Climate research in AICS

Computational Climate Science Research Team / AICS
TL : Hirofumi TOMITA

Who am I?

- The University of Tokyo,
  Department of Aeronautics and Astronautics
  - 1999: Dr. Eng.
  - Doctoral thesis :The pattern fomrmation in the Benard Marangoni convection
    - Relation of energy flow and convection pattern
- 1999: Frontier Research System for Global Change project
  post-doctoral researcher
- 2004: Japan Agency of Marine Science and Technology
  Research Scientist
- 2007~2010: JAMSTEC/ Senior Scientist
- 2011～ AICS/ RIKEN, Team Leader

Development of high resolution atmospheric model

Outline

- Introduction:
  - Importance of clouds in the climate
    - Cloud-aerosol interaction
  - Recent advance in global climate modeling
    - Methodology change from conventional model to GCRM
  - What are big subjects in climate modeling?
    - Need of more sophisticated modeling
- Purpose and plan of our team
  - What is needed for accurate estimation of cloud role on the climate?
  - How should we do on K-computer and next post-peta flops computer environment?
- Summary

Introduction

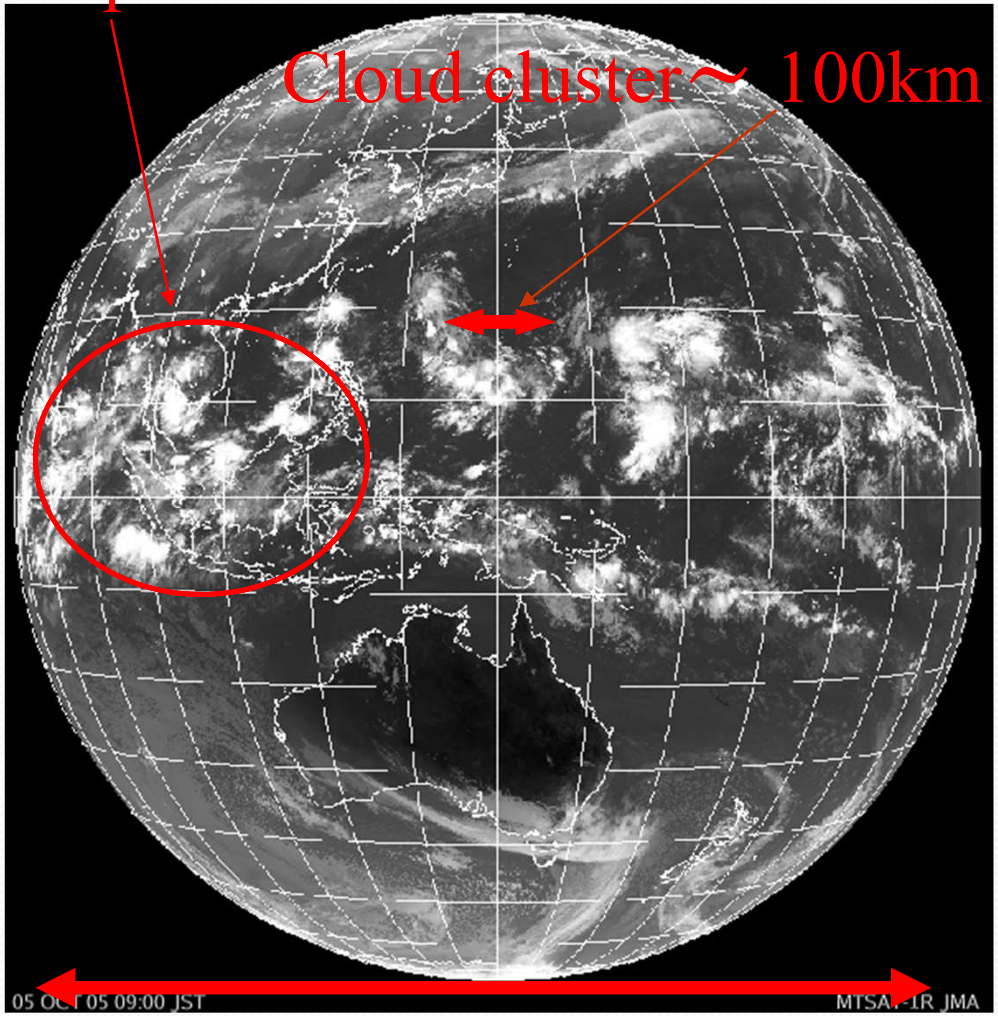
Cloud! Cloud! Cloud!

Various cloud types exist in our earth!

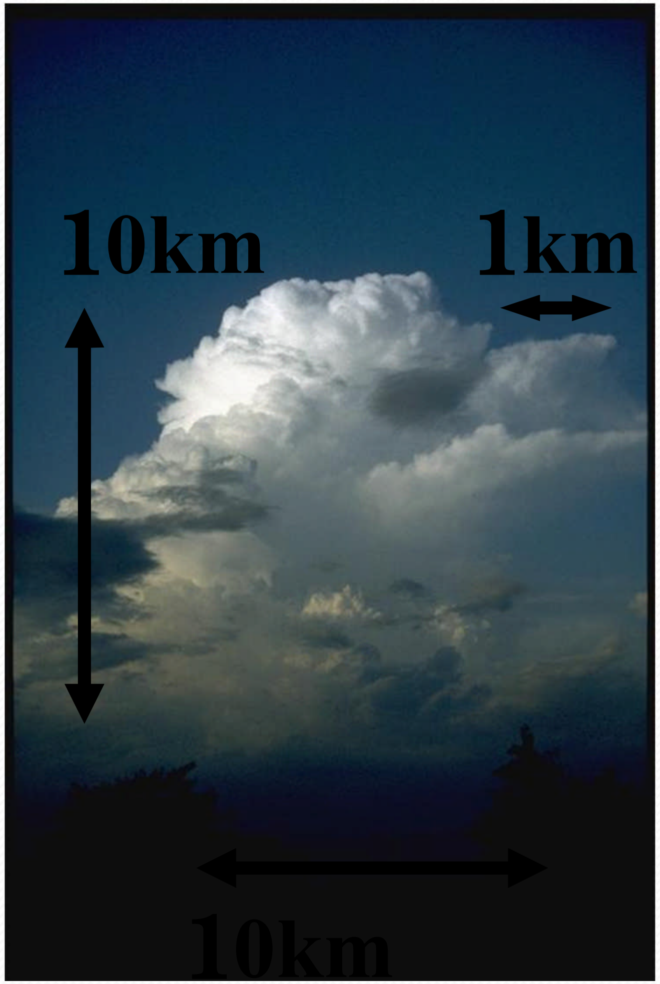
Very difficult to model the cloud!

Overview of cloud disturbance over the globe
---- organization of hierarchical structure of clouds

Super cloud cluster～ 1000km → MJO



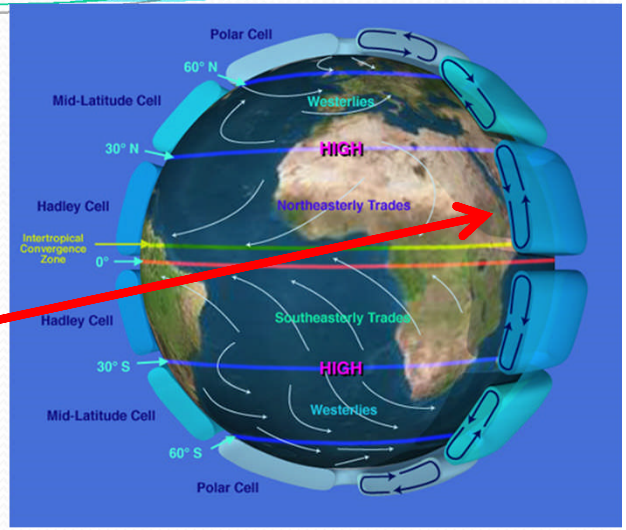
Cloud element: cumulus



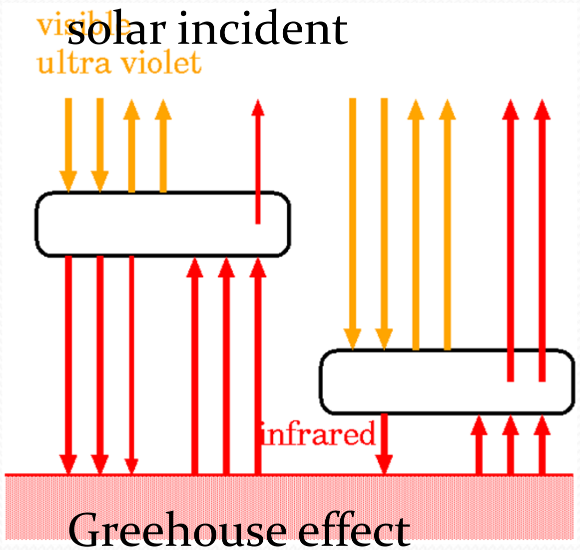
Earth diameter :12740km

Why are clouds important in climate/weather?

- Importance as the engine for general circulation :
  - Cumulus has an important role for atmospheric heat transfer over the globe.
    - Heat transport in the latitudinal direction.
    - Hierarchical structure generates many phenomena.
      - Cloud cluster , super cloud cluster, tropical cyclone, MJO.
- Importance for energy budget in climate:
  - Cloud has two aspect on climate!
    - Parasol effect : reduce the incoming solar incidence.
    - Green house effect : cloud emits infrared radiation into the surface and space.
  - Cloud has a large impact on energy balance through the interaction with aerosol.
    - Indirect effect of aerosol : optical thickness of cloud and cloud life time.
    - Direct effect of aerosol is also important.

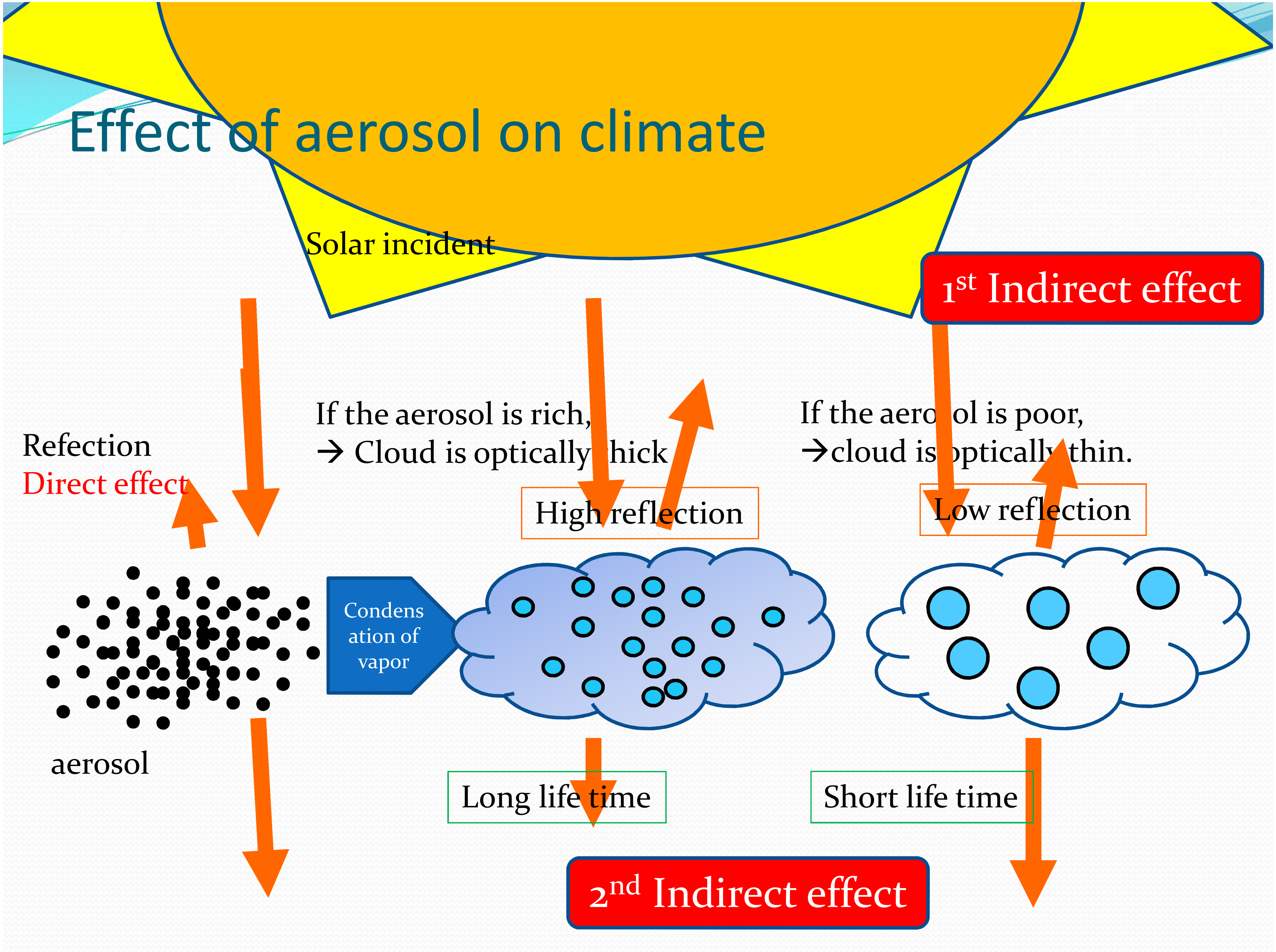


Parasol effect
Reflection of solar incident

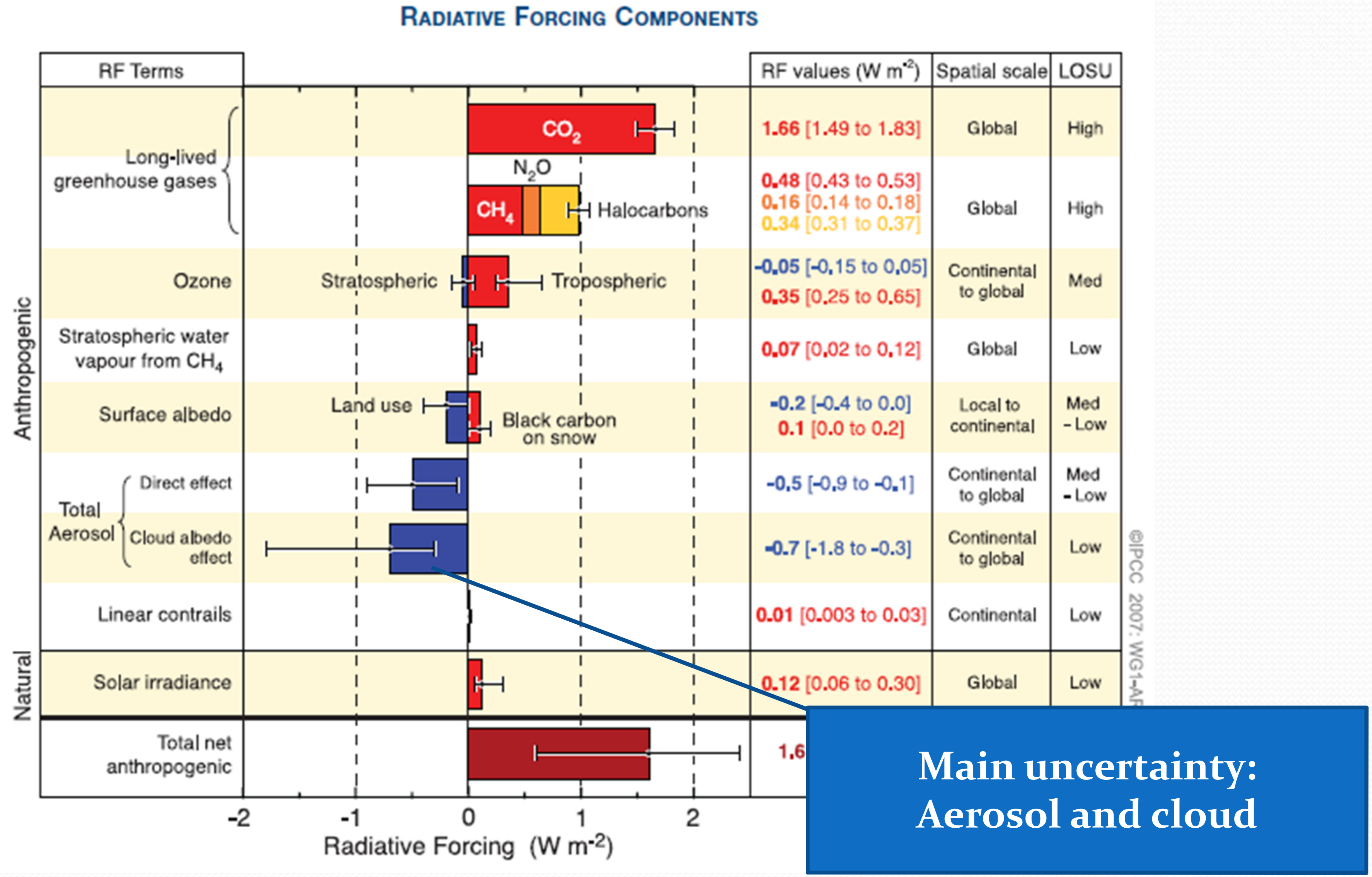


Greehouse effect
Emision of infrare

Effect of aerosol on climate



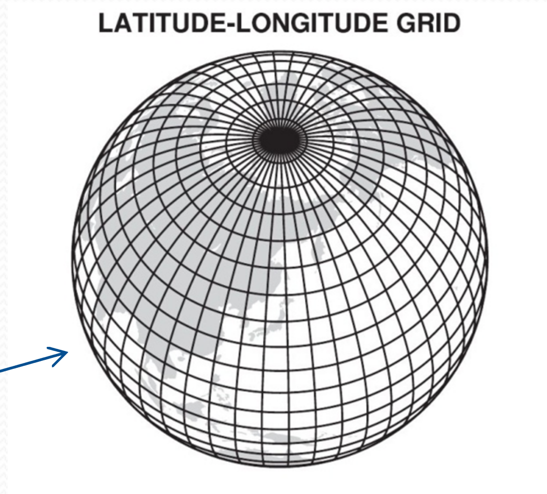
Radiative forcing of each of anthropogenic components between industrial era and present（from IPCC AR4）



Recent advance of global atmospheric model

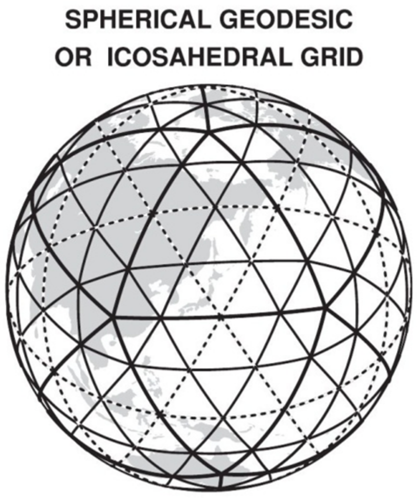
Conventional climate model

- Governing equation
  - Hydrostatic equation : balance between PGF and G.
- Discretization
  - Horizontal: Spectra transform method / lat-lon grid with semi-Lagrangian scheme
  - Vertical discretization
    - Finite Difference method
  - Temporal scheme
    - Semi-implicit scheme
      - fast mode(linear part) : implicit
- Typical resolution
  - IPCC : 100km
    → need to parameterize the subgrid cloud.



Global cloud-system resolving model

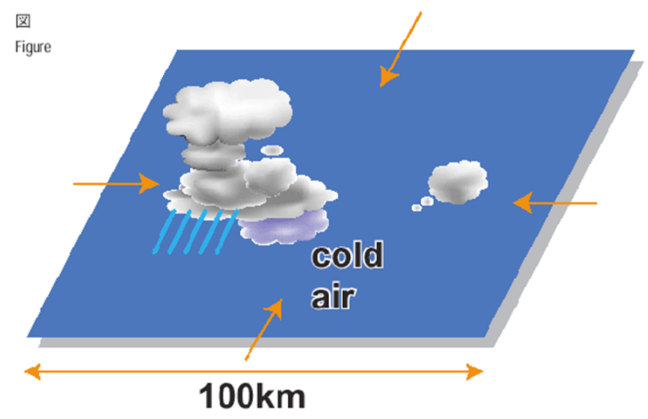
- Governing equation
  - Non-hydrostatic equation: explicit vertical motion for clouds
- Discretization
  - Horizontal: quasi-homogenious grid (e.g. icosahedral grid)
    - In order to avoid the pole problem and heavy calculation of spectral method
  - Vertical discretization
    - Finite Difference method
  - Temporal scheme
    - Semi-implicit scheme
      - fast mode(linear part) : implicit
    - Time splitting explicit scheme
      - Fast mode (accoustic and gravity wave) : short dt
        - 1D-helmholtz equation
      - Sloow mode : large dt

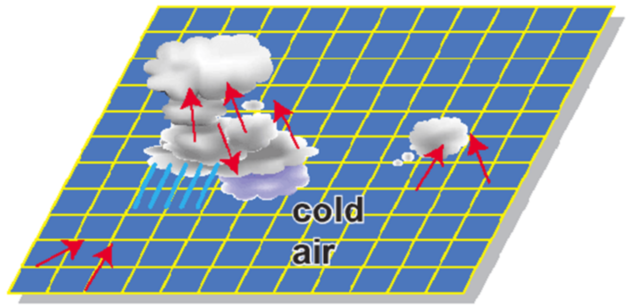


- Typical resolution
  - NICAM (Tomita and Satoh 2004, Satoh et al.2008) : 7km, 3.5km
    → need to parameterize the subgrid cloud.

Essential difference between conventional GCM & GCRM

- Cloud expression
  - Conventional GCM
    - Cumulus parameterization & Large scale condensation
  - GCRM
    - No cumulus parameterization/ instead, microphysics scheme only.
    - Each of clouds explicitly is resolved
- What is an advantage of GCRM?
  - Explicit expression of cloud dynamics
    - Each of clouds
      → cloud cluster
      → super cloud cluster
      → moist Kelvin wave
      → Madden Julian occilation
    - Explicit expression of cloud hierarchy

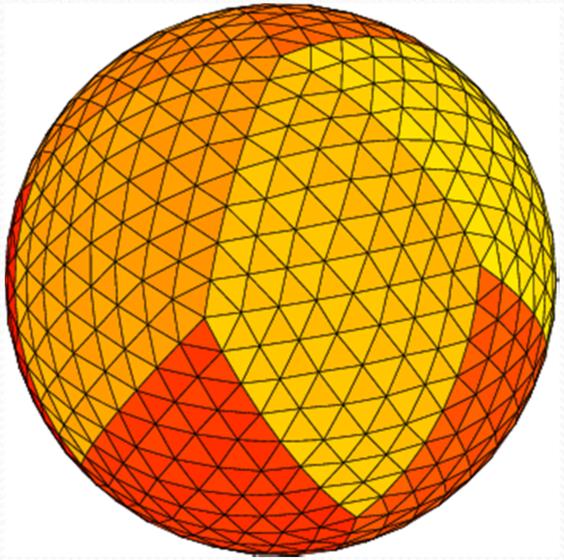




NICAM project

- NICAM project (~2000)
  - Dynamical core
    - Horizontal grid : icosahedral grid
      (grid modification : Tomita et al. 2001, 2002)
    - Dynamics : Non-hydrostatic scheme
      (energy conservation : Satoh 2002, 2003)

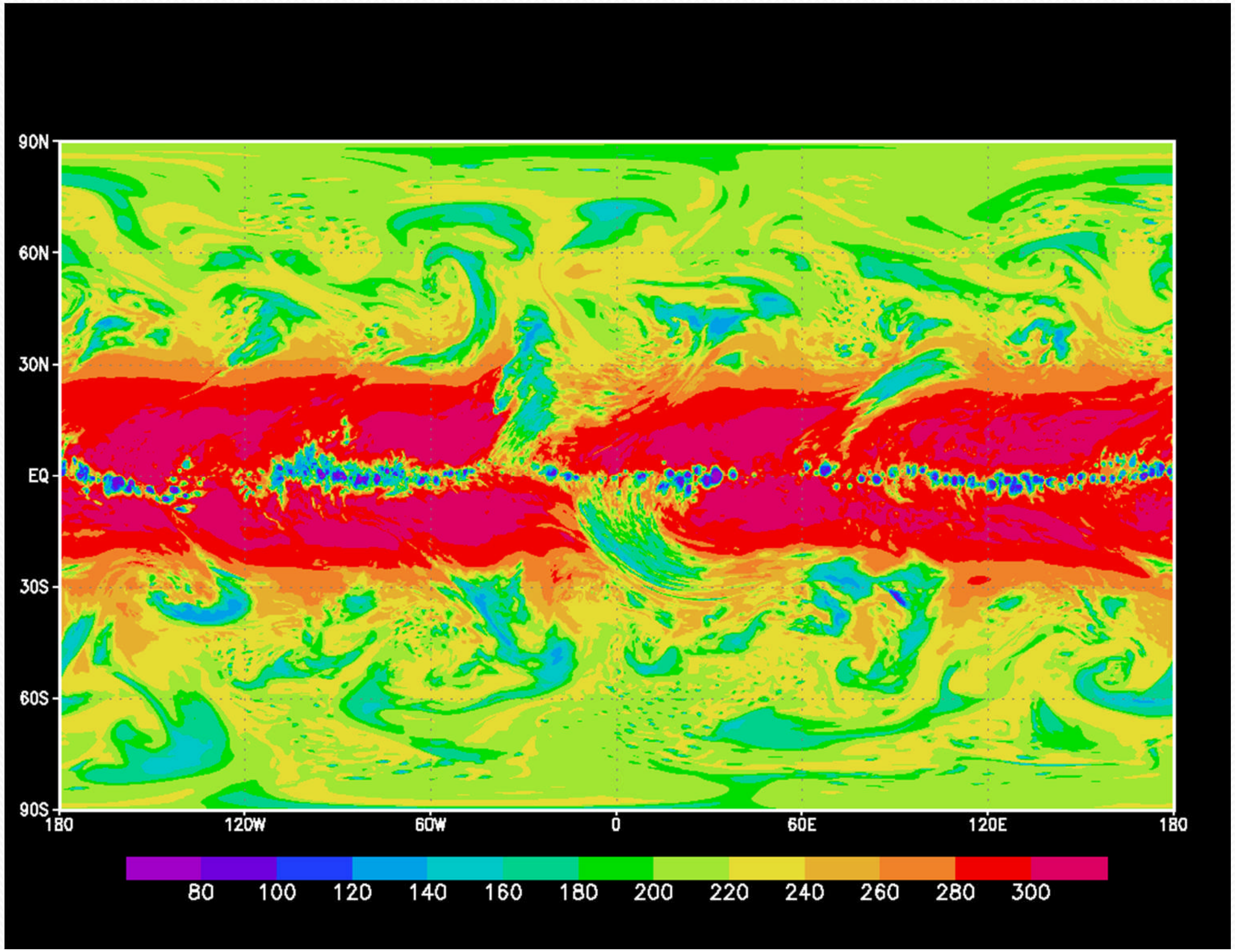
    → 3D DC(Tomita & Satoh 2004)
  - Cloud representation
    - Avoid "cumulus parameterization"
    - Microphysics only.



- Computational tuning
  - for the massively
    parallel vector computer system (ES, ES2)
  - Now, code tuning on K-computer

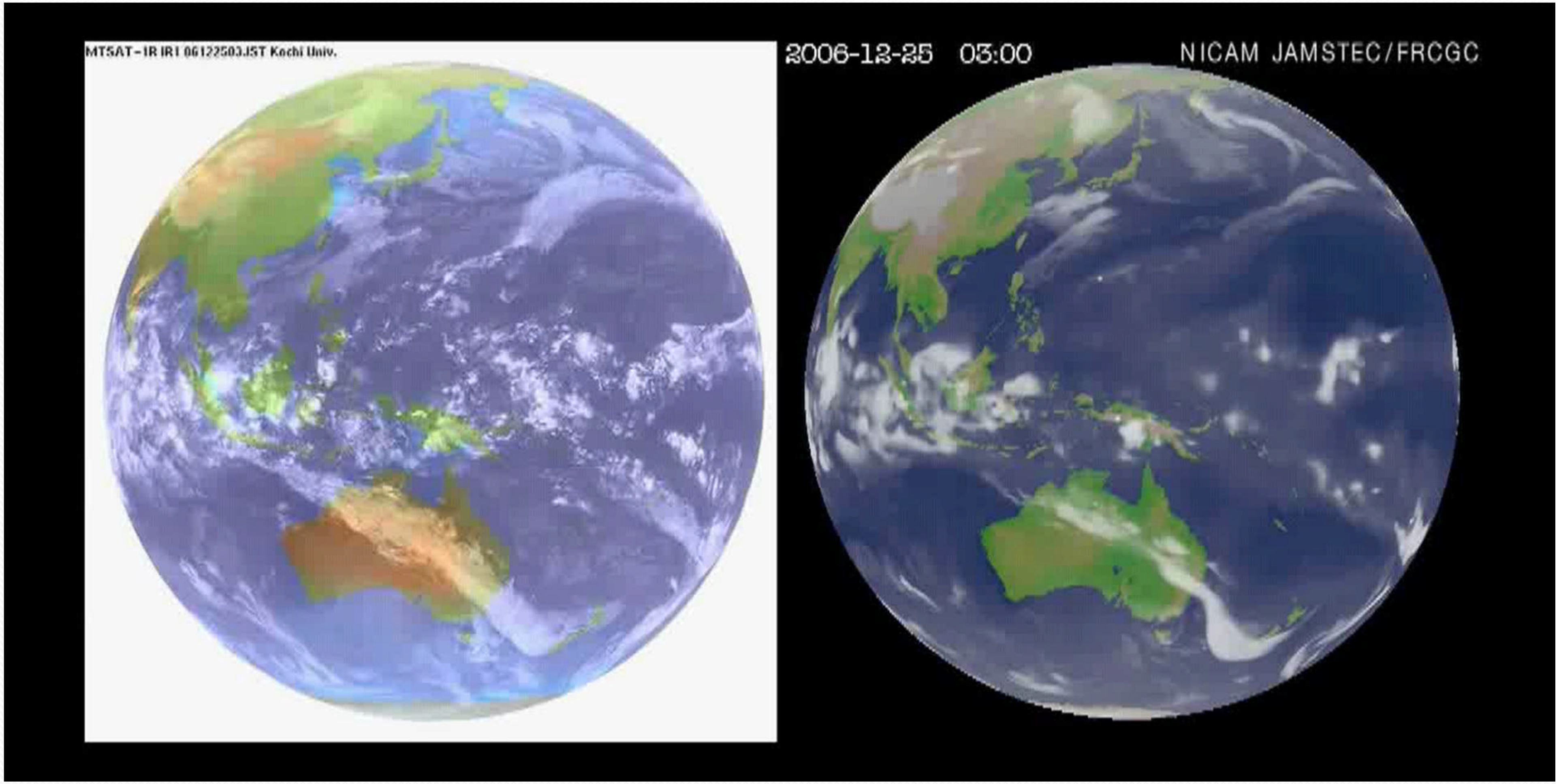
Recent GCRM simulation by NICAM(1)

- Aqua planet experiment (Tomita et al. 2005, GRL)
  - The first cloud-system resolving simulation over the world (landmark work)
  - Eastward propagation of SCC/Westward propagation of CC.



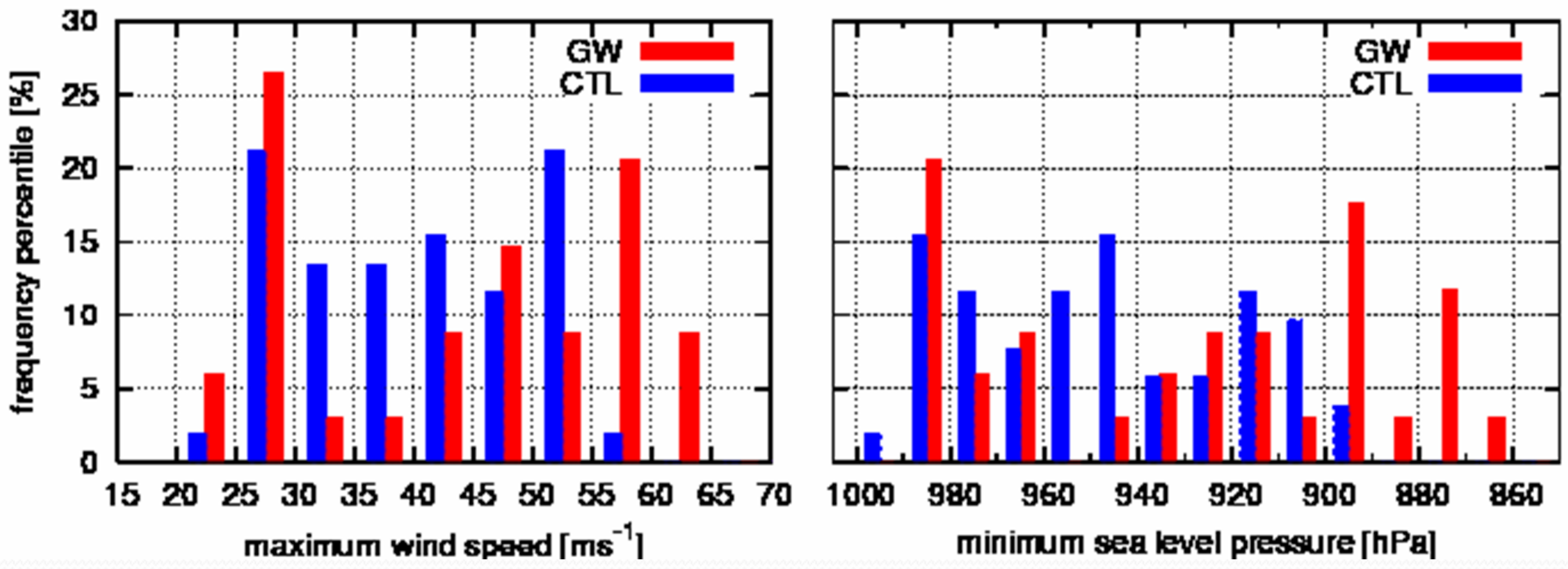
Recent GCRM simulation by NICAM(2)

- Madden Julian Oscillation (Miura et al. 2007, Science)
  - The successful MJO simulation by GCRM



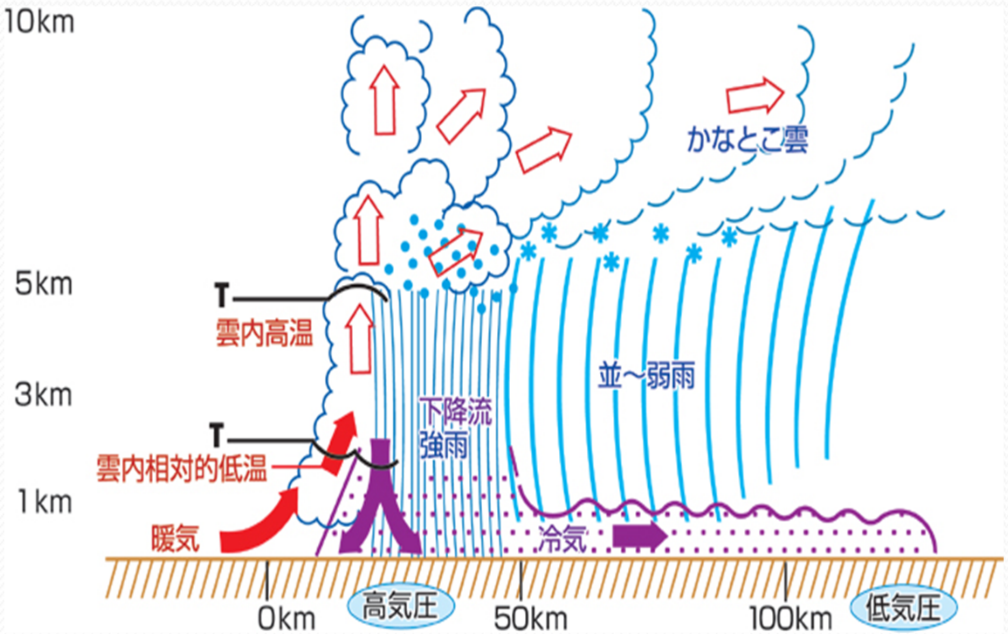
Recent GCRM simulation by NICAM(3)

- Tropical cyclone change in the GW era (Yamada et al. 2010, GRL)
  - 3months integration for GW environment and Present evironment
  - Intensity : increase/ frequency : decrease
  - Question : Is it true?
    - HPCI strategic program reveal it by more statistical approach.



Significance of GCRM, so far

- Explicit expression of cold pool dynamics
  - Story
    - Cloud generation
    - Rain by aggregation
    - Rain sedimentation
    - Evaporation
    - Cold pool
    - Generation of next cloud

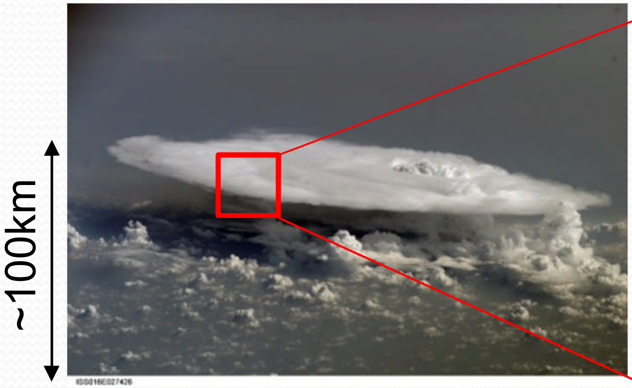


DRASTIC IMPROVEMENT OF CLOUD DYNAMICS

- However, current GCRM is not yet sufficient as a climate model.
  - Current model : very simple and idealized method
    - Roughly estimation of cloud droplet size
  - Radiation : tuned for energy budget suitable to energy balance.

Change from bulk method to spectral bin method!

Each of clouds



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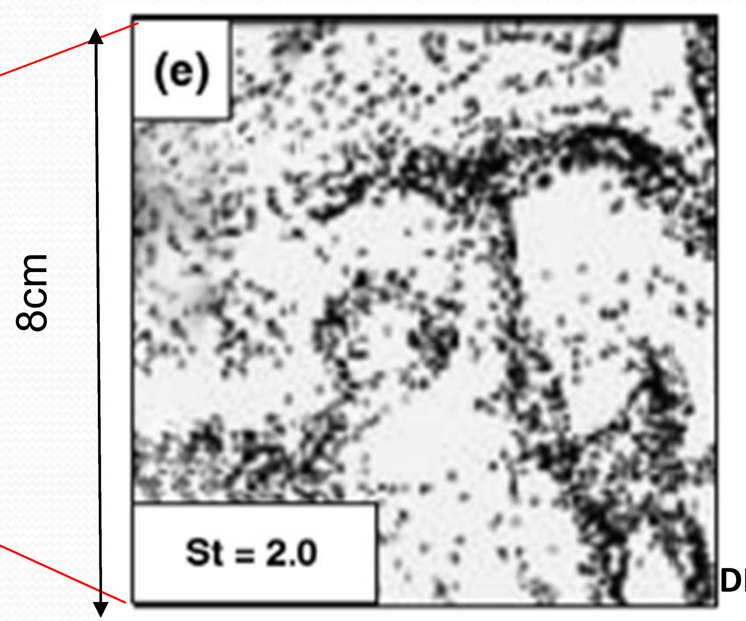
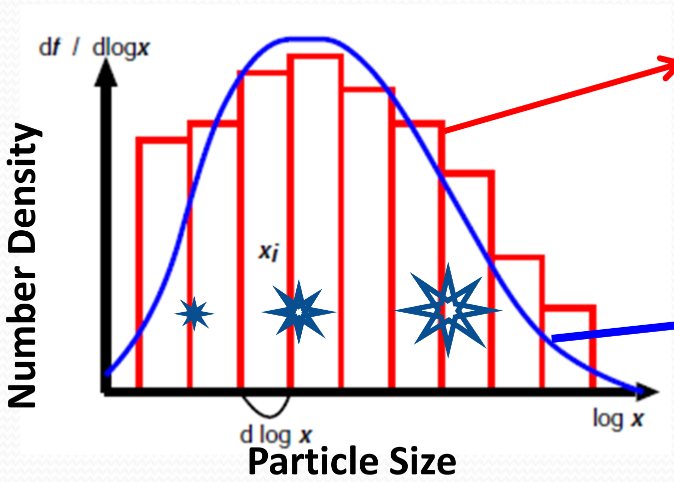
Particle Dynamics



DNS by Khain et al. (2007)



Spectrally discretized by Bin:
Able to treat precise size distribution

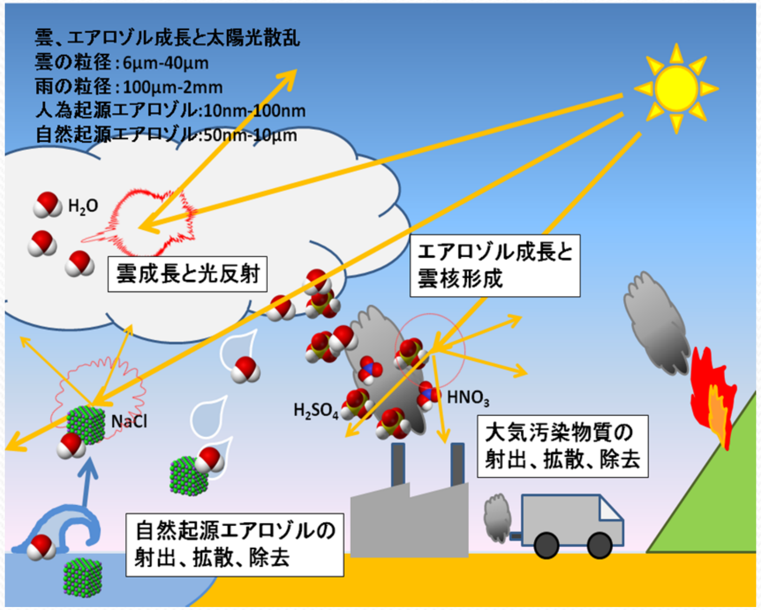
$$f(x) = A\,x^{\nu}\,\exp(-\lambda x^{\mu})$$
$$M^{(k)} = \int_0^{\infty} x^k f(x)\,\mathrm{d}x,$$

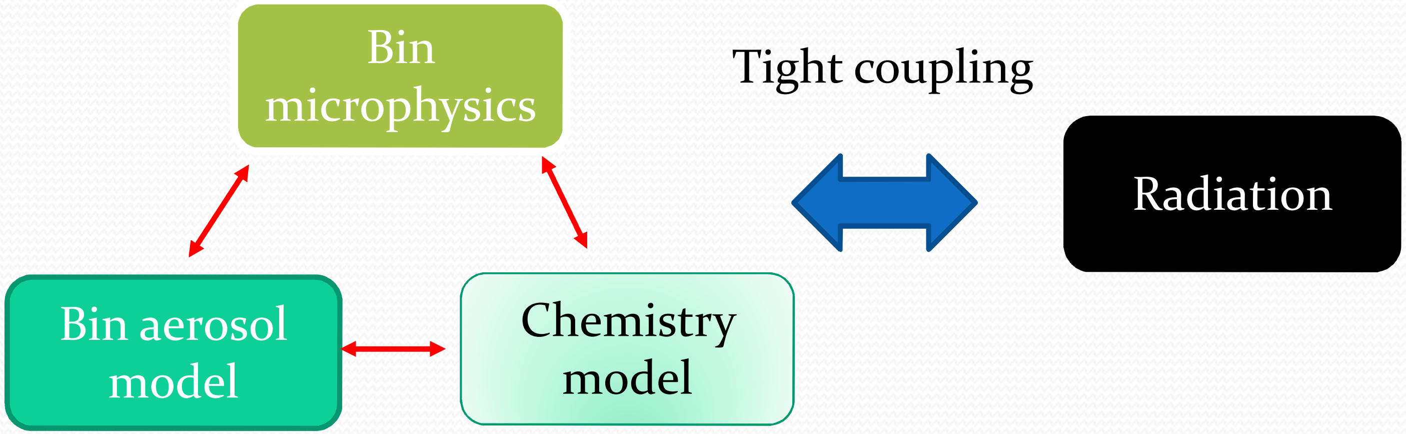
Bulk method : function type is prescribed

Same situation
in aerosol model

Tight coupling of aerosol and microphysics with radiation is needed!

- Need to change the bulk method to spectral bin method
  - Microphysics
  - Aerosol model
- Chemistry is also very important for interaction with aerosol.





Purpose and plan of our team

The mission of out team

- Main purpose :
  Reconstruction of infrastructure of climate modeling toward the peta-scale & post-peta scale
  - Basic research (Computational science aim)
    - Suggestion of future framework to climate modeling community through the research with computer science people.
      - Reconsideration of dynamical core
      - Fault torelance, I/O, scalability
  - Application research (Scientific aim)
    - Construct more sophisticated physics.
      - For accurate climate assessment.

Sophisticated modeling in physics part

- Upgrading the cloud model
  - Bulk model → Bin model
- Upgrading the aerosol model
  - Bulk model (SPRINTARS) → bin model
- Implementation of chemical transport model
  - Still, NICAM does not have a chemical model.
- Upgrading the radiation model
  - Plane parallel model (2D) → 3d radiation model

Upgrading the microphysics (step by step)

	Method	Application	Prognostic Variables	Cost	Expressible
Challenge	Spectral Bin	Single Column Model Idealized Experiment	Each Particle mass (~ 30 size sections)	30 x 30	Turbulence effect on particles Individual particle shape
Default	1Moment Bulk	Weather Forecasting Regional Research Global Climate Research	Mass	1	Mass flux
Latest	2Moment Bulk	Regional Research	Mass, Number	2 x 2	+Cross-section, Surface Area Effective Radius, Mean Volume
Next	3Moment Bulk	Regional Research	Mass, Number, Radar Reflectivity	3 x 3	+ Broadness of drop spectra

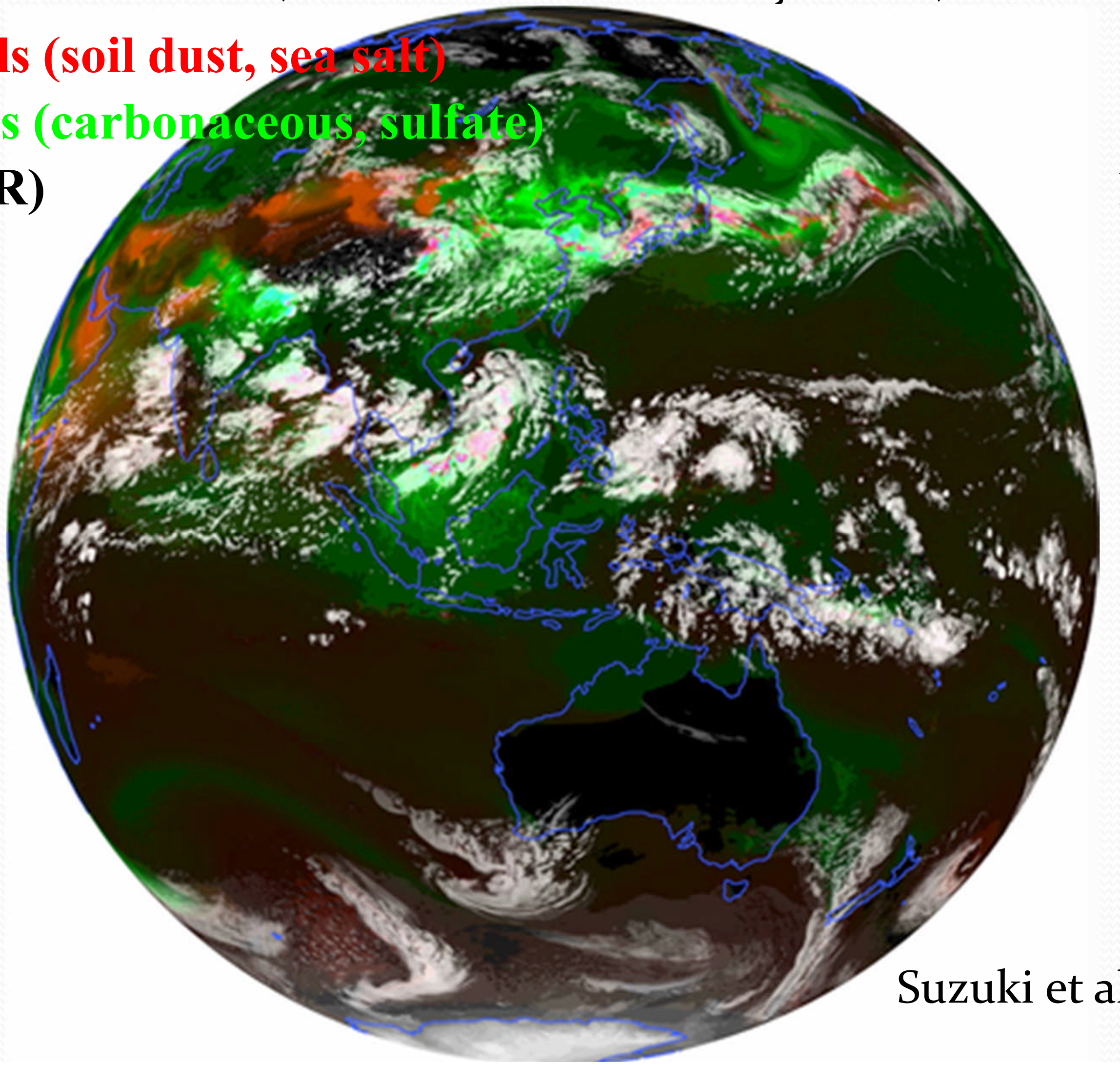
Upgrading the aerosol model

- Now, NICAM has a bulk aerosol model (old version of SPRINTARS, still bulk)
  - First attempt of cloupling of microphsycs and aerosol in convection-resolving model.
- Next phase : bin aerosol model (extension of SPRINTARS by Suzuki)

Red: coarse aerosols (soil dust, sea salt)

Green: fine aerosols (carbonaceous, sulfate)

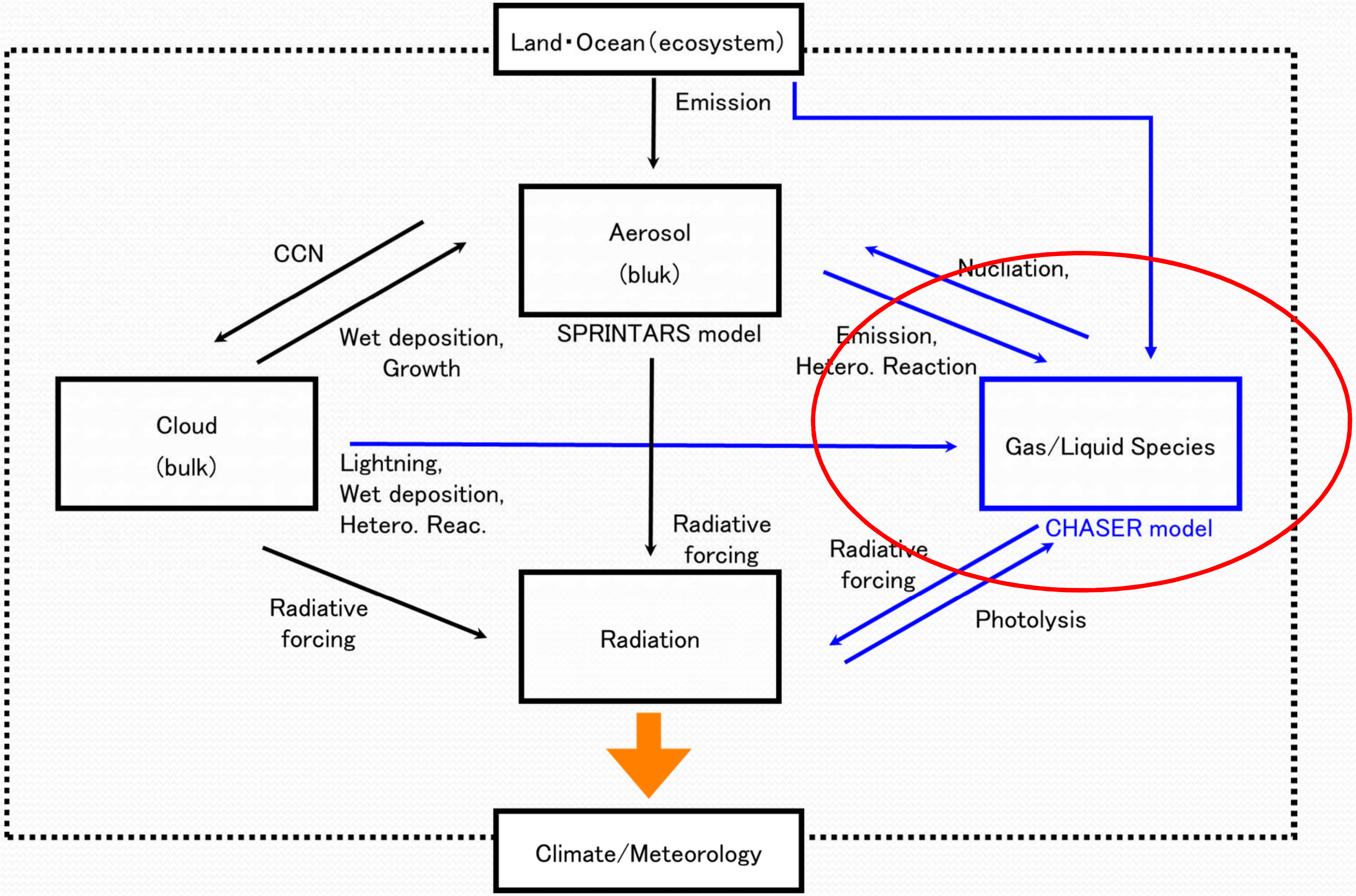
White: clouds (OLR)



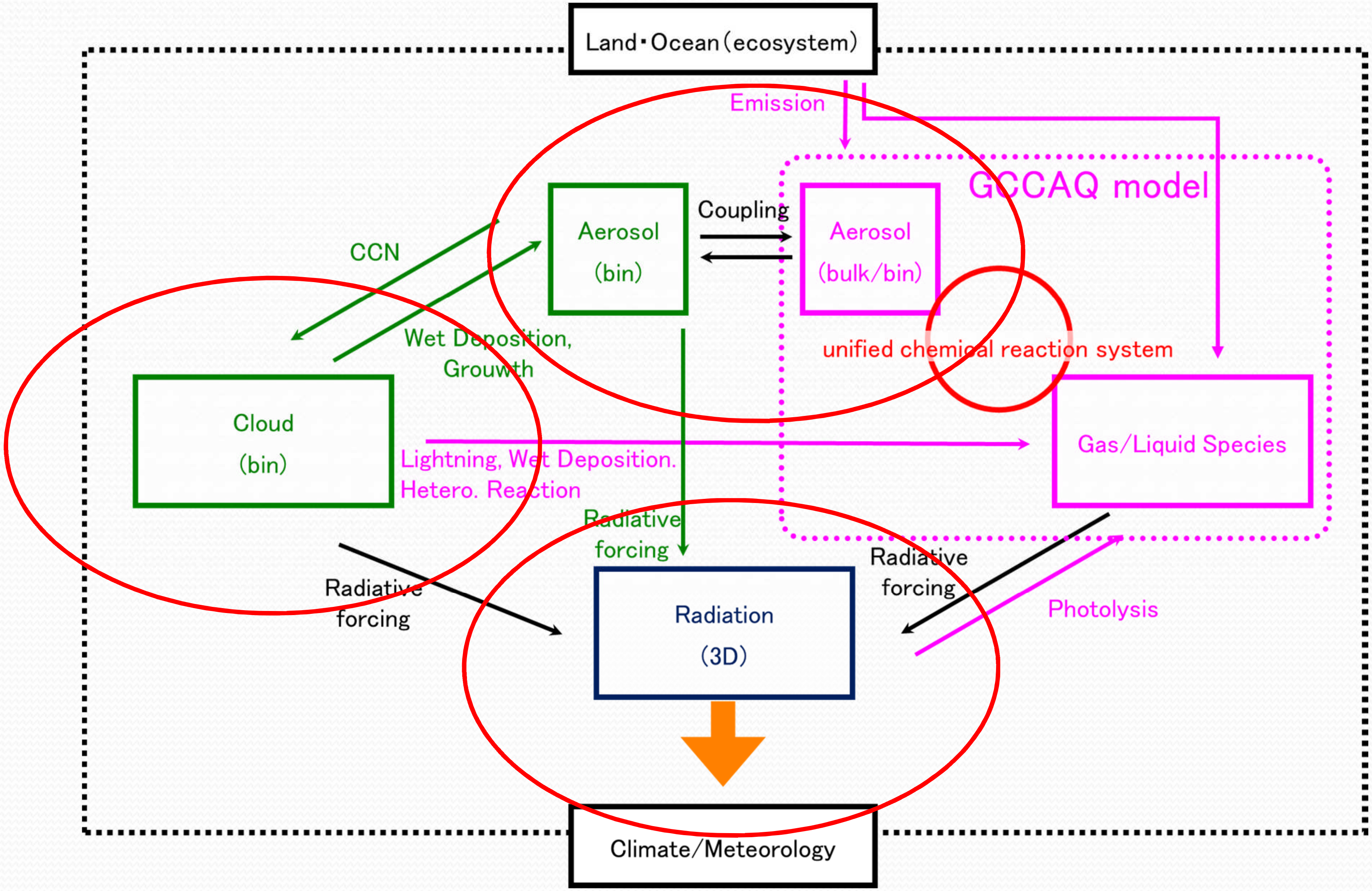
1-8, 2006

Suzuki et al. 2008, GRL

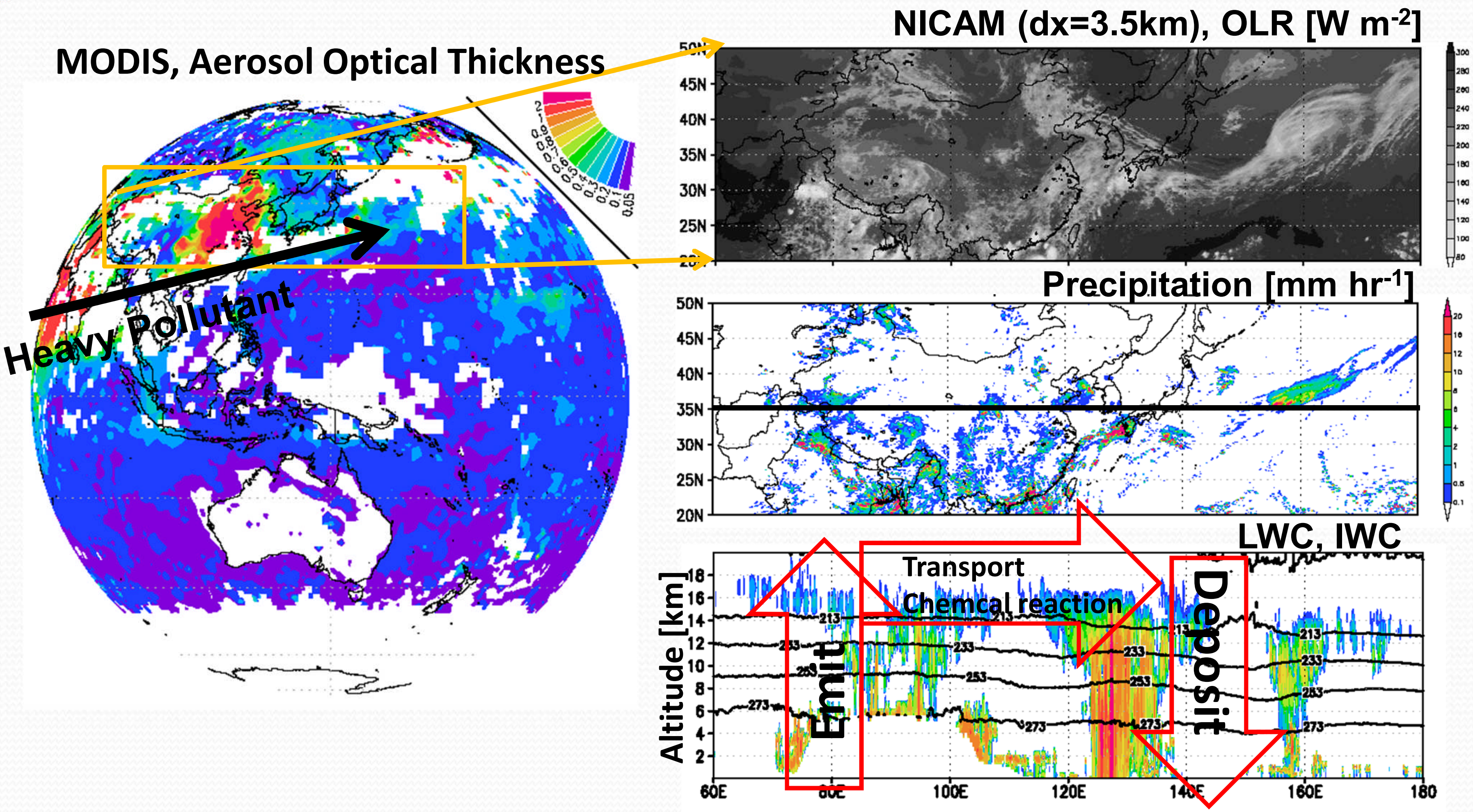
Implementation of chemical model



Schematic figure of the new model (phase #2)



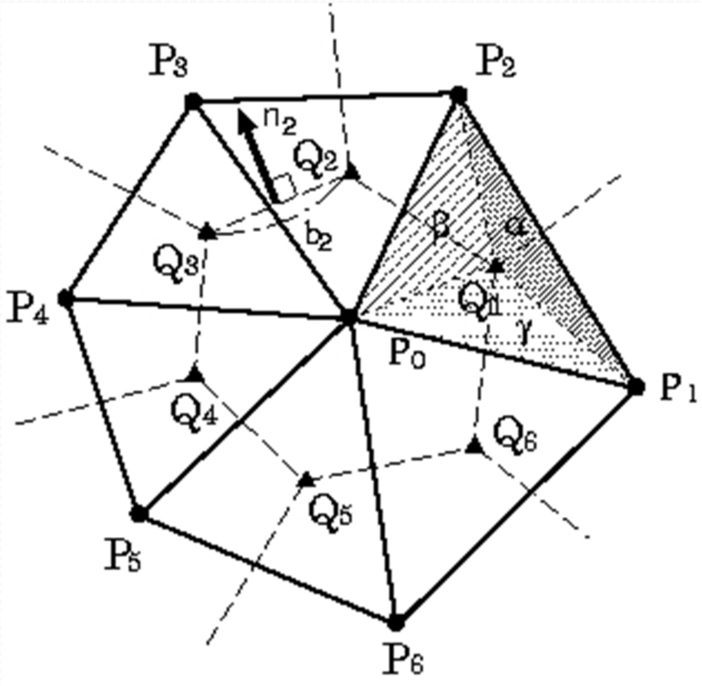
Pollutant Assessment by GCRM+Chemistry

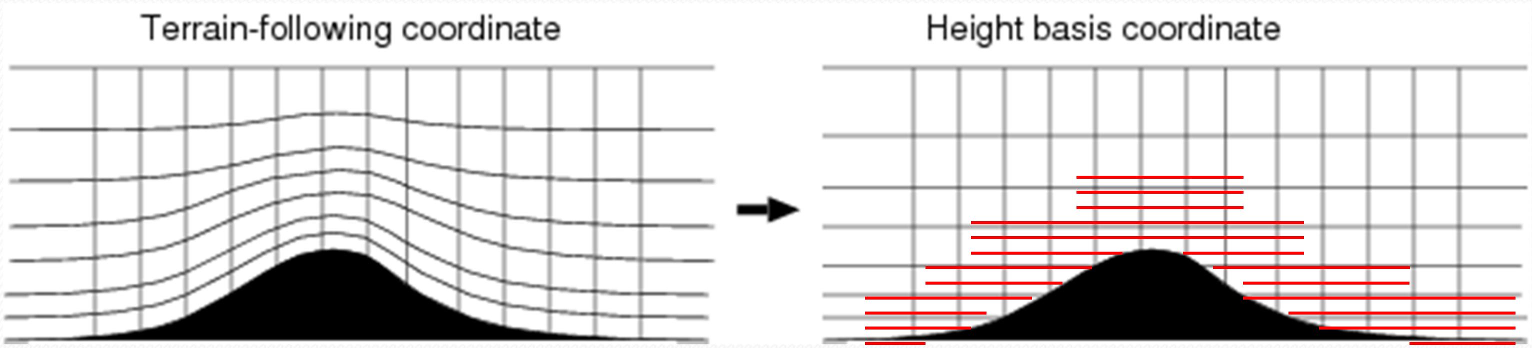


We can study **Long Term Transportation** resolving Emission, Liquid Phase Reaction, Transportation, and Deposition over the globe!

Basic research for the post-Petaflops

- Improvement of NICAM dynamical core itself
  - Current DC:
    - Icosahedral grid(quasi-homogeneous)
    - Vertical discretization : terrain-following coordinate
    - Horizontal A-type grid
  - Future plan
    - Topologically flexible configuration based on Icosahedral grid
    - Vertical discretization : cut-cell method
    - Horizontal B or C type staggard grid? or other?



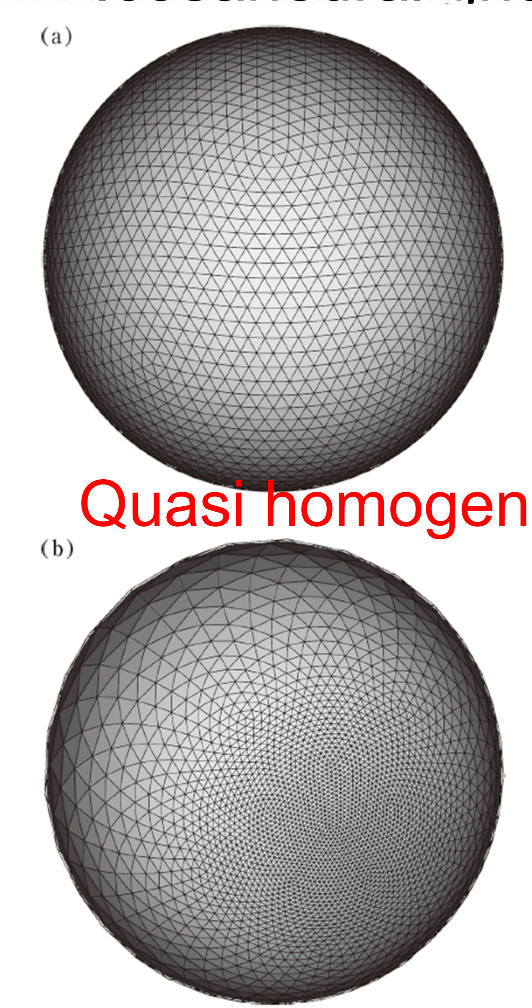


Example of various grids

Newly proposed

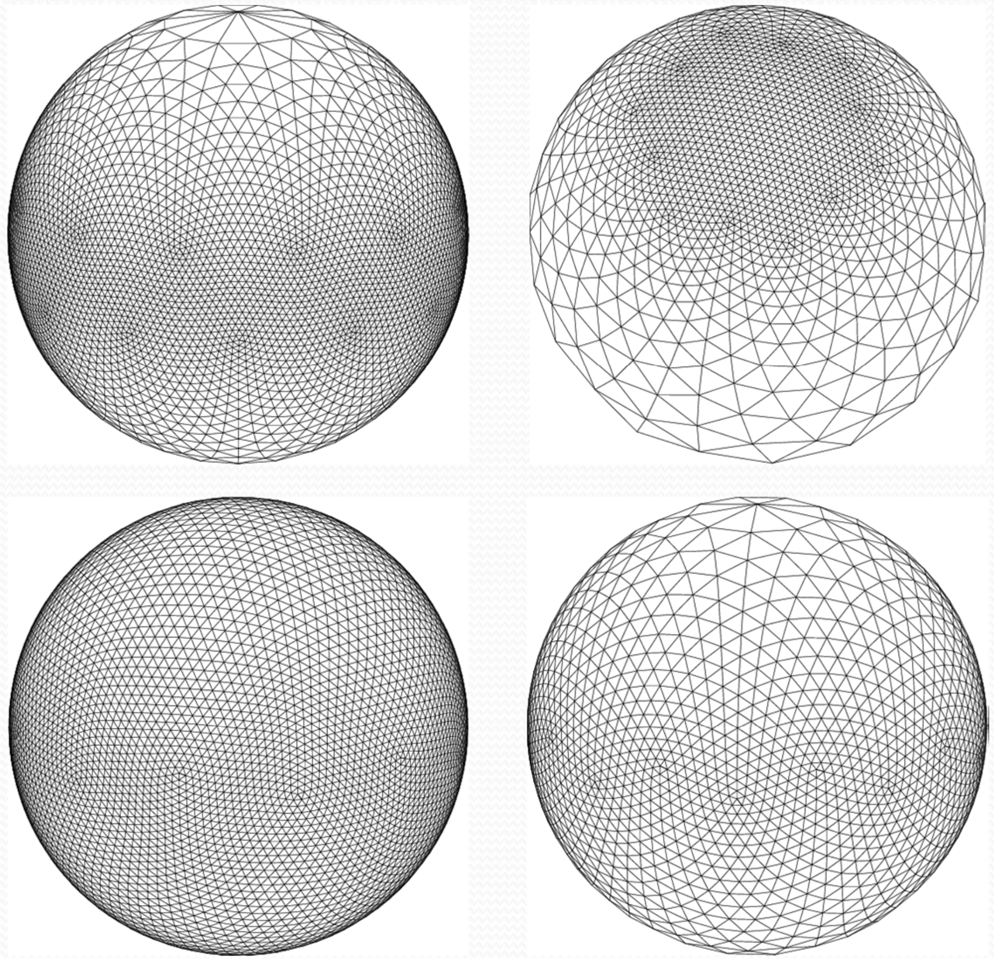
Iga (2010)

Icosahedral grid



Stretched (Tomita2008)

Change of region topology



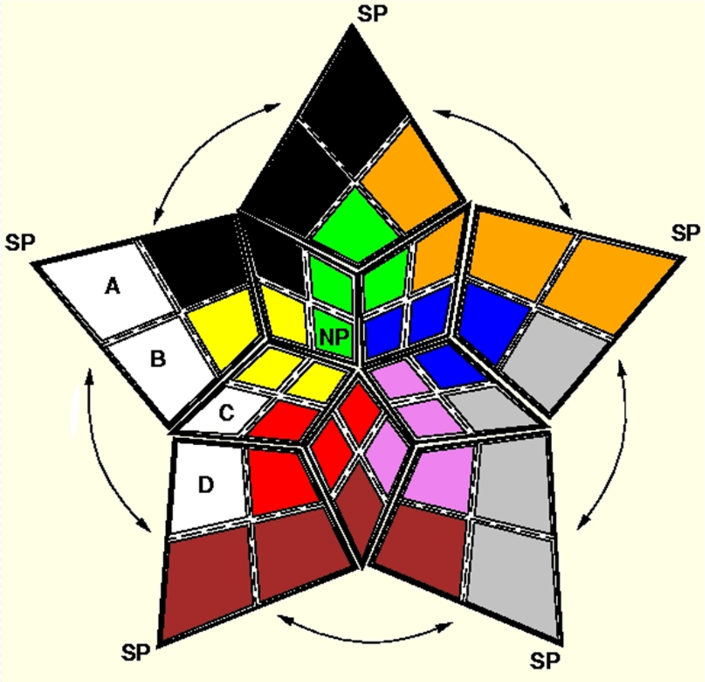
Non-homogeneous grid

Basic research for the post-Petaflops(2)

- Trends of architecture and problem
  - Many core / narrow band width per core
  - Interconnection topology
    - A kind of crossbar is unrealistic.
  - I/O bottle neck
  - Fault torelance

- Question : Getting a good scalability on future machine?
  - NICAM is basically built up, suitable to massively parallel computer.
  - However, is it true on the future computer system?
  - Reconstruction of dynamical core both in the viewpoints of numerical scheme and computer evironment

  Post-NICAM or NICAM version 2

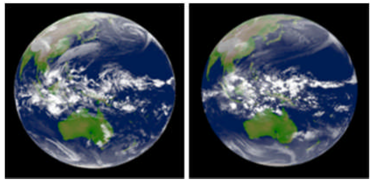


Schematic figure of 2d-decomposition of NICAM

気候科学分野

全球雲解像手法の幕開け

熱帯雲擾乱の階層構造、相互作用の理解
- 全球の積乱雲(深い雲)を直接解像
- 水平解像度数km／鉛直54層



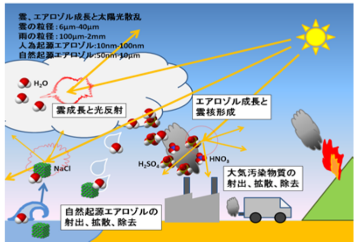
ひまわり6号　　NICAM3.5km計算

モデル精緻化

物理過程モデル高度化による雲・放射・エアロゾルフィードバックの理解

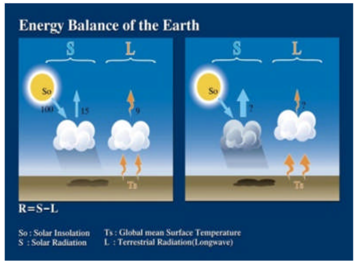
精緻化モデルコンポーネント
- マルチモーメント/ビン雲微物理
- 3D放射スキーム
- 詳細エアロゾルモデル
- 大気化学モデル

上記タイトなカップリング



物理過程が精緻化されたモデルによる雲の気候感度の信頼度の高い見積もり

長期間積分
- 高度化されたコンポーネントによる長期間積分。
- 正確な雲放射強制力の把握
- 将来気候ではどうなる？



モデル高解像度化

空間高解像度化による雲の力学特性の更なる理解

真の「全球雲システム解像実験」
- 全球水平1km以下、鉛直100層
- 積乱雲の表現向上
- 境界雲の表現向上

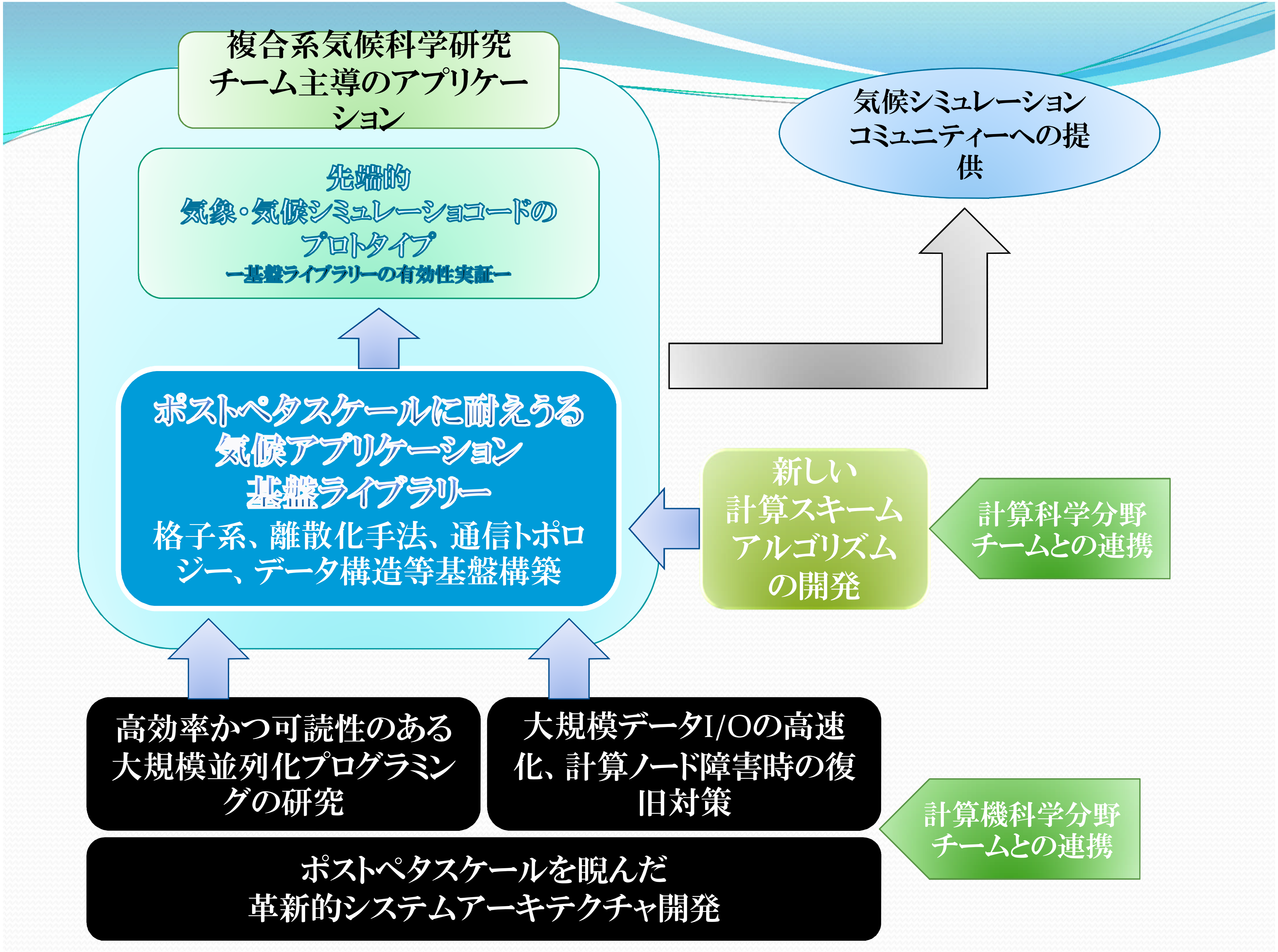
http://flickr.com/photos/95118988@N00/197143641

高度化された物理過程を含む全球超高解像モデル

- 全球水平・鉛直50mの超高解像度
- 全球雲解像と精緻化された物理による大気をまるごとLarge Eddy Simulation
- 細かな雲まで直接解像。
- 信頼度高い気候変動予測への期待

2010　　2015　　2020

0.1 PF　　1–10 PF　　100 PF　　1000 PF


複合系気候科学研究チーム主導のアプリケーション
気候シミュレーションコミュニティーへの提供
先端的
気象・気候シミュレーショコードのプロトタイプ
ー基盤ライブラリーの有効性実証ー
ポストペタスケールに耐えうる気候アプリケーション基盤ライブラリー
格子系、離散化手法、通信トポロジー、データ構造等基盤構築
新しい計算スキームアルゴリズムの開発
計算科学分野チームとの連携
高効率かつ可読性のある大規模並列化プログラミングの研究
大規模データI/Oの高速化、計算ノード障害時の復旧対策
計算機科学分野チームとの連携
ポストペタスケールを睨んだ革新的システムアーキテクチャ開発

Summary

- Computational Climate Science Research Team:
  - Suggests the strategy of climate modeling in the future computer environment (post-peta scale)
    - Tightly collaborating with computer science researcher, we will reconstruct the prototype of modeling framework.
      - E.g. tackling to problem of scalability, I/O, and fault torelance
      - Develop the advanced algorithm of climate model
  - Sophisticates physical components such as radiation, aerosol, cloud microphysics, and chemistry
    - Precise assessment of role of clouds in the climate, including the aerosol direct/indirect effects.

Feedback and provide our knowledge and results to climate/meteorological community.