CMA report

Xueshun Shen

WGNE28, Toulouse, Nov.2012

Martin … Oct.31

Outline

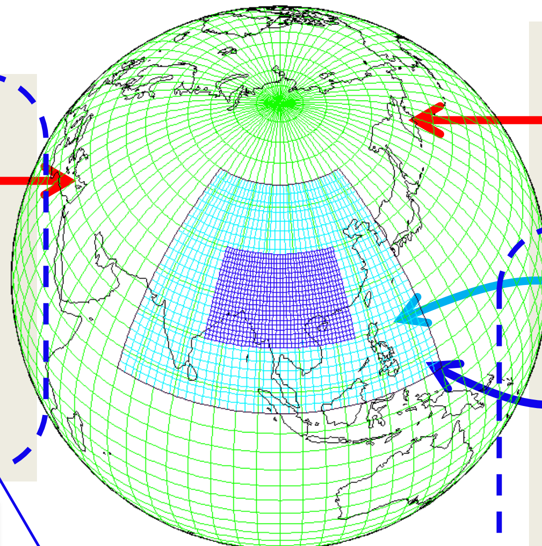
- Production systems
  - Current status
  - Upgrade activities in 2012
  - Next 2-year plan
- Research Issues
  - New dynamics
- Chinese satellites and plan
- New computer plan

CMA Operational NWP System

Introduced Spectral model

- GLB 10-day deterministic:
  - T639L60
- Global ensemble forecast:
  - T213L31, M15
- Global Typhoon forecast:
  - T213L31

Data assimilation: GSI



CMA-developed GRAPES

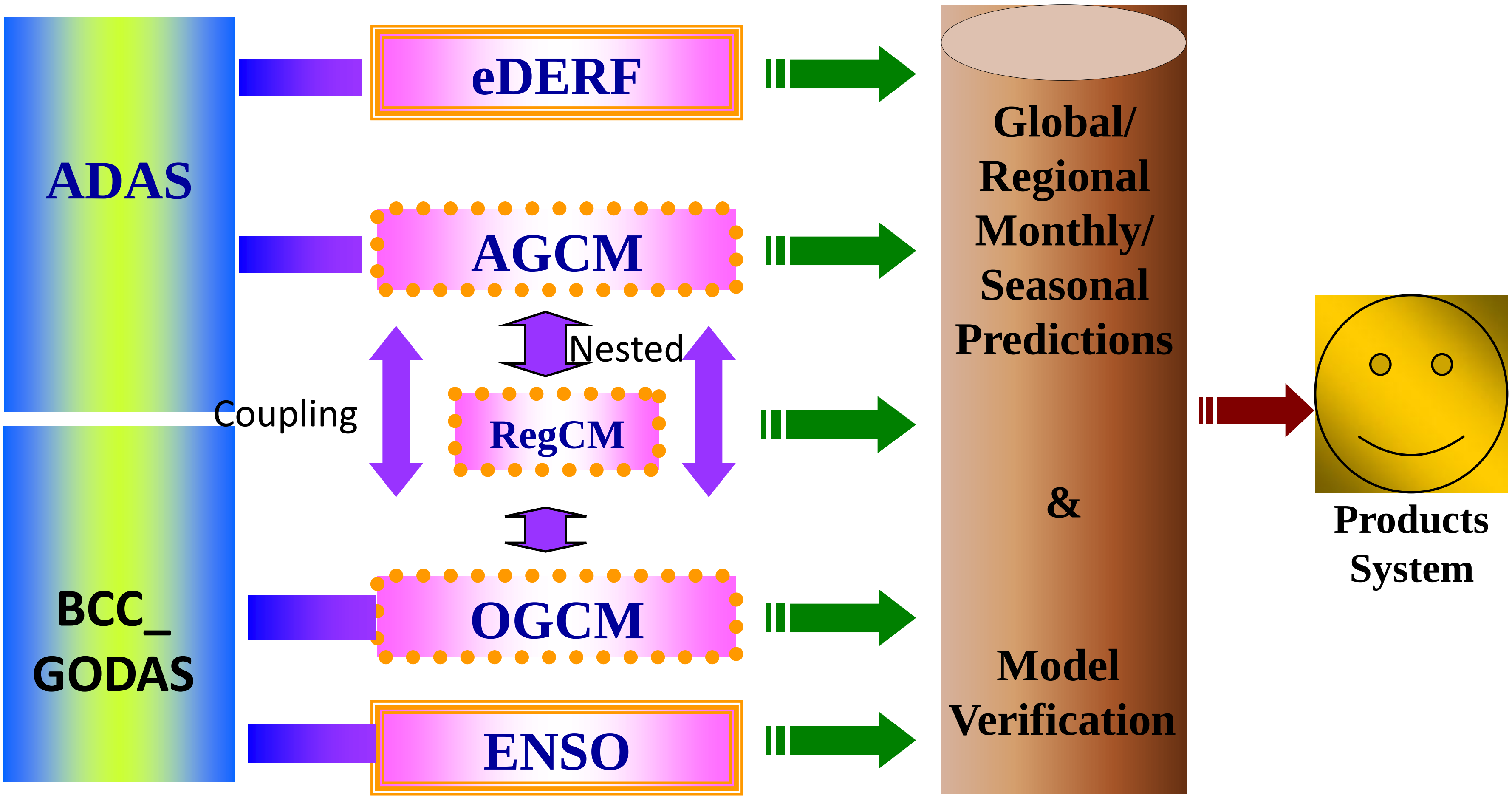
- GLB 10-day deterministic:
  - GRAPES_GFS 50km

  Parallel run vs. T639
- Meso-scale :
  - GRAPES_Meso 15km
- Typhoon forecast:
  - GRAPES_Meso 15km
- Rapid update:
  - GRAPES_RAFS 15km

Data assimilation: GRAPES_3DVAR

Main production systems

Monthly, seasonal and annual prediction system (DCMPS1.0)



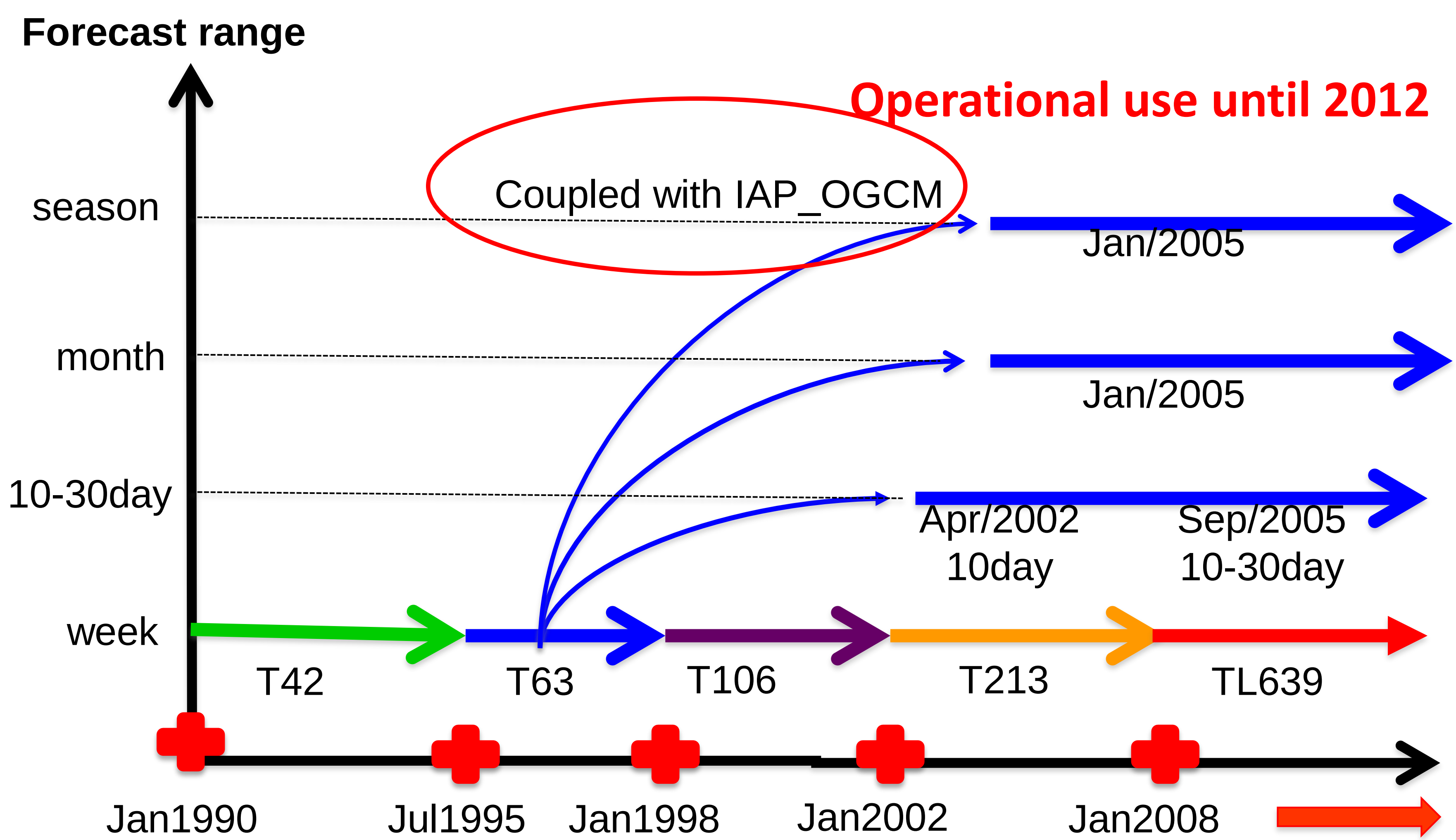
Model System
模式系统

ADAS: Atmosphere Data Assimilation System
ODAS: Ocean Data Assimilation System
AGCM: Atmosphere General Circulation Model(T63L16)
RegCM: Regional Climate Model
OGCM: Ocean General Circulation Model(GT63L30)
eDERF: Ensemble Dynamic Extent Range Forecast by AGCM
ENSO: Simplified ocean-atmosphere coupled model for ENSO Prediction

Prediction System
预测系统

Products System
产品系统

History of CMA monthly/seasonal prediction system



The satellite data used in T639L60 GSI

NOAA POES some channels:

- Operational with limitations
- Degraded performance
- Not operational

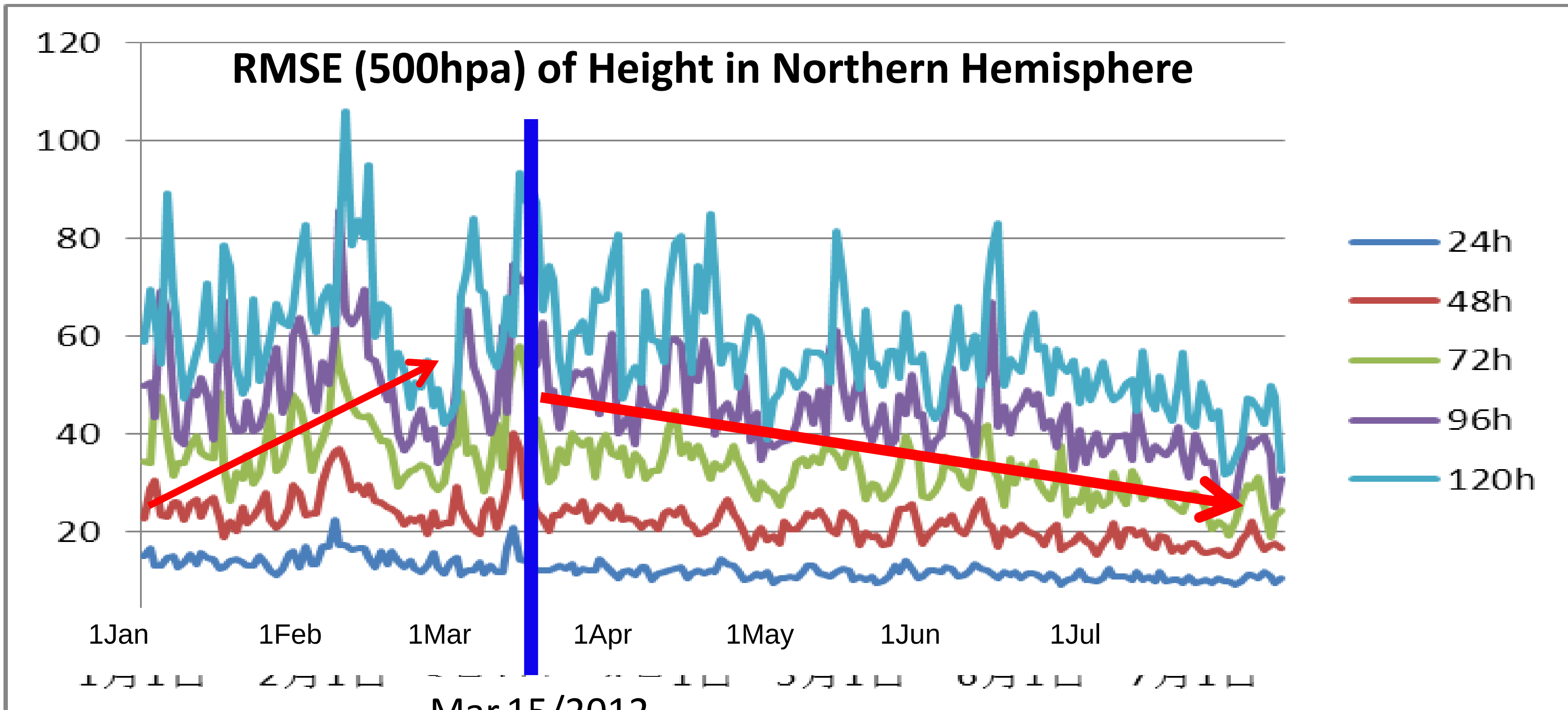
Need to add new satellite data into GSI to keep the model performance

http://www.oso.noaa.gov/poesstatus/

Active Spacecraft and Mission Status

Spacecraft	Mission Operational Status
METOP-A	AM Primary
NOAA 11	Decomissioned 16 June 2004.
NOAA 12	Decommissions 10 Aug 2007
NOAA 14	Decommission on 23 May 07
NOAA 15	AM Secondary
NOAA 16	PM Secondary
NOAA 17	AM Backup
NOAA 18	PM Secondary
NOAA 19	PM Primary

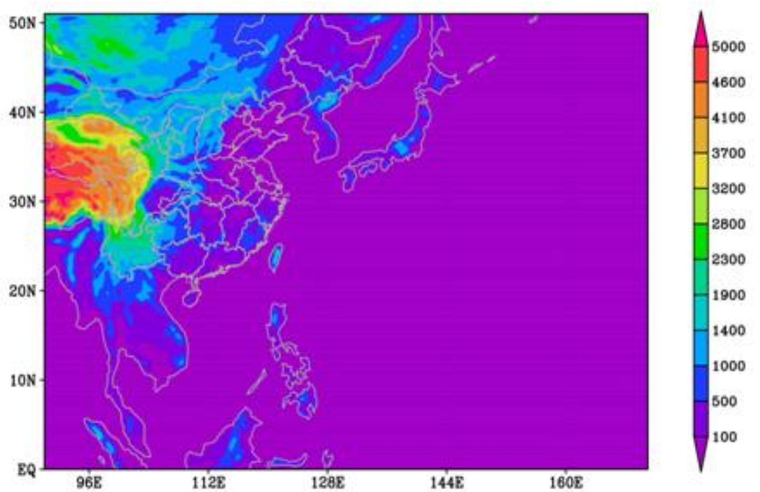
Added NOAA-18 radiance, to stabilize the performance of operational spectral model system



Before March 15 2012, the satellite data we used in NWP include the microwave radiances of NOAA-15/16/17. But the data quality of some instruments has declined, so NOAA-18 radiance data is added to T639.

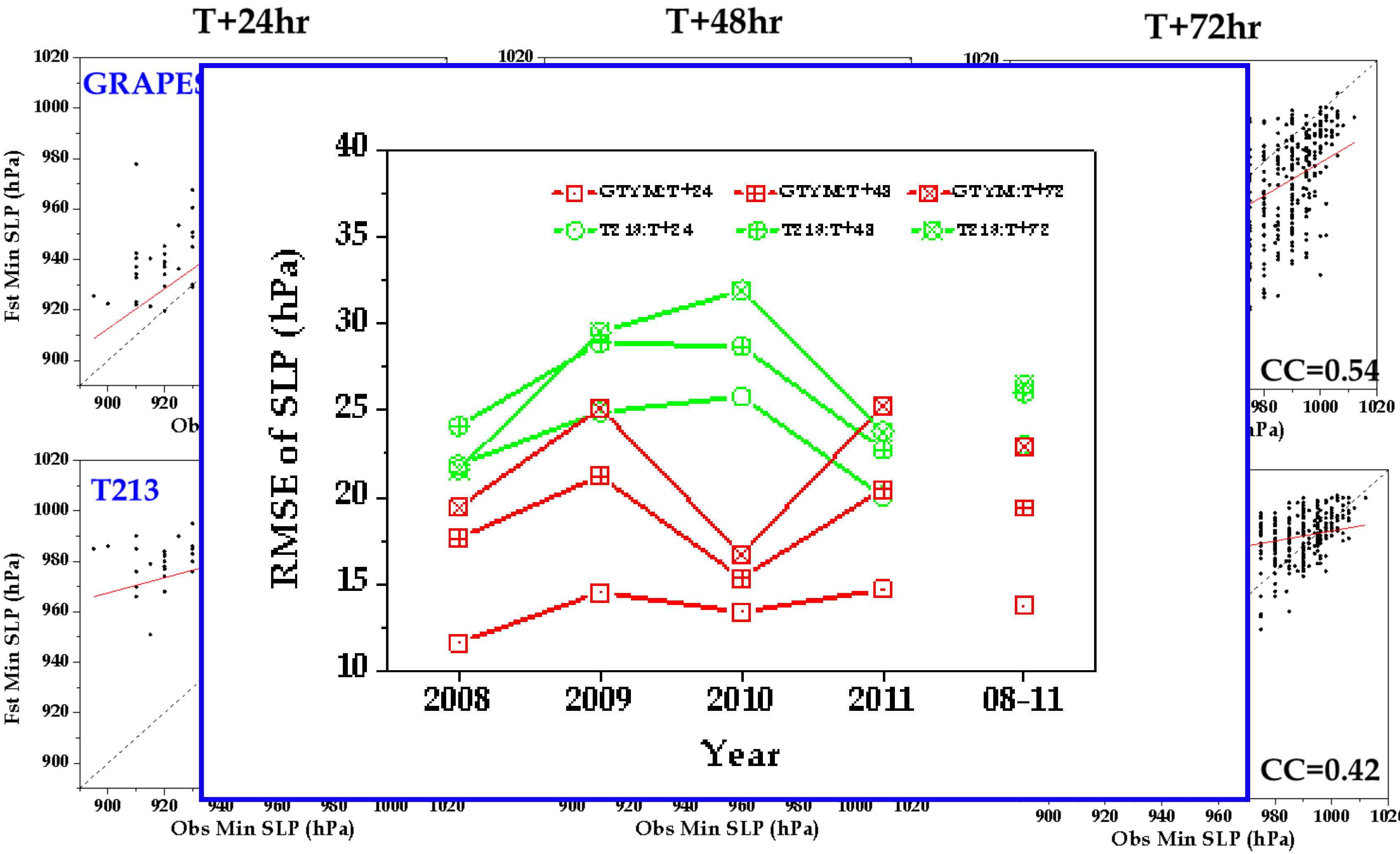
Newly implemented system GRAPES_TYM

- For **typhoon intensity forecast**
- Based on GRAPES_Meso
- 00UTC、12UTC: 72-hr forecast range
- Initial: vortex relocation & intensity adjustment

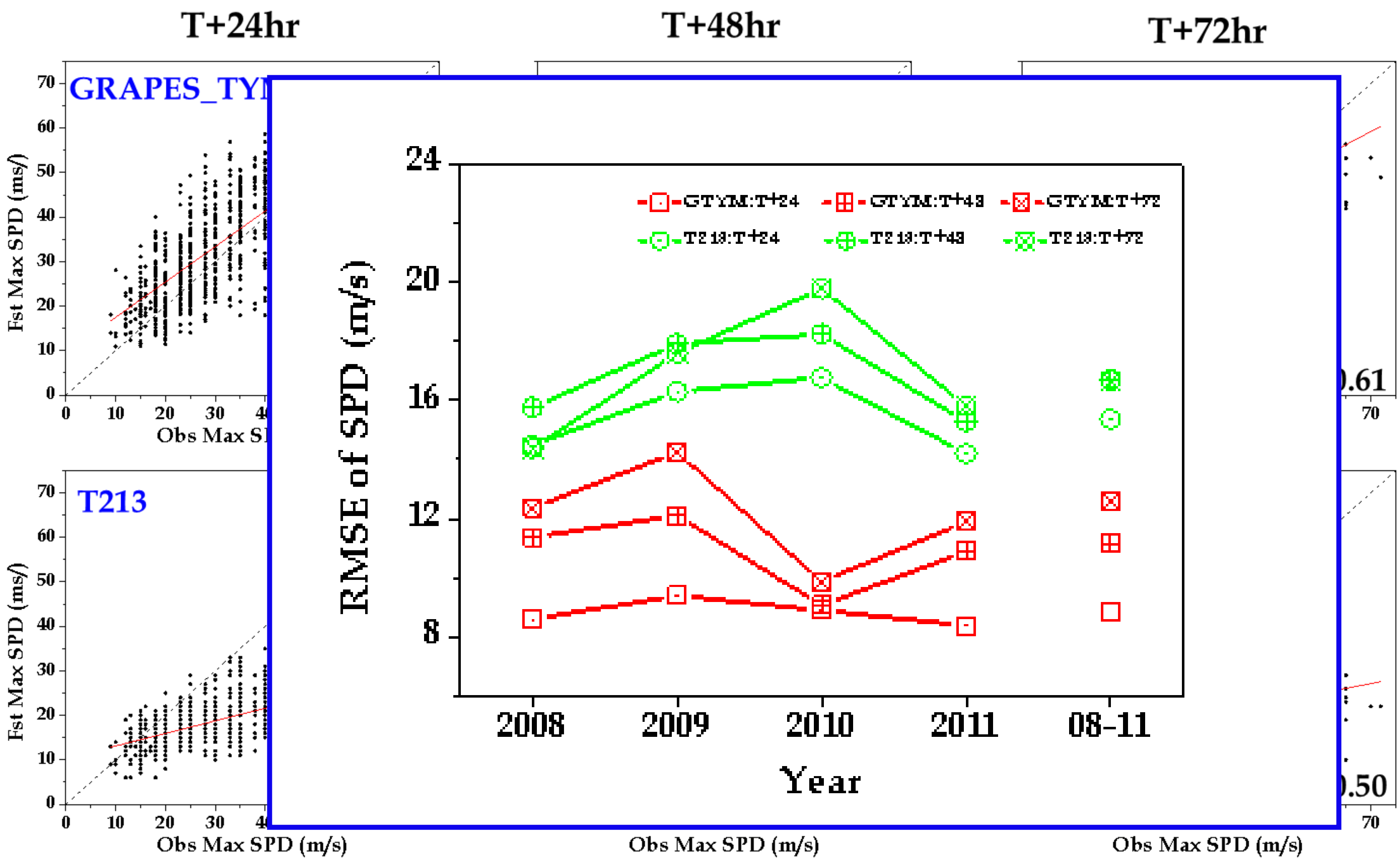


GRAPES_TYM(15km/L31)

MinSLP (Obs. Vs. FCST)



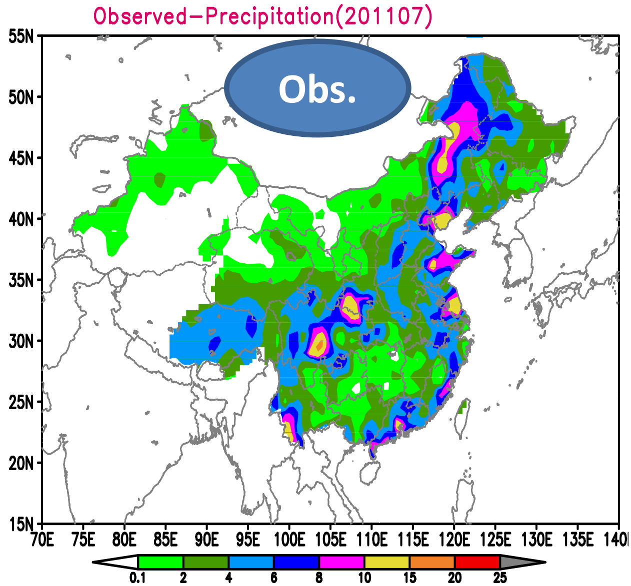
Max SPD (Obs. vs. FCST)



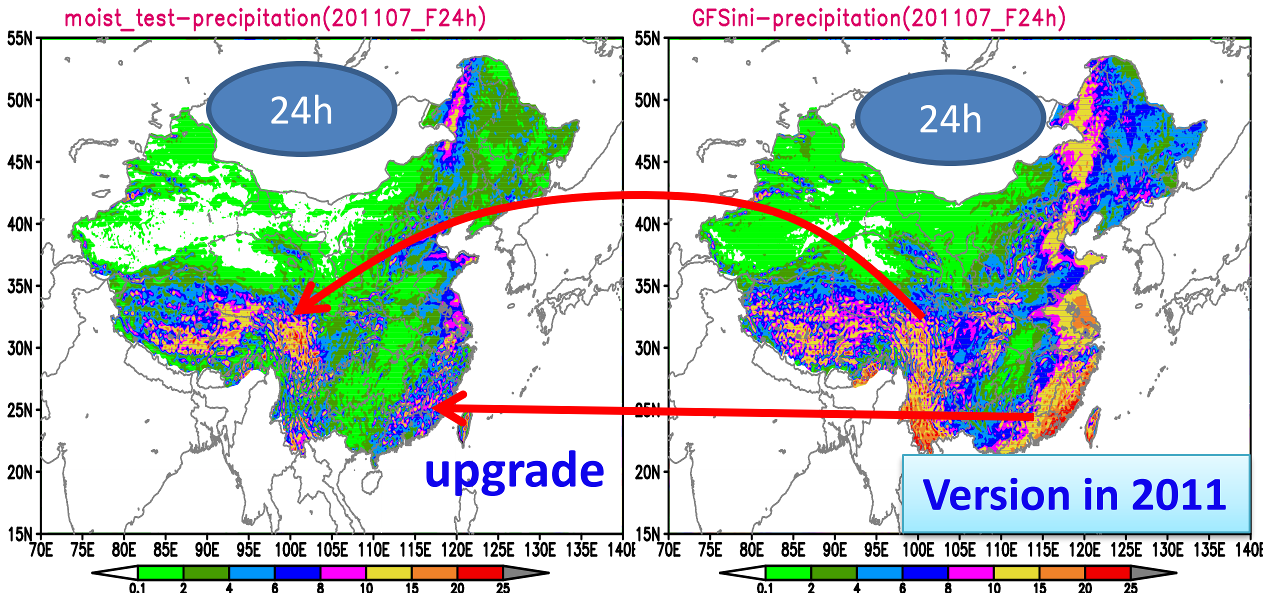
GRAPES_Meso upgrade

- Add 4th-order horizontal diffusion for stability
- Vertical coordinate from terrain-following Z to hybrid coordinate (Schar, 2002)
- Inclusion of thermal expansion effect in continuity equation
- Some bug fix in microphysics & land surface scheme
- Refinement of back ground error covariance in 3DVAR

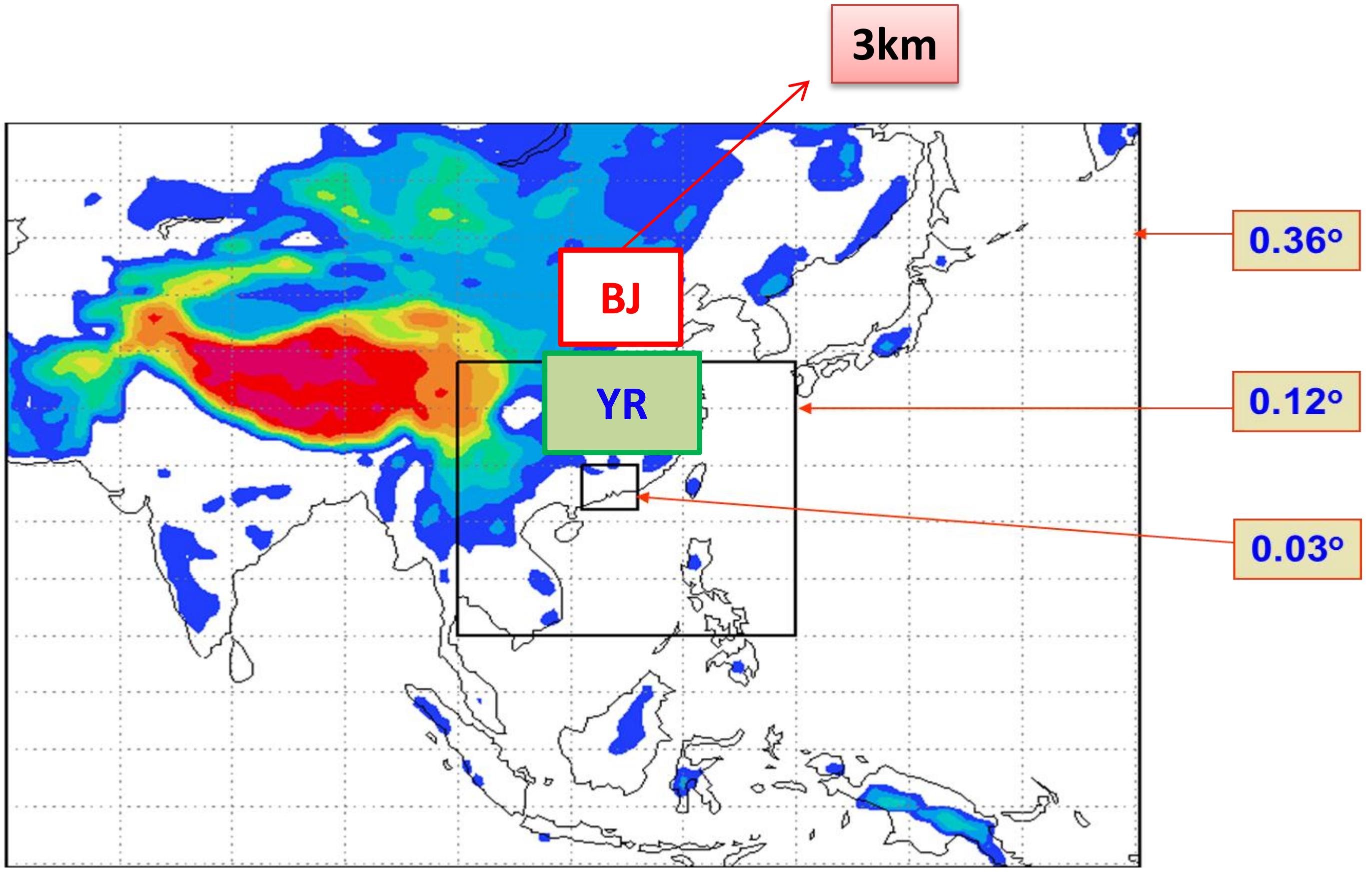
Improve the precip. forecast



1-month average 24-h precip.

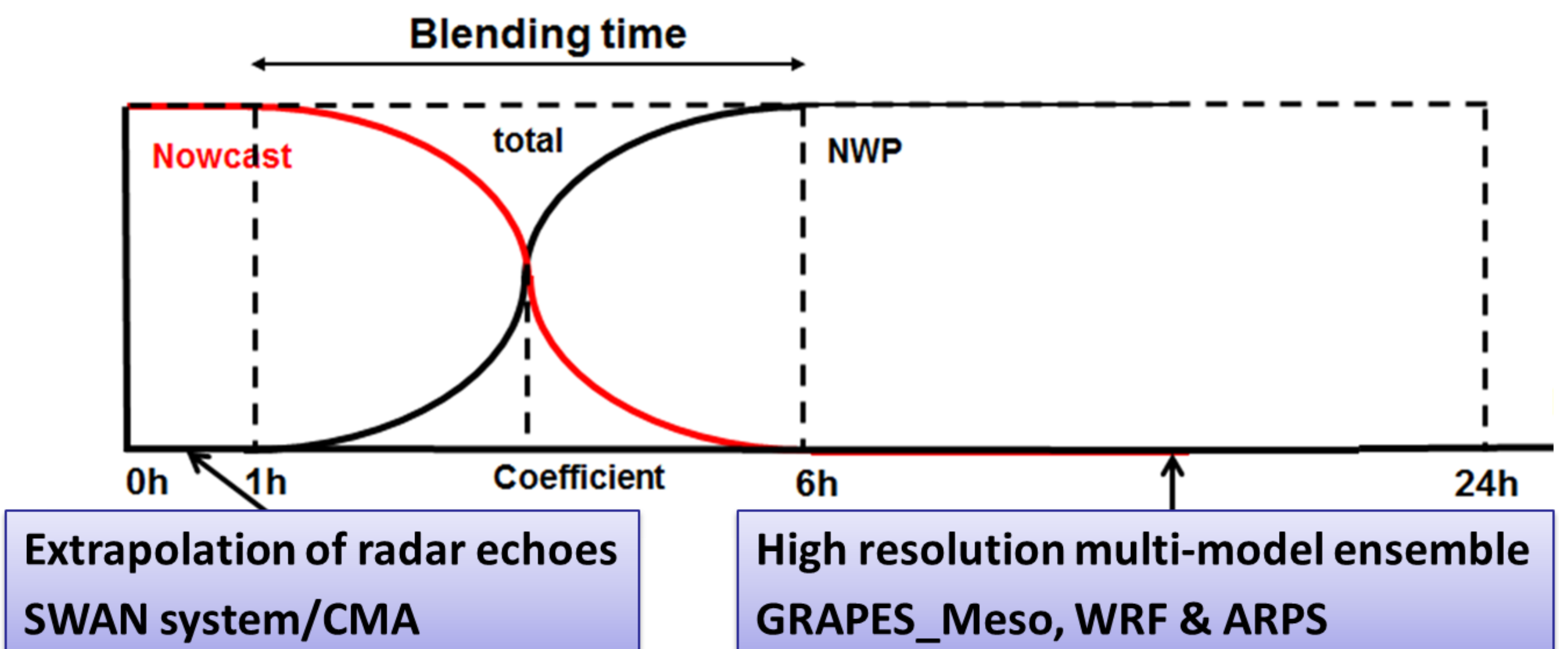


Two high resolution windows testing



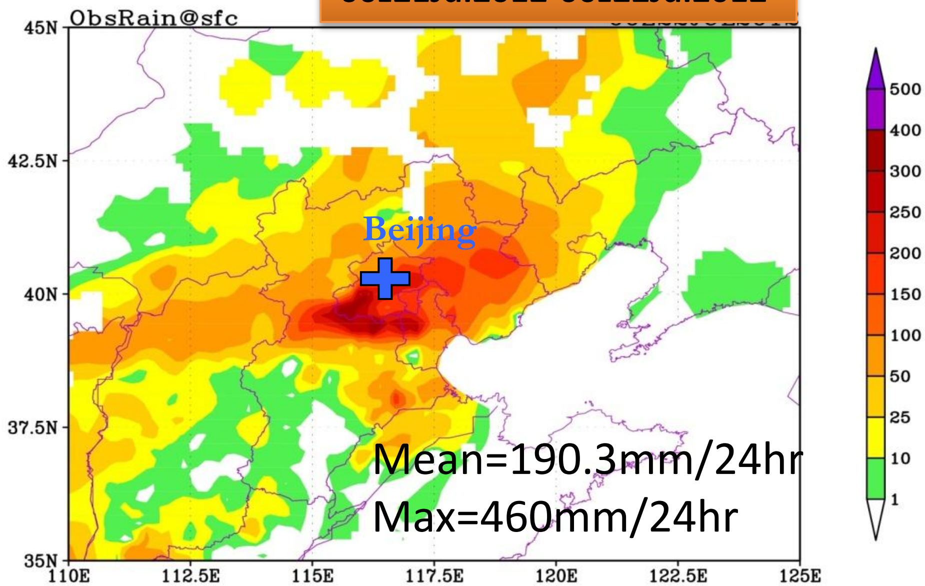
Plan in next two years

- 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.)



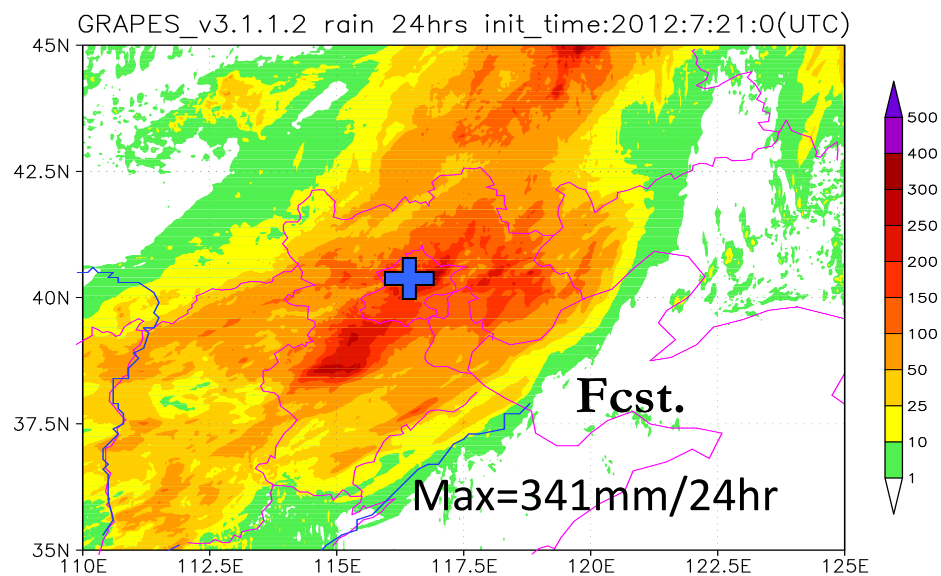
Heavy rainfall event on Jul.21/2012 Beijing

00z21Jul2012-00z22Jul2012

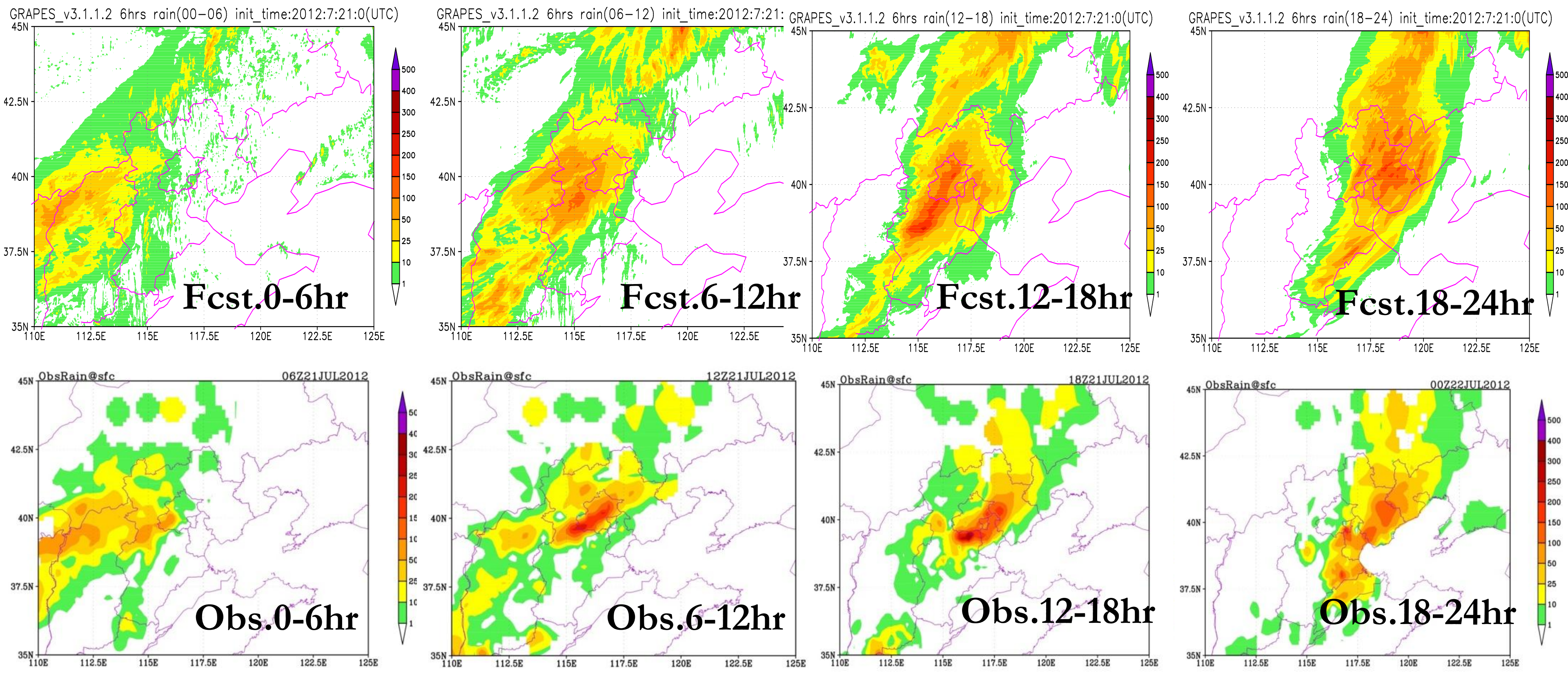


Initial: global analysis
BC: global forecast
Grid size:3km
Physics:
- microphysics: WSM6
- radiation: RRTM S&L
- pbl : MRF
- land surface : NOAH

24-hour accumulated rainfall



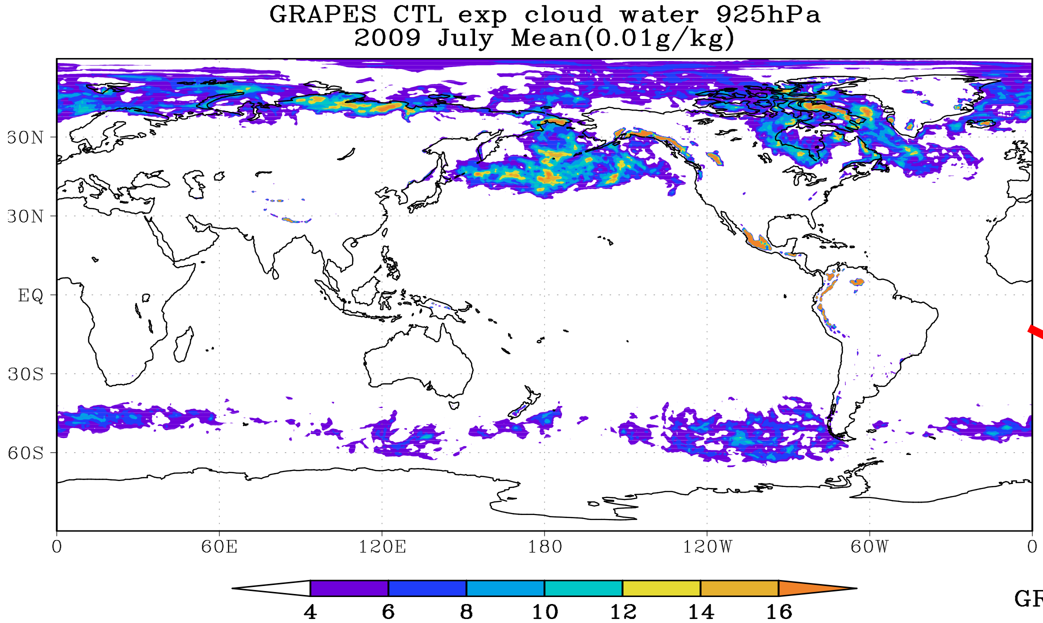
Comparison of precipitation every 6-hour between Obs. & Fcst.



GRAPES_GFS upgrade

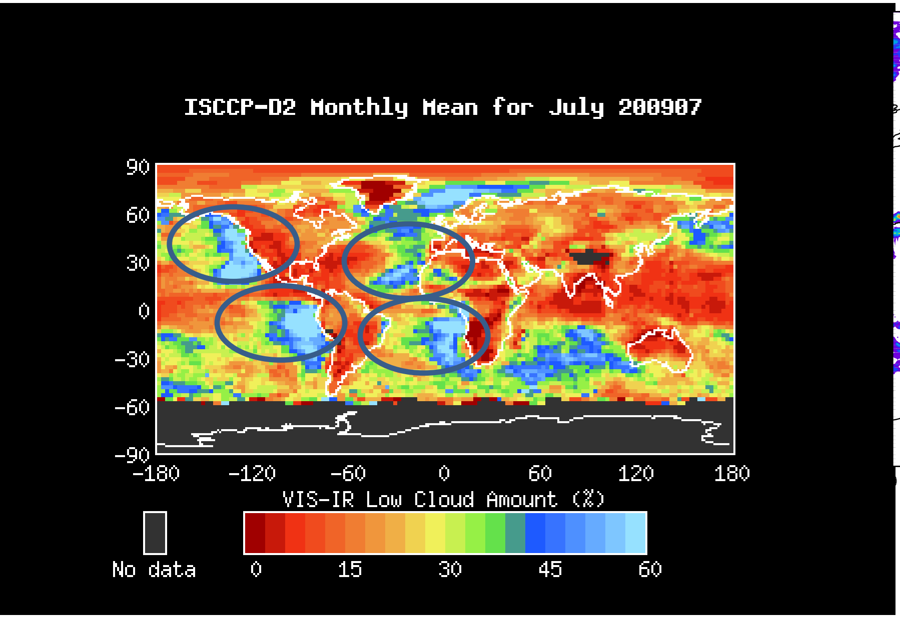
Model upgrade

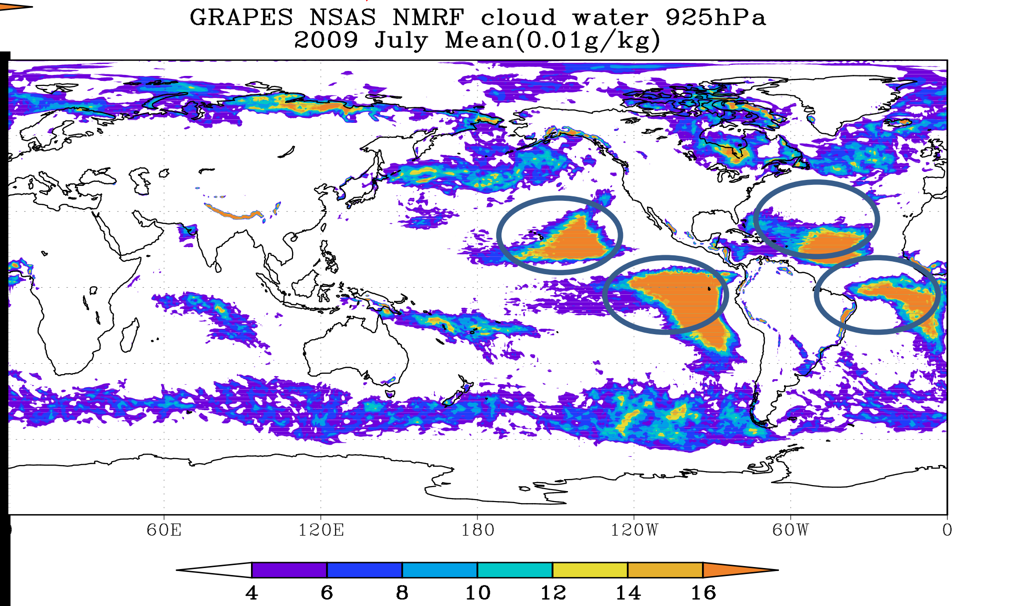
- **Conservative semi-Lagrangian scalar advection**
- **Revised simplified Arakawa-Schubert cumulus**
  - Maximum allowable cloud base mass flux defined based on local CFL (Jacob and Siebesma, 2003)
  - Introduce the organized entrainment (Betchtold et al., 2008)
  - Introduce convective momentum transport due to convection-induced pressure gradient force (Han & Pan, 2006)
- **Revised PBL**
  - Include stratocumulus-top driven turbulence mixing
  - Use local diffusion for the nighttime stable PBL rather than a surface layer stability based diffusion profile
- **Revised shallow convection**
  - From turbulence diffusion based scheme to mass flux based
  - Mass flux at cloud base is given as a function of the surface buoyancy flux (Grant, 2001)
  - Entrainment rate based on Siebesma et al.2003
- **Microphysics + macro-scale cloud + prognostic cloud cover**



Revised SAS, shallow convection & PBL

Improve the stratocumulus clouds
But overestimated

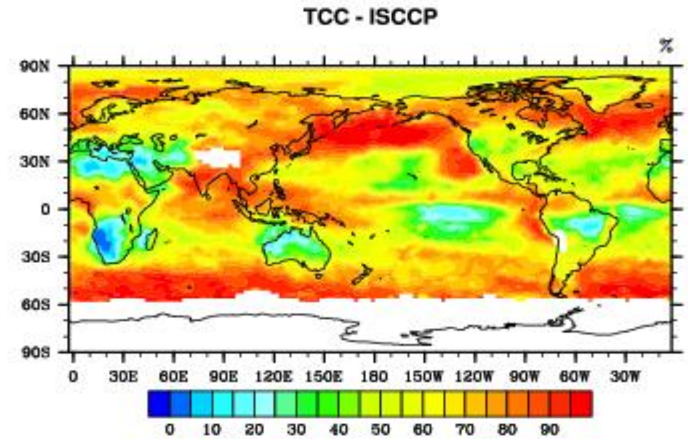


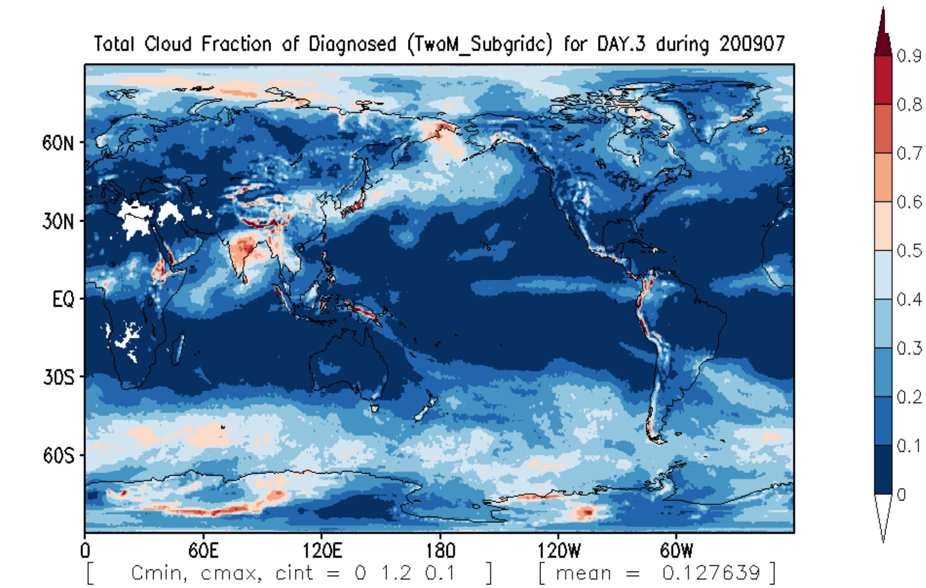


ISCCP low cloud cover
July/2009

Microphysics + macro-scale cloud + prognostic cloud cover

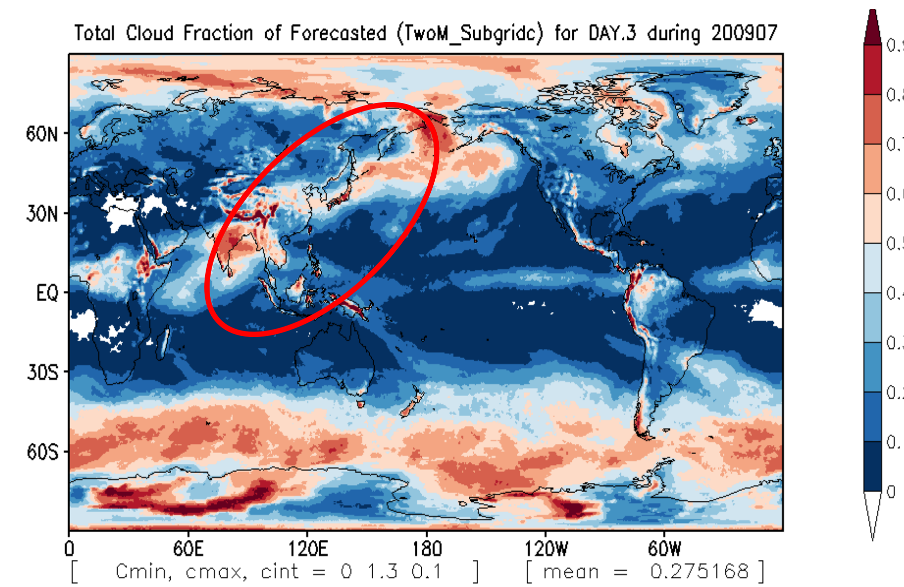
Better Total Cloud Cover
Over Indian monsoon region,
Warm pool, East Asia & North Pacific





Diagnostic cloud scheme

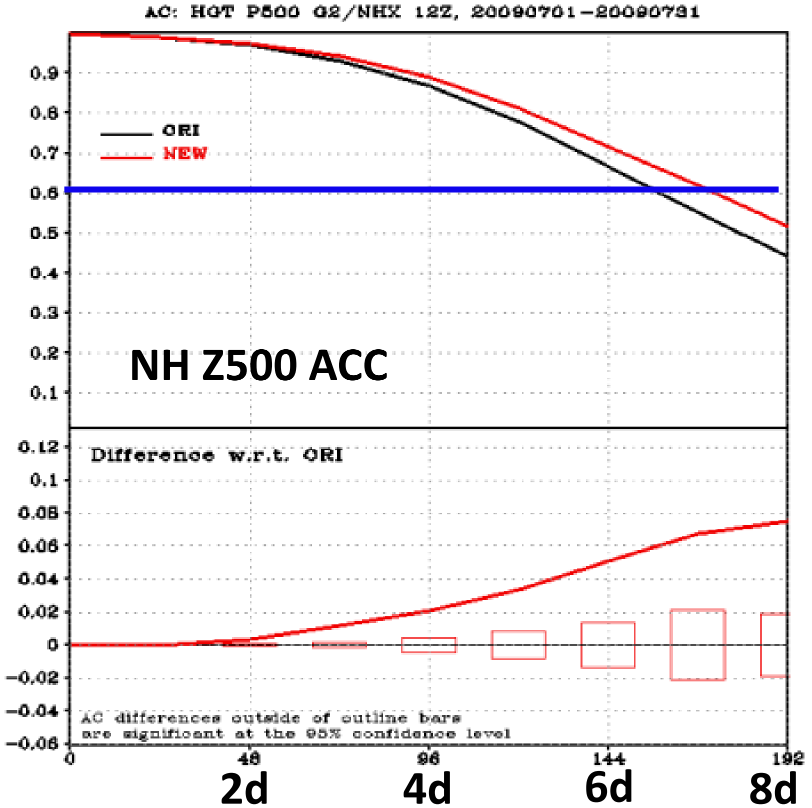
GrADS: COLA/IGES

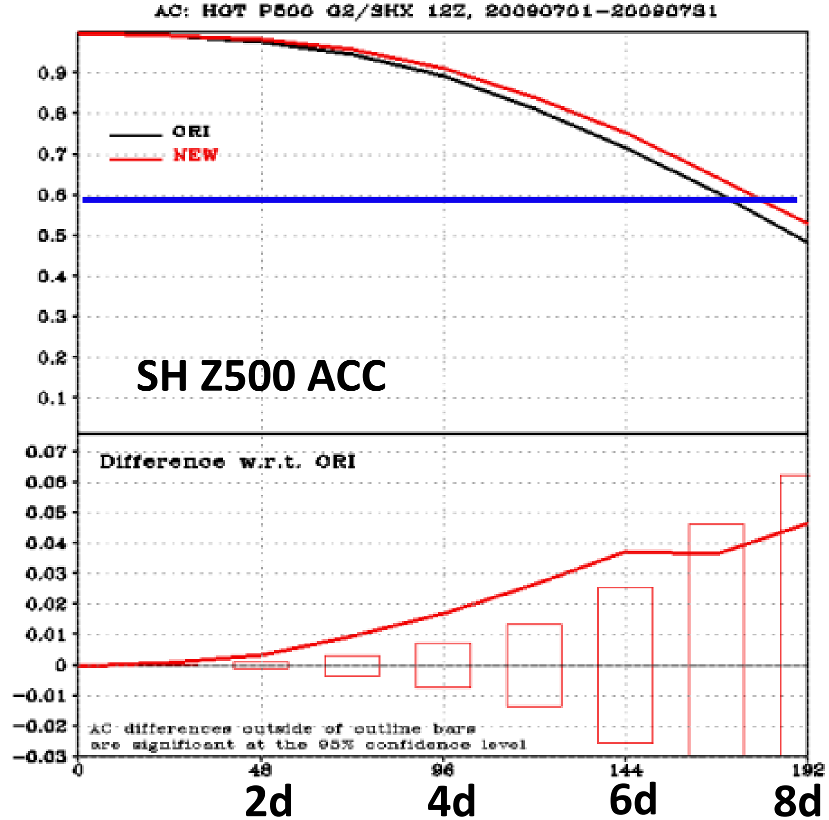


Prognostic cloud scheme

GrADS: COLA/IGES

Monthly average, 3-day forecast


AC: HGT P500 G2/NHX 12Z, 20090701-20090731
ORI
NEW
NH Z500 ACC
Difference w.r.t. ORI
AC differences outside of outline bars
are significant at the 95% confidence level
0
48
96
144
192
2d
4d
6d
8d


AC: HGT P500 G2/SHX 12Z, 20090701-20090731
ORI
NEW
SH Z500 ACC
Difference w.r.t. ORI
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0
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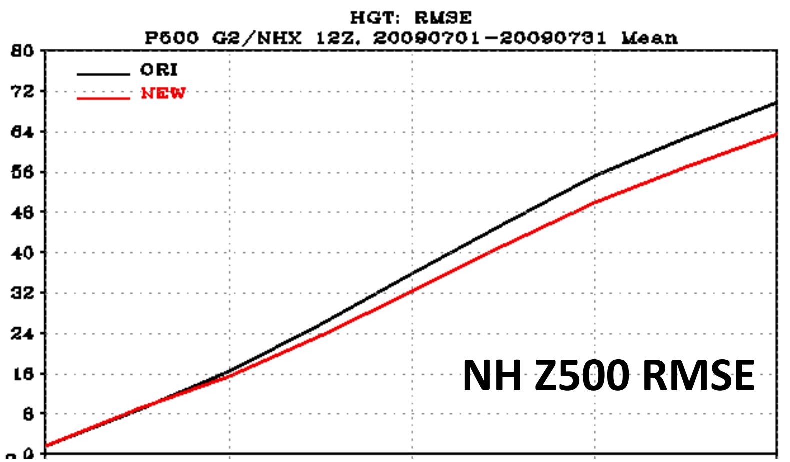
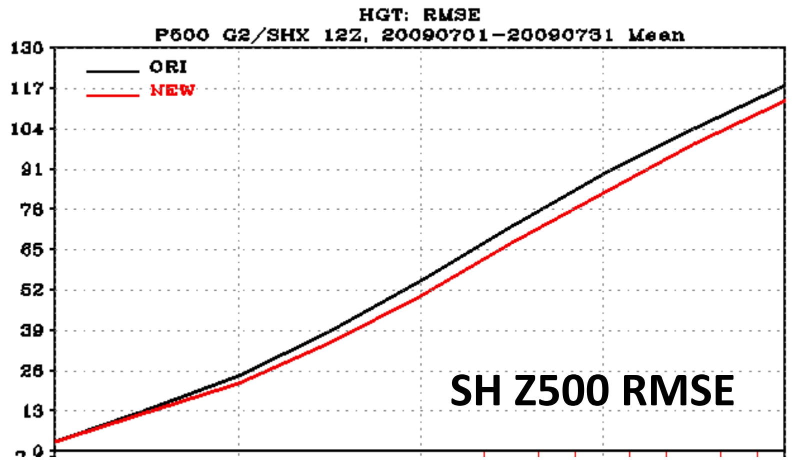
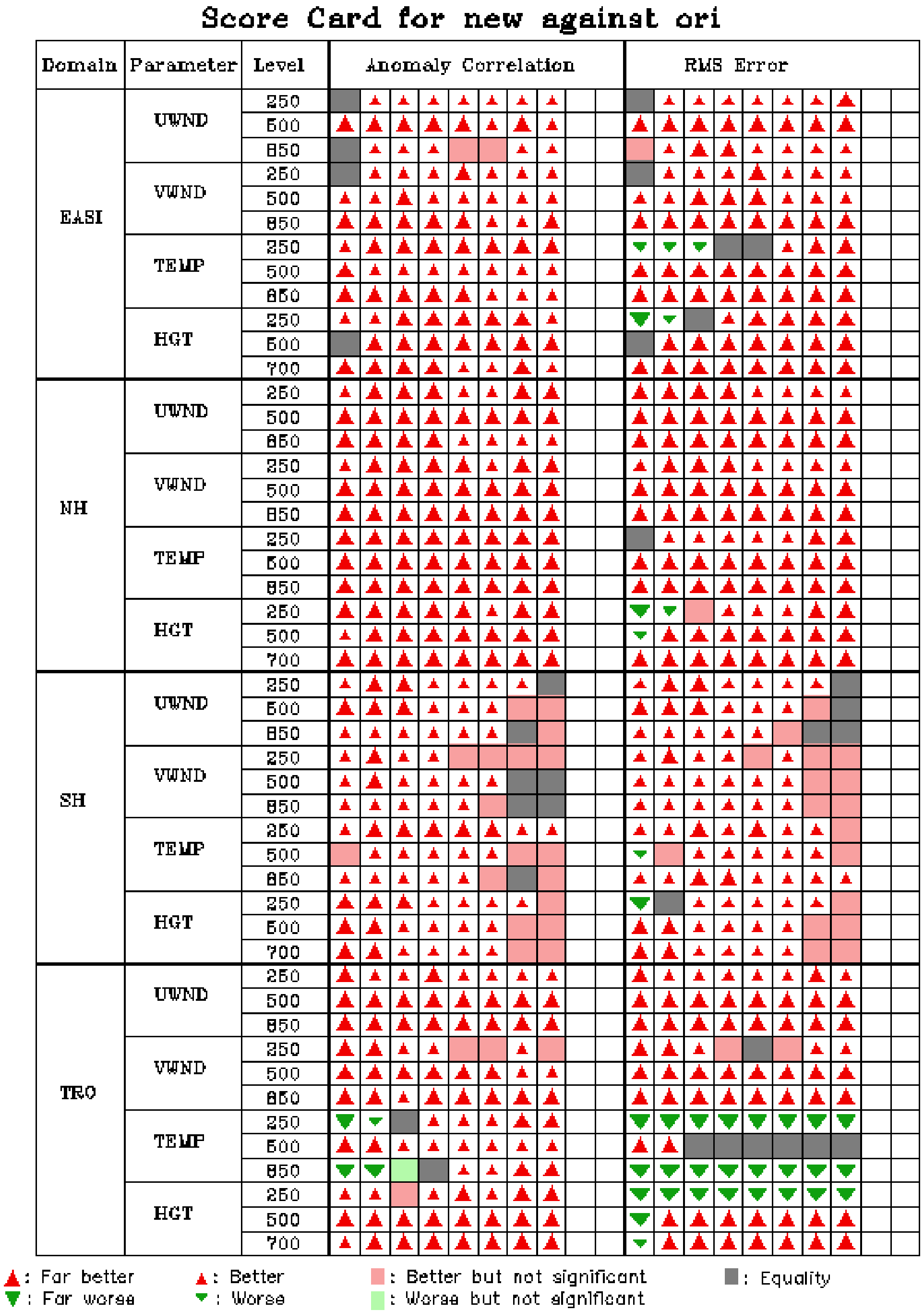

HGT: RMSE
P500 G2/NHX 12Z, 20090701-20090731 Mean
ORI
NEW
NH Z500 RMSE


HGT: RMSE
P500 G2/SHX 12Z, 20090701-20090731 Mean
ORI
NEW
SH Z500 RMSE



Symbol legend:
(d: score difference s: confidence interval width)
Far better : d/s > 3
Better : 3 >= d/s >= 1
Better but not significant : 1 > d/s >= 0.5
Equality : 0.5 > d/s > -0.5
Worse but not significant : -0.5 >= d/s > -1
Worse : -1 >= d/s >= -3
Far worse : d/s < -3
Verification Time : 1-10 days (every grid)

GRAPES_GFS upgrade

GRAPES 3DVAR upgrade

- Arakawa-A & pressure level to model grid space analysis
- RTTOV: RTTOV7 → RTTOV10
- Statistical method for balance relationship
- Add NOAA-19
- Revised bias correction of **FY-3/MWTS**
- Revised Height adjustment by 1DVAR for **FY-2E AMV**

Satellite data in GRAPES

✓ *ATOVS microwave* (NOAA 15 16)		radiances
✓ NOAA-18	microwave	radiance
✓ Metop	microwave	radiance
✓ GPS/RO		refraction
✓ 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 (black) — Will be used (blue) — Research (red)

Next 2-year operational implementation plan

- **GRAPES_GFS** : medium-range global forecast
  - GRAPES_Global 50km L36 with model top at 10 hPa
  - GRAPES_3DVAR at 1.125 degree
  - 6-hourly cycle
  - 240 hour forecast (00,12UTC)
  - Assimilated Obs.
    - GTS conventional data
    - NOAA15、16、18、19
    - METOP-2 amsu
    - COSMIC Refraction
    - AIRS
    - FY-3 radiance
    - METEOSAT-9 & MTSAT AMV
    - MODIS polar AMV

Primary task

Plan for T639-based Global Typhoon forecast

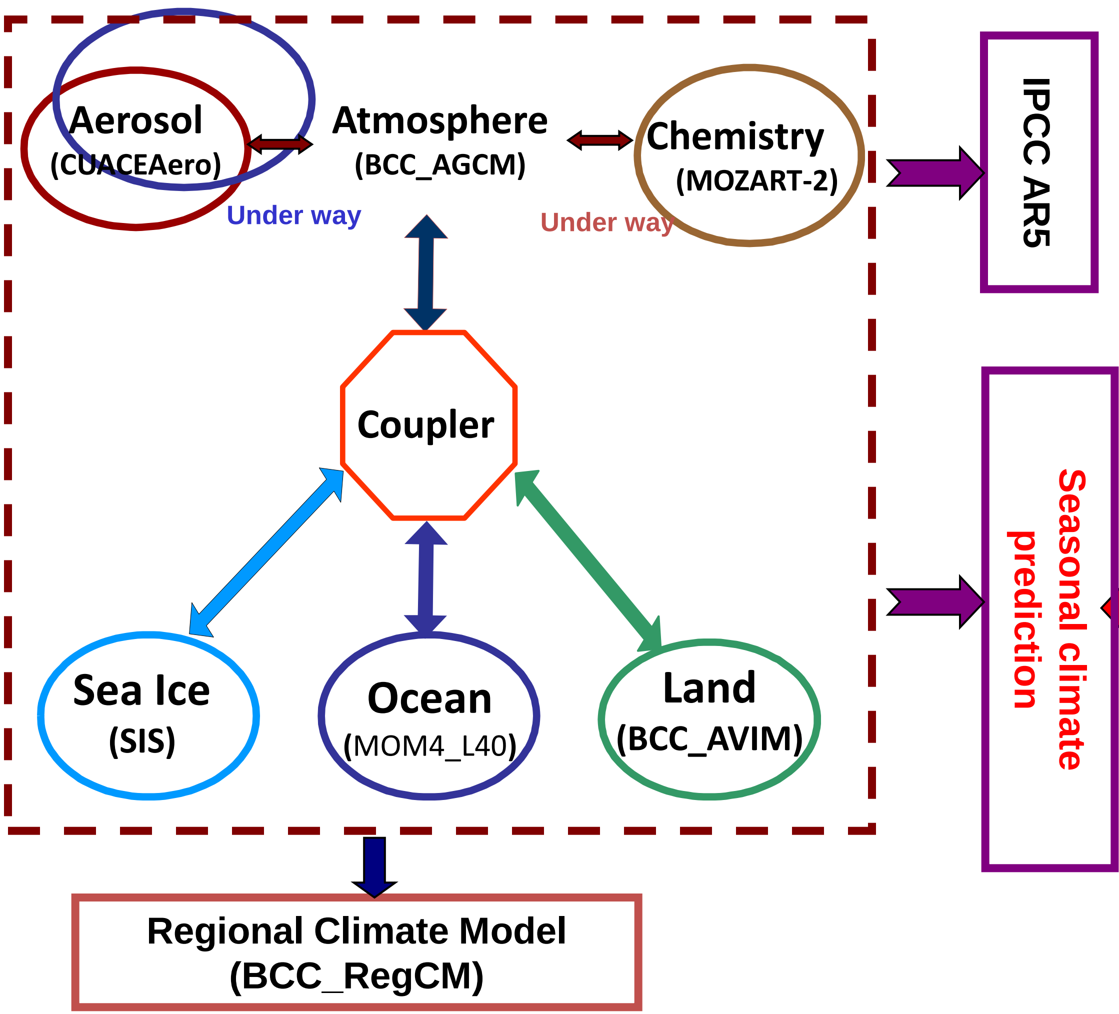
- Inserting Vortex → Bogus Data Assimilation
- Operation on the next generation HPC in 2013

Plan for T639-based Global EPS

- Perturbation method
  - BGM based Initial perturbation method
  - Stochastic physics
- Operation on the next generation HPC in 2013

2013: new operational system for long-range prediction

Beijing Climate Center Climate System Model (BCC_CSM)



BCC_AGCM2.2 (T106L26)

Originated from CAM3， Developed by BCC.
Model Dynamics: Wu et al.(2008, *J.Atmos.Sci.*)
Model Physics：
Wu et al. (2010, *Climate Dynamics*)
Wu, 2011, *Climate Dynamics*

BCC_AVIM1 (T106)

Developed by BCC.
Coupled with the dynamic vegetation and land carbon cycle processes.

MOM4_L40v2 (1/3~1°)

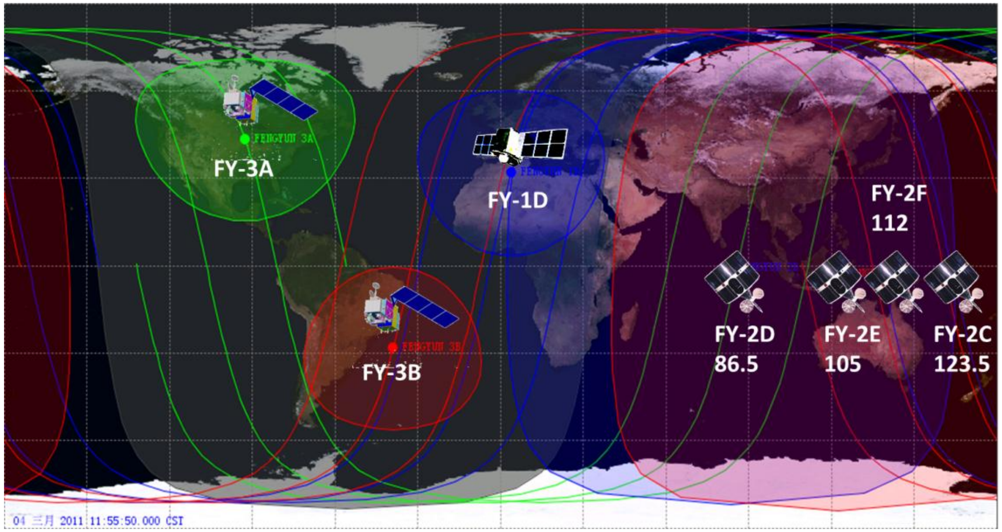
Developed by GFDL， Modified by BCC.
A carbon cycle module (from OCMIP2) with simple biogeochemical processes was introduced.

SIS (gx1v1)

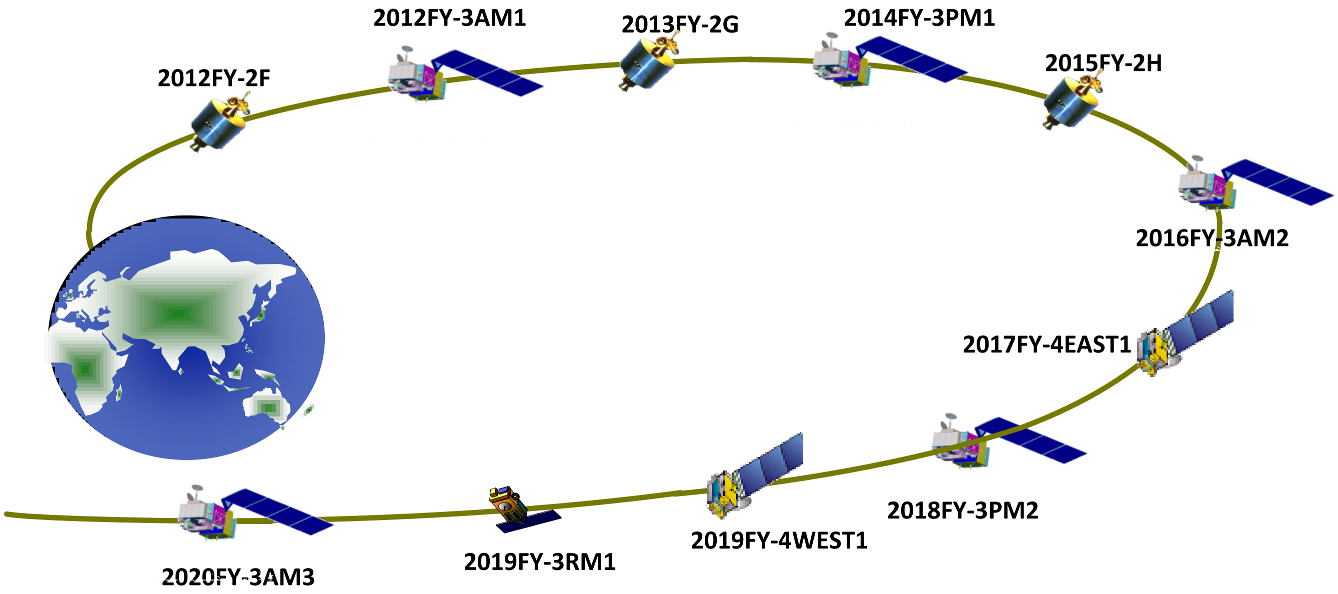
Developed by GFDL.

Chinese Satellites

On Orbit Satellite



Future FY Series



Tentative Schedule for Future FY Series

Schedule	GEO.		LEO.
	FY-2	FY-4	FY-3
2011			
2012	Operational		Operational (A.M. Orbit)
2013	Operational		
2014			Operational (P.M. Orbit)
2015	Operational		
2016			Operational (A.M. Orbit)
2017		Operational (Optical SAT)	
2018			Operational (P.M. Orbit)
2019		Operational (Optical SAT)	Operational (Rain Fall Massion)
2020			Operational (A.M. Orbit)

FY-3A/B follow-on

FY-3 OPERATIONAL SATELLITE INSTRUMENTS	FY-3C	FY-3D	FY-3E	FY-3F
MERSI – Medium Resolution Spectral Imager (I, II)	√(I)	√(II)	√(II)	√(II)
MWTS – Microwave Temperature Sounder (II)	√	√	√	√
MWHS – Microwave Humidity Sounder (II)	√	√	√	√
MWRI – Microwave Radiation Imager	√	√		√
WindRAD - Wind Radar			√	
GAS - Greenhouse Gases Absorption Spectromete		√		√
HIRAS – Hyperspectral Infrared Atmospheric Sounder		√	√	√
OMS – Ozone Mapping Spectrometer			√	
GNOS – GNSS Occultation Sounder	√	√	√	√
ERM – Earth Radiation Measurement (I, II)	√(I)		√(II)	
SIM – Solar irritation Monitor (I, II)	√(I)		√(II)	
SES – Space Environment Suite	√	√	√	√
IRAS – Infrared Atmospheric Sounder	√			
VIRR – visible and Infrared Radiometer	√			
SBUS – Solar Backscattered Ultraviolet Sounder	√			
TOU – Total Ozone Unit	√			

FY-3C/D/E/F Payload Configuration

FY-3 series is expected to last its measurements at least 15 years with additional four satellites. There are **16 improved or new instruments** will be configured from FY-3C to FY-3F in the schedule.

New Instruments

- **HIRAS** (Hyperspectral Infrared Atmospheric Sounder) is an IASI/Metop-like instrument to improve the measured temperature and moisture profile instead of the IRAS
- **OMS** (Ozone Mapping Spectrometer) is a SCIAMACHY/Envisat-like instrument to detect the ozone and the other atmospheric chemical species as well instead of the suite of TOU and SBUS. The total column content and the profile of trace gases can be retrieved from the nadir view and limb view separatively.
- **WindRAD** (Wind Radar) will measure the sea wind
- **GAS** (Greenhouse Gases Absorption Spectrometer) will measure the CO2 and CH4 globally
- **GNOS** (GNSS Occultation Sounder) will improve the measured temperature and moisture profile at the upper atmosphere

Research Activities

New dynamic core

Based on multi-moment constrained finite volume method

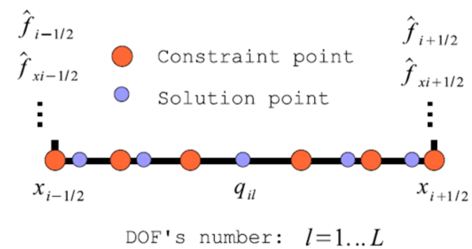
Multi-moment constrained finite volume method

Definition of multi-moments: the line-integrated average value (LIA moment), the point value (PV moment) and the derivative value (DV moment)

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

$$q_{cp}(t) \equiv q(x_{cp},t),$$

$$\partial_x^k q_{cp}(t) \equiv \frac{\partial^k}{\partial x^k} q(x_{cp},t); \text{ with } k=1,2,\cdots$$



Reconstruction:

A Lagrange interpolation polynomial of degree (L-1) is constructed as

$$\Psi\left(\phi : x\right) = \sum_{l=1}^{L}\left(\mathcal{B}_l \phi_l\right)$$

where $\mathcal{B}_l = \prod_{p=1,p\neq l}^{L} \frac{(x-x_p)}{(x_l-x_p)}$

DOFs and multi-moment constraints are connected via the reconstruction polynomial

$$\begin{bmatrix} \phi_{i1} \\ \phi_{i2} \\ \cdot \\ \cdot \\ \cdot \\ \phi_{iL} \end{bmatrix} = M \begin{bmatrix} \overline{\phi}_i^{(x)} \\ \phi_{icp_1} \\ \cdot \\ (\partial_x \phi)_{icp_n} \\ \cdot \\ \cdot \end{bmatrix}$$

- X. L. Li, C. G. Chen, X. S. Shen and F. Xiao, 2012: A multi-moment constrained finite volume model for non-hydrostatic atmospheric dynamics, Mon. Wea. Rev., in revision.
- Li, X. L., X. S. Shen, X. D. Peng, F. Xiao, Z. R. Zhuang, and C. G. Chen, 2012: Fourth order transport model on yin-yang grid by multi-moment constrained finite volume scheme, Procedia Computer Science, 9, 1004-1013.

Governing equations with the effects of topography in the curviliear Cartesian system

Reference state:

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

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

local hydrostatic balance

$$\frac{\partial \bar{p}}{\partial z} = -\bar{\rho} g$$

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

Height-based terrain following coordinate

$$z(\zeta) = \zeta + z_s(x)\frac{\sinh[(z_T - \zeta)/s]}{\sinh(z_T/s)}$$

Governing equations:

$$\frac{\partial \rho'}{\partial t} + \frac{1}{\sqrt{G}}\left[\frac{\partial(\sqrt{G}\rho u)}{\partial x} + \frac{\partial(\sqrt{G}\rho \tilde{w})}{\partial \zeta}\right] = 0,$$

$$\frac{\partial(\rho u)}{\partial t} + \frac{1}{\sqrt{G}}\left[\frac{\partial(\sqrt{G}\rho u^2 + \sqrt{G}p')}{\partial x} + \frac{\partial(\sqrt{G}\rho u\tilde{w} + \sqrt{G}G^{13}p')}{\partial \zeta}\right] = 0,$$

$$\frac{\partial(\rho w)}{\partial t} + \frac{1}{\sqrt{G}}\left[\frac{\partial(\sqrt{G}\rho w u)}{\partial x} + \frac{\partial(\sqrt{G}\rho w\tilde{w} + p')}{\partial \zeta}\right] = -\rho' g,$$

$$\frac{\partial(\rho\theta)'}{\partial t} + \frac{1}{\sqrt{G}}\left[\frac{\partial(\sqrt{G}\rho\theta u)}{\partial x} + \frac{\partial(\sqrt{G}\rho\theta\tilde{w})}{\partial \zeta}\right] = 0,$$

where the metric term $\sqrt{G} = \frac{\partial z}{\partial \zeta}$ $\quad G^{13} = \frac{\partial \zeta}{\partial x}$ $\quad \tilde{w} = \frac{d\zeta}{dt}$

Spatial discretization: multi-moment constrained finite volume method

$$\frac{d}{dt}(q_{lm}) = \sum_{\beta=1}^{5} \mathcal{M}^{(x)}_{4l\beta}\mathcal{F}_{4\beta m} + \sum_{\beta=1}^{5} \mathcal{M}^{(\zeta)}_{4m\beta}\mathcal{G}_{4l\beta} + \mathcal{S}(q_{lm}), \text{ for } l, m = 1, 2, 3, 4.$$

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

$$\mathrm{M}_4^{(\zeta)} = \begin{bmatrix} 0 & 0 & -1 & 0 & 0 \\ \frac{4}{3\Delta \zeta_j} & -\frac{4}{3\Delta \zeta_j} & \frac{4}{27} & \frac{5}{27} & \frac{4\Delta \zeta_j}{27} \\ \frac{4}{3\Delta \zeta_j} & -\frac{4}{3\Delta \zeta_j} & \frac{4}{27} & \frac{5}{27} & -\frac{4\Delta \zeta_j}{27} \\ 0 & 0 & 0 & -1 & 0 \end{bmatrix} \text{ and } \mathbf{G}_4^{(\zeta)} = \begin{bmatrix} \hat{g}_{l1} \\ \hat{g}_{l4} \\ \left(\partial_\zeta \hat{g}\right)_{l1} \\ \left(\partial_\zeta \hat{g}\right)_{l4} \\ \left(\partial_\zeta^2 \hat{g}\right)_{cm} \end{bmatrix}$$

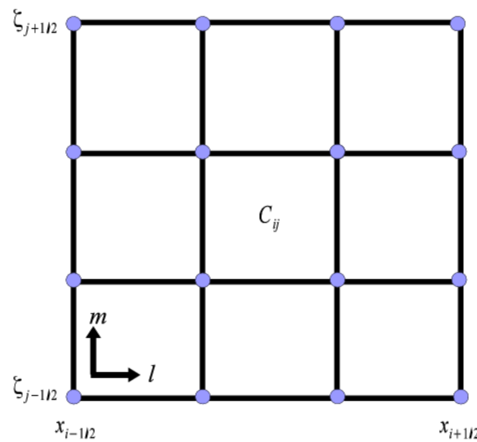
Time stepping: 3rd TVD Runge-Kutta method

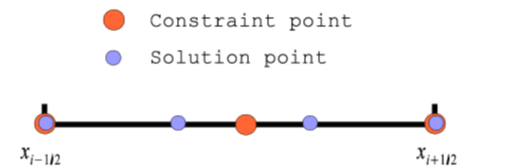
$$\frac{dq_{lm}}{dt} = \mathcal{L}\left(q_{lm}\right)$$

$$q_{lm}^{(1)} = q_{lm}^{n} + \Delta t \mathcal{L}(q_{lm}^{n})$$

$$q_{lm}^{(2)} = \frac{3}{4}q_{lm}^{n} + \frac{1}{4}q_{lm}^{(1)} + \frac{1}{4}\Delta t \mathcal{L}(q_{lm}^{(1)})$$

$$q_{lm}^{n+1} = \frac{1}{3}q_{lm}^{n} + \frac{2}{3}q_{lm}^{(2)} + \frac{2}{3}\Delta t \mathcal{L}(q_{lm}^{(2)}).$$



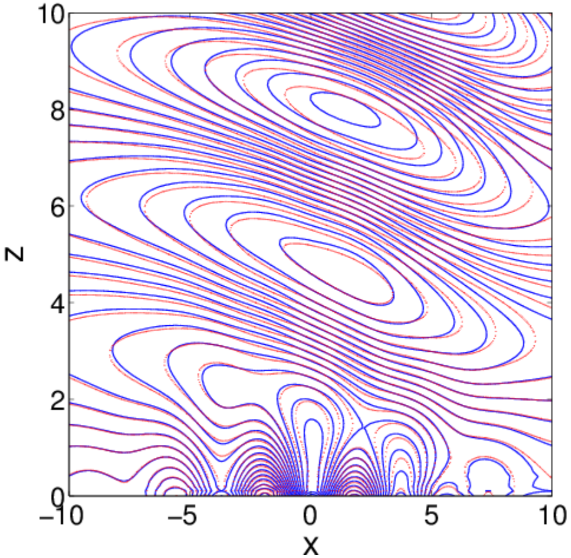


$x_1 = x_{i-\frac{1}{2}}$, $x_2 = x_{i-\frac{1}{2}} + \Delta x_i/3$, $x_3 = x_{i-\frac{1}{2}} + 2\Delta x_i/3$, $x_4 = x$

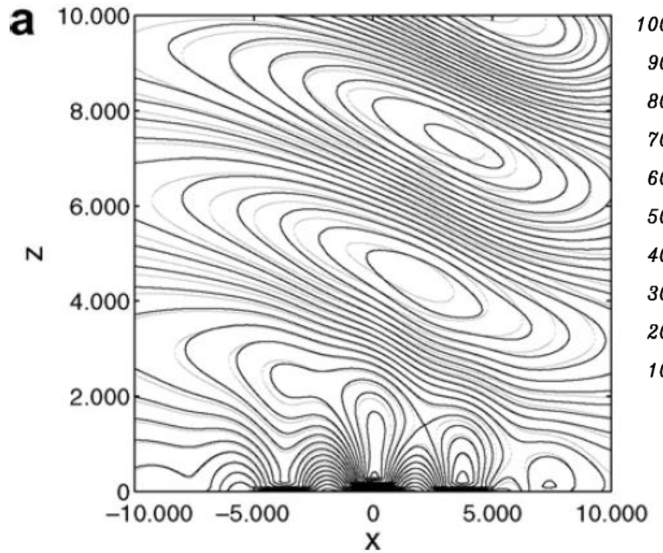
The 4 equi-distanced-point configuration along the line segment.

The equidistant solution points within one single cell

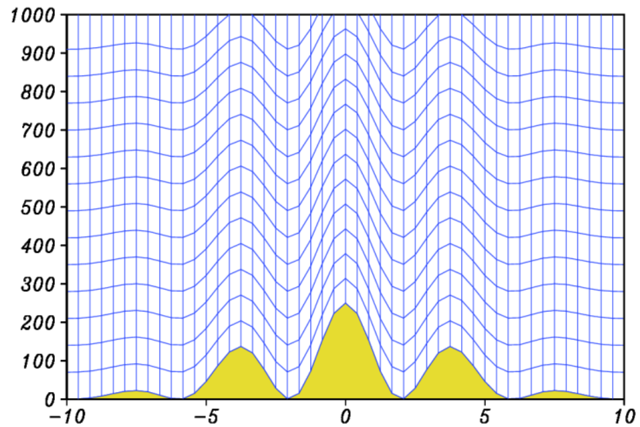
Red lines: analytic solution, blue lines: our results



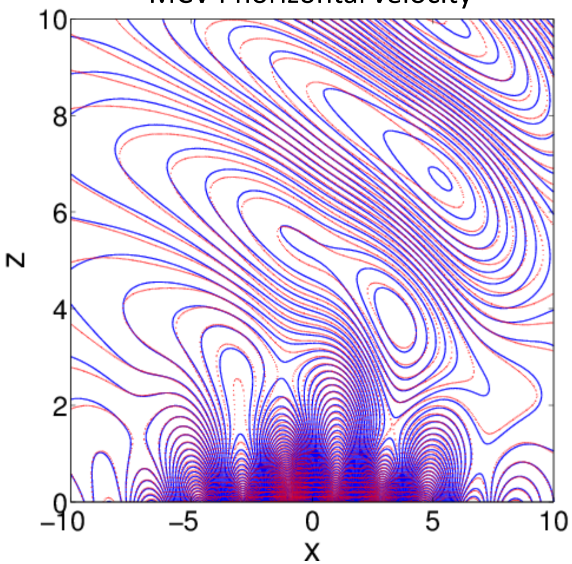
MCV4 horizontal velocity



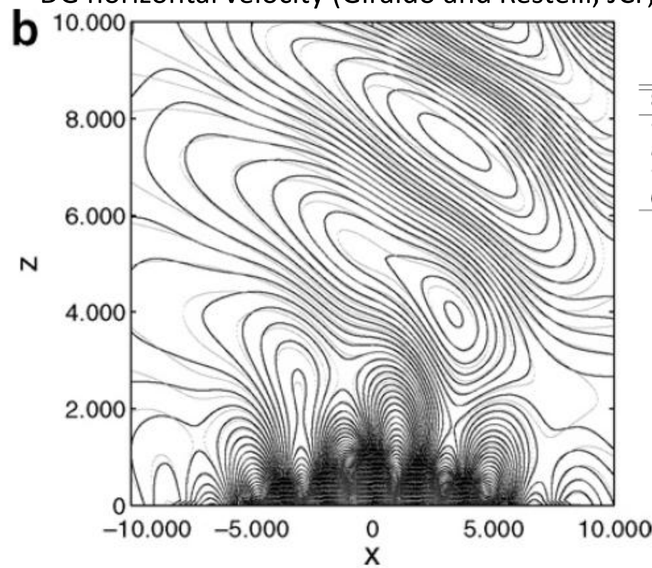
DG horizontal velocity (Giraldo and Restelli, JCP,2008)



Schär mountain (2002)



MCV4 vertical velocity



DG vertical velocity (Giraldo and Restelli, JCP,2008)

Schemes	MCV3	MCV4	SE3	DG3
π	5.25×10^{-6}	5.27×10^{-6}	8.27×10^{-6}	7.36×10^{-6}
u	9.21×10^{-2}	9.24×10^{-2}	2.26×10^{-1}	1.94×10^{-1}
w	2.76×10^{-2}	2.93×10^{-2}	7.66×10^{-2}	7.51×10^{-2}
θ	4.19×10^{-2}	4.39×10^{-2}	6.78×10^{-2}	5.84×10^{-2}

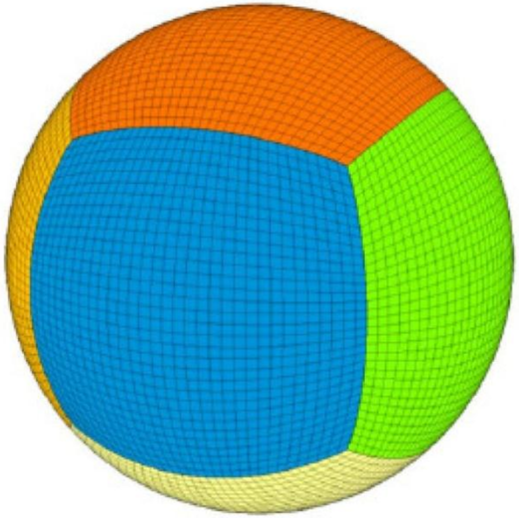
Red frame: our results, blue frame: SE/DG results

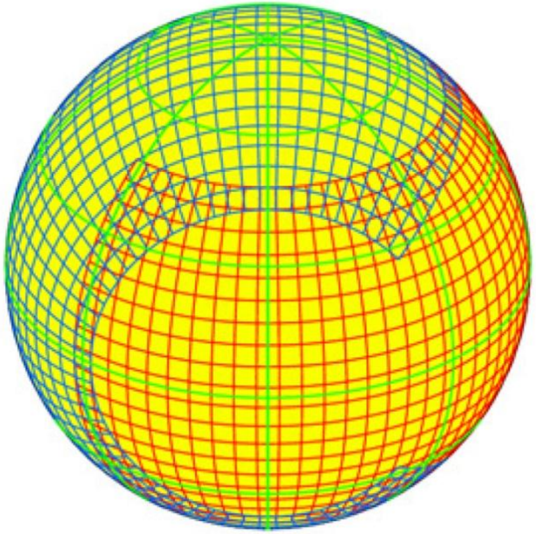
Root-mean-square errors of the schär mountain for different physical fields after 10 hours.

The RMS errors of our results are smaller in this test case

Near future plan

MCV (3rd and 4th order) + cubed grid or Yin-Yang grid





Further researches will be continued to develop 3D dynamical cores using the same methodology based on the popular structured spherical grids, such as structured cubed grid, Yin-Yang grid.

CMA's super computer system will be upgraded in 2013

	Oct. 2004- Now	Sep. 2009 – Now	2013-
	IBM Cluster1600 	Sunway4000A 	
Total Peak Performance	21.5 TFlops	33.75 TFlops	**Will up to over 1000TFlops totally**
Node Configuration	322×p655 nodes （8CPU/16GMEM） +58×p655 nodes （8CPU/32GMEM） +4×p690 nodes （32CPU/256GMEM）	168 Computing nodes （8CPU/36G MEM） +128 Computing nodes （12CPU/36G MEM） +16 IO nodes（24G MEM） +6 Server nodes （8CPU/24G MEM）	About 50000 cores 4GB memory/core
Network	IBM High Performance Switch 2*2GB/s (node to node)	Infiniband 80GB/s (one-way Bidirectional bandwidth)	About 80GB/s(one-way Bidirectional bandwidth)
Storage	128TB	384TB	Will up to over **3000TB** totally

THANK YOU