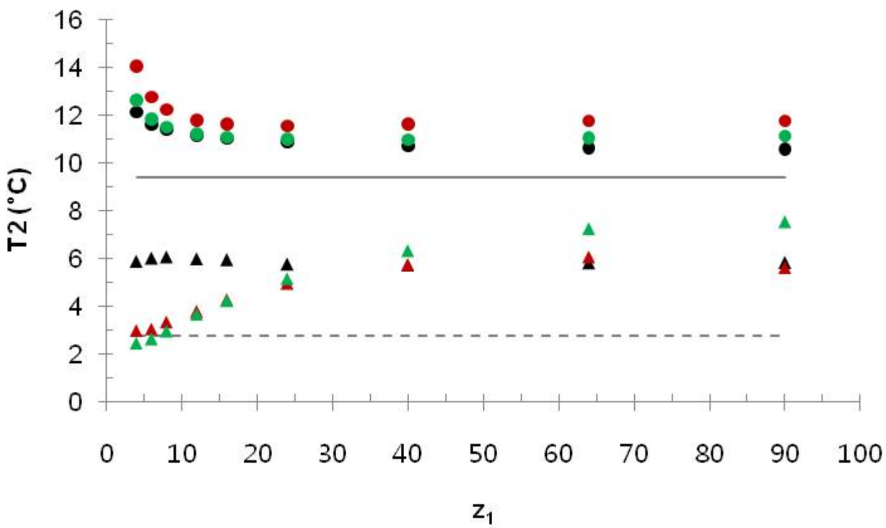
(SBL)

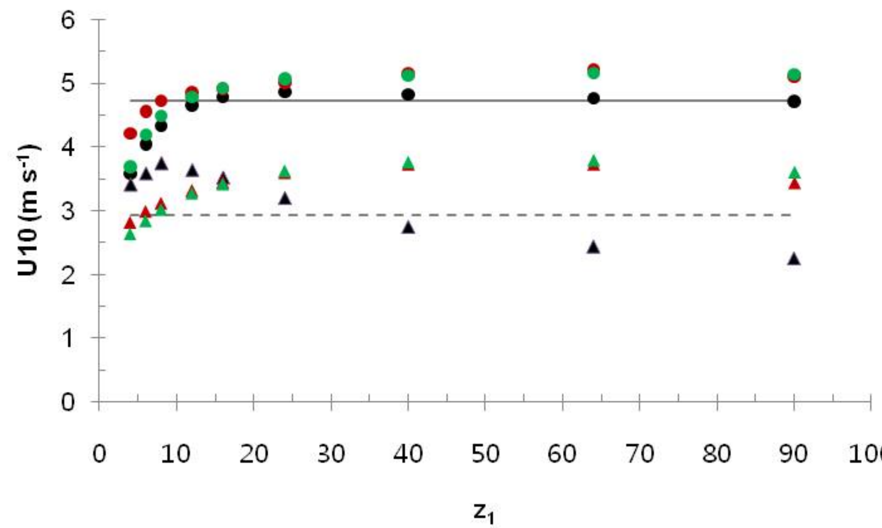
The **shallower** the z_1 is,

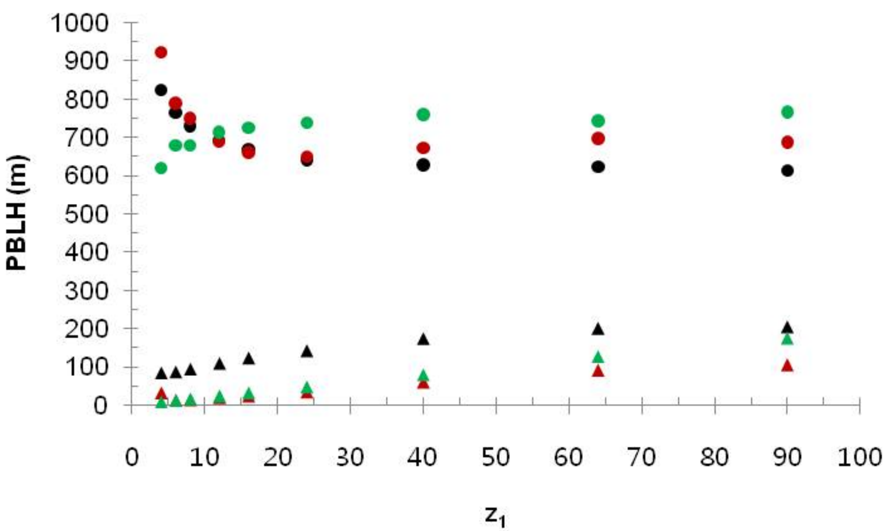
the **better** the **results** are.

Impacts of z_1 3.1. Surface variables

- **Summary of surface variables**







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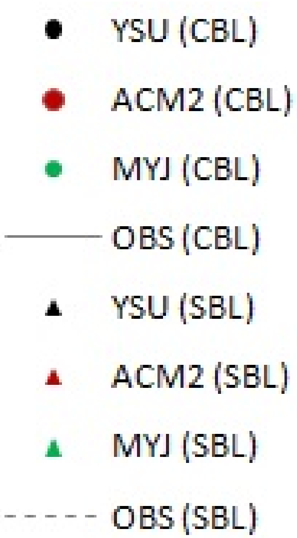
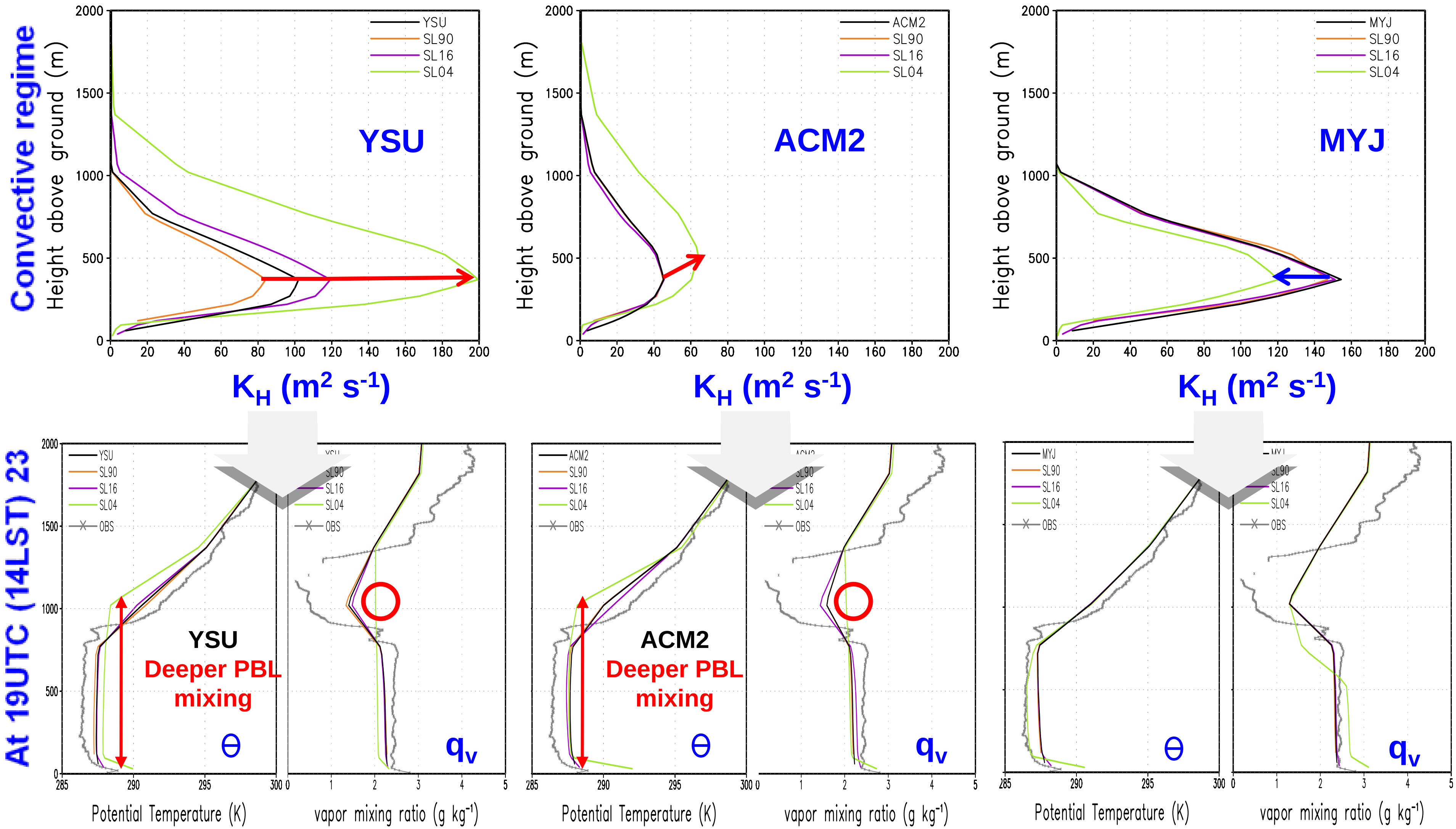


Impacts of z_1 3.2. PBL structures

- K_H (m^2 s^{-1}), Θ (K), and q_v (g kg^{-1})

CTL Z_1 ~ 40 m | SL90 Z_1 ~ 90 m | SL16 Z_1 ~ 16 m | SL04 Z_1 ~ 4 m



Impacts of z_1 3.2. PBL structures

- K_M (m^2 s^{-1}), and U (m s^{-1})

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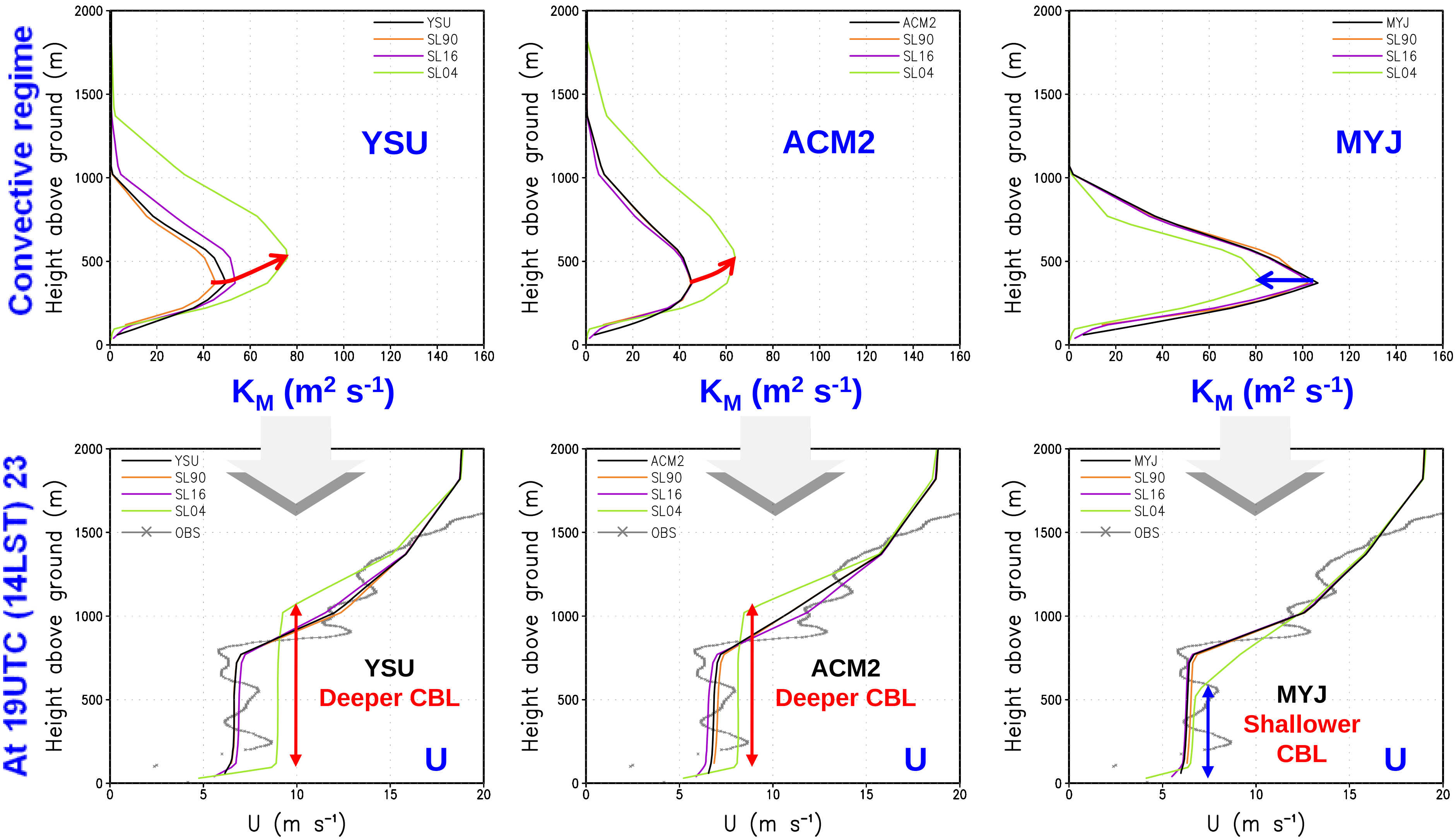

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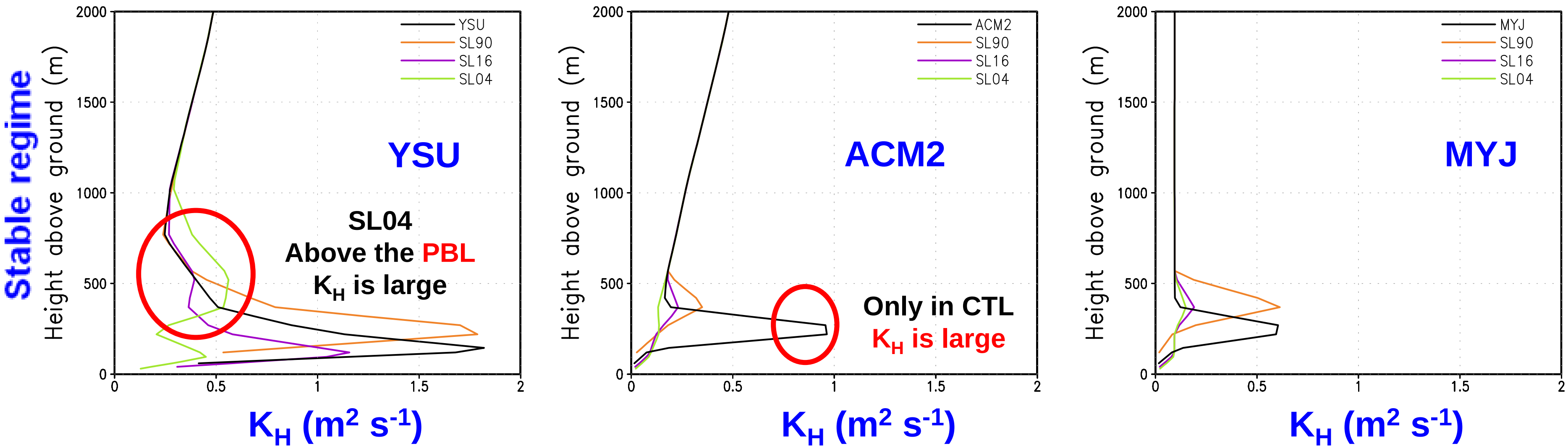

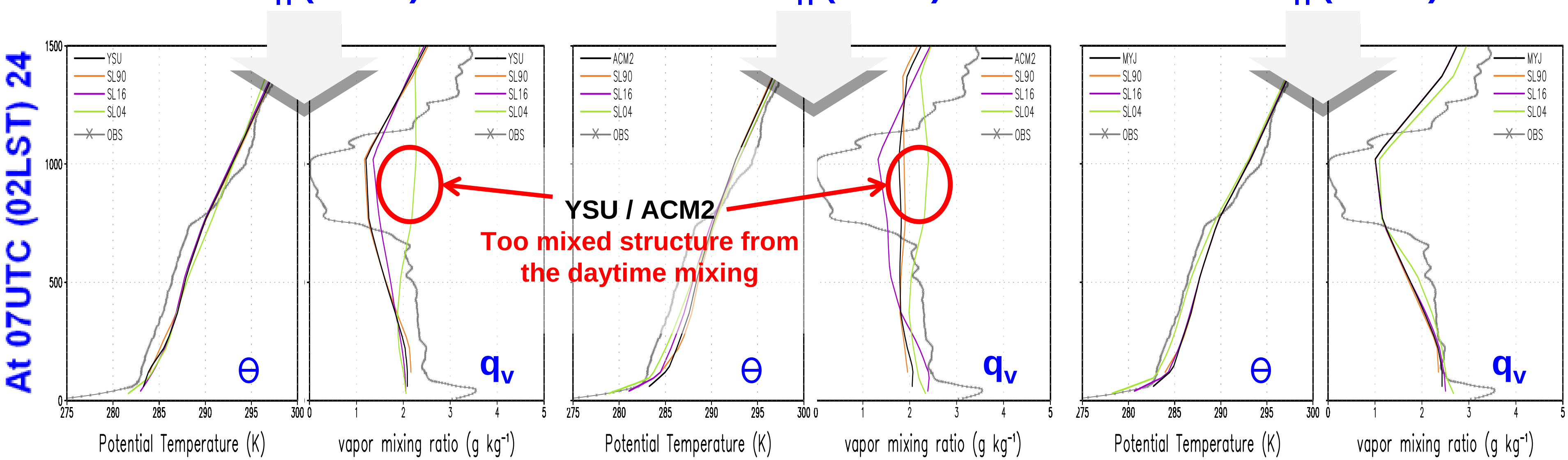

Impacts of z_1 3.2. PBL structures

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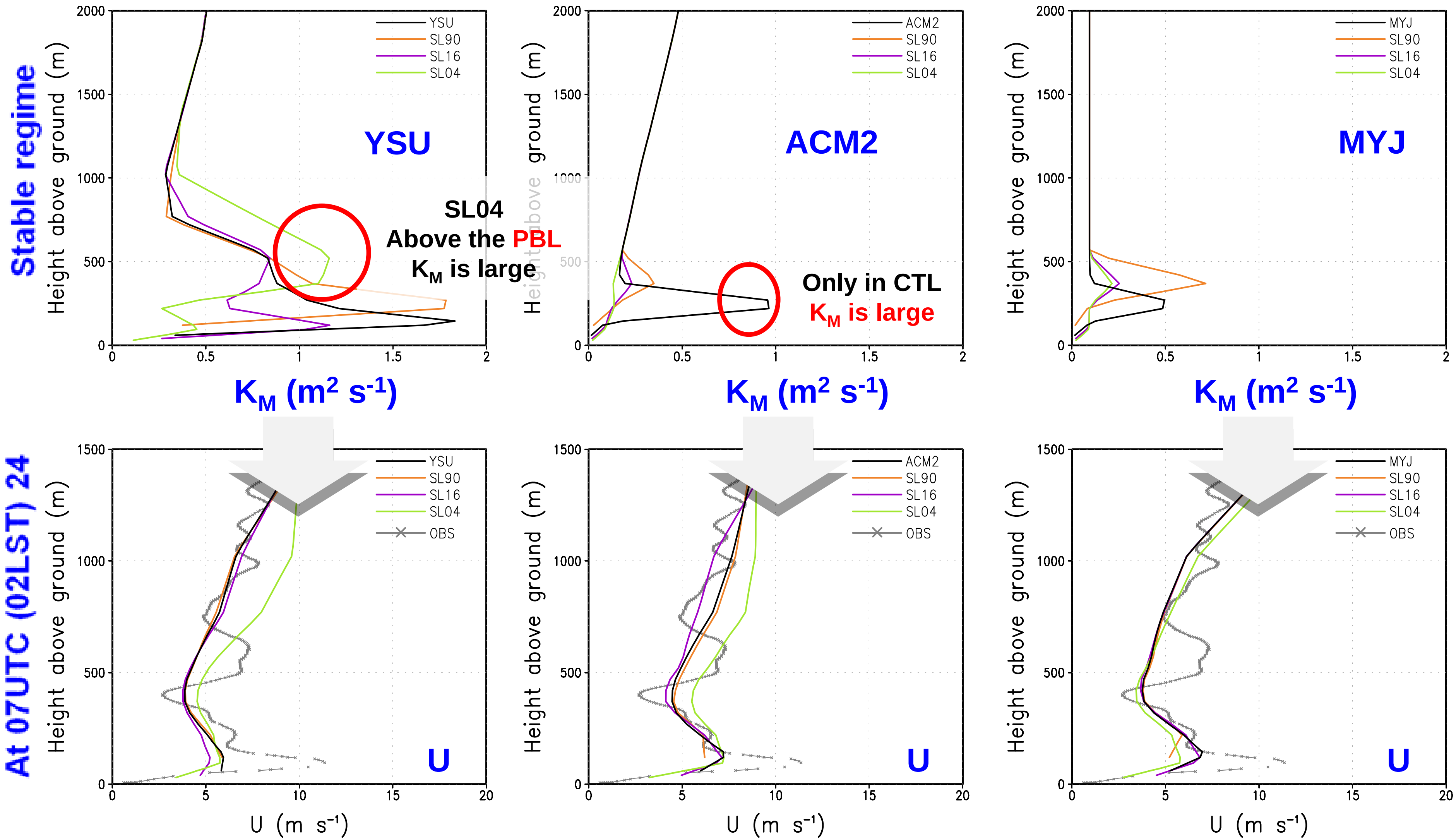
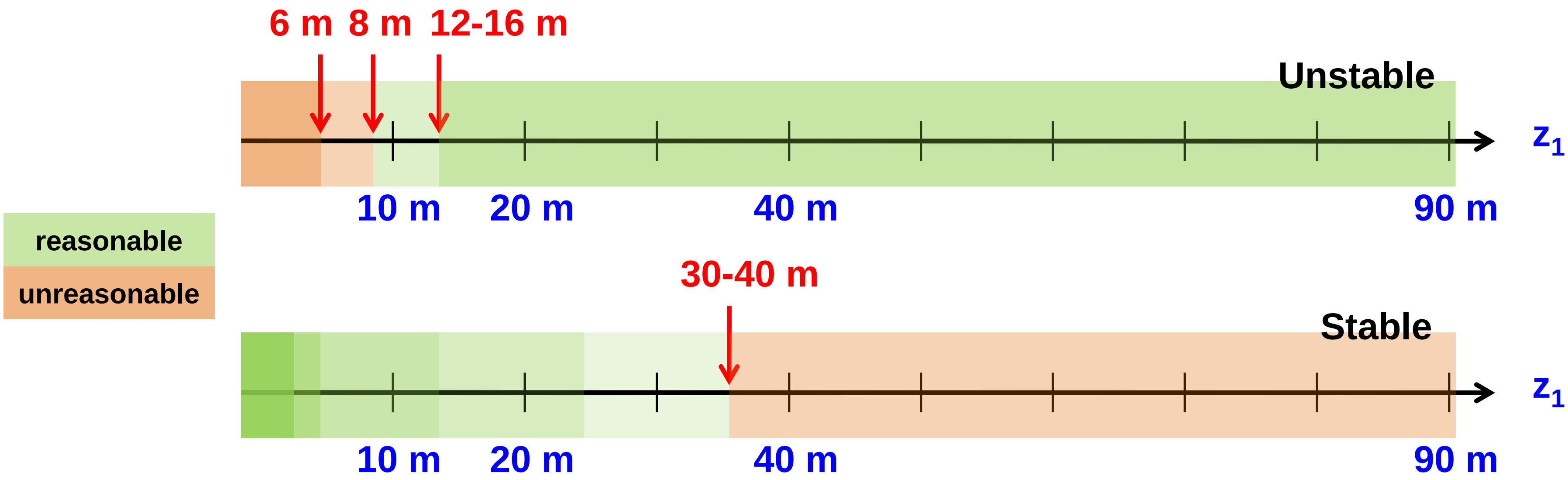


Concluding Remarks

- **Performance of PBL parameterizations according to the z_1**



: The lowest model layer height about **10 m** is suggested as **an optimal value** that can be **satisfactory for both unstable/stable conditions**.

Concluding Remarks

- **Future study**

- More statistically significant assessment of **impacts of the lowest model layer height** on **numerical forecasts** based on this study.

- To suggest **a method in adequately determining the surface layer height** instead of the lowest model layer height.

  1) Changing the lowest model layer height as realistic surface layer depth every time step → vertically unbalanced meteorological fields.

  2) Using the **time-varying surface layer depth** only in **surface layer and boundary layer physics**.

Acknowledgement

** The authors appreciate all scientists who involved in the CASES-99 field experiment.*

(The surface and sounding measurements data in this study are provided by:

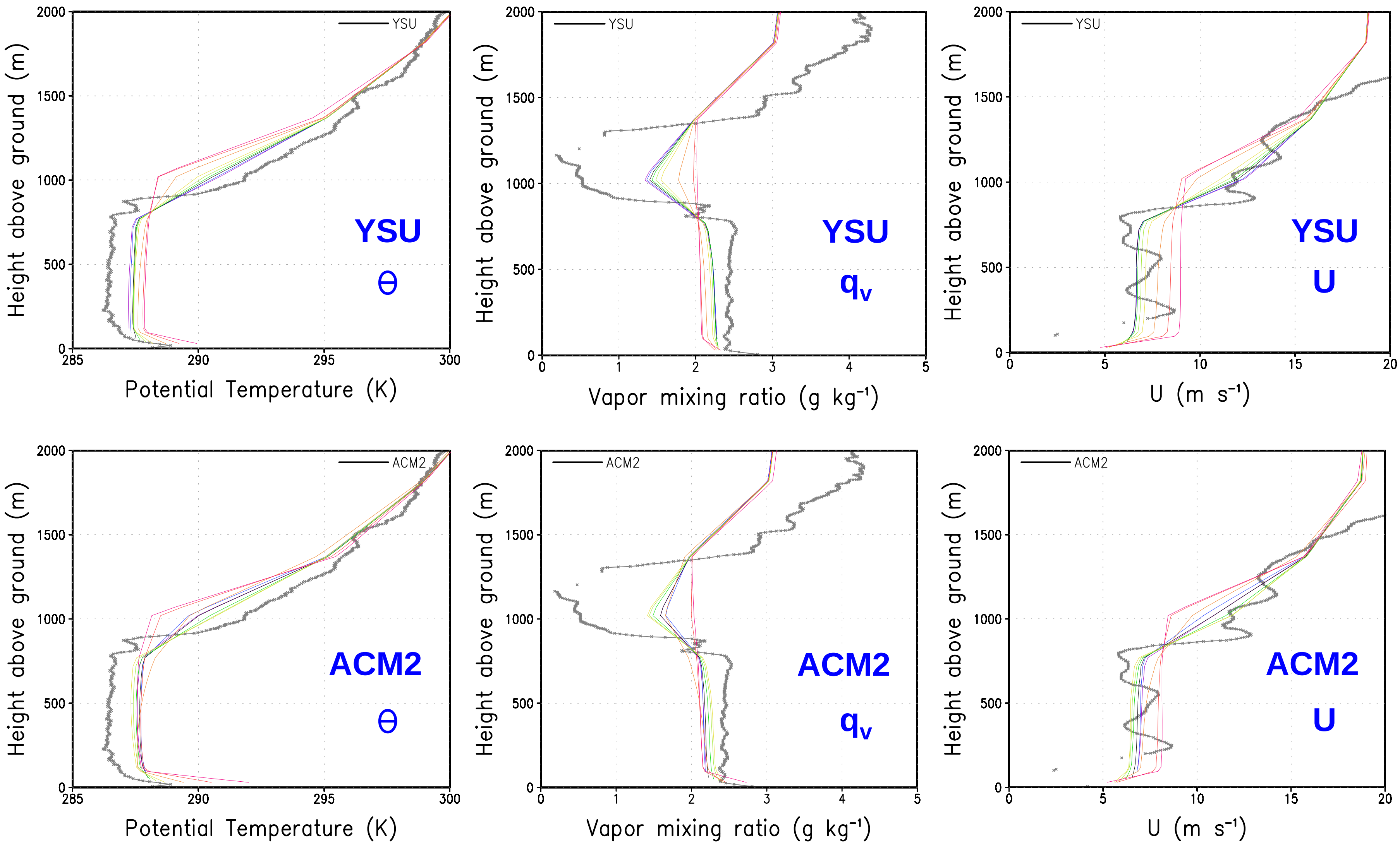
http://www.eol.ucar.edu/isf/projects/cases99/asciiDownload.jsp http://www.eol.ucar.edu/projects/cases99/)

Sensitivity to the 9 z_1 values…

SL90 (sigma1 = 0.978) z_1 = 90 m
SL64 (sigma1 = 0.984) z_1 = 64 m
SL40 (sigma1 = 0.990) z_1 = 40 m
SL24 (sigma1 = 0.994) z_1 = 24 m
SL16 (sigma1 = 0.996) z_1 = 16 m
SL12 (sigma1 = 0.997) z_1 = 12 m
SL08 (sigma1 = 0.998) z_1 = 8 m
SL06 (sigma1 = 0.9985) z_1 = 6 m
SL04 (sigma1 = 0.999) z_1 = 4 m

Sensitivity to the 9 z_1 values…

At 19UTC (14LST) 23



At 19UTC (14LST) 23

Sensitivity to the 9 z_1 values…

At 19UTC (14LST) 23