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Spatial Analysis of Hourly Surface Air Temperature – Entering the Gate to Spatiotemporal Statistical Modelling

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Motivation

- Temperature grid data sets today are mostly limited to daily temporal resolution
- This limits applications, especially with processes that exhibit a diurnal cycle
- To overcome these limitations, we develop a method to produce temperature analyses at an hourly timescale in an area of complex topography
- To reproduce physically plausible and continuous diurnal variations we integrate station measurements over both space and time, experimenting with a spatiotemporal (ST) statistical model

Model and Experiment

- We experiment with an ST model from the framework of dynamic linear models:

- Data Model: $\boldsymbol{Z}_t = \boldsymbol{H}_t \boldsymbol{Y}_t + \boldsymbol{\varepsilon}_t \qquad \boldsymbol{\varepsilon}_t \sim N(0, \boldsymbol{\Sigma}_\varepsilon)$

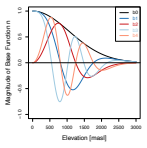


Figure 1: Basis Functions

$\boldsymbol{Z}_t$ hourly temperature observations
observation matrix, contains
$\boldsymbol{H}_t$ basis functions for the non-linear elevation dependence (figure 1)
$\boldsymbol{Y}_t$ latent process vector
$\boldsymbol{\varepsilon}_t$ error term

- Process Model: $\boldsymbol{Y}_t = \boldsymbol{M}_t \boldsymbol{Y}_{t-1} + \boldsymbol{\eta}_t \qquad \boldsymbol{\eta}_t \sim N(0, \boldsymbol{\Sigma}_\eta)$

$\boldsymbol{M}_t$ propagator matrix
$\boldsymbol{\eta}_t$ random perturbations

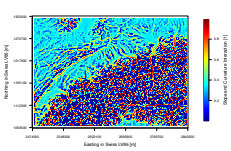
- Estimated the evolution of a vertical temperature profile during two episodes (winter-time inversion, summer-time boundary layer)
- Applied the model to hourly observations of 2m temperature from 22 stations in Switzerland which cover a large range of elevations.
- Compared the ST model to a spatial-only Model
- Predicted an ensemble of vertical temperature profiles using MCMC

Predicting Cold-Air Pools (CAPs) in Complex Terrain

- Prediction in 2D Space requires spatial covariates
- A CAP covariate is crucial

Attempts so far:

- Interaction of transformed Slope and Curvature[1]
- Dynamical Simulation of Cold-Air Advection



- No satisfactory result yet
- Advice is welcome!

Result 1

	Spatial-only Model	ST Model	Reduction of Error
January 2020			
MAE	1.34 °C	1.22 °C	8.8%
RMSE	1.85 °C	1.64 °C	10.9%
July 2020			
MAE	1.14 °C	1.06 °C	6.4%
RMSE	1.55 °C	1.39 °C	9.8%

Table 1: Prediction Errors of the Spatial-only and ST models for a winter and a summer episode, obtained using a leave-one-out cross-validation. The last column gives the relative difference in prediction errors.

Result 2

- The ST model is much less sensitive to erroneous or missing observations than the spatial-only model due to the integration of information across time

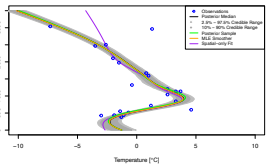


Figure 2: Observations (blue) and predictions of the vertical temperature profile over northern Switzerland on 25.1.2020 at 2:00 local time. The ST model (grey shading) is much less sensitive to an erroneous outlying data point than the spatial-only model (purple line).

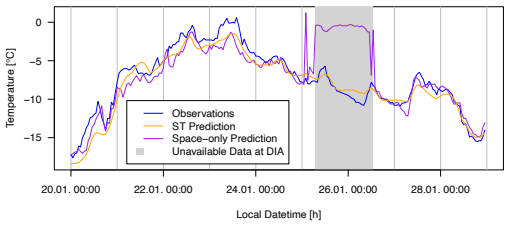


Figure 3: Time series of observations (blue) and predictions at the Titlis high-mountain station. During the grey-shaded period, data are missing at the only other station with a similar elevation, which causes the spatial-only model (purple) to deviate strongly from observations. The ST model, on the other hand, remains robust (orange).

Conclusions

- We successfully applied ST statistics for an hourly analysis of the temporal development of non-linear temperature profiles

Integrating information over time by using an ST model brings added value in:

- Robustness to erroneous and missing observations
- Higher predictive skill at unobserved locations

We expect these benefits over spatial-only models to increase with model complexity

References

1. Lundquist, Jessica D., Nicholas Pepin, and Caitlin Rochford. 2008. 'Automated Algorithm for Mapping Regions of Cold-Air Pooling in Complex Terrain'. *Journal of Geophysical Research Atmospheres* 113 (22). https://doi.org/10.1029/2008JD009879.

Result 3

The ST model is capable of accurately and robustly reproducing the buildup, diurnal variation and decay of a winter-time inversion

