Considerations on the importance of planetary boundary layer depths over complex terrain for carbon cycle studies

UNIVERSITY of VIRGINIA
DEPARTMENT of ENVIRONMENTAL SCIENCES

Gert-Jan Duine [1] and Stephan F. J. De Wekker [1]

[1] Department of Environmental Sciences, University of Virginia, Charlottesville, VA, USA

Gert-Jan Duine
E-mail: gd6s@virginia.edu

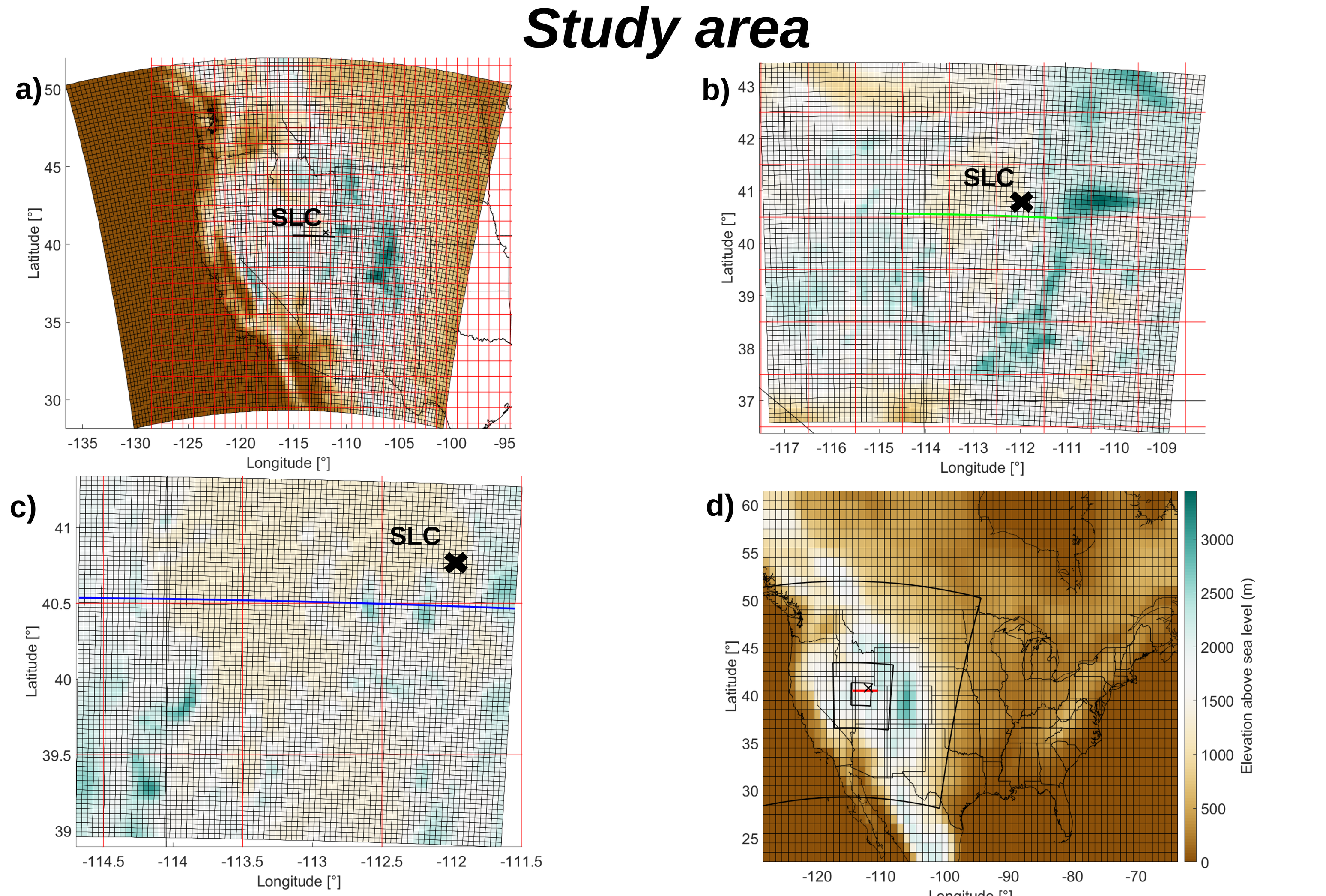
Motivation

The difficulty of modeling atmospheric transport and mixing processes introduces significant uncertainties in the fluxes estimated with inverse carbon transport models. An important diagnostic for vertical transport and mixing is the planetary boundary layer (PBL) depth, the height above the surface up to which surface fluxes of heat, moisture, momentum, and trace gases such as CO2 are transported and mixed on a diurnal time scale. Typically, near-surface CO2-concentrations are inversely related to PBL depths. Current offline global transport models used for CO2-flux estimations, such as TM5 for CarbonTracker, are known to fail occasionally in reproducing daily cycles and absolute CO2 concentrations. These models are typically run on very coarse grid spacing (i.e. around 100 km), introducing uncertainties which may lead to incorrect estimations of PBL depths and, eventually, CO2-budgets. The coarse resolution leads for example to smoothing of the terrain, which will affect the representation of PBL depths. Important questions that we are trying to answer in an effort to understand and possibly reduce the uncertainty in these large-scale transport models in simulating PBL depths are:

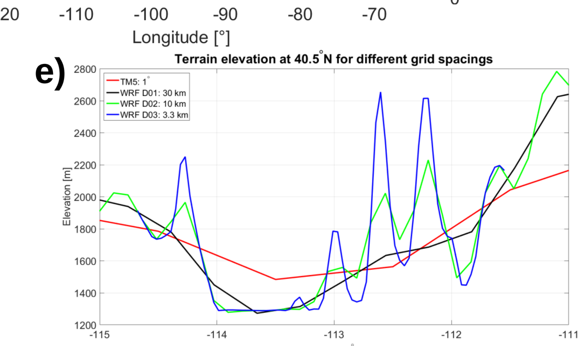
1) How does missing subgrid-terrain variability affect simulated PBL depths?
2) How can we best compare simulated PBL depths at various grid spacing with observed PBL depths at specific locations?

To determine the effects of subgrid variability, and to understand how we can compare observations to large-scale grids, we use an aggregation approach, and test this for two different models with different grid spacing: the Weather Research and Forecasting (WRF) model and the TM5 model. We compare the different domains and examine the influence of missed subgrid terrain variability on the PBL depth for consecutive fair weather days in July 2013. For the analysis, we use WRF model output from the operational 4DWX forecast system developed by the NCAR Research Applications Laboratory, and TM5 model output. The study area is focused over western USA, which comprises considerable terrain height variability.

Study area

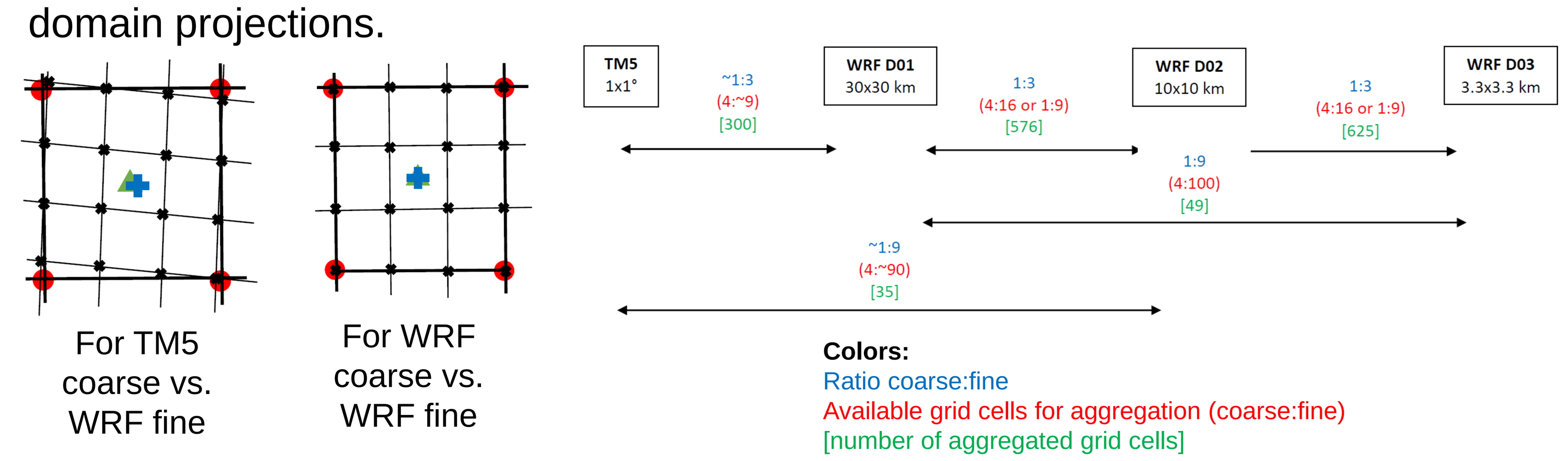


Terrain elevation in WRF domains 1, 2 and 3 (a, b and c), TM5 (d), cross section for terrain elevation of (e) – locations are given in a to d. The TM5-grid is also shown in red in a, b and c.

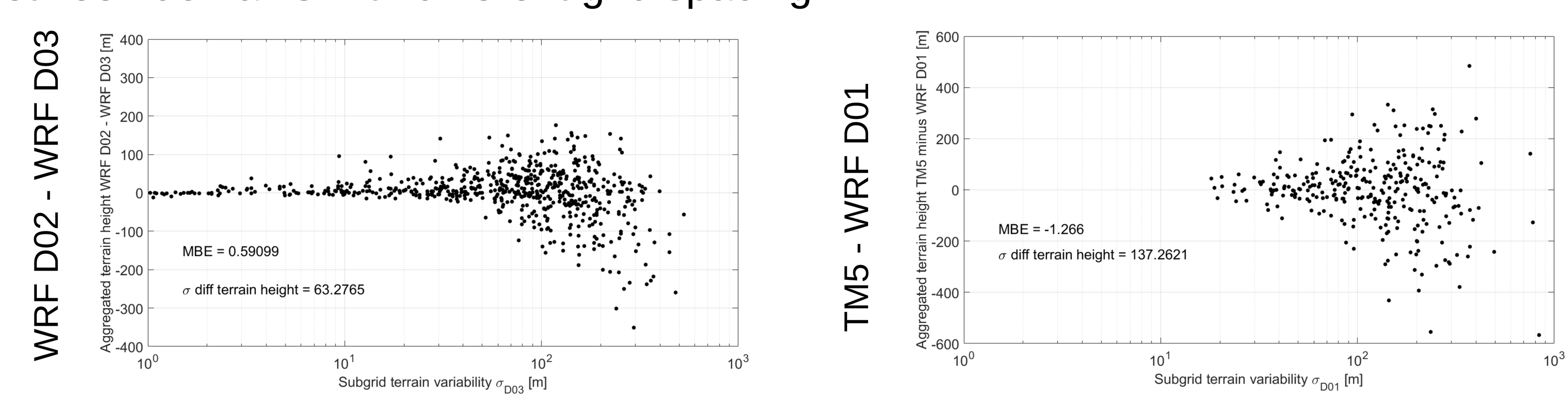


Aggregating TM5 and WRF

For a proper comparison between different model domains at different grid spacing, we develop an aggregation method. Large-scale grid points (red circles) and fine-scale grid points (black crosses) are aggregated with the green triangle and blue triangle as a respective result. Note that TM5 and WRF have different domain projections.

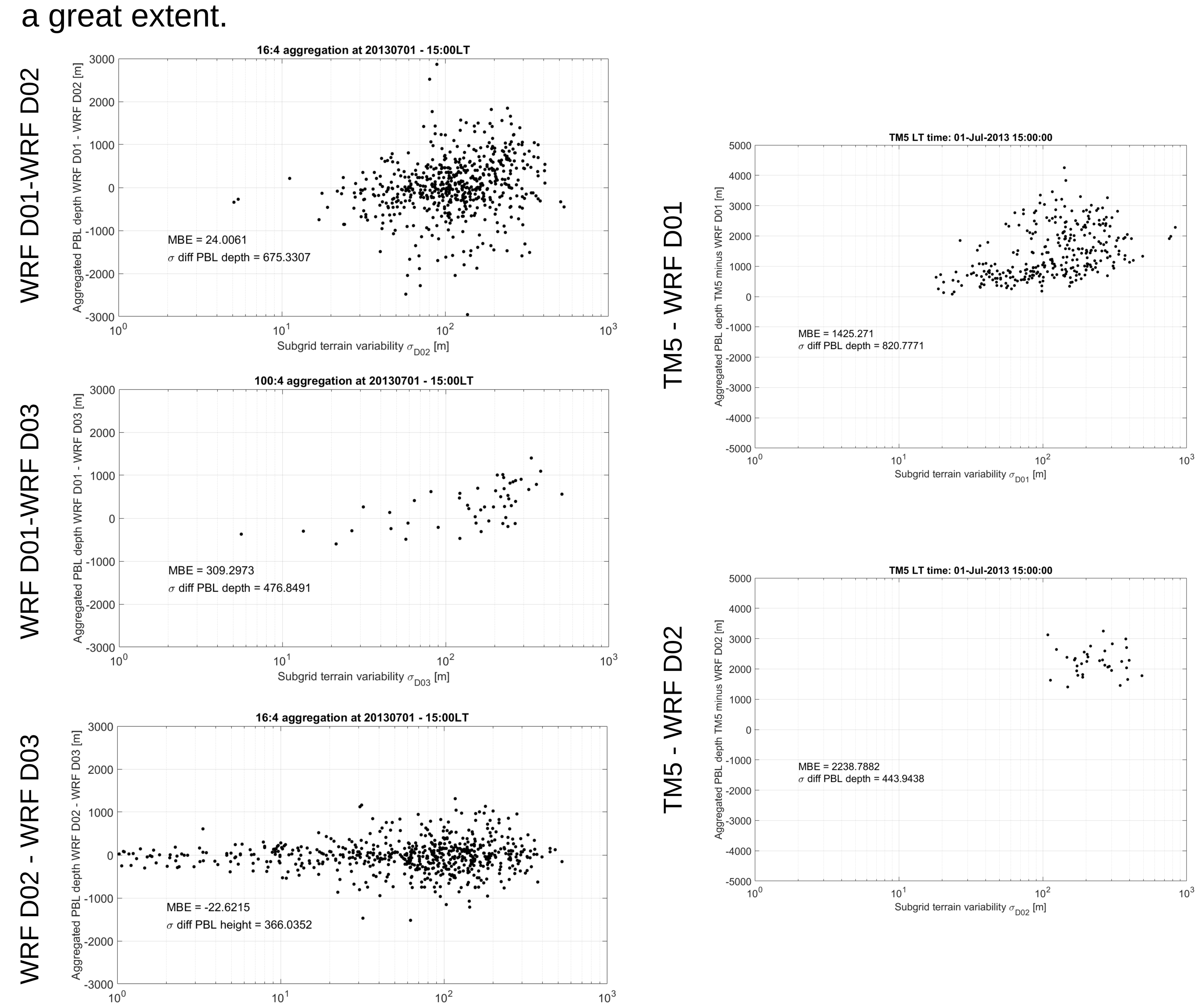


Subgrid terrain variability is expressed by calculating the variance of the terrain height of the fine-scale grid points. Aggregated terrain height leads to differences between domains with different grid spacing.



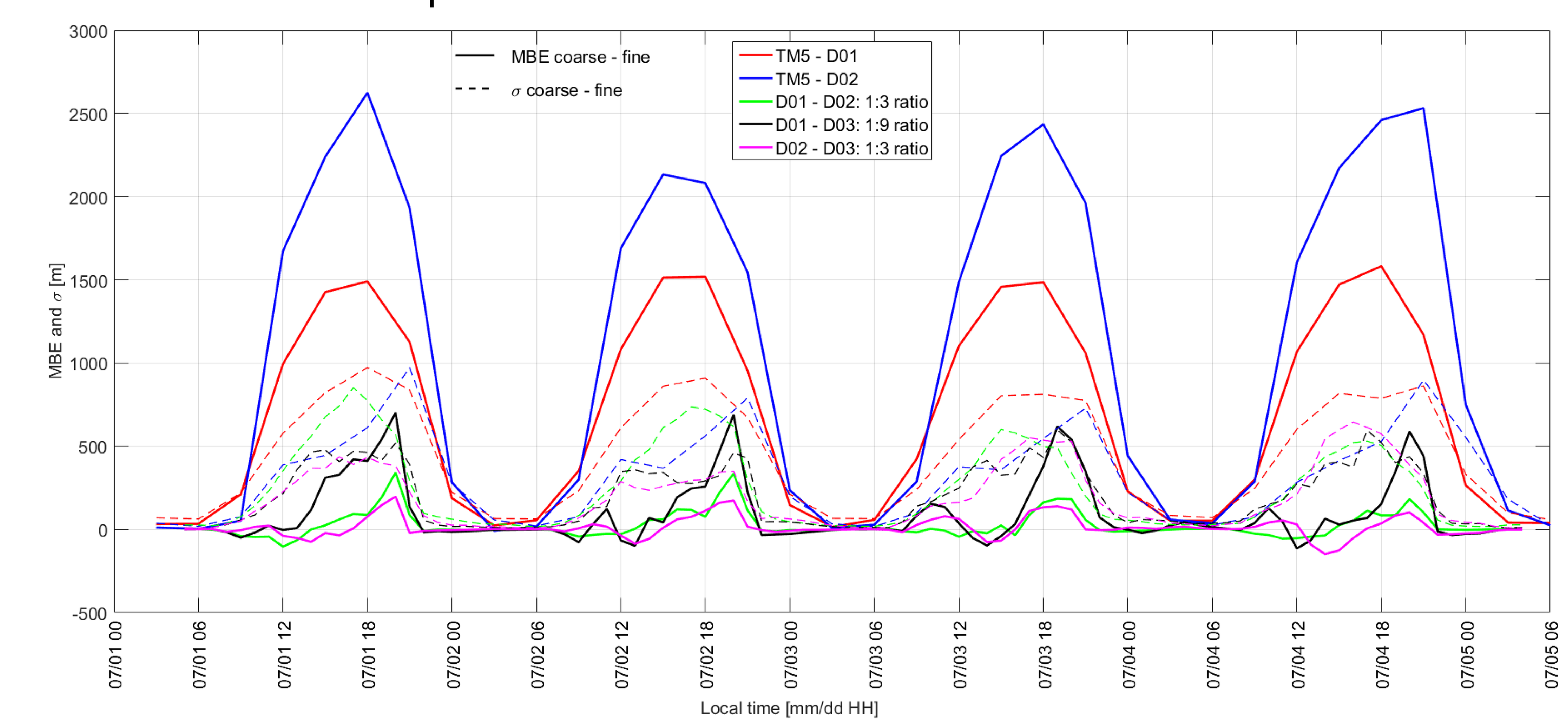
PBL variability over complex terrain

With increasing terrain variability, an increased difference in PBL depth is shown for all fine and coarse domains comparisons. TM5 overestimates WRF PBL depths to a great extent.



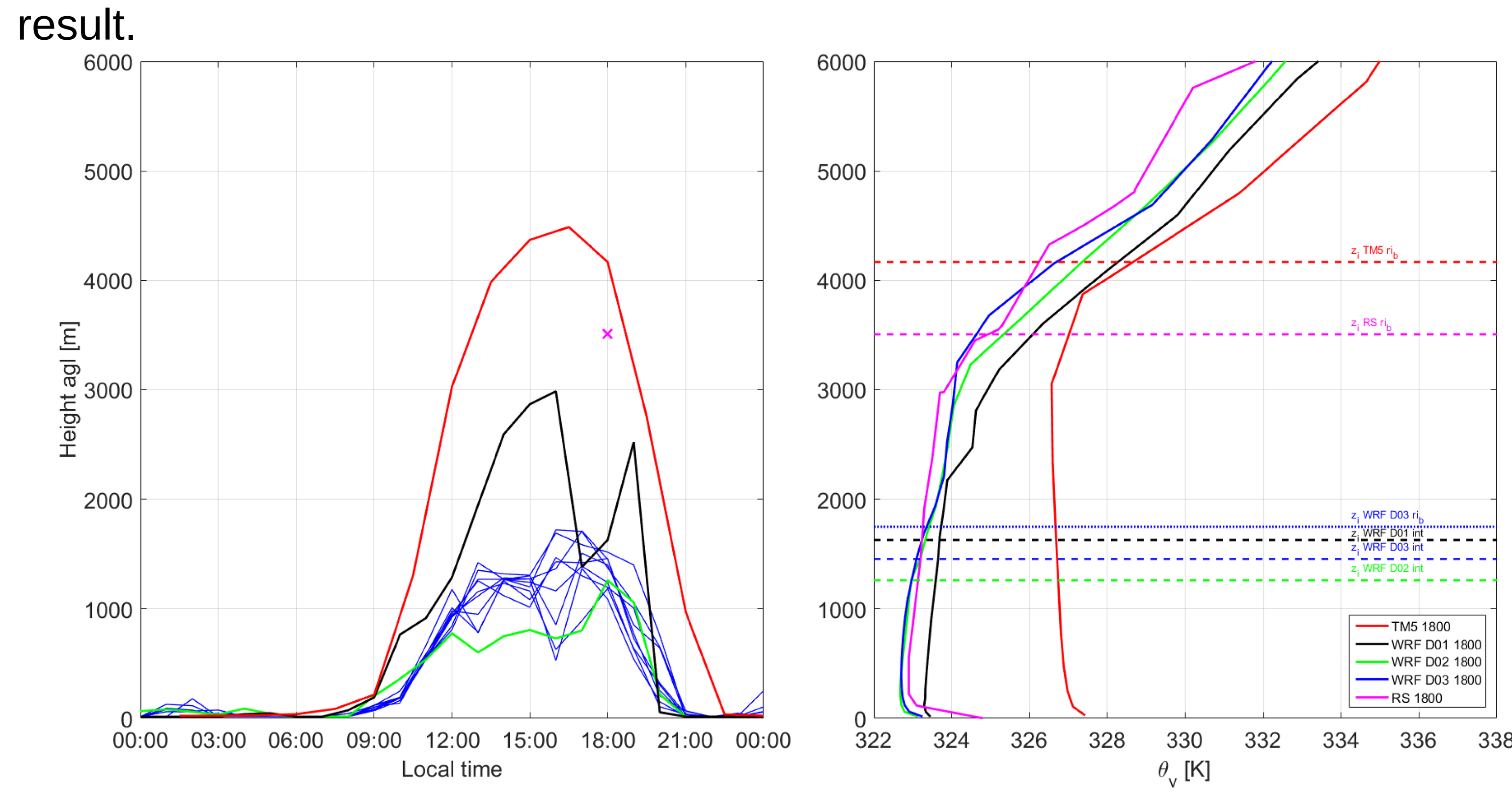
Evolution of PBL depth

Regardless of the large uncertainty, mean differences between coarse and fine simulations show general patterns for a series of days with well-defined afternoon boundary layers. Parent-child comparisons show least difference; 'grandparent-grandchild' comparison shows largest differences in both WRF and TM5 model comparisons.



Other concerns

Large differences in the temporal evolution and spatial variability of PBL depth in WRF and TM5 are found. However, PBL depth in TM5 compares well with radiosonde (RS) observations at SLC airport, but this is likely a fortuitous result.



SUMMARY

To better understand the uncertainty in large-scale transport models in simulating PBL depths, and to improve simulated CO2-budgets in such models, we investigate the effect subgrid terrain variability on PBL depth development. Missed sub-grid terrain variability leads to an increasing difference of PBL depths between coarse and fine simulations. Afternoon and early-evening PBL depths are generally overestimated in coarser scale domains.

Future work The case study will be extended to a 2-year data period to test if the results are general. We are planning to develop a methodology to represent the effects of sub-grid scale topography on PBL depths in large-scale transport models.

ACKNOWLEDGMENTS

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