A Mixed-Layer Model perspective on stratocumulus steady states in a perturbed climate

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Stratocumulus clouds

Scientific questions:
1. What are the stratocumulus steady-states for a wide range of different atmospheric conditions?
2. How are the steady-states affected by perturbations of large scale forcings?
Stratocumulus clouds

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2. How are the steady-states affected by perturbations of large scale forcings?
Experiment set-up

\[ w_0 \left(1 - e^{-\frac{z}{z_w}}\right) \]

SST = 19°C
Experiment set-up

$$w_0 \left(1 - e^{-\frac{z}{z_w}}\right)$$

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Experiment set-up
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\[ LTS = \theta(z = 3000m) - \theta_0 \]

\[ \Delta q_t = q_t(z = 3000m) - q_{t0} \]

\[ w_0 \left(1 - e^{-\frac{z}{z_w}}\right) \]

\[ \Delta F_R(q_t) \]

SST = 19°C

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Experiment set-up

Decoupling: entrainment efficiency (Zhang et al., 2005)
ABL thermodynamic state

MLM + Nicholls and Turton (1986) entrainment parameterization
ABL thermodynamic state

MLM + Nicholls and Turton (1986) entrainment parameterization

\[ \begin{align*}
\theta_{\text{ML}} & \rightarrow w_e \rightarrow \theta_{I,\text{ML}} \\
|\Delta q_t| & \rightarrow \Delta F_R \rightarrow \theta_{I,\text{ML}}
\end{align*} \]
ABL thermodynamic state

MLM + Nicholls and Turton (1986) entrainment parameterization

\[ \text{LTS} \uparrow \rightarrow w_e \downarrow \rightarrow \theta_{I,ML} \downarrow, \]

\[ \left| \Delta q_t \right| \uparrow \rightarrow \Delta F_R \uparrow \rightarrow \theta_{I,ML} \downarrow \]
ABL thermodynamic state

MLM + Nicholls and Turton (1986) entrainment parameterization

\[ \Delta q_t \uparrow \rightarrow \Delta F_R \uparrow \rightarrow \theta_{I,ML} \downarrow \]

\[ \text{LTS} \uparrow \rightarrow w_e \downarrow \rightarrow \theta_{I,ML} \downarrow \]

\[ |\Delta q_t| \uparrow \rightarrow q_{t,ML} \downarrow \]
Cloud base and top height

MLM + Nicholls and Turton (1986) entrainment parameterization

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Cloud base and top height

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Liquid water path (LWP)

MLM + Nicholls and Turton (1986) entrainment parameterization

\[ \text{LTS} \uparrow \implies z_i \downarrow \text{ and } z_b \downarrow \implies \text{LWP} \downarrow \]

\[ |\Delta q_t| \uparrow \implies z_i \uparrow \text{ and } z_b \uparrow \implies \text{LWP} \downarrow \]
Perturbed climate set-up

\[ w_0 \left( 1 - e^{-\frac{z}{z_w}} \right) \]

\[ \Delta F_R(q_t) \]
Response to a climate perturbation

\[
\frac{d\text{LWP}}{d\text{SST}} = \frac{\text{LWP}\big|_{PC} - \text{LWP}\big|_{CTL}}{\text{SST}\big|_{PC} - \text{SST}\big|_{CTL}}
\]

- cloud thinning;
- increasing of decoupling;

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Response to a climate perturbation

\[ \frac{dLWP}{dSST} = \frac{LWP|_{PC} - LWP|_{CTL}}{SST|_{PC} - SST|_{CTL}} \]

- cloud thinning;
- increasing of decoupling;

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Response to a climate perturbation

\[
\frac{dLWP}{dSST} = \frac{LWP|_{PC} - LWP|_{CTL}}{SST|_{PC} - SST|_{CTL}}
\]

dLWP/dSST (g/m²/K)

- Cloud thinning;
- Increasing of decoupling;

→ in line with LES results (Bretherton et al., 2013).

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MLM interpretation of cloud-climate feedback

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Summary

**Control climate**

What are the stratocumulus steady-states for a wide range of different atmospheric conditions?

- LTS $\uparrow \implies z_i \downarrow$ and $z_b \downarrow \implies \text{LWP} \downarrow$;
- $|\Delta q_t| \uparrow \implies z_i \uparrow$ and $z_b \uparrow \implies \text{LWP} \uparrow$. 
Summary

**Control climate**

What are the stratocumulus steady-states for a wide range of different atmospheric conditions?

- **LTS** ↑ \(\Rightarrow\) \(z_i\) ↓ and \(z_b\) ↓ \(\Rightarrow\) **LWP** ↓;
- \(|\Delta q_t|\) ↑ \(\Rightarrow\) \(z_i\) ↑ and \(z_b\) ↑ \(\Rightarrow\) **LWP** ↑.

**Perturbed climate**

How are the steady-states affected by perturbations of large scale forcing?

- net effect: cloud thinning and increase of decoupling;
- **SST (LTS and RH are conserved)** ↑ \(\Rightarrow\) \(\Delta F_R\) ↓ \(\Rightarrow\) \(w_e\) ↓ \(\Rightarrow\)
  \(z_i\) ↓ but \(z_b\) ↑ \(\Rightarrow\) **LWP** ↓.
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Thank you!
The effect of entrainment parametrization

Lock, 1998

Stage and Businger, 1981

Stevens 2006

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The effect of entrainment parametrization

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LW radiative cooling

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