Presentations about NWP in CMA

- Numerical Weather Prediction Systems
- GRAPES_meso and its applications
- NWP product and service
- Research activities and future plan

- *How to use GRAPES_meso*

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GRAPES_meso and its applications

Jian Sun
NWP Center of CMA
12/2012

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Outline

- 1、Milestones of GRAPES_Meso
- 2、Main features of GRAPES_Meso
- 3、Real time implementations at NMC
- 4、Applications

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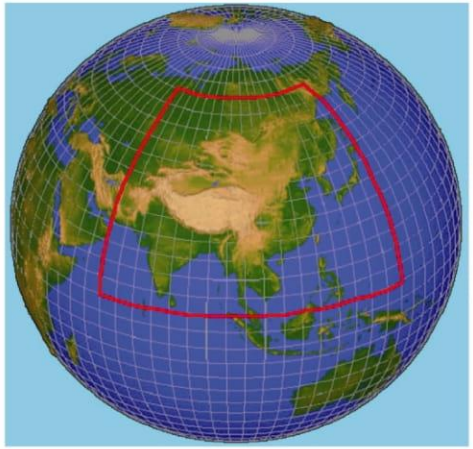
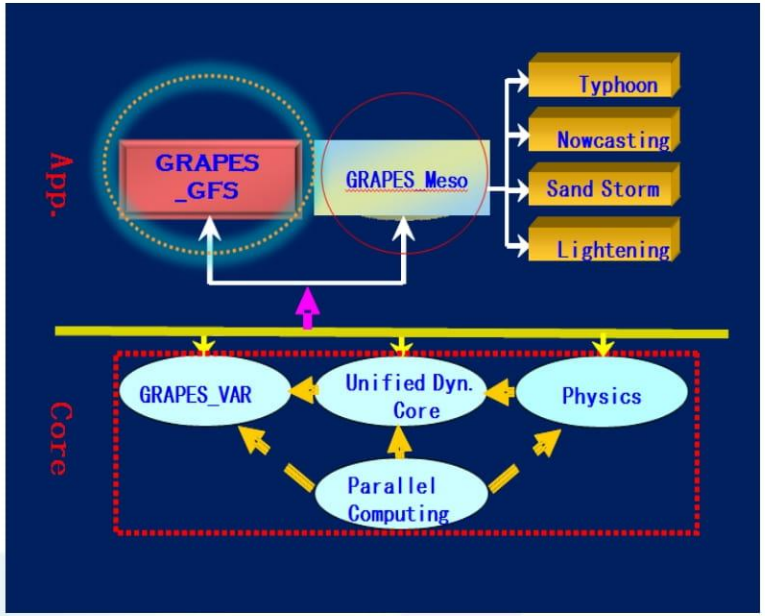
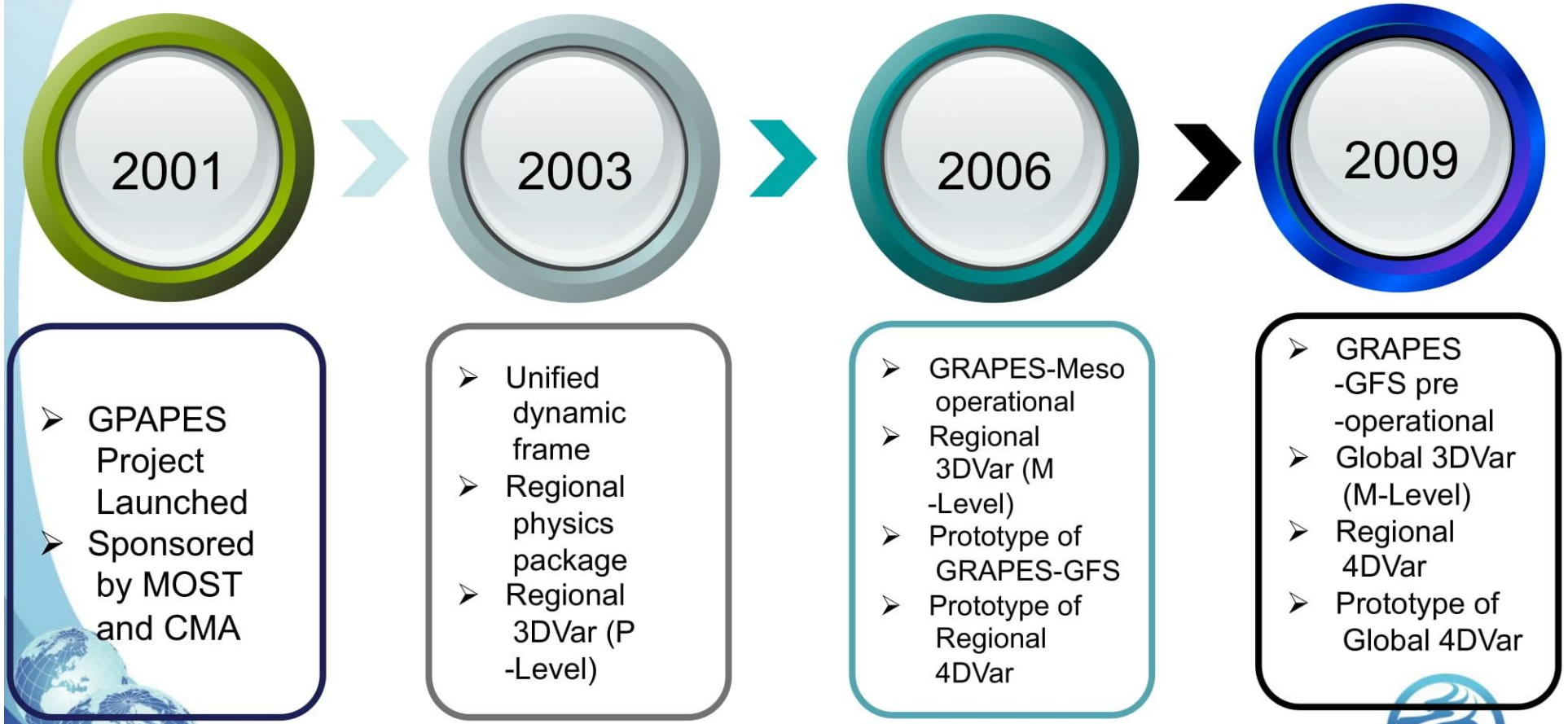
Development of NWP system

- GRAPES
  - Global and Regional Assimilation and Prediction System
  - A Unified NWP system
    - *a common dynamic core with different configurations of physics for different applications*
  - Four main sub-projects
    - *Variational DAS*
    - *Unified dynamic core*
    - *Physical parameterization scheme*
    - *Parallel computing*
  - *Operational implementation*
    - *Regional as well as Global*





Story about GRAPES



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1. Milestones of GRAPES_Meso

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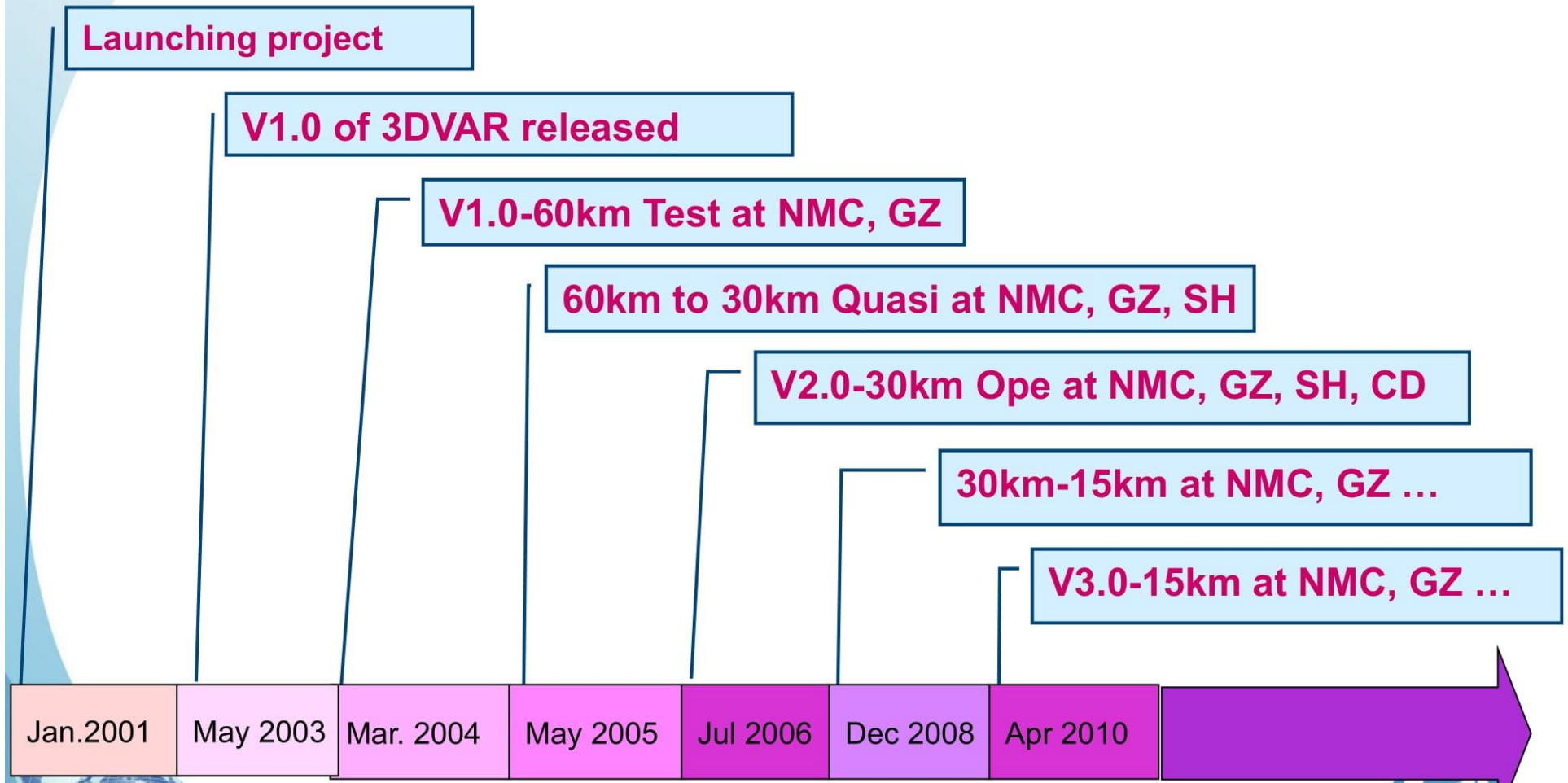
Milestone of GRAPES_Meso



Since this year, ***Perforce*** has been used for Code-management

GRAPES Project Collaborators

- **Principal Partners:**

  CMA: CAMS, NMC, NSMC

  GZ, SH, WH, …

- **Participating Collaborators:**

  CMA: NCC, CD, LZ

  CAS: IAP, ICR

  Universities: PU, US&TD, NJU, NJMI

- **Special collaborator:** NCAR-WRF Group

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2. Main Features of GRAPES_Meso

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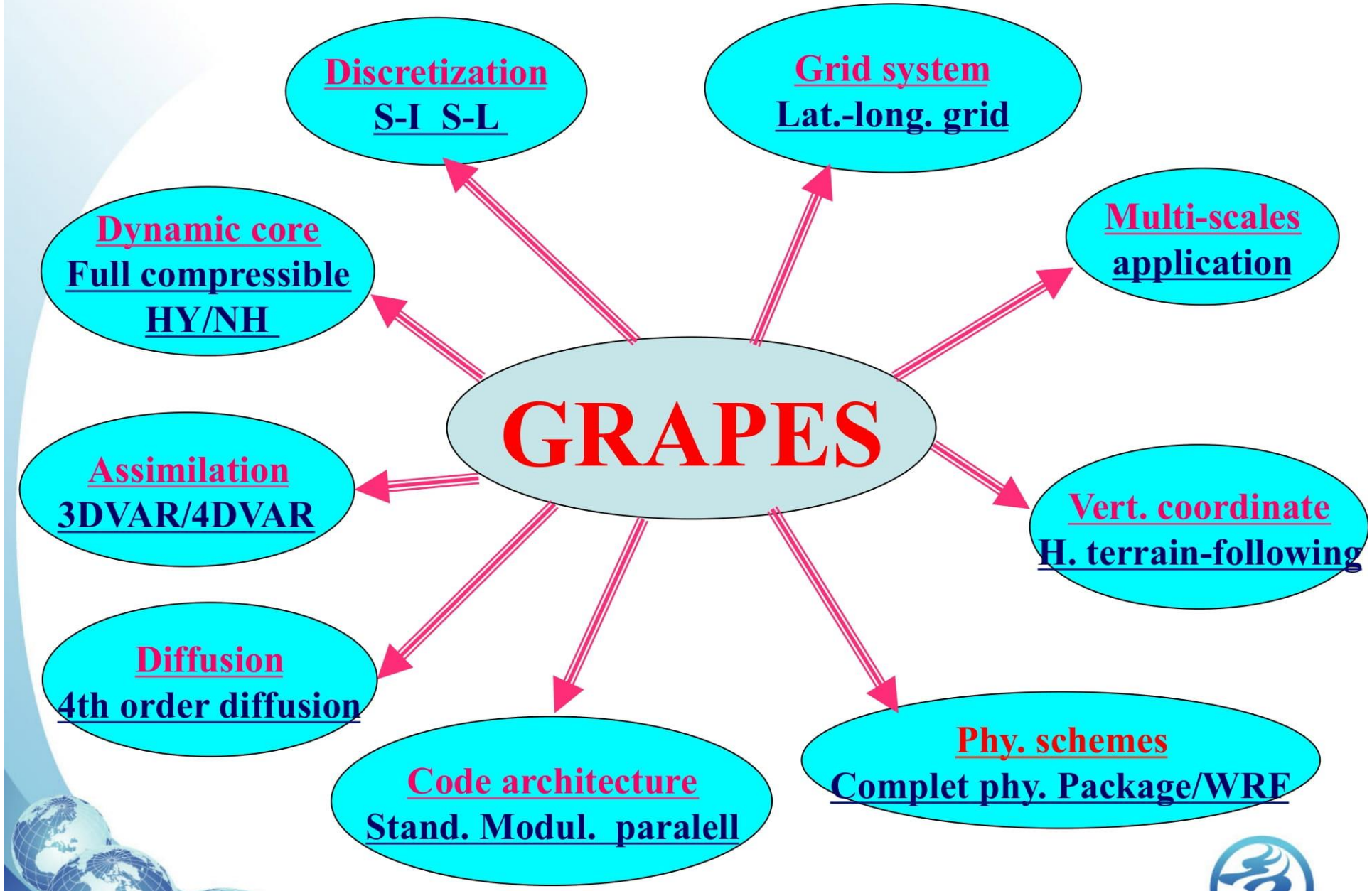

Main features of GRAPES

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Details of GRAPES_3DVAR

Grid analysis	A+P with flexible resolution setup	
incremental	$x_a=x_b+\delta x$	
Variable options	analysis	Φ/T, u, v, rh
	control	ψ, χ , Φ_u , rh
preconditioning	control space ⇒ model space	$\delta x=Uw$,$U \Leftrightarrow U_pU_vU_h$
	Regional : Recursive filter	for U_h
	Global : Spectral filter	for U_h
Minimization	Limited memory BFGS method	
Mass-wind constraint	Linear balance equation (now) Nonlinear balance equation (on testing)	
Programming	Fortran90, Modular structure, to be paralleled	

GRAPES-3DVar

- Incremental formulation (Courtier et al. 1994)

$$J(\mathbf{x}_a) = \frac{1}{2}(\mathbf{x}_a - \mathbf{x}_b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}_a - \mathbf{x}_b) + \frac{1}{2}(H(\mathbf{x}_a) - \mathbf{y}^o)^{\mathrm{T}}\mathbf{R}^{-1}(H(\mathbf{x}_a) - \mathbf{y}^o)$$

$$J(\delta\mathbf{x}_a) = \frac{1}{2}\delta\mathbf{x}_a{}^{\mathrm{T}}\mathbf{B}^{-1}\delta\mathbf{x}_a + \frac{1}{2}(\mathbf{H}\delta\mathbf{x}_a + \mathbf{d})^{\mathrm{T}}\mathbf{R}^{-1}(\mathbf{H}\delta\mathbf{x}_a + \mathbf{d})$$

$$\nabla_{\delta\mathbf{x}_a} J = (\mathbf{B}^{-1} + \mathbf{H}^T R^{-1}\mathbf{H})\delta\mathbf{x}_a + \mathbf{H}^T R^{-1}\mathbf{d}, \quad \mathbf{d} = H\mathbf{x}^b - \mathbf{y}^o$$

$$\delta\mathbf{x}_a = \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}\mathbf{d}$$

$$\delta x_u = \mathbf{\Sigma}_u \mathbf{U} w = \mathbf{\Sigma}_u \mathbf{U}_v \mathbf{U}_h w$$

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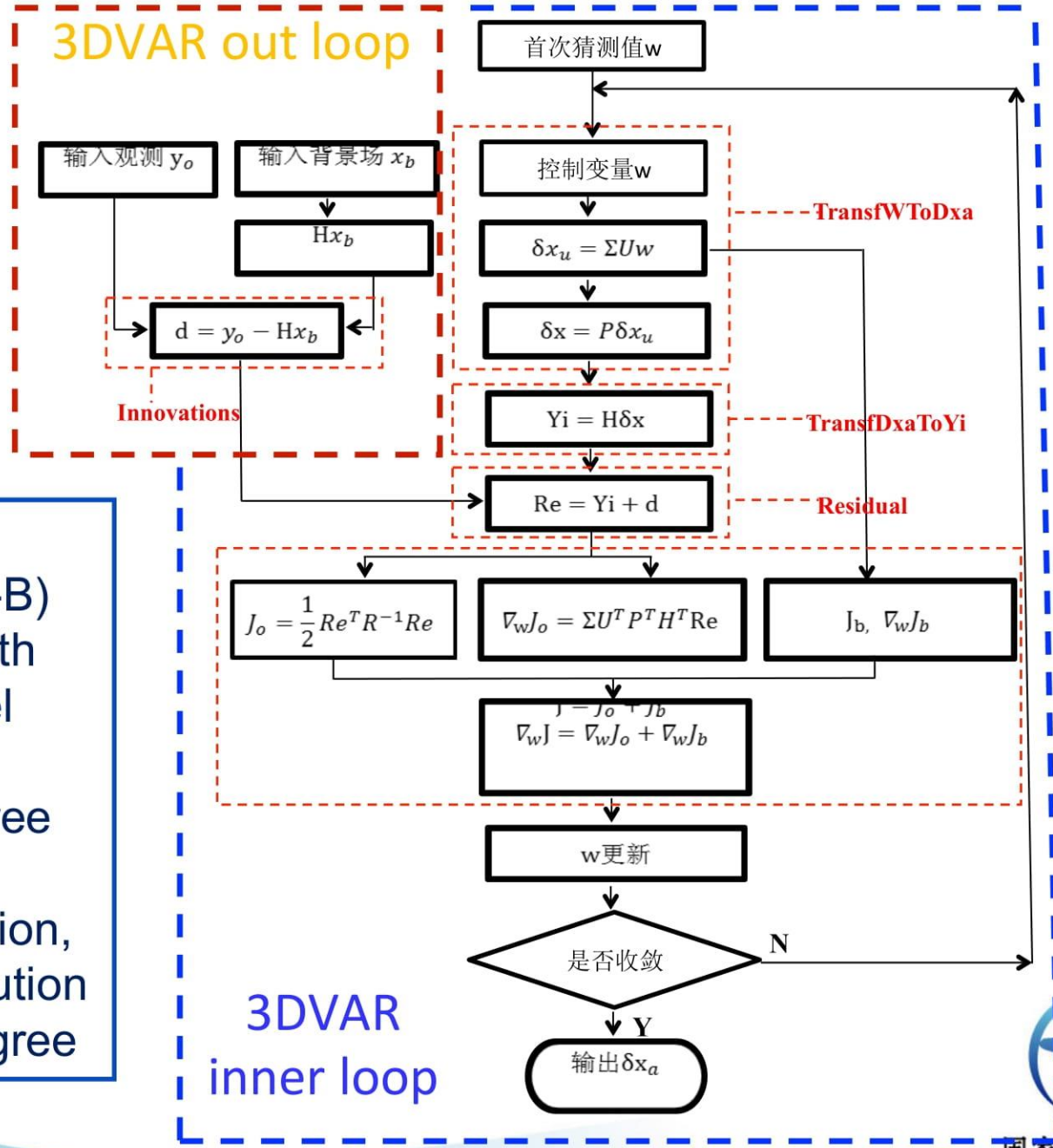

Outloop

- Innovation (O-B) calculation, with forecast model resolution
- GFS:0.5 degree

Innerloop

- Analysis iteration, with low resolution
- GFS:1.125degree

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Satellite data assimilation in GRAPES

- Observation Operator for Radiance Assimilation
  - ♦ RTTOV: RTTOV6 → RTTOV7 → RTTOV9 → RTTOV10
- Bias correction
  - ♦ Harris and Kelly(2001)

    scan correction + air-mass correction, automatic update
- Cloud detection (AMSUA)
  - ♦ Sea: SI : scattering index

    abs(SI) > 1500 ⟶ cloud
  - ♦ Land: $abs(b\text{-}o)_{chan4}$>1.5K ⟶ cloud
- Observation error tuning
- Channel selection: not use surface and lower channels
- Data thinning: ~250 km

Satellite data in GRAPES

- ✓ *ATOVS microwave* (NOAA15 16 17) radiances
- ✓ NOAA-18 microwave radiance
- ✓ Metop microwave radiance
- ✓ GPS reflectivity
- ✓ FY-3A /MWTS microwave radiance
- ✓ AIRS Hyper-spectral radiance
- ✓ FY-2E AMV wind
- ✓ NOAA-19 microwave radiance
- ✓ IASI Hyper-spectral radiance
- ✓ FY-3A /MWHS microwave radiance
- ✓ FY-3B /MWTS/MWHS microwave radiance

Data used in the last version

Data will be integrated

Researching data

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AWS Data Assimilation

Old approach

Elevation ≥ The model's Lowest level

Used as the upper air data

Elevation < The model's Lowest level

the observed site is assumed to be located at model's lowest level.

New approach

Elevation ≥ The model's Lowest level

Used as the upper air data

Elevation < The model's Lowest level

Data retrieved to model lowest level based on the background state and OBS.

$$\frac{\partial \Phi}{\partial \ln P} = -RT$$

$$P_2 = P_1 \times e^{-\frac{2g}{R(Tv_1+Tv_2)}(h_2-h_1)}$$

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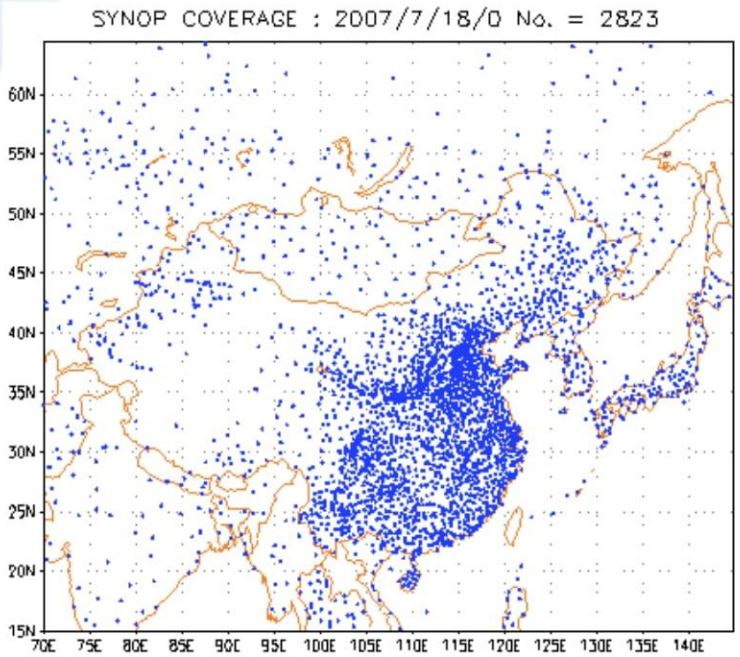
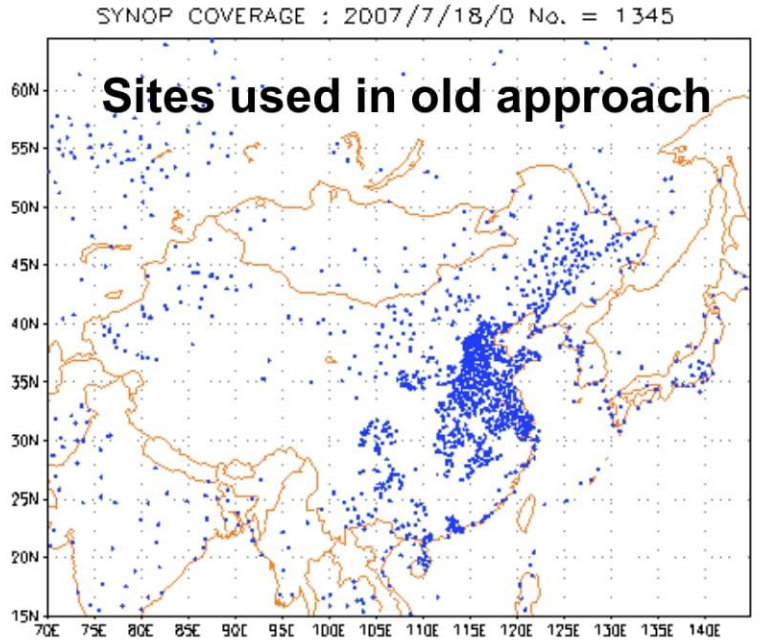
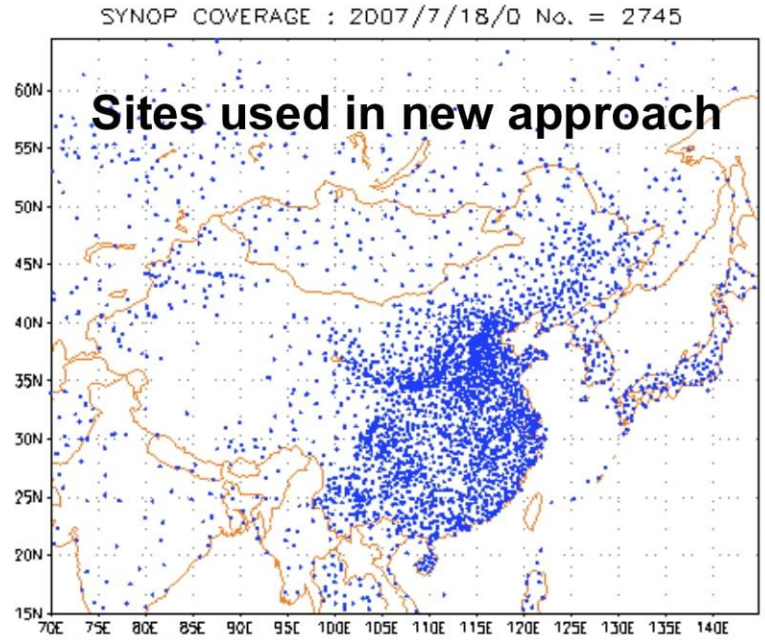


Available observation sites





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Doppler radar VAD data assimilation

- About 158 Doppler radar around China
- Most along east coast line
- Available to be used
- Key Problem—Quality Control!

Error source

Raw data : velocity folding, noisy and isolate echo point, ground echo and etc.

VAD algorithm: data not satisfying assumptions, insufficient coverage rate

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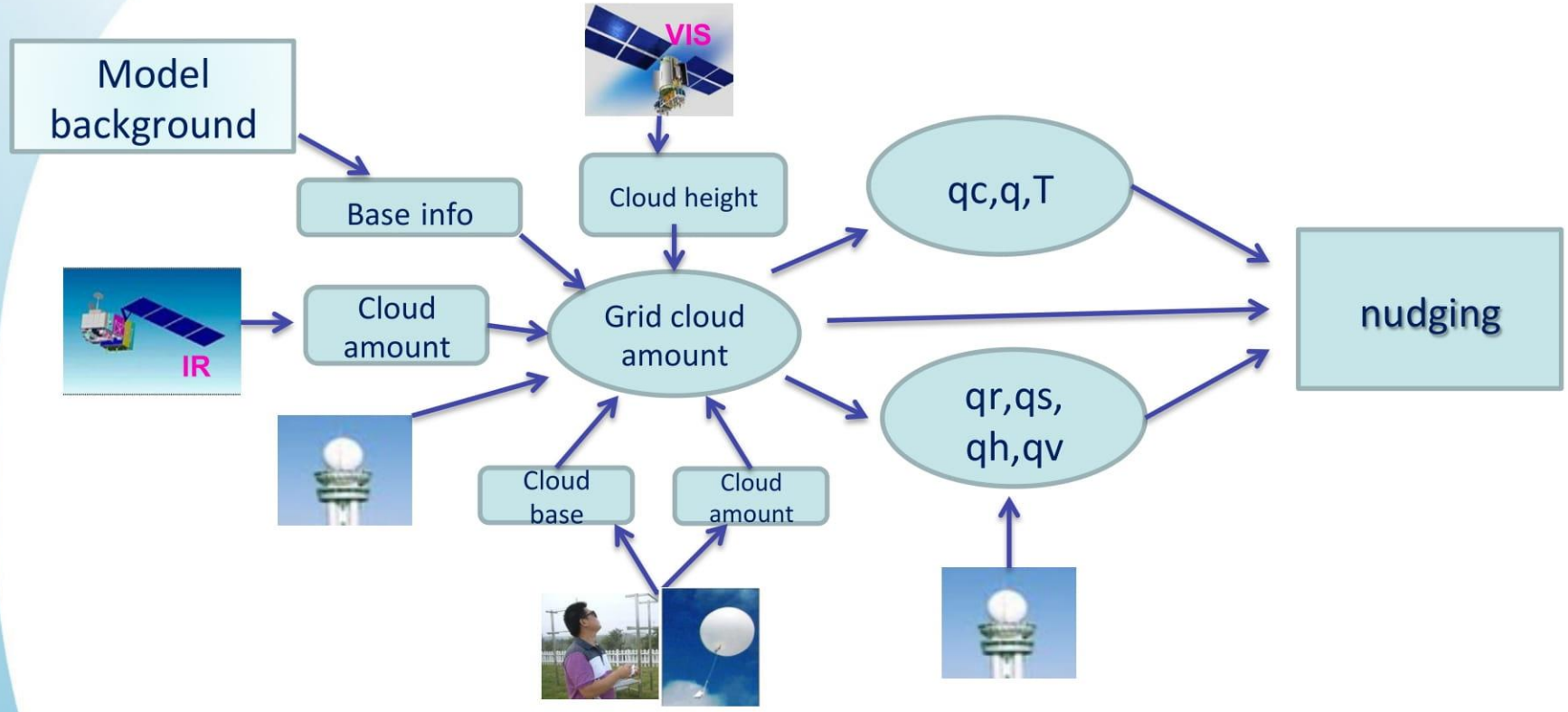
According to different error source, take different measures

Error source	Program based on	Qc method
Noisy points/Isolated Echo Point	Bergen,1988， Gong,2003	remove
Circle data coverage	Data coverage； Valid data angular magnitude Vacancies	Limit on Data coverage； Valid data angular magnitude Vacancies
Velocity folding	Gong(2005)	Background error covariance method
Outlier circle data	VAD sine curve distribution and Assumptions	Multi- iterations quality control
VAD algorithm	Data error theory	Root-mean-square error check
The impact of low-level clutter	Statistic experience	Remove low level data
Small wind	Statistic experience NCEP experience	Remove small wind
The relative deviation of the background field large	Numerical weather prediction quality control method	Vertical consistency check; Background check; Climate extreme check

INTRODUCTION OF CLOUD ANALYSIS



Data used: (1)NWP background; (2)Doppler Mosaic (3)reflectivity data; (4)sounding data collected per minute vertical interval; (5)surface obs; (6)Sat TBB; (7)Sat cloud total amount

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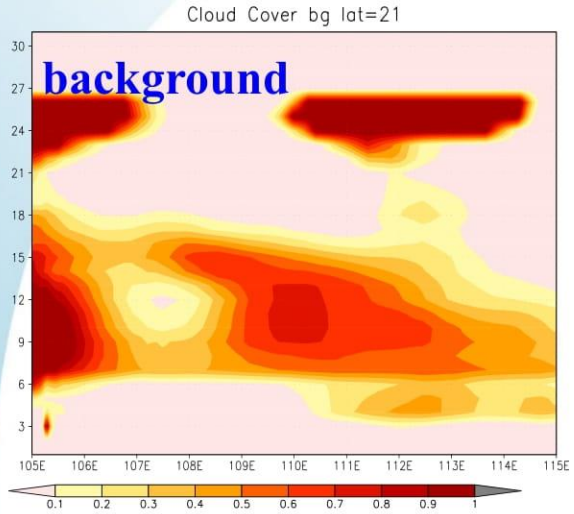
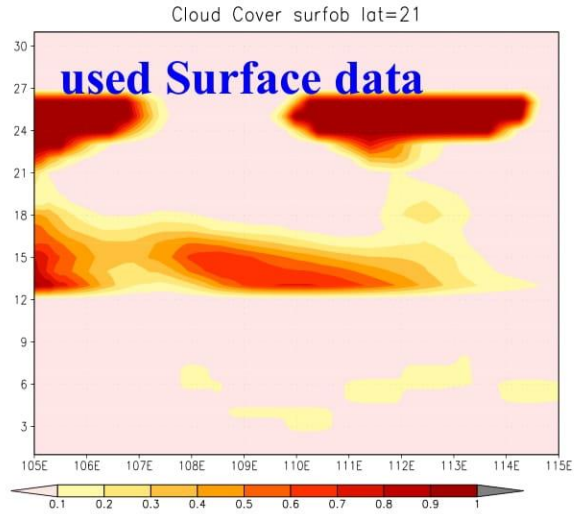
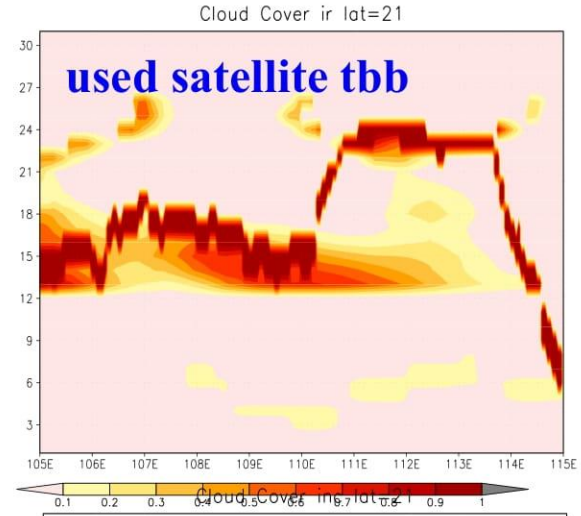
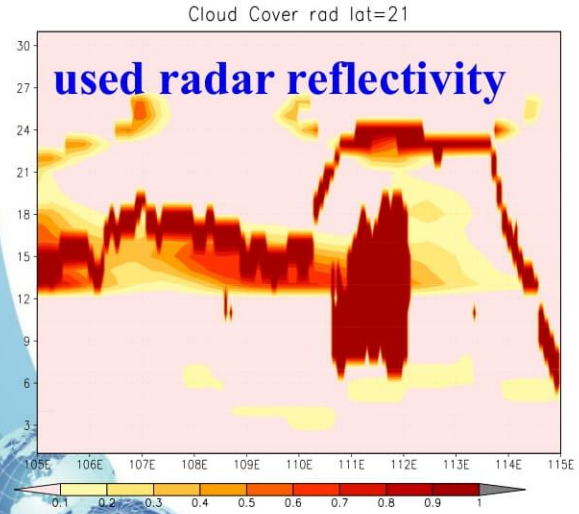
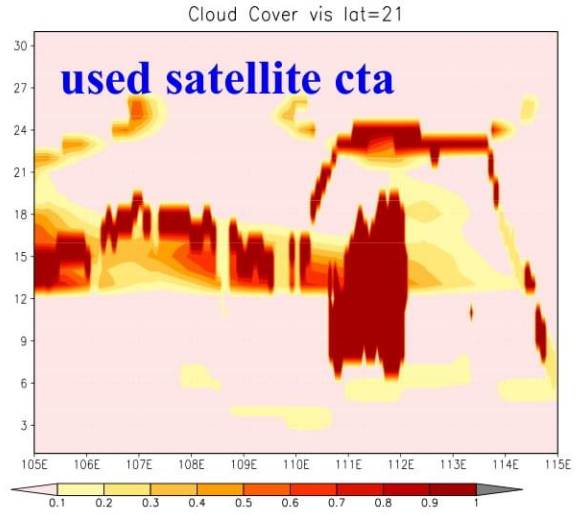
Result of Cloud Cover

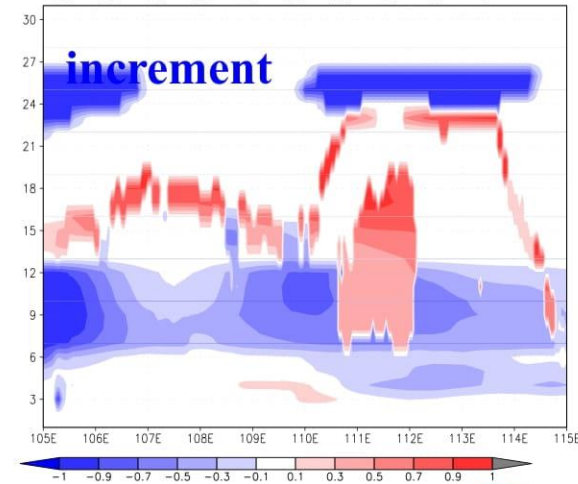












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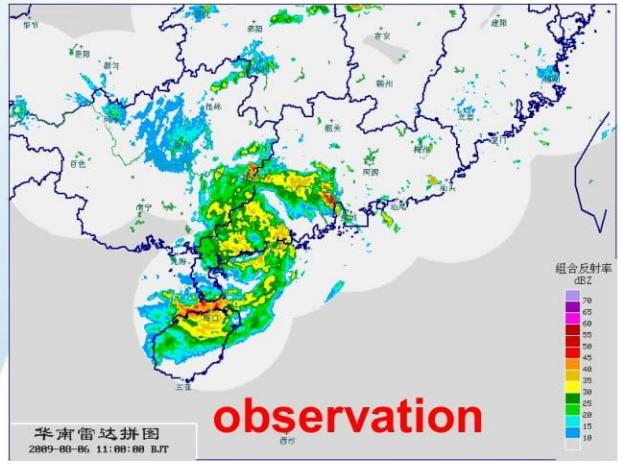
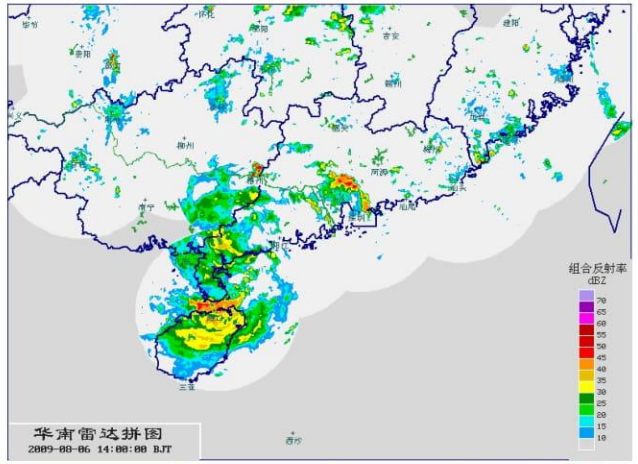
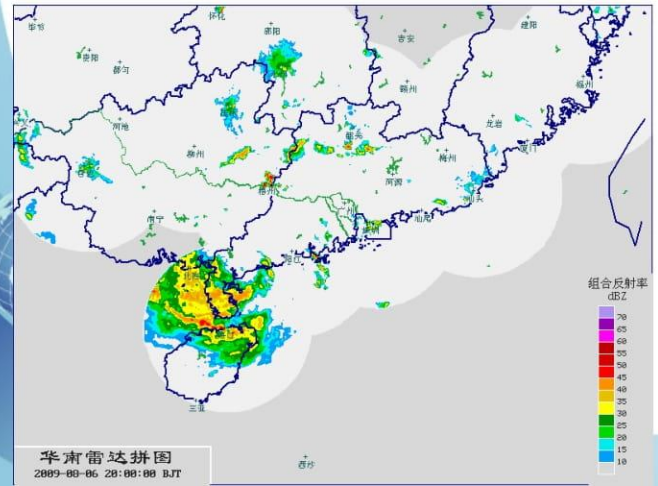
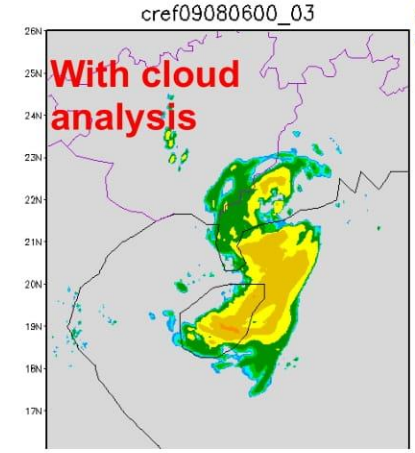
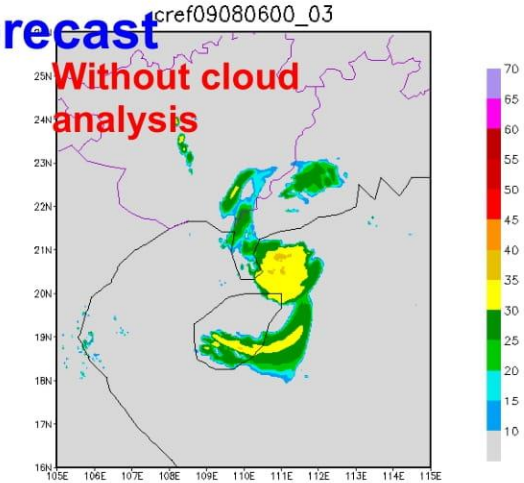


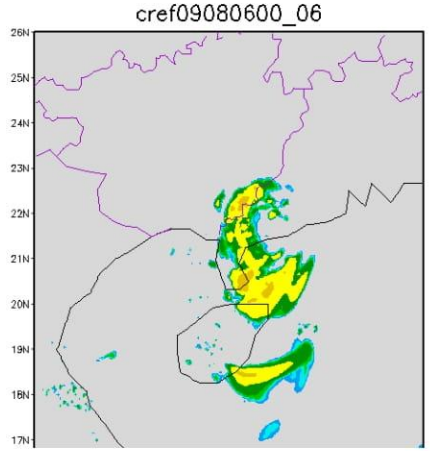




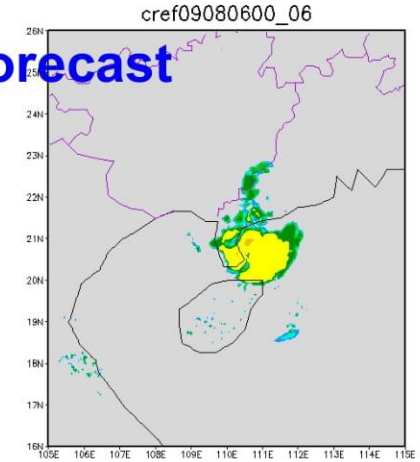


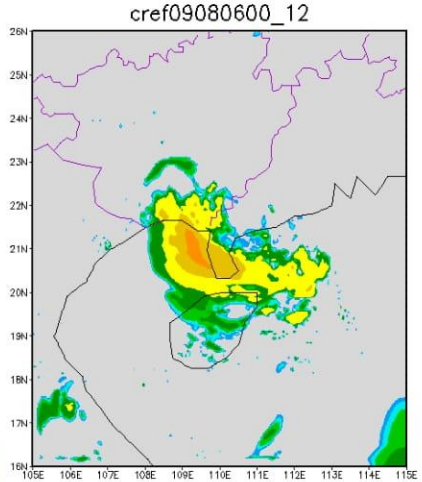
3h forecast



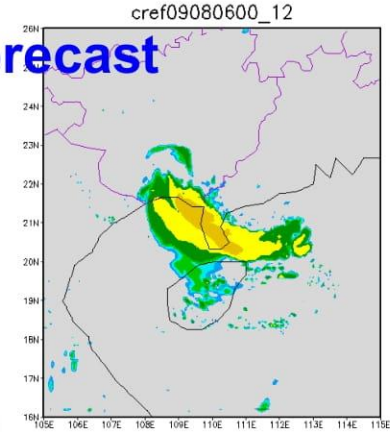


6h forecast



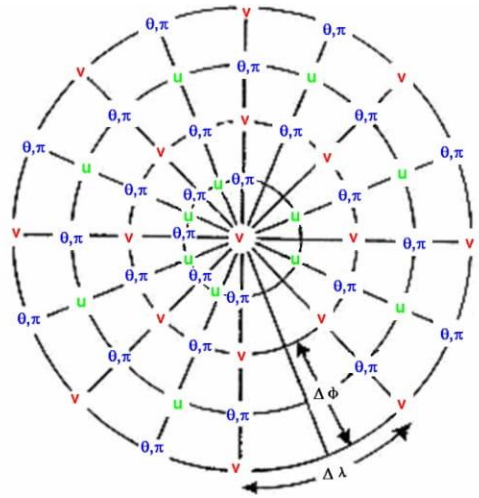


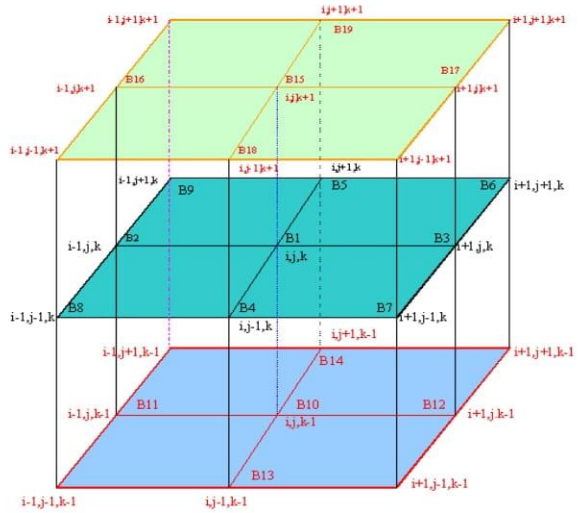
12h forecast



GRAPES Dynamic Core

- Fully compressible equations
- Height-based terrain-following coordinate
- Option of hydrostatic and non-hydrostatic
- Arakawa staggered C lat-lon horizontal grid but V at poles
- Charney-Phillips vertical arrangement of prognostic variables
- 2-time-level SI-SL time-stepping scheme
- QMSL or PRM for scalar variable advection (q spec humid)
- Spherical & polar effects of trajectory calculation
- 3D vector form for momentum equations
- GCR –solver for Helmholtz Eq.
- Mass fixer
- Polar filter

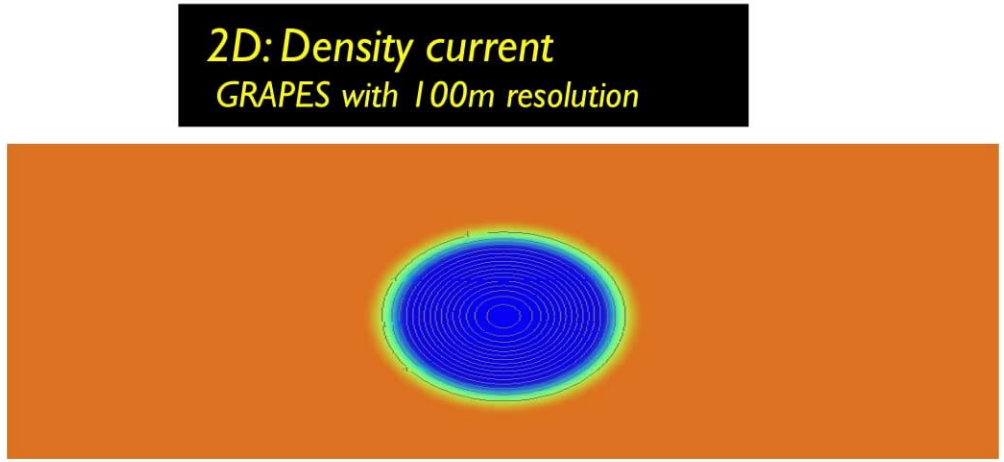


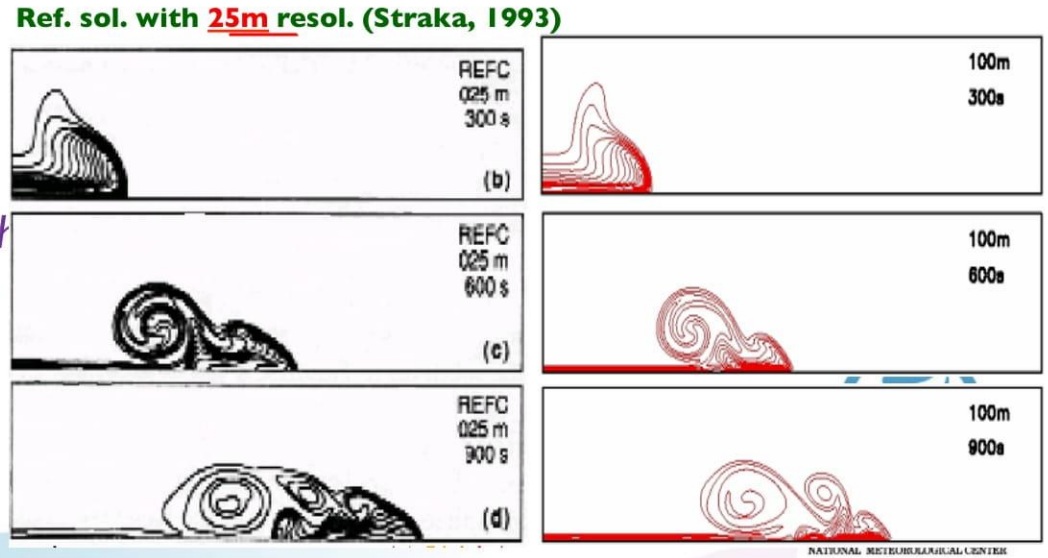


For given point (i,j,k), non-zero coefficients of 19 grid point. In GRAPES, the Pre_GCR (Skamarock et al., 1997) is used to solve the Helmholtz equation

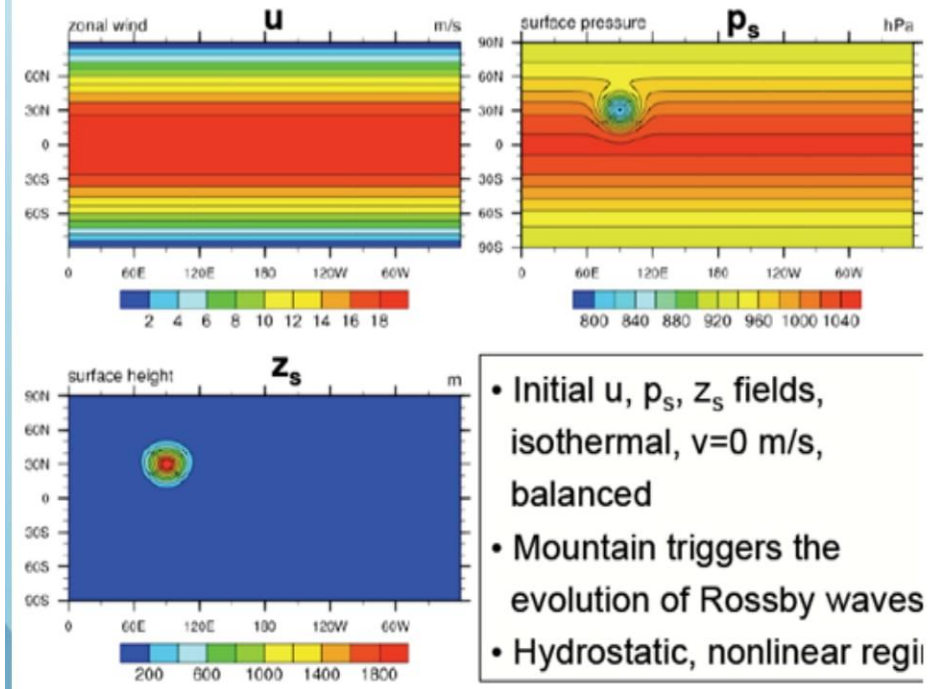
Idealized tests for dynamic core

- 2D test cases
  - *Density current*
  - *Warm bubble*
  - *Mountain wave*
- 3D test cases
  - *3D tracer transport*
  - *Geostrophic balanced flow*
  - *Held & Suarez test*
  - *Rossby-Haurwitz wave*
  - *Mountain-triggered Rossby wave*
  - *Mountain-triggered Rossby wave with tracer*
  - *Baroclinic instability wave*

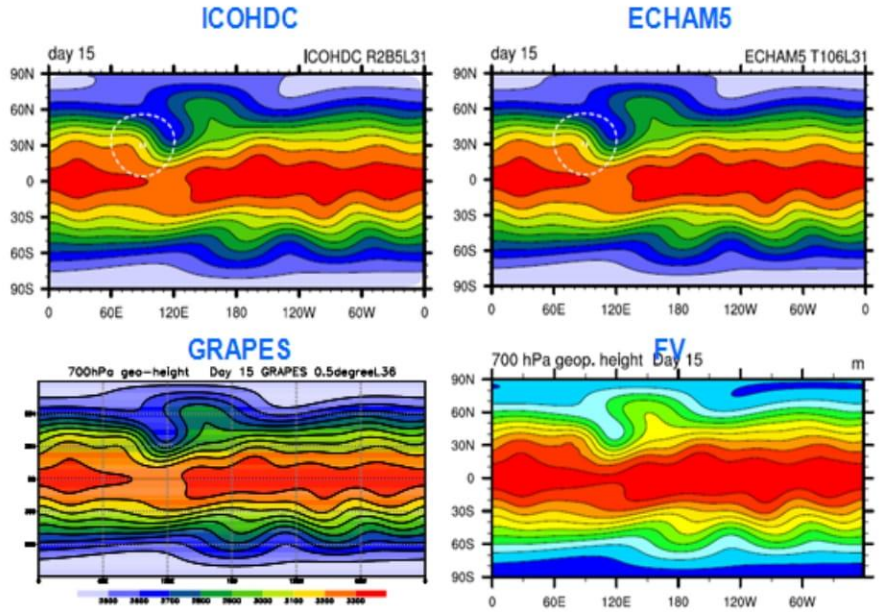




3D: Mountain Triggered Rossby Wave



- Initial u, p_s, z_s fields, isothermal, v=0 m/s, balanced
- Mountain triggers the evolution of Rossby waves
- Hydrostatic, nonlinear regi



D-15 simulations of G. H. at 700hPa

ICOHDC and ECHAM5 results from H.Wan's PhD.Thesis (2009)
FV results from Jablonowski et al. NCAR ASP 2008 summer colloquium (2008)

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Optimization of Physical package from WRF' model

- The code-architecture of GRAPES is made refering to WRF model's. It is easy to transfer the physical package and to use the static data set from WRF model

- Physics package
- - CU: Betts-Miller-Janjic, KF/SAS
  - MP: WSM6/DM（Liu et al.）
  - Radiation: RRTM
  - PBL: MRF
  - LSM: NOAH

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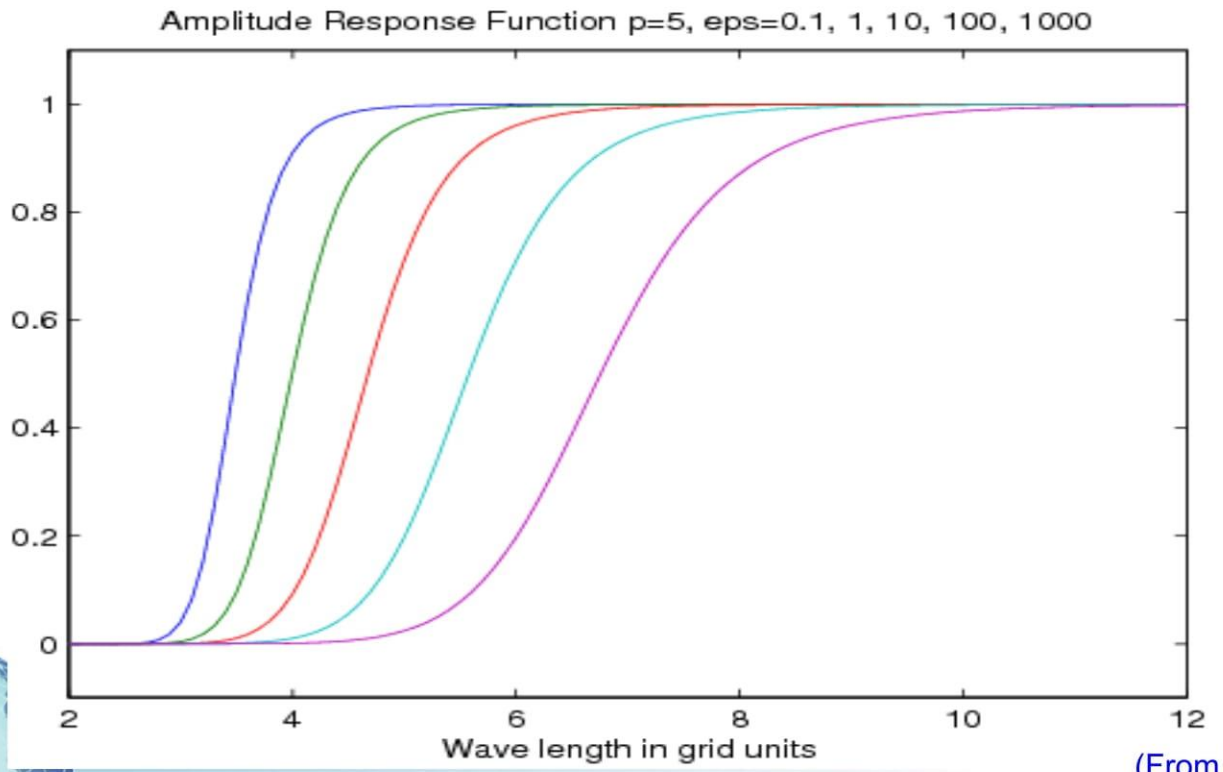
Model orography

- Interpolated from HR
- Interpolated + filtered

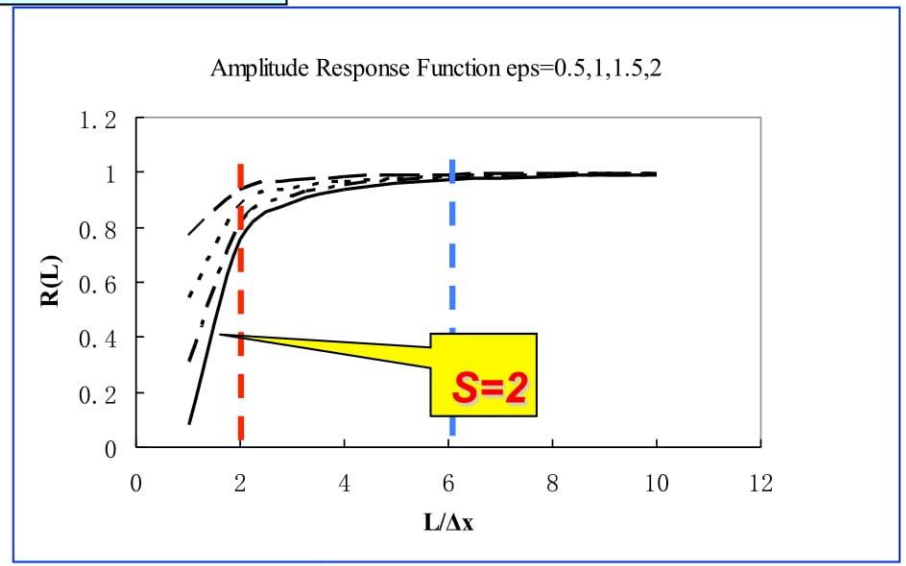


(From Liu et Chen, 2009)

5 points running averaged

$$\widetilde{F}_{i,j}^{xy} = F_{ij} + \frac{S}{4}(F_{i+1,j} + F_{i,j+1} + F_{i-1,j} + F_{i,j-1} - 4F_{i,j})$$

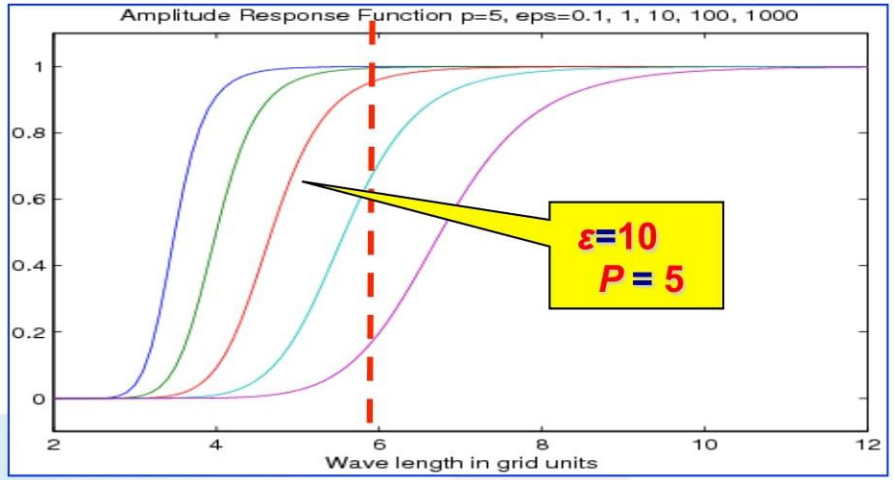
$$R(S,k,l)_5 = 1 - S(\sin^2\frac{k\Delta x}{2} + \sin^2\frac{l\Delta y}{2})$$



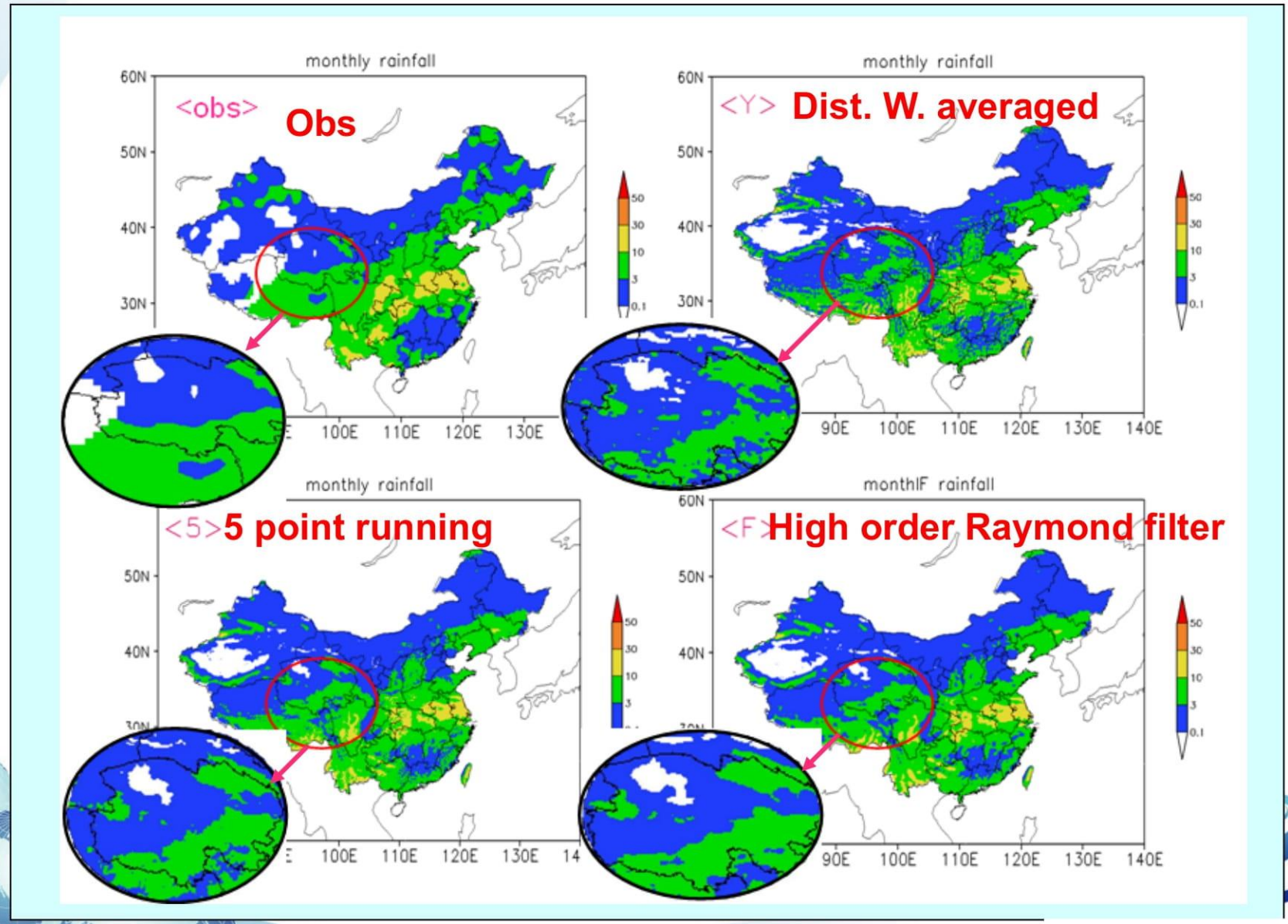
Raymond filter (1988)

$$[S^{2p}]u_n^F + (-1)^p \varepsilon [L^{2p}]u_n^F = [S^{2p}]u_n$$

$$H(x) = [1 + \varepsilon \tan^{2p}(\pi / x)]^{-1},$$

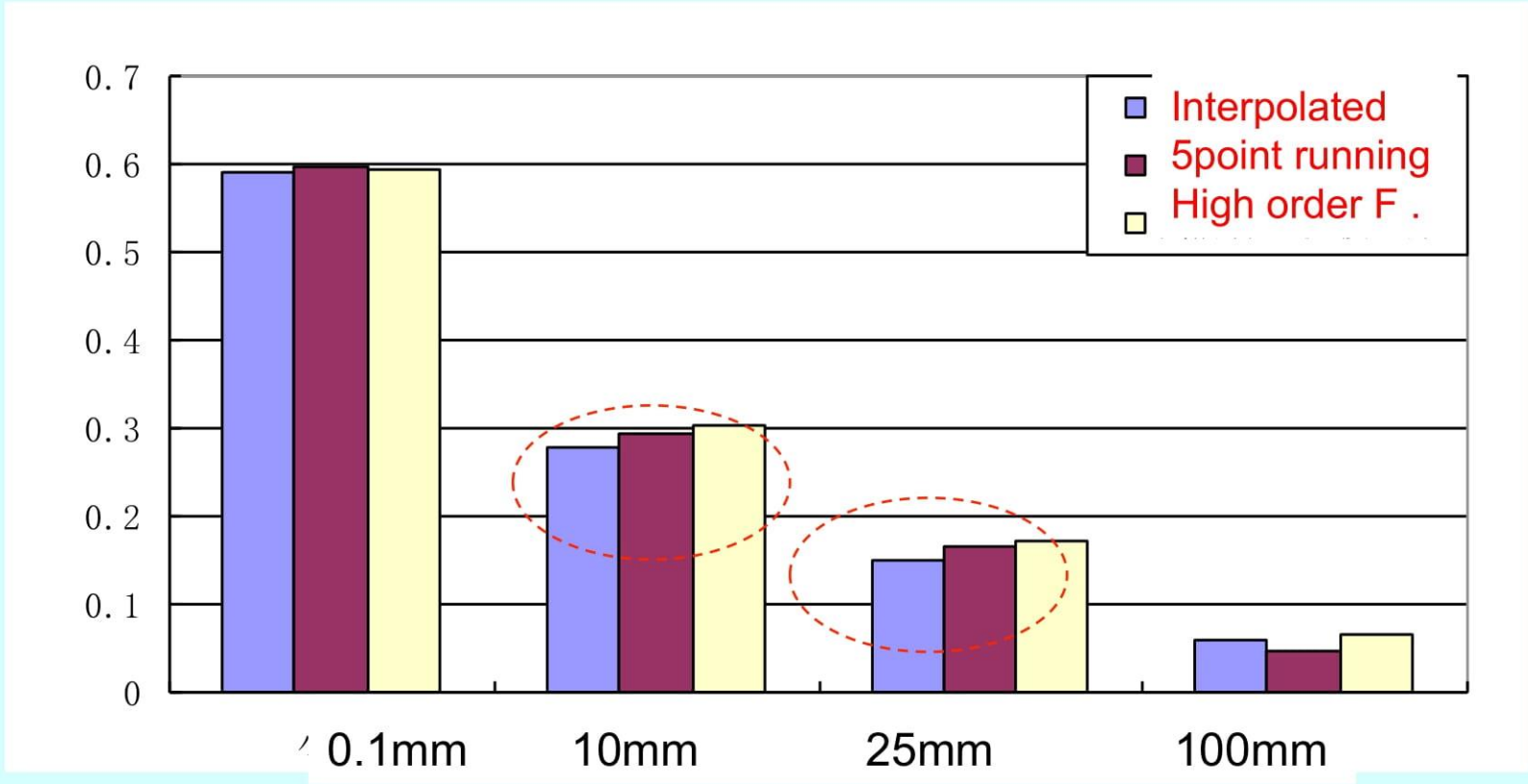


Monthly averaged 24h forecast of rainfalls for July, 2007



(From Liu et Chen, 2009)

TS-verification of 24h forecast of precipitation for July, 2007 on the whole Chinese territories



Comments: improved for higher thresholds: above 10mm/d

(From Liu et Chen, 2009)

Real-time implementations at NMC

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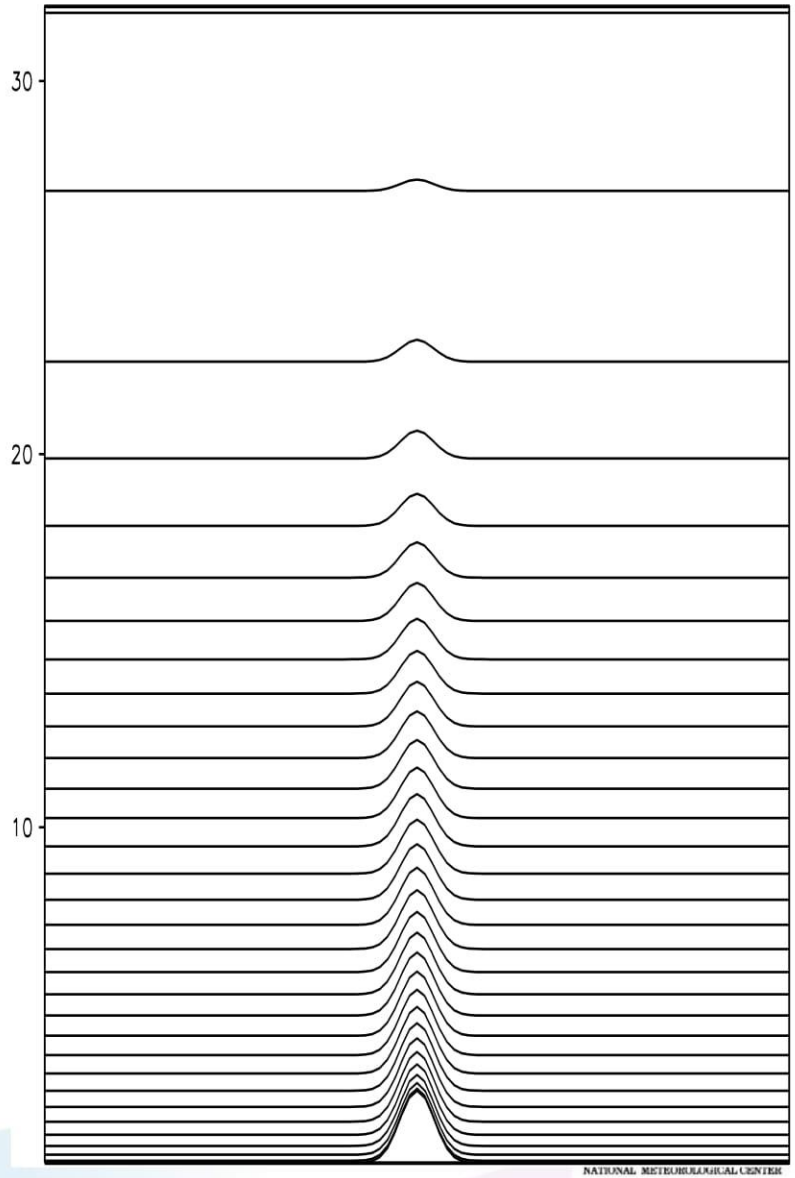
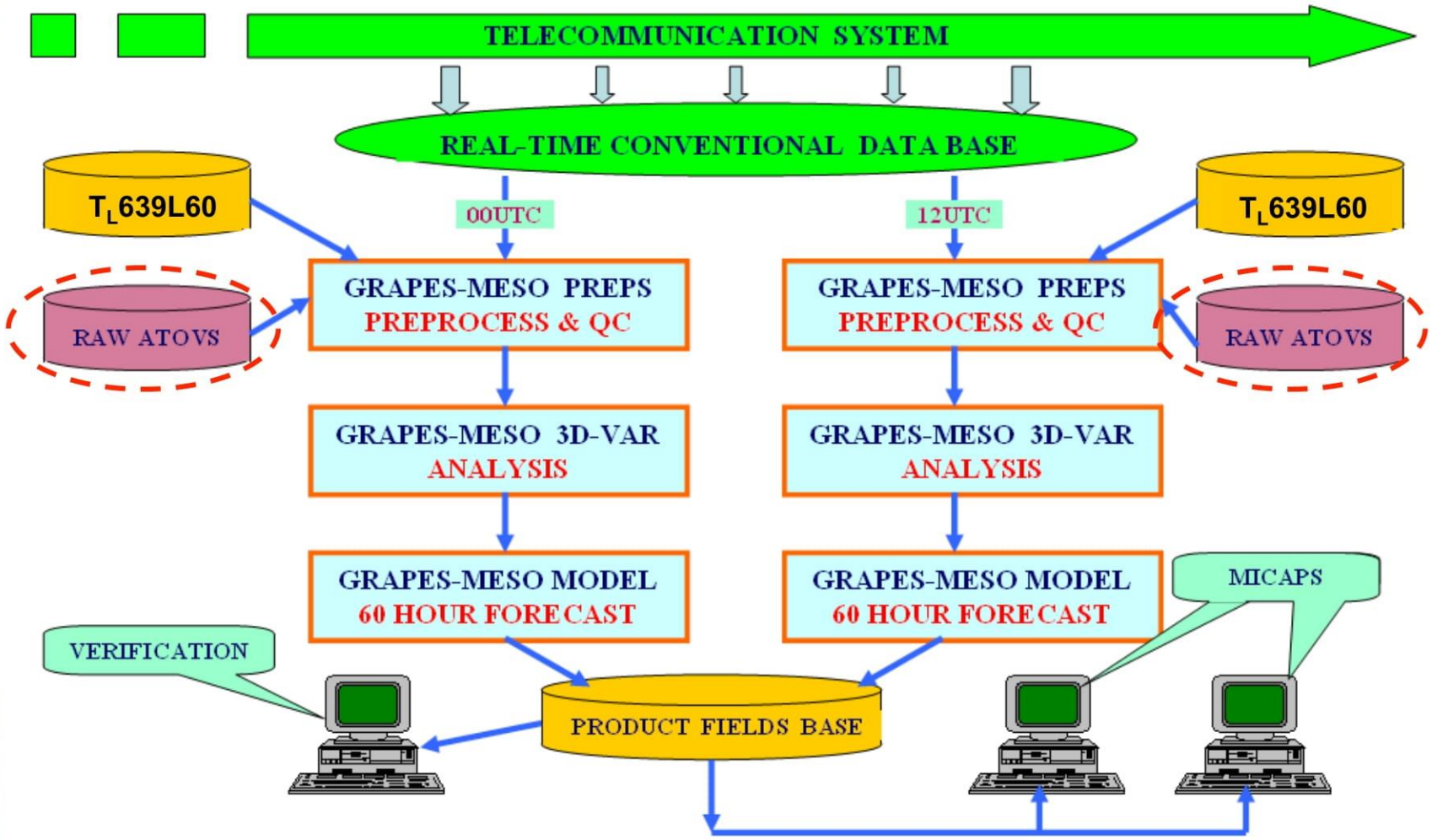
Configuration

- **Horizontal Resolution**
  - 15km current
- **Vertical layers**
  - 33 levels, top-34km
- **FQ and LBC**
  - T_L639L60, 06h
- **Physics schemes**
  - CU: BMJ
  - MP: WSM6
  - Radiation: RRTM
  - PBL: MRF
  - L.S.M.: NOAH
- **Daily routine**
  - DAS: 4 times/day, every 6 hrs
  - Forecasts: 2 times/day at 00 and 12Z
  - Domain: Chinese territories & all around-E.A.



Flowchart of GRAPES_Meso



Data use in GRAPES-3DVAR

- ✓ *ATOVS microwave* (NOAA15 16 17 18) radiances
- ✓ MTSAT & METEOSAT AMV
- ✓ MODIS (Aqua, Terra) AMV
- ✓ COSMIC
- ✓ Sondes geop/ humidity / wind
- ✓ Synops geop/ humidity/ wind
- ✓ Ships geop/ humidity/ wind
- ✓ Airep temp/ wind
- ✓ Satob wind
- ✓ Doppler radar radial wind and reflectivity

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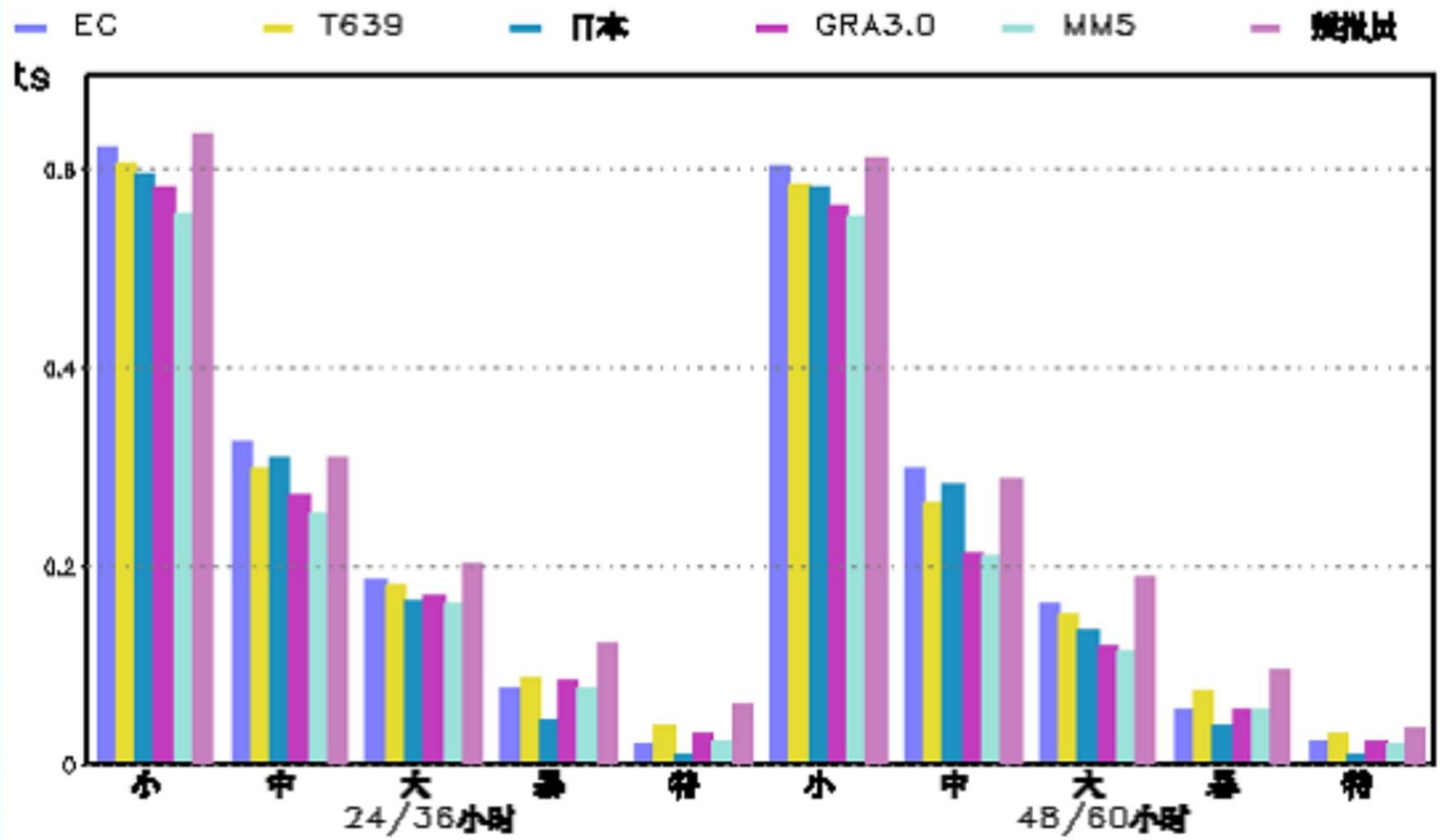
全国各种降水预报累加检验评分
2010年03月24日－2010年11月30日



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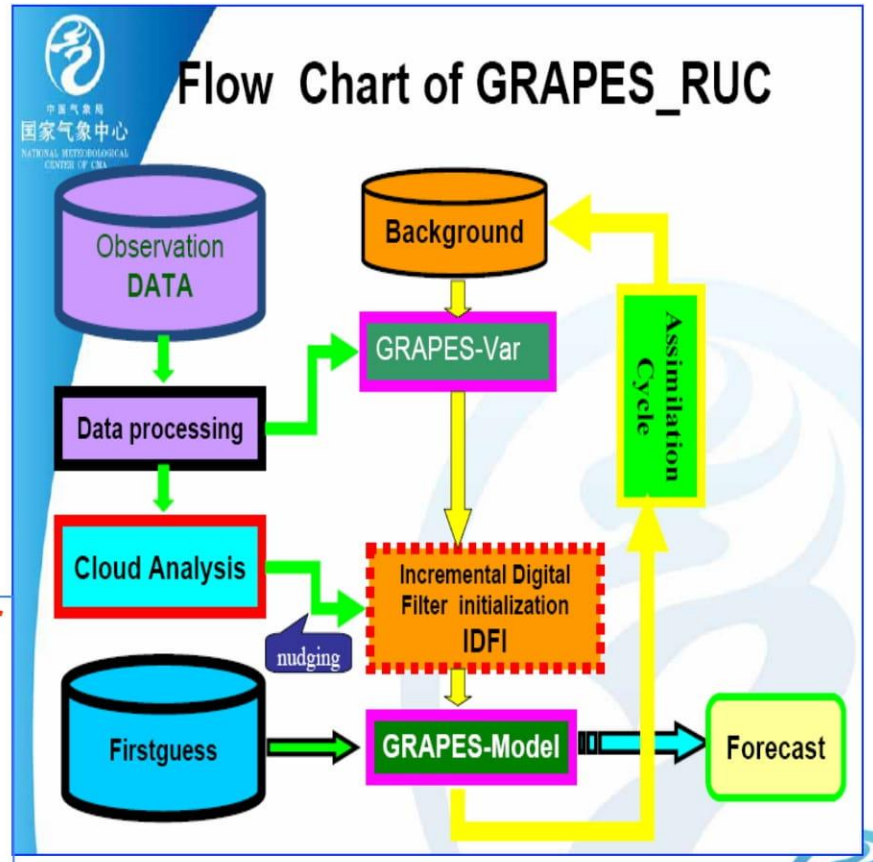
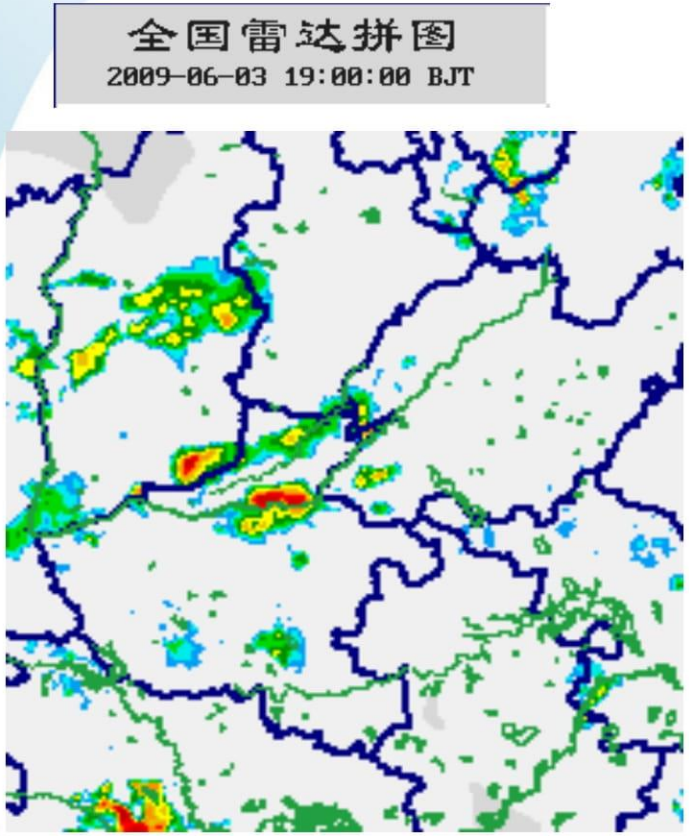
GRAPES_RUC -- Rapid Updated Cycle

- **GRAPES_RUC**: **heavy-rainfall warning & disaster reduction**
  - GRAPES_Meso 15km L31
  - GRAPES_3DVAR (model grid space)
  - 3-hourly cycle
  - 12 hour forecast (03,06,09,15,18,21UTC)
  - 24 hour forecast (00,12UTC)
  - GTS, local radio sonde, Doppler radar VAD, AWS, GPS/PW, FY-2C/2D cloud drift wind
  - Cloud analysis based on radar reflectivity



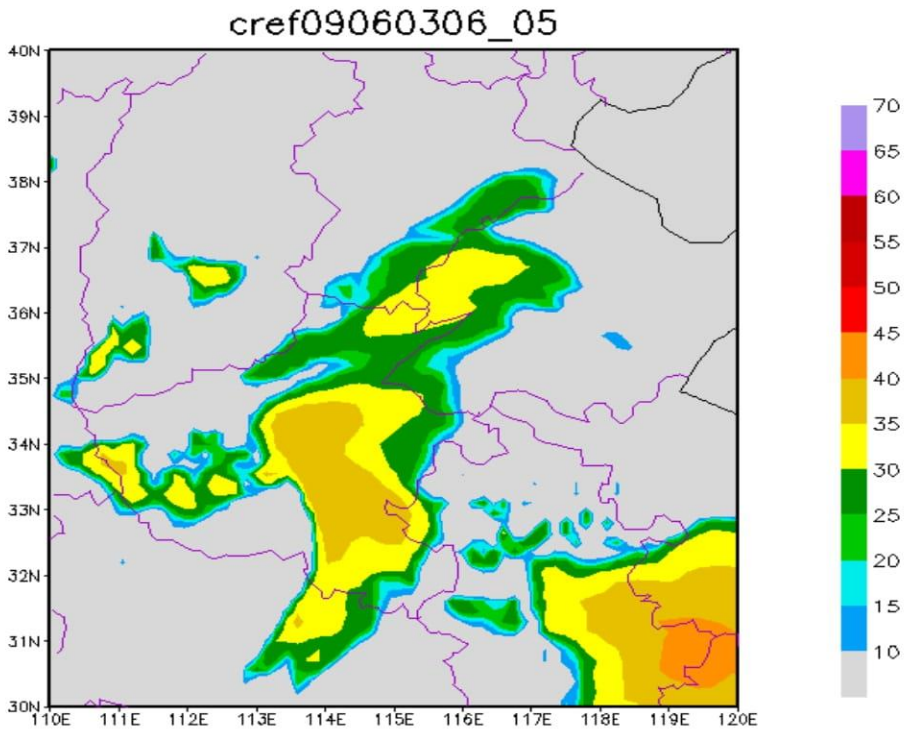
(From Xu et al., 2010)

2009 June 3，strong convection case



Radar reflectivity

（Initial 06UTC June 3/2009）

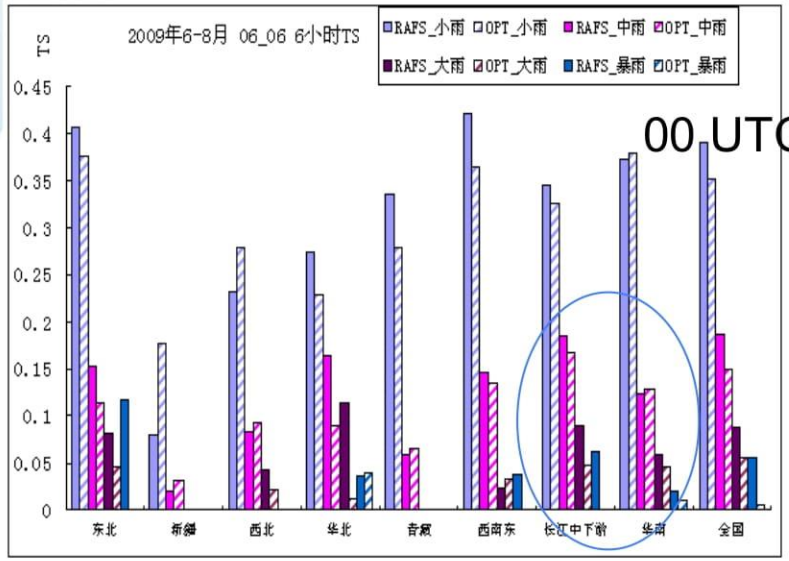


GRAPES_RUC

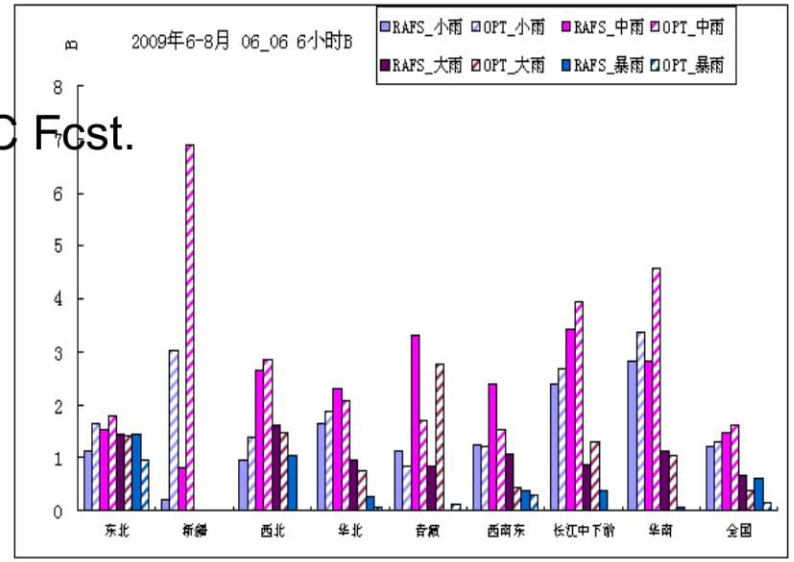
Well captured the location, movement and intensity

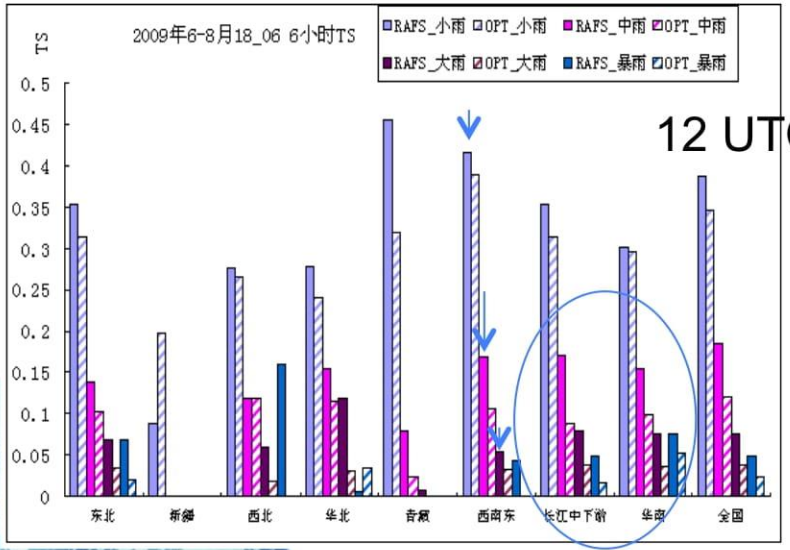
(From Xu et al., 2010)

GRAPES_RUC has higher skill for 6-hour forecast

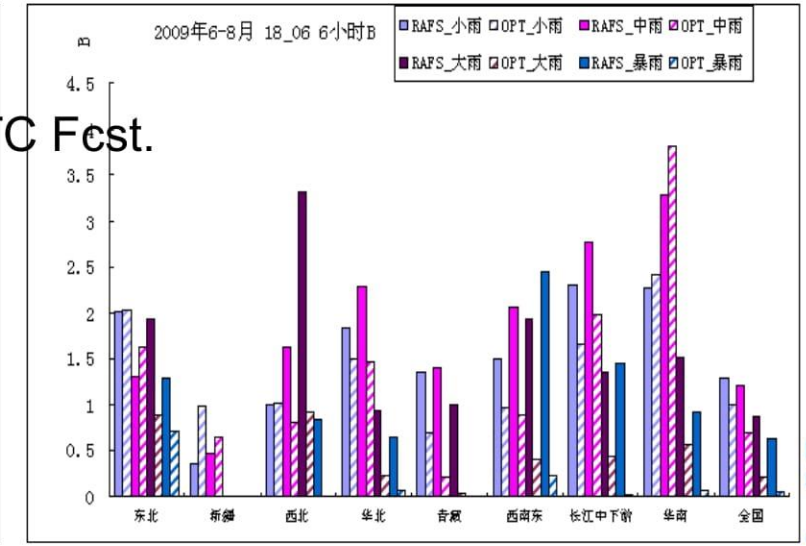


00 UTC Fcst.





12 UTC Fcst.



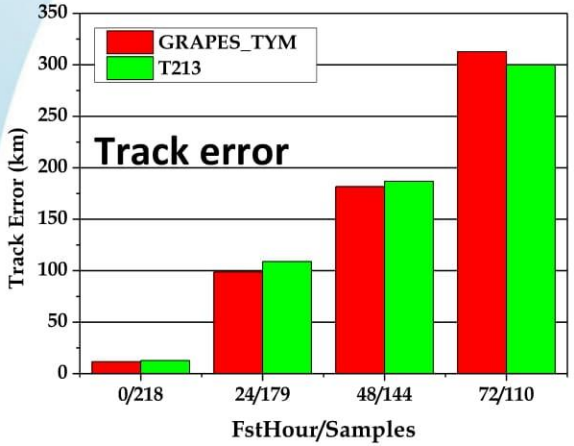
(From Xu et al., 2010)

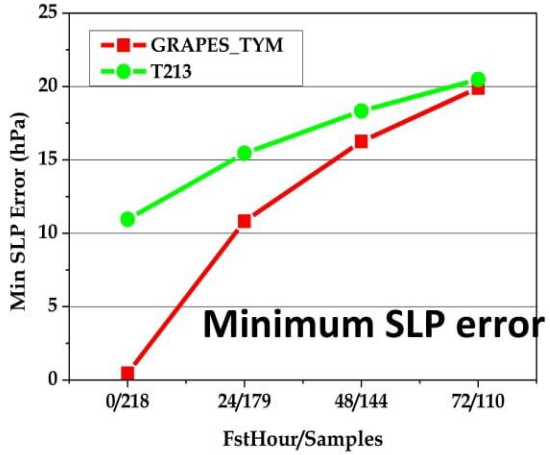
GRAPES_TYM

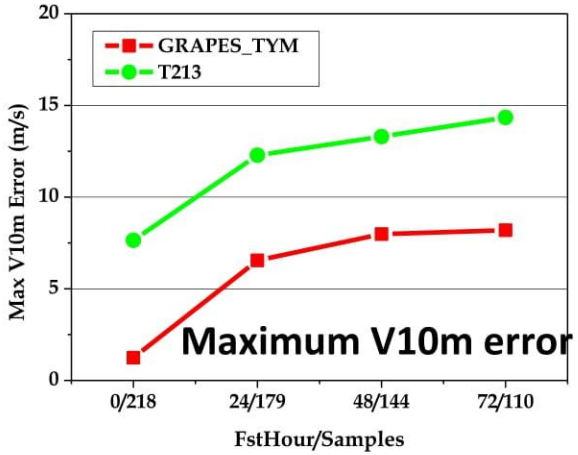
Model	**GRAPES_MESO3.0**
Domain	**90º~171ºE，0º~51ºN**
Grid points	**541×341**
Initial time	**00UTC、12UTC**
Initialization	**Bogus-relocated +intensity-adjustment**
F. lenth	**72hrs**
Interval-out	**3hrs**
Physical schemes	**Micro：WSM6 Cumul：SAS PBL：YSU LSM：SLAB**

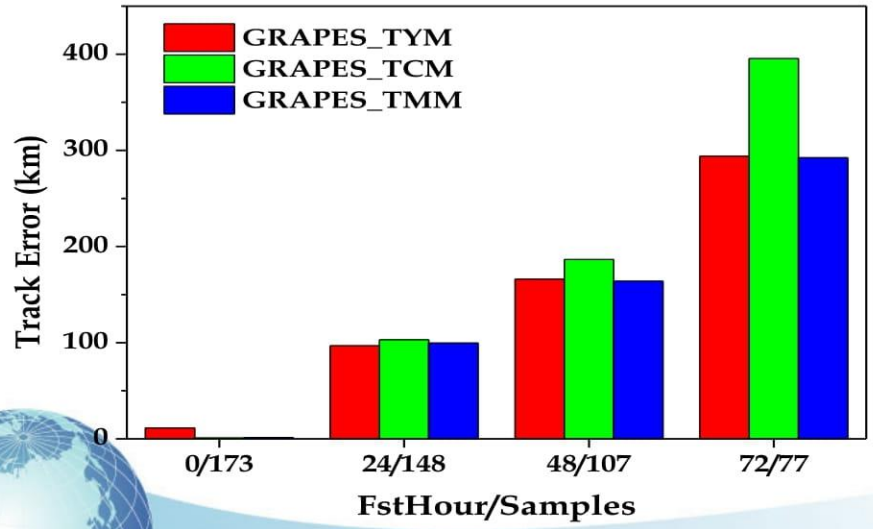
(From Ma et al., 2012)

Development of GRAPES_TYM for Typhoon intensity forecast





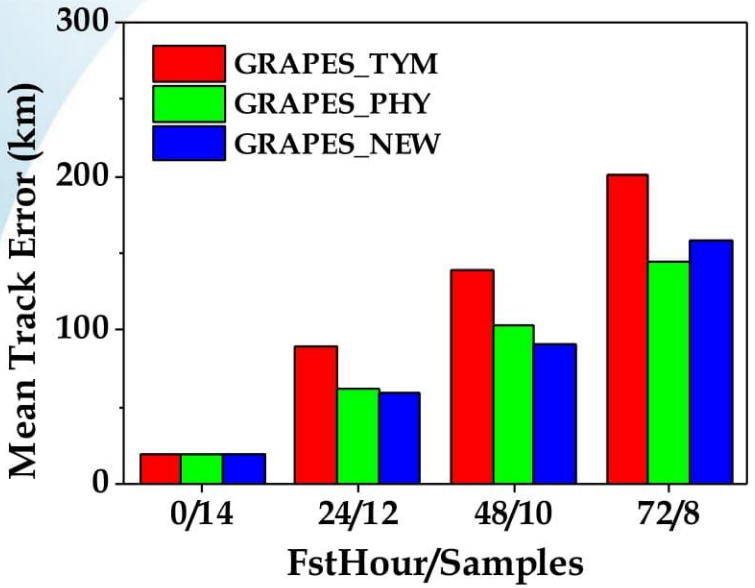


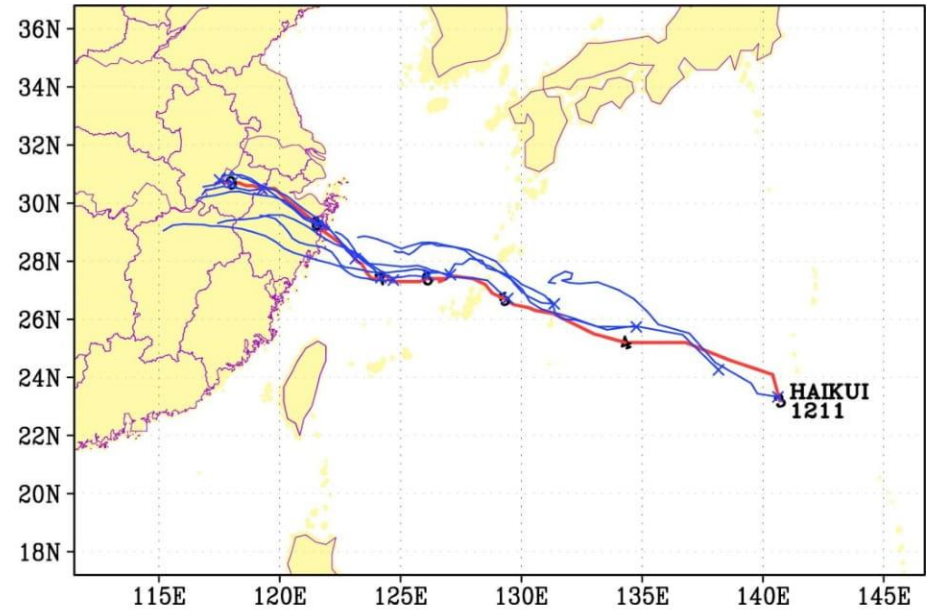


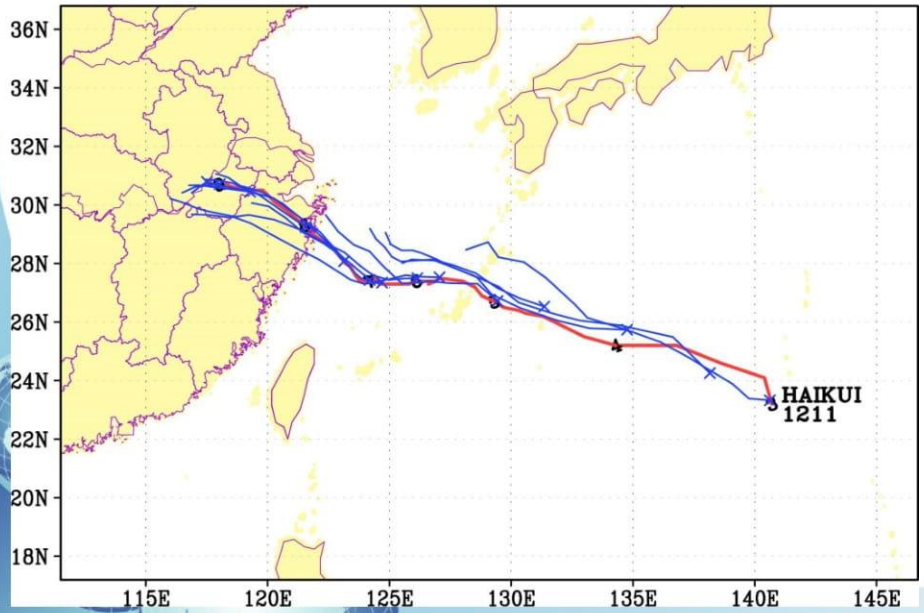
Mean track errors of GRAPES_TYM to GRAPES_TMM、GRAPES_TCM

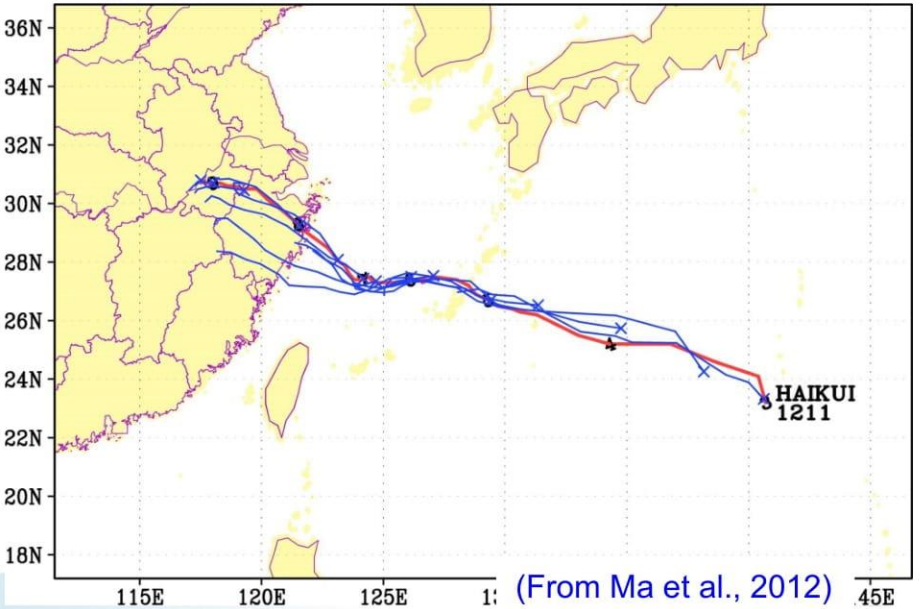
(From Ma et al., 2012)

Case of 2012-11 HAIKUI



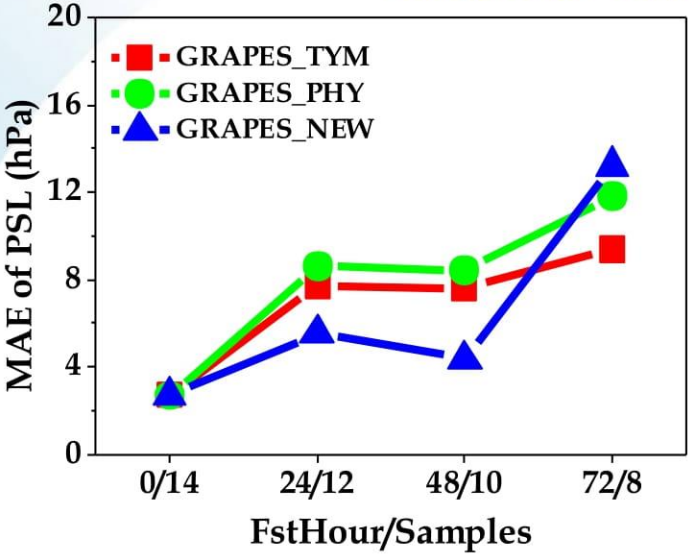


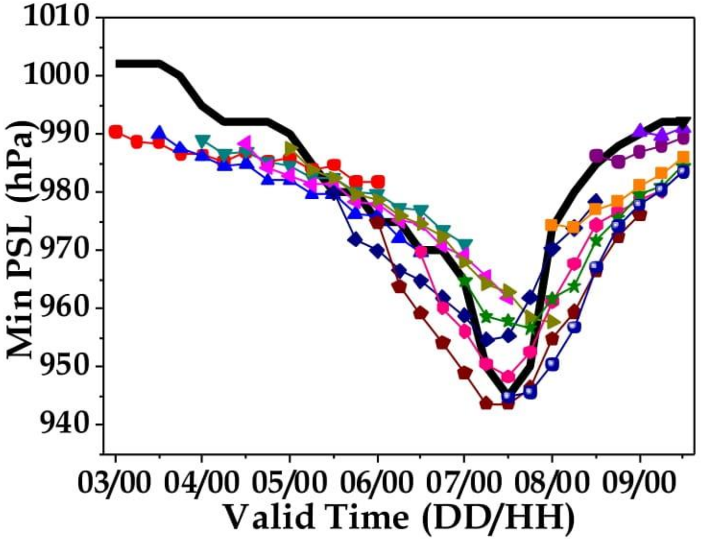


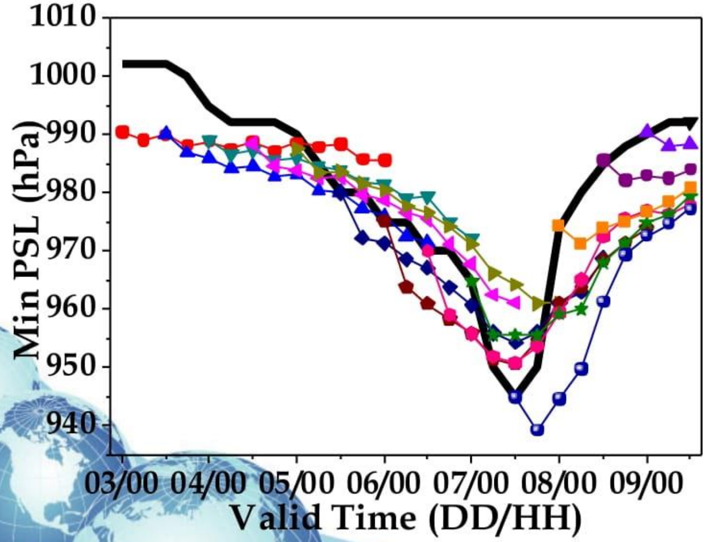


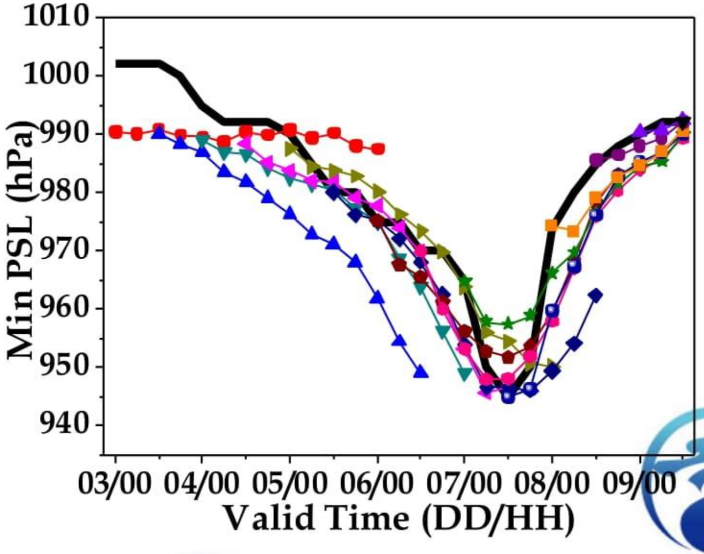
(From Ma et al., 2012)

Case of 2012-11 HAIKUI



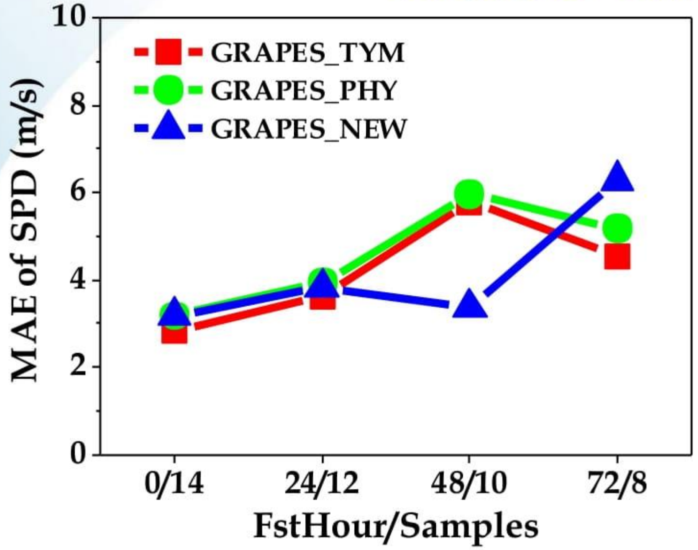


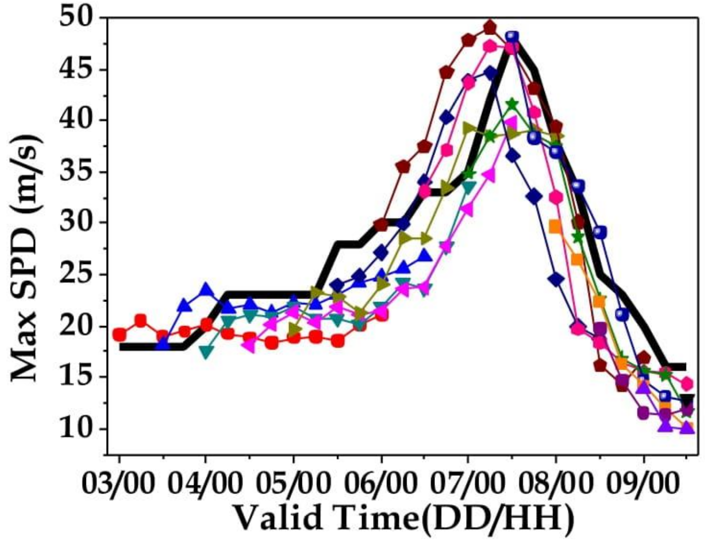


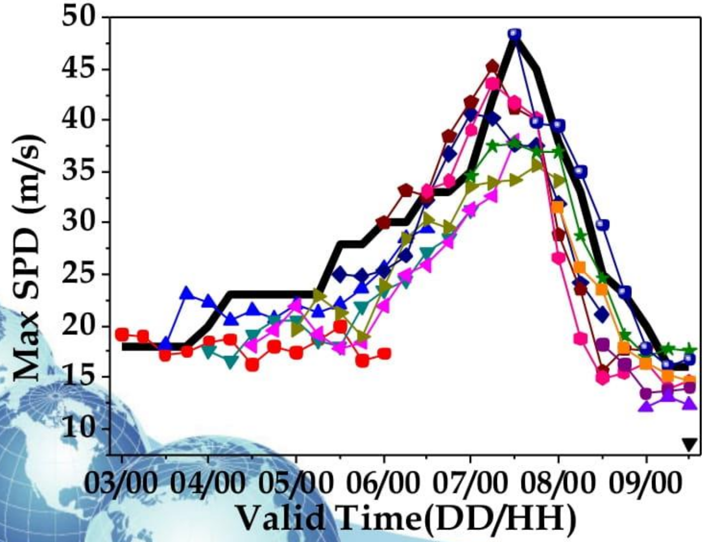


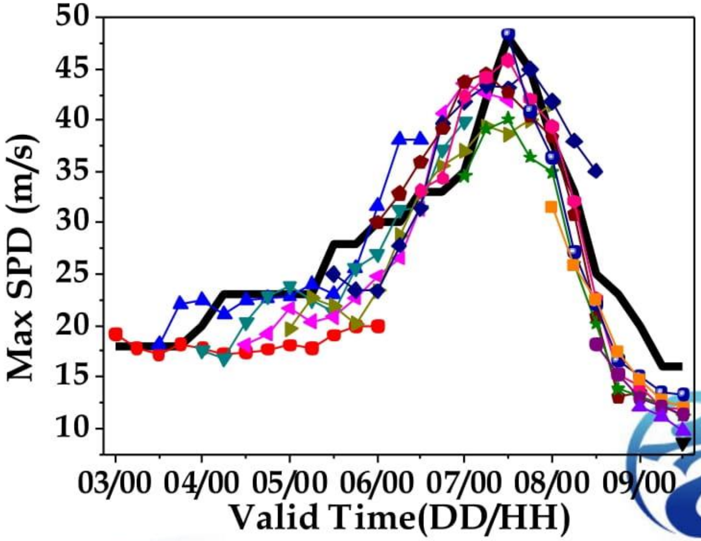
(From Ma et al., 2012)

Case of 2012-11 HAIKUI









(From Ma et al., 2012)

GRAPES community

more than 50 users including universities, research institutes

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Implementation at Shanghai Typhoon Institute for East C.S.

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GRAPES_Tropical Cyclone Model

- Based on GRAPES_Meso-V2.5
- **Initialization:** bogus: GFDL method (Yoshio Kurihara, Morris A. Bender and Rebecca J. Ross. 1993) & cyclic BDA(Liang et al.)
- H. Res. 25km; V. Res. 31 levels
- Domain: East-China & W.N. Pacific Ocean
- IC + LBC: provided by AVN of NCEP

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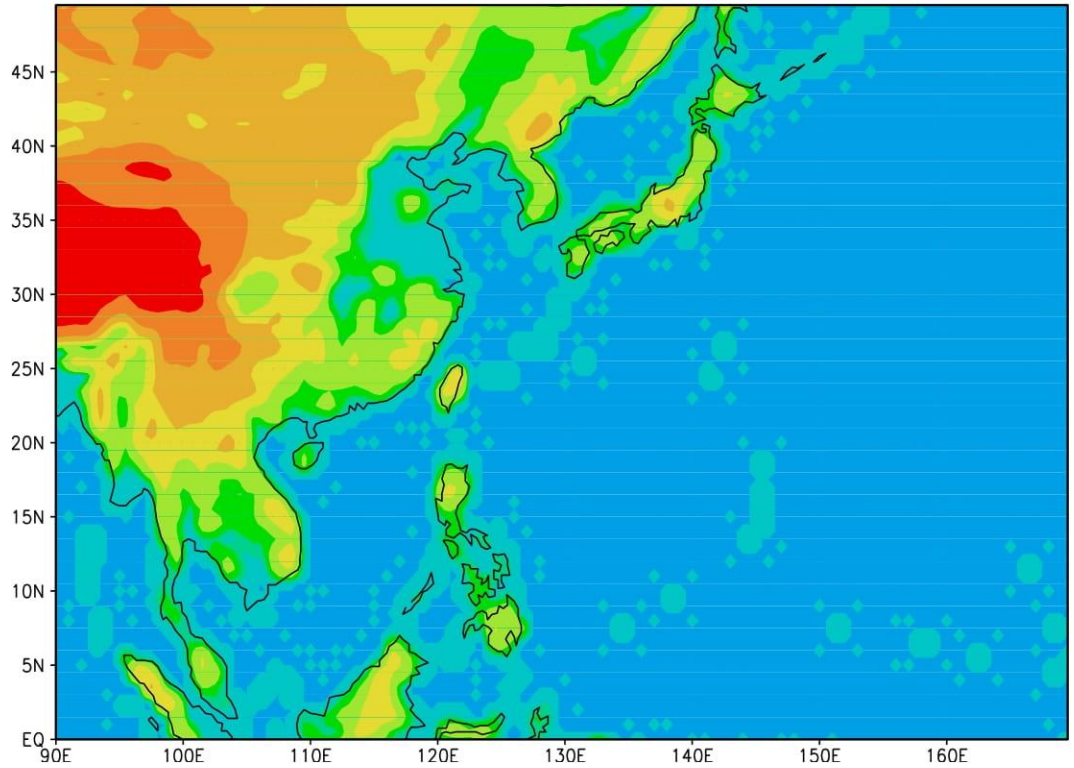


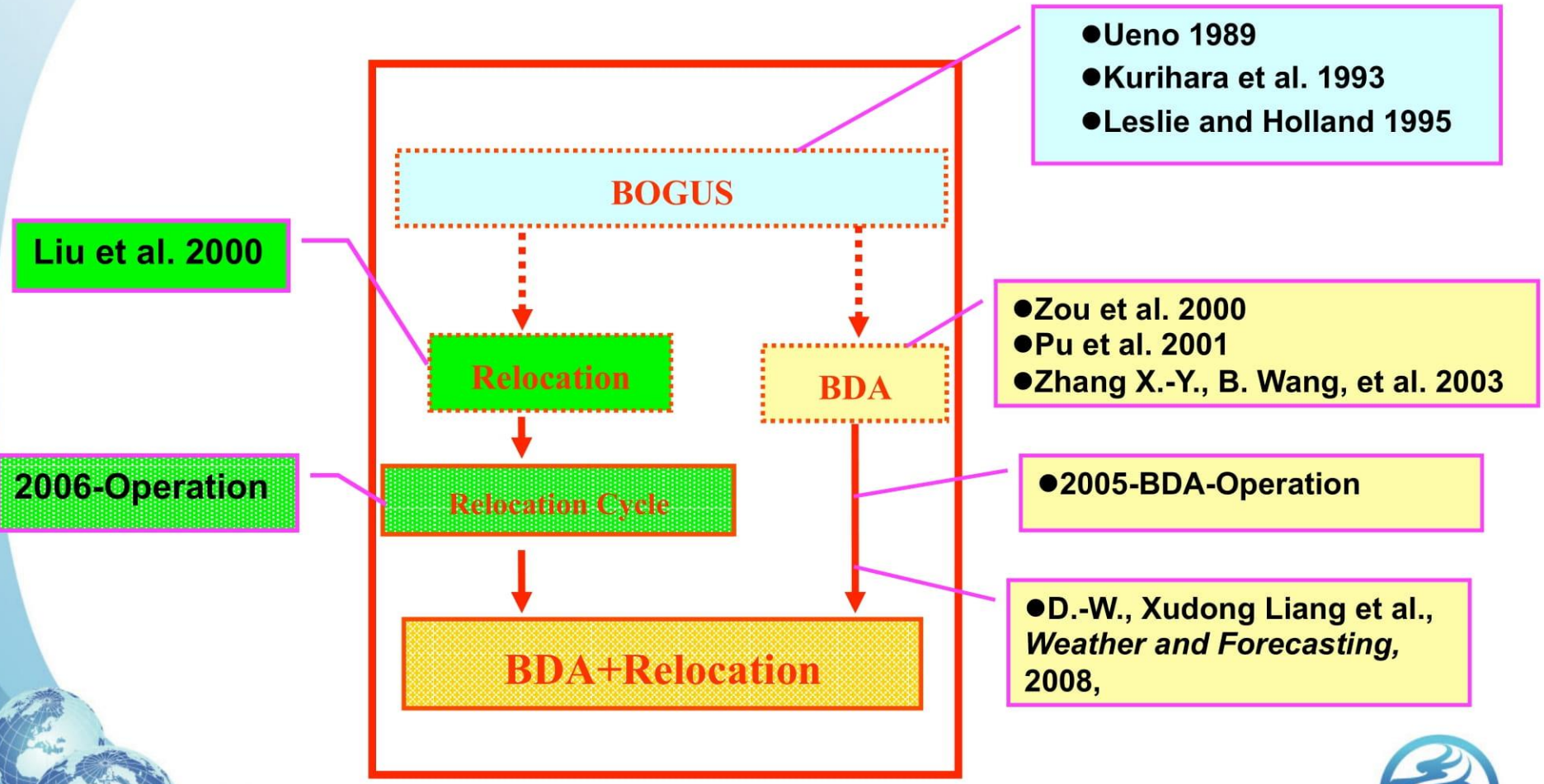
Fig: Topography of the domain

- **Configuration**
  - Domain: E90°~E170°,N0°~N50°
  - Hor. Res.: 0.25°x0.25°
  - Grids: 321x201
  - V. res.: 31(ztop: 35000m)

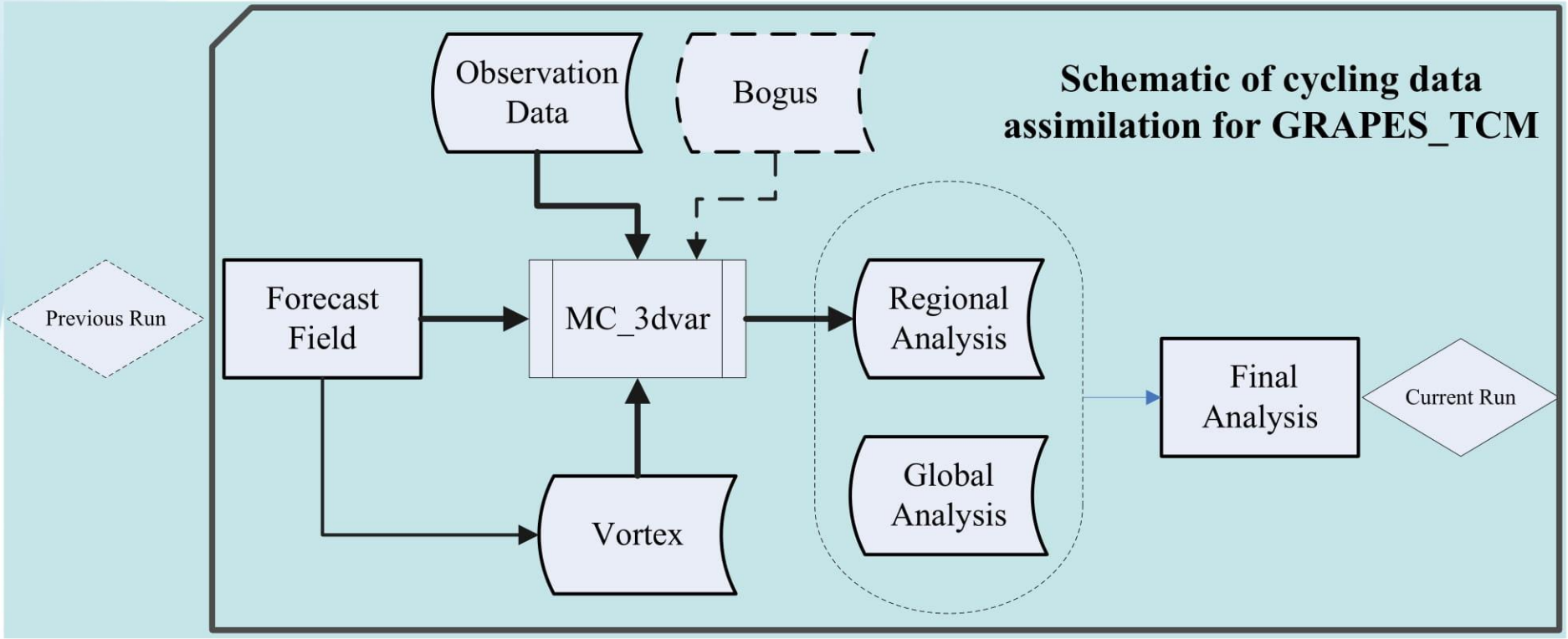
- **Physics**
  - Cumulus：KF-eta
  - PBL: YSU
  - Micro: NCEP cloud3
  - LSM: SLAB scheme
  - Radia.: RRTM scheme

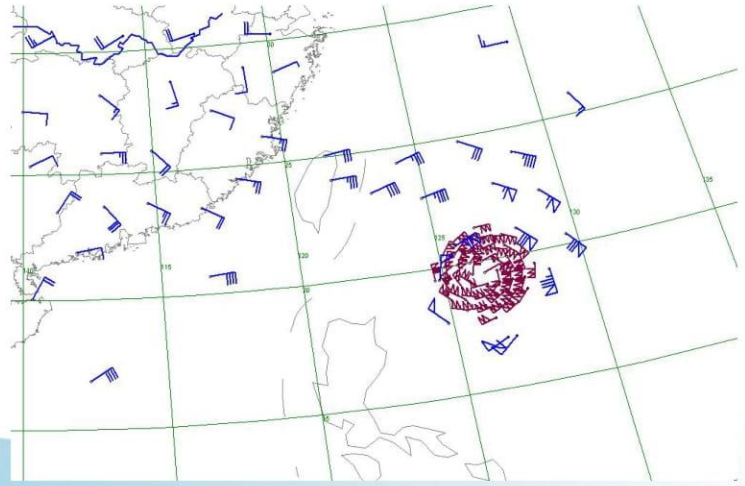
(From Wang et al., 2010)

BDA-Cycling



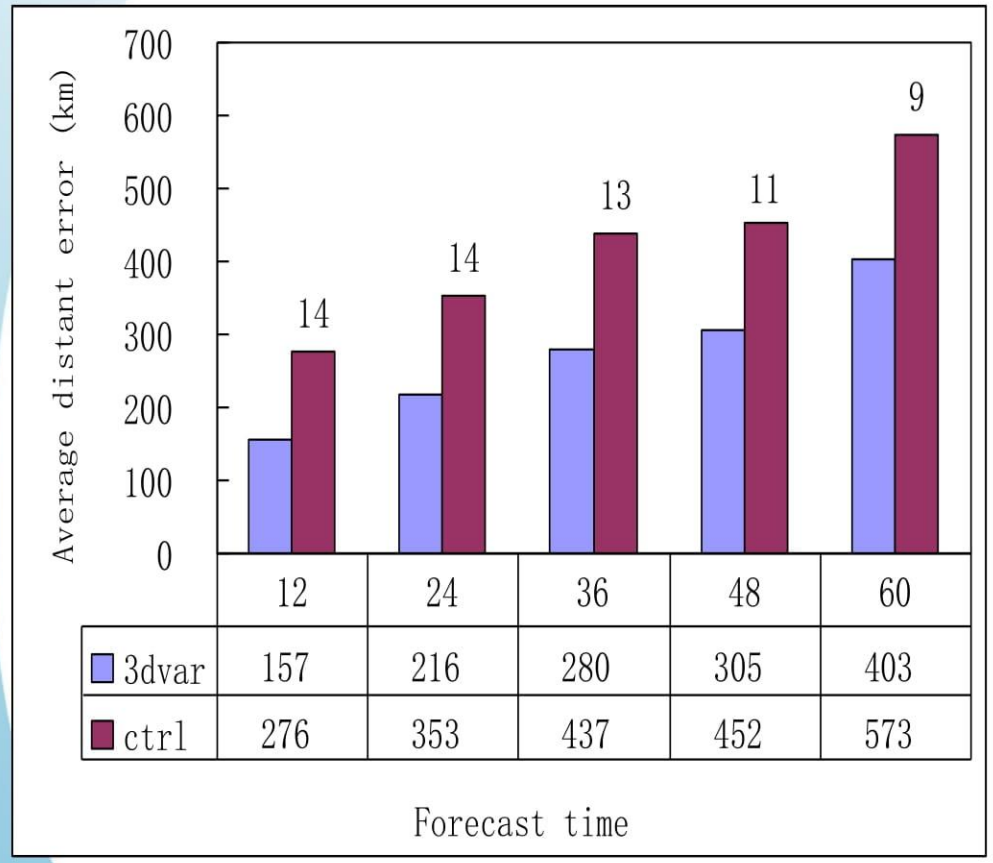
(From Wang et al., 2012)

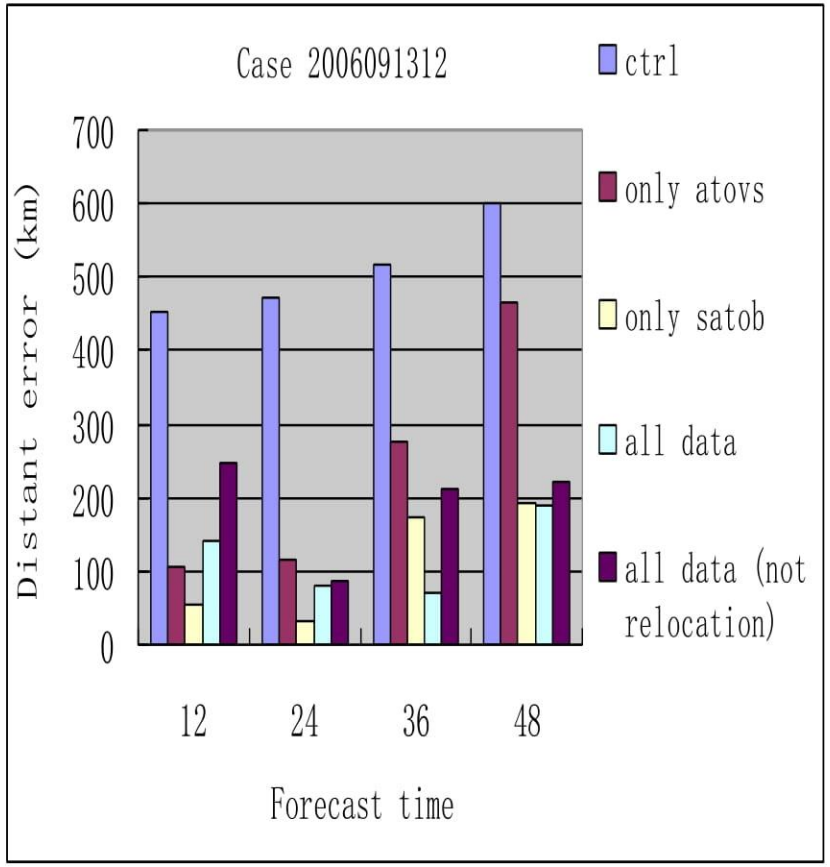




(From Wang et al., 2012)

Impacts of 3DVar and various data uses

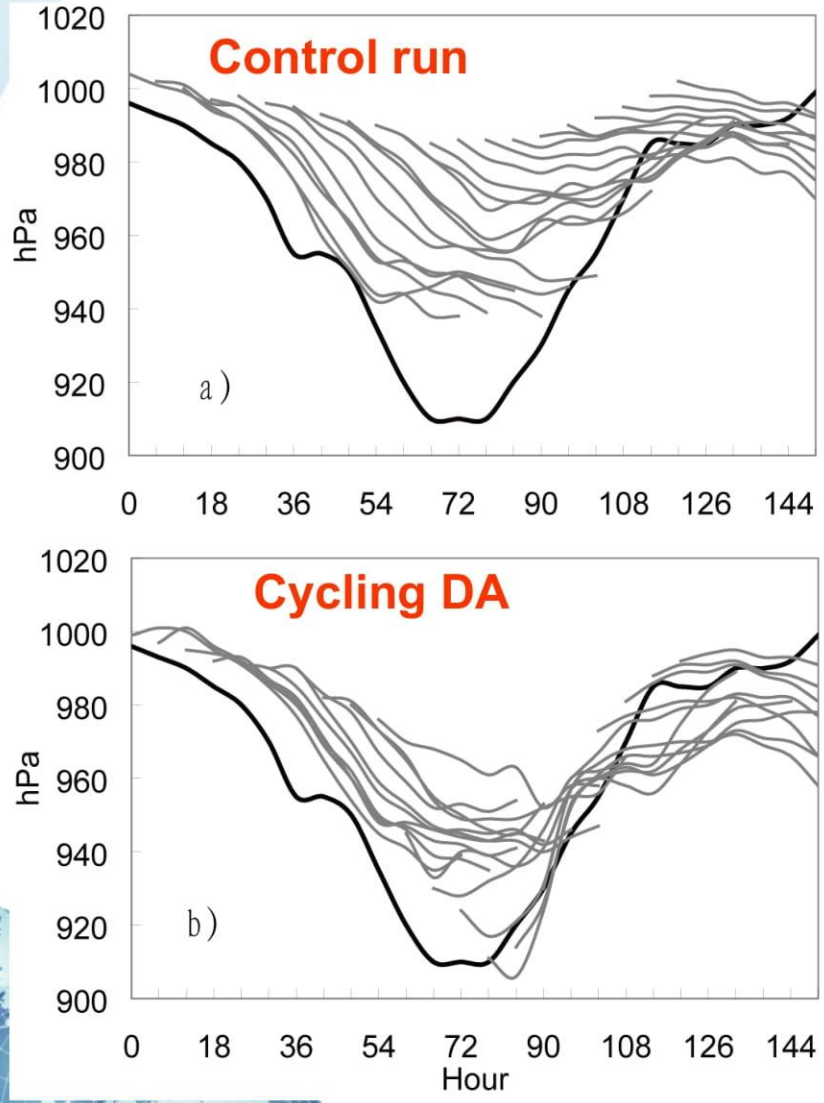


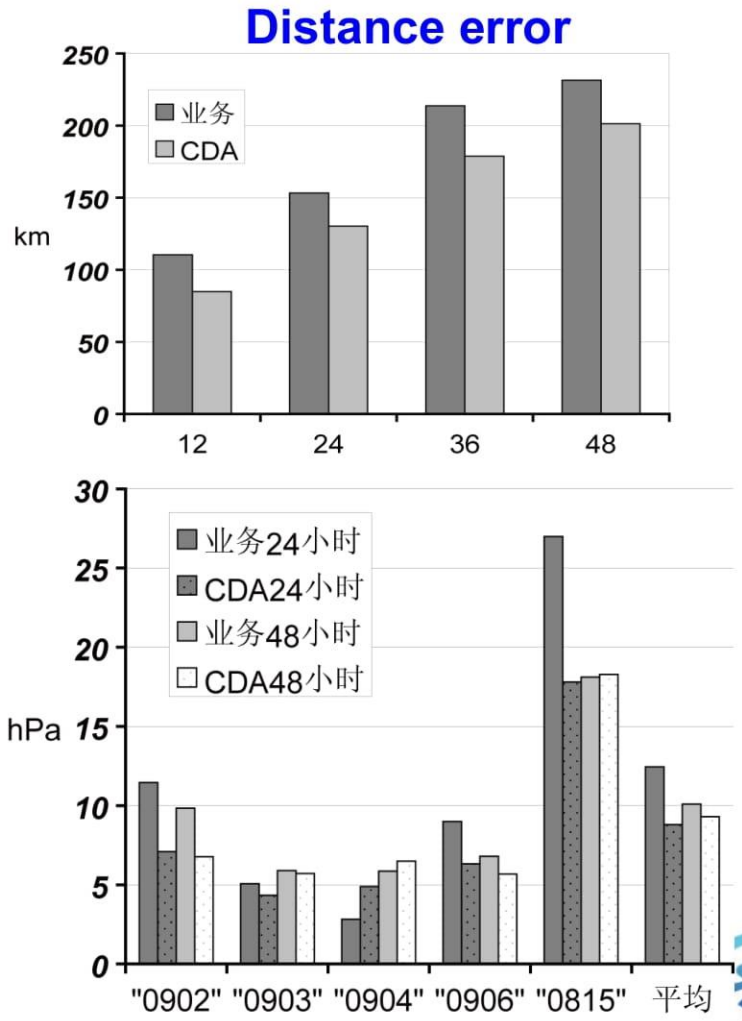


- Impacts of GRAPES_3DVAR
- Impacts of various data uses

(From Wang et al., 2010)

Impacts of Cycling DA for 2009





(From Wang et al., 2010)

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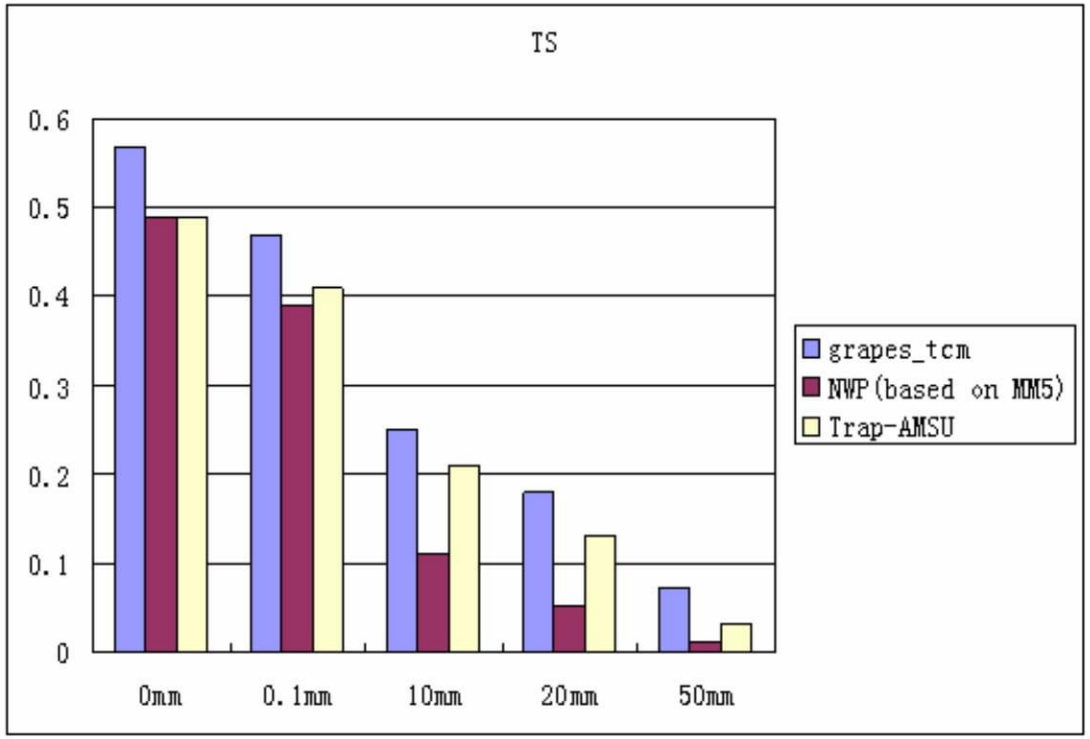
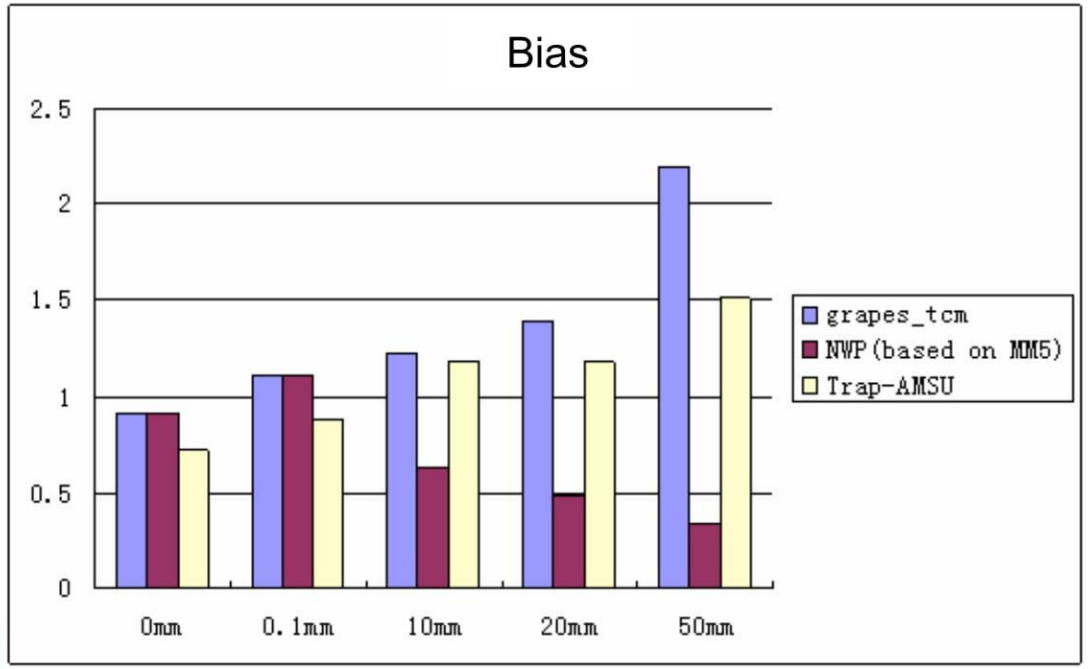


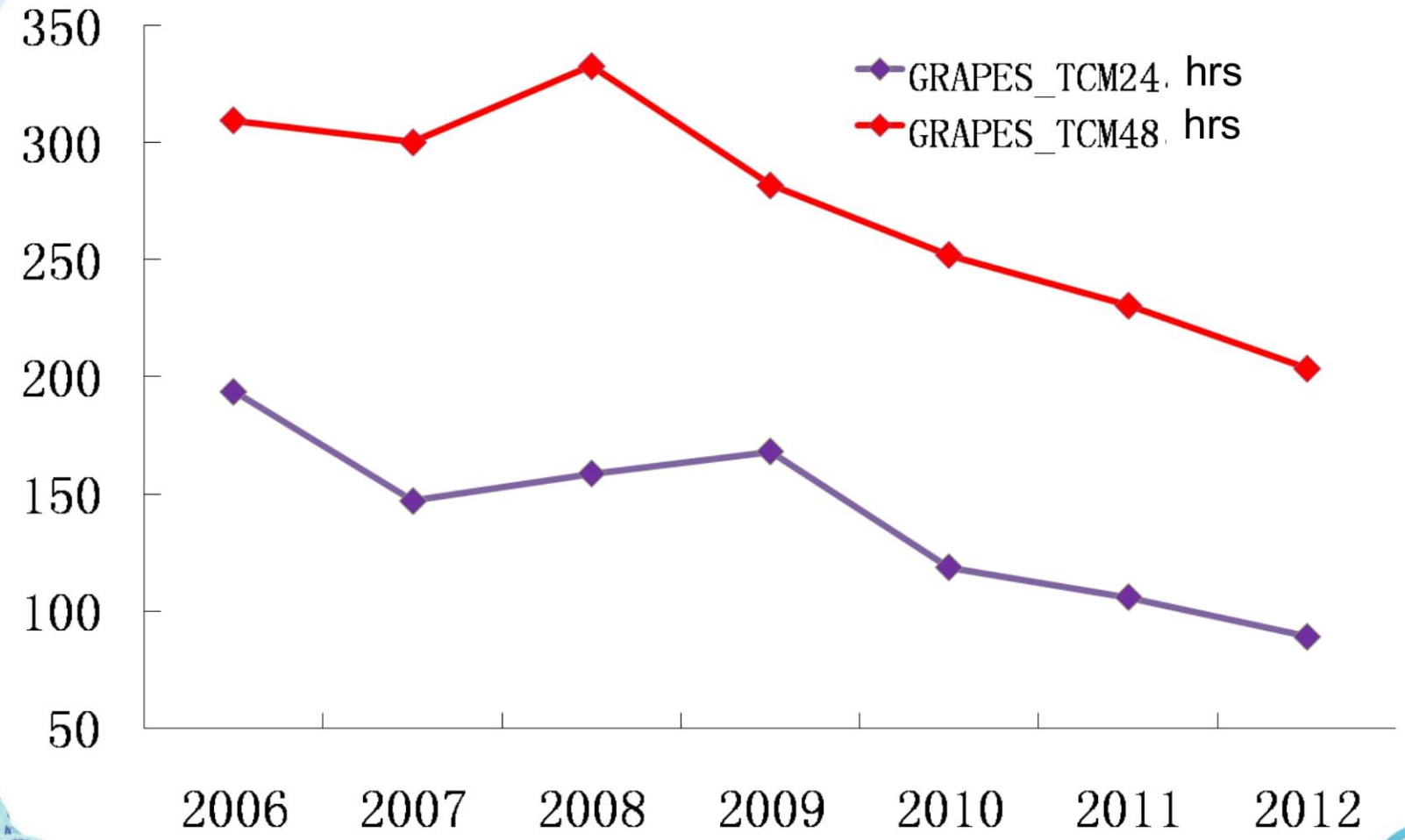
Threat Score verification against observations

24 h precipitation forecast by GRAPES_TCM at Shang Hai Typhoon Institute

(From Wang et al., 2010)



Evolution of mean track errors



(From Wang et al., 2012)

Implementation at Guangzhou Tropical Meteor. Institute for S. C. S.

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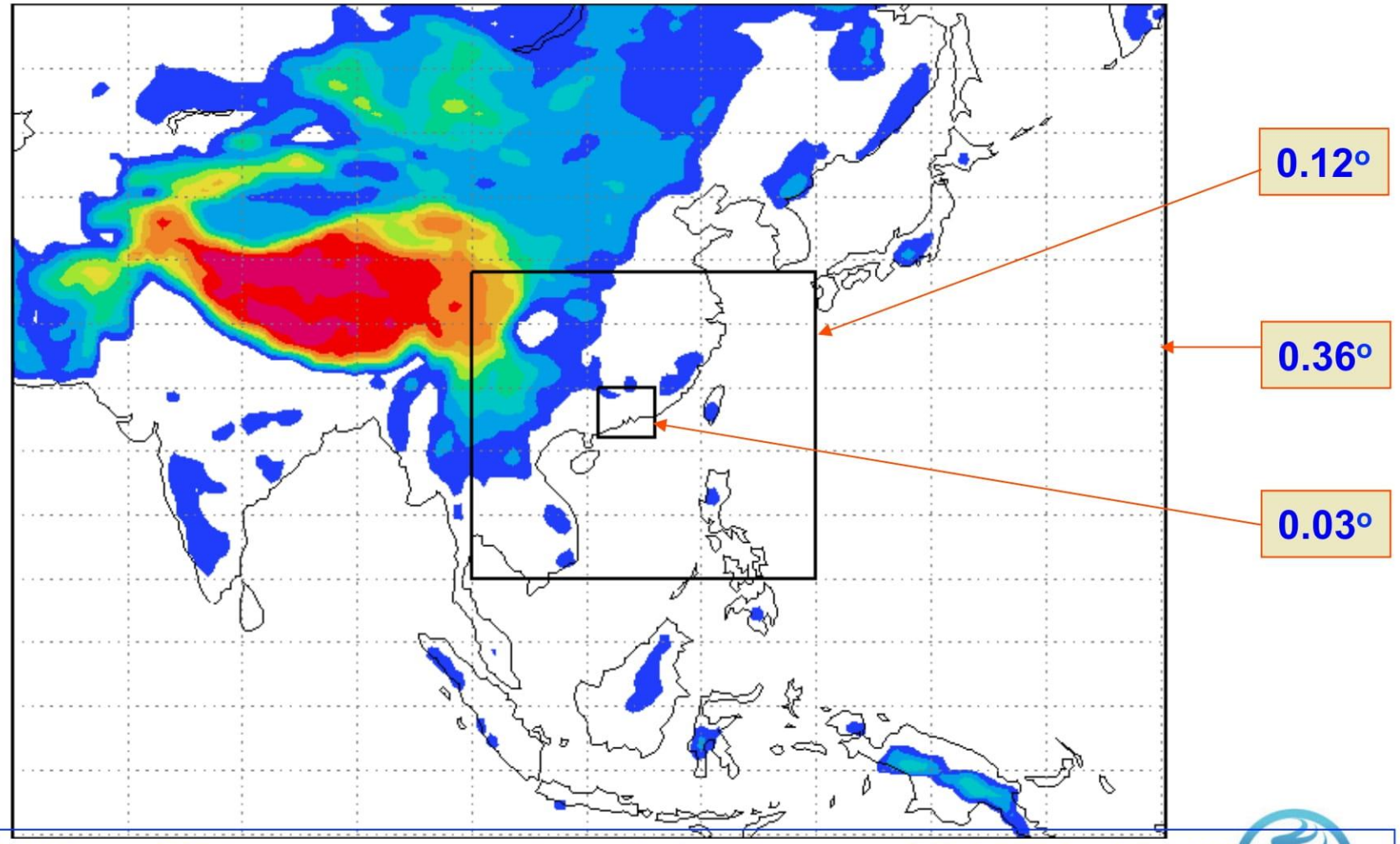
Domains of GRAPES_TMM at GZ



Since 2003, GZ began to operationally implement GRAPES_3DVAR, and then GRAPES_Meso for establishment of GRAPES_TMM, which is a three-nested model system

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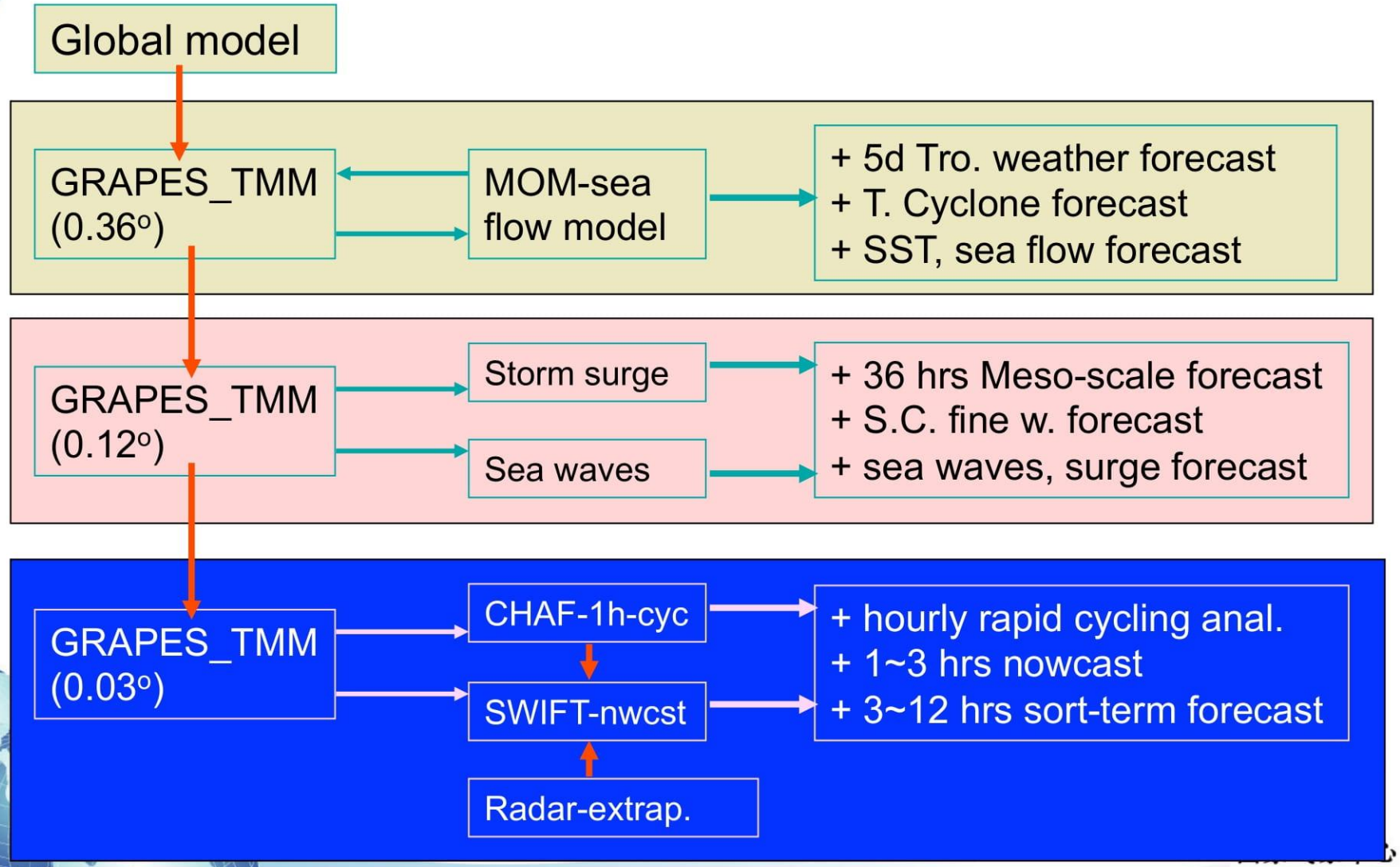
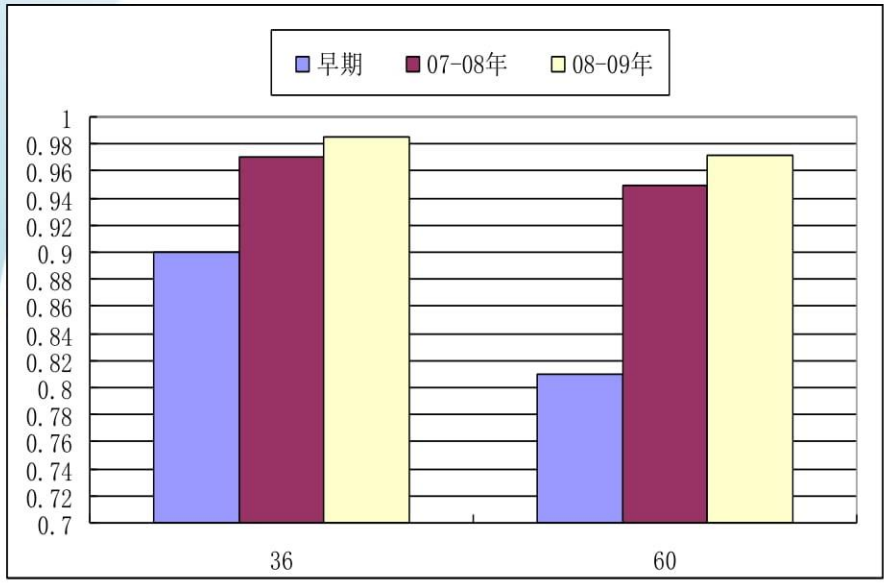
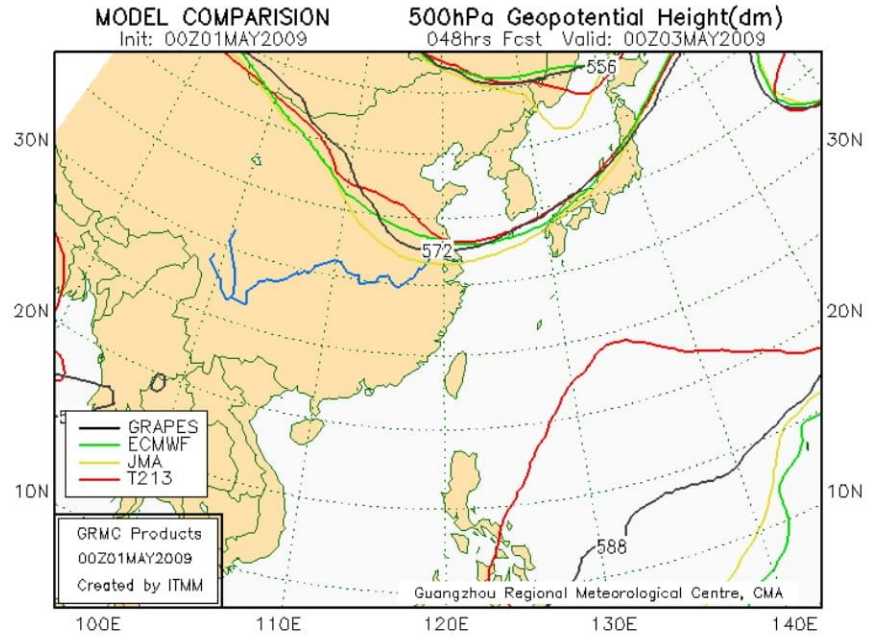
Since 2003， GZ began to operationally implement GRAPES_3DVAR, and then GRAPES_Meso for establishment of GRAPES_TMM, which is a three-nested model system:



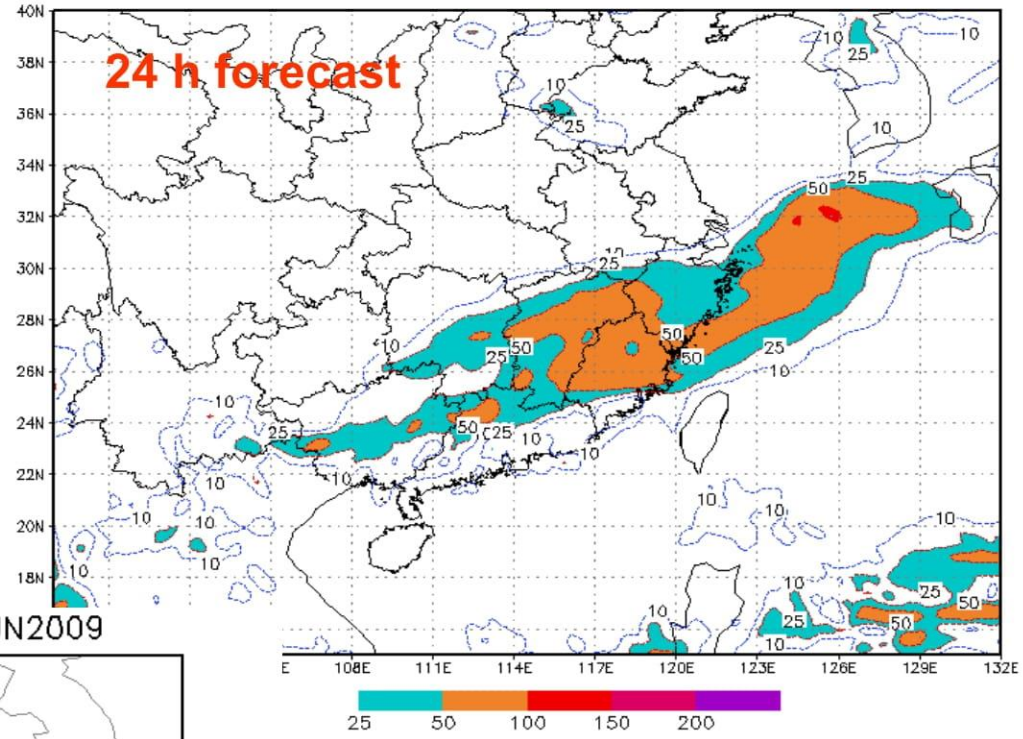


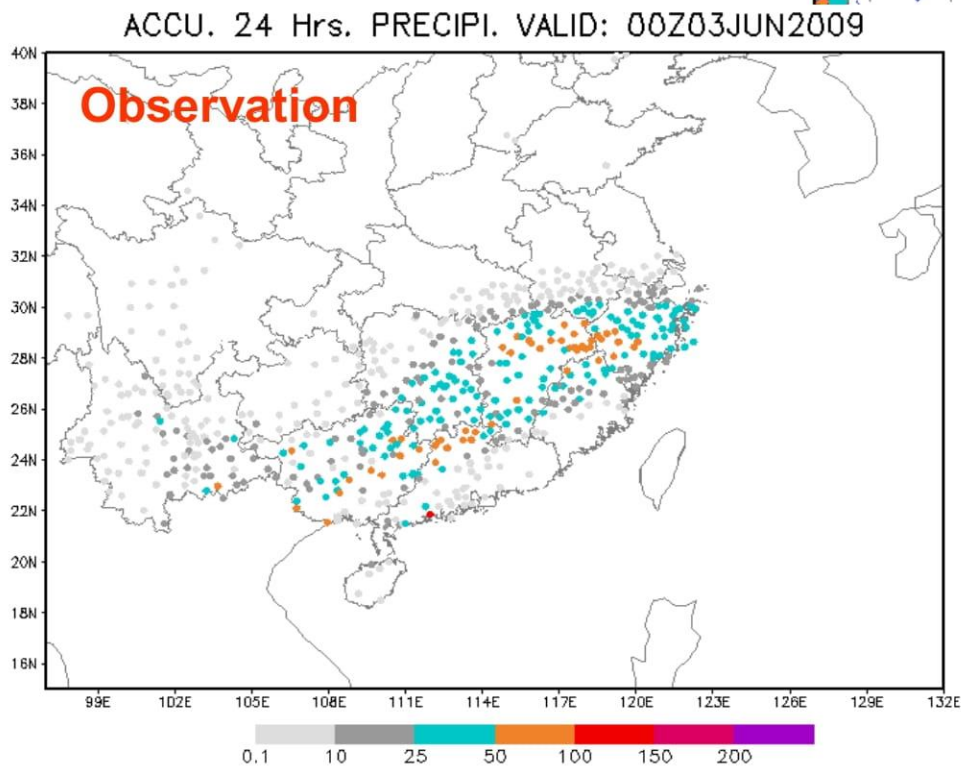
ACC of 36, 60 hrs forecasts of G.H. at 500hPa. Blue-Earlier; Blown (07~08) and Yellow (08~09)



Iso-G.H. at 500hPa by TMM (grey), ECMWF (green), JMA (yellow) and T213 (red)

(From Wan et al., 2010)

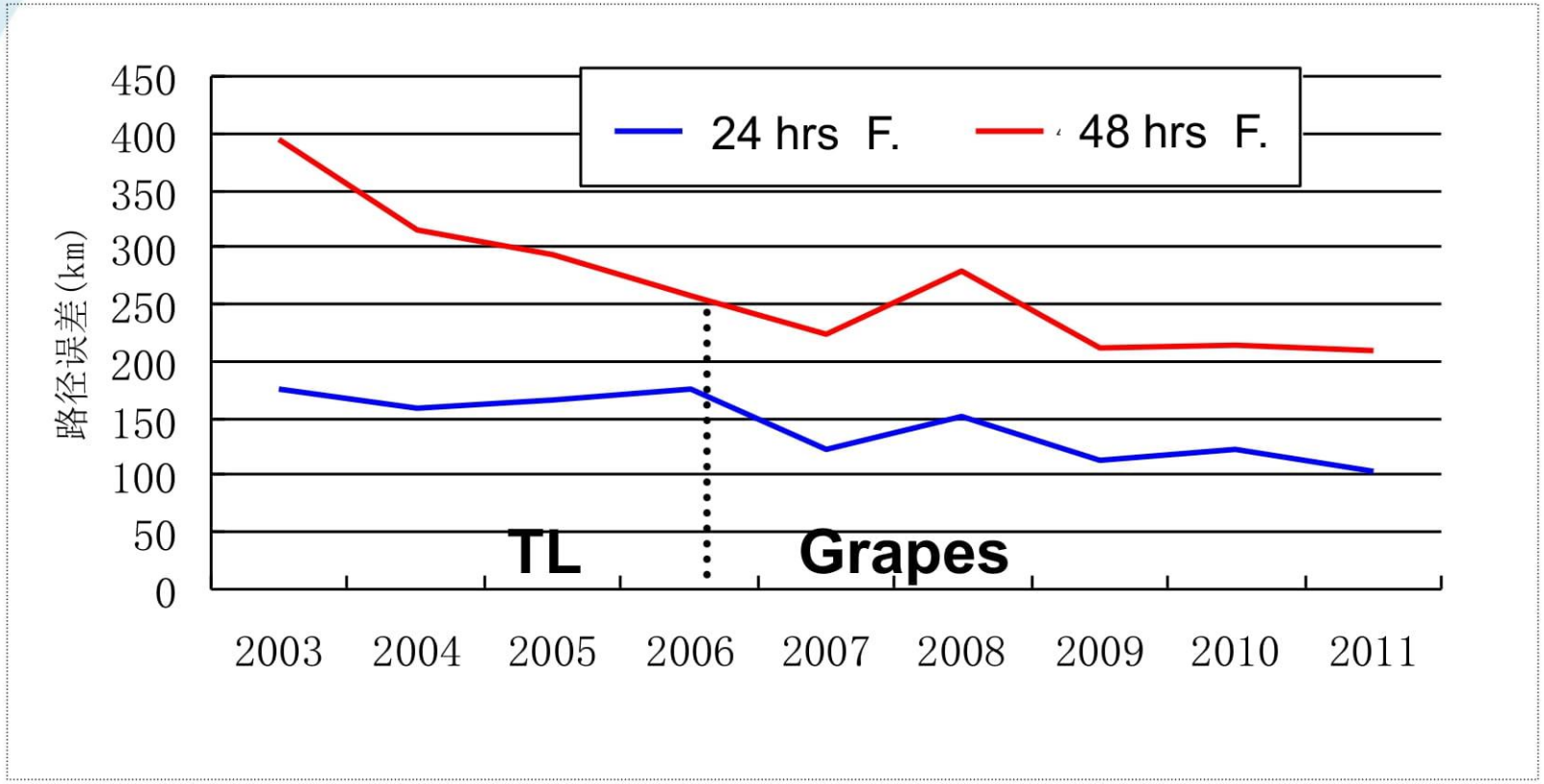




Valid: 00Z03Jun2009

(From Wan et al., 2010)

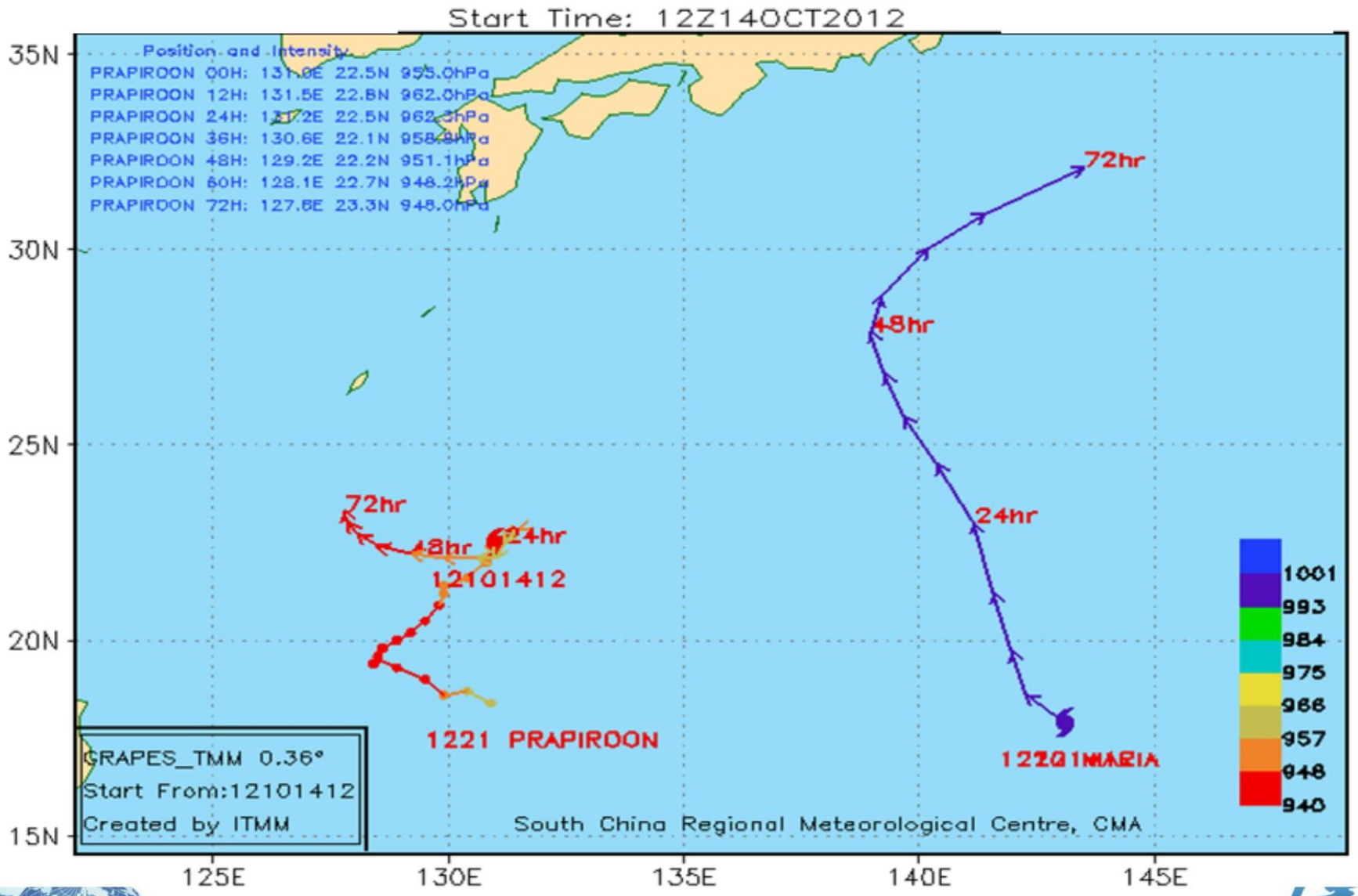
Evolution of Yearly Mean Track Errors



Mean Track errors2012

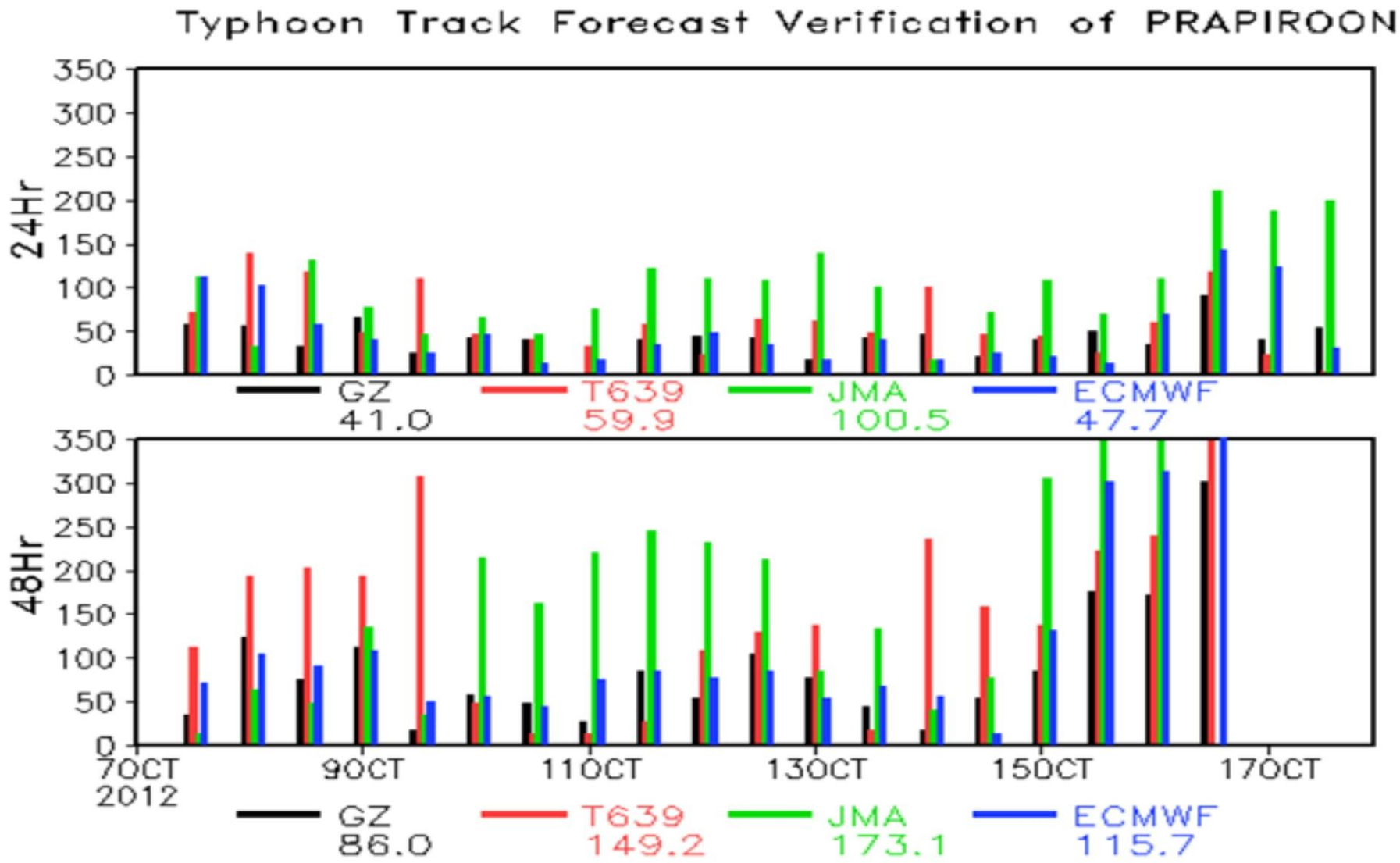
24h	48h	72h
96.5 km	176.7km	235.6km

(From Chenn et al., 2010)



Complicated Track of Prapiroon-2012

(From Chenn et al., 2010)



Inter-comparison to ECMWF, JMA, T639 and GRAPES_TMM (Initial Time: 12UTC, 00UTC)

(From Chenn et al., 2010)

Sand and Dust storm forecast; Hydro-meteor. forecast

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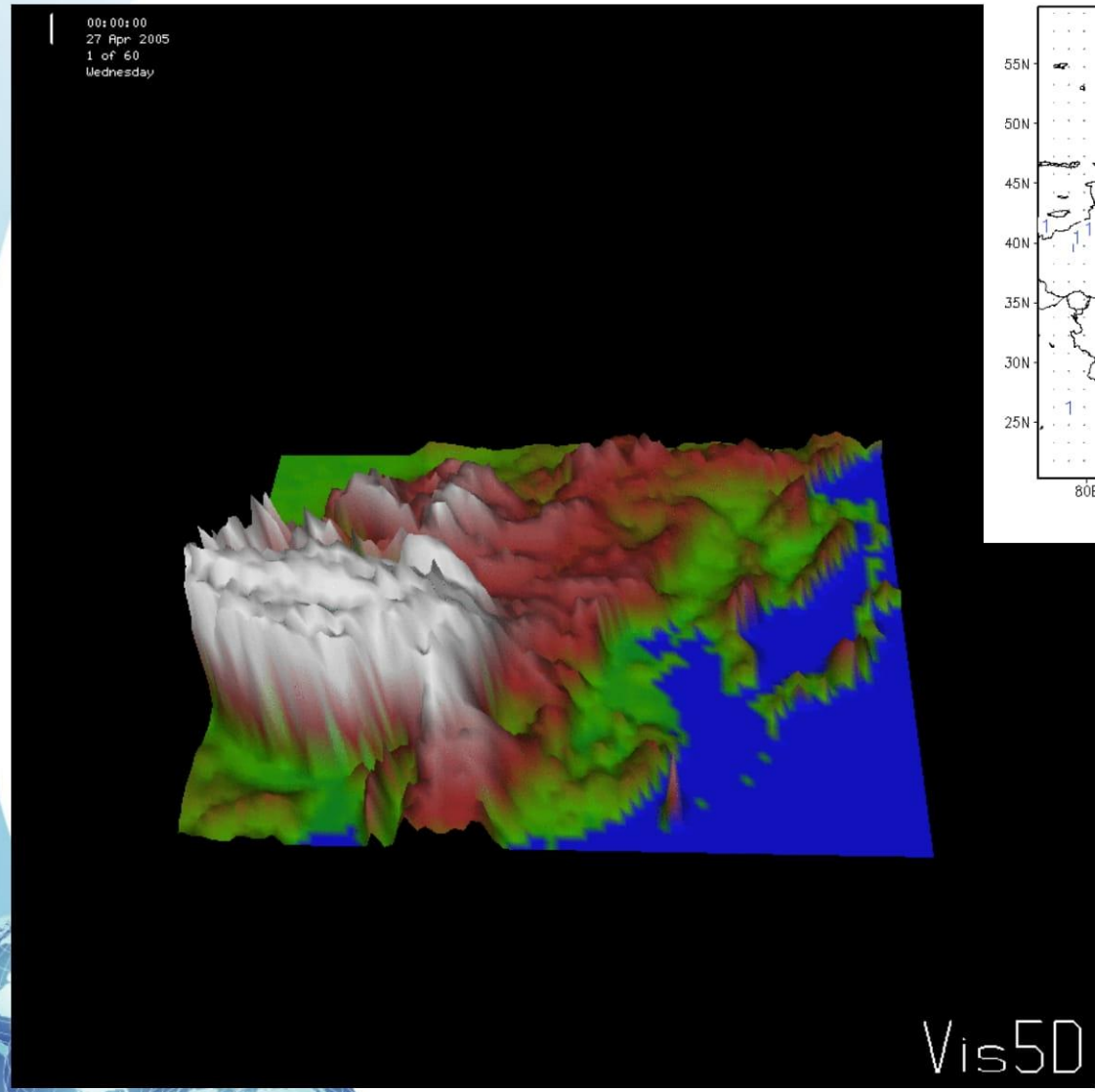
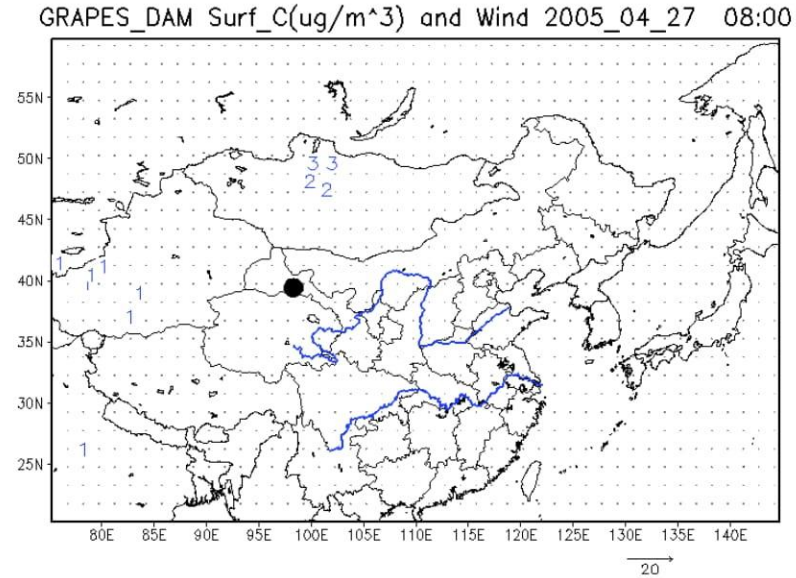
Sand and Dust storm forecast with GRAPES-DAM





Sand storm on Apr 27 2005 initiating in northwestern China, model output updated every 3hours

(from Wang and Chen, 2006)

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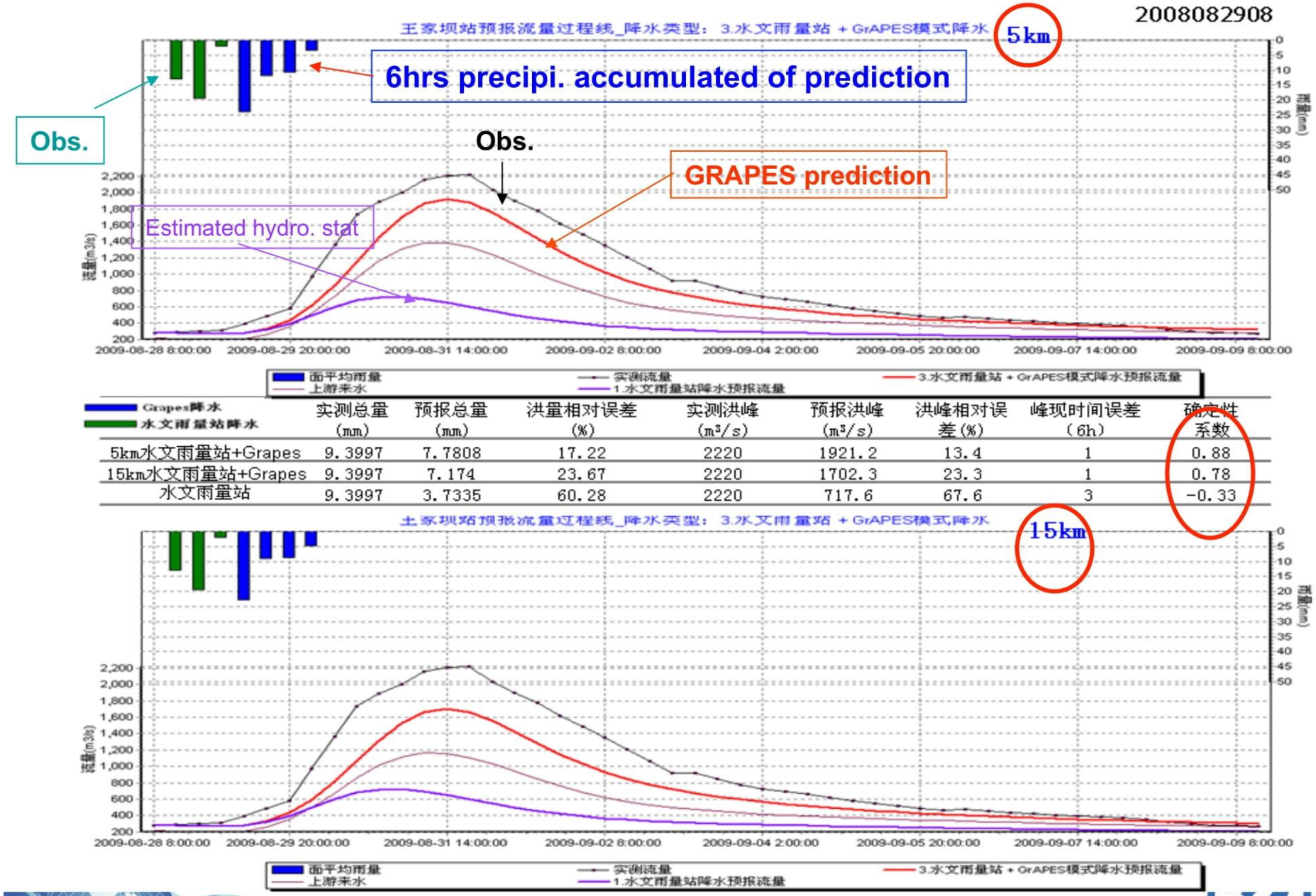
2008082908



Grapes降水 水文雨量站降水	实测总量 (mm)	预报总量 (mm)	洪量相对误差 (%)	实测洪峰 (m^3/s)	预报洪峰 (m^3/s)	洪峰相对误差(%)	峰现时间误差 (6h)	确定性系数
5km水文雨量站+Grapes	9.3997	7.7808	17.22	2220	1921.2	13.4	1	0.88
15km水文雨量站+Grapes	9.3997	7.174	23.67	2220	1702.3	23.3	1	0.78
水文雨量站	9.3997	3.7335	60.28	2220	717.6	67.6	3	-0.33

(Flooding height and volume; Initial time at 00UTC, 29th August, 2009. from Wang and Chen, 2010)

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Summary

GRAPES-SDM
沙尘模式

GRAPES-TYM
台风模式

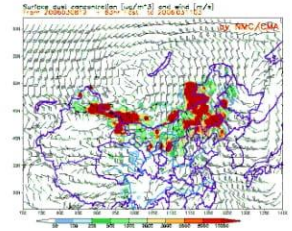
GRAPES-RAFS
快速同化预报系统

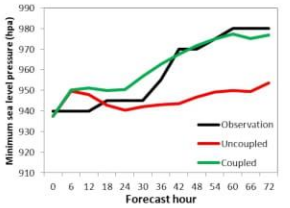
GRAPES air-sea Coupled model
海气耦合模式

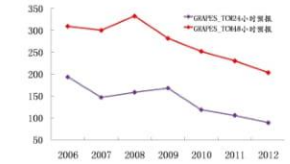
GRAPES-TCM
台风模式

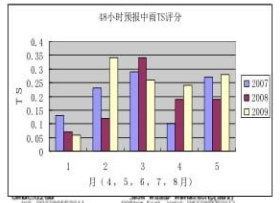
GRAPES-TMM
热带模式

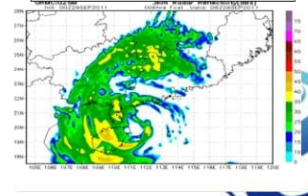
GRAPES-CHAF
快速同化循环











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Thank you!

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