ICON: current status of development

Günther Zängl

and the ICON development tean

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Outline

- General overview of ICON and its current development status
- Special measures taken to cope with steep slopes
- Results for idealized tests for resting atmosphere and orographic gravity waves

ICON = ICOsahedral Nonhydrostatic model

- **Joint development project of DWD and Max-Planck-Institute for Meteorology for the next-generation global NWP and climate modeling system**
- **Nonhydrostatic dynamical core for triangles and hexagons as primal grid; C-grid discretization; coupling with physics parameterizations almost completed**
- **Two-way nesting for triangles as primal grid, capability for multiple nests per nesting level; vertical nesting, one-way nesting mode and limited-area mode are also available**
- **Positive-definite tracer advection scheme (Miura) with 2nd-order or 3rd-order accuracy, 2nd-order MUSCL and 3rd-order PPM for vertical advection**

Max-Planck-Institut für Meteorologie

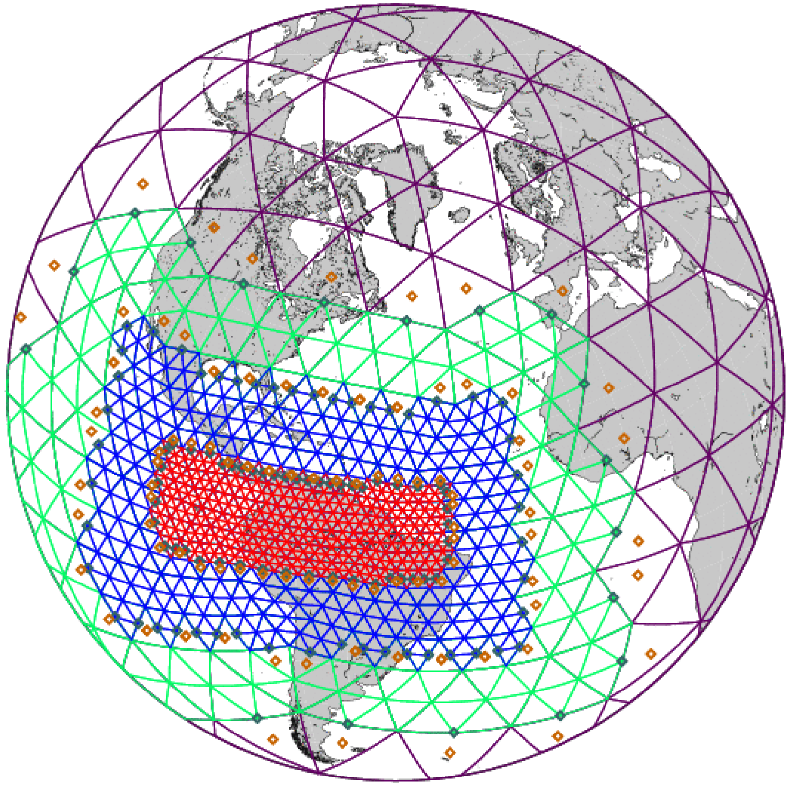
Project teams at DWD and MPI-M

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

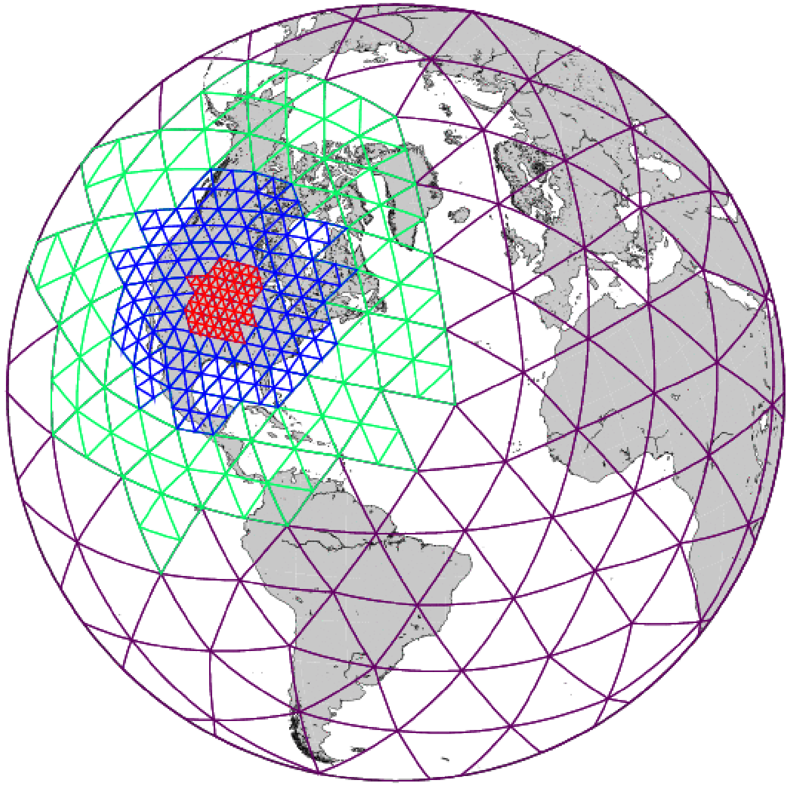
G. Zängl	**Project leader DWD (since 06/2010)** two-way nesting, parallelization, optimization, numerics	***M. Giorgetta***	**Project leader MPI-M**
D. Majewski	**Project leader DWD (till 05/2010)**	*M. Esch*	software maintenance
H. Asensio	external parameters	*A. Gaßmann*	NH-equations, numerics
M. Baldauf	NH-equation set	*P. Korn*	ocean model
K. Fröhlich	physics parameterizations	*L. Kornblueh*	software design, hpc
M. Köhler	physics parameterizations	*L. Linardakis*	parallelization, grid generators
D. Liermann	post processing, preprocessing IFS2ICON	*S. Lorenz*	ocean model
D. Reinert	advection schemes	*C. Mosley*	regionalization
P. Ripodas	test cases, power spectra	*R. Müller*	pre- and postprocessing
B. Ritter	physics parameterizations	*T. Raddatz*	external parameters
A. Seifert	cloud microphysics	*F. Rauser*	adjoint version of the SWM
U. Schättler	software design	*W. Sauf*	Automated testing (Buildbot)
MetBw		*U. Schulzweida*	external post processing (CDO)
T. Reinhardt	physics parameterizations	*H. Wan*	3D hydrostatic model version

External: *R. Johanni*: MPI-Parallelization

Grid structure with nested domains



latitude-longitude windows



circular windows

Nonhydrostatic equation system

$$\frac{\partial v_n}{\partial t} + (\zeta + f) v_t + \frac{\partial K}{\partial n} + w \frac{\partial v_n}{\partial z} = -c_{pd} \theta_v \frac{\partial \pi}{\partial n}$$

$$\frac{\partial w}{\partial t} + \nabla \cdot (\vec{v}_n w) - w \nabla \cdot \vec{v}_n + w \frac{\partial w}{\partial z} = -c_{pd} \theta_v \frac{\partial \pi}{\partial z} - g$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\vec{v} \rho) = 0$$

$$\frac{\partial \rho \theta_v}{\partial t} + \nabla \cdot (\vec{v} \rho \theta_v) = 0$$

v_n,w: normal/vertical velocity component

ρ: density

θ_v: Virtual potential temperature

K: horizontal kinetic energy

ζ: vertical vorticity component

π: Exner function

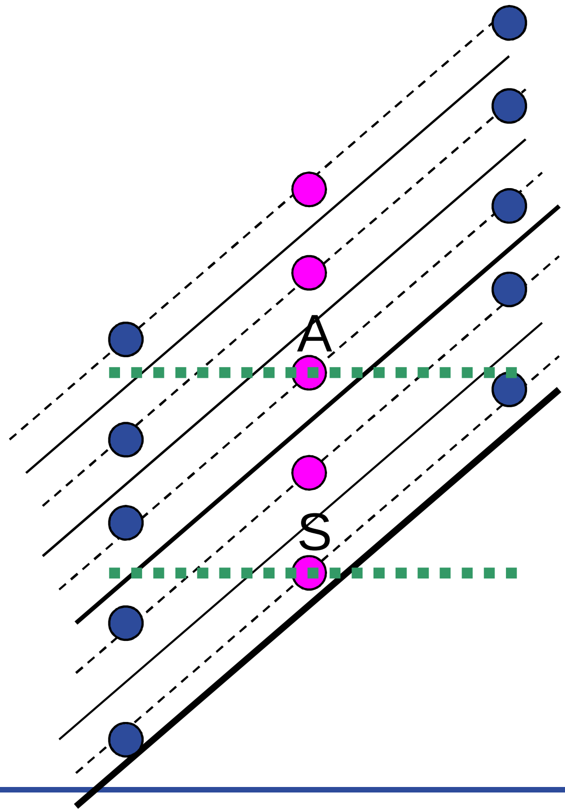
blue: independent prognostic variables

Numerical implementation

- **Momentum equation: Rotational form for horizontal momentum advection (2D Lamb transformation), advective form for vertical advection, conservative advective form for vertical wind equation**
- **Flux form for continuity equation and thermodynamic equation; Miura scheme (centered differences) for horizontal (vertical) flux reconstruction**
- **implicit treatment of vertically propagating sound waves, but explicit time-integration in the horizontal (at sound wave time step; not split-explicit)**
- **Two-time-level Matsuno-type time stepping scheme**
- **Mass conservation and tracer mass consistency**
- **Option for truly horizontal temperature diffusion over steep slopes**

Discretization of horizontal pressure gradient
(apart from conventional method)

- **Precompute for each edge (velocity) point at level the grid layers into which the edge point would fall in the two adjacent cells**



dashed lines: main levels
pink: edge (velocity) points
blue: cell (mass) points

Discretization of horizontal pressure gradient

- **Reconstruct the Exner function at the mass points using a quadratic Taylor expansion, starting from the point lying in the model layer closest to the edge point**

$$\tilde{\pi}_c = \pi_c + \frac{\partial \pi_c}{\partial z}(z_e - z_c) + \frac{1}{2}\frac{g}{c_p \theta_v^2}\frac{\partial \theta_v}{\partial z}(z_e - z_c)^2$$

- **Note: the quadratic term has been approximated using the hydrostatic equation to avoid computing a second derivative**
- **Treatment at slope points where the surface is intersected:**

$$\left.\frac{\partial \pi}{\partial x}\right|_S = \left.\frac{\partial \pi}{\partial x}\right|_A + \frac{g}{c_p \theta_v^2}\left.\frac{\partial \theta_v}{\partial x}\right|_A (z_S - z_A)$$

Test case

- Isolated circular Gaussian mountain, e-folding width 2000 m, various mountain heights (see subsequent slides)
- Isothermal atmosphere at rest or with u_0 = 20 m/s
- Horizontal mesh size ≈ 300 m
- 50 vertical levels, top at 40 km, gravity-wave damping layer starts at 27.5 km
- dry dynamical core with turbulence scheme for vertical mixing
- Results are shown after 6 h of integration time

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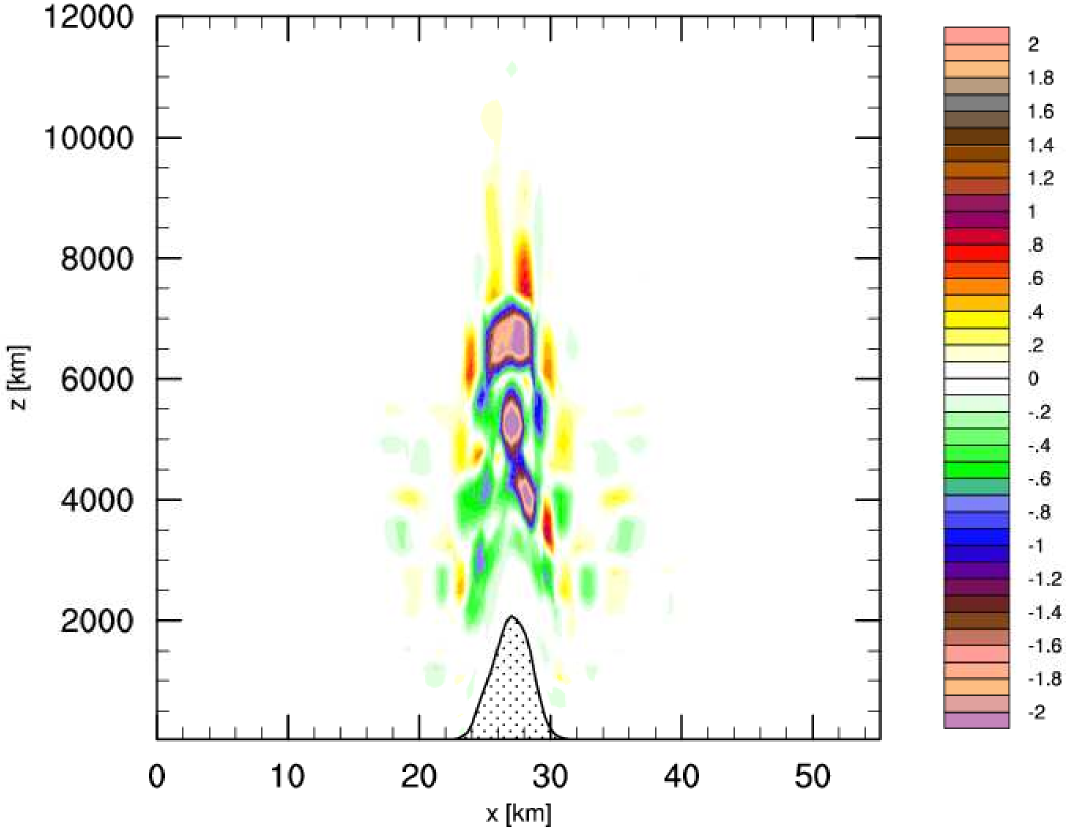
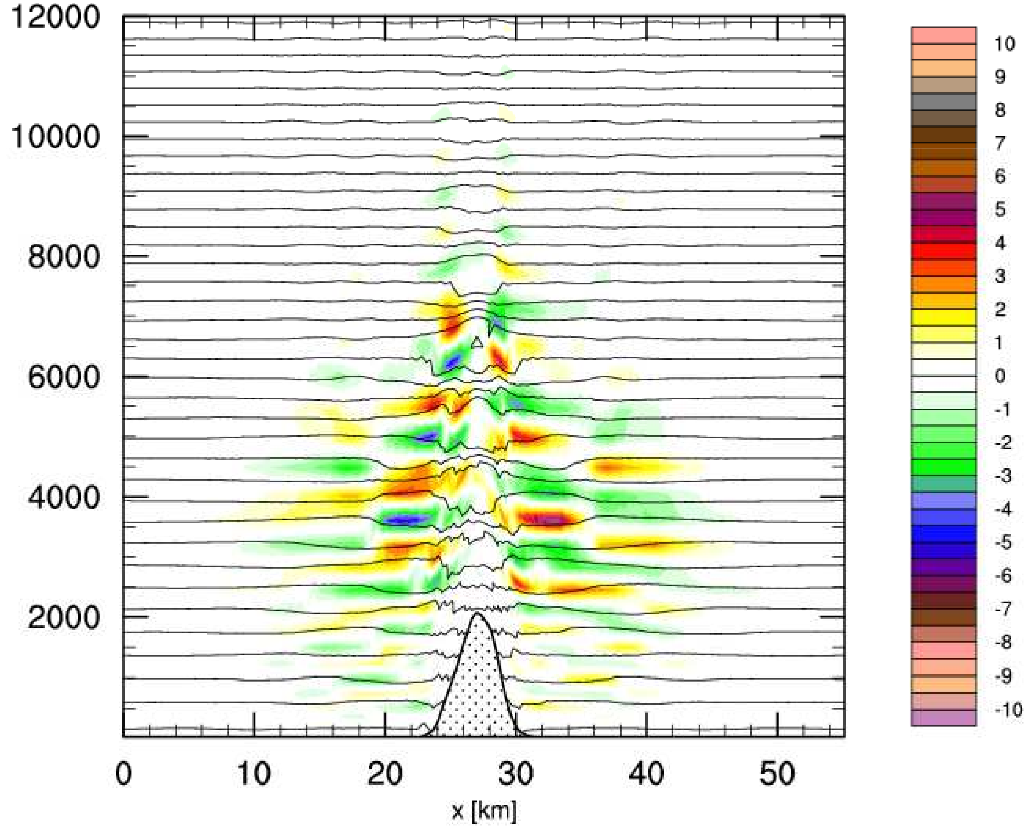
conventional pressure gradient discretization, no z-diffusion of temperature



vertical wind speed (m/s)

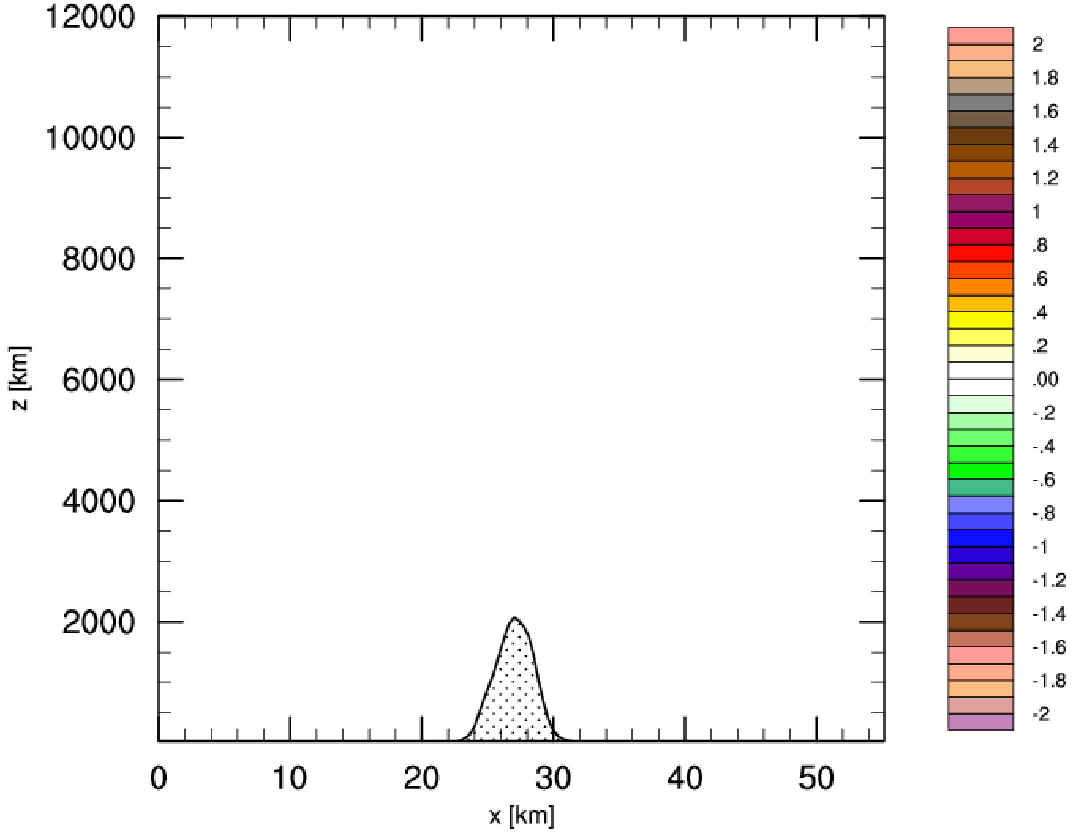


potential temp. (c.i. 4 K), hor. wind speed (m/s)

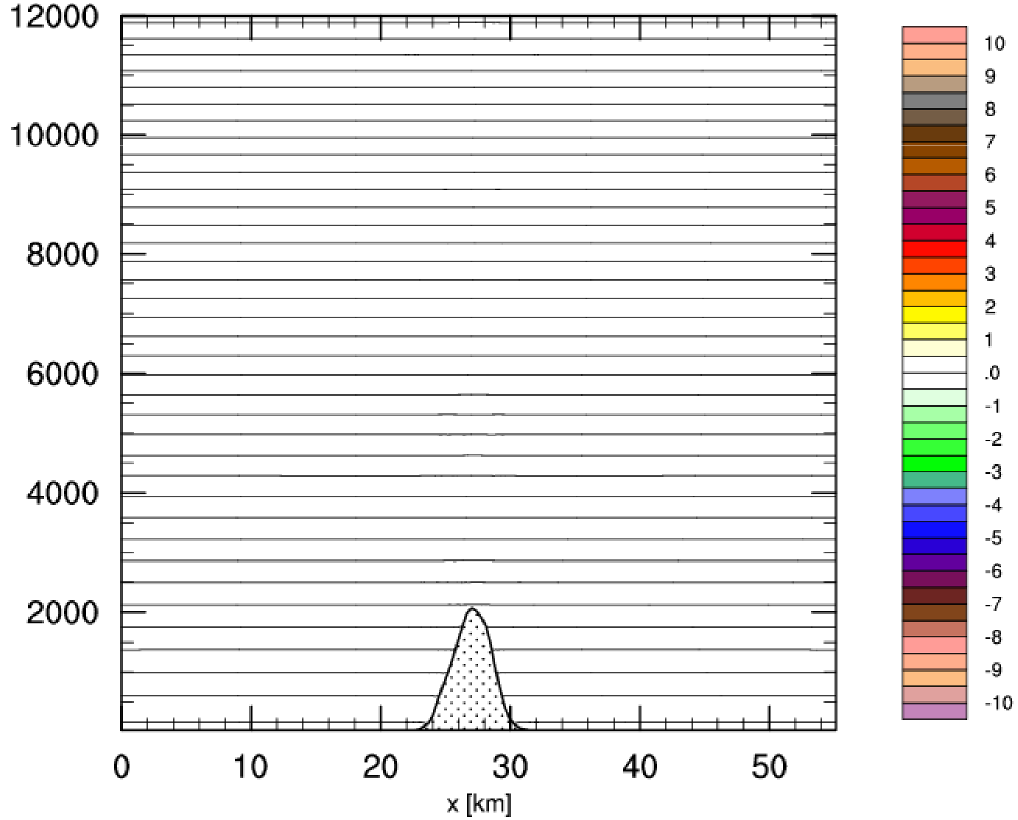
mountain height: 2.25 km, isothermal atmosphere at rest

maximum slope 0.95 (43.5°)

conventional pressure gradient discretization, with z-diffusion of temperature



vertical wind speed (m/s)



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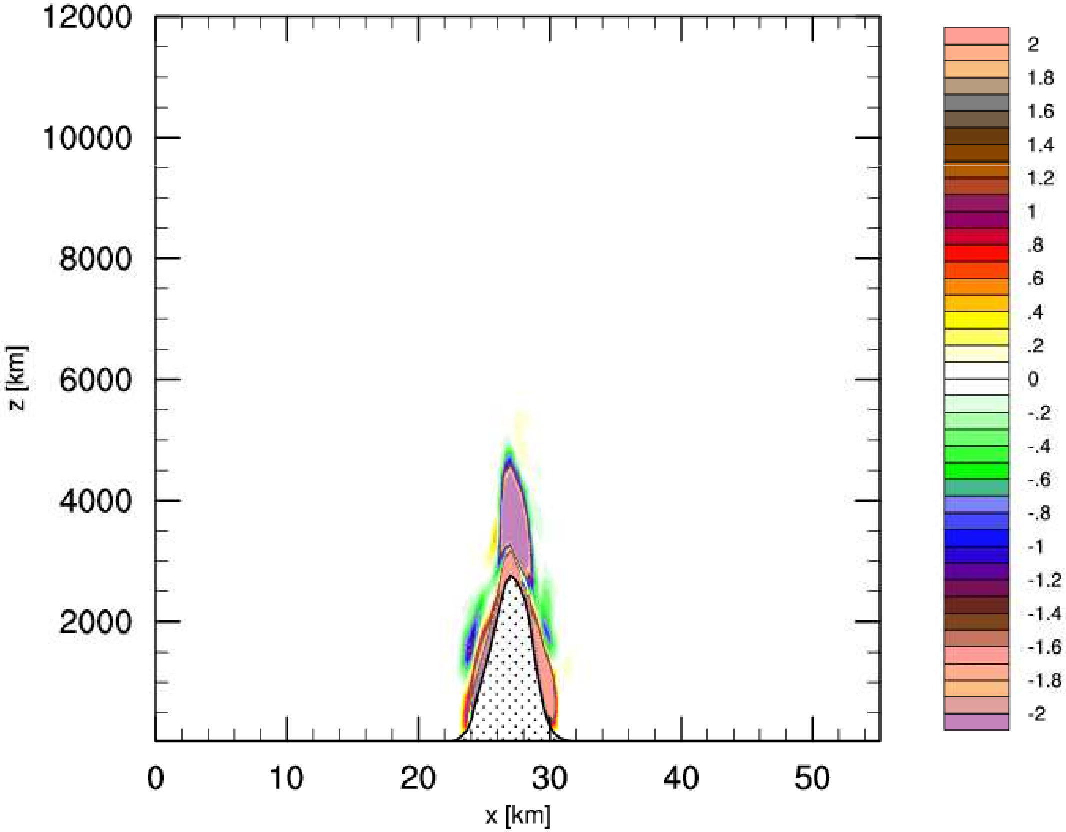
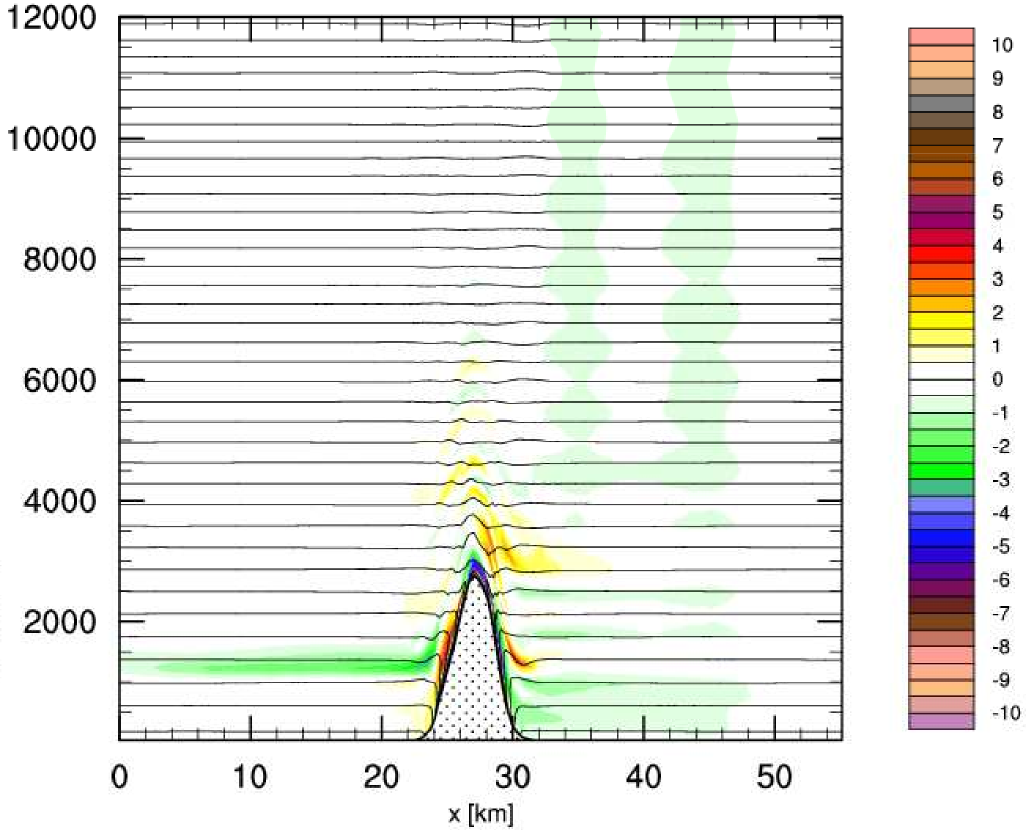


vertical wind speed (m/s)

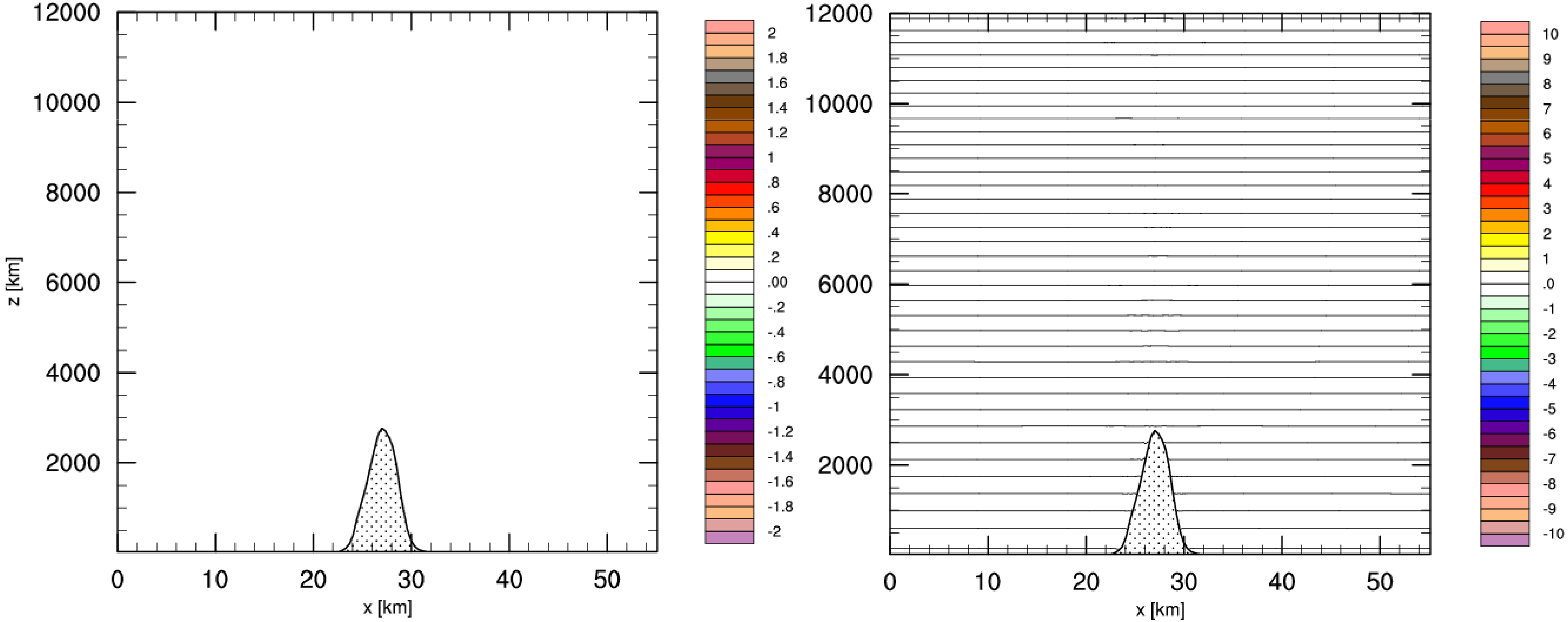


potential temp. (c.i. 4 K), hor. wind speed (m/s)

mountain height: 3.0 km, isothermal atmosphere at rest

maximum slope 1.27 (52°)

z-based pressure gradient discretization, and z-diffusion of temperature



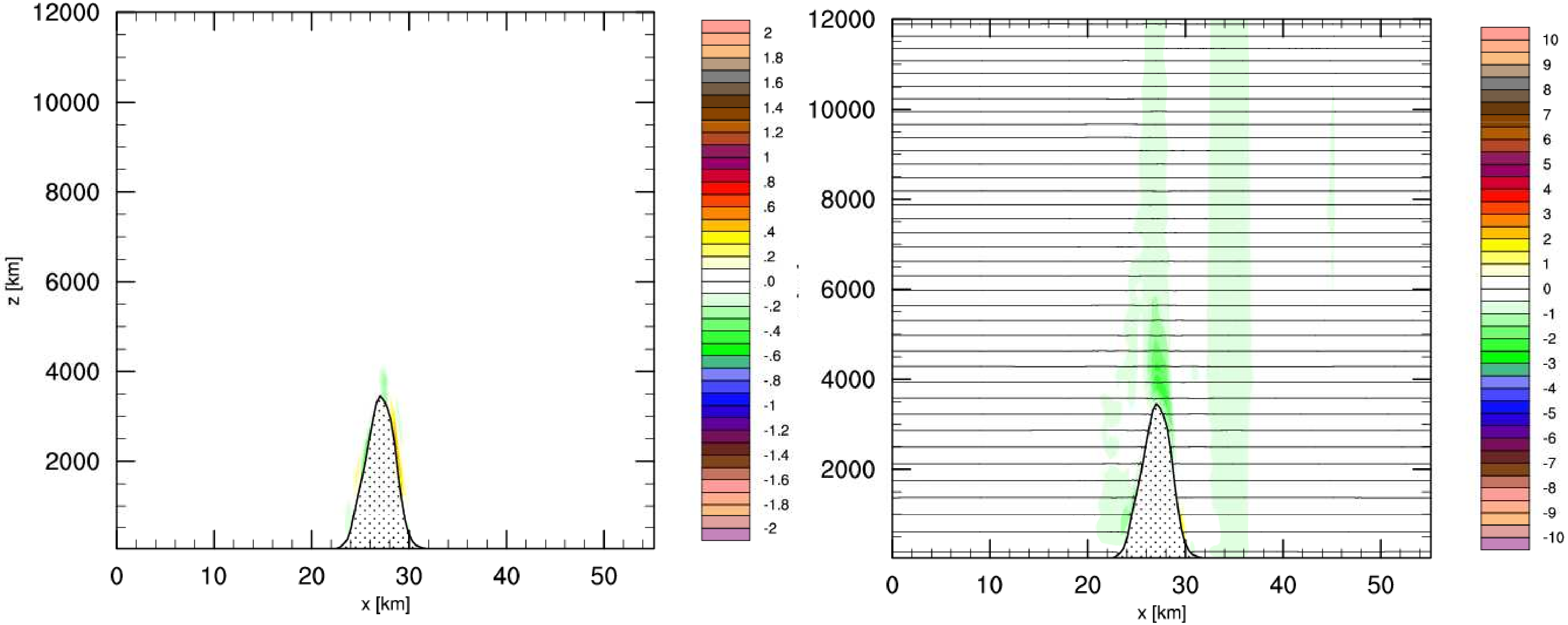
vertical wind speed (m/s)

potential temp. (c.i. 4 K), hor. wind speed (m/s)

mountain height: 3.0 km, isothermal atmosphere at rest

maximum slope 1.27 (52°)

z-based pressure gradient discretization, and z-diffusion of temperature

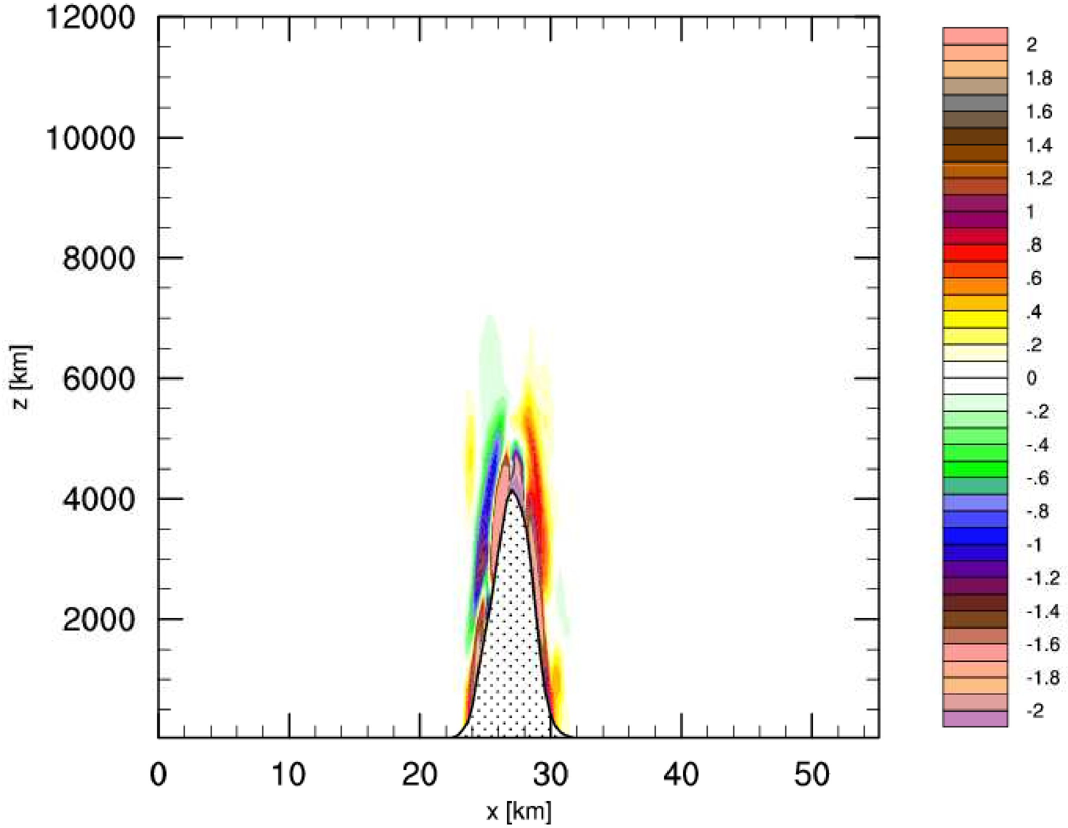


vertical wind speed (m/s) **potential temp. (c.i. 4 K), hor. wind speed (m/s)**

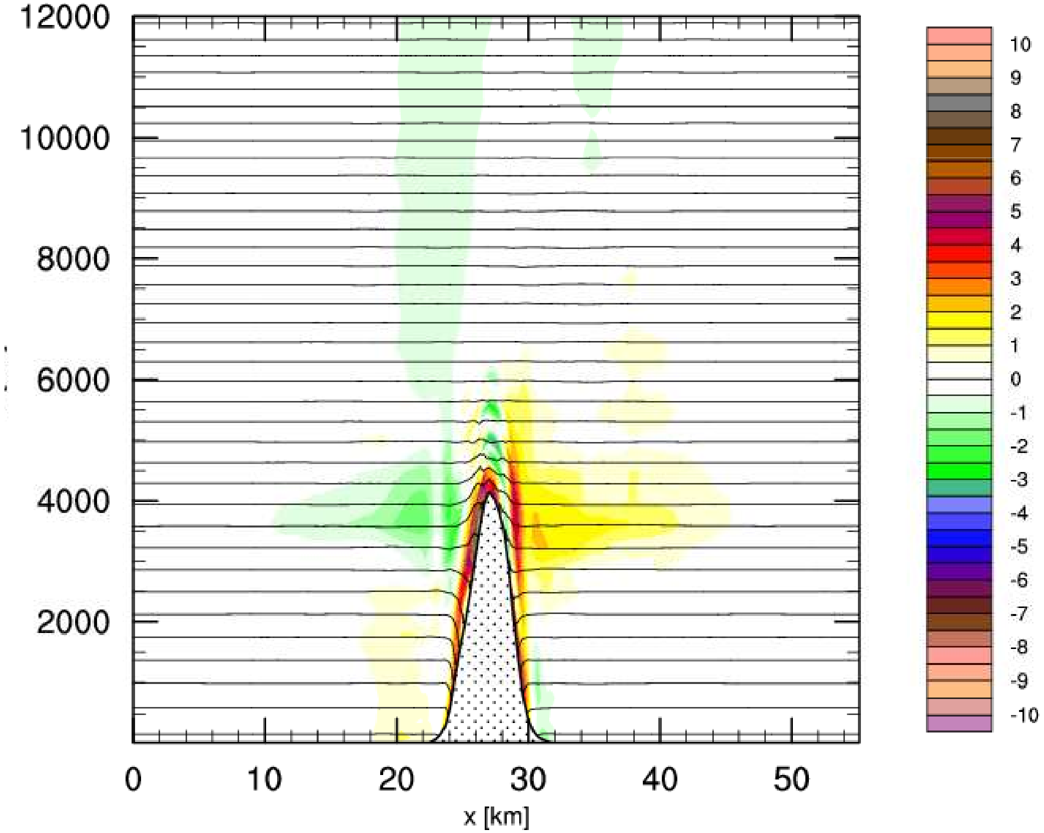
mountain height: 3.75 km, isothermal atmosphere at rest

maximum slope 1.59 (58°)

z-based pressure gradient discretization, and z-diffusion of temperature



vertical wind speed (m/s)

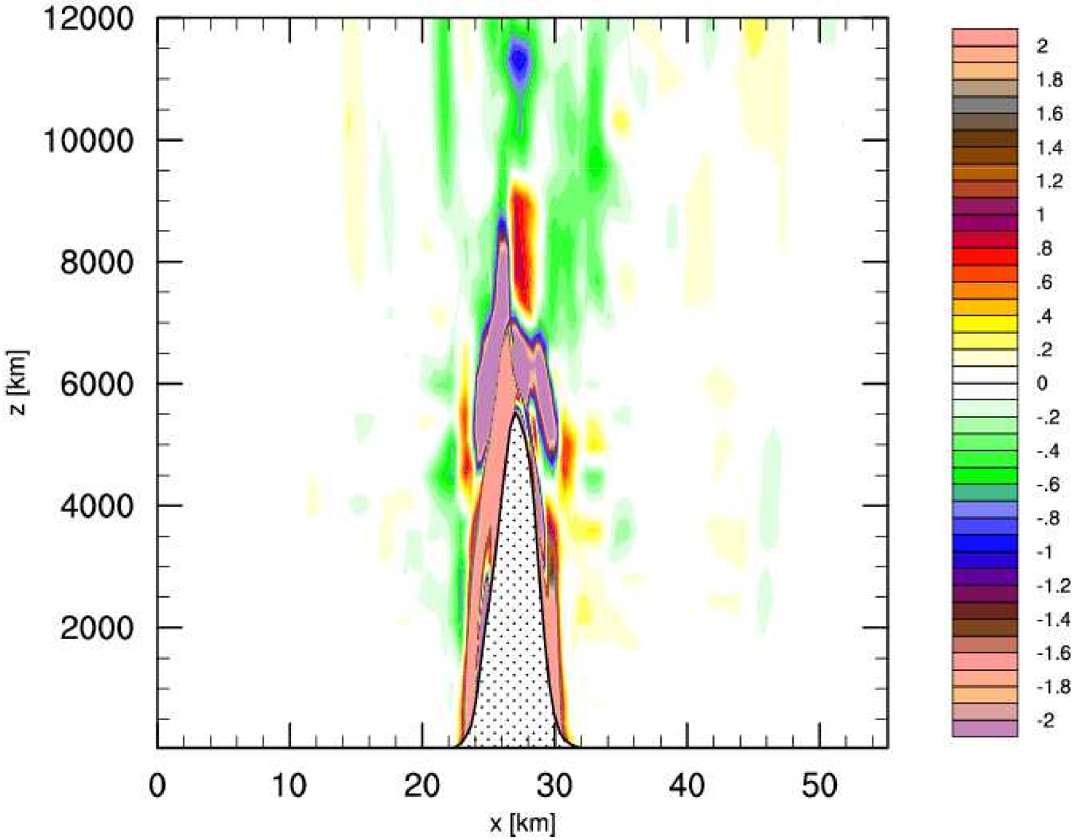


potential temp. (c.i. 4 K), hor. wind speed (m/s)

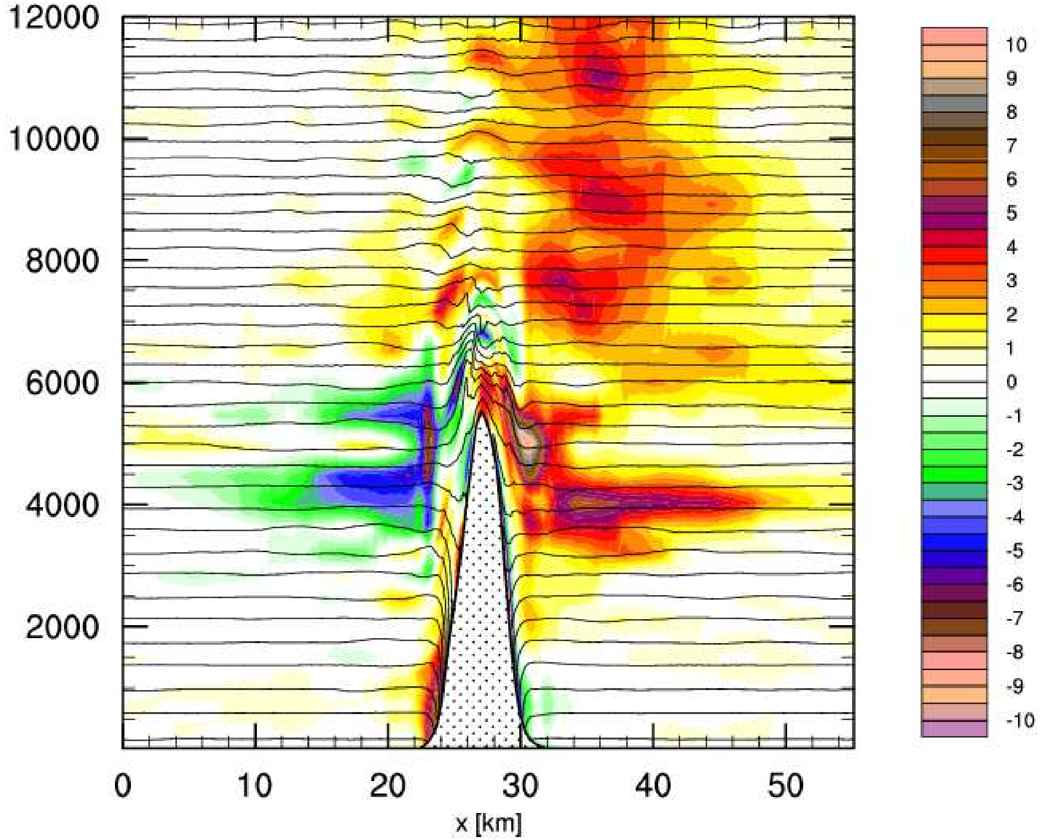
mountain height: 4.5 km, isothermal atmosphere at rest

maximum slope 1.90 (62°)

z-based pressure gradient discretization, and z-diffusion of temperature



vertical wind speed (m/s)

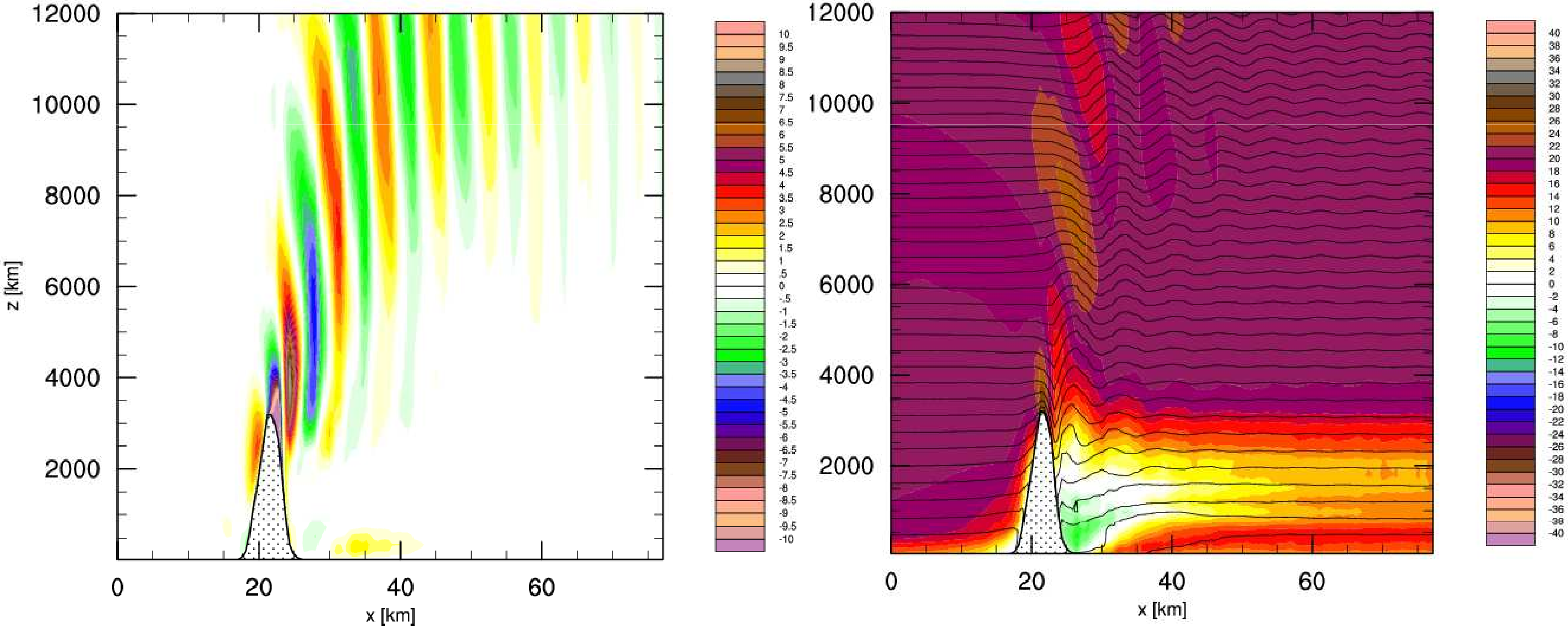


potential temp. (c.i. 4 K), hor. wind speed (m/s)

mountain height: 6.0 km, isothermal atmosphere at rest

maximum slope 2.54 (69°)

z-based pressure gradient discretization, and z-diffusion of temperature

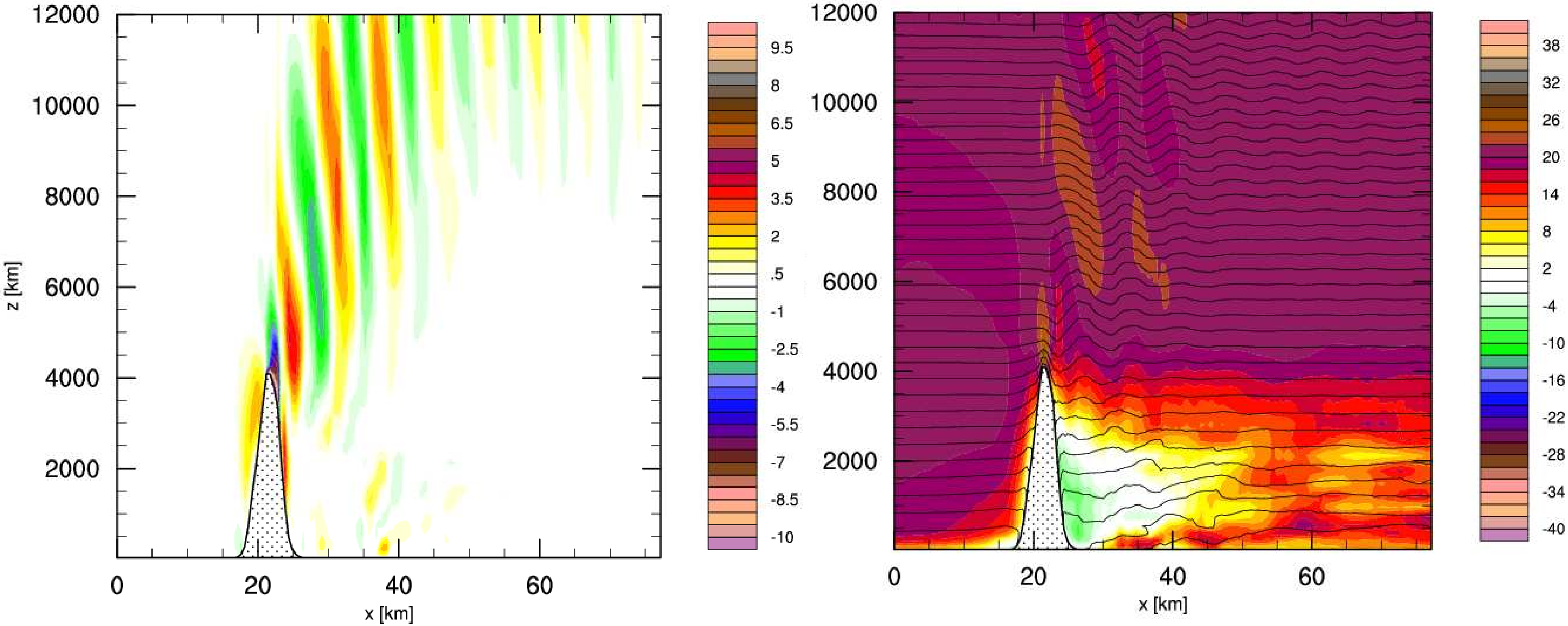


vertical wind speed (m/s) **potential temp. (c.i. 4 K), hor. wind speed (m/s)**

mountain height: 3.5 km, isothermal atmosphere with u_0 = 20 m/s

maximum slope 1.49 (56°)

z-based pressure gradient discretization, and z-diffusion of temperature

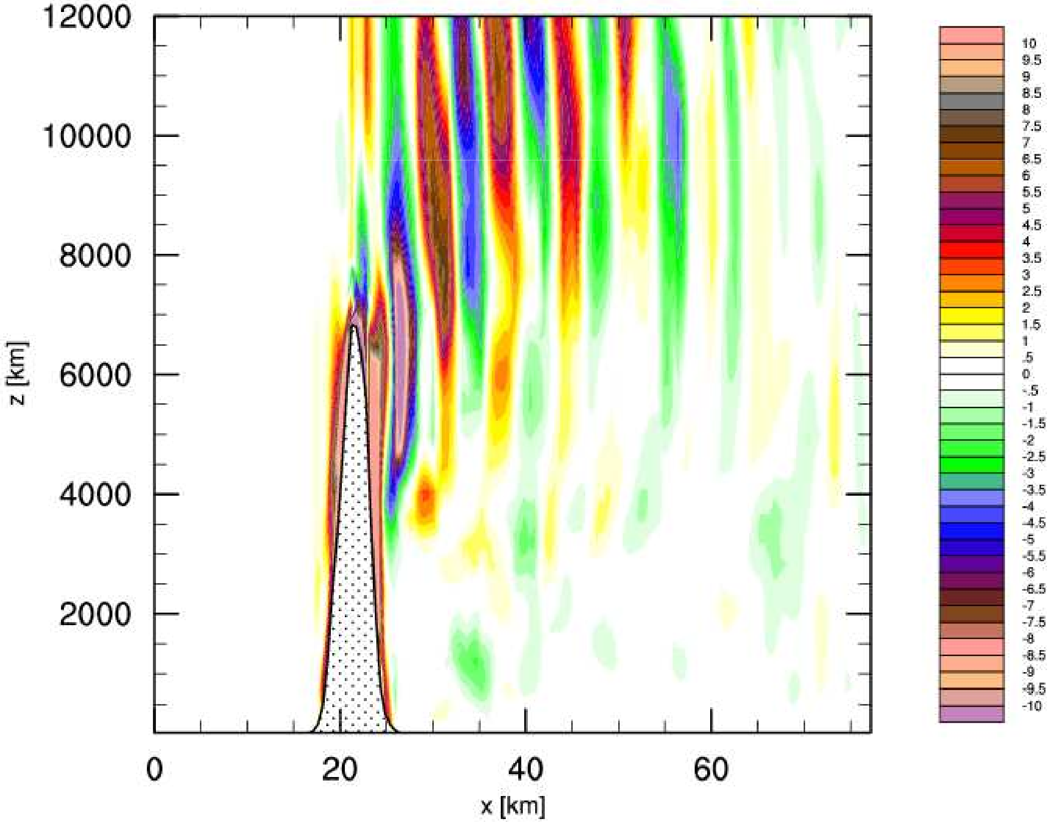


vertical wind speed (m/s) **potential temp. (c.i. 4 K), hor. wind speed (m/s)**

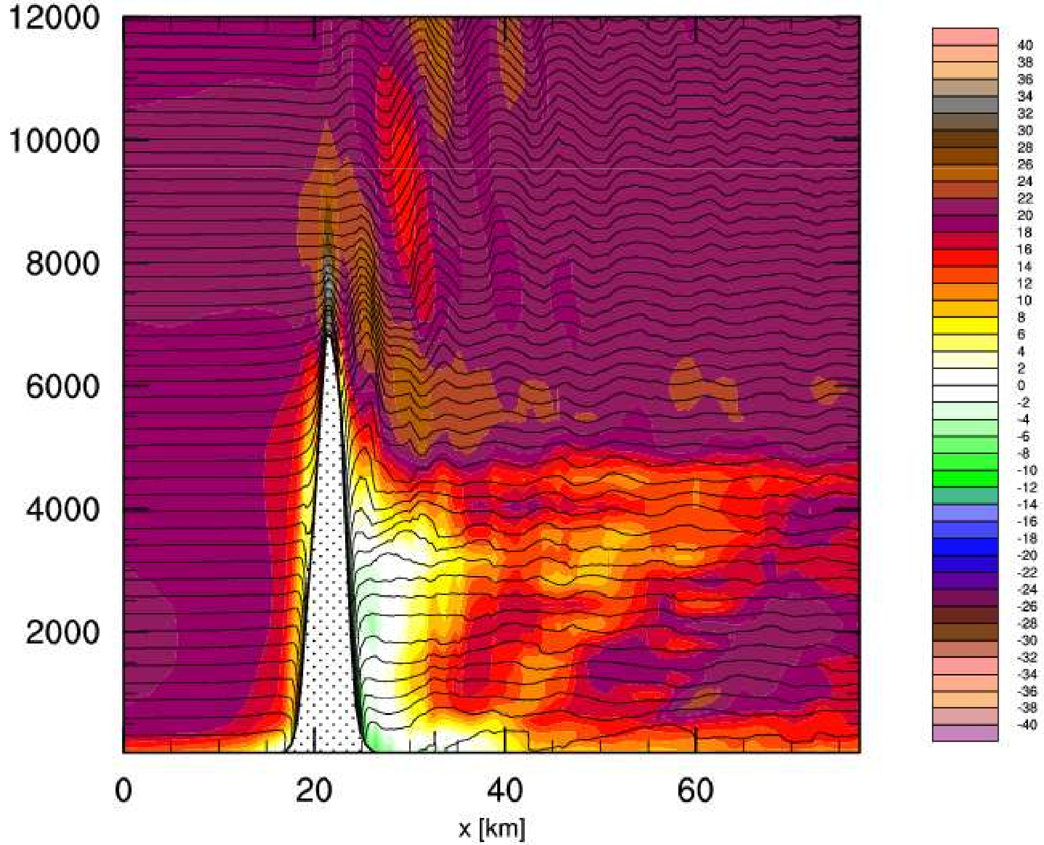
mountain height: 4.5 km, isothermal atmosphere with u_0 = 20 m/s

maximum slope 1.90 (62°)

z-based pressure gradient discretization, and z-diffusion of temperature



vertical wind speed (m/s)



potential temp. (c.i. 4 K), hor. wind speed (m/s)

mountain height: 7.5 km, isothermal atmosphere with u_0 = 20 m/s

maximum slope 3.18 (73°)

Conclusion

ICON is being primarily developed for global NWP and climate modeling

but

- **it can also be used as a limited-area model at truly nonhydrostatic scales**

and

- **it can handle significantly steeper orography than most presently available mesoscale models**

For slope angles exceeding 60°, we will probably have to move to a z-coordinate system