Center for Climate Systems Modeling (C2SM)

Modelling the mountain boundary layer: Does higher resolution improve model performance?

Brigitta Goger

The Mountain Boundary Layer (MoBL) is very heterogeneous and complex

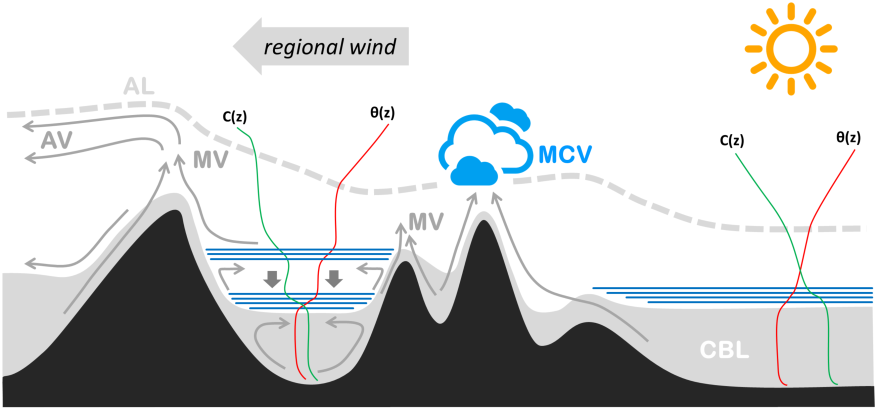
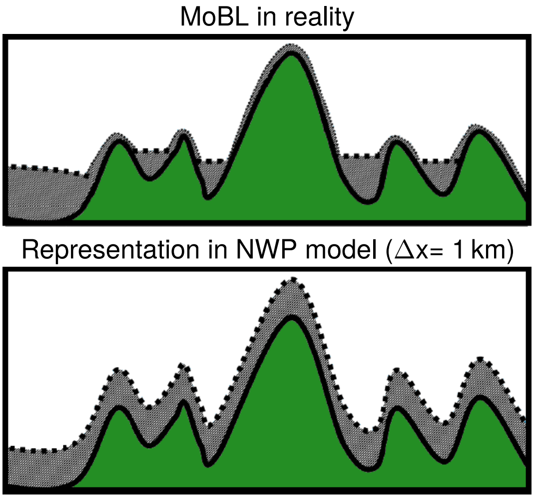


Image from Serafin et al. (2018)

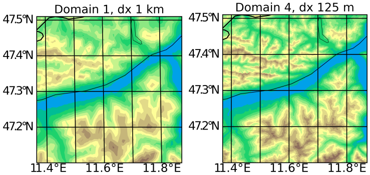
The mountain boundary layer is a challenge for NWP Models



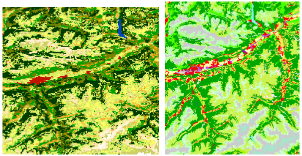
Rotach and Zardi (2007)

What can we improve in model set-ups?

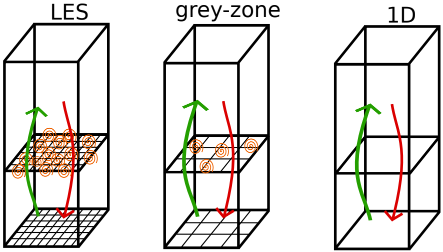
Topography representation → go towards hectometric range?



Land-use → Change LU dataset?

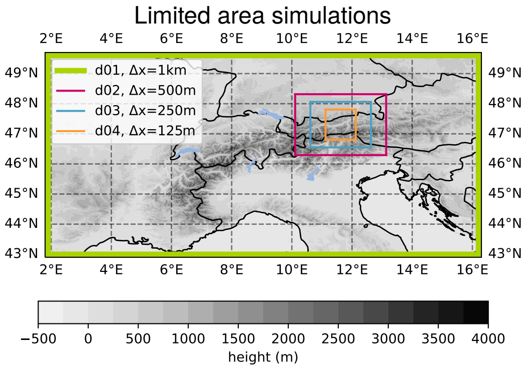


Turbulence representation → towards 3D turbulence schemes



adapted from Honnert et al. (2011)

ICON - Icosahedral Nonhydrostatic Model Set-up



Model Set-up

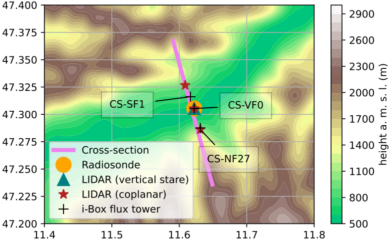
- 4 domains, one-way nesting, 80 vertical levels
- BC: IFS-HRES (Δx=9 km)
- IC: COSMO-1 Analysis (Δx=1 km)
- Model runtime 24 hours, init 00 UTC
- Shallow convection off
- **Sensitivity Runs:**
    1. GLOBCOVER vs. CORINE Land-use
    2. 1D TKE vs. 3D Smagorinsky closure

5 case studies: Aug 4 | Aug 14 | Aug 30 | **Sept 13** | Sept 14

Observations of mountain boundary layer processes

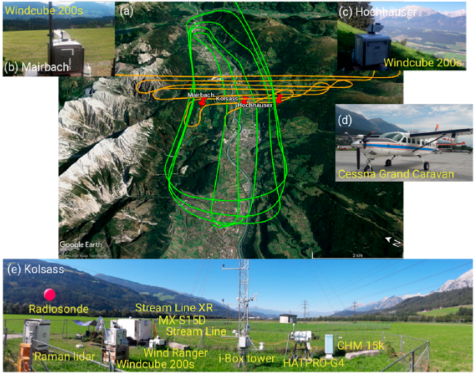
Inn Valley, Austrian Alps

i-Box Turbulence flux towers



CROSSINN Campaign (Summer/autumn 2019)

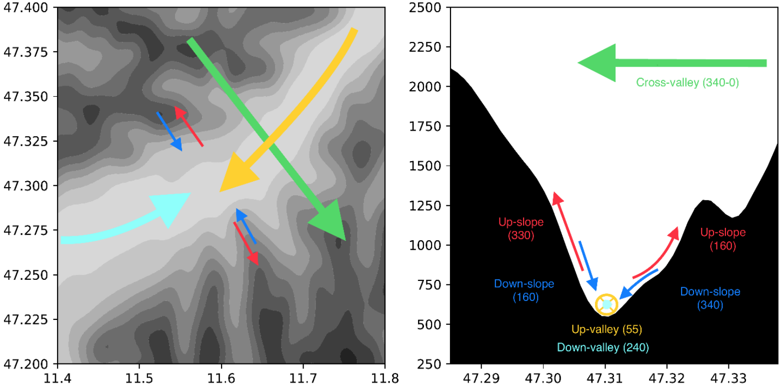
LIDAR, Temperature profilers, etc.



Adler et al. (2021)

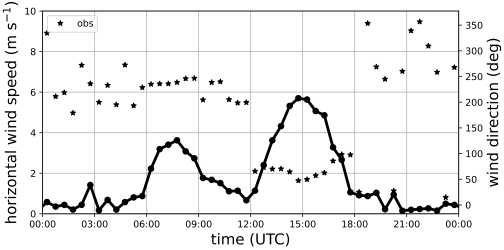
Why the thermally-induced valley wind circulation?

- Well-known mountain boundary layer phenomenon
- Boundary layer processes dominate, ideal for investigation of impact of land surface representation and/or turbulence parameterizations
- Valley is already well-resolved at $\Delta x = 1\,\text{km} \rightarrow$ wind structure as well?

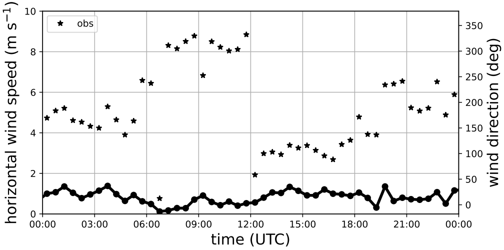


Wind structure is very heterogeneous

Valley floor (CS-VF0)

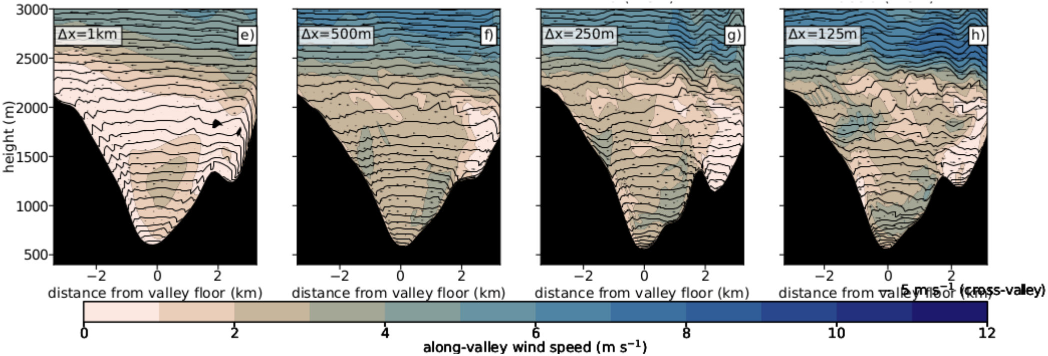


North-facing slope (CS-NF27)



Impact of Δx on valley boundary layer structure

03 UTC - stable boundary layer



Impact of Δx on valley boundary layer structure

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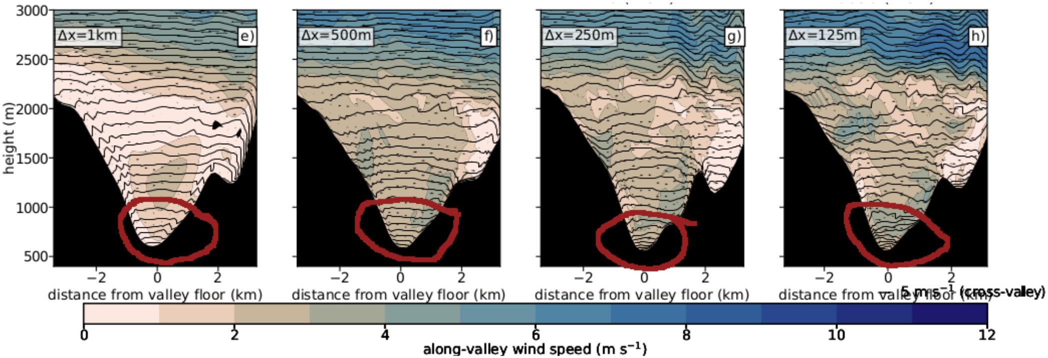
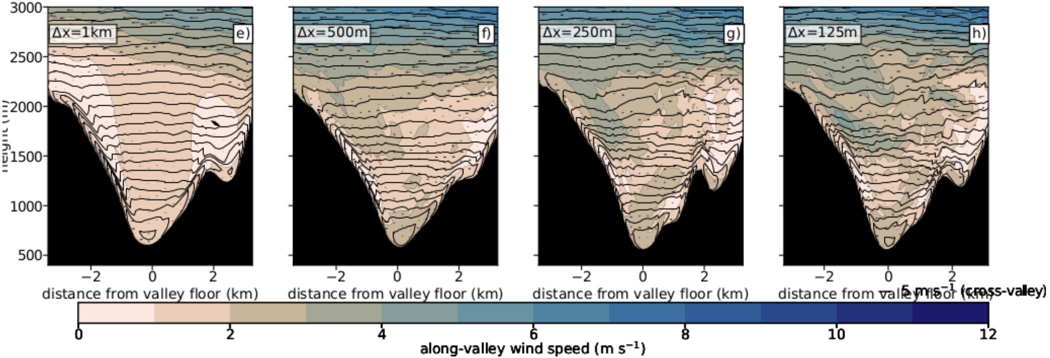


Impact of Δx on valley boundary layer structure

09 UTC - convective boundary layer



Impact of Δx on valley boundary layer structure

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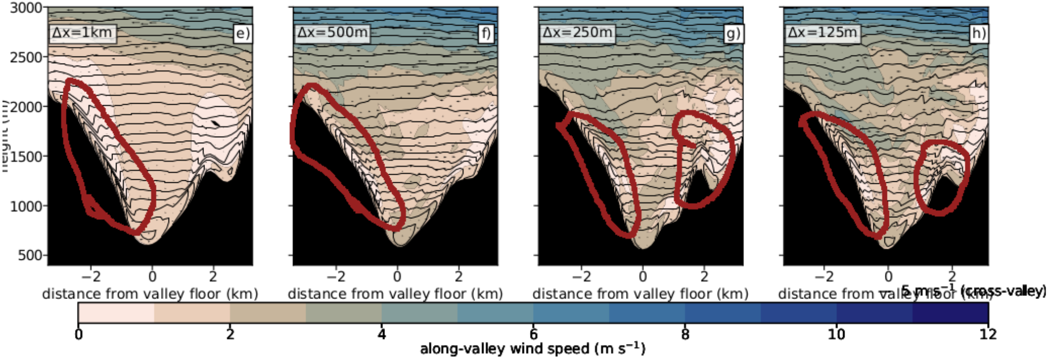
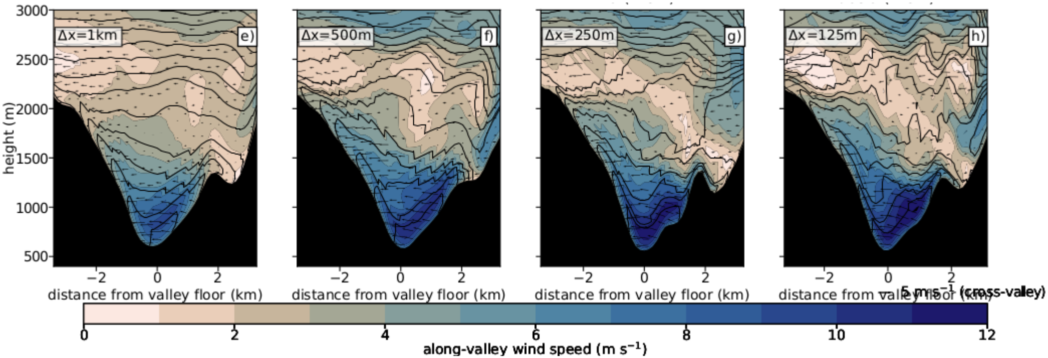


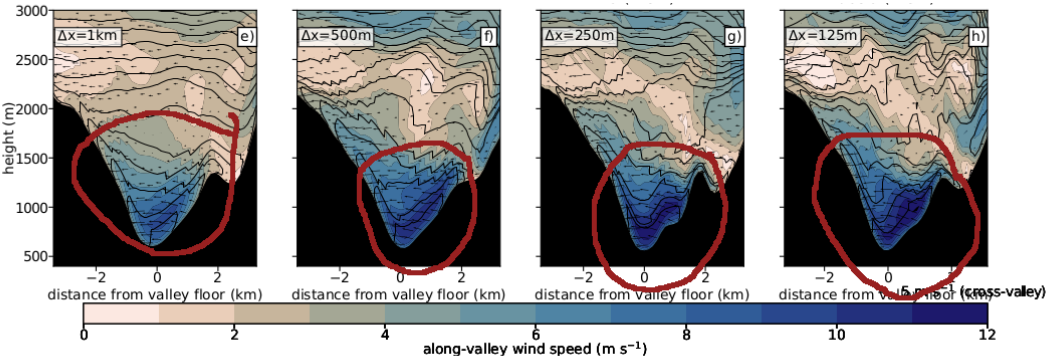
Impact of Δx on valley boundary layer structure

15 UTC shear-driven boundary layer



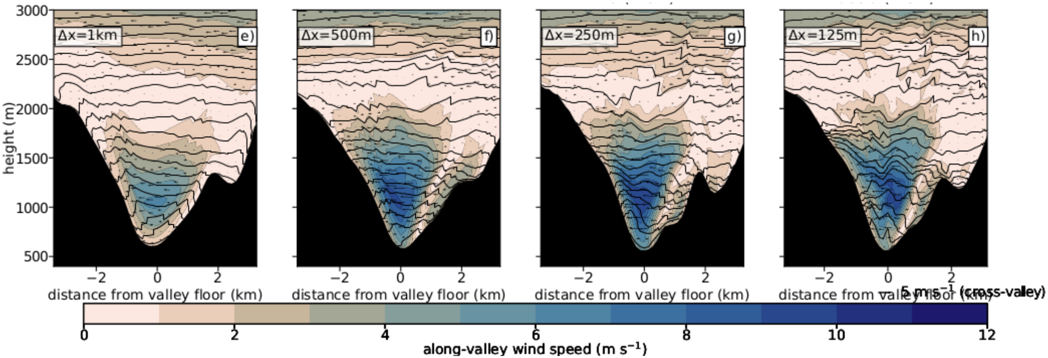
Impact of Δx on valley boundary layer structure

15 UTC shear-driven boundary layer



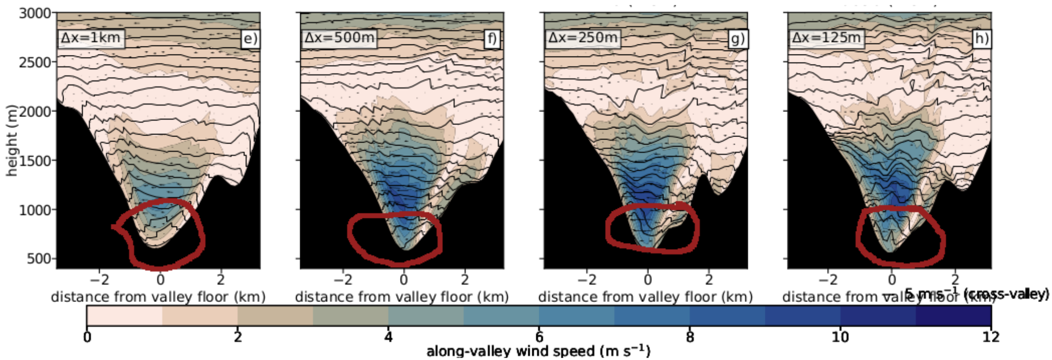
Impact of Δx on valley boundary layer structure

20 UTC - evening transition



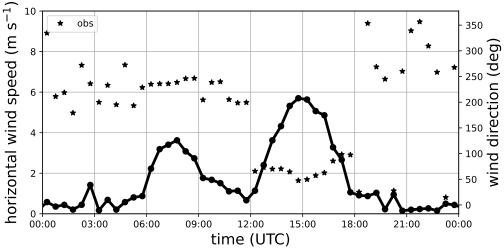
Impact of Δx on valley boundary layer structure

20 UTC - evening transition

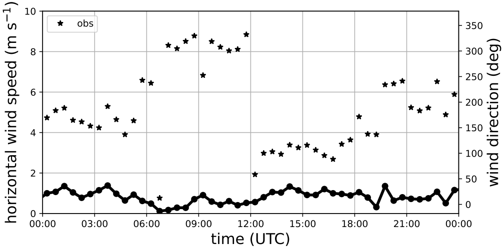


Wind structure is very heterogeneous

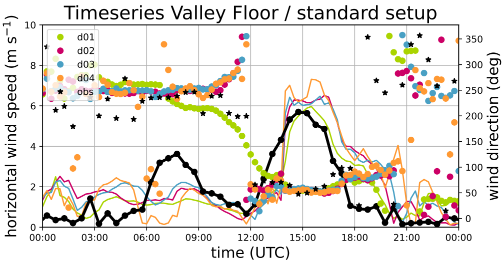
Valley floor (CS-VF0)

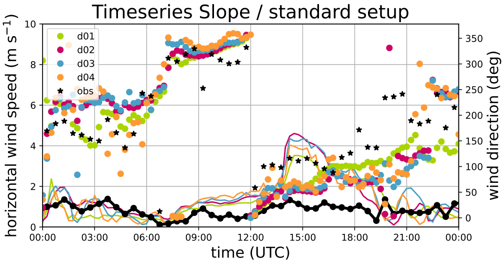


North-facing slope (CS-NF27)

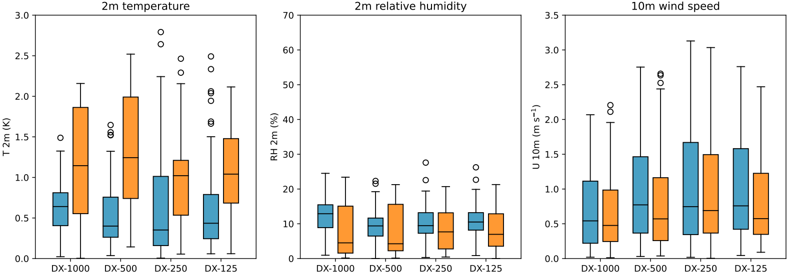


Wind structure is very heterogeneous

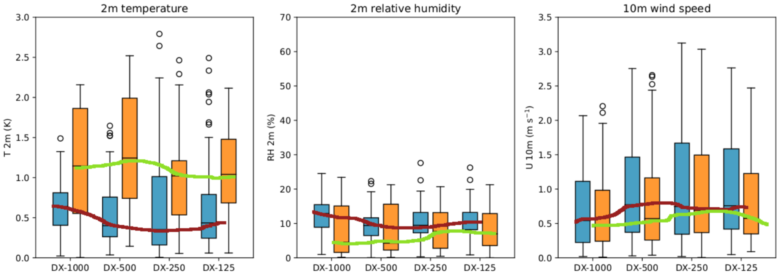




Model validation (5 cases) - Valley floor and slope



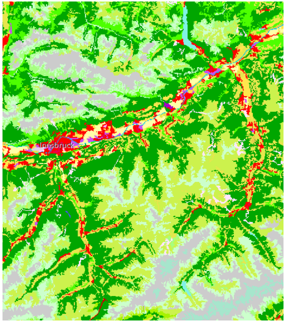
Model validation (5 cases) - Valley floor and slope



Impact of surface representation (land use datasets)

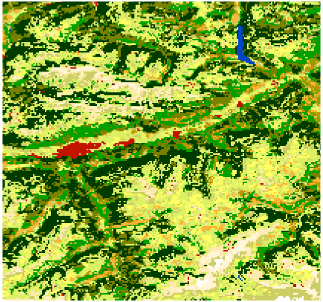
CORINE

- year: 2018
- Δx=100 m
- land cover classes: 44
- Europe only

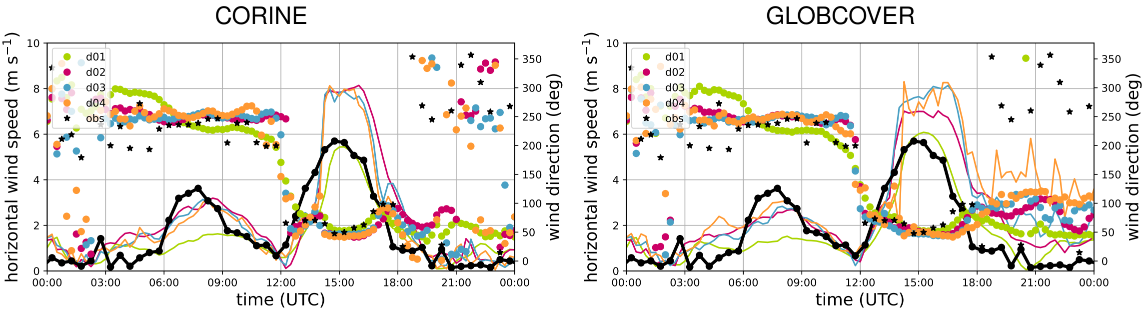


GLOBCOVER

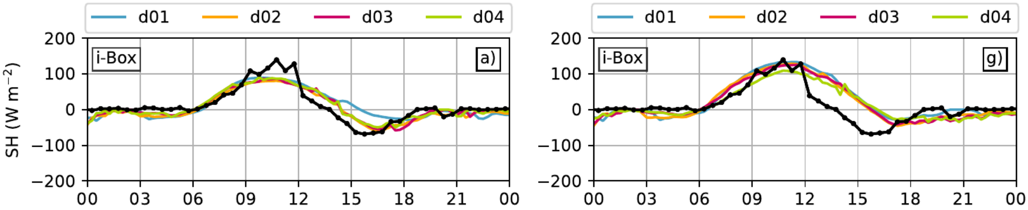
- year: 2009
- Δx=300 m
- land cover classes: 22
- Global dataset (advantage!)



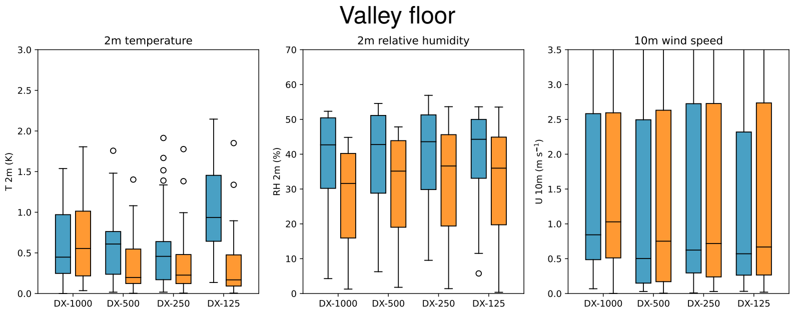
Valley floor: Wind Structure and Sensible Heat Flux



Sensible heat flux

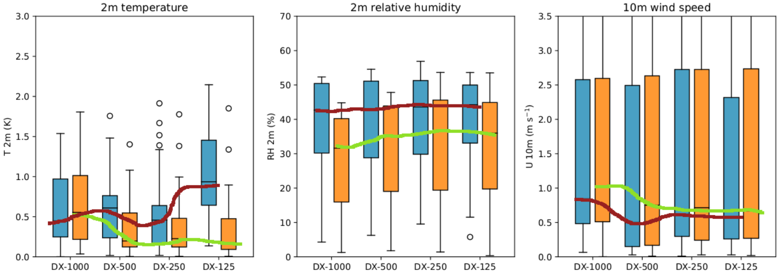


Model validation - GLOBCOVER vs CORINE



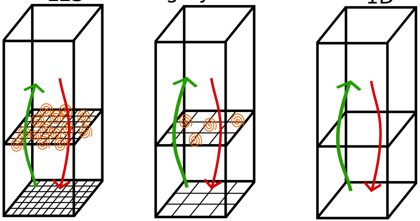
Model validation - GLOBCOVER vs CORINE

Valley floor



Impact of turbulence scheme

What is the smallest physically accepted scale for 1D turbulence schemes? (Honnert and Masson, 2014)



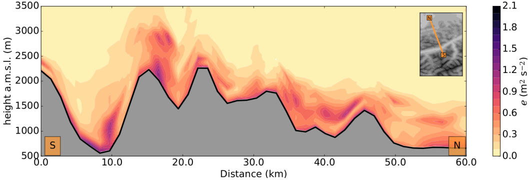
adapted from Honnert et al. (2011)

Turbulence schemes in ICON

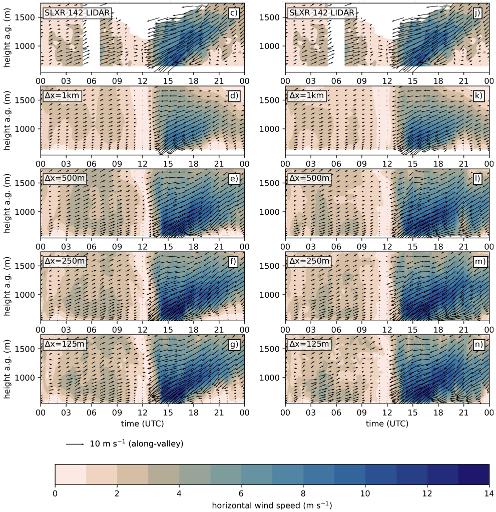
1. 1D TKE-based scheme (Mellor-Yamada, M. Raschendorfer)
2. 3D Smagorinsky closure (A. Dipankar)

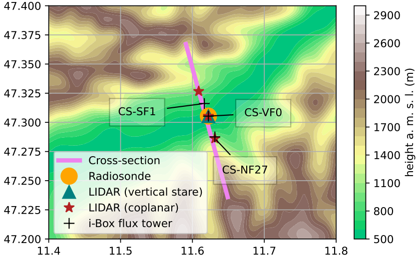
Turbulence in complex terrain

3D effects are already important at $\Delta x = 1\,\text{km}$ (Goger et al., 2018, 2019)



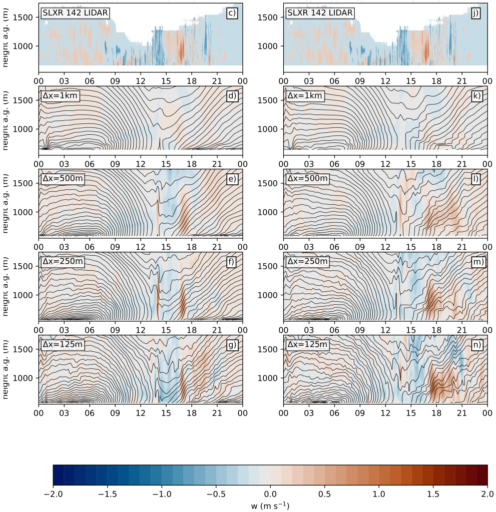
Diurnal cycle at valley floor – vertically pointing Lidar vs. Model

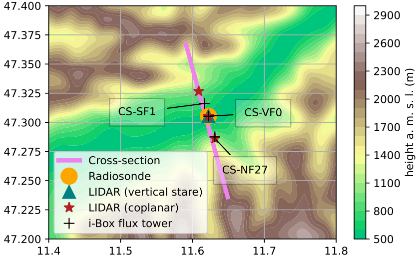




- Overestimated wind speeds at the hectometric range
- Delayed evening transition in the 3D Smagorinsky scheme

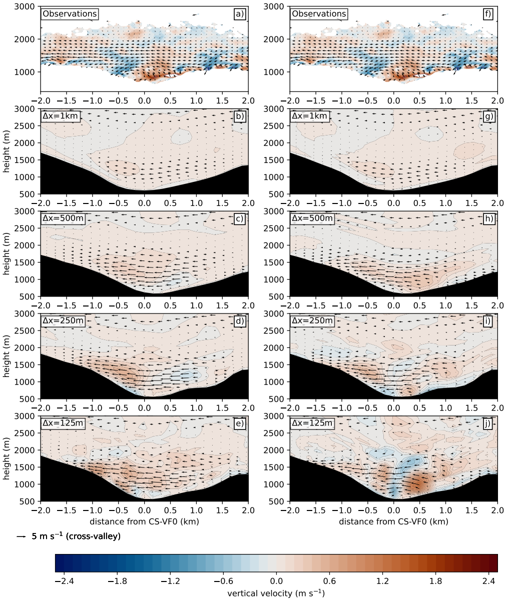
Diurnal cycle at valley floor – vertically pointing Lidar vs. Model

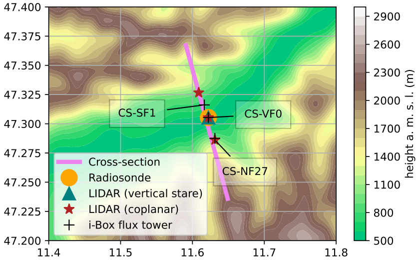




- Overestimated wind speeds at the hectometric range
- Delayed evening transition in the 3D Smagorinsky scheme

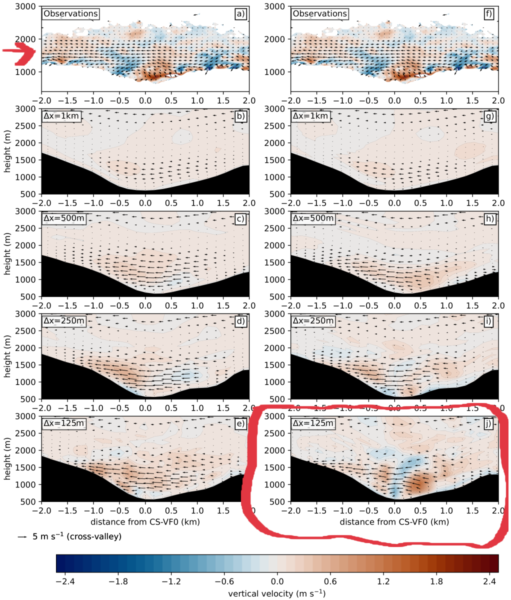
Evening transition - co-planar Lidar vs. Model

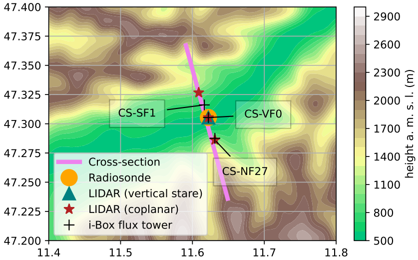




- 3D Smagorinsky scheme at 125 m is the only setup which simulates a qualitatively similar vertical velocity structure

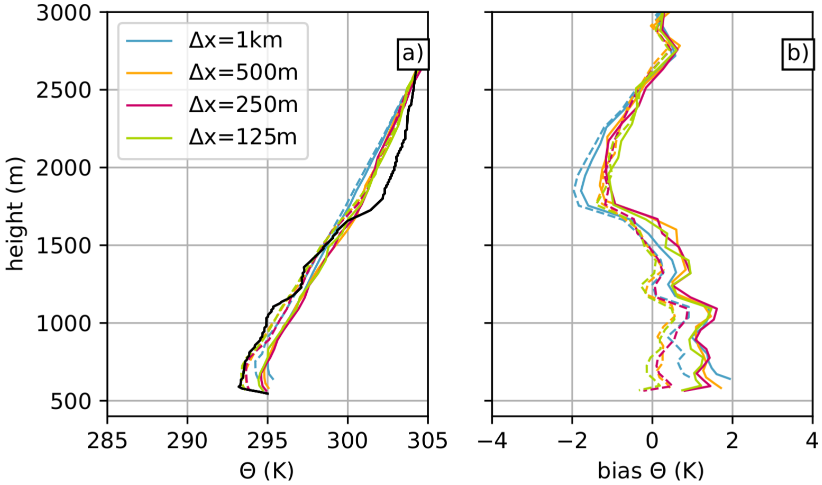
Evening transition - co-planar Lidar vs. Model





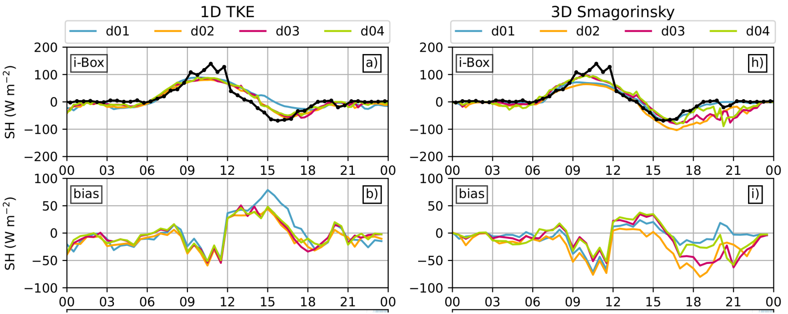
- 3D Smagorinsky scheme at 125 m is the only setup which simulates a qualitatively similar vertical velocity structure

Valley boundary layer structure (09 UTC)



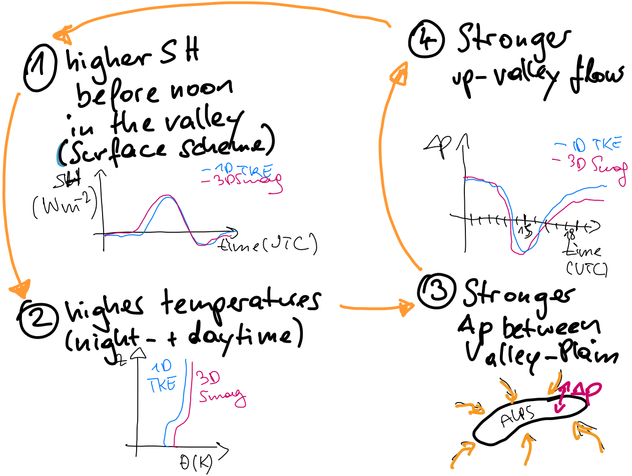
dashed: 1D TKE; full lines: 3D Smagorinsky

Sensible heat flux at the valley floor

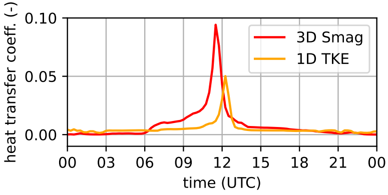


higher sensible heat fluxes in the 3D Smagorinsky scheme during 9-12 h (convective boundary layer)

Delayed Evening Transition in the 3D Smagorinsky scheme

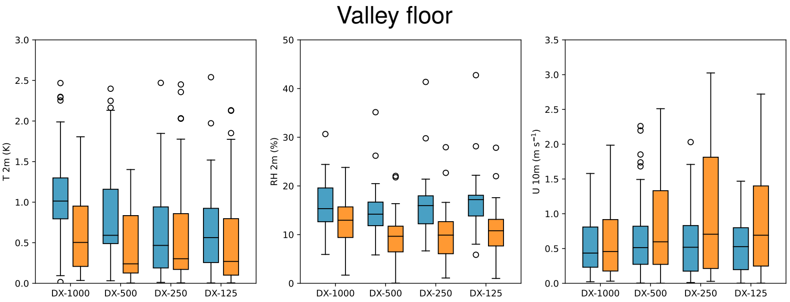


The source of the differences is in the different surface exchange schemes!



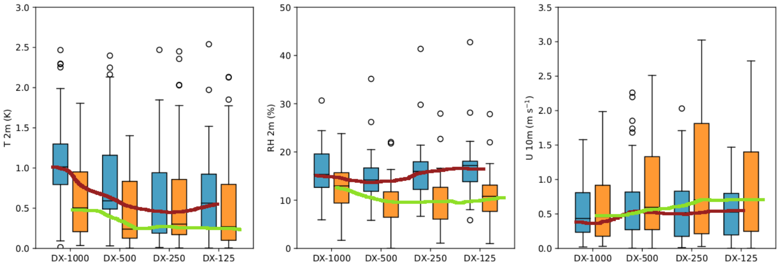
- Realistic surface exchange and land-use representation are essential for the hectometric scale

Model validation (5 cases) - 1D TKE vs 3D Smagorinsky

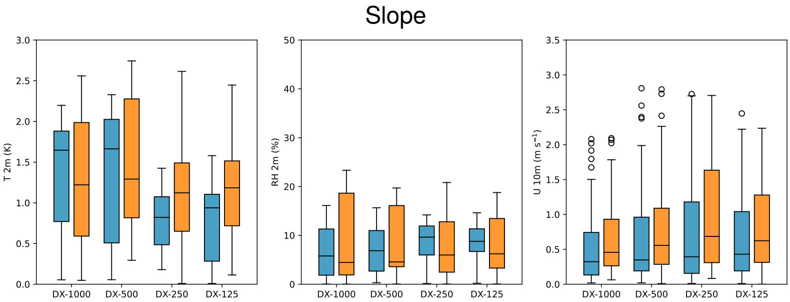


Model validation (5 cases) - 1D TKE vs 3D Smagorinsky

Valley floor



Model validation (5 cases) - 1D TKE vs 3D Smagorinsky



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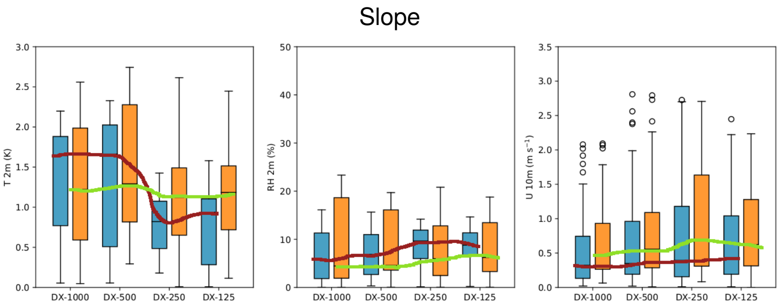

Summary – ICON at the hectometric range

Impact of...

1. Δx: vertical structure, slope station
2. Land-use: more realistic sensible heat fluxes, improves evening transition
3. Turbulence scheme: Changes are more related to the surface transfer scheme, detailed ABL representation at Δ x=125 m with LES closure

Preprint at arXiv
Goger and Dipankar, 2023: "A critical evaluation of the added value of increased horizontal resolution in the hectometric range on the simulation of the mountain boundary layer"
https://arxiv.org/abs/2311.05528

Overall Conlusions – Model validation at hectometric range

Does the model produce the right fields for the right reason?

- Well-resolved topography and land use are essential! $\rightarrow$ surface fluxes
- Be aware of the length scale of the processes you want to simulate to give your model a "chance" to perform well
- High-resolution simulations require high-resolution observations

TEAMx

Would you like to evaluate your model?

- CROSSINN Campaign (2019) - available!
- TEAMx Pre-campaign (2021) - available!
- TEAMx campaign (2025)

Thank you! Questions?

Observations from

universität innsbruck

Karlsruher Institut für Technologie

Simulations were performed within

C2SM Center for Climate Systems Modeling

EXCLAIM

CSCS

References I

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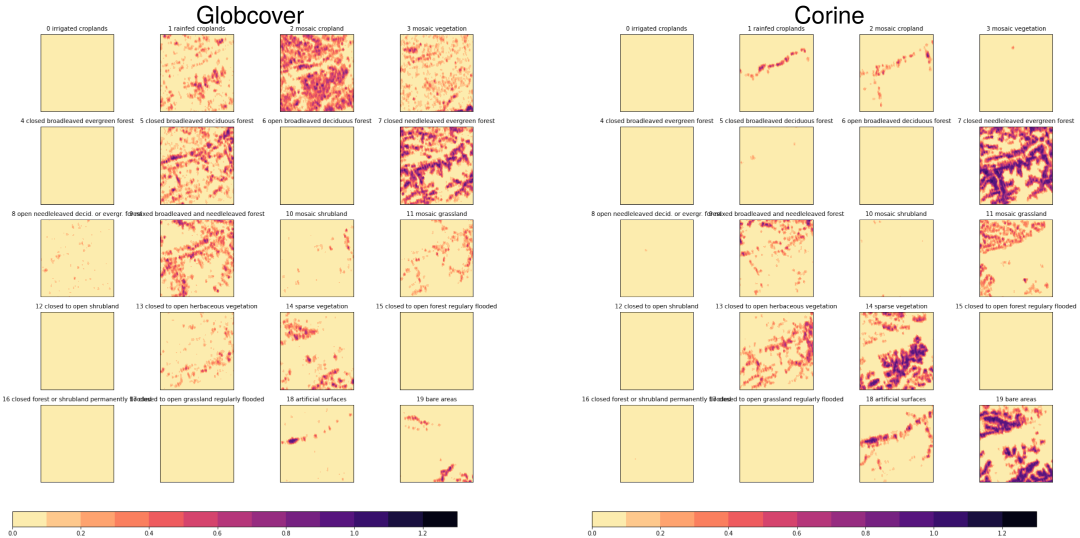
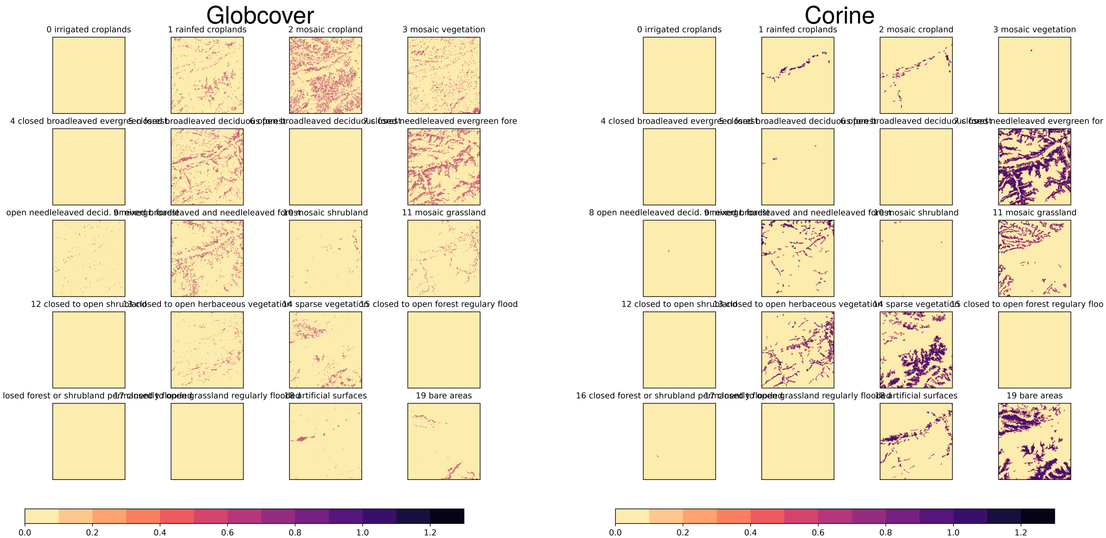
Wagner, J. S., A. Gohm, and M. W. Rotach, 2014: The Impact of Horizontal Model Grid Resolution on the Boundary Layer Structure over an Idealized Valley. *Mon. Wea. Rev.*, **142 (9)**, 3446–3465, doi:10.1175/MWR-D-14-00002.1.

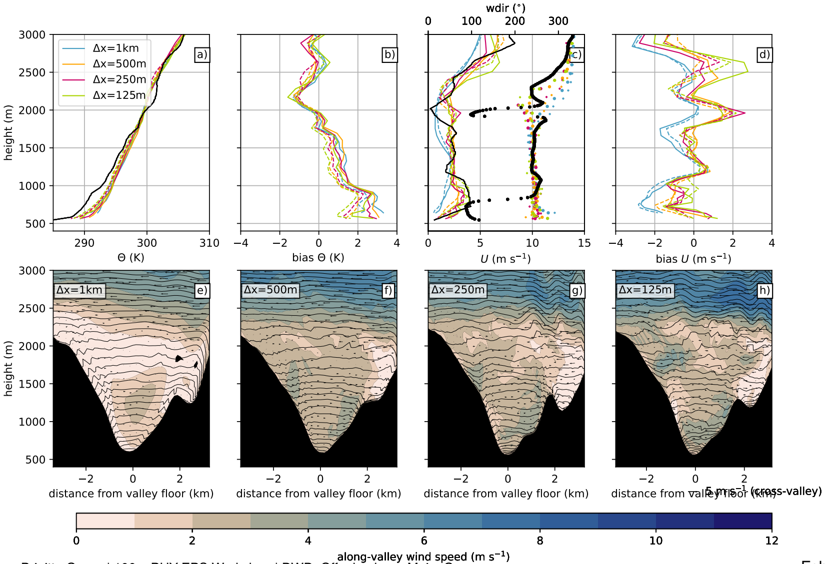
Land use in ICON at 1 km (Extpar file)



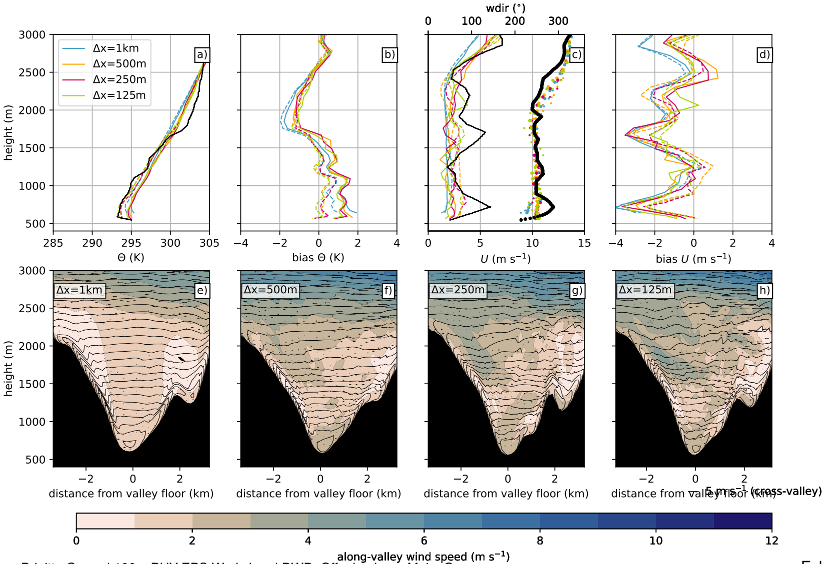
Land use in ICON at 125 m (Extpar file)



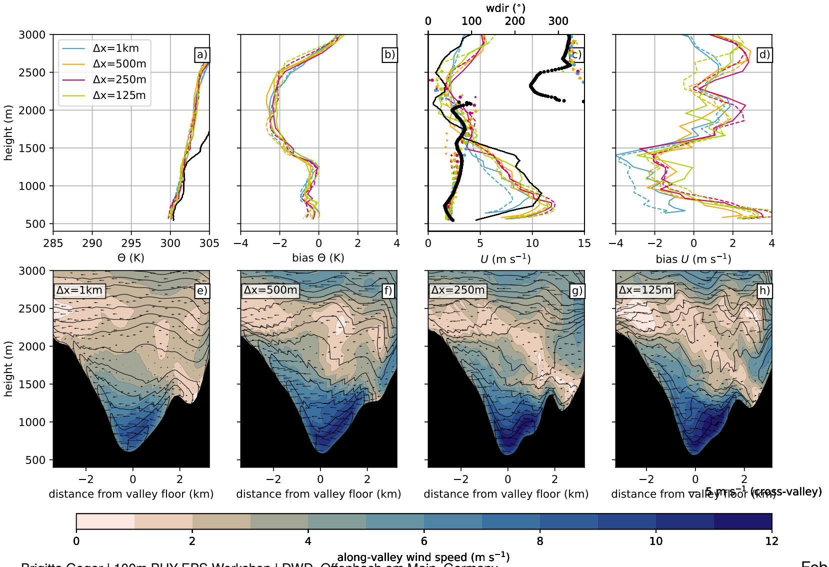
Valley boundary layer structure (03 UTC)



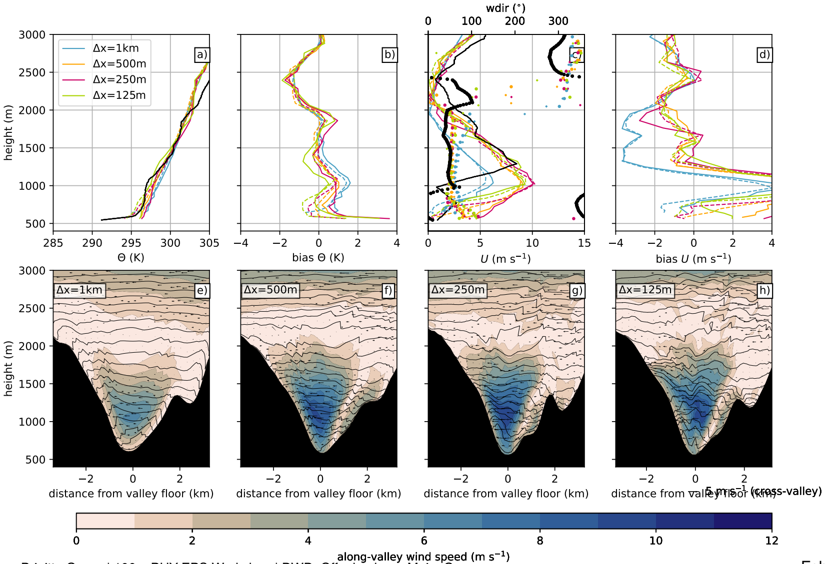
Valley boundary layer structure (09 UTC)



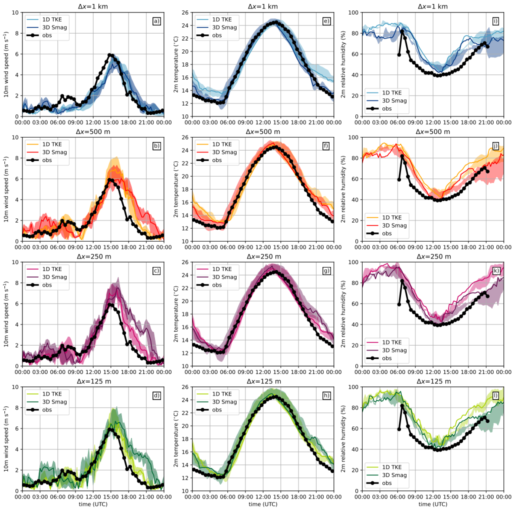
Valley boundary layer structure (15 UTC)



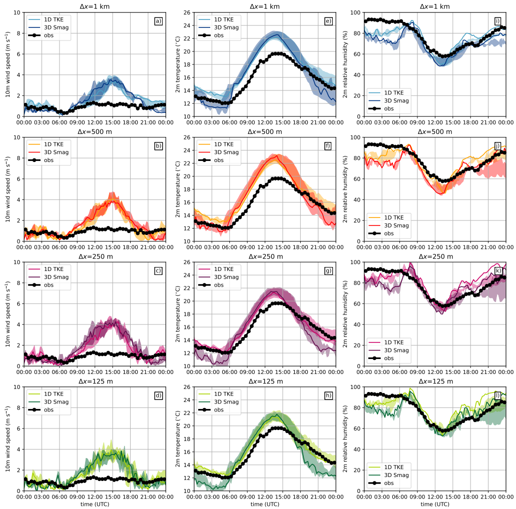
Valley boundary layer structure (20 UTC)



Averaged time series - valley floor



Averaged time series - slope



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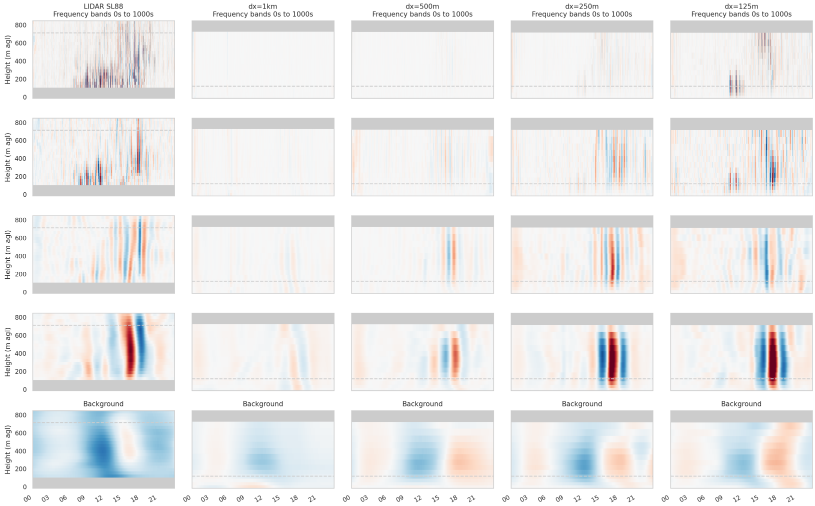
Turbulence Structure - spatiotemporal analysis



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