GFD-Dennou Club DCMODEL project

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Introduction

- The simulation models have become so complicated...
  - Simple calculation of fluid motion + many kinds of physical processes (e.g. radiation, turbulence, clouds, precipitation, phase changes...)
- Not easy to understand the program
  - Difficult to check the validity of the simulation model
    - Comparison with elementary process models
    - Reduction of the system in order to build up a conceptual model

⇒ "model-gap" problem (Held 2005)

Introduction

- In order to fill the "gap",
  - Necessary to compare these results by use of an arbitrary set of models in a hierarchical fashion with various levels of complexity
  - Software environment that enables to perform multiple simultaneous numerical experiments

DCMODEL project

a series of hierarchical numerical models with various complexity is developed and maintained
`http://www.gfd-dennou.org/library/dcmodel/`

Features of the models of DCMODEL

- Model series with various complexities
  - From simple models (elementary process models, conceptual models) to complicated simulation models
  - To understand various phenomena and check validity of the models
- A common “style” of program codes
  $\Rightarrow$ increase of readability of the software
  - Common programing style, naming rules, input/output routines, data format
  - Build up various models and perform experiments efficiently
    - Learning one of the models $\Rightarrow$ quick understanding of the other models
  - Readability is important also for model users
    - To understand how the source codes of the models realize the original physical systems

Features of the models of DCMODEL

- Open source codes of the models to the public
  - Anyone can use and modify the models/programs
  - Important to perform follow-up experiments
- Scalability of the models
  - Execution on various scales of computational resources
  - Students can use the same models for forefront studies after graduating schools
- Documentation and presenting a method for writing reference manuals
  - Tutorials, references, instruction manuals in a common style
  - Important not only for using models but also for development and maintenance

Main components of dcmodel

Input/Output library

- gtool5

Libraries for spectral transformations

- ISPACK/spml

Various models

- spmodel
- deepconv
- dcpam

Tool for documentation

- rdoc-f95

gtool5

- Fortran90 library providing data input/output interfaces and various utilities
- Data format : NetCDF
  - Conventions suitable for numerical research in fluid dynamics in the Earth and planetary sciences (gtoo4 netCDF conventions)
- Procedures can be easily implemented in a same way independent of the scales of the programs
  - Data input/output
  - Addition of meta-data for post-processing

$\Rightarrow$ readability of the program codes improved

  - Simultaneous numerical experiments and post-analyses with multiple programs can be performed easily
  - Comparison and examination of the calculation results efficiently

ISPACK/spml

Libraries for spectral transformations

- ISPACK : Fortran77 library
  - (Possibly) the fastest FFT subroutines in the world
- SPML : Fortran90 wrapper library of ISPACK
  - Array-handling functions with systematic naming rules
    $\Leftarrow$ one of the features of Fortran90
  - Similar to the contraction convention of the tensor calculus

```
g_e(e_Data)     !conversion from spectral to grid data
e_g(g_Data)     !conversion from grid to spectral data
e_Dx_e(e_Data) !differentiation on the x coordinate
g_Data2 = g_e(e_Dx_e(e_g(g_Data1)))
```

  - Source codes can be written with a form easily deduced from the math. expressions of the governing eqs.

Example of spml modules

module name	geometry	function series for transformation
ae module	1-dim. cyclic domain	FFT
at module	1-dim. finite domain	Chebyshev
l module	1-dim. finite domain	Legendre
aq module	1-dim. finite domain	Matsushima Marcus polynomials
ee module	2-dim. double cyclic domain	FFT
esc module	2-dim. channel domain	FFT + sin, cos
et module	2-dim. channel domain	FFT + Chebyshev
eq module	2-dim. disk domain	FFT + Matsushima Marcus polynomials
w module	2-dim. spherical domain	Spherical harmonics
wa module	2-dim. spherical domain (multiple layers)	Spherical harmonics
wt module	3-dim. spherical shell domain	Spherical harmonics + Chebyshev
wq module	3-dim. sphere domain	Spherical harmonics + Matsushima Marcus polynomials
wtq module	3-dim. sphere and spherical shell domain	Spherical harmonics + Chebyshev + Matsushima Marcus polynomials

Table: Modules of spml and geometries

SPMODEL

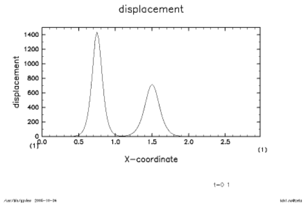
- Collection of sample programs using “spml”
  - Providing the base-kit for simple numerical experiments of GFD
  - Programing style for spml $\Leftarrow$ program source codes can be written with a form easily deduced from the math. expressions of the governing eqs.
- E.g. : 1-dim. KdV equation

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

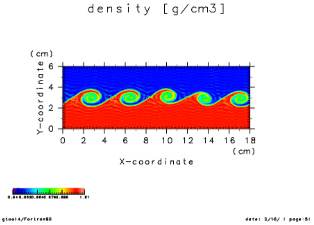
SPMODEL programing code becomes

```
e_DZetaDt = -e_g(g_e(e_Zeta)*g_e(e_Dx_e(e_Zeta)))
            -e_Dx_e(e_Dx_e(e_Dx_e(e_Zeta)))
```

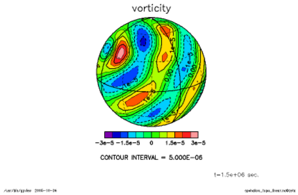
Sample output of SPMODEL



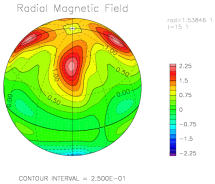
Soliton solution of KdV equation



Kelvin-Helmholtz instability



Propagation of Rossby waves on a rotating sphere



MHD dynamo in a rotating spherical shell

Deepconv

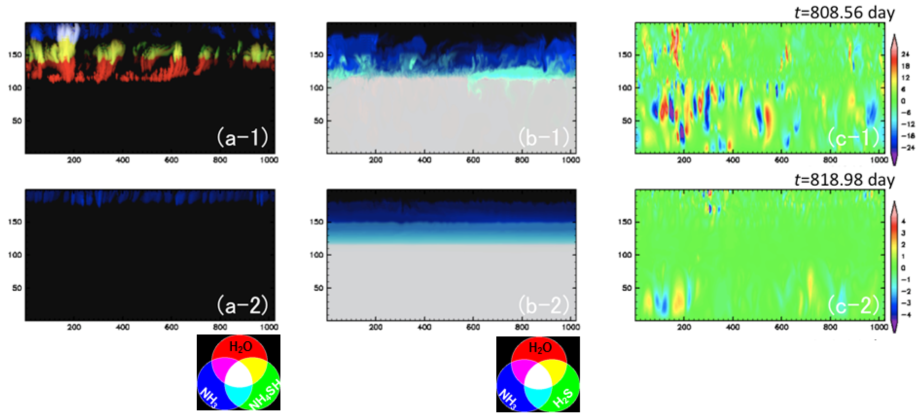
- Non-hydrostatic cloud resolving model for planetary atmospheres
  - Chemical reaction and phase changes of multiple constituents of the atmospheres are implemented $\Rightarrow$ simulate various clouds of planetary atmospheres
  - 2-dim. and 3-dim. calculations are easily switched

Dynamics	Quasi-compressible system (Klemp and Wilhelmson, 1978) Horizontal grids : regular intervals Vertical grids : irregular intervals
Turbulence	1.5-order closure (Klemp and Wilhelmson, 1978)
Precipitation	Multiple condensation constituents Condensation of the major component Parameterization of Kessler (Kessler 1969) Diffusive growth of cloud droplets
Radiation	Homogeneous cooling/heating Radiation model for the earth's atmosphere
Surface fluxes	Bulk method and/or simple diffusion

Table: Major specifications of cloud resolving model "deepconv"

Sample output of deepconv

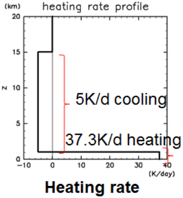
- Cloud convection of Jovian atmosphere
  - Upper panel: active period. Lower panels: quiet period

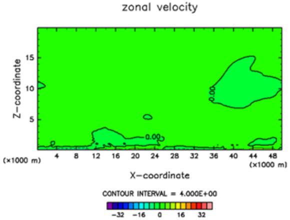


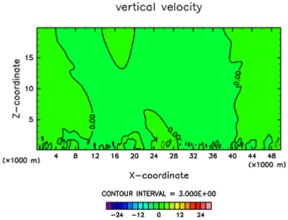
Mixing ratio of the clouds Mixing ratio of the vapors Vertical velocity

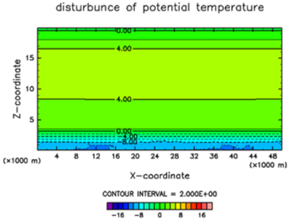
Sample output of deepconv

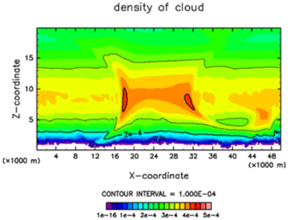
- Cloud convection of Martian atmosphere in the polar region











dcpam

- General circulation model (GCM) of the planetary atmospheres
  - Earth, Mars, and (simplified) Venus can be treated.

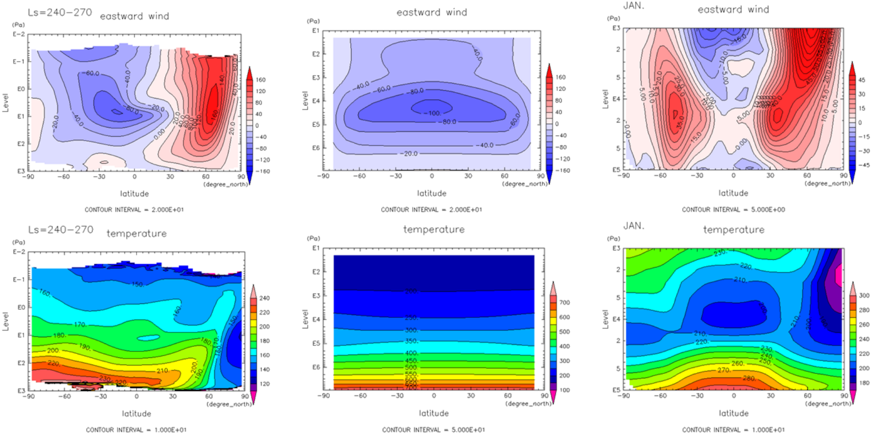
Dynamics	Primitive equation system Horizontal : spectral method (ispack/spml) Vertical : finite difference method (Arakawa Suarez 1983)
Radiation	Earth : CO2, H2O, O3, water cloud (Chou et al, 1996) Mars : CO2, dust Grey atmosphere
Turbulence	Turbulent mixing : Mellor and Yamada lelel 2 (Mellor and Yamada 1974, 1982) Surface flux scheme by Louis (Louis et al. 1982)
Condensation	Relaxed Arakawa-Schubert (Moorthi and Suarez, 1992) Large scale condensation : Manabe et al. (1965) CO2 condensation
Surface	Bucket model (Manabe, 1969) Thermal conduction model in the ground
Clouds	Simple prediction of cloud water density Disregard of cloud ice Elimination with constant lifetime, Considering turbulent mixing, Disregard of sub-grid scale partial clouds

Table: Major specification of dcpam

Sample output of dcpam

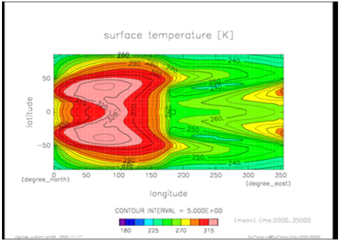
- General circulations of the terrestrial planets
  - Upper panels:longitudinal wind. Lower panels: temperature

Mars | Venus | Earth

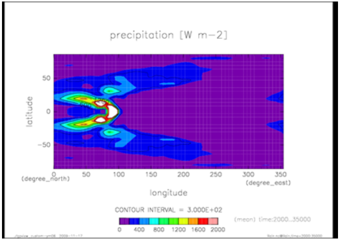


Sample output of dcpam

- Sample calculation of general circulation of synchronously rotating planet



Surface temperature



Precipitation

rdoc-f95

- Automatic generator of reference manuals of Fortran90/95 programs
  - Dependency of modules, functions, and subroutines in the multiple program are analyzed
  - list up the namelist variables

The reference manual of dcpam generated by rdoc-f95

Summary

- DCMODEL project
  - A series of hierarchical numerical models with various complexity is developed and maintained
- Simultaneous numerical experiments of simple programs with common “style” and high-end complicated models

  $\Leftarrow$ Deeper understanding of various phenomena in planetary atmospheres and interiors
- Trial for conquest of difficulties with “expanded” source codes
  - Can we overcome the difficulties with hierarchical models?

DCMODEL project home page:

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