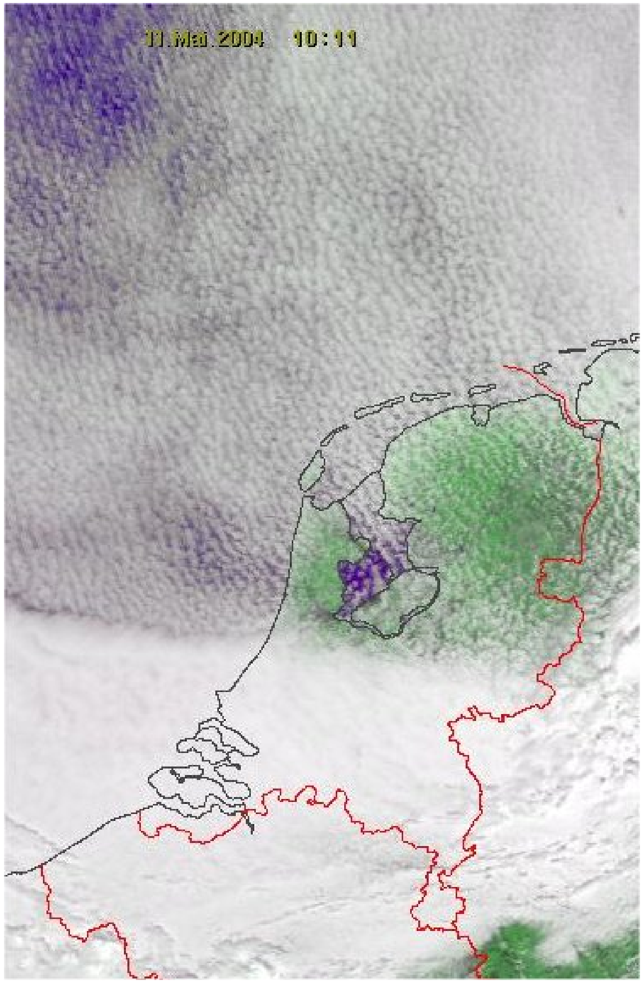
Entrainment rates in stratocumulus computed from a 1D TKE model



Stephan de Roode

KNMI

Turbulent mixing and entrainment in simple closure models

Computation of the flux $\overline{w'\psi'} = -K_\psi \frac{\partial \overline{\psi}}{\partial z}$

Representation of entrainment rate w_e

1. K-profile $K = w_e \Delta z$, w_e from parametrization
2. TKE model $K(z) = TKE(z)^{1/2}\, l(z)$, w_e implicit

Question

Does w_e from a TKE model compare well to w_e from parametrizations?

Entrainment parameterizations designed from LES of stratocumulus (*Stevens 2002*)

- Nicholls and Turton (1986)

$$w_e = \frac{2.5 A W_{NE}}{\Delta\theta_{v,NT} + 2.5A\left(T_2 \Delta\theta_{v,dry} + T_4 \Delta\theta_{v,sat}\right)}$$

- Lilly (2002)

$$w_e = \frac{A_{DL} W_{NE,DL}}{\Delta\theta_{v,DL} + A_{DL}\left(L_2 \Delta\theta_{v,dry} + L_4 \Delta\theta_{v,sat}\right)}$$

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$$w_e = \frac{A W_{NE}}{T_2 \Delta\theta_{v,dry} + T_4 \Delta\theta_{v,sat}}$$

- Lock (1998)

$$w_e = \frac{2A_{AL} W_{NE} + \alpha_t A_W \Delta F_L /\left(\rho c_p\right)}{\Delta\theta_v}$$

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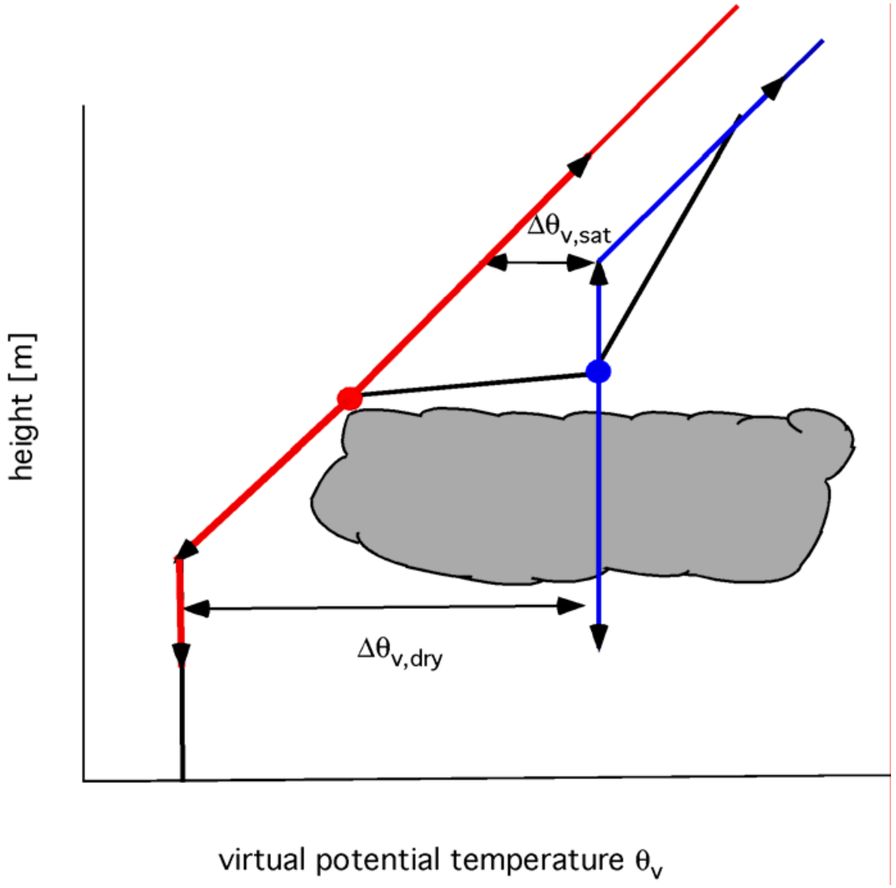
$$w_e = \frac{A_M \overline{w'\theta_l'} + \Delta F_L \left(3 - e^{-\sqrt{b_m L}}\right)/\left(\rho c_p\right)}{\Delta\theta_l}$$

Stability jumps



$\Delta\theta_{v,sat} = \Delta_2$ (the CTEI criterion, Randall 1980, Deardorff 1980)

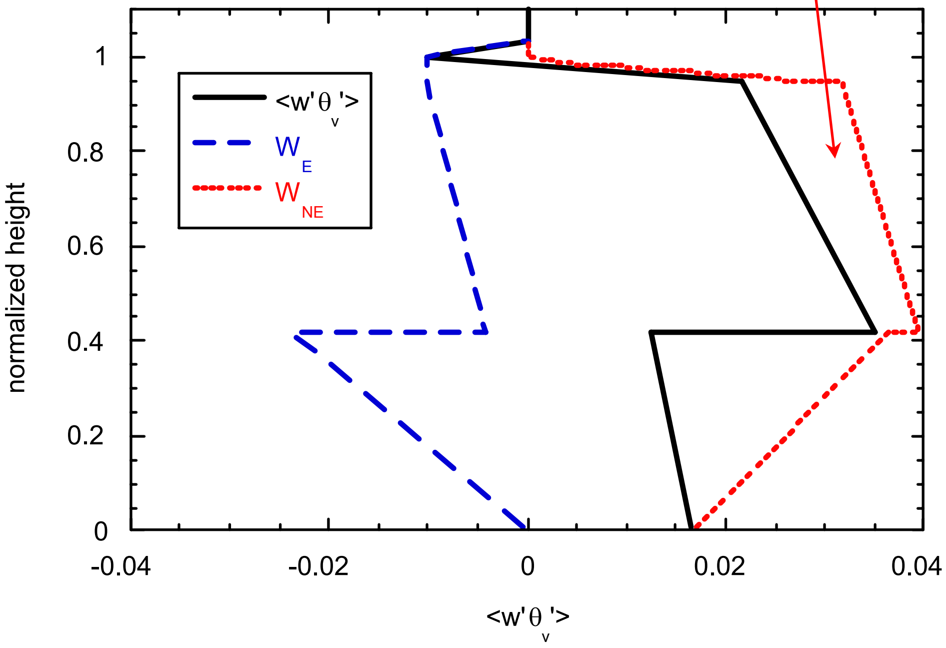
Solve entrainment rate for a stratocumulus-topped boundary layer

$$w_e = A \frac{w_*^3}{\frac{g}{\theta_0} H \, \Delta\theta_v}$$

solve for
entrainment rate

$$\Rightarrow$$

$$\boxed{w_e = \frac{2.5 A W_{NE}}{\Delta\theta_v + 2.5A\left(T_2 \Delta\theta_{v,dry} + T_4 \Delta\theta_{v,sat}\right)}}$$



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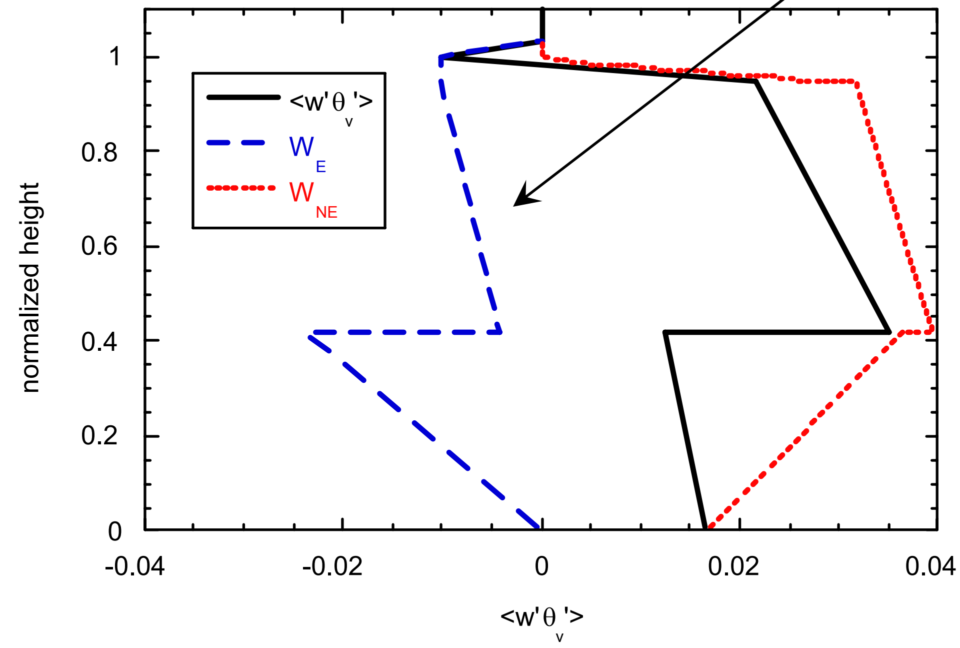

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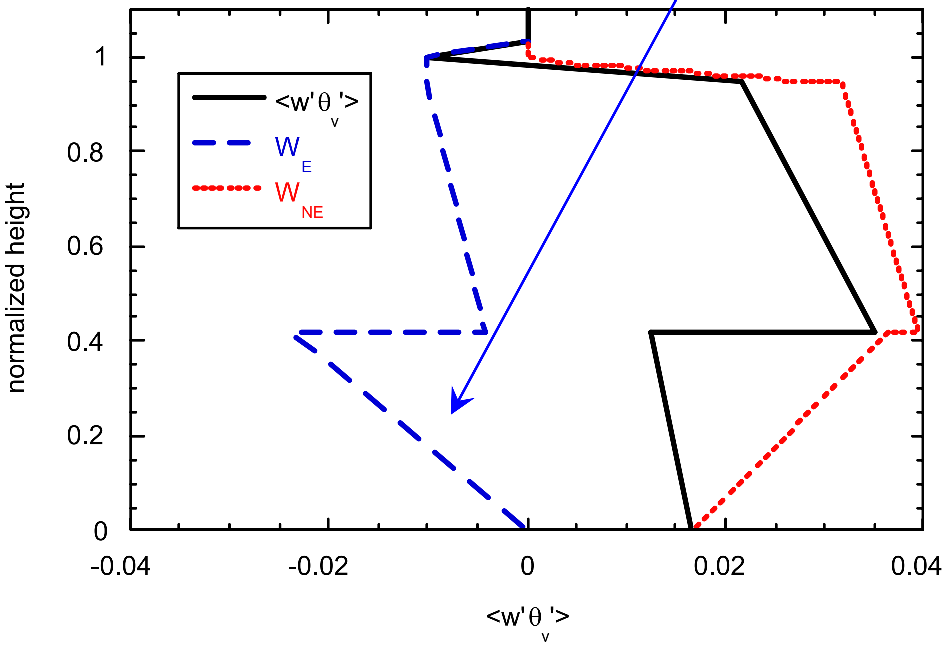

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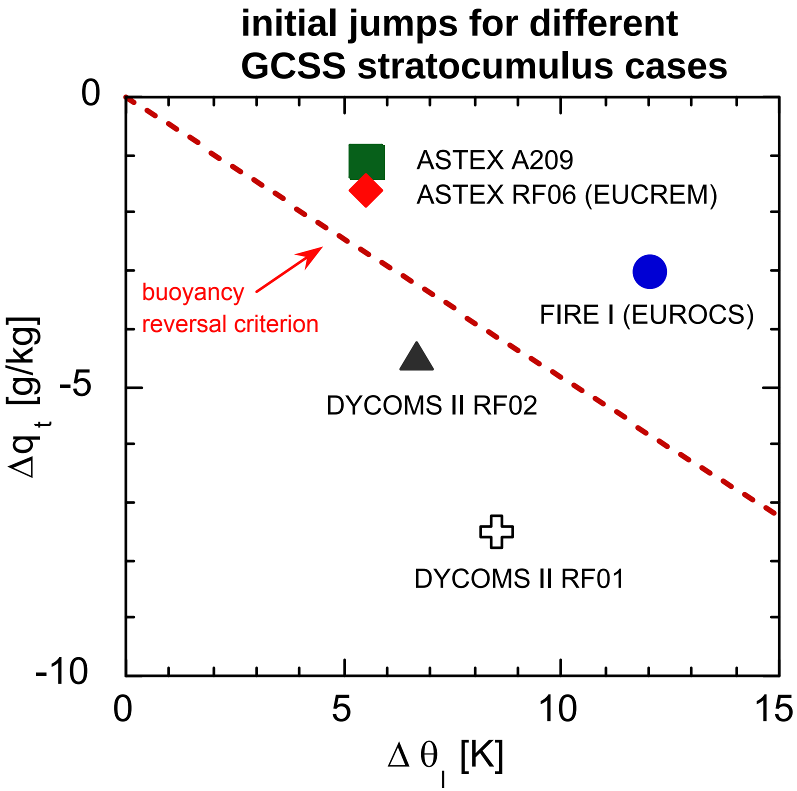
GCSS stratocumulus cases

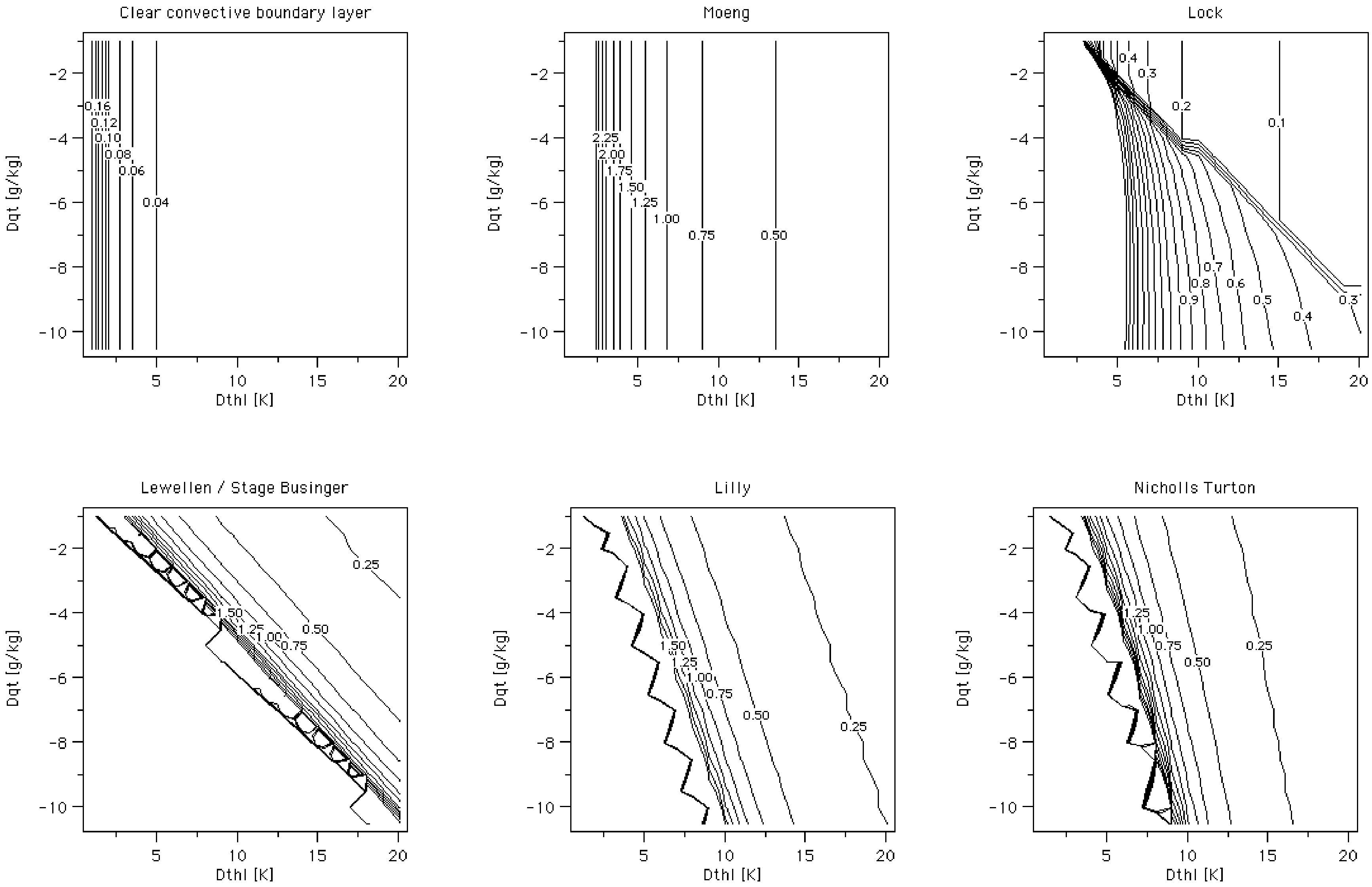


ASTEX A209 boundary conditions

cloud base height	= 240 m
cloud top height	= 755 m
sensible heat flux	= 10 W/m^2
latent heat flux	= 30 W/m^2
longwave flux jump	= 70 W/m^2
max liq. water content	= 0.5 g/kg
LWP	= 100 g/m^2
$\Delta\theta_l$	= 5.5 K
Δq_t	= -1.1 g/kg

fill in these values in parameterizations, but vary the inversion jumps $\Delta\theta_l$ and Δq_t

Entrainment rate [cm/s] sensitivity to inversion jumps - Boundary conditions as for ASTEX A209



Some details of the TKE model simulation

- TKE equation

$$\frac{\partial \overline{E}}{\partial t} = \frac{g}{\overline{\theta_v}}\overline{w'\theta_v'} - \overline{u'w'}\frac{\partial U}{\partial z} - \overline{v'w'}\frac{\partial V}{\partial z} - \frac{\partial}{\partial z}\left(\overline{w'E'} + \frac{\overline{w'p'}}{\rho}\right) - \varepsilon$$

- Flux

$$\overline{w'\psi'} = -c_\psi \sqrt{TKE}\,\ell \frac{\partial \overline{\psi}}{\partial z}$$

- 'integral' length scale

$$\frac{1}{\ell} = \frac{1}{\ell_u} + \frac{1}{\ell_d}$$

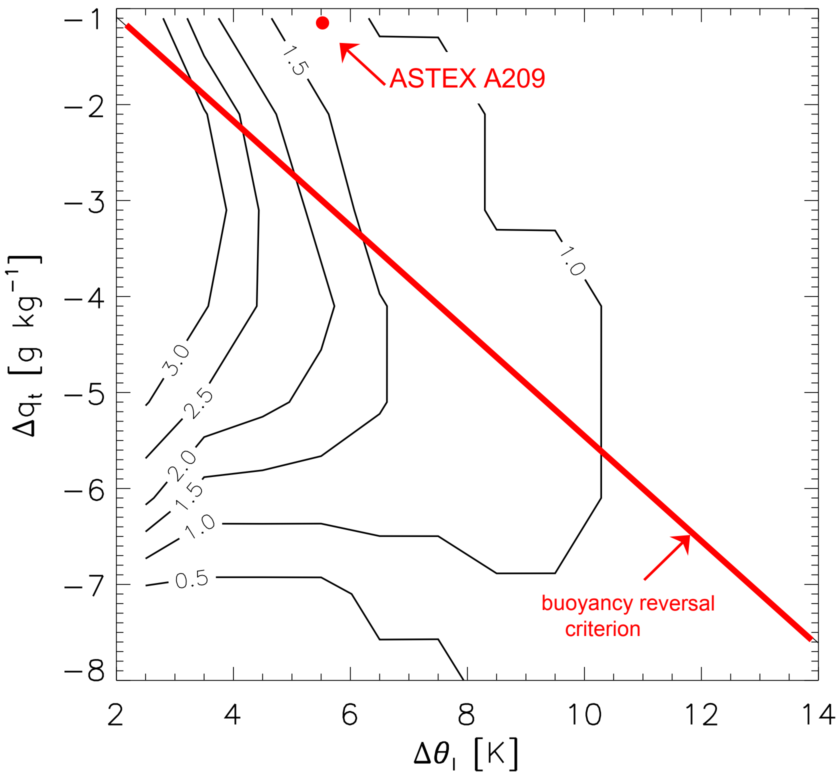
(Lenderink & Holtslag 2004)

- buoyancy flux weighed with cloud fraction

$$\overline{w'\theta_v'} = -c_H \sqrt{\overline{E}}\,\ell \left[\sigma\left(A_w \frac{\partial \overline{\theta_l}}{\partial z} + B_w \frac{\partial \overline{q_t}}{\partial z}\right) + (1-\sigma)\left(A_d \frac{\partial \overline{\theta_l}}{\partial z} + B_d \frac{\partial \overline{q_t}}{\partial z}\right)\right]$$

- ASTEX A209 forcing and initialization
- $\Delta t = 60$ s , $\Delta z = 5$ m
- Mass flux scheme turned off, no precipitation

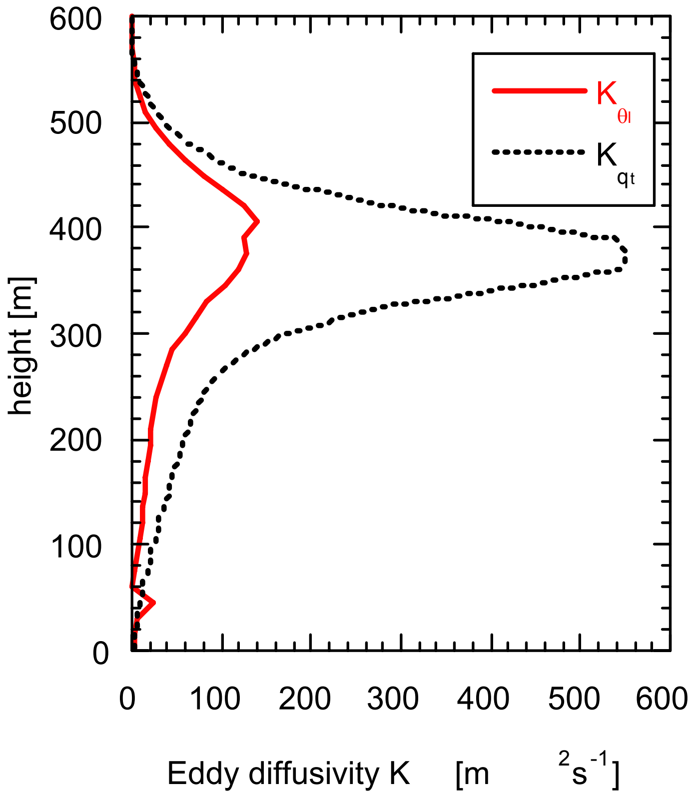
Entrainment sensitivity to inversion jumps from a TKE model



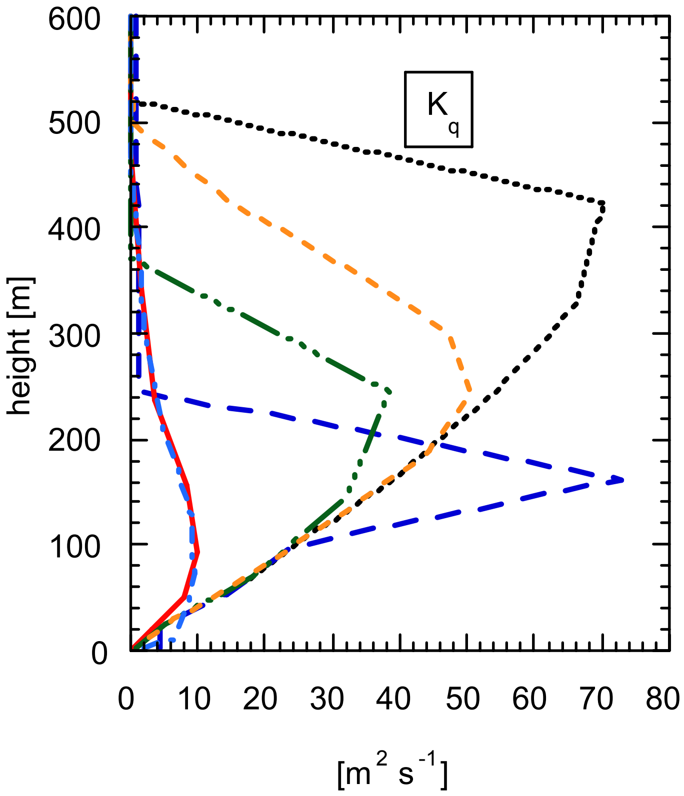
- Moisture jump sensitivity
- No buoyancy reversal: entrainment rates slightly larger than parameterizations
- Buoyancy reversal: entrainment rates decrease

Eddy diffusivities in K-closure models - Results from the EUROCS stratocumulus case

LES result



results from 6 differents SCMs



- LES: Eddy diffusivities for heat and moisture differ (like CBL, Wyngaard and Brost 1980)
- SCM: typically smaller values than LES

Should we care about eddy diffusivity profiles in SCMs?

Simple experiment

1. Prescribe surface latent and sensible heat flux

2. Prescribe entrainment rate

$\Rightarrow$ Given jumps of θ_l and q_t, fluxes at BL top are fixed

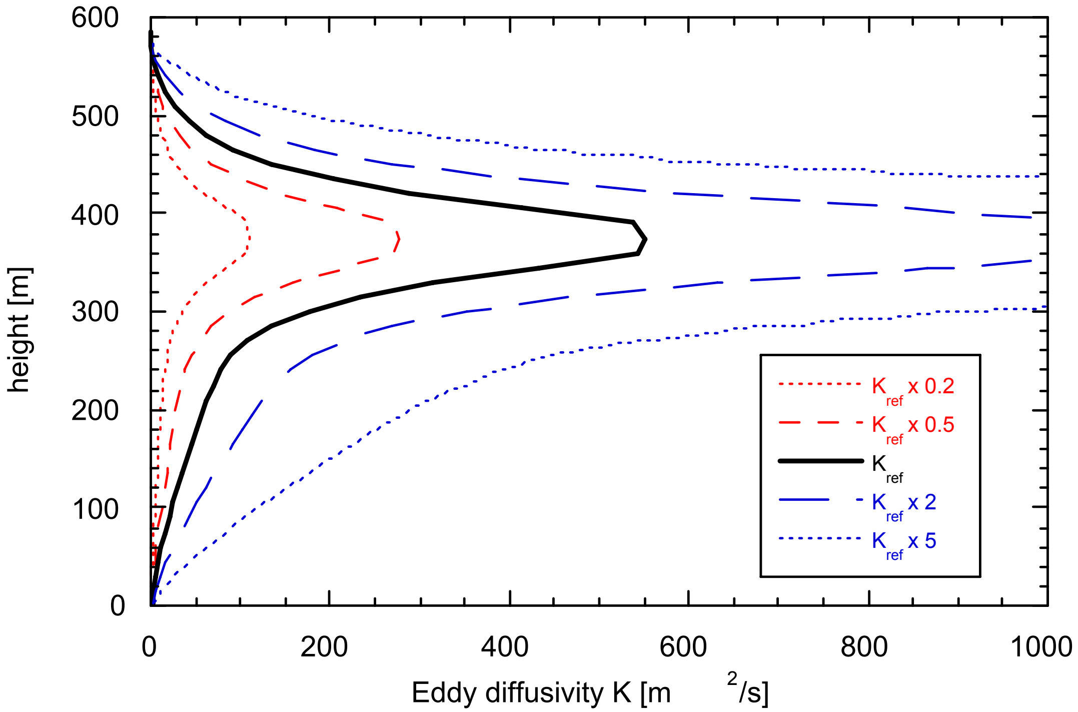
3. Consider quasi-steady state solutions

$\Rightarrow$ fluxes linear function of height

Consider mean state solutions from

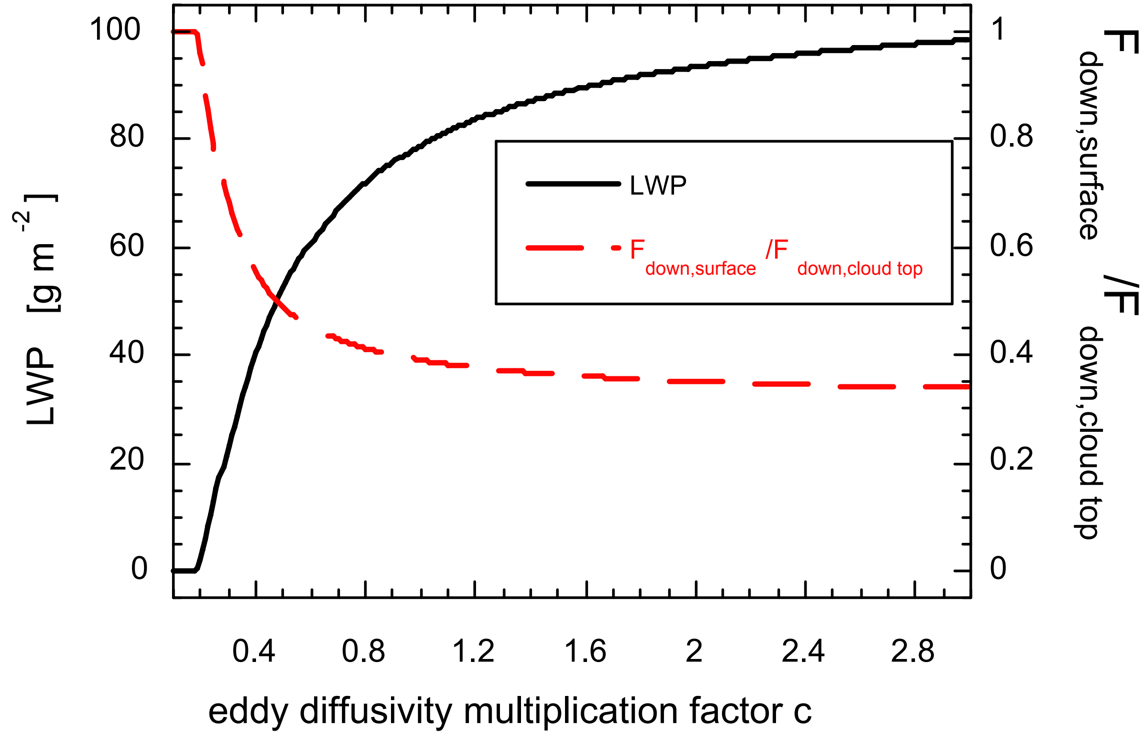
$$\overline{\psi}(z) = \psi_0 - \int_{z'=0}^{z'=z} \frac{\overline{w'\psi'}(z')}{K_\psi(z')} dz'$$

Vary eddy diffusivity profiles with a constant factor

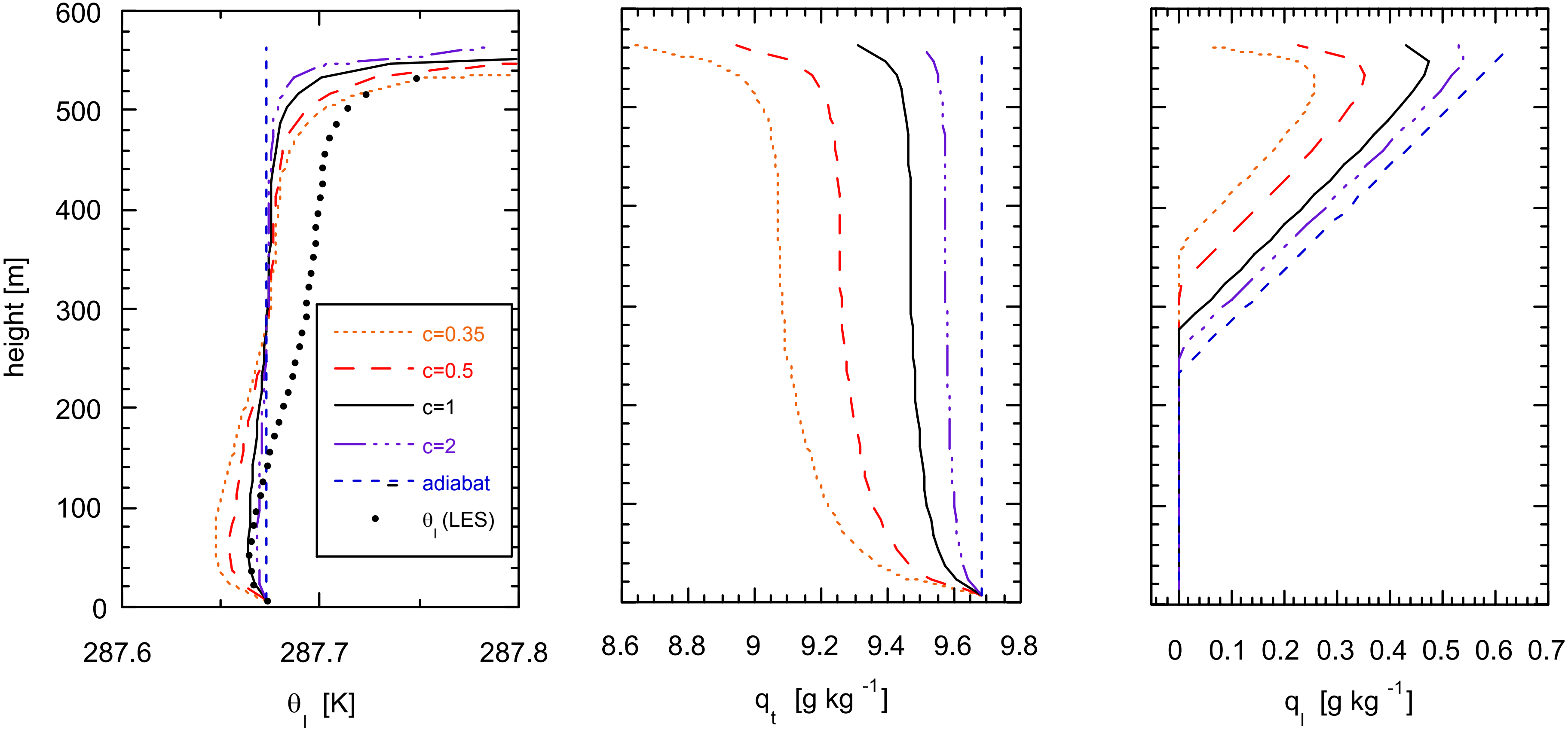


- K_{ref} is identical to K_{qt} from LES
- 0.2 x K_{ref} is very close to K_{ql} from LES

LWP and shortwave radiation (normalized) solutions as a function of the eddy-diffusivity multiplication factor c



Mean state solutions



Similar K profiles for heat and moisture - Interpretation

Gradient ratio:

$$\frac{\partial\overline{\theta_l}/\partial z}{\partial\overline{q_t}/\partial z} = \frac{\overline{w'\theta_l'}/K}{\overline{w'q_t'}/K} = \frac{H}{LE}\frac{L_v}{c_p}$$

(K drops out)

Typical flux values near the surface for marine stratocumulus:

H=10 W/m^2 and LE = 100 W/m^2

Then a 0.1 K decrease in θ_l corresponds to a change of 0.4 g/kg in q_t

The larger the latent heat flux LE, the larger the vertical gradient in q_t will be!

Conclusions

TKE model

- appears to be capable to represent realistic entrainment rates

Eddy diffusivity experiments

- stratocumulus may dissappear by incorrect BL internal structure, even for 'perfect' entrainment rate

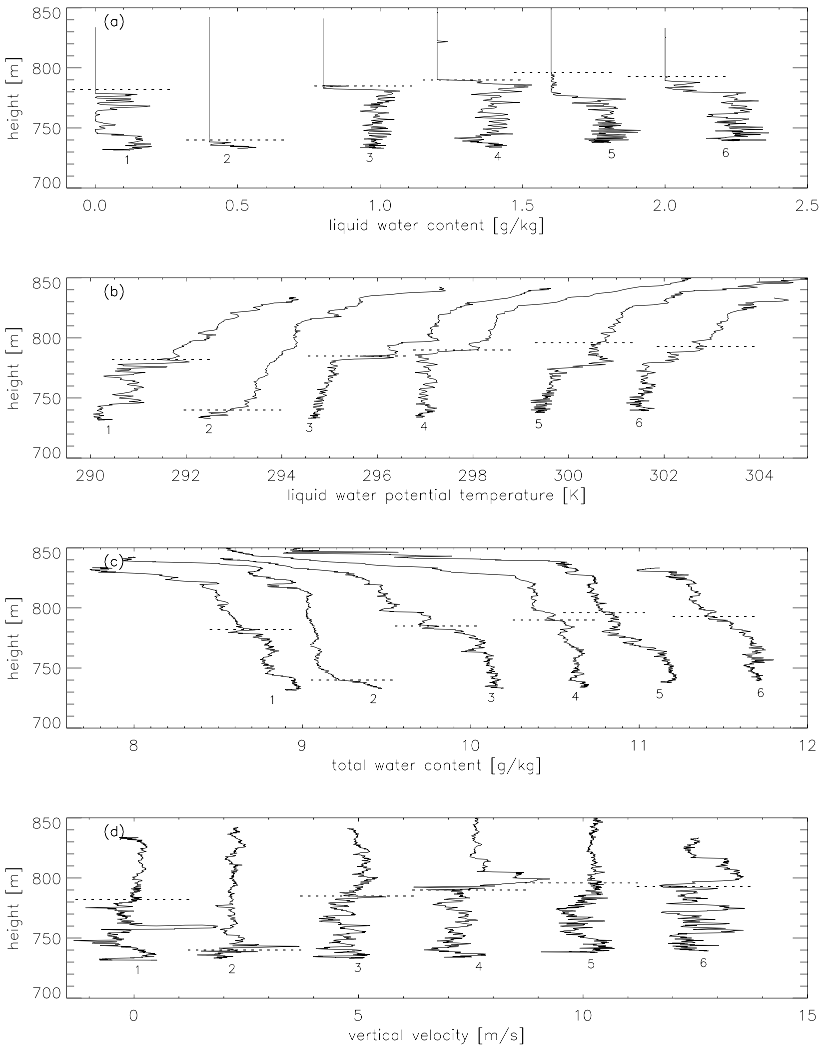
- observations often show adiabatic LWPs (Albrecht et al. 1990, Bretherton et al. 2004), suggesting large values for Kqt

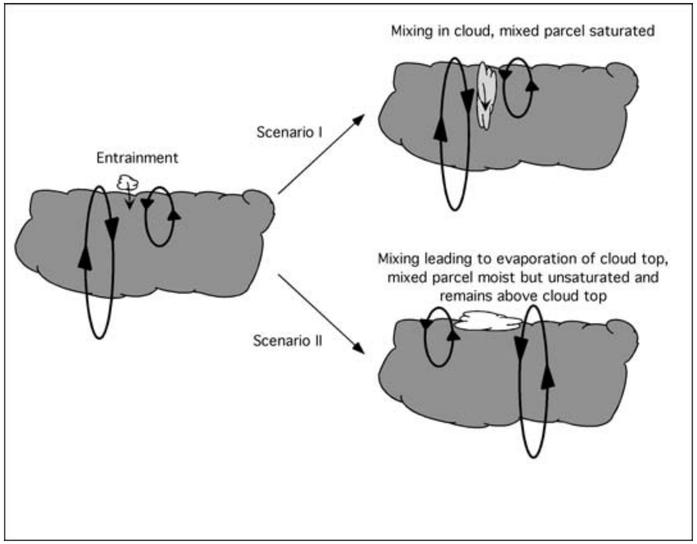
Recommendation

- pay more attention to K-profiles from LES

http://www.knmi.nl/~roode/publications.html

FIRE I stratocumulus observations of the stratocumulus inversion structure





de Roode and Wang : Do stratocumulus clouds detrain? FIRE I data revisited. BLM, in press