LES of ASTEX Lagrangian Case with EULAG

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Introduction

University of Warsaw participates in the EUCLIPSE Project (WP3) with the anelastic nonhydrostatic model EULAG.

The EULAG model is used for LES Astex Lagrangian experiment on stratocumulus to cumulus transition.

EULAG is a research fluid solver and the basic version of the model does not include any sophisticated atmospheric parameterizations.

Part of the work was focused on development of that parametrization, since they are crucial for realistic modeling of cloud-topped boundary layer.

The EULAG model and computational resources

Basic technical features of EULAG:

- unstaggered A-grid (z=0 is the lowest model level)
- prognostic thermodynamic variables: qv, qc, qr, θ
- physical altitude as a vertical coordinate

The code was/is run at:

1. Swiss National Supercomputer Center (MeteoSwiss) on **Cray XT/4** (by the end of 2011)

2. National Center for Atmospheric Research (NCAR) on **Cray XT/5m** (currently)

Technical limitations:
As a guest user we are strongly constrained from too extensive use of the machines since they are shared among many other users. This issue has also a strong influence on a progress of the project.

New features of the code (1)

For the purpose of Astex Lagrangian experiment the following modifications to the EULAG code were introduced:

• vertical stretching (mainly required in physical parameterizations)

• radiation schemes

  • longwave radiation scheme based on prescribed profiles of net radiative fluxes

  • shortwave radiation scheme from DALES model

  • full radiation code from CCM2 model (NCAR)

New features of the code (2)

- time-dependent vertical subsidence based on upstream scheme
- time-dependent absorbers (a sponge layer)
- dynamic (i.e. time-and-flow-dependent) heat and latent heat surface fluxes
- improvement of the surface fluxes distribution (PBL)
- improvement of microphysical scheme
- 'smooth starting' that includes progressive incorporation of driving processes (mainly radiation) during spin-up time
- NetCDF I/O

Radiation (1)

• Simple parameterization of long-wave radiation effects that prescribes the profiles of net radiative fluxes for Sc was employed:

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

$$Q(a, b) = \kappa \int_a^b \rho r_l \, dz$$

Stevens et al. (2005)

• To represent the effects of solar heating a short-wave radiation code from DALES model was implemented (*thanks to Johan van der Dussen*).

Radiation (2)

The model was able to reconstruct basic features of radiative cooling, but:

- the solution was strongly sensitive to a set of free parameters, i.e. boundary conditions at the top and bottom of the domain and others.

- difficult to find an equilibrium for both radiative cooling and large-scale subsidence above the inversion.

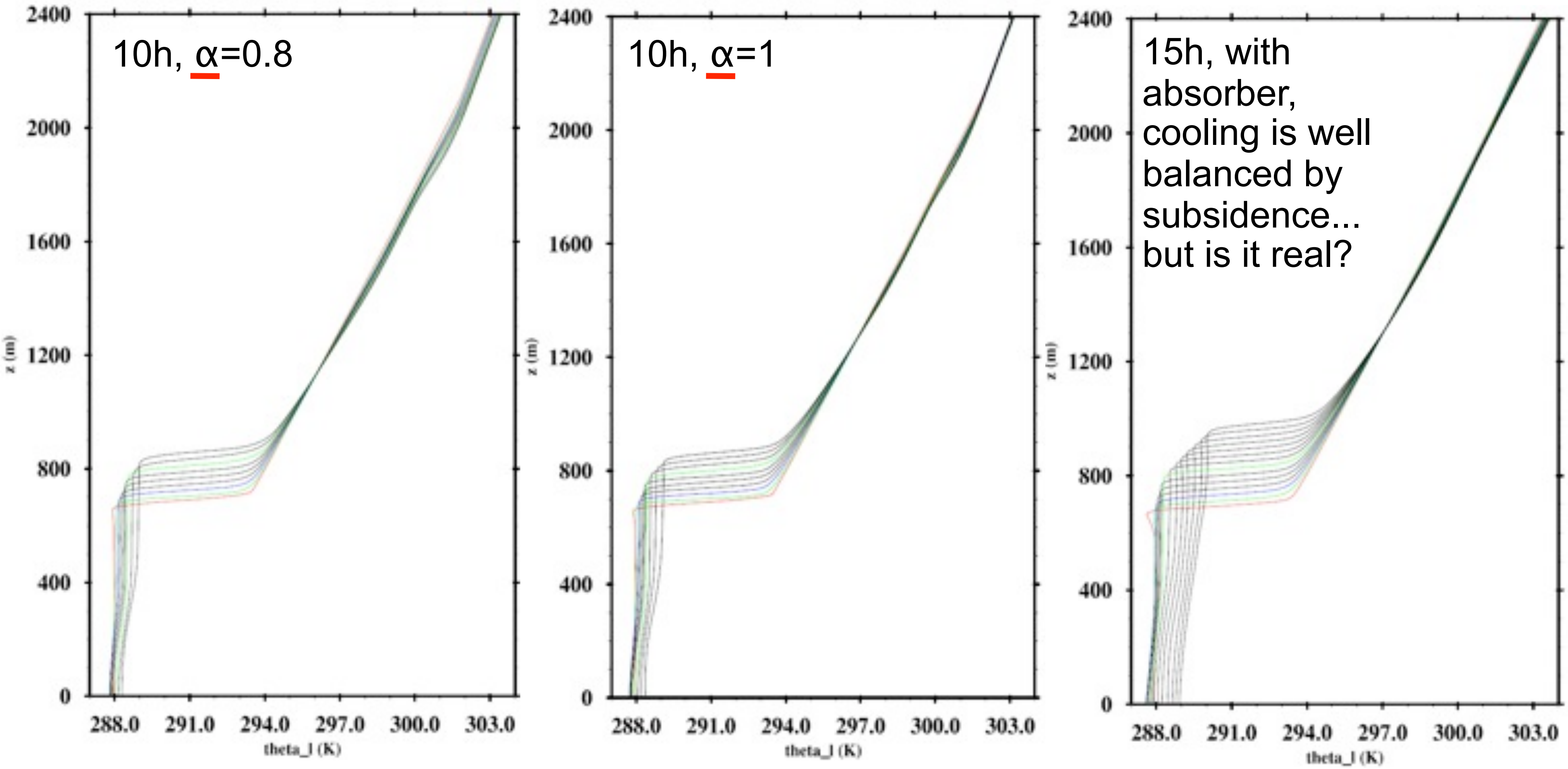
- gradual smoothing of the temperature inversion was observed.

All those effects are small but cumulate in time and become important after many (O(10)) hours.

Radiation (5)

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

Stevens et al. (2005)



Radiation (3)

Full radiation code was implemented.

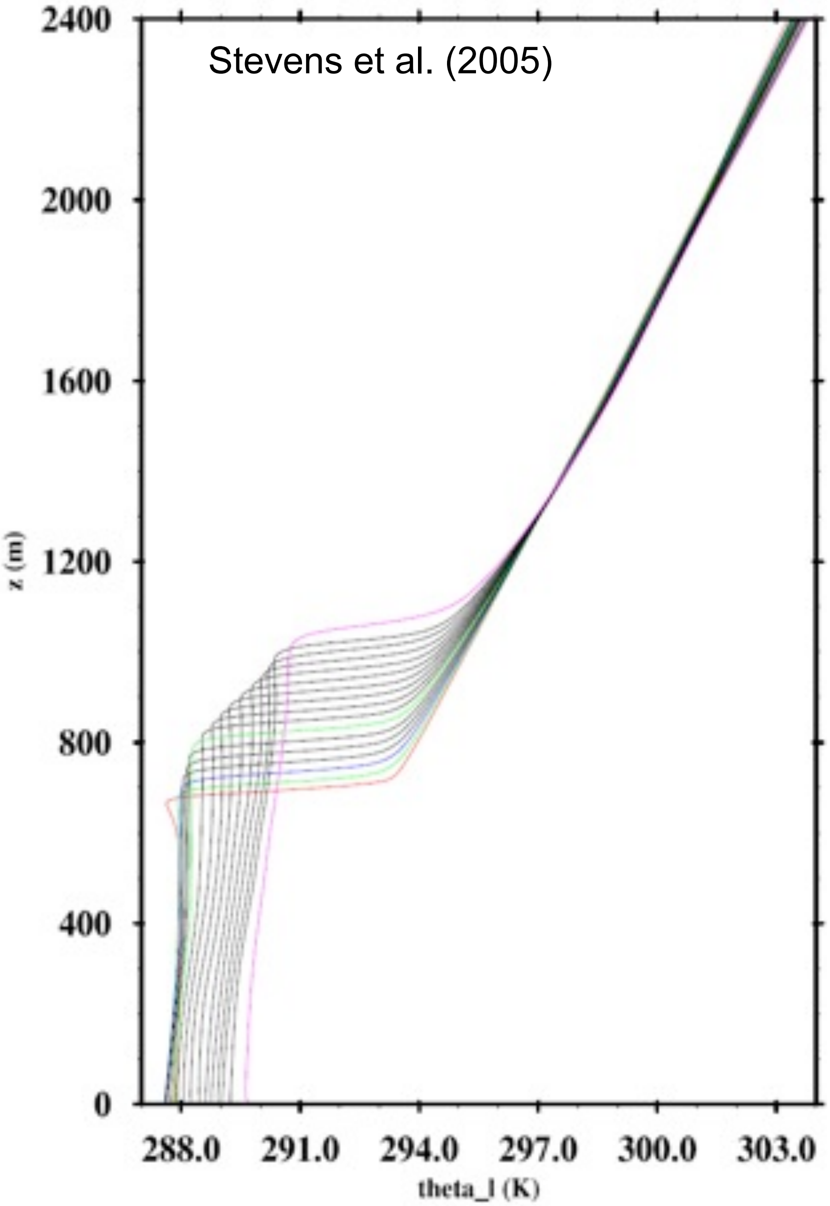
The actual radiation code is based on CCM2 model from NCAR.
It was implemented with help of W. Grabowski and A. Wyszogrodzki (NCAR).

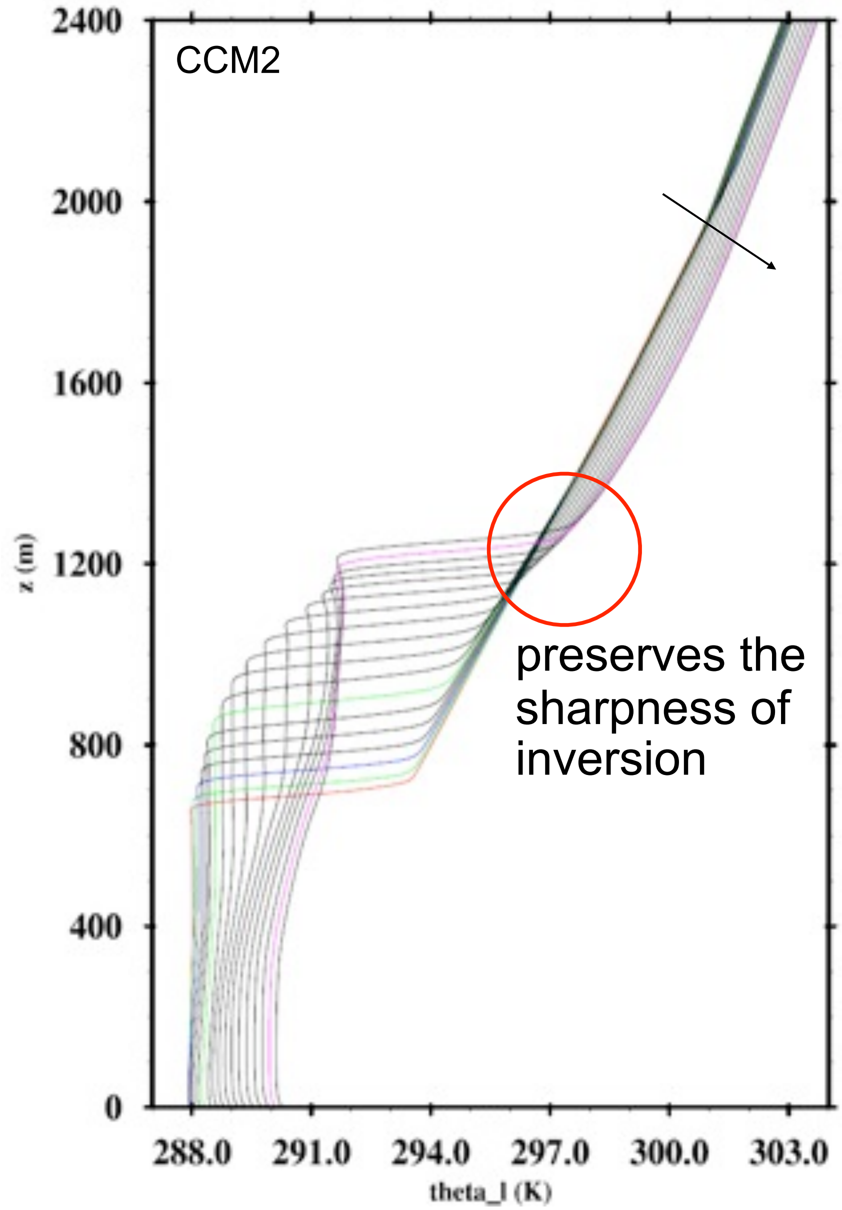
The code works in vertically extended domain (up to ~48km) and in a pressure coordinate system.

The full radiation code is computationally expensive, therefore shortwave and longwave energy fluxes are calculated once every 2 min. For broken Sc the time interval should probably be shorter.

Radiation (6)

'simple' LW radiation vs full radiation

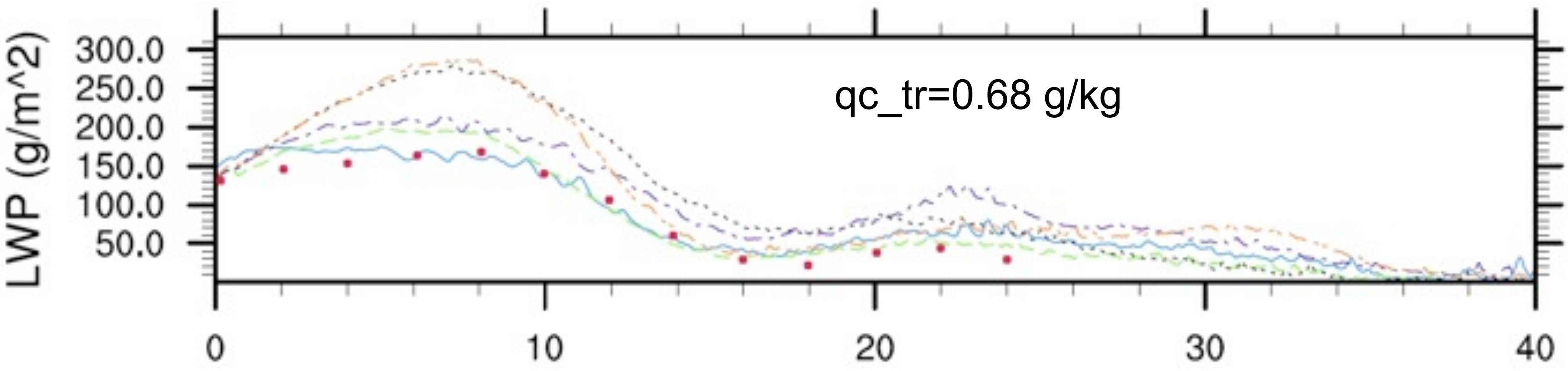




Microphysics – drizzle parameterization

Basic version of EULAG employs simple parameterization of warm rain formation based on Kessler (1969) scheme (i.e. autoconversion ~ (qc-qc_threshold))

In Sc simulations, this parameterization is extremely sensitive to the choice of autoconversion threshold.



Eventually Khairoutdinov and Khogan (2000) was aded.

$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = 1350 q_c^{2.47} N_c^{-1.79} \qquad \left(\frac{\partial q_r}{\partial t}\right)_{\text{accr}} = 67 (q_c q_r)^{1.15}$$

Boundary layer (1)

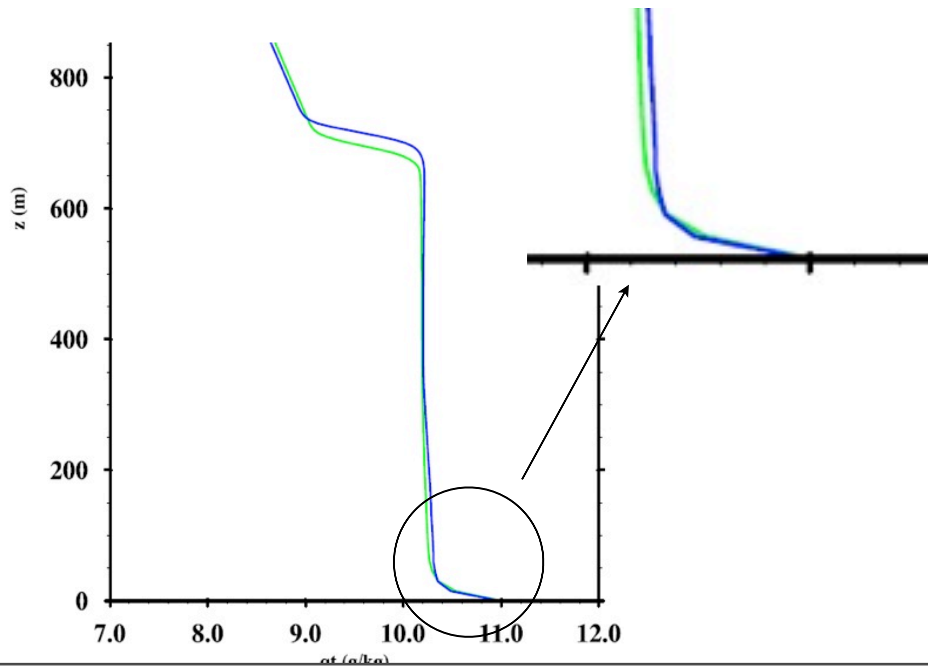
For LES the distribution of surface fluxes is mainly carried out by subgrid-scale transport.

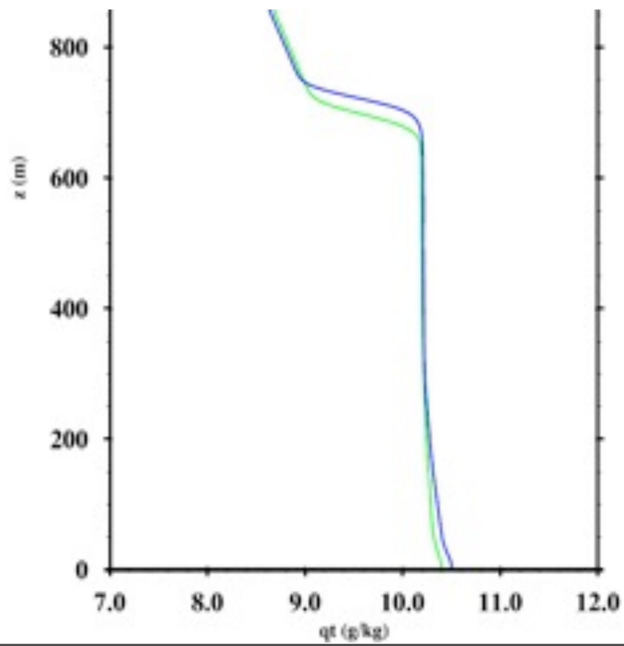
There is no PBL parameterization available in the EULAG, and the subgrid-scale turbulence alone seems to be not sufficiently effective for a given resolution.

Using prescribed (e-folding) vertical profiles of the fluxes, the forcings are:

$$Ft(z) = div_z(Hfx \cdot \exp(-z/z0)),$$

where $z0 \sim 70$m

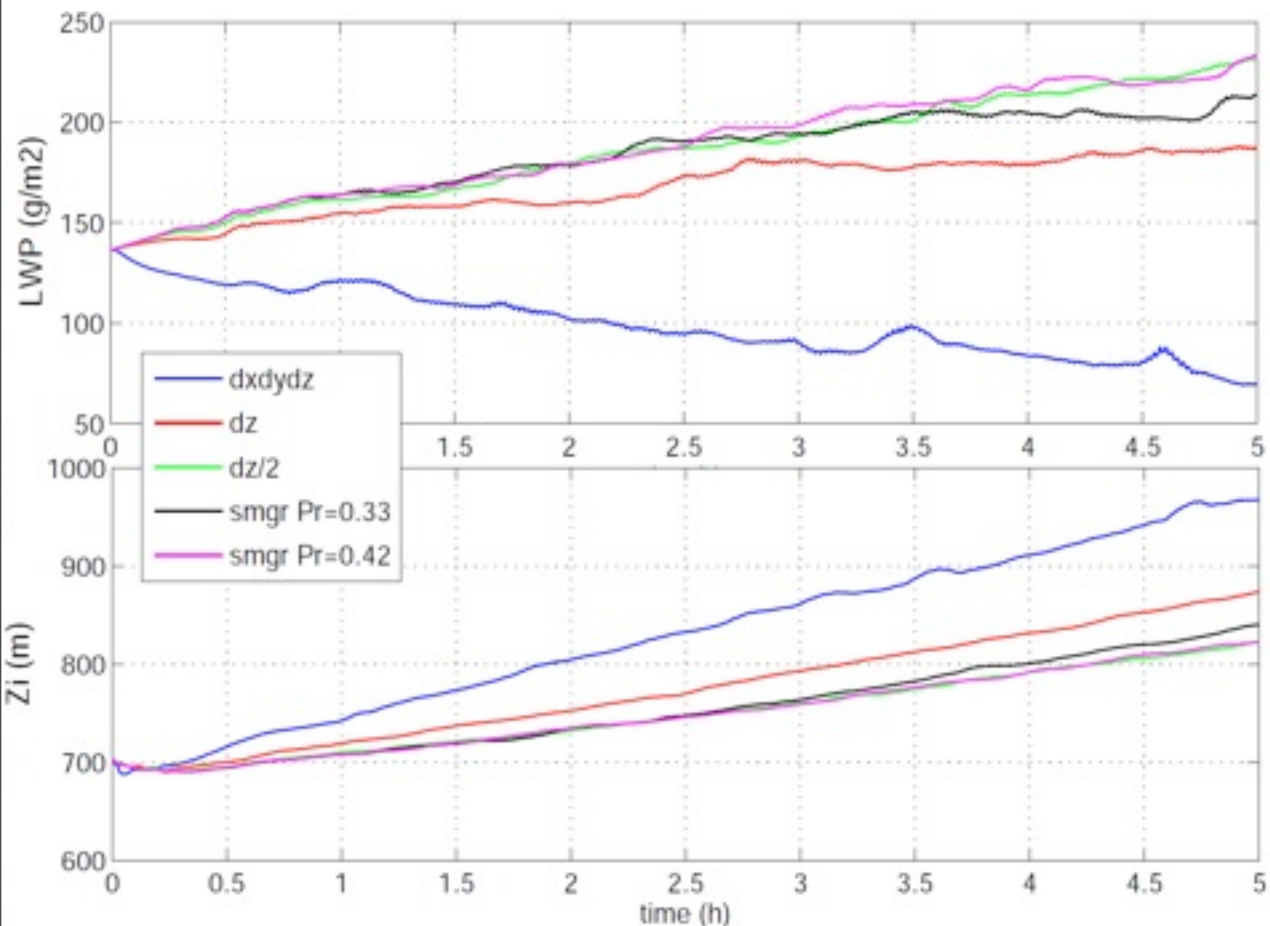




Boundary layer (2)

The subgrid-scale turbulent transport affects:

- mixing within boundary layer
- mass exchange at the top of the cloud layer (i.e. entrainment rate).



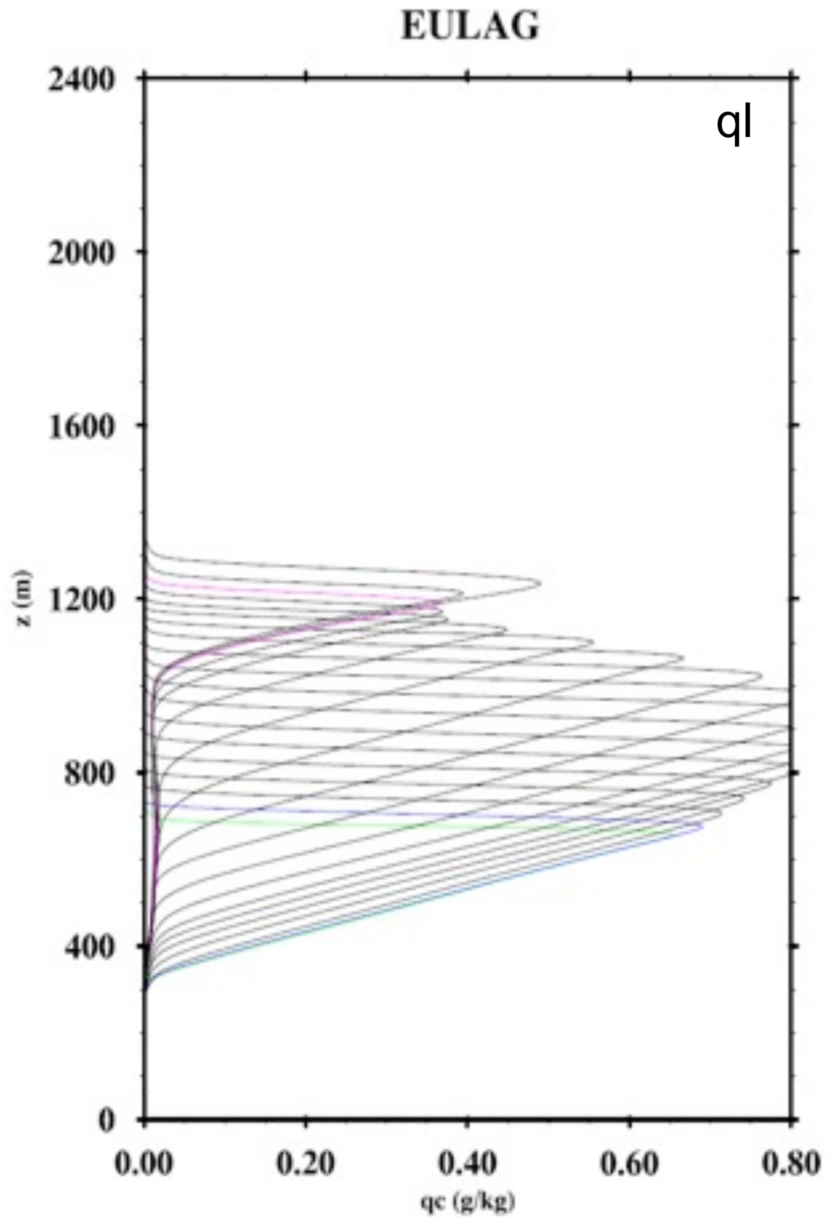
In EULAG, there are available two subgrid-scale turbulence schemes:

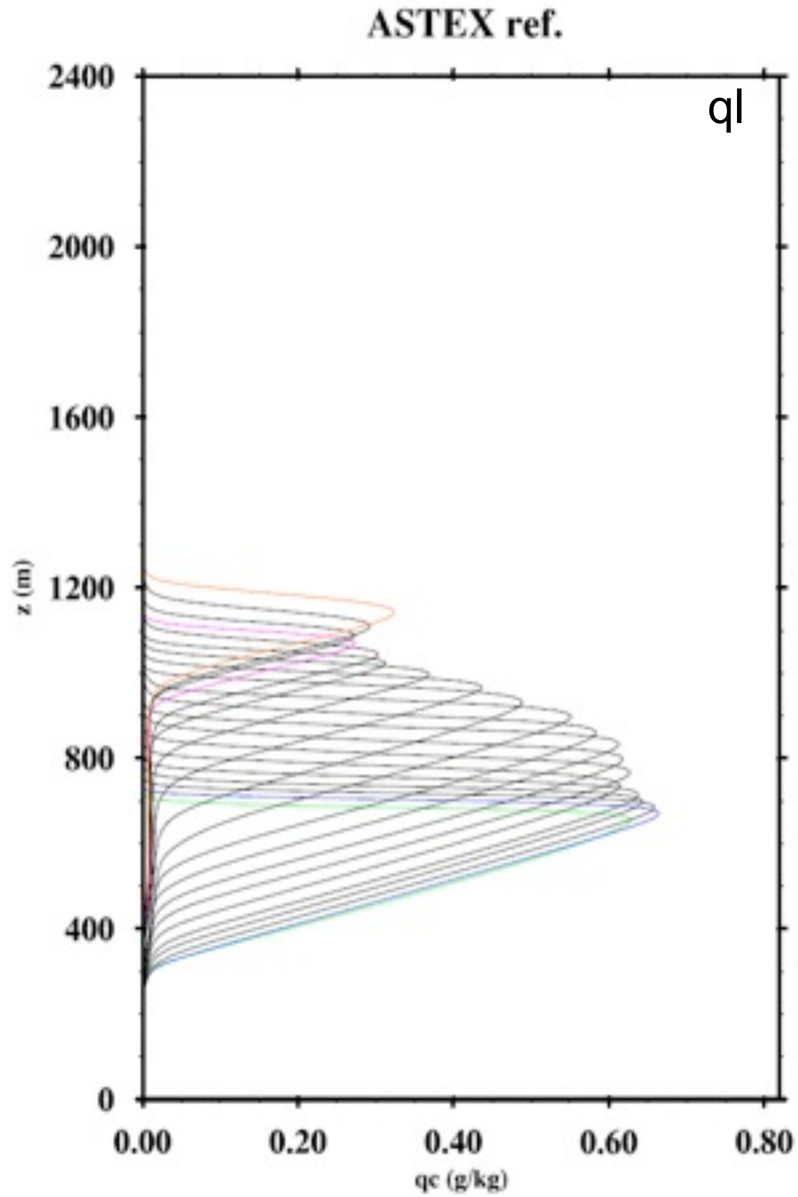
1) Schumann (1990); based on prognostic TKE equation
2) Smagorinsky

In the TKE a mixing length has to be defined. It is usually proposed as $(dxdydz)^{1/3}$ but only for dry PBL and uniform grid. Here (dx/dz~3-7).

Recent LES results (1)

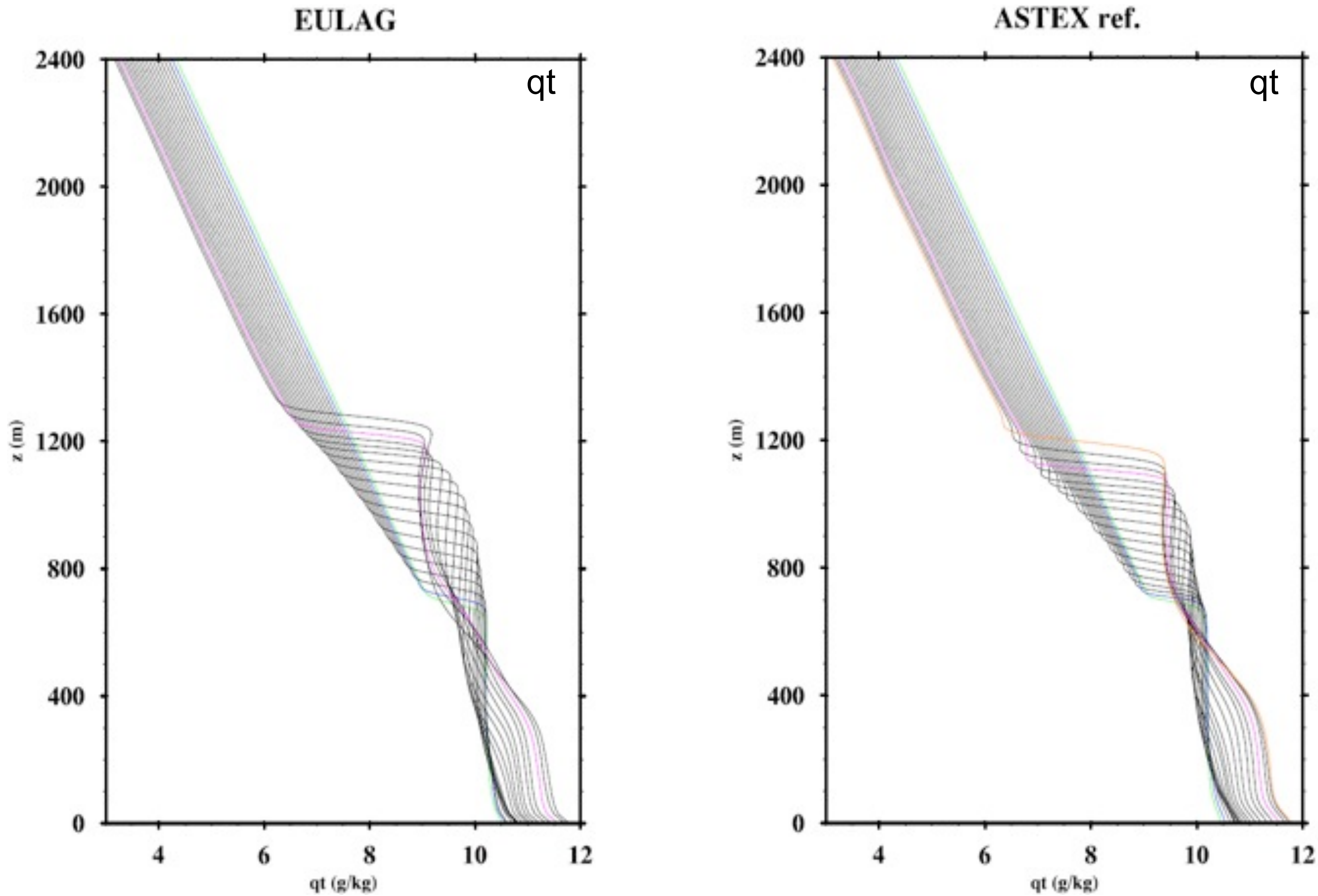
Comparison of hourly averaged profiles





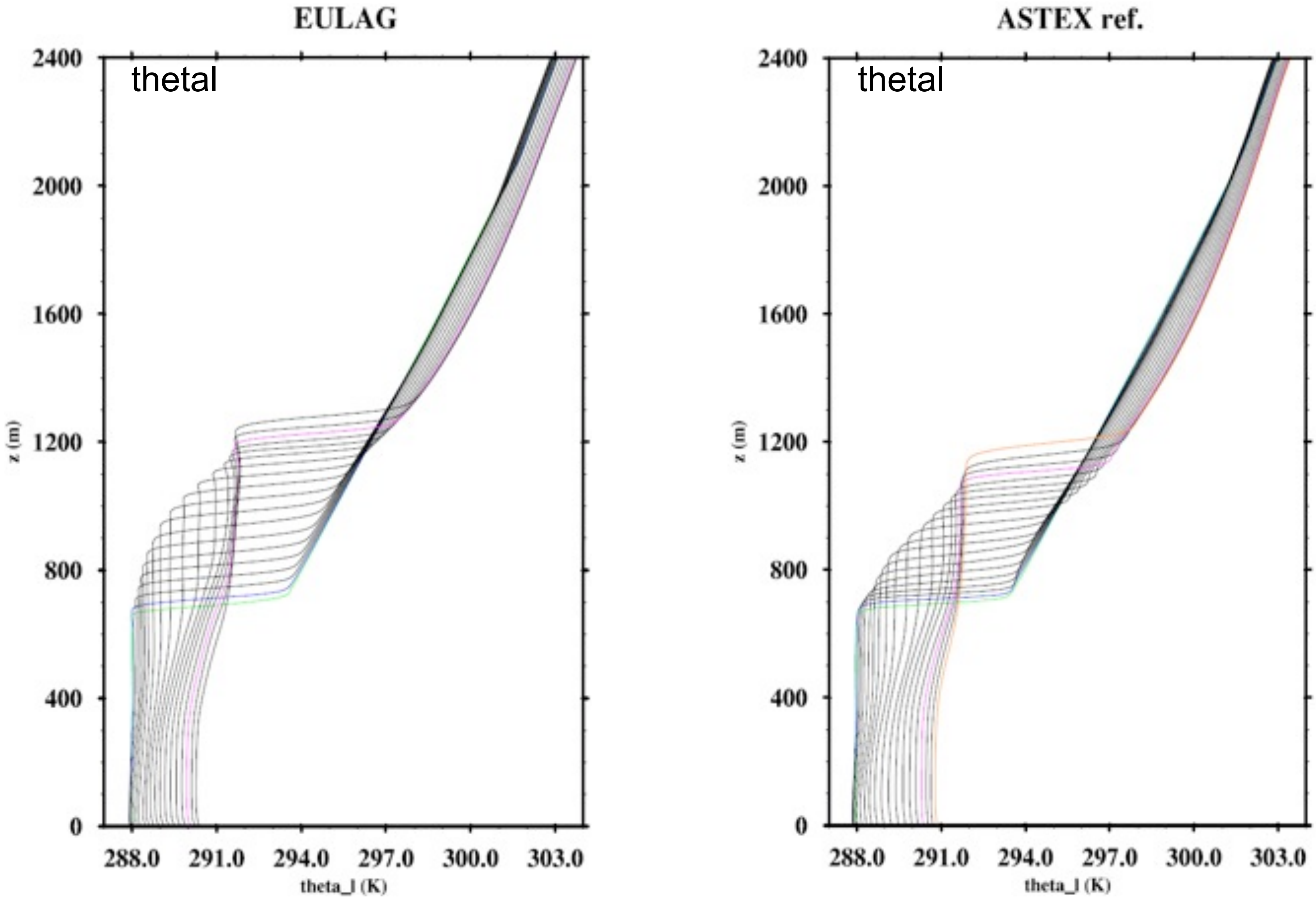
Recent LES results (2)

Comparison of hourly averaged profiles



Recent LES results (3)

Comparison of hourly averaged profiles

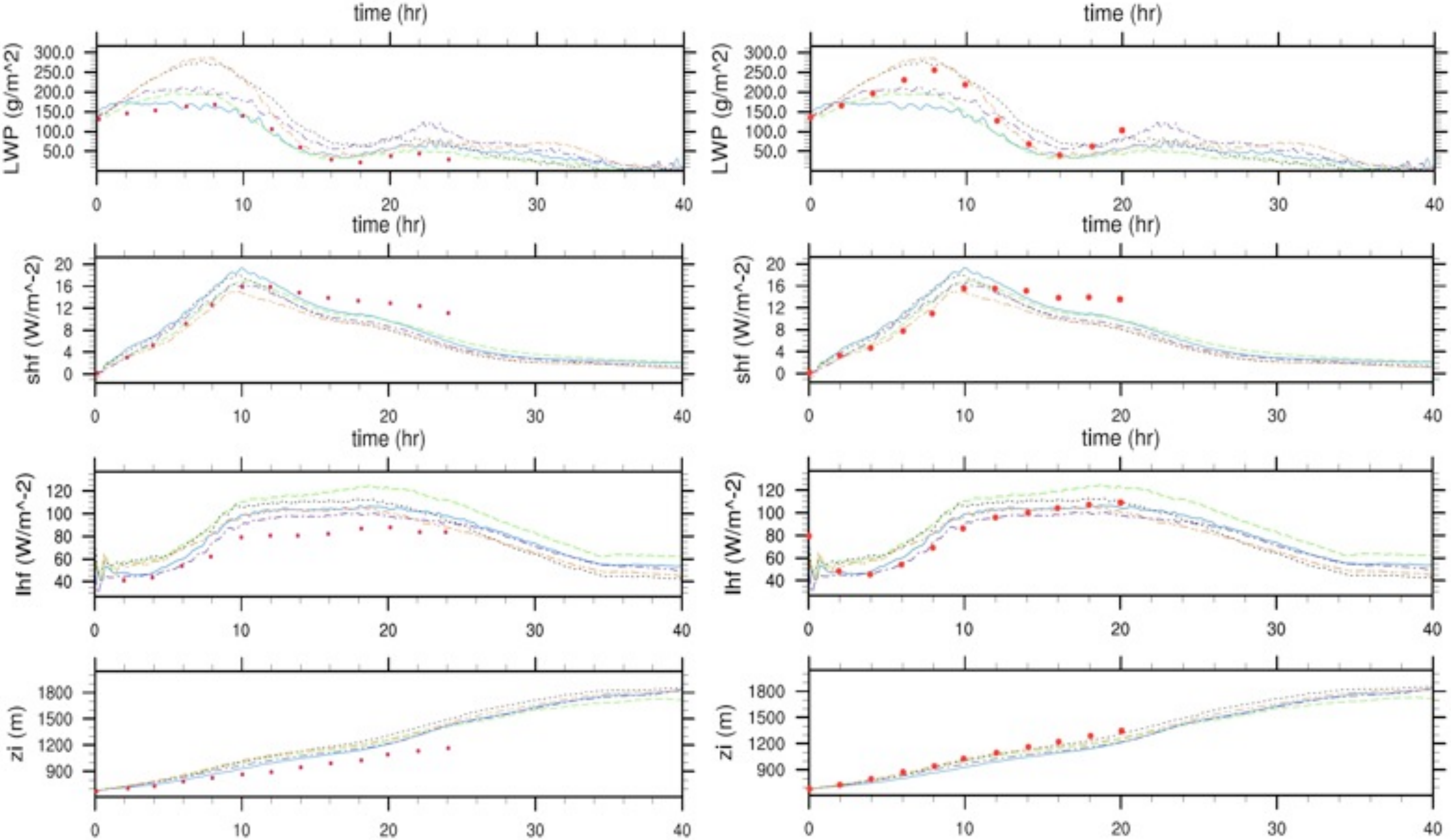


Recent LES results (4)

'old' radiation and microphysics

Comparison of domain averaged scalars

Improved radiation and microphysics



Future plans

Test and choose final microphysical scheme.

Implement and test more sophisticated BL scheme (?).

Verify influence of domain height on the solution.

Complete the 'composite' transition cases
(3x72h, i.e. fast, medium and slow transition).

Thank you
for your attention!

Initialization (1)

Basic technical features of EULAG:

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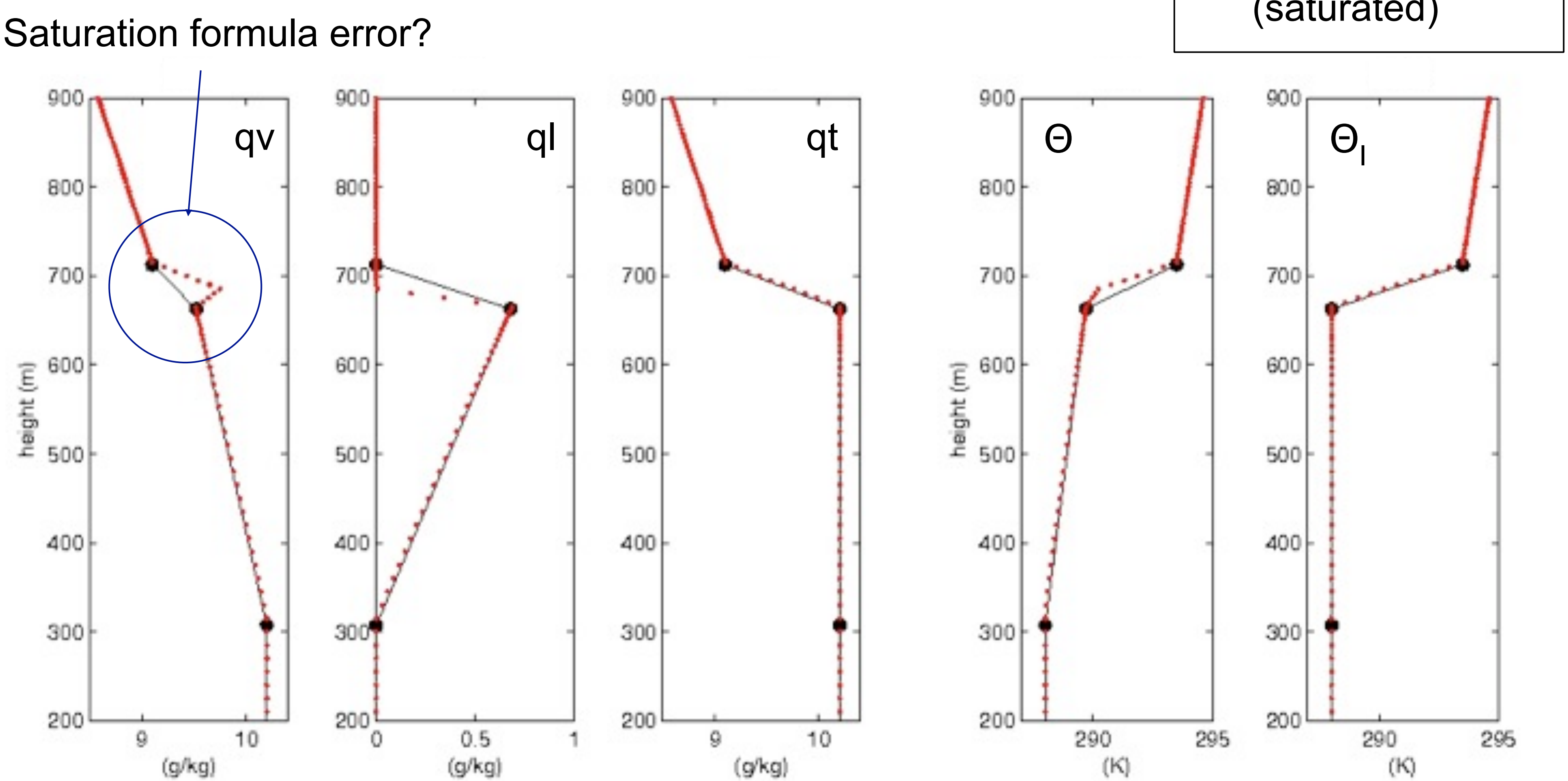
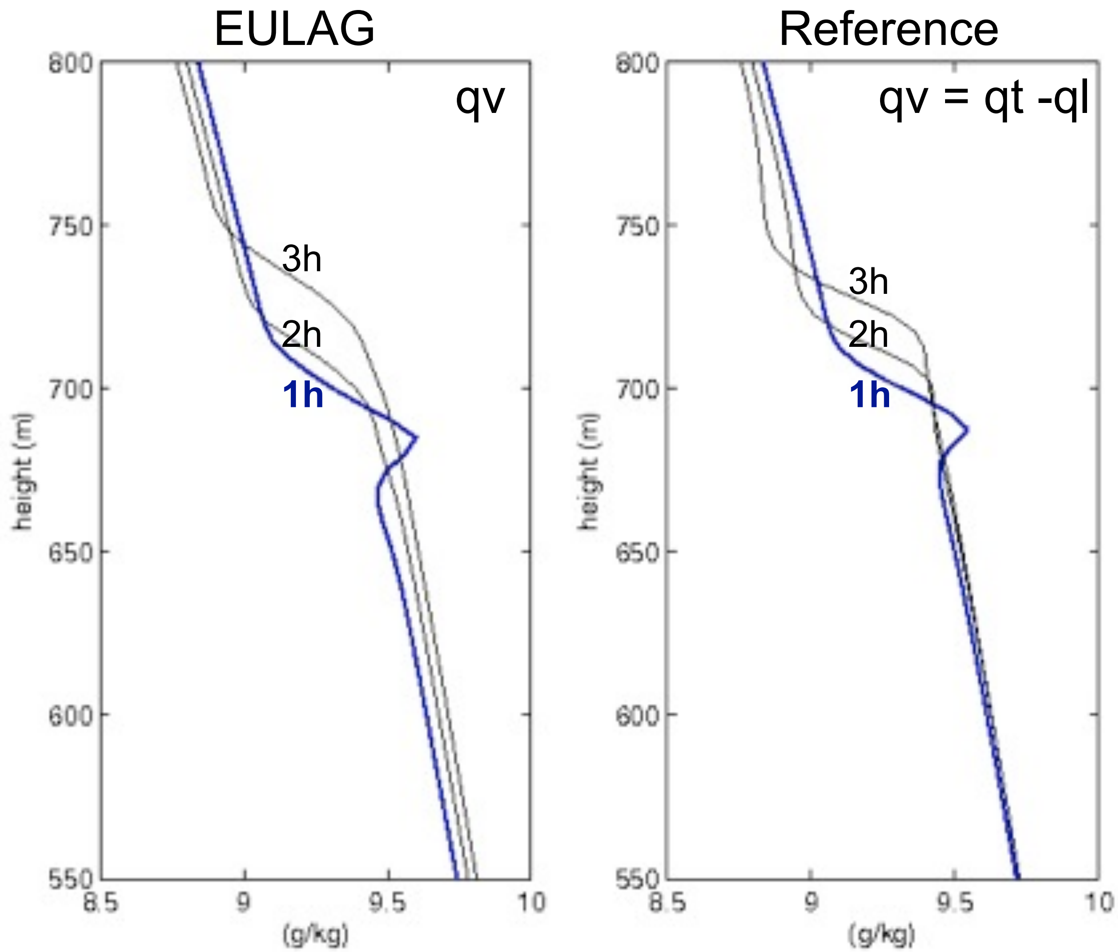
- prognostic thermodynamic variables: qv, qc, qr, θ
- physical altitude as a vertical coordinate

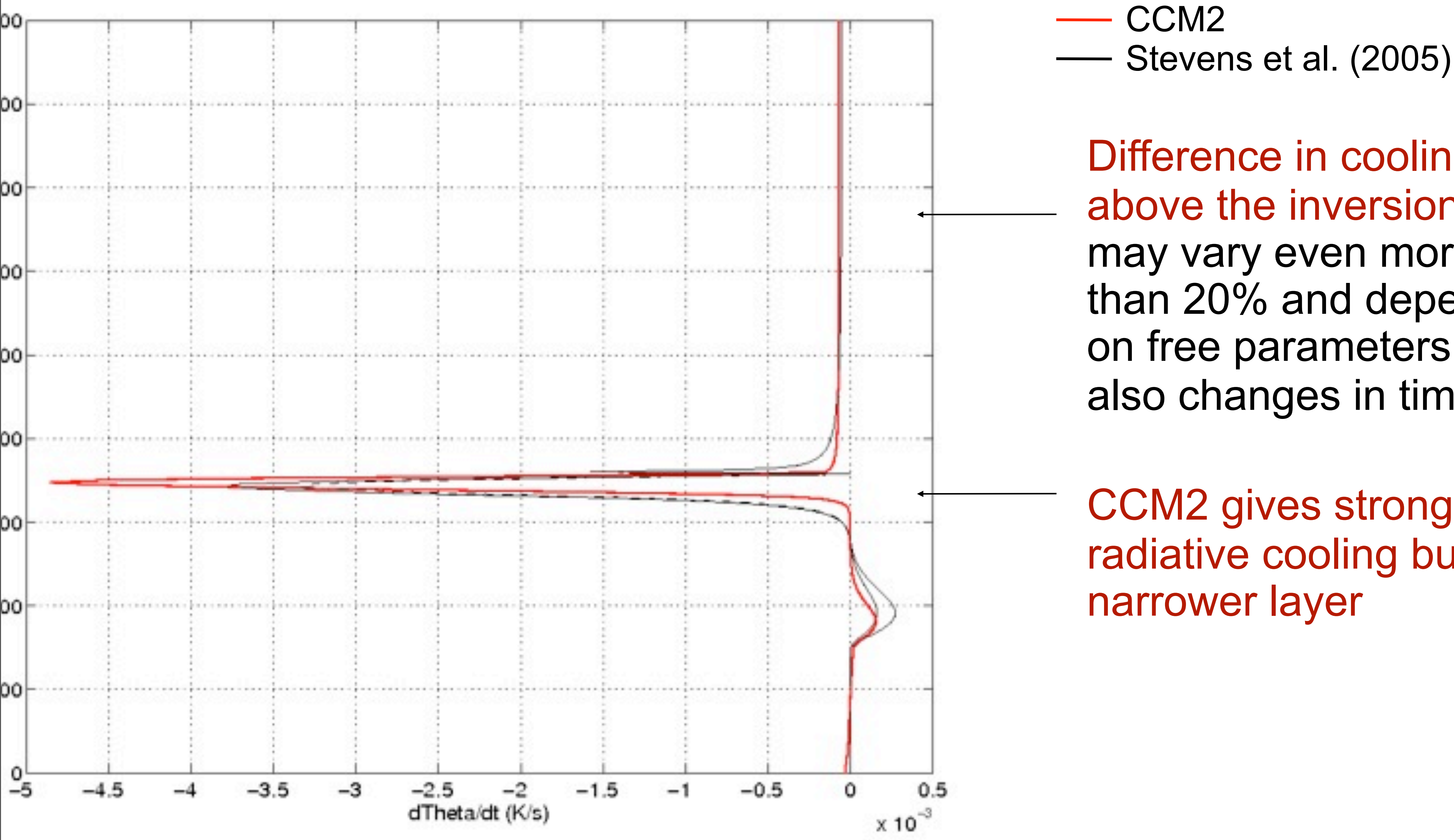


Initialization (2)

Comparison of hourly averaged profiles for EULAG and reference model (*thanks to Johann van der Dussen*) shows that overshooting in qv is a feature of the initial profile resulting from linear data interpolation at the inversion. It disappears for subsequent hours.



Radiation (4)



Difference in cooling above the inversion may vary even more than 20% and depends on free parameters; it also changes in time

CCM2 gives stronger radiative cooling but in narrower layer

Surface fluxes

In a simplified boundary layer parameterization we assume constant drag coefficient Cd=0.0014. Surface fluxes are:

$$Qfx = -Cd \cdot |U_1| \cdot (q_1 - q_{surf}(t))$$

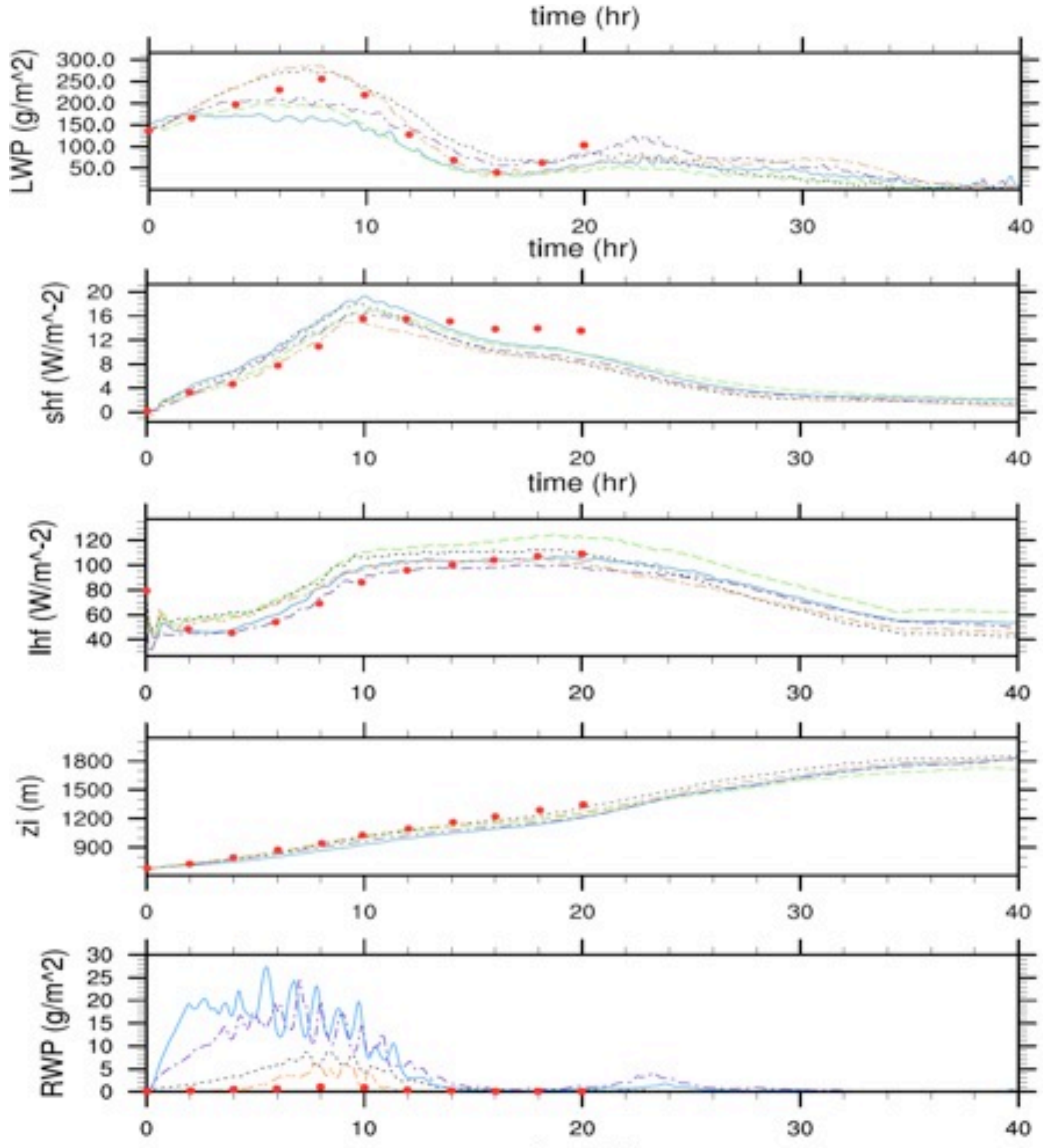
$$Hfx = -Cd \cdot |U_1| \cdot (\Theta_1 - \Theta_{surf}(t)) \qquad (1)$$

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 (!). Based on experimental verification, (1) should to be modified to:

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

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



Jeszcze raz rysunek z RWP (rain water path – u nas jest g... malo