A discussion on the paper “Stable Atmospheric Boundary Layers and Diurnal Cycles”

By A. A. M. Holtslag et al., 2013,BAMS

Presented by Xiaoyan Zhang
Sept. 9, 2016

Outline

- Introduction
- Stable Atmospheric Boundary Layers
- Diurnal Cycles
- Summary and Prospects

Introduction

- The atmospheric boundary layer (ABL): the lower part of the atmosphere, has continuous interaction with Earth's surface owing to friction and heating or cooling.
- Main characteristics of the ABL: turbulent and has pronounced diurnal variations.
- Turbulence in the ABL: 3D, chaotic with time scales ranging from second to an hour and spatial scales varying from mm to the ABL height, efficient transport way of momentum, heat, water vapor, and other matter (e.g., air pollutants).
- Appropriate representation of the overall effects by turbulence is an essential part of atmospheric models dealing with the prediction and study of weather, climate, air quality, wind energy, and other environmental issues.

Introduction (cont.)

- Turbulence closure is extremely important for solving the equations of motions but a big challenge. "Local" closure is useful for stably stratified turbulence and "nonlocal" mixing is required to present the mixing processes for unstable and convective boundary layer.

- Implementations in different models show that the parameterization schemes have large variations of diurnal cycles of near-surface temperature and wind.

- Current understanding and capability of modeling the stably stratified conditions are limited but they have important impact on model results.

Introduction (cont.)

Turbulence closure

K theory (First-order parameterization)

$$\overline{u'_j\zeta'} = -K\frac{\partial\overline{\zeta}}{\partial x_j}$$

Turbulence length theory

$$K_m \propto V l_m$$

TKE parameterization

$$\frac{\partial\overline{u'_1u'_2}}{\partial t} = \cdots - \left(\frac{\partial\overline{u'^2_1u'_2}}{\partial x_1} + \frac{\partial\overline{u'_1u'^2_2}}{\partial x_2} + \frac{\partial\overline{u'_1u'_3u'_2}}{\partial x_3}\right) + \cdots$$

TKE equation

Introduction (cont.): ECMWF performance (Exam. 1)

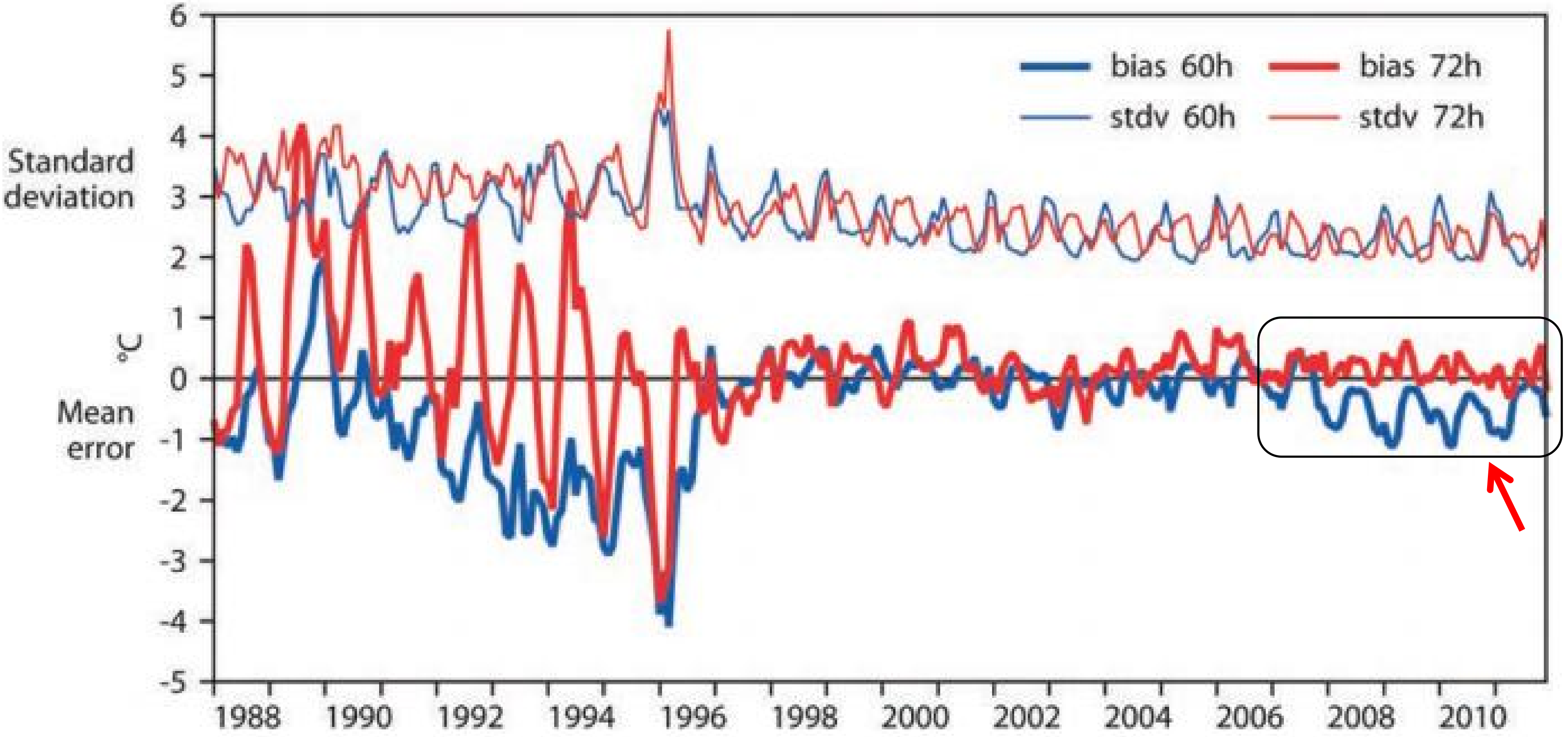


Fig.1 *Long-term history of 2-m temperature errors (°C) of daily 60-h (blue,verifying at 0000 UTC) and 72-h forecasts (red, verifying at 1200 UTC) in the* ***ECMWF model over Europe****.*

Improved but became worse at nighttime over the past several years !

Introduction (cont.): CAM performance (Exam. 2)

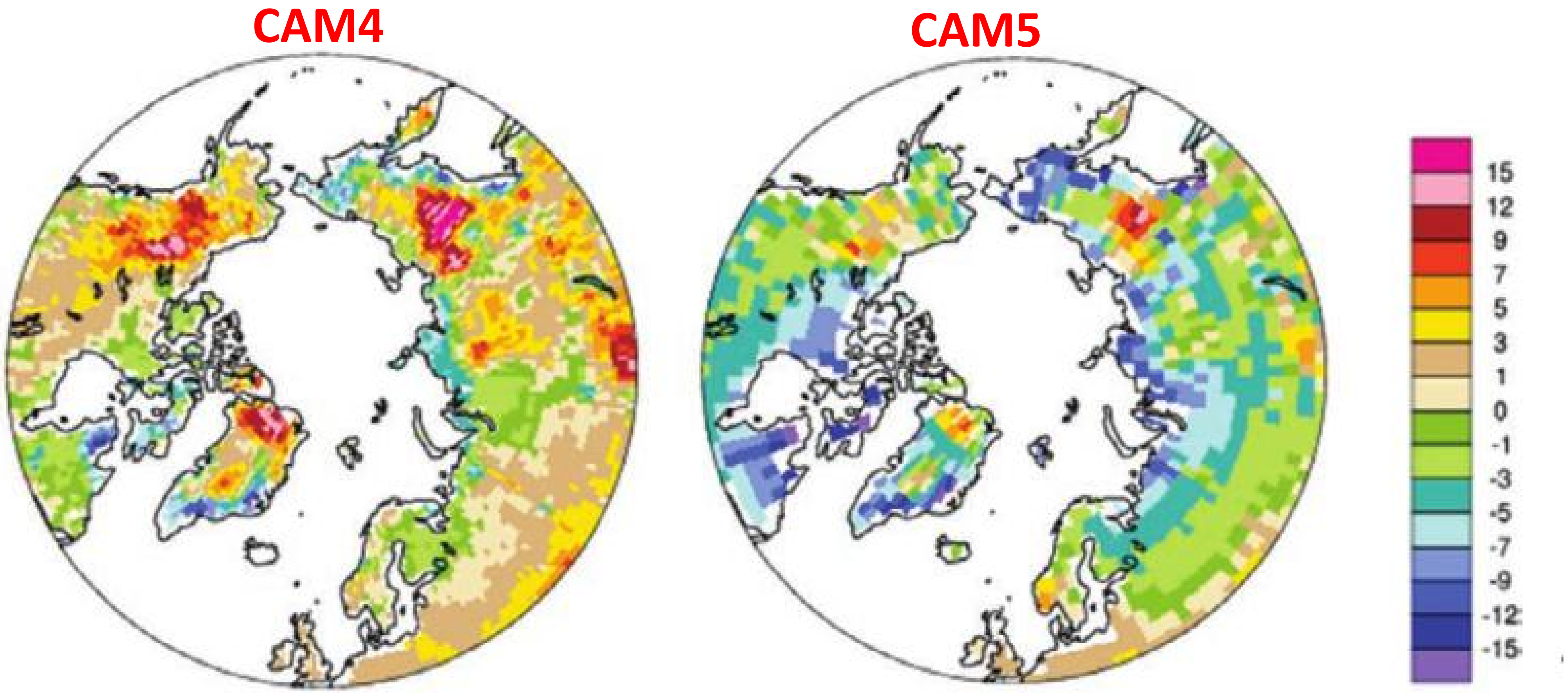


Fig.2 *Wintertime [December–February (DJF)]* ***differences for the 2-m temperature*** *(°C) climatologies of AMIP simulations and observations over land and ice for the Northern Hemisphere.*

Introduction (cont.): SCMs for GABLS (Exam. 3)

Winter

Summer

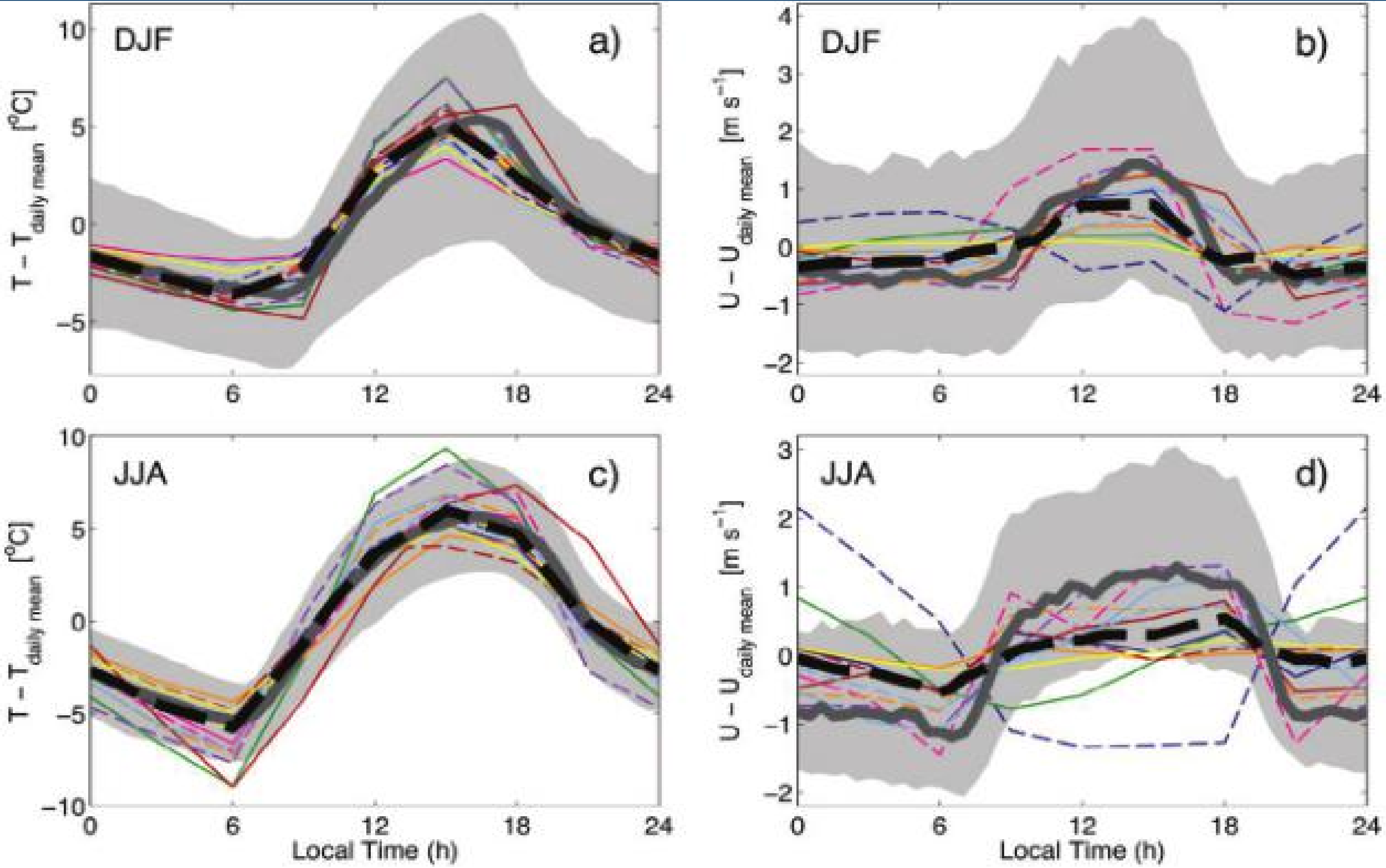
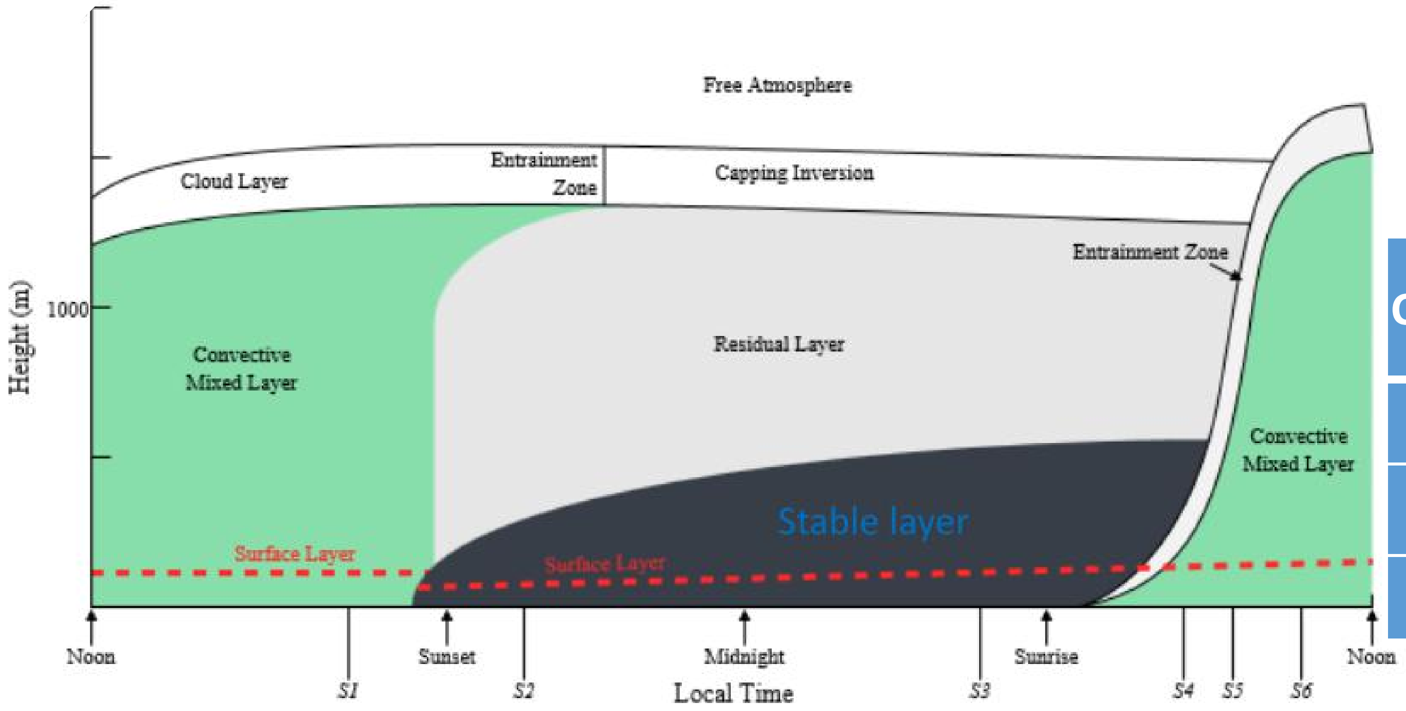


Fig.3 Observed and modeled diurnal cycles of 2-m temperature and wind speed with respect to their daily means for the ARM SGP main site (36.6°N, 97.5°W)

GABLS: Global Energy and Water Exchange (GEWEX) Atmospheric Boundary Layer Study, **SCMs**: Single-column versions of models

Stable Atmospheric Boundary Layers

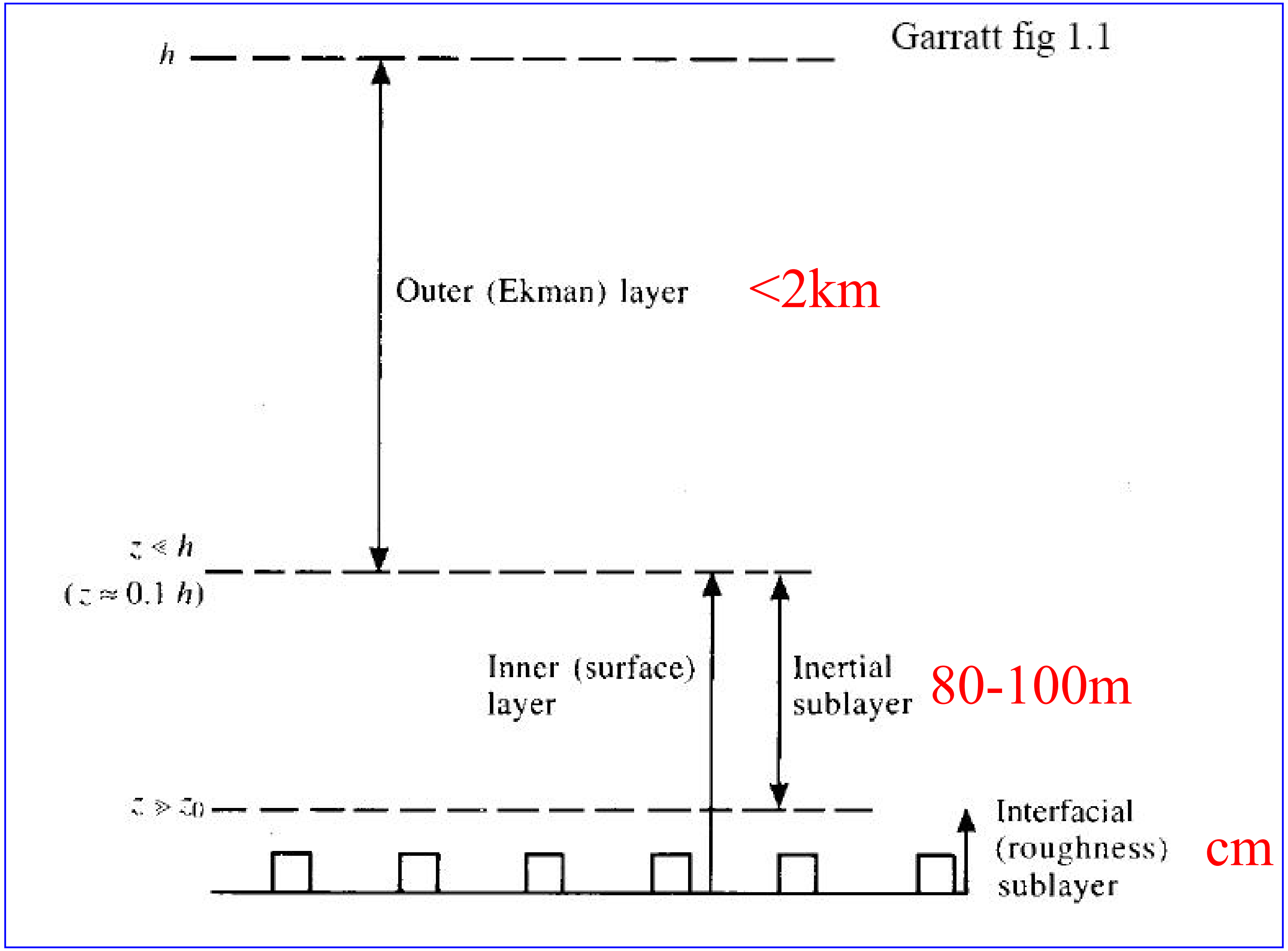
SABL and SABL parameterizations



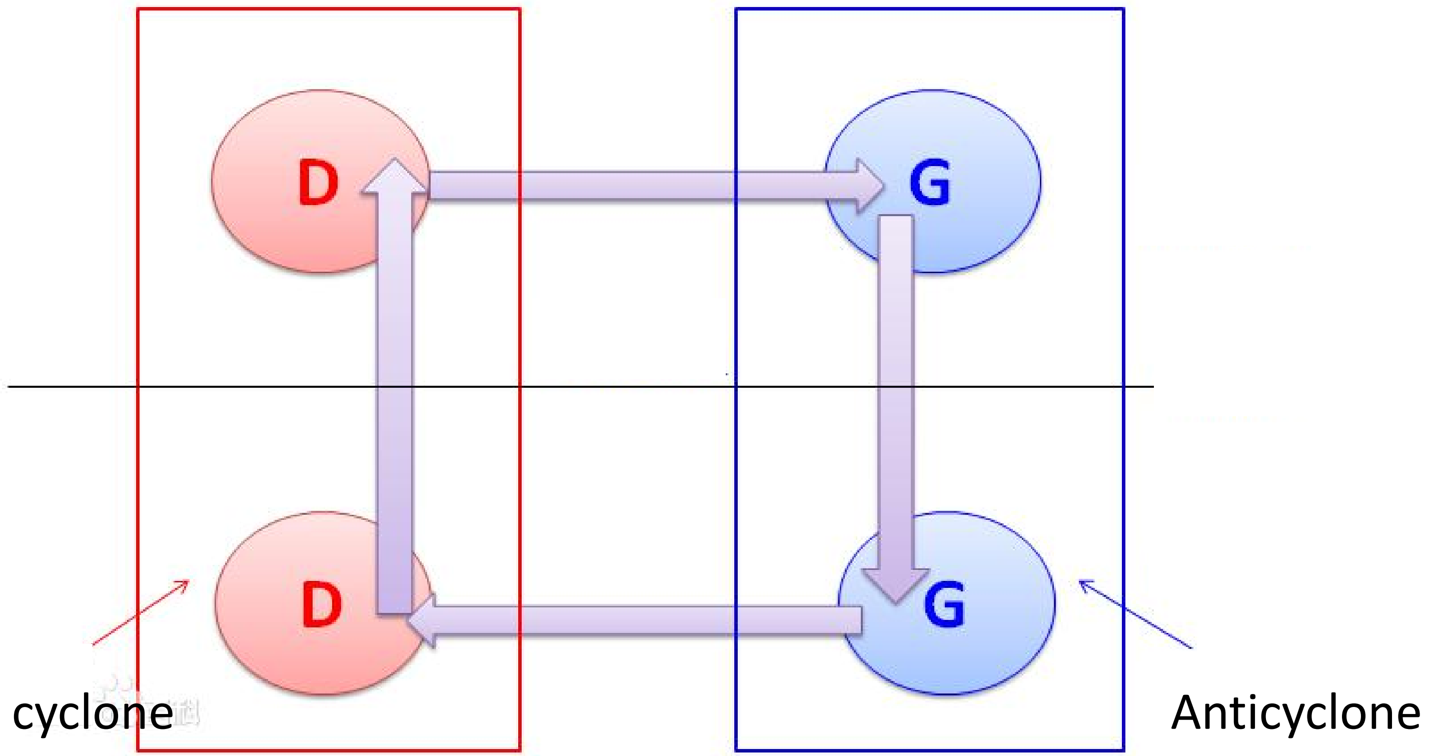
Convective boundary layer CBL
Stable boundary layer SBL
Neutral boundary layer BL

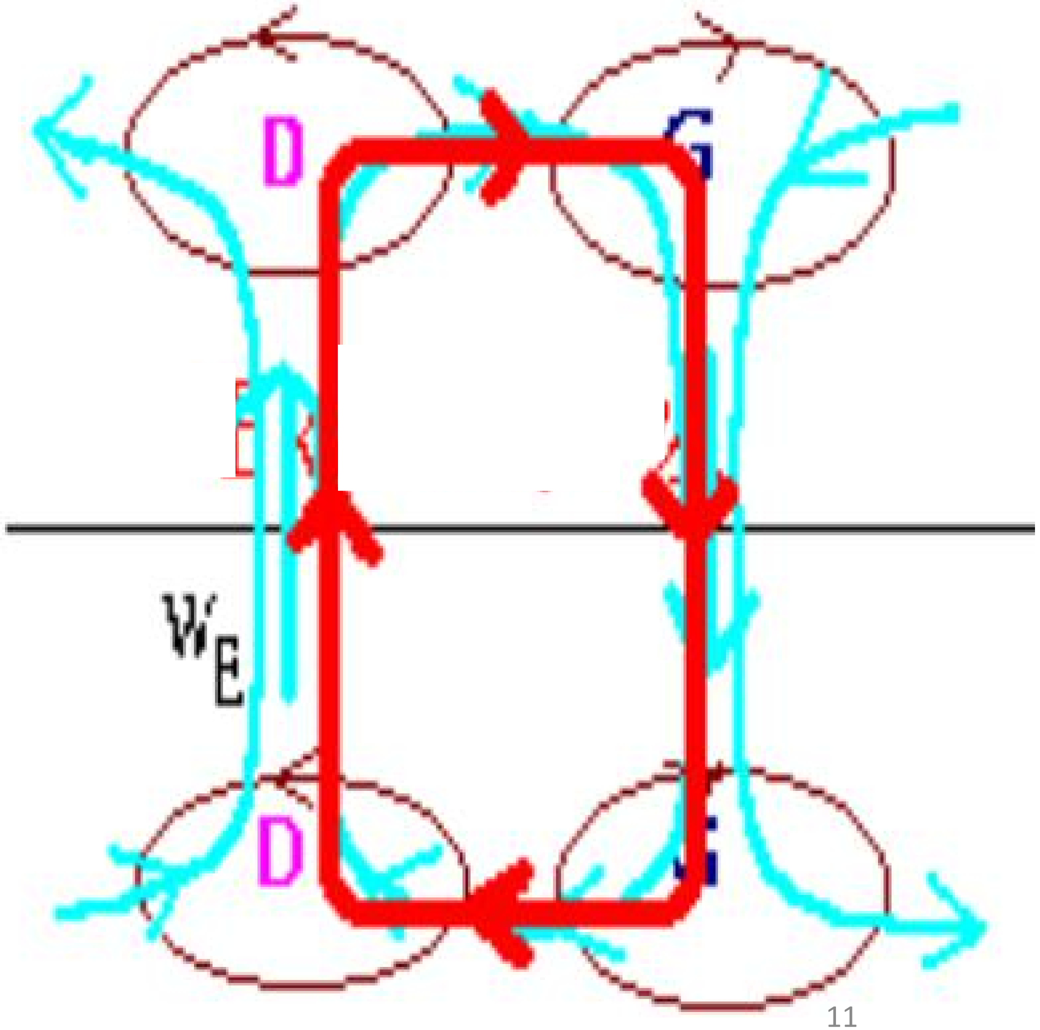
Classification	Occurred at**	Turbulence intensity	Eddy scale
CBL	Daytime	strong	large
SBL	Nighttime	weak	small
BL	Neutral	Windy day	middle

Vertical structure of the SABL



SABL: Ekman Pumping





Impact of stability functions on 2-m temperature simulations (ECWMF)

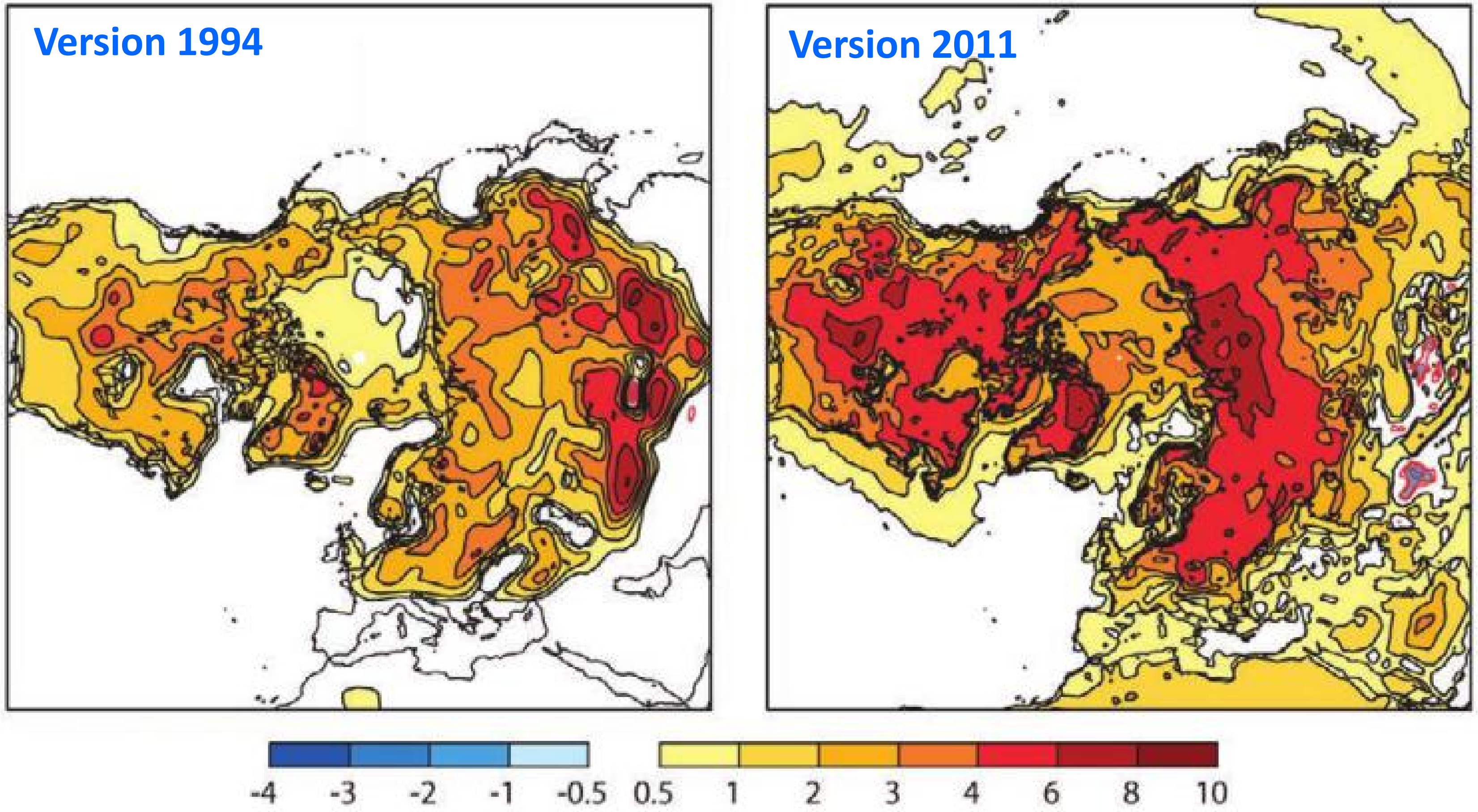


Fig.4 *Difference in 2-m temperature (°C) averaged over January 1996 between simulations with two different stability functions in the ECMWF model.*

Simulated profiles of potential temperature

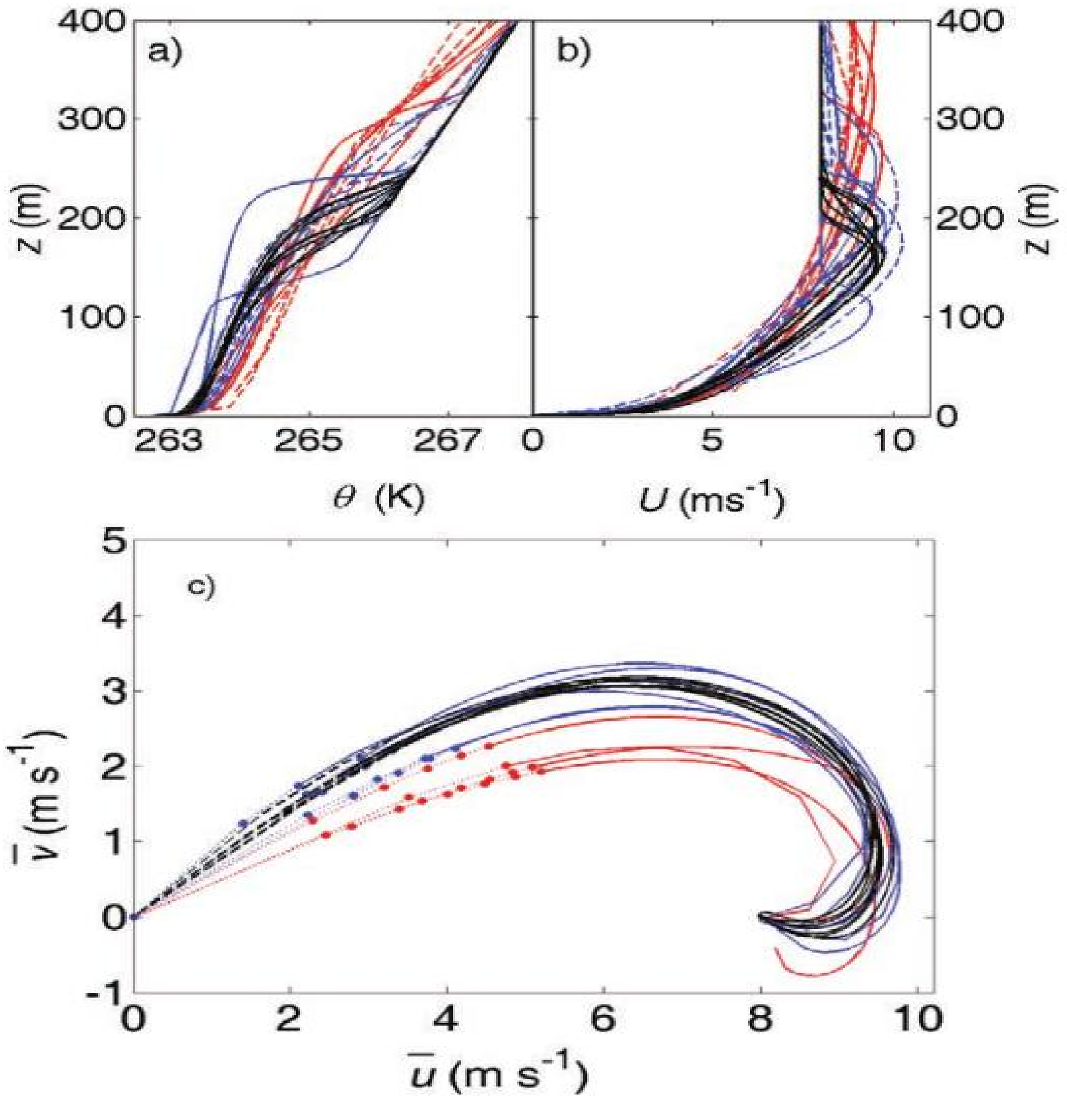


Fig .5 Results of SCMs in GABLS1 for (a) potential temperature (K), (b) total horizontal wind speed (m/s), and (c) boundary layer wind turning.

The operational models have more enhanced mixing, a deeper boundary layer, and smaller turning of wind with the height, larger integrated cross-isobar flux, and direct impact on the large-scale flow through Ekman pumping. As a result, too active cyclones and too high extremes for wind and precipitation.

Simulated profiles of heat and momentum fluxes

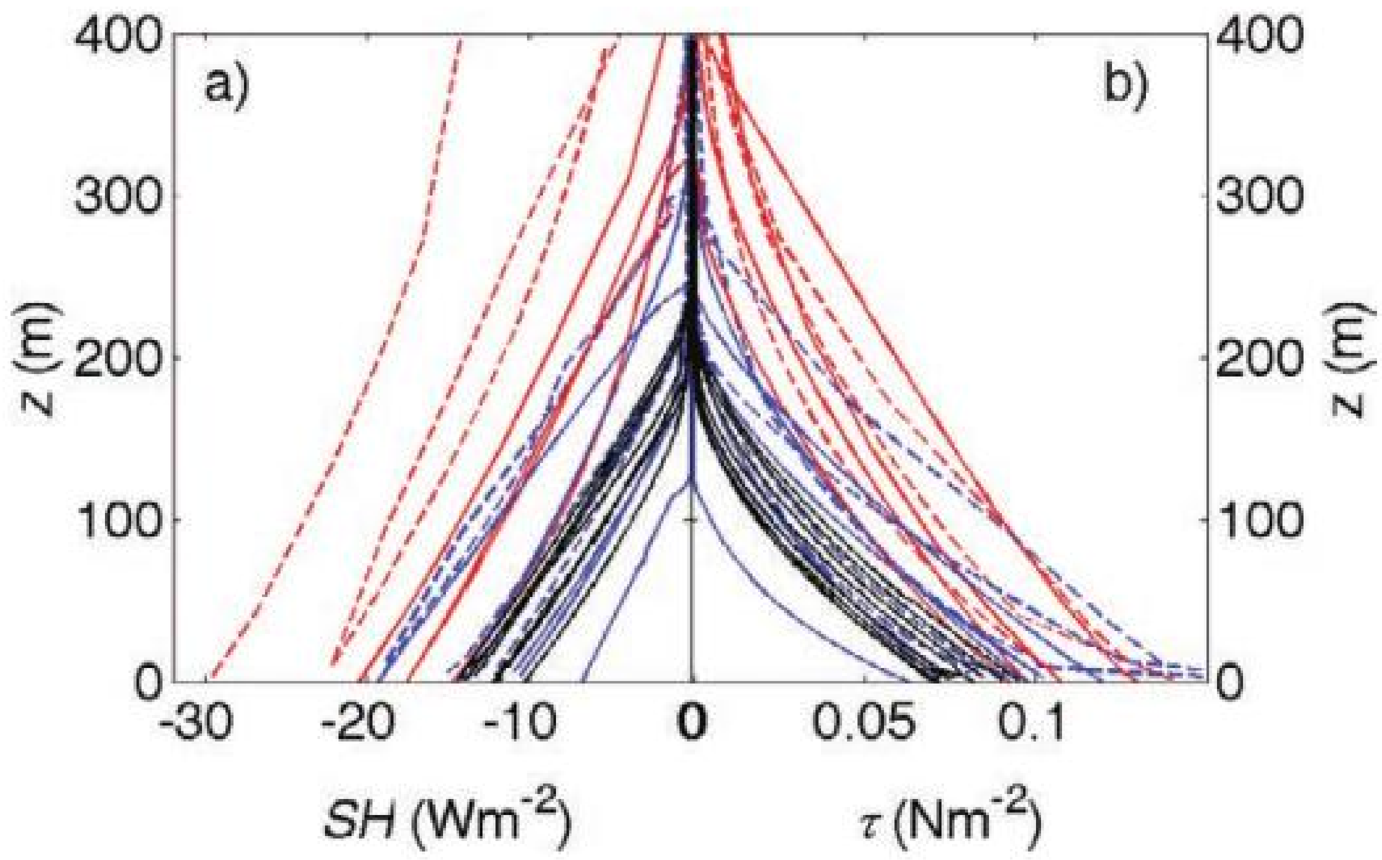
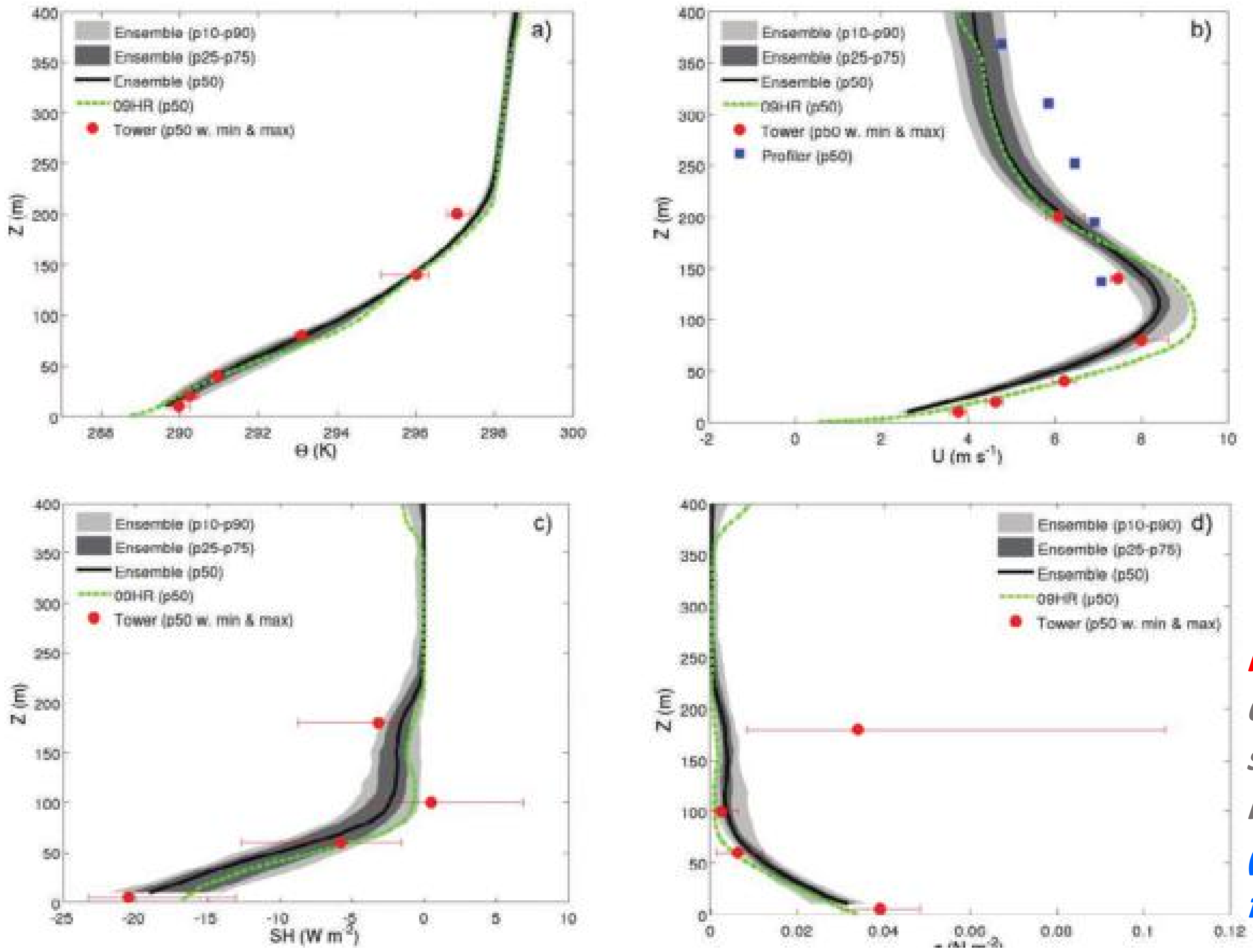


***Fig .6** As in Fig. 5 but for (a) turbulent heat f lux and (b) turbulent momentum flux.*

LES results and observations for the GABLS3 case



LES does a great job on simulating vertical profiles.

Fig.7 *LES model results (with a vertical resolution of 6.25 m) and observations for the GABLS3 case study corresponding to 0300–0400 UTC 2 Jul 2006. Results are for (a) potential temperature (K), (b)wind speed magnitude (m·s^{-1}), (c) sensible heat flux (W·m^{-2}), and (d) momentum flux (N·m^{-2}).*

Diurnal cycle comparison for GABLS2 (obs. vs. sim.)

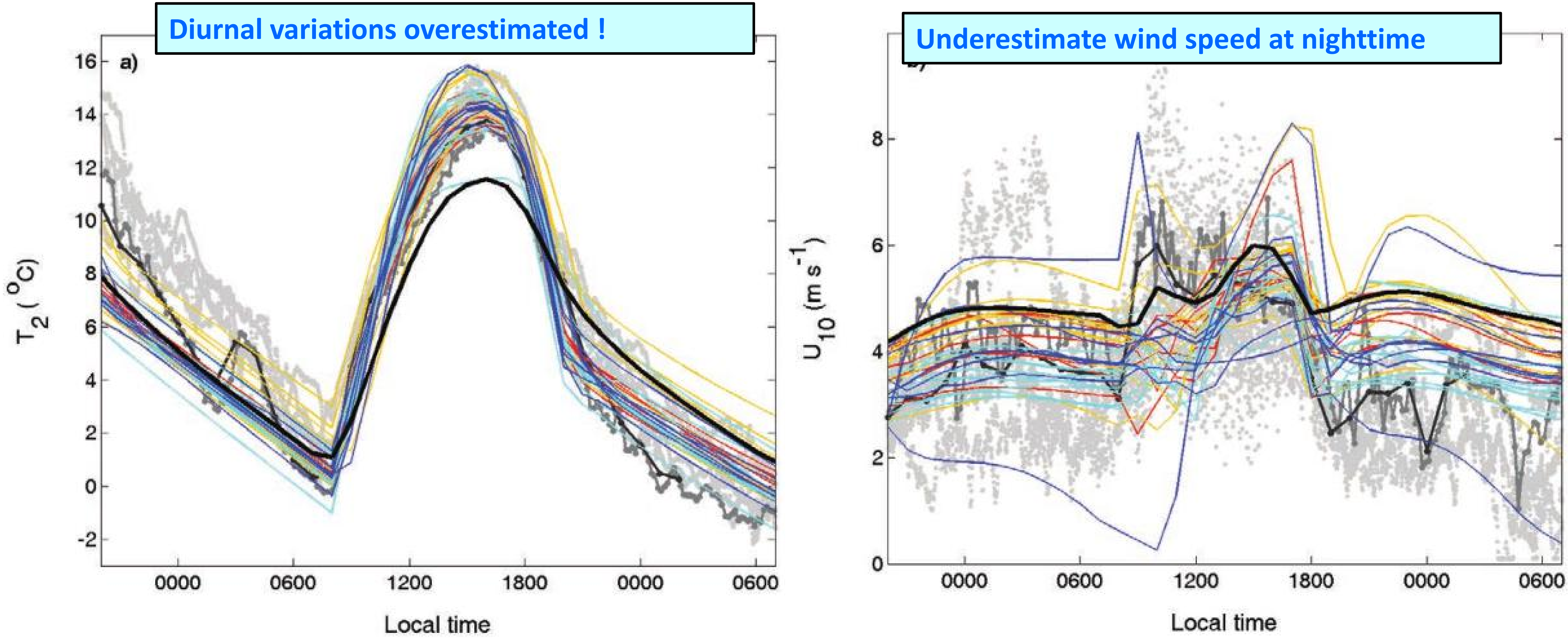


Fig.8 *Time series of observed and* ***GABLS2*** *model results for (a) temperature at 2 m AGL and (b) wind speed at 10 m AGL.*

Diurnal cycle comparison for GABLS3 (obs. vs. sim.)

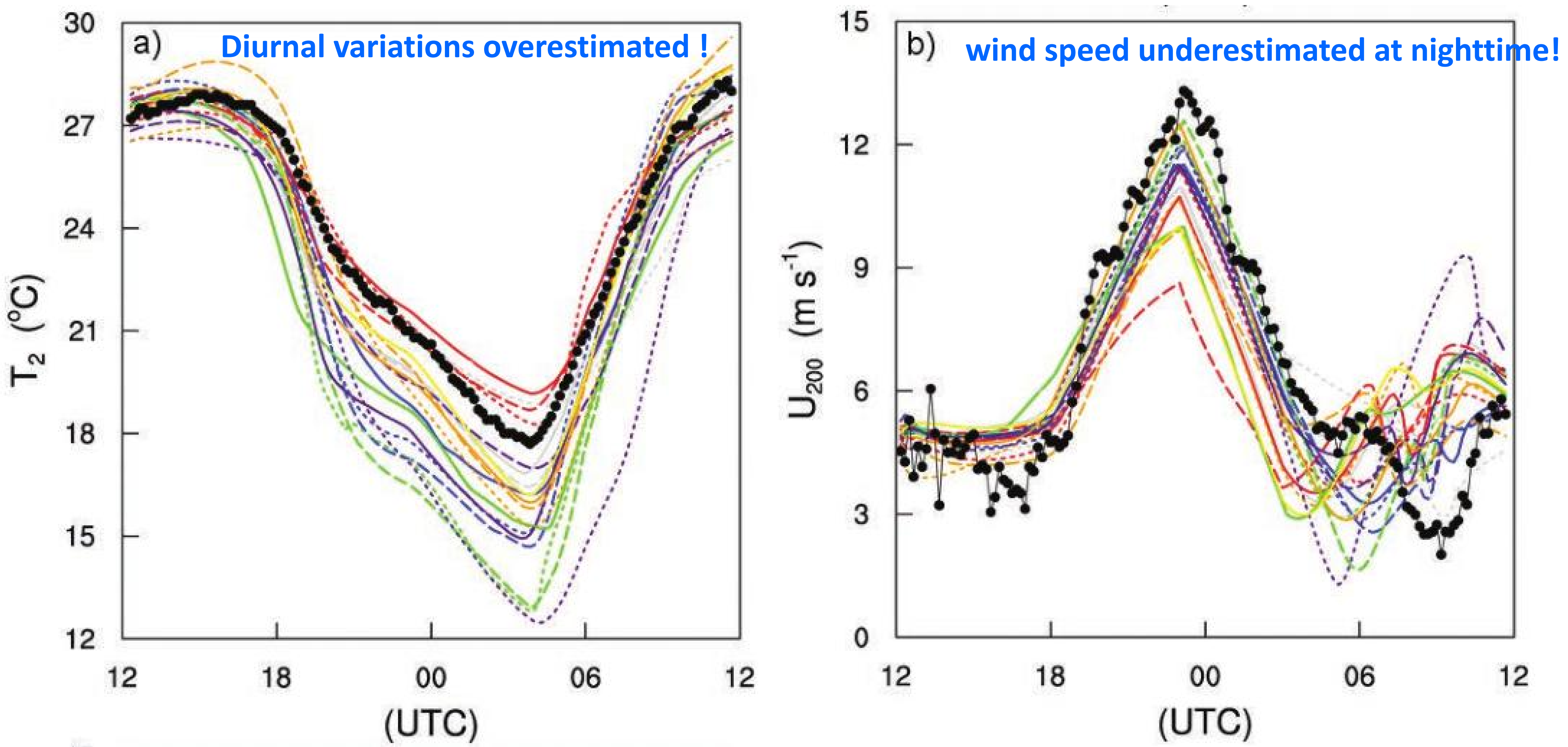


***Fig.9** Time series observed(black line with dots) and **GABLS3** model results (other lines) for (a) Temperature at 2m and (b) wind speed at 200m.*

Summary and Prospects

- Accurate representation of the atmospheric boundary layer in numerical weather and climate models has important practical implication for air quality, wind energy, climate, and Earth system studies.
- Most large-scale atmospheric models utilize overly diffusive boundary schemes in stably stratifies conditions. (too thick boundary layer, too little wind turning with height, and understate of the nocturnal jet).
- Operational models have too much mixing in the stable conditions.
- Coupling between the atmosphere and the land surface is key for a good representation of the diurnal cycles of temperature, wind, and other variables.
- There is still a clear need for a better understanding and a more general description of the atmospheric boundary layer, particularly under stably stratified conditions in the future.
- This study only discussed the weakly to moderately stably stratified boundary layers. It will become more challenge to model strongly stratified conditions.
- Finally, it is recommended to study the ABL in interaction with other atmospheric and surface processes.

Some ideas for my research

- To evaluate performance of current PBL schemes implemented in the regional numerical weather prediction models (e.g., WRF) on simulating 2-m temperature and winds under the stable or neutral boundary layer conditions (nighttime or over Lake Taihu) by using the modified NCAR's LES model (or WRF/LES).

- To quantify the impact of stability functions and eddy diffusivity calculations on $PM_{2.5}$ and ozone predictions (WRF/Chem).

THANKS