Stratocumulus Cloud Thinning

Influence of Inversion Stability

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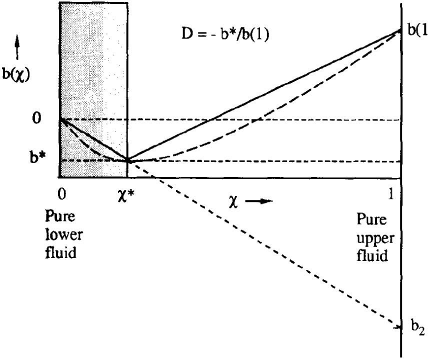
Introduction
Cloud Top Entrainment Instability

- Evaporative cooling can cause entrained parcels to become negatively buoyant
- Theory: buoyancy reversal leads to runaway entrainment → rapid breakup of cloud layer



Siems et al. (1990) *Buoyancy reversal and cloud-top entrainment instability*

Introduction
Cloud Top Entrainment Instability

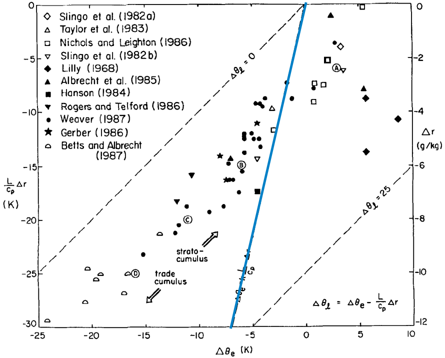
Occurence of CTEI described using inversion properties Δq_T and $\Delta\theta_L$:

$$\kappa = 1 + \frac{c_p}{L_v}\frac{\Delta\theta_L}{\Delta q_T} > 0.23.$$

Criterion derived by Randall (1980) and Deardorff (1980).

Introduction

CTEI - does it occur? I



"Two thirds of the stratocumulus observations lie to the left of the critical curve and hence are at odds with the predictions of the thermodynamic theory of cloud top entrainment instability."

Kuo and Schubert (1988) *Stability of Cloud-topped Boundary Layers*

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Introduction
CTEI - does it occur? II

"this phenomenon does not appear to occur in the range of hydrodynamic parameters characteristic of mixing at the inversion capping a subtropical stratocumulus cloud layer. Thus it appears unlikely that CEI triggers stratocumulus breakup."

Siems et al. (1990)
Buoyancy reversal and cloud-top entrainment instability

"Since the positive feedback of CTEI is weak, cloud breakup is not expected when the clouds are strongly maintained by other processes."

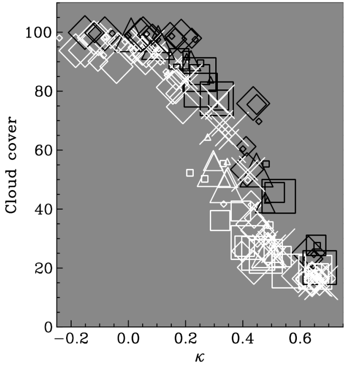
Yamaguchi and Randall (2008)
Large-Eddy Simulation of Evaporatively Driven Entrainment in Cloud-Topped Mixed Layers

Introduction

Nevertheless strong relation between κ and cloud cover

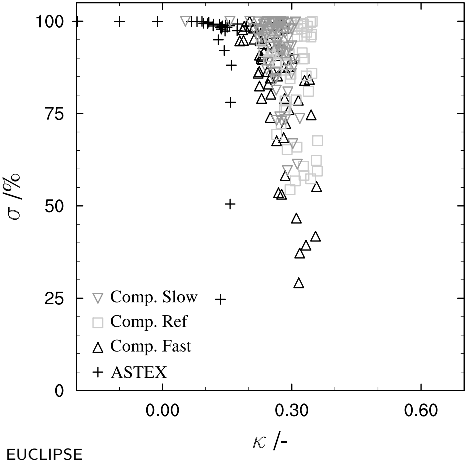
- Different symbols denote LES sensitivity experiments
- Symbol size increases with time
- Many simulations with different Δq_T and $\Delta \theta_L$

Note: transition is smooth rather than abrupt



Lock (2009)
Factors Influencing Cloud Area at the Capping Inversion for Shallow Cumulus Clouds

Introduction
Transition cases

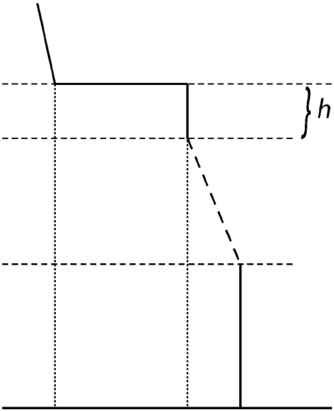


See also SCM results presented at EUCLIPSE meeting in Paris by Roel Neggers

Theory

Budget for stratocumulus LWP

- Use analysis of Randall (1984) *"Stratocumulus Cloud Deepening Through Entrainment"*
- Assume well-mixed, adiabatic stratocumulus layer
- Include
  - entrainment
  - cloud base fluxes
  - precipitation
  - radiation
  - large scale subsidence



Wood and Bretherton (2004)
Boundary Layer Depth, Entrainment, and Decoupling in the Cloud-Capped Subtropical and Tropical Marine Boundary Layer

Theory

Contributions to LWP budget

$$\frac{\partial \mathrm{LWP}}{\partial t} = \mathrm{Ent} + \mathrm{Base} + \mathrm{Rad} + \mathrm{Prec} + \mathrm{Subs}$$

Van der Dussen, de Roode and Siebesma (2013)
Factors controlling rapid stratocumulus cloud thinning
(under review)

Theory

Contributions to LWP budget

$$\frac{\partial \text{LWP}}{\partial t} = \text{Ent} + \text{Base} + \text{Rad} + \text{Prec} + \text{Subs}$$

$$
\begin{aligned}
\text{Ent} &= \rho w_e \left(\eta \Delta q_T - \Pi \gamma \eta \Delta \theta_L - h_c \Gamma_{q_L}\right) \\
\text{Base} &= \rho \eta \left(\overline{w' q_T'}^{\,b} - \Pi \gamma \overline{w' \theta_L'}^{\,b}\right) \\
\text{Rad} &= \rho \eta \gamma \delta \widehat{F}_r \\
\text{Prec} &= -\rho \delta \widehat{F}_p \\
\text{Subs} &= -\rho h_c \Gamma_{q_L} \overline{w}(z_i)
\end{aligned}
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Van der Dussen, de Roode and Siebesma (2013)
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Results

LWP tendency due to entrainment

$$\text{Ent} \quad = \quad \rho w_e \left(\eta \Delta q_T - \Pi\gamma\eta\Delta\theta_L - h_c \Gamma_{q_L}\right)$$

Substitute definition κ:

$$\left.\frac{\partial \text{LWP}}{\partial t}\right|_{\text{Ent}} = \rho\eta w_e \left(\frac{c_p}{L_v}\frac{\Delta\theta_L}{\kappa - 1} - \Pi\gamma\Delta\theta_L - \frac{h_c \Gamma_{q_L}}{\eta}\right)$$

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Results

LWP tendency due to entrainment

Substitute simple entrainment relation*:

$$w_e = A \frac{\delta \widehat{F}_r}{\Delta \theta_L}$$

- A assumed constant 1.3
- no dependency on Δq_T

*Stevens et al. (2005)
Evaluation of Large-Eddy Simulations via Observations of Nocturnal Marine Stratocumulus

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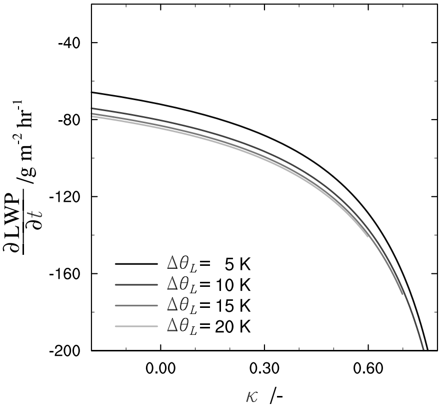

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Results

What about the other processes?

Find zeros of LWP tendency equation:

$$\frac{\partial \mathsf{LWP}}{\partial t} = 0 = \mathsf{Ent} + \mathsf{Base} + \mathsf{Rad} + \mathsf{Prec} + \mathsf{Subs}$$

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Equations define equilibrium set of inversion jumps (Δq_T^*, $\Delta \theta_L^*$)

$$\Delta q_T^* = f\left(\Delta\theta_L^*, \overline{w' q_T'}^{\,b}, A, \ldots\right)$$

Results

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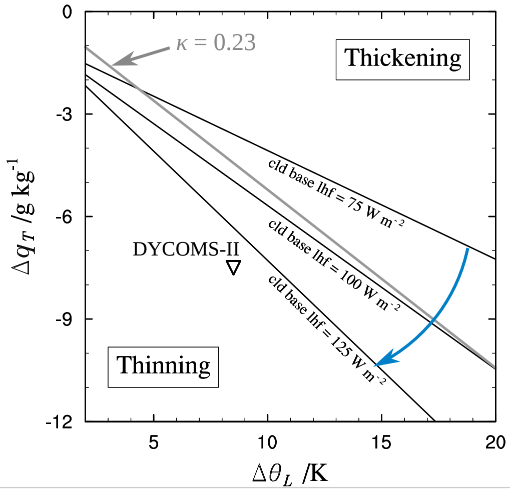
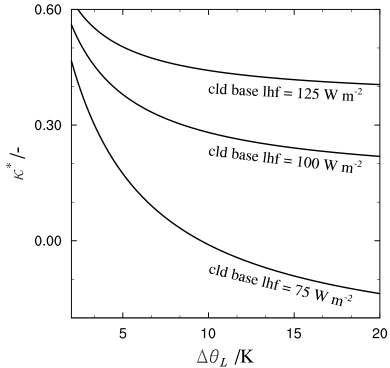


Results

Equilibrium value of κ

$$\kappa = 1 + \frac{c_p}{L_v}\frac{\Delta\theta_L}{\Delta q_T}$$ is used to substitute out Δq_T



κ^* is not a constant, but depends on many parameters (mainly $\overline{w'q'_T}^{\,b}$)

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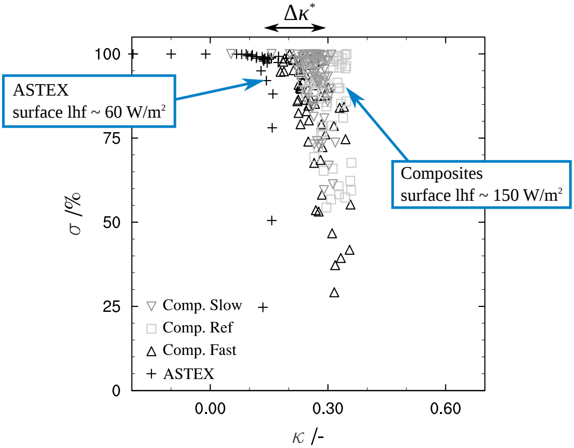
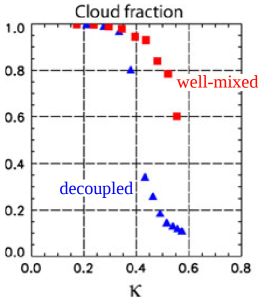
Discussion

Qualitative agreement with LES results of transition cases



Discussion
Effect of decoupling

Reduced moisture flux from surface to cloud layer lowers κ^*



Xiao et al. (2010)
Buoyancy Reversal, Decoupling and the Transition from Stratocumulus to Shallow Cumulus Topped Marine Boundary Layers

Thanks for your attention!