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Evaluation of the transition to deep convection in COSMO-1 using Large Eddy Simulations

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Acknowledgments: Anne Roches, Dani Lüthi, Christoph Schär, Uli Blahak and the COSMO-1 team

18 March 2014

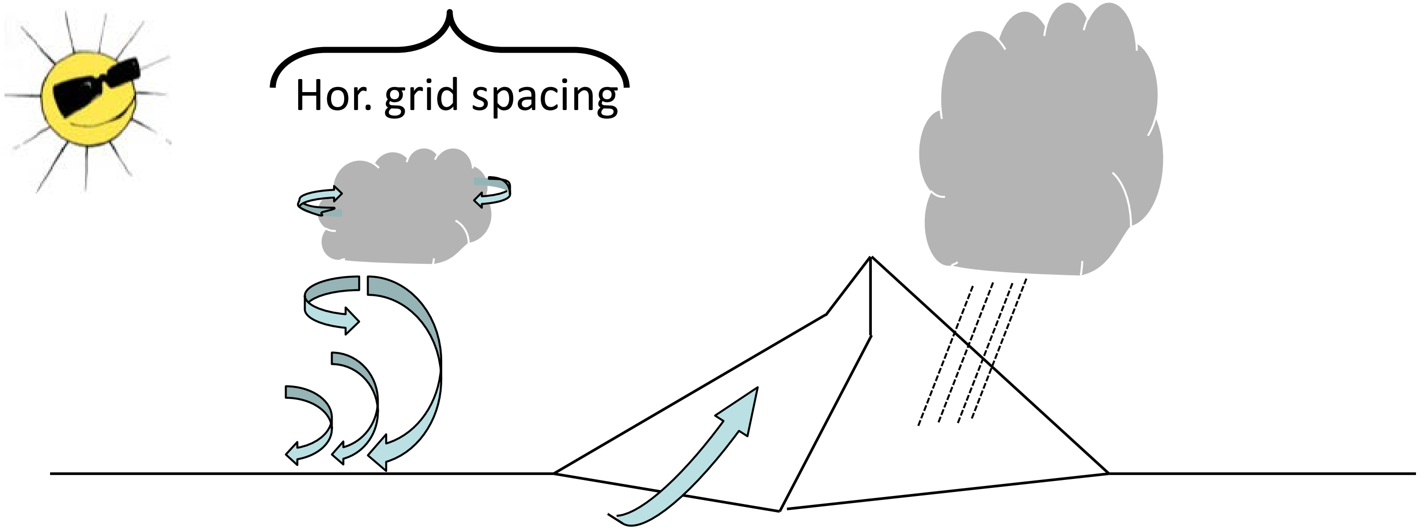
Idealized studies within Turb-i-Sim

- Using COSMO for LES of moist convection
- Shallow cumulus convection at the kilometer-scale resolution
- Influence of topography: some preliminary results
- Toward deep convective cases

Photo: Horia Varlan

Motivation

- Numerical Weather Prediction moving towards the kilometer-scale
- What is in the “grey zone”: shallow convection, slope flows, valley winds, BL-turbulence, mixing between deep convective clouds and their environment

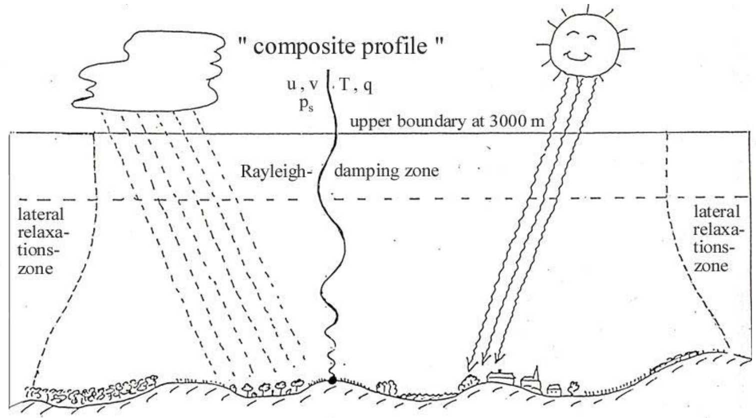


- Focus: shallow convection and triggering of deep convection
- Idealized framework to develop and test new ideas

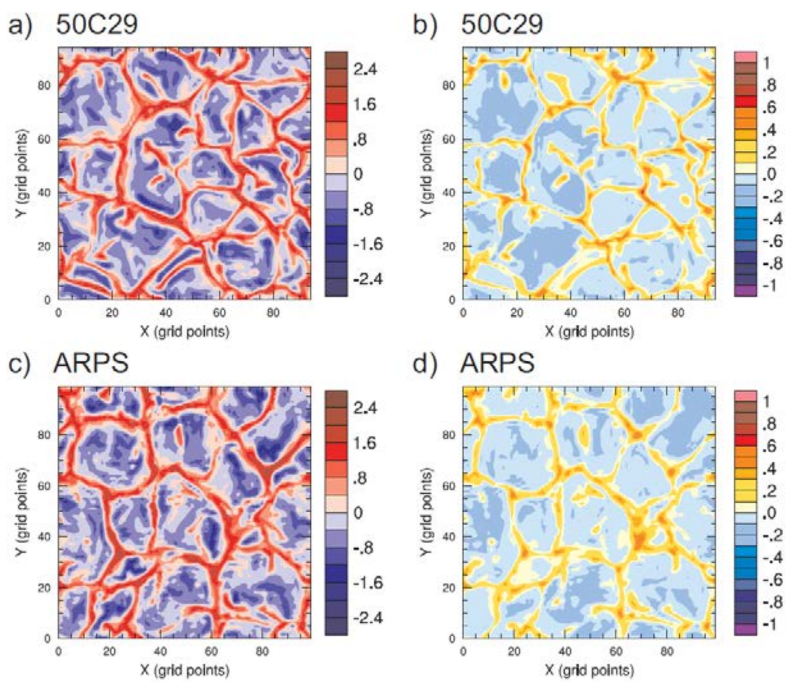
Using COSMO as an LES

Previous work

- **Herzog et al. 2002**, LLM (see also tech Report 4, changes Uli Blahak)

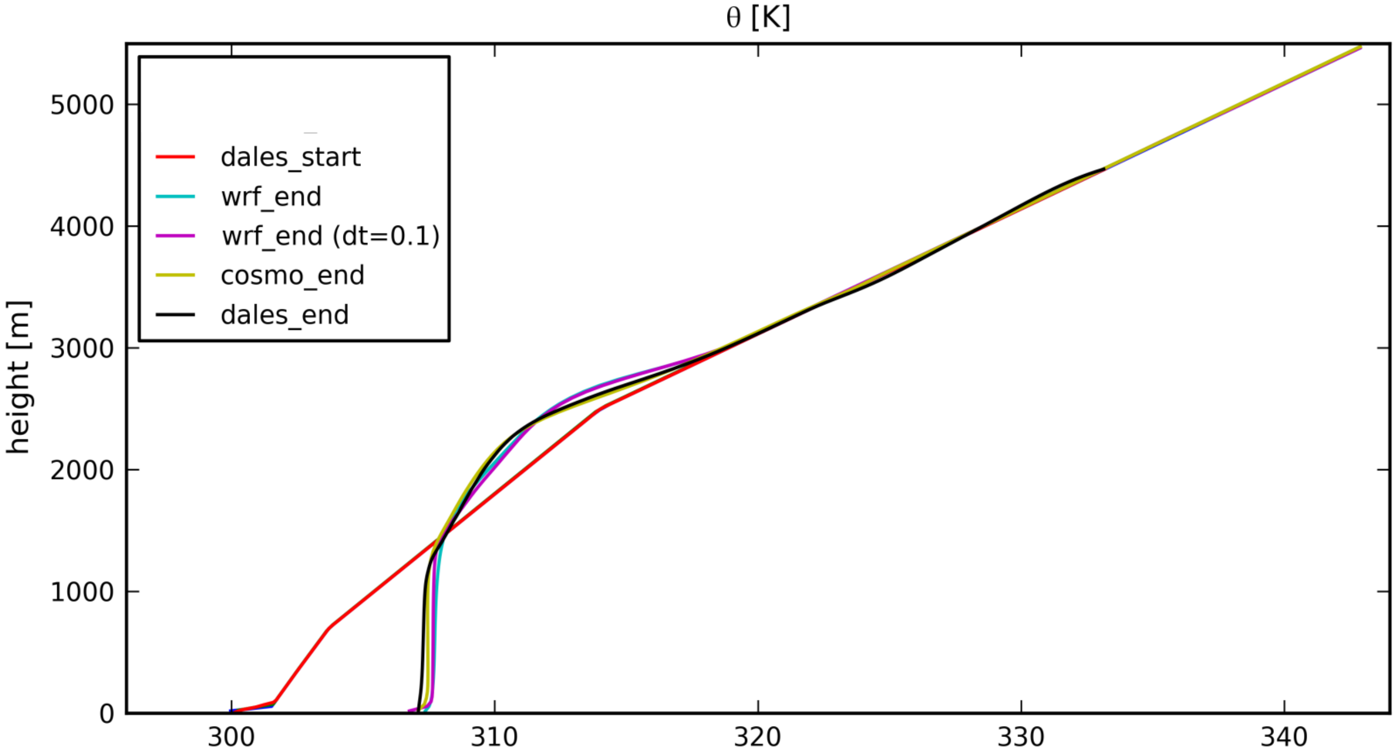


- **Langhans et al. 2012**
  Lilly-Smagorinsky scheme
  COSMO newsletter 12
  Tests for dry convection



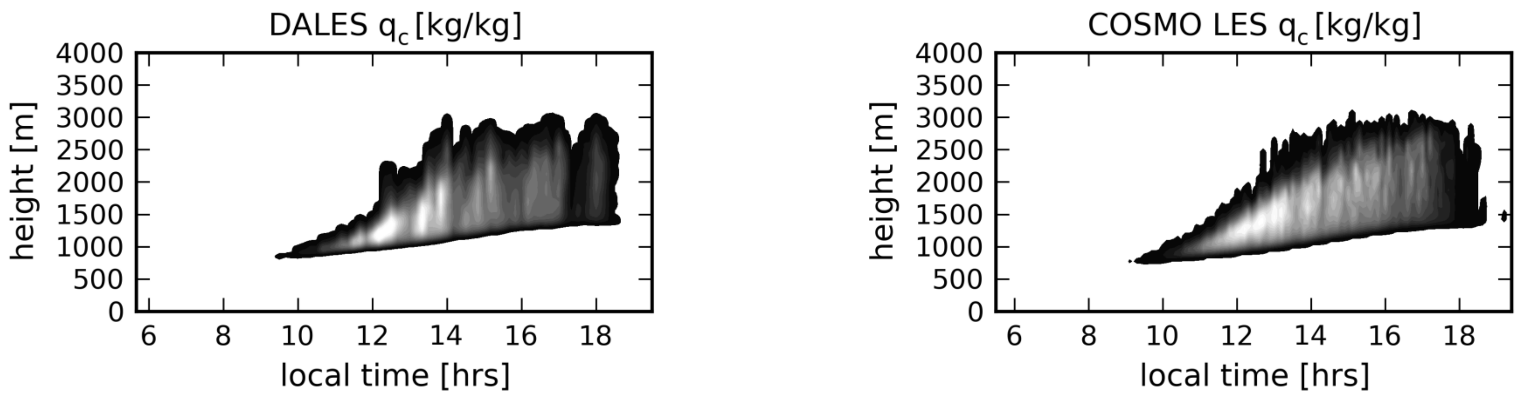
Sanity checks for shallow convection case

- Based on Brown et al 2002 (GCSS ARM), Δx=67 m
- Check for correct surface moisture and heat inputs



Evaluation of the diurnal cycle

Diurnal cycle of shallow cumulus, no topography



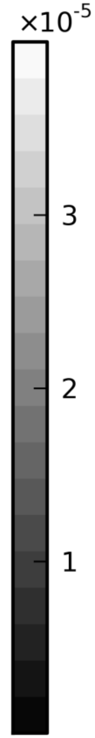
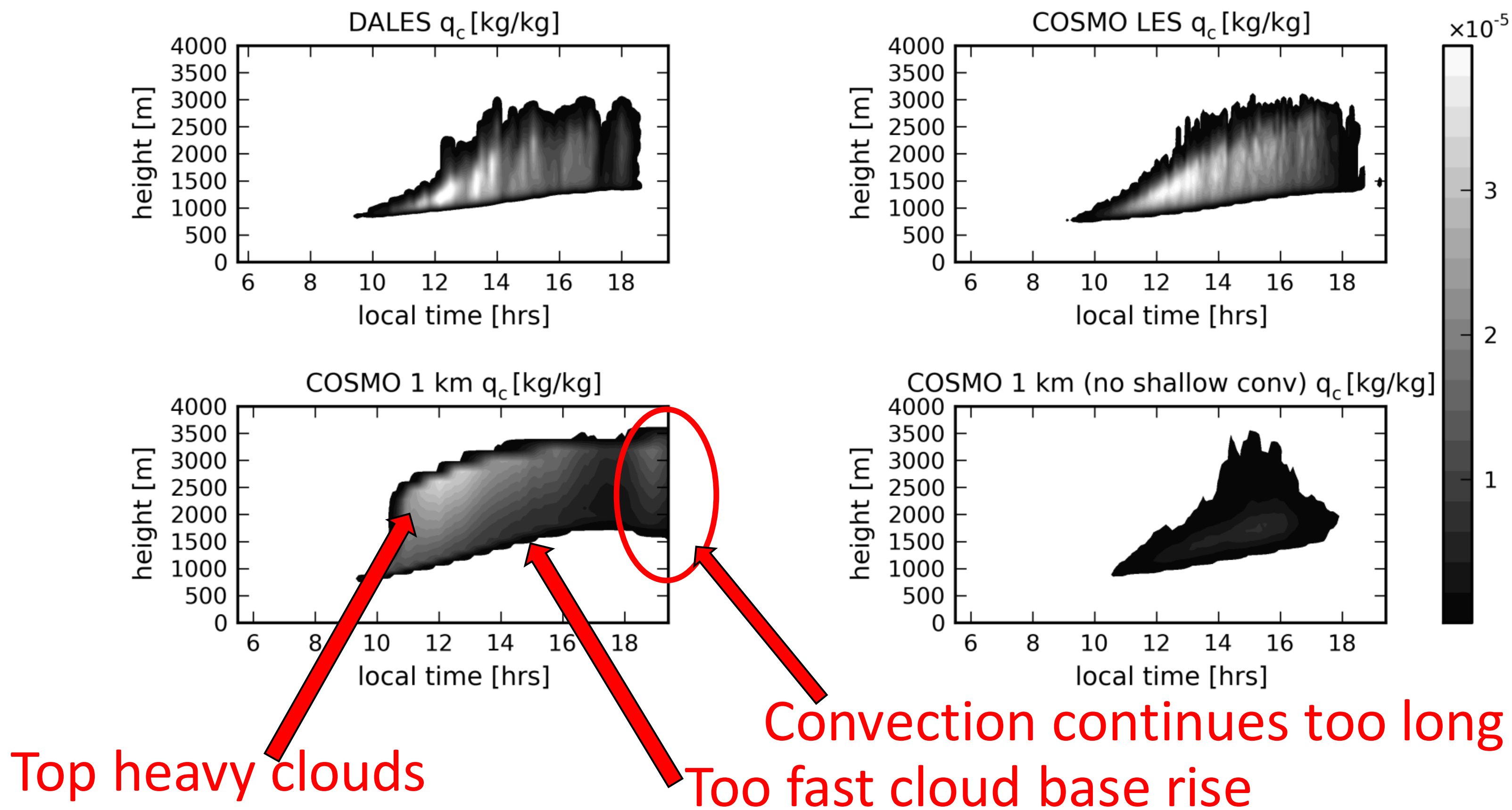


Photo: Lynn Roeder, ARM

What does a 1-km simulation do?

Diurnal cycle of shallow cumulus, no topography

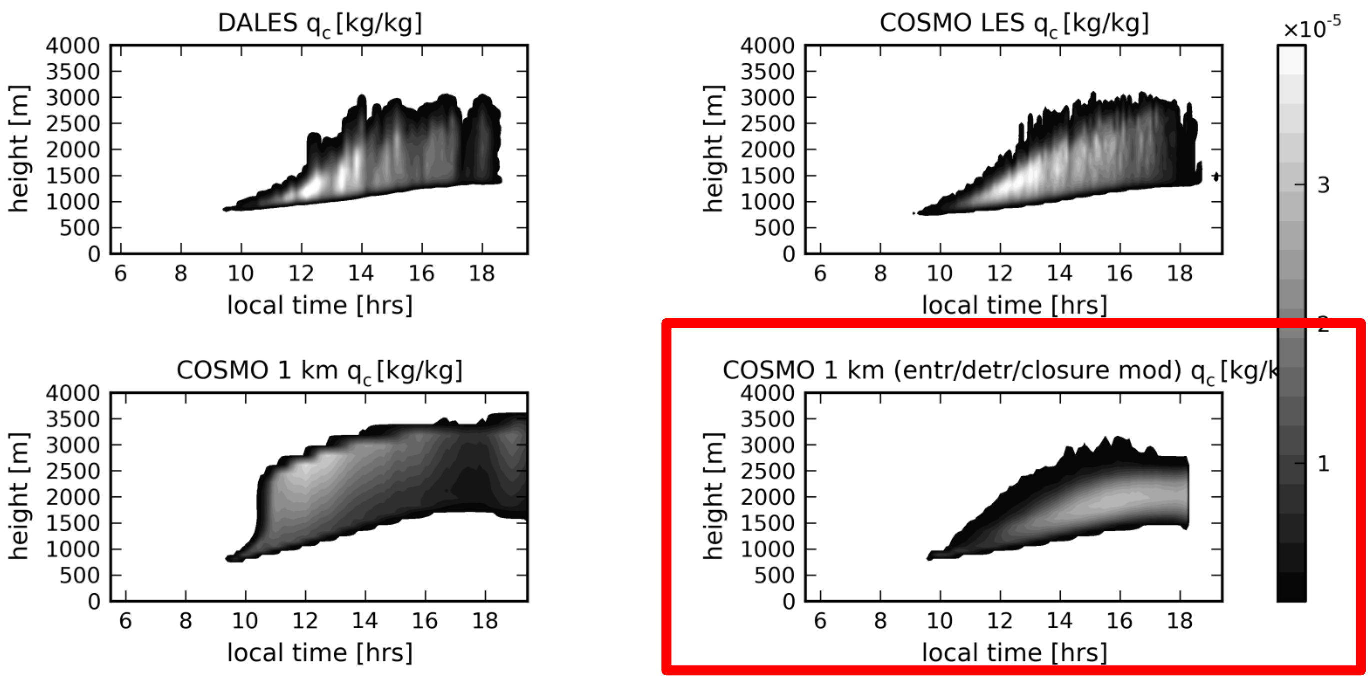
DALES vs COSMO-LES vs COSMO-1 (~ MeteoSwiss COSMO-NExT setup)



Changing the shallow convection scheme?

Closure: Grant & Brown (1999), based on $w^*_{\text{sub}} = \left(\frac{g z_b}{\Theta_v^0} (\overline{w' \theta_v'})_s \right)^{1/3}.$

Entrainment/**detrainment** similar to De Rooy & Siebesma (2008)

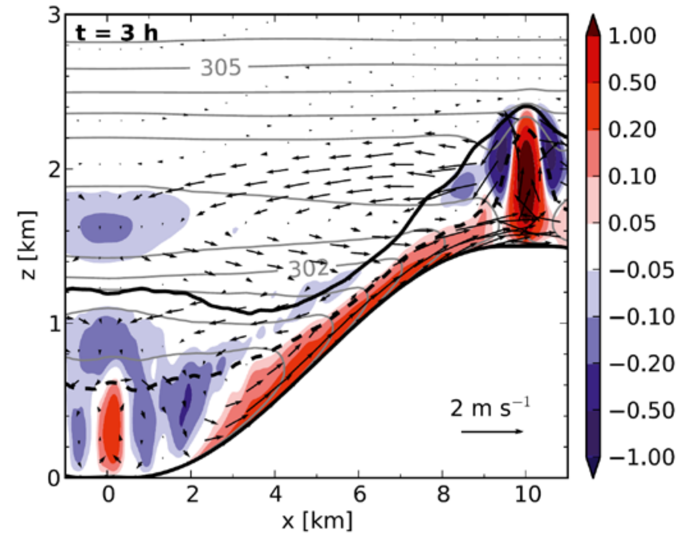


Validation of a slope flow case

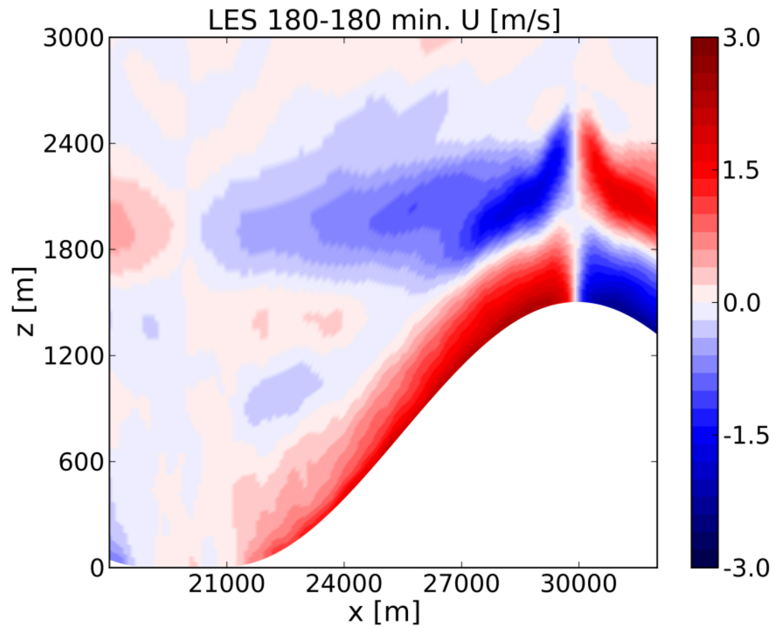
Dry convection, setup follows Schmidli 2013

New Fast-Wave solver improved results

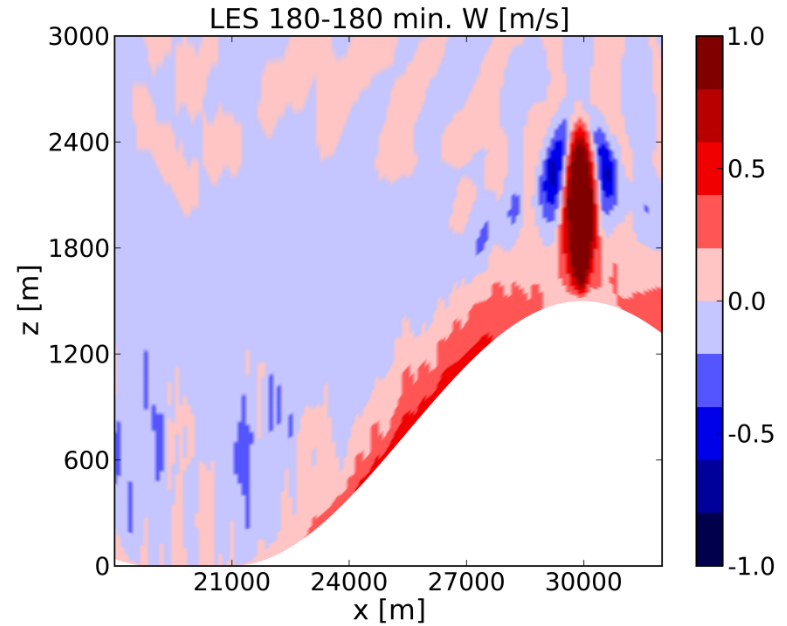
ARPS W



COSMO LES U



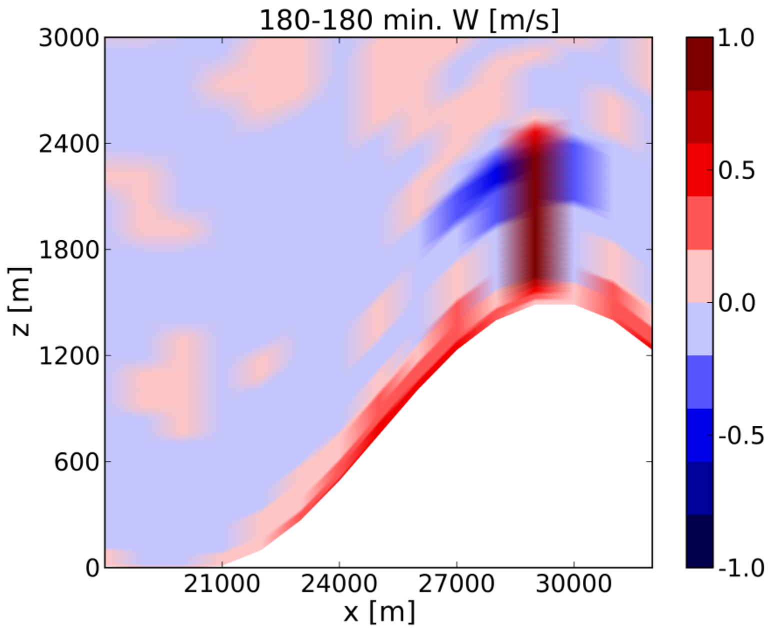
COSMO LES W



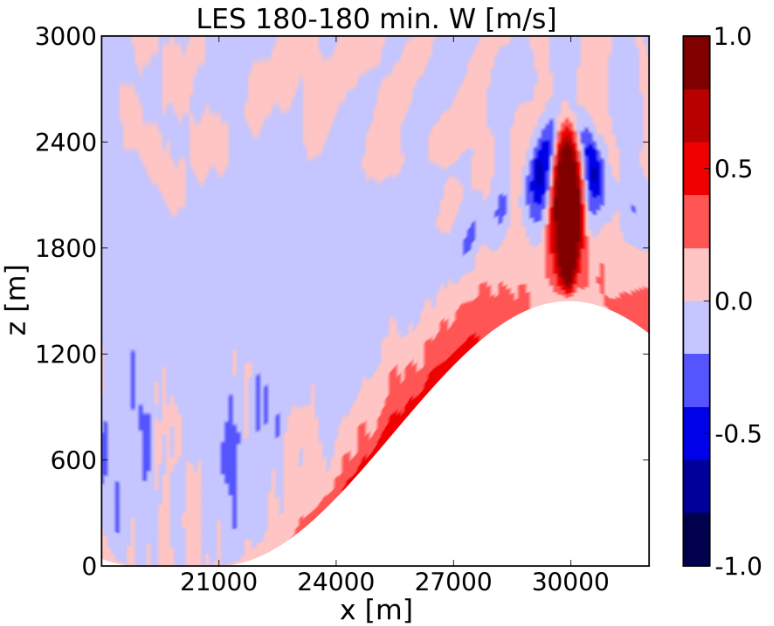
Kilometer scale results

- Cf. 1 km WRF studies by Johannes Wagner (U. Innsbruck)
- Test 2D true Smagorinsky scheme for horizontal mixing at 1 km?

W (COSMO 1 km)



W (LES)



Some preliminary results

Diurnal cycle of shallow cumulus with topography

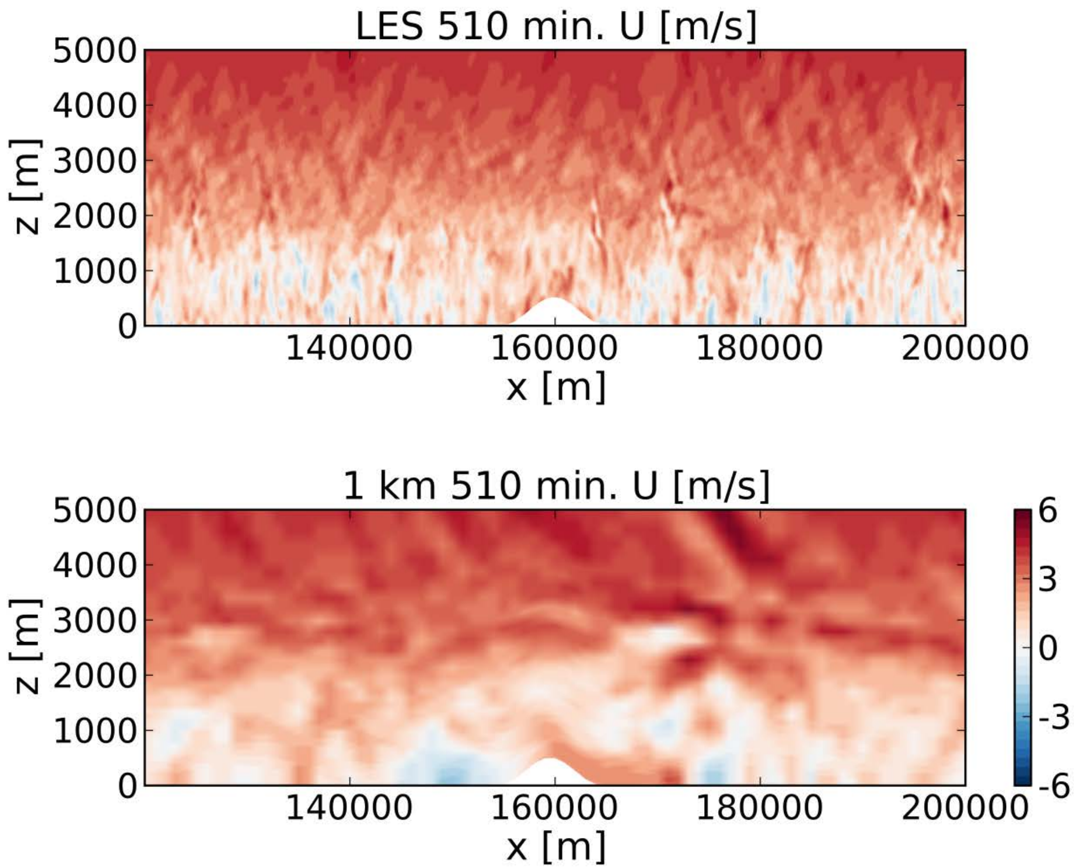
Flow over a 2D ridge

Weak wind

Periodic inflow

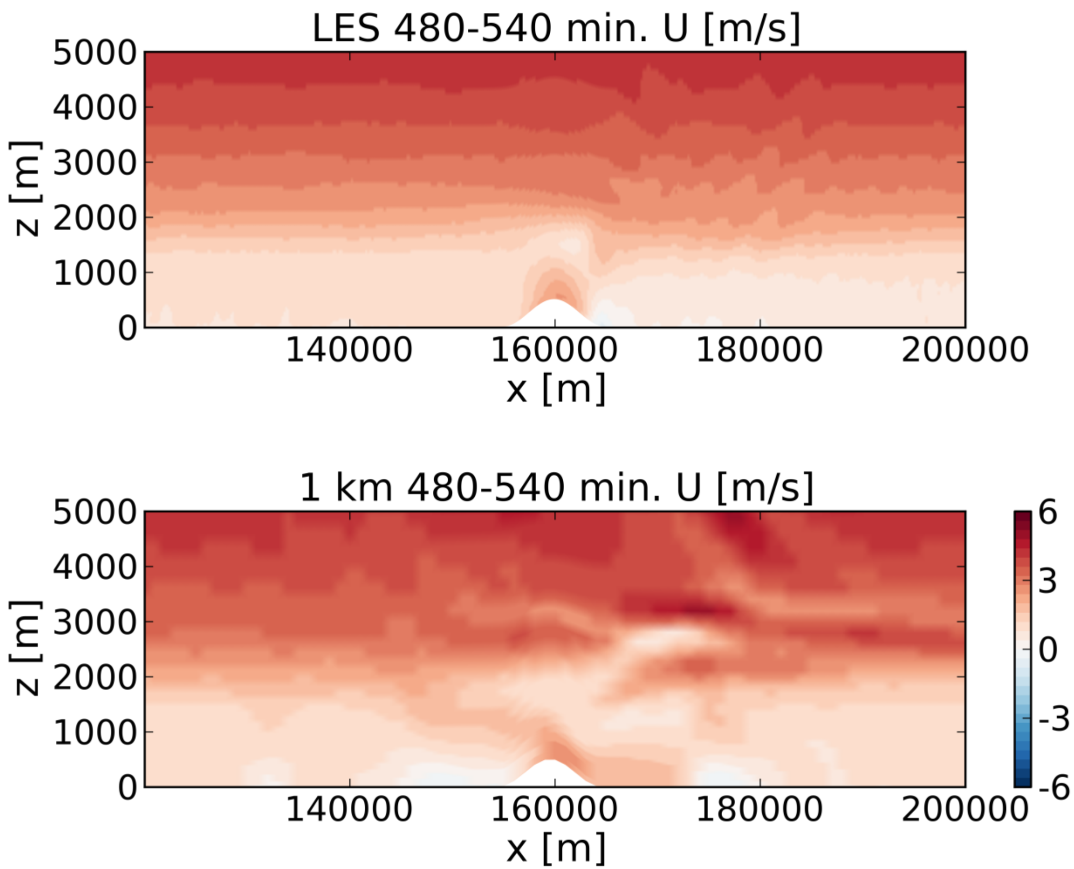
"LES": 200 m resolution

Instantaneous U



Some preliminary results

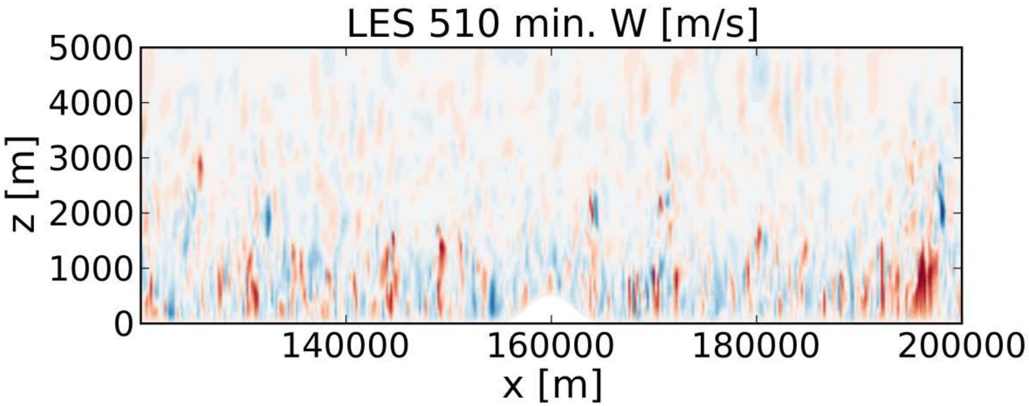
Time-averaged and space flow fields show patterns in 1D are stationary

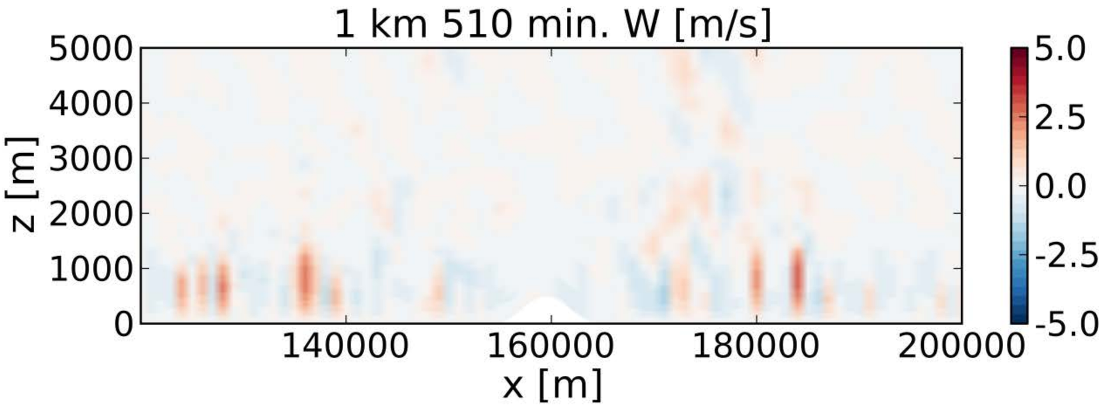


Some preliminary results

A snapshot of the vertical velocity field

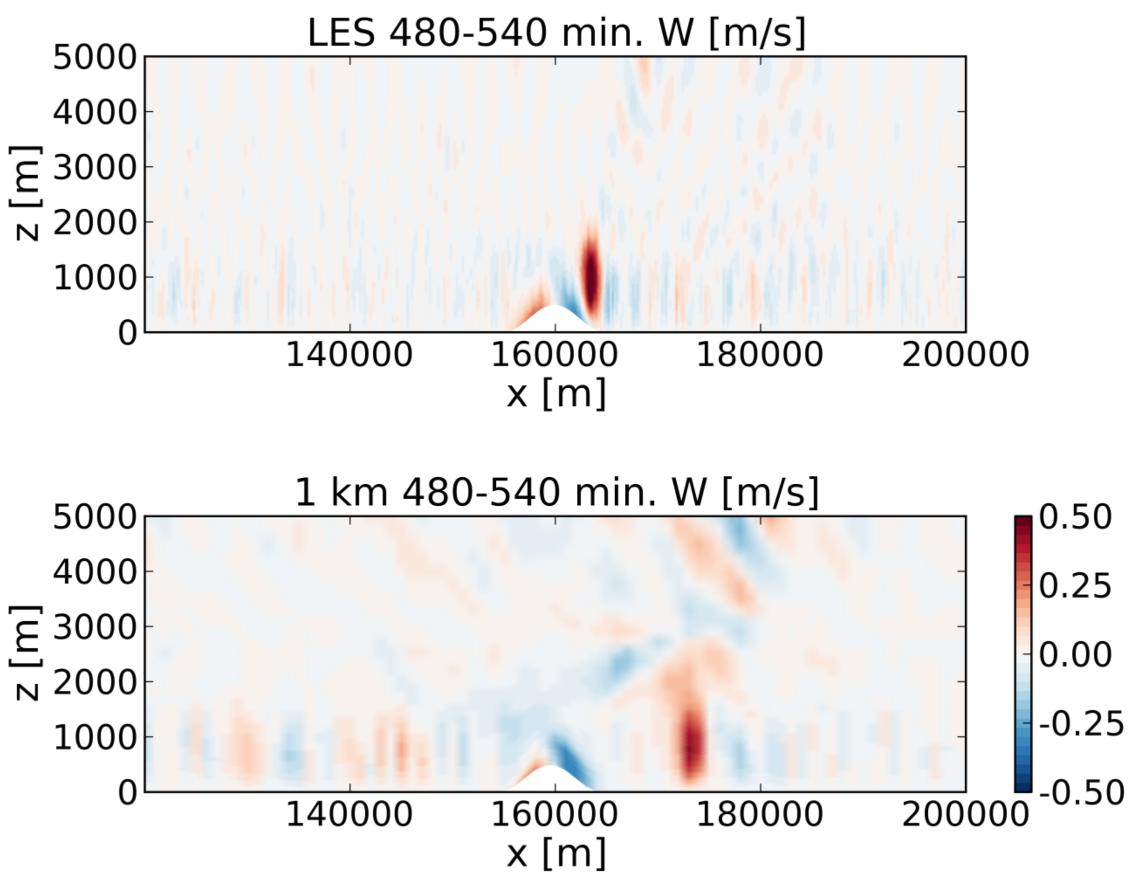
Weak resolved updrafts in 1-km simulation





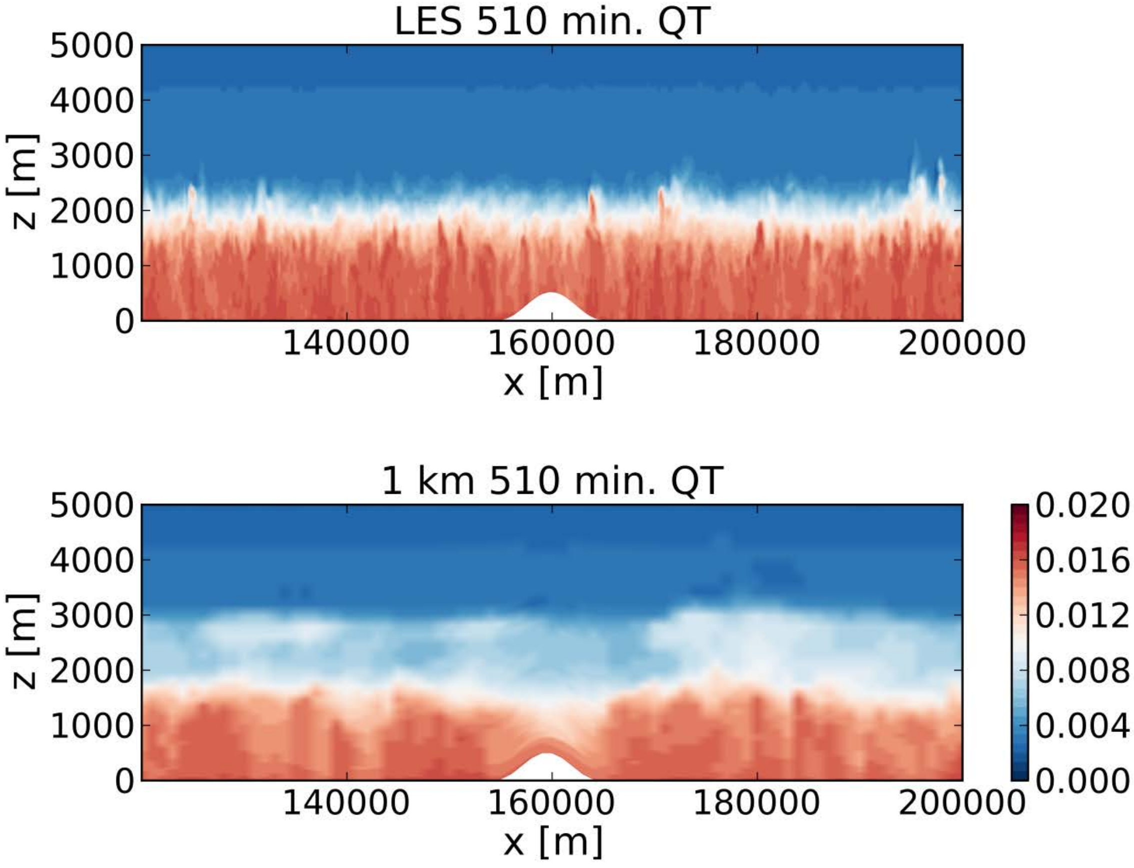
Some preliminary results

Location of slope flows



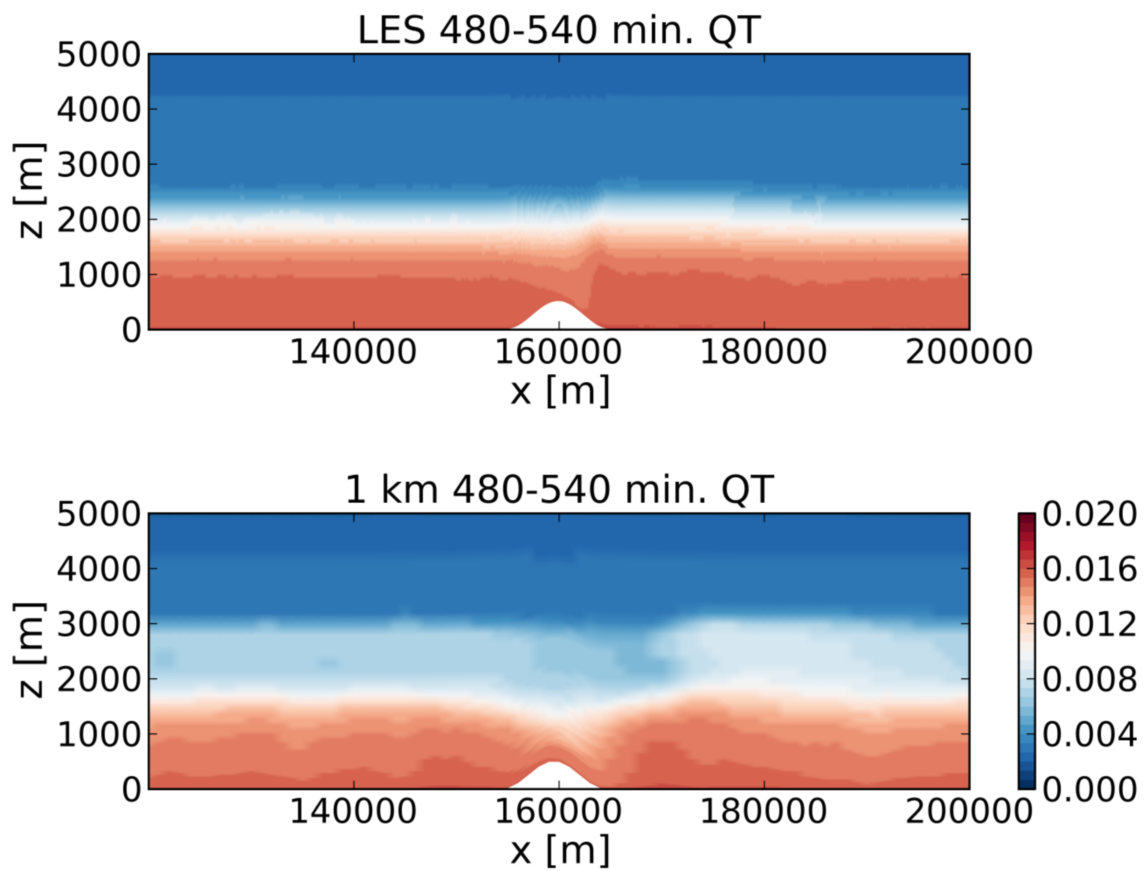
Some preliminary results

Moisture field also shows "weak plumes" 1D



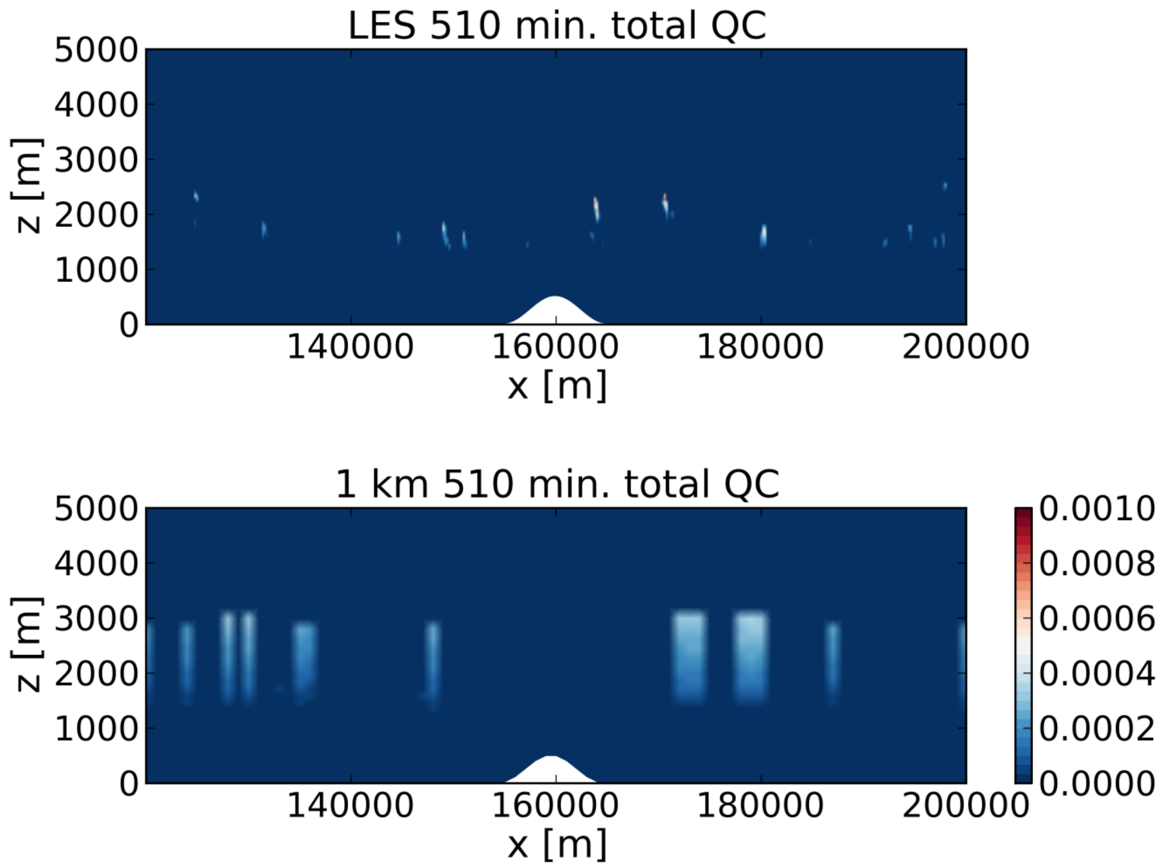
Some preliminary results

Moisture field also shows these “weak plumes”



Some preliminary results

Top heavy clouds, position shifted further down the lee



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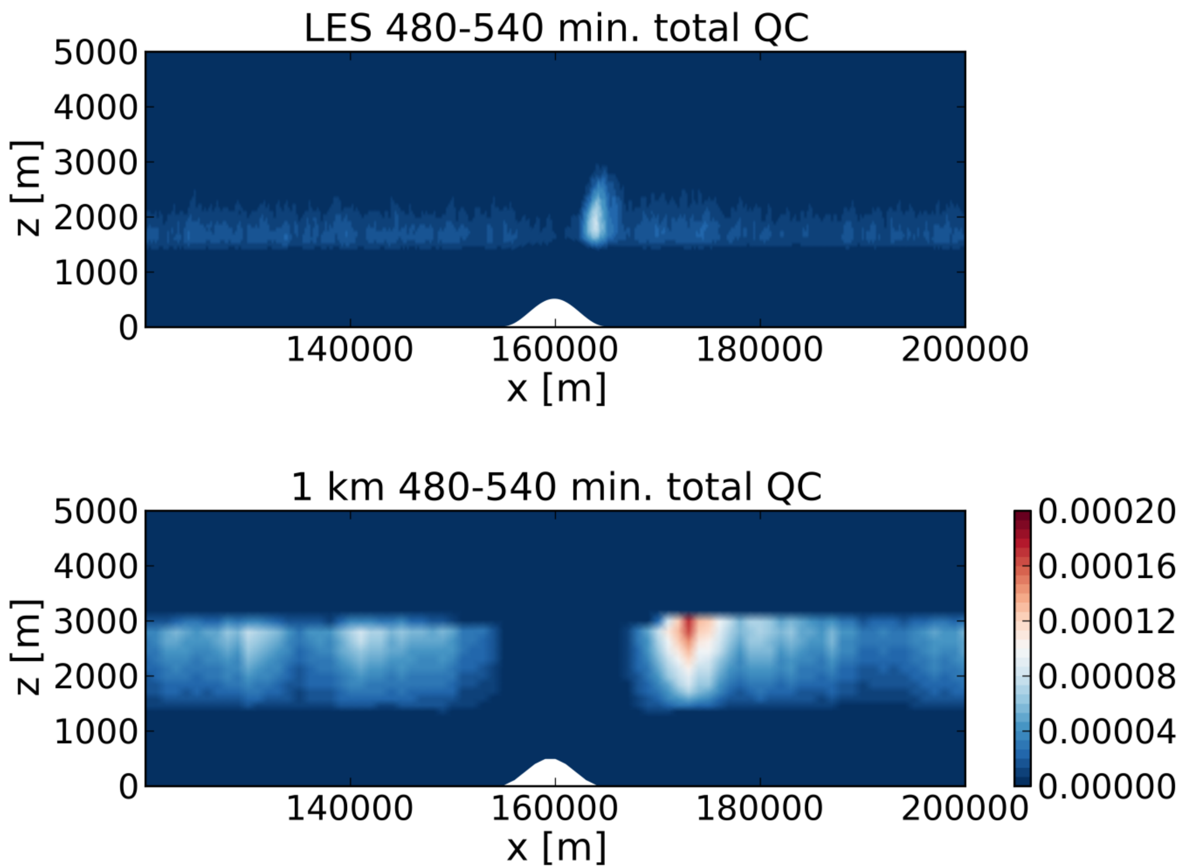
Some preliminary results

Top heavy clouds, position shifted further down the lee

Photo: NASA/JPL



Deep convection: proof of principle

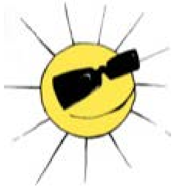
- $1536 \times 1536 \times 179$ grid points, Δx=200 m
- 500 m isolated hill
- Graupel scheme
- Prescribed surface fluxes, no radiation
- Run on Piz Daint, CSCS

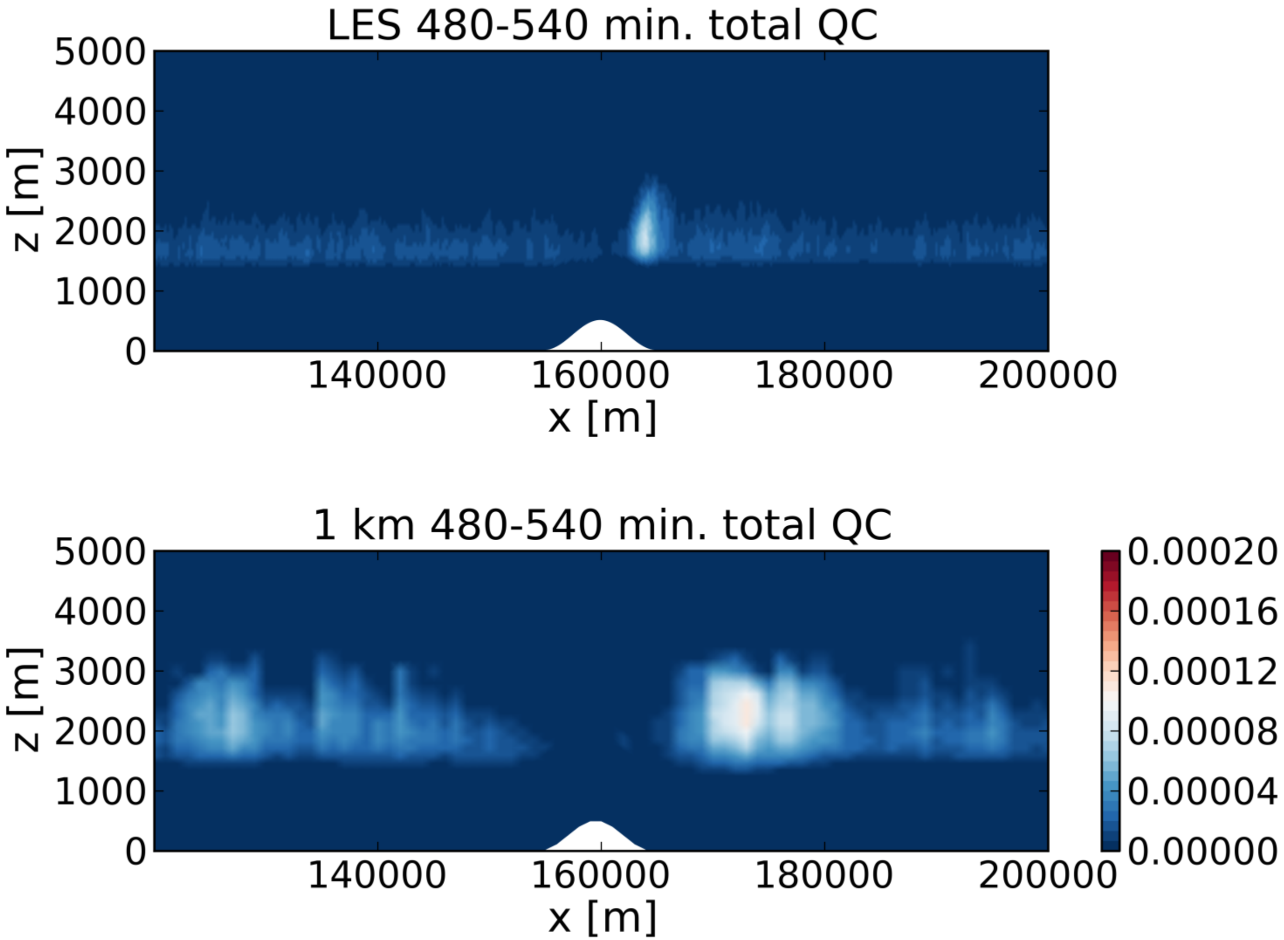
Photo: CSCS

Outlook

- Consolidate setups
- Test new developments, e.g.
    - Horizontal TKE-advection in the 1D PBL scheme
    - Test new turbulence options, e.g. TKE-Scalar Variance (Machulskaya & Mironov, COSMO Newsletter 13)

Identify relevant processes for
1 km simulations




LES 480-540 min. total QC
5000
4000
3000
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z [m]
140000
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4000
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1000
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z [m]
140000
160000
180000
200000
x [m]
0.00020
0.00016
0.00012
0.00008
0.00004
0.00000

COSMO turbulence parameterization

Current

- 1D MY PBL scheme with inconsistent SGS clouds (turbulence: SD77; radiation: RH criterion)

Possible extensions

- 1D MY scheme with 2D Smagorinsky for horiz. mixing
- 3D MY scheme (3D transport and horiz. shear prod.)
- **TKE-SV and new SGS clouds scheme**
- New mixing length formulation (e.g. Teixeira and Cheinet, or Bogenschutz and Krueger 2013)
- Mixed schemes (e.g. Moeng et al., 2010)
- Unified schemes (e.g. Bogenschutz and Krueger, 2013)

Focusing on non-precipitating convection

Kirshbaum DJ, Grant ALM. 2012. Invigoration of cumulus cloud fields by mesoscale ascent. Q. J.R. Meteorol. Soc.138: 2136 – 2150. DOI:10.1002/qj.1954
Tian, Wenshou, Douglas J. Parker, Charles A. D. Kilburn, 2003: Observations and Numerical Simulation of Atmospheric Cellular Convection over Mesoscale Topography. Mon. Wea. Rev., 131, 222–235.
Yonggang Wang, Bart Geerts, Observations of detrainment signatures from non-precipitating orographic cumulus clouds, Atmospheric Research, Volume 99, Issue 2, February 2011, Pages 302-324
(haven't looked at this in detail yet)

On precipitating convection / the onset of precipitation (you may not want to read these in detail yet)

Houze, R. A.Jr. (2012), Orographic effects on precipitating clouds, Rev. Geophys., 50, RG1001,
Fuhrer, Oliver, Christoph Schär, 2005: Embedded Cellular Convection in Moist Flow past Topography. J. Atmos. Sci., 62, 2810–2828.
Fuhrer, Oliver, Christoph Schär, 2007: Dynamics of Orographically Triggered Banded Convection in Sheared Moist Orographic Flows. J. Atmos. Sci., 64, 3542–3561.
Kirshbaum, Daniel J., George H. Bryan, Richard Rotunno, Dale R. Durran, 2007: The Triggering of Orographic Rainbands by Small-Scale Topography. J. Atmos. Sci., 64, 1530–1549.

Dry convection over topography

Schmidli, Juerg. "Daytime Heat Transfer Processes over Mountainous Terrain." *Journal of the Atmospheric Sciences* 70.12 (2013).

Focusing on the effects of resolution

Wyngaard, J.C., 2004: Toward numerical modeling in the “Terra Incognita”. J. Atmos. Sci., 61, 1816–1826.
Craig, George C., Andreas Dörnbrack, 2008: Entrainment in Cumulus Clouds: What Resolution is Cloud-Resolving?. J. Atmos. Sci., 65, 3978–3988.
Wolfgang Langhans, Juerg Schmidli, Christoph Schär. (2012) Bulk Convergence of Cloud-Resolving Simulations of Moist Convection over Complex Terrain. Journal of the Atmospheric Sciences 69:7, 2207-2228

COSMO model: LES formulations

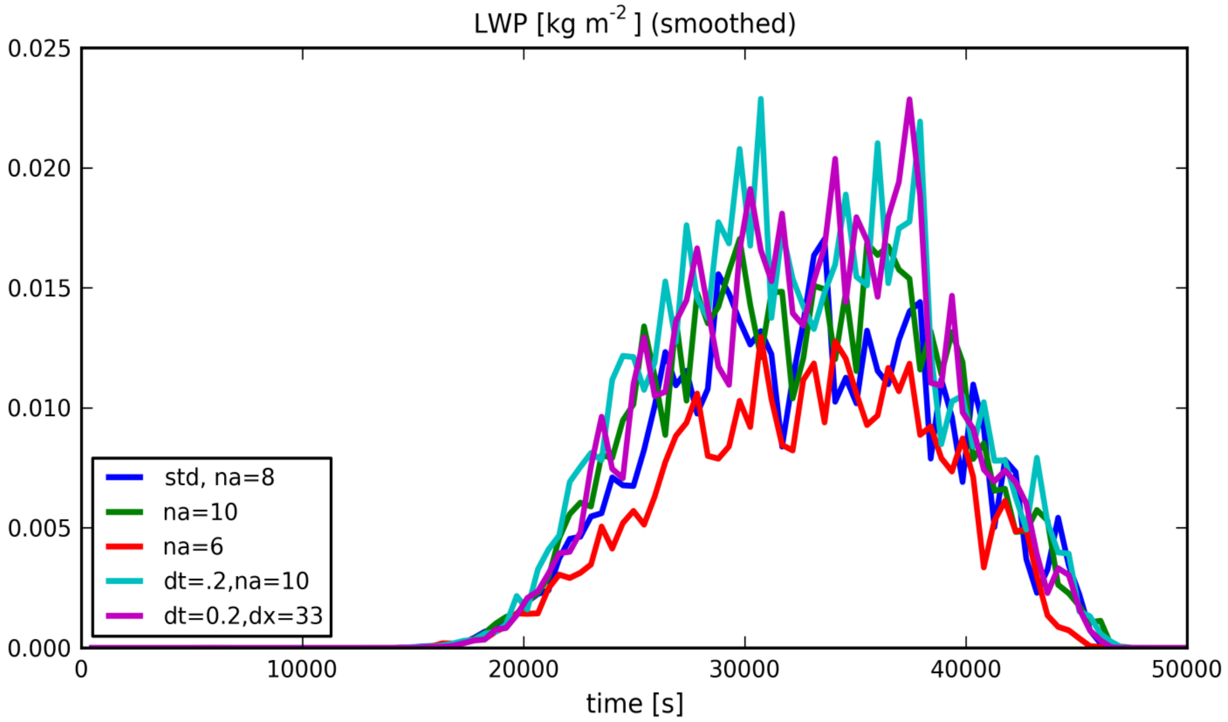
Herzog, H-J., G. Vogel, and U. Schubert. "LLM–a nonhydrostatic model applied to high-resolving simulations of turbulent fluxes over heterogeneous terrain." Theoretical and applied climatology 73.1-2 (2002): 67-86.
Langhans, Wolfgang, Jürg Schmidli, and Balazs Szintai. "A Smagorinsky-Lilly turbulence closure for COSMO-LES: Implementation and comparison to ARPS." COSMO newsletter 12 (2012): 20-31.

COSMO model: new turbulence parameterization

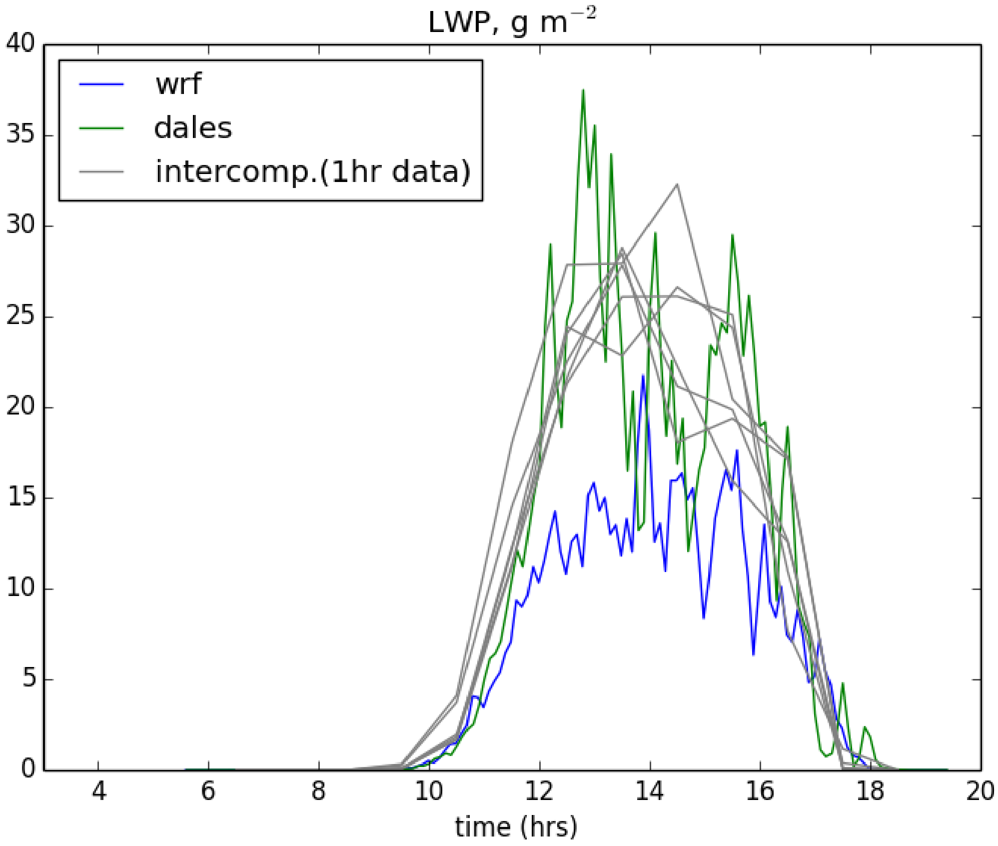
Machulskaya, Ekaterina, and Dmitrii Mironov. "Implementation of TKE–Scalar Variance Mixing Scheme into COSMO." COSMO newsletter 13 (2013)

WRF convergence tests

- Questionable if WRF has convergenced even at dt=0.2 s, dt_ac=0.02 s



Tests of the full Brown et al (2002) case



Liquid water path of WRF (0.5 s) below ensemble