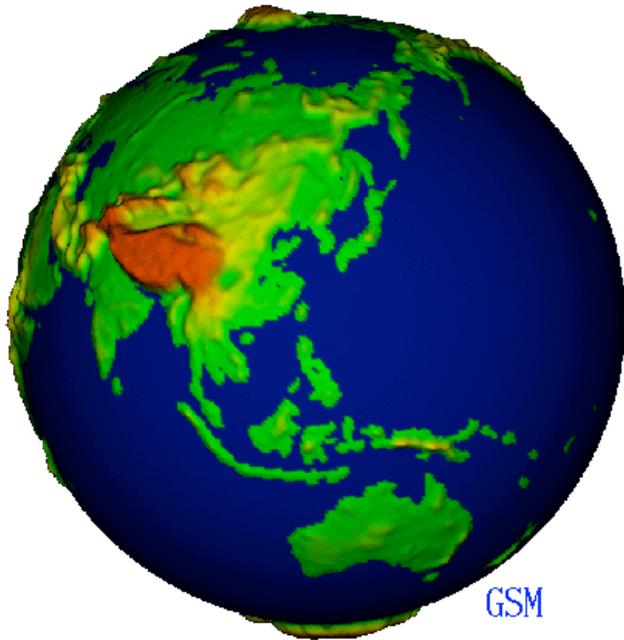# Cloud and convection in the JMA NWP Models

Kazuo SAITO

Numerical Prediction Division, Japan Meteorological Agency
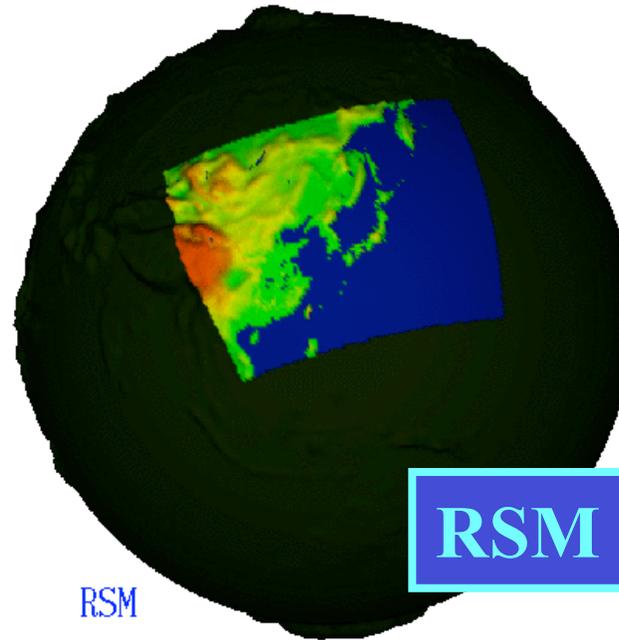*1-3-4, Otemachi, Chiyoda-ku, Tokyo 100-8122, JAPAN, ksaito@npd.kishou.go.jp*

1. NWP models at JMA
2. Cloud and convection in the global model
3. Cloud and convection in the regional models
4. Cloud and convection in the nonhydrostatic model
5. High-resolution run with the Earth Simulator
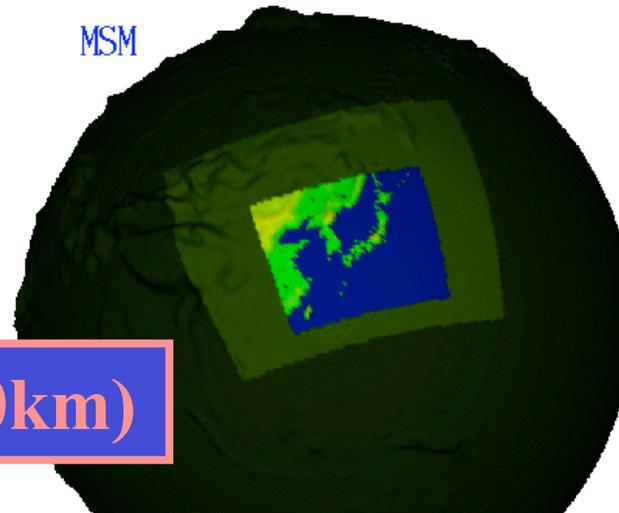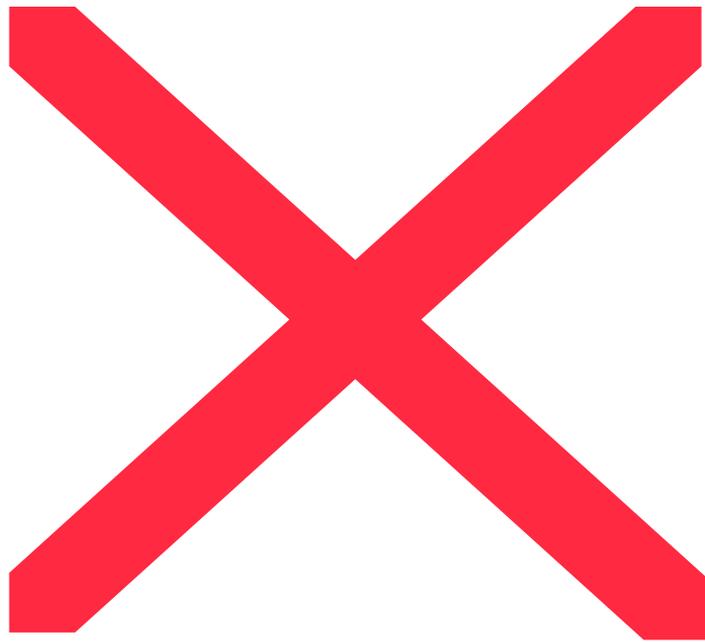6. Future plans

1. NWP models at JMA

GSM

RSM

MSM

RSM (20km)
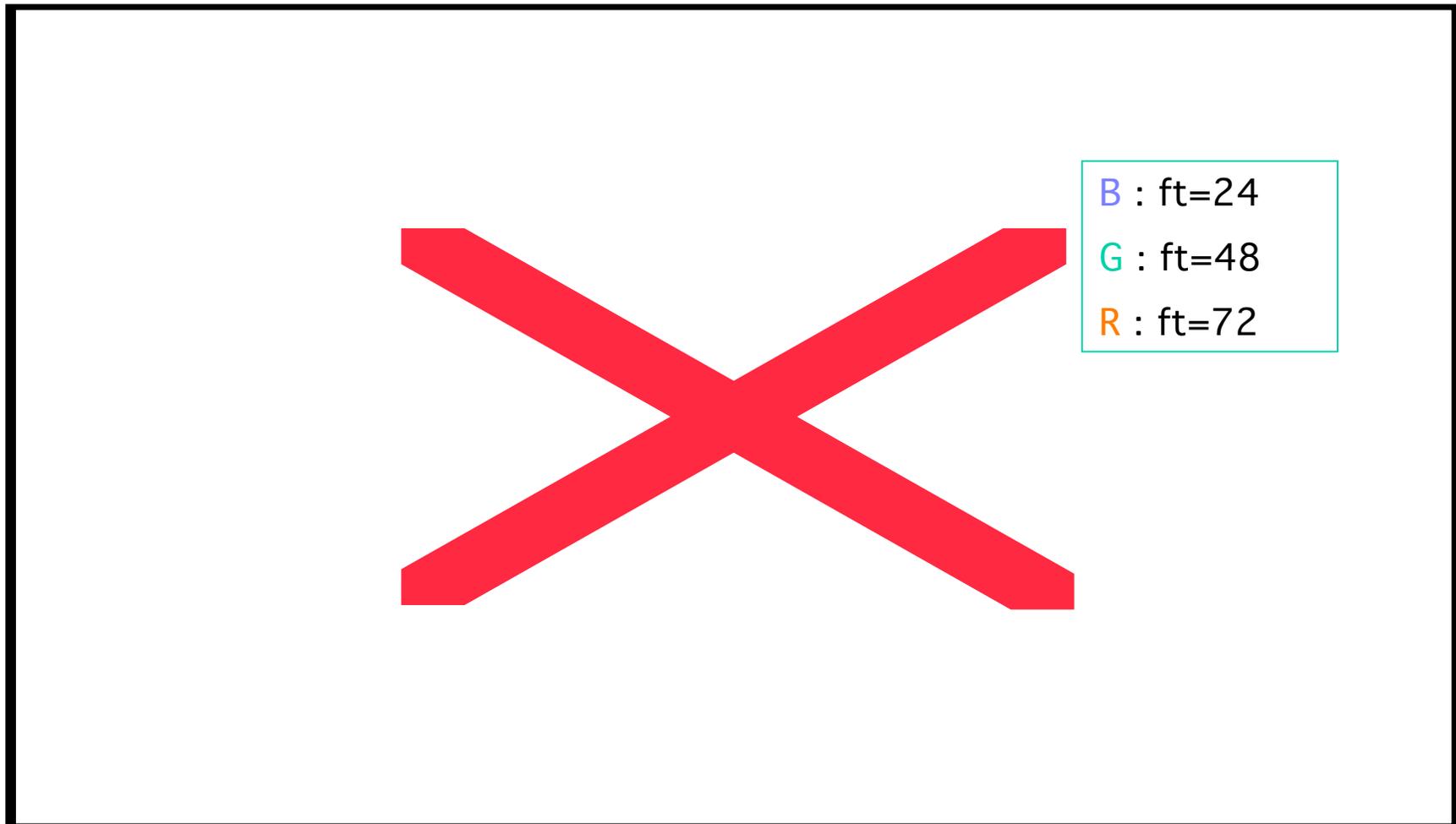
GSM (60km)

MSM (10km)

NWP models at JMA

2. Cloud and convection in the global model

B : ft=24
G : ft=48
R : ft=72

88.3, 89.11 Model change
96.3 Arakawa-Schubert scheme
99.12, 01.03 Revise Arakawa-Schubert scheme

(Ref.) Dynamical framework of JMA GSM

❧ Global spectral model with triangular truncation

    FFT and Legendre transform, Gaussian grid

❧ Semi-implicit (Gravity waves, axi-symmetric advection (water vapor and vorticity))

❧ Hybrid σ-p coordinates

❧ Euler time integration scheme

❧ 4-th order hrizontal diffusion

❧ Nonlinear normal mode initialization with physical processes and tidal waves

Physical processes of JMA GSM
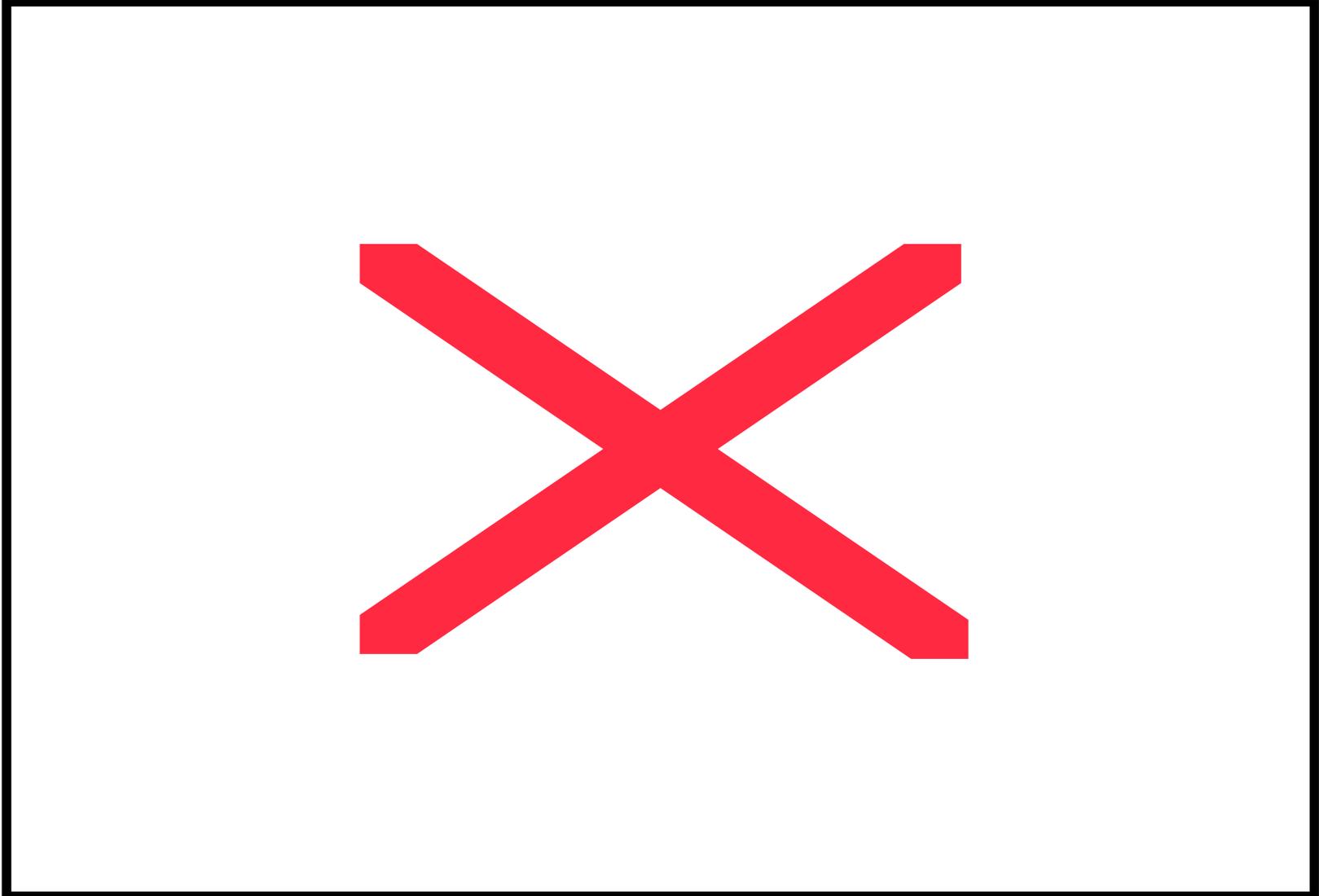
# Recent changes of cloud and convection in GSM

96.03   implementation of the Arakawa-Schubert
         scheme (change from Kuo)

99.12 implementation of the prognostic cloud water
         vertical transportation of horizontal momentum

01.03   evaporation of convective precipitation
         change of computation of static energy at
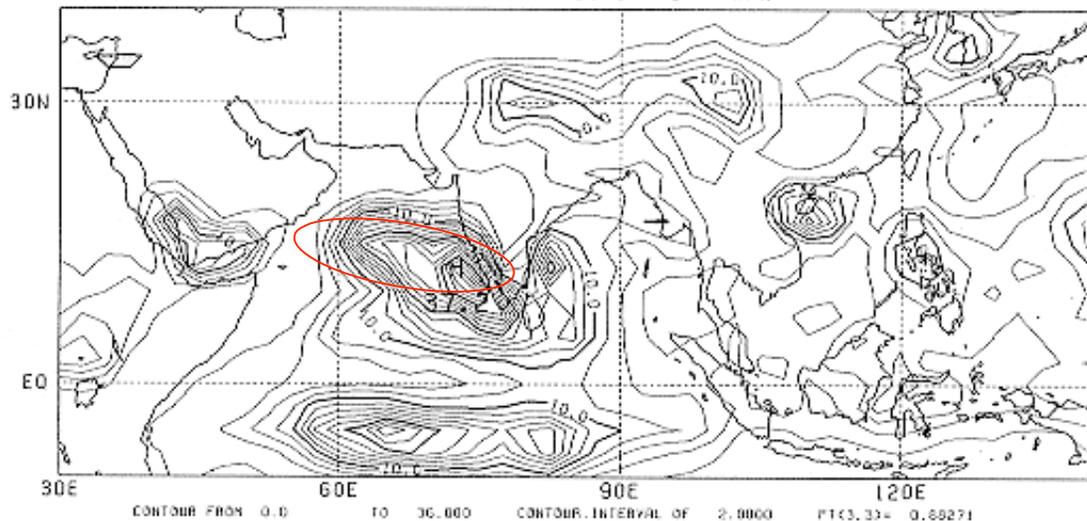   cloud base

Precipitation by Indian monsoon

Kuo

T63
30 day
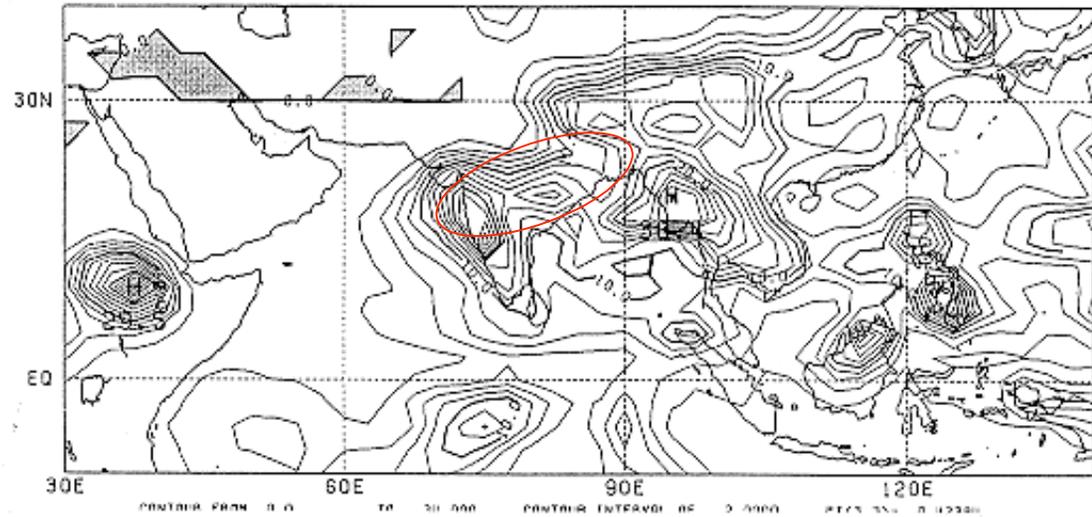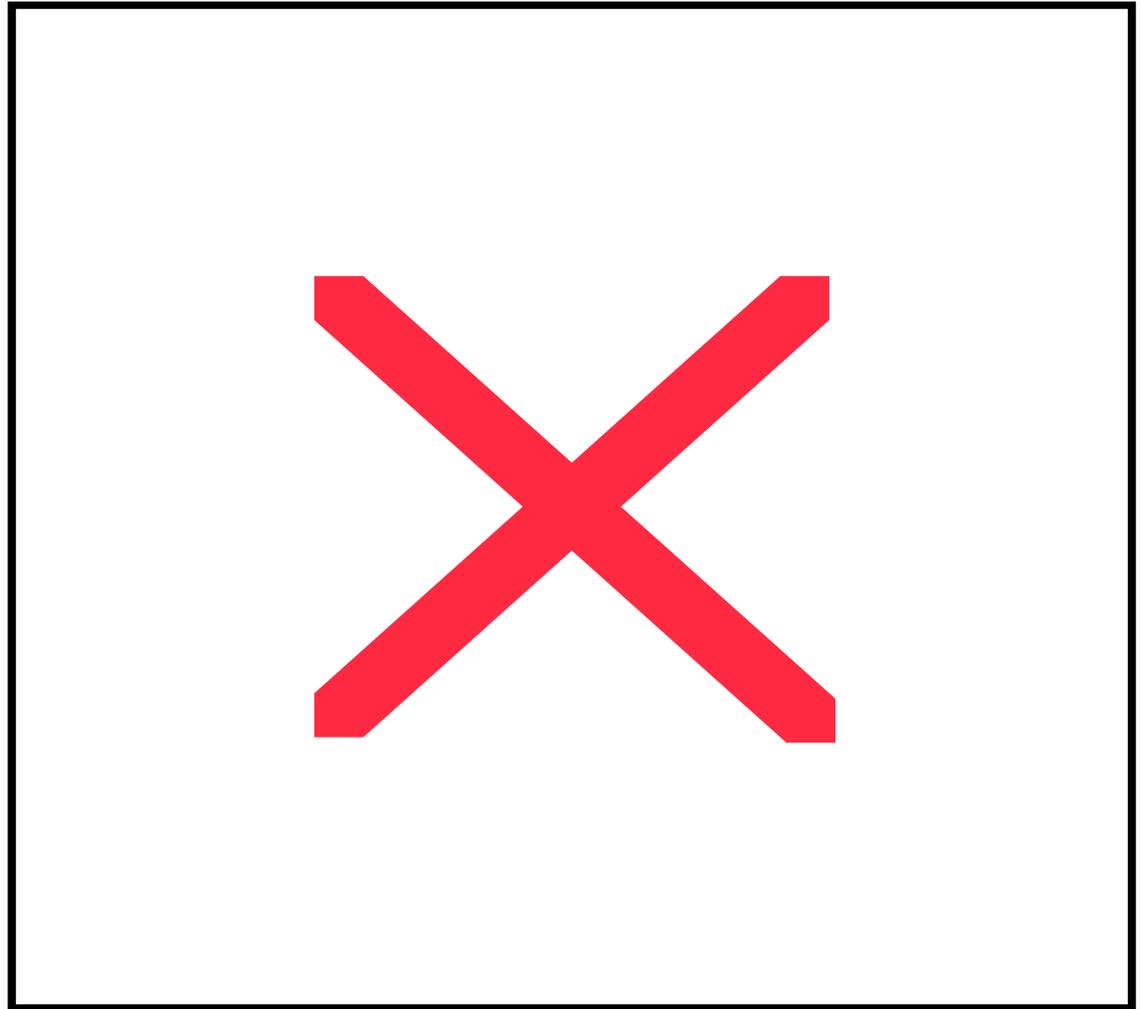
Arakawa-Schubert
GSM9603

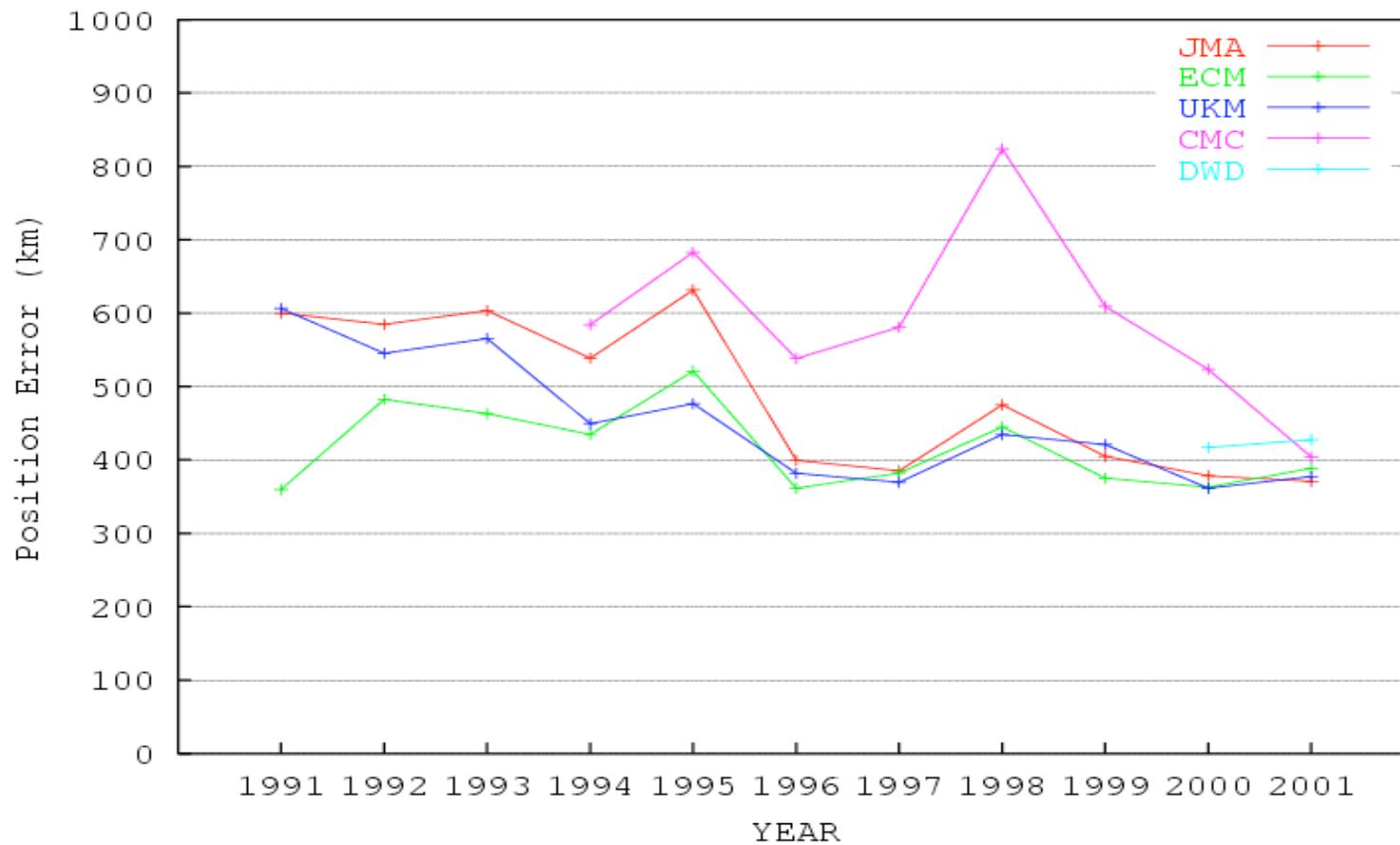# TC track forecast

T106L21 model

Typhoon   8
cases   21

Time series of the position error of 72 hour predictions
of typhoon in Western North Pacific Region

T500 RMSE (NH)

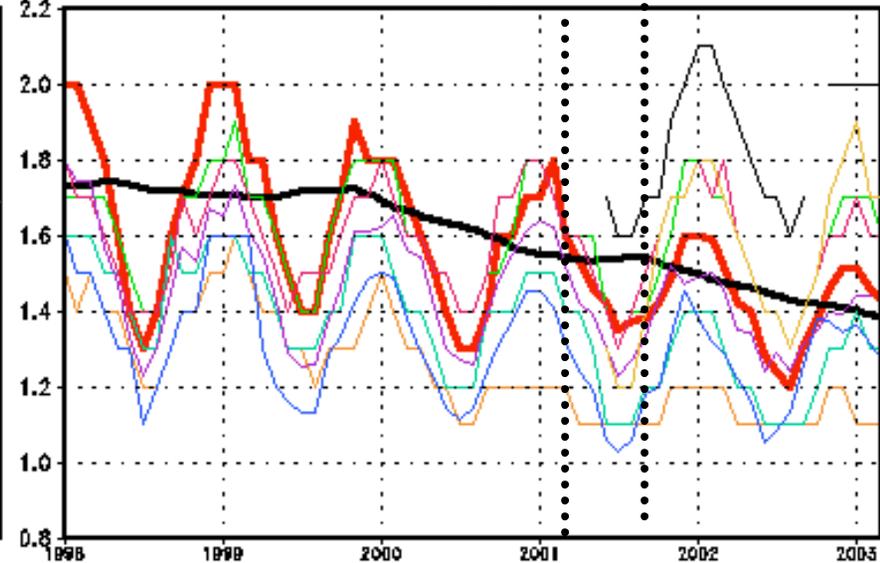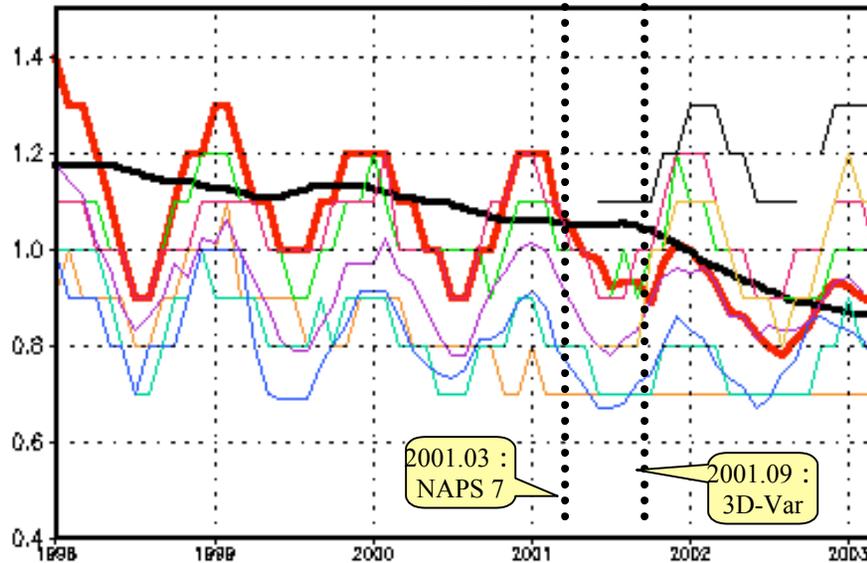JMA (&12month mean)   ECMWF   NCEP   UKMO
MFR   DWD   CMC   NCMRWF   BoM

FT24

2001.03 :
NAPS 7

2001.09 :
3D-Var

FT48

Wind250 RMSEV (NH)

JMA (&12month mean)   ECMWF   NCEP   UKMO
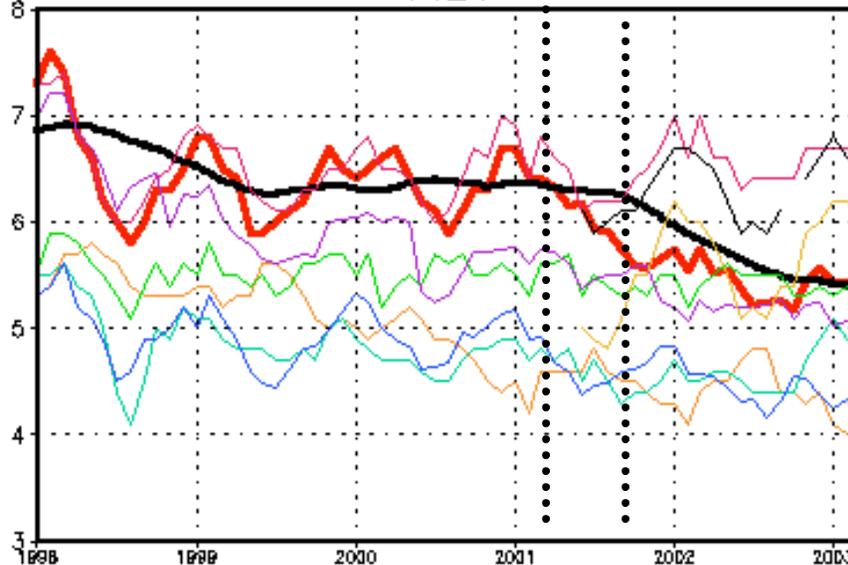MFR   DWD   CMC   NCMRWF   BoM

FT24

FT48
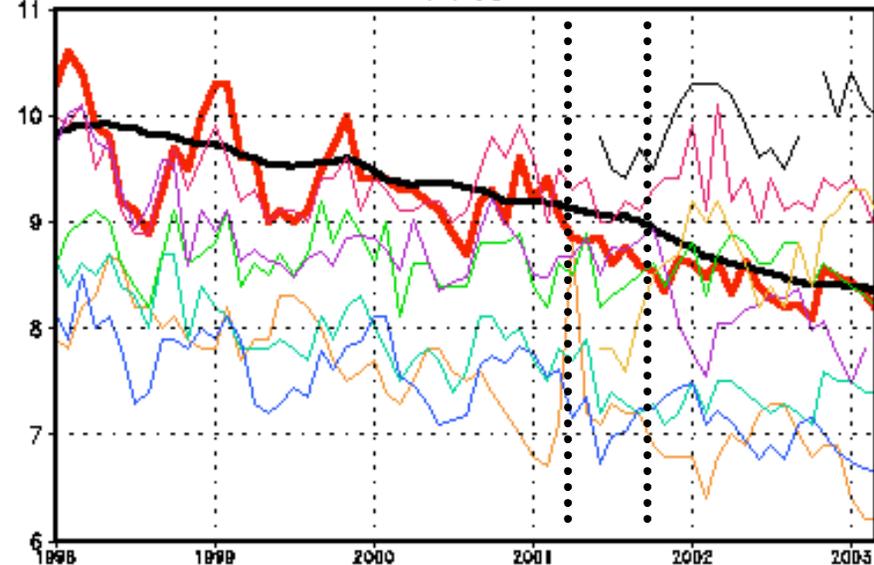
Position errors of TC track forecast by TYM and GSM
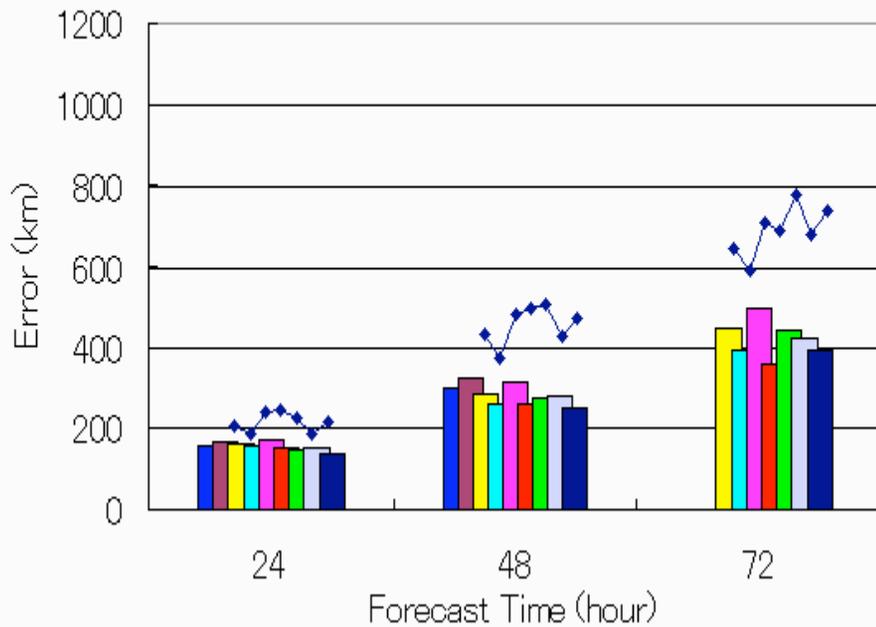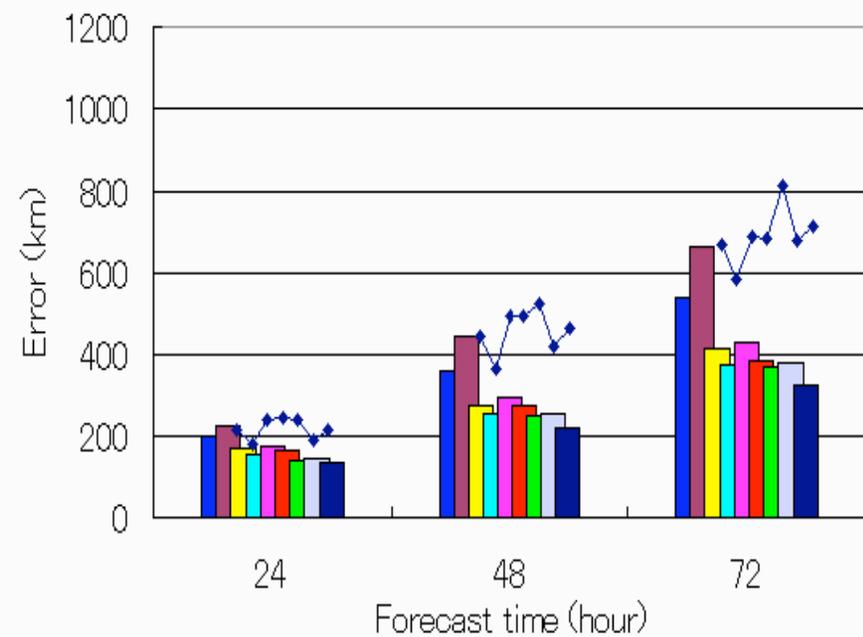
Bias error of 72 hour predictions
# in Western North Pacific Region
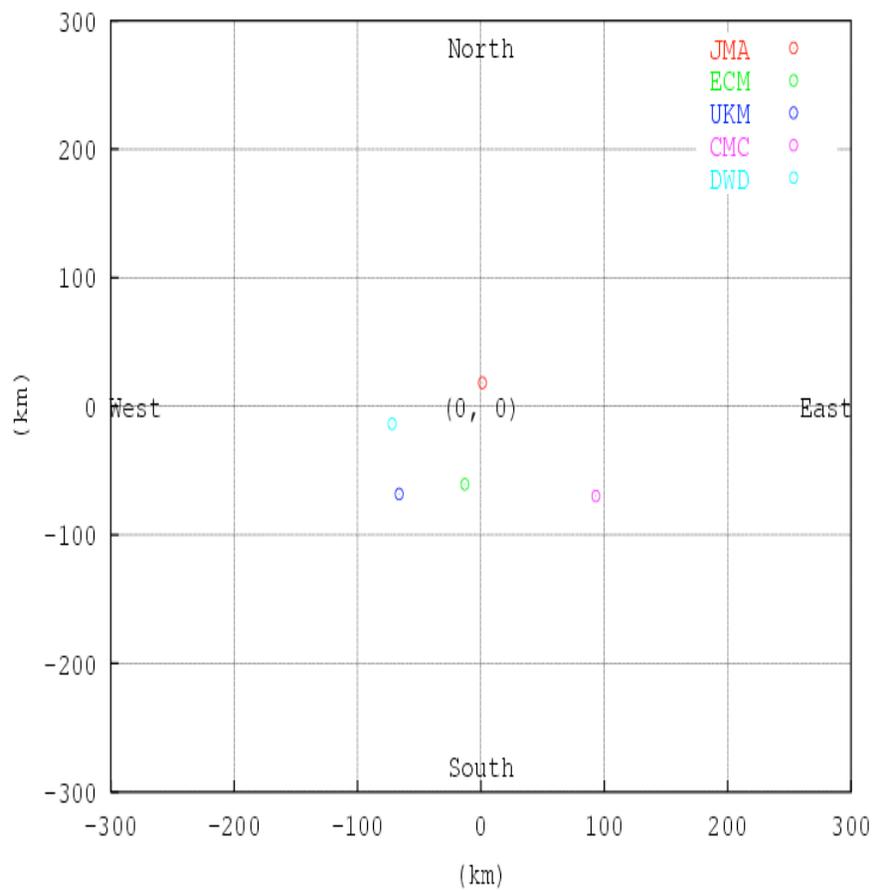

Before recurvature
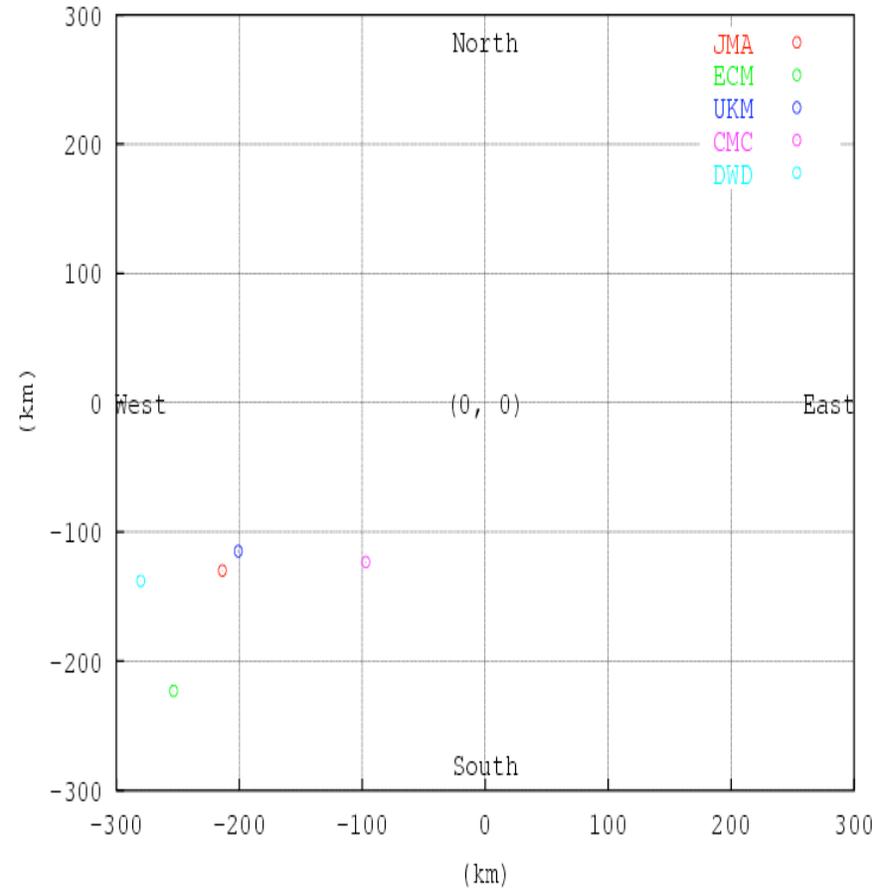
After recurvature

Coming soon

03.05   Revision of AS scheme
entrainment and detrainment in convective downdraft
entrainment and detrainment in vertical transportation of horizontal momentum
inhibit evaporation of convective precipitation (tuning)

(03.05 Direct assimilation of ATOVS (AMUS-A, B) in 3D-Var
03.09   Semi-Lagrangian scheme in GSM
04.09 Implemetation of 4D-Var)

entrainment and detrainment in convective downdraft
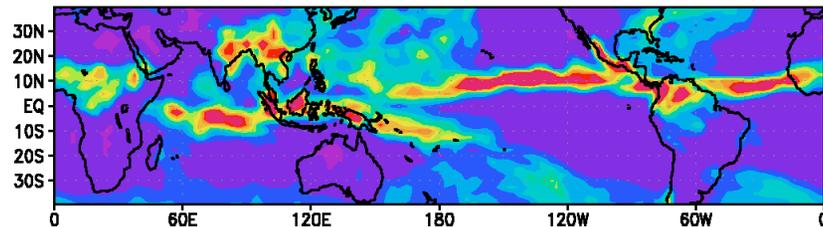
Obs. Precip.

convective downdraft

entrainment
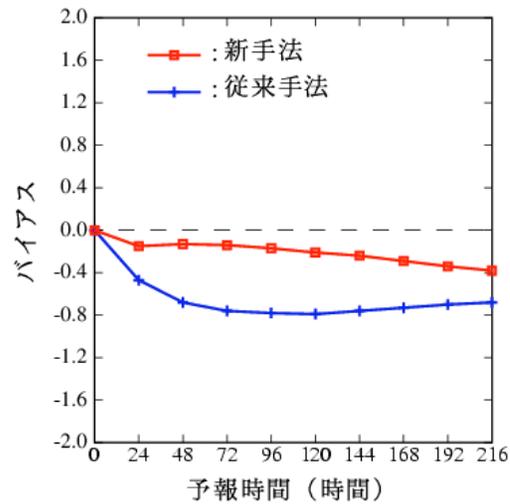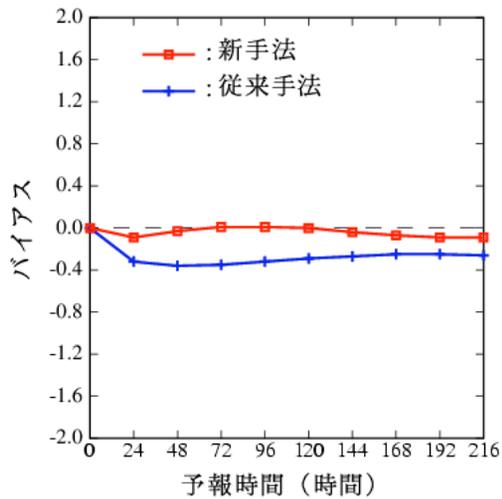detrainment
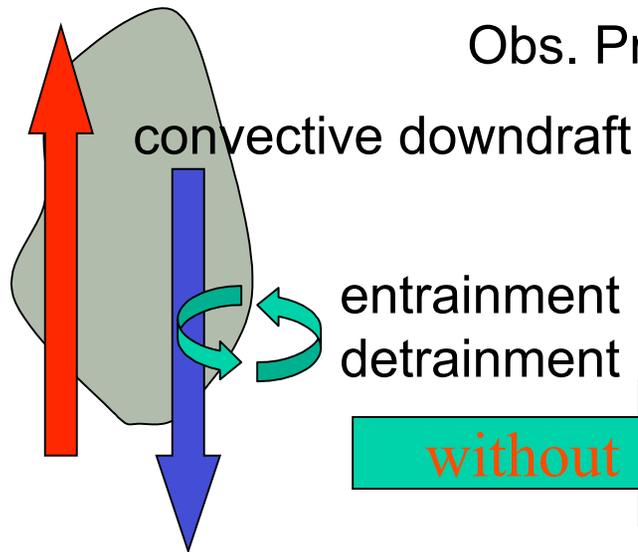
TRMM 3B43 2000 AUG.
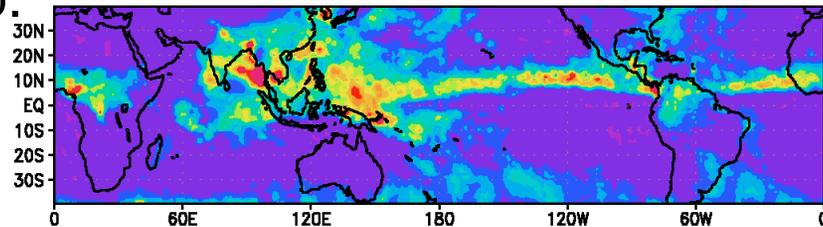
without

no ent/det downdraft

with

with ent/det downdraft

With entrainment and detrainment in convective
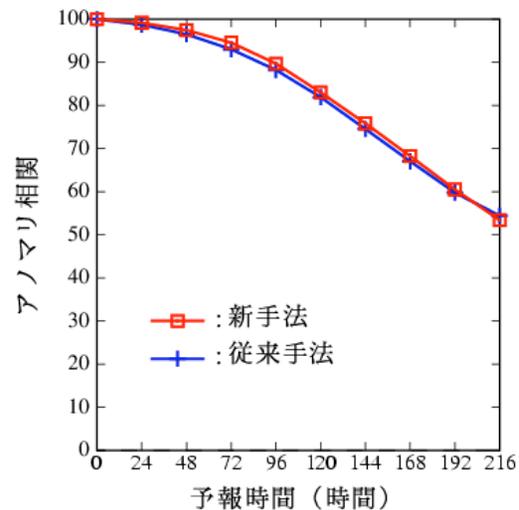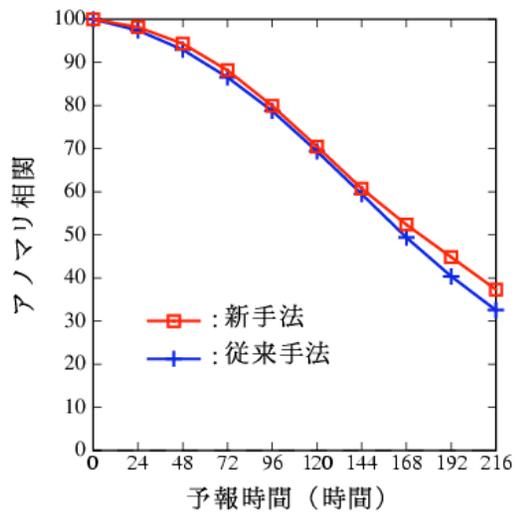downdraft, distribution of precipitation in tropics is improved.

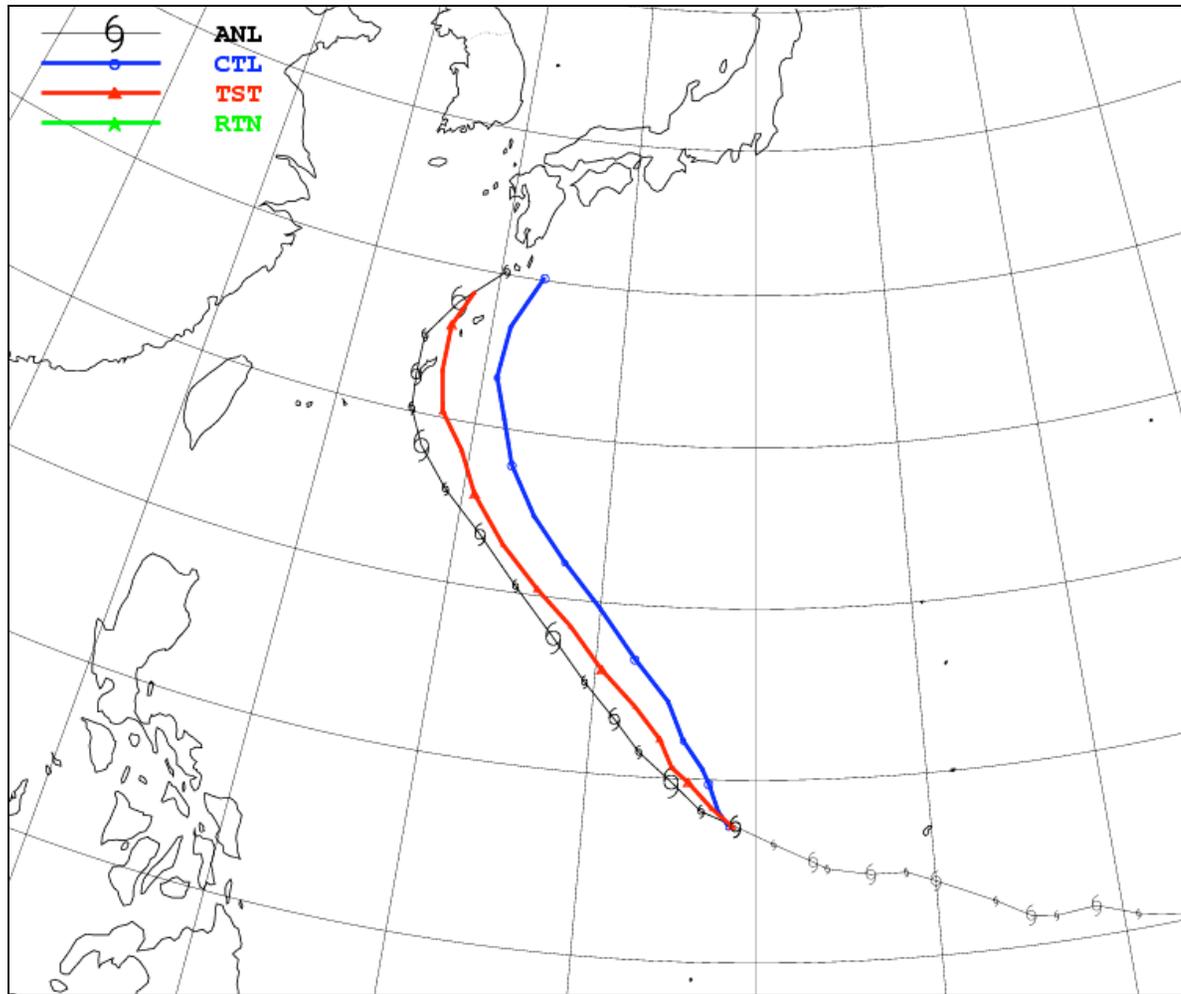# Bias of temperature field at 850 hPa in tropics

Blue: Routine
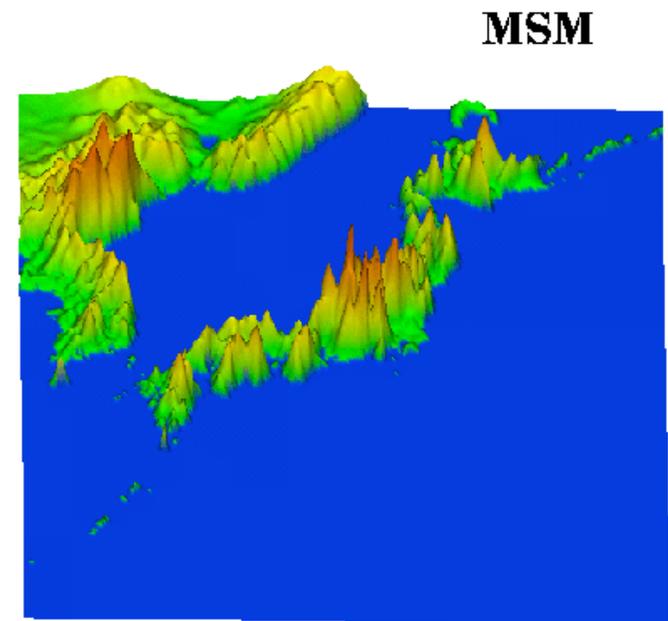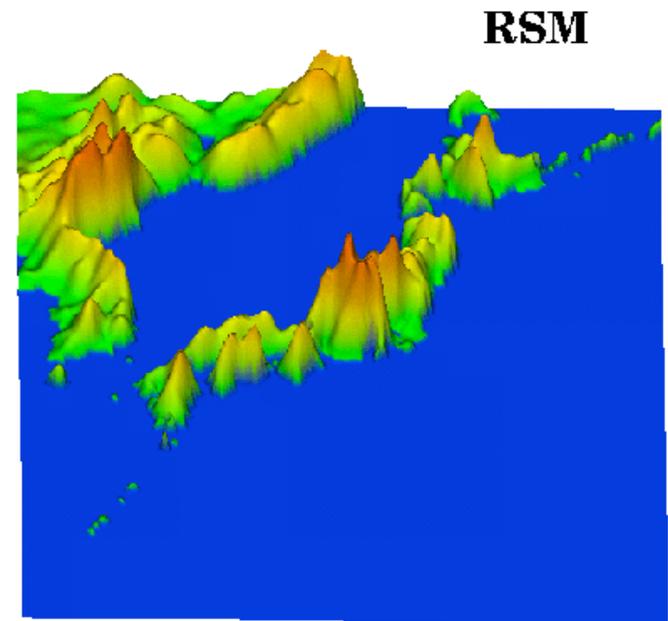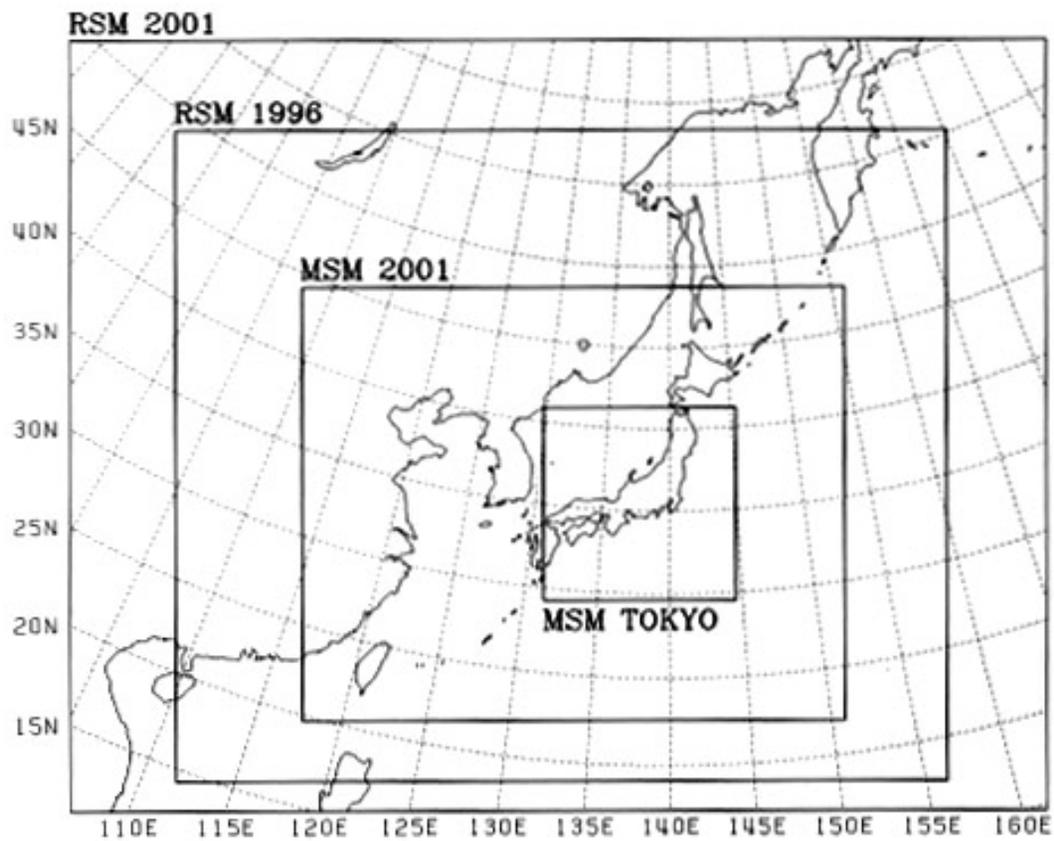Red: Test

Jul. 2002   **Dec. 2001**

Anomaly correlation for global area

TC track forecast
 Initial at 12 UTC,11 July 2002

3. Cloud and convection
in the regional models

Recent changes of cloud and convection in regional models of JMA

96.03   implementation of the Arakawa-Schubert
       scheme (change from Convective
adjustment)
96.07   Use of Convective adjustment together with
        the Arakawa-Schubert scheme for mid-level
        convection
98.10 Physical initialization for RSM

(01.03 Operation of MSM
02.03 Implementation of 4D Var for MSM)

The Meso 4D-Var system of JMA

- Improvement of the initial condition is essential for the short range NWP.

- JMA developed a 4-dimensional variational data assimilation system for MSM [Meso 4D-Var].

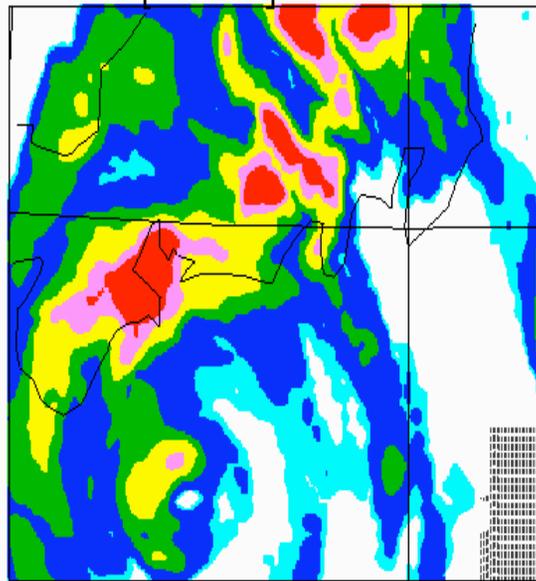- The Meso 4D-Var has been in operation since Mar 2002.
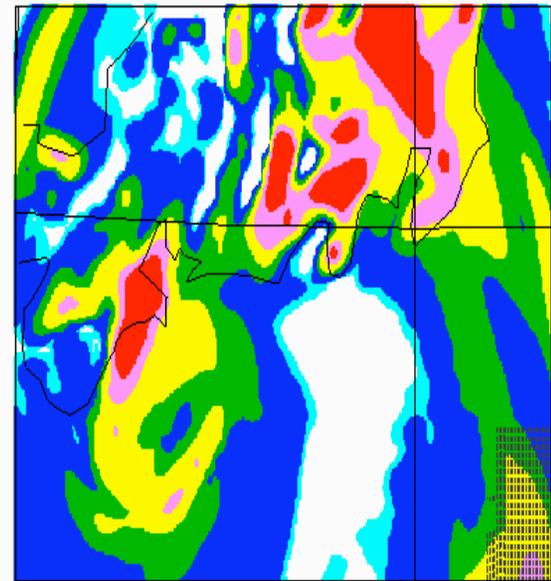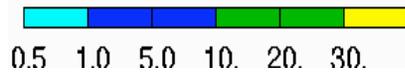
Meso 4D-Var in MSM

Routine   **Observation**   **4D-Var**
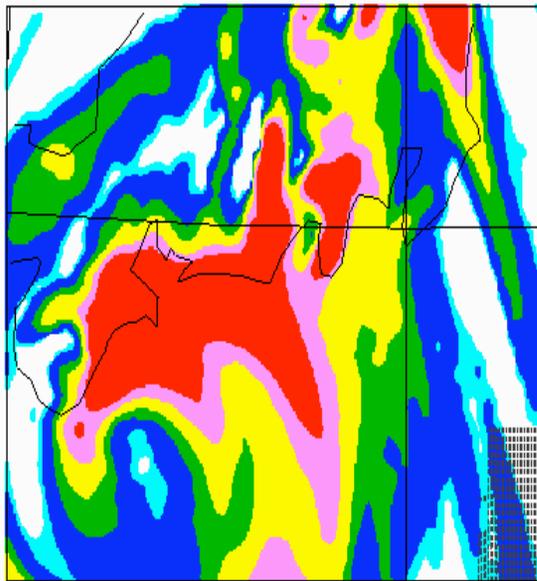
valid: 9/10 03Z - 9/10 06Z   valid: 9/10 03Z - 9/10 06Z   valid: 9/10 03Z - 9/10 06Z

0.5 1.0 5.0 10. 20. 30.

3 hour accumulated rainfall of 18 fours forecast of MSM Initial time 12UTC, 9 September

Coming soon

03.06 Implemetation of 4D-Var for RSM

03.09 Implementation of the prognostic cloud water
        and the AS scheme of GSM9912 in TYM and
     RSM

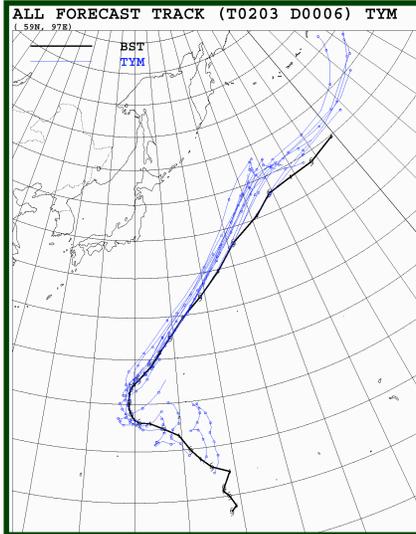04.03 Nonhydrostatic model, replacing MSM

Implementation of the prognostic cloud water and the AS scheme of GSM9912 in TYM

・ physical processes of GSM9912 is implemented to TYM (currently, GSM9603)

- **prognostic cloud water interaction with radiation**

- **new prognostic equation for cloud base mass flux**
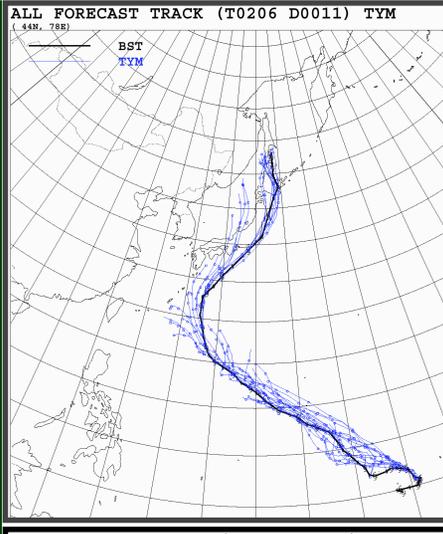
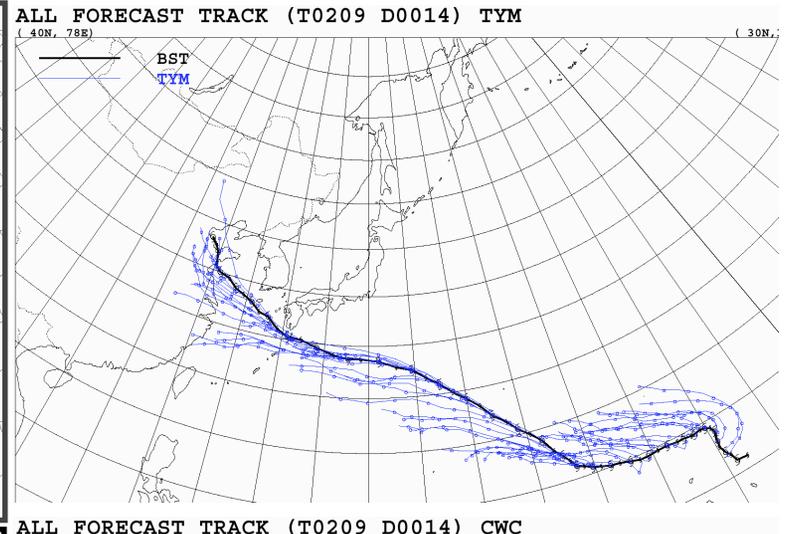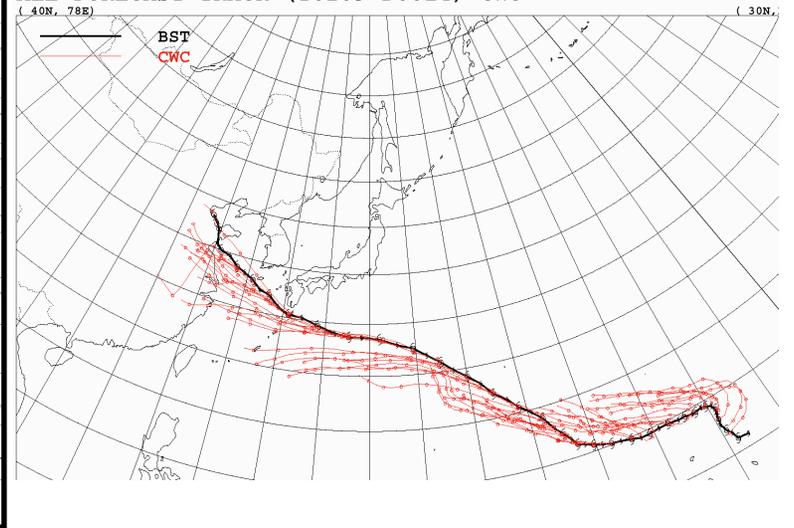- **mid level convection**

Typhoon track forecasts by TYM

T0203　　　　　T0206　　　　　T0209
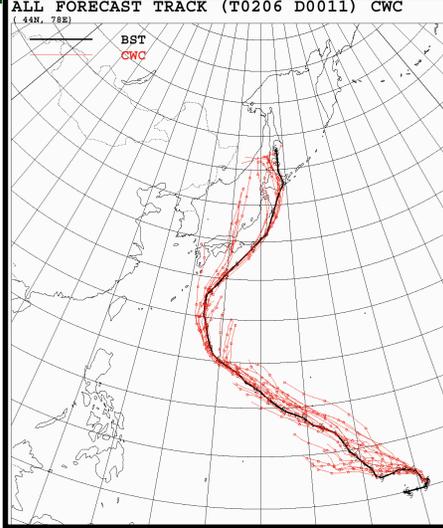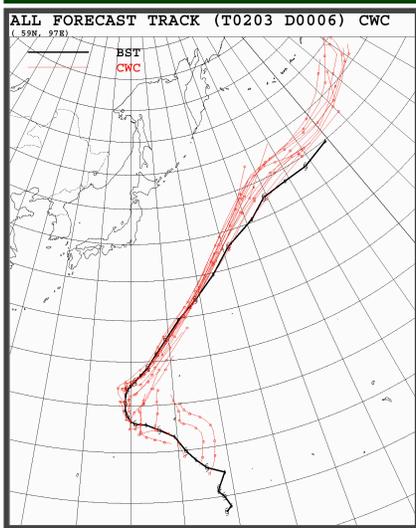
Routine

Test

Enlarged view of forecasts for T0206

①routine TYM
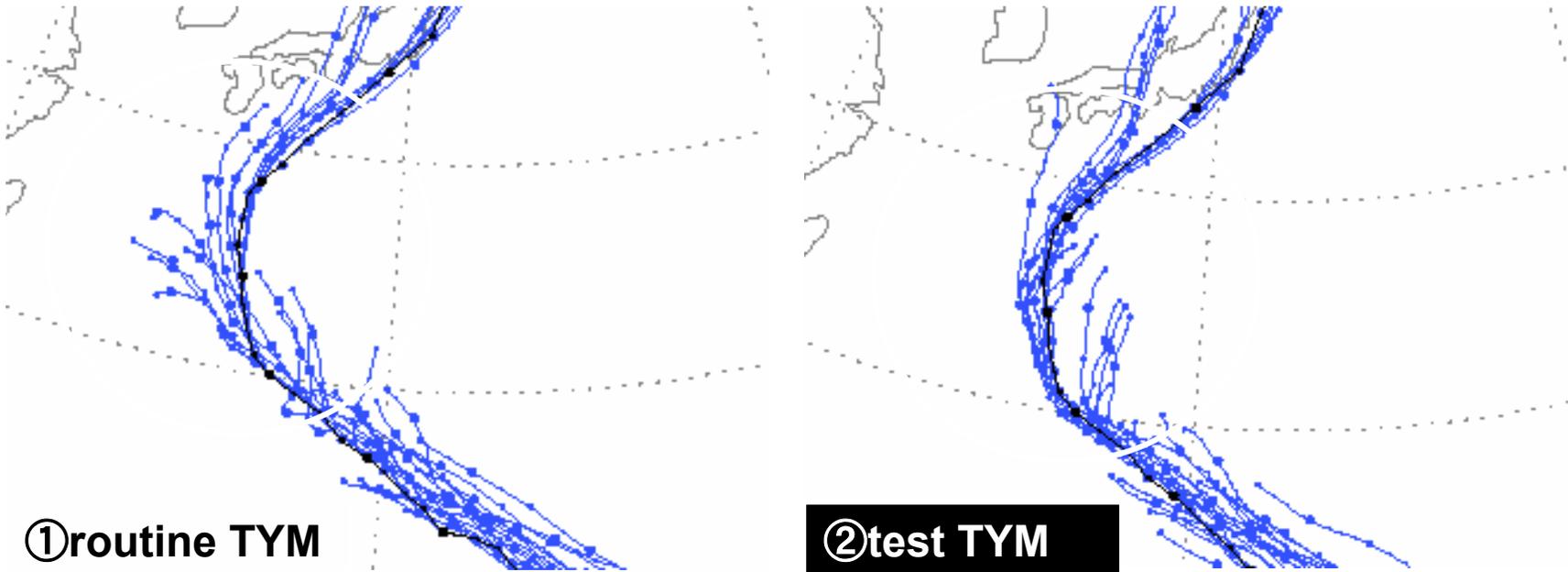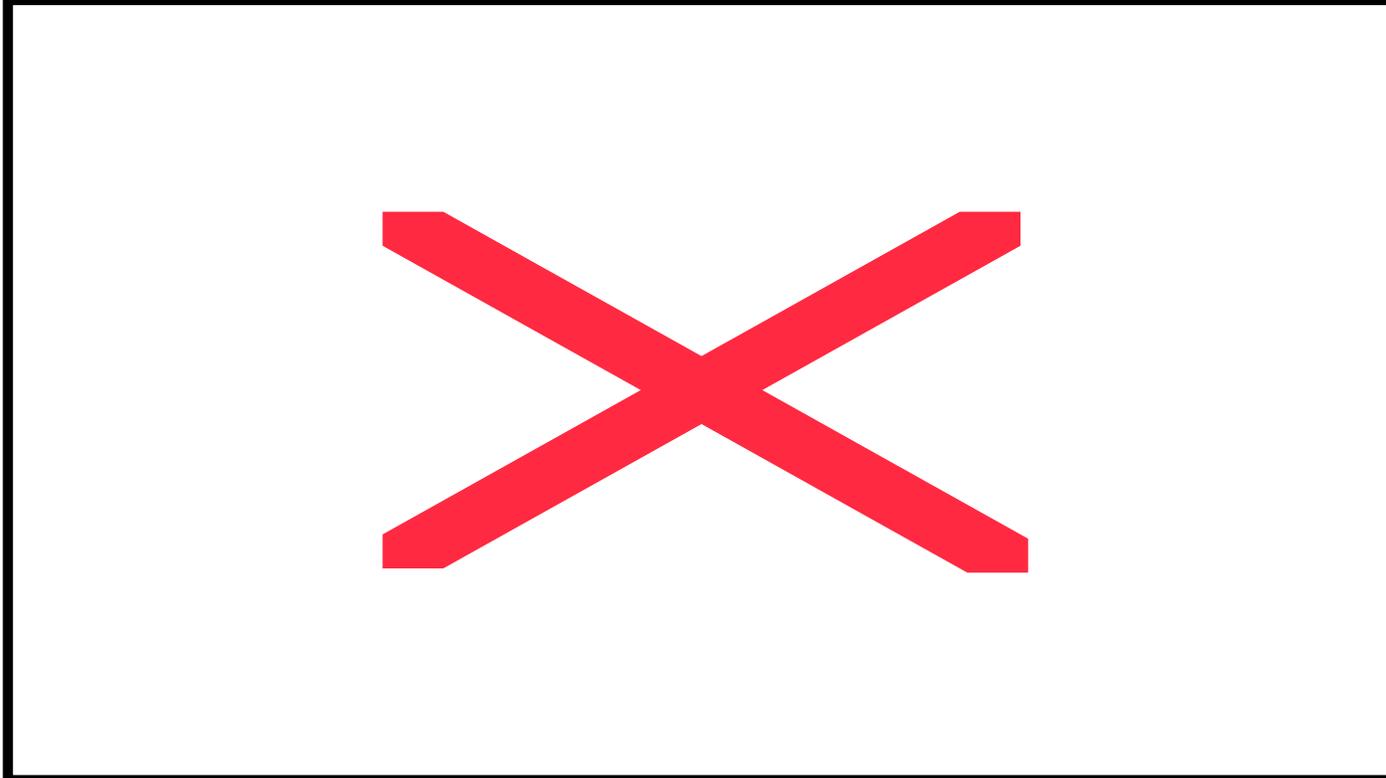
②test TYM

・ **Recurvatures are well simulated by test TYM.**

Typhoon track forecasts by TYM
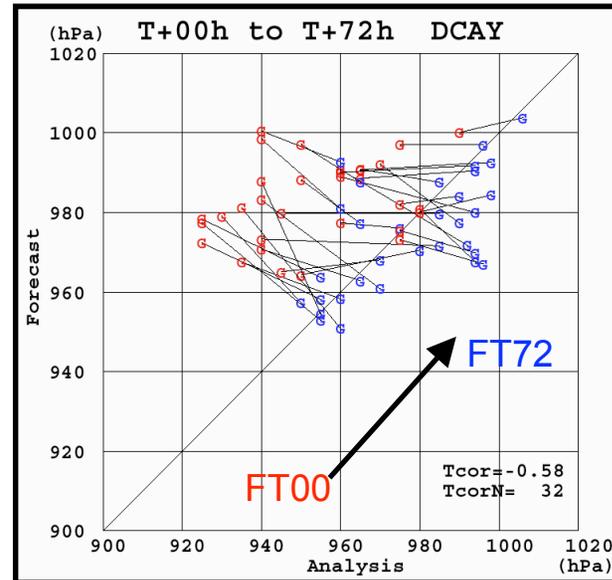

mean position errors are decreased with the new scheme
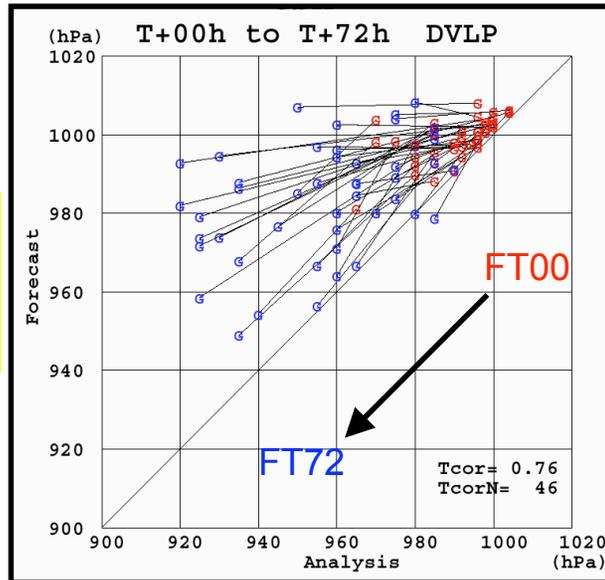
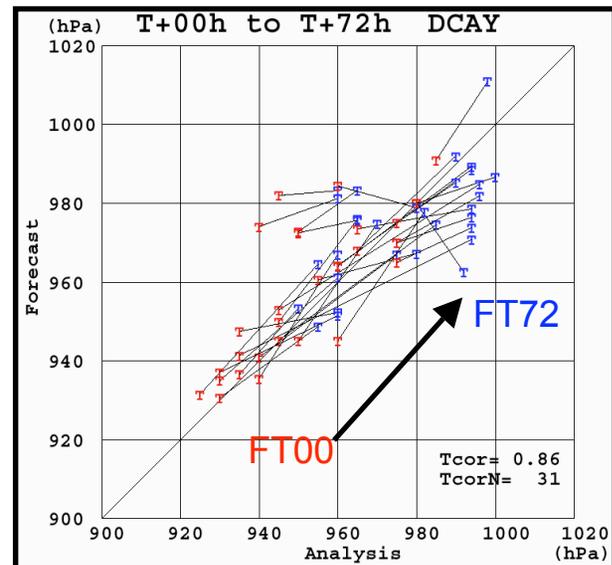# Intensity forecast of GSM9912 and routine TYM for typhoons in 2000
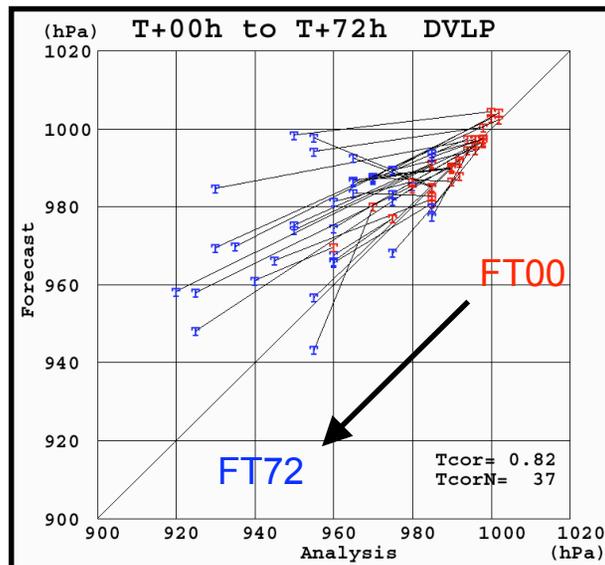
Intensity forecast of routine and test TYM
for typhoons in 2000

routine TYM
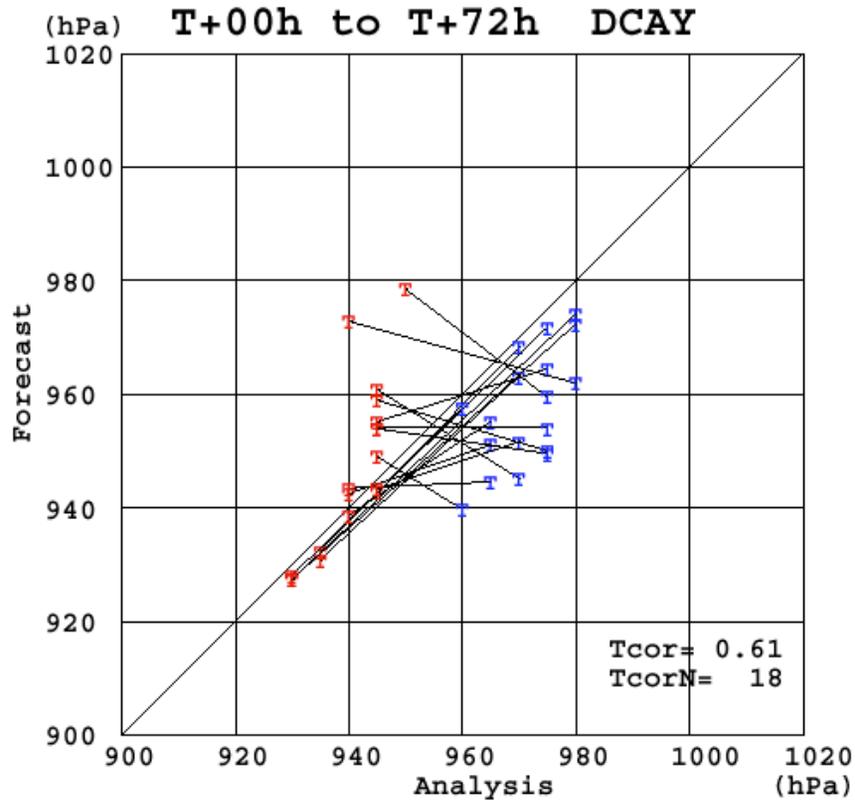
test TYM

Tendency in decaying is not good as in GSM9912

Intensity forecast of GSM0103 and routine TYM
for typhoons in 2001

Decaying stage GSM0103

Decaying stage routine TYM

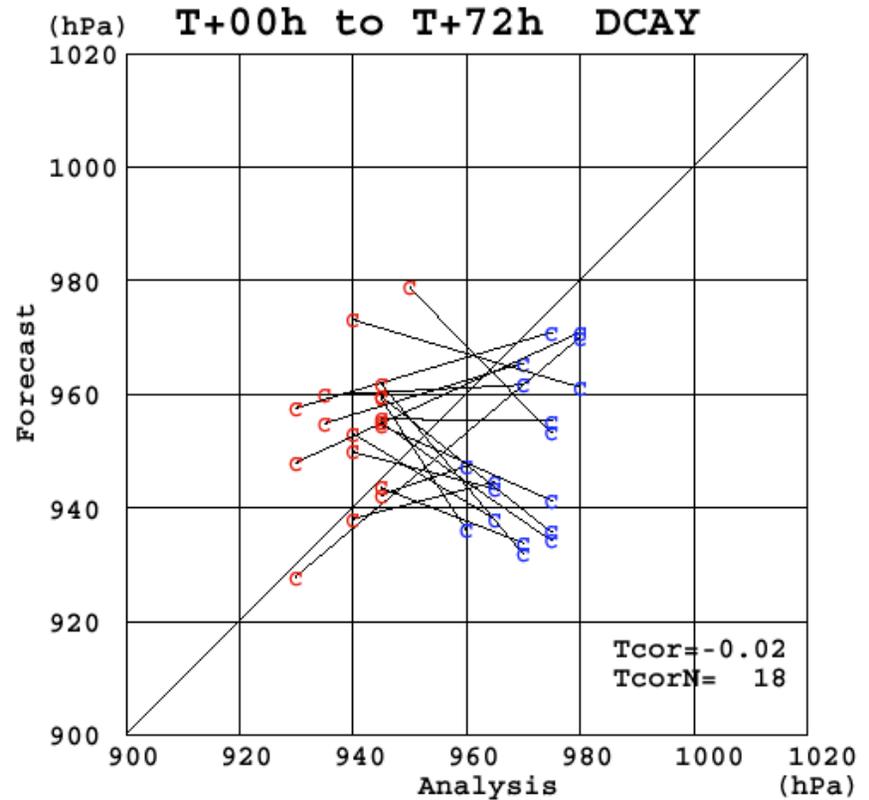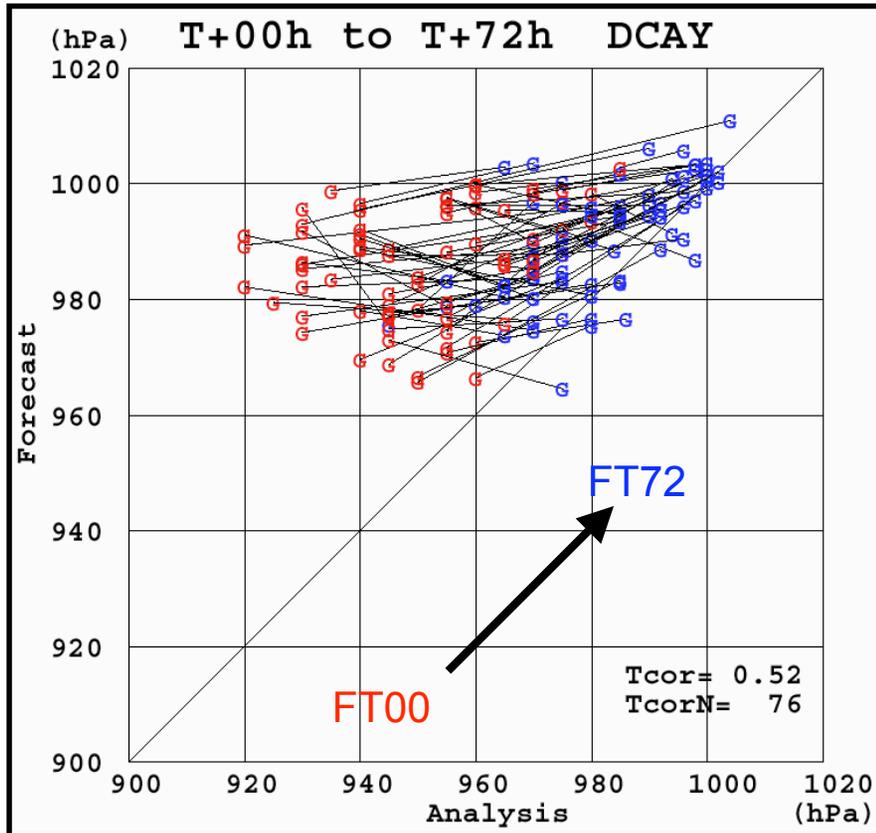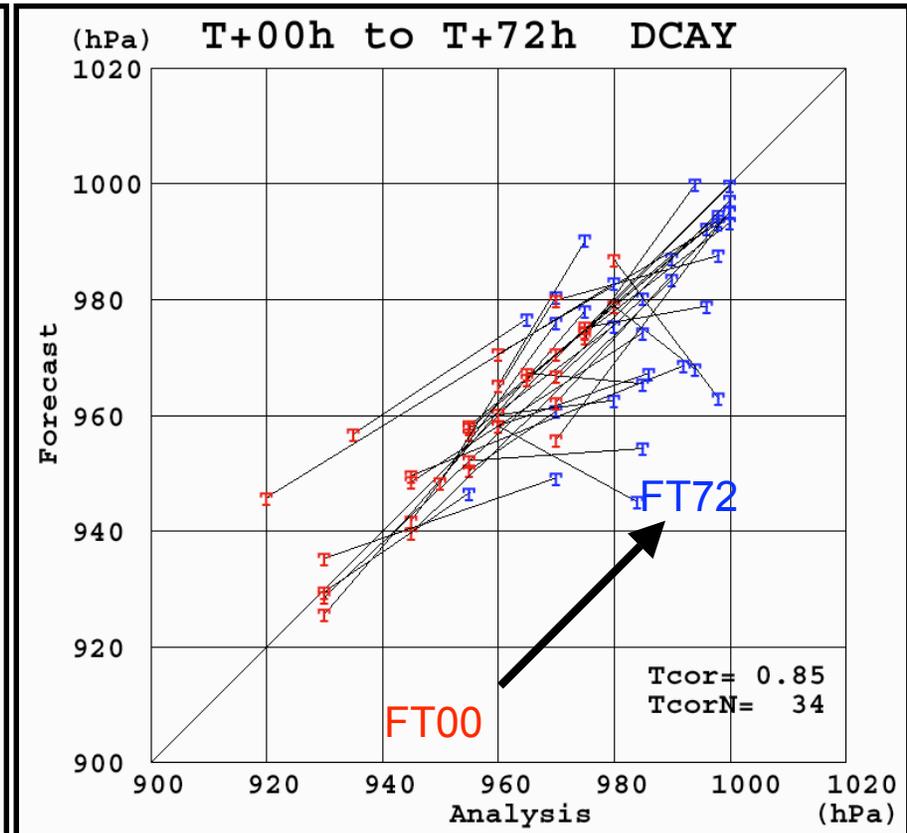Tendency in decaying is not bad in GSM0103

The JMA Nonhydrostatic Model!

○*Fully compressible, no linearization by the reference atmosphere*
○*Three dynamical cores (AE, HI-VI, HE-VI)*
○*Full evaluation of the diabatic heating term in pressure equation*

$$\frac{\partial p}{\partial t} = -C_S^2 \left(\frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} \right) + C_S^2 \frac{\rho}{\theta} \frac{\partial \theta}{\partial t}$$

....
divergence   diabatic
heating

○*Mass-virtual potential temperature*

$$\theta_m \equiv \theta (1 + 0.61 q_v)(1 - q_c - q_r - q_i - q_s - q_g)$$

$$\rho = \frac{p_0}{R \theta_m} \left(\frac{p}{p_0} \right)^{C_v / C_p}$$

○*Fall-out of precipitable water substances in continuity equation*

$$\frac{\partial \rho}{\partial t} + m^2 \left\{ \frac{\partial}{\partial x} \left(\frac{\rho u}{m} \right) + \frac{\partial}{\partial y} \left(\frac{\rho v}{m} \right) \right\} + m \frac{\partial}{\partial z} \left(\frac{\rho w}{m} \right) = Prc,$$

$$Prc \equiv \frac{\partial}{\partial z} \left(\rho V_r q_r + \rho V_s q_s + \rho V_g q_g \right).$$

Diurnal evolution of convection on 27 Nov 1999

- Horizontal convection in morning, and sea-breeze front along the coast.

- Shallow clouds associated with the Rayleigh-Benard convection, inland.

- Cloud merger along the east-west line-shaped convergence zone.

- Explosive growth of deep convection after the merging stage.

Left: Visible GMS image on 27 November 1995.
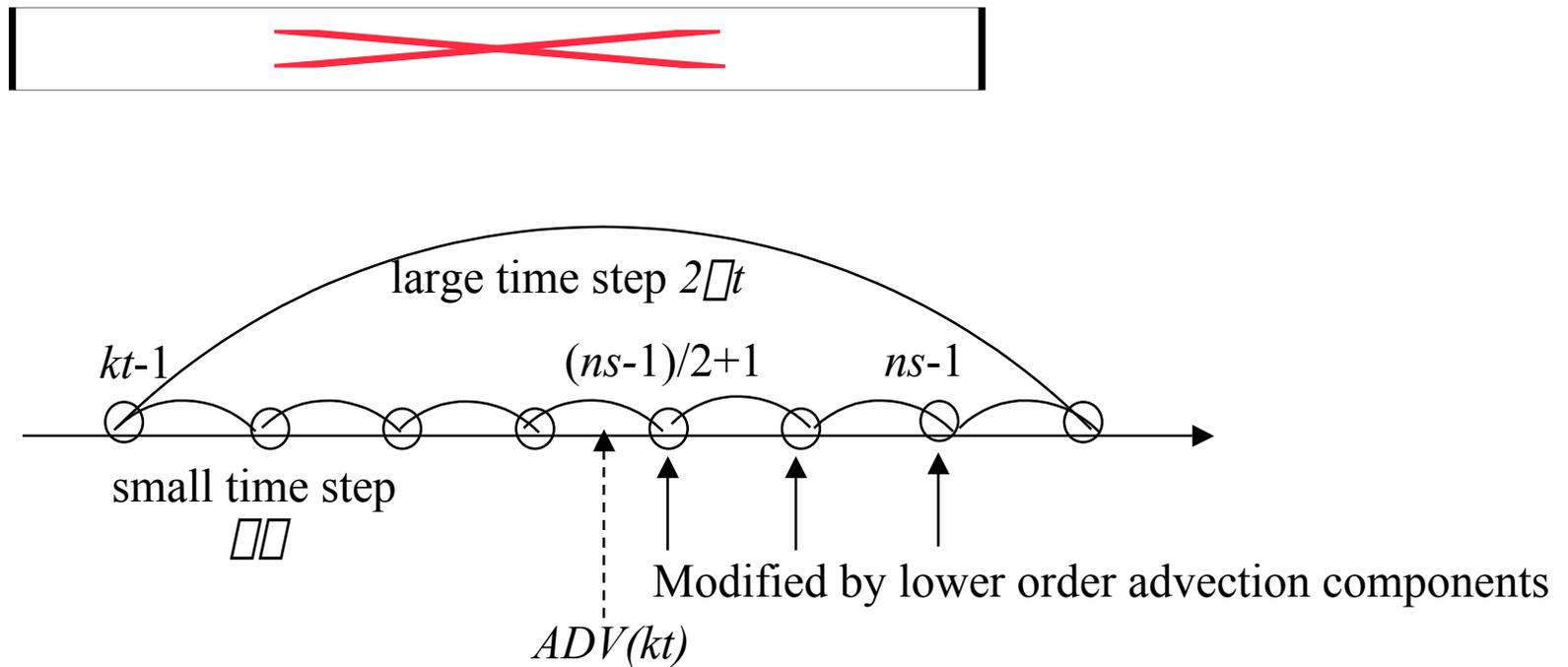**Right: Corresponding numerical simulation by 1 km NHM.**
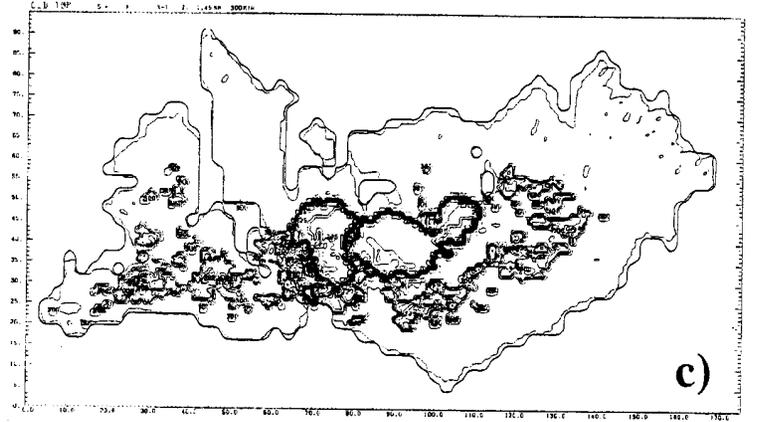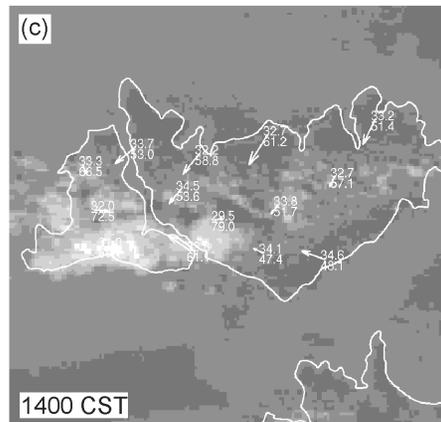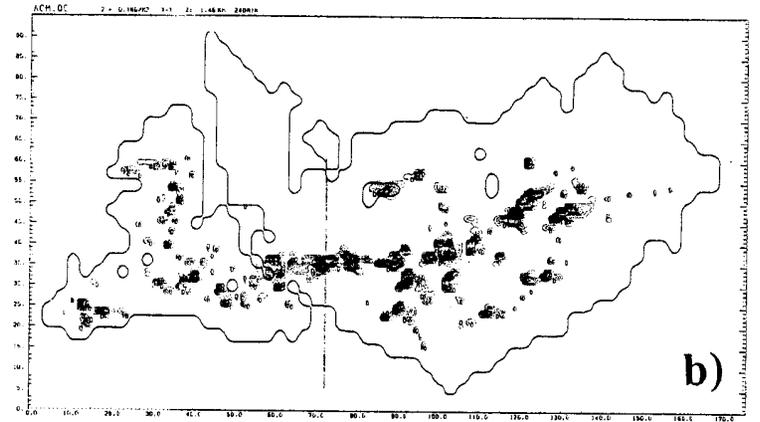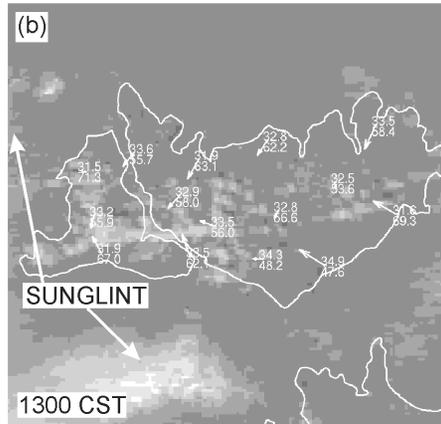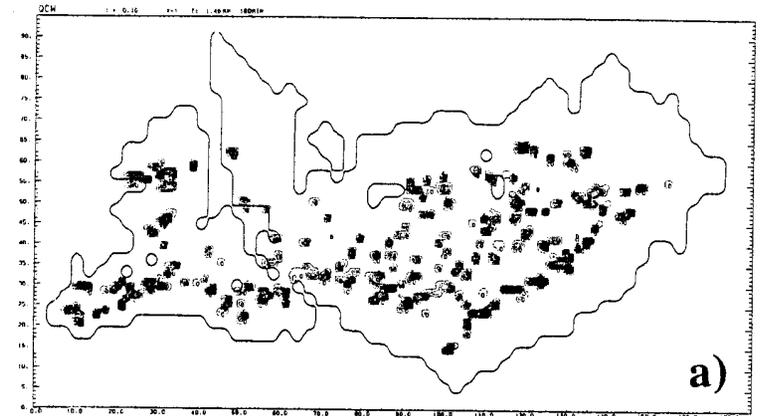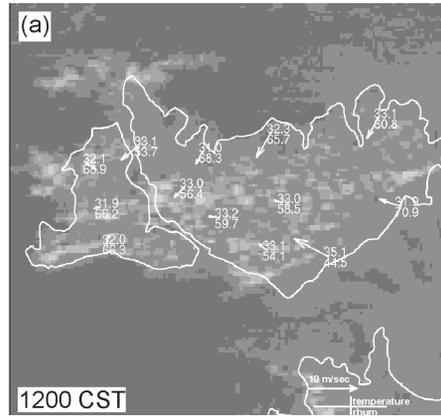
Specifications of NHM

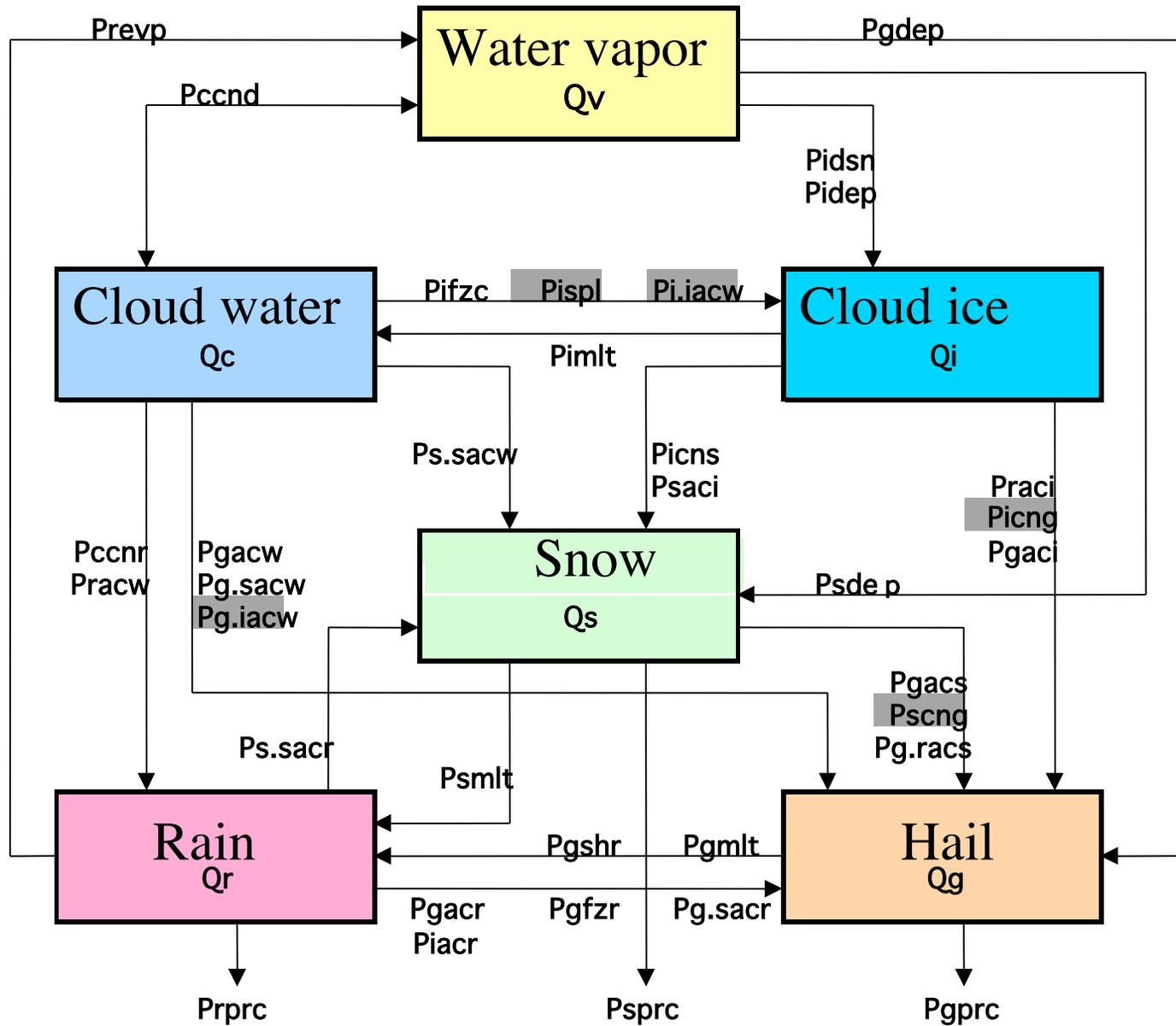| Category	Current specification of operational NHM	Optional choice for research or Under development*
Basic equations	Fully compressible with a map factor !	Quasi-compressible Anelastic, Hydrostatic
Vertical coordinate	Terrain-following, Lorenz type	!
Horizontal coordinate	Conformal projection with Arakawa C	Spherical coordinate*
Advection term	Flux form, fourth order with the flux correction (FCT) and time-splitting	Flux form with third/fifth order*
Dynamical core	Split-explicit (HE-VI), gravity waves is split	Semi-implicit (HI-VI) Anelastic filtering (AE)
Turbulent closure model	Deardorff level 2.5 TKE Implicit treatment for vertical diffusion	!
Cloud microphysics	Predict Qv, Qc, Qr, Qi, Qs (, Qg) Box-Lagrangian scheme for rain and graupel	Predict Ni, Ns and Ng
Cumulus	Explicit, with moist convective adjustment	Arakawa-Schubert, Kain-Fritsch
Atmospheric radiation	Long- and short-wave radiation specified by relative humidity	Specified by cloud microphysics
Surface layer (land) (sea)	Monin-Obukhov Sommeria (1976) Kondo (1975)	Free slip !
Lower boundary	Prognostic 4 soil level ground temperature	New SiB*
Upper boundary	Rigid lid with the Rayleigh friction	!
Lateral Boundary	Boundary relaxation	Radiative nesting Open (Orlanski), Cyclic
Initialization	Meso 4D-Var (hydrostatic)	Variational calculus for AE Digital filter
Numerical diffusion	4--th order damping and nonlinear damping	

Time-splitting of advection term

In order to enhance the computational robustness, advection terms of momentum and potential temperature are split at small time step

At the center of the Leapfrog time step, high-order advection terms are fully evaluated with the flux correction, and then second-order components are adjusted at each short time steps in the later half of the Leapfrog time integration


large time step $2\Delta t$

kt-1 $(ns$-1$)$/2+1 ns-1

small time step
$\Delta\tau$

Modified by lower order advection components

$ADV(kt)$

Advection terms are fully evaluated by higher order difference with flux correction

Cloud microphysics

Water vapor
Qv

Cloud water
Qc

Cloud ice
Qi

Snow
Qs

Rain
Qr

Hail
Qg

Prevp

Pccnd

Pgdep

Pidsn
Pidep

Pifzc   Pispl   Pi.iacw

Pimlt

Ps.sacw

Picns
Psaci

Praci
Picng
Pgaci

Pccnr
Pracw

Pgacw
Pg.sacw
Pg.iacw

Psde p

Pgacs
Pscng
Pg.racs

Ps.sacr

Psmlt

Pgshr   Pgmlt

Pgacr
Piacr

Pgfzr

Pg.sacr

Prprc

Psprc

Pgprc

3 hours forecasts of NHM and MSM start from Meso 4DVAR at 06 UTC 15 May 2002

NHM FST SURF   INIT 2002 05 15 06 00 KT=03
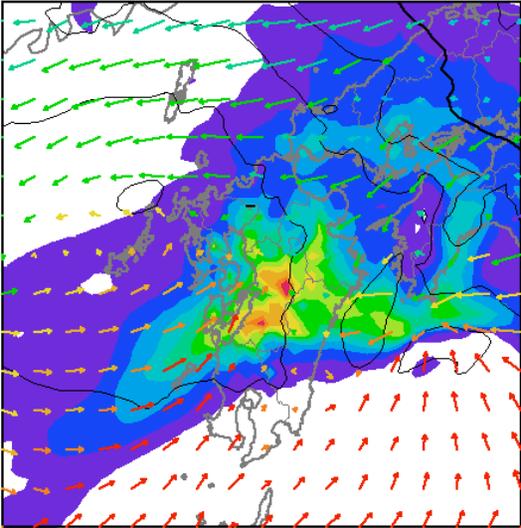
WIND(COLOR...T) PSEA RAIN3 SR8000

RADAR−AMEDAS   2002 05 15 09
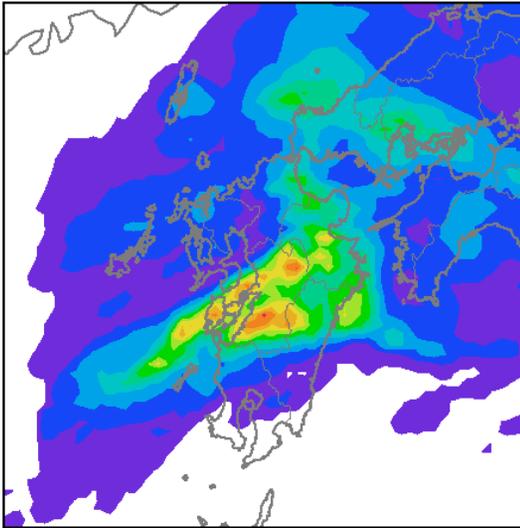
RAIN3 SR8000

MSM FST SURF   INIT 2002 05 15 06 00 KT=03
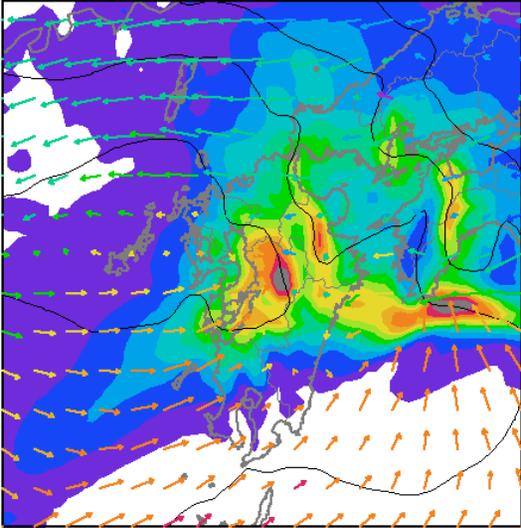
WIND(COLOR...T) PSEA RAIN3 SR8000

RSM FST SURF   INIT 2002 05 15 00 00 KT=09
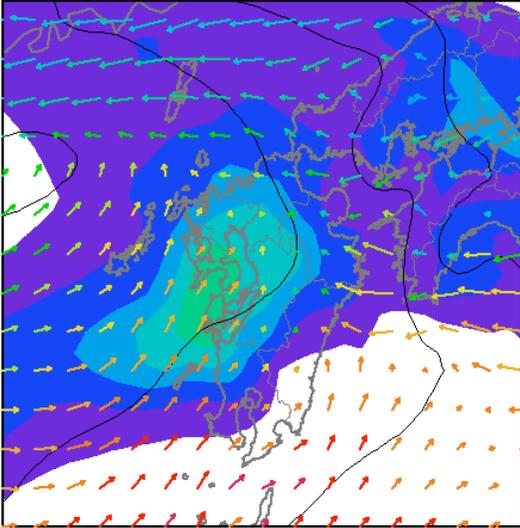
WIND(COLOR...T) PSEA RAIN3 SR8000

15 hours forecasts of NHM and MSM start from Meso 4DVAR at 06 UTC 9 July 2002

NHM FST SURF   INIT 2002 07 09 06 00 KT=15
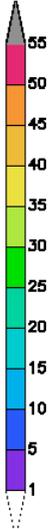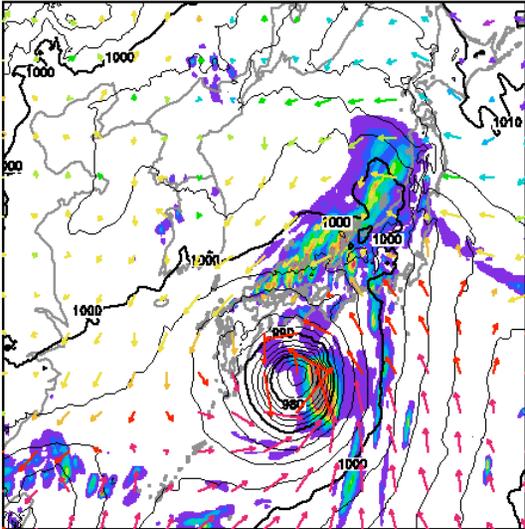
RADAR-AMEDAS   2002 07 09 21
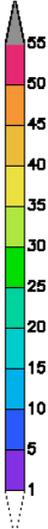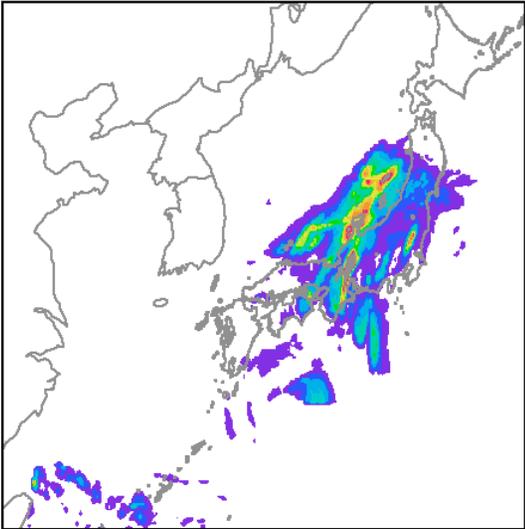
MSM FST SURF   INIT 2002 07 09 06 00 KT=15
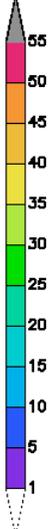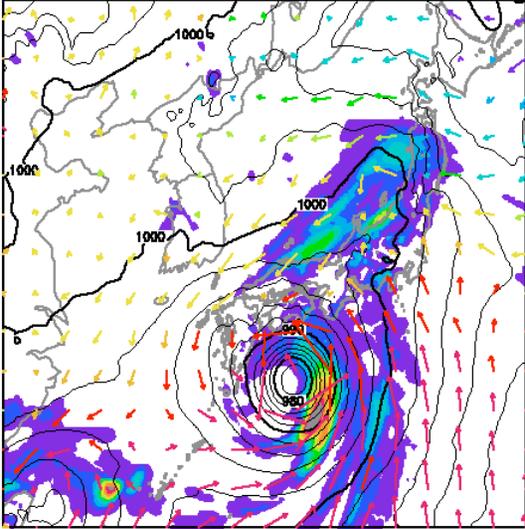
RSM FST SURF   INIT 2002 07 09 00 00 KT=21
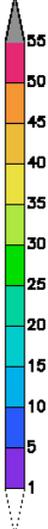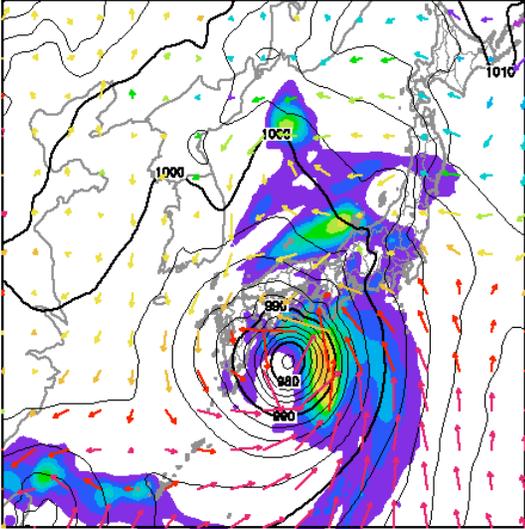
WIND(COLOR...T) PSEA RAIN3 SR8000

WIND(COLOR...T) PSEA RAIN3 SR8000
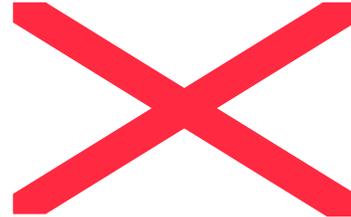
Bias scores for June and July 2002

MSM vs
R/A max

NHM vx
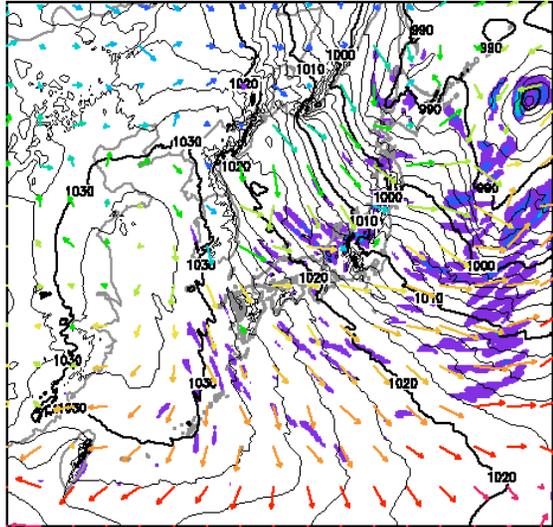R/A max

MSM vs
R/A mean
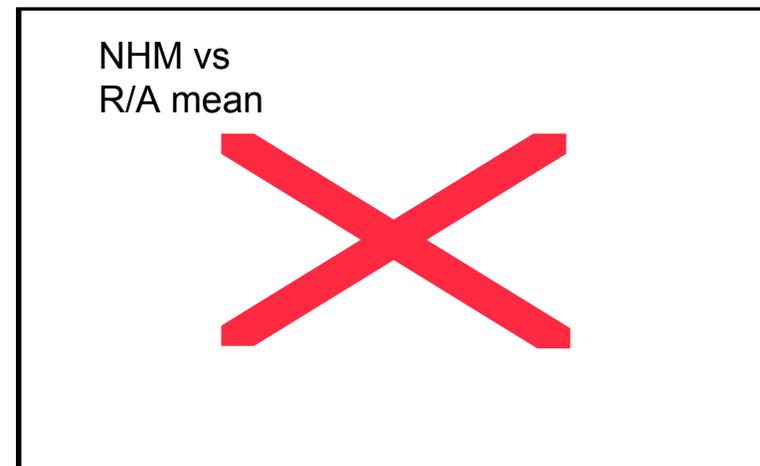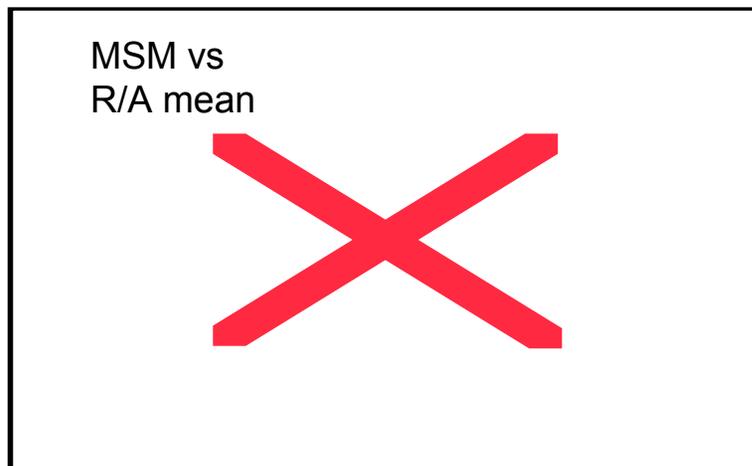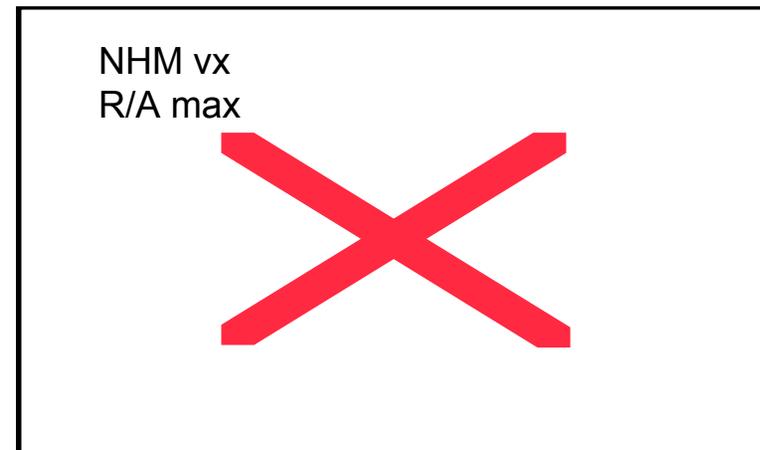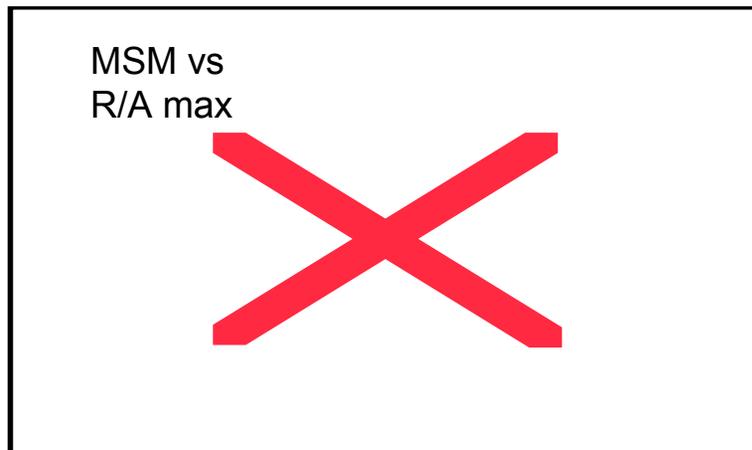
NHM vs
R/A mean

Forecast
time (h)

Forecast
time (h)

Moist convective adjustment is used with bulk cloud microphysics

Threat scores for June and July 2002
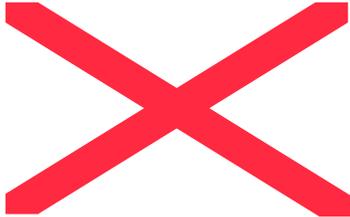
MSM vs
R/A max

NHM vs
R/A max

MSM vs
R/A mean

NHM vs
R/A mean
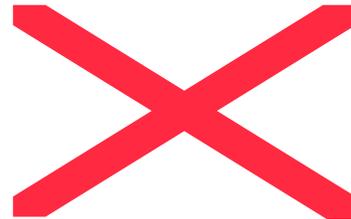
Forecast
time (h)

Forecast
time (h)

Verification grid size 10 km

Test of the Kain-Fritsch parameterization on NHM

- Implement source code of WRF with the courtesy of
  Dr. Jack Kain of Oklahoma university

- First implementation November 2002

- Bug-fixes

- Tuning initial mass flux of updraft

Cloud microphysics only

Cloud micro. with MCA

Cloud micro. with KF original

Cloud micro. with KF

NHM-MCA、NHM-K-F、MSM

NHM: CLD+MCA

NHM: CLD+K-F

NHM FST SURF   INIT 2003 04 07 06 00 KT=15
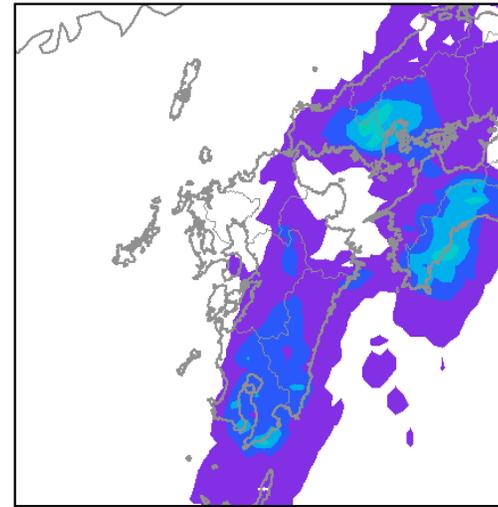
NHM FST SURF   INIT 2003 04 07 06 00 KT=15

MSM FST SURF   INIT 2003 04 07 06 00 KT=15

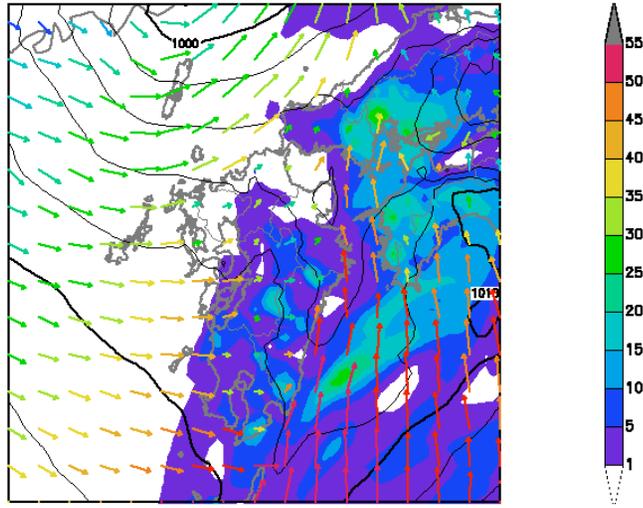RADAR-AMEDAS   2003 04 07 21

MSM：A-S+MCA

R/A Obs.

K-F scheme

- Looks effective to damp grid scale updraft

- Snow streaks over sea by the cold air outbreak decrease in the later half of forecast period

.. may excessively stabilize shallow convection ?

\>\> modify K-F by increasing the height of layer which checks CAPE from surface to 75 hPa AGL
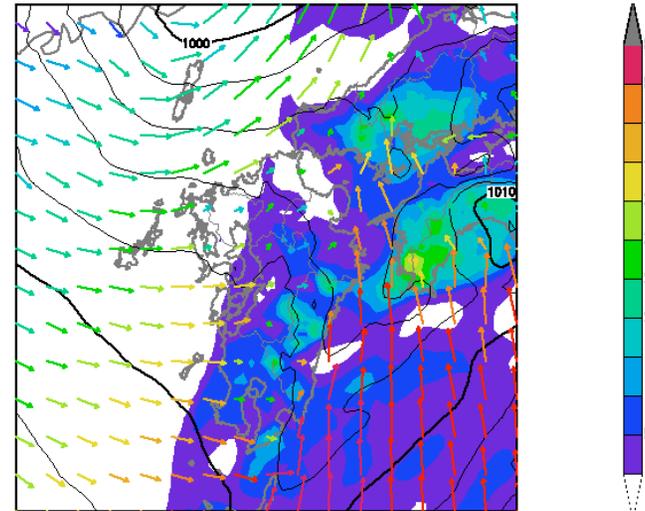
NHM with modified K-F

CLD+K-F(original)
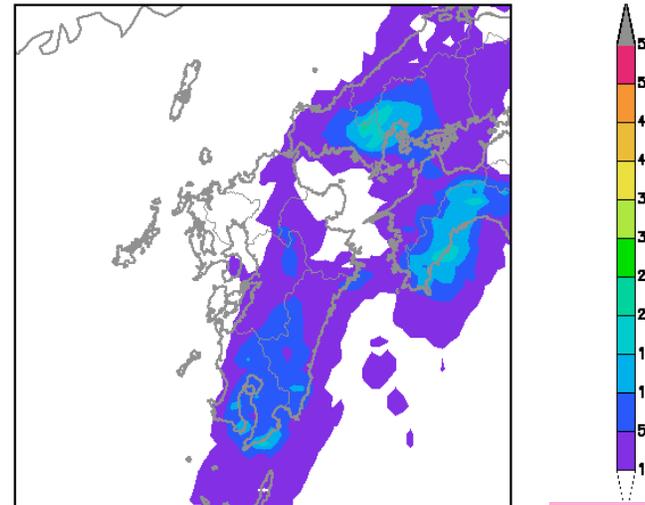
CLD+K-F(3)
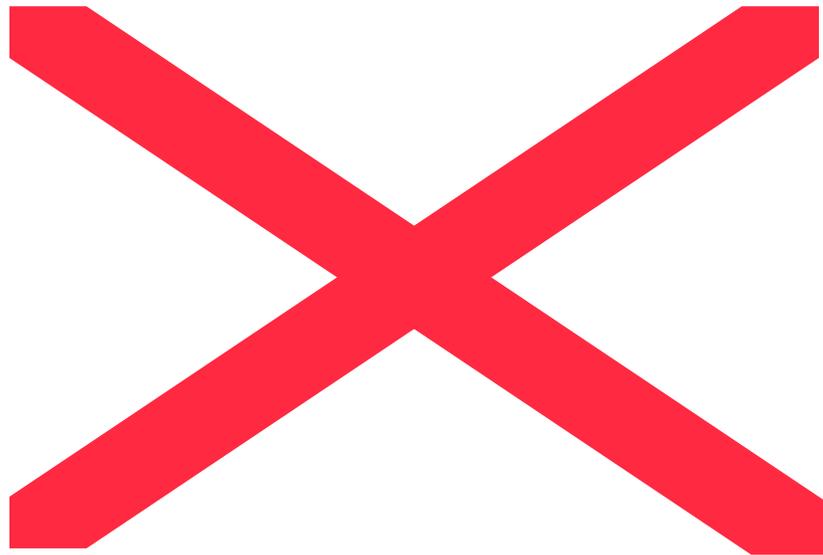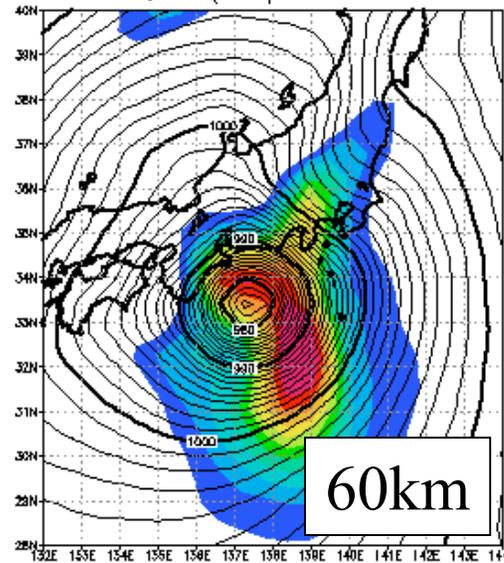

CLD+K-F(4)

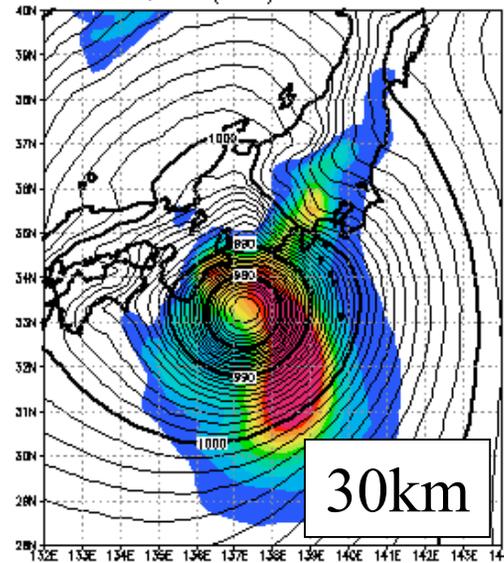R/A Obs.

Plans of NWP at JMA
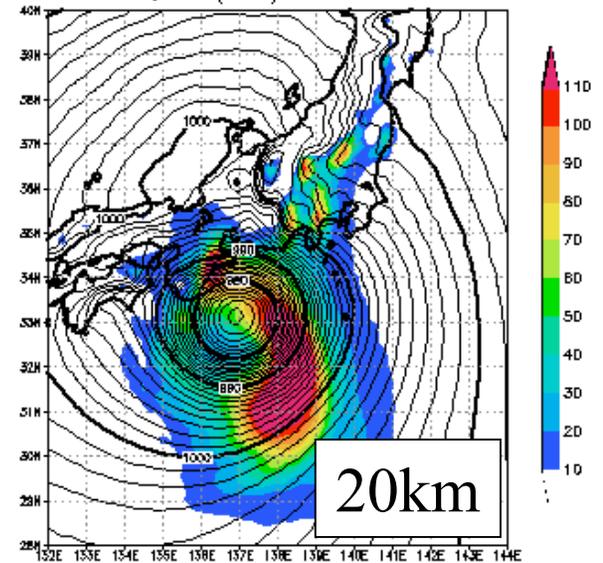
Test of high resolution GSM

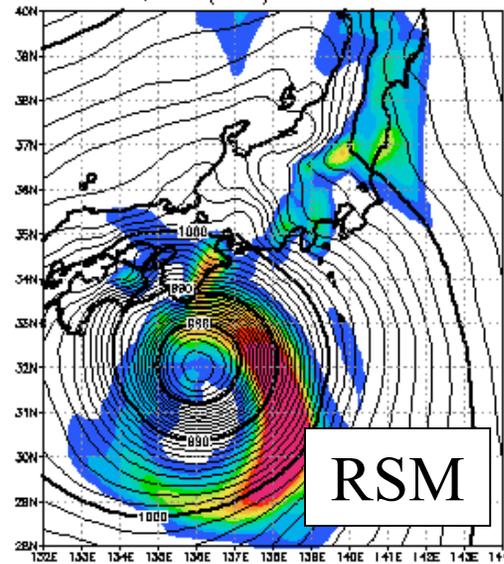T213 PSEA,RAIN(12h) 2001.9.7.12Z T=60 — 60km

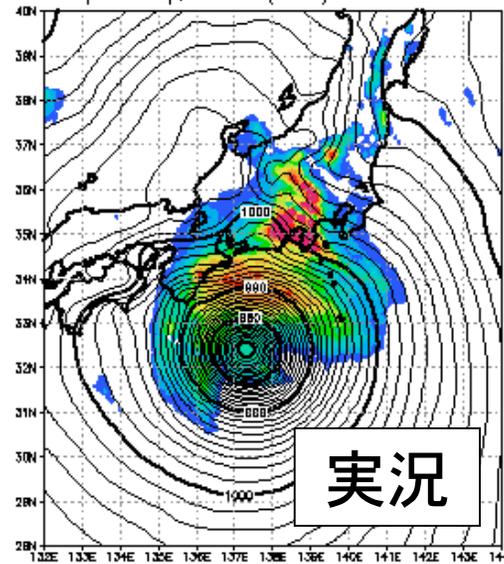T426 PSEA,RAIN(12h) 2001.9.7.12Z T=60 — 30km

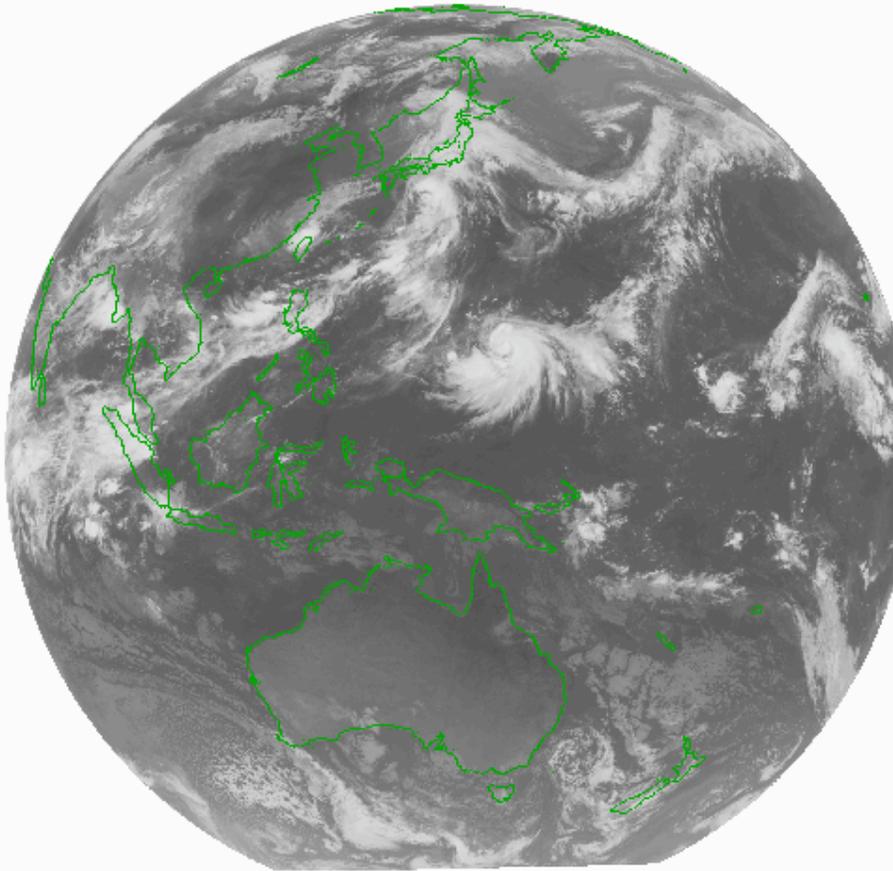T682 PSEA,RAIN(12h) 2001.9.7.12Z T=60 — 20km

RSM PSEA,RAIN(12h) 2001.9.8.00Z T=48 — RSM

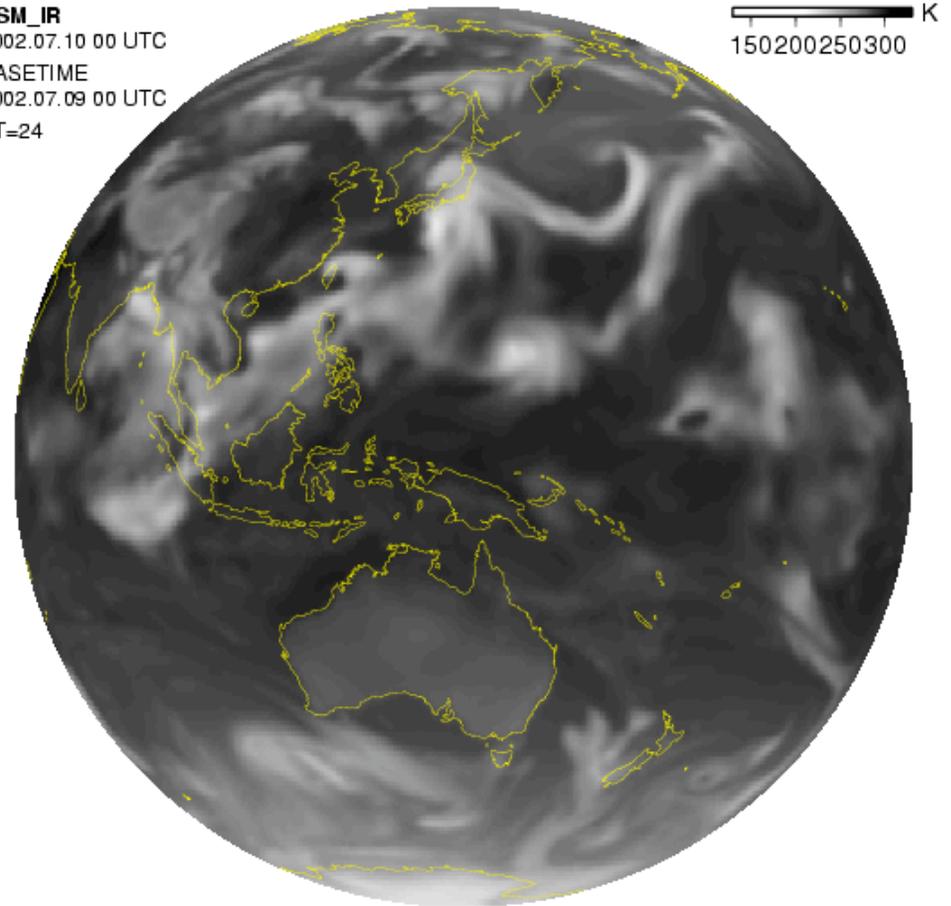PSEA(RANAL),RADAR(12h) 2001.9.10.00Z — 実況

8 September 2001 (ft=60hours)

Satellite image and current GSM (60 km)

GSM_IR
2002.07.10 00 UTC
BASETIME
2002.07.09 00 UTC
KT=24

150 200 250 300 K

GMS-5 obs. 10 Jul 2002 00UTC

60km-GSM T213L40 2002.7.9.00Z FT=24

Satellite GMS5

10 July 2002, 00UTC IR

60km GSM

10 July 2002, 00UTC initial, ft=24

Satellite image and high resolution GSM (20 km)
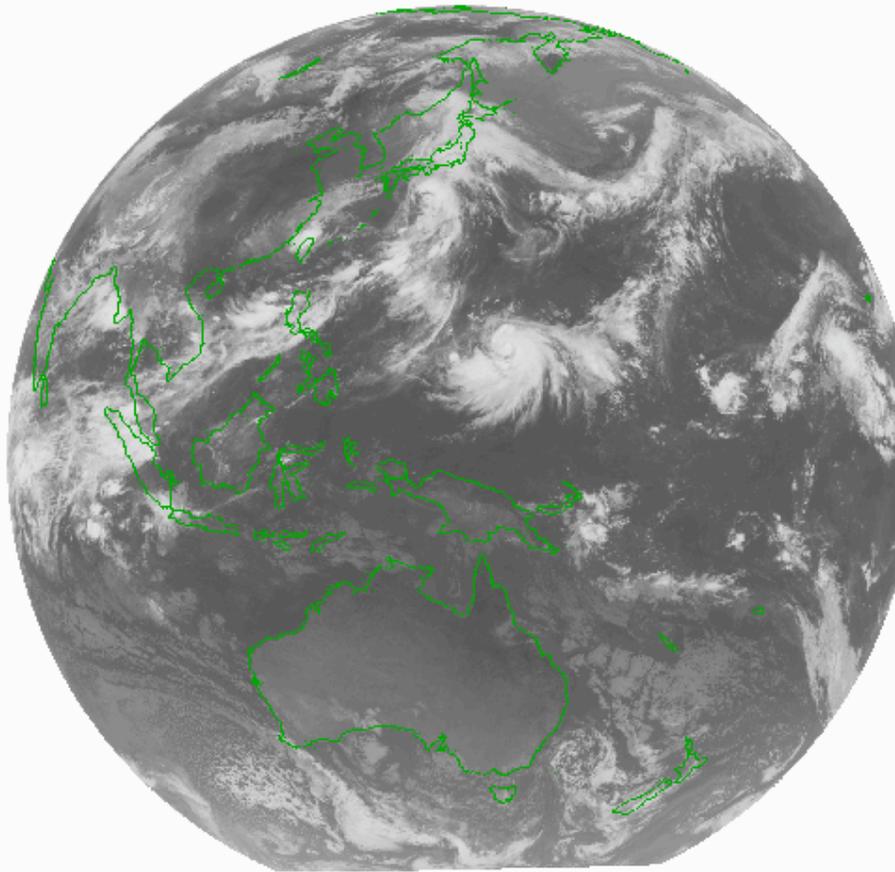
GMS-5 obs. 10 Jul 2002 00UTC

GSM_IR
2002.07.10 00 UTC
BASETIME
2002.07.09 00 UTC
KT=24

K
150 200 250 300
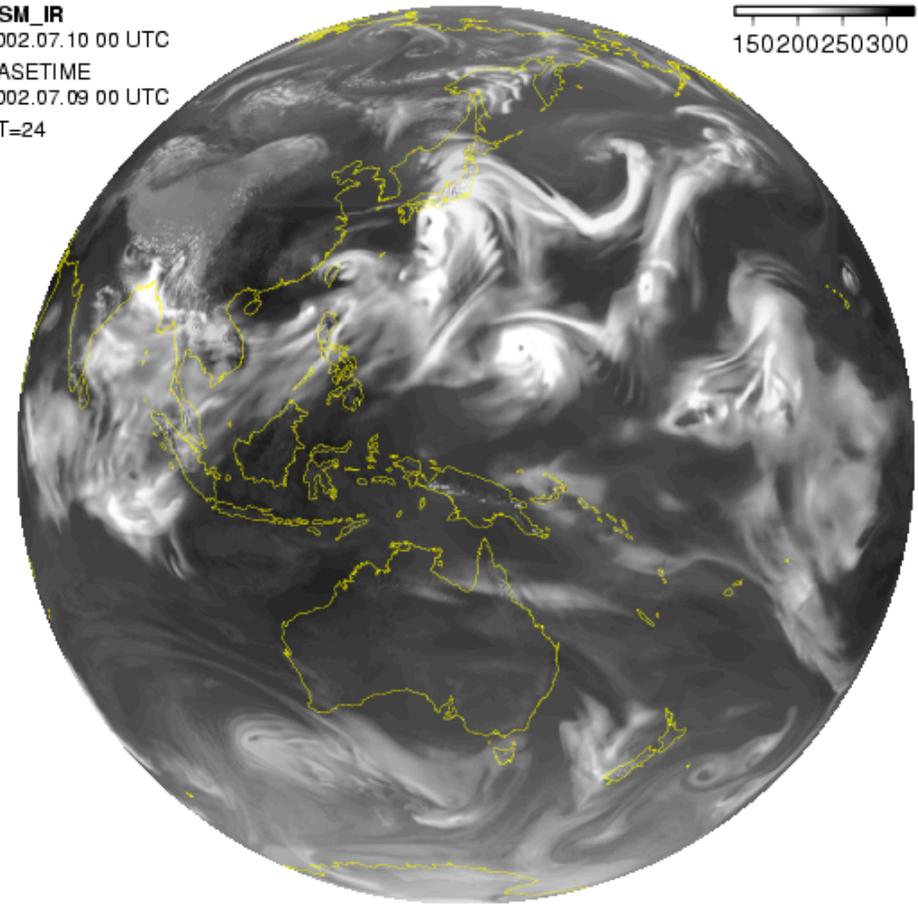
20km-GSM TL1023L40 2002.7.9.00Z FT=24

Satellite GMS5
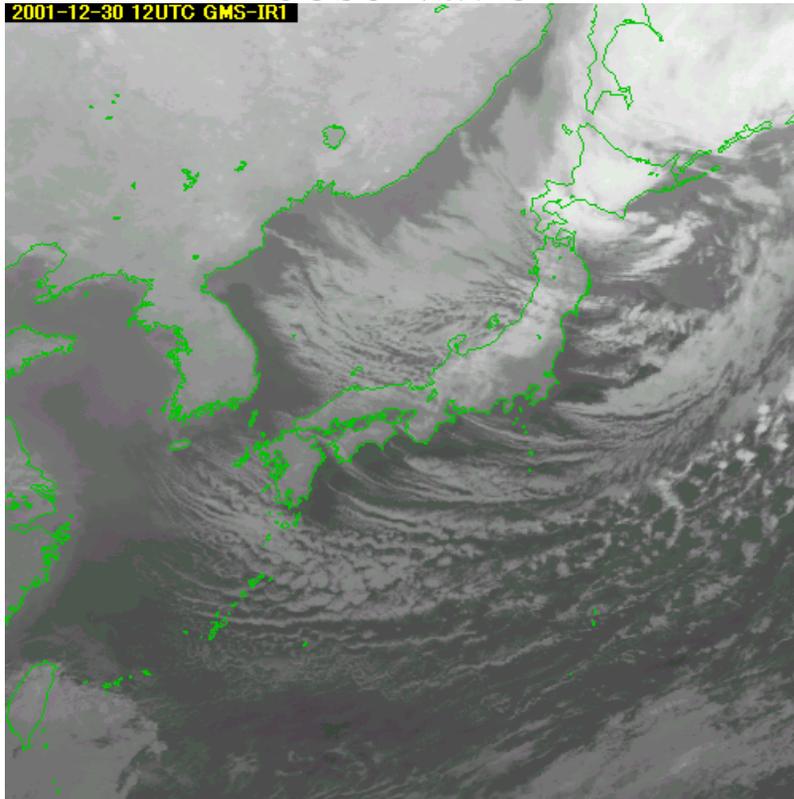10 July 2002, 00UTC IR

20km GSM
10 July 2002, 00UTC initial, ft=24

Computed with Earth Simulator

Satellite image and high resolution NHM (3 km)

observation

2001-12-30 12UTC GMS-IR1

forecast

2001-12-30 12UTC GPV-FIR
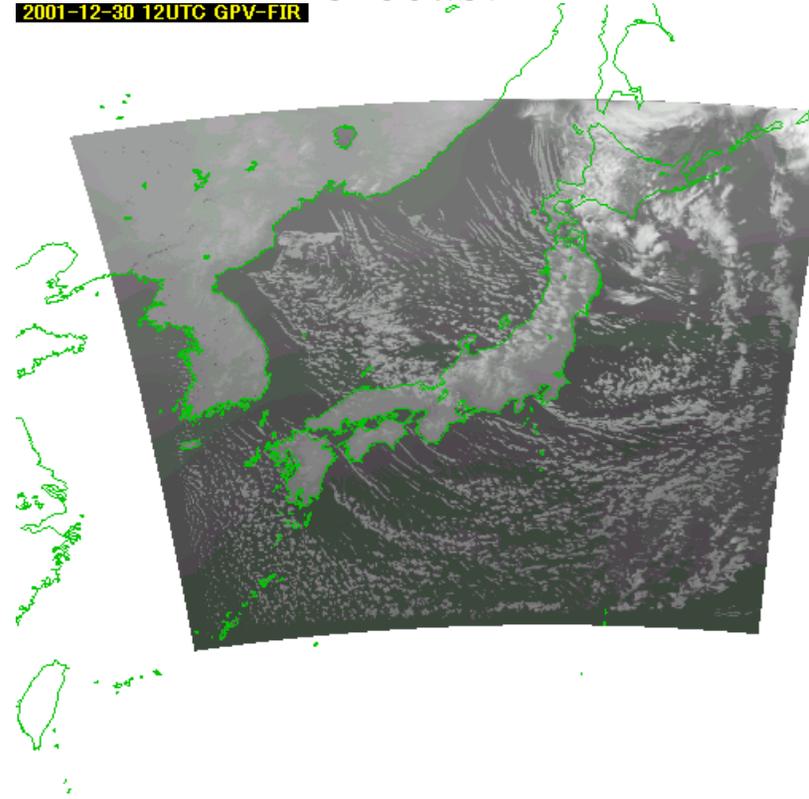
Satellite GMS5
30 December 2001, 00-12 UTC, IR

3 km NHM
30 December 2001,
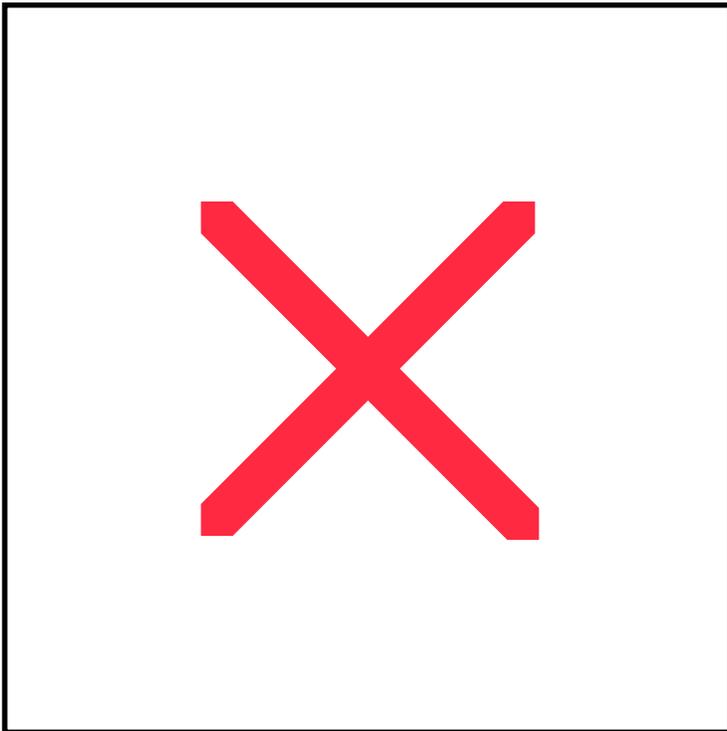00UTC initial, ft=0-12

Computed with Earth Simulator

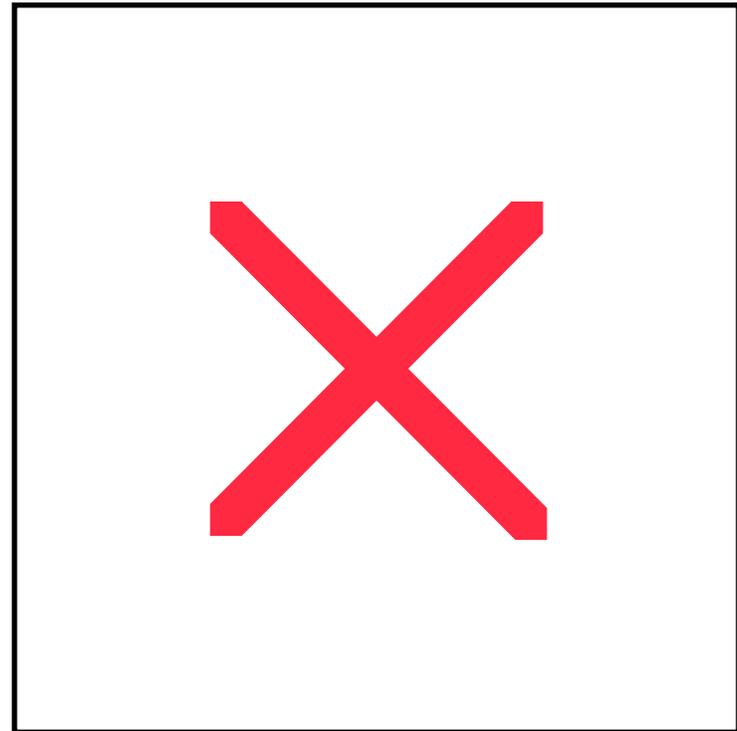# Super high (1km) resolution simulation
by Eito et al (2003)

NHM （5 km-NHM）
Resolution: 5 km
Grids: 500 x 500 x 38
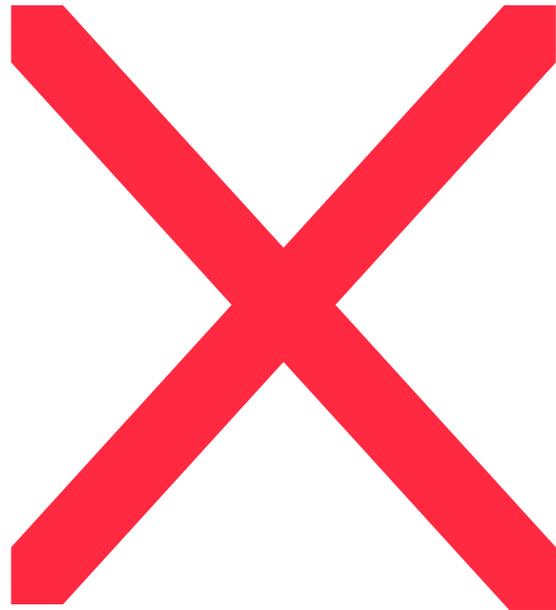Time interval: 10 s
INITIAL: 10 JST 14 JAN.

NHM （1 km-NHM）
Resolution: 1 km
Grids: 2000 x 2000 x 38
Time interval: 5 s
INITIAL: 10 JST 14 JAN.

# Satellite Image

15JST 14 JAN. 2001

Numerical simulation

1km-NHM : Total Water Path

15JST 14 JAN. 2001

●The 1km-NHM successfully reproduced cloud bands extending southeastward from the base of the Korean Peninsula to the San-in and Hokuriku district over the Sea of Japan.
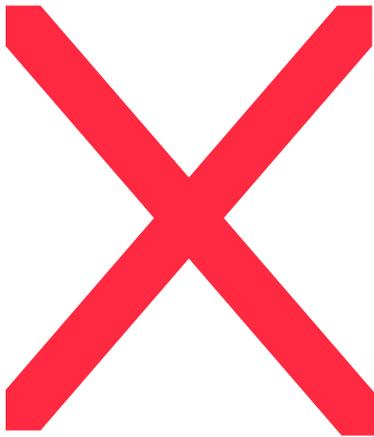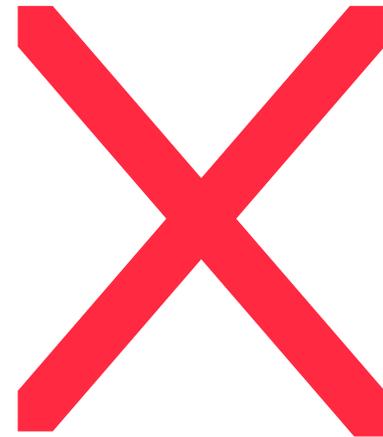●Several cloud streets were also calculated around cloud bands.

Eito et al. (2003)

Computed with Earth Simulator
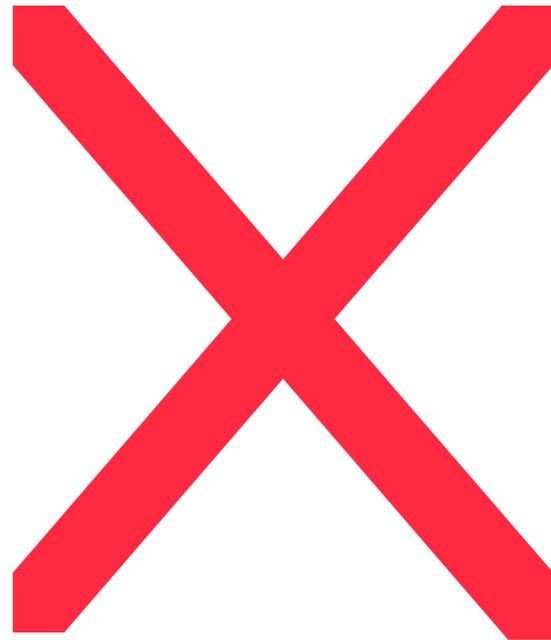
Dependence on the Horizontal Resolution

Total Water Path : 5 hour forecast (15JST 14 JAN. 2001)

5km-NHM

1km-NHM

●The 5km-NHM also well reproduced the features of cloud bands and other clouds
●More detailed features have been well reproduced by 1km-NHM.

Future

- Modify AS scheme considering the vertical profile of the entrainment ratio and pressure gradient force in momentum transport
- Continue test of KF scheme for 10 km NHM for operation of March 2004
- Test Kain-Fritsch parameterization in high resolution GSM
- Test 5km NHM with/without convective parameterization for operation in 2006
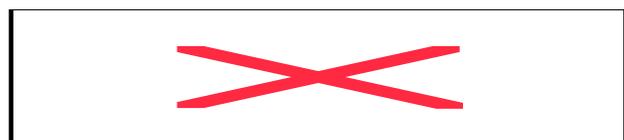
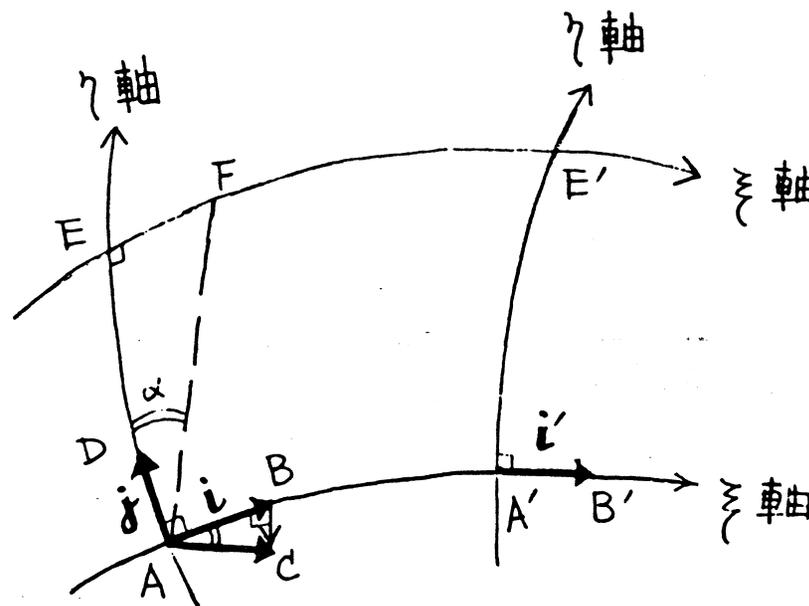# Global version of MRI/NPD-NHM

Saito (2001)
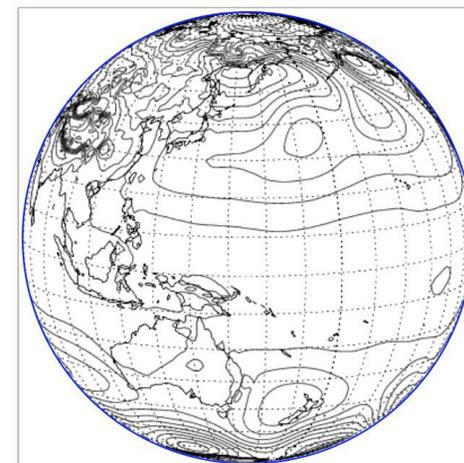
Based on the curvilinear orthogonal coordinate (ξ, η)
unit vector along the ξ-axis i,
unit vector along the η-axis j,
unit vector in the vertical direction k
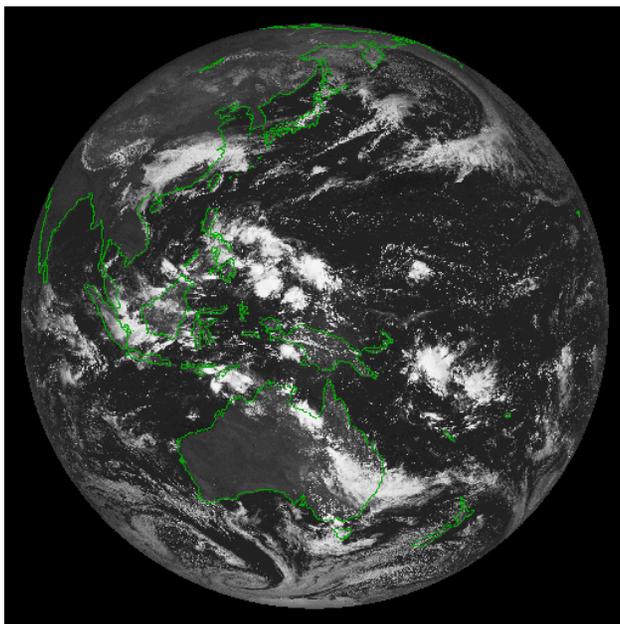
Distance between two points
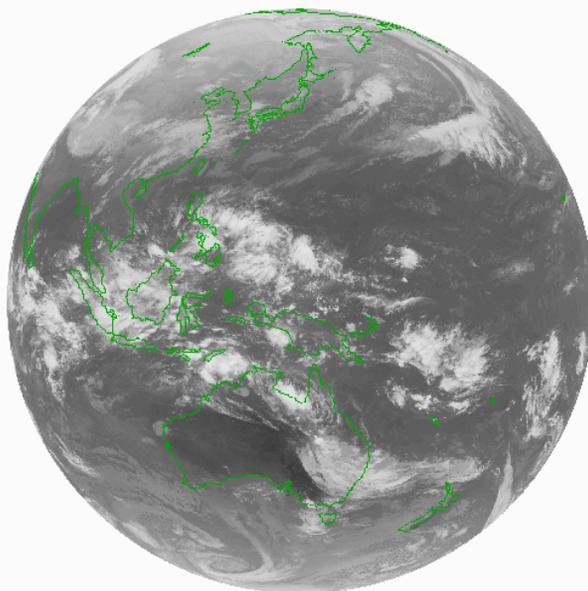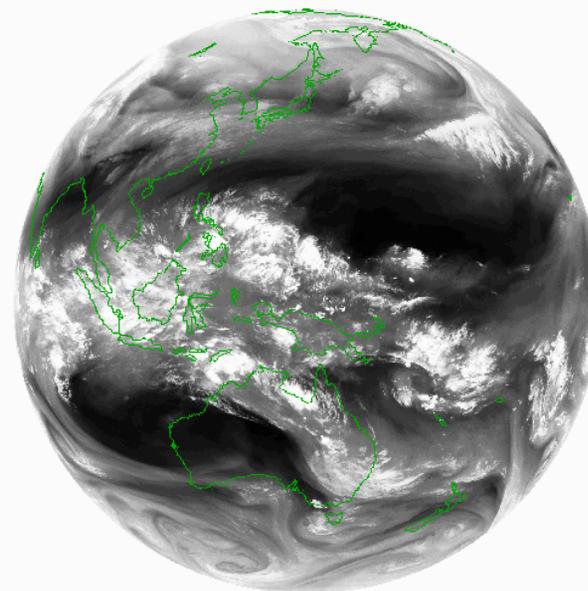$P (\xi, \eta, z)$ and $Q(\xi+d\xi, \eta+d\eta, z+dz)$

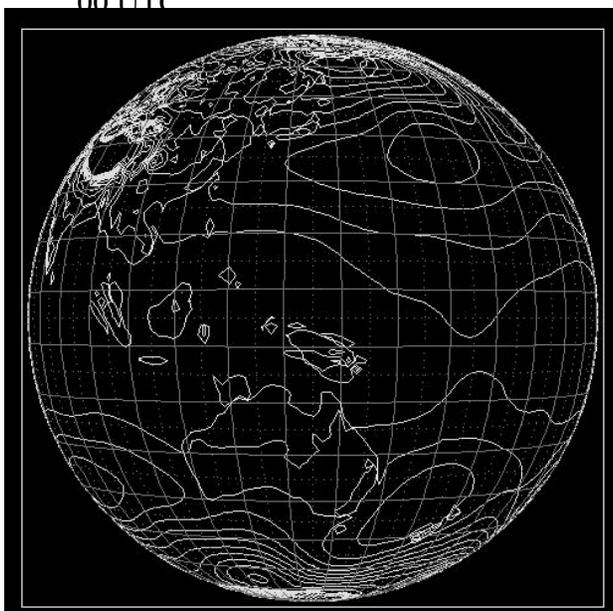m, n; map factors

第 A 1.1 図　$z = const$ の面の曲線座標系

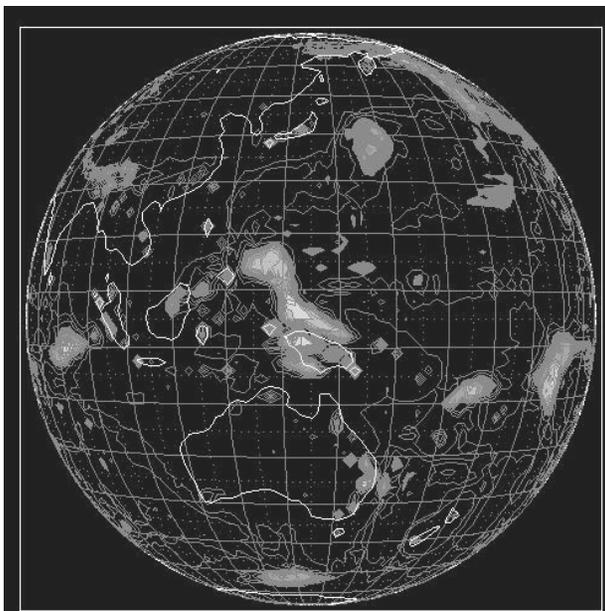GMS visible 03 UTC 2 March 1999
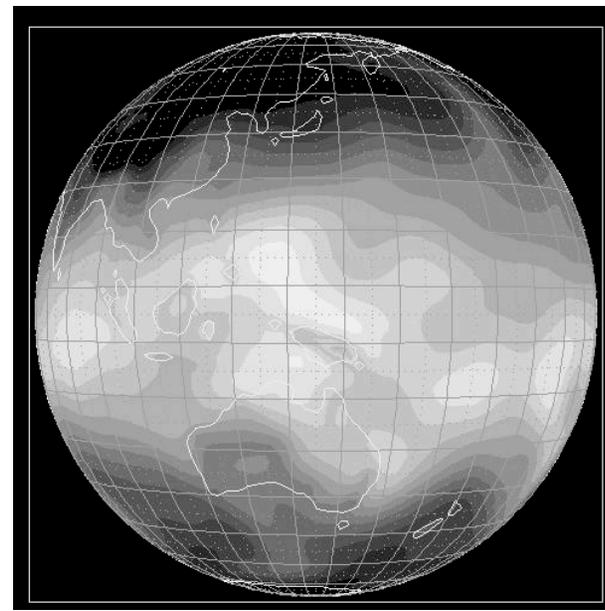00 UTC

GMS infrared 00 UTC

GMS water vapor

Global nonhydrostatic model MSL pressure
water vapor

Vertically accumulated cloud water

Vertically accumulated