

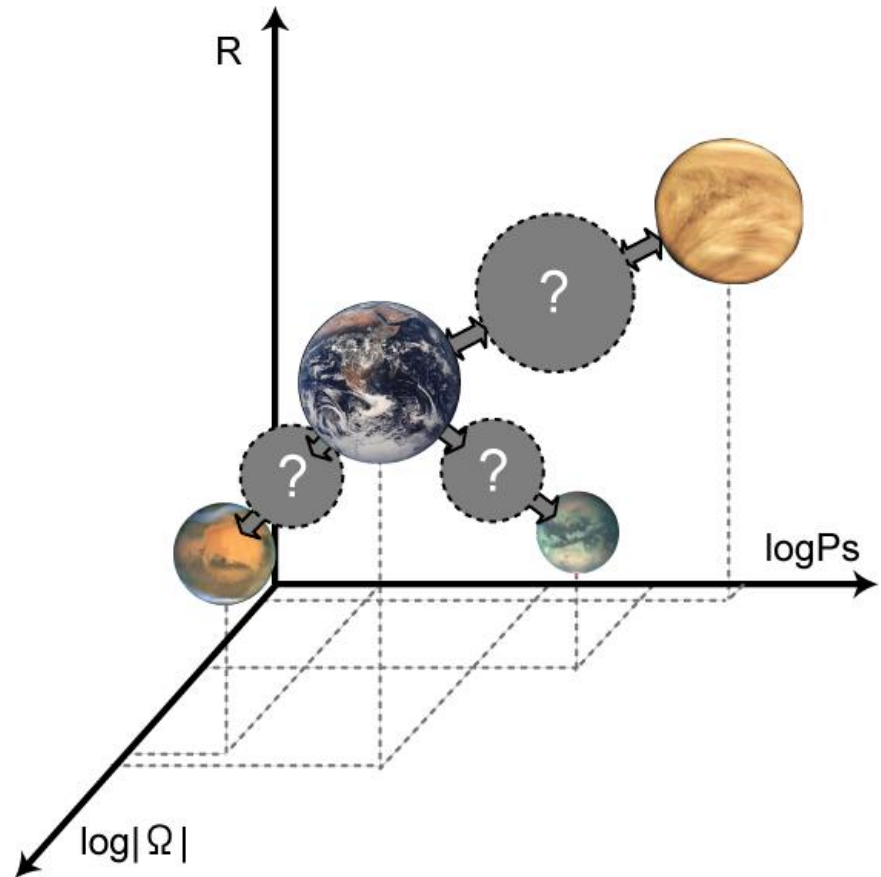
Development of a general circulation model for (shallow) planetary atmospheres, DCPAM

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Motivations of model (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.



dcmode model/library/tool line-up

<http://www.gfd-dennou.org/library/dcmode/>

- Models

- DCPAM

- general circulation model

- deepconv

- cloud resolving model (e.g., Sugiyama et al., 2014)

- dcrtm

- radiation model

- spmodel sample programs

- models for understanding dynamics of geophysical fluid (Takehiro et al., 2006)

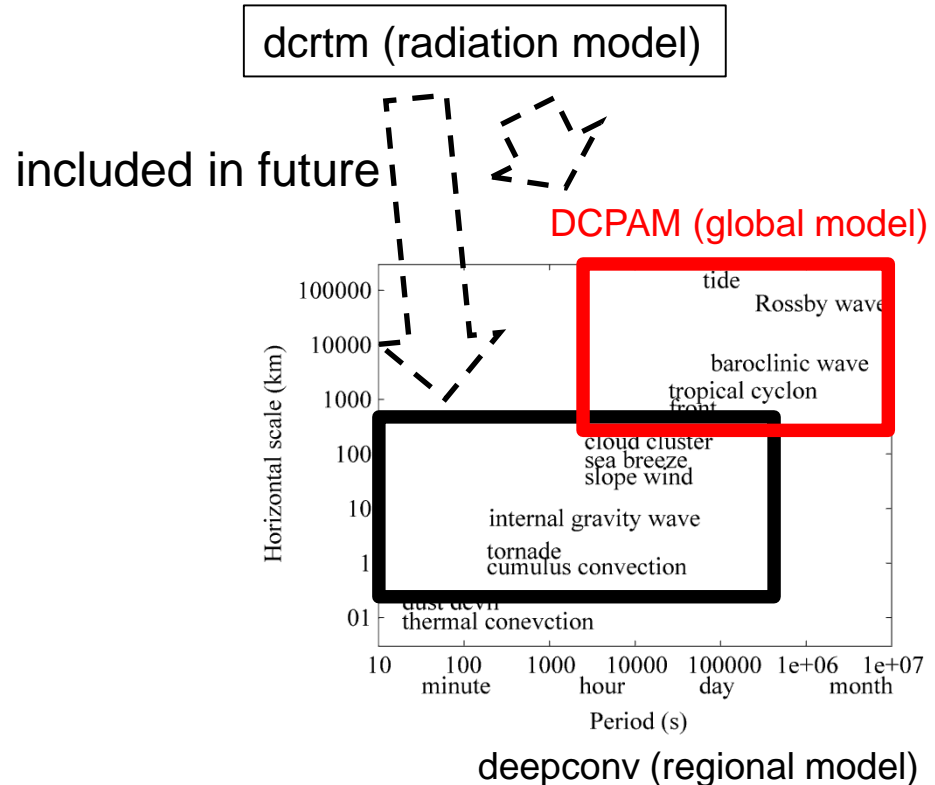
- Tools

- Input/Output library

(Ishiwatari et al., 2012)

- Spectral transformation library

- Utility for documentation



understanding of fluid dynamics

spmodel (simple models)

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

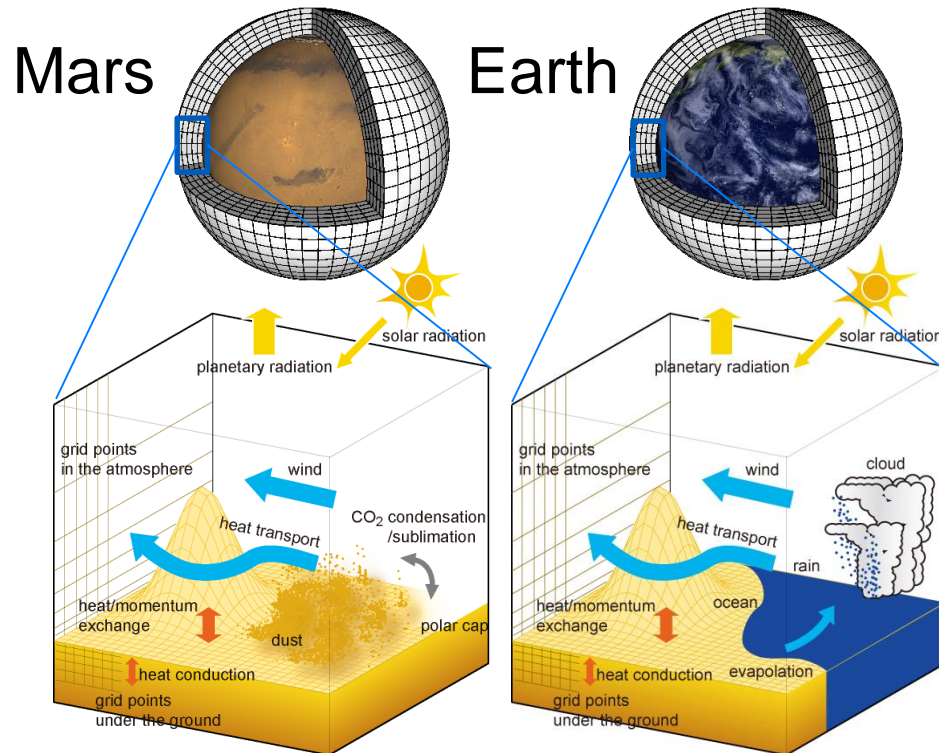
- Condensation

- Cloud

- Soil model, Bucket model

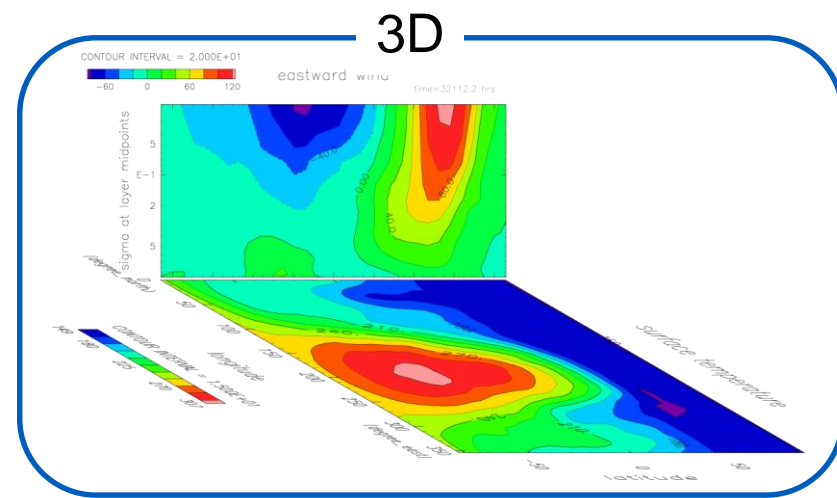
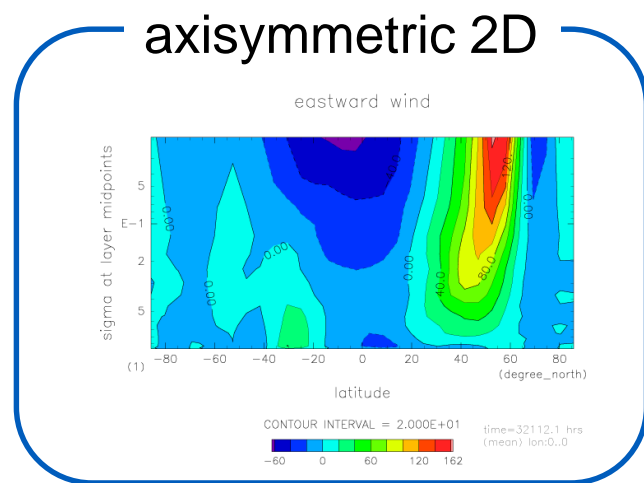
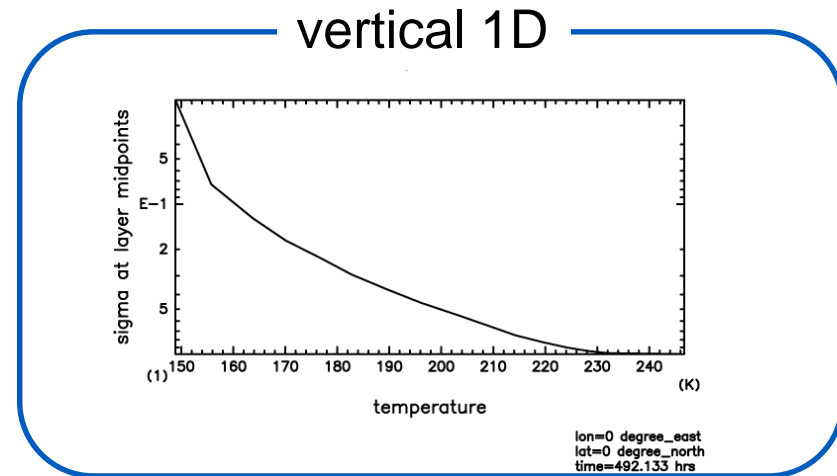
- Note

- 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.



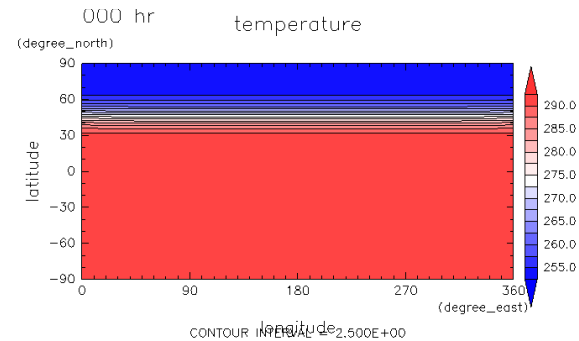
Examples of experiments by the use of DCPAM

- Validation/Idealized experiments
 - Experiments with dynamical core only
 - Experiments with specific physics only
- Planets in solar system
 - Earth
 - Mars
 - Venus with simplified forcing
- Virtual planets / exoplanets(?)
 - Aqua-planet
 - Land planet
 - Tidally locked planets

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

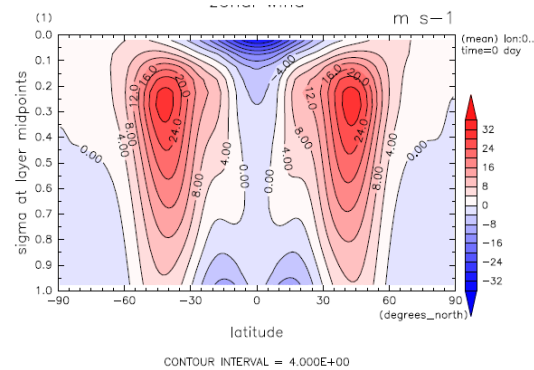
Baroclinic wave



Temperature at lowest level, T341L20

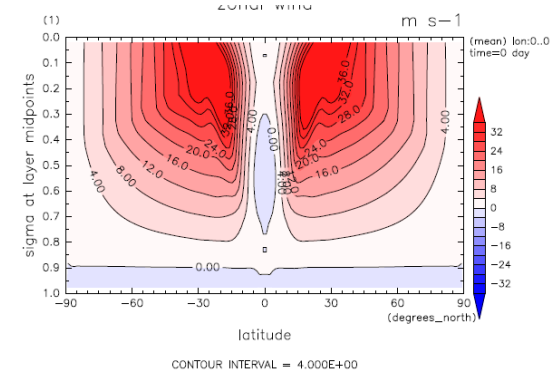
Dynamical core exp.

3D exp.



Zonal mean zonal wind, T85L20

Axisymmetric exp.



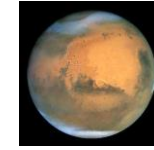
Examples of DCPAM experiments: Venus, Earth, Mars



Venus
(Newtonian cooling)

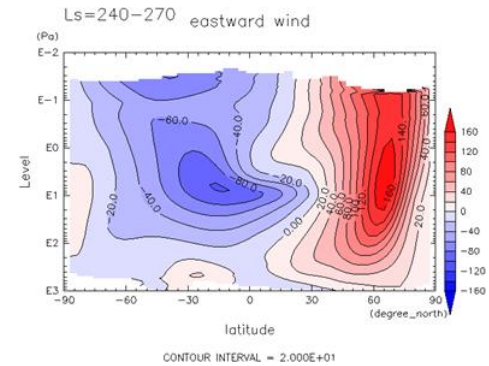
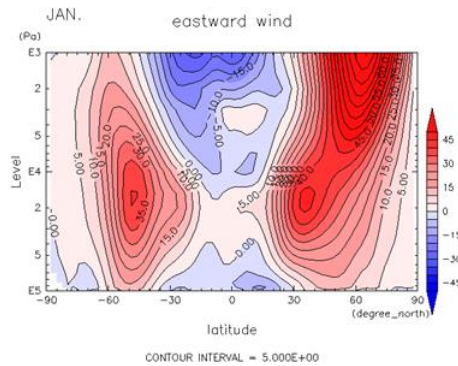
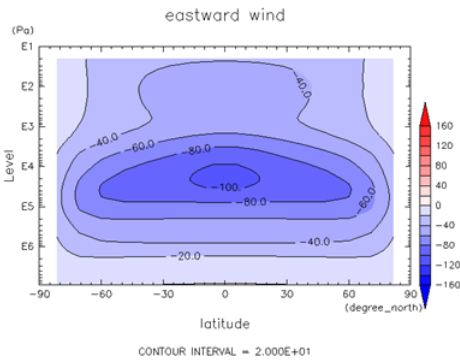


Earth

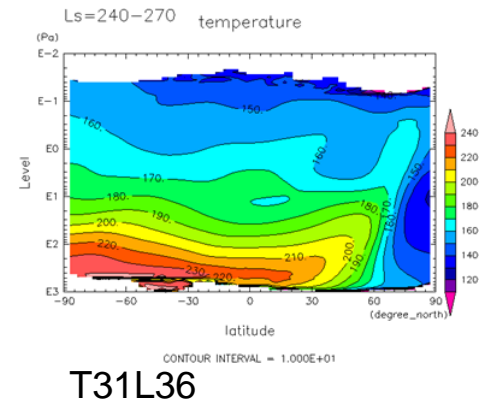
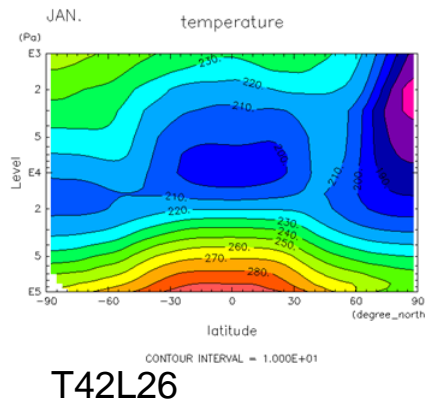
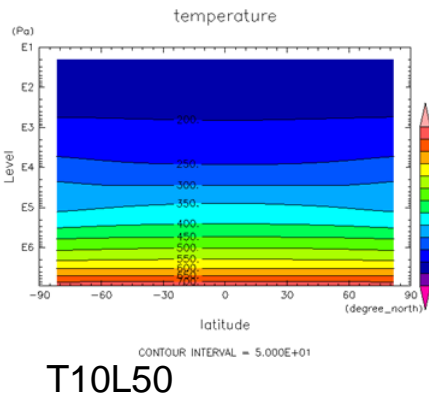


Mars

Zonal
wind



Temperature



Color code and vertical axes are different in three figures.

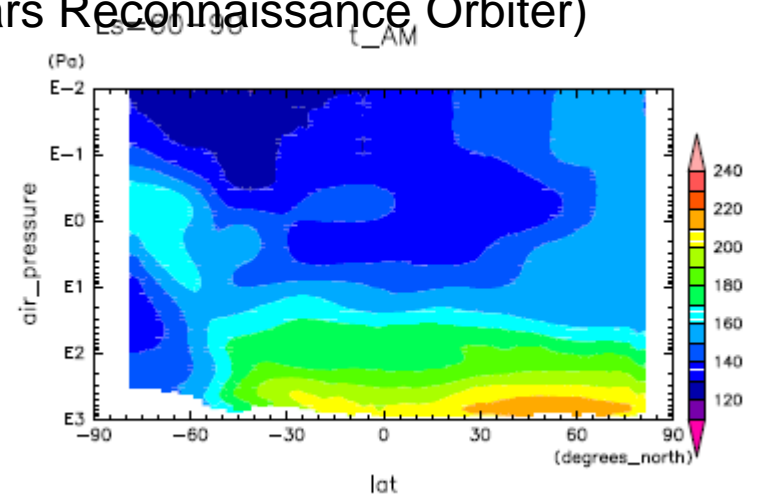
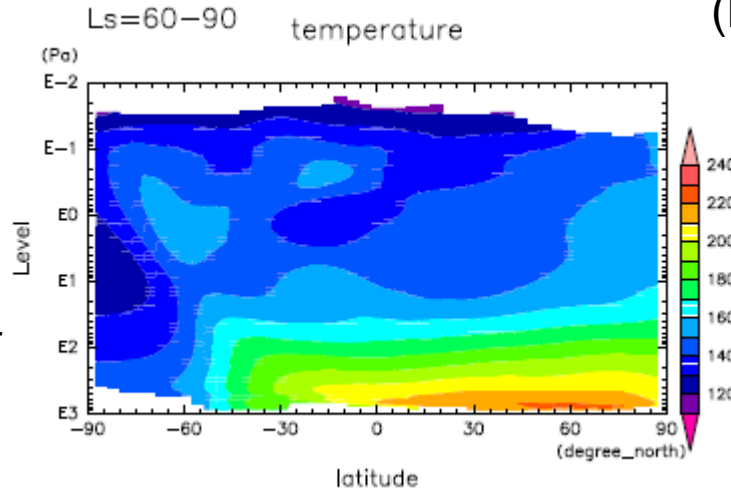


Examples of DCPAM experiments: Mars, comparison with observation

model

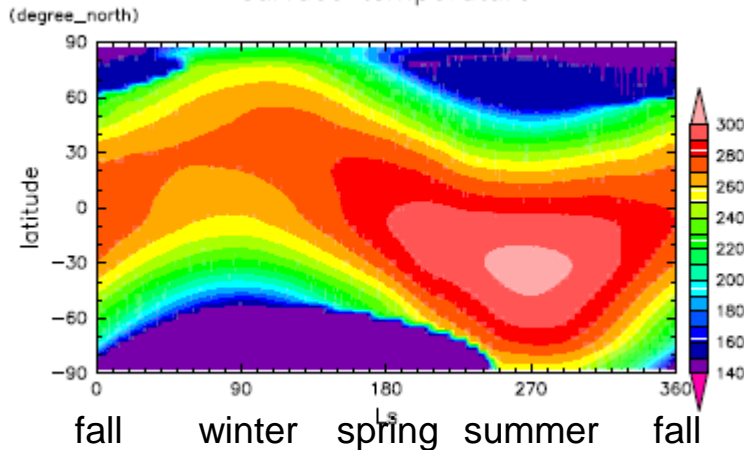
observation

(Mars Reconnaissance Orbiter)

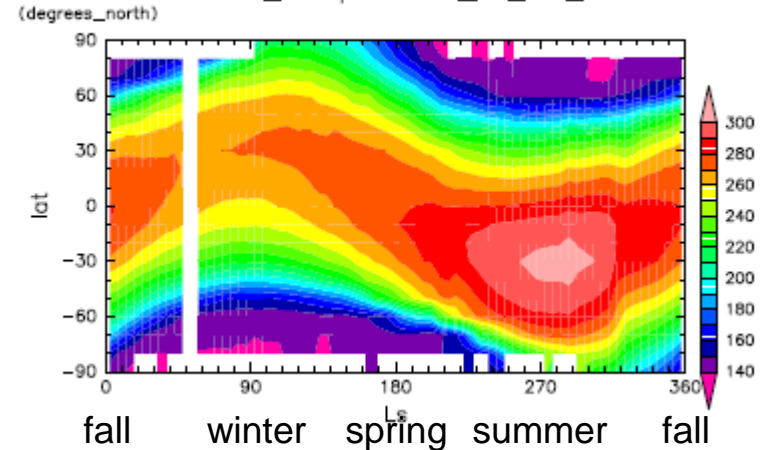


atmospheric
temperature
at 03 LST and
at northern summer

spring summer fall winter spring
surface temperature



spring summer fall winter spring
surface_temperature_at_14_LST

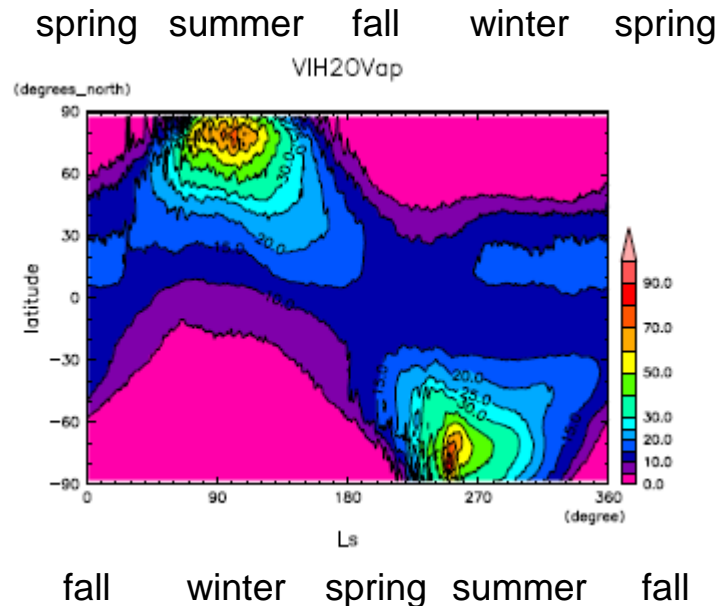


surface
temperature
at 14 LST

Examples of DCPAM experiments: Mars, comparison with observation

Water vapor in the atmosphere

model



observation

(Mars Global Surveyor)

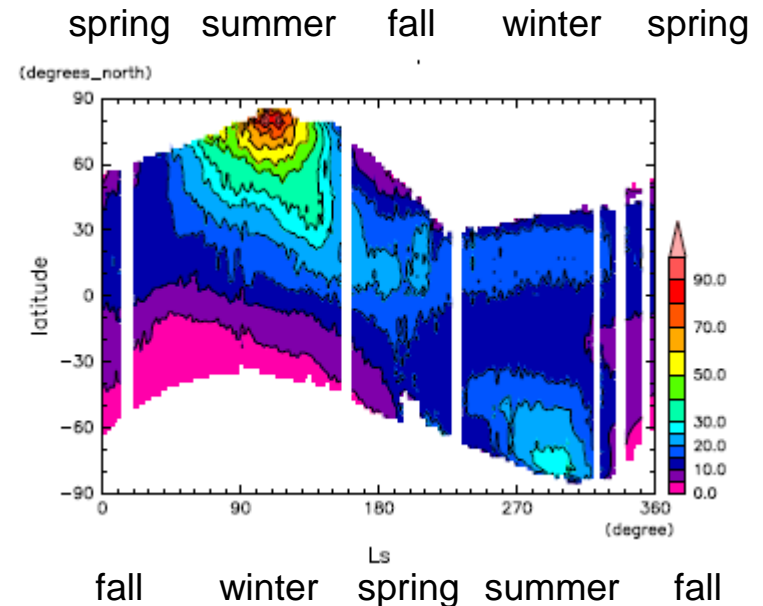


Figure above does not look so bad.
But, we do not understand behavior of the model.

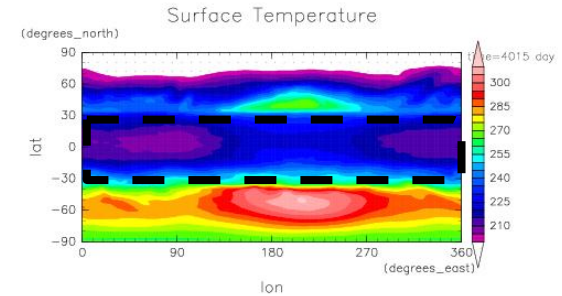
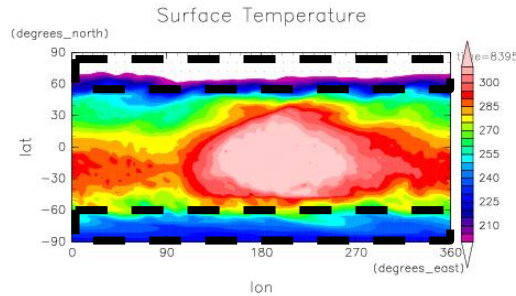
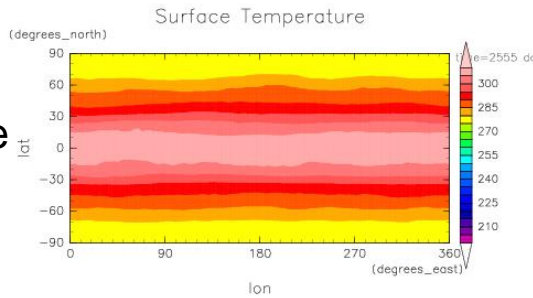
Examples of DCPAM experiments: Virtual aqua planet and land planets

Aqua planet
(obliquity 23.4°)

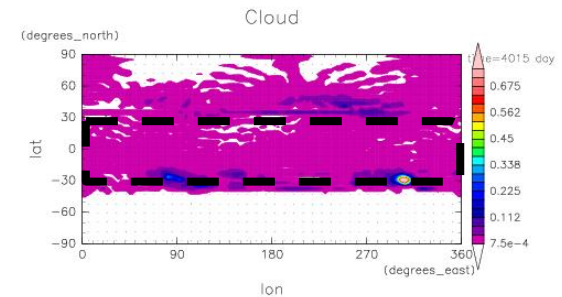
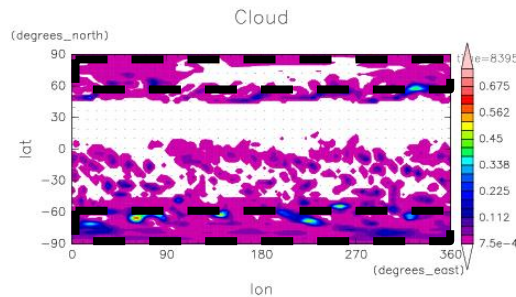
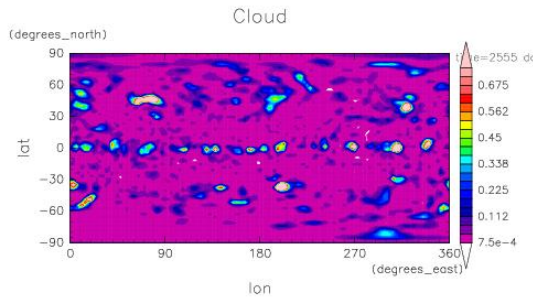
Land planet
(obliquity 23.4°)

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)

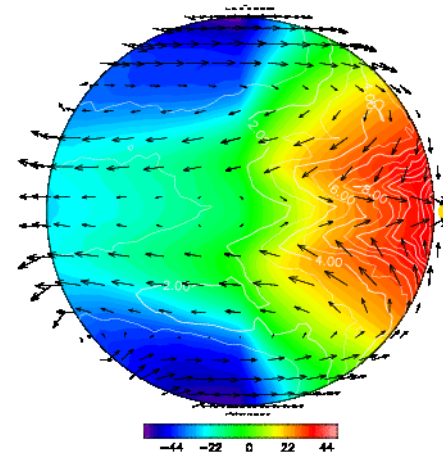


Examples of DCPAM experiments: Virtual tidally-locked planets

- Tidally locked
 - terrestrial planet
 - Noda et al. (2017)
 - Ishiwatari et al.
 - giant planet
 - Takehiro et al.



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



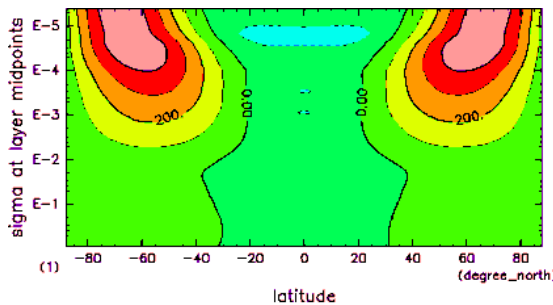
Sensitivity of zonal wind on incoming radiation flux of virtual tidally locked giant planet

Incoming radiation flux

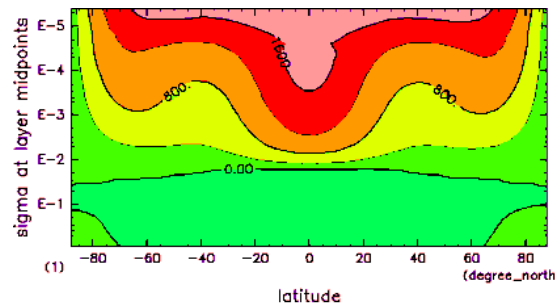
10^3 Wm^{-2}

10^5 Wm^{-2}

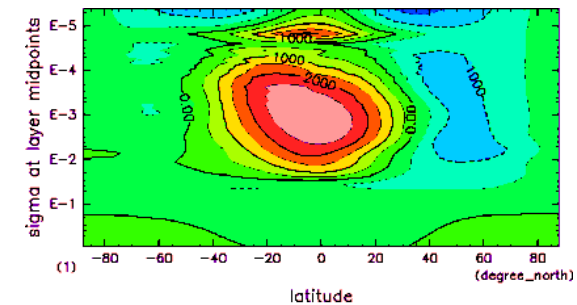
10^7 Wm^{-2}



CONTOUR INTERVAL = 1.000E+02
-400 -200 0 200 400



CONTOUR INTERVAL = 4.000E+02
-1600 -800 0 800 1600



CONTOUR INTERVAL = 5.000E+02
-3000 -1500 0 1500 3000

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)

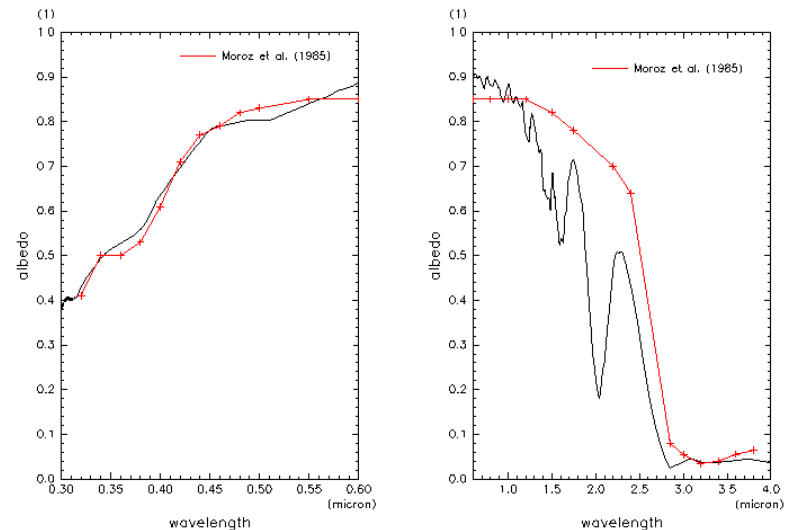


Summary

- We are working on the development of a general circulation model for planetary atmospheres, such as the Earth, Mars, exoplanets, and so on.
- 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.
 - Kawai-san will give a talk on its latest results.

Preliminary result of radiative transfer calculation of Venus atmosphere

- Line-by-line calculation
- Temperature
 - VIRA
- Composition and cloud distribution are assumed based on observations.
- In future, we want to include radiation model to DCPAM.



Bond albedo is 0.76, which is close to that by Moroz et al. (1985)