To what degree does the resolution matter?

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Introduction

In the context of the multi-scale modeling framework, we explore how simulations of Stratocumulus degrade as the resolution coarsens. In particular, we investigate the importance of horizontal resolution for resolving PBL eddies, by examining the mean dynamic and thermodynamic state of the STBL, as well as the cloud-depth evolution and the entrainment of the overlying free-tropospheric air into the boundary layer. We base our conclusions on a set of experiments performed by UCLA LES with horizontal grid size varying from 50m to 6400m and fine vertical resolution (5m in 250m-deep layer enclosing the inversion).

We further explore the caveats of the initial analysis by concentrating on three horizontal resolutions (50m, 200m and 1600m) and examining the effects of vertical grid resolution, subgrid-scale model and number of points in horizontal. Vertical resolution is varied from 5m to 80m in the 'inversion layer'; Smagorinsky model for scalar diffusion is turned on and off; and number of points is varied from 32^2 to 128^2. Because the 1600m horizontal resolution is the most pertinent to the MMF, we illustrate these results and only comment on the finer resolutions.

Horizontal Resolution

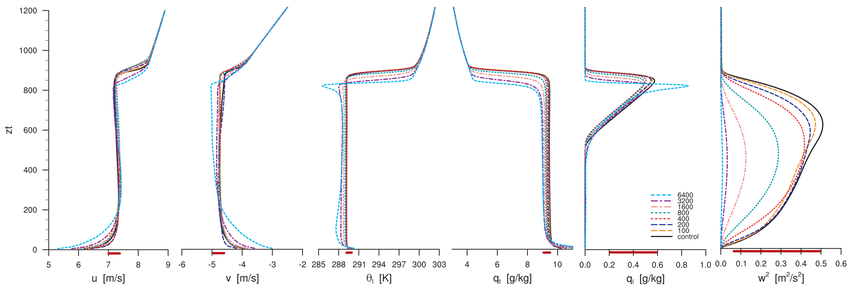

Figure 1: Horizontally-averaged profiles of winds, liquid-water potential temperature, specific humidity, condensed water and variance of vertical velocity for experiments with varying horizontal grid-box sizes. All the profiles are averages over the last hour of simulation. The red bars represent the spread of results of GCSS LES comparison.

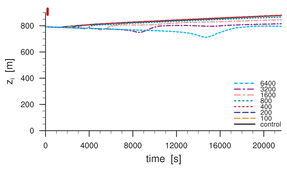

Figure 2: Time series of PBL height, for the duration of simulation (6 h). Red bar as in Fig. 1. Experiments as in Fig. 1.

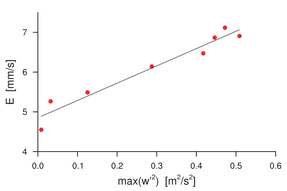

Figure 3: Scatter-plot of entrainment and PBL-maximum of w variance for all 8 experiments. Overlaid line is a linear regression, with slope $4{\cdot}10^{-3}$ $(m/s)^{-1}$. Experiments as in Fig. 1.

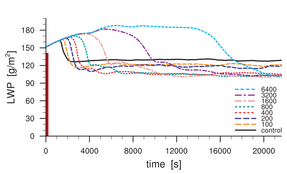

Figure 4: Time series of liquid-water path, for the duration of simulation (6 h). Red bar as in Fig. 1. Experiments as in Fig. 1.

Profiles of wind, temperature, moisture and condensed water, depicted in Fig. 1, suggest the overall good agreement between the LES results with varying horizontal resolution. The exception is the experiment with 6400m grid size and spin-up time exceeding duration of the simulations. The red bars on Fig. 1, 2 and 4 indicate a spread of results of the GCSS comparison of the LESs with the same setup as the one we use for this study. As the profiles in Fig. 1 indicate, the effect of the coarseness of the resolution is comparable to the effect of the differences in the physics and numerics between the fine-resolution models.

A reduction of the STBL height with the decreased resolution is depicted in profiles in Fig. 1, as well as in the time series of the inversion height in Fig. 2. It indicates an abate of the strength of the resolved PBL eddies, which is confirmed and additionally illustrated with the profiles of w' variance (Fig. 1) and an almost linear relationship between the entrainment and the PBL-maximum of the w' variance (Fig. 3).

The combination of the resolution effects on thermodynamic and dynamic state of the STBL reflects mostly on the cloud top, whereas the cloud base lifts to the lesser degree (Fig. 1). However, as Fig. 4 indicates, the depth of the outcoming shallower clouds is still well within the range of the depths of the GCSS clouds.

Vertical Resolution

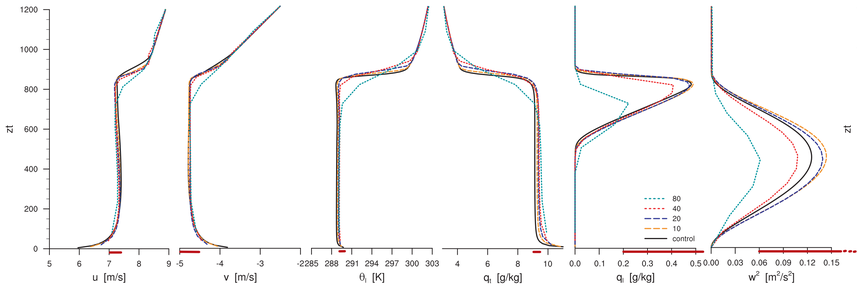

Figure 5: Horizontally-averaged profiles of winds, liquid-water potential temperature, specific humidity, condensed water and variance of vertical velocity for experiments with 1600m horizontal mesh size and varying vertical resolution. All the profiles are averages over the last hour of simulation. Red bars as in Fig. 1.

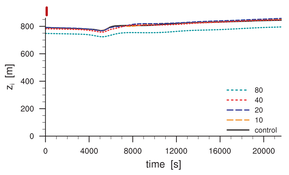

Figure 6: Time series of PBL height, for the duration of simulation (6 h). Red bar as in Fig. 1. Experiments as in Fig. 5.

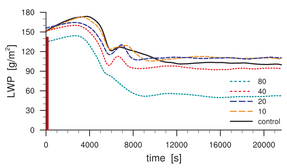

Figure 7: Time series of liquid-water path, for the duration of simulation (6 h). Red bar as in Fig. 1. Experiments as in Fig. 5.

Profiles in Fig. 5 suggest that the coarseness of vertical resolution does not have a too profound effect on the mean state of the STBL. Even the most coarse resolution of 80m in 'inversion layer' fits well in the range of results of the GCSS comparison (red bars on figures). However, the profile of vertical-velocity variance suggests that the 80m grid is too coarse to comply the other fine-resolution LESs.

Time series of the STBL height displayed in Fig. 6 implies that the growth rate of the STBL does not depend on the vertical representation and that the STBL simulated with this coarse horizontal resolution is too shallow comparing to the GCSS STBLs.

Liquid-water path depicted in Fig. 8, indicates that these simulations generally sustain Stratocumulus as well as the GCSS-high-resolution simulations, and that the 80m grid is the least accurate.

The effect of vertical resolution on two finer horizontal resolutions (50m and 200m) is similar to the one we discussed, but amplified and with a wider spread of results for finer vertical resolutions.

Subgrid-scale Model

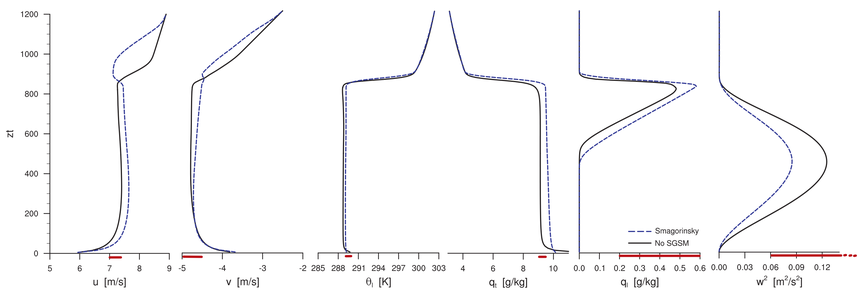

Figure 8: Horizontally-averaged profiles of winds, liquid-water potential temperature, specific humidity, condensed water and variance of vertical velocity for experiments with fixed horizontal resolution (1600m) exploring the effect of SGS model. All the profiles are averages over the last hour of simulation. Red bars as in Fig. 1.

Wind profiles (Fig. 8) indicate that the SGS model causes a misrepresentation of momentum in the vicinity of the inversion layer, which is not present in finer-resolution experiments. Profiles of temperature, moisture and vertical-velocity variance (Fig. 8) illustrate a well-mixed STBL when SGS model is applied. This opposes the results of simulations with finer resolutions, which profiles have characteristics of a decoupled SBTL. A profile of liquid water (Fig. 8) and a time series of liquid-water path (Fig. 10) depict the thicker cloud when SGS model is employed, while the profile of moisture illustrates slight over-moistening of the STBL compared to the GCSS simulations.

As time series of the STBL depth (Fig. 9) implies a growth of the STBL, the thickening of the cloud when the SGS model is applied indicates that the main effect of the SGS model on the 1600m simulation is the transport of moisture from the surface to the STBL interior. In finer-resolution simulations, the SGS model cease to produce this moistening effect, while the growth of the STBL due to the entrainment persists.

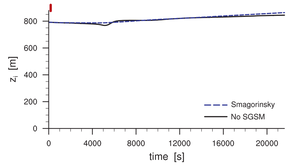

Figure 9: Time series of PBL height, for the duration of simulation (6 h). Red bar as in Fig. 1. Experiments as in Fig. 8.

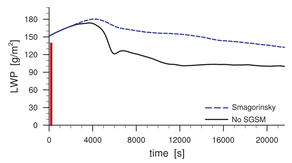

Figure 10: Time series of liquid-water path, for the duration of simulation (6 h). Red bar as in Fig. 1. Experiments as in Fig. 8.

Number of Points in Horizontal

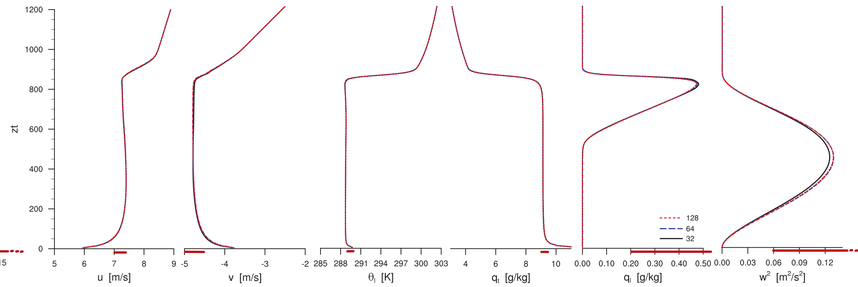

Figure 11: Horizontally-averaged profiles of winds, liquid-water potential temperature, specific humidity, condensed water and variance of vertical velocity for simulations with grid resolution of 1600m and varied domain size in horizontal. All the profiles are averages over the last hour of simulation. Red bars as in Fig. 1.

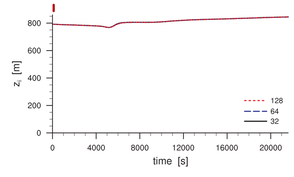

Figure 12: Time series of PBL height, for the duration of simulation (6 h). Red bar as in Fig. 1. Experiments as in Fig. 11.

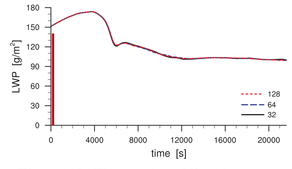

Figure 13: Time series of liquid-water path, for the duration of simulation (6 h). Red bar as in Fig. 1. Experiments as in Fig. 11.

Figures 11-13 indicate that the number of points in horizontal, in range of 32^2 - 128^2, does not affect the representation of the mean STBL state, variance of the vertical velocity and evolution of the STBL and cloud depths.

For the finer horizontal resolutions, vertical-velocity variance and liquid-water path are somewhat swayed by the number of horizontal points, but still remain in the range of the GCSS results.

Summary

A set of simulations of the STBL with varying horizontal resolution, no SGS model for scalars and fine vertical resolution indicates that the degradation of Stratocumulus with coarsening of resolution is present. However, the results stay in the range of the GCSS intercomparison results for all analyzed variables, except for the STBL depth. Moreover, the coarsening of the resolution seems to affect the depth of the cloud less than the change in the physics and numerics of the simulations.

Simulations with fixed horizontal resolution, no SGS model for scalars and varying vertical resolution imply that the degradation is more evident from the vertical then from the horizontal coarseness, which is more pronounced at finer horizontal resolution.

Experiments with only varying the number of points in horizontal show that only the fine-horizontal-resolution simulations are slightly affected by the horizontal size of the domain.

A set of experiments exploring an impact of SGS model for scalars reveal that the effects depend on the choice of horizontal resolution. While the finer-resolution simulations mostly 'feel' increased mixing at the inversion level, the coarser-resolution simulations have additional moistening that prevents the Stratocumulus from the degradation.

A question of LES behavior with coarsening of the resolution in presence of drizzle is still open. Please visit www.atmos.ucla.edu/~verica/research/ in the near future to find out UCLA-LES results when drizzle is included.

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