Development of a general circulation model for (shallow) planetary atmospheres, DCPAM

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Motivations of GCM development

- Unified understanding of atmospheric circulation of planets in solar system and plausible exoplanets, and so on.
  - “What causes the atmospheric circulation of the Earth, Mars, and so on?”
  - One way to consider this issue is to understand position of each planet in a parameter space like right figure.
DCPAM
(http://www.gfd-dennou.org/library/dcpam/)

• General Circulation model for planetary atmospheres
  • Brief description
    – Dynamics
      • Primitive eq.
        – Vertical hydrostatic equilibrium
        – Shallow atmosphere assumption
      • spmodel (and ispack) is used for spectral transformation
    – Radiation
      • Earth model
      • Mars model
      • Gray atmosphere model
      • Radiation model for a various atmosphere is under development.
    – Turbulent mixing
    – Condensation
    – Cloud
    – Soil model, Bucket model
  • Note
    – The gtool is used for input/output of the model.
Capability of 1D, 2D, and 3D calculations: Example of Mars atmosphere calculation

- DCPAM is designed to be used for 1D and 2D (axisymmetric calculation) as well as 3D calculations.

Color codes are different in three figures.
Experiments by the use of DCPAM

- Validation experiments
  - 1D, 3D
- Planets in solar system
  - Earth
  - Mars
  - (Venus)
- Virtual planets (exoplanets?)
  - Aqua-planet
  - Land planet
  - Tidally locked planets

This is also valuable for model validation.
Examples of DCPAM experiments: GFD experiments/Validation experiments

- Baroclinic wave experiment (Polvani et al., 2004)
- Dynamical core experiment (e.g., Held and Suarez, 1994)
  - 3-dimensional experiment
  - Axisymmetric experiment
Examples of DCPAM experiments: Venus, Earth, Mars

Zonal wind

Temperature

T10L50 (Newtonian cooling)

Color code and vertical axes are different in three figures.
Examples of DCPAM experiments: Earth, comparison with observation

The model represents observed structure, qualitatively, but has some biases.
Examples of DCPAM experiments: Mars, comparison with observation model

atmospheric temperature at 03 LST and at northern summer

surface temperature at 14 LST

observation (Mars Reconnaissance Orbiter)
Issues on future model development

- DCPAM represents gross features of current climate and global circulation of the Earth and Mars.
- However, the current DCPAM has several biases and uncertainties.
  - Zonal mean temperature in the model is ~20 K lower than observed values in polar regions.
  - Water distribution in Mars simulation is sensitive to the calculation method.
  - We need to take care about those features of model results. We are trying to improve the model further.
Examples of DCPAM experiments: Virtual aqua planet and land planets

- **Aqua planet** (obliquity 23.4°)
- **Land planet** (obliquity 23.4°)
- **Land planet** (obliquity 90°)

Surface temp.

Cloud mass

Rectangle shows wet / snow covered regions.

Setup of land planet experiments are similar to those by Abe et al. (2005)
Examples of DCPAM experiments: Virtual tidally-locked planets

- Tidally locked
  - terrestrial planet
    - Ishiwatari et al.
  - giant planet
    - Takehiro et al.

Surface temperature and wind of a tidally-locked virtual terrestrial planet

Sensitivity of zonal wind on incoming radiation flux of virtual tidally locked giant planet

Incoming radiation flux

- $10^3$ Wm$^{-2}$
- $10^5$ Wm$^{-2}$
- $10^7$ Wm$^{-2}$

Zonal mean zonal wind at tidally locked giant planets solar insolation of $10^3$ Wm$^{-2}$ (left), $10^5$ Wm$^{-2}$ (center), and $10^7$ Wm$^{-2}$ (right)
Summary

• We are working on the development of a general circulation model for planetary atmospheres, such as the Earth, Mars, exoplanets, and so on.
  – This model is based on a spectral transformation and input/output libraries developed by our colleagues.

• The GCM represents some observed features of planetary atmospheres in the solar system, and are used for virtual planet experiments.

• But, we are still working on improvement of the models, especially, the development of a radiation model is an important target.

• In parallel with developing above models, we are now developing an ocean general circulation model to investigate a climate of a planet with an ocean.
  – Current status will be given by Kawai et al.