Numerical experiments on vertically fine structures of water vapor in the tropics

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Introduction

- Recent understandings of
  - Convections in the tropics
  - Meridional circulation

- Thin moist layers in tropical mid-troposphere
  - Observation

Model Settings

Results

Summary
Cumulus convections and meridional circulation in the tropics

Johnson et al. (1999)

Hadley cell

Cumulonimbus

Tropopause

Mid-level inflow

Cumulus congestus

Shallow return flow

Melting level

Trade inversion

Trade cumulus
Meridional circulation and Moisture transport

Relative humidity of TAO ship sondes
2-11 Nov 2000, 95W (Zhang et al., 2004)

- Hadley circulation
- Dry southerly (e.g., Mapes 2001)
- Shallow return flow (e.g., Zhang et al. 2004)
- Trade winds
Vertically fine structures of water vapor in the mid-troposphere

• Often observed by rawinsonde and airborne observations
• Not well-understood
  – Dynamics
  – Statistics
• Ozone sonde observations in the eastern Pacific region (Shiotani et al., 2002)
Observed Layers

- Radio sonde sounding taken over tropical eastern Pacific in Sep 1999 (Shiotani et al., 2002)
- Moist and ozone-poor layers
Why we need numerical experiments?

• Sonde, plane, lidar: 1-D measurements
• GPS radio occultation: will be available in near future (Prof. Tsuda’s talk)
• Global analyses: sparse in space and time

• Meso-scale models can provide 3-D dataset with sufficient time-spatial resolution
  – Vertical resolution
Model Settings

- NCAR/PSU MM5 Version 3.6.1
- 2-way nesting
- Initial and boundary conditions: NCEP Final Analyses
- Model top: 10 hPa
- 62 levels
  - $dz \sim 300$ m in mid-troposphere

<table>
<thead>
<tr>
<th></th>
<th>Domain1</th>
<th>Domain2</th>
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<tbody>
<tr>
<td>Horizontal grid</td>
<td>63 km</td>
<td>21 km</td>
</tr>
<tr>
<td>Grid number</td>
<td>$40 \times 120$</td>
<td>$73 \times 211$</td>
</tr>
<tr>
<td>Cumulus</td>
<td>Anthes-Kuo</td>
<td>Grell</td>
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<tr>
<td>Time interval</td>
<td>60 s</td>
<td>20 s</td>
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Definition of the thin moist layers

1. Take a local maximum of a RH vertical profile
2. Starting from the local maximum, search for the points above and below it at which the RH difference from the local maximum exceeds 35% for the first time
3. If height difference of 2 points $< 2 \text{ km}$ → a thin moist layer
A case study: Sep 1999

- Time series of a layer (orange region)
- A layer formed at 5 km in altitude
Trajectory analysis / Streamlines

• A saddle exists between two synoptic vortices. Horizontal displacement of the saddle with height → vertical shear of horizontal wind field

• This shear stretches the boundary of dry air and moist air, resulting in a layered structure.
Schematic diagram

Layered structure
Seasonal cycle

• Period: 1 Jan 2005–31 Dec 2006 (2 years)
• 3-day integrations with 1-day overlaps
Layers in 4-7 km and convective activities

Time series in a sub-region

Occurrence ratio of the layers

Mean cloud top height

\[ z = 4000 - 7000 \text{m} \]

\[ 107.5^\circ W - 94.4^\circ W \]
Occurrence ratio of the layers (top) and Cloud top height (bottom)

West
120.6W–107.6W, 3.0N–16.2N

Middle
107.4W–94.4W, 3.0N–16.2N

East
94.2W–81.2W, 3.0N–16.2N

Latitude

Time
Jan 2005
Jul 2005
Jul 2006

Cloud top height
120.6W–107.6W, 30–day running mean
107.4W–94.4W, 30–day running mean
94.2W–81.2W, 30–day running mean

Latitude

Time
01Jan 01Jun 01Sep
01Jan 01Jun 01Sep
01Jan 01Jun 01Sep
Zonal projection

- **Mar 2006**
  - Shallow convections
  - Many layers above them
- **Jul 2006**
  - Deep convections
  - Layers are seen out of convective region
  - 5 km and 10 km

**Tone: occurrence ratio of the layers, contour: water**
Zonal mean

Layer (dz=2km) & Cloud, Jul 2006

RH (x=5–57), Jul 2006

V (x=5–57), Jul 2006
Summary

• **A case study of a thin moist layer in Sep 1999**
  – An example of layering by synoptic scale wind shear

• **Seasonal cycle of thin moist layers in 2005-2006**
  – Annual cycle is dominant
    • High occurrence ratio in boreal winter
  – Related to convective activities
  – Peaks at 5 km and 10 km in altitude in boreal summer

• **Moist layers are important for moisture transport and radiation processes in the tropics**
  – Satellite measurements in future
Vertical distribution

Jan 2005–Dec 2006

occurrence ratio per unit height [m]

RH PDF
Comparison with observation

- San Cristobal, Galapagos Islands