Convergence behavior of convection-resolving simulations of summertime deep convection over land

Davide Panosetti, Linda Schlemmer and Christoph Schär

Institute for Atmospheric and Climate Science, ETH Zurich

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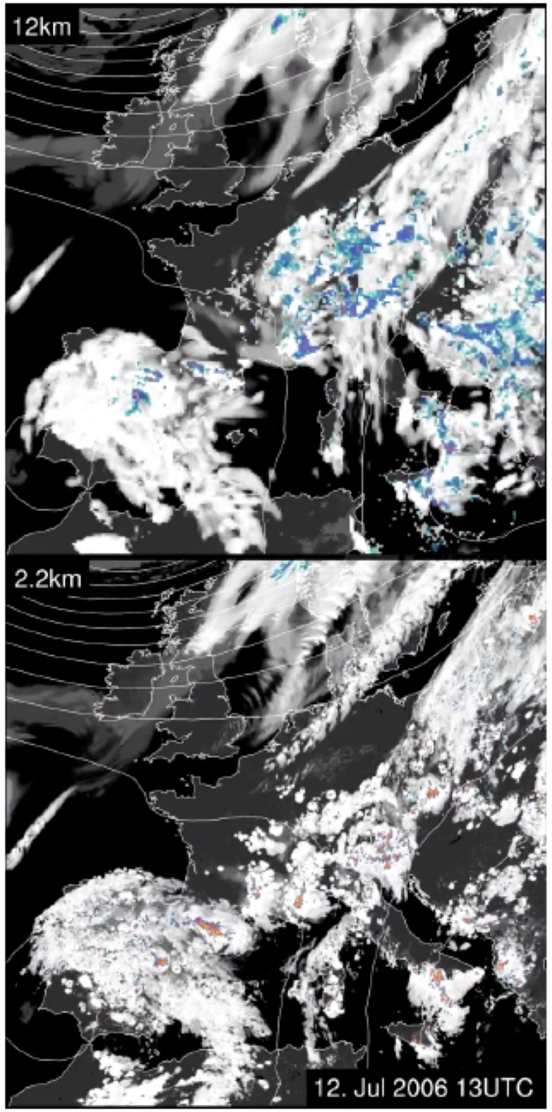
Convection-Resolving Models (CRMs)

- Clouds and convective transport partly resolved (e.g. Weisman et al. 1997, Hohenegger et al. 2008, Baldauf et al. 2011)

- Better representation of topography and surface fields

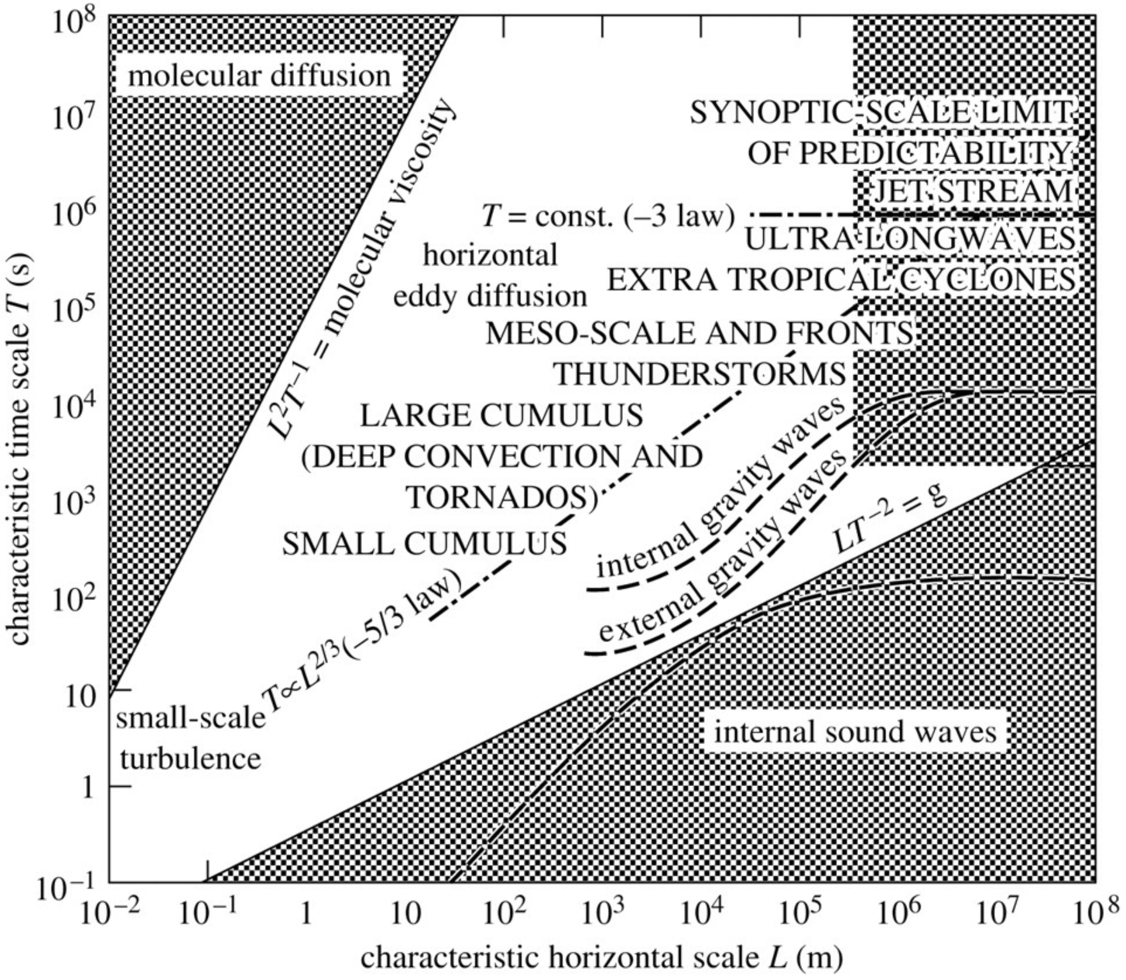
- Improved diurnal cycle of precipitation compared to convection-parameterizing models (e.g. Richard et al. 2007, Ban et al. 2014)

- Can be applied to decade-long, continental-scale climate simulations (e.g. Ban et al. 2014, Leutwyler et al. 2016)



Leutwyler et al. (2016)

The "grey zone" of convection



Smagorinsky (1974)

- Fully resolving deep convection needs LES at Δx < 100 m
- Traditional assumptions behind convection parameterizations break down
- At Δx = O(1 km), the smallest features are sensitive to details of the numerical filter (e.g. grid-scale storms)

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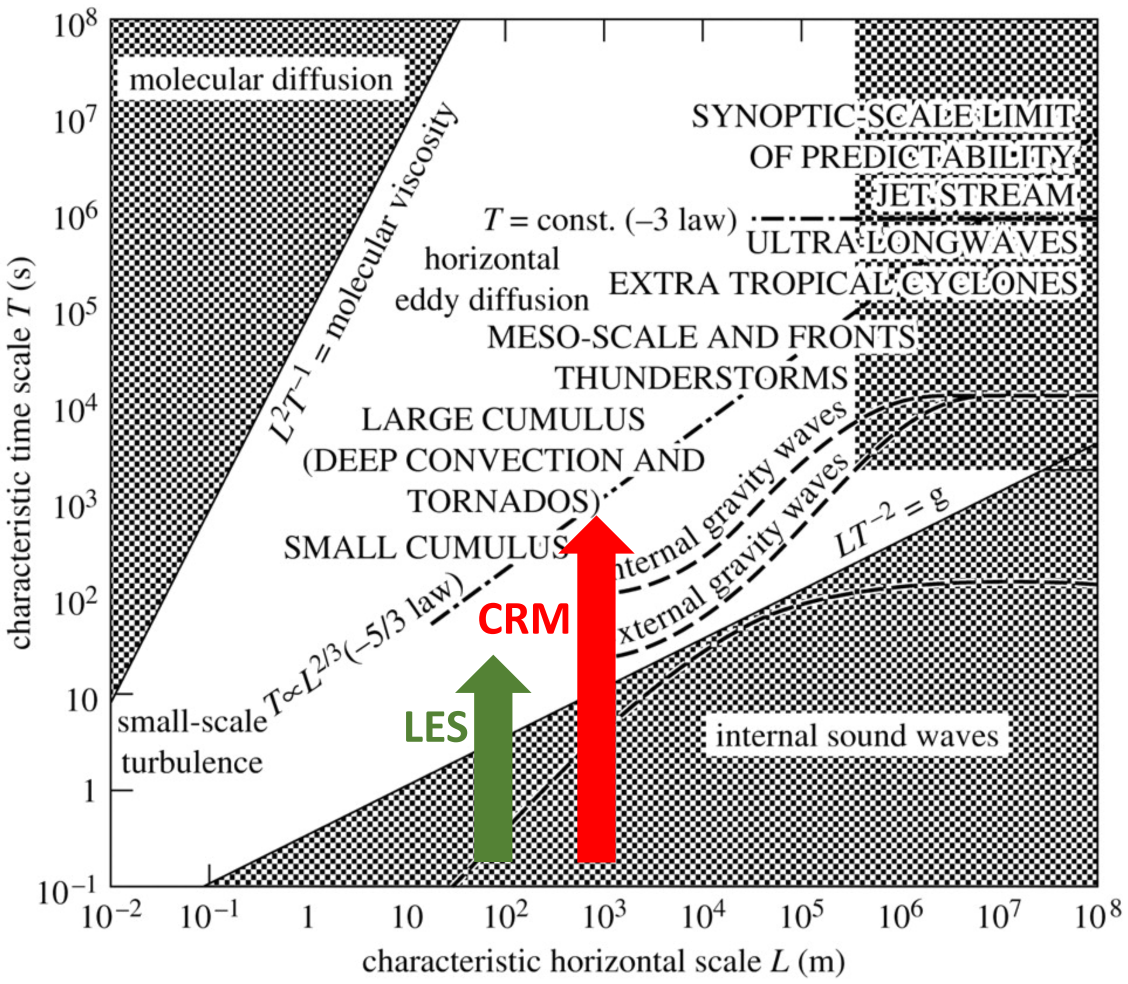

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Structural convergence

"Convergence of statistics and scales of individual clouds and updrafts."

e.g. Bryan et al. (2003), Dauhut et al. (2015), Jevanjee (2017)

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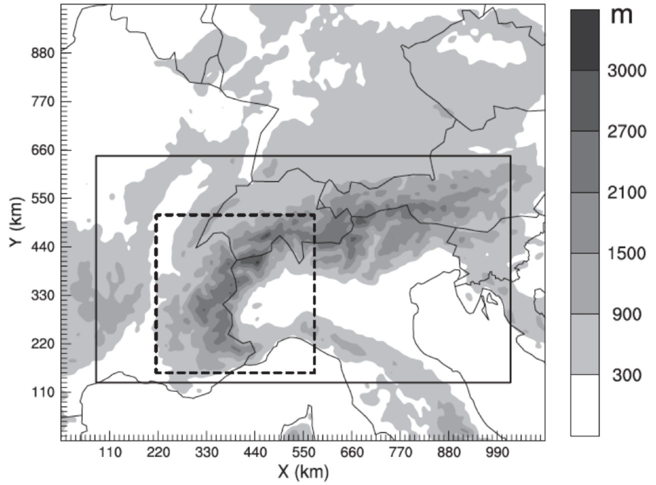
Bulk convergence

"Convergence of domain-averaged and integrated properties related to a large ensemble of convective cells."

e.g. Langhans et al. (2012), Harvey et al. (2017)



Langhans et al. (2012)

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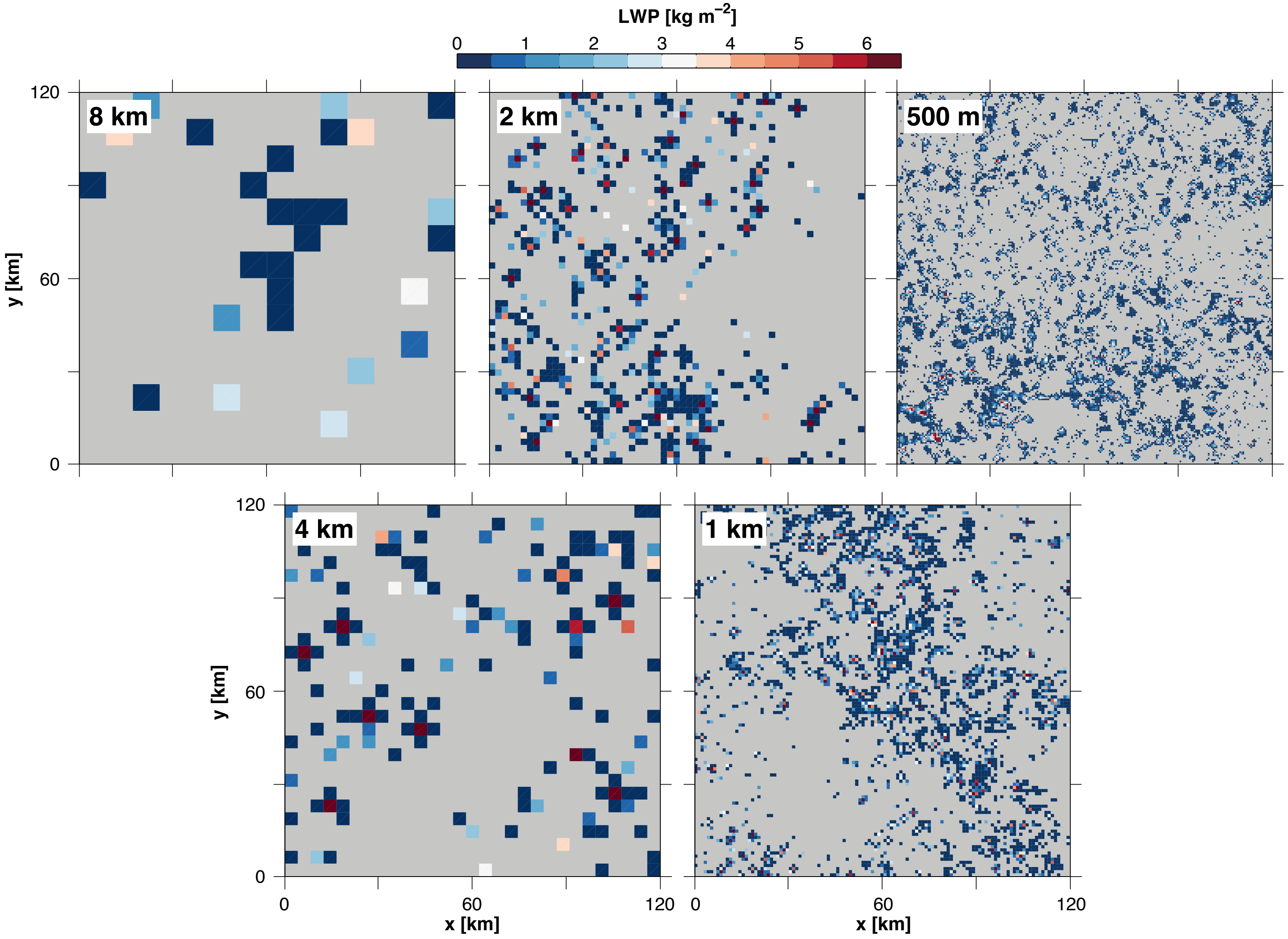

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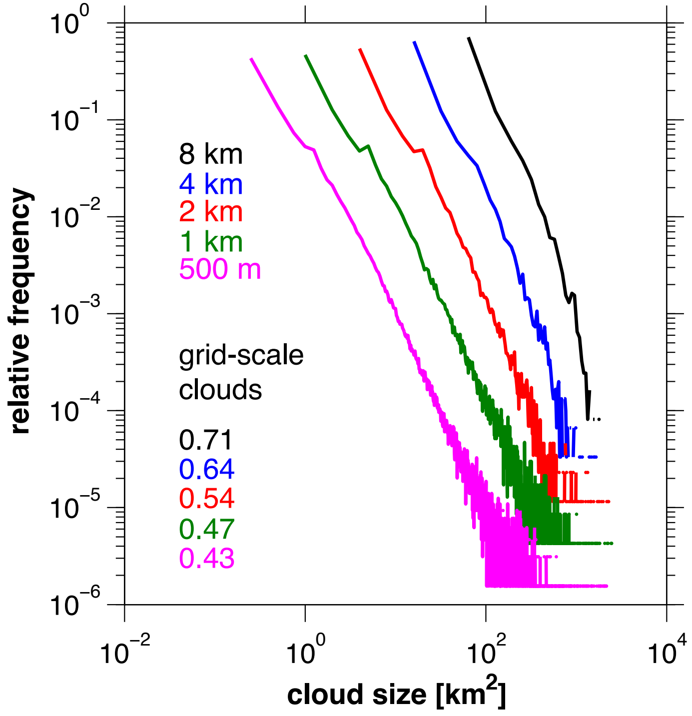
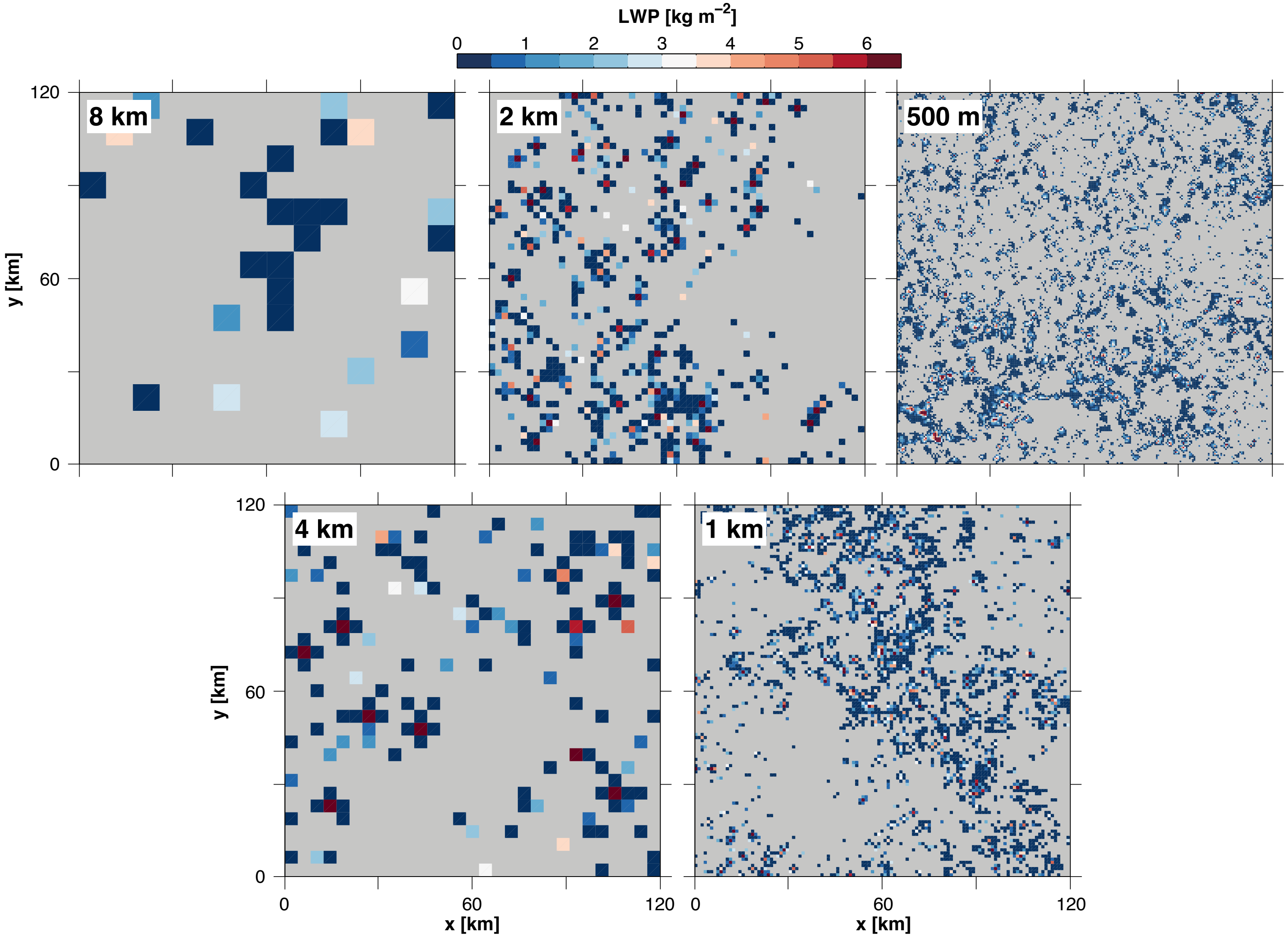
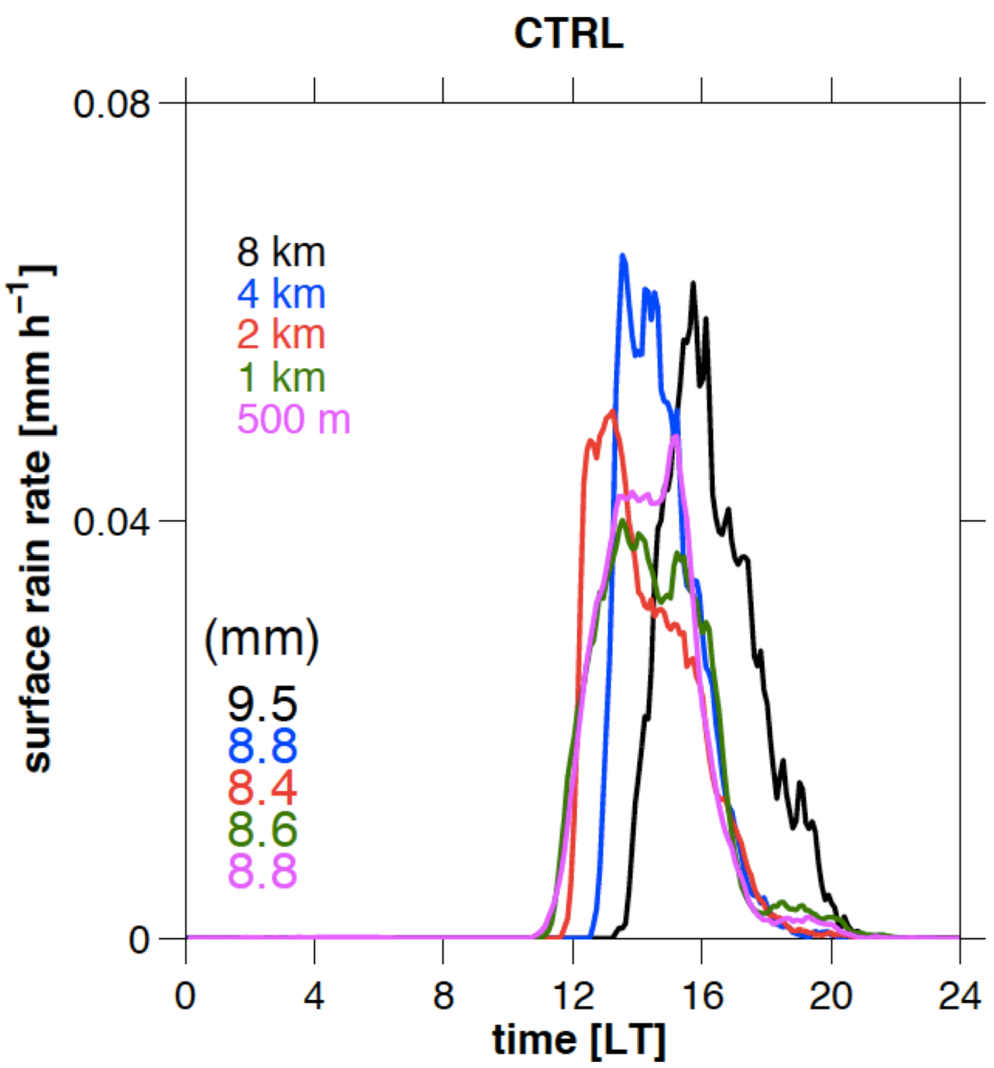
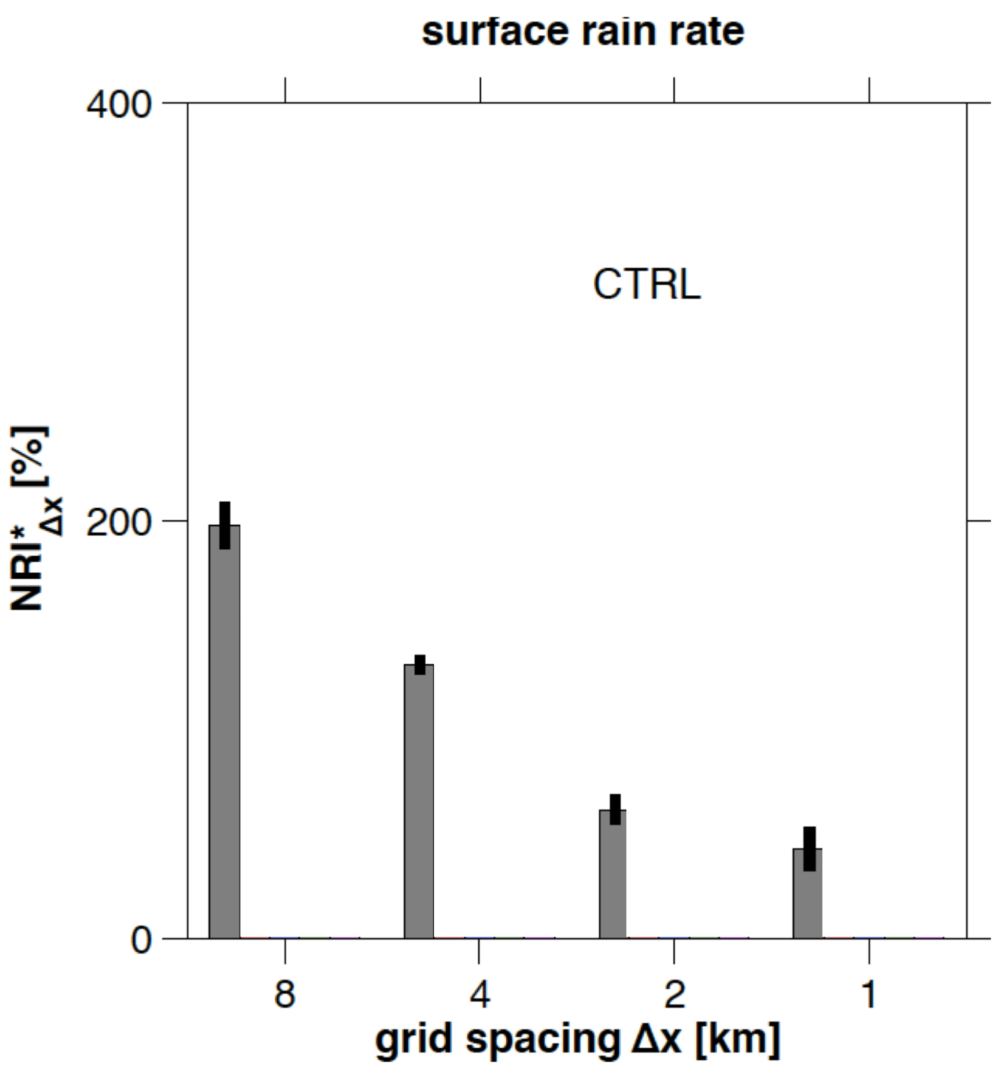




Surface precipitation





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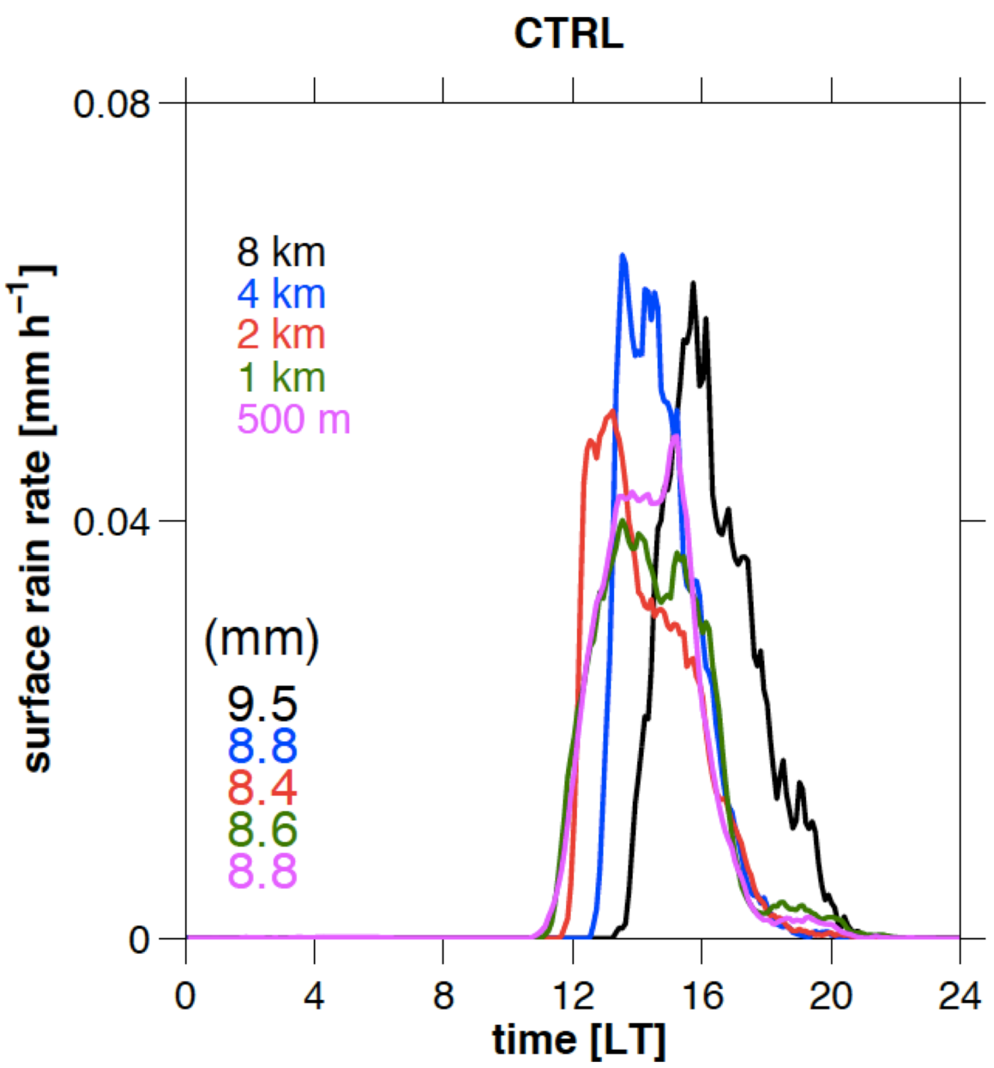
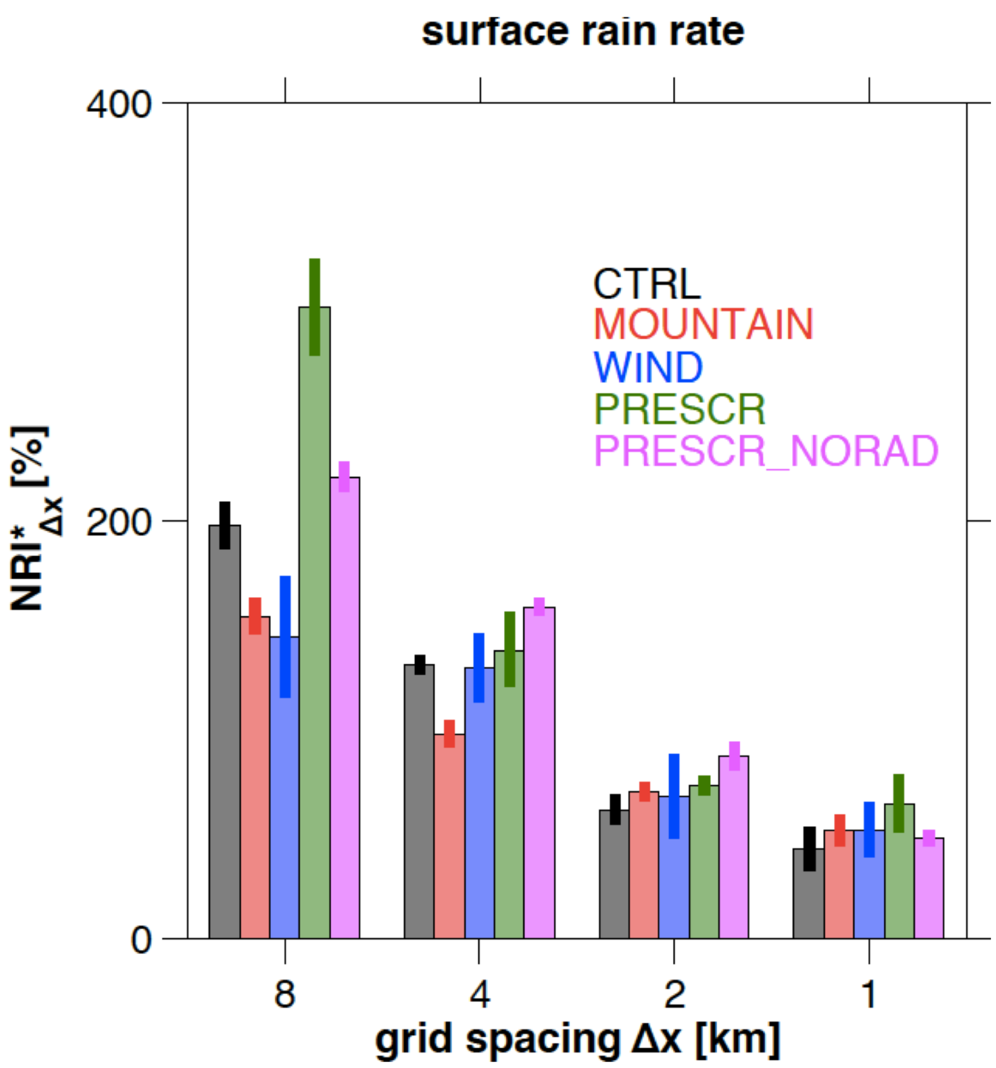
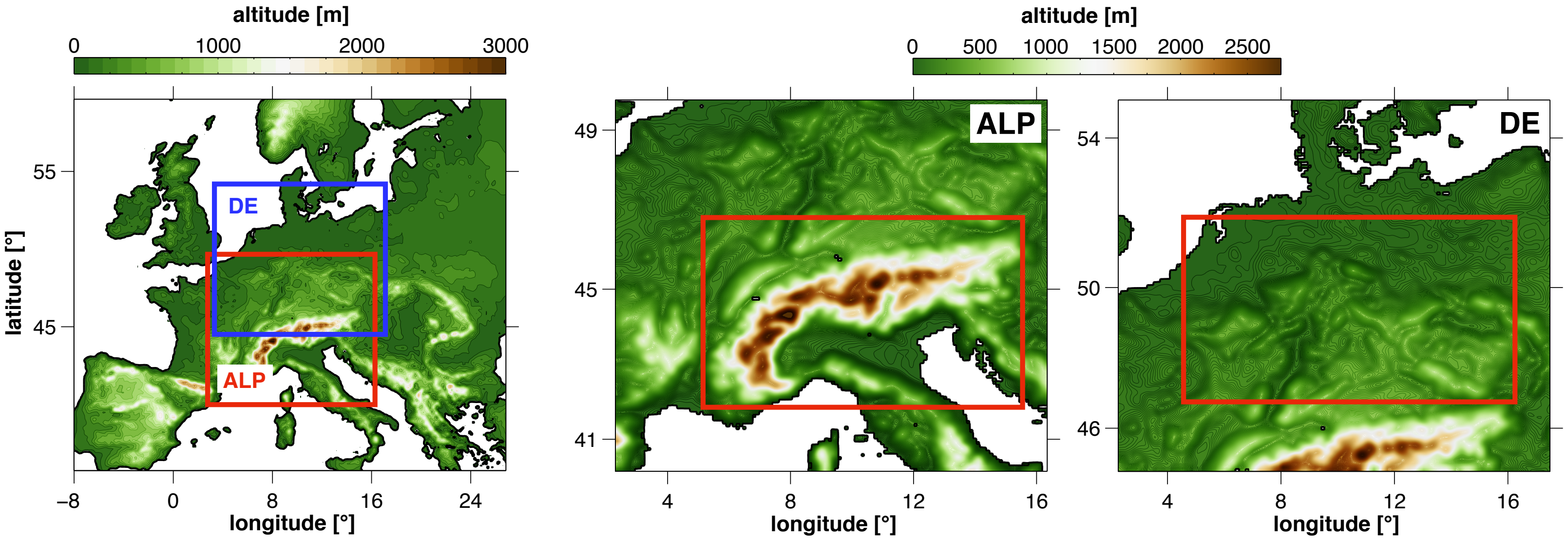




davide.panosetti@env.ethz.ch

Real-case simulations



Basic setup

- Domain 1160 x 1090 km^2
- **COSMO v5.0** @ Δx = 8.8, 4.4, 2.2, and 1.1 km and 550 m
- 14-member ensemble at Δx = 2.2 km
- Soil initialized from 10-yr climate run at 12-km horizontal grid spacing (Ban et al. 2014)
- Initialized with and driven by 12-km run with parameterized convection
- Explicit convection, hybrid 1D TKE-based/2D Smagorinsky turbulence scheme

Experiments

ALP: 11-20 July 2006 (e.g. Langhans et al. 2012)

DE: 4-13 June 2007 (e.g. Keller et al. 2015)

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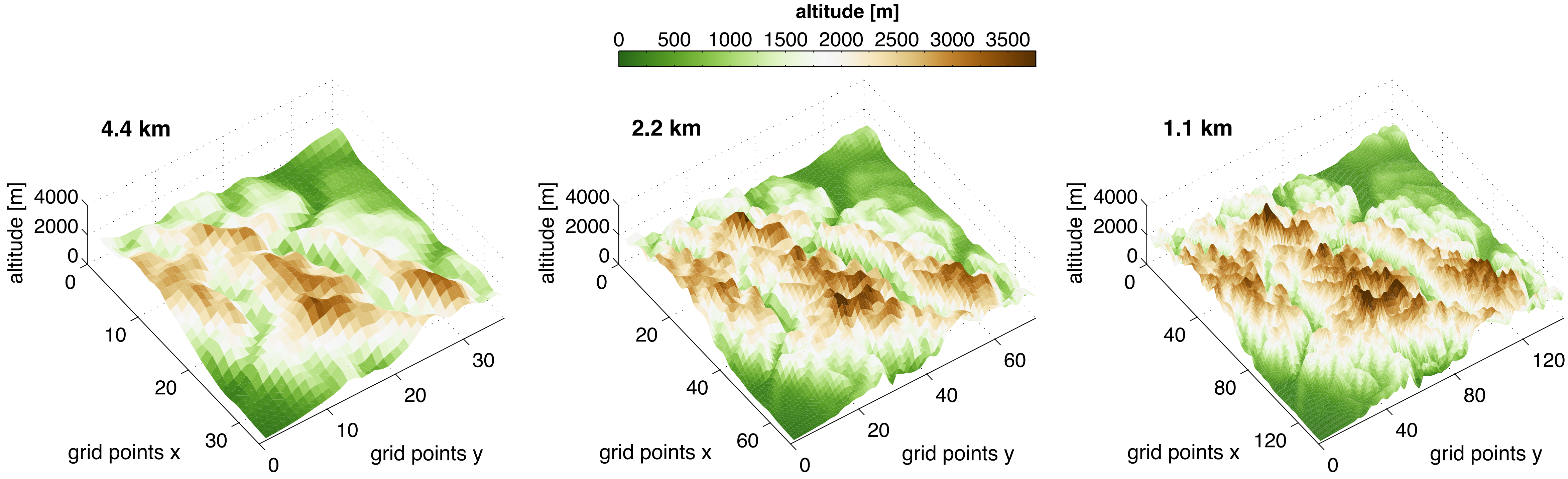

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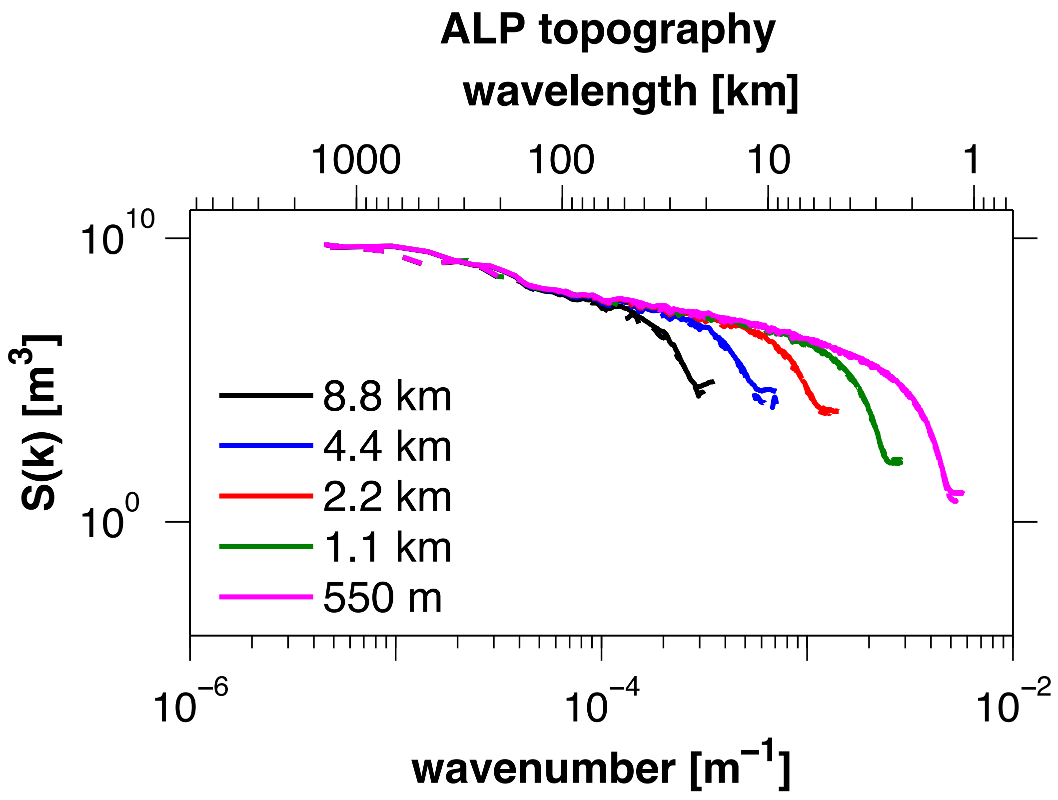
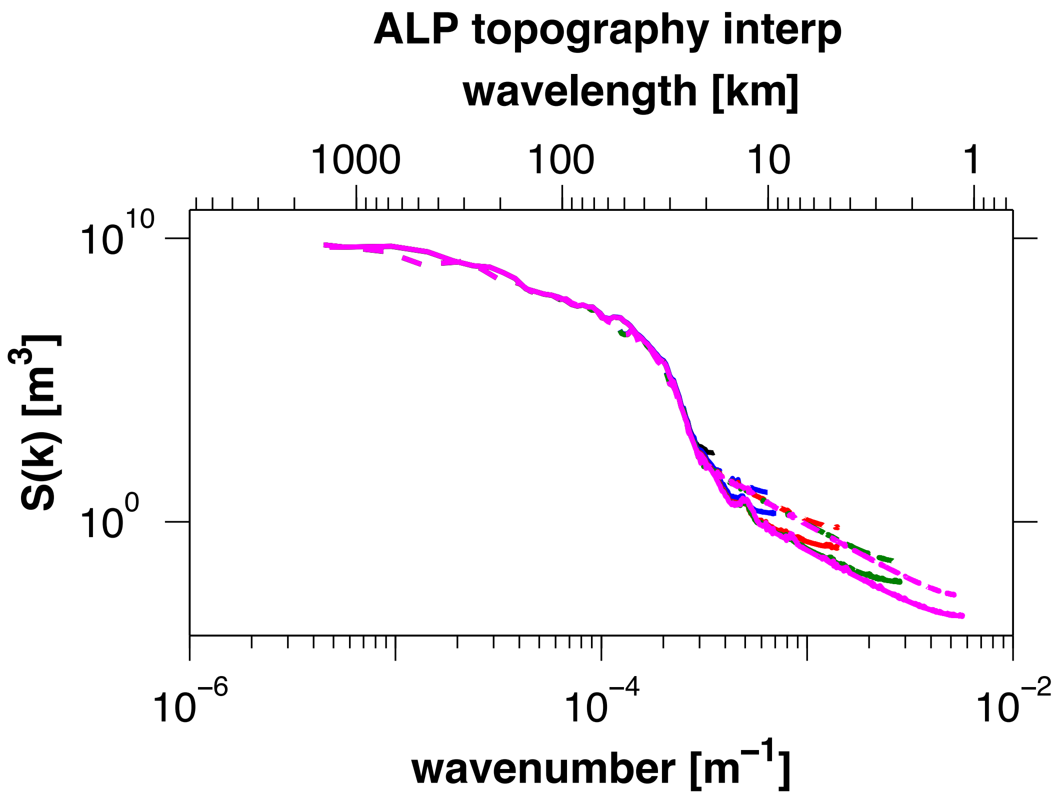
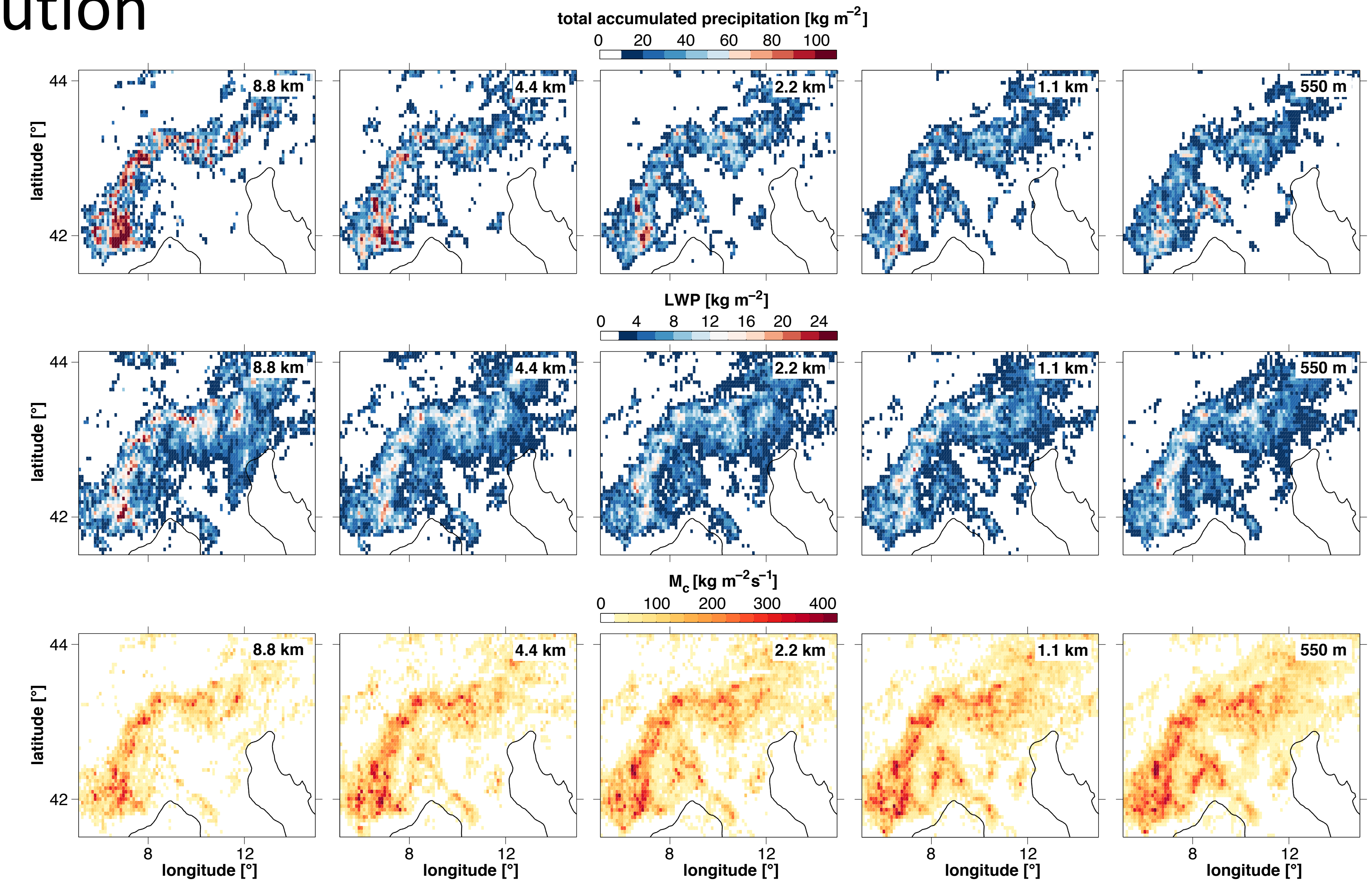




Spatial distribution



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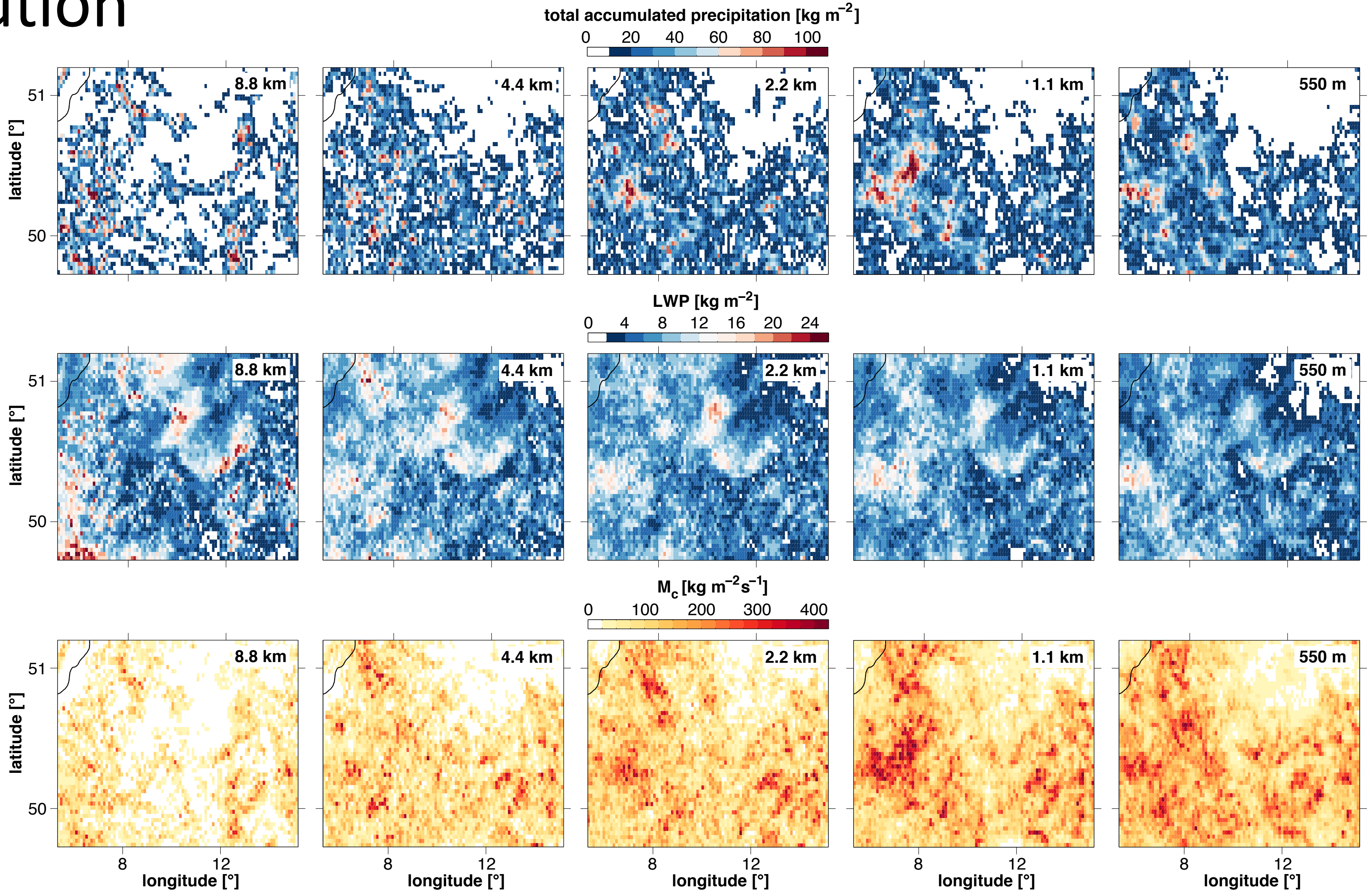

Bulk heat tendencies

$$\frac{\partial \theta}{\partial t} = -\mathbf{v} \cdot \nabla \theta - \frac{1}{\rho c_p}(\nabla \cdot \mathbf{H}) - \frac{1}{\rho c_p}(\nabla \cdot \mathbf{R}) + L_m$$

$$\mathbf{H} = \rho c_p \overline{\mathbf{v}'' \theta''}$$

$$\underbrace{\frac{1}{M}\int_V \rho \frac{\partial \theta}{\partial t} dV}_{\text{TOT}} = \underbrace{-\frac{1}{M}\int_V \rho \mathbf{v} \cdot \nabla \theta \, dV}_{\text{ADV}} + \;\ldots .$$

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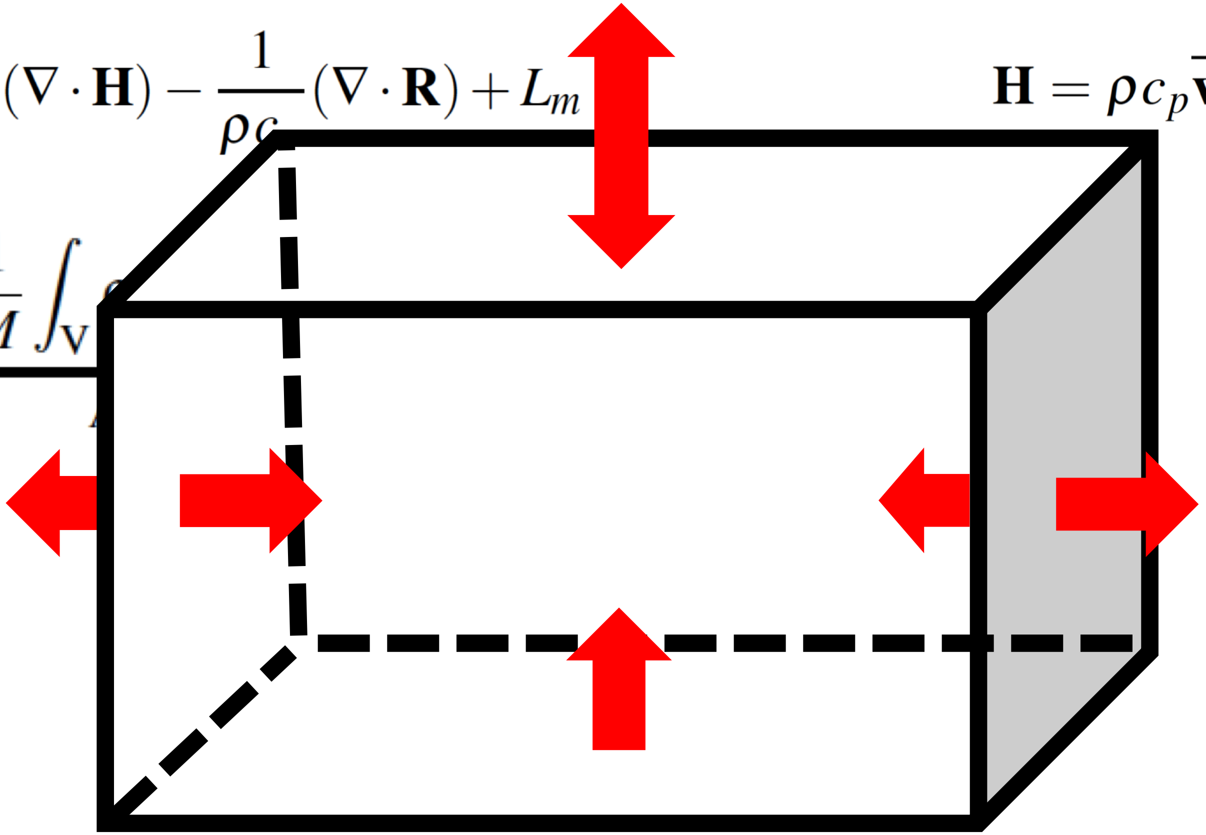

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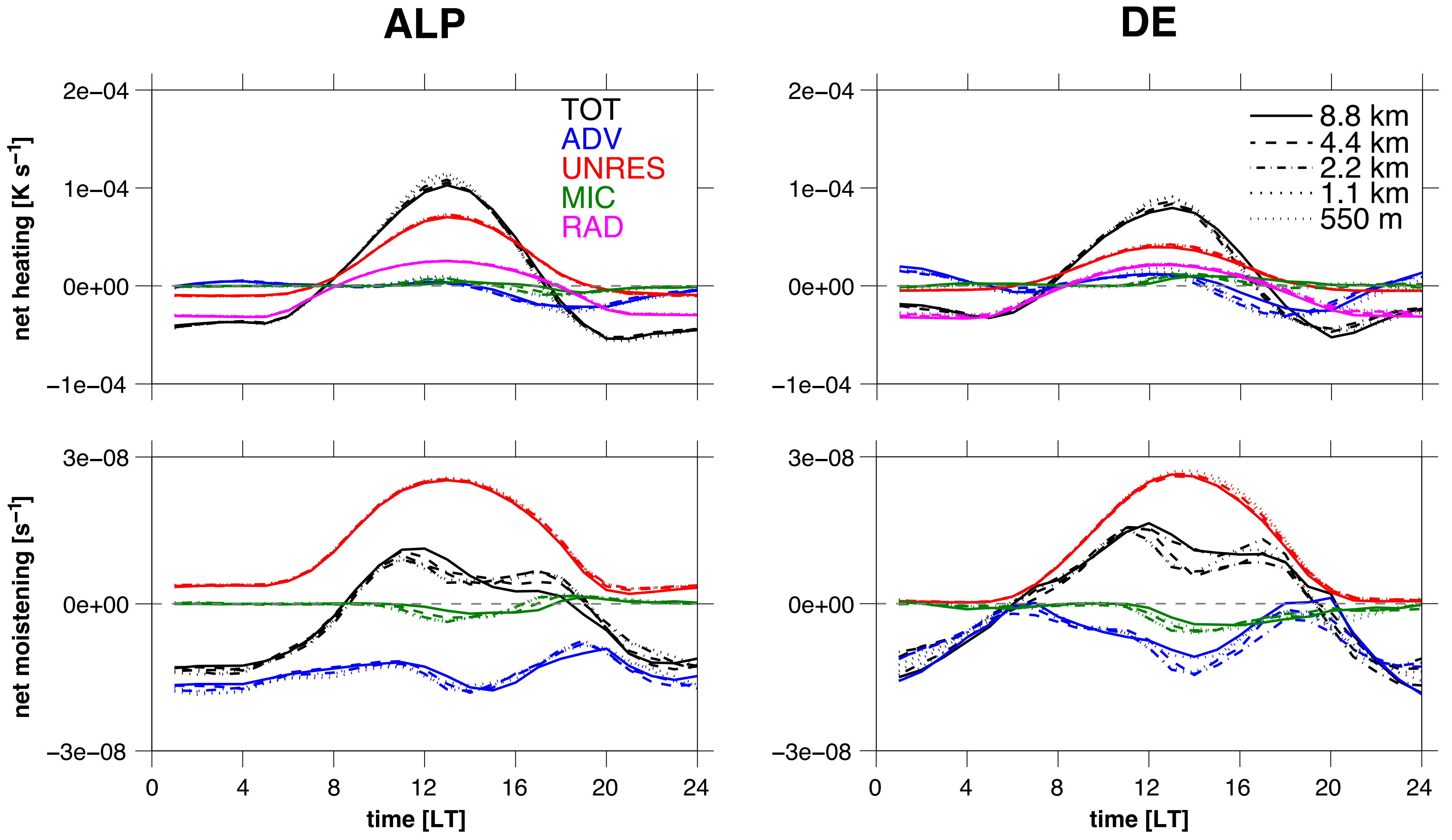
Bulk water vapor tendencies

$$\underbrace{\frac{1}{M}\int_{\mathrm{V}}\rho\frac{\partial q_v}{\partial t}dV}_{\mathrm{TOT}} = \underbrace{-\frac{1}{M}\int_{\mathrm{V}}\rho\mathbf{v}\cdot\nabla q_v\,dV}_{\mathrm{ADV}} + \underbrace{\frac{1}{M}\int_{\mathrm{V}}-\frac{1}{l_v}(\nabla\cdot\mathbf{L})dV}_{\mathrm{UNRES}} + \underbrace{\frac{1}{M}\int_{\mathrm{V}}S_m\,dV}_{\mathrm{MIC}}$$

$$\mathbf{L} = \rho l_v \overline{\mathbf{v}''q_v''}$$

Mean diurnal cycle



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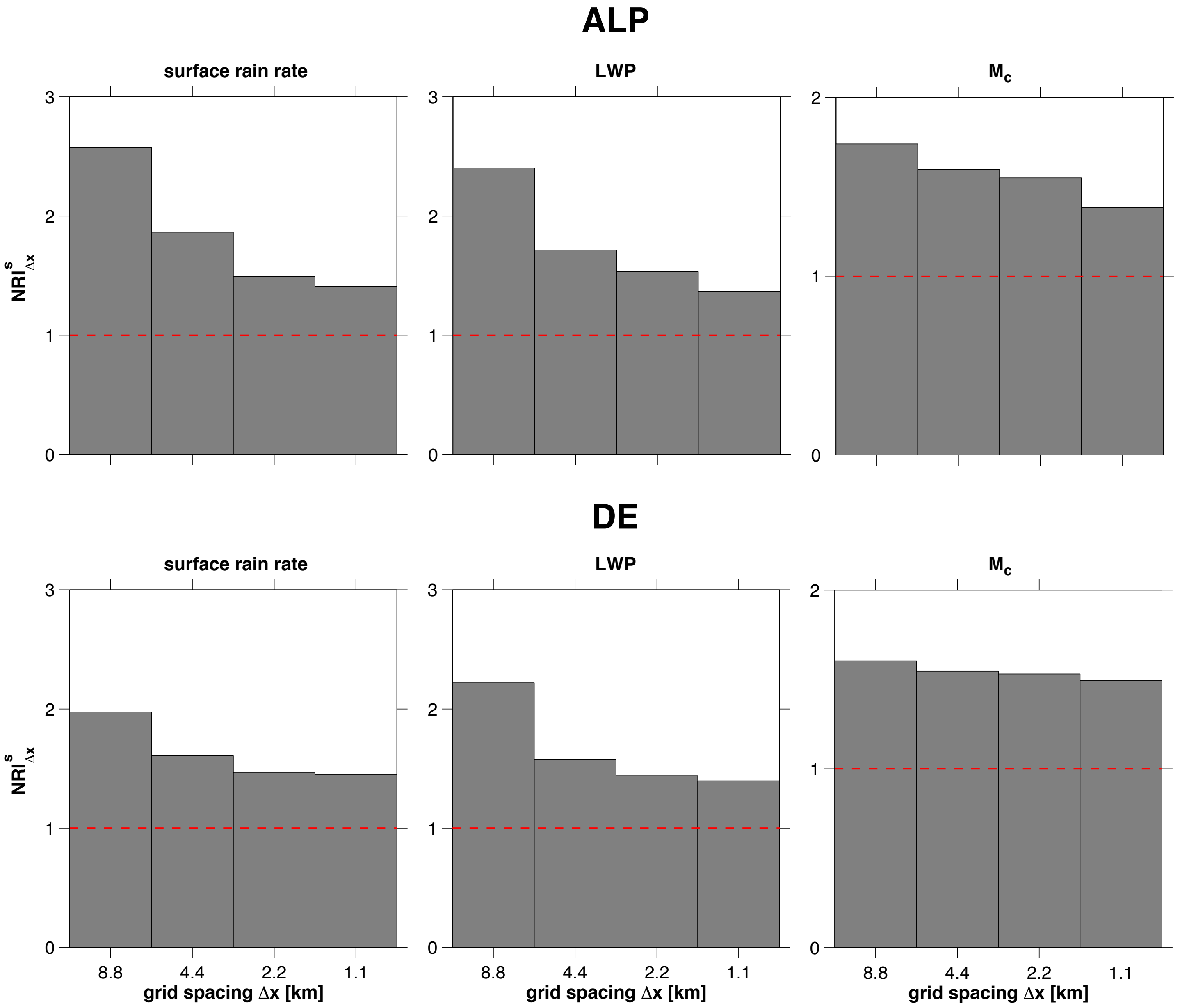
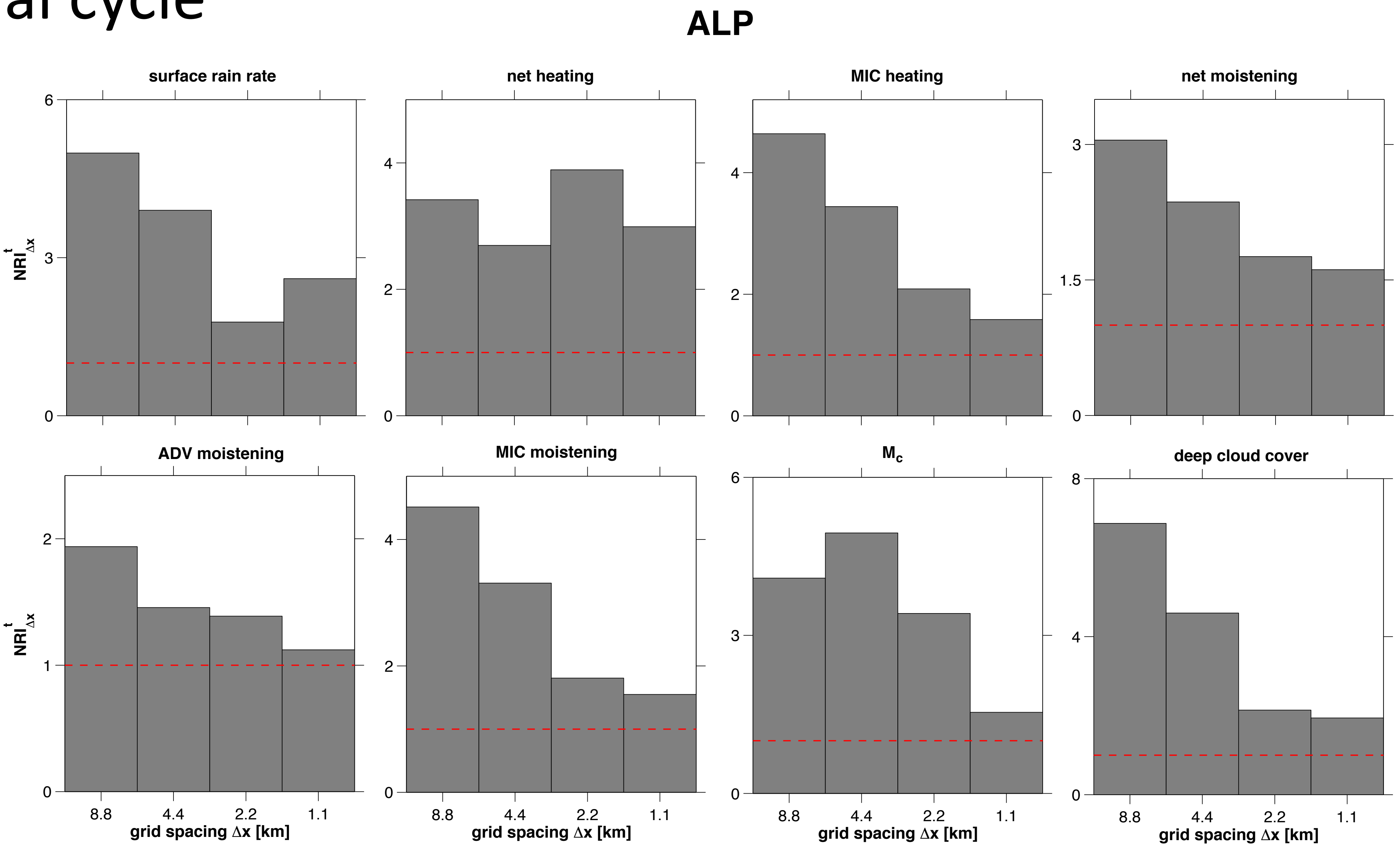
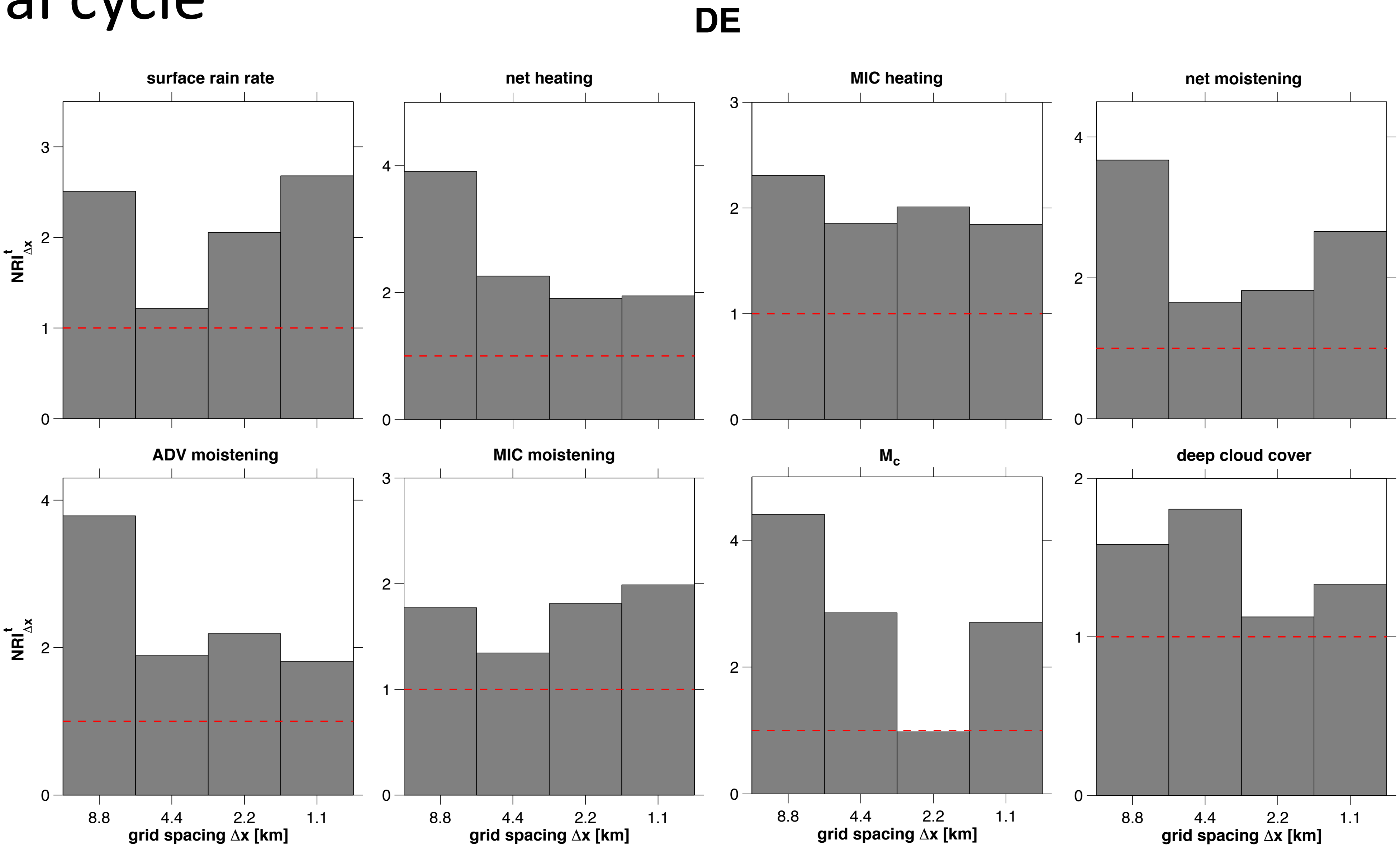


Mean diurnal cycle

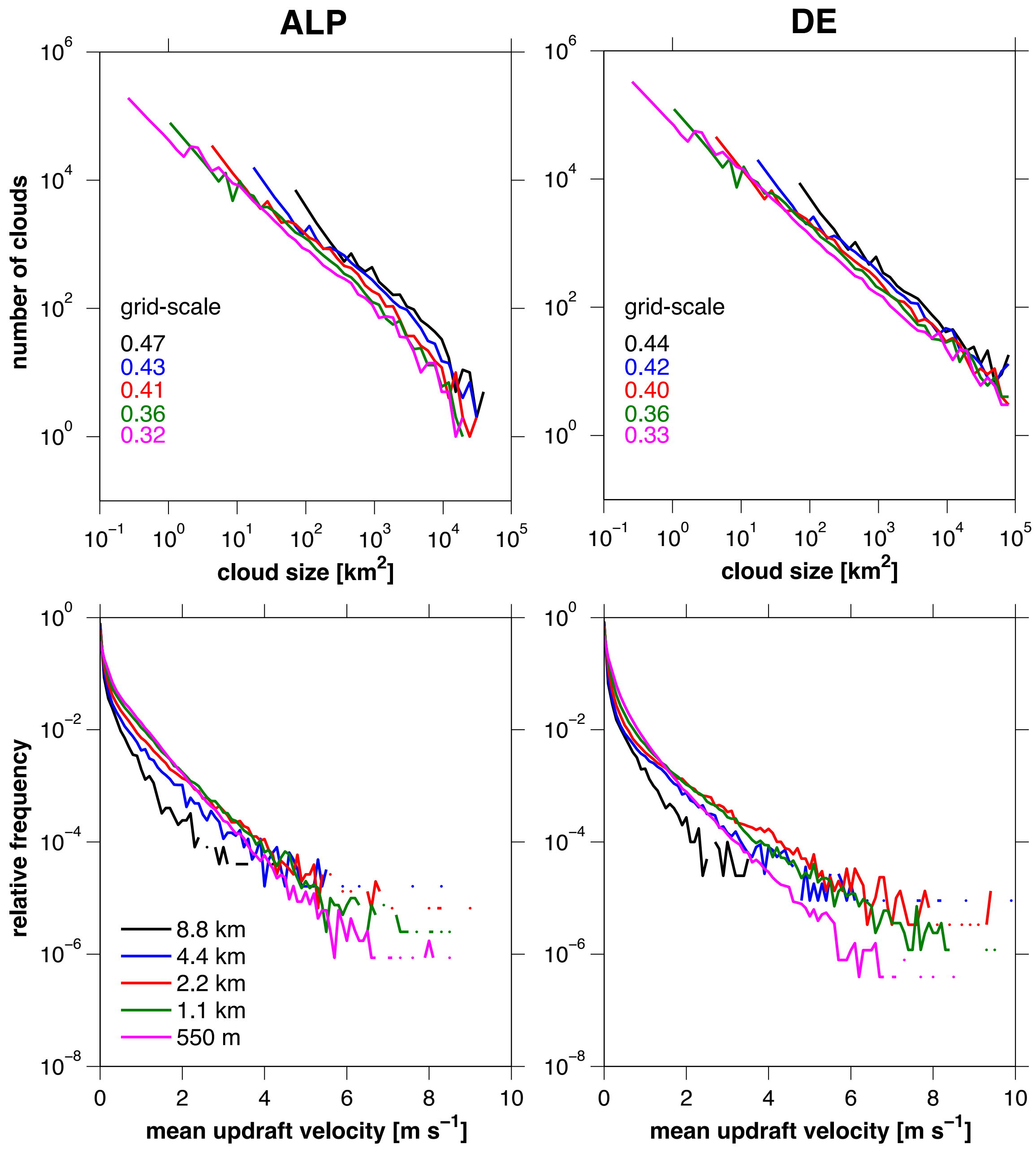


Mean diurnal cycle



Structural convergence

- Size of smallest clouds largely determined by Δx
- More large clouds at coarse resolutions
- Mean updraft velocity within clouds changes with Δx



Summary

- Bulk convergence systematically achieved for spatial distribution
- Bulk convergence generally achieved also for mean diurnal cycle in **ALP**, but not in **DE**
- Orographic forcing reduces resolution sensitivity and generally helps achieving bulk convergence
- Structural convergence not yet achieved at kilometer scale

References

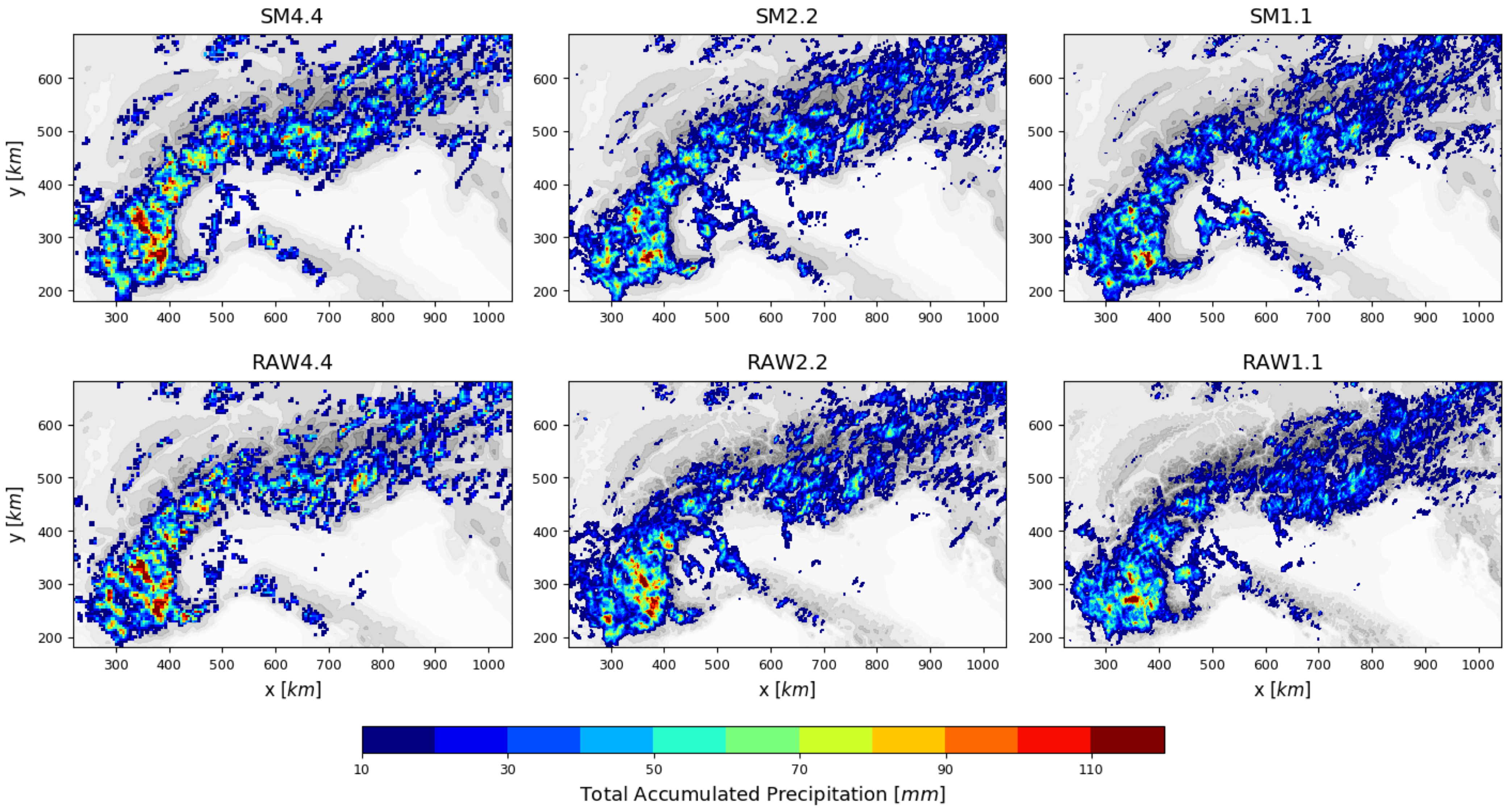
Panosetti D., L. Schlemmer and C. Schär, 2018: **Convergence behavior of idealized convection-resolving simulations of summertime deep convection over land.** *Clim. Dyn.*

Panosetti D., L. Schlemmer and C. Schär, 2018: **Bulk and structural convergence at convection-resolving scales in real-case simulations of summertime moist convection over land.** *Quart. J. Roy. Met. Soc.*, submitted

Outlook

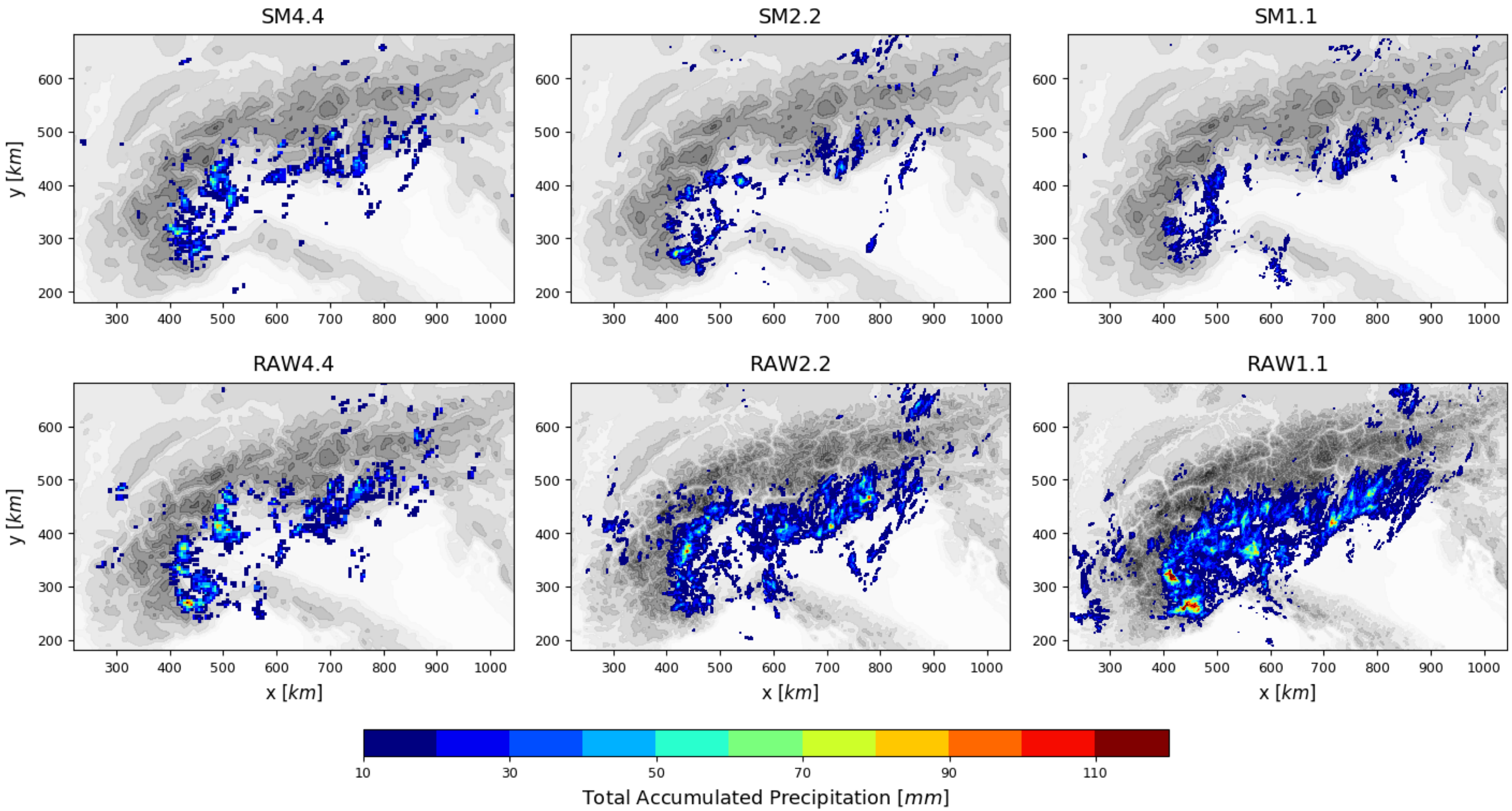
Influence of the resolution of topography and surface fields in real-case simulations of summertime moist convection over the Alps

Outlook



SM4.4
SM2.2
SM1.1
RAW4.4
RAW2.2
RAW1.1
y [km]
x [km]
200
300
400
500
600
300
400
500
600
700
800
900
1000
10
30
50
70
90
110
Total Accumulated Precipitation [mm]

Outlook



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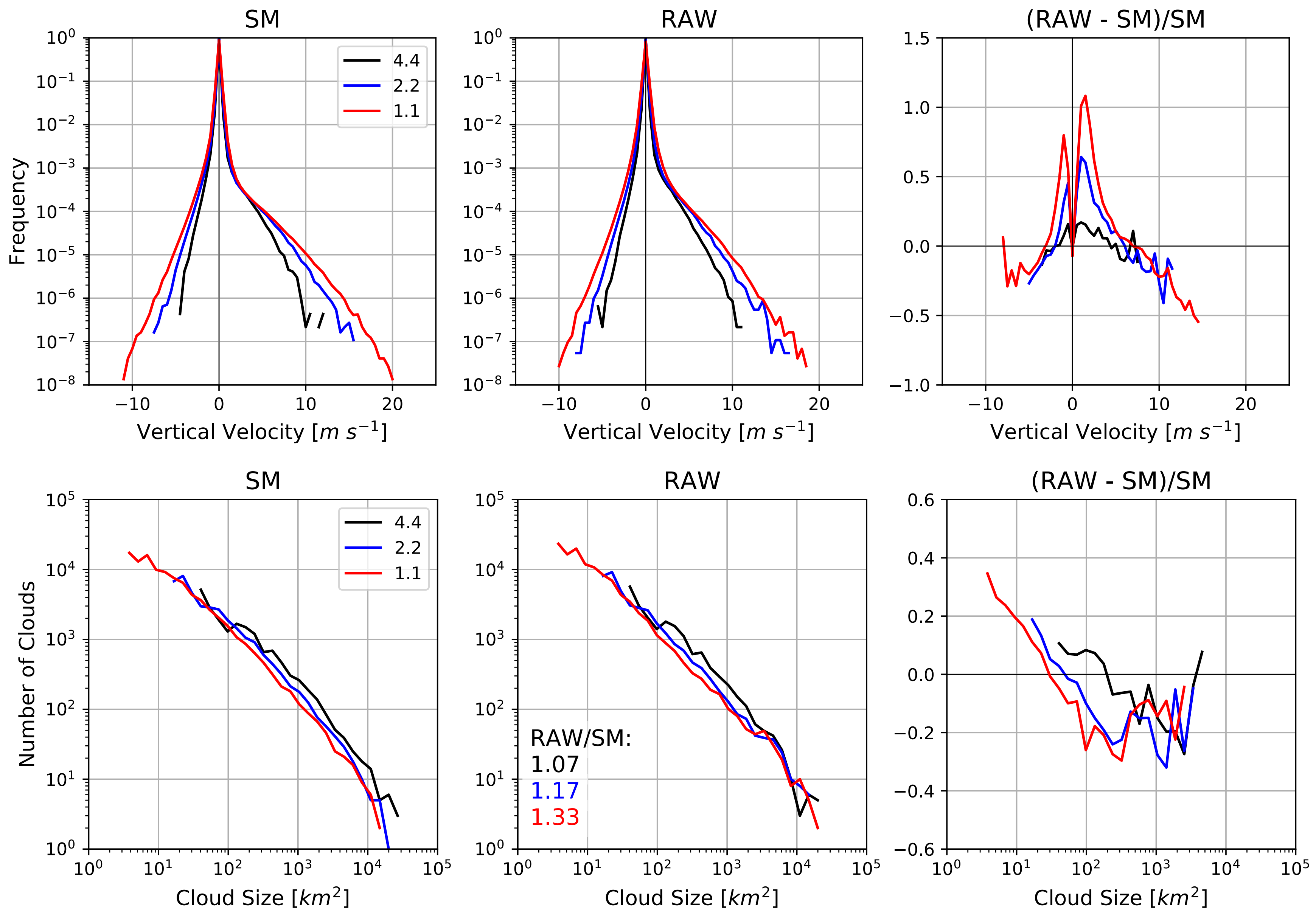

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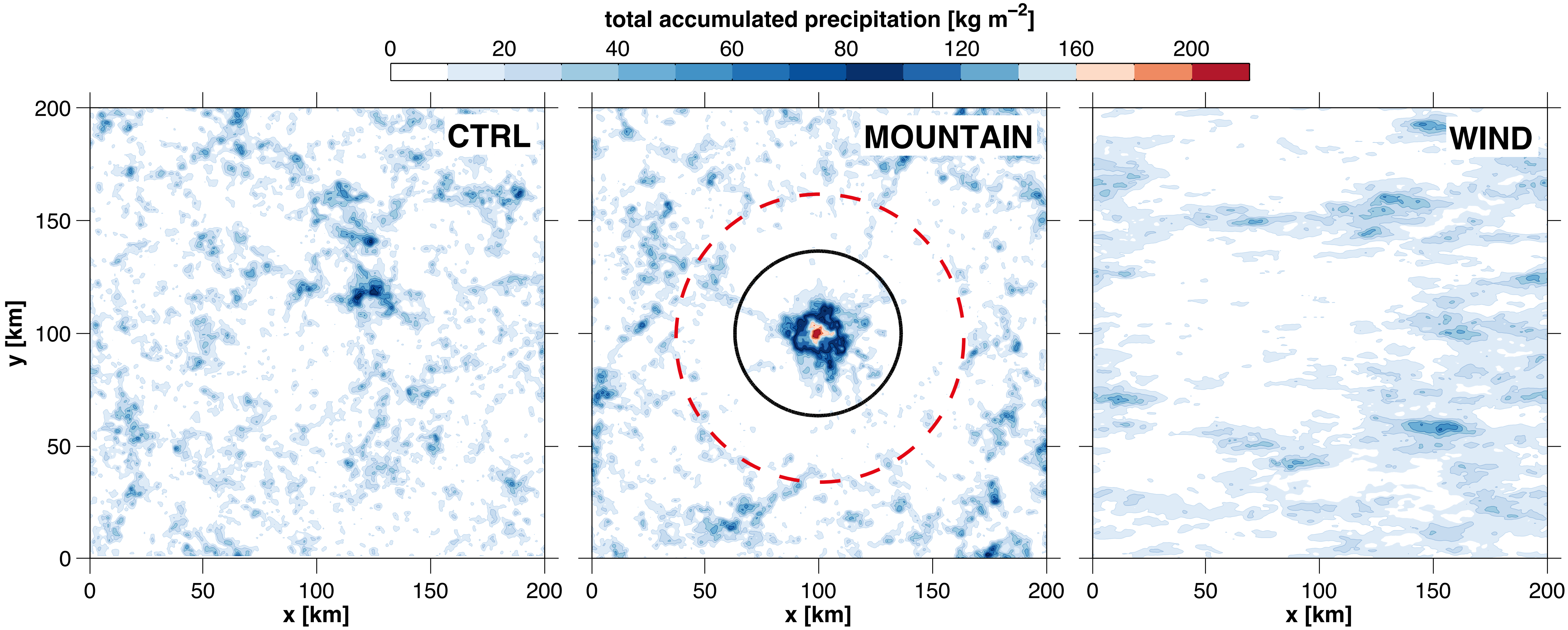
Idealized simulations



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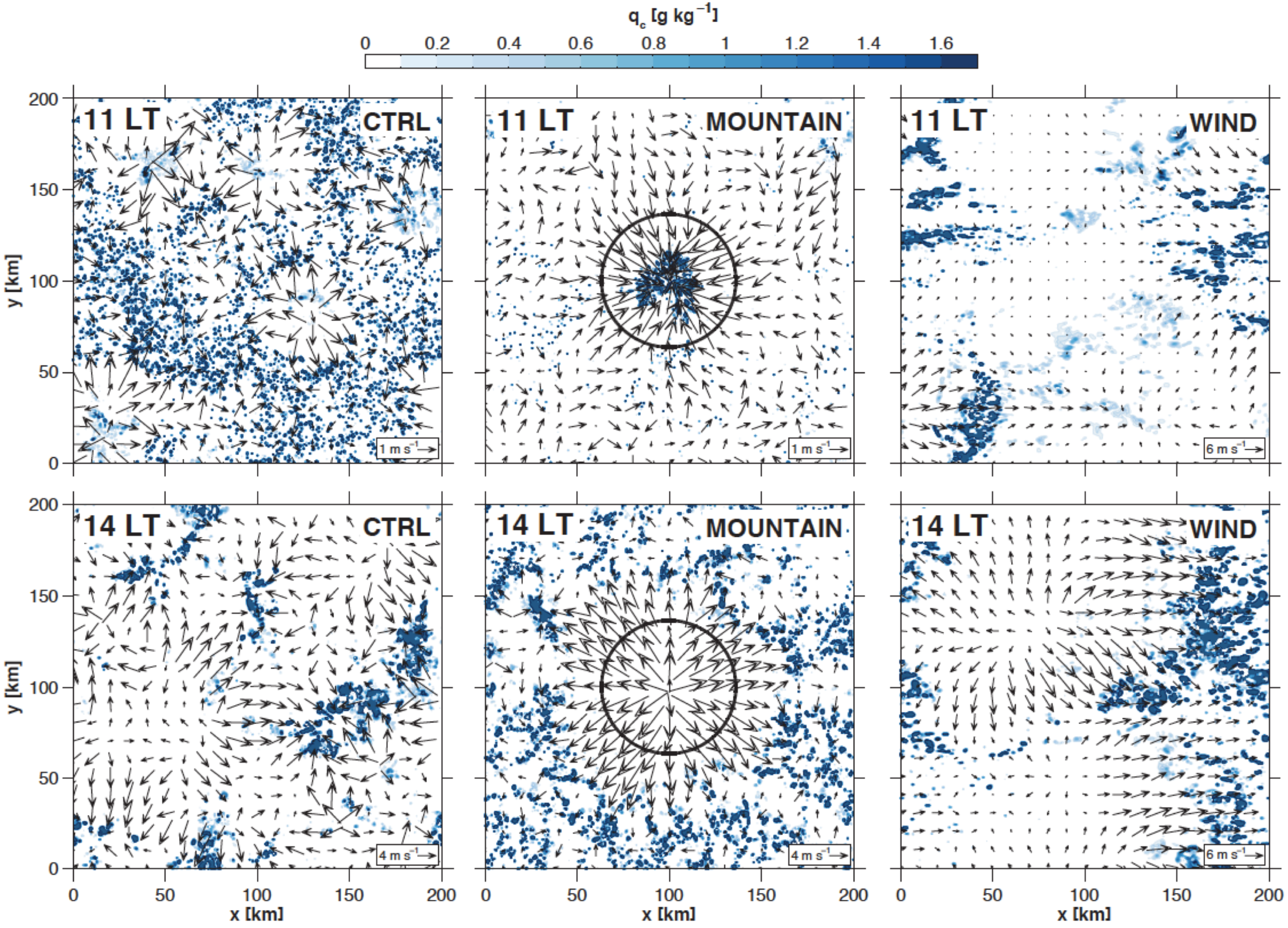
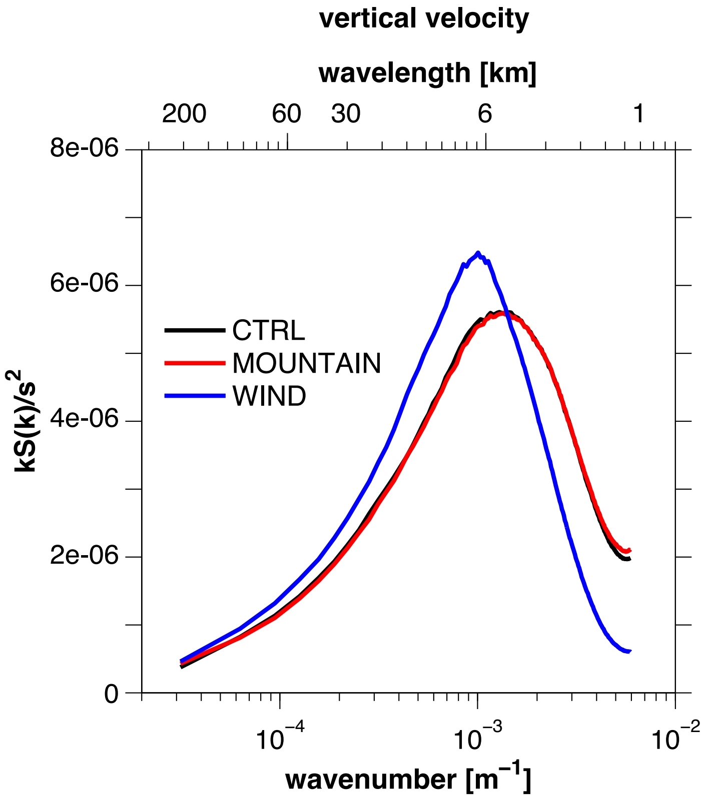


Idealized simulations

MOUNTAIN: pronounced (mesoscale) surface forcing determines initiation timing of precipitation

WIND: cloud clustering → dominant scales to smaller wavenumbers



- spectral peak at smaller wavelengths
- more energy at the large scales
- less energy at very small scales

Real-case simulations