Modeling of subtropical stratocumulus to cumulus transition with EULAG

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Outline

1. Motivation
   - the EUCLIPSE project

2. ASTEX Lagrangian case
   - stratocumulus-topped boundary layer
   - setup of the experiment
   - adaptation of the EULAG model

3. Results
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   - comparison with other models
   - sensitivity tests

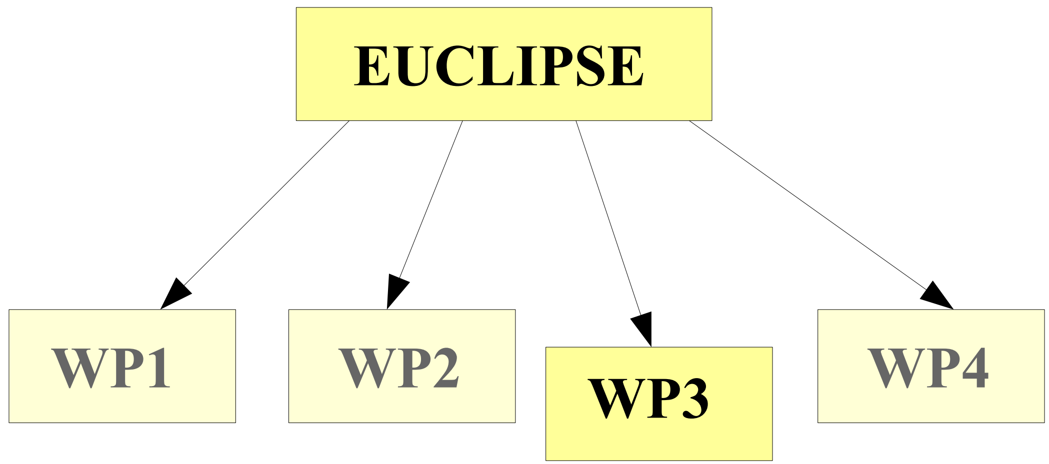
4. Summary and conclusions

EUCLIPSE

The project (http://www.euclipse.eu/) is an international effort, funded under theme 9 "Environment" of Framework Program 7 of the European Union, designed to **improve the evaluation, understanding and description of the role of clouds in the Earth's climate** with a focus on the cloud feedback in a warming climate.

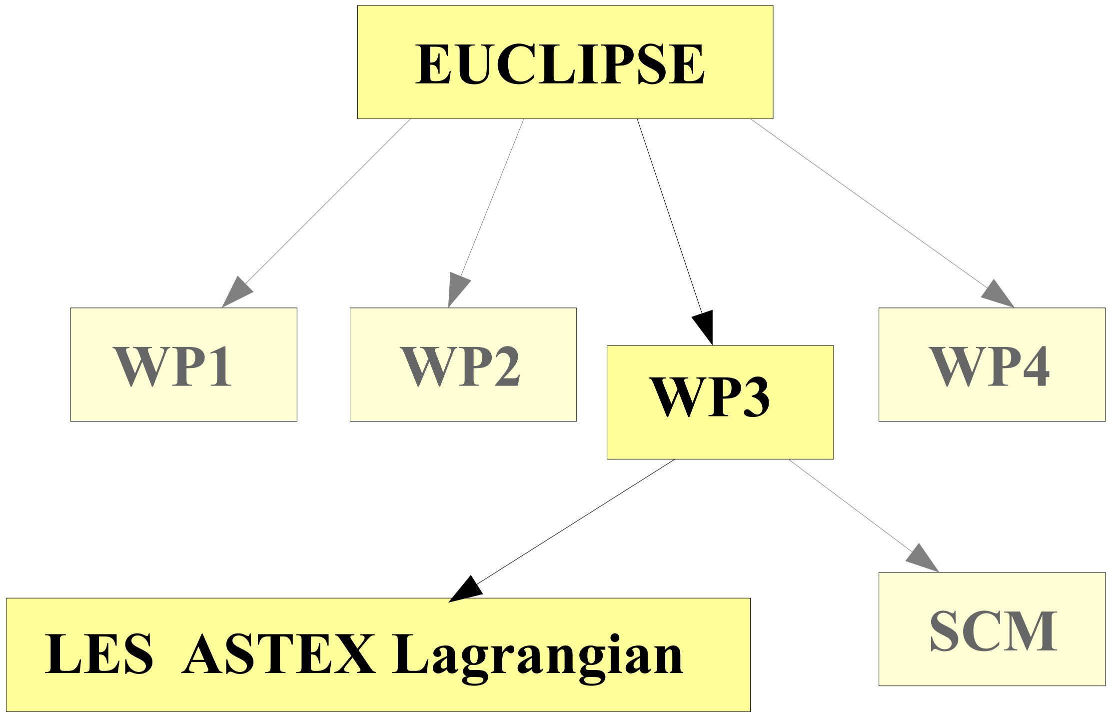
The strength of the EUCLIPSE project is the combination of detailed **modeling and observation** at the level of individual clouds and the evaluation and analysis of clouds in the climate system in global climate models using the latest diagnostic techniques and satellite products.

The EUCLIPSE project is a collaborative effort of **12 institutes** from Netherlands, UK, Germany, France, Greece, Sweden, Poland and Switzeland. The work is divided among four work packages (WP1, WP2, WP3, WP4).



Main object: WP3 aims to evaluate how the large-scale forcing conditions control cloud cover, cloud amount, precipitation, and how these cloud properties influence the radiative budget and to what extend this is faithfully reproduced by the Earth System Models (ESMs). The focus is on the subgrid processes that act on the grid scales of ESM (of the order of 100 km) and smaller.

1. Introduction



- the effect of drizzle and cloud droplet sedimentation on the entrainment rate during the First Lagrangian of ASTEX
- how do the cloud liquid water path and cloud cover evolve? Can we predict favorable conditions for the transition of solid stratocumulus to scattered shallow cumulus clouds?
- length scale analyses and the effect of subdomain sizes on second- order moments

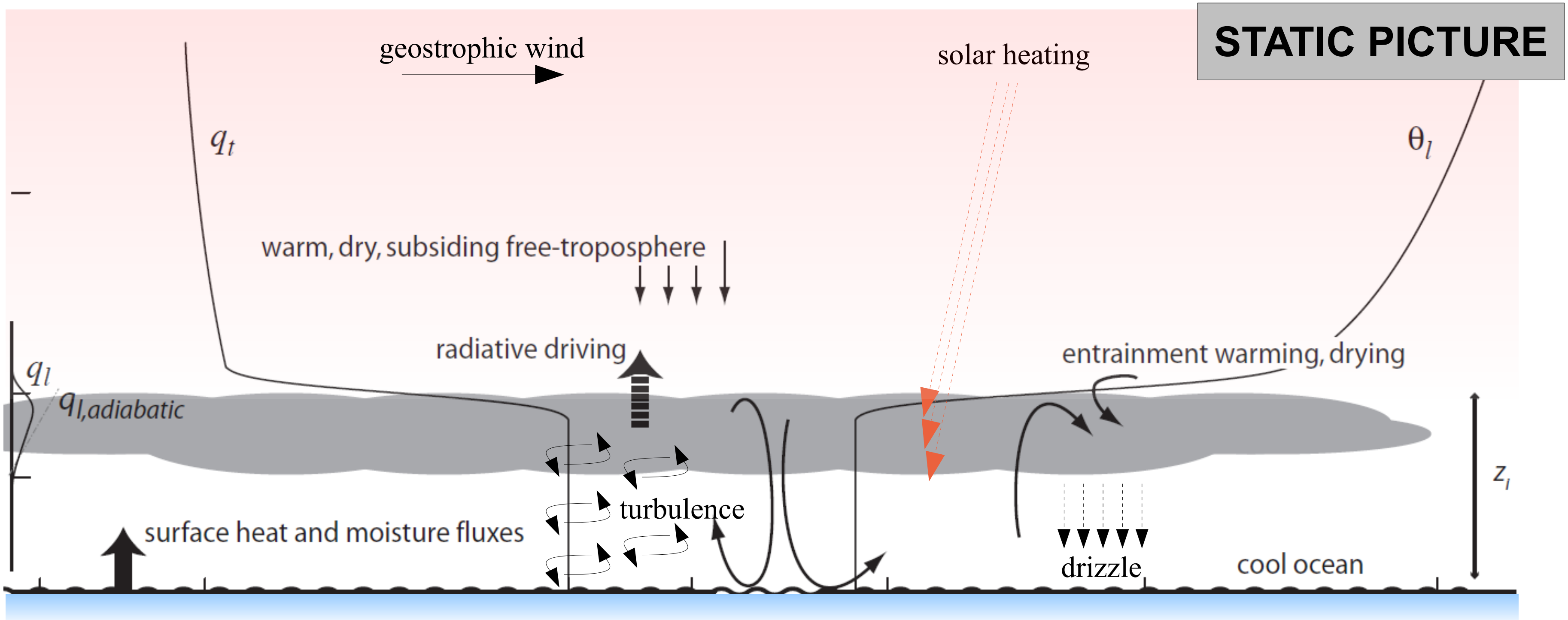
What is ASTEX Lagrangian about?

ASTEX Lagrangian is the **intercomparison study** of LES models (8?) which takes place 11 years after the first ASTEX intercomparison study (SCM, Bretherton, 1999) and almost 20 years after ASTEX campaign.

University of Warsaw (prof. H. Pawlowska) participates in the EUCLIPSE Project (WP3) with the anelastic nonhydrostatic model EULAG. The EULAG model is used for LES in ASTEX Lagrangian experiment on **stratocumulus to cumulus transition**.

Adaptation of EULAG

As the model is a research fluid solver, a set of modules was implemented or modified in order to establish **atmospheric model** capable of simulating evolution of moist boundary layer driven by radiation and time-dependent boundary conditions.



from Stevens et al., 2007

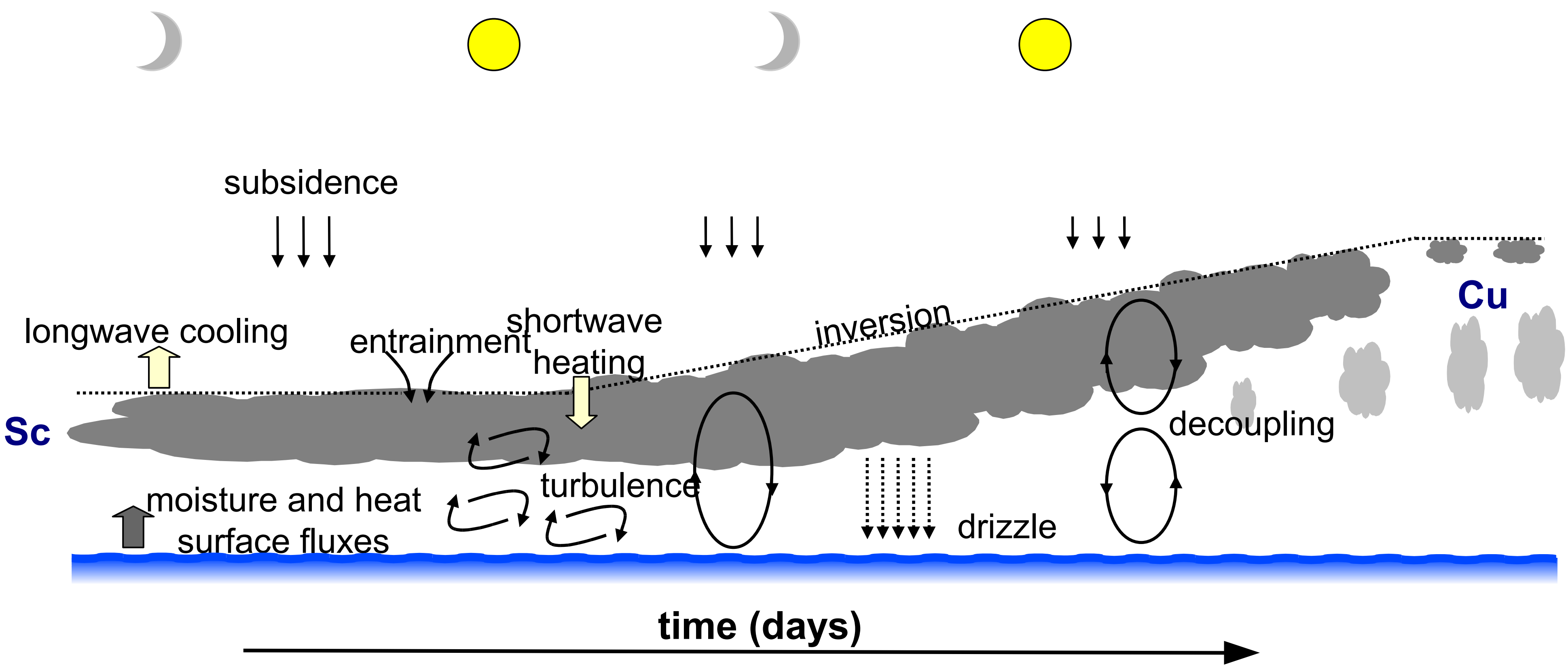
Stratocumulus = loss + production of cloud water

- entrainment / mixing
- drizzle
- solar heating
- sensible surface heat flux
- ...

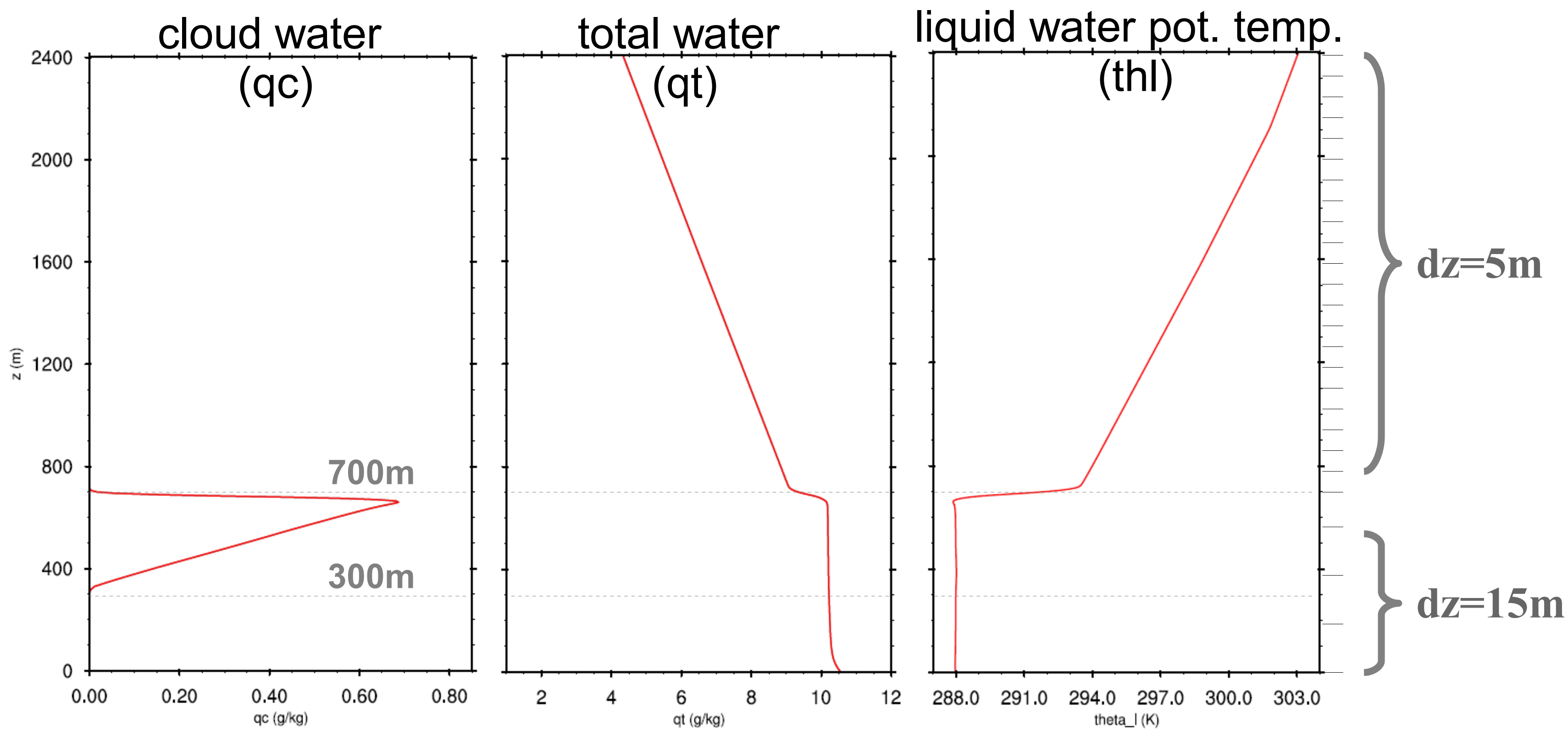
System of mutually linked processes

- entrainment / mixing
- large-scale subsidence
- radiative cooling
- latent surface heat flux
- ...

DYNAMIC PICTURE



(but also SST(t), subsidence(t), radiation(t), geostrofic wind(t), etc.)



Domain: 4.48 x 4.48 x 2.4 km = 128 x 128 x 400 (10^7) gp

Integration time: 40 hours => at least 5 real days (10-12 in practice)

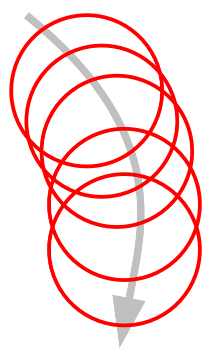
SST: 290.4 K → 294.7 K

l-s divergence: 5e-6 s^{-1} → 1e-6 s^{-1}

geostr. wind: varying with time (12 m/s → 3 m/s)

short wave radiation: diurnal cycle

surface fluxes: depend on flow and near-surface conditions



Lagrangian air mass tracking

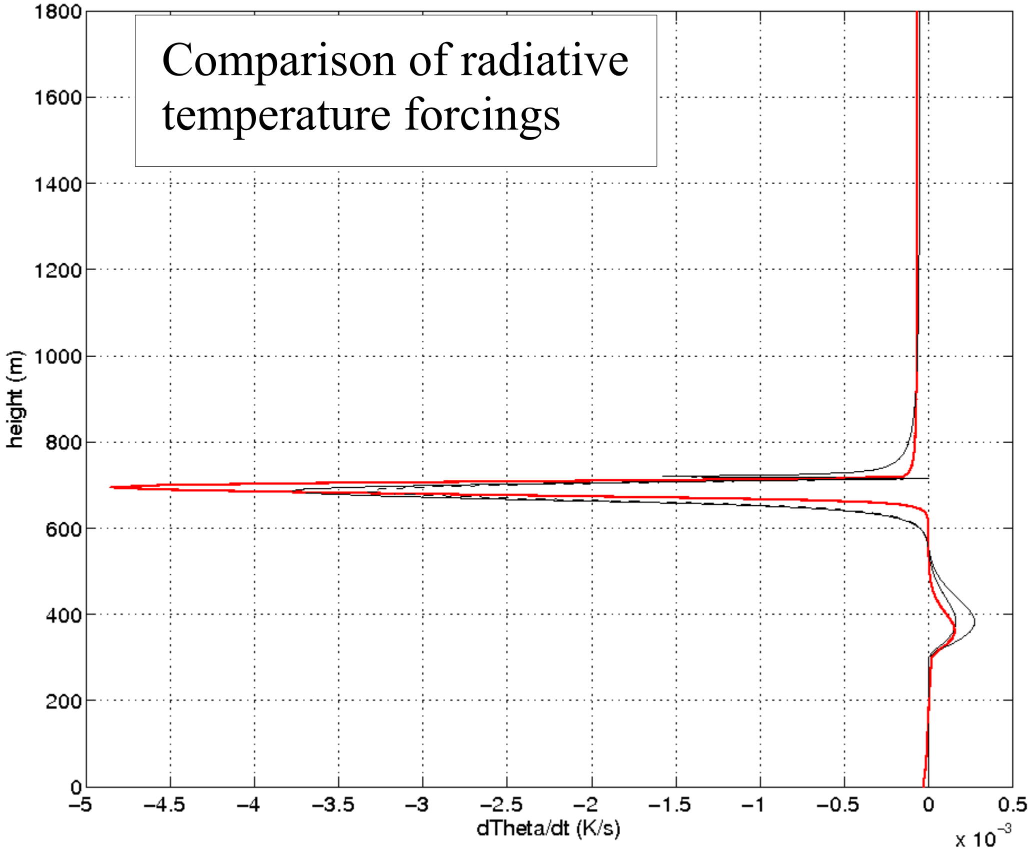
Code adaptation:

- setup of the initial and time-dependent boundary conditions based on external profiles of temperature, humidity, pressure, velocity, surface temperature, etc.,
- vertical stretching (mainly required in physical parameterizations)
- longwave radiation scheme responsible for radiative cooling of the cloud top - based on prescribed profiles of net radiative fluxes
- shortwave radiation scheme responsible for heating of the cloud due to a solar radiation (from DALES model)
- upgrade of radiation scheme to full radiation code from CCM2 model (NCAR)
- time-dependent vertical subsidence based on upstream scheme
- nudging and time-dependent absorbers (a sponge layer)
- dynamic (i.e. time-and-flow-dependent) heat and latent heat surface fluxes
- improvement of one moment microphysical scheme
- simple surface fluxes distribution (PBL)
- 'smooth start' that includes progressive incorporation of driving processes (mainly radiation) during spin-up time
- data processing: time and space characteristics of the boundary layer

Two schemes tested:

1. 'simple' long wave radiation + short wave radiation from DALES
2. CCM2 (NCAR)

$$F_{\mathrm{rad}}(x, y, z, t) = F_0 e^{-Q(z,\infty)} + F_1 e^{-Q(0,z)} + \rho_i c_p D \alpha_z \left[\frac{(z - z_i)^{4/3}}{4} + z_i (z - z_i)^{1/3} \right]$$

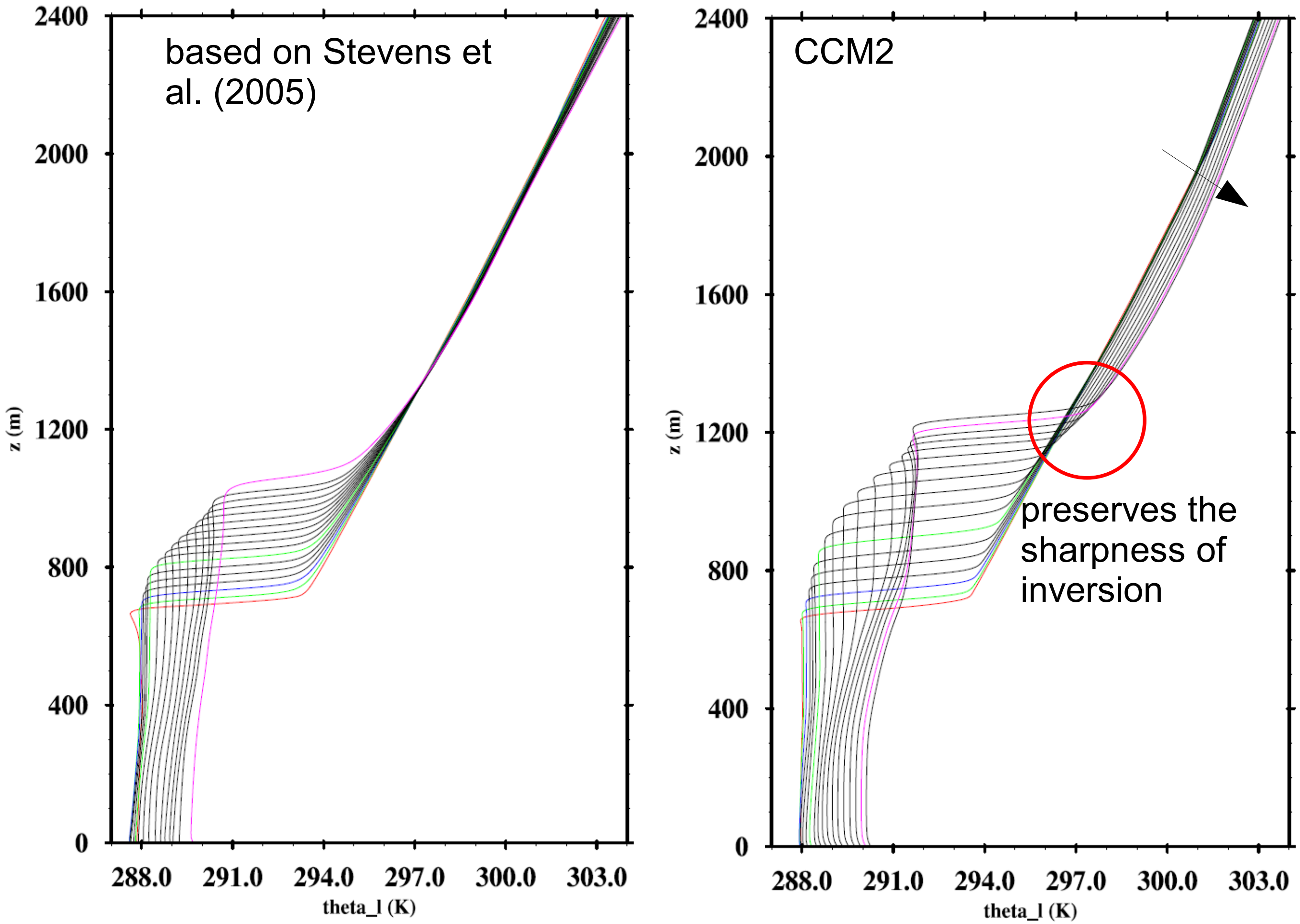


CCM2

Stevens et al. (2005)

Difference in cooling above the inversion may vary even more than 20% and depends on free parameters

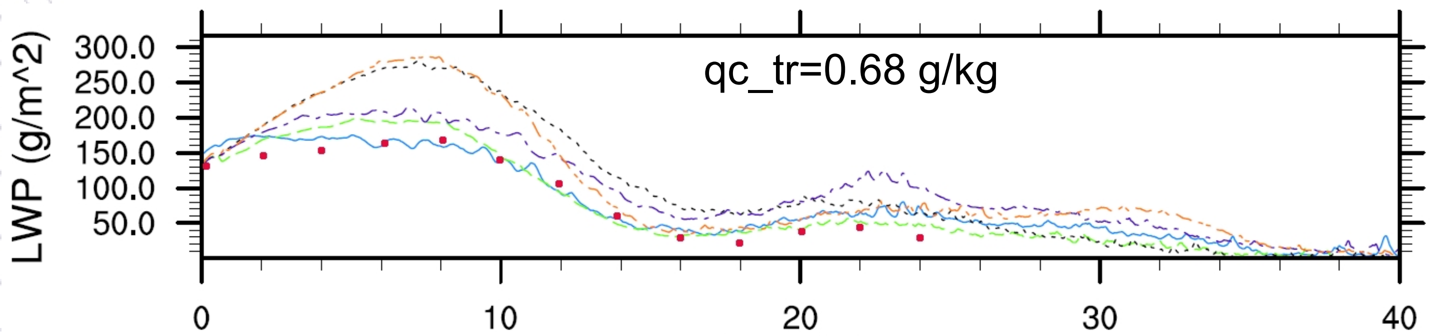
CCM2 gives stronger radiative cooling but in narrower layer 'simple' radiation vs. full radiation



CCM2 radiation works in vertically extended domain (up to 48km) in pressure coords.

Three schemes tested:

1. Kessler (1969) - solution extremely sensitive to the choice of autoconversion threshold. Since cloud water affects radiative cooling, and thus the dynamics, the domain averaged results (LWP, we, TKE, etc.) could differ easily by a factor of two depending on the choice of a threshold.



2. Berry and Reinhardt (1974) – ok for Cu but does not work for Sc; autoconversion and terminal velocity are both too large and cloud quickly decays.

3. Khairoutdinov and Khogan (2000) - turned out to provide realistic results for this case (final choice).

Simplified approach:
Constant drag coefficient Cd=0.0014 is assumed. Surface fluxes are defined as:

$$Qfx = -Cd\cdot|U_1|\cdot(q_1 - q_{surf}(t)) \qquad \text{latent}$$
$$Hfx = -Cd\cdot|U_1|\cdot(\Theta_1 - \Theta_{surf}(t)) \qquad \text{sensible} \qquad (1)$$

where (q_{surf},Θ_{surf}) represents saturated conditions at the sea surface, U_1 q_1 Θ_1 are velocity, humidity and pot. temp. at the lowest level.

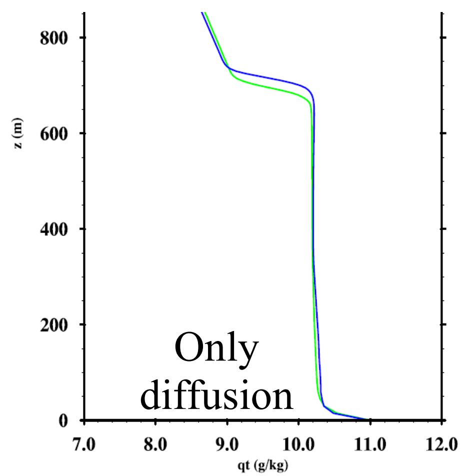
However, for A-grid representation, z=0 is the lowest level of the model (i.e. atmosphere), but also a sea surface (!). Thus (1) should to be modified to:

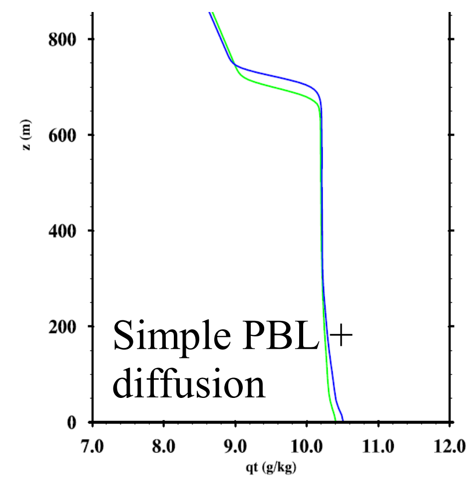
$$Qfx = -Cd\cdot|0.5(U_1+U_2)|\cdot(q_1 - q_{surf}(t))$$
$$Hfx = -Cd\cdot|0.5(U_1+U_2)|\cdot(\Theta_1 - \Theta_{surf}(t)) \qquad (2)$$

For the resolution of dx=dy=35m and dz=15m the subgrid-scale turbulence seems to be not sufficiently effective in distribution of surface fluxes. Thus a simple scheme transporting water and energy into the upper model layers was employed, based on prescribed vertical profiles of mean fluxes:

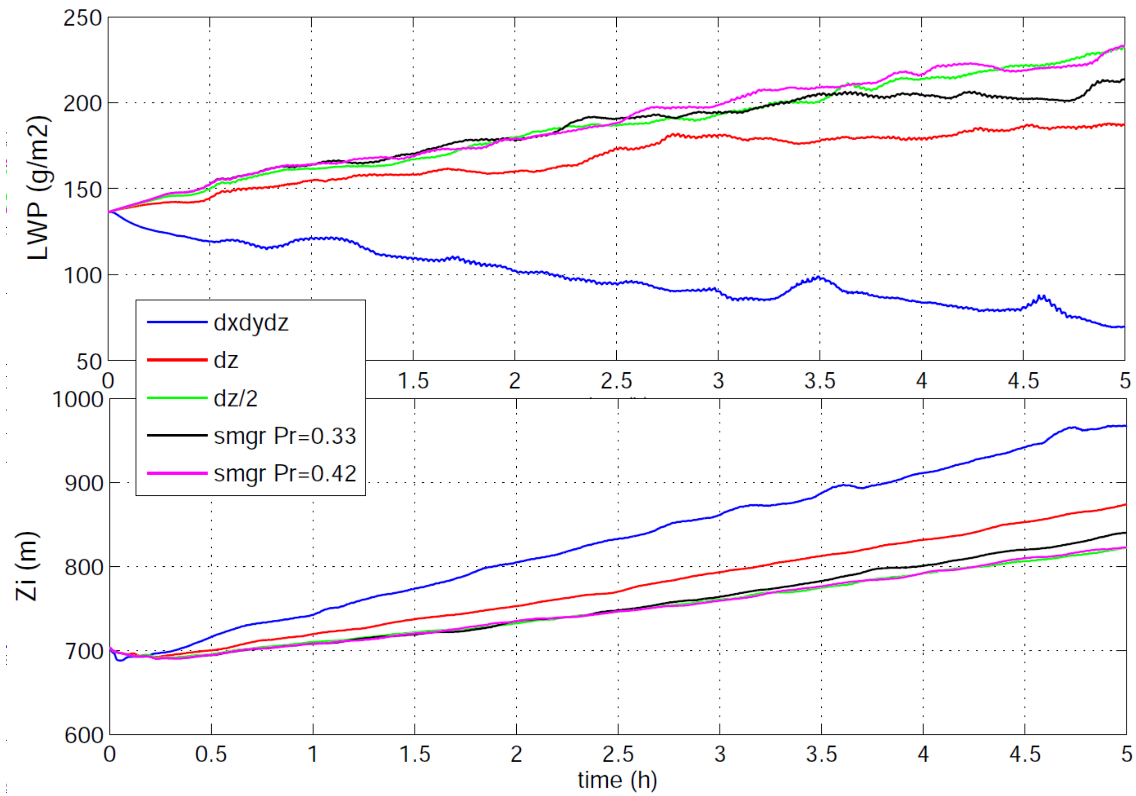
$$Ft(z) = div_z(Hfx \bullet exp(-z/z0)), \qquad \text{where } z0 \sim 70m$$

Once 'injected' into the few lowest levels of PBL the fluxes are then redistributed by the subgrid-scale turbulence. Test experiments have shown that there is weak dependence of the solution on z0 ranging in between 60-80m, while subgrid-scale turbulence supports the process with effective vertical mixing.





Subgrid-scale transport <=> entrainment velocity



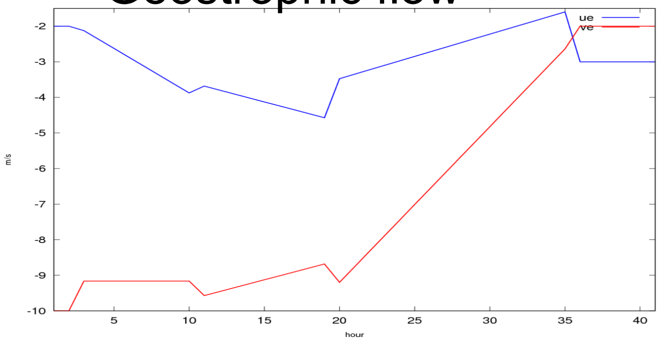
~30% in LWP

~40% difference in entrainment velocity

Final setup: **Pr = 1** (as for stable BL)

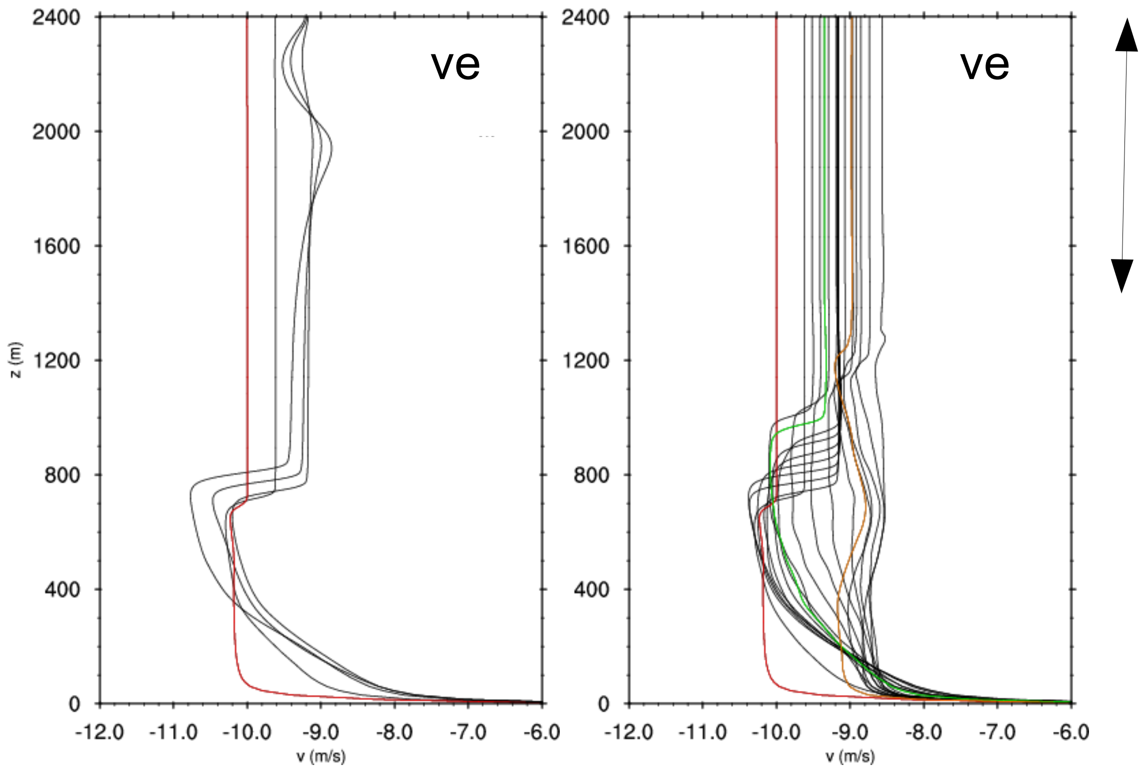
$\mathbf{\Lambda = \Delta z}$ (the smallest explicit scale)

Geostrophic flow



Time-varying geostrophic flow:

1. due/dt, dve/dt (default is 0)
2. sponge layer 350m above inversion following dz_inv/dt with (ue,ve) as a reference solution

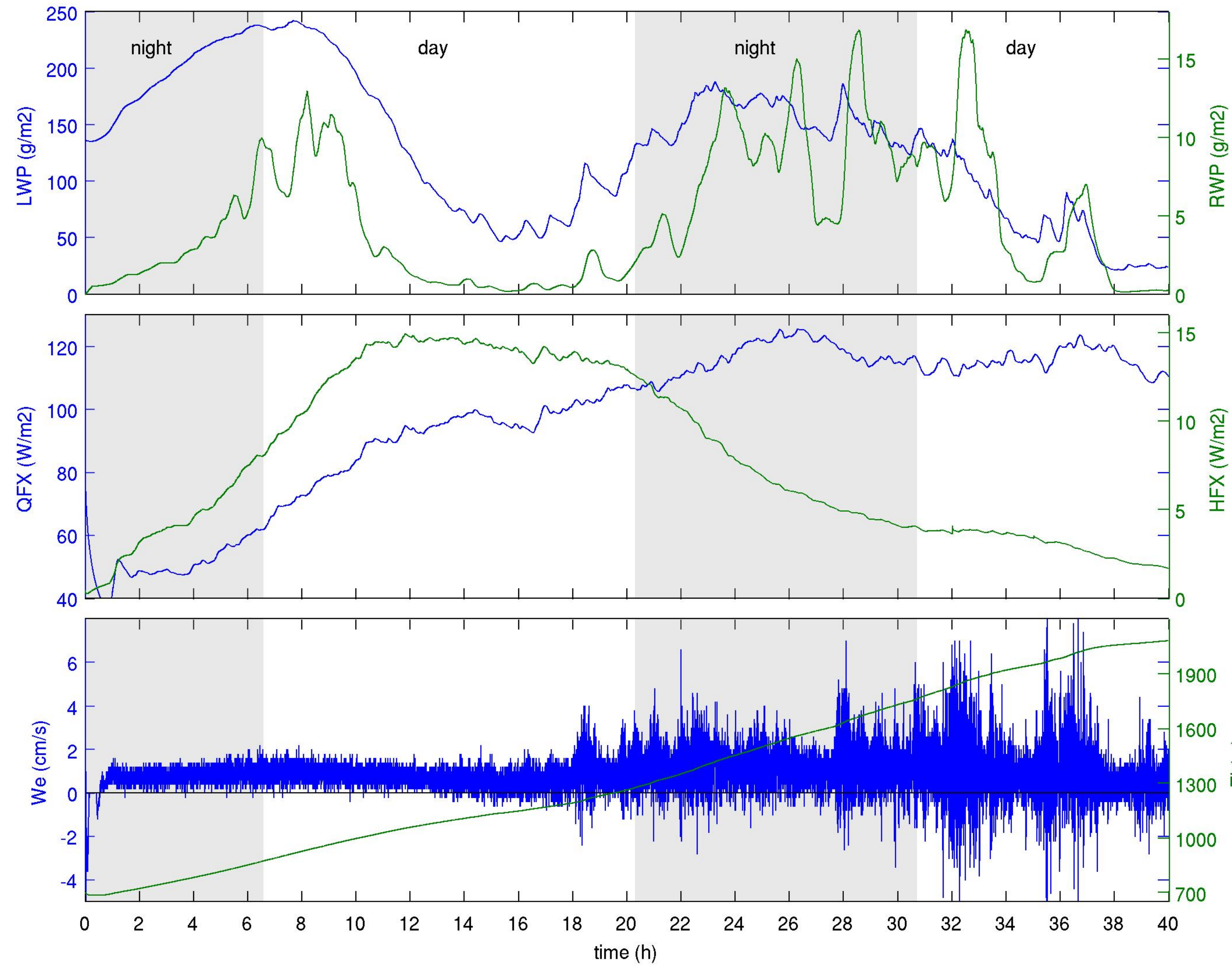


Attenuation to [ue(t),ve(t)]

Liquid water path

Latent heat flux

Entrainment velocity

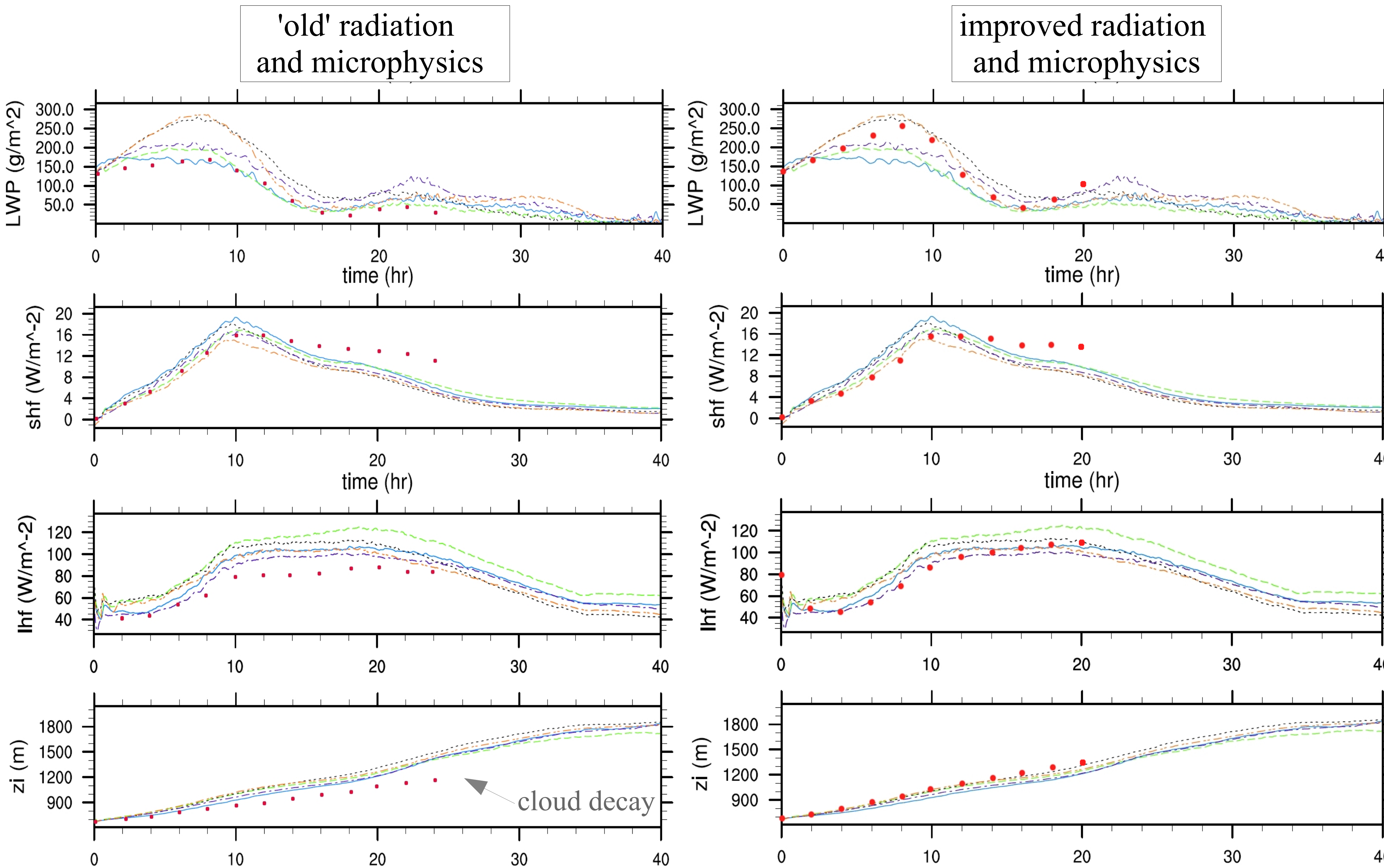


Rain water path

Sensible heat flux

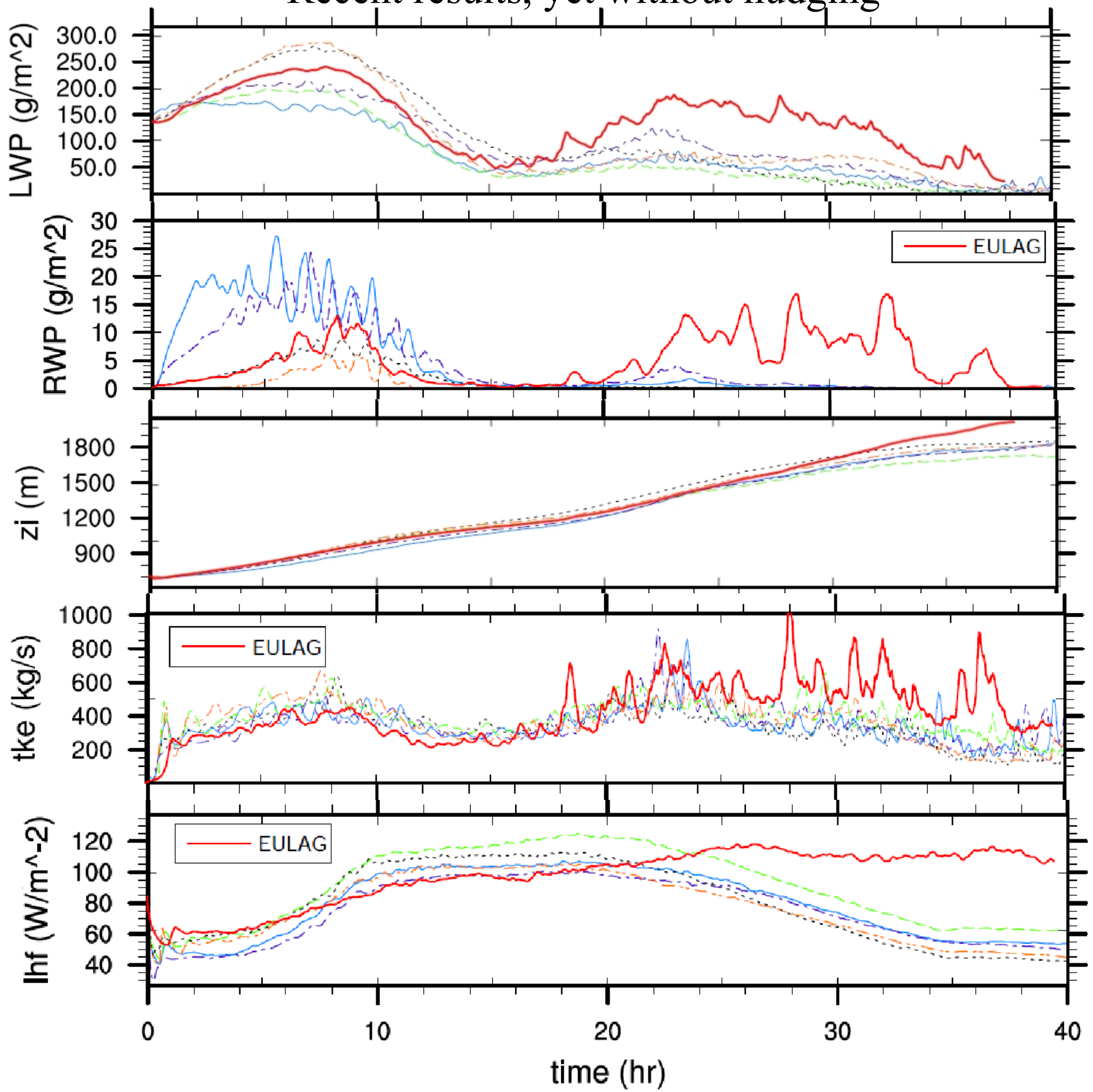
Inversion height

Comparison of domain averaged scalars



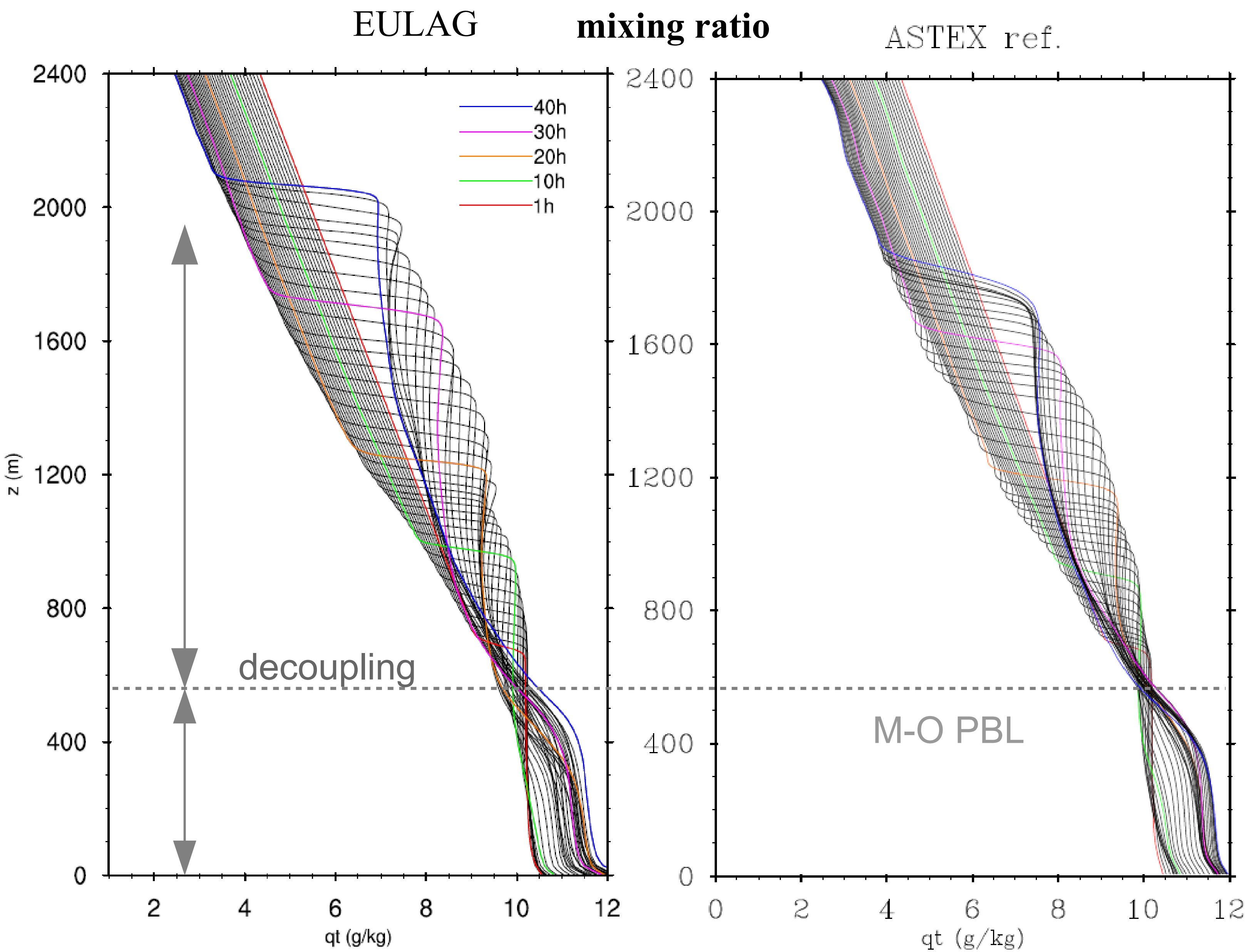
Comparison of domain averaged scalars

Recent results, yet without nudging



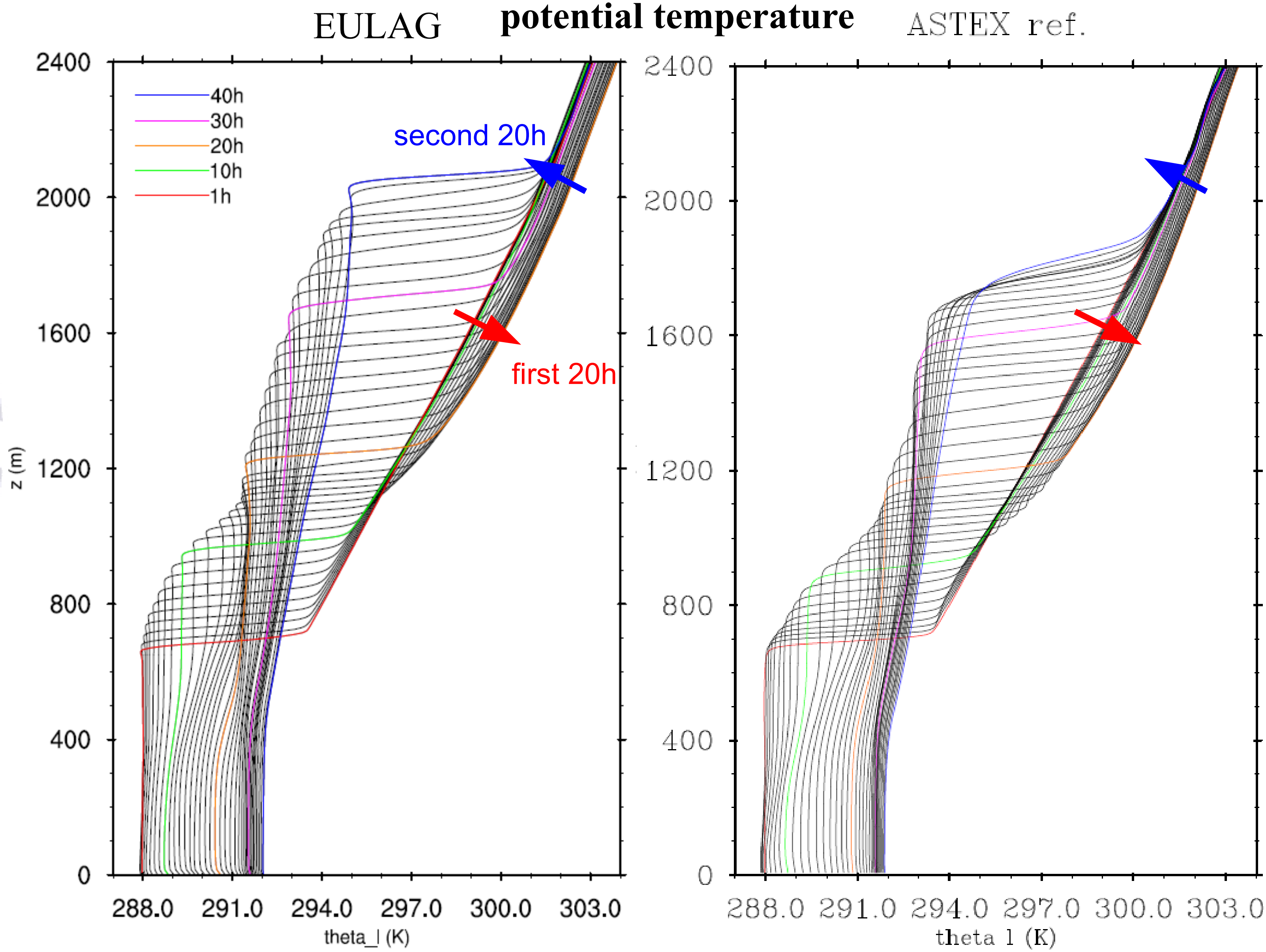
Comparison of hourly averaged profiles

Total water mixing ratio

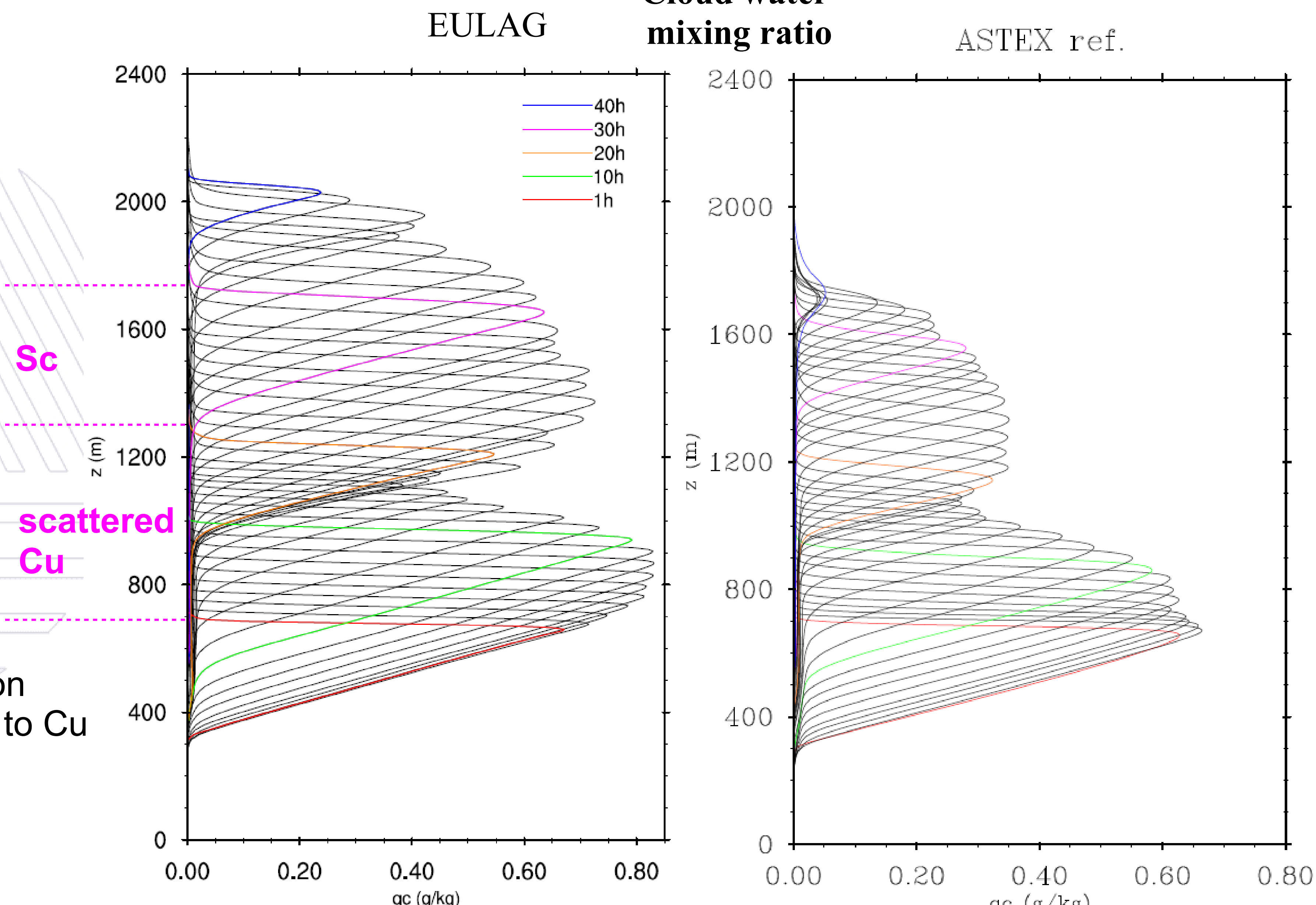


Comparison of hourly averaged profiles

Liquid water potential temperature



Cloud water mixing ratio



Transition from Sc to Cu

Summary and conclusions

• the EULAG model was set up for simulating Sc to Cu transition for a multi-day simulation (~forecast) with time-varying boundary conditions

• a set of available physical parameterizations was verified and (if necessairy) improved in order to provide more realistic results

• it turned out that the case is extremely sensitive to the details of radiation, microphysics and turbulence which can become relevant only after many hours; there is no one particular process that controls development of BL

• the comparison with reference atmospheric models helps to understand our results; we get closer to the ensemble result with everymodel improvement (convergence?)

Future: to complete the 'composite' transition cases (3x72h, i.e. fast, medium and slow transition defined by different inversion depth)

Thank you for your attention

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