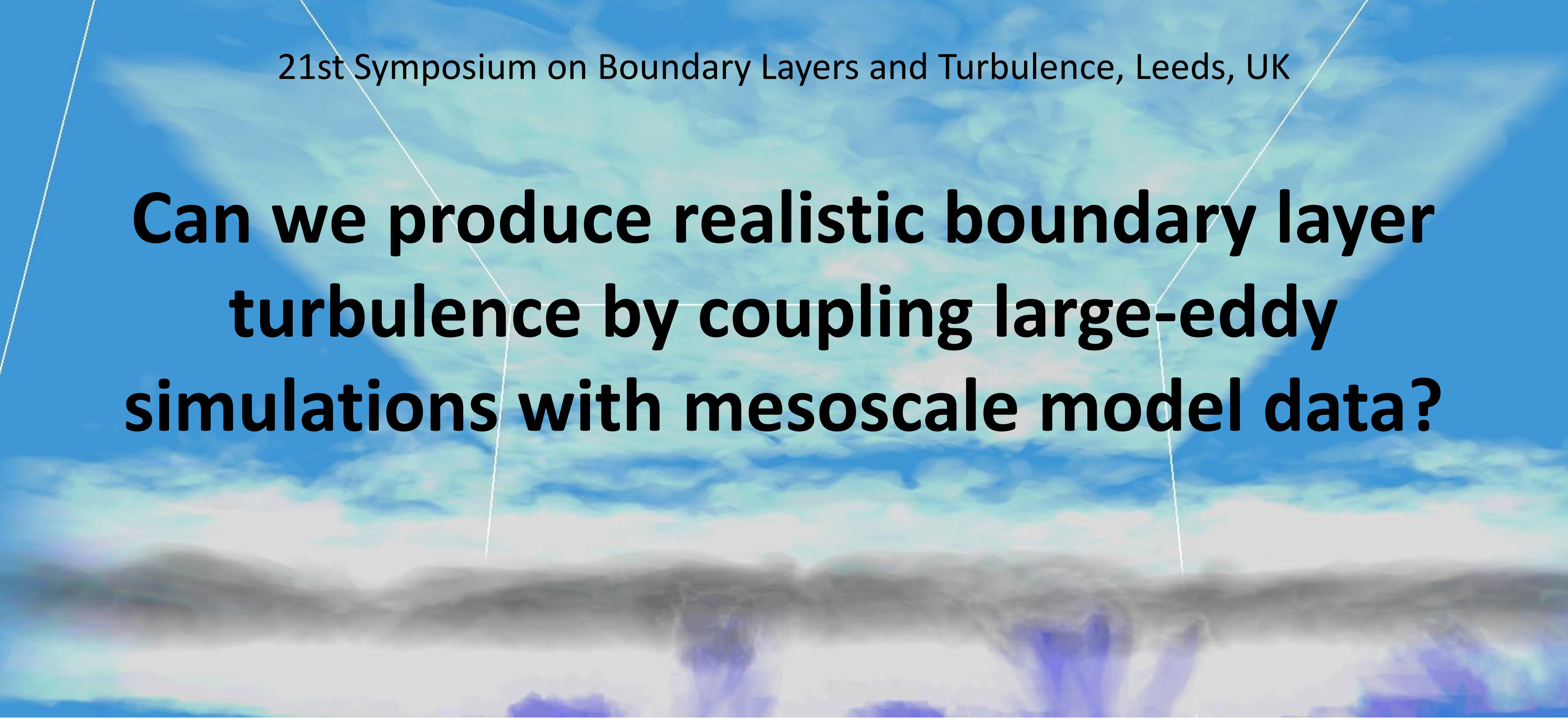


21st Symposium on Boundary Layers and Turbulence, Leeds, UK

Can we produce realistic boundary layer turbulence by coupling large-eddy simulations with mesoscale model data?

Rieke Heinze

Lennart Böske

Siegfried Raasch

Leibniz Universität Hannover

Christopher Moseley

Bjorn Stevens

Max-Planck-Institut für Meteorologie

Session: Theoretical and practical issues associated with multi-scale simulations

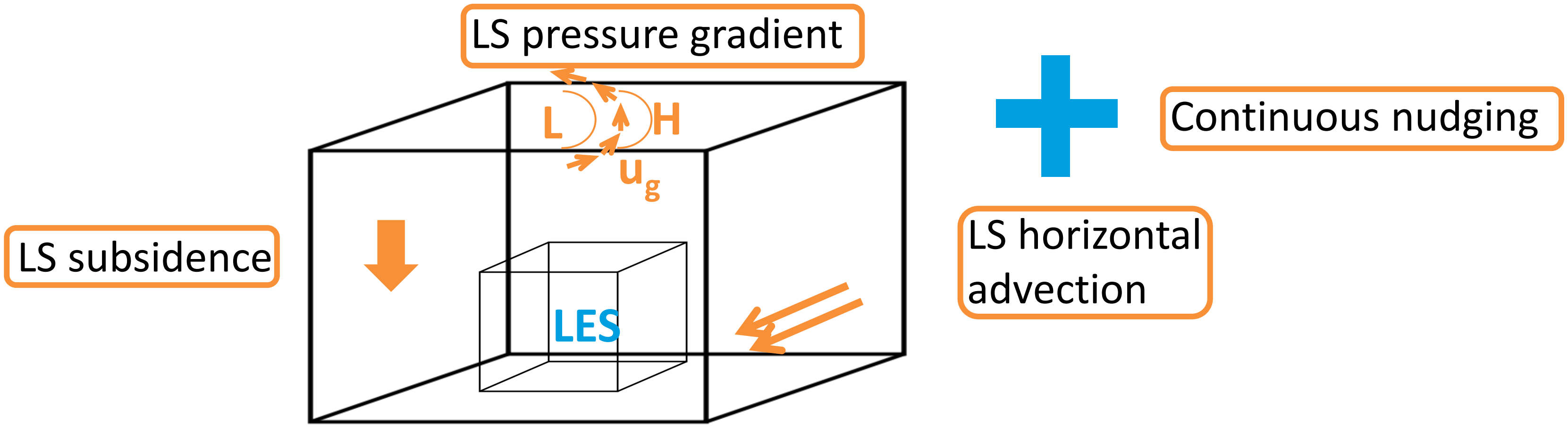
11th June 2014

Realistic boundary layer turbulence

- Important for e.g.
  - Environmental applications (wind engineering)
  - Parameterization development
- Method of choice: large-eddy simulation (LES)

single-day LES → long-term LES

- Long-term LES: recent approach (Neggers et al., 2012, Neggers and Siebesma, 2013)



⇒ Verification by observations from measurement campaign **HOPE**

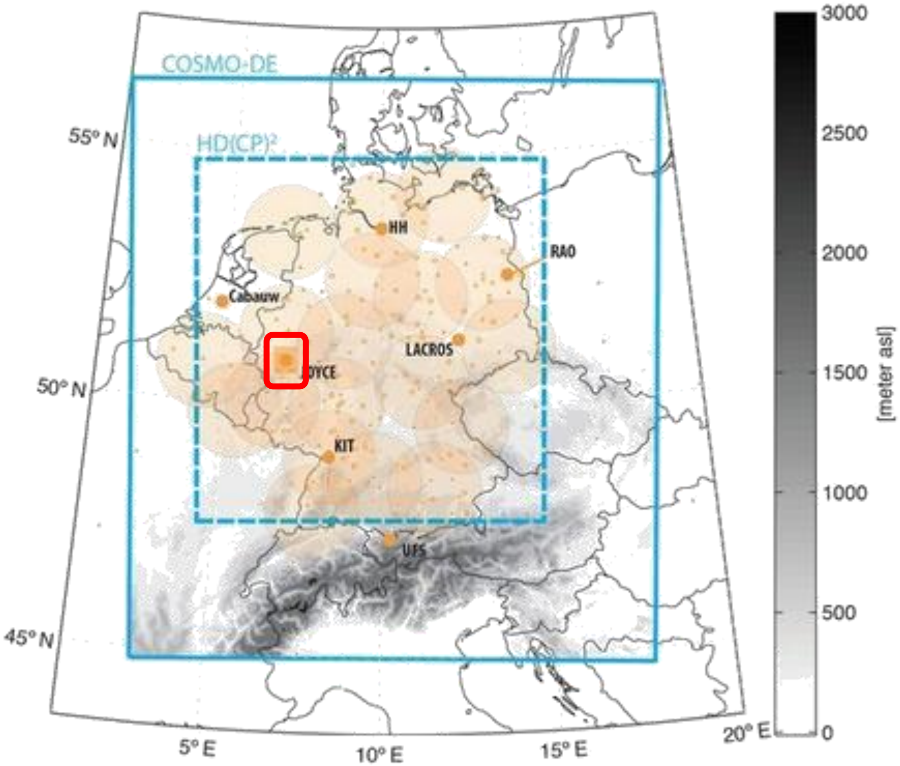
HD(CP)²
High definition clouds and precipitation for advancing climate prediction

HOPE: HD(CP)² Observational Prototype Experiment

HD(CP)²
High definition clouds and precipitation for advancing climate prediction

Main goal:
Build and run a climate/NWP model with very high resolution (Δx≈100m): ICON-LES

Sub-project HOPE:
April-May 2013 centered around *Jülich Forschungszentrum*

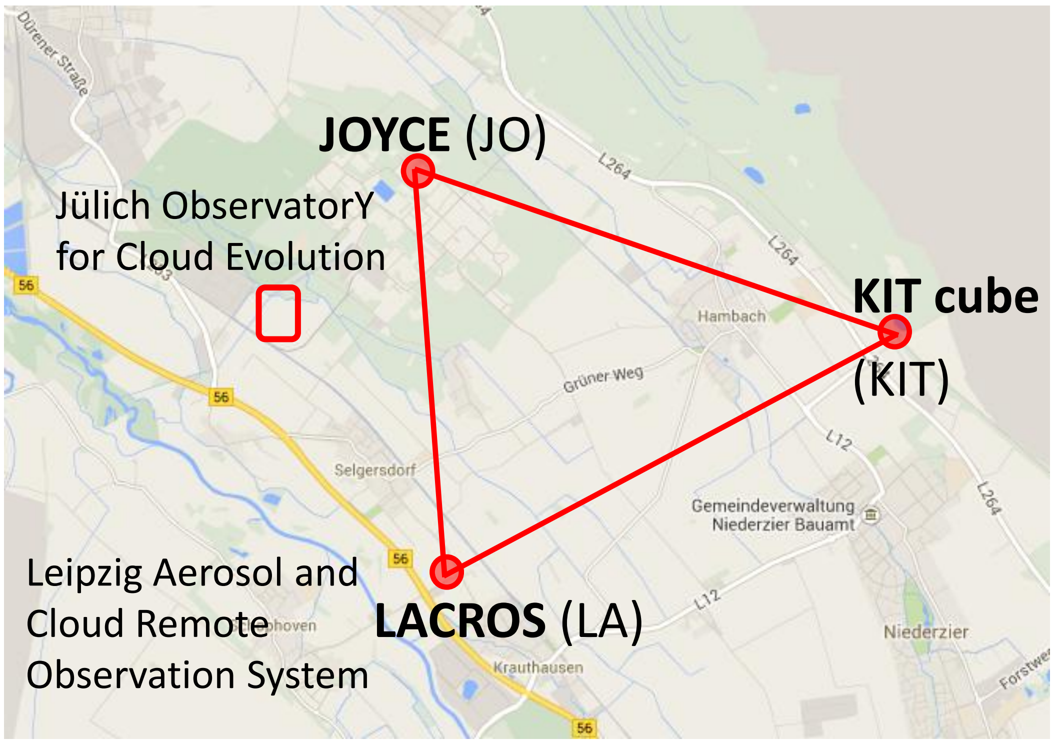


HOPE: HD(CP)² Observational Prototype Experiment

HD(CP)²
High definition clouds and precipitation
for advancing climate prediction

Main goal:
Build and run a climate/NWP model with very high resolution (Δx≈100m): ICON-LES

Sub-project HOPE:
April-May 2013 centered around *Jülich Forschungszentrum*

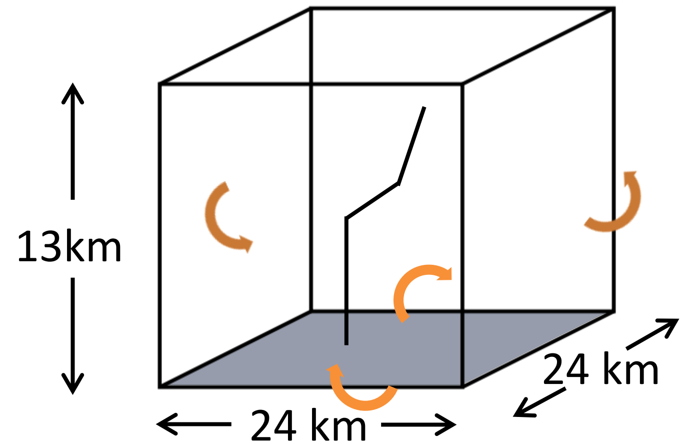


Equipment

- Remote sensing ins- truments (lidars, radars, microwave radiometers)
- Radiosondes
- EC-stations
- Meteorological tower
- Radiation measurements
- …

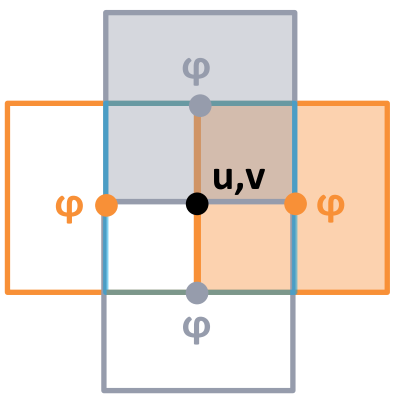
Models and large-scale forcing

- LES models: PALM and UCLA-LES
  - Δ = 50 m, t = 72h (24-26 April 2013)
  - Prescribed θ(t) and q(t) at surface
  - Initial profiles from large-scale forcing
  - Two-moment, warm microphysics



- Large-scale hor. advection:

COSMO-DE analysis data (2°x2° mean)



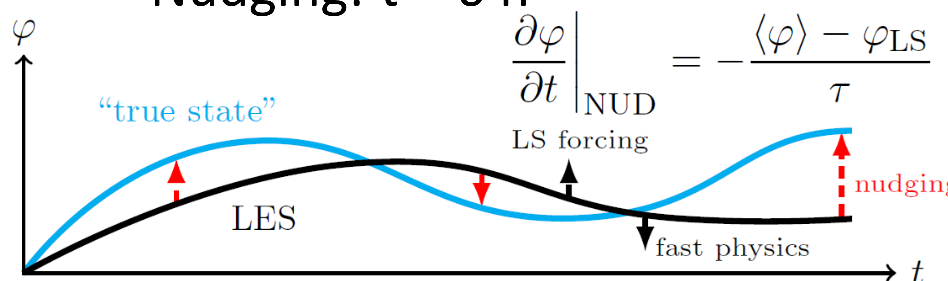
$$\left.\frac{\partial \varphi}{\partial t}\right|_{\mathrm{LSA}} = -\left(u_{\mathrm{LS}}\frac{\partial \varphi_{\mathrm{LS}}}{\partial x} + v_{\mathrm{LS}}\frac{\partial \varphi_{\mathrm{LS}}}{\partial y}\right)$$

- Large-scale vert. advection:

$$\left.\frac{\partial \varphi}{\partial t}\right|_{\mathrm{SUB}} = -w_{\mathrm{LS}}\frac{\partial \varphi}{\partial z}$$

- Geostrophic wind: $\vec{v}_{\mathrm{g}}(t)$
- Nudging: τ = 6 h

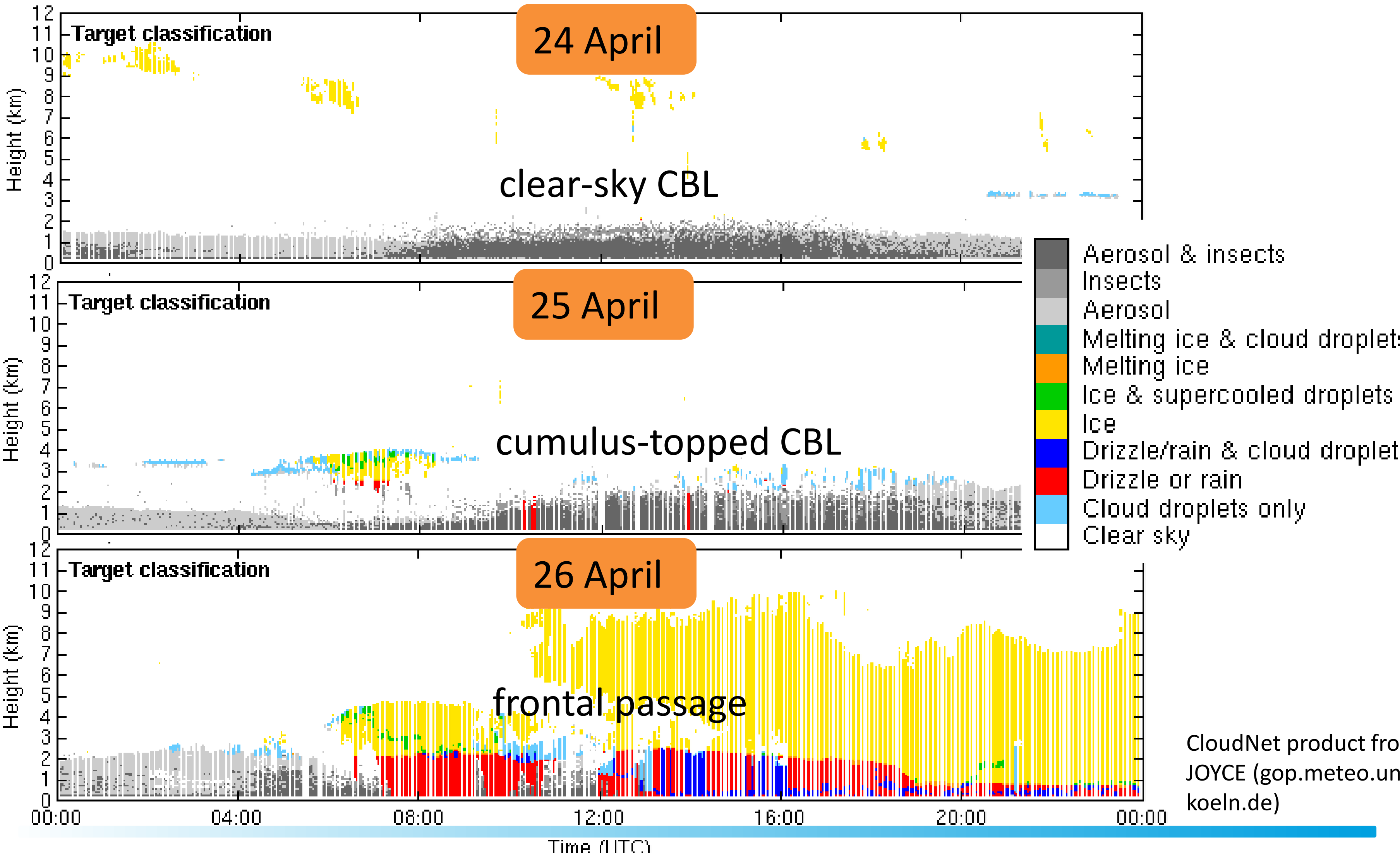
$$\left.\frac{\partial \varphi}{\partial t}\right|_{\mathrm{NUD}} = -\frac{\langle\varphi\rangle - \varphi_{\mathrm{LS}}}{\tau}$$



based on Neggers et al., 2012

HD(CP)²
High definition clouds and precipitation for advancing climate prediction

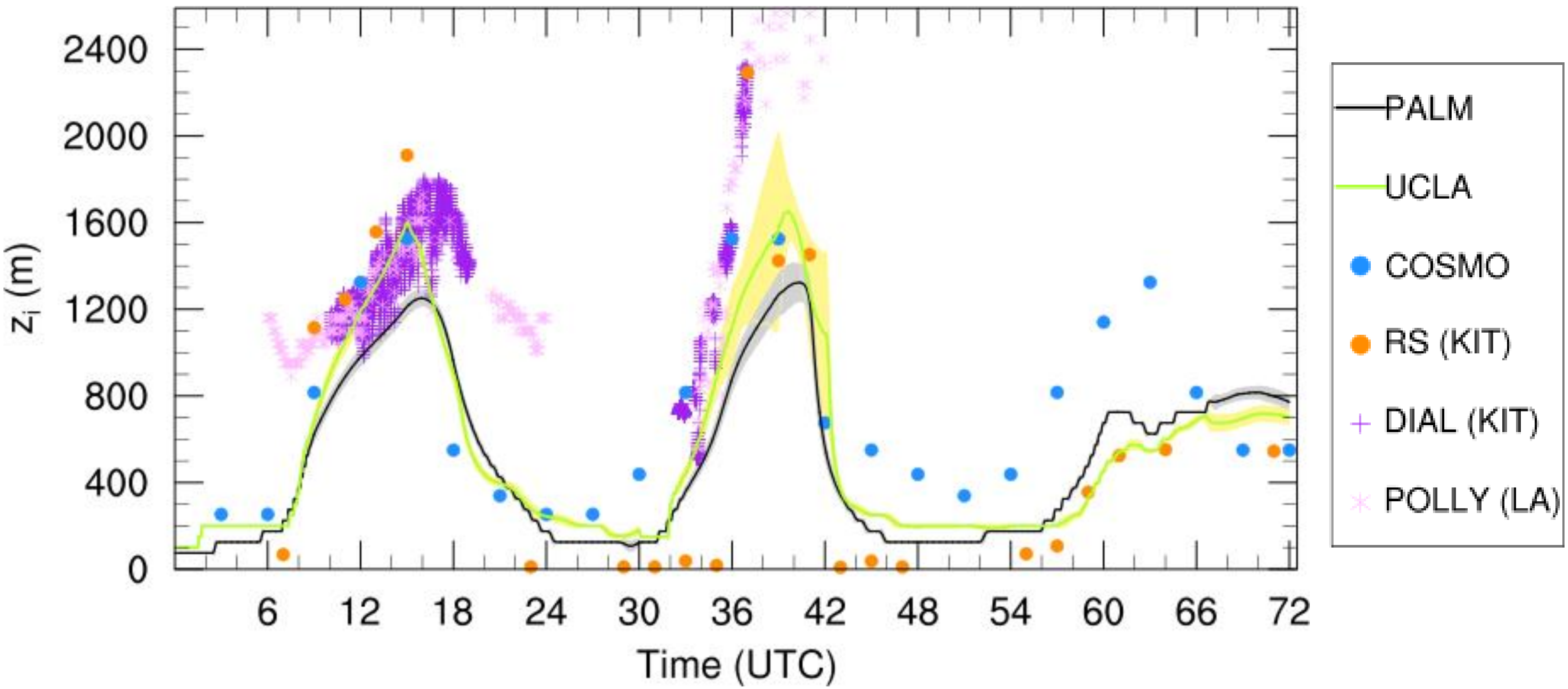
24-26 April – as seen by remote sensing instruments



CloudNet product from JOYCE (gop.meteo.uni-koeln.de)

Boundary layer depth

z_i: height where $\mathrm{Ri_b} = \frac{g}{\theta_{v0}} \frac{\theta_v - \theta_{v0}}{u^2 + v^2} z$ is larger than 0.25 (e.g. Richardson et al., 2013)

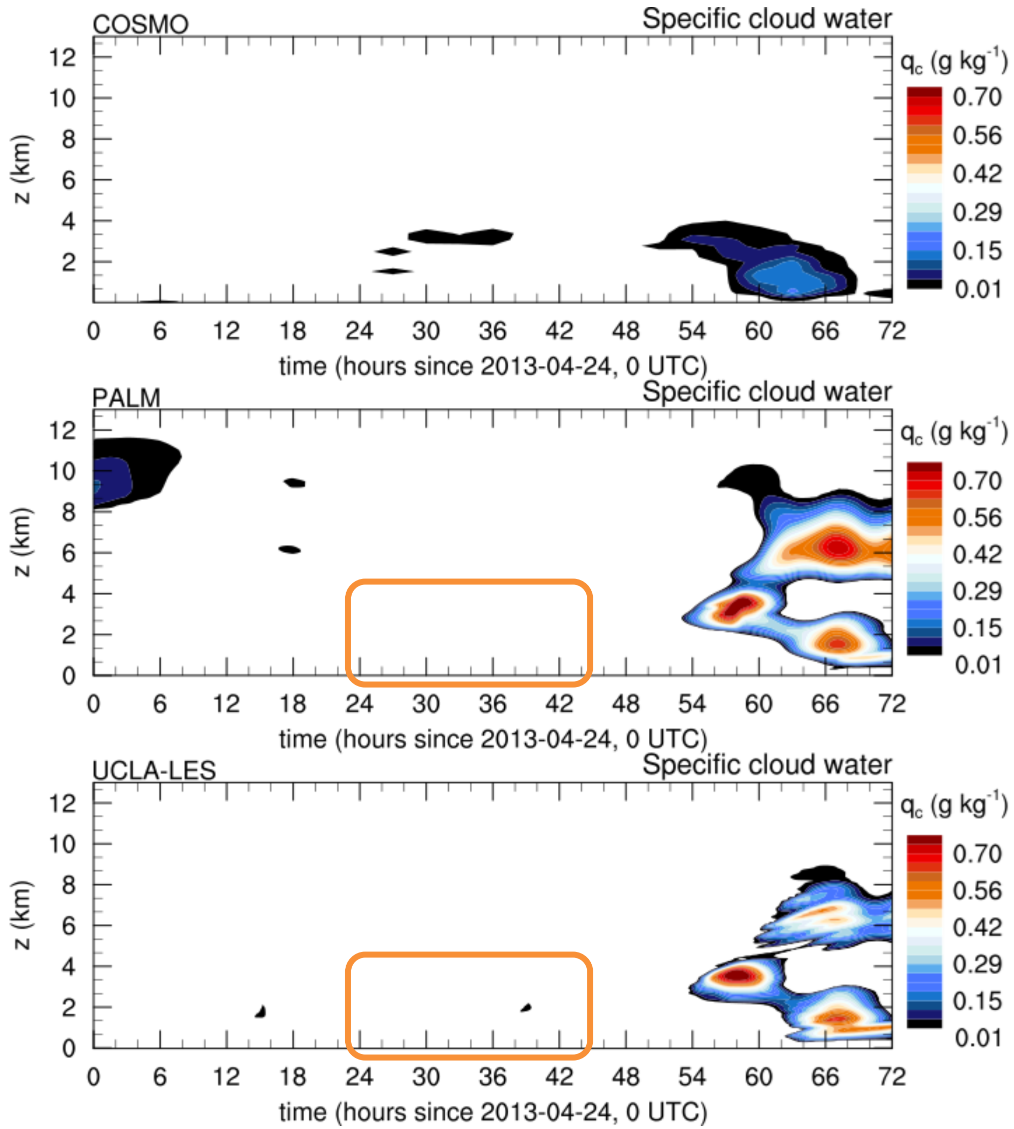


⇒ LES produce daily cycles in reasonable agreement with observations

Clouds and precipitation

- Deeper cloud layers on 26/4 can be simulated by both LES models

- Shallow cloud layer on 25/4 is missing (completely) in LES

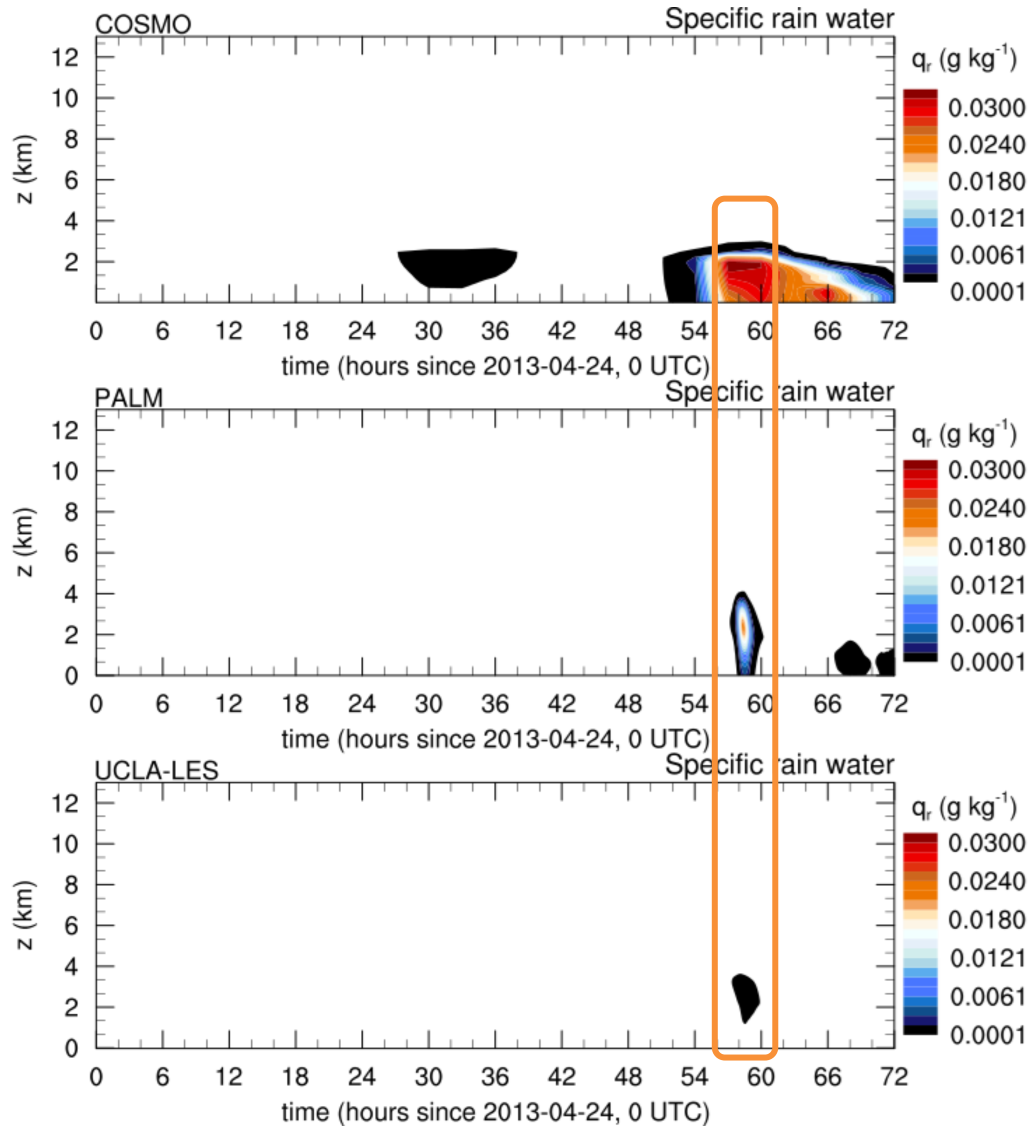


HD(CP)²
High definition clouds and precipitation for advancing climate prediction

Clouds and precipitation

- Deeper cloud layers on 26/4 can be simulated by both LES models
- Shallow cloud layer on 25/4 is missing (completely) in LES
- Peak in rain water at same time as in forcing
- LES were run with warm-microphysics only

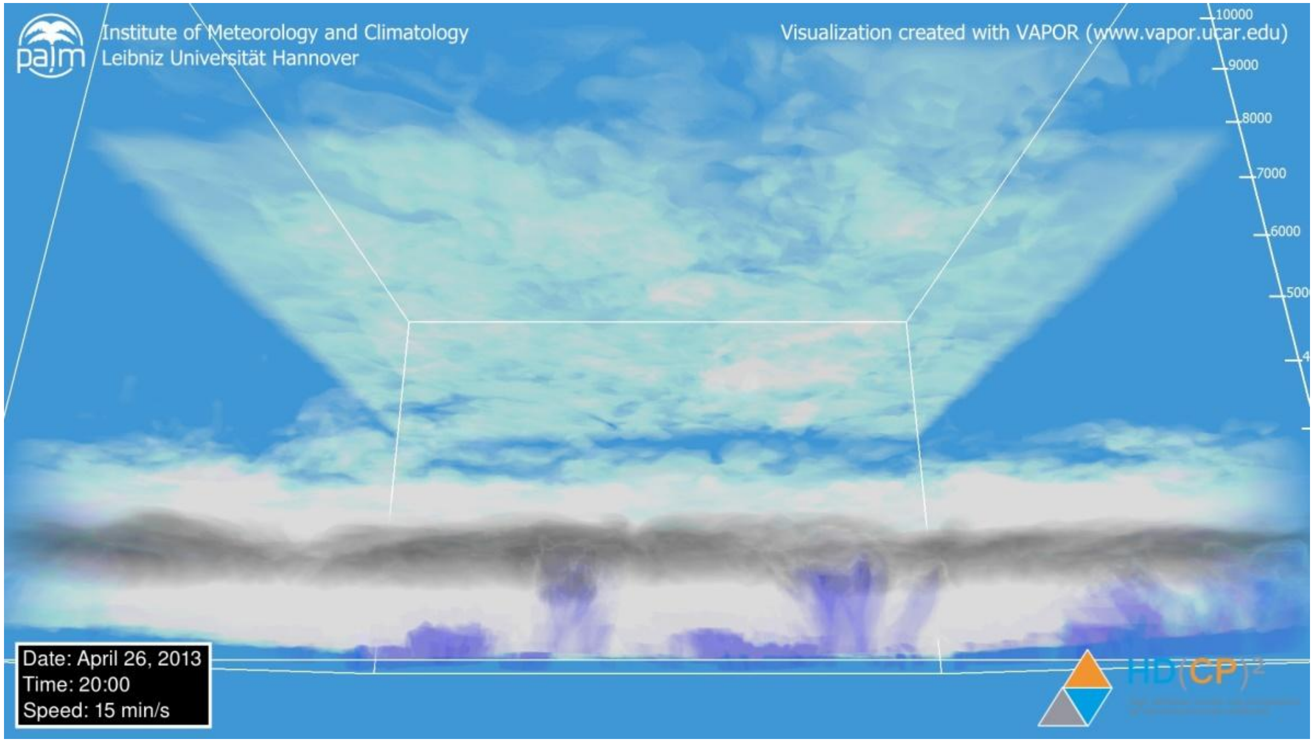
⇒ Clouds are a bit tricky

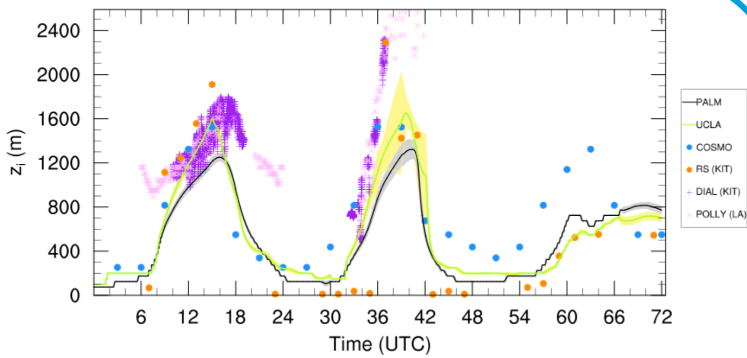


HD(CP)²
High definition clouds and precipitation for advancing climate prediction

Animation

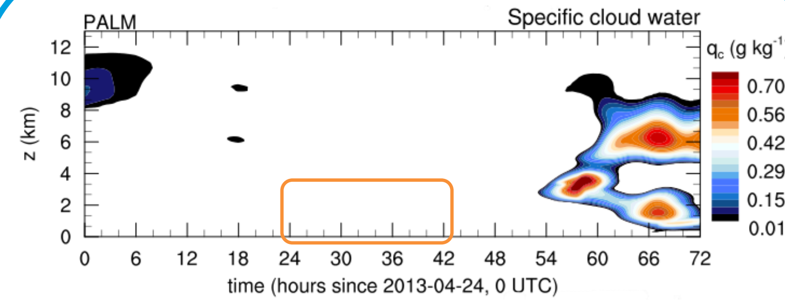
- Model: PALM
- Quantities: q_c and q_r
- Note: large-scale forcing from 0.25°x0.25° COSMO mean used





- Long-term LES approach gives reasonable daily cycles

⇒ Observed situations can principally be reproduced



- Shallow cumulus clouds could not be simulated

⇒ Strong dependence on large-scale advective forcing

⇒ Long-term LES approach works - but LES remain a virtual laboratory

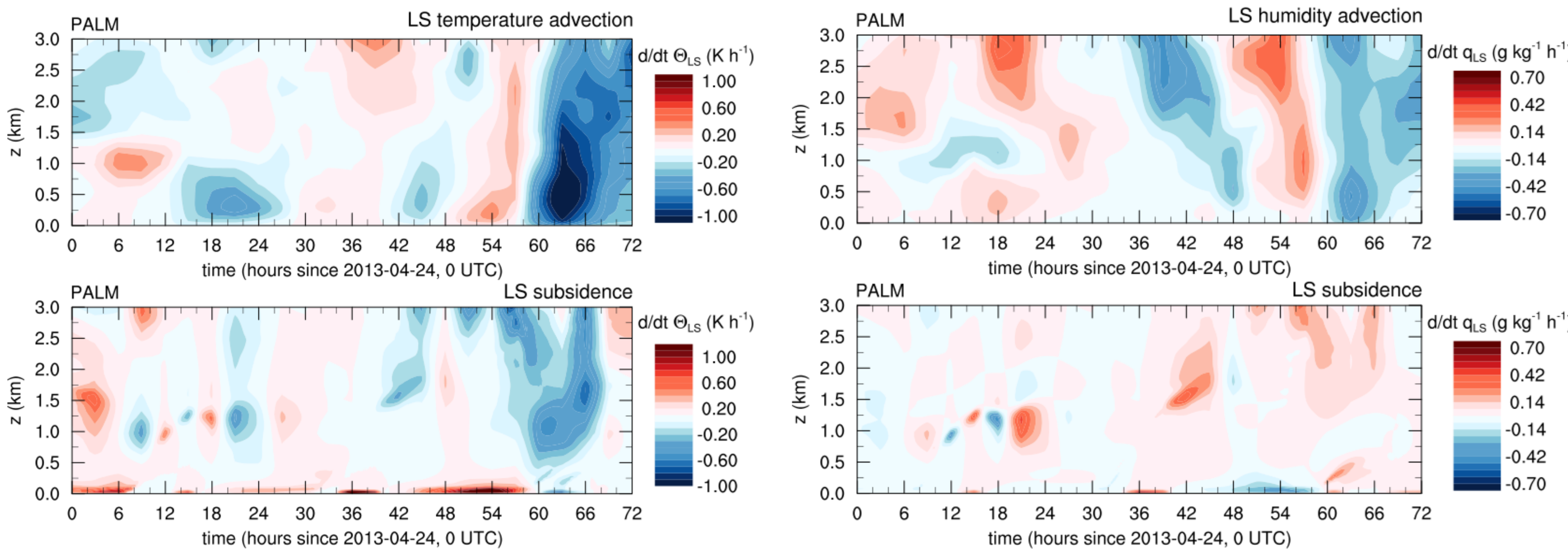
Outlook:

- In-depth evaluation of large-scale forcing dependency
- Heterogeneous surface

Supplementary material

Large-scale forcing tendencies

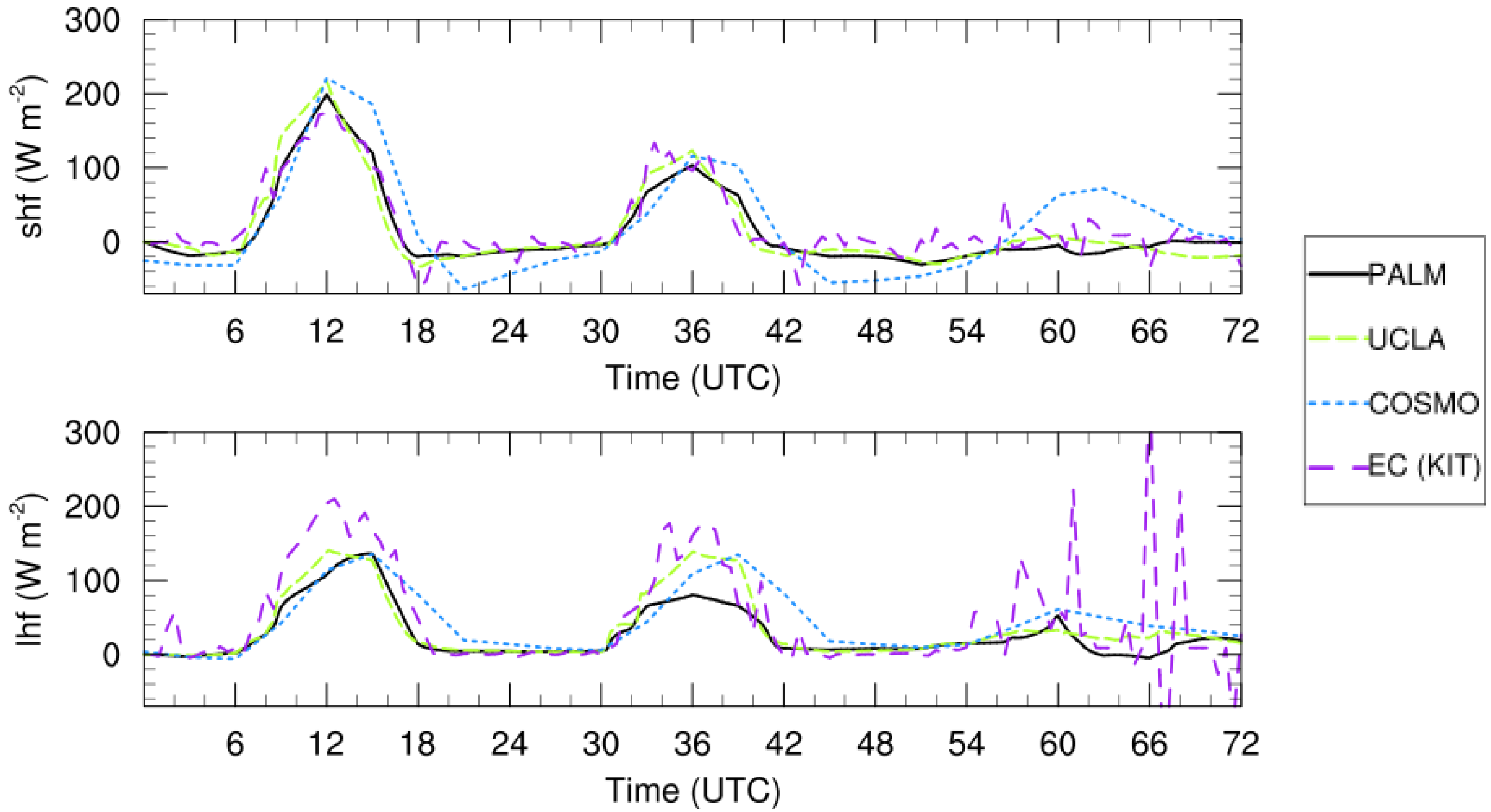
Large-scale horizontal advection: $$\left.\frac{\partial \varphi}{\partial t}\right|_{\mathrm{LSA}} = -\left(u_{\mathrm{LS}}\frac{\partial \varphi_{\mathrm{LS}}}{\partial x} + v_{\mathrm{LS}}\frac{\partial \varphi_{\mathrm{LS}}}{\partial y}\right)$$



Large-scale vertical advection: $$\left.\frac{\partial \varphi}{\partial t}\right|_{\mathrm{SUB}} = -w_{\mathrm{LS}}\frac{\partial \varphi}{\partial z}$$

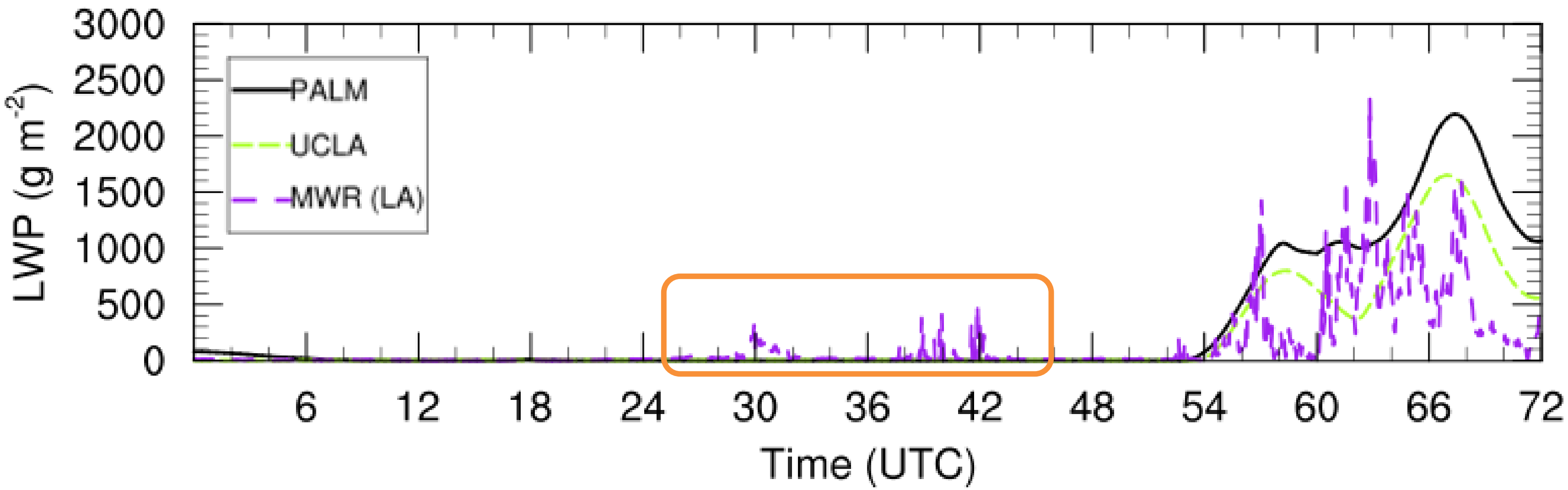
Surfaces fluxes

Surface sensible (shf) and latent (lhf) heat fluxes

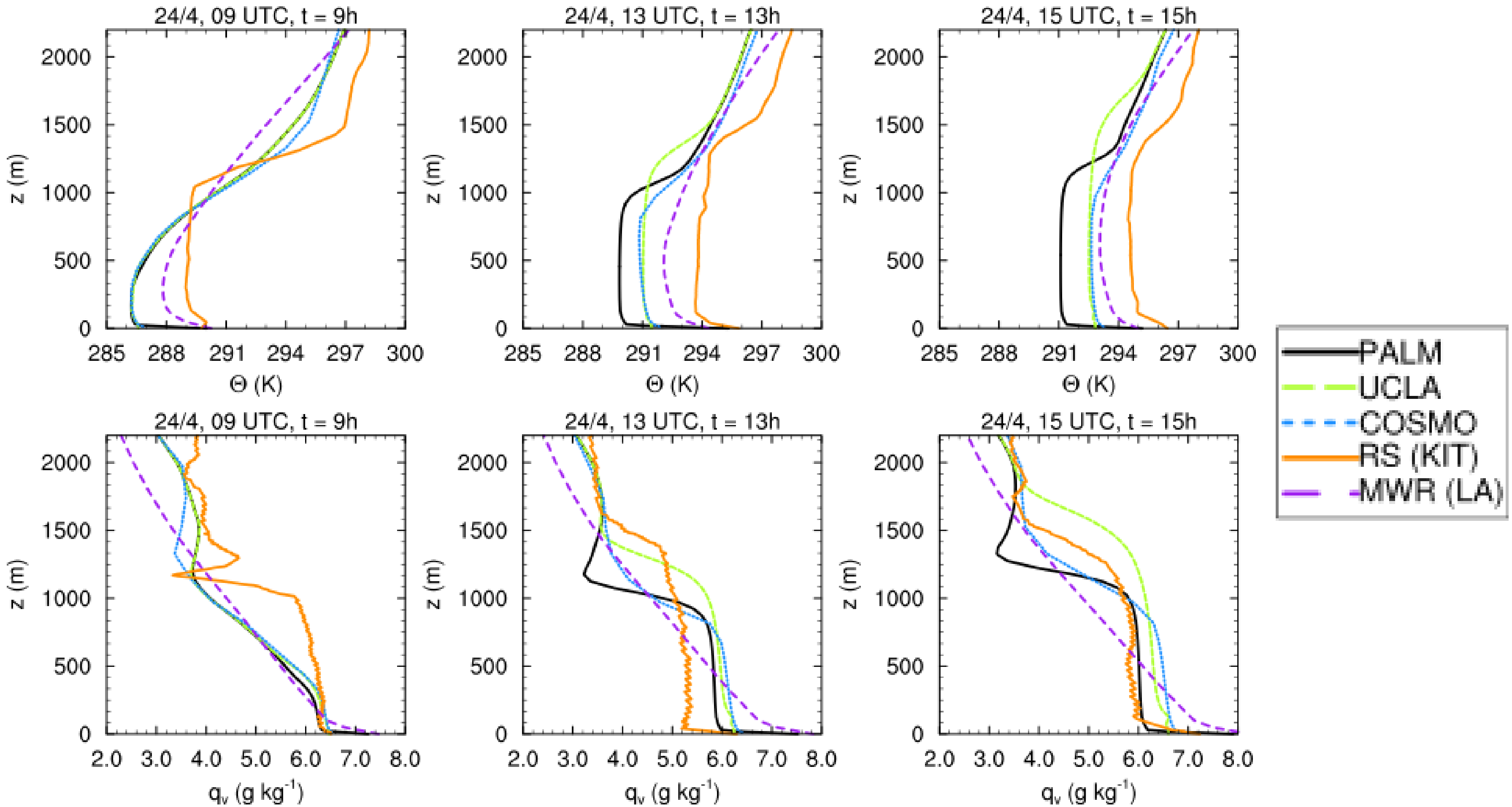


⇒ LES fluxes are representative for HOPE site

Liquid water path



Mean profiles: Boundary layer developing on 24/4

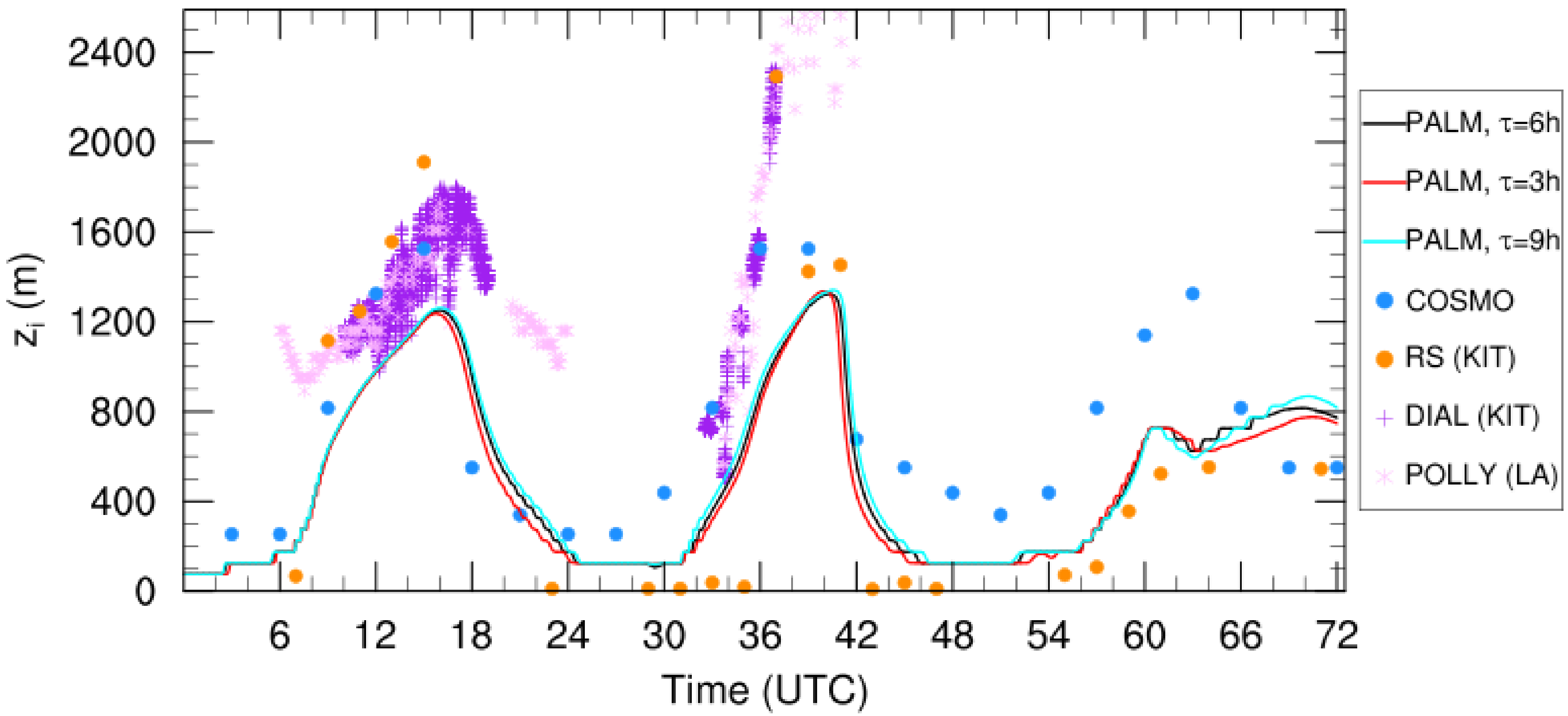


⇒ Simulated boundary layers are colder than in observations

HD(CP)²
High definition clouds and precipitation for advancing climate prediction

Sensitivity to relaxation time scale τ

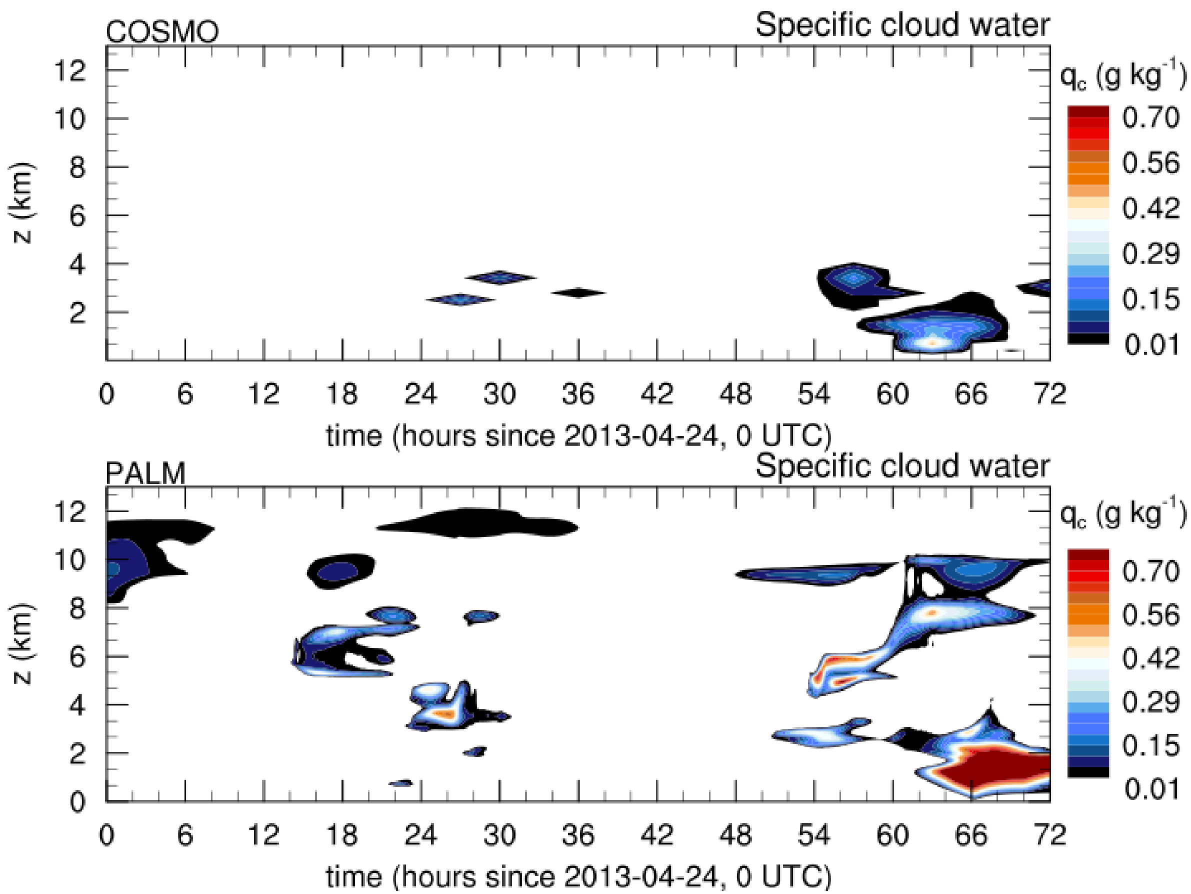
Nudging tendency: $$\left.\frac{\partial \varphi}{\partial t}\right|_{\mathrm{NUD}} = -\frac{\langle \varphi \rangle - \varphi_{\mathrm{LS}}}{\tau}$$



⇒ Virtually no dependence on relaxation time scale

Setup for animation

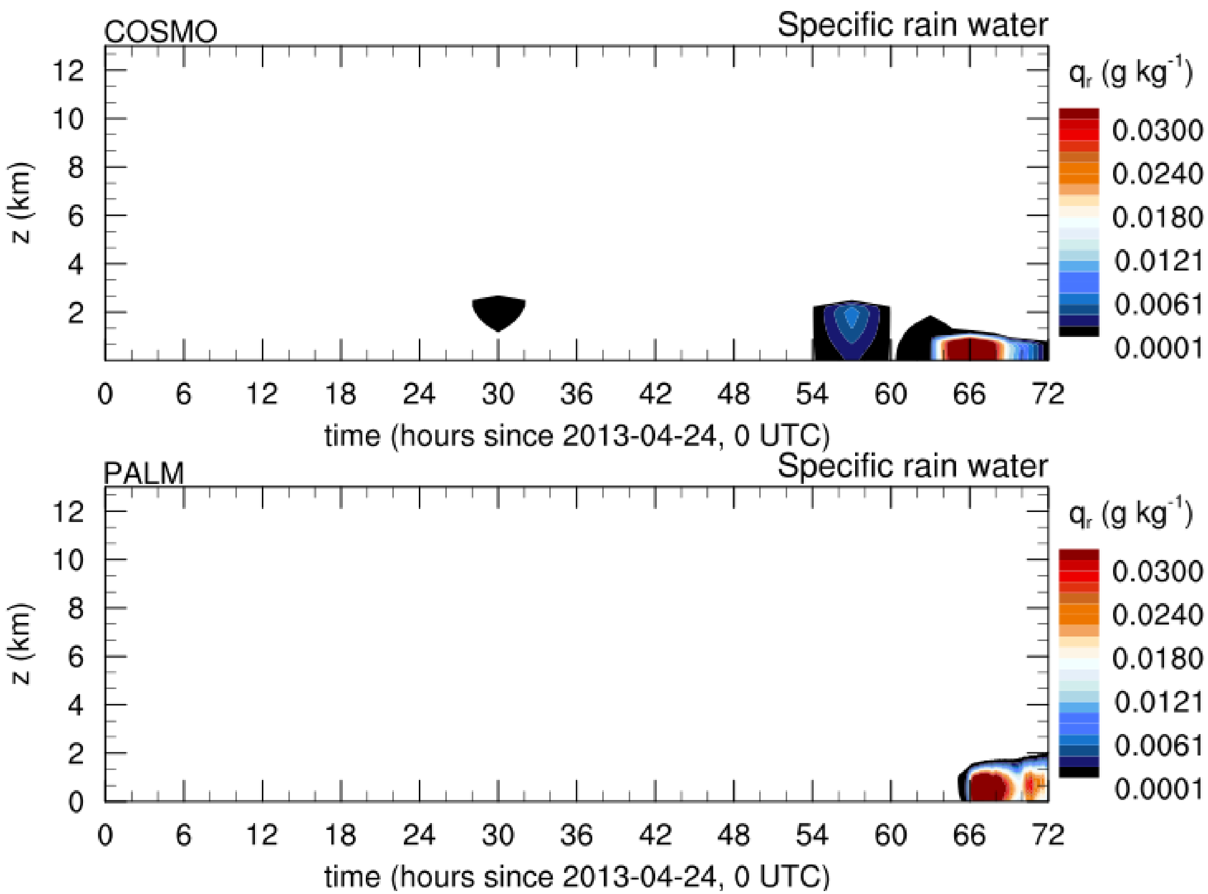
Note: large-scale forcing from 0.25°x0.25° COSMO mean



Results are sensitive to large-scale forcing

Setup for animation

Note: large-scale forcing from 0.25°x0.25° COSMO mean



Results are sensitive to large-scale forcing