On the Use of A-Train Data for Studying Convective Dynamics

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CALIPSO-CloudSat 10-Year Progress Assessment and Path Forward Workshop
Paris, France, June 8-10 2016
What is cloud dynamics?

“...the *macrophysical* features of cloud formation and growth”

Cloud Physics usually refers to cloud microphysics
Outlines

1. Motivation

2. **Example 1**: Penetrative deep convection & burps into the lower stratosphere

3. **Example 2**: Convective vertical velocity & mass flux

4. Summary
Penetrative Deep Convection (PDC)
In searching for very cold/tall deep convection, we found the following three types, in relation to the *cold point tropopause*:

Warm(cold) means warmer (colder) than the cold point T
High(low) means higher (lower) than the cold point H

Luo et al. (2008)
An important indicator of convective strength: *radar echo top height*

- **Strong convection:** 0 dBZ or 10 dBZ close to cloud top (17 km)
- **Weaker convection:** 0 dBZ or 10 dBZ much lower than the cloud top
larger radar echoes mean larger particles and/or greater cloud water content.
What can we infer from the three types of penetrating convection?

We hypothesize that:

1) CL is *newly developed*, “undiluted” convection most likely in the early stage of the penetrative convective lifecycle.

2) CH is associated with the *mature stage* of the penetrative convection.

3) WH is associated with the *dissipating stage* with large particles already falling back to lower levels.
Penetrative deep convection can burp bubbles into the lower stratosphere


CALIPSO

CloudSat

Ground/Sea
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A-Train data provide important info for inferring convective dynamics near cloud top

Cloud-top $w$

$$w = \left( \frac{\partial T}{\partial z} \right)^{-1} \frac{dT_{BB}}{dt}$$

Luo et al. (2014)
A-Train data provide important info for inferring convective dynamics near cloud top

\[ B = g \frac{T_{\text{parcel}} - T_{\text{env}}}{T_{\text{env}}} \]

\[ T_{\text{parcel}} = 193 \text{ K}; \]
\[ T_{\text{env}} = 198 \text{ K (b/c CTH = 15km)} \]

Negatively buoyant!

Luo et al. (2010); Wang et al. (2014)
A-Train data provide important info for inferring convective dynamics near cloud top.

\[
B = g \frac{T_{\text{parcel}} - T_{\text{env}}}{T_{\text{env}}}
\]

Cloud-top buoyancy

Luo et al. (2010); Wang et al. (2014)
A single-column plume model

- Basic equations

\[
\frac{1}{2} \frac{\partial w_c^2}{\partial z} = a_B B - \epsilon w_c^2 - c_D w_c^2,
\]

\[
\frac{\partial (h_c - L_i q_i)}{\partial z} = -\epsilon (h_c - L_i q_i - h_a),
\]

\[
\frac{\partial q_{w}}{\partial z} = -\epsilon q_w + \frac{1}{w_c} (\dot{q}_{\text{cond}} - \dot{q}_{\text{auto}}),
\]

As far as \( w_c \) is concerned, the most important parameter is the entrainment rate (\( \epsilon \)).

Masunaga and Luo (2016)
Simulated buoyancy ($\Delta T/T$) and $w_c$ profiles under different $\epsilon$

$\epsilon$: 0 – 0.4/km (red to blue)

Masunaga and Luo (2016)
Observations (cloud-top buoyancy and $w_c$) are used to constrain different possibilities

$$\hat{w}_c(z) \equiv \sum_i p(\epsilon_{\text{tur},i} \mid z_T, \Delta T_T) w_{c,i}(z) = \sum_i p(\epsilon_{\text{tur},i}) p(z_T, \Delta T_T \mid \epsilon_{\text{tur},i}) w_{c,i}(z),$$

Hundreds of thousands of observed data points are used to weigh these different profiles.

Masunaga and Luo (2016)
Composite Observations w.r.t. Convective Life Stages

a) Instantaneous observations

Day $i$

\[ 0 \quad 1:37\text{ AM/PM} \quad 24 \text{ (LT)} \]

CloudSat \quad TRMM

Day $j$

\[ \vdots \]

\[ D_{t_i} \]

CloudSat \quad TRMM

Day $k$

\[ \vdots \]

\[ D_{t_i} \]

CloudSat \quad TRMM

b) Composite time

\[ \text{CloudSat} \quad \text{TRMM} \quad \text{CloudSat} \]

\[ t=0 \]

\[ D_{t_i} \quad D_{t_k} \quad D_{t_j} \]

Masunaga (2012);
Masunaga and Luo (2016)
$W_c$ relatively invariant over time

$M_c$ follows convective life cycle, controlled by convective coverage

![Image](image.png)

a) In-cloud convective vertical velocity [m/s]

b) Convective mass flux [1.e-2 kg/m2s]  

$M_c = \sigma W_c$

Masunaga and Luo (2016)
\[ \overline{M} = M_c + M_R + M^* \], where \[ \frac{M_R \partial S_a}{\partial p} = \frac{Q_R}{g} \]

b) Convective mass flux $[1 \text{e-2 kg/m2s}]$

(d) Total large-scale mass flux $[1 \text{e-2 kg/m2s}]$

(e) Residual mass flux $[1 \text{e-2 kg/m2s}]$

Masunaga and Luo (2016)
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Summary

- CloudSat/CALIPSO add new insights into penetrative deep convection processes
  - CloudSat + MODIS reveal convective life stage
  - CALIPSO picks up irreversible stratosphere-troposphere exchange

- A-Train data (CloudSat, IIR, MODIS, AIRS), aided by a plume model, piece together the convective mass flux jigsaw puzzle
  - A-Train enables new observations that have bearings on convective dynamics (e.g., buoyancy, vertical velocity)
  - A plume model can assimilate such info and generate convective mass flux estimates
Ground-based Ka band radar (34 GHz). Gray shading marks up attenuation.

A prejudice against CloudSat-CALIPSO (10 yrs ago): W-band radar and lidar are for fluzzy clouds and aerosol; they are not serious players in studying convection.

Stephens and Wood (2007)
Congratulations, CALIPSO and CloudSat!