THE INFLUENCE OF MISREPRESENTING THE NOCTURNAL BOUNDARY LAYER ON IDEALIZED CONVECTION IN LARGE-EDDY SIMULATION

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INTRODUCTION

To increase the understanding of clouds and precipitation (CP) and its representation in GCMs, the *High Definition Clouds and Precipitation for advancing Climate Prediction* (HD[CP]2) project aims at performing large-eddy simulation (LES) hind casts of diurnal cycles of convection using (horizontal) grid spacings of Δ=100m at spatial scales as large as Germany. These grid spacings are sufficient to explicitly represent dry/shallow convection and avoid modeling issues in the convective grey zone, but leave some other processes unresolved. One potentially import process is the stable nocturnal boundary layer (NBL), requiring a grid spacing of O(1m) (Fig 2). Given the projects focus on daytime convection, this raises the question: **How sensitive is the development of daytime convection on the representation of the NBL? Can we accurately simulate the diurnal cycle of convection in LES using a grid spacing as coarse as 100 m?**

LARGE-EDDY SIMULATION CODE

UCLA-LES 4.0 is used for the numerical experiments, with a (non-dynamic) Smagorinsky-Lilly type sub-grid scheme as it is a likely candidate for the HD[CP]^2 model setup. A simple land-surface model (LSM) was added to allow for feedbacks between the surface and atmosphere.

SETUP OF THE NUMERICAL EXPERIMENTS

The physical setup is summarized by Fig. 1: within a 21 hour simulation, ~3 hours of convection (Fig 1a) is followed by the development of a stable NBL (Fig 1b) and a second day with convection (Fig 1c). To cover the typical summertime NBL conditions (characterized from measurements at Cabauw and Hamburg), the geostrophic wind and surface cooling rate is varied over three experiments (Table 1). Variation of the surface cooling rate is achieved by reducing the thermal diffusivity of the skin layer (Λ_{sk}) in the LSM. As we focus on the dynamical (turbulent) aspects, moisture is excluded from the setup. For each experiment a sensitivity study on resolution is performed, increasing the grid spacing in factors of two from Δ=3.125^3 m (Δ_3, *reference*) to Δ=100×100×25 m (Δ_{100}) in a 3200×3200×2000 m large domain.

Table 1. *Overview of the physical experiments*

	U_g (m/s)	Λ_{sk} (W/m2/K)
U_{10}	10	10
U_5	5	"
U_{8L}	8	1

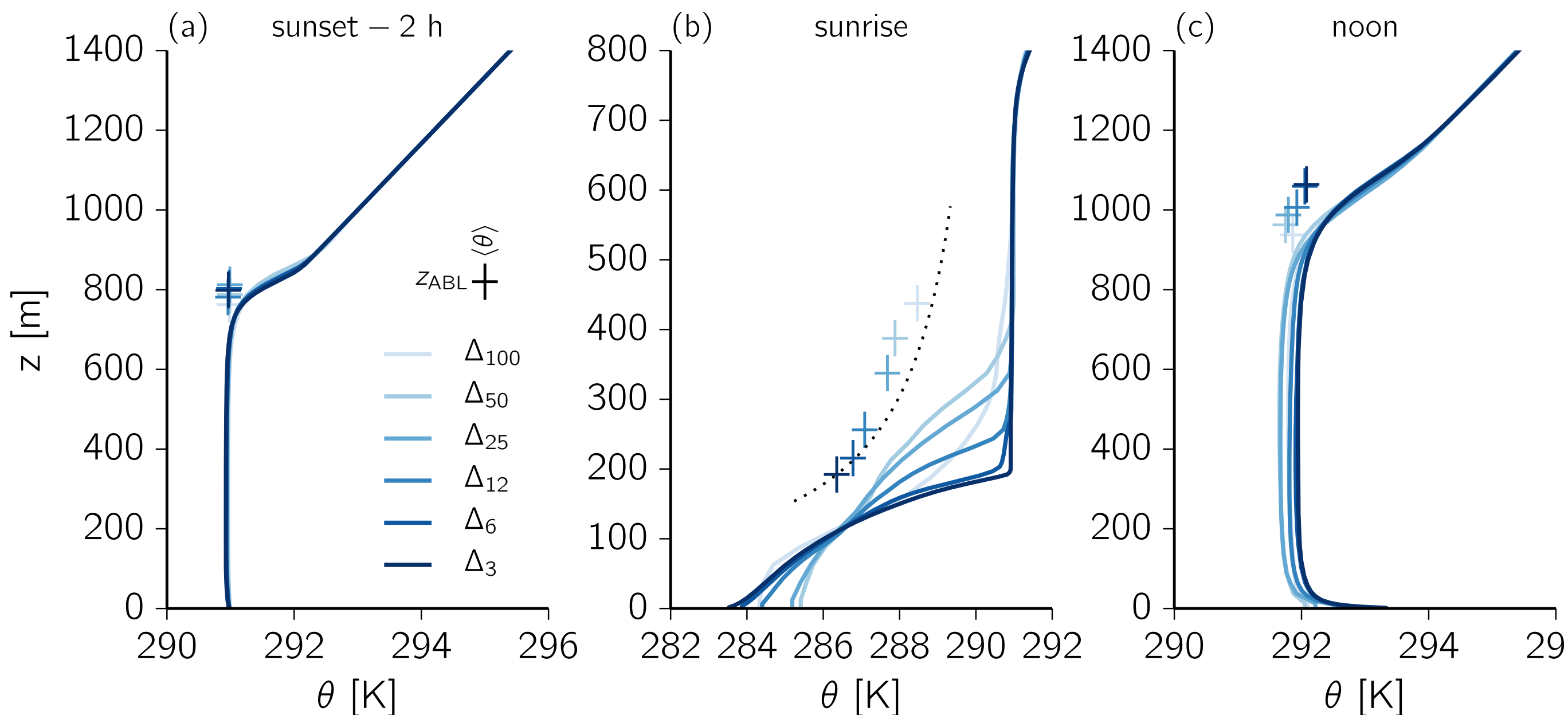

Figure 1. *Vertical profiles (case U_{10}) of potential temperature at the end of the first convective day (a), end of the NBL period (b) and noon during the second day of convection. Crosses indicate the ABL from a bulk perspective; the ABL depth, and ABL-averaged temperature.*

RESULTS

The ABL depth and ABL-averaged potential temperature biases (compared to the Δ_3 reference cases) at sunset-2h (t=i), sunrise (t=ii) and noon during the second day of convection (t=iii) are summarized in Figure 3.

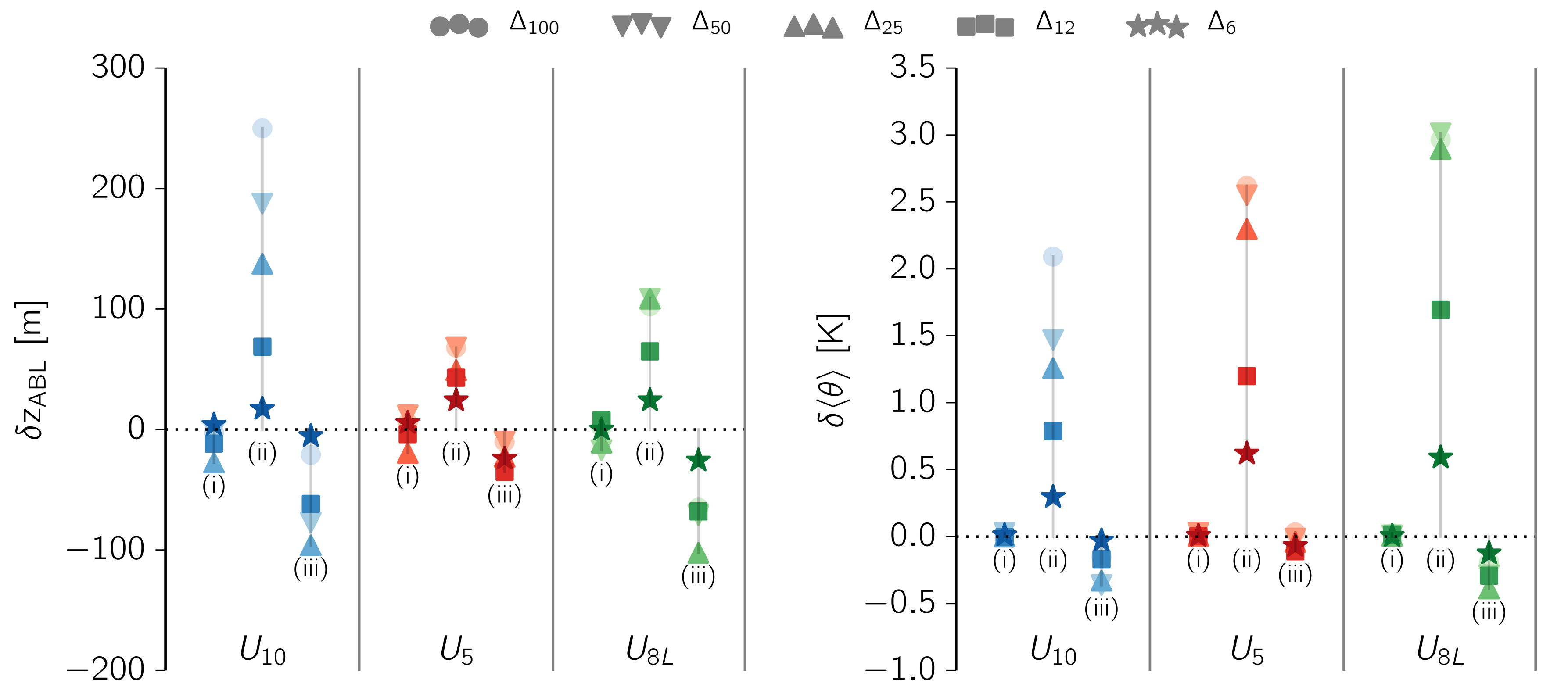

Figure 3. *Biases in ABL depth (δz_{ABL}) and ABL averaged temperature (δ⟨θ⟩) at sunset minus two hours (i, t=2.75 h), sunrise (ii, t=13.25 h) and noon (iii, t=21 h). All statistics are averaged over one hour (t=1.75-2.75 h, t=12.25-13.25 h, t=20-21 h).*

① As expected, the Smagorinsky sub-grid scheme requires a grid spacing of O(1-10m) for LES of the NBL. At coarser resolutions the NBL development is driven by sub-grid diffusion, resulting in an overestimation of the NBL depth and temperature (Fig. 3).

② Despite the relative large NBL biases, there is little influence on the subsequent day of convection with maximum biases in the afternoon ABL depth and potential temperature of ~100 m and ~0.5 K, respectively. In terms of the mixed-layer top relative humidity (RH, assuming a constant moisture mixing ratio), the ABL depth and temperature biases partially compensate, resulting in RH biases of 2-3% (Fig. 4).

③ The interactive LSM plays an important role: both the feedback between surface temperature and outgoing longwave radiation ($Lw_{up} = \sigma T_s^4$), and ability of the soil to provide heat to the surface, strongly regulates the surface fluxes and prevents e.g. runaway surface cooling.

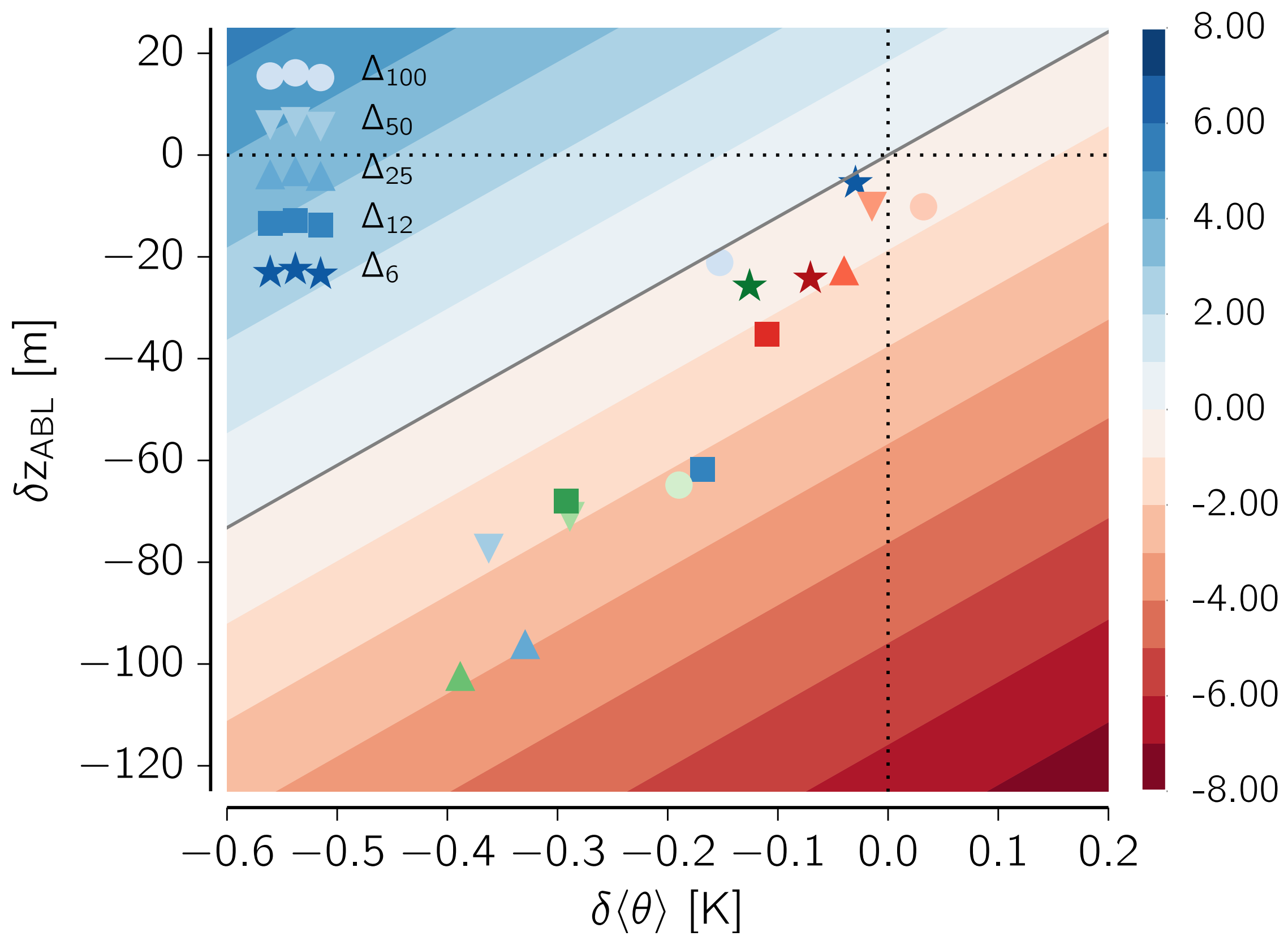

Figure 4. *Combined influence of ABL-depth and temperature biases on the mixed-layer top relative humidity (shaded contours, at noon, t=21h), assuming a fixed moisture content in the ABL.*

CONCLUSION AND OUTLOOK

Although insufficient resolution introduces significant biases in the NBL, the influence of these dynamically introduced biases on daytime convection is small.

However, being focused on dynamics, our experiments neglect the influence of moisture. With moisture included, the relative large NBL biases might result in the (spurious) formation of fog or low clouds. When interacting with radiation, this could further amplify the biases in the NBL. We will address this question in future work.

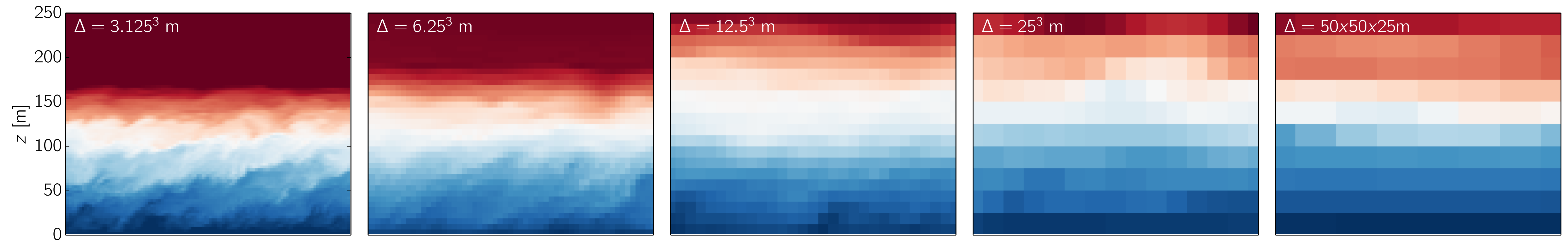

Figure 2. *Cross sections of potential temperature in the NBL at grid spacings ranging from 3.125 m to 50 m.*

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HD(CP)^2 High definition clouds and precipitation for advancing climate prediction