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

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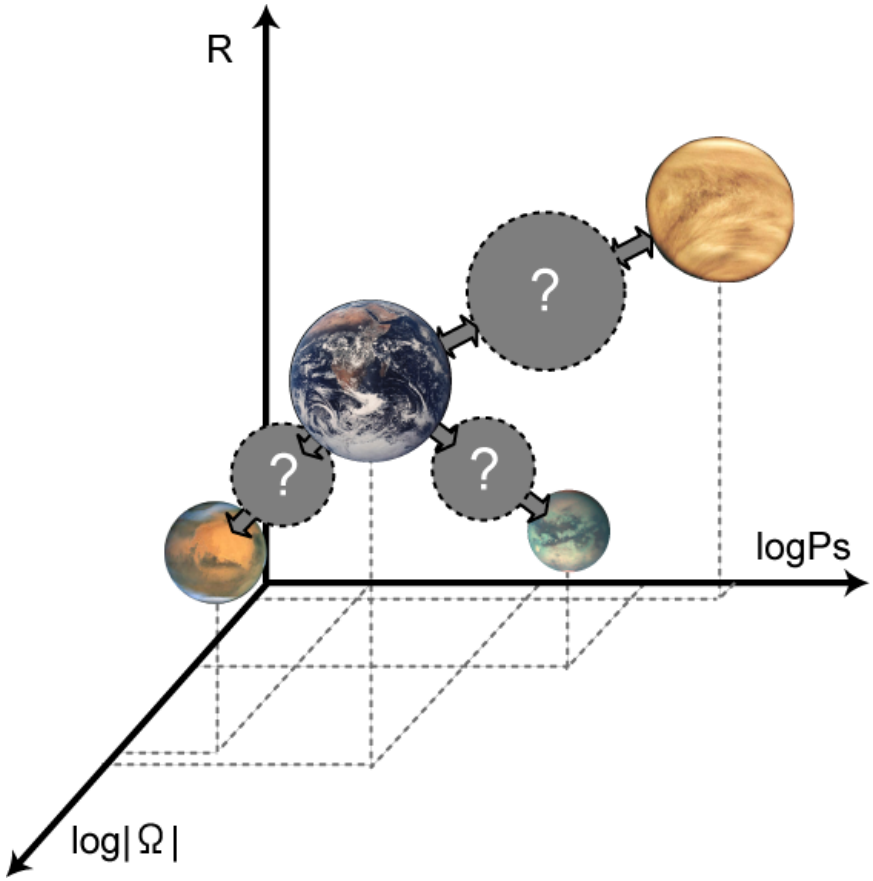
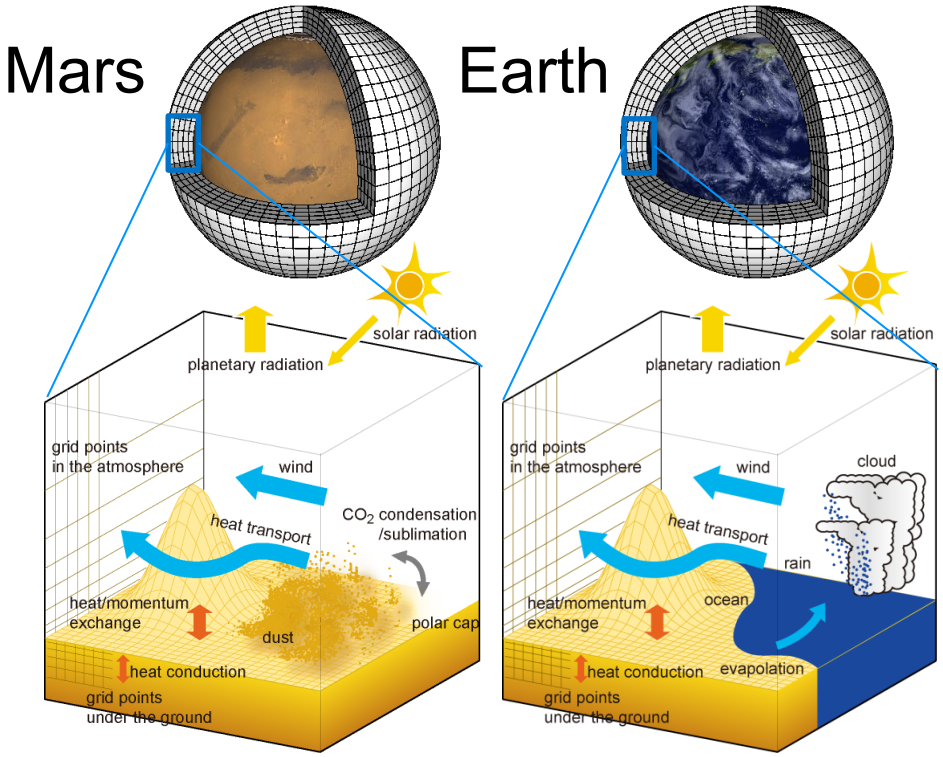
Motivations of GCM development

- 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

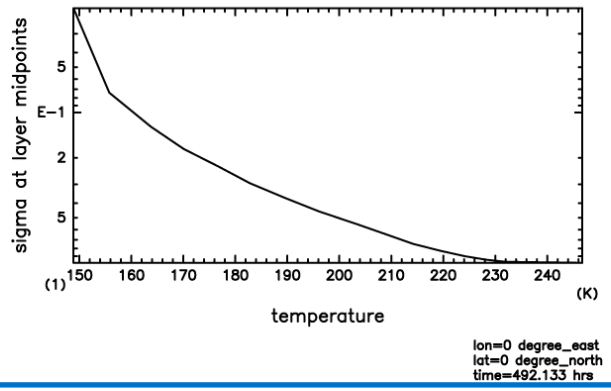


- Brief description
  - Dynamics
    - Primitive eq.
      - Vertical hydrostatic equilibrium
      - Shallow atmosphere assumption
    - spmodel (and ispack) is used for spectral transformation
  - Radiation
    - Earth model
    - Mars model
    - Gray atmosphere model
    - Radiation model for a various atmosphere is under development.
  - Turbulent mixing
  - Condensation
  - Cloud
  - Soil model, Bucket model
- Note
  - The gtool is used for input/output of the model.

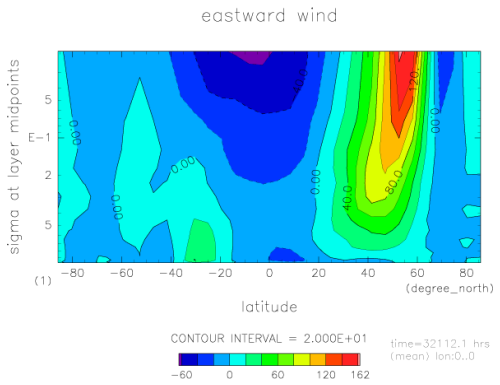
Capability of 1D, 2D, and 3D calculations: Example of Mars atmosphere calculation

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

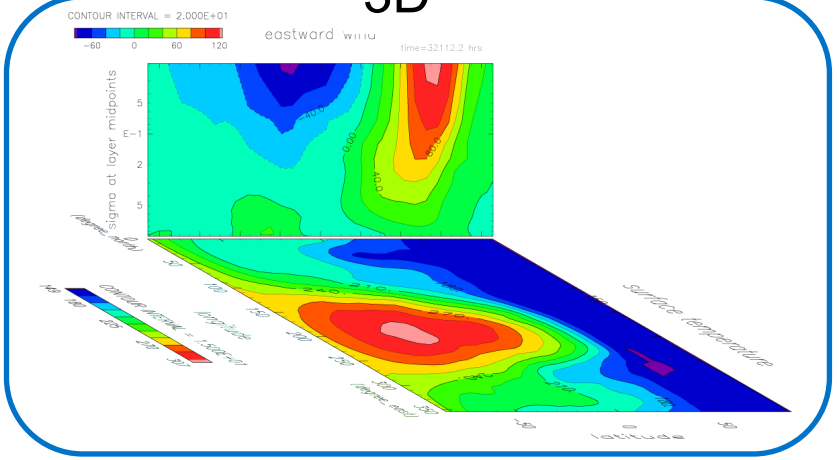
vertical 1D



axisymmetric 2D



3D



Color codes are different in three figures.

Experiments by the use of DCPAM

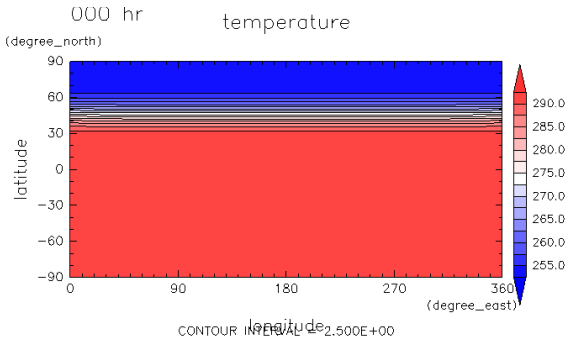
- Validation experiments
  - 1D, 3D
- Planets in solar system
  - Earth
  - Mars
  - (Venus)
- Virtual planets (exoplanets?)
  - Aqua-planet
  - Land planet
  - Tidally locked planets

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

Baroclinic wave

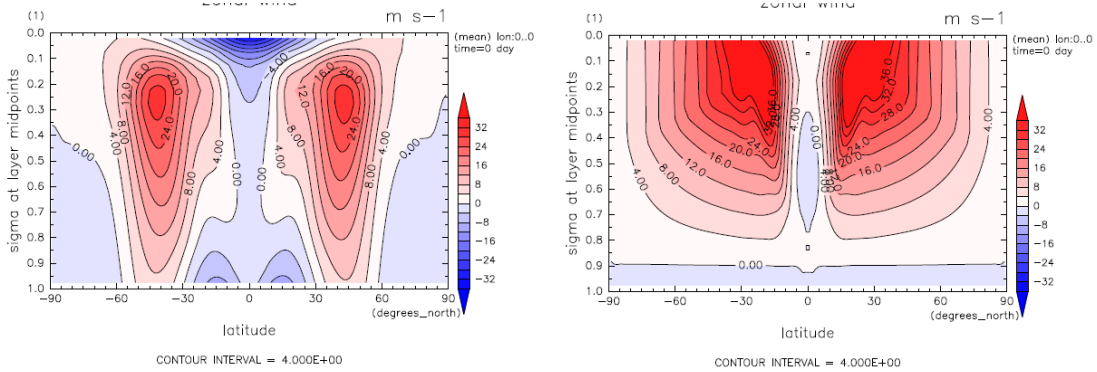


Temperature at lowest level, T341L20

Dynamical core exp.

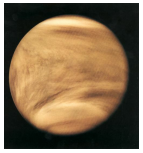
3D exp.

Axisymmetric exp.

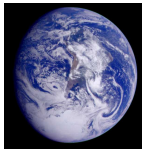


Zonal mean zonal wind, T85L20

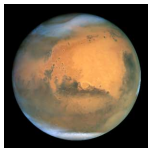
Examples of DCPAM experiments: Venus, Earth, Mars



Venus

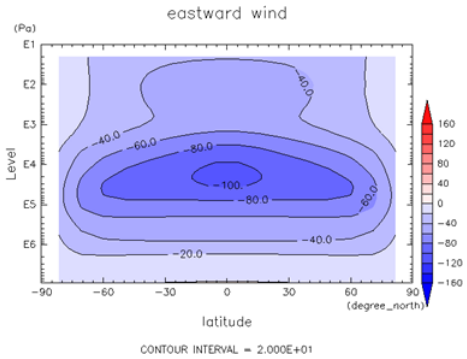


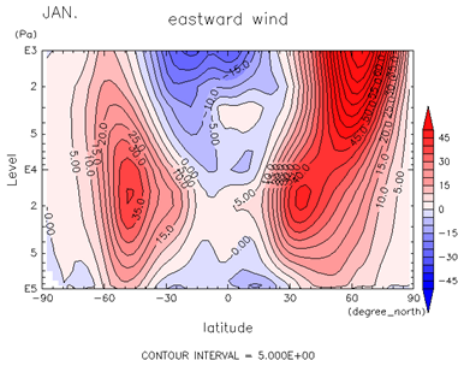
Earth

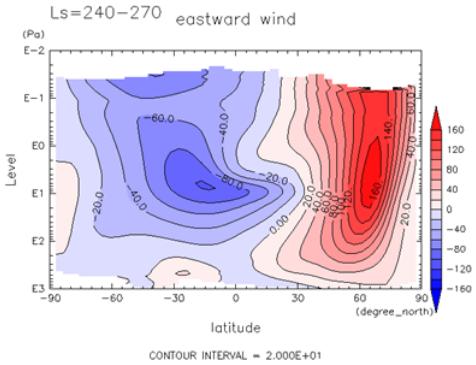


Mars

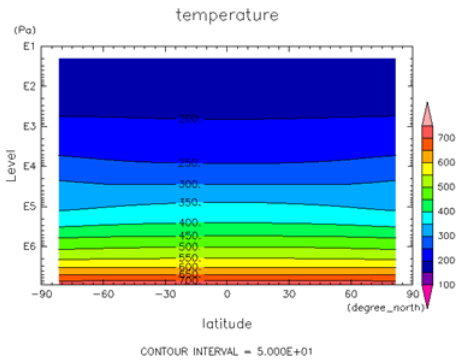
Zonal wind

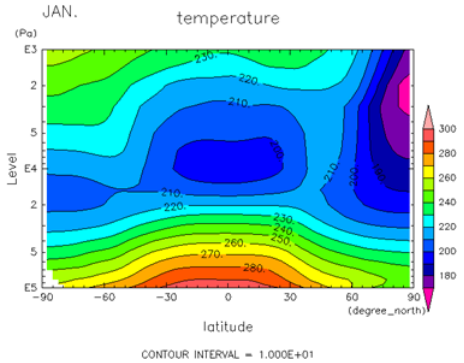


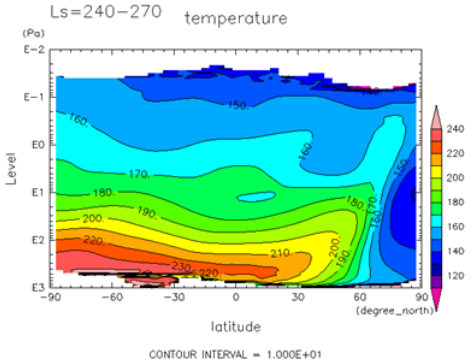




Temperature







T10L50
(Newtonian cooling)

T42L26

T31L36

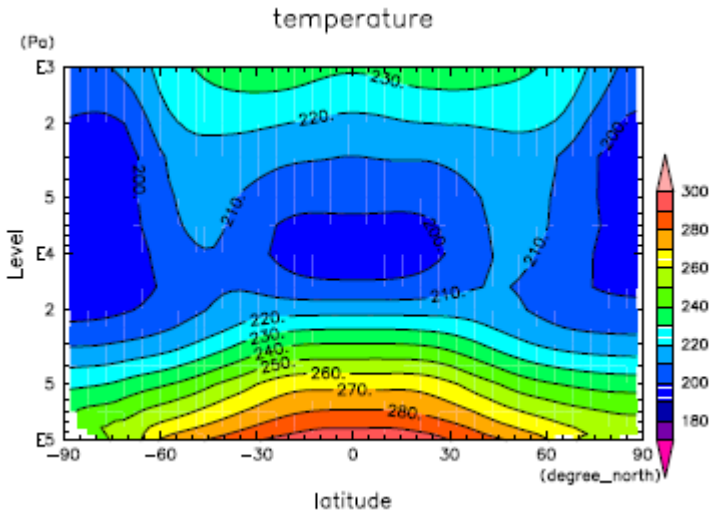
Color code and vertical axes are different in three figures.

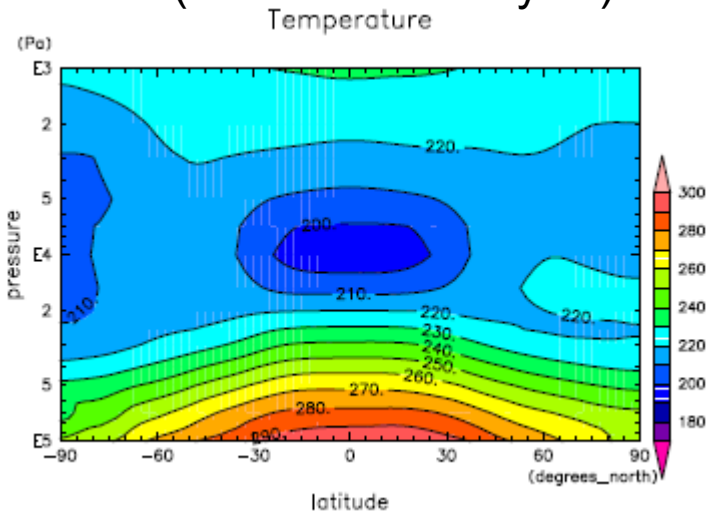
Examples of DCPAM experiments: Earth, comparison with observation

model

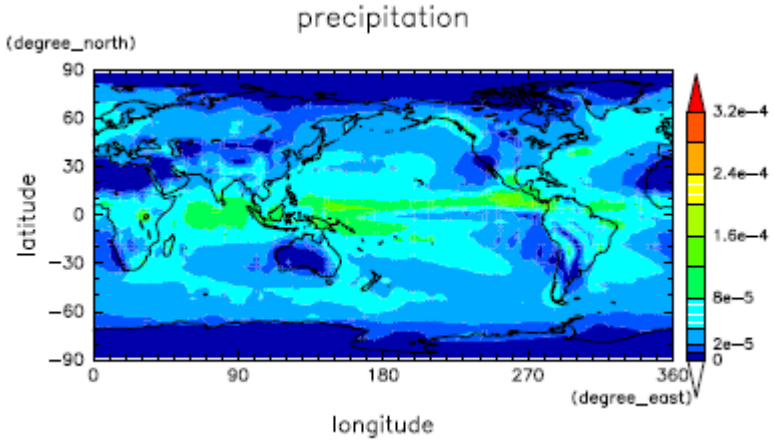
"observation" (ECMWF reanalysis)

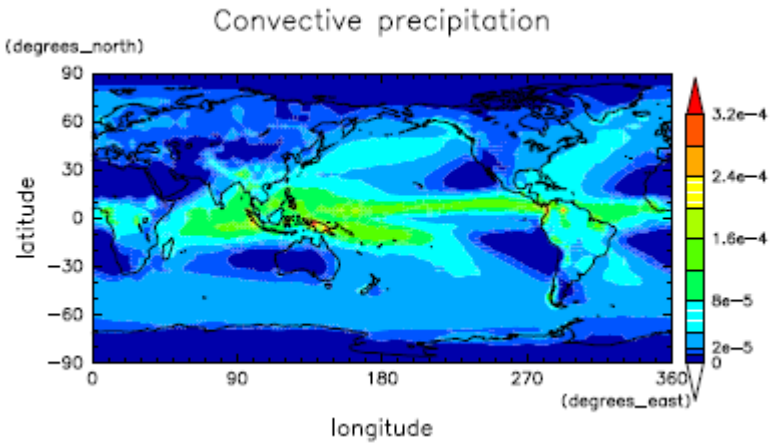
annual mean atmospheric temperature





annual mean precipitation





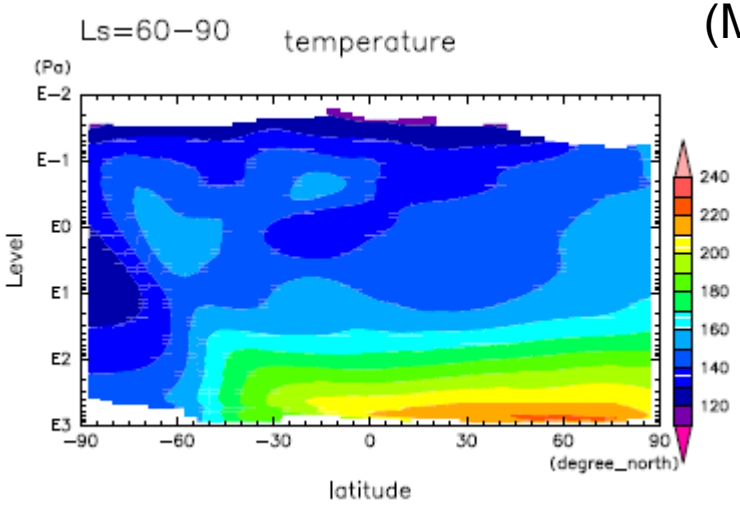
The model represents observed structure, qualitatively, but has some biases.

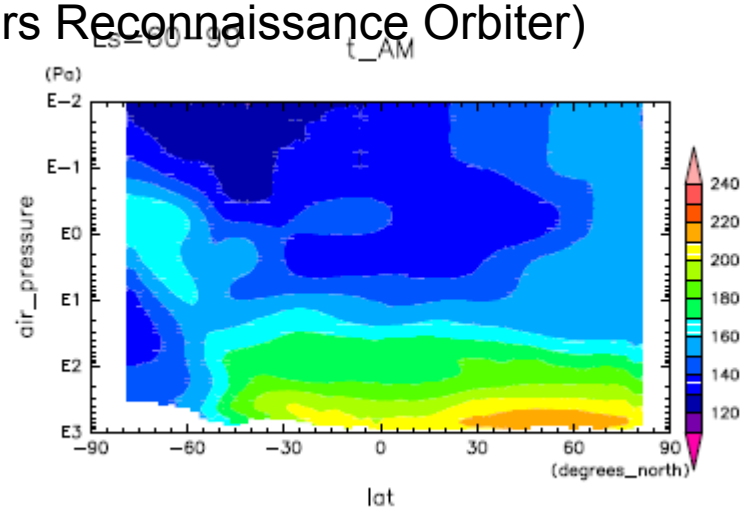
Examples of DCPAM experiments: Mars, comparison with observation

model

observation
(Mars Reconnaissance Orbiter)

atmospheric temperature at 03 LST and at northern summer

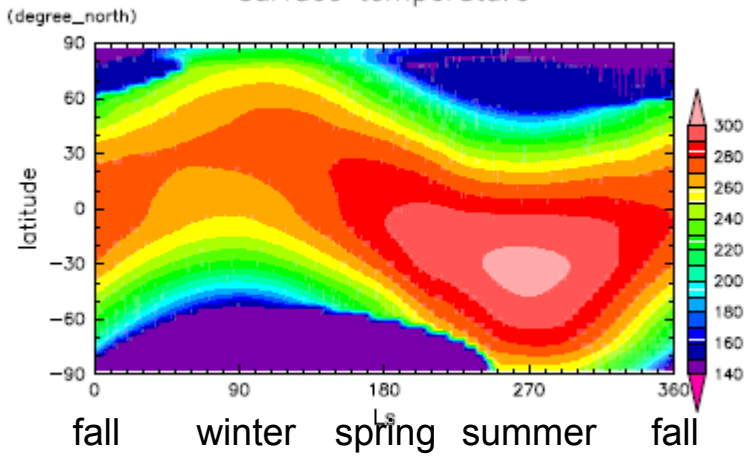


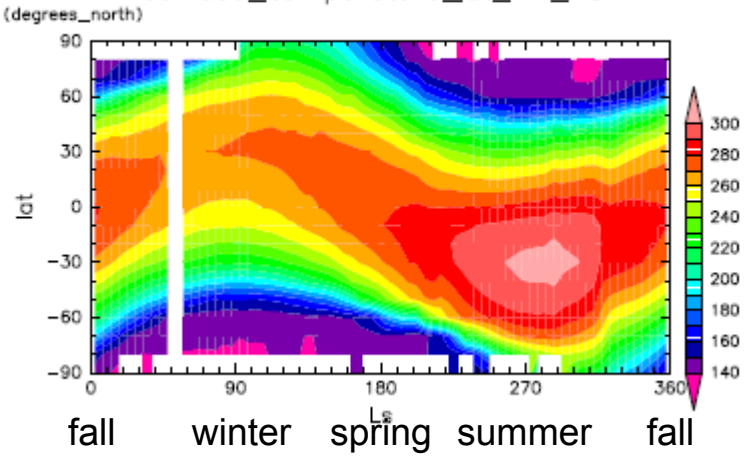


spring summer fall winter spring

spring summer fall winter spring

surface temperature at 14 LST





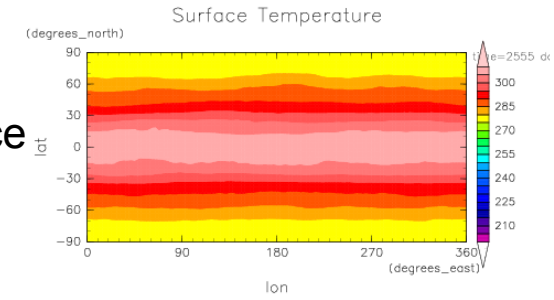
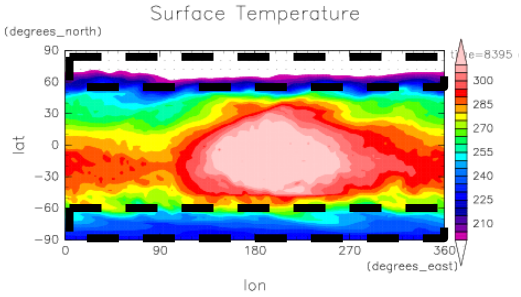
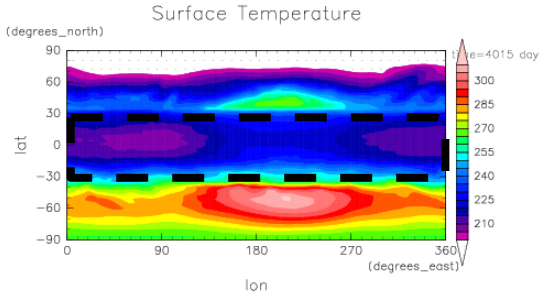
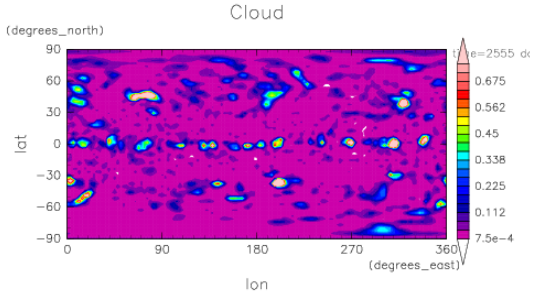
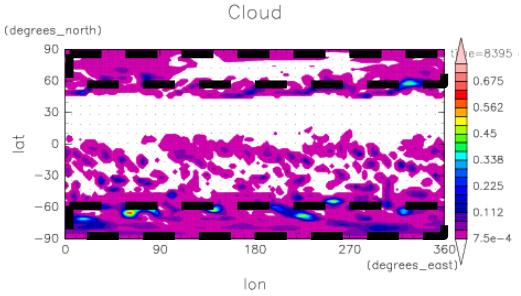
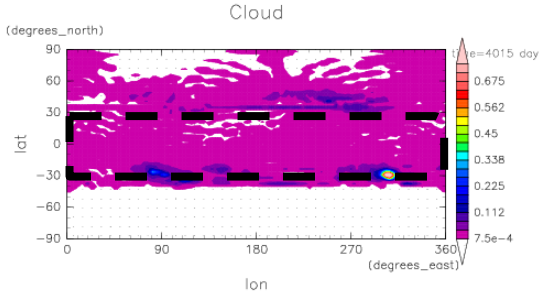
fall winter spring summer fall

fall winter spring summer fall

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			

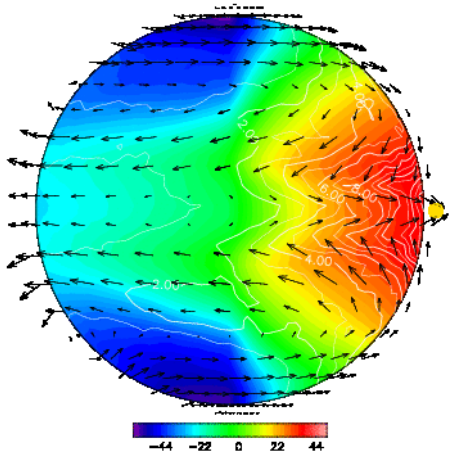
Rectangle shows wet / snow covered regions.

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.

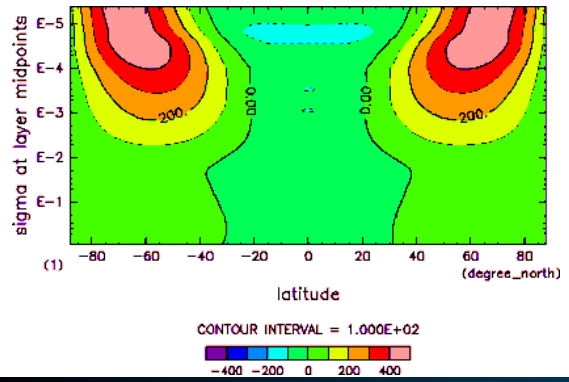
Surface temperature and wind of a tidally-locked virtual terrestrial planet



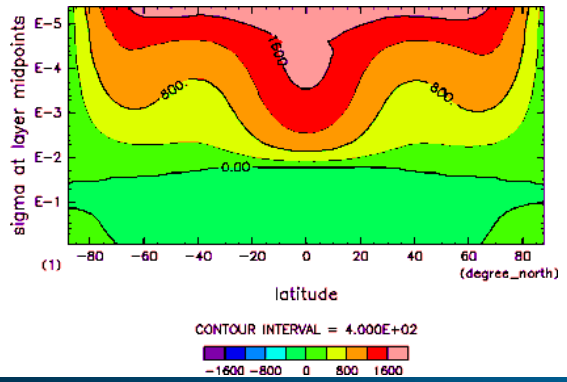
Sensitivity of zonal wind on incoming radiation flux of virtual tidally locked giant planet

Incoming radiation flux

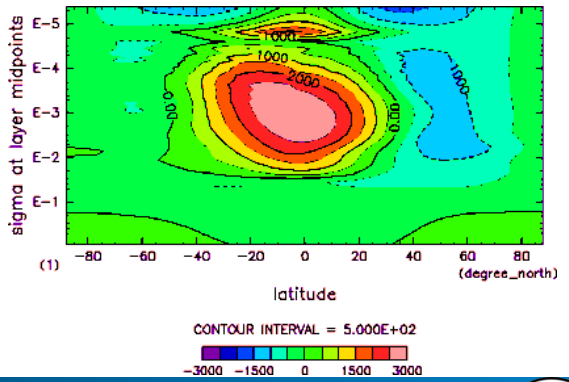
10^3 Wm^{-2}



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.