DCMODEL: Hierarchical models for geophysical fluid dynamics and planetary atmospheres

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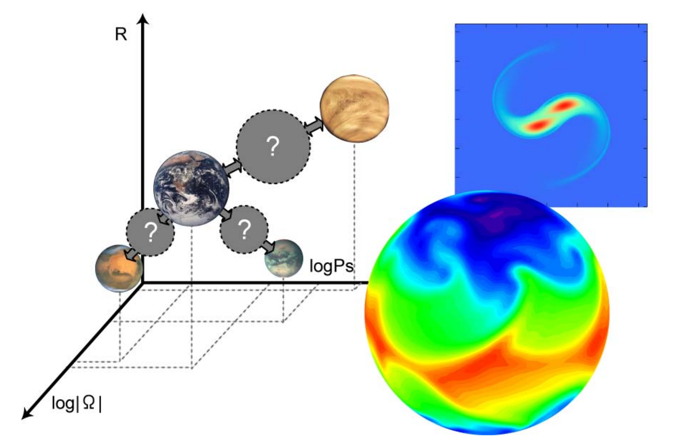
Introduction

Numerical models used for simulations of various aspects of planetary atmospheres are getting more and more complex. Correspondingly, it is getting harder and harder to understand what is going on in the model (Held, 2005). As an effort to provide a tool-set for filling the gap between complex simulation models and simple conceptual thoughts, "dcmodel" is a project of GFD Dennou Club† to develop a series of hierarchical models for research and education of the fields of geophysical fluid and planetary atmospheres.



"Dcmodel" is composed of a several subgroups of models that have various complexities but with a rather unified coding style:

- spmodel, a series of spectral models for geophysical fluid dynamics,
- dcpam, a 3D global circulation model on a sphere with the primitive equation,
- deepconv, a 2D atmospheric convection resolving model with the non-hydrostatic quasi-elastic equation,
- gtool, a common input/output library

†GFD Dennou Club is a research and development activity of an inter university basis whose members are scattered in several research/educational institutions in Japan.

Gtool: Fortran90/95 Input/Output library

The current version of gtool is gtool5. Gtool5 is a library including Fortran90/95 wrapper of NetCDF library (http://www.unidata.ucar.edu/software/netcdf/) and some softwares which help us develop numerical models. Gtool5 library forces numerical models to include data attributes such as units, long names, axis data and so on in their output NetCDF files with a prescribed standard style. This feature enhances the convenience of data manipulation by model users.

Spmodel: a series of spectral models for geophysical fluid dynamics

Spmodel is a series of spectral models by using a spectral model library (spml) which is based on the spectral transformation library of ispack. The spectral models of spmodel are based on various levels of approximate equations that appear in the field of geophysical fluid dynamics.

The use of spml has following advantages in coding numerical models based on spectral method:

- Facility of programming
  - The main part of the source program code shows a good correspondence with the original mathematical expression of the governing equation especially when the governing equations are simple.
- Readability of program source codes
  - Since program source codes are written in a similar form to the original mathematical expressions, the programs can be understood easily.
- Facility of modification or alteration
  - Thanks to the above two features, we can modify or alter the programs quite easily.

Example : 1D KdV equation

1D KdV equation

$$\frac{\partial\varsigma}{\partial t} = -\varsigma\frac{\partial\varsigma}{\partial x} - \frac{\partial^3\varsigma}{\partial x^3},$$

is transformed to

$$\tilde{\varsigma}_m^{\tau+1} = \tilde{\varsigma}_m^{\tau} + (\Delta t)\times\left\{-\left[\widetilde{\varsigma\frac{\partial\varsigma}{\partial x}}\right]_m^{\tau} - \left[\widetilde{\frac{\partial^3\varsigma}{\partial x^3}}\right]_m^{\tau}\right\},$$

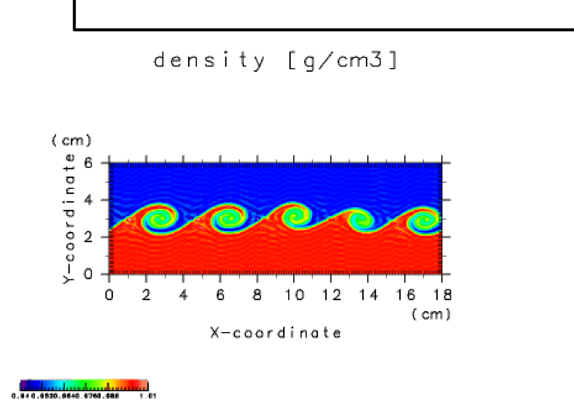
where the Euler scheme is applied to time derivative and

$$\tilde{\varsigma}_m(t) = \frac{1}{L}\int_0^L \varsigma(x,t)e^{2\pi imx/L}dx, \quad \varsigma(x,t) = \sum_m \tilde{\varsigma}_m(t)e^{-2\pi imx/L}$$

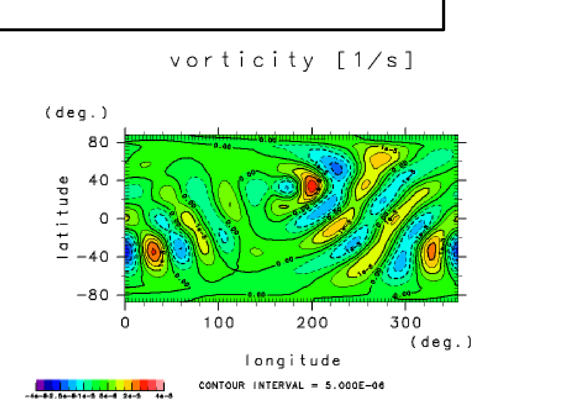
By the use of spml, this discretized equation is coded as follows:

```
do it=1,nt
   e_Zeta = e_Zeta + dt * &
            ( -e_g(g_e(e_Zeta)*g_e(e_Dx_e(e_zeta))) &
            - e_Dx_e(e_Dx_e(e_Dx_e(e_zeta))) )
end do
```

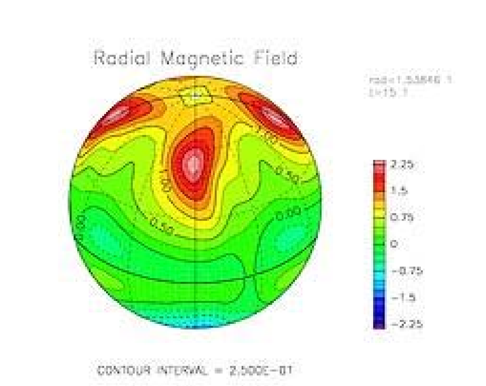
e_Zeta	: $\tilde{\varsigma}_m(t)$
dt	: time step
e_g	: spectral transformation
g_e	: inverse spectral transformation
e_Dx_e	: x derivative in spectral space



Kelvin-Helmholtz instability simulated in a two-layer model. In the initial condition, x-component of velocities in upper and lower layers are positive and negative, respectively.



Rossby wave propagation on a sphere simulated in a shallow water equation system.



Magnetic field generated by convection simulated in a magneto-hydrodynamical fluid model in a spherical shell.

References

- Held, I. M., 2005: The gap between simulation and understanding in climate modeling. *Bull. Am. Meteor. Soc.*, **86**, 1609-1614.
- Held, I. M., and Suarez, M. J., 1994: A proposal for the intercomparison of the dynamical cores of atmospheric general circulation models. *Bull. Am. Meteor. Soc.*, **75**, 1825-1830.
- GFD Dennou Club: http://www.gfd-dennou.org/index.html.en
- spmodel: http://www.gfd-dennou.org/library/spmodel/index.htm.en
- dcpam: http://www.gfd-dennou.org/library/dcpam/index.htm.en
- deepconv: http://www.gfd-dennou.org/library/deepconv/index.htm.en
- gtool: http://www.gfd-dennou.org/library/gtool/gtool5.htm.en
- ispack: http://www.gfd-dennou.org/library/ispack/ (at the moment, Japanses page only)

Dcpam: a 3D global circulation model on a sphere

- Dcpam is a 3D spectral atmospheric general circulation model (GCM) on a sphere:
  - primitive equation system solved with the spectral method by the use of spml,
  - subgrid scale processes, i.e., moist convective adjustment, large scale condensation, turbulence,
  - surface and subsurface heat budget equation,
  - simple radiation model.

  → See posters by Noda et al. and Takahashi et al. for details of the model and results.

Dry atmosphere experiment by dcpam (Held and Suarez, 1994)

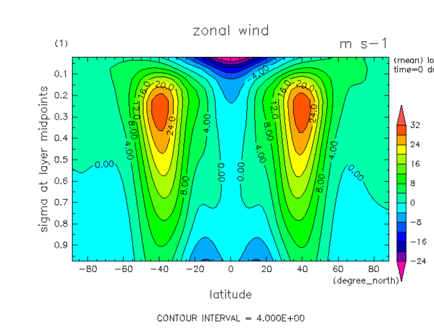


Figure . Zonal mean zonal wind in a dry atmosphere experiment proposed by Held and Suarez (1994).

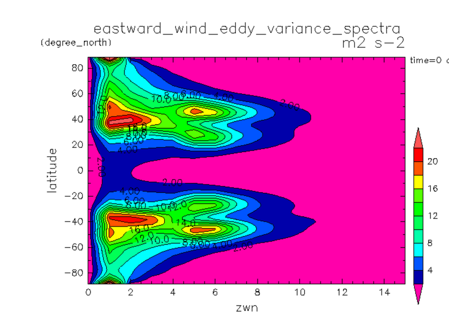


Figure . Vertically integrated variance spectrum of zonal wind in a dry atmosphere experiment proposed by Held and Suarez (1994).

Simulation of an Earth-like planet (see poster by Takahashi et al.)

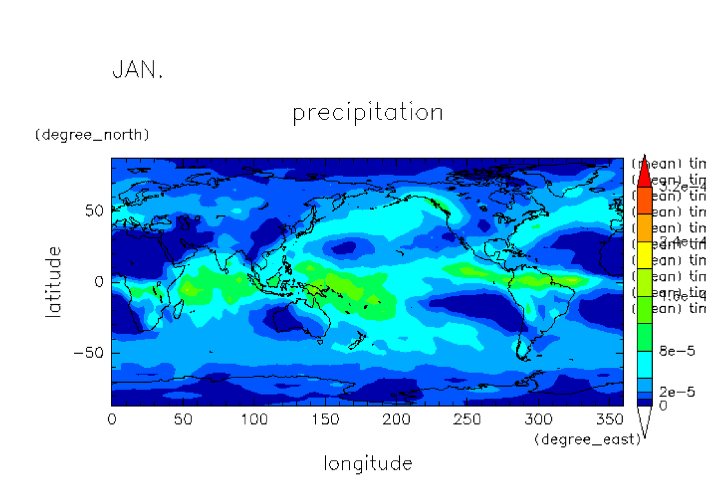


Figure . Precipitation distribution on January in an Earth-like planet simulation.

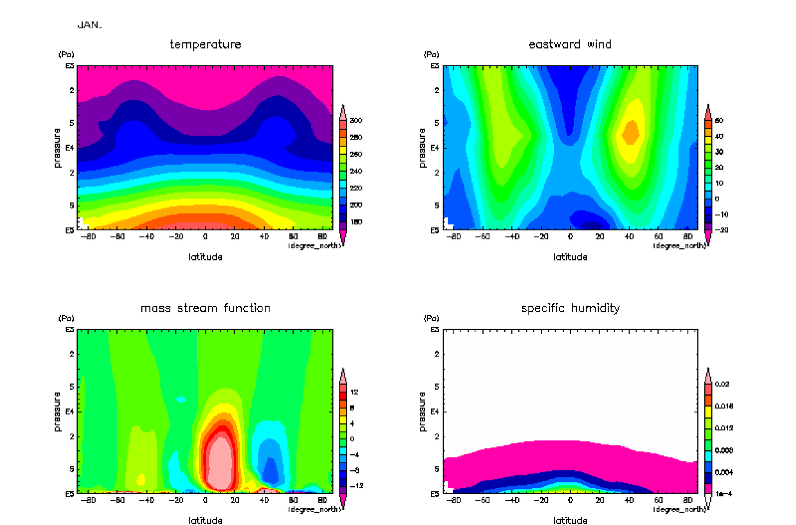


Figure . Zonal mean temperature (top left), zonal wind (top right), mass stream function (bottom left), specific humidity (bottom right) on January in an Earth-like planet simulation

Simulation of a synchronously rotating planet (see poster by Noda et al.)

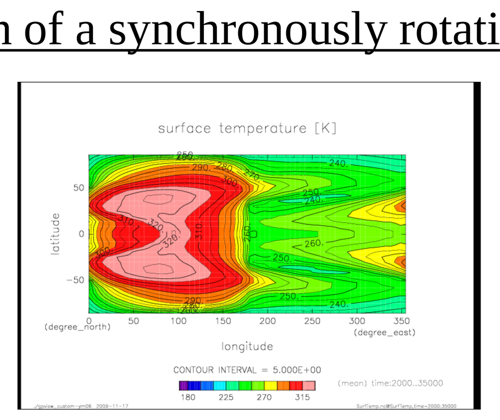


Figure. Time-mean surface temperature in a synchronously rotating planet whose rotational velocity is same as the Earth. The subsolar point is 0N, 90E.

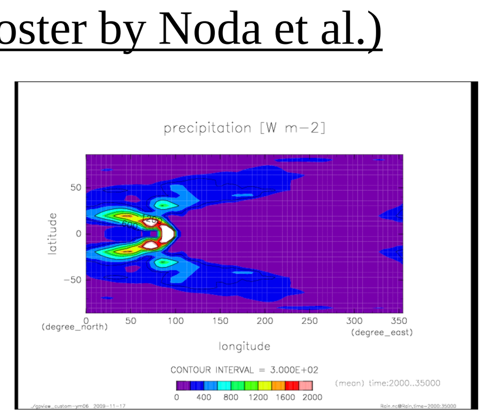


Figure. Same as left figure, but for precipitation.

Deepconv: an atmospheric convection resolving model

- Deepconv is a grid-point convection resolving model (at the moment, mainly 2D):
  - quasi-elastic equation system,
  - simple thermal forcing by imposing constant cooling rate,
  - subgrid scale turbulence.

  →See posters by Sugiyama et al. and Yamashita et al. for details of the model and results.

Simulation of Jovian atmosphere (see poster by Sugiyama et al.)

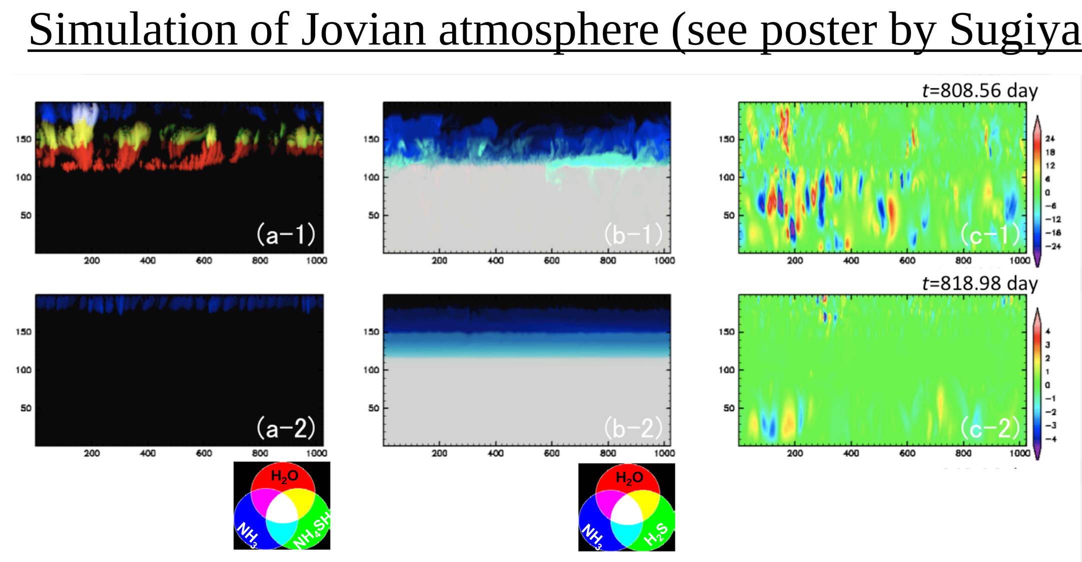
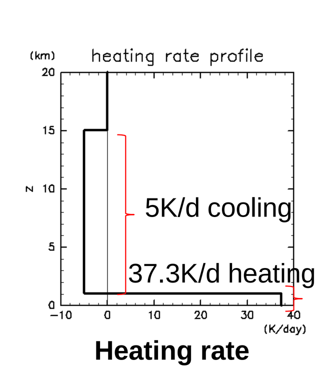


Figure. Distributions of cloud mixing ratios (a), vapor mixing ratios (b), and vertical velocity (c). Panels (a-1), (b-1), and (c-1) show distributions for the active period, and (a-2), (b-2), and (c-2) are for the quiet period. Cloud mixing ratios are plotted on a logarithmic scale from 1.0e-8 to 5e-4 kg/kg. Vapor mixing ratios are plotted on a linear scale normalized to the initial values.

Simulation of polar region of Martian atmosphere (see poster by Yamashita et al.)



Heating rate imposed in the simulation.

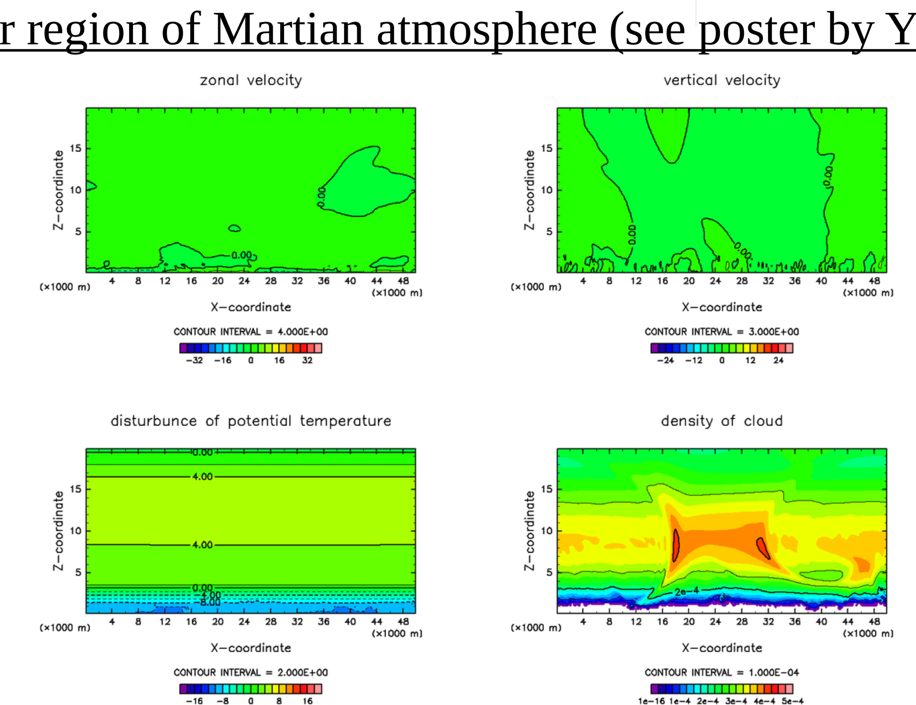


Figure. Horizontal wind velocity (top left), vertical wind velocity (top right), potential temperature deviation from the basic state (bottom left), and density of cloud (bottom right). The simulation is performed with critical saturation ratio of 1.35 (strong supersaturation is allowed).

Acknowledgements

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