Numerical simulations of planetary atmospheres with land and the ocean by using a general circulation model

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Introduction

- A variety of planetary atmospheric circulation and surface environment
- What causes such a variety?
  - In this study, the general circulation model (GCM) simulations are performed to have insights into the processes characterizing the Earth and Mars atmospheric circulation.

<table>
<thead>
<tr>
<th></th>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>rotation period</td>
<td>1 day</td>
<td>1.03 day</td>
</tr>
<tr>
<td>declination angle</td>
<td>23.4°</td>
<td>25.2°</td>
</tr>
<tr>
<td>radius</td>
<td>6378 km</td>
<td>3391 km</td>
</tr>
<tr>
<td>length of a year</td>
<td>365 days</td>
<td>669 (Mars) days</td>
</tr>
<tr>
<td>others</td>
<td>moist processes</td>
<td>cold and dry condition dust storms</td>
</tr>
</tbody>
</table>
Motivation and Purpose of this study

We focus on the north-south asymmetry and latitudinal width of Hadley circulation.

- The latitudinal width of solstitial Hadley circulation on Mars is larger than that on the Earth.

GCM experiments are performed to investigate the effects of

- moist processes,
- planetary radius,
- length of a year

on the latitudinal width of Hadley circulation on an Earth like planet.
Model description

• An atmospheric general circulation model developed in GFD Dennou Club, dcpam (under development)

• Dynamics
  – primitive equation system
    • Spectral method is used with spectral transform library ispack (Ishioka, 2009), and spmodel library (Takehiro et al., 2006).

• Physics
  – turbulent mixing (Mellor and Yamada (1982) Level 2)
  – radiation
    • long wave radiation of H$_2$O, CO$_2$ (Roewe and Liou, 1978)
      – effects of cloud is neglected
    • absorption of short wave radiation by H$_2$O (Lacis and Hansen, 1974)
      – scattering by molecular particles and cloud droplet is not considered explicitly, but the solar insolation is reduced 20%.
  – moist convective adjustment (Manabe, 1965)
  – large scale condensation (Manabe, 1965)
  – bucket model (Manabe, 1969)
  – energy equation for soil
Experimental condition

- **Resolution**
  - T31L16
    - horizontal grid interval: $3.75^\circ$
    - number of vertical levels: 16
- **4 experiments are performed.**
  - Integration is performed for 20 years.

<table>
<thead>
<tr>
<th>Case</th>
<th>Ocean</th>
<th>Radius</th>
<th>Length of a year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1 “Land and ocean”</td>
<td>Yes</td>
<td>Earth</td>
<td>Earth (365 days)</td>
</tr>
<tr>
<td>Case 2 “No ocean”</td>
<td>No</td>
<td>Earth</td>
<td>Earth</td>
</tr>
<tr>
<td>Case 3 “Mars radius”</td>
<td>No</td>
<td>Mars</td>
<td>Earth</td>
</tr>
<tr>
<td>Case 4 “Mars year”</td>
<td>no</td>
<td>Mars</td>
<td>Mars (669 days)</td>
</tr>
</tbody>
</table>

- ocean: Climatology of sea surface temperature is prescribed.
- land: Earth’s topography is assumed regardless of radius.
- no ocean: The ocean region is assumed to be a land with 0 m height.
Results: Case 1,
Zonal mean field in “Aug.”
Results: Case 2,
Zonal mean field in “Aug.”
Results: Case 3, Zonal mean field in “Aug.”
Results: Case 4,
Zonal mean field in “Aug.”

- Temperature
- Eastward wind
- Mass stream function
- Specific humidity
Changes of Hadley circulation

- Hadley cell in Case 2
  - small vertical extent
  - weak
    - qualitatively the same as a result shown by Miyoshi and Morita (1993).
    - Because surface temperature in case 2 would not be significantly different from that in Case 1, it is expected,
      - difference between moist and dry adiabatic lapse rate results in the height of Hadley cell,
      - radiative cooling by water vapor affects the strength of Hadley cell.

- Hadley cell in Case 3
  - latitudinal width almost the same as those in Cases 1 and 2
    - Change is small compared to the variation of ratio of Rossby deformation radius to planetary radius ($\sim \sqrt{2}$).
    - Surface temperature distribution is dominant factor?

- Hadley cell in Case 4
  - latitudinal width larger than those in Cases 1-3.
    - Eddy momentum transport may be different between Cases 3 and 4 because of the large equator-pole temperature difference in Case 4.
Summary

- In order to have insights into the processes characterizing the north-south asymmetry and latitudinal width of the Earth and Mars Hadley circulation, the GCM simulations of the planetary atmospheres with land and the ocean have been performed.

- Simulation shows:
  - moist processes affect height and strength of Hadley cell significantly, but does not affect latitudinal width significantly,
  - planetary radius does not affect latitudinal width of Hadley cell significantly for no ocean case,
    - It is expected that the latitudinal width of Hadley cell may change by changing the ratio of Rossby deformation radius to planetary radius, but this is not the case. The distribution of surface temperature may constrain the latitudinal width of Hadley cell.
  - length of a year affects the latitudinal width of Hadley cell,
    - It is imagined that the momentum transport by atmospheric waves causes the difference in latitudinal width.

- Present work is just a preliminary attempt to search for the variety of circulation features of the terrestrial planets.

- Future work:
  - A lot of experiments with wide range of parameters, such as, planetary radius, and length of a year, will be performed to show the effects of these parameters explicitly.
  - Analysis of momentum transport by atmospheric waves will be performed.
Acknowledgement

- This study uses following software developed and maintained by GFD Dennou Club (http://www.gfd-dennou.org/index.html.en):
  - SPMODEL library,
    - http://www.gfd-dennou.org/library/spmodel/index.htm.en,
  - ISPACK,
    - http://www.gfd-dennou.org/library/ispack/,
  - gtool5,
    - http://www.gfd-dennou.org/library/gtool/gtool5.htm.en,
  - Dennou Club library (DCL),
    - http://www.gfd-dennou.org/library/dcl/,
  - products by Dennou Ruby Project,