# Sub-mesoscale temperature variability in observed and simulated convective cold pools

**Bastian Kirsch**, Leah D. Grant, Nicholas M. Falk, Christine A. Neumaier, Jennie Bukowski, Felix Ament, and Susan C. van den Heever

Contact: bastian.kirsch@uni-hamburg.de

Universität Hamburg — DER FORSCHUNG | DER LEHRE | DER BILDUNG

Hans-Ertel-Zentrum für Wetterforschung

Colorado State University

UCLA Institute of the Environment & Sustainability

Grant number: NSF AGS-2029611

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EGU General Assembly 2023

## 1 Introduction

Convective cold pools are mesoscale areas of cool air formed by downdrafts of precipitating clouds. They are critical for convective organization, but their impact on the **sub-mesoscale (100 m to 10 km)** variability of near-surface air temperature is unclear due to insufficient observations:

- How do cold pools over mid-latitude land modify the sub-mesoscale temperature variability across scales?
- Do models with sub-km grid spacing correctly represent the observed temperature variability inside cold pools?

## 2 Method

- We use temperature data at **99 locations** of a dense station network covering an area of 30 km in diameter as featured during the FESSTVaL 2021 field experiment (Fig. 1).
- The spatial temperature variability is quantified using **experimental variograms** and modified **"gradiograms"** (i.e., mean gradients) for distances between 100 m and 15 km (Eq. 1, 2, Fig. 2).
- We compare the actual observations of the FESSTVaL station network to virtual observations in idealized and realistic simulation setups with sub-km grid spacing.

## 3 Findings

- The cold pool **enhances the spatial variance** on all analyzed scales compared to the pre-event state, but the signal is **highly variable in time** (Fig. 3a).
- **Sub-km temperature gradients are reduced** inside the cold pool, except for the phase of peak intensity (Fig. 3b). Hypothesized processes for the suppressed gradients include mechanical stirring of surface layer air and dampening of turbulent surface fluxes.
- Idealized simulations as well as realistic case-study simulations reproduce the observed variogram shape well; however, the **absolute variance inside the cold pool is underestimated** (Fig. 5a) despite similar maximum temperature perturbation (Fig. 4).
- Reduction of grid spacing improves agreement with observations only marginally (Fig. 5a).
- Spatial temperature variance due to turbulent mixing (well-mixed BL; Fig. 5b) as well as local effects (stable BL; Fig. 5c) are well captured and, therefore, do not explain underestimation of cold pool signal.

**COLD POOLS IN OBSERVATIONS ENHANCE SPATIAL TEMPERATURE VARIABILITY MORE THAN IN SIMULATIONS.**

Abstract EGU23-13748

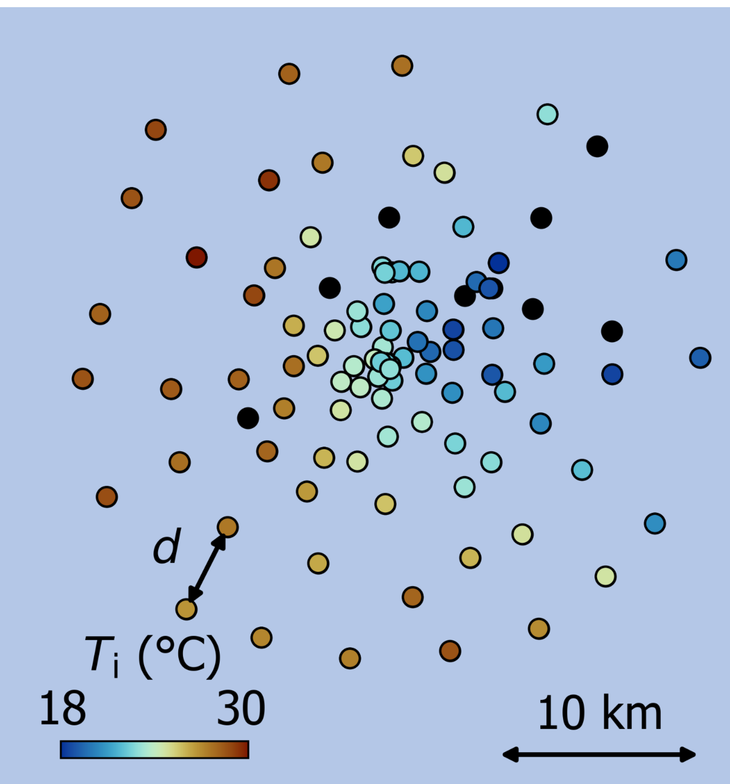



Fig. 1: Network of 99 measurement stations for FESSTVaL 2021 experiment (Hohenegger et al., 2023), example temperature data $T_i$ during a cold pool event (color-coded), and distance $d$ between station pairs.

$$\hat{\gamma}(d) = \frac{1}{2}\frac{1}{N(d)}\sum_{i\neq j}\left(T_j - T_i\right)^2 \quad \textbf{(Eq. 1)}$$

$$\hat{\gamma}_g(d) = \frac{1}{N(d)}\sum_{i\neq j}\frac{|T_j - T_i|}{|d|} \quad \textbf{(Eq. 2)}$$

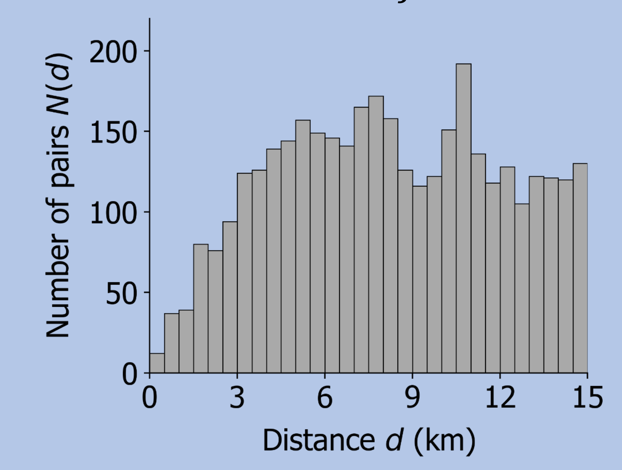



Fig. 2: Number distribution $N(d)$ of distance $d$ between station pairs used for variogram and gradiogram calculation (bin width: 500 m).

**Data sets**

- **Observations:** 1-min data from APOLLO and WXT stations custom-built for FESSTVaL experiment in eastern Germany during summer 2021 (Kirsch et al., 2022).
- **Idealized simulations:** RAMS model, deep boundary layer with cold pool in dry continental environment, $\Delta x$=[50,100] m, 5 min output, interactive surface fluxes, no microphysics, no heterogeneity in surface type or terrain (Grant and van den Heever, 2018).
- **Realistic simulations:** ICON-LES model for FESSTVaL case study, $\Delta x$=[156,312] m, [15,60] min output, forced by operational ICON-D2, 3D-turbulence, 1" orography, 100 m land cover.

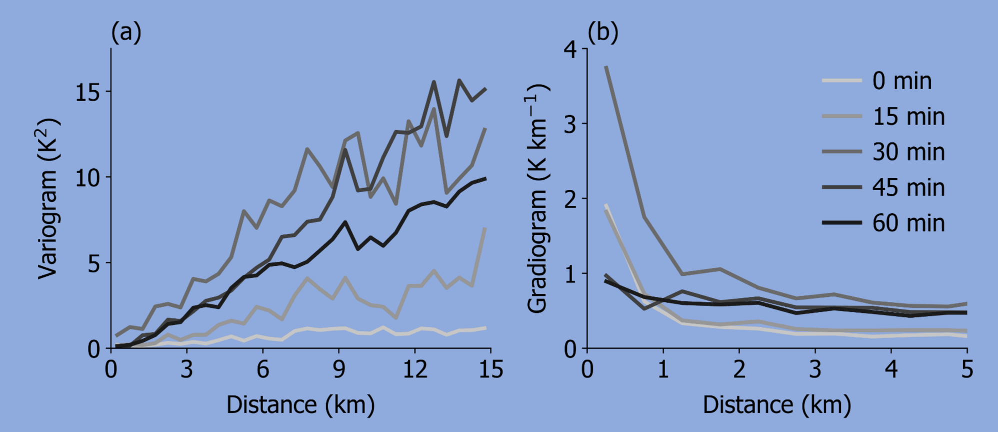



Fig. 3: Time variation of observed variograms and gradiograms relative to the onset of a cold pool event on 29 June 2021.

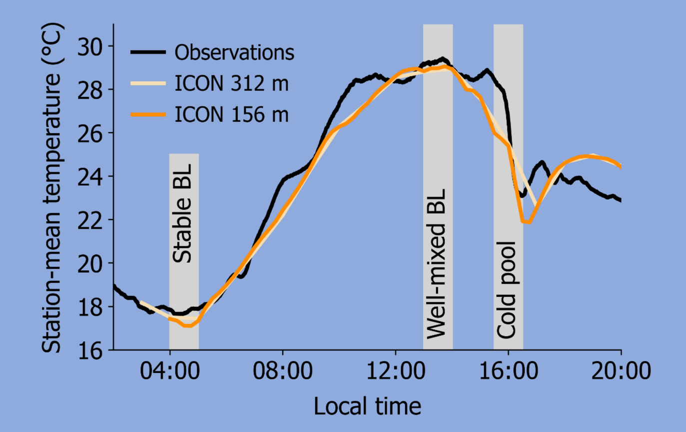
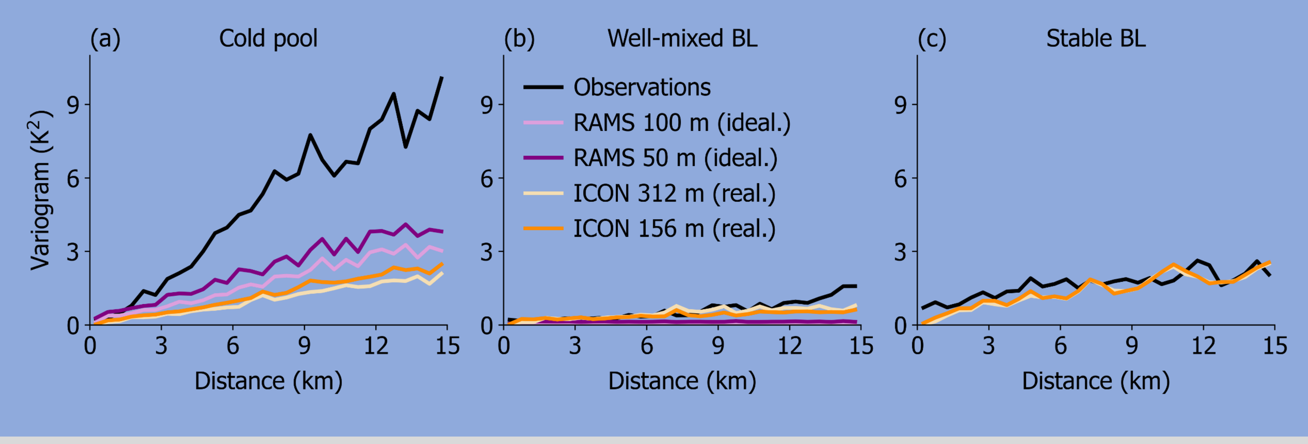



Fig. 4: Observed and simulated station-mean temperature on 29 June 2021.

Fig. 5: Observed and simulated variograms and gradiograms averaged over 1-hour periods of cold pool, well-mixed boundary layer, and stable boundary layer as marked in Fig. 4.




**References**

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