Model development in GFD Dennou Club

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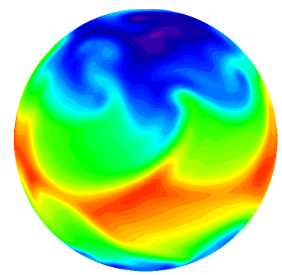
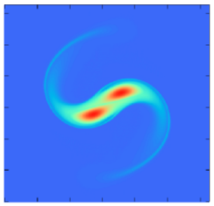
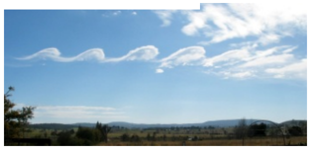
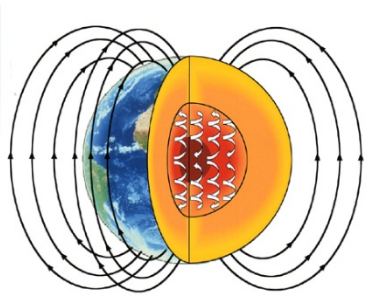
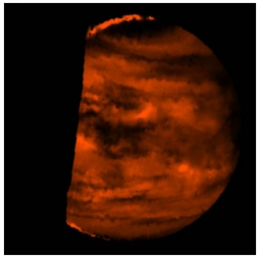
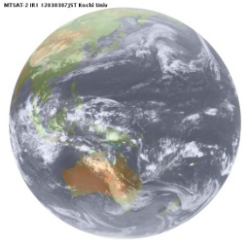
dcmodel project

http://www.gfd-dennou.org/library/dcmodel/

Development of models and tools for study and education of a variety of geophysical fluid,

- planetary atmospheres, ocean & climate,
- planetary cores,
- idealized systems of above-mentioned fluid.


Difficulty in numerical studies

- Current simulation models (climate models) are very complex.
- It is difficult for us to understand what is going on in simulations.
  - It is difficult
    - to check validity of the model,
    - to understand the code.
  - If we use a comprehensive model, which reproduce the reality, the use of the model is almost the same as (high density) observation.

- “The Gap between Simulation and Understanding in Climate Modeling” (Held, 2005)

Target features of models/tools development

- Models and programs that anyone can use
  - Anyone can freely download, edit, and redistribute them.
  - Anyone can perform the same experiments shown in papers.
- Models with a variety of complexities.
  - Comparison between the results from simple (conceptual) model and those from complex model enable us to understand the phenomena.
- Models which are written in the same "style"
  - Common
    - variable naming rule,
    - Input/Output library
      - data format, NetCDF
    - spectral transform library.
  - These features would enable us to use several models, easily.
- Models that can run on a variety of computers
  - One can run a model on a supercomputer as well as a PC.
- Models with documents
  - Documents help education.

dcmodel tool/model line-up

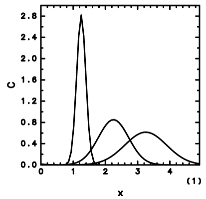
- Input/Output library
  - gtool5
- Spectral transformation library
  - ispack
  - spml (wrapper of ispack)
- Models
  - spmodel sample programs
    - models of spectral transformation method
  - deepconv
    - cloud resolving model
  - DCPAM
    - general circulation model
- Utility for documentation
  - rdoc-f95

- Those tools/models can be downloaded from GFD Dennou Club web site http://www.gfd-dennou.org/.

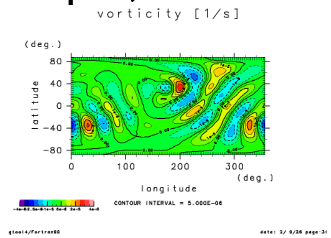
Hierarchy of models developed in dcmodel project

1D	2D	3D

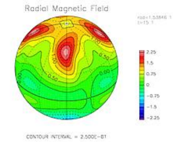
- adv.-diff. eq.



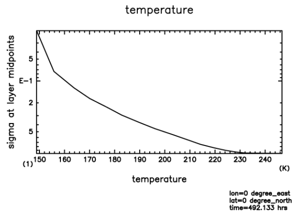
- barotropic, shallow wat. eq.



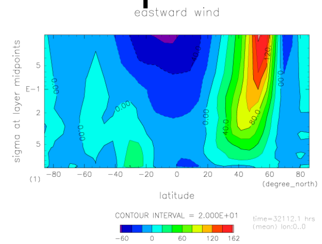
- MHD eq. for spherical shell

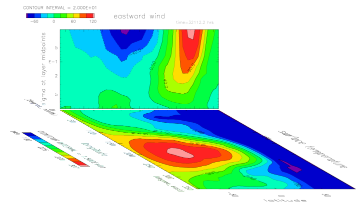


- SCM (DCPAM)



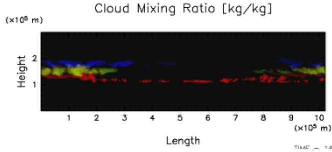
- 2D/3D primitive eq. (DCPAM)





using ispack/spml

- 2D/3D quasi-compressible eq. (deepconv)



using gtool

gtool5

http://www.gfd-dennou.org/library/gtool/gtool5.htm

- Input/Output library written in Fortran90
- Design for easy input/output of data with self-descriptive format NetCDF
  - Metadata can be put on the data with a few steps
  - Common use in multiple models
    - This may enable us to use multiple models easily.
  - NetCDF:
    - http://www.unidata.ucar.edu/software/netcdf/

ispack/spml

- ispack: http://www.gfd-dennou.org/library/ispack/
  - Spectral transformation library written in Fortran77
    - FFT in ispack is the fastest over the world on Intel processors
- spml: http://www.gfd-dennou.org/library/spmodel/
  - Fortran90 wrapper library of ispack
  - Design for “Program like mathematical expressions”
    - Systematic naming rules
    - Use of Fortran90 array-valued functions

spml naming rules and library functions

- Naming rules for variables
  - Dimensions are represented with identifiers
    - (dimension identifiers)_(variable name)
    - Examples:
      - x_Temp : x 1D temperature
      - xyz_Temp : xyz 3D temperature
      - e_Temp : wavenumber space 1D temperature
      - w_Press : spherical harmonics pressure
- Library functions
  - Examples of functions:
    - e_g(x_Data) : Conversion from grid to spectral data
    - g_e(e_Data) : Conversion from spectral to grid data
    - e_Dx_e(e_Data) : Differentiation of spectral data with x
  - Example of combination of functions:
    - x_Data2 = g_e(e_Dx_e(e_g(x_Data1)))

Example of program using spml 1

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

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

where the Euler scheme is applied to time derivative and

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

Example of program using spml 2

By the use of spml, the discretized equation shown in a previous slide 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
```

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

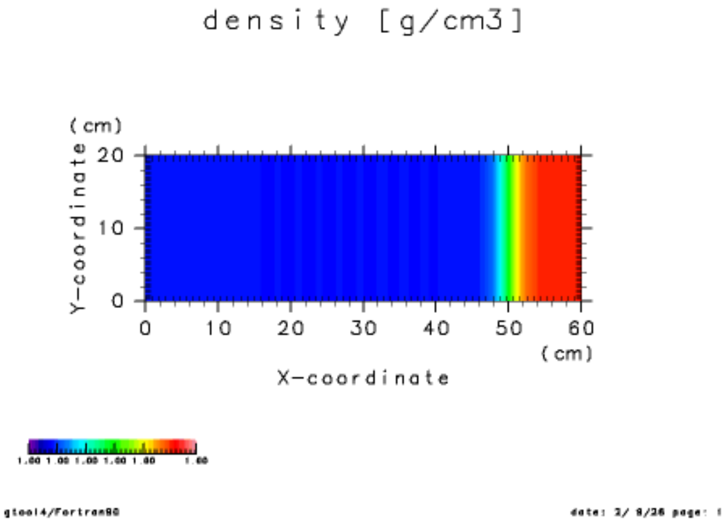
spmodel (sample programs)

- http://www.gfd-dennou.org/library/spmodel/

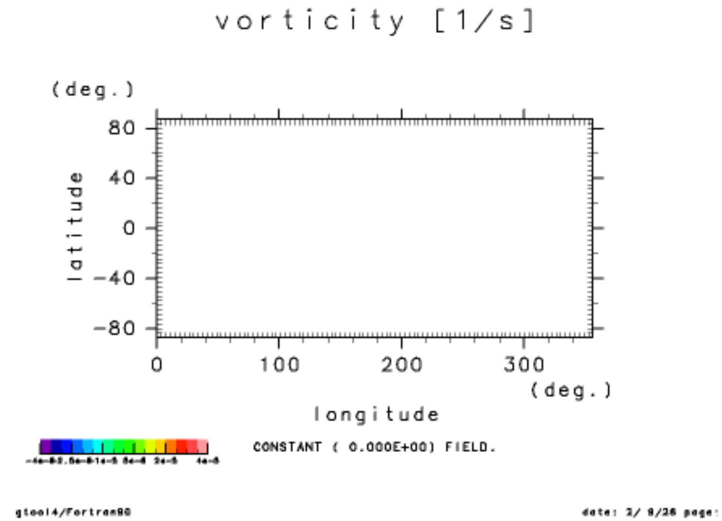
- Sample programs using spml for various Geophysical Fluid Dynamics problems
  - Advection eq., Shallow water eq., Boussinesq eq., and so on.
- Purpose
  - Understanding Geophysical Fluid Dynamics
    - Understanding basic properties of geophysical fluid, such atmosphere, planetary internal fluid, and so on.
    - Easy connection of our understanding on GFD from mathematical expressions to numerical experiments

Examples of spmodel experiments
(http://www.gfd-dennou.org/library/spmodel/gallery/index.htm.en)

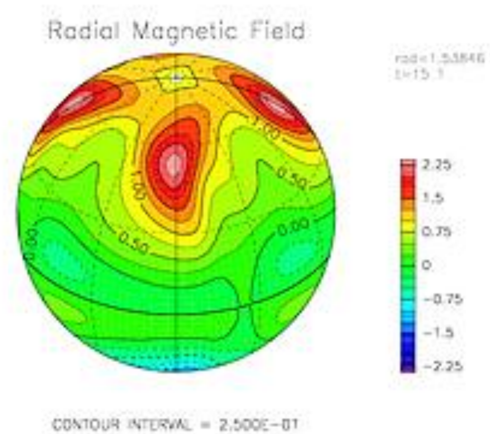
Density current



Rossby wave on a sphere



Convection in a spherical shell (MHD Bousinessq eq.)



Another example for atmosphere of giant planets will be shown by Takehiro-san on Thursday.

deepconv

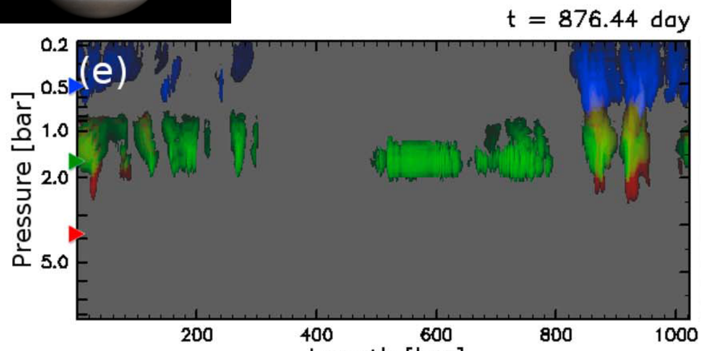
- http://www.gfd-dennou.org/library/deepconv/

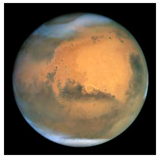
- Cloud resolving model for planetary atmospheres
  - 2D / 3D quasi-compressible eq.
- Purpose
  - Understanding of cloud convection in a various planetary atmospheres

- Brief description
  - Dynamics
    - Quasi-compressible eq.
      - Some terms except advection are linearized.
  - Turbulent mixing
    - 1.5 order closure (Klemp and Wilhelmson, 1978)
    - Surface flux based on bulk method
  - Cloud micro-physics
    - “warm rain” parameterization (Kessler, 1969 ; Nakajima, 1998)
  - Simple thermal forcing

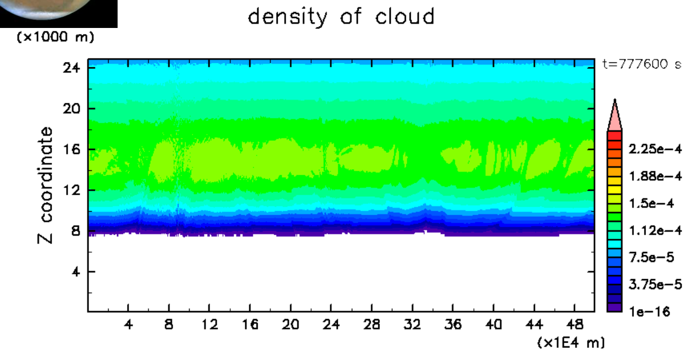
Examples of deepconv experiments

Jupiter

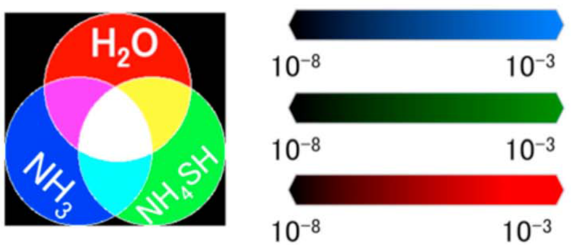




Ancient Mars

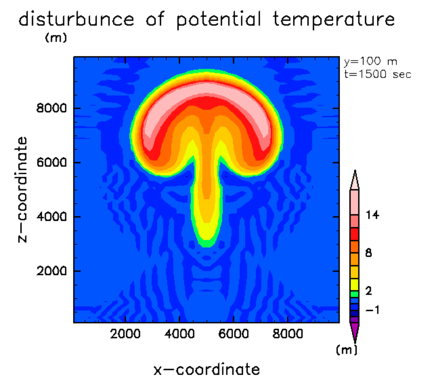


Cloud density



Cloud mixing ratio

Idealized thermal experiment

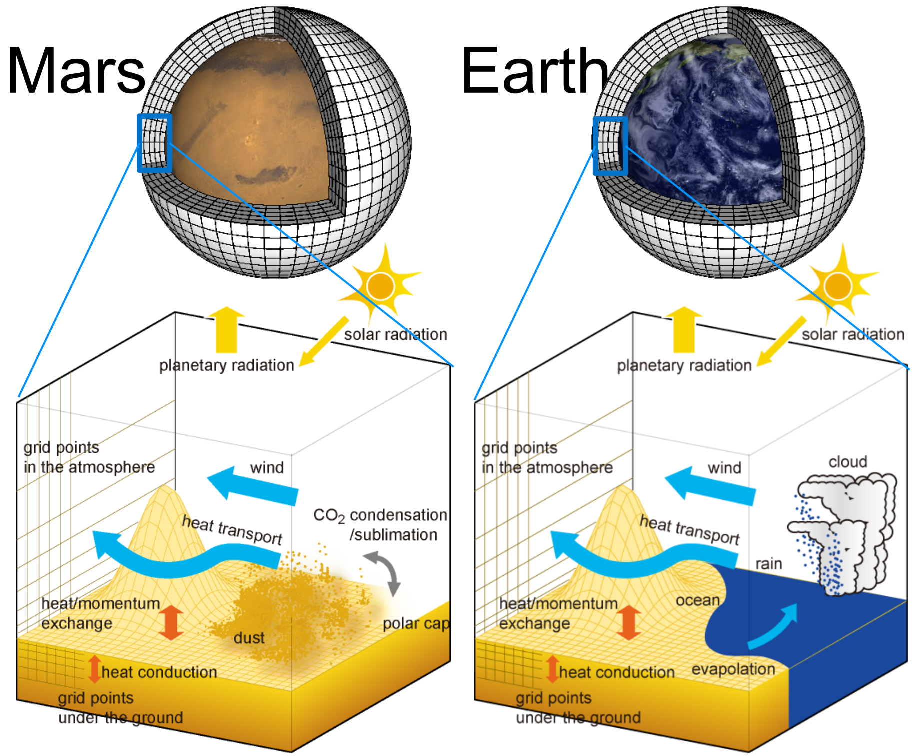


Potential temperature

Results of Jupiter and ancient Mars experiments will be shown by Sugiyama-san and Odaka-san, respectively.

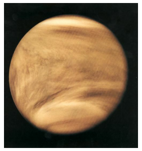
DCPAM

- http://www.gfd-dennou.org/library/dcpam/
- General Circulation model for planetary atmospheres



- Brief description
  - Dynamics
    - Primitive eq.
      - Vertical hydrostatic equilibrium
  - Radiation
    - Earth model
    - Mars model
    - grey atmosphere model
    - New model is being developed by Onishi-san.
  - Turbulent mixing
  - Cumulus convection
  - Soil model, Bucket model

Examples of DCPAM experiments 1: Venus, Earth, Mars

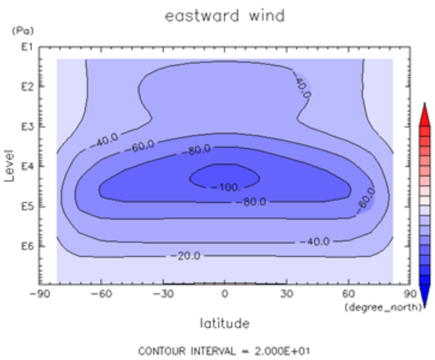


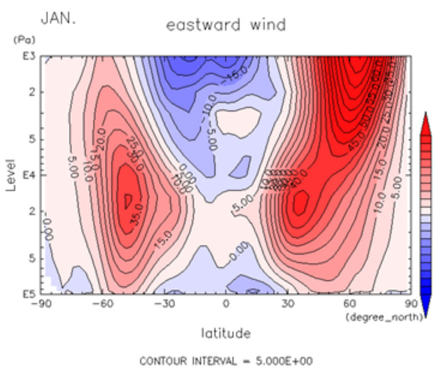
Venus

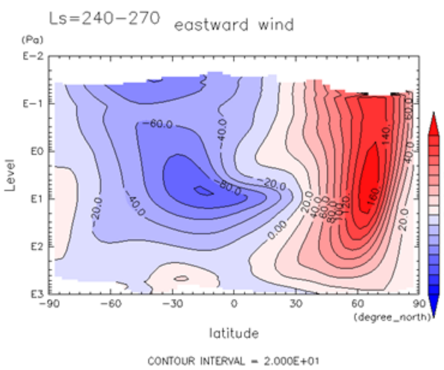
Earth

Mars

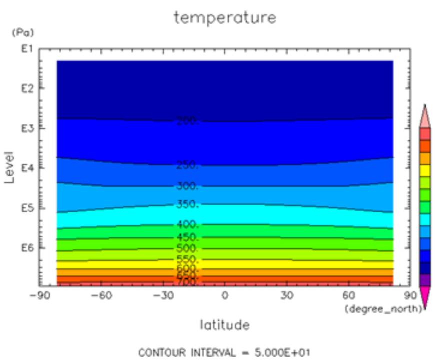
Zonal wind

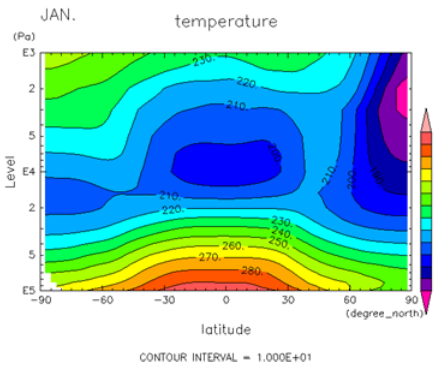


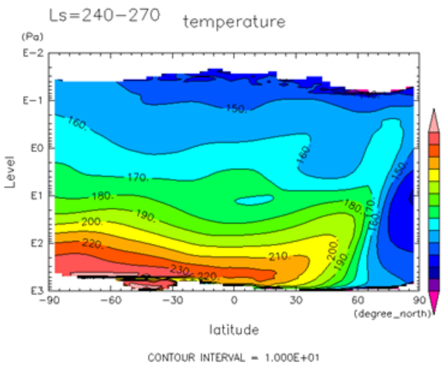




Temperature







T10L50
(Newtonian cooling)

T42L26

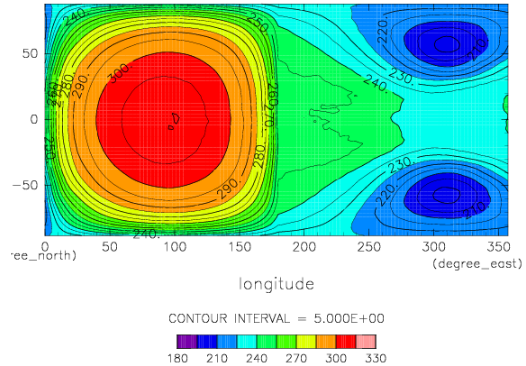
T31L36

Color code and vertical axes are different in three figures.

Examples of DCPAM experiments 2: Idealized calculation/Virtual planets

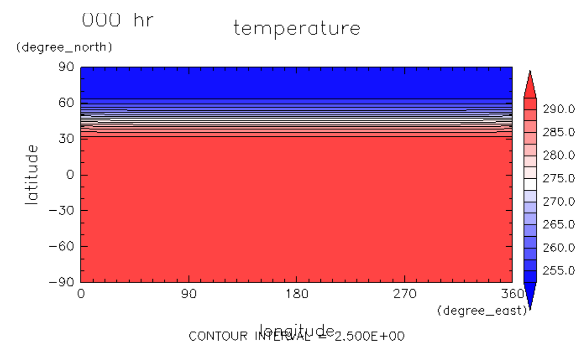
- Virtual planets
  - Aqua-planet
  - Tidally-locked planet
    - Results will be give by Hayashi-sensei.
- Idealized calculation
  - inviscid calculation
    - baroclinic wave calculation (Polvani et al., 2004)
  - dynamical core test (Held and Suarez, 1994)

Tidally-locked planet



Tiime mean Surface temperature, T42L22 （Ishiwatari et al.）

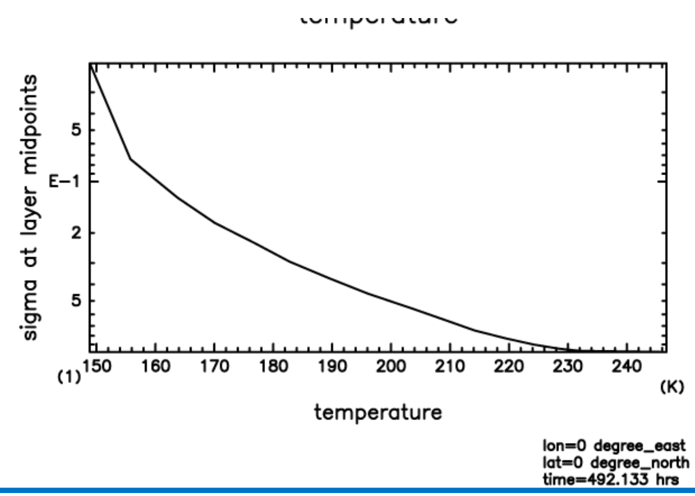
Baroclinic wave



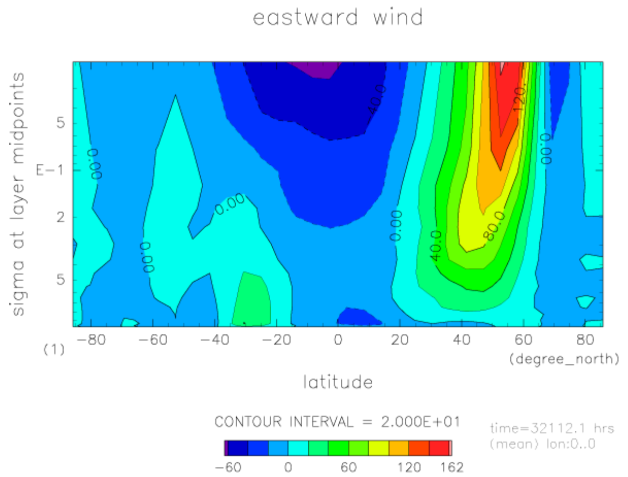
Temperature at lowest level, T341L20

Examples of DCPAM experiments 3: 1, 2, 3D calculation of Mars atmosphere

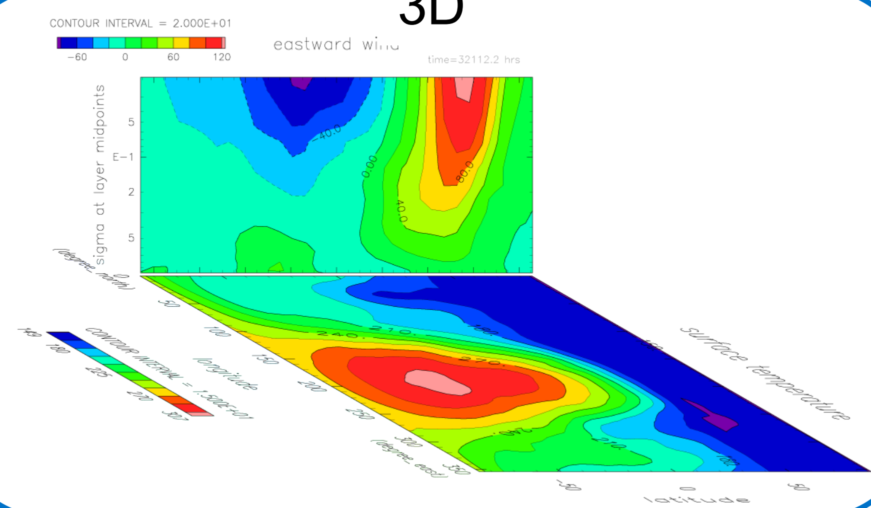
vertical 1D



axisymmetric 2D



3D

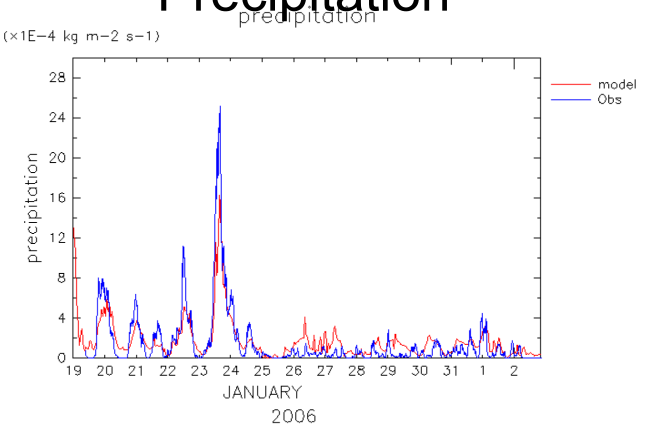


Color codes are different in three figures.

Examples of DCPAM experiments 4: 1D experiment of tropical convection

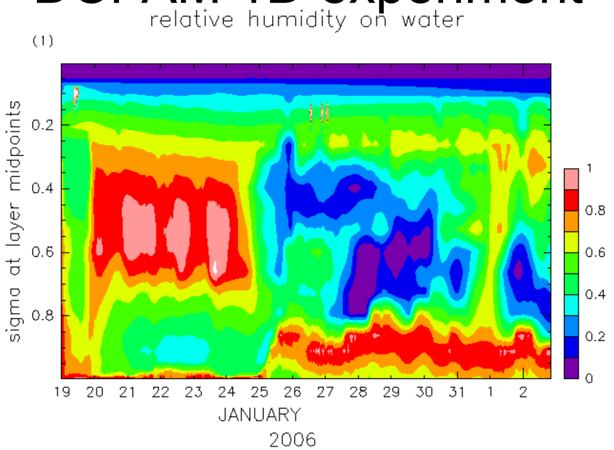
- Intercomparison of Earth's tropical observation campaign 1D experiment
  - TWP-ICE SCM intercomparison (Davies et al., 2013)

Precipitation

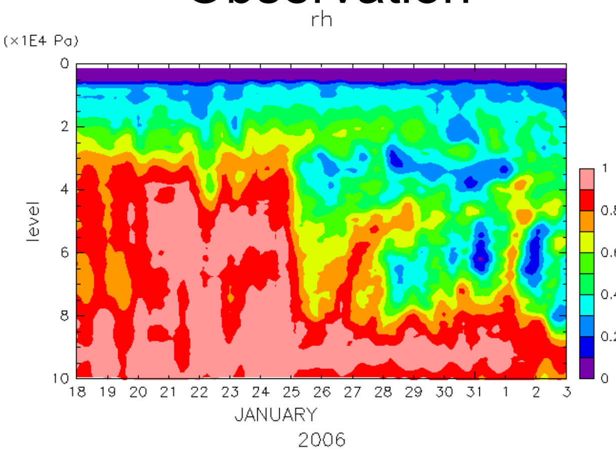


Relative humidity

DCPAM 1D experiment



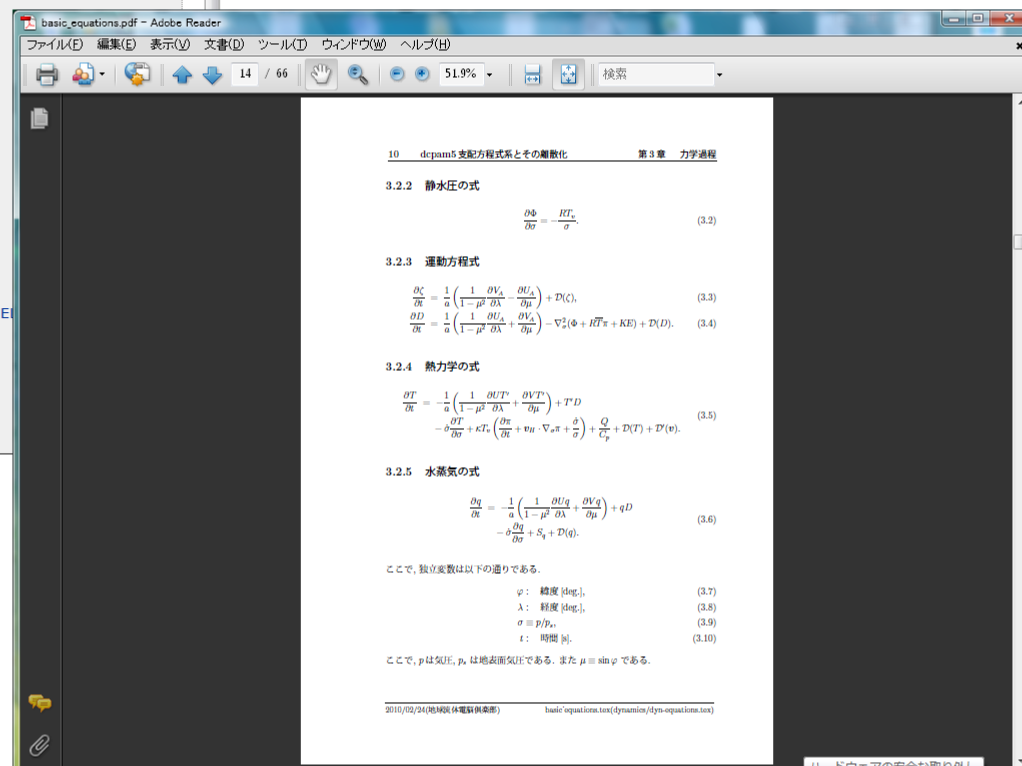
Observation



dcmodel documentation

Reference manual
(rdoc-f95)

Explanation of governing eq.
(TeX)



Summary

- We are working on the development of tools and models for research and education of a variety of geophysical fluids, including planetary atmospheres.
  - Anyone can use the model/programs.
  - Hierarchical models
  - Documentation (hopefully)
- Line-up
  - gtool5
  - ispack / spml (wrapper program of ispack)
  - spmodel sample programs
  - deepconv (cloud resolving model)
  - DCPAM (general circulation model)
  - rdoc-f95 (documentation utility)