High Resolution Modelling of Storm Events over the complex Alpine Terrain

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6 February 2024

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Content

1. Introduction

1. Mountain Boundary Layer

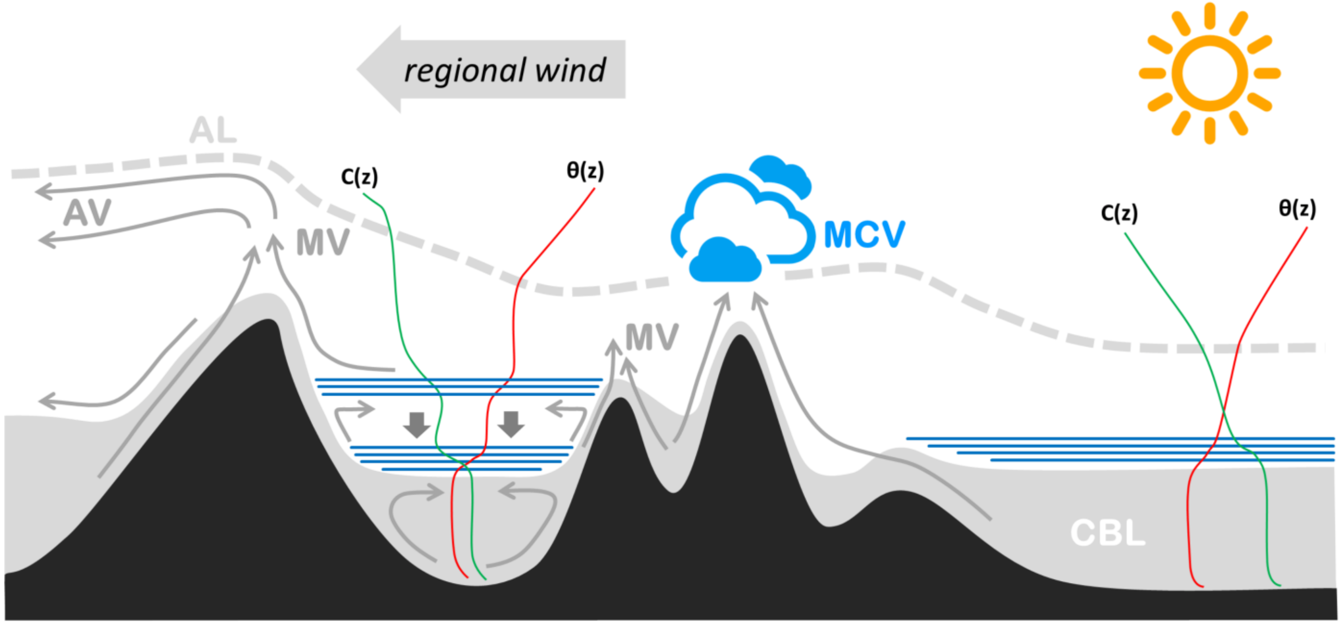
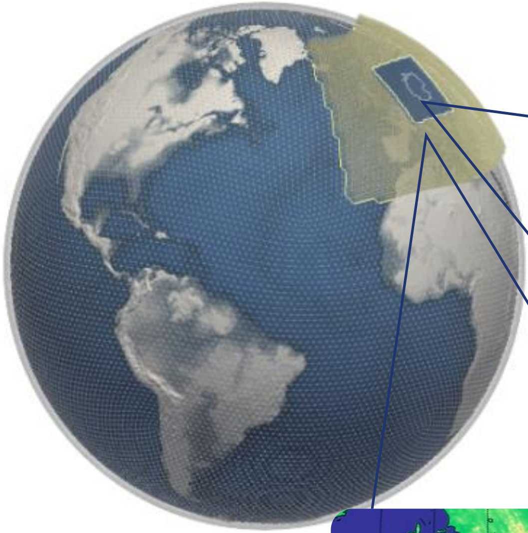


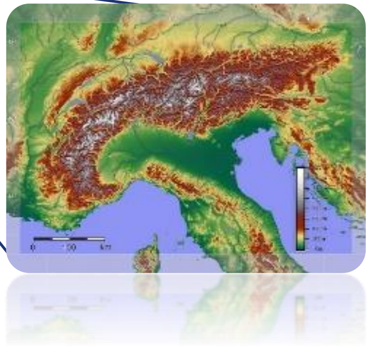
Figure 1: Schematically shown process of orographic uplift of moist air advection at rainy slope and sinking dry air mass at lee *(Sarafin 2018)*.

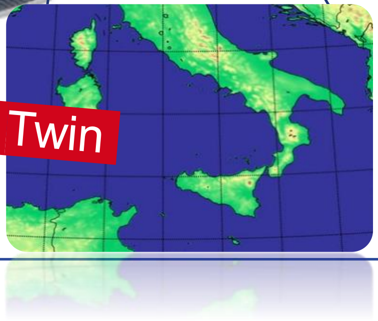
Global-to-Regional-ICON Digital Twin (GLORI)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Tri-lateral Cooperation
Germany, Italy, Switzerland







Work on the Glori Twin has started

global-to-regional short-range high resolution Digital Twin

configurable

on-demand

based on the prediction capability of the ICON earth system model and the Data Assimilation Coding Environment DACE

2. Model Setup

ICOsahedral Non-hydrostatic model (ICON)

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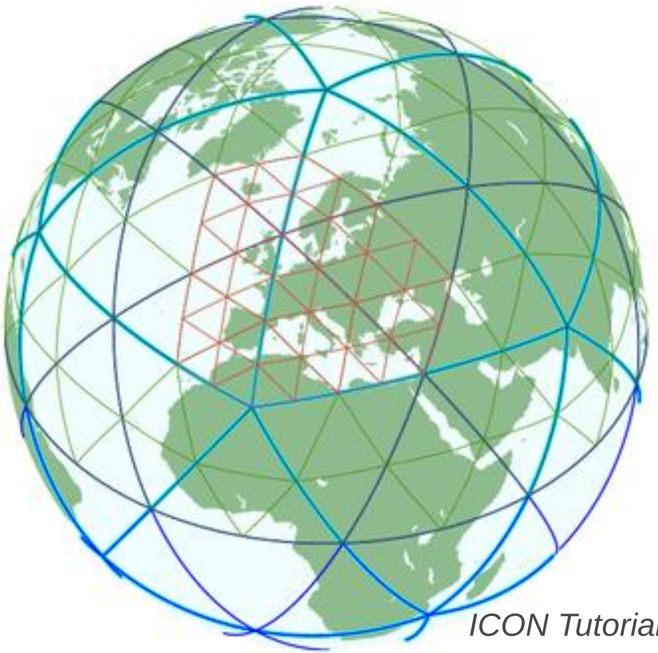

ICON Tutorial (2020)

- Fully compressible non-hydrostatic core
- Unified model system (climate & numerical weather prediction)
- From low resolution (~80 km) to high-resolution (~75 m)
- No pole problem

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2. The current Model Domain

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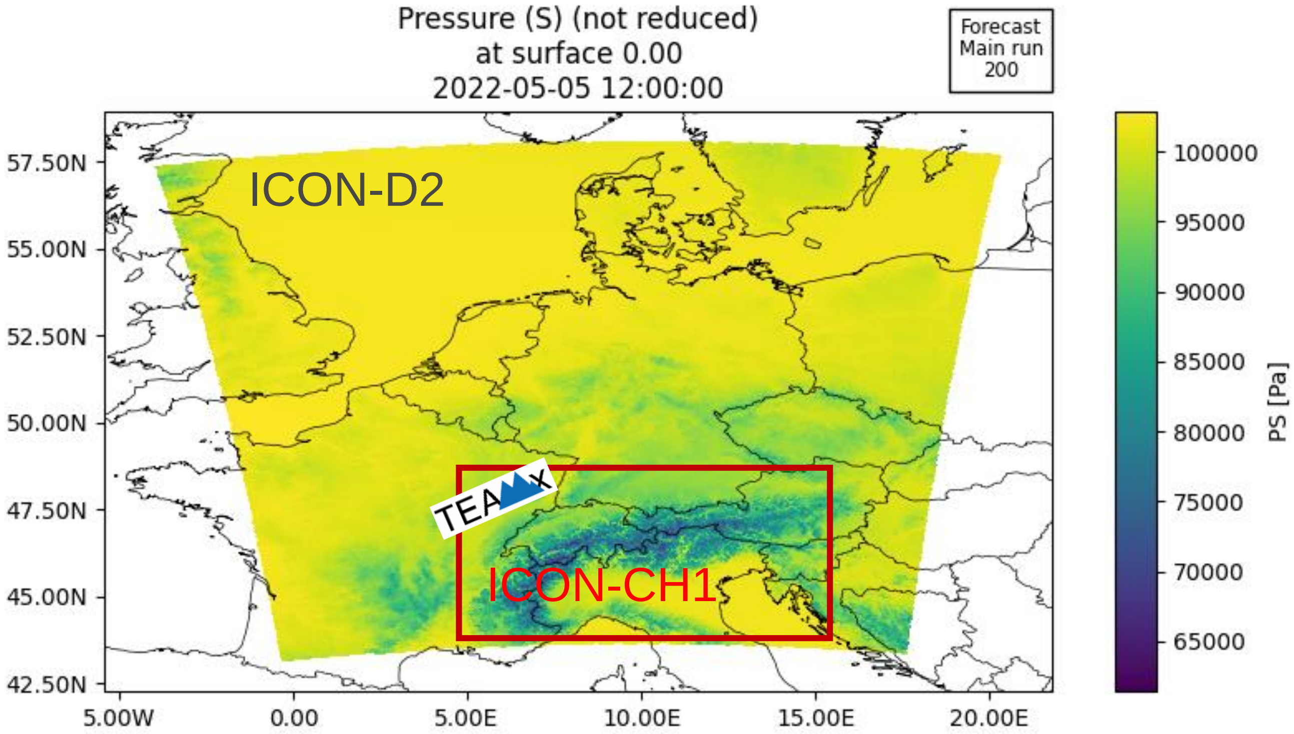

TEAMx
Multi-scale Transport and Exchange Processes in the Atmosphere over Mountains – Programme and experiment

<u>Figure:</u> Operational ICON-D2 domain, including a Nest over the Alps, the TEAMx domain ICON-CH1.

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2. Model Setup

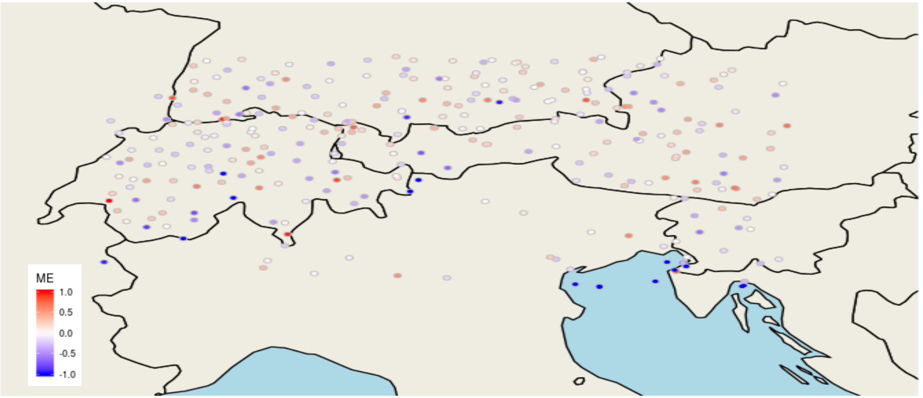

Figure 2: Meteorological stations used for the comparison to the model results. The colors show the mean error (ME) of the model for the temperature at 2m height above ground.

Model top	22 km
Vertical level	65 full (66 half)
Hor. grid scale	2 km, 1 km, 500 m*
LATBC (at start)	Analysis (ICON-EU)
Forecast restart	12 h
Duration	36 h
2-way-Nesting	
Model version 2.6.6	

** Not yet included in GLORI*

2. Modell Setup

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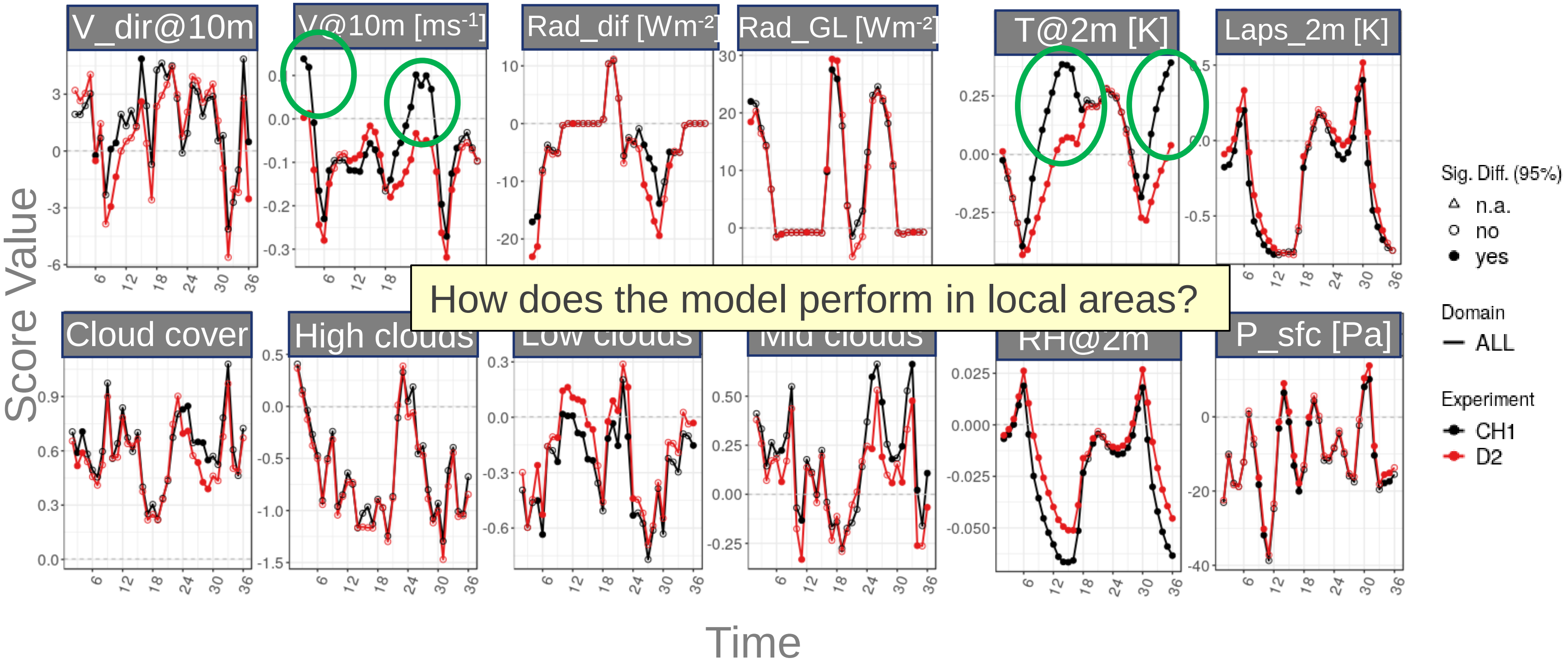
Parametrization	
Orography	Orographic gravity wave drag[1]
Mircrophysics	double-moment[2]
Turbulence	Turbdiff (TKE closure)[3]
Surface Transfer	Turbtran (TKE extension)[3]
Land Surface	TERRA[4]

1. *Lott an Miller (1997)*
2. *Seifert and Beheng (2006)*
3. *Mellor and Yamada (1982), and Raschendorfer (2001)*
4. *Schrodin and Heise (2001), Schulz et al. (2016), and Mironov et al. (2012)*

3. Experiments

3.1. Control Experiment

Mean Error for May 2022 – ICON-D2 vs. ICON-CH1



3.1. Controll Experiment: Valley stations

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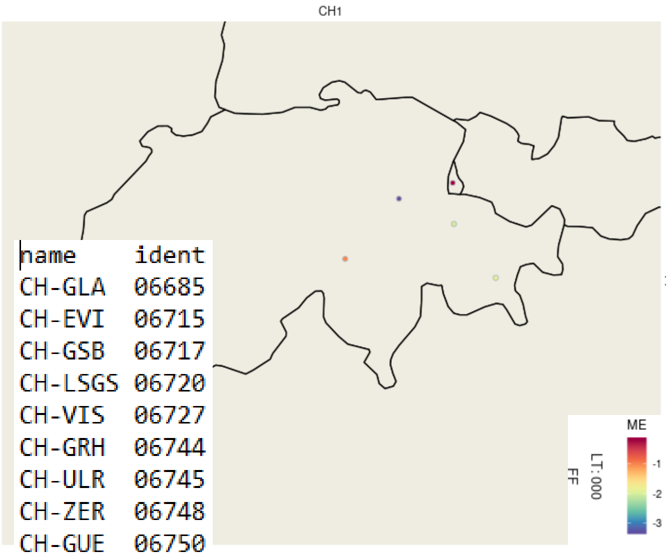
Wetter und Klima aus einer Hand

2022.05.01-01UTC - 2022.05.30-23UTC
INI: 12



name	ident
CH-GLA	06685
CH-EVI	06715
CH-GSB	06717
CH-LSGS	06720
CH-VIS	06727
CH-GRH	06744
CH-ULR	06745
CH-ZER	06748
CH-GUE	06750
CH-PIO	06753
CH-WFJ	06780
CH-CHU	06786
CH-SAM	06792
CH-VAD	06990

- High-resolution land surface data-set (2018)
  → Improving wind speed performance for large & medium valleys

atmosphere MDPI

Article

Accuracy of Simulated Diurnal Valley Winds in the Swiss Alps: Influence of Grid Resolution, Topography Filtering, and Land Surface Datasets

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Received: 23 February 2018; Accepted: 15 May 2018; Published: 18 May 2018

check for updates

- 30% more soil moisture (2023)
  → Improve performance of near-sfc wind speed in a small valley

meteorology MDPI

Article

Diurnal Valley Winds in a Deep Alpine Valley: Model Results

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* Correspondence: schmidli@iau.uni-frankfurt.de

3.1. Controll Experiment: Valley stations

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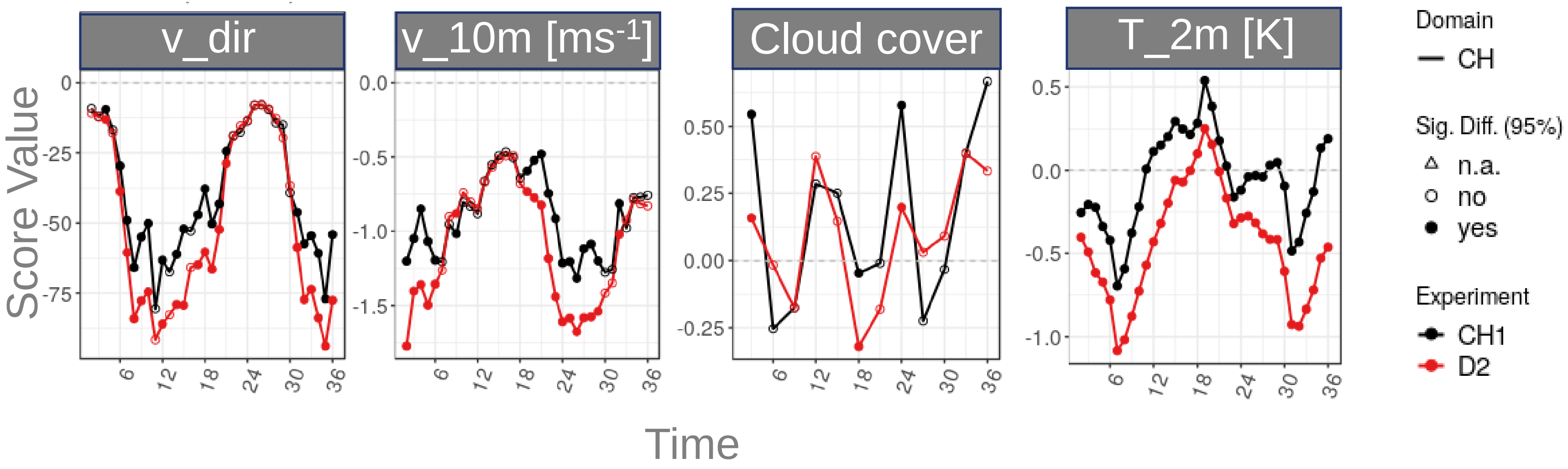
Mean Error for May 2022 – ICON-D2 vs. ICON-CH1



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3.2 Turbulence Test

Why are the results not improving?

- Hypothesis I: 3D terms are missing and become important by increasing the grid resolution

- Hypothesis II: Turbulence is now partly resolved and the parametrized turbulence need to be tuned down

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3.2. Turbulence Test - Hypothesis I

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Horizontal shear term (TKE source term):

$$q_{sh} = \underbrace{l_h^2 \sqrt{C^3 \alpha_m}} \left[\sqrt{\hat{q}_{ij}{}^2 + \hat{q}_{ij-}{}^2 + c_1^2 \hat{q}_{ij+}{}^2} - c_1 \hat{q}_{ij+} \right]^3$$

$C = 0.5$
$\alpha_m = 16.6$

$$\hat{q}_{ij} = \left(\partial_j \hat{u}_i + \partial_i \hat{u}_j\right)$$
$$\hat{q}_{ij-} = \left(\partial_i \hat{u}_i - \partial_j \hat{u}_j\right)$$
$$\hat{q}_{ij+} = \left(\partial_i \hat{u}_i + \partial_j \hat{u}_j\right)$$

$$l_h = \frac{\alpha_{hs} \, \Delta x}{Ri^{2/3}} f(q^2)$$

Boundary-Layer Meteorol (2018) 168:1–27
https://doi.org/10.1007/s10546-018-0341-y

CrossMark

RESEARCH ARTICLE

The Impact of Three-Dimensional Effects on the Simulation of Turbulence Kinetic Energy in a Major Alpine Valley

Brigitta Goger[1] · Mathias W. Rotach[1] · Alexander Gohm[1] · Oliver Fuhrer[2] · Ivana Stiperski[1] · Albert A. M. Holtslag[3]

Symbols:

C	Stability factor
α_m	Momentum variance factor
α_{hs}	Length scale factor for hori. shear
l_h	Effective horizontal length scale
Δx	Horizontal grid spacing
Ri	Gradient Richardson number
$f(q^2)$	TKE correction function

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3.2. Turbulence Test - Hypothesis I

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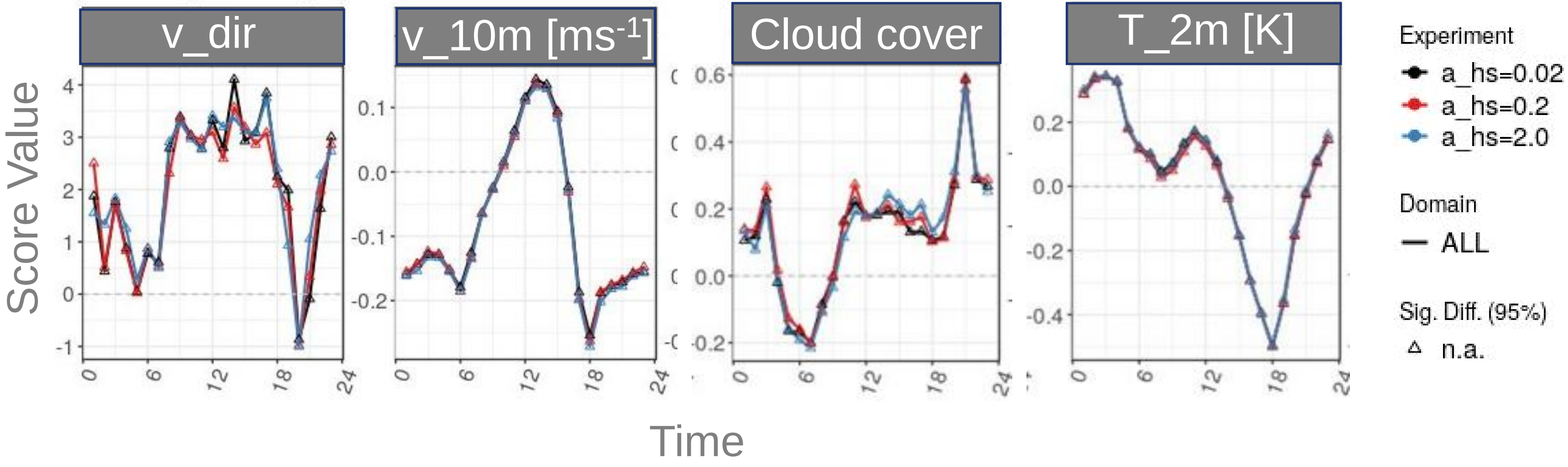
Mean Error for May 2022 – ICON-CH1



→ The adjustments in the horizontal shear term has no significant impact on ICON-CH1

3.2 Turbulence Exchange

Why are the results not improving?

- Hypothesis I: 3D terms are missing and become important by increasing the grid resolution
  → Horizontal shear term has no significant impact on ICON-CH1

- Hypothesis II: Turbulence is now partly resolved and the parametrized turbulence need to be tuned down

3.2. Turbulence Test - Hypothesis II

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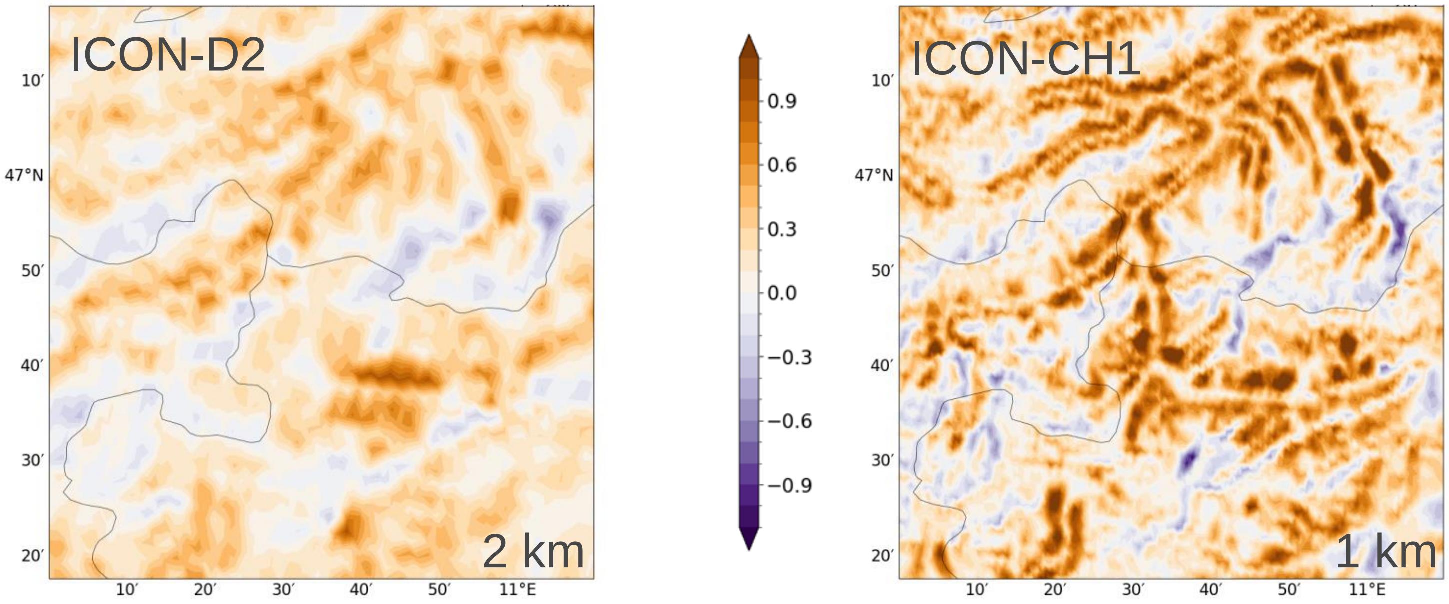
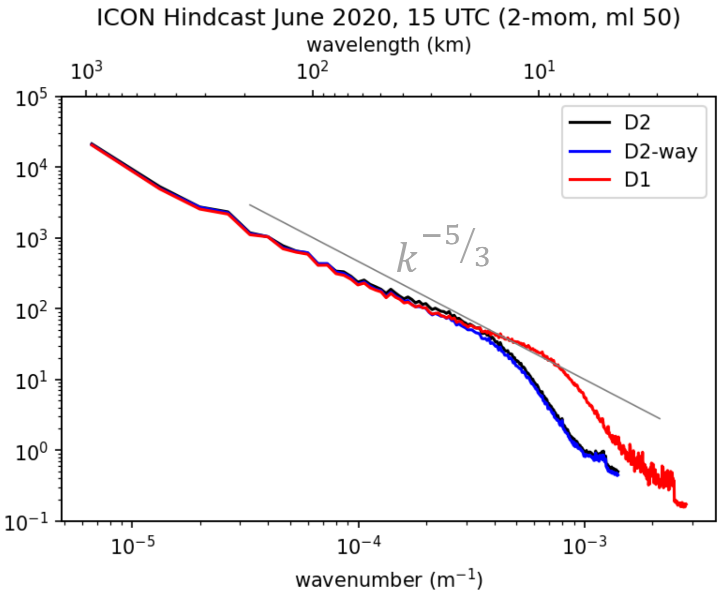
Vertical wind speed at 10m [ms^{-1}]



3.2. Turbulence Test - Hypothesis II

Calculated energy spectra from ICON-D2 and ICON-D1 for the nested domain



Credit: Philipp Zschenderlein

3.2. Turbulence Test - Hypothesis II

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With increasing horizontal resolution, more small-scale turbulence is resolved and the turbulent mixing length scale, as well as the minimum turbulent diffusion coefficient for heat need to be adjusted:

Turbulent diffusion coefficient:

$$K_h = l\, S_h \sqrt{2e}$$

Turbulent mixing length scale:

$$l = \frac{\kappa z}{1 + \frac{\kappa z}{l_0}}$$

Blackadar (1962)

Symbols:
K_h: Turb. diff. coeff., l : Turb. mix. length scale, S_h : Stability function, e: Turb. kin. Engergy, z: Height, κ: von Karman constant, l_0 :Asympt. length scale

Table 1: Overview of the namelist switches set by default (control) and the adjusted settings of the asymptotic length scale parameter (turlen), as well as the minimum value of the turbulent exchange coefficient (khmin) and without any convection scheme (noconv).

Parameter	control	turlen	khmin	noconv
l_0(m)	500	300	500	500
K_{h_min}	0.75	0.75	0.01	0.75
convection	shallow	shallow	shallow	none

3.2. Turbulence Exchange - Hypothesis II

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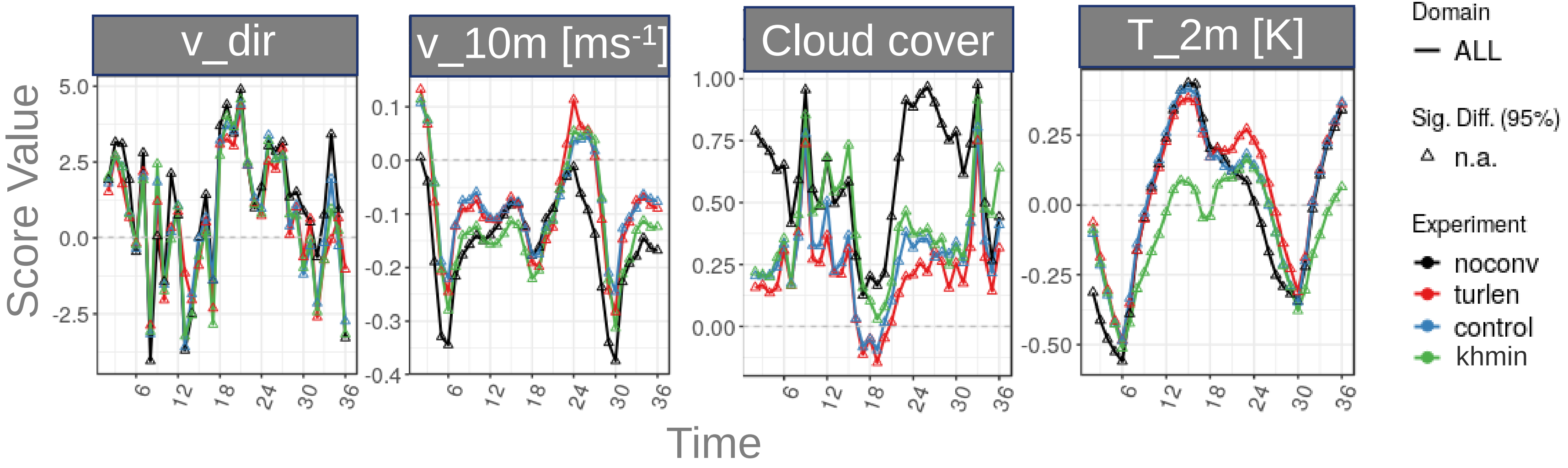
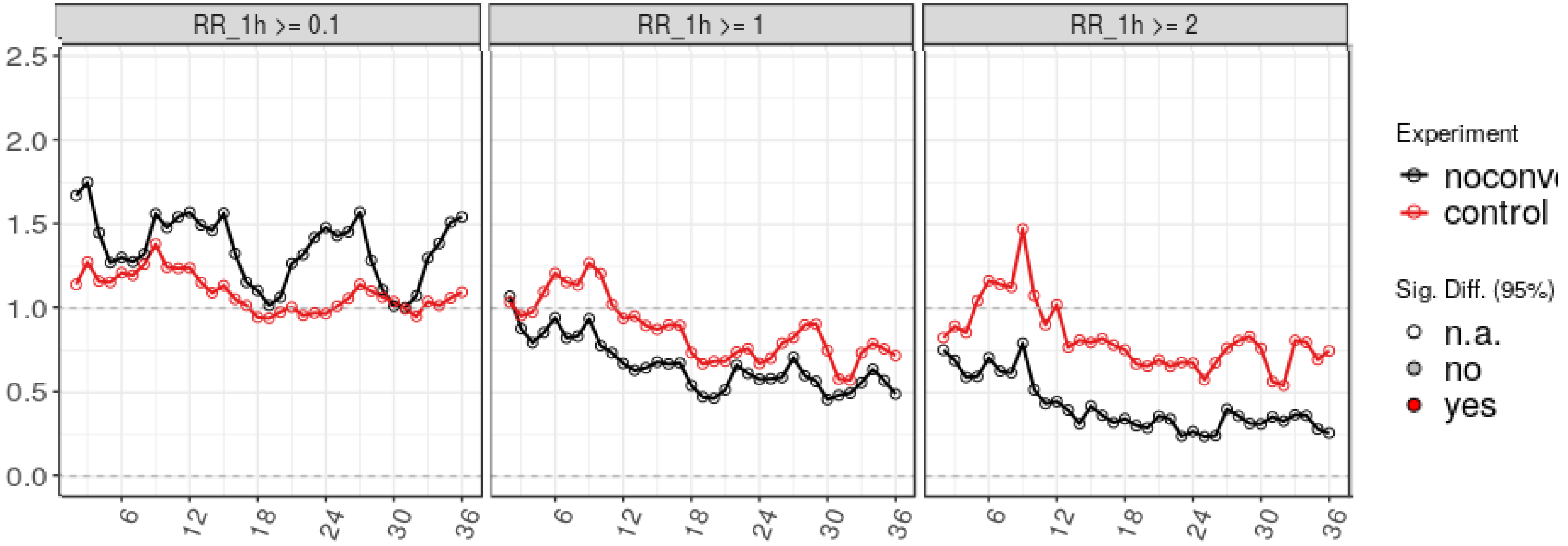
Mean Error for May 2022 – ICON-CH1



→ Low sensitivity of the turbulent mixing length scale

Bonus

Frequency Bias for May 2022 – ICON-CH1



→ Switching of the convection schemes does not improve the precipitation

4. Summary

4. Summary

- With increasing resolution small-scale processes are getting resolved
  → Bias of the near surface temperature and of wind speed increase
- Changes in the TKE length scale parameter have no significant impact
- Using no convection scheme shows larger bias in the precipitation
  → Low sensitivity of the model
- More suficticated changes in horizontal shear needed?
  →Implementation of Leonard-Term?

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Daniela Littmann

Appendix

A.1. Turbulent Kinetic Energy (TKE)

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$$\frac{d}{dt}\frac{q^2}{2} = -K_{\mathrm{h}}\frac{g}{\theta}\frac{\partial\theta}{\partial z} + K_{\mathrm{m}}\left[\left(\frac{\partial\hat{v}_i}{\partial z}\right)^2 + \left(\frac{\partial\hat{v}_j}{\partial z}\right)^2\right] + \frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\left[\alpha\bar{\rho}lq\frac{\partial}{\partial z}\left(\frac{q^2}{2}\right)\right] - \frac{q^3}{B_1 l} + q_{\mathrm{sh}}.$$

tendency | *buoyancy* | *vertical shear production* | *turbulent transport* | *dissipation* | *horizontal shear* (q_{sh})

turbulent velocity scale $q := \sqrt{2e}$.

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A.2. Cloud cover (800 hPa) in ICON-CH1

5. May 2022 – 20 h