Downscaling Near-Surface Atmospheric Fields With Multi-Objective Genetic Programming

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ABSTRACT

Coupled models of the soil-vegetation-atmosphere systems are increasingly used to investigate interactions between the system components. Due to the different spatial and temporal scales of relevant processes and computational restrictions, the atmospheric model generally has a lower spatial resolution than the land surface and subsurface models. We employ multi-objective Genetic Programming (MOGP) using the Strength Pareto Evolutionary Algorithm (SPEA) to bridge this scale gap. We generate high-resolution atmospheric fields using the coarse atmospheric model output and high-resolution land surface information (e.g., topography) as predictors. High-resolution atmospheric simulations serve as reference. It is impossible to perfectly reconstruct the reference fields with the available information. Thus, we simultaneously optimize the root mean square error (RMSE) and two objective functions quantifying spatial variability. Minimization solely with respect to the RMSE provides too smooth high-resolution fields. Additional objectives help to recover spatial variability. We apply MOGP to the downscaling of 10 m temperature. Our approach reproduces a larger part of the variability and is applicable for a wider range of weather conditions than a linear regression based downscaling.
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CCS CONCEPTS

•Computing methodologies → Genetic programming; •Applied computing → Earth and atmospheric sciences; *Mathematics and statistics;*

KEYWORDS

geosciences, atmospheric sciences, soil-vegetation-atmosphere system, spatial variability, SPEA

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1 INTRODUCTION

Numerical models of the atmosphere are fundamental tools to predict weather and climate. However, the atmosphere is not a closed system but interacts with the land surface and the subsurface (soil) through the exchange of mass, energy and momentum: precipitation infiltrates into the ground; water evaporates from the surface into the atmosphere; solar radiation propagates through the atmosphere heating atmosphere, ground and soil; etc. The integrated modelling platform TerrSysMP [3] couples an atmospheric model, a land surface model, and a subsurface/hydrological model to simulate interactions between atmosphere, land surface and subsurface. Land surface and subsurface are highly heterogeneous systems with relevant processes on very small spatial scales. The respective models are therefore run with a relatively small grid spacing. Atmospheric models are computationally very expensive and are therefore typically employed with a coarser grid spacing. In integrated modelling systems the difference in grid spacing is problematic. The fluxes of mass, energy and momentum are calculated by nonlinear functions of the land surface and lower atmospheric state. Thus, the use of spatially averaged parameters or state variables for the lower atmosphere (or at the land surface) can introduce biases in the estimates of the fluxes. An appropriate representation of subgrid-scale heterogeneity improves the flux estimates [2].

2 METHOD

We consider temperature downscaling from a grid spacing of 2.8 km to 400 m. Following [1] we first apply a spline-interpolation to smooth the coarse temperature field. Then we employ multi-objective Genetic Programming (MOGP) to evolve downscaling rules

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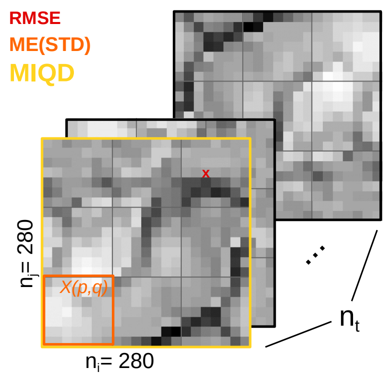

Figure 1: Spatial scales of the different objectives.

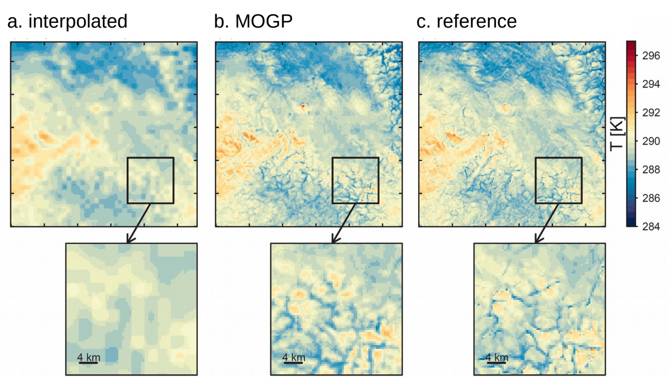

Figure 2: 10 m temperature on Sept. 18th 2014 1:00 UTC.

that predict the fine-scale temperature anomalies (with respect to the interpolated temperature field) using as predictors the coarse-scale atmospheric model output and high-resolution information on invariant surface properties such as topographic height. The MOGP code is based on the GPLAB toolbox for MATLAB [4]. As reference for training and validation we use a set of high-resolution atmospheric simulations over a 168 km × 168 km domain covering parts of western Germany, Netherlands and Belgium. To avoid biases in the downscaled temperature fields the coarse pixel mean is conserved. This is done by subtracting the mean anomaly predicted over a coarse pixel from the predicted anomalies at every pixel on the fine scale before evaluating the performance of the downscaling rules.

For multi-objective optimization we use SPEA [6]. Four objective functions are considered: the root-mean-square-error (RMSE) between downscaled and reference field, the mean error of the subgrid-scale standard deviation (ME(STD)) within the coarse pixels $X(p, q)$, the mean integrated quadratic distance (MIQD), which aims at minimizing the differences between the empirical probability distributions of downscaled and reference fields, and the size (number of nodes) of the downscaling rules.

3 RESULTS

In the following selected results from the approach introduced in [5] are presented. Figure 2 shows the performance of a downscaling rule evolved by MOGP for a 10 m temperature field during a clear sky night. Written as an equation, the downscaling rule reads

IF $T^*_{so} > tp_3$

$$T^* = 0.61\ h^*\ T_{gr60} - 1.16\ h^*\ T^2_{gr60} - tp^*_1$$

ELSE

$$T^* = 0.61\ h^*\ T_{gr60} - 1.16\ h^*\ T^2_{gr60}$$

i.e., the fine-scale temperature anomaly T^* is related to the topographic height anomaly h^*, the vertical temperature gradient of the lowest 60 m T_{gr60} and a topography parameter quantifying the location of a fine-scale pixel within terrain (valley or mountain top) tp^*_1. The exact relation between predictors and predictands depends on the soil temperature T_{so} and the location of a pixel within the terrain (local slope) tp_3.

Especially in the mountainous regions in the southern and northwestern model domain, we see channel like structures in the reference temperature field. During clear sky nights radiative cooling is strong, especially near the surface. The cold air drains into the valleys and creates the channel like cold air temperature patterns. The overall pattern is well captured by the MOGP downscaling rule, but the channel structures appear slightly thicker and smoother compared to the reference. On average over the full validation data set the example downscaling rule reduces the ME(STD) by 67 % and the MIQD by 82 % without any increase in RMSE compared to the interpolated field.

4 DISCUSSION AND OUTLOOK

Also the application of the MOGP algorithm to other atmospheric parameters shows promising results. For the 10 m wind speed the ME(STD) can be reduced by 64 % and the MIQD by 84 % with a minor increase of the RMSE of about 5 % and also for humidity and incoming long-wave radiation potentially useful downscaling models are derived. The MOGP based downscaling rules are currently implemented into the integrated modelling platform TerrSysMP to investigate the effect of the downscaling on the estimation of the exchange fluxes of mass, energy and momentum at the surface. Further recent work aims at integrating a spatial noise generator into the MOGP rule search algorithm.

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