Current research and future plan of NWP systems in CMA

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NWP center of CMA

12/2012

中国气象局 China Meteorological Administration

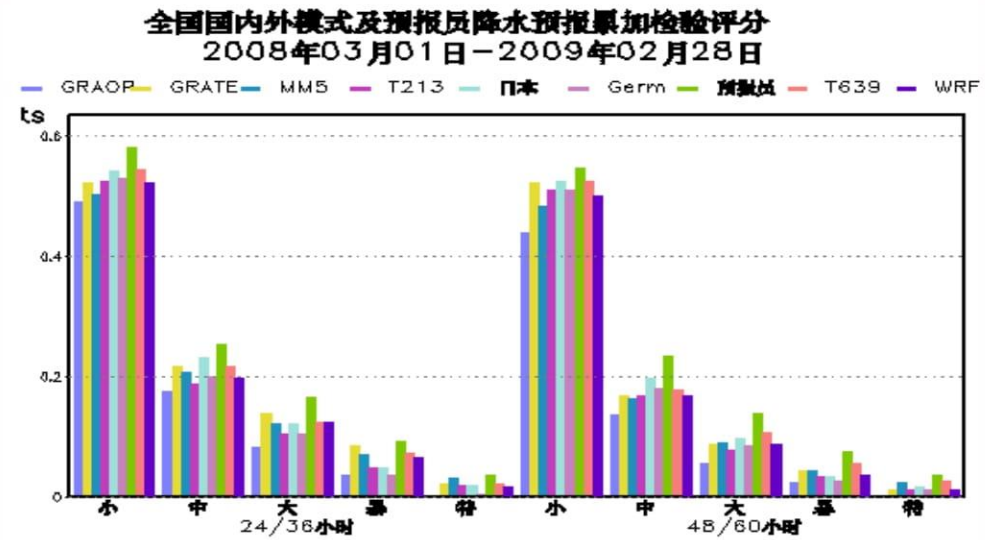
Content

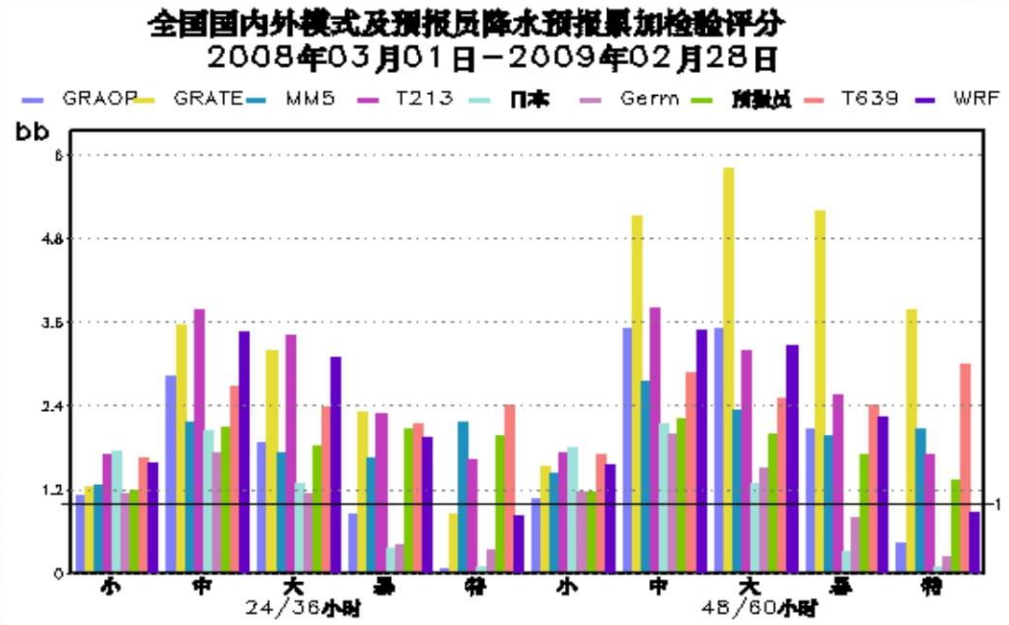
- Current problems, under-going research and future plan
  - GRAPES_meso, HR systems
  - GRAPES_GFS
- Current and future work will include
  - Data assimilation
  - Dynamic core
  - Physics

GRAPES_meso

- BIAS of the precipitation forecast
- RMSE of 500hPa HGT prediction
- Research work
  - Land-surface and atmosphere interaction
  - Topography related processes
  - Precipitation processes
  - Couple between dyn. and phy.

BIAS of the precipitation forecast

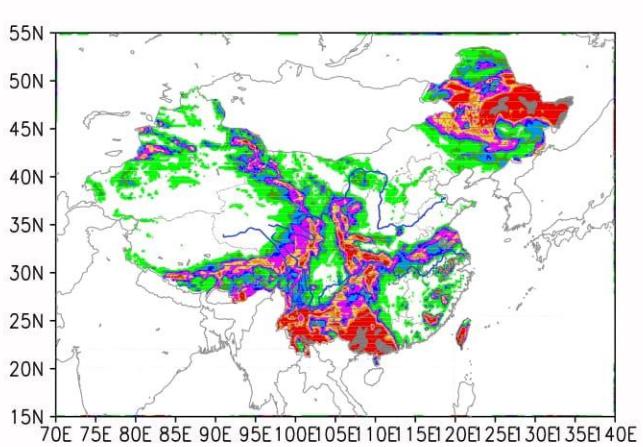


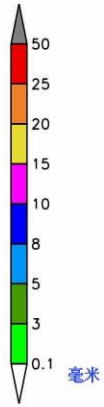


中国气象局 China Meteorological

GRAPES_v3.0降水预报(12－36小时)

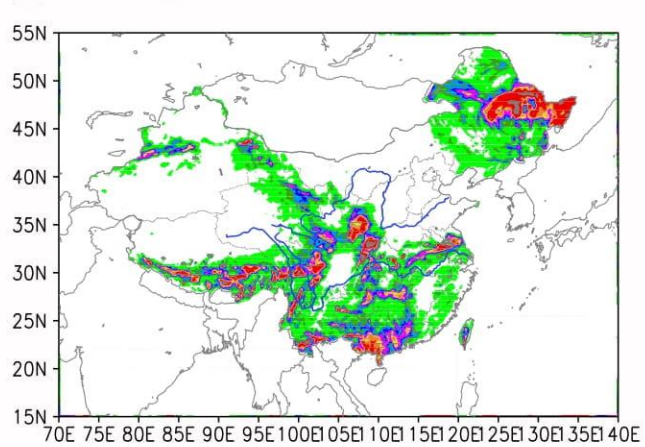
模式起始时间:2008:7:15:12(UTC)
预报时间:2008:7:16:0－2008:7:17:0(UTC)





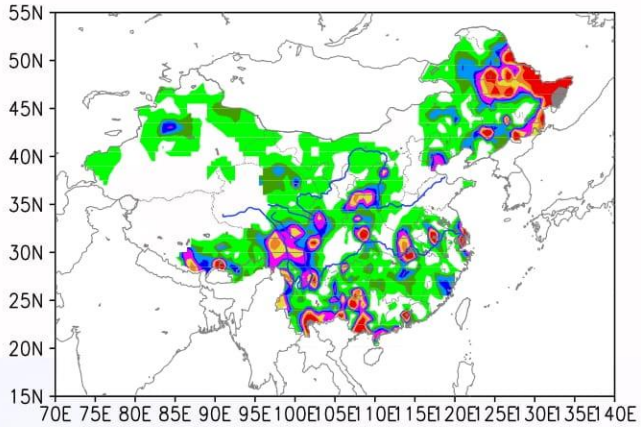
WRF_v3.2降水预报(12－36小时)

模式起始时间:2008:7:15:12(UTC)
预报时间:2008:7:16:0－2008:7:17:0(UTC)

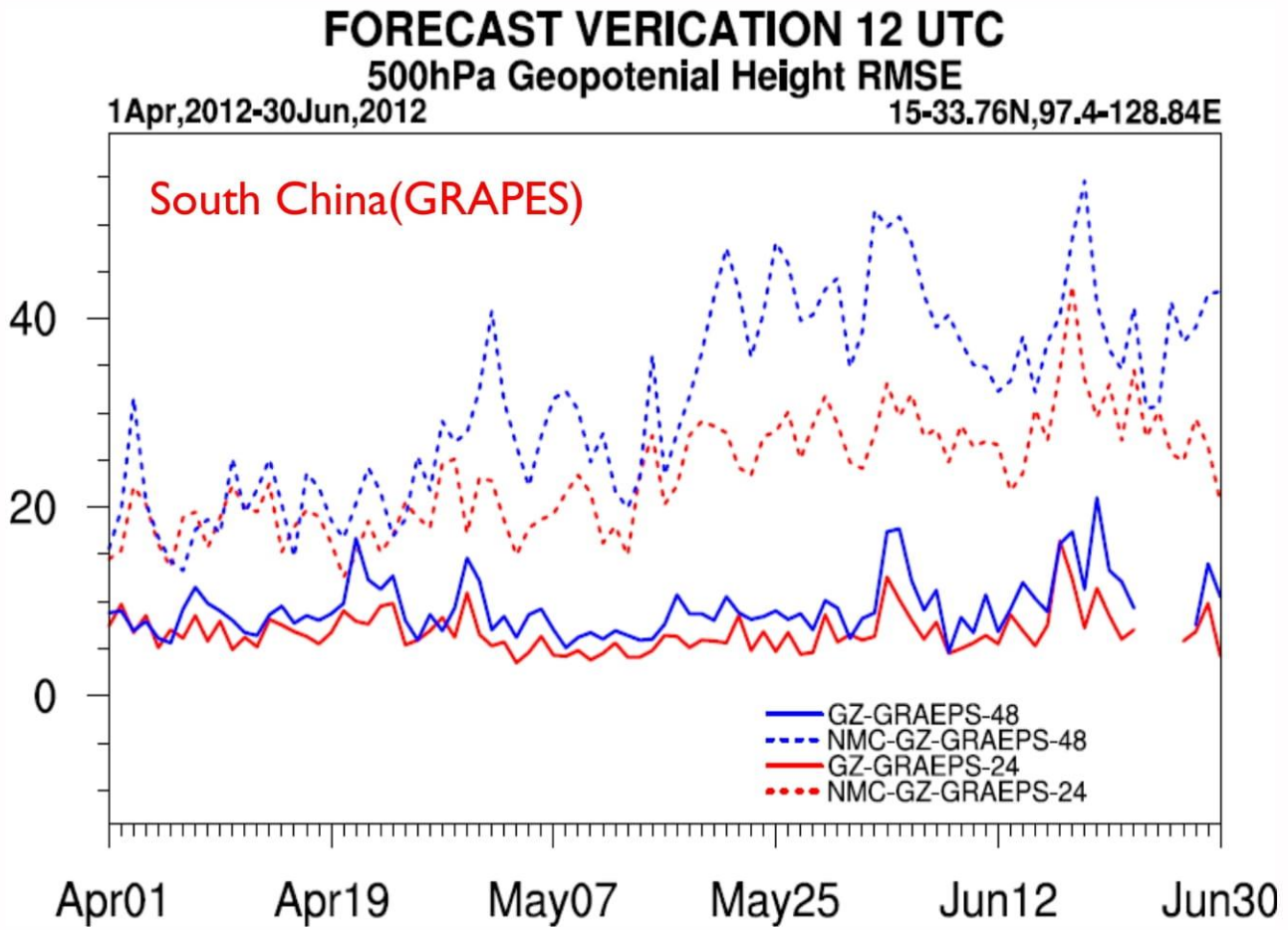


Observed－Precipitation

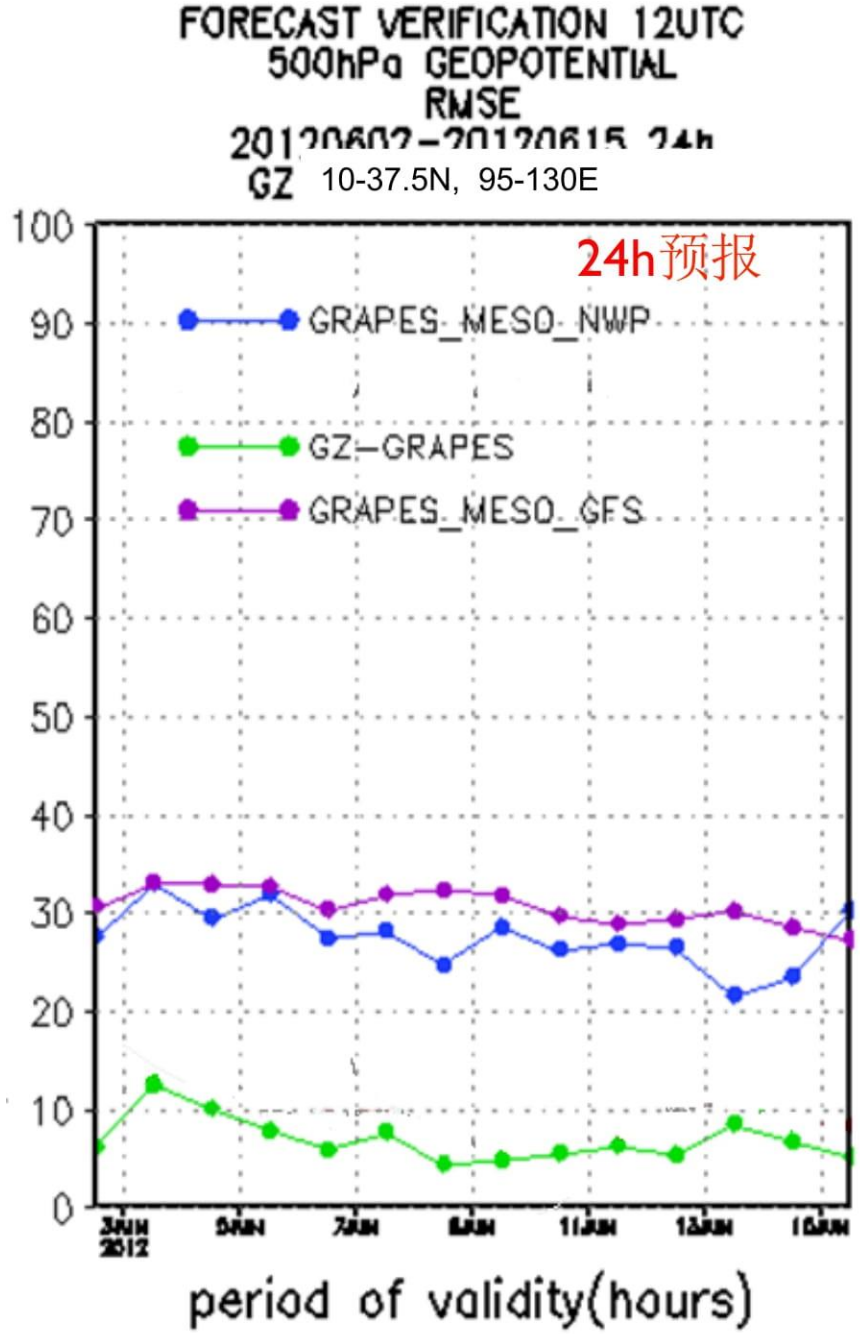
Period:2008:7:16:0－2008:7:17:0UTC

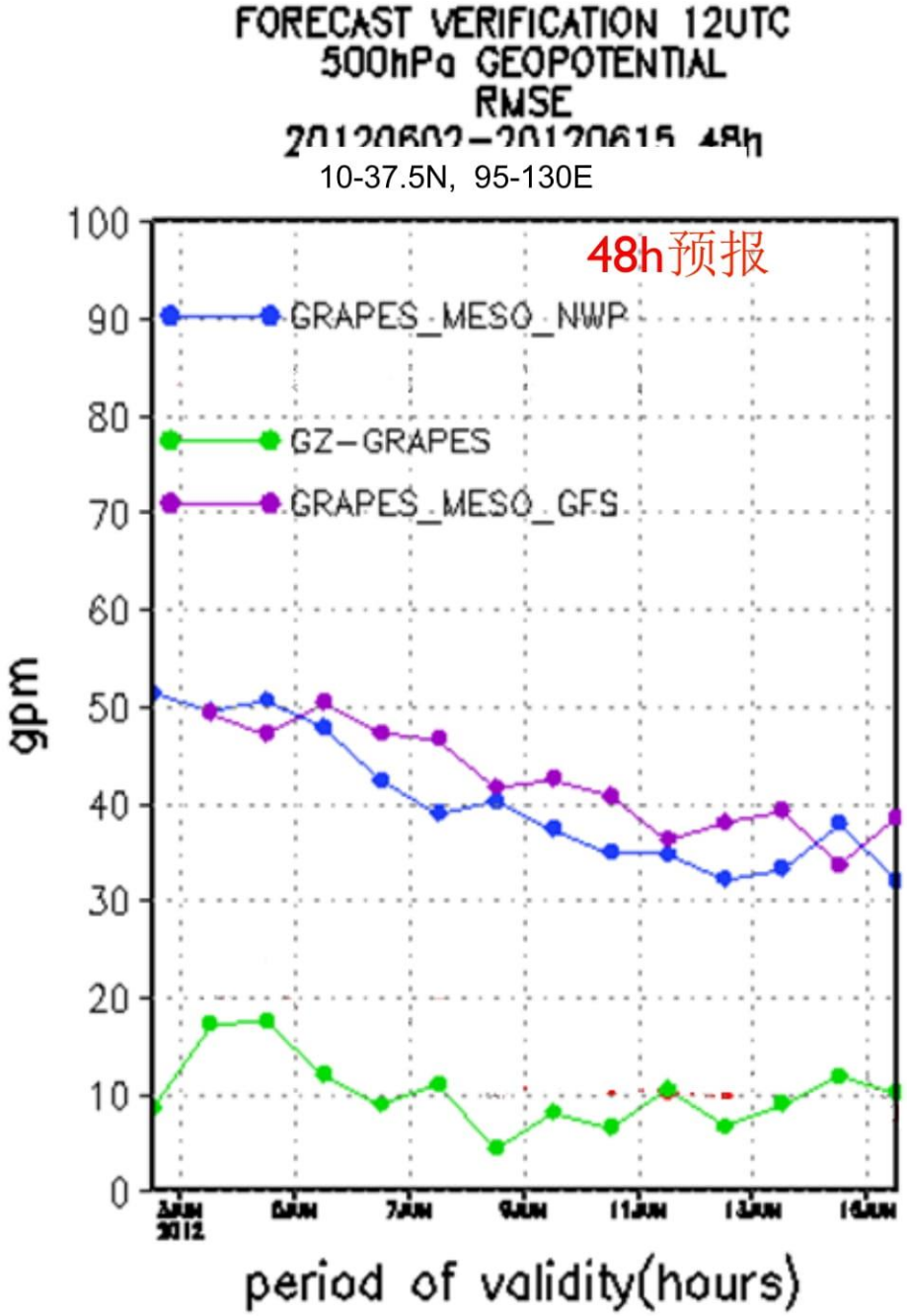


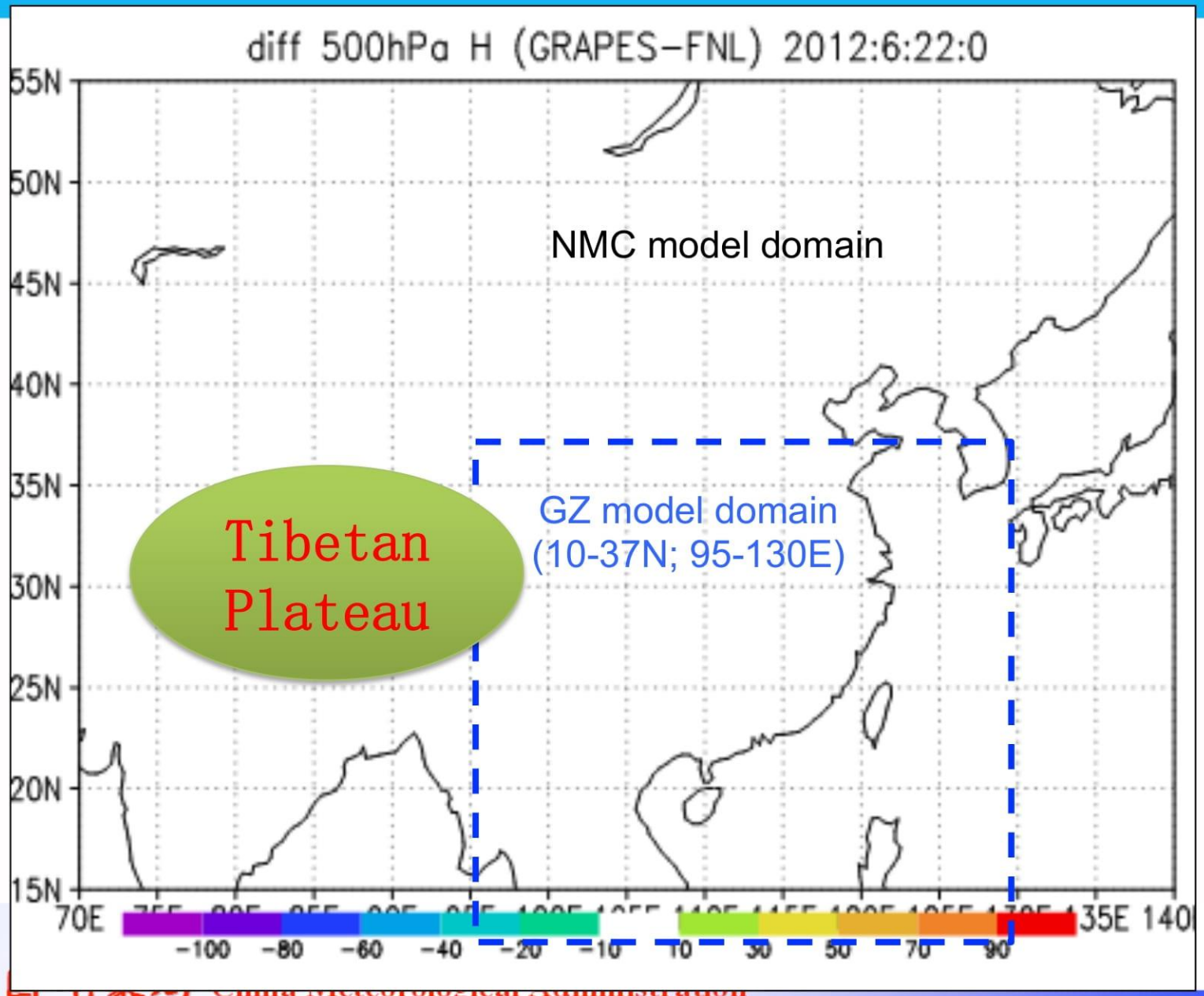
RMSE of 500hPa HGT prediction

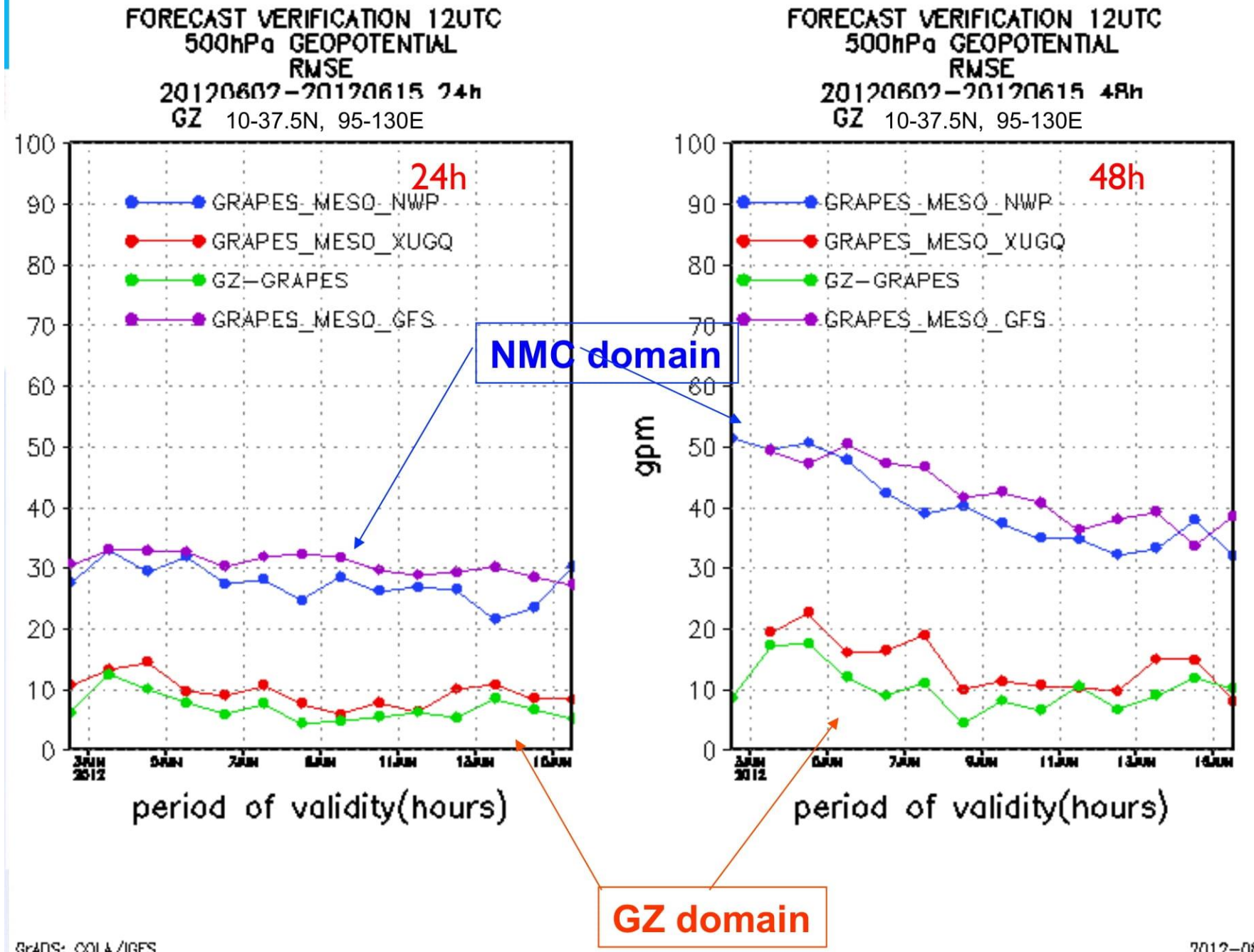


Solid：regional center；dashed：NMC

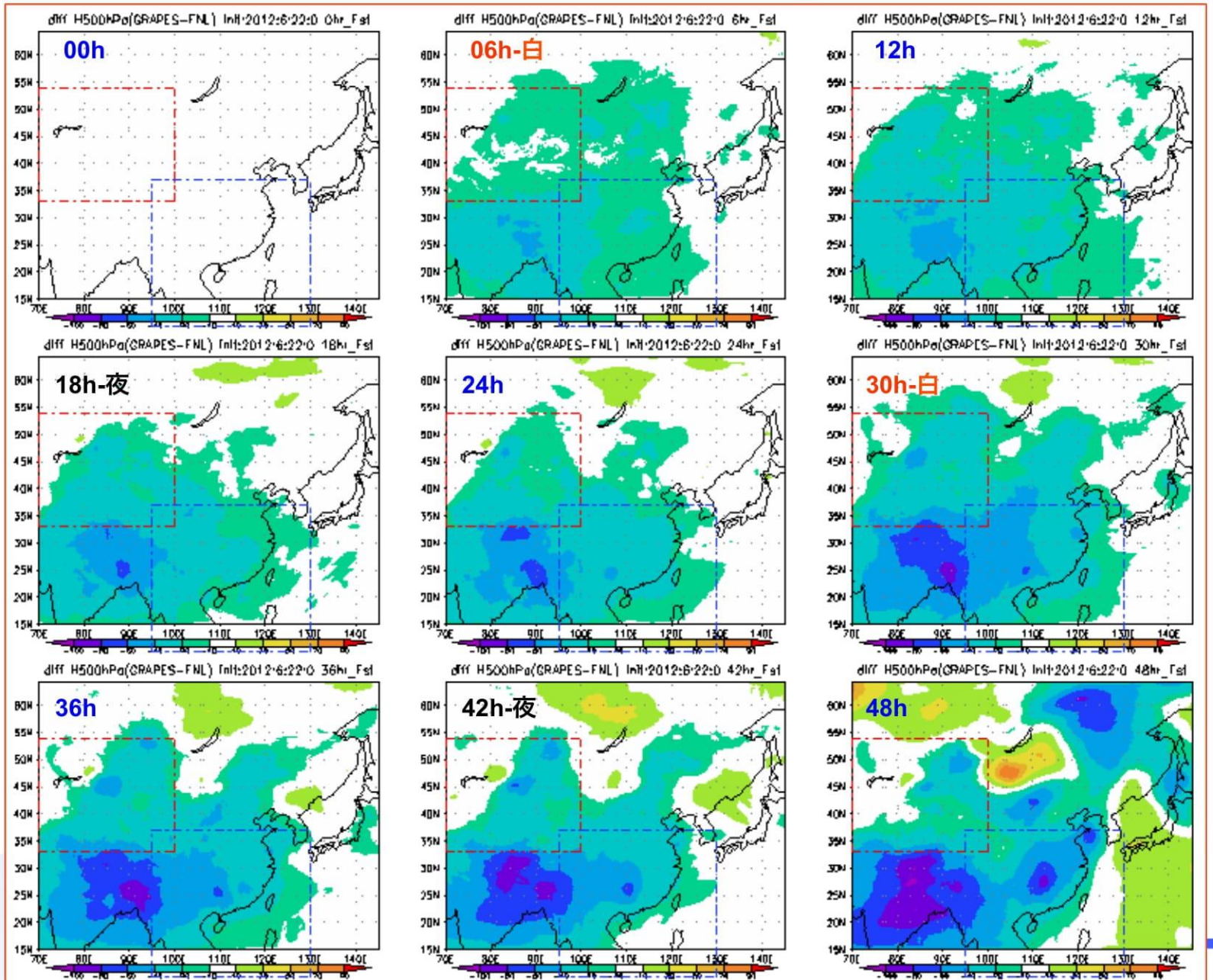

FORECAST VERIFICATION 12UTC
500hPa GEOPOTENTIAL
RMSE
20120602-20120615 24h
GZ 10-37.5N, 95-130E
24h预报
GRAPES_MESO_NWP
GZ-GRAPES
GRAPES_MESO_GFS
100
90
80
70
60
50
40
30
20
10
0
period of validity(hours)


FORECAST VERIFICATION 12UTC
500hPa GEOPOTENTIAL
RMSE
20120602-20120615 48h
10-37.5N, 95-130E
48h预报
GRAPES_MESO_NWP
GZ-GRAPES
GRAPES_MESO_GFS
gpm
100
90
80
70
60
50
40
30
20
10
0
period of validity(hours)

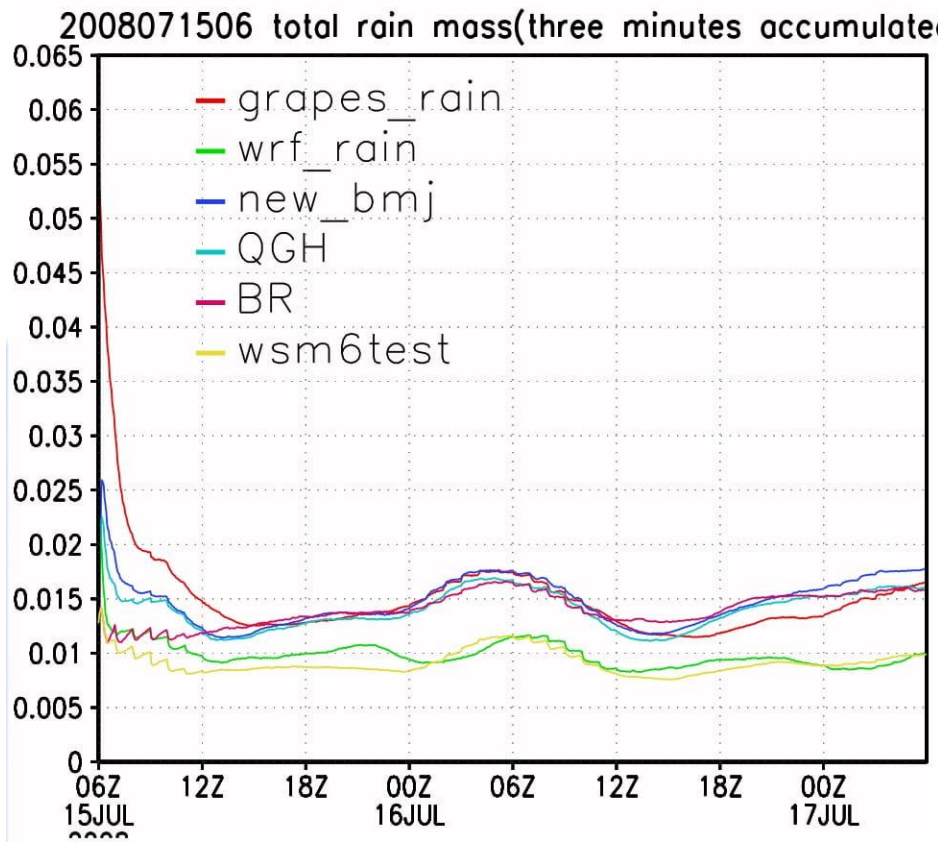

diff 500hPa H (GRAPES-FNL) 2012:6:22:0
55N
50N
45N
40N
35N
30N
25N
20N
15N
70E
35E 140
-100 -80 -60 -40 -20 -10 10 30 50 70 90
NMC model domain
GZ model domain
(10-37N; 95-130E)
Tibetan
Plateau

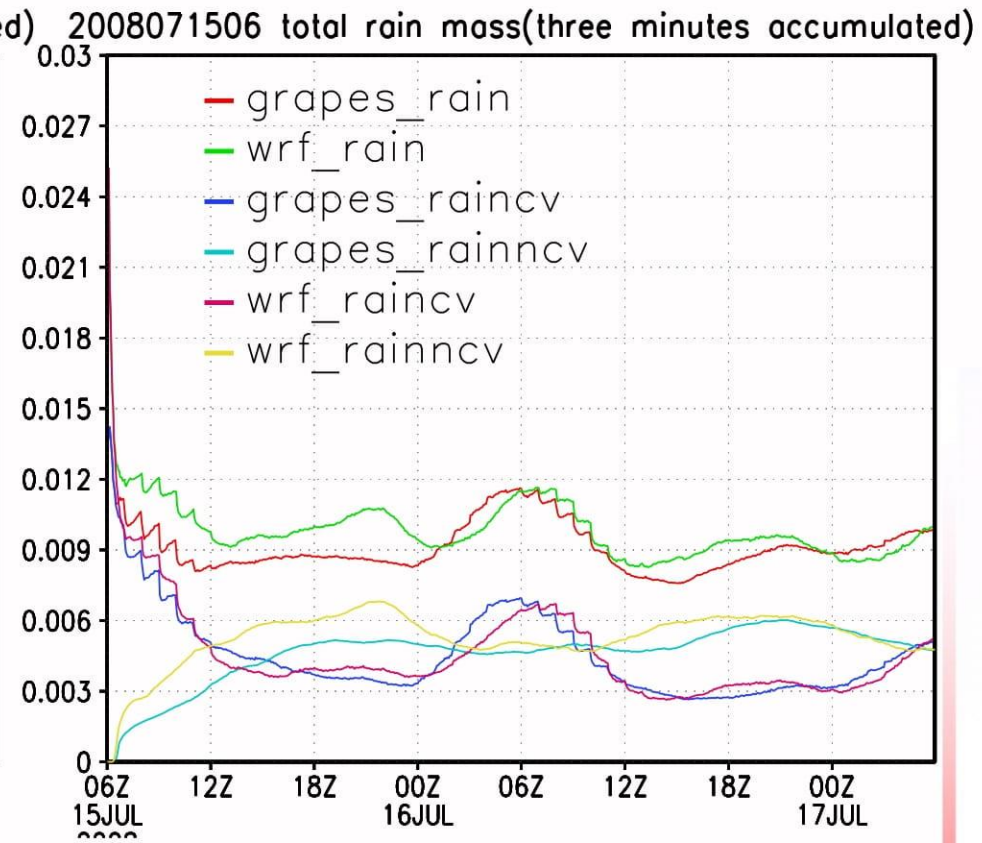

FORECAST VERIFICATION 12UTC
500hPa GEOPOTENTIAL
RMSE
20120602-20120615 24h
GZ 10-37.5N, 95-130E
24h
GRAPES_MESO_NWP
GRAPES_MESO_XUGQ
GZ-GRAPES
GRAPES_MESO_GFS
NMC domain
gpm
period of validity(hours)
FORECAST VERIFICATION 12UTC
500hPa GEOPOTENTIAL
RMSE
20120602-20120615 48h
GZ 10-37.5N, 95-130E
48h
GRAPES_MESO_NWP
GRAPES_MESO_XUGQ
GZ-GRAPES
GRAPES_MESO_GFS
period of validity(hours)
GZ domain
GrADS: COLA/IGES
2012-08-24-10:02

Tibetan Plateau: system bias



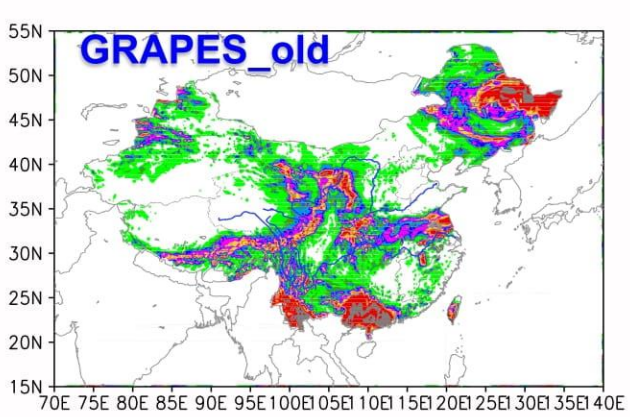
Put WSM6 to the model full level

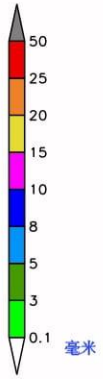




GRAPES_v3.0_bak降水预报(18－42小时)

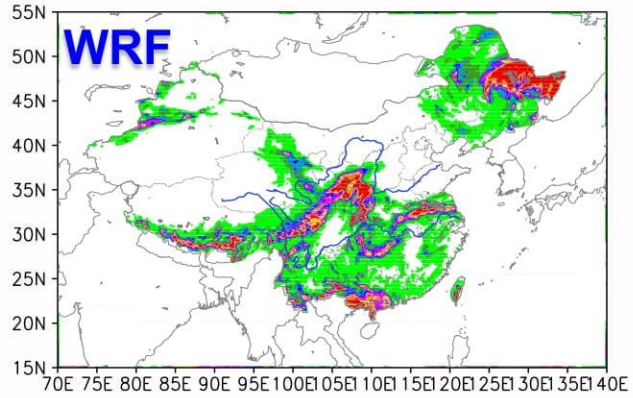
模式起始时间:2008:7:15:6(UTC)
预报时间:2008:7:16:0－2008:7:17:0(UTC)





WRF_v3.2降水预报(18－42小时)

模式起始时间:2008:7:15:6(UTC)
预报时间:2008:7:16:0－2008:7:17:0(UTC)



GRAPES_v3.0_wsm6test降水预报(18－42小时)

模式起始时间:2008:7:15:6(UTC)
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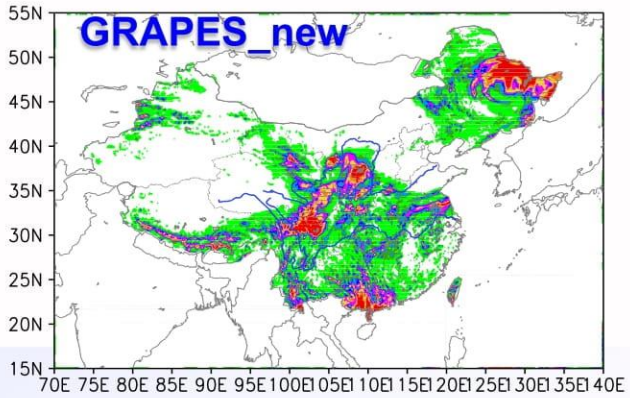
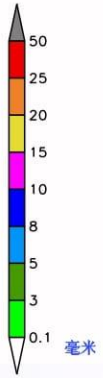
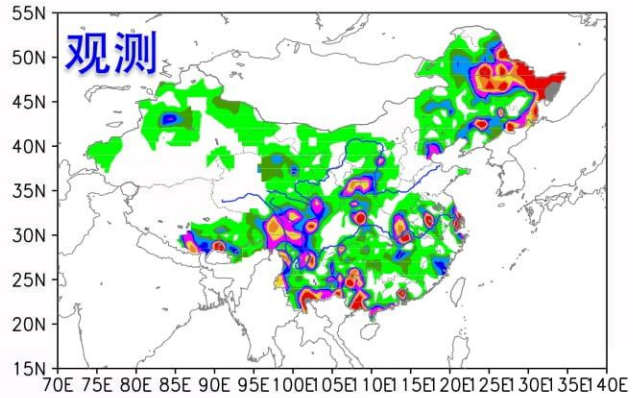




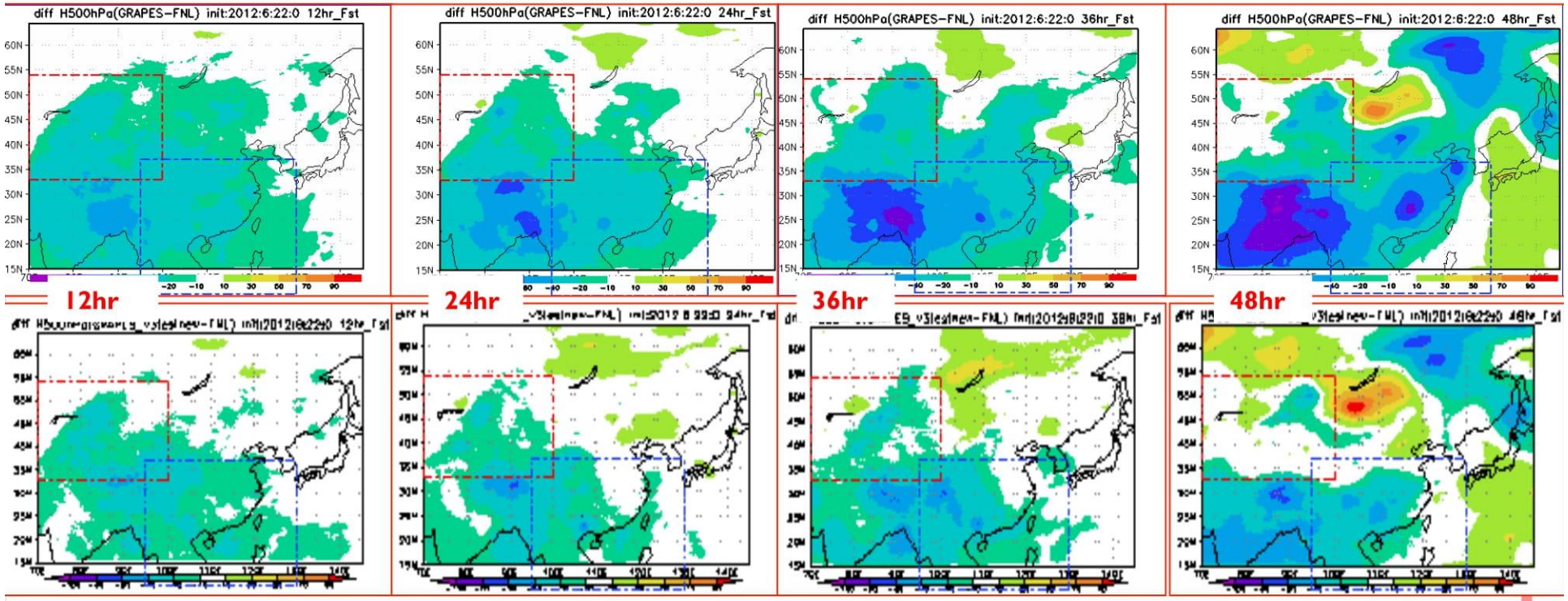
Observed－Precipitation

Period:2008:7:16:0－2008:7:17:0UTC



Forecast bias

V3.0 oper



GRAPES_MESO3.1.1.2

GRAPES_meso data assimilation

- Frame work of data assimilation
  - Hybrid or 4dvar
- Satellite data assimilation
- Doppler radar assimilation
- O.I. : T_{2m}, RH_{2m}, → T_{soil}, RH_{soil}

GRAPES_3DVAR(or 4DVAR)-Hybrid: Method

Extended control variable method (Lorenc 2003; Wang 2010):

$$J(\mathbf{x}_1', \boldsymbol{\alpha}) = \beta_1 J_1 + \beta_2 J_e + J_o$$

$$= \beta_1 \frac{1}{2} \mathbf{x}_1'^{T} \mathbf{B}^{-1} \mathbf{x}_1' + \beta_2 \frac{1}{2} \boldsymbol{\alpha}^{T} \mathbf{C}^{-1} \boldsymbol{\alpha} + \frac{1}{2} \left(\mathbf{y}^{o'} - \mathbf{H}\mathbf{x}'\right)^{T} \mathbf{R}^{-1} \left(\mathbf{y}^{o'} - \mathbf{H}\mathbf{x}'\right)$$

Extra term associated with extended control variable

$$\mathbf{x}' = \mathbf{x}_1' + \sum_{k=1}^{K} \left(\boldsymbol{\alpha}_k \circ \mathbf{x}_k^e\right)$$

Extra increment associated with ensemble

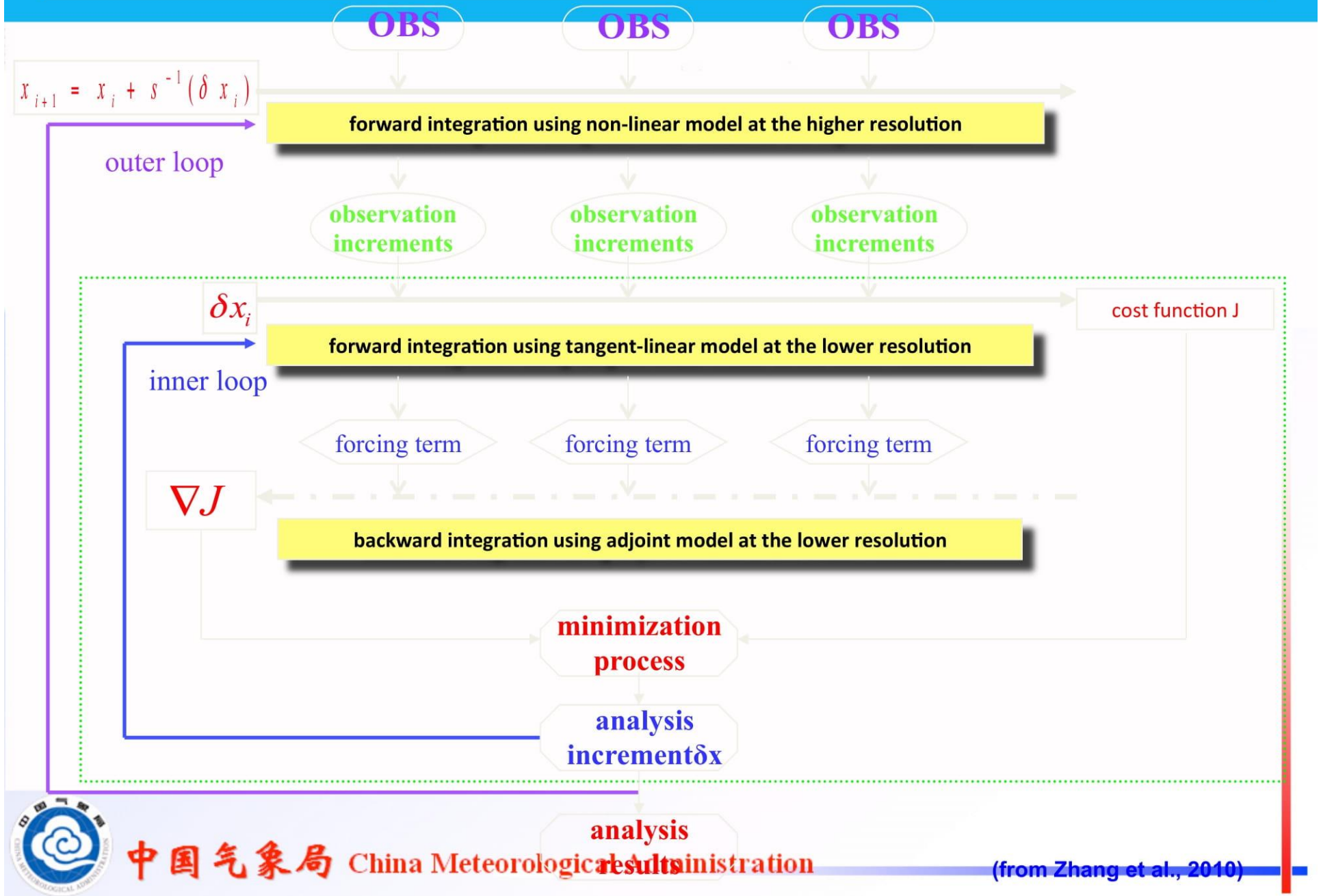
$\mathbf{B}$ 3DVAR static covariance; $\mathbf{R}$ observation error covariance; K ensemble size;
$\mathbf{C}$ correlation matrix for ensemble covariance localization; $\mathbf{x}_k^e$ kth ensemble perturbation;
$\mathbf{x}_1'$ 3DVAR increment; $\mathbf{x}'$ total (hybrid) increment; $\mathbf{y}^{o'}$ innovation vector;
$\mathbf{H}$ linearized observation operator; β_1 weighting coefficient for static covariance;
β_2 weighting coefficient for ensemble covariance; $\boldsymbol{\alpha}$ extended control variable.

Regional GRAPES_4DVAR

- Finish the development: TL & Adjoint model
- Introduce:
  - **Vertical Diffusion**
  - **PBL**
  - **Large-scale condensation**
  - **Cumulus Convection**

  into the TL forward operator
- Establish a test version of GRAPES meso-scale forecast system with regional GRAPES_4DVAR

Flowchart of regional GRAPES 4DVAR



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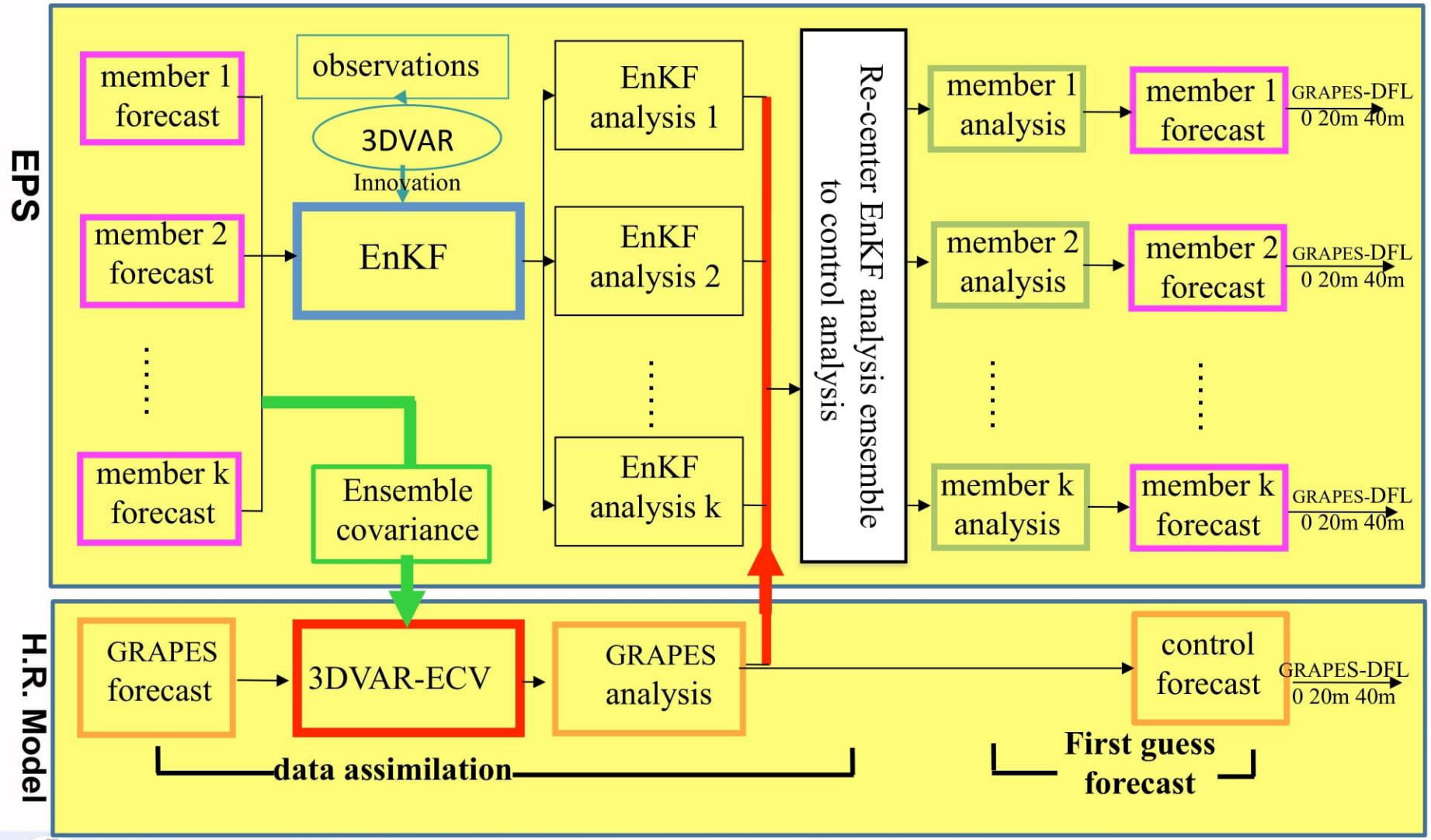
(from Zhang et al., 2010)

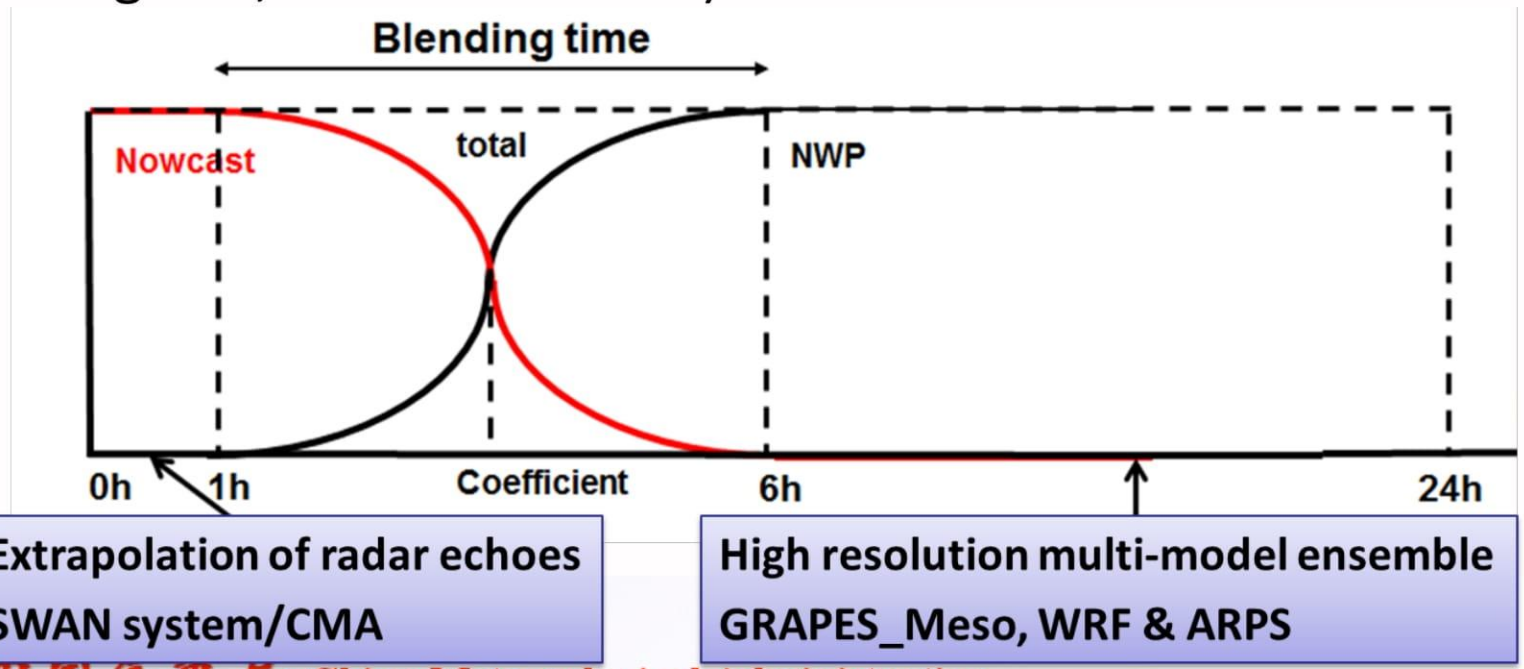
Future HR GRAPES -DA and Prediction System



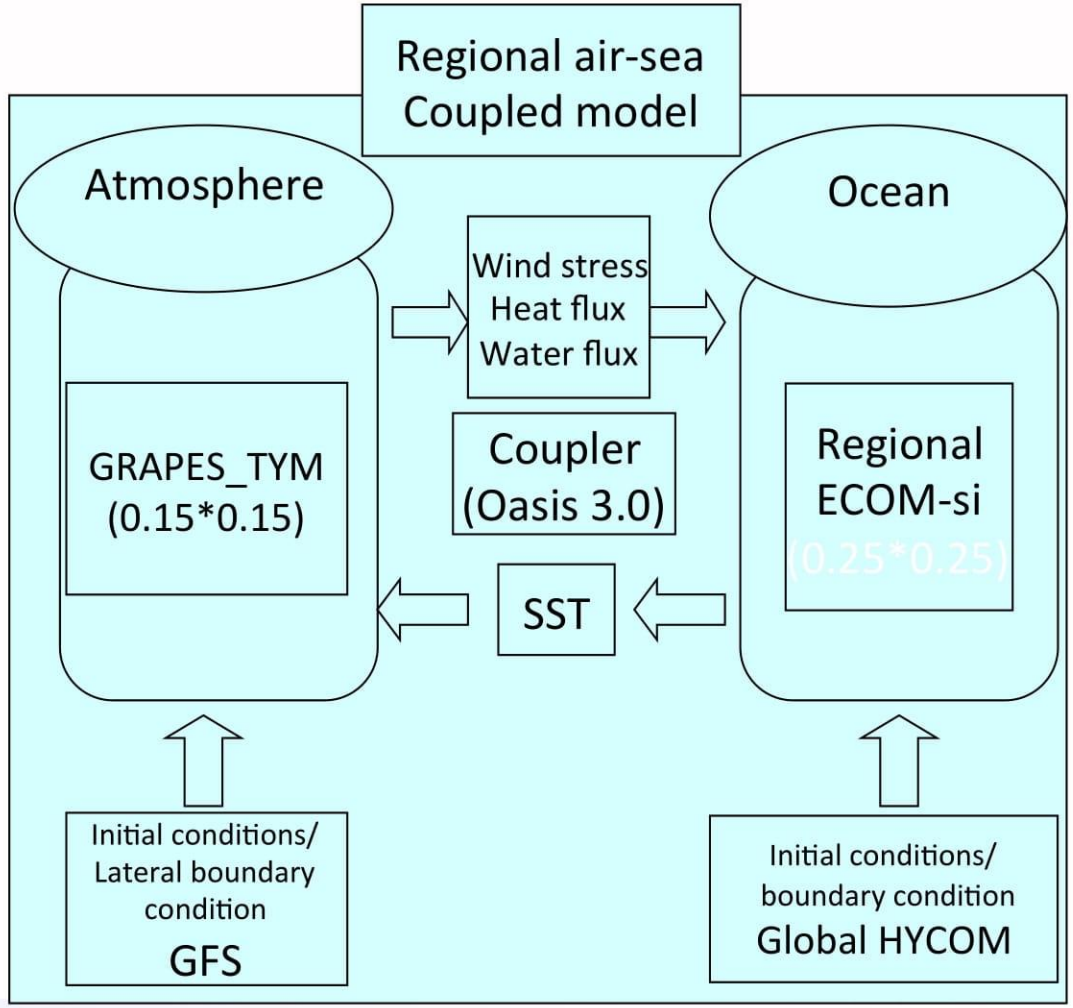
DAS: EnKF/3DVAR Hybrid DA System

Blending Nowcast with GRAPES_HR

- Implement a very-short term forecast system with 3km resolution based on multi-model ensemble including GRAPES_Meso, WRF and ARPS (collaborate with Nanjing University)
- Data assimilation: hybrid DA (3DVAR+EnKF) (collaborate with Ming Xue, Oklahoma Univ.)

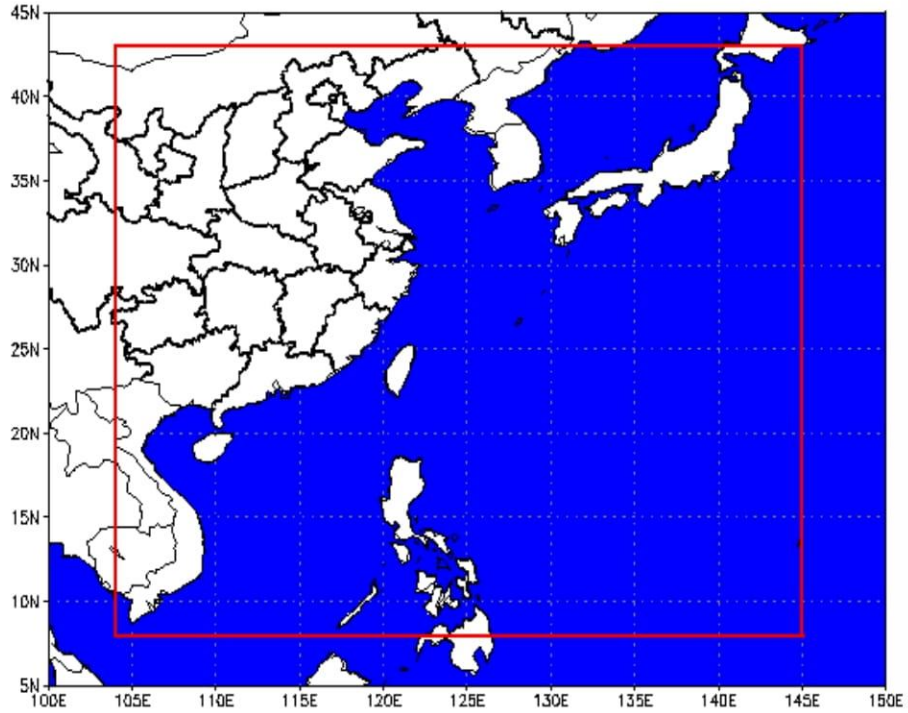


Coupled Typhoon-Ocean Model

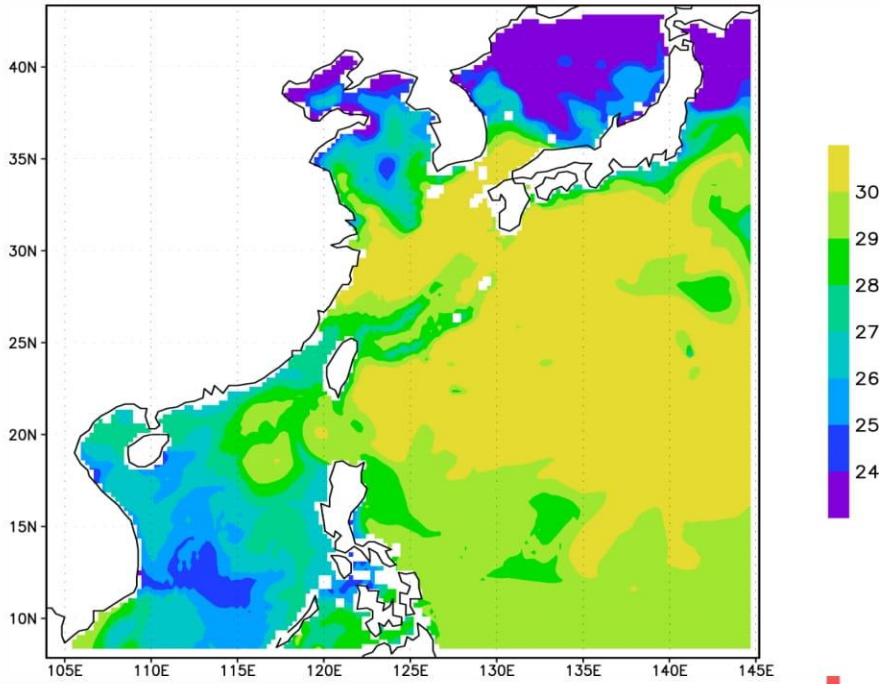


(From Sun et al., 2012)

Model domain



ECOM:
Horizontal resolution: 0.25°x 0.25°
Domain：104°E~145°E, 8°N~43°N
Provided：SST



GRAPES:
Horizontal resolution : 0.15°x 0.15°
Domain：100°E~150°E, 5°N~45°N
Provided: wind stress, solar flux, heat flux, water flux;
Fluxes are exchanged every 360s.

(From Sun et al., 2012)

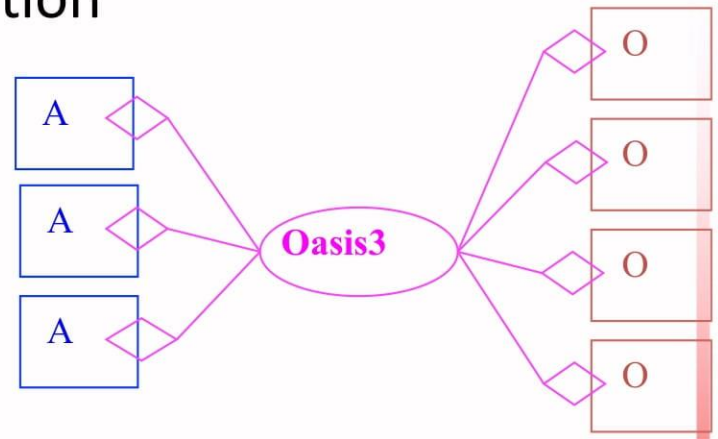
OASIS3 coupler

OASIS: Ocean Atmosphere Sea Ice Soil
---------Developed since 1991 in CERFACS

- performs:
  - synchronisation of the component models
  - coupling fields exchange and interpolation
  - I/O actions

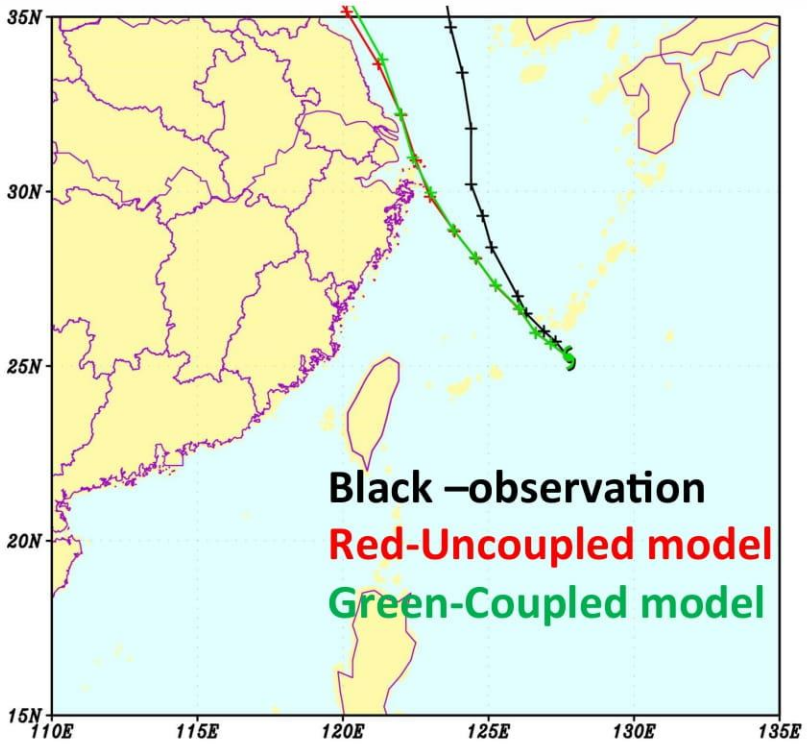
- External library and module used:

  NetCDF/parallel NetCDF
  libXML, mpp_io, SCRIP
  MPI1 and/or MPI2

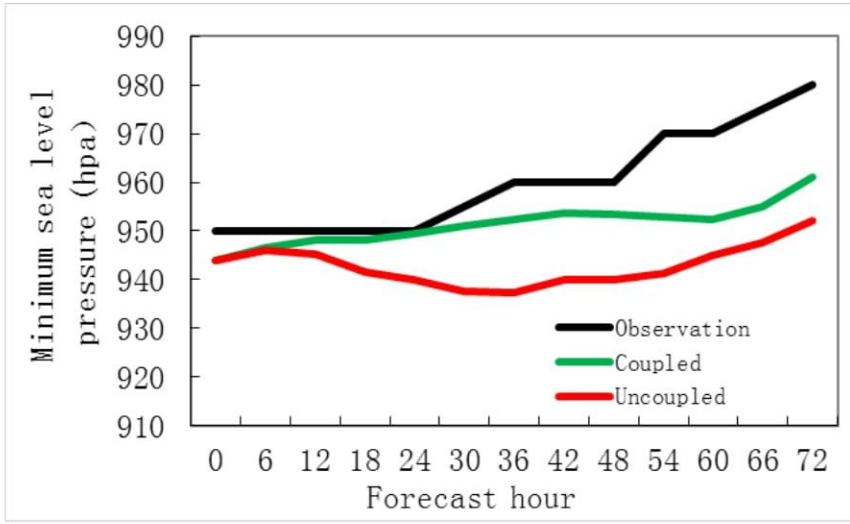


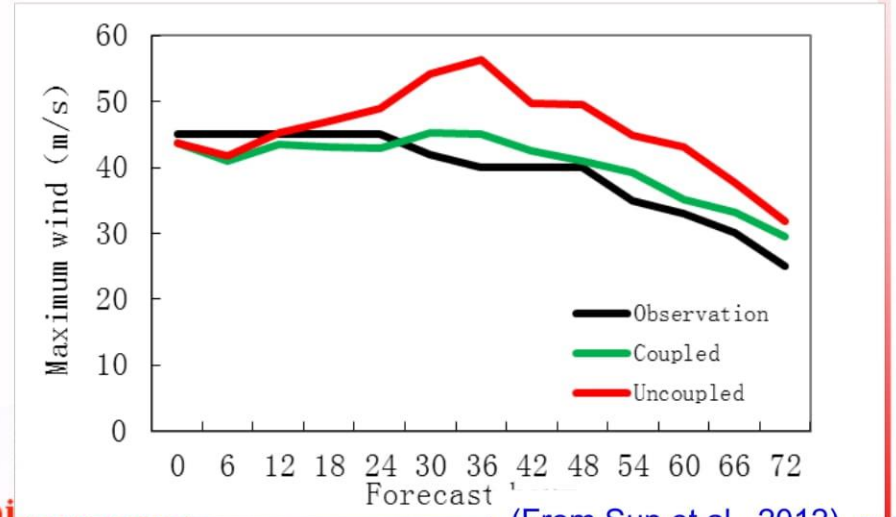
(From Sun et al., 2012)

Typhoon Muifa – impact of coupling



Tropical Cyclone Muifa (2011)
INITIAL TIME 00:00 UTC, 5 August 2011



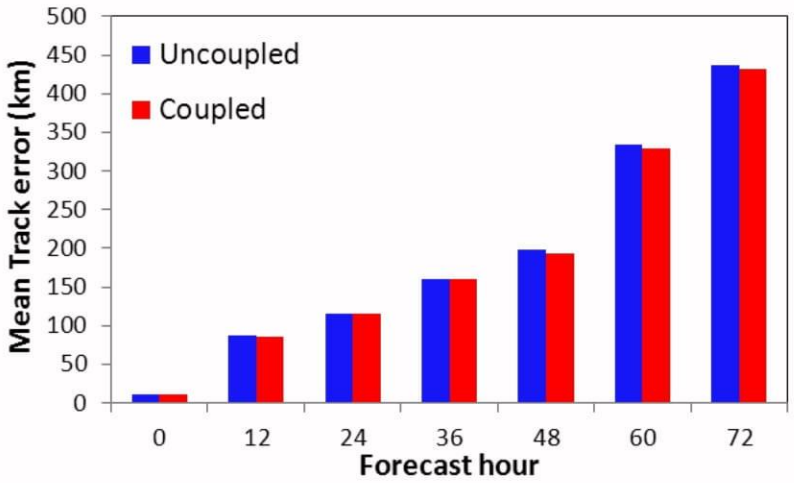


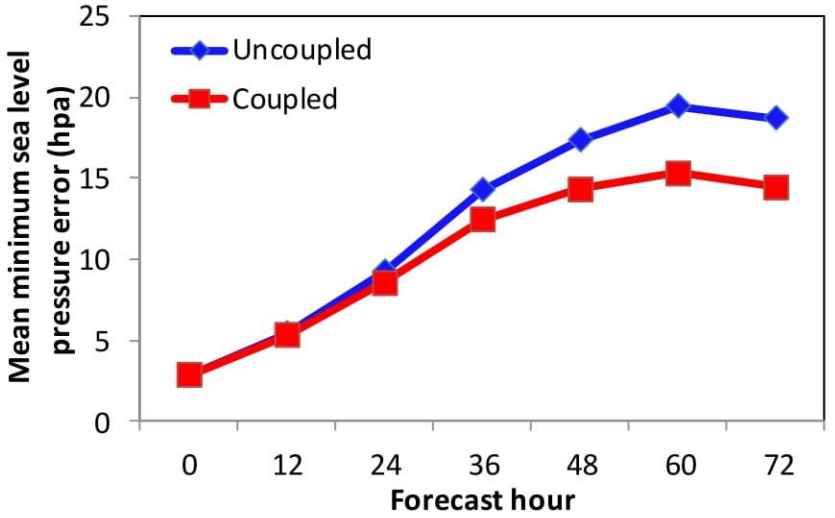
- Too strong in GRAPES_tym
- Coupling weaken the intensity

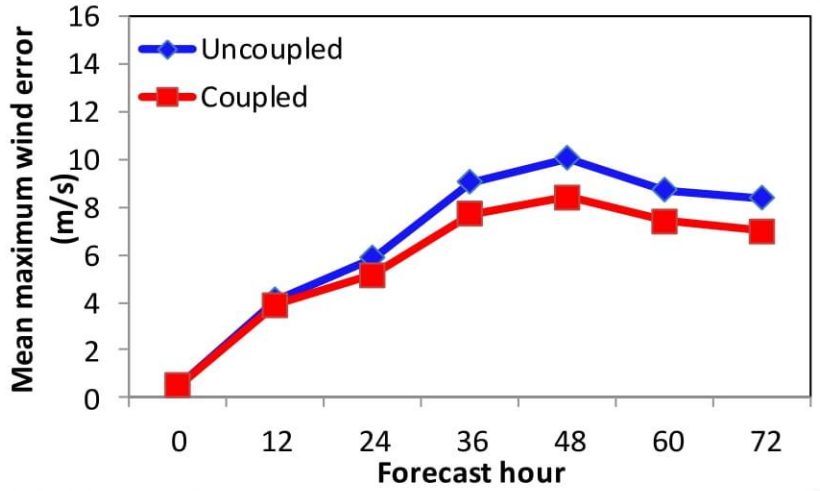
(From Sun et al., 2012)

Forecast verification of Nine TC in 2011

Number of cases (72,72,56,56,49,44,44)







(From Sun et al., 2012)

China Meteorological Admi

High Resolution Modeling Activities in CMA Based on GRAPES_Meso

Upgrade activities

- Vertical coordinate from terrain-following Z to hybrid coordinate (Schar, 2002)
- Inclusion of thermal expansion effect in continuity equation
- Improve the interpolation accuracy in physics-dynamics interface
- Refinement of 2-moment microphysics scheme
- Some bug fix in land surface scheme
- Refinement of back ground error covariance in 3DVAR

Modification of TF coordinate

- In order to design a new TF coordinate, we rewrite the formulation of Gal-Chen and Sommerville (1975) in a common formulation:

$$\hat{z} = Z_T \frac{z - Z_s(x,y)}{Z_T - Z_s(x,y)}$$

$$\longrightarrow \quad z = \hat{z} + b \cdot Z_s(x,y)$$

with $b = (1 - \frac{\hat{z}}{Z_T})$ It is a decaying coefficient of the coordinate surface with height. It is possible to use different "b" to accelerate the decaying.

New TF coordinates

- The different decaying coefficients “b” can be defined as:

G.C.S.

$$b = (1 - \frac{\hat{z}}{Z_T})$$

(Gal-Chen and Sommerville, 1974)

SLEVE1

$$b_h = \frac{\sinh[(Z_T - \hat{z}) / h^*]}{\sinh[Z_T / h^*]}$$

SLEVE2

$$b_H = \sum_{i=1}^{2} \frac{\sinh[(Z_T - \hat{z}) / h_i^*]}{\sinh[Z_T / h_i^*]}$$

(Schar, 2002)
h*: scale of ref-topography; h^*_1 and h^*_2: large and small-scale of ref-topogr.

COS

$$b_C = \begin{cases} \left(1 - \frac{\hat{z}}{Z_T}\right) \cdot \left[\cos\left(\frac{\pi}{2} \frac{\hat{z}}{\hat{z}_c}\right)\right]^n & \hat{z} \le \hat{z}_c \\ 0 & \hat{z} > \hat{z}_c \end{cases}$$

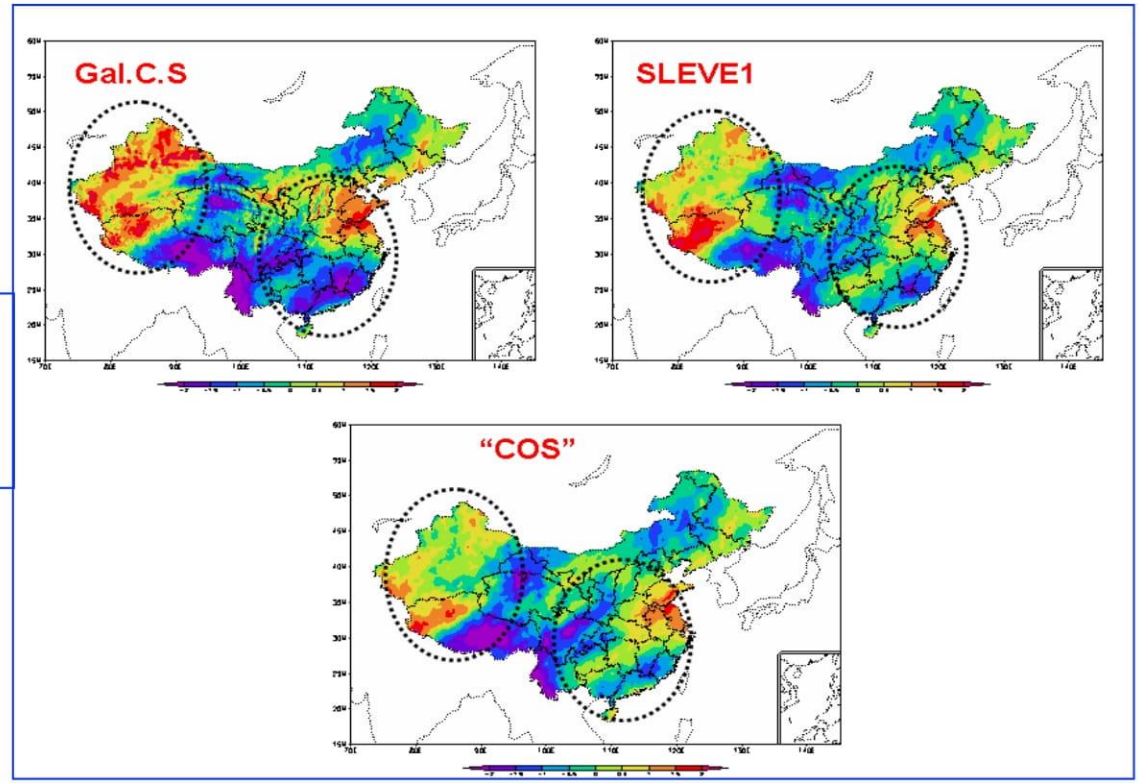
(similar to Klemp, 2011)
“n>2”: an empirical number; z_c : a reference height from which the coordinate surface becomes horizontal.

(From Li et Chen, 2012)

The preliminary results with new TF coordinates in GRAPES_Meso

- The preliminary results with regional GRAPES (15km) are quite encouraging:

Monthly mean of 24h forecast of geopotential height at 100hPa

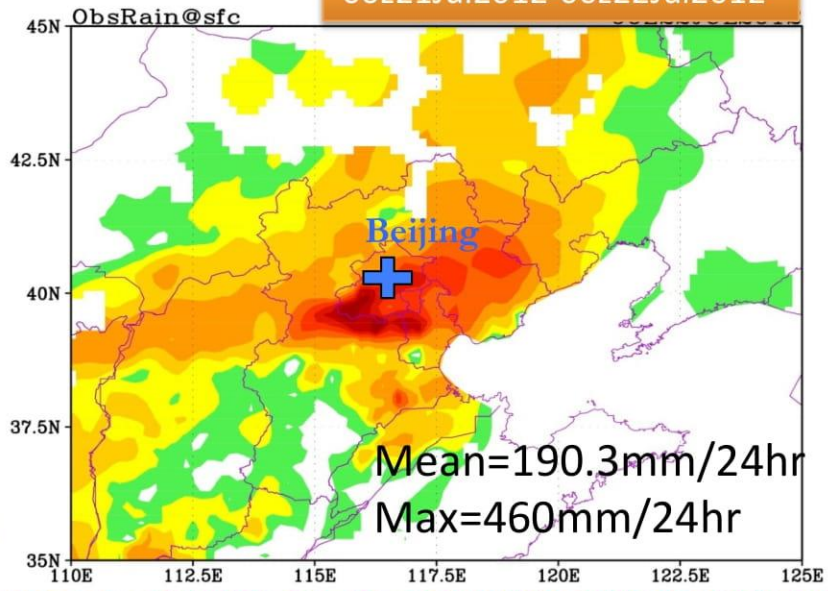


(From Li et Chen, 2012)

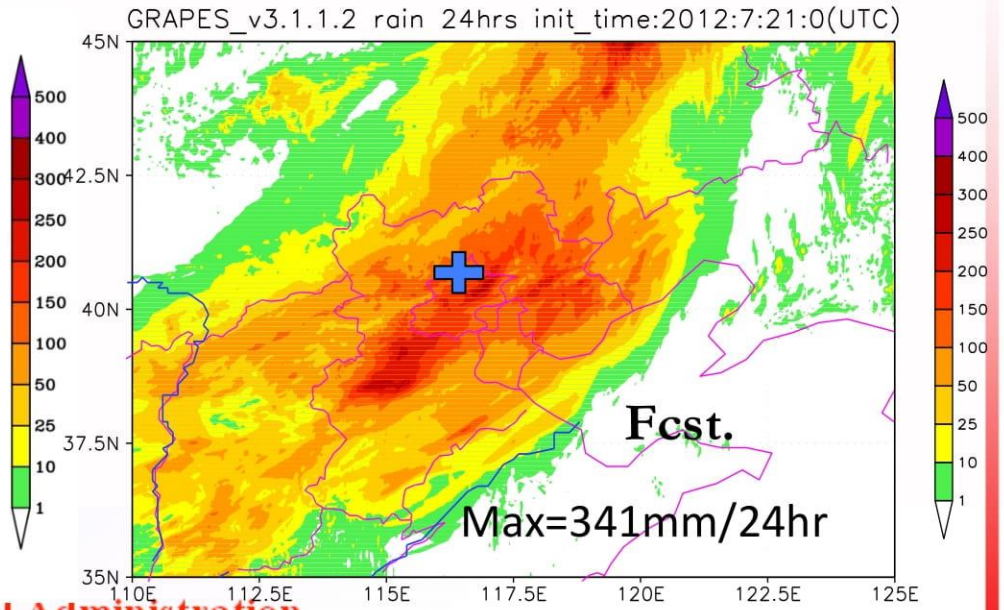
HR GRAPES cases exp.

Torrential rainfall event on Jul.21/2012 in Beijing，the worst the city has seen in more than 60 years

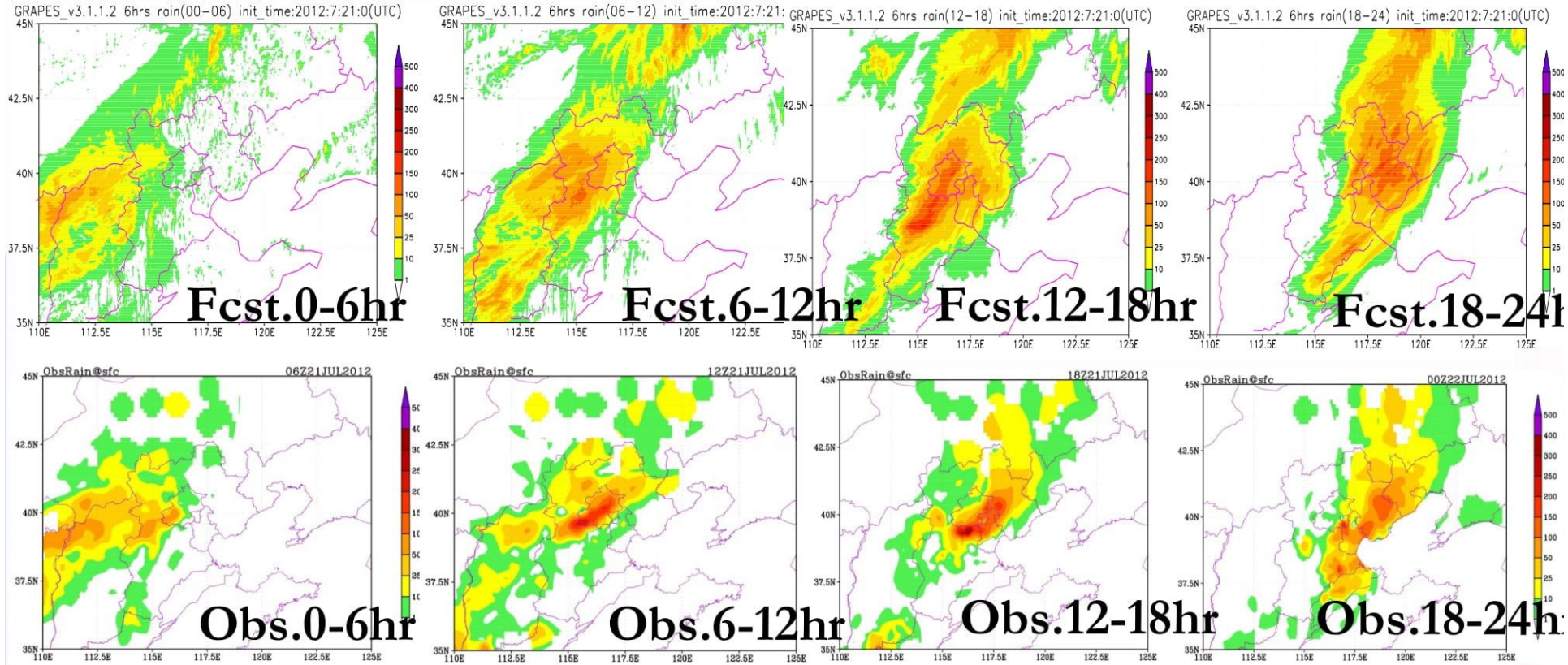
00z21Jul2012-00z22Jul2012



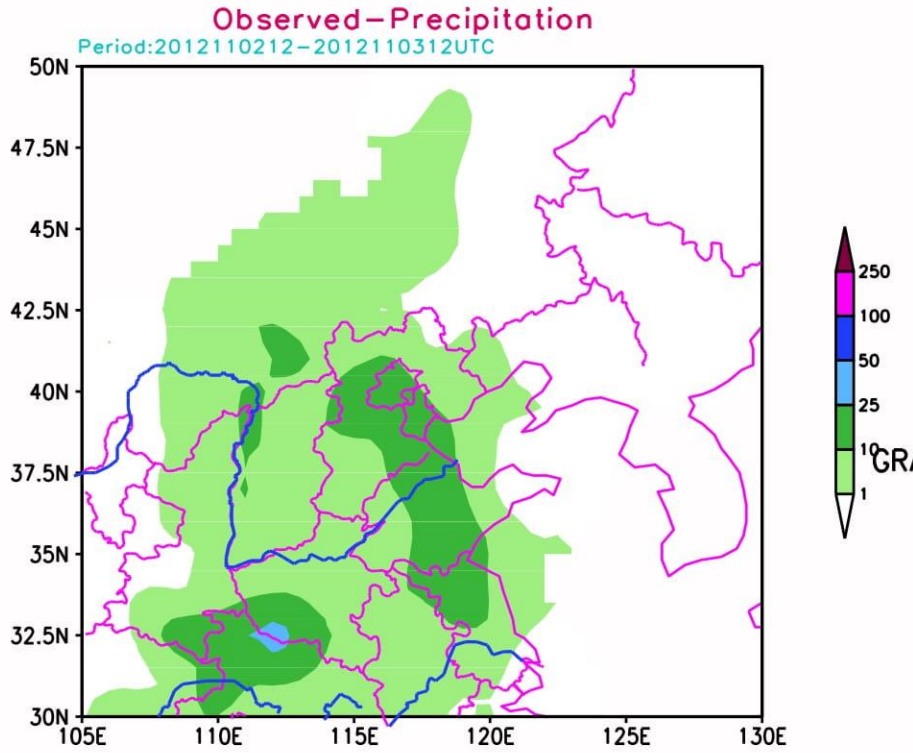
24-hour accumulated rainfall

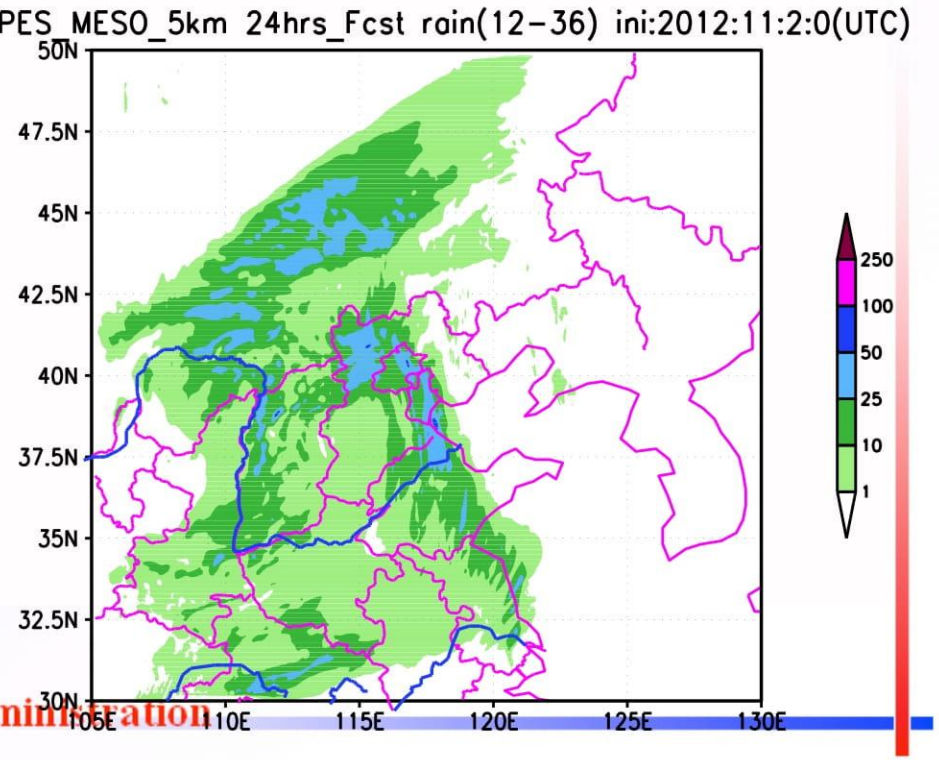


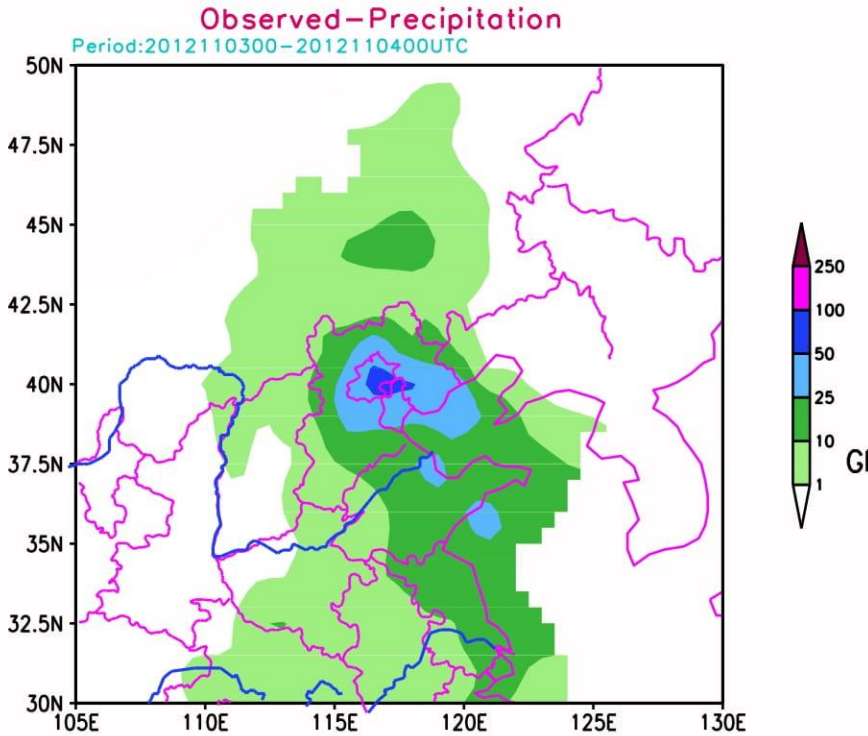
Comparison of precipitation every 6-hour between Obs. & Fcst.

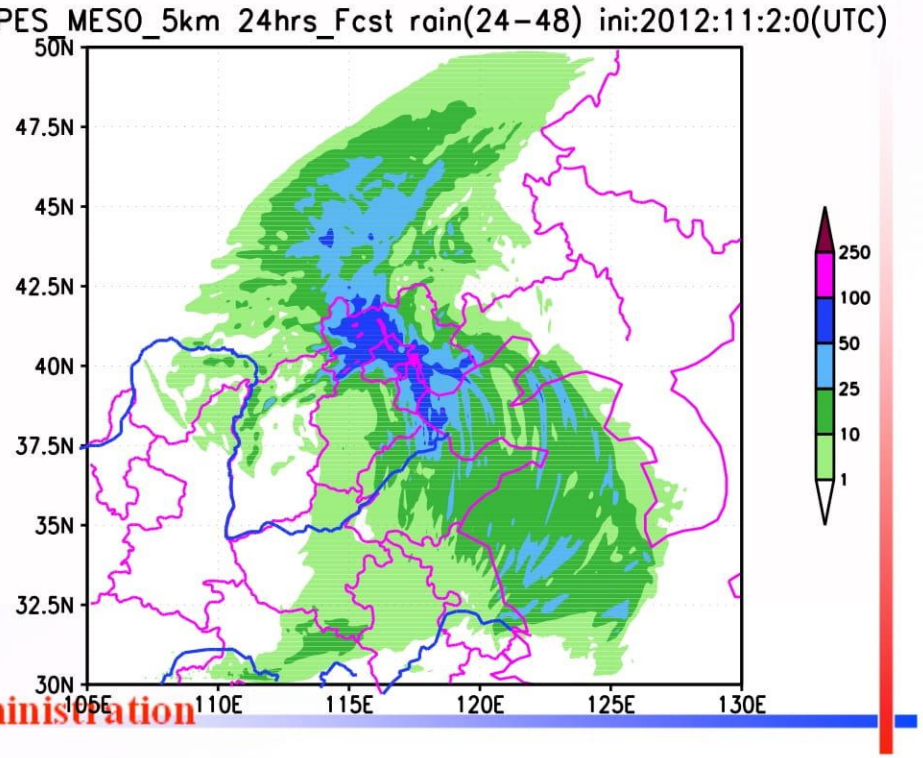


The first snow in this winter -- GRAPES-5km



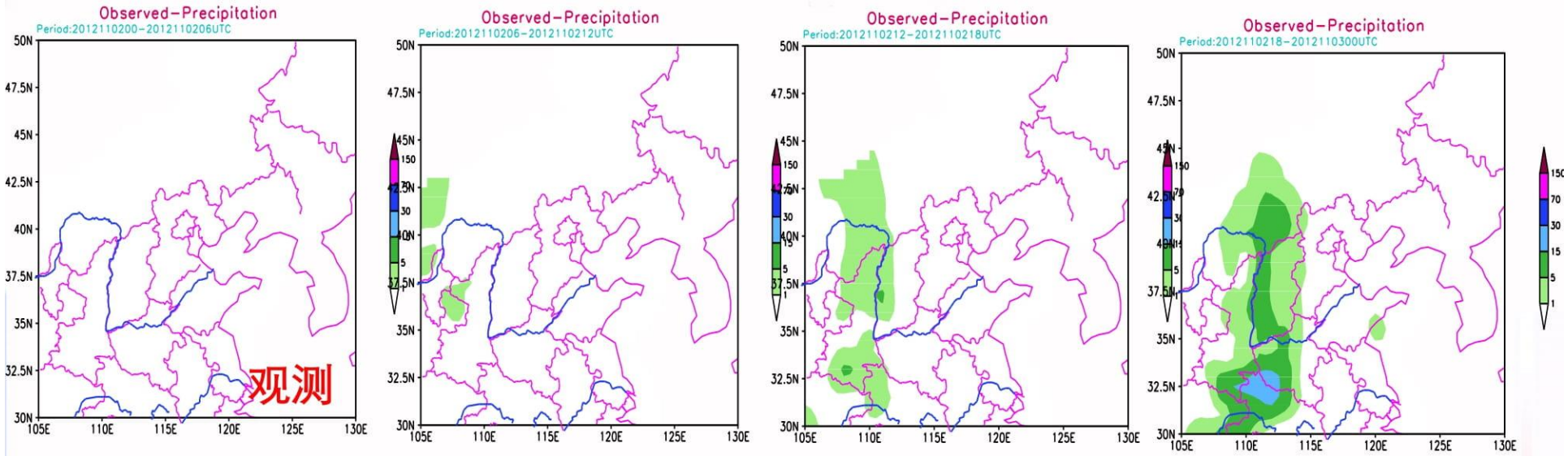


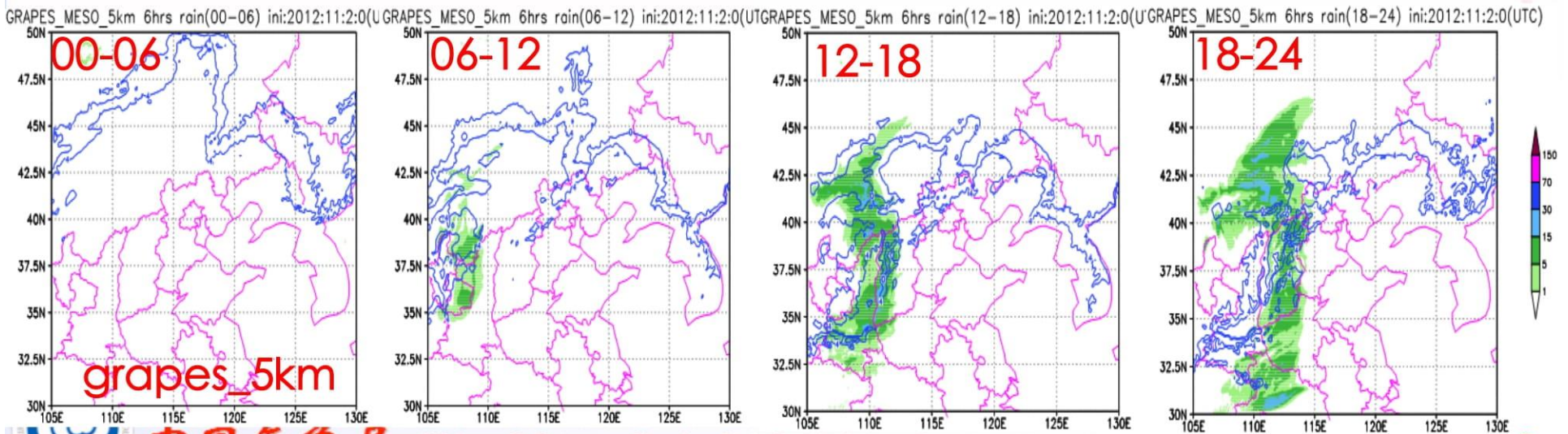

Observed–Precipitation
Period:2012110300–2012110400UTC
50N
47.5N
45N
42.5N
40N
37.5N
35N
32.5N
30N
105E
110E
115E
120E
125E
130E
250
100
50
25
10
1

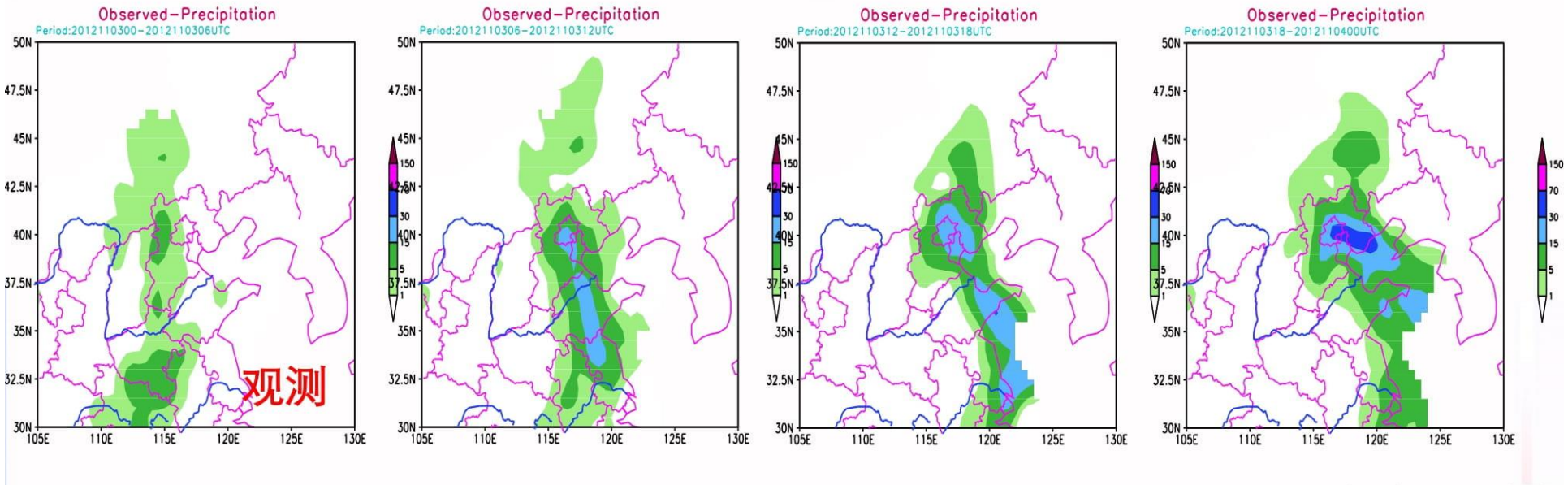

GRAPES_MESO_5km 24hrs_Fcst rain(24–48) ini:2012:11:2:0(UTC)
50N
47.5N
45N
42.5N
40N
37.5N
35N
32.5N
30N
105E
110E
115E
120E
125E
130E
250
100
50
25
10
1

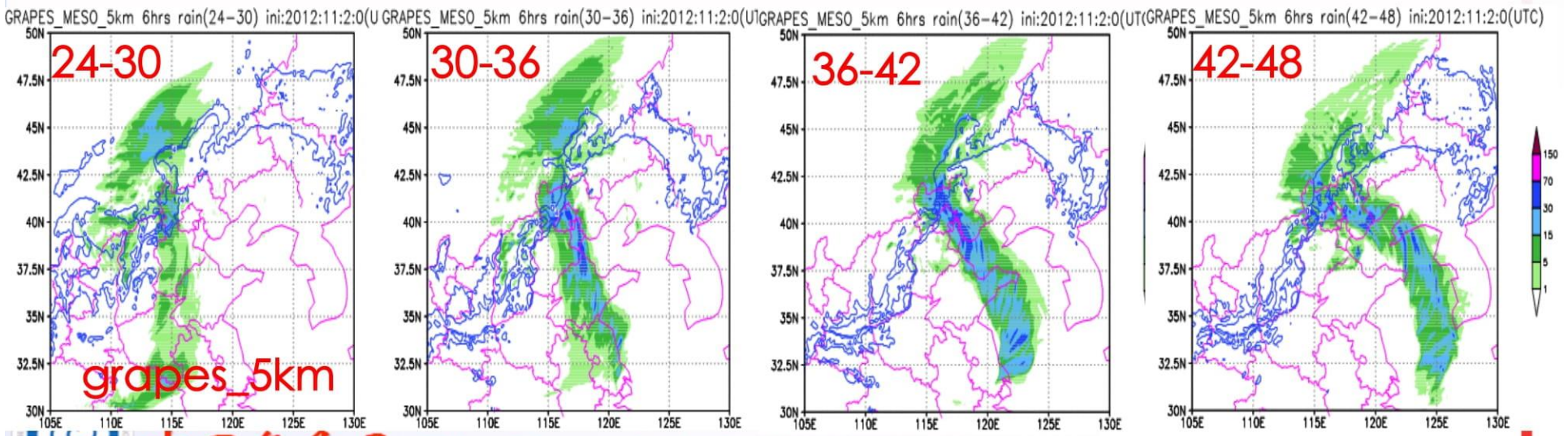
6h accumulated precipitation

(Blue line for the 0/4 T2m)





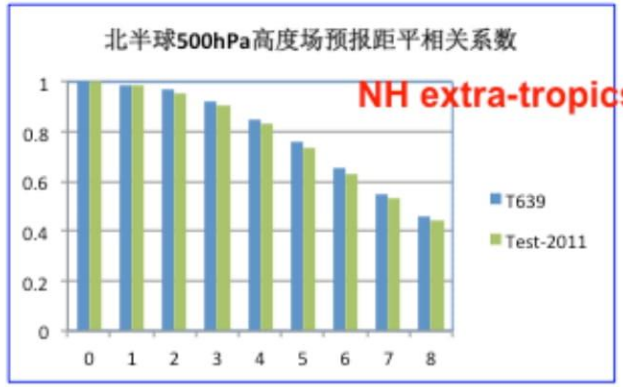

Observed-Precipitation
Period:2012110300-2012110306UTC
Observed-Precipitation
Period:2012110306-2012110312UTC
Observed-Precipitation
Period:2012110312-2012110318UTC
Observed-Precipitation
Period:2012110318-2012110400UTC
观测

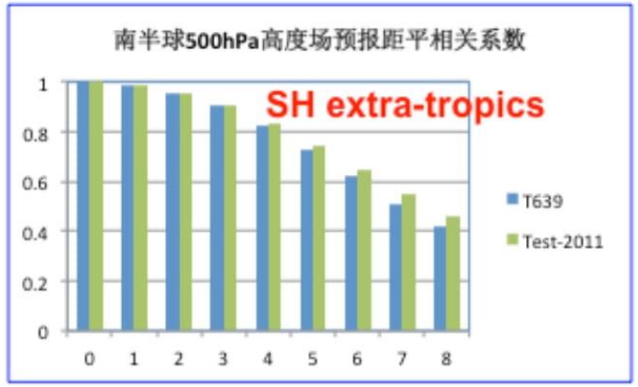

GRAPES_MESO_5km 6hrs rain(24-30) ini:2012:11:2:0(U
GRAPES_MESO_5km 6hrs rain(30-36) ini:2012:11:2:0(U
GRAPES_MESO_5km 6hrs rain(36-42) ini:2012:11:2:0(UT
GRAPES_MESO_5km 6hrs rain(42-48) ini:2012:11:2:0(UTC)
24-30
30-36
36-42
42-48
grapes_5km

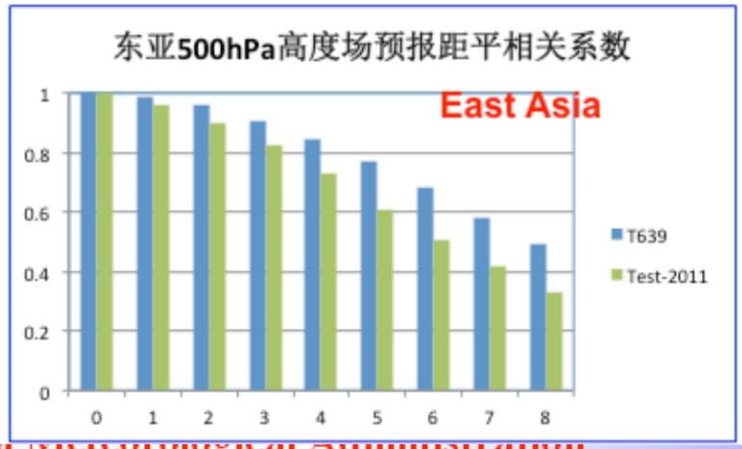
GRAPES_GFS

- Forecast skill over east-Asia

500hPa Z ACC（T639 vs. GRAPES_GFS)







Efforts in improving the forecast skill of GRAPES_GFS

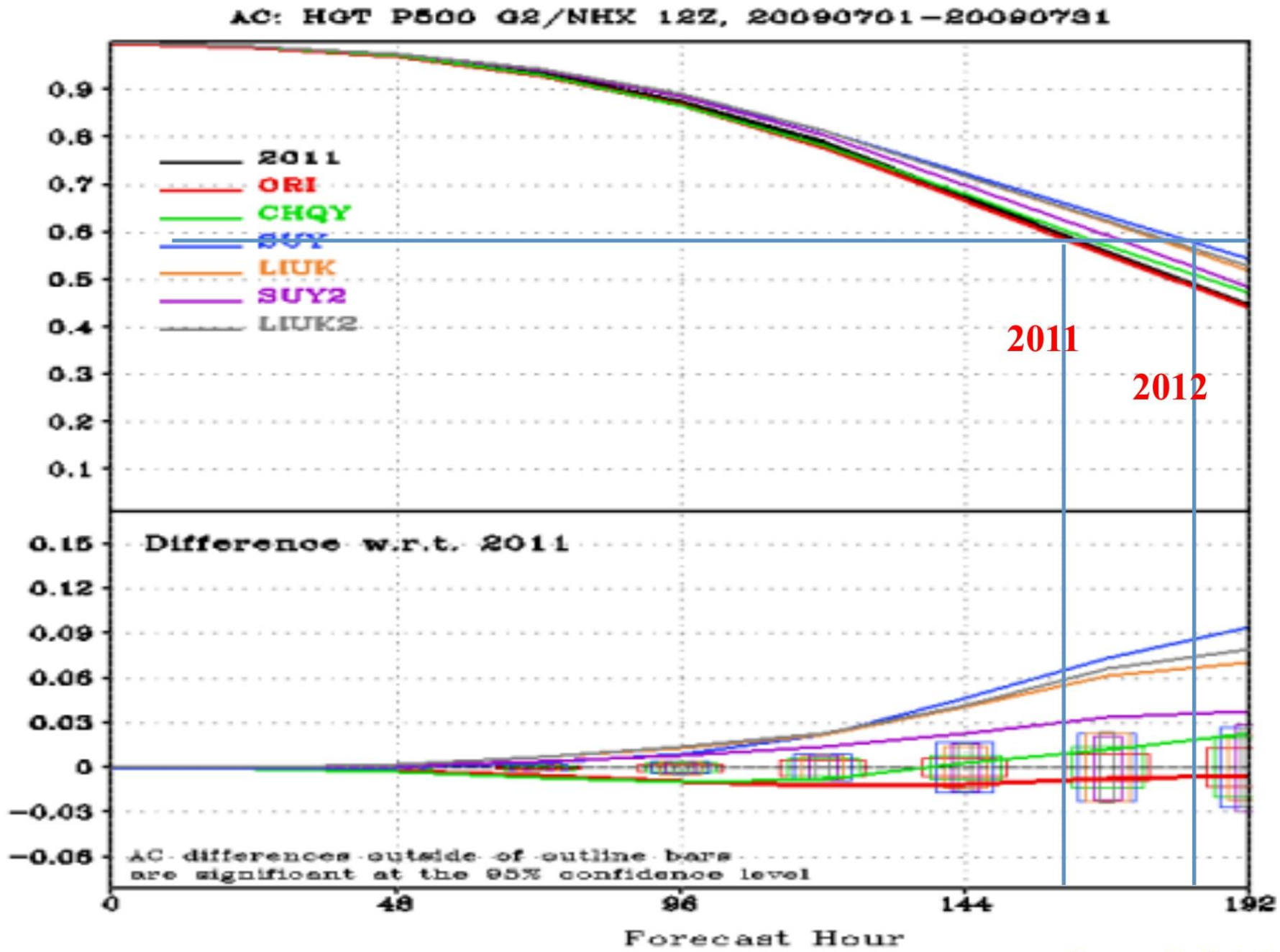
- **More satellite data**
  - *ATOVS(NOAA-19,METOP,FY3)*
  - *AIRS*
  - *IASI*
- **Assimilation from pressure level to model grid space**
- **Improve model performance**
  - *The dynamic core refinement: conservation issue*
  - *Hybrid vertical coordinate: from terrain-following to terrain-following & Z*
  - *Increase the vertical resolution and model top lift-up*
  - *Tuning of physical processes*
    - Land surface: CoLM
    - GWD
    - SSO
    - Microphysics + fractional cloud treatment
    - Cumulus scheme tuning
    - cloud-radiation interaction issue

Work finished in 2012

- PRM-scalar variable advection
- dyn/phys interface interpolation: 3-order spline
- 4-order diffusion for momentums u & v
- N_SAS+N_MRF

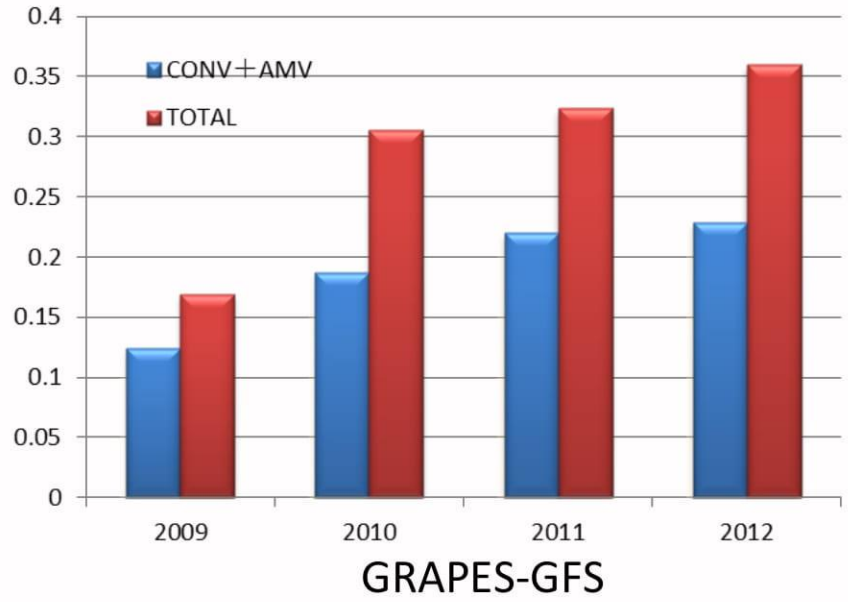
(from su, Liu K.et al., 2012)

NH ACC 500

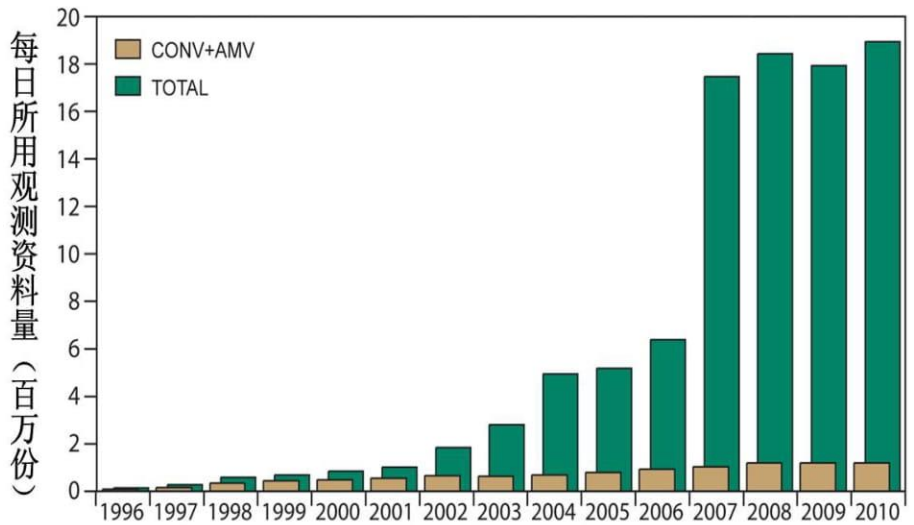


(from su, Liu K.et al., 2012)

Satellite data assimilation



GRAPES-GFS

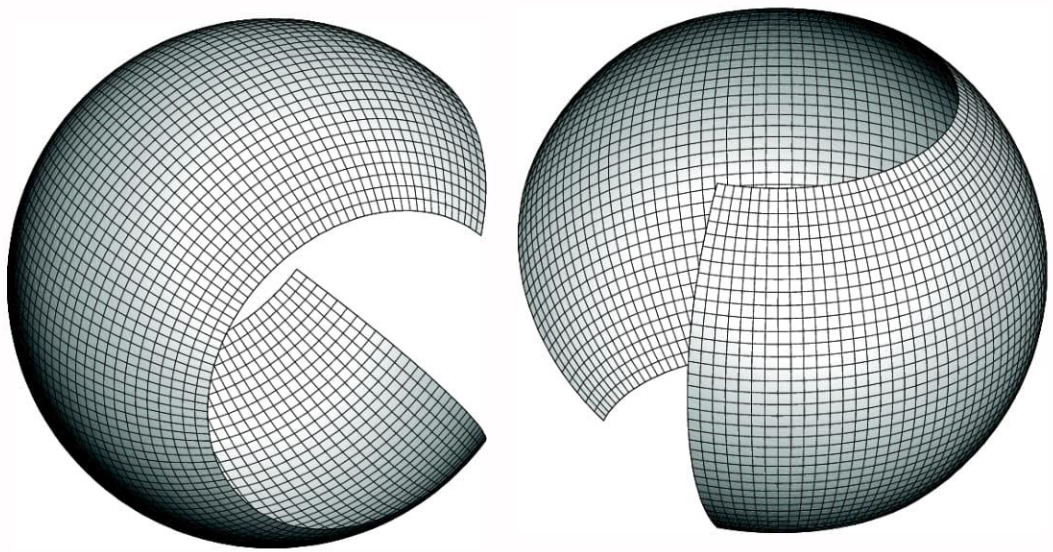


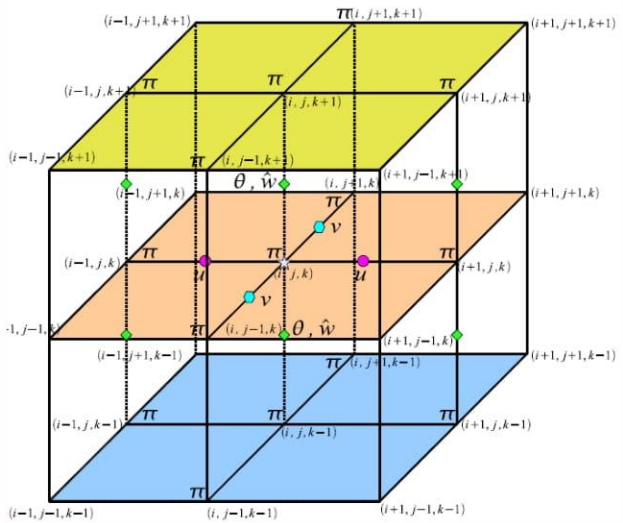
ECMWF

Progress of GRAPES Yin-Yang grid

✓The Helmholtz equation of GRAPES in the Yin-Yang overset grid are solved.
✓The transplant of the whole GRAPES dynamical core is finished. However, some bugs exist and it need to be debuged in the next step.

Helmholtz equation: $\nabla^2\pi - \mu^2\pi = H$



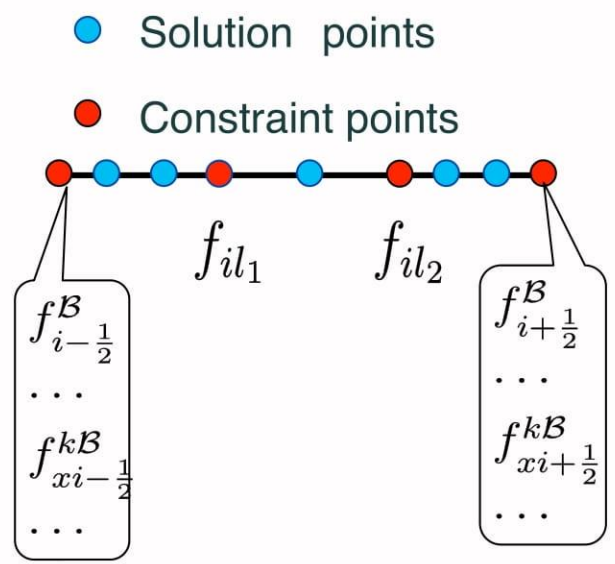


High order Multi-moment Constrained finite Volume (MCV) method

We define the moments *within single cell*, i.e. the cell-averaged value, the point-wise value and the derivatives of the field variable

$$\overline{q}_m^{(x)}(t) \equiv \frac{1}{\Delta x_i}\int_{\delta x} q_m(x,t)dx,$$

$$\partial_x^k q_{cpm}(t) \equiv \frac{\partial^k}{\partial x^k} q(x_{cpm},t);\ \text{with } k=0,1,\cdots$$



Constraint conditons:

$$\frac{d}{dt}[\overline{q}_m^{(x)}(t)] = -\frac{1}{\Delta x_i}\left(\hat{f}_{Lm} - \hat{f}_{1m}\right)$$

$$\frac{d}{dt}[q_{1m}(t)] = -\partial_x \hat{f}_{1m} \text{ and } \frac{d}{dt}[q_{Lm}(t)] = -\partial_x \hat{f}_{Lm}$$

$$\partial_t (q_x)_{cm}(t) = -\partial_x^2 \hat{f}_{cm},$$

Approximate Riemann solvers $$f^{k\mathcal{B}}_{xi_p} = \frac{1}{2}\left(f^{k-}_{xip} + f^{k+}_{xip} - R_{ip}|\Lambda_{ip}|R^{-1}_{ip}(q^{k+}_{xip} - q^{k-}_{xip})\right)$$

The unknowns (solution points) are updated in a fourth order mcv scheme, for example,

$$\begin{bmatrix} \frac{d}{dt}(q_{1m}) \\ \frac{d}{dt}(q_{2m}) \\ \frac{d}{dt}(q_{3m}) \\ \frac{d}{dt}(q_{4m}) \end{bmatrix} = \mathbf{M}_4^{(x)}\mathbf{F}_4^{(x)} \qquad \mathbf{M}_4^{(x)} = \begin{bmatrix} 0 & 0 & -1 & 0 & 0 \\ \frac{4}{3\Delta x_i} & -\frac{4}{3\Delta x_i} & \frac{4}{27} & \frac{5}{27} & \frac{4\Delta x_i}{27} \\ \frac{4}{3\Delta x_i} & -\frac{4}{3\Delta x_i} & \frac{4}{27} & \frac{5}{27} & -\frac{4\Delta x_i}{27} \\ 0 & 0 & 0 & -1 & 0 \end{bmatrix} \text{ and } \mathbf{F}_4^{(x)} = \begin{bmatrix} \hat{f}_{1m} \\ \hat{f}_{4m} \\ \left(\partial_x \hat{f}\right)_{1m} \\ \left(\partial_x \hat{f}\right)_{4m} \\ \left(\partial_x^2 \hat{f}\right)_{cm} \end{bmatrix}$$

The same in multi-dimension, for example, y direction

A nonhydrostatic atmospheric governing equation sets in the Cartesion system

$$\frac{\partial \rho'}{\partial t} + \frac{1}{\sqrt{G}}\frac{\partial}{\partial \tilde{x}^j}\left(\sqrt{G}\rho\tilde{u}^j\right) = 0$$

$$\frac{\partial \rho u}{\partial t} + \frac{1}{\sqrt{G}}\left(\frac{\partial}{\partial \tilde{x}^j}\left(\sqrt{G}\rho u\tilde{u}^j\right) + \frac{\partial}{\partial \tilde{x}^j}\left(\sqrt{G}G^{1j}p'\right)\right) = 0$$

$$\frac{\partial \rho w}{\partial t} + \frac{1}{\sqrt{G}}\left(\frac{\partial}{\partial \tilde{x}^j}\left(\sqrt{G}\rho w\tilde{u}^j\right) + \frac{\partial p'}{\partial \tilde{x}^3}\right) = -\rho' g$$

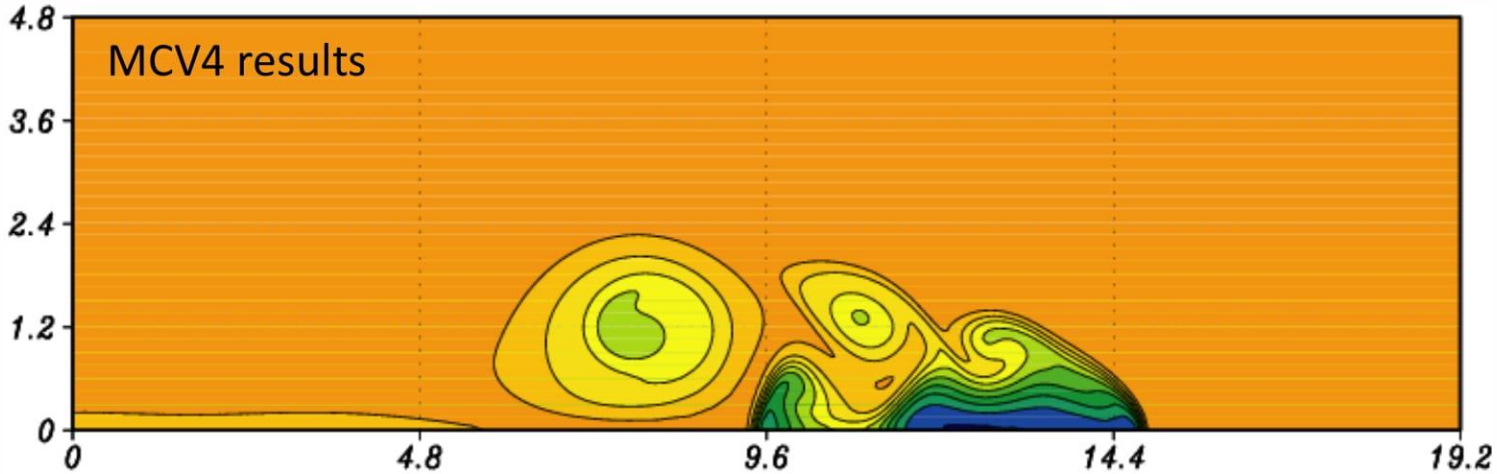
$$\frac{\partial (\rho\theta)'}{\partial t} + \frac{1}{\sqrt{G}}\frac{\partial}{\partial \tilde{x}^j}\left(\sqrt{G}\rho\theta\tilde{u}^j\right) = 0$$

$$\rho(\mathbf{x},t) = \bar{\rho}(\mathbf{x}) + \rho'(\mathbf{x},t)$$

$$p(\mathbf{x},t) = \bar{p}(\mathbf{x}) + p'(\mathbf{x},t)$$

$$(\rho\theta)(\mathbf{x},t) = \overline{(\rho\theta)}(\mathbf{x}) + (\rho\theta)'(\mathbf{x},t)$$

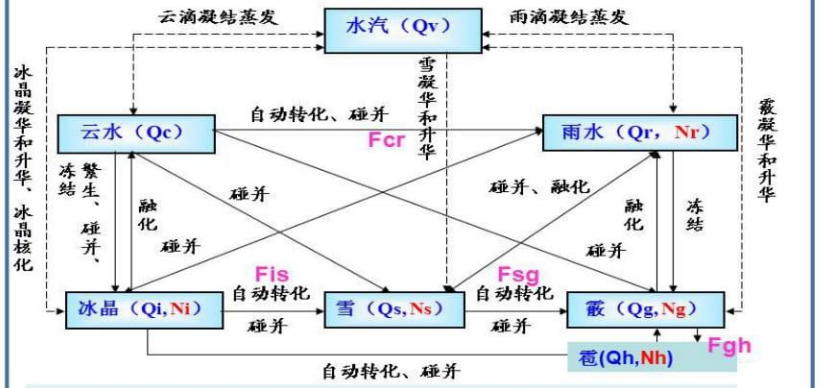
Height-based terrain-following vertical coordinate (Gal-chen & Somerville 1975) is used. $\sqrt{G}$ is transformation Jacobian.



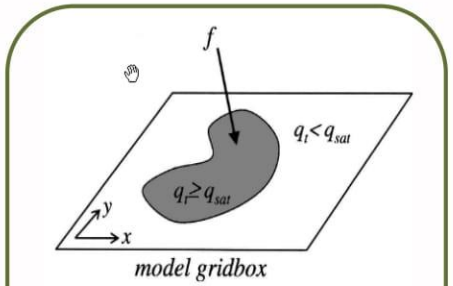
Numerical solution of Straka et al. (1993) density current at t=900s.

microphysics、macro-cloud and subgrid-cloud

Double moment MP



该方案包括Qv，Qc，Qr,，Qi，Qs，Qg,Qh7个比含水量和Nr，Ni，Ns，Ng,Nh 5个比浓度量，并详细考虑了云微物理过程



Macro-cloud: partial cloud in gridbox

Cloud fraction forecast

$$\frac{\partial q_x}{\partial t} = A(q_x) + S^{q_x}_{macro} + S^{q_x}_{micro} + S_{conv}(q_x) + S_{sed}(q_x) + D(q_x)$$

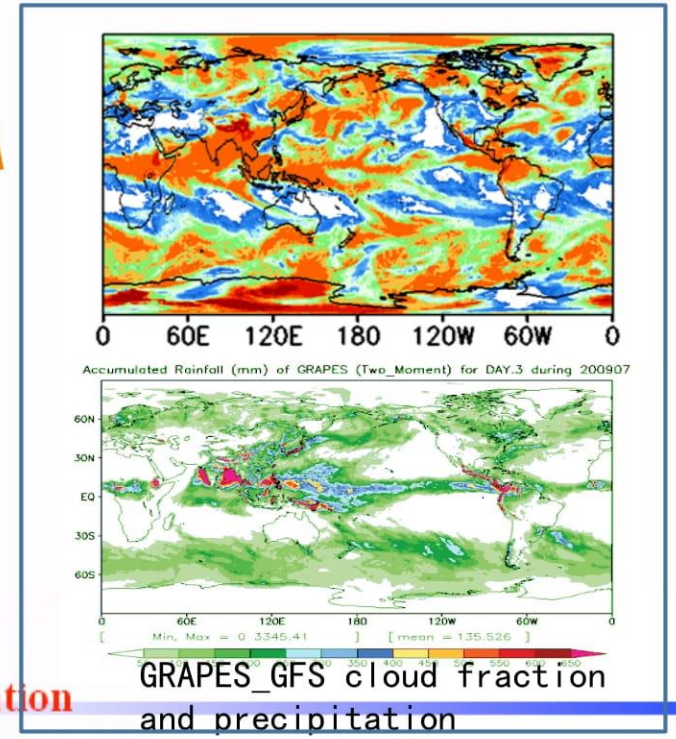
$$\frac{\partial N_x}{\partial t} = A(N_x) + S^{N_x}_{macro} + S^{N_x}_{micro} + S_{conv}(N_x) + S_{sed}(N_x) + D(N_x)$$

$$\frac{\partial a}{\partial t} = A(a) + S^{a}_{strat} + S^{a}_{conv} + D(a)$$

对流质量通量对格点尺度云含水量、数浓度和云量影响

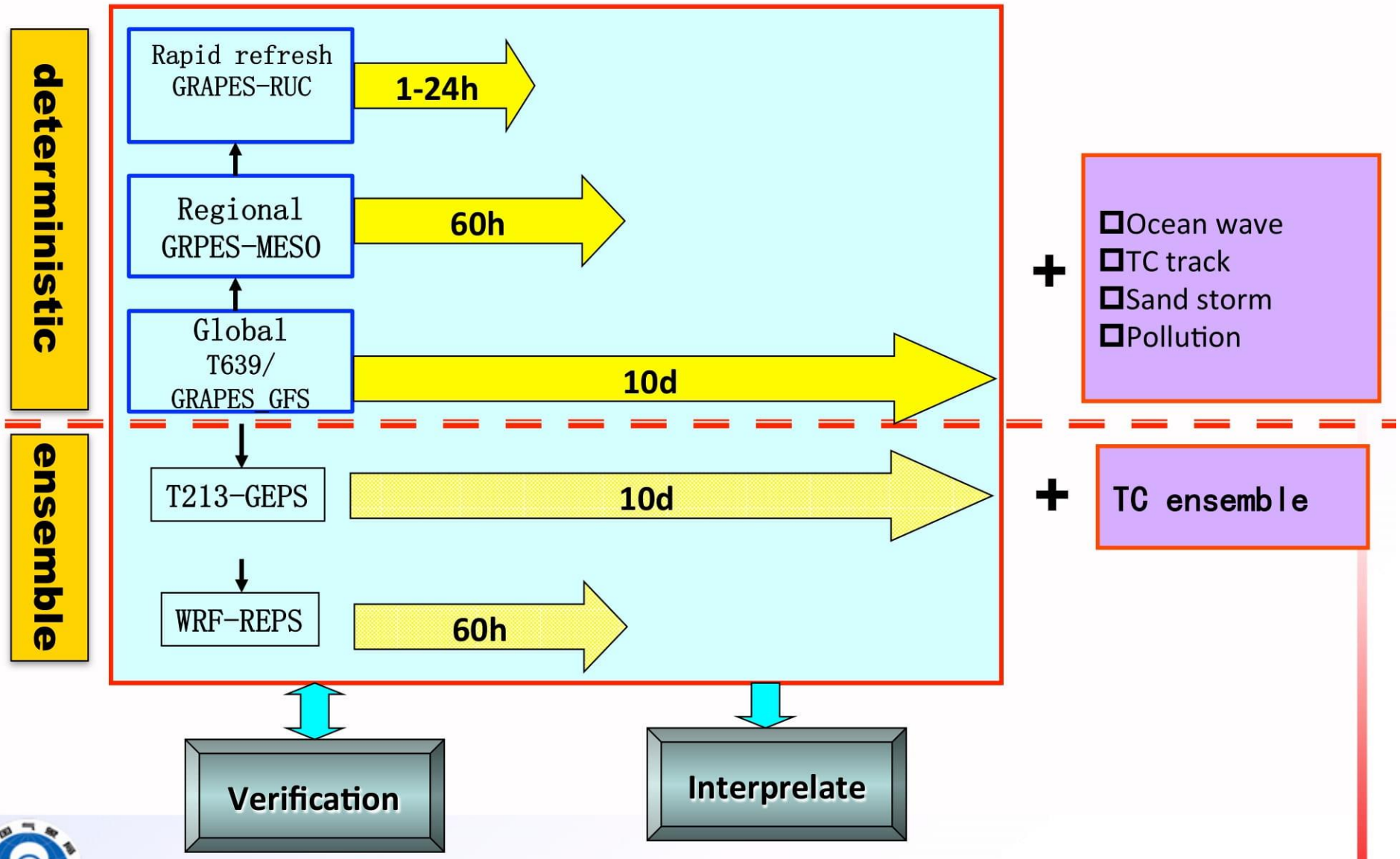
$$S^{q_x}_{conv} = D_{up} l^{q_x}_{up} + \frac{M_{up}}{\rho}\frac{\partial q_x}{\partial z} \qquad S^{a}_{conv} = D_{up} + \frac{M_{up}}{\rho}\frac{\partial a}{\partial z}$$

$$S^{N_x}_{conv} = D_{up} l^{N_x}_{up} + \frac{M_{up}}{\rho}\frac{\partial N_x}{\partial z}$$

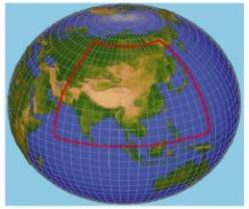


GRAPES_GFS cloud fraction and precipitation

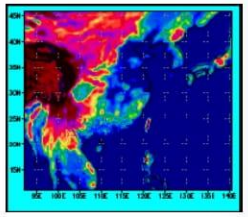
Current NWP systems in CMA



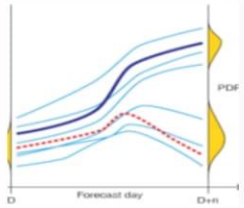
Plan before 2015



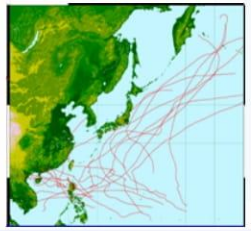
GRAPES_GFS (7.5~8 days)
SISL+3DVAR
Res. ~ 25km
Top at 0.1hPa



GRAPES_Meso
SISL+4DVAR/hybrid
Res. ~ 3km



GRAPES_GEPS & MEPS
Res. ~50km & ~15km
30 Members
Perturb: Singular Vector



GRAPES Global Typhoon
Res. ~50km
Top at 0.1hpa