

# 全球雲解像モデルによる気候研究

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第二回「計算科学による新たな知の発見・統合・創出」シンポジウム  
計算科学の戦略と次世代スーパーコンピュータ

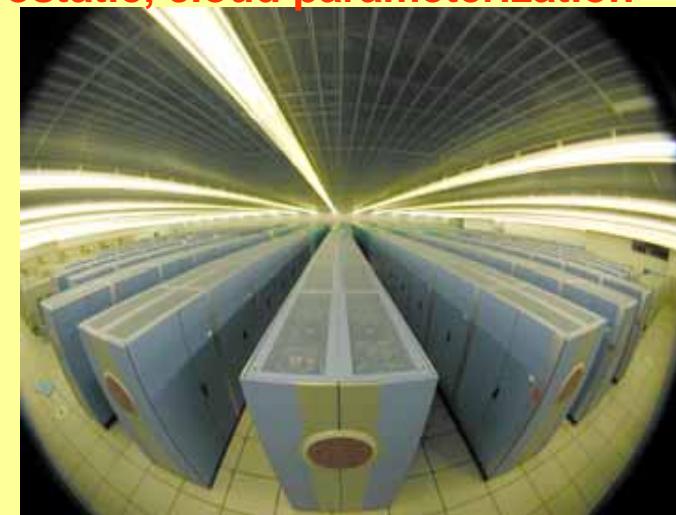
つくば国際会議場(エポカルつくば)  
平成18年4月4日(火曜日), 5日(水曜日)

# Outlines

## Global Cloud Resolving Model

### NICAM (Nonhydrostatic ICosahedral Atmospheric Model)

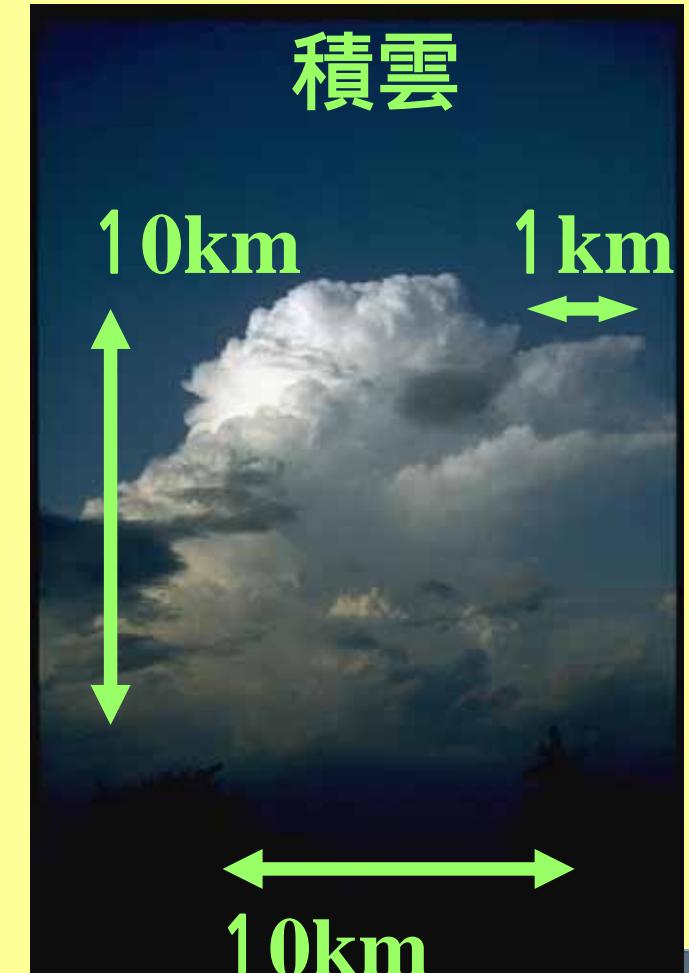
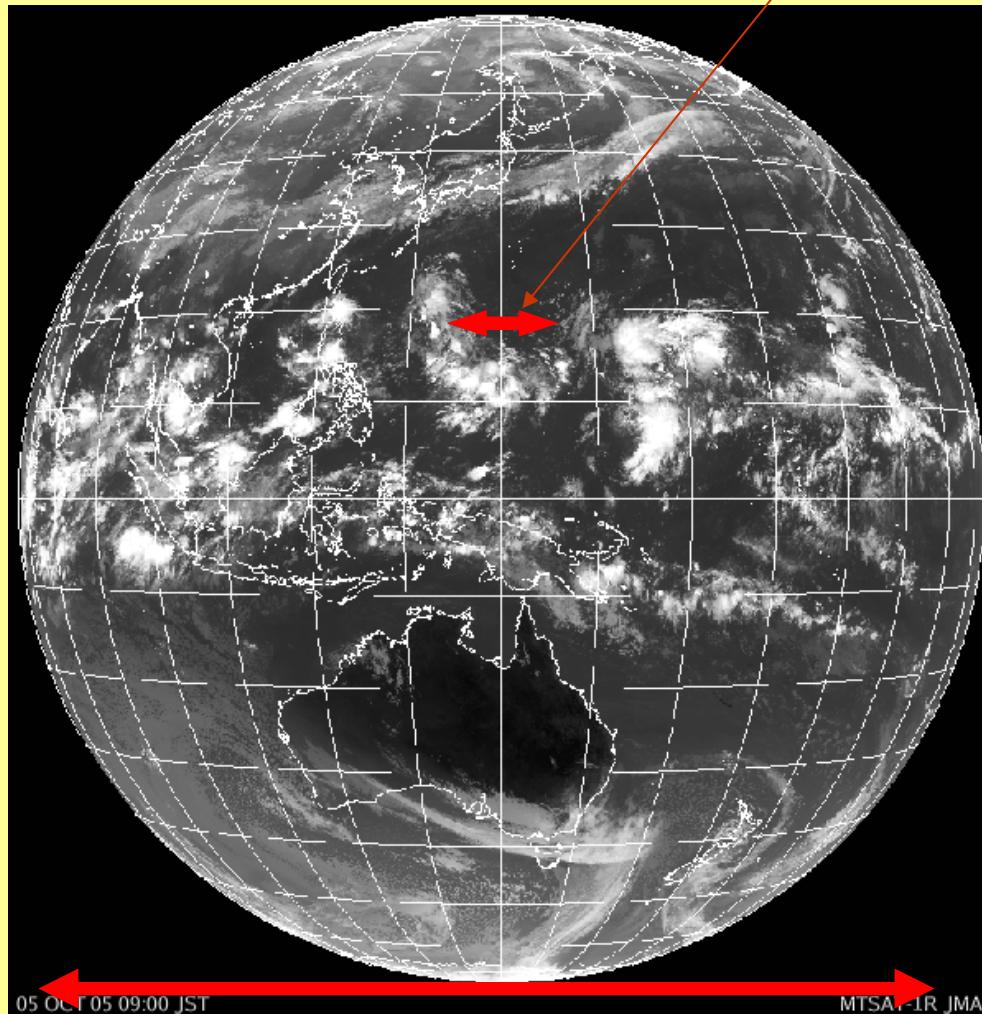
- Icosahedral grid & Nonhydrostatic model & Explicit cloud physics
- Development since 2000: number of test cases
- Problems of Current GCMs:  $x \sim 20\text{km}$  at best & hydrostatic, cloud parameterization
- Horizontal resolution: up to  $\Delta x = 3.5\text{km}$



- Global cloud resolving simulations with NICAM
  - 3.5km-mesh Aqua Planet Experiment
  - GCM experiments with realistic land/sea distribution
    - Short-term simulation for Apr. 2004: preliminary results with 14km-mesh 10days run
    - Perpetual July, 60days run with 14km-mesh
- Computer performance on the Earth Simulator
- Toward 10PF era



積雲クラスタ～数100km



# 台風の雲



スペースシャトルから  
撮った写真  
1985年9月  
Hurricane Elena

画像提供 NASA  
<http://earth.jsc.nasa.gov/>  
Next Generation Climate Model



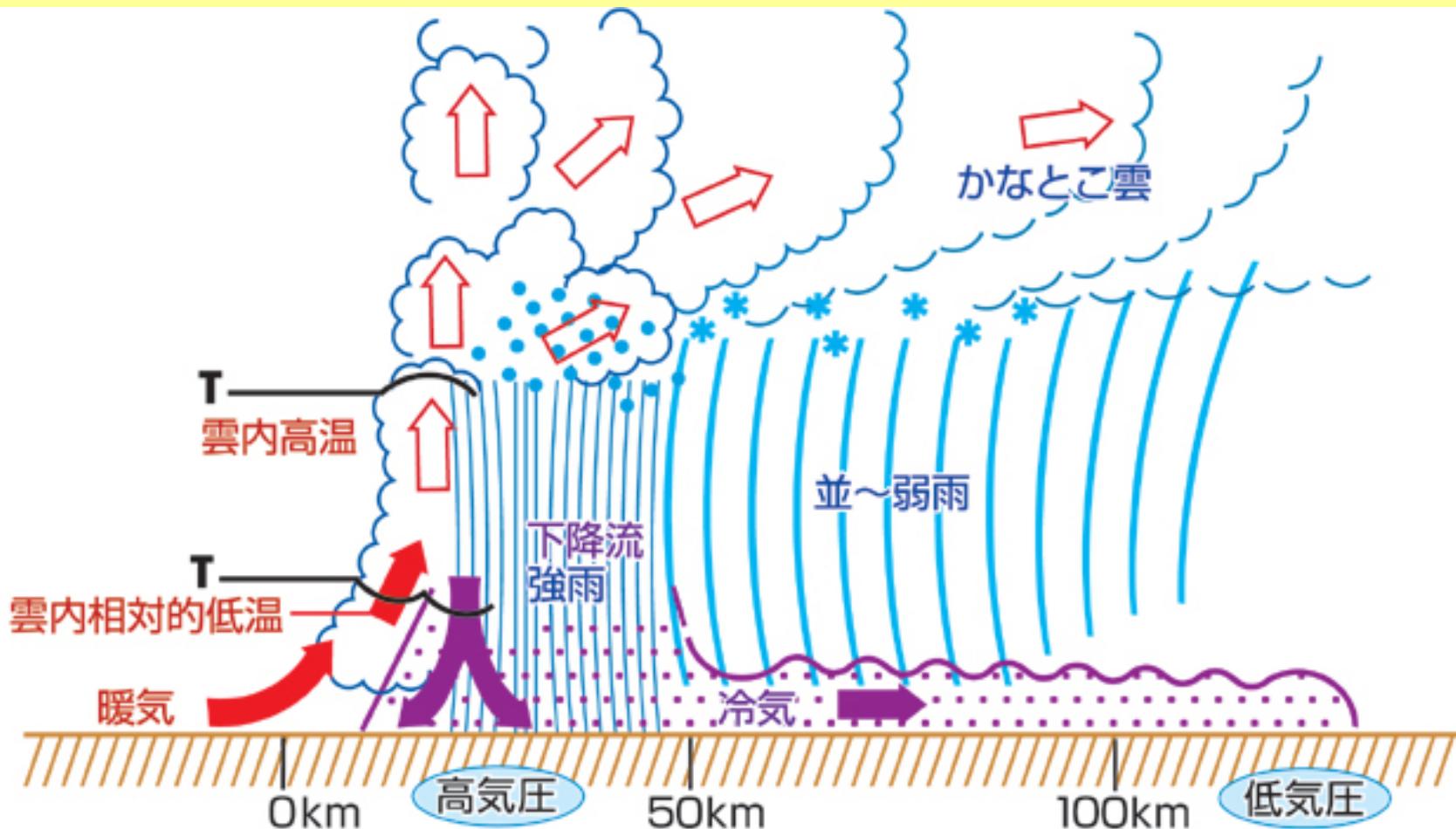
ク

10km

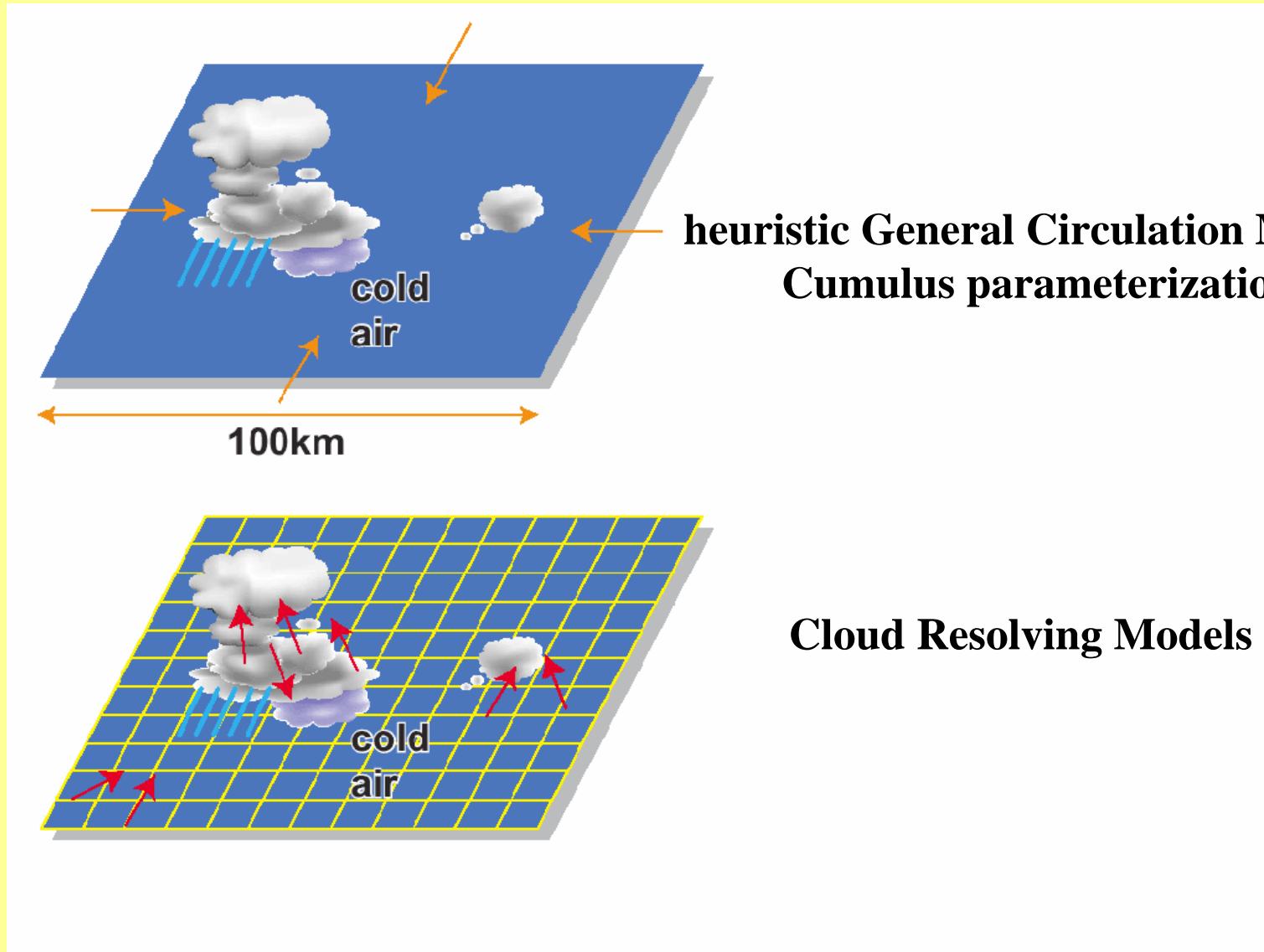
5km

3km

1km



# GCM vs Cloud Resolving Model



# Big jumps in meteorology

- Synoptic scale disturbances  
~200km: GCM
- Deep convection <5km: GCRM  
ES
- Shallow clouds <500m: GLEM  
京速?



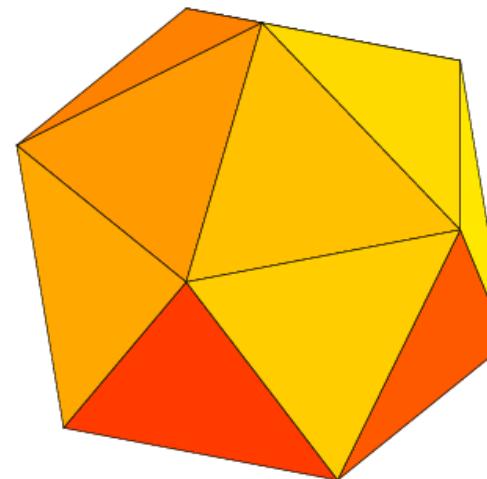
# **3.5km-mesh Aqua Planet Experiment with NICAM**



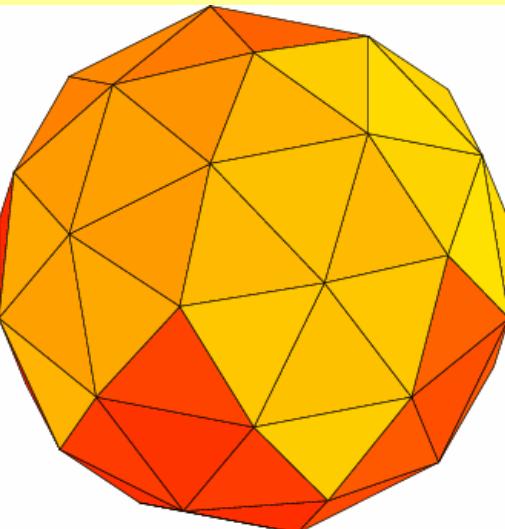
# Icosahedral grids

Original Icosahedron

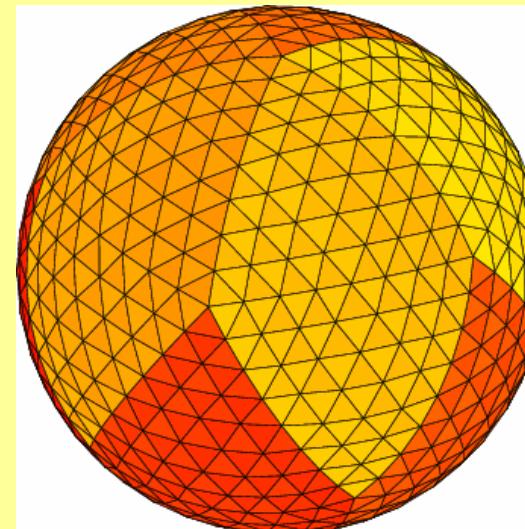
Glevel-0



Glevel-1



Glevel-3

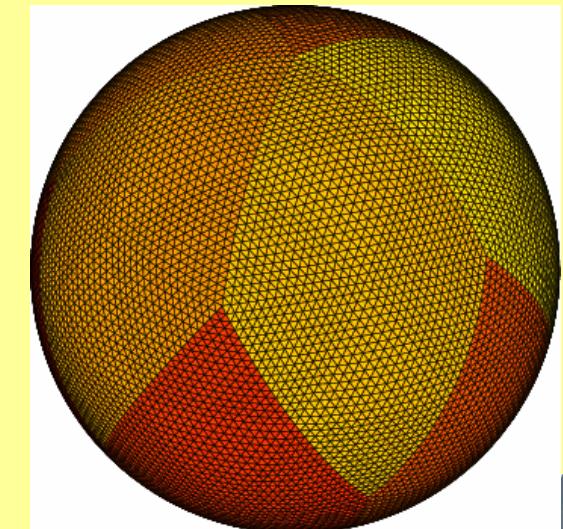


Glevel-9:  $x=14\text{km}$

Glevel-10:  $x=7\text{km}$

Glevel-11:  $x=3.5\text{km}$

Glevel-5



# Model description

## ■ Dynamics

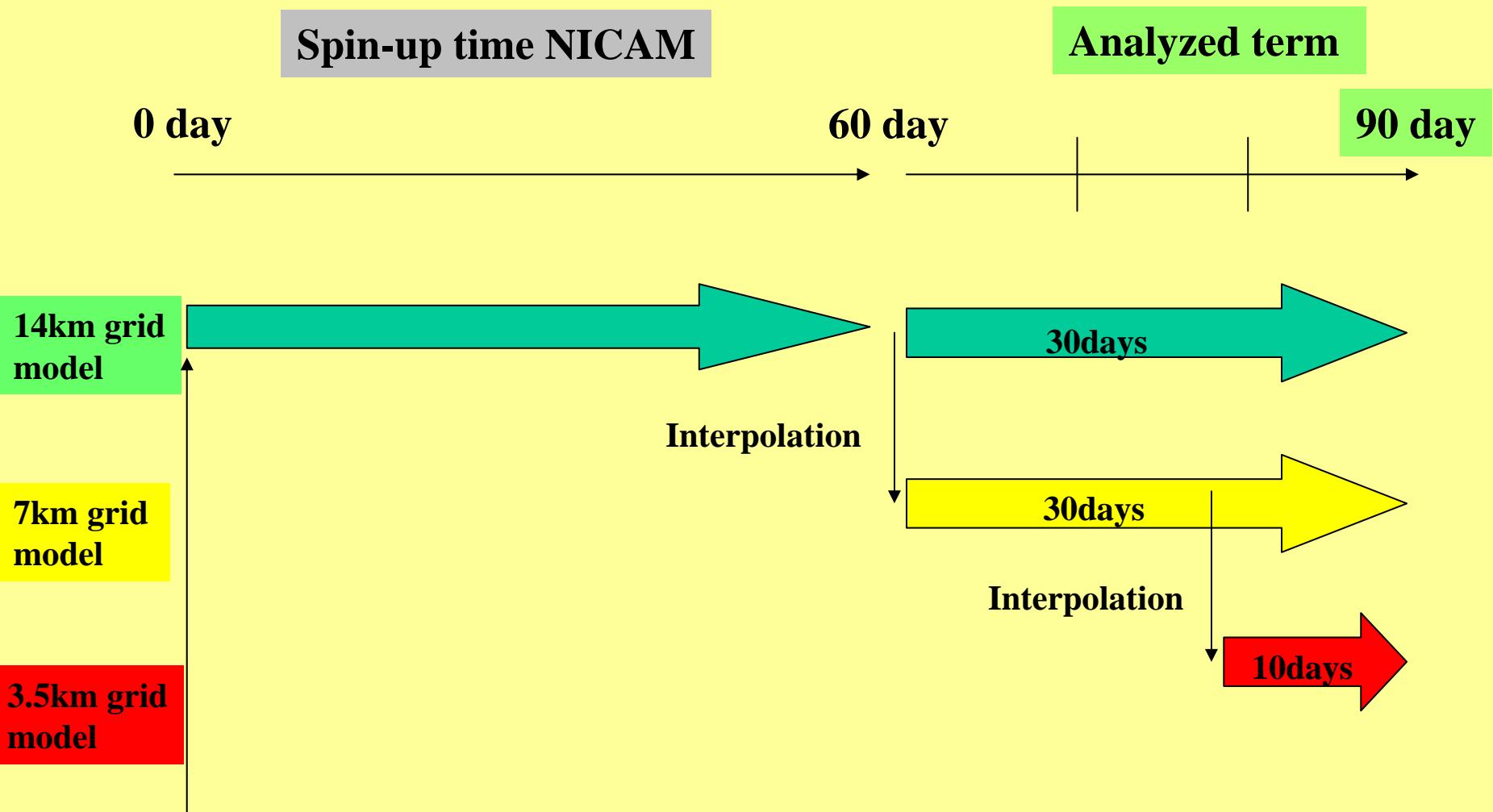
Governing equations	Fully compressible non-hydrostatic system (with acoustic waves)
Spatial discretization	Finite Volume Method
Horizontal grid configuration	Icosahedral grid
Vertical grid configuration	Lorenz grid
Topography	Terrain-following coordinate
Conservation	Total mass, total energy
Temporal scheme	Slow mode - explicit scheme (RK2) Fast mode - Horizontal Explicit Vertical Implicit scheme

## ■ Physics: Same as CCSR/NIES/FRCGC AGCM except for explicit cloud physics

Turbulence, surface flux	Mellor & Yamada 2 with moist closure (Smith 1990) /Louis(1979), Uno et al.(1995)
Radiation	MSTRNX (Sekiguchi and Nakajima, 2005)
Cloud physics	Kessler; Grabowsky(1998,1999); Lin et al.(1983);
Shallow clouds	no
Cumulus parameterization	Relaxed/prognostic AS (used for coarser exp.)
Land process	Bucket; MATSIRO

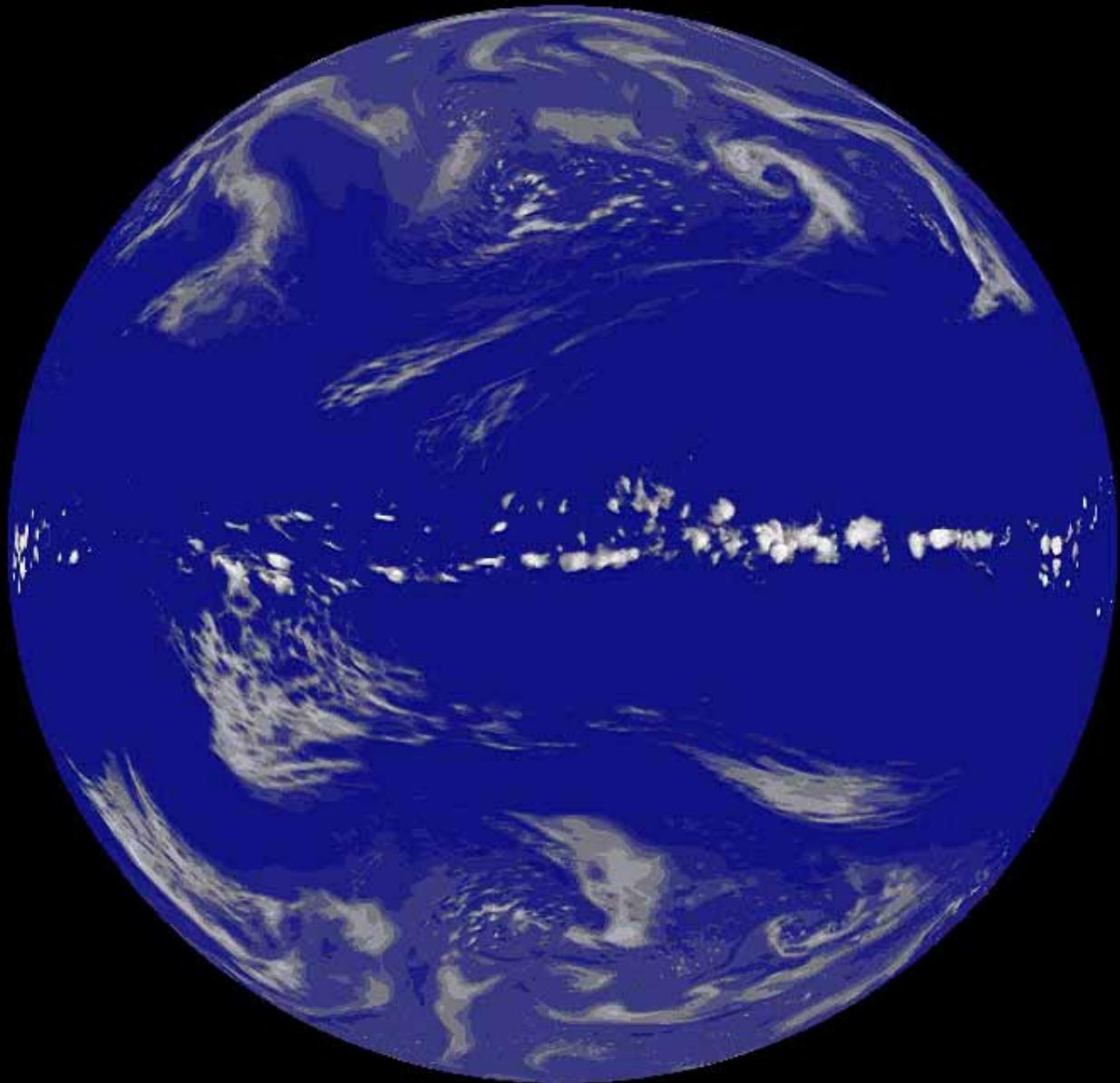


# Aqua planet experiments

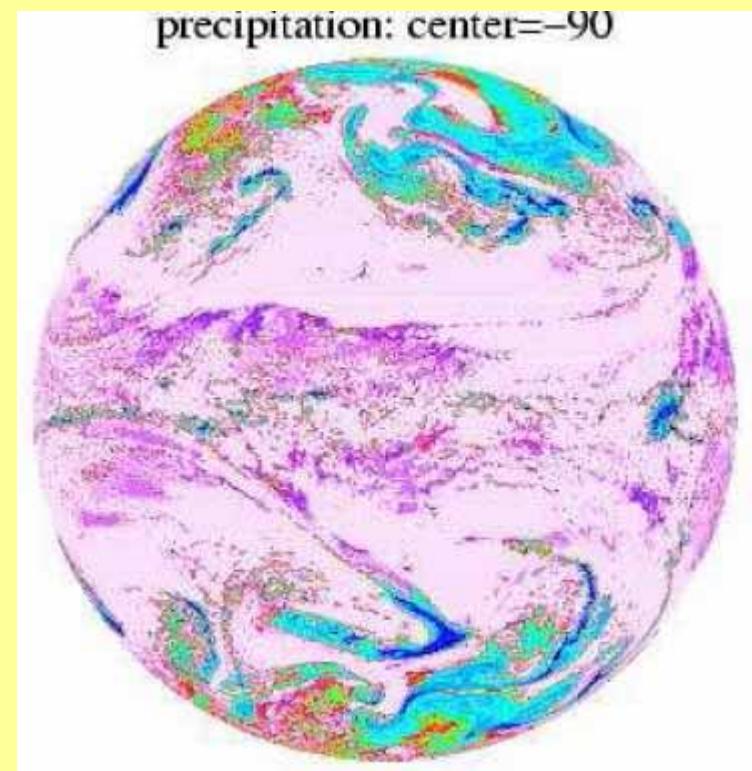
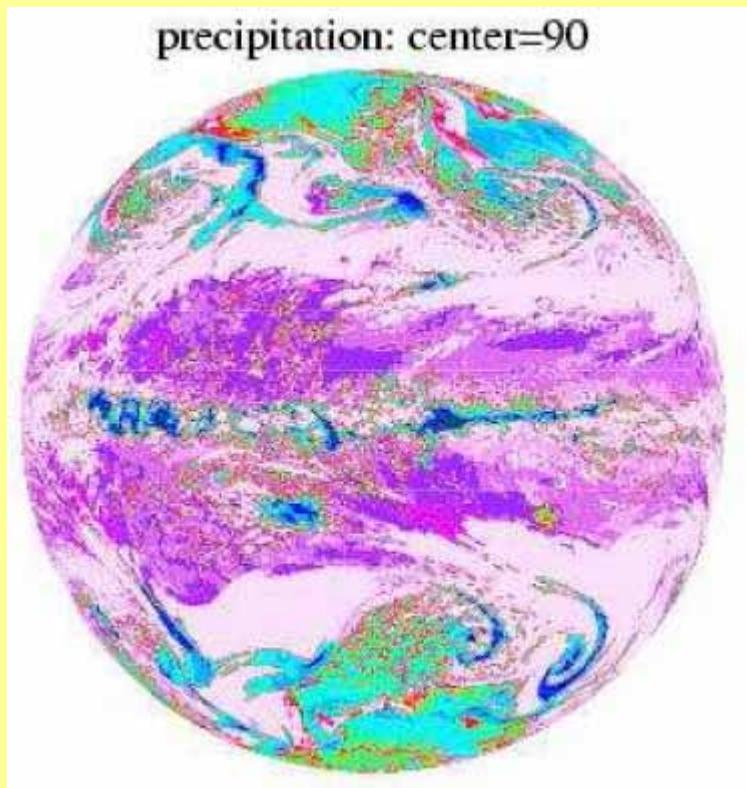


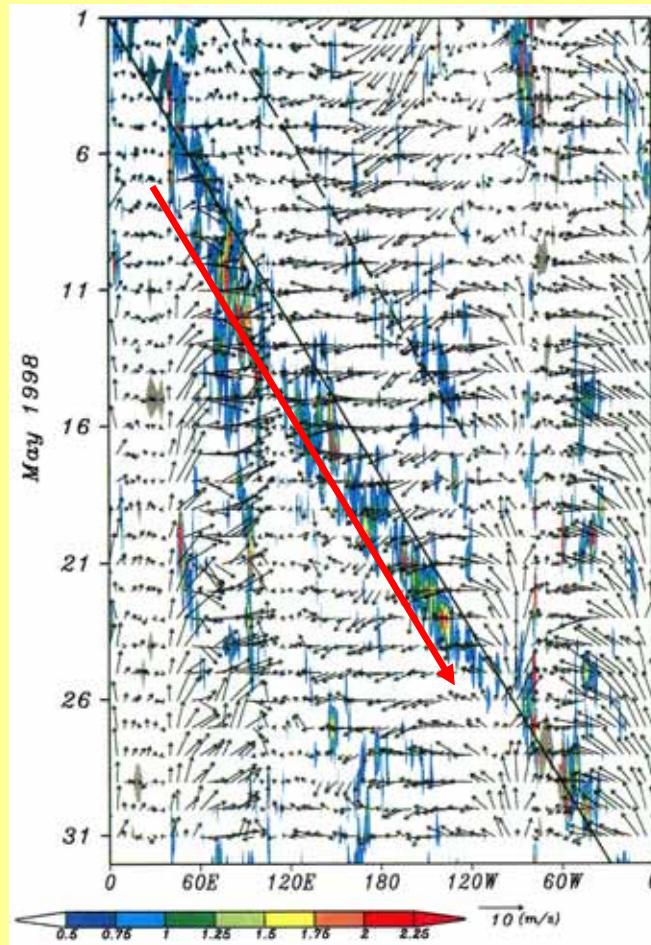
**Initial condition:** 3year average of T42 result with  
CCSR/NIES/FRCGC AGCM ver 5.7



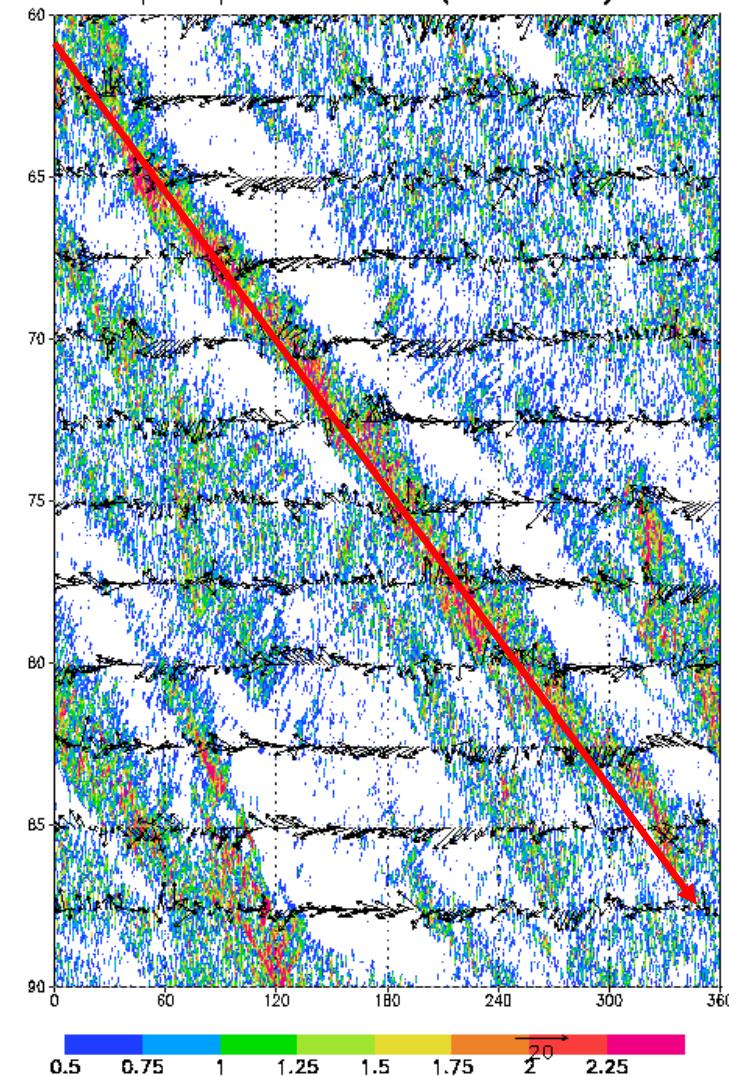


# Precipitation at day 85

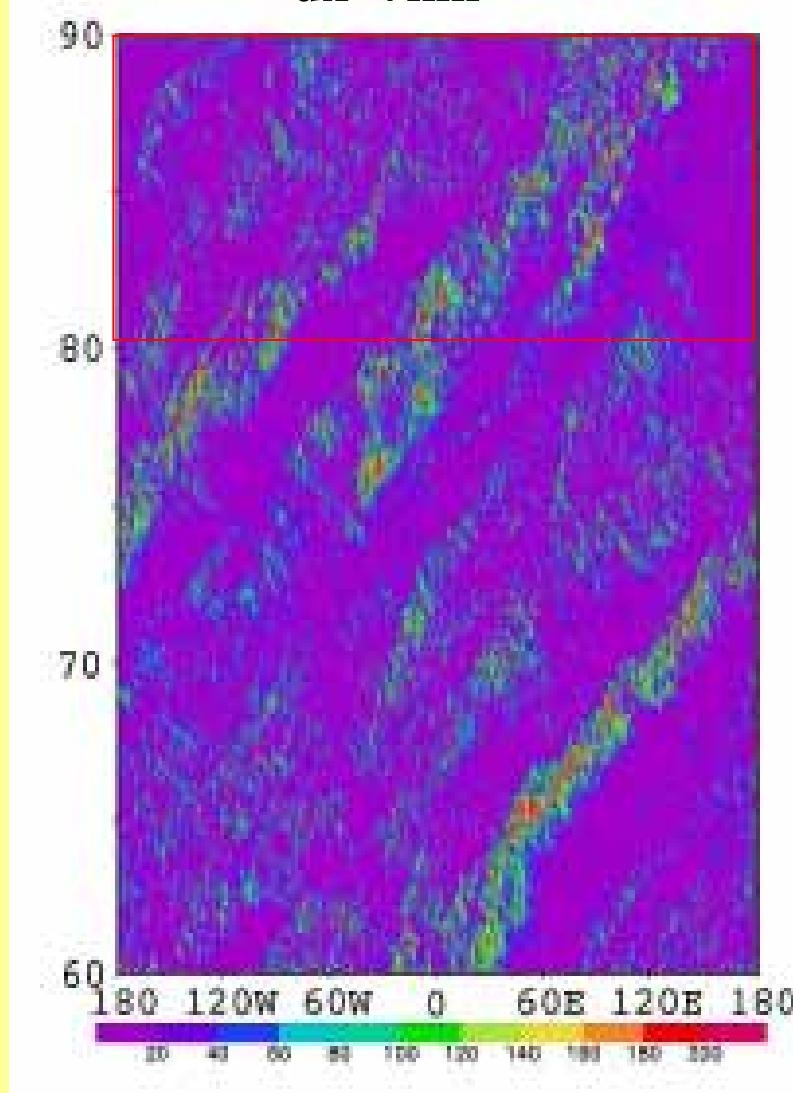
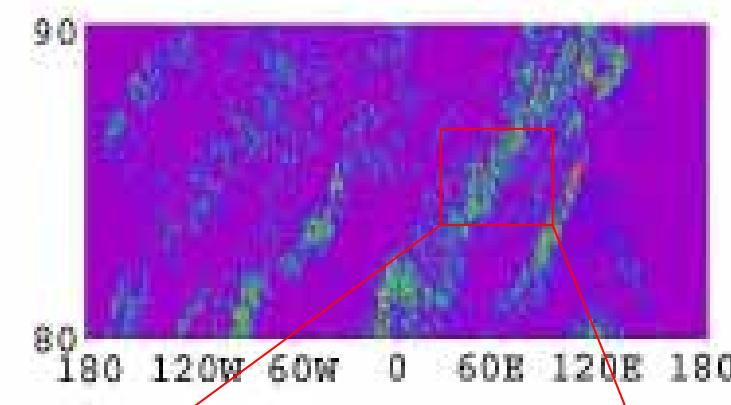
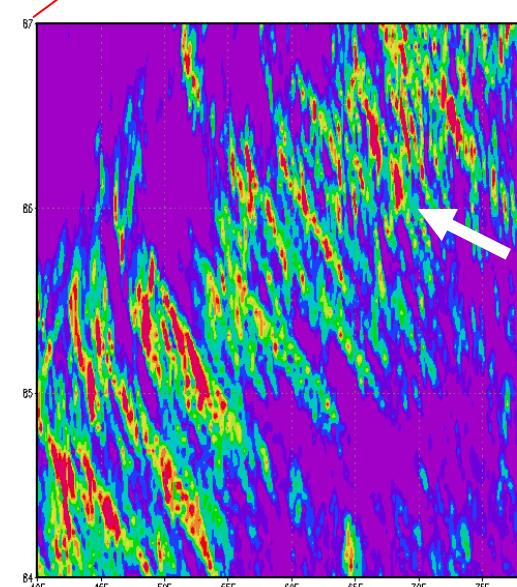


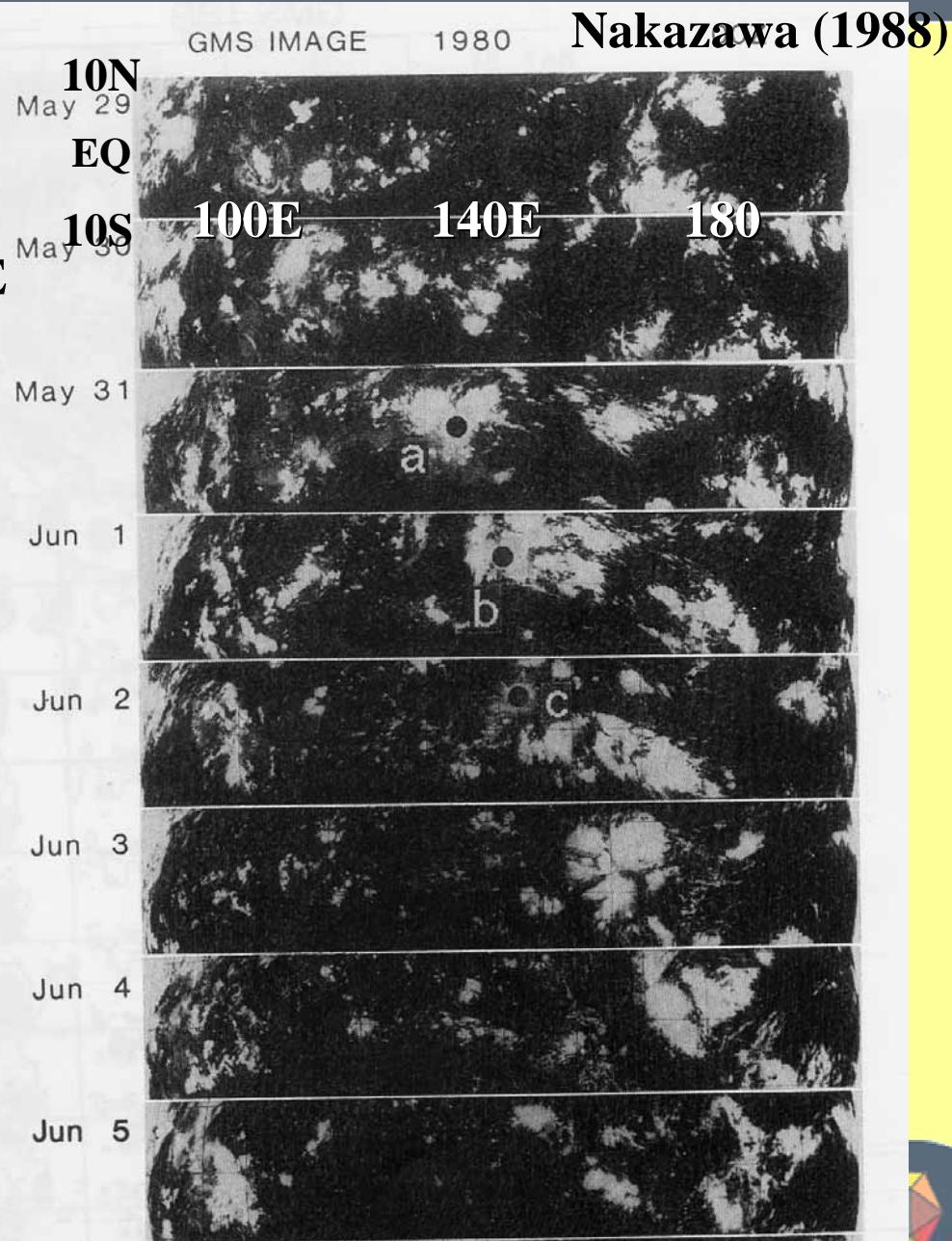
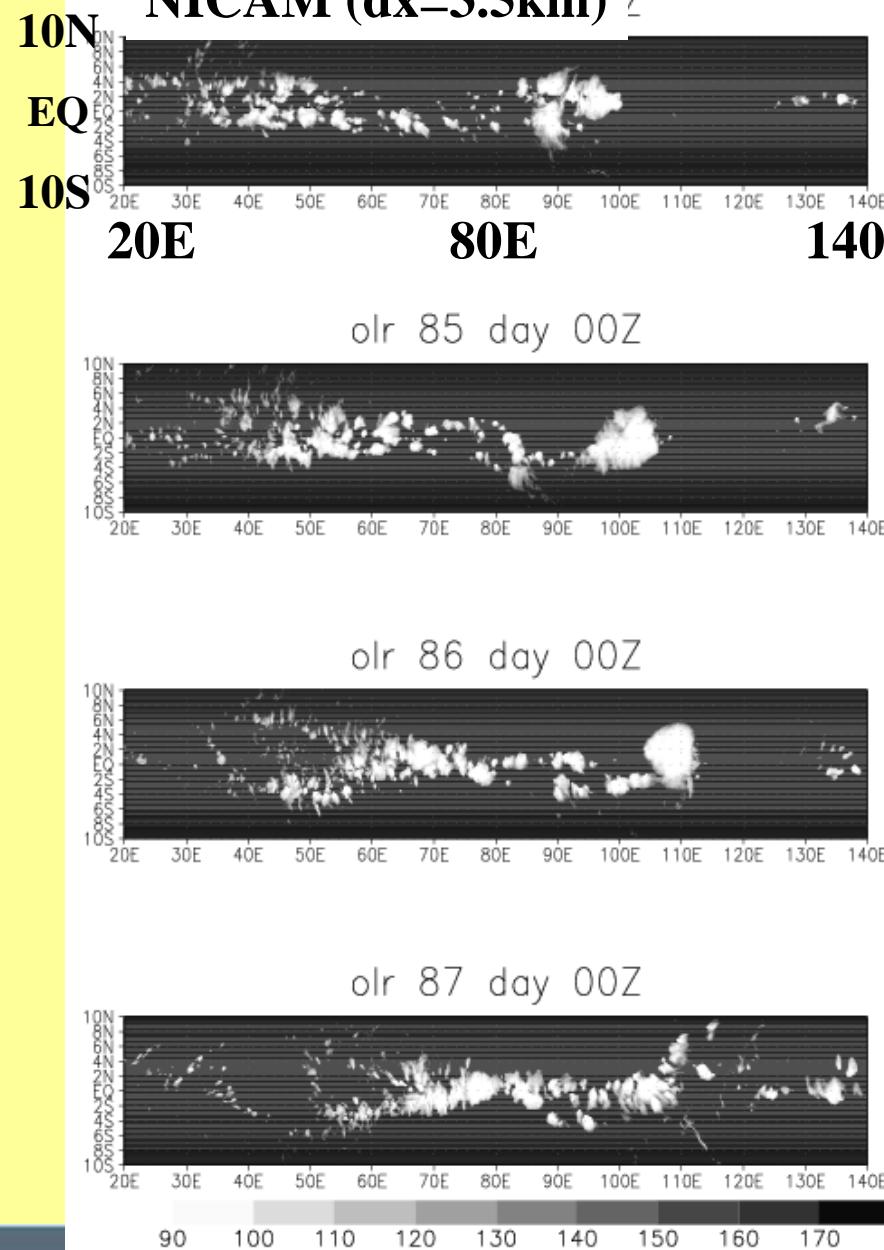
**May 1995, Observed****Takayabu(2002)****NICAM**

precipitation rate (10S–10N)

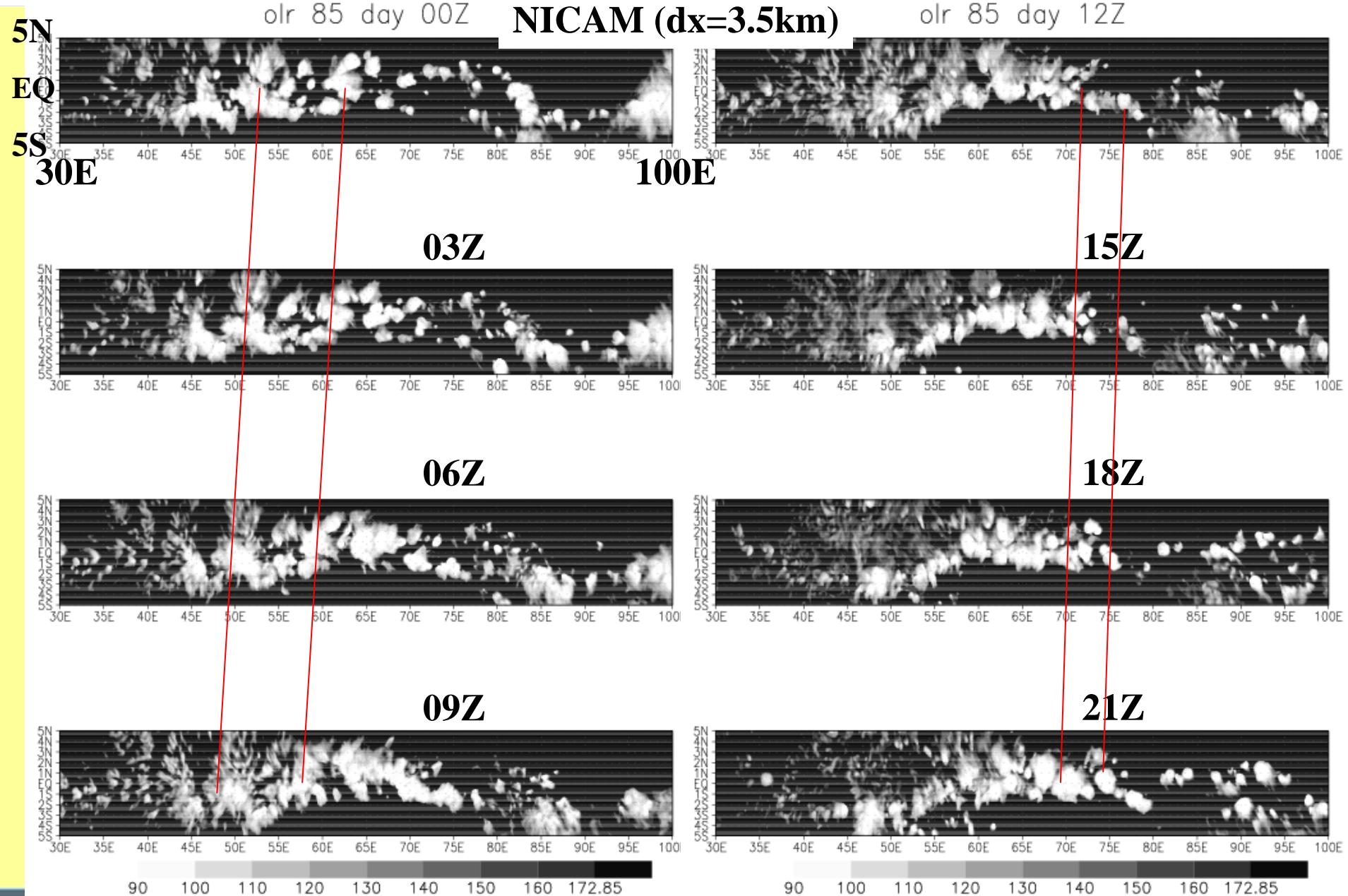


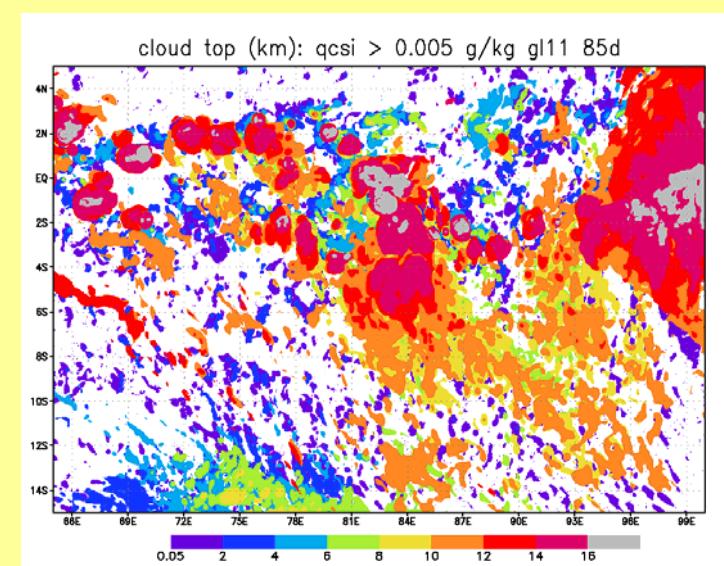
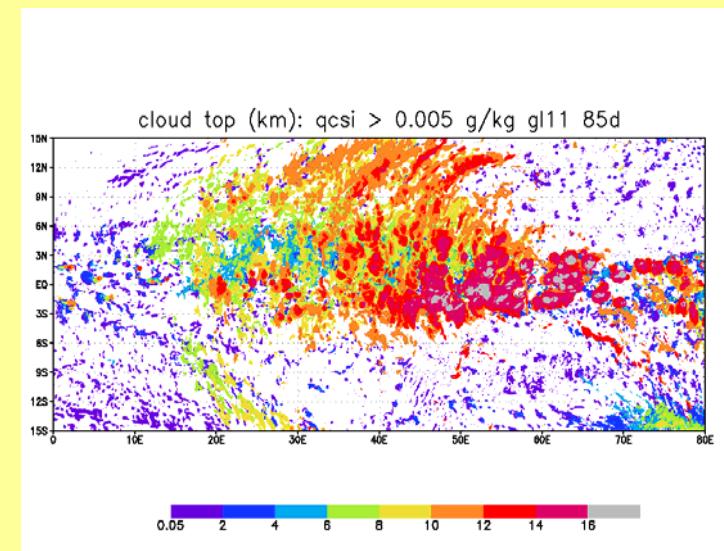
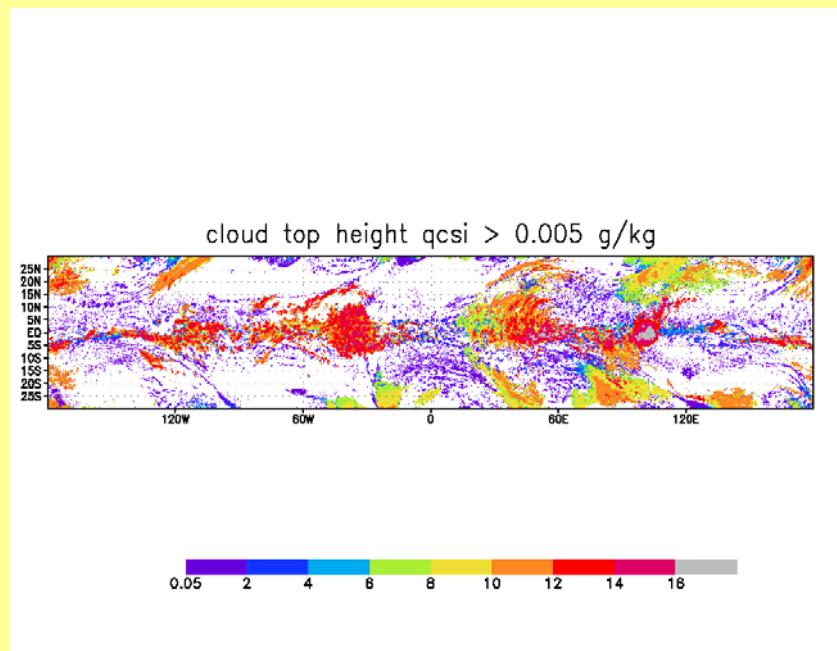
## Precipitation (2S-2N)

**dx=7km****dx=3.5km****87d****86d****85d****84d****40E 60E 80E**

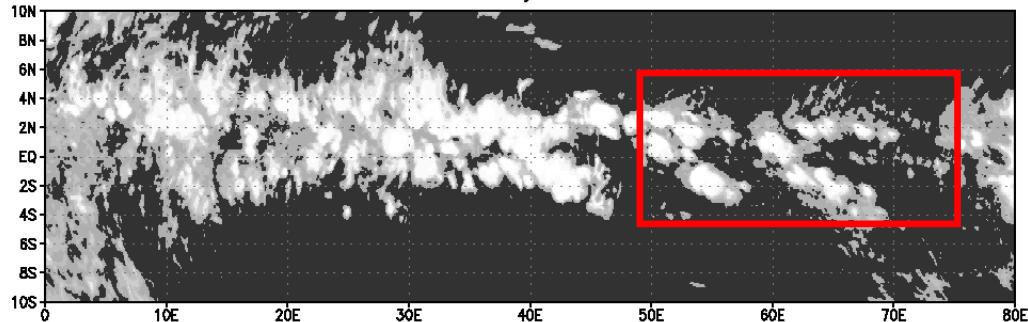
**NICAM (dx=3.5km) Z**

# Westward movement of cloud clusters

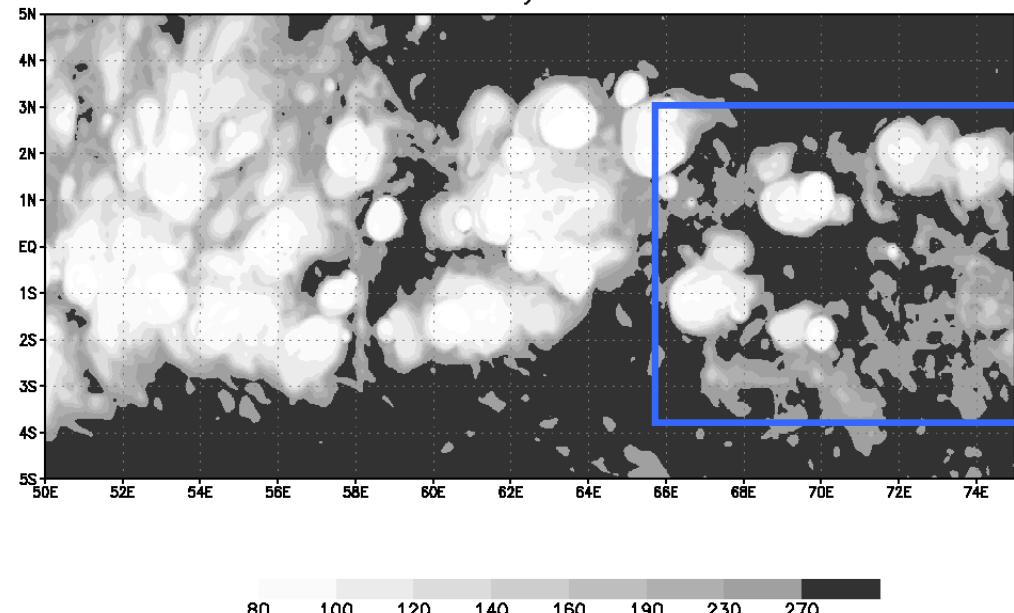




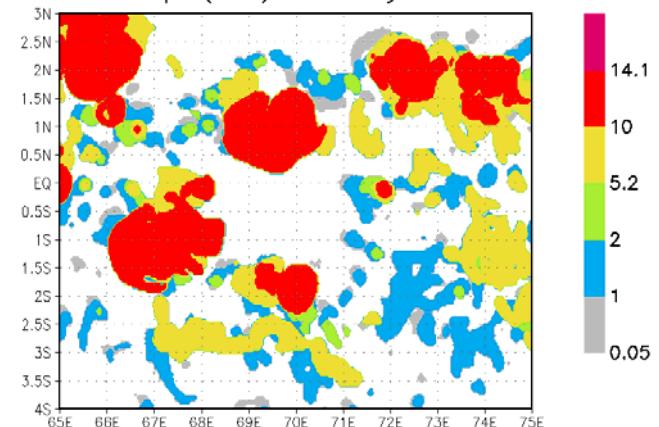
olr 83 day 6–7.5h



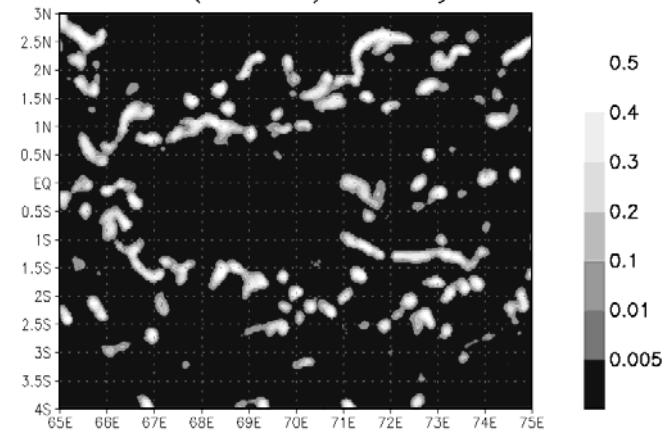
olr 85 day 10 min



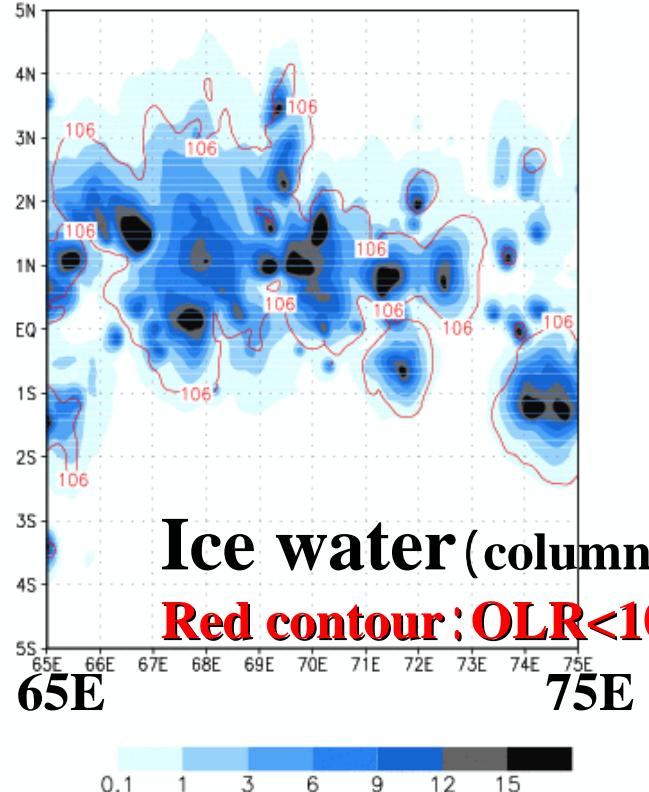
clout top (km) 85 day 10 min



cloud water ( $z=1\text{km}$ ) 85 day 10 min



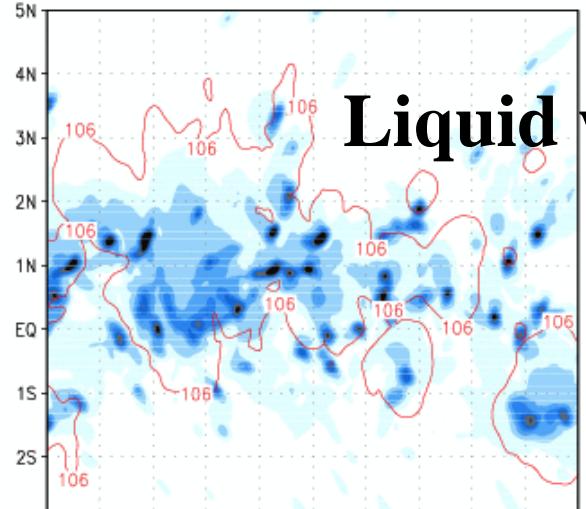
ice water path 86 day 00Z



Ice water(column)

Red contour: OLR<106

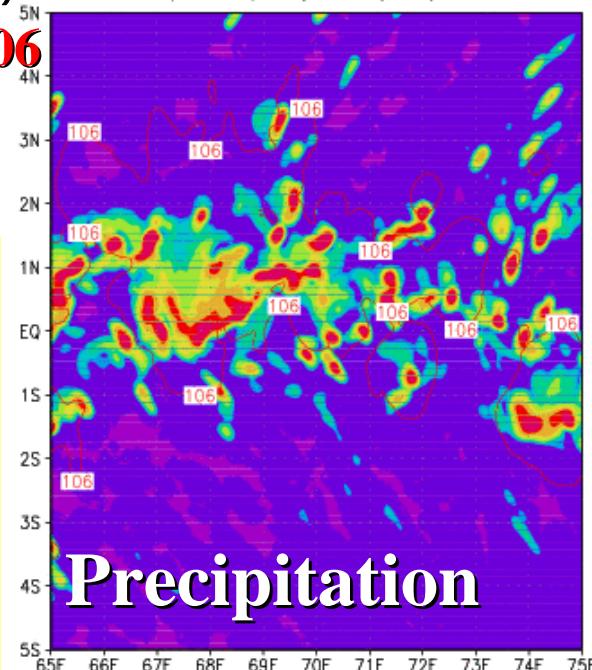
liquid water path



NICAM (dx=3.5km)

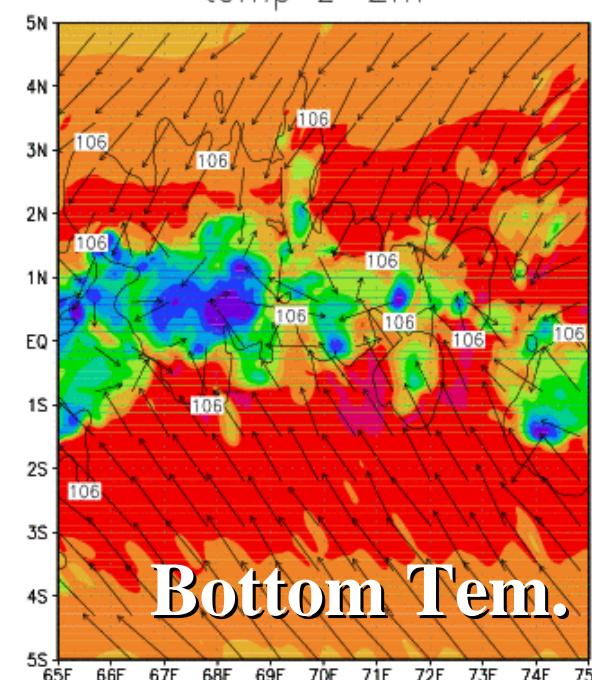
Liquid water(column)

precip (mm/h)



Precipitation

0 0.3 0.5 1 2 5 10 20 30



Bottom Tem.

295.529 296.529 297.529 298.529 299.5300

JST/CREST  
科学技術推進機構/戦略的創造推進事業

応募研究領域:

マルチスケール・マルチフィジックス現象の統合シミュレーション  
矢川領域総括

研究課題名:

全球雲解像大気モデルの  
熱帯気象予測への実利用化に関する研究

代表者:佐藤正樹

期間:2005年10月 - 2011年3月

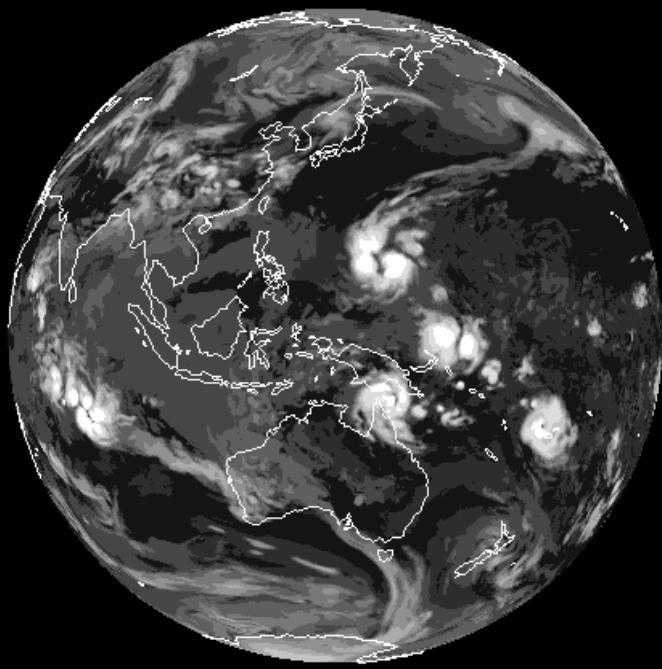


# Preliminary results of a global cloud-resolving simulation with realistic topography

- **dx=14km (glevel9) L40 without parameterization**
- **(dx=7, 3.5km, on going)**
- **Apr. 2004, short-term (H.Miura)**
- **Perpetual July experiment, statistics (S.Iga)**

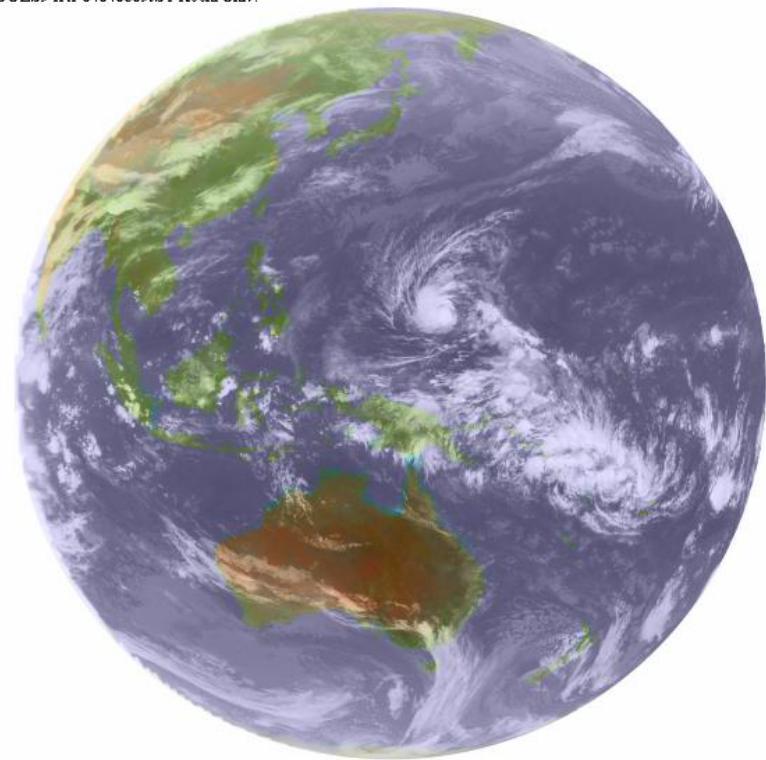


## Apr. 2004 short term exp.



NICAM 14km

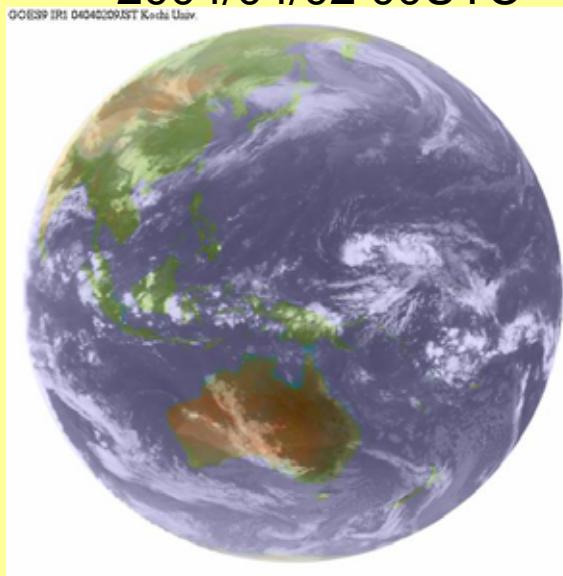
GOES9 IR1 04040609JST Kochi Univ.



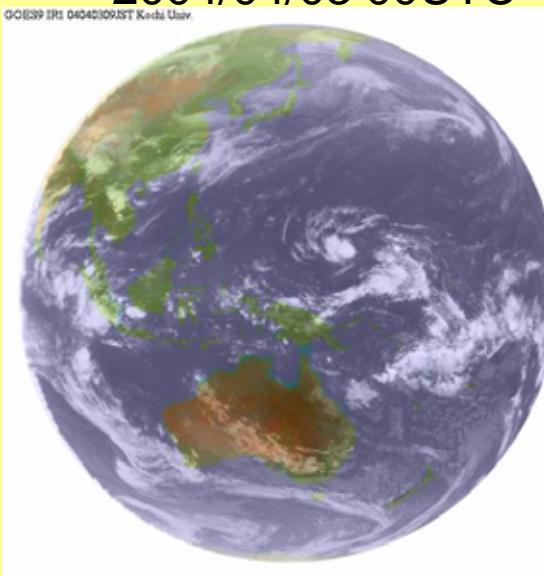
GMS/GOES



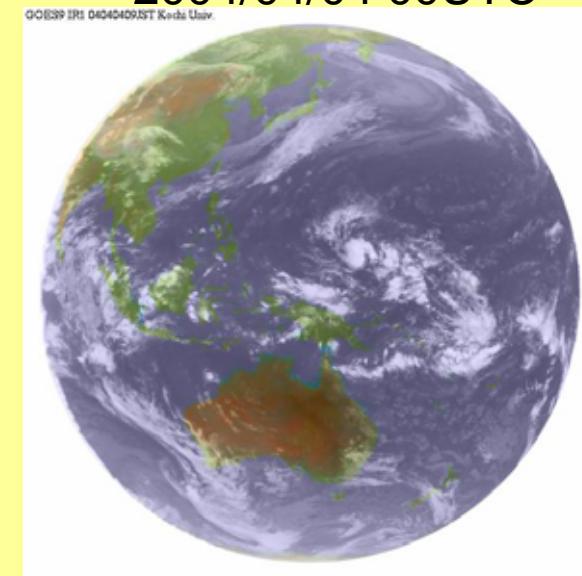
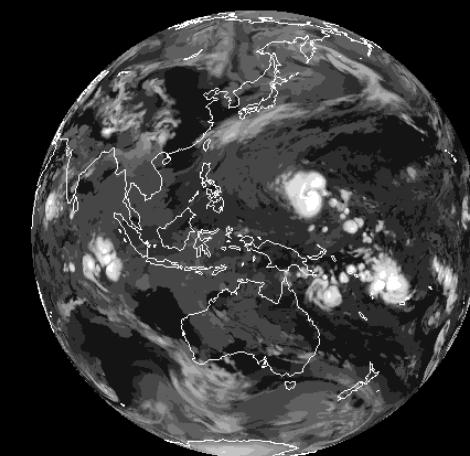
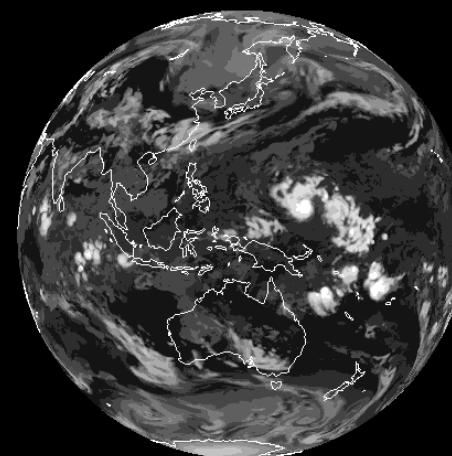
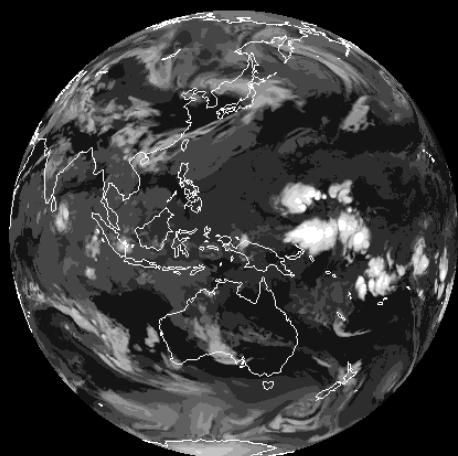
2004/04/02 00UTC



2004/04/03 00UTC



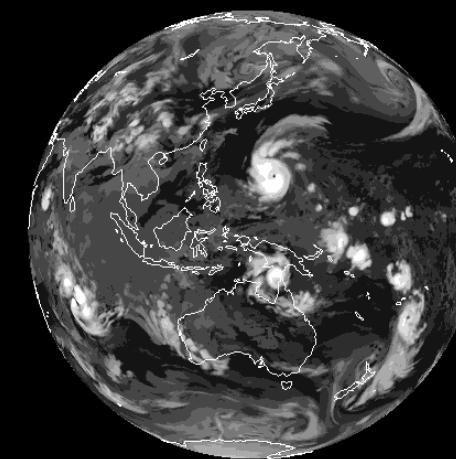
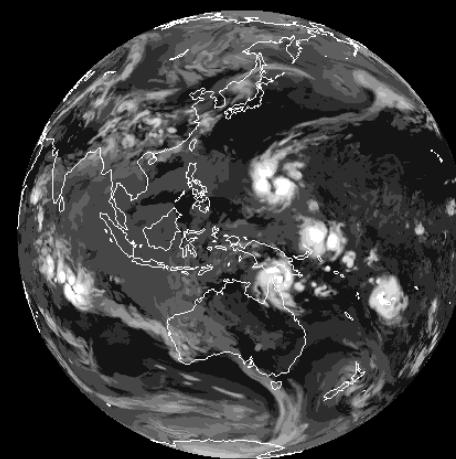
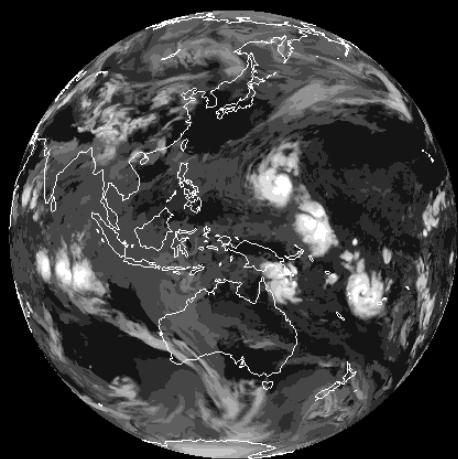
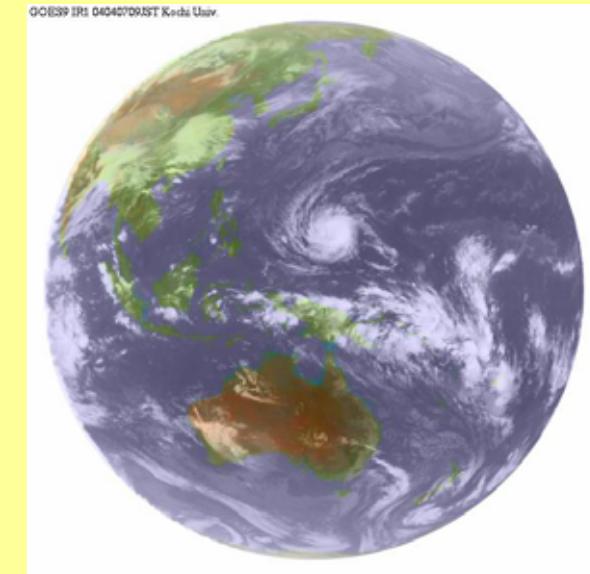
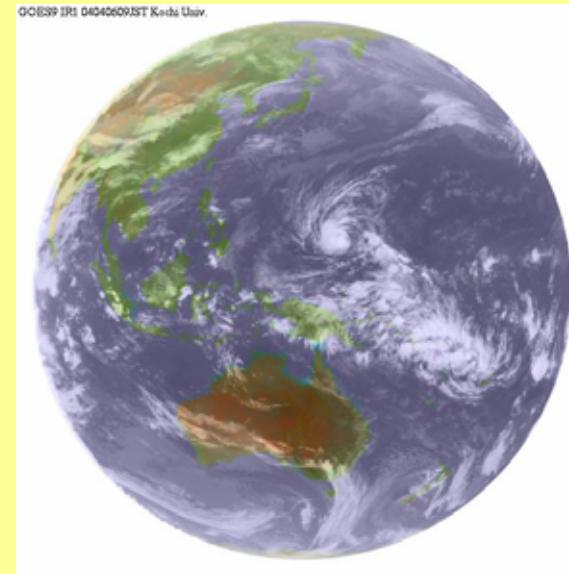
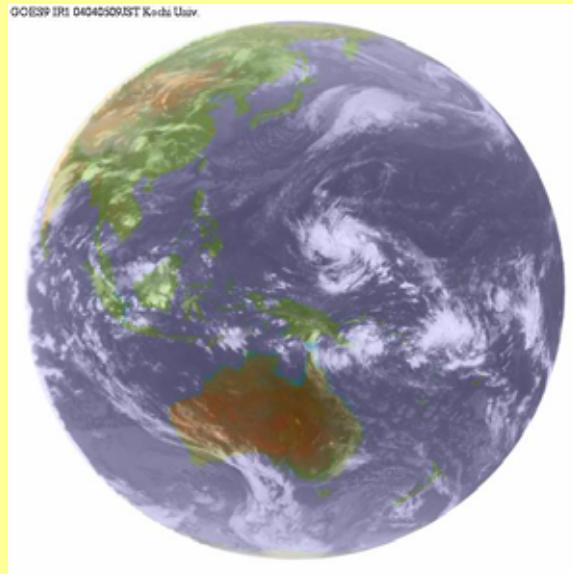
2004/04/04 00UTC

GOES-9 Kochi-Univ. (<http://weather.is.kochi-u.ac.jp/>)

2004/04/05 00UTC

2004/04/06 00UTC

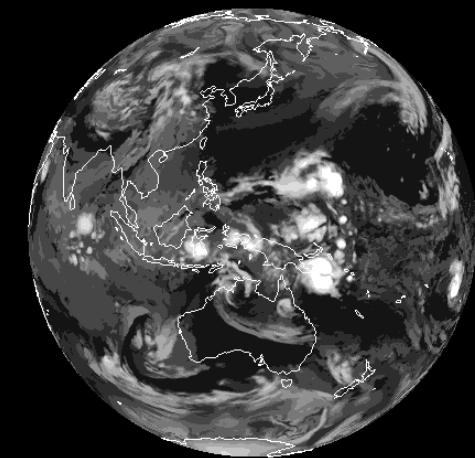
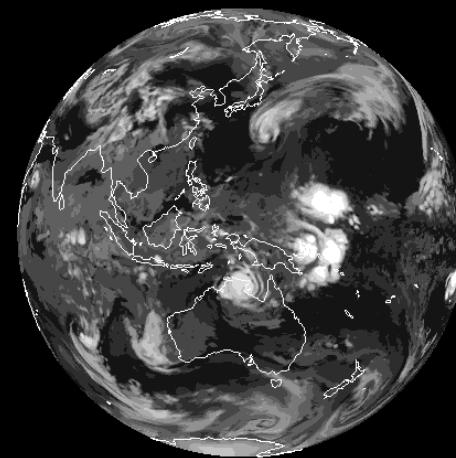
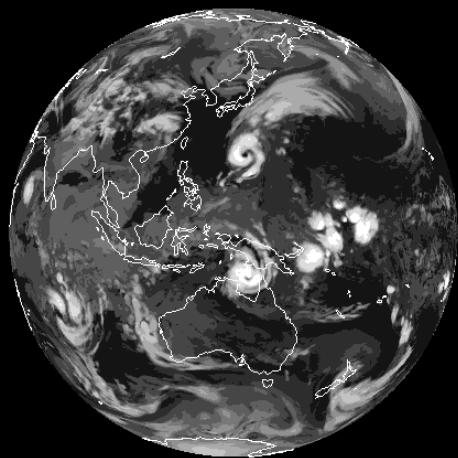
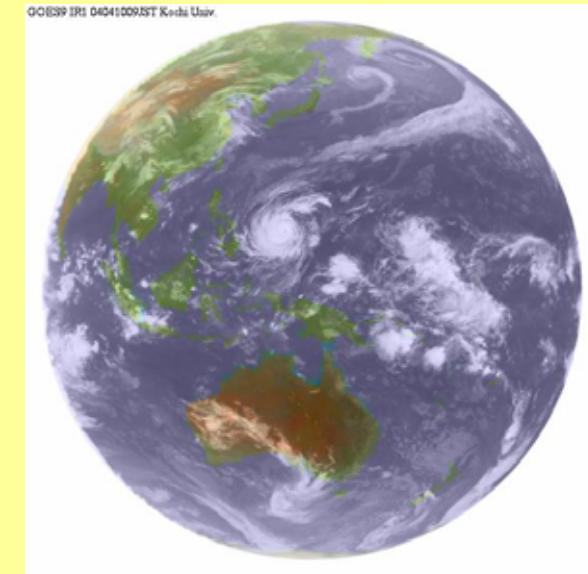
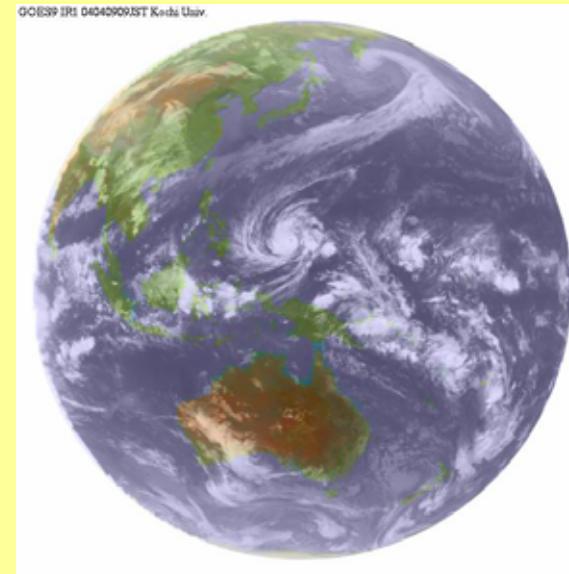
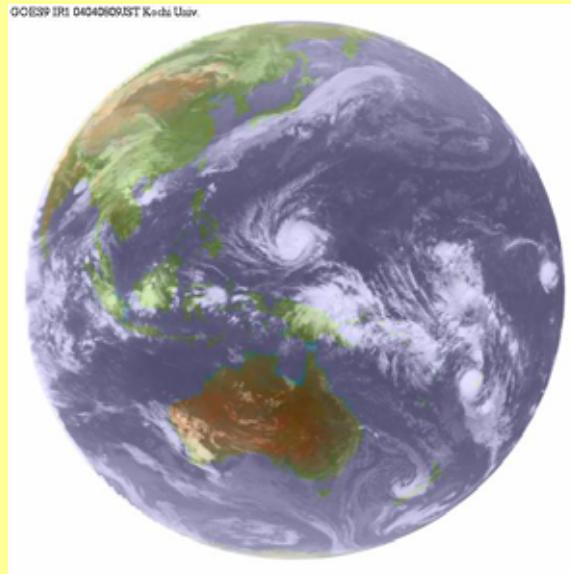
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2004/04/09 00UTC

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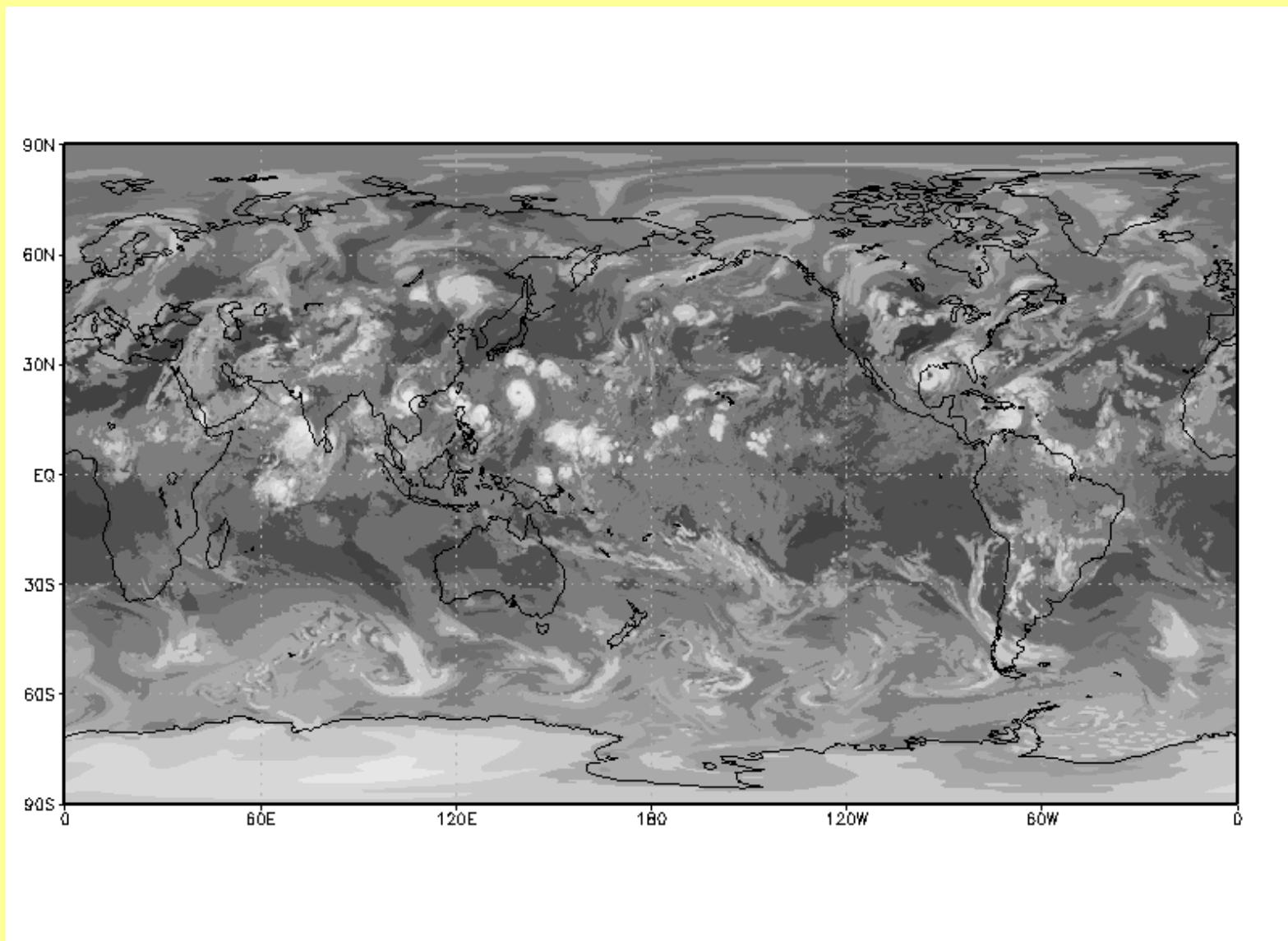


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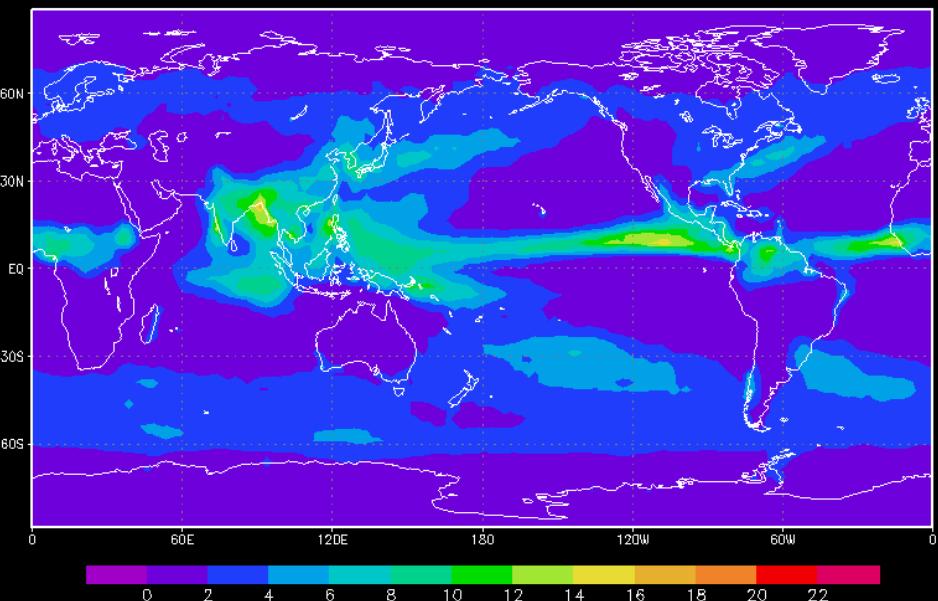
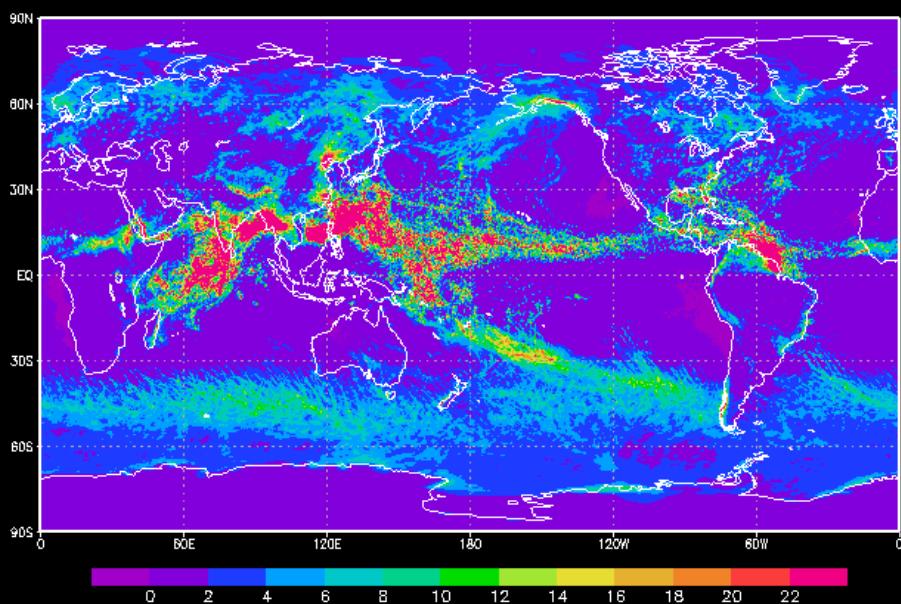
# Long wave radiation (38<sup>th</sup> day)



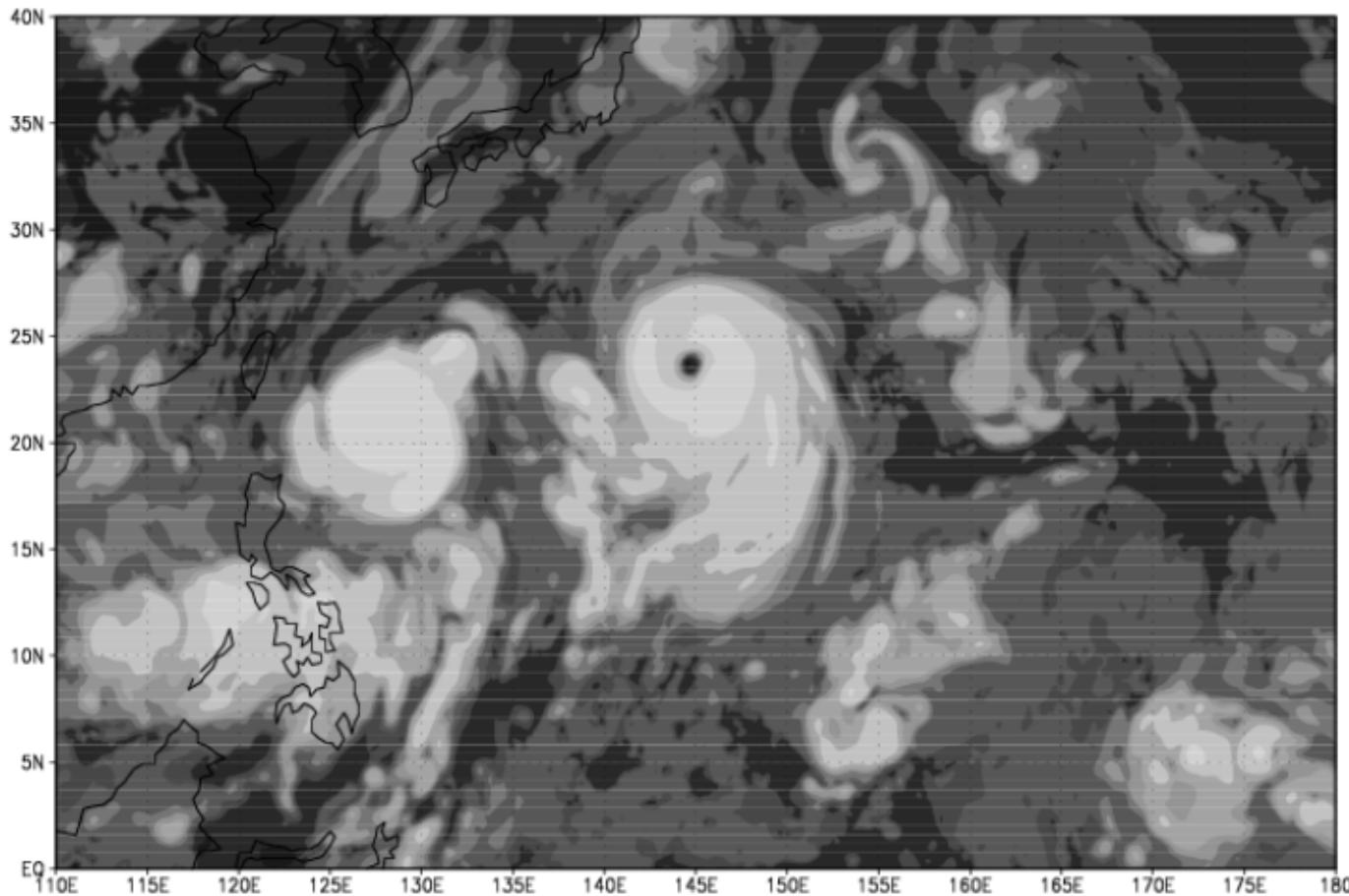
# July mean precipitation

30 day mean precipitation  
(NICAM)

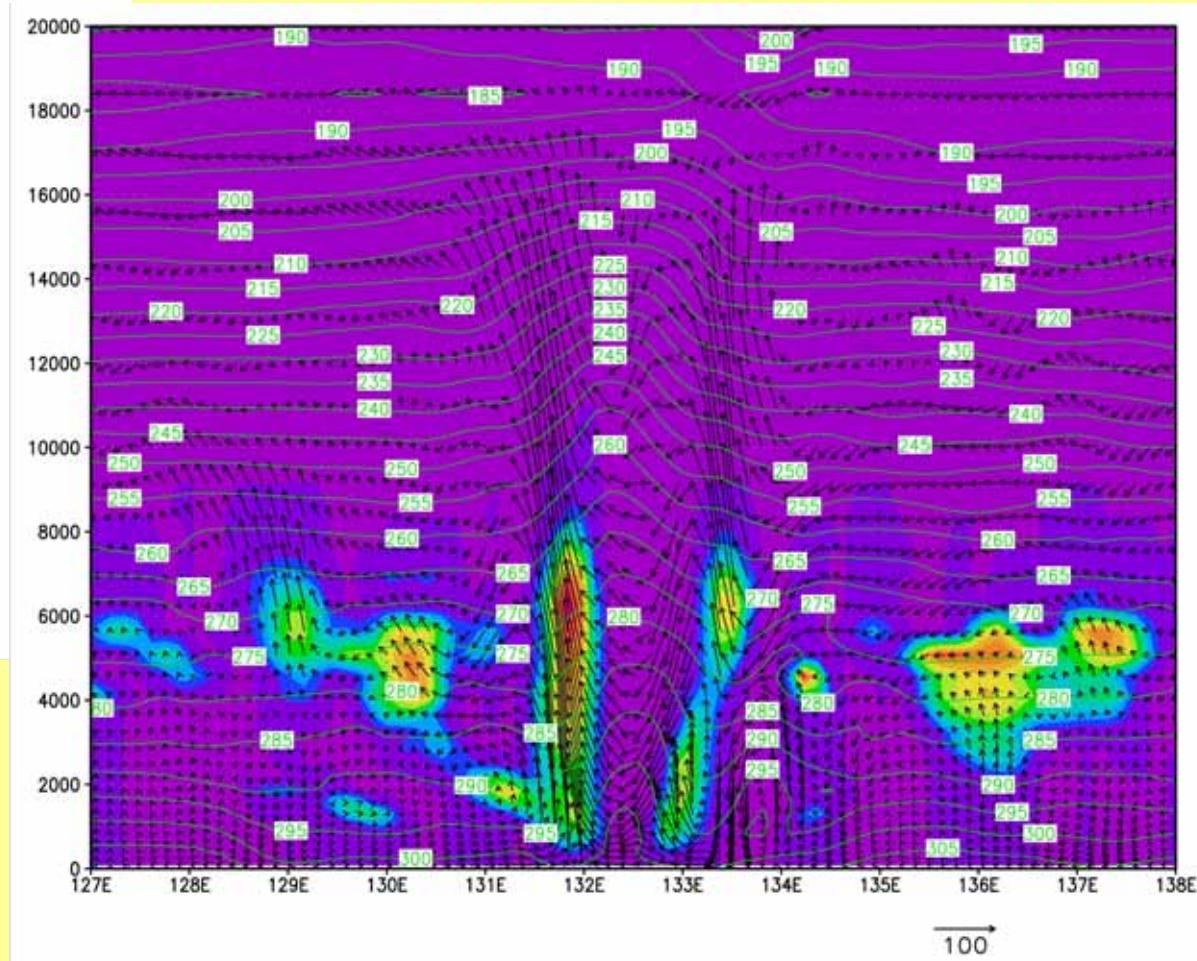
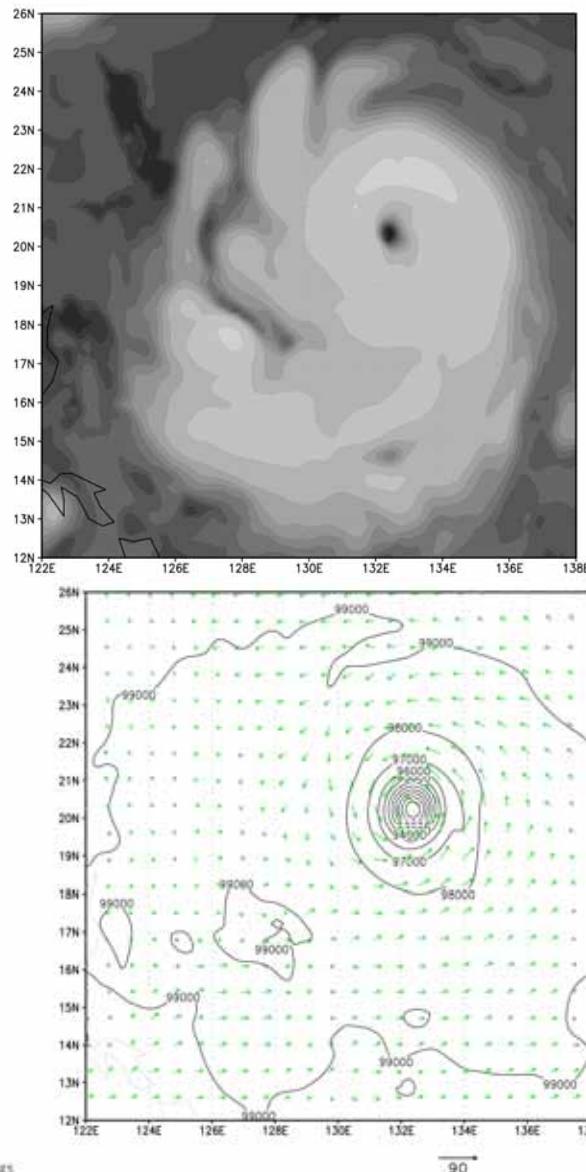
GPCP July1979-2005



# Long wave at top of atmosphere



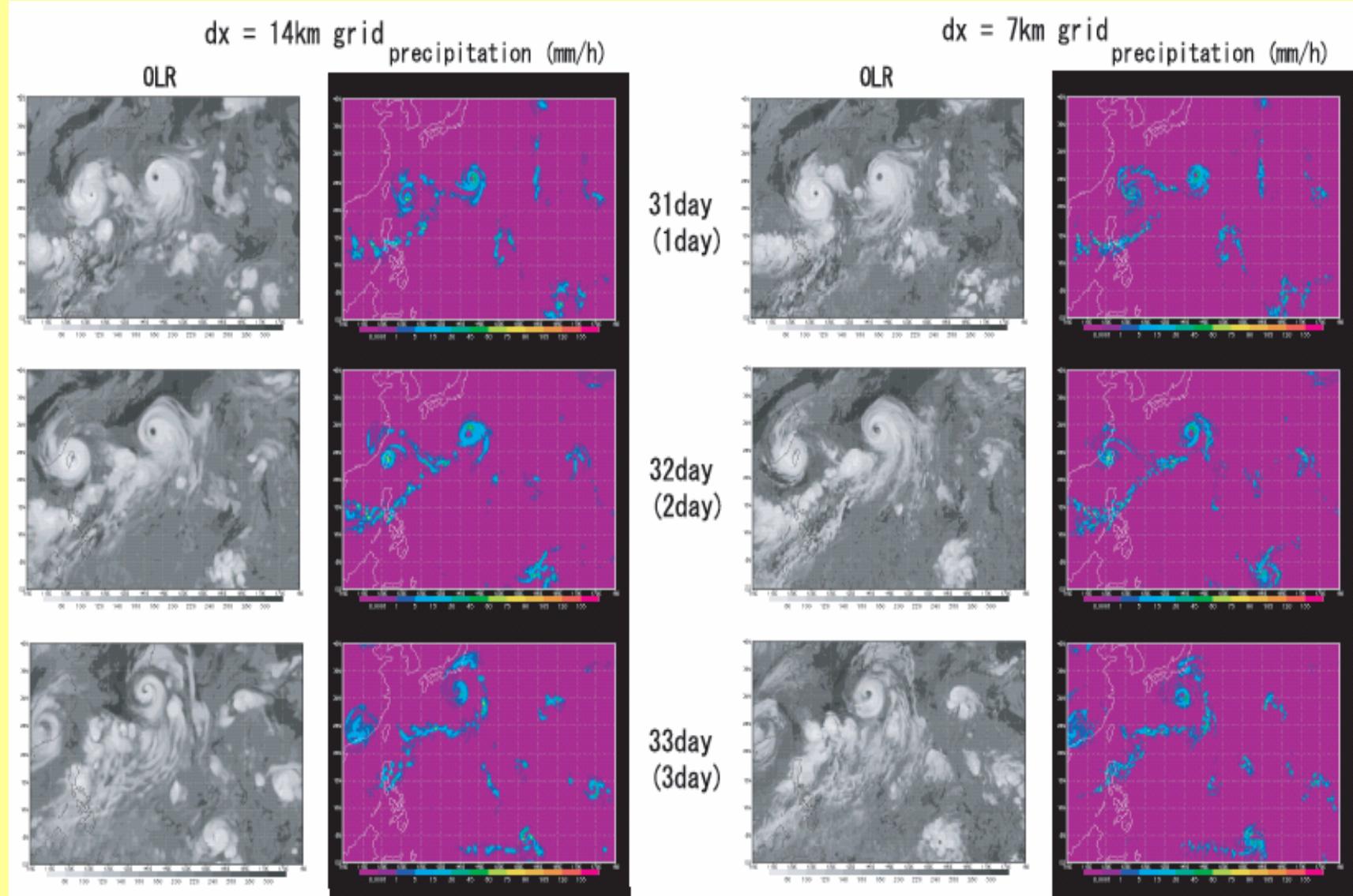
# Typhoon



Pressure at the center is less than 870hPa!



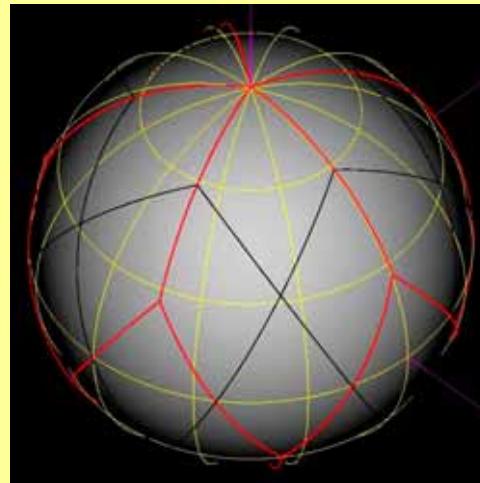
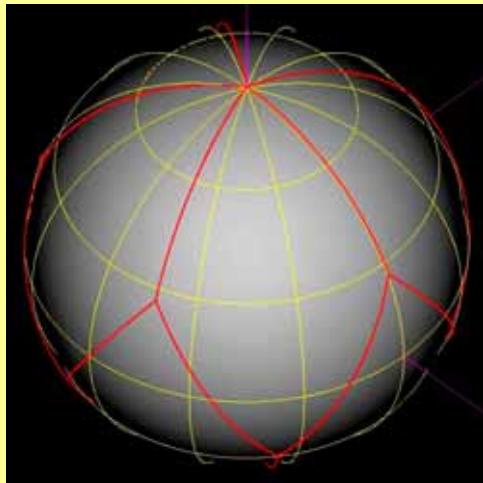
# Typhoon: 14km vs 7km



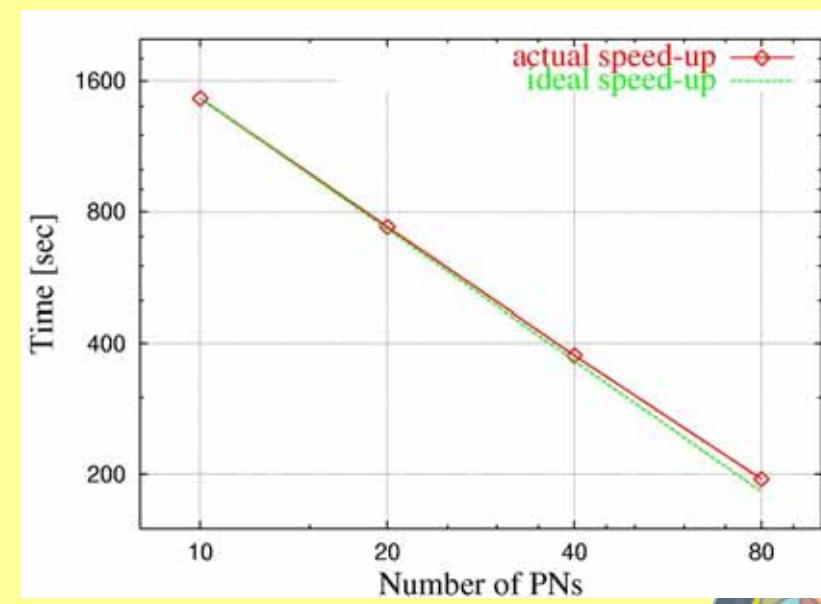
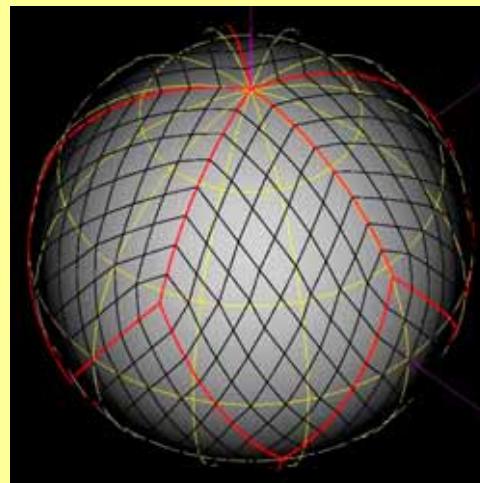
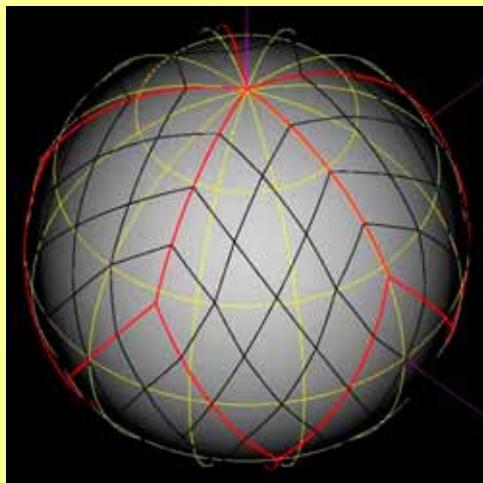
# Computer performance on the Earth Simulator



# Parallelization & Scalability



**glevel-8:  $dx \sim 30\text{km}$ ,  
L100  
1node=8CPU**



Satoh et al.(2005, *J. Earth Simulator*)**Table 2** Computational performance of the aqua planet experiments with NICAM.

NICAM	glevel 9	glevel 10	glevel 11
$\Delta x$	14 km	7 km	3.5 km
$\Delta t$ [sec]	30	30	15
nodes	80	320	320
1 day time [hr]	0.64	0.81	5.28
GFLOPS	1911.8	7607.6	7701.5
sustained performance[%]	37.3	37.1	37.6

**5h for 1day exp. using half of ES****3.5km-10days exp. requires 1% of 1year ES resource****1TB for 3.5km-10days exp., 90min interval**

## ■ Earth Simulator

- 3.5km mesh global model の1日積分  
ES の半分(320ノード)を用いて 6h

## ■ 10PF machine: 250 times of ES

- 高解像度化: 400m-メッシュ全球モデル  
ES の  $8 \times 8 \times 4 = 256$  倍
- 長期積分: 3.5km-メッシュ 100年
- 物理過程の精緻化: ビンモデル (30bins) &エアロゾル  
3次元放射、乱流
- 大気海洋結合、統合化モデル(生態系、化学、エアロゾル、...)
- 全球雲解像モデルによる多様な感度実験、アンサンブル



- 気象学では、先端マシンだけでなく、通常業務・研究に使えるマシンが必要
  - 1日計算してすぐに結果がわかる程度のサイズの研究が主体
  - 高解像度化が目標ではなく、予測精度の向上が目標
- ESや京速計算機のような先端マシン
  - demonstration run, product run (IPCC run)  
可能性を示すための計算、後にどう続くか道筋の提示が必要
  - パラメータスタディは行いにくい  
感度実験  
Ensemble run: cf. 1000個の実験
- 京速時代への期待:
  - さらなる高解像度化はdemonstration runとして価値
  - ESによってリードしたポジションを維持
  - 「全球雲解像モデル」が当たり前に使えるようになる状況が望ましい: ES class が汎用的に
- Vector vs scalar
  - 気象モデルのコアとしては、大規模ベクトルが望ましい  
高解像度、長期積分
  - massive scalarへの移行はさほど困難ではない?
- Vector-scalar hybrid
  - 統合モデルにより、多様なプロセスが導入される  
ベクトルになじまないコード
  - ベクトル・スカラーhybridマシーンの利用は未知数
- 専用チップ?
  - 各物理過程ごとにコード: 放射チップ?
- 新しい計算技術、スキームの開発
  - 気象学の分野の中できちんと人材を育てるべき
  - 汎用カップラーなどの計算周辺ツールの開発



# Summary

- A global cloud resolving model (GCRM)
  - Nonhydrostatic system & Icosahedral grid: NICAM
  - avoid ambiguity of cumulus parameterizations
  - Use of the Earth Simulator
- An aqua-planet-experiment  $dx=3.5\text{km}$  and 54 layers
  - Hierarchical structure of cloud convection
  - Moist Kelvin wave structure with realistic phase speed
  - Stronger rain, higher cloud top, larger clusters
- GCRM runs on the realistic land-ocean distribution
  - Short term exp.(Apr.2004) with  $dx=14\text{km}$
  - Perpetual July with  $dx=14\text{km}$
  - $dx=7, 3.5\text{km}$ , on-going
- Toward 10PF era
  - High-res., longer, more physics, ensemble
  - GCRM becomes a standard tool

