Dutch Atmospheric Large-Eddy Simulation Model (DALES v3.2)

CGILS-S11 results

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DALES development:
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Steef Boing (Delft University of Technology)

McICA code:
Robert Pincus (NOAA)
Bjorn Stevens (MPI-Hamburg)

Many thanks to the CGILS-LES group for helpful suggestions!

Dutch Atmospheric Large-Eddy Simulation Model (DALES v3.2)

Open source code (GIT)

• *KNMI, University of Wageningen, Delft Technical University of Technology (Thijs Heus: MPI-Hamburg)*

Benefits to users: Additions of new physics routines

• McICA Radiation: *Pincus and Stevens 2009, implemented by Thijs Heus*

• CGILS-radiation scheme close to be fully operational in DALES v3.2

• Coupled Surface Energy Balance model: *van Heerwaarden, Wageningen University*

However, it requires a lot of dedication to keep up with the modifications

• increase in the number of switches

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Simulation details

Simulation time

10 days
adaptive time step, dtmax = 10 secs
radiation time step = 60 secs

Domain size

4.8 x 4.8 x 4 km^3, 96 x 96 x 128 grid points (Δz = 25 m in lower part)

Total CPU hours on 32 processors

2700 hours

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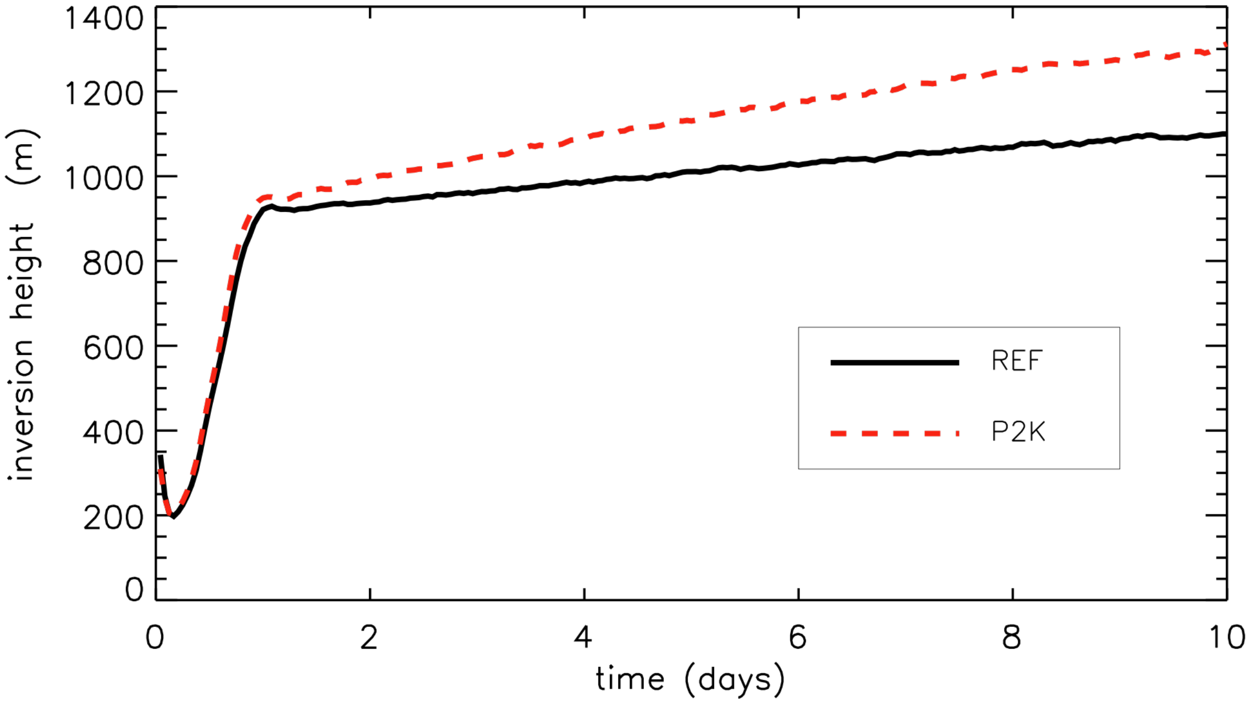
Inversion height



$$\frac{\partial z_{inv}}{\partial t} = w_e + w_{subs}\left(z = z_{inv}\right)$$

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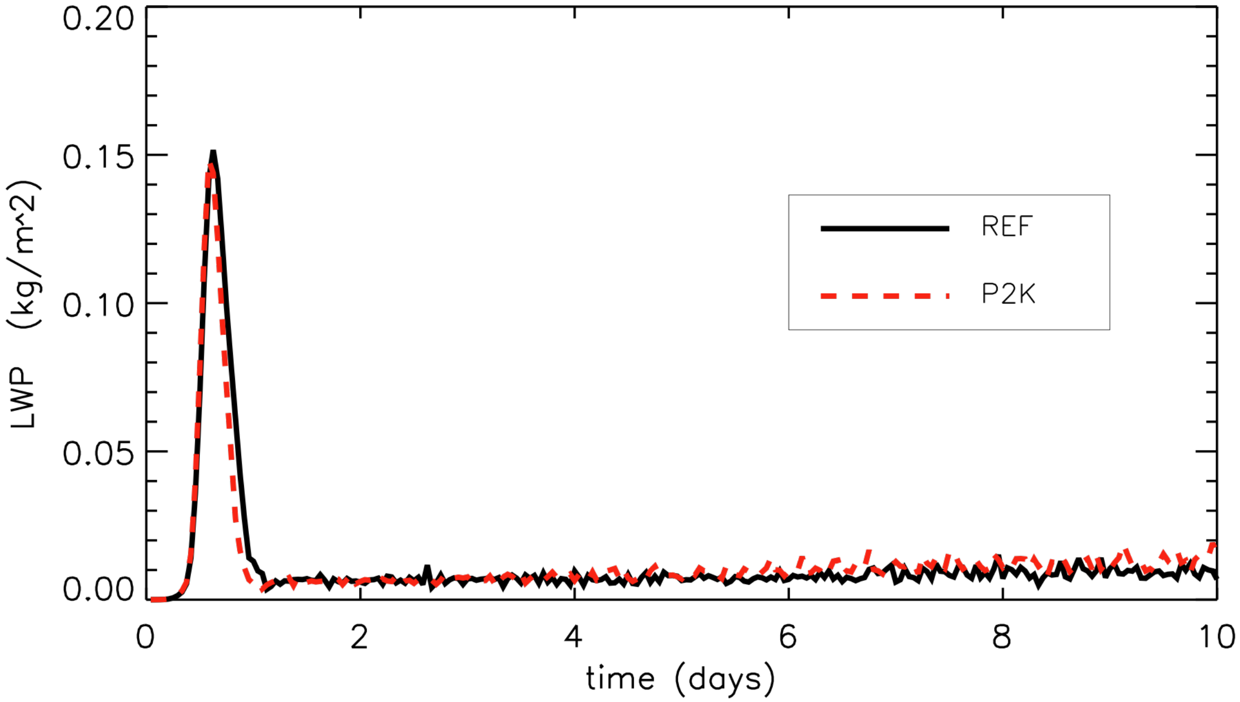
Cloud liquid water path (LWP)



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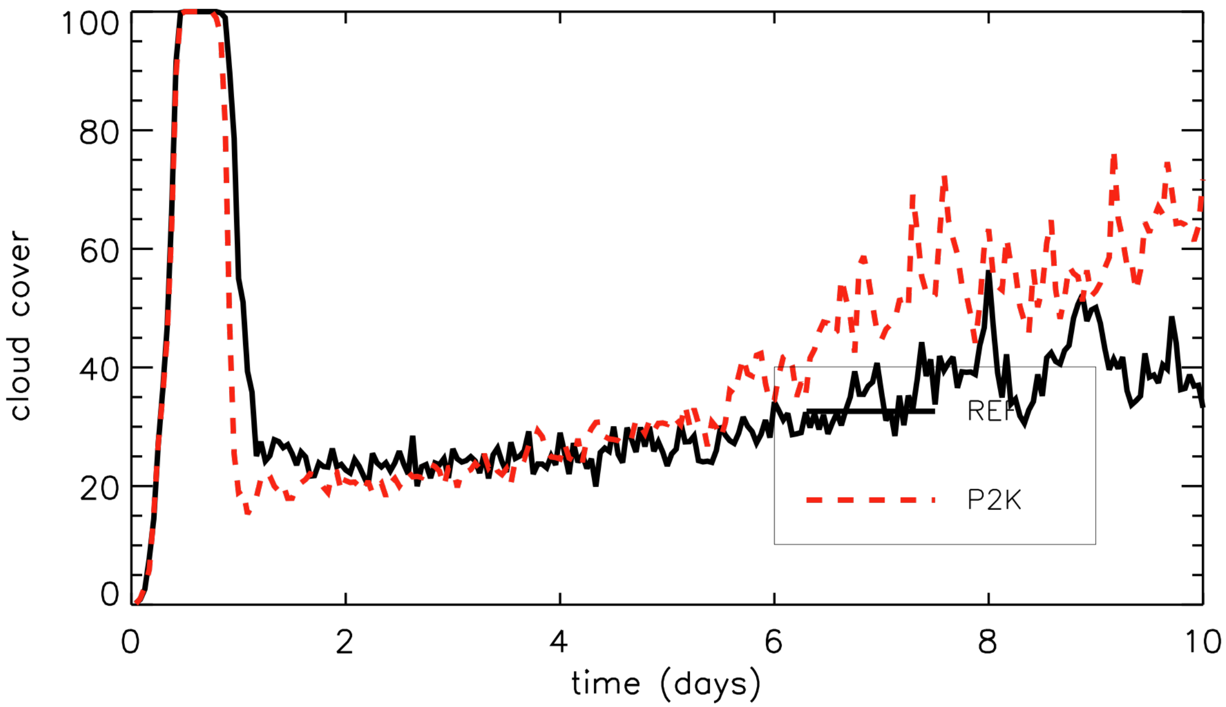
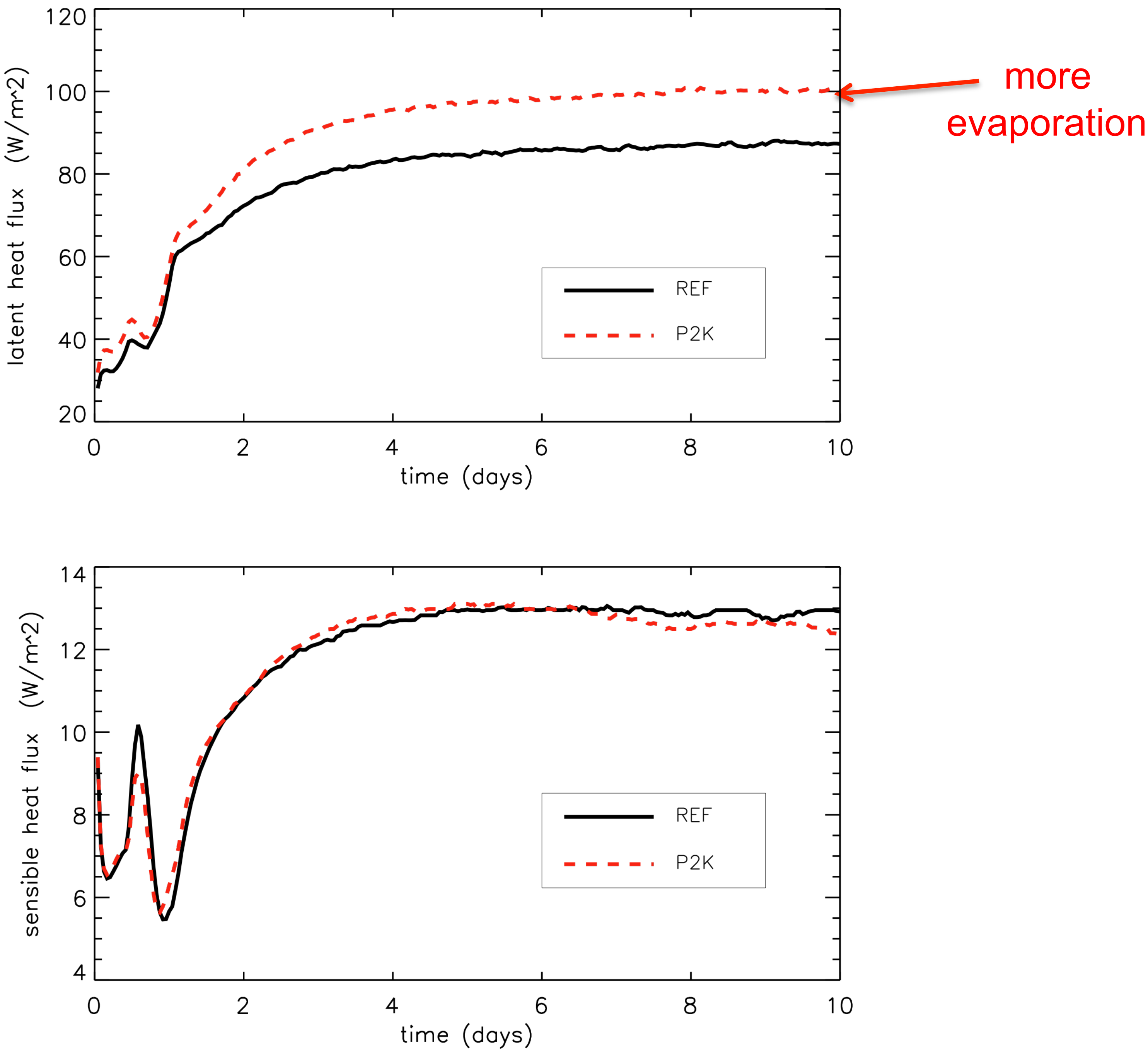
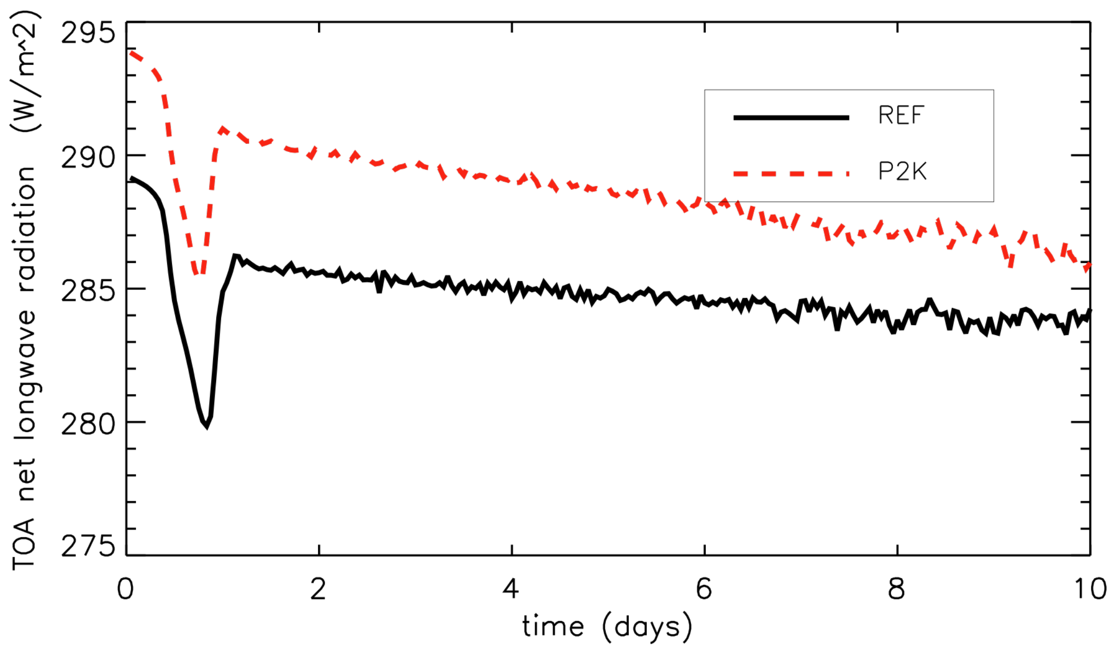
Cloud cover

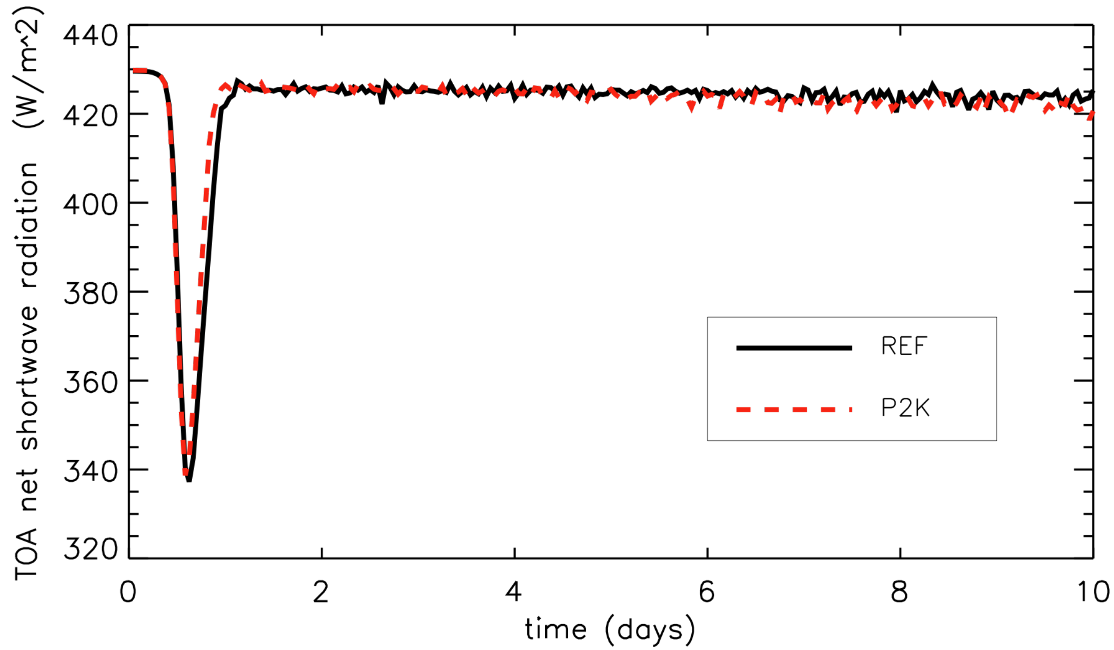


Turbulent Surface Fluxes



Top Of Atmosphere Net Radiative Fluxes





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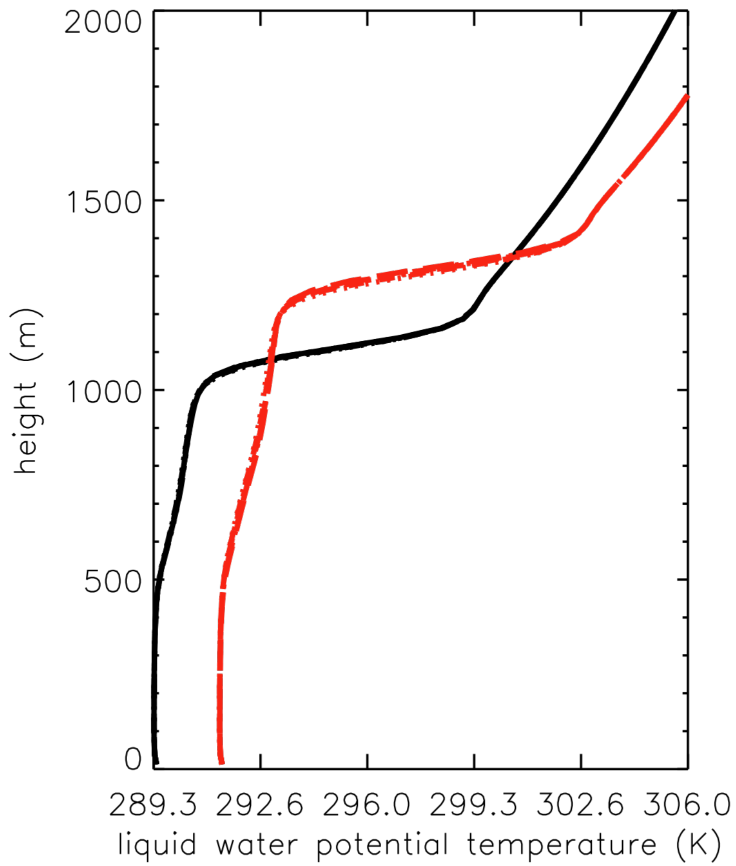
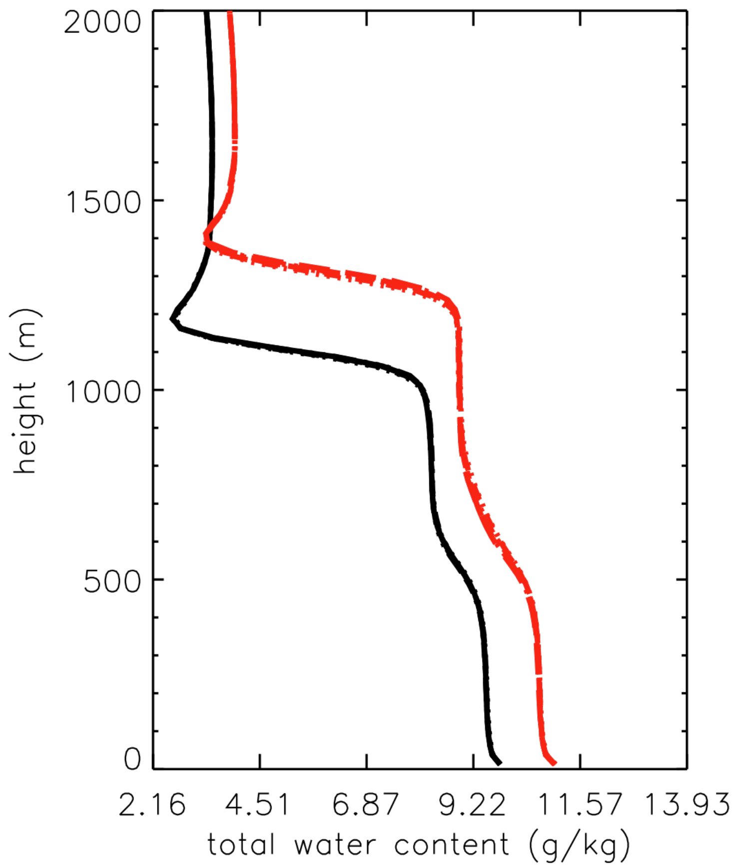
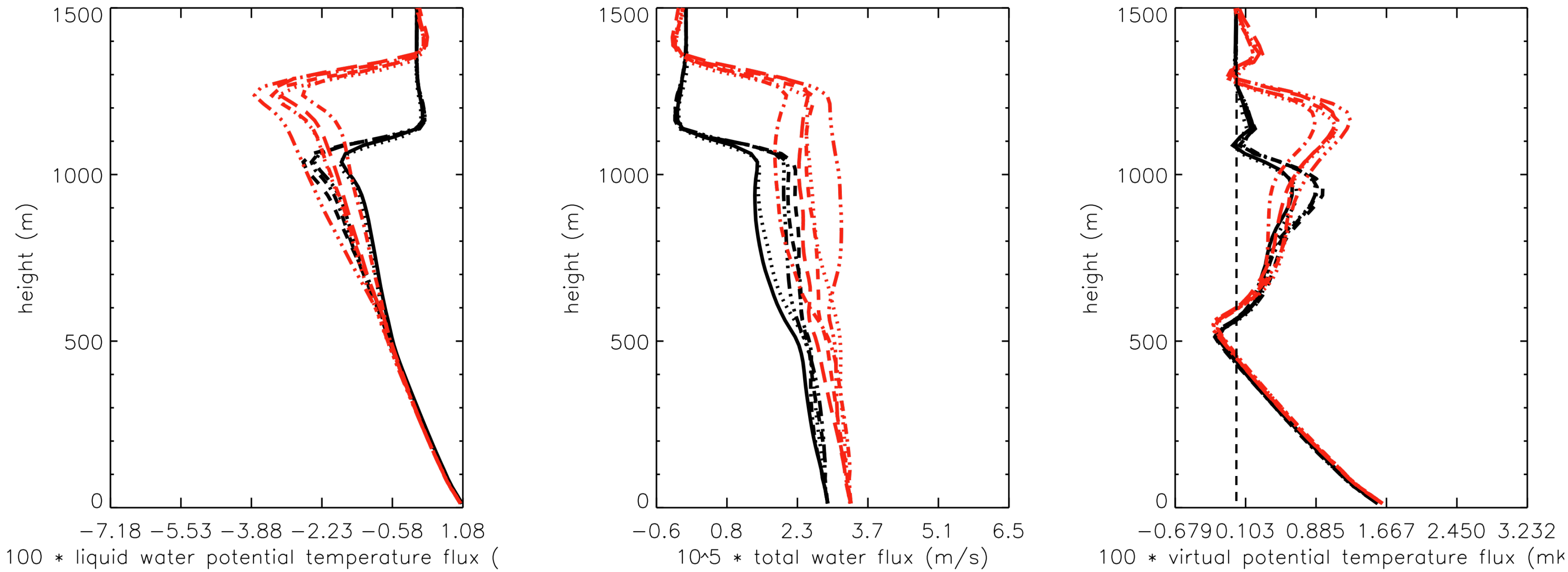
Hourly-averaged vertical mean profiles during the last 5 hours





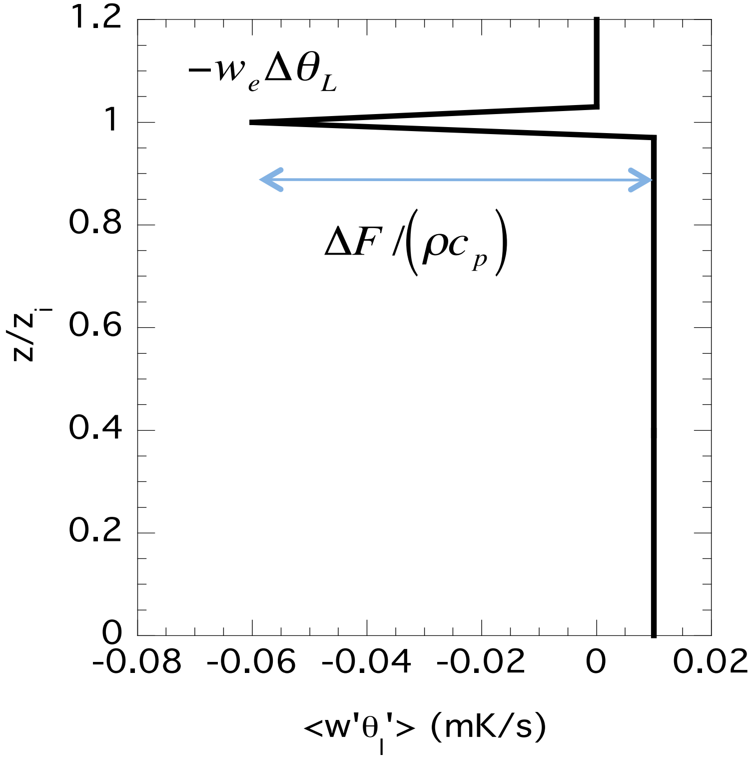
CGILS

Hourly-averaged turbulent fluxes during the last 5 hours



Steady state solutions

Example: longwave radiative cooling at cloud top

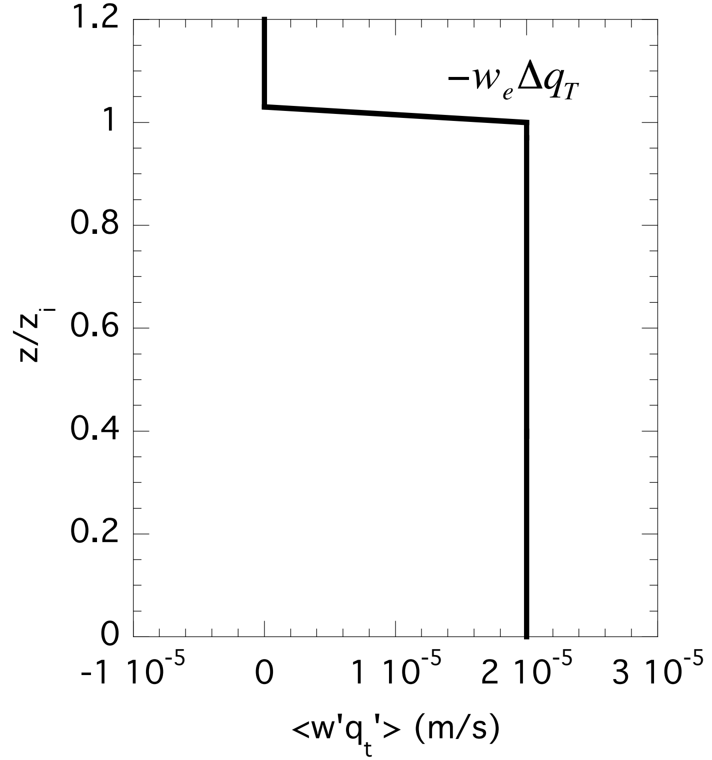


Steady state $$\frac{\partial \langle \theta_L \rangle}{\partial t} = 0$$

Requires constant flux $$-\frac{\partial \langle w' \theta_L' \rangle}{\partial z} = 0$$

Steady state solutions

Example: no precipitation



Steady state

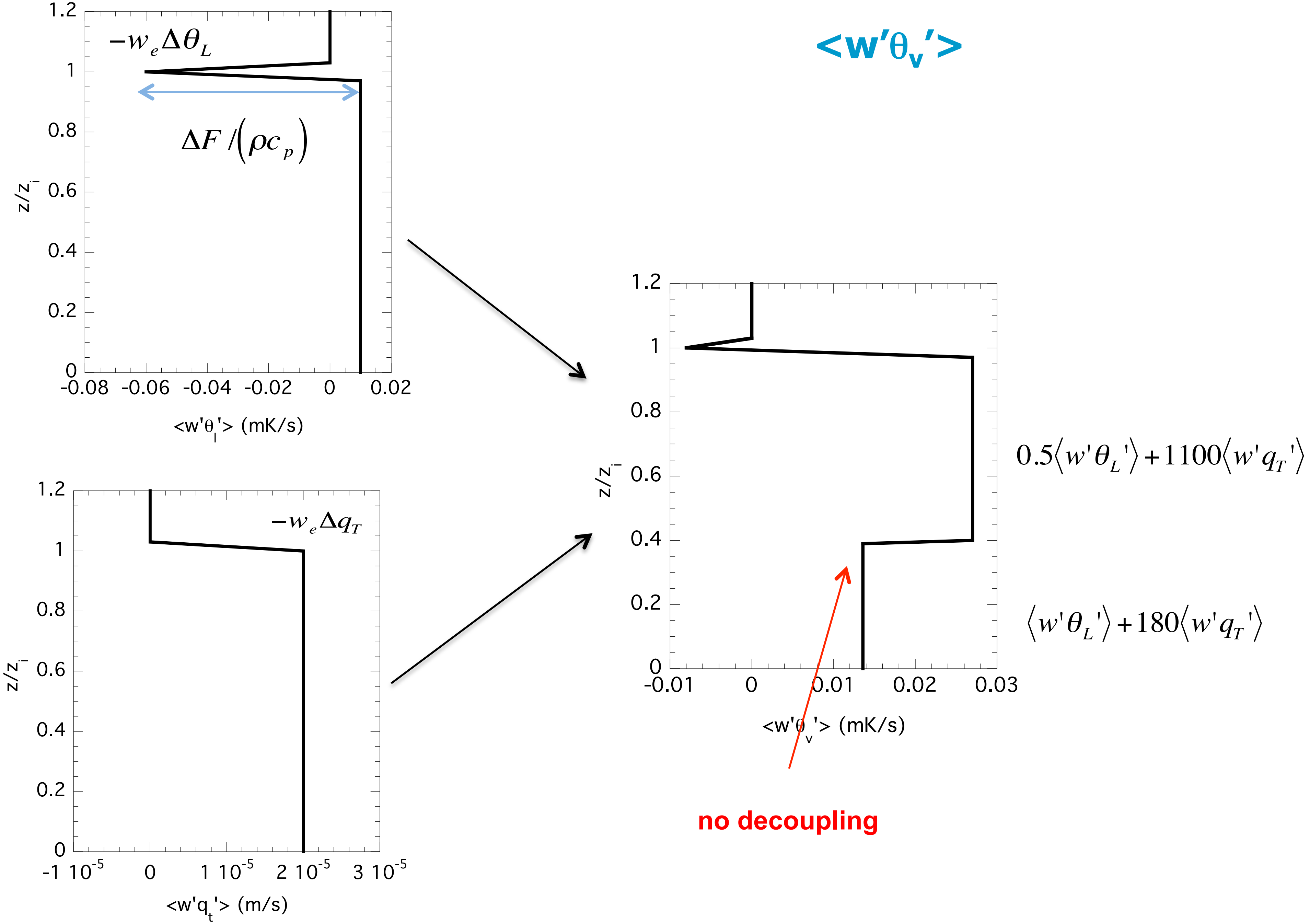
$$\frac{\partial \langle q_T \rangle}{\partial t} = 0$$

Requires constant flux

$$-\frac{\partial \langle w' q_T' \rangle}{\partial z} = 0$$

Steady state solutions:

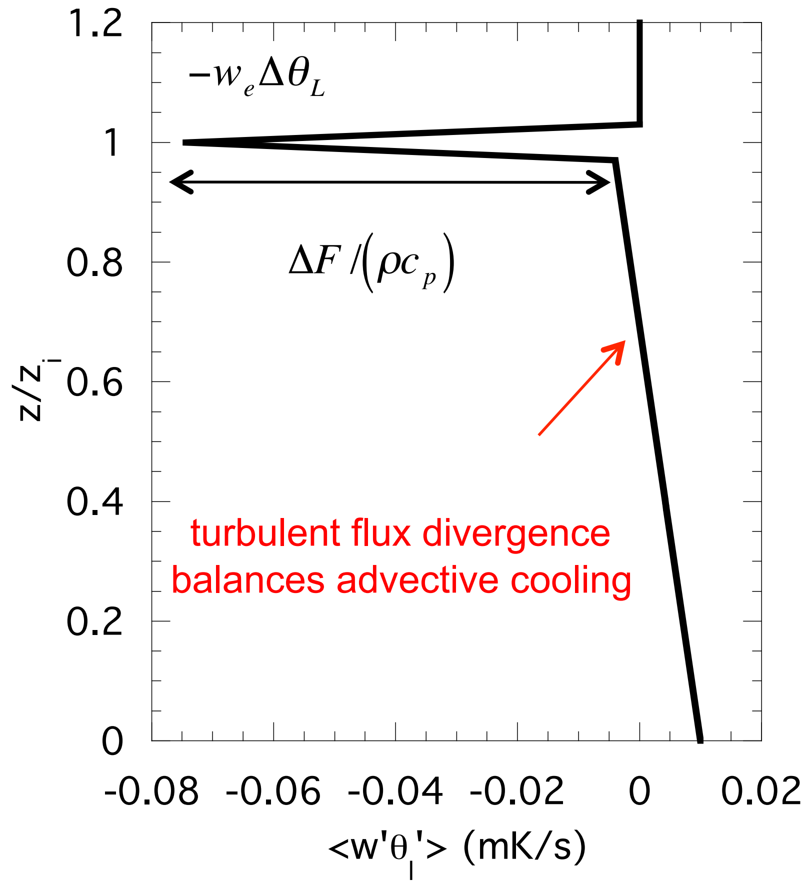
<w'θv'>



Steady state solutions

Example:

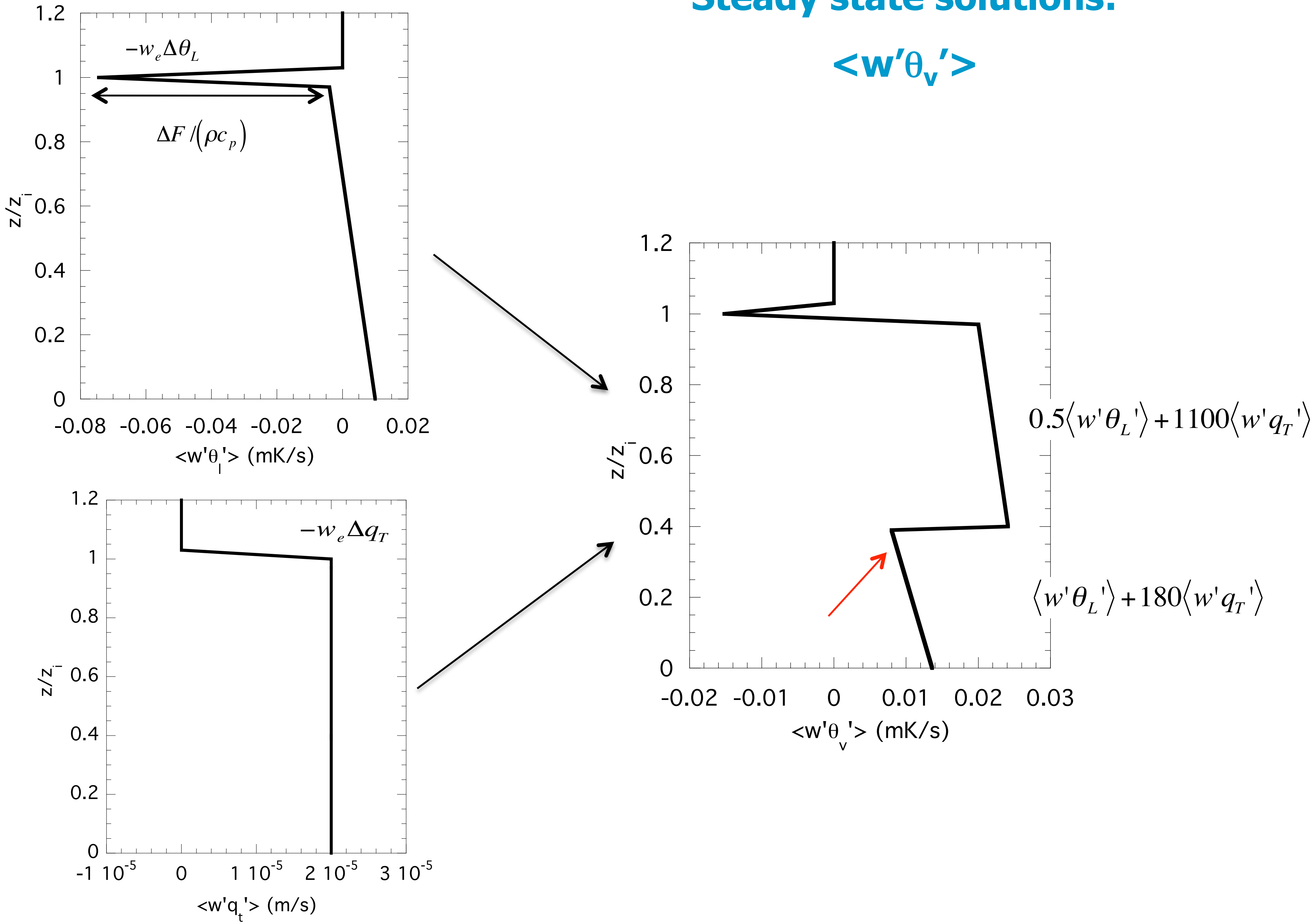
- longwave radiative cooling
- large-scale horizontal advection



$$-\frac{\partial\langle w'\theta_L'\rangle}{\partial z} = \left(U\frac{\partial\theta_L}{\partial z}\right)_{\mathrm{large-scale}}$$

Steady state solutions:

<w'θv'>



Steady state solutions & decoupling

No decoupling[(#)] if $\langle w'\theta_V'\rangle > 0$ at cloud base height z_{base}

So $$\langle w'\theta_L'\rangle_{z_{base}} > -\frac{B_d}{A_d}\langle w'q_T'\rangle_{z_{base}}$$

Flux divergence:

$$-\frac{\partial\langle w'\theta_L'\rangle}{\partial z} = -\frac{\langle w'\theta_L'\rangle_{z_{base}} - \langle w'\theta_L'\rangle_0}{z_{base}} < \frac{\frac{B_d}{A_d}\langle w'q_T'\rangle_{z_{base}} + \langle w'\theta_L'\rangle_0}{z_{base}}$$

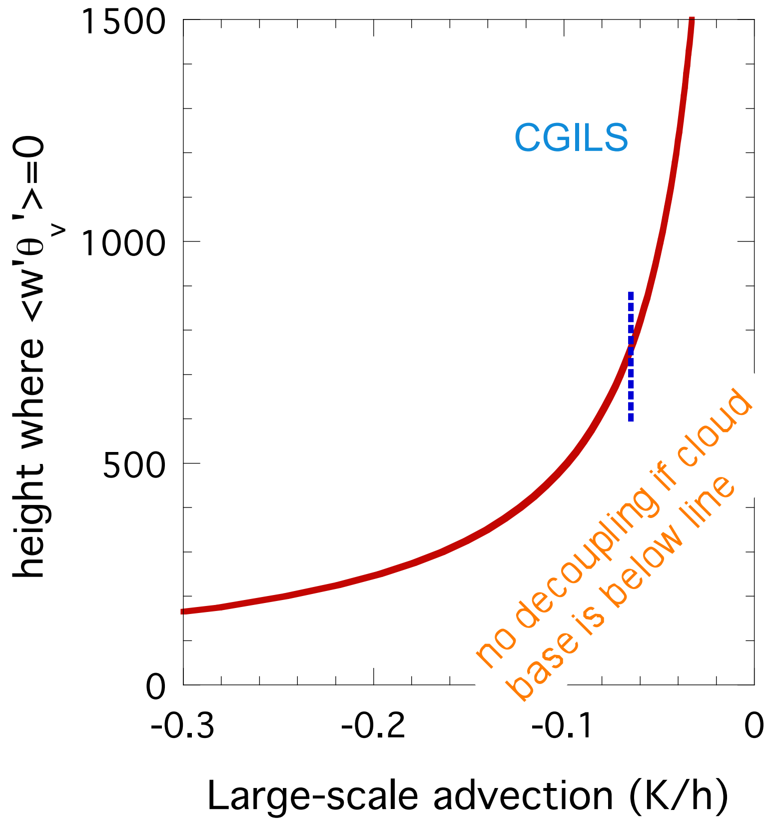
(#) This is a weak criterion. In fact, the flux can be slightly negative without the BL getting decoupled

Steady state solutions & decoupling

Steady state if $$-\frac{\partial\langle w'\theta_L'\rangle}{\partial z} = \frac{\frac{B_d}{A_d}\langle w'q_T'\rangle_{z_{base}} + \langle w'\theta_L'\rangle_0}{z_{base}} = \left(U\frac{\partial\theta_L}{\partial x}\right)_{\substack{\text{large}\\ \text{scale}}}$$

Steady state solutions & decoupling

Steady state if $$-\frac{\partial\langle w'\theta_L'\rangle}{\partial z} = \frac{\frac{B_d}{A_d}\langle w'q_T'\rangle_{z_{base}} + \langle w'\theta_L'\rangle_0}{z_{base}} = \left(U\frac{\partial\theta_L}{\partial x}\right)_{\substack{\text{large}\\ \text{scale}}}$$



Steady state solutions & decoupling

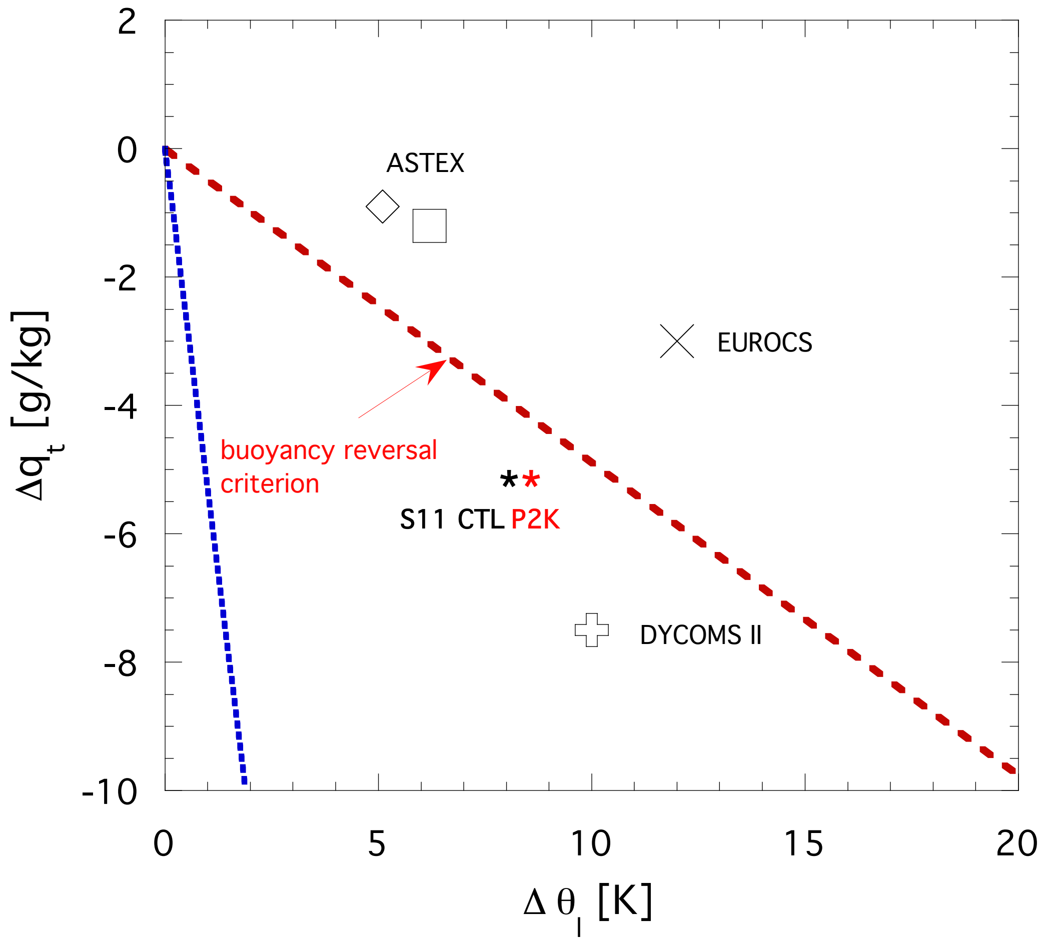
Decoupling due to large-scale advection alone not very likely

However, two other processes cause steeper $<w'\theta_v'>$ gradients

In the subcloud layer:

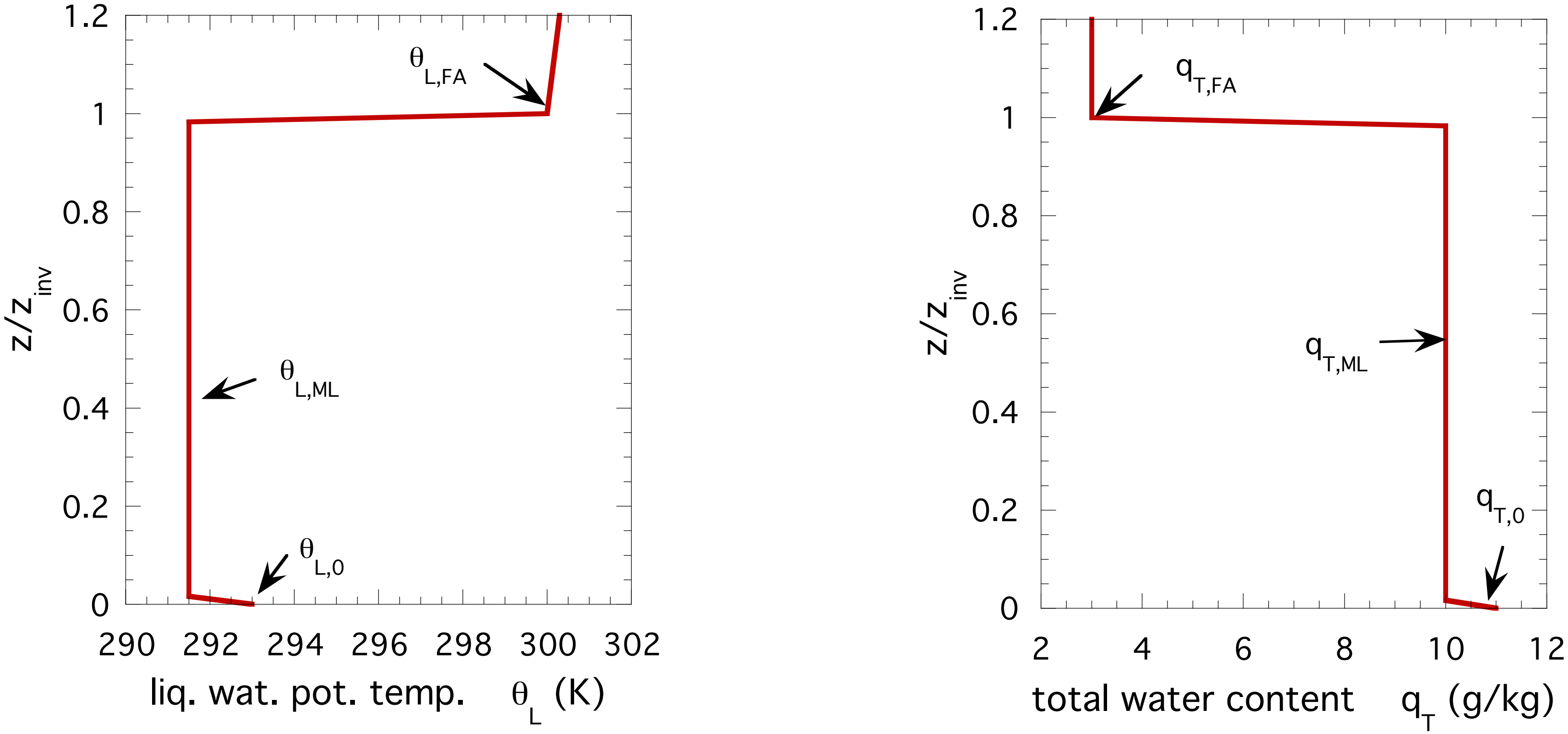
- evaporation of drizzle
- longwave radiative cooling

CGILS: Inversion jumps (after 10 days)



Mixed-layer model

$$\frac{\partial \overbrace{\psi_{ML}}^{\text{BL mean}}}{\partial t} = -\frac{\overbrace{-w_e\left(\psi_{FA}-\psi_{ML}\right)}^{\text{entrainment flux}} - \overbrace{c_D U_{ML}\left(\psi_0-\psi_{ML}\right)}^{\text{surface flux}} + \overbrace{\Delta S_{\psi}}^{\text{source/sink}}}{z_i}$$



Mixed-layer model

$$\frac{\partial \overbrace{\psi_{ML}}^{\text{BL mean}}}{\partial t} = -\frac{\overbrace{-w_e\left(\psi_{FA} - \psi_{ML}\right)}^{\text{entrainment flux}} - \overbrace{c_D U_{ML}\left(\psi_0 - \psi_{ML}\right)}^{\text{surface flux}} + \overbrace{\Delta S_\psi}^{\text{source/sink}}}{z_i}$$

$$\frac{\partial z_{inv}}{\partial t} = w_e + \langle w \rangle_{\text{subs}} = w_e - D z_i$$

Mixed-layer model

$$\frac{\partial \overbrace{\psi_{ML}}^{\text{BL mean}}}{\partial t} = -\frac{\overbrace{-w_e\left(\psi_{FA} - \psi_{ML}\right)}^{\text{entrainment flux}} - \overbrace{c_D U_{ML}\left(\psi_0 - \psi_{ML}\right)}^{\text{surface flux}} + \overbrace{\Delta S_\psi}^{\text{source/sink}}}{z_i}$$

$$\frac{\partial z_{inv}}{\partial t} = w_e + \langle w \rangle_{\text{subs}} = w_e - D z_i$$

Closure(#):

$$w_e = A \frac{\Delta F_{rad}}{\theta_{L,FA} - \theta_{L,ML}}$$

(#) This closure is inspired by *Moeng (2000)*. Other closures need humidity jumps, cloud base height etc.

Mixed-layer model

$$\frac{\partial \overbrace{\psi_{ML}}^{\text{BL mean}}}{\partial t} = -\frac{\overbrace{-w_e\left(\psi_{FA} - \psi_{ML}\right)}^{\text{entrainment flux}} - \overbrace{c_D U_{ML}\left(\psi_0 - \psi_{ML}\right)}^{\text{surface flux}} + \overbrace{\Delta S_\psi}^{\text{source/sink}}}{z_i}$$

$$\frac{\partial z_{inv}}{\partial t} = w_e + \langle w \rangle_{\text{subs}} = w_e - D z_i$$

Closure:

$$w_e = A \frac{\Delta F_{rad}}{\theta_{L,FA} - \theta_{L,ML}}$$

Upper BC:

$$\theta_{L,FA}(z) = \theta_{L,0} + \Gamma_\theta z$$

$$q_{T,FA} = q_{T,0} + \Delta q_T$$

Mixed-layer model solutions

$$\frac{\partial z_{inv}}{\partial t} = w_e + \langle w \rangle_{\text{subs}} = w_e - Dz_i$$

Closure:

$$w_e = A\frac{\Delta F_{rad}}{\theta_{L,FA} - \theta_{L,ML}}$$

Approximation:

$$\theta_{L,0} - \theta_{L,ML} << \Gamma_\theta z_i$$

(surface jump much smaller than inversion jump)

Equilibrium height for the boundary layer

$$z_i = \sqrt{\frac{A\Delta F_{rad}}{D\Gamma_\theta}}$$

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Conclusions

S11 goes to an equilibrium state

Longwave radiative cooling, entrainment warming and large-scale advection
Evaporation, entrainment drying, and large-scale advection

Radiation in a future climate

Hardly any change in radiation at top of the atmosphere if SST + 2K

Outlook

Do shallow cumulus and stratus runs
Check influence advection scheme