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.

	Earth	**Mars**
rotation period	1 day	1.03 day
declination angle	23.4°	25.2°
radius	6378 km	3391 km
length of a year	365 days	669 (Mars) days
others	moist processes	cold and dry condition dust storms

Motivation and Purpose of this study

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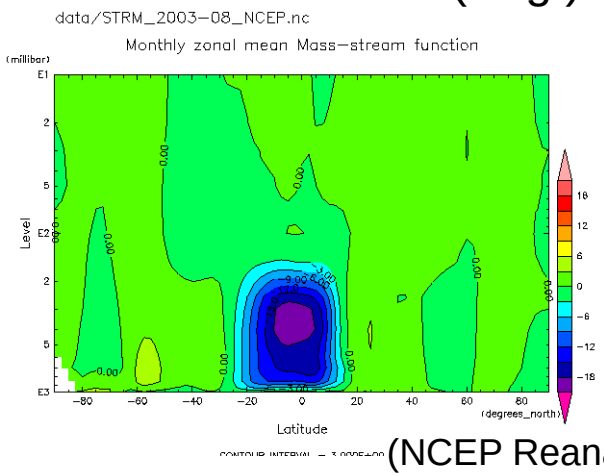
Earth

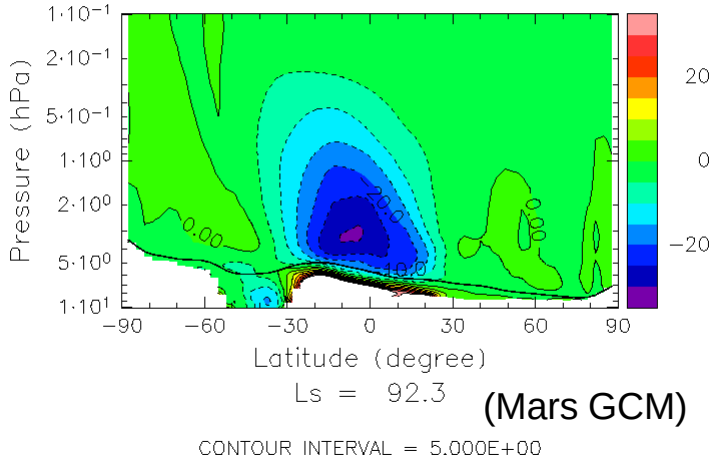
Northern summer (Aug.)



(NCEP Reanalysis)

Mars

Northern Summer



(Mars GCM)

- 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)
  - http://www.gfd-dennou.org/library/dcpam/
- 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_2O, CO_2 (Roewe and Liou, 1978)
      - effects of cloud is neglected
    - absorption of short wave radiation by H_2O (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°
    - number of vertical levels 16
- 4 experiments are performed.
  - Integration is performed for 20 years.

	Ocean	Radius	Length of a year
Case 1 “Land and ocean”	Yes	Earth	Earth (365 days)
Case 2 “No ocean”	No	Earth	Earth
Case 3 “Mars radius”	No	Mars	Earth
Case 4 “Mars year”	no	Mars	Mars (669 days)

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.”

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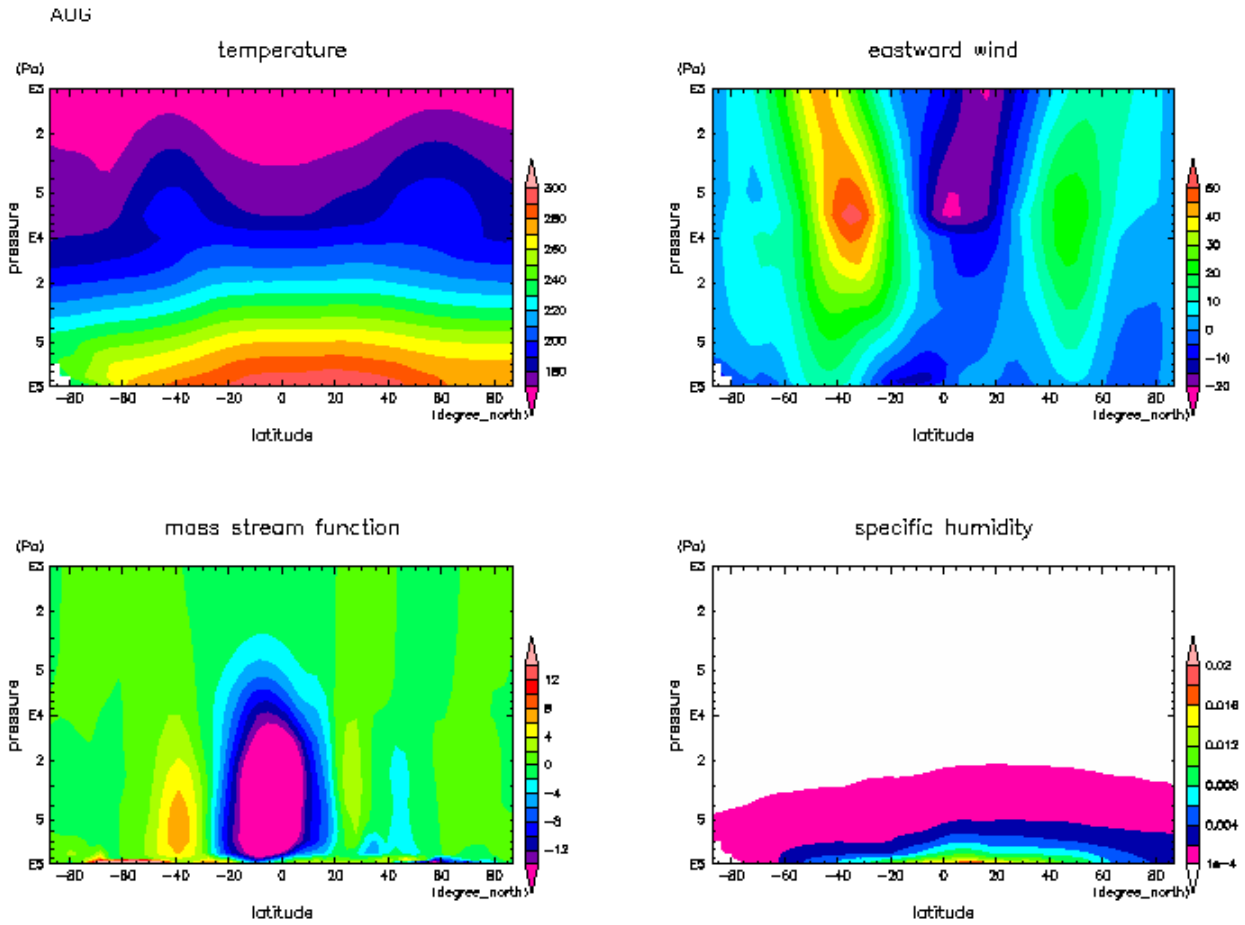

Results: Case 2, Zonal mean field in “Aug.”

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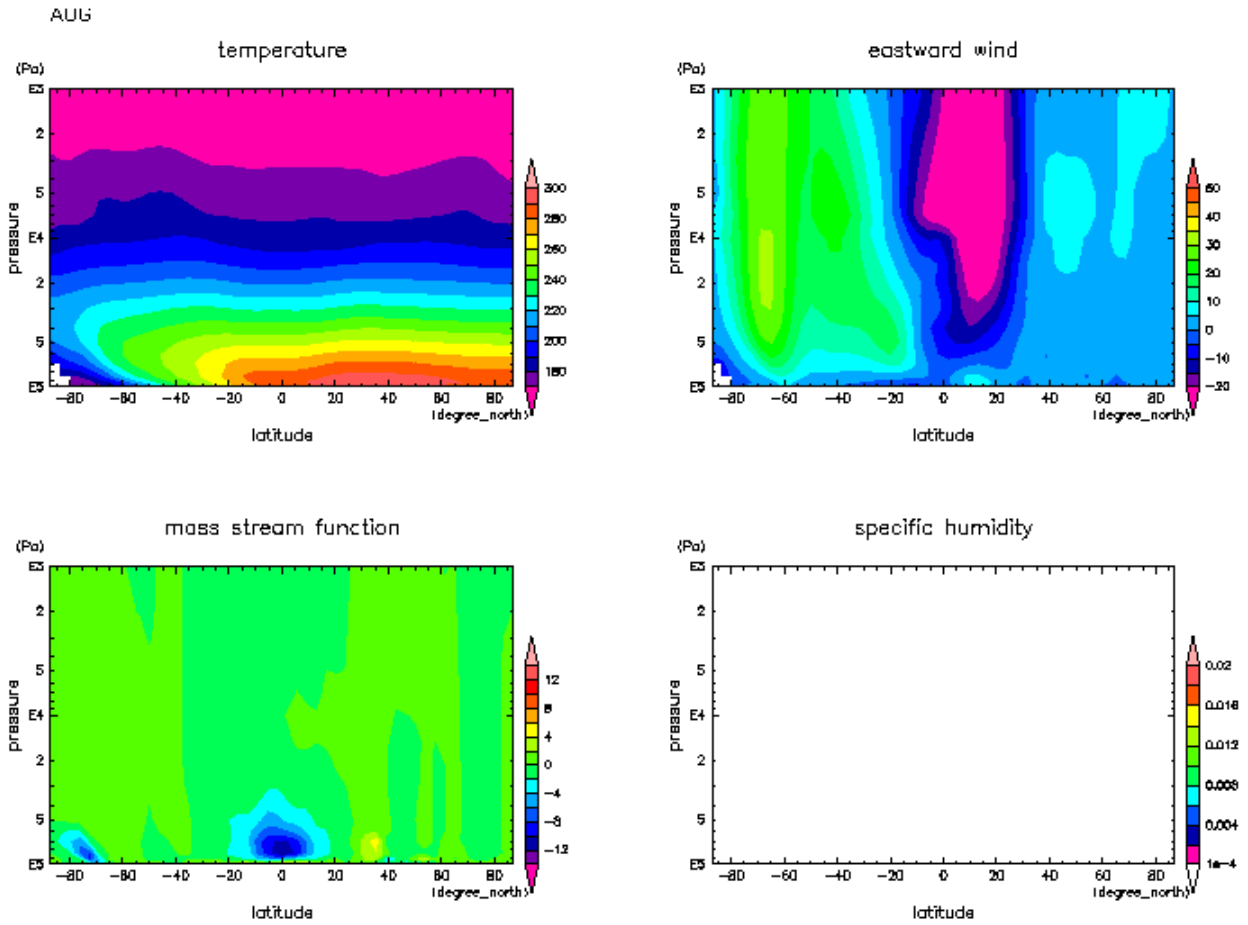

Results: Case 3, Zonal mean field in “Aug.”

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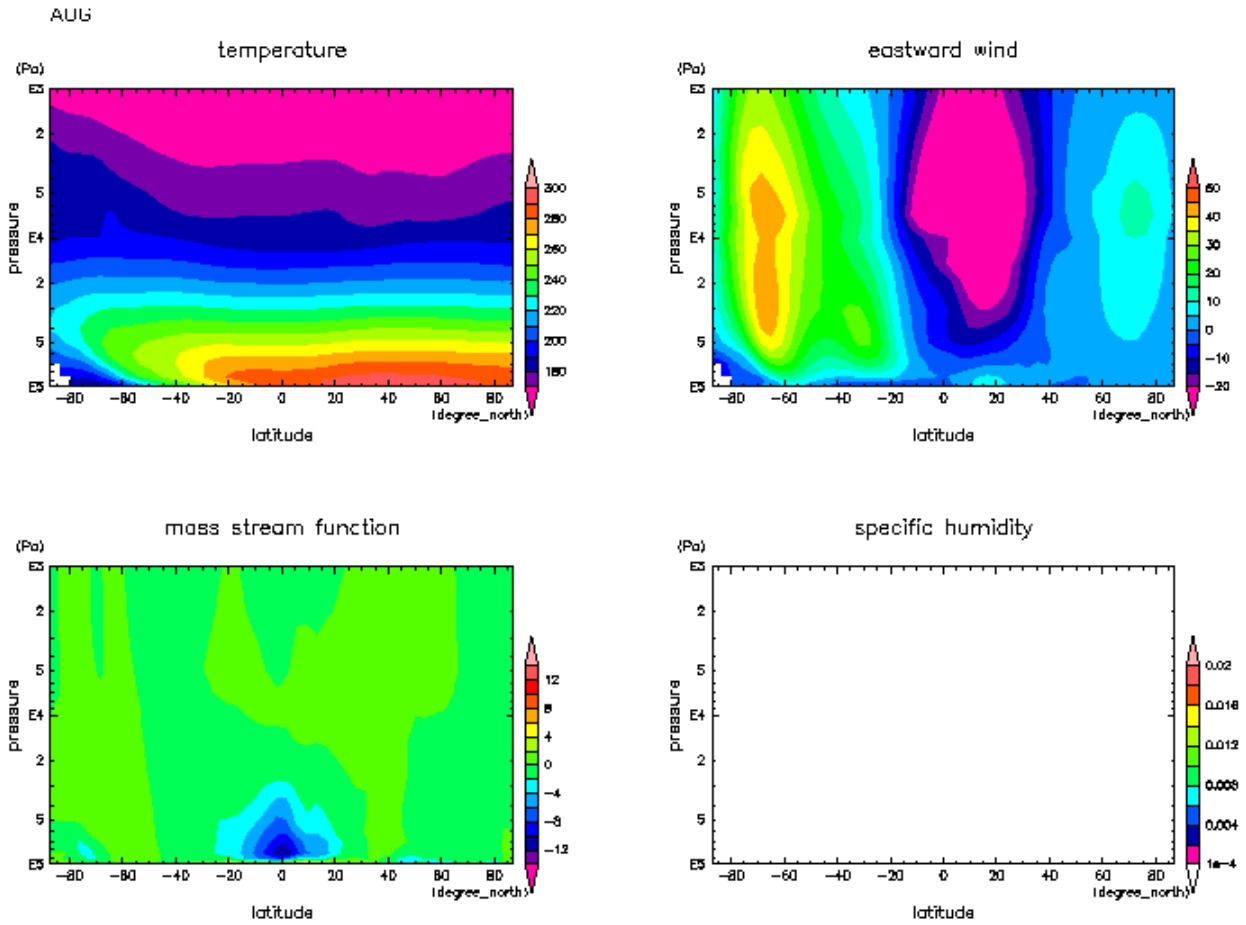

Results: Case 4, Zonal mean field in “Aug.”

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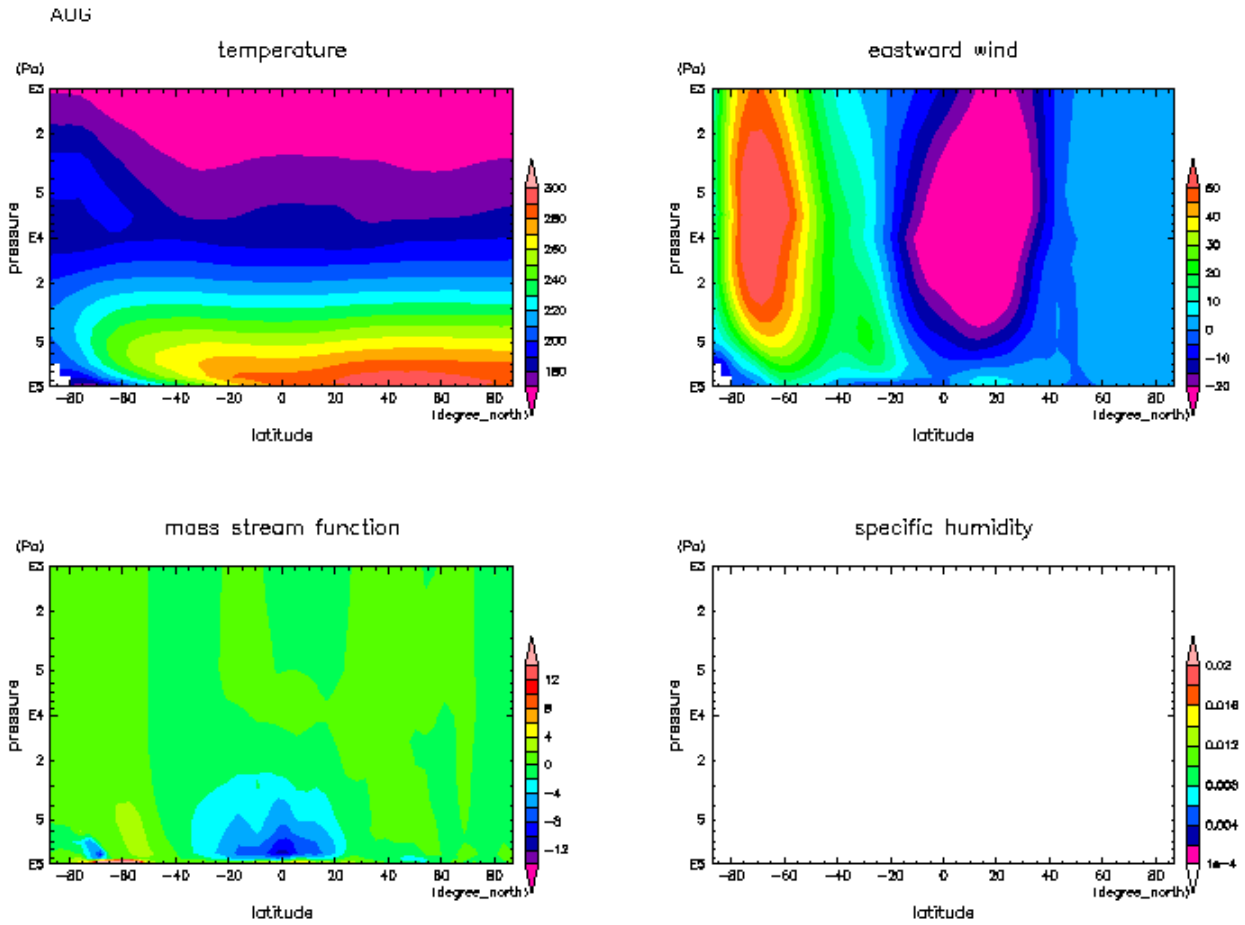

Changes of Hadley circulation

- 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

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  - 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,
    - http://www.gfd-dennou.org/library/ruby/.