Development of Tropical Atmospheric Modeling System (TRAMS)

Institute of Tropical and Marine Meteorology/Guangdong Provincial Key Laboratory of Regional Numerical Weather Prediction，CMA，Guangzhou 510080，China

Zitong CHEN, Guangfeng DAI, Daosheng XU

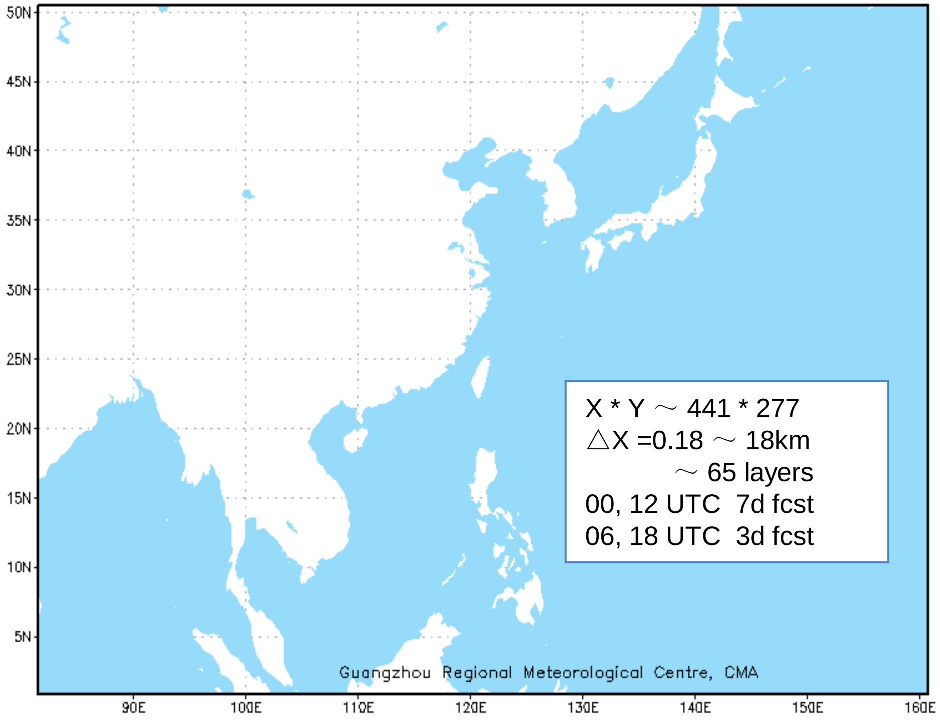
Outline

- **The introduction of Tropical Atmospheric Modeling System(TRAMS)**
  - **Configurations of TRAMS**
  - **The upgrading of TRAMS**
  - **Typhoon forecast in 2017**
- **The development of high resolution model (TRAMS~ 9km)**
  - **Technical scheme and test**
  - **The progress of new model**
- **Planning and outlook**

The introduction of TRAMS

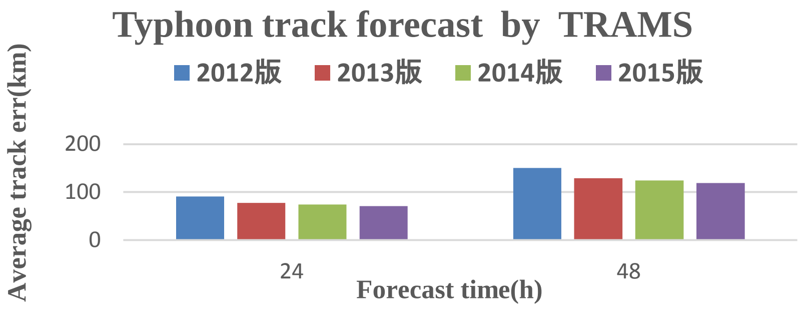
Dynamics:
1) non-hydrostatic
2) Terrain following height coordinates system
3) Iterative SISL scheme
4) PRM Moist scheme

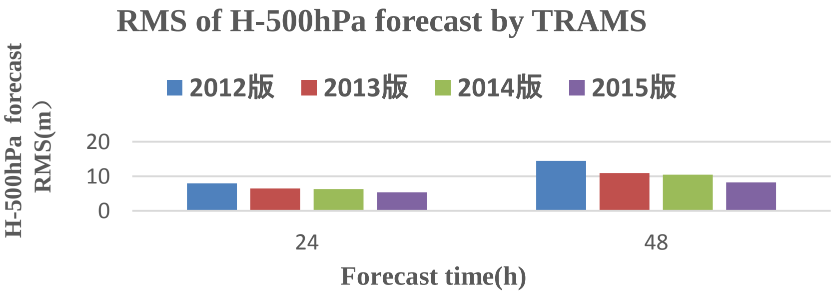
Physics:
1) microphysics: wsm6
2) PBL : new MRF scheme
3) Convection : NSAS
4) Land surface : SMS



The introduction of TRAMS

The upgrading of TRAMS





One year (2013) test of the same initial field

2012 -> 2013

- Introducing and improving SAS convective parameterization scheme
- Introducing MRF boundary layer scheme and adjusting the treatment of surface layer
- Introducing topographic gravity waves parameterization

2013 -> 2014

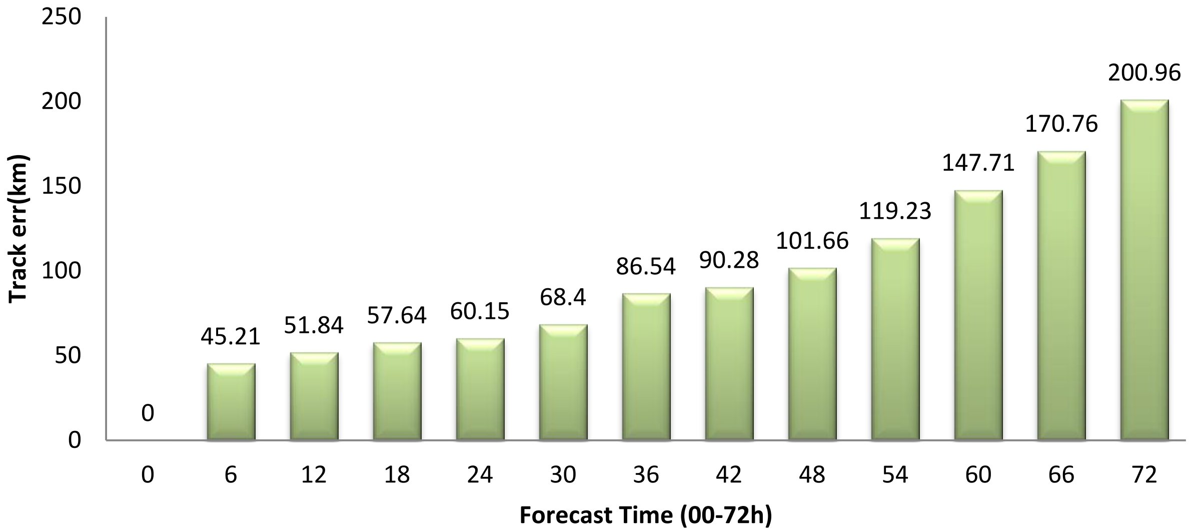
- Introducing Coriolis Forces term into momentum equation
- Adjusting the time integration scheme
- Developing a coupling scheme between dynamics and physcis processes

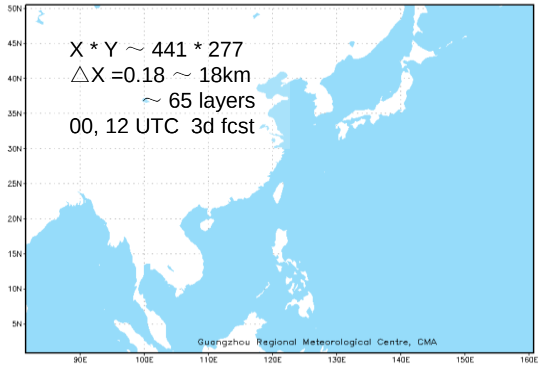
2014 -> 2015

- Upgrading the semi-implicit semi-Lagrangian advection scheme
- Introducing a self-developed 3D hydrostatic reference atmosphere scheme
- Developing a basic version of sea and land surface parameterization scheme

From 2016, begin to develop TRAMS-9km

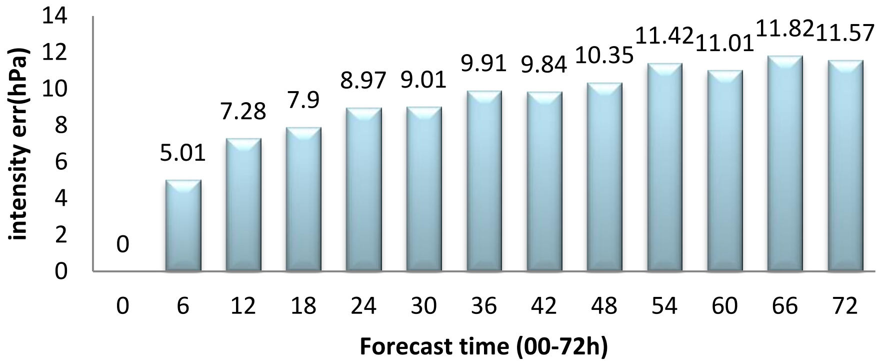
The introduction of TRAMS



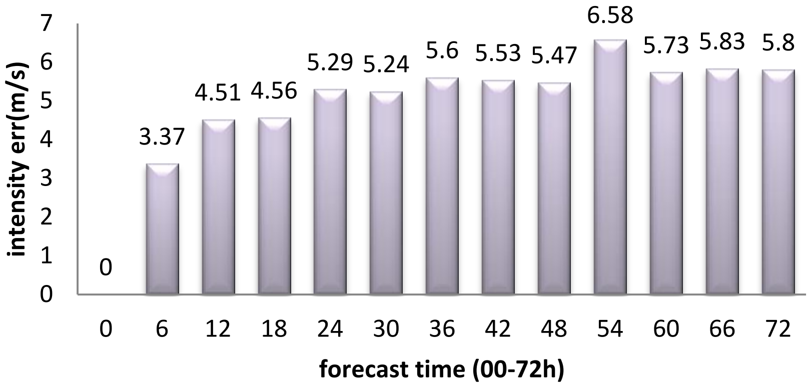


Average error of typhoon track forecast in 2017(all typhoons in the model domain,twice forecast one day)

The introduction of TRAMS



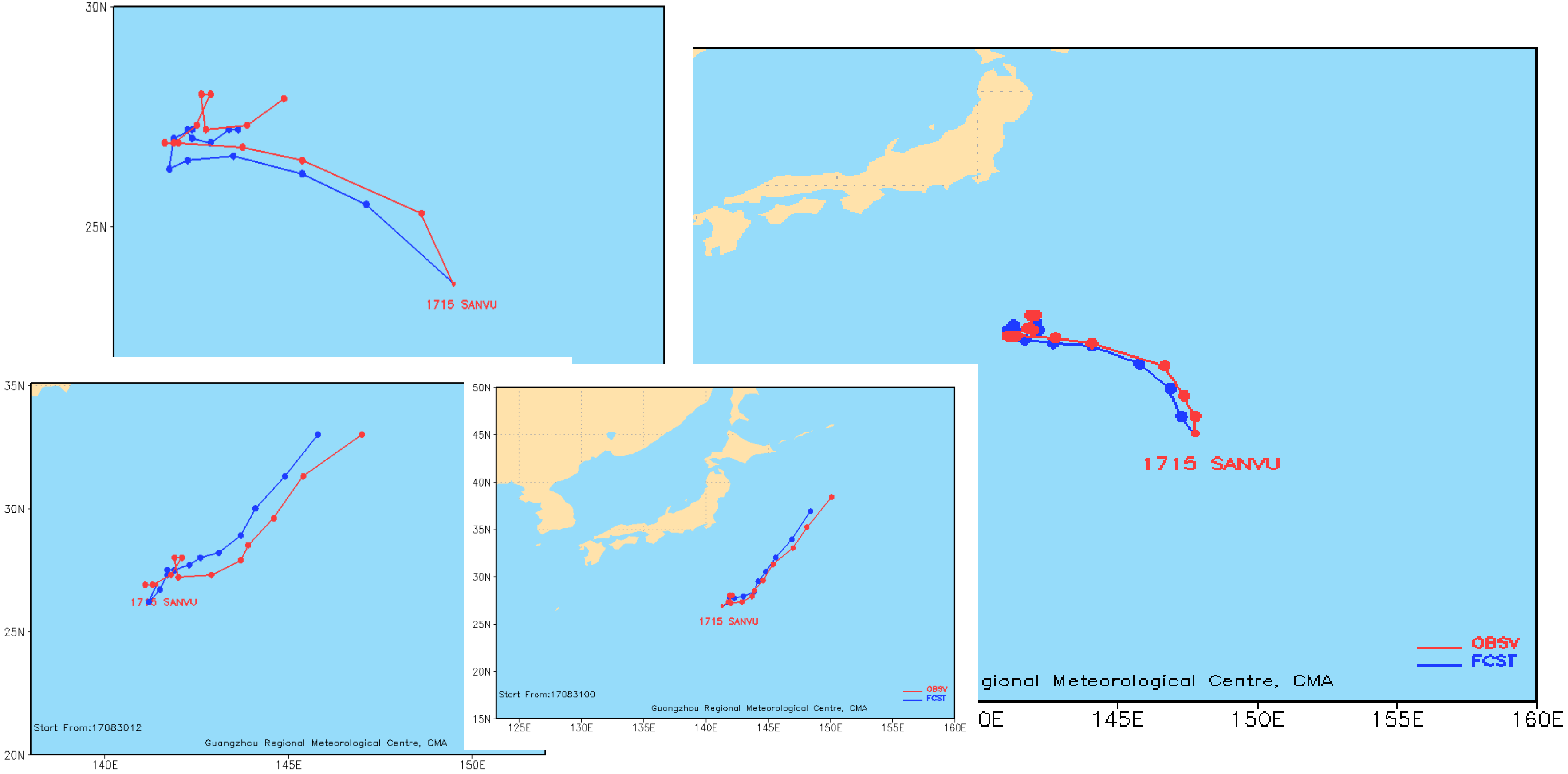
Average error of typhoon intensity forecast(pressure) in 2017



Average error of typhoon intensity forecast(wind) in 2017

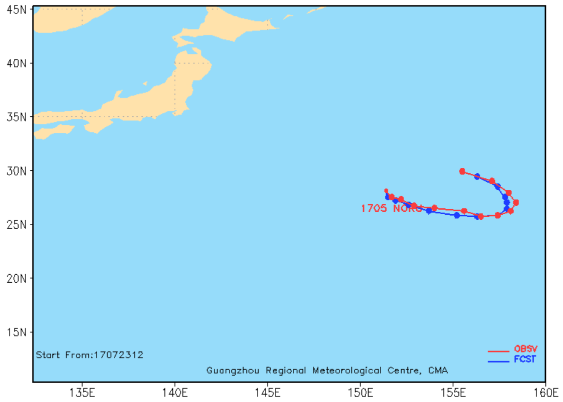
The introduction of TRAMS

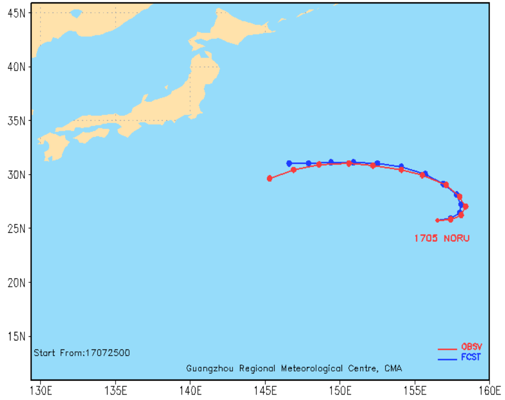
- Typhoon forecast in 2017: typhoon in the ocean (SANVU)

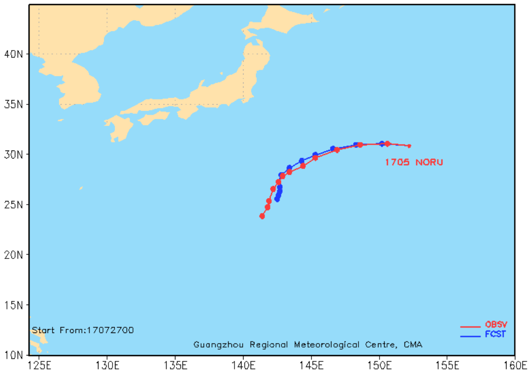


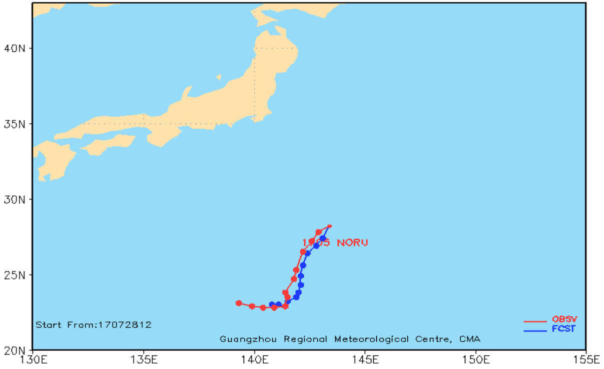
The introduction of TRAMS

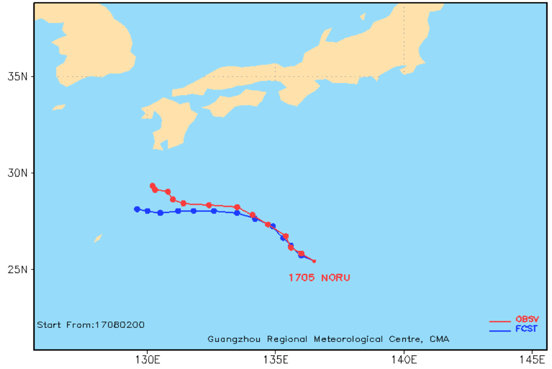
- **Typhoon forecast in 2017: typhoon in the ocean,and make landfall in Japan(NORU)**

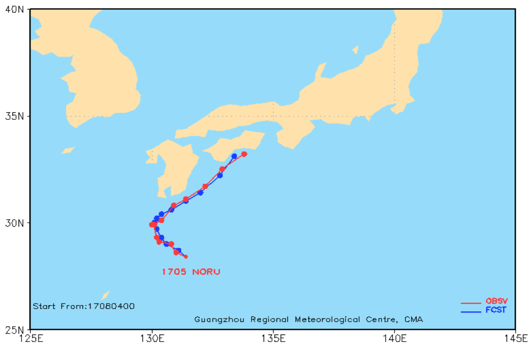






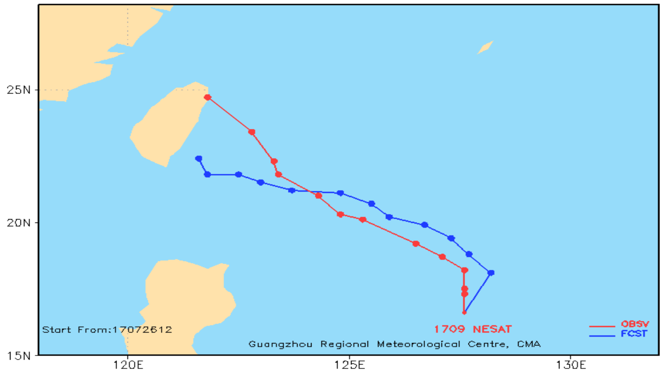


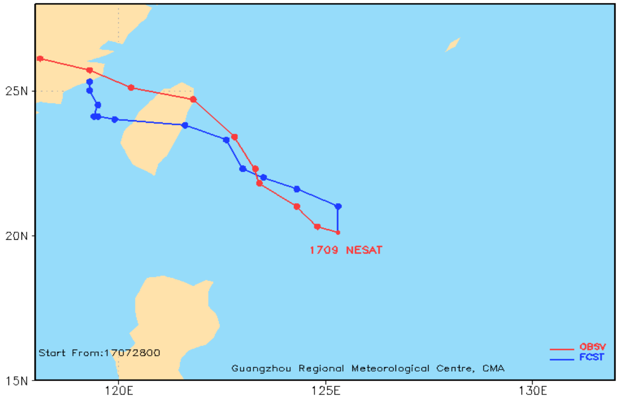


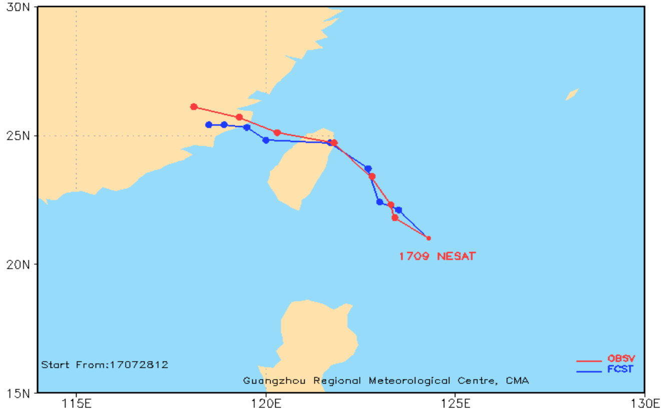


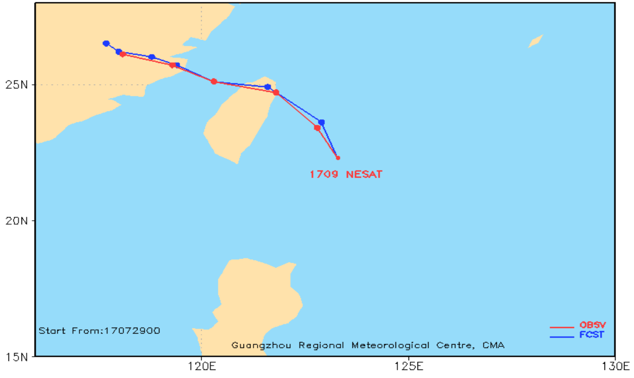
The introduction of TRAMS

- **Typhoon forecast in 2017: make landfall in East China (NESAT)**



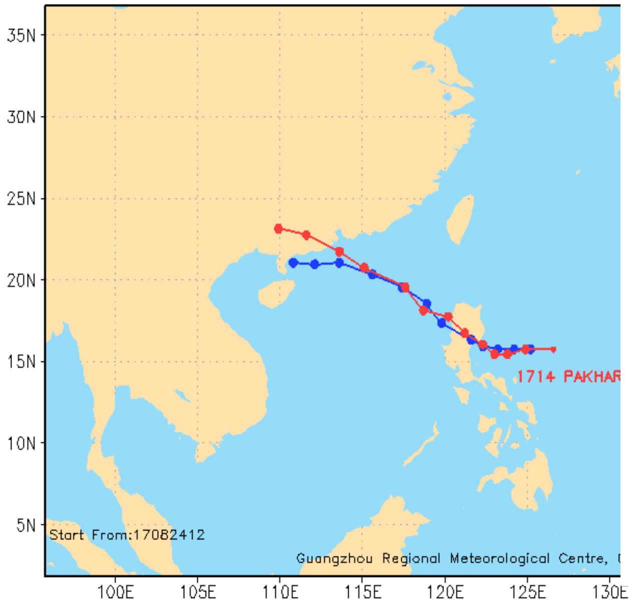


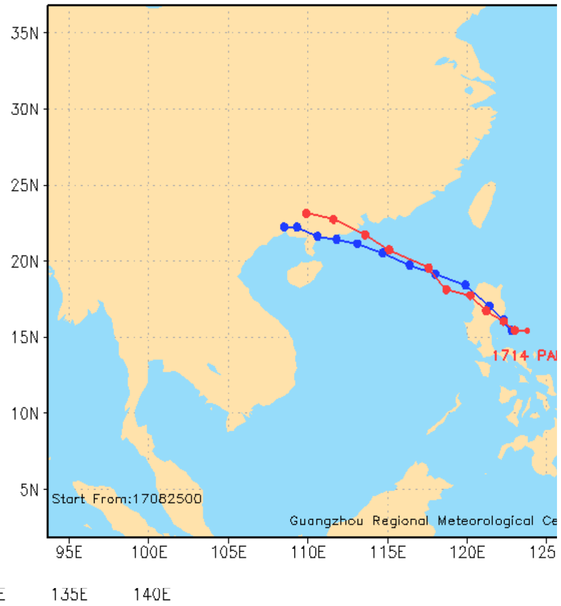


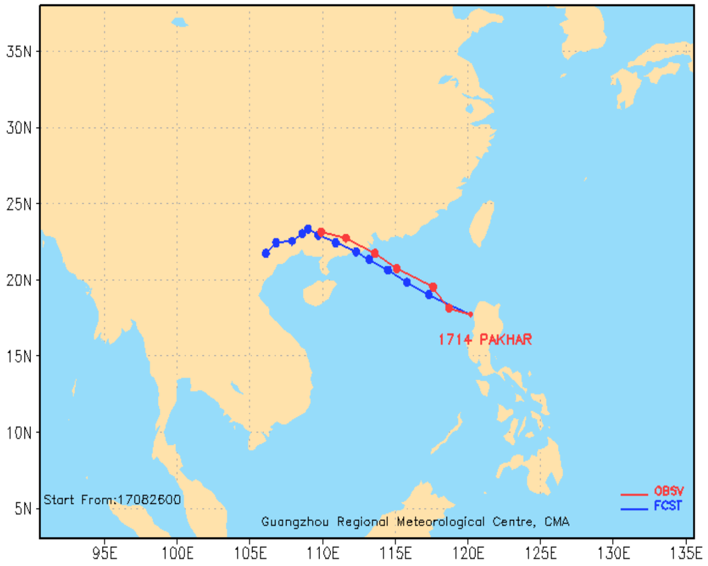


The introduction of TRAMS

- **Typhoon forecast in 2017: make landfall in South China (PAKHAR)**

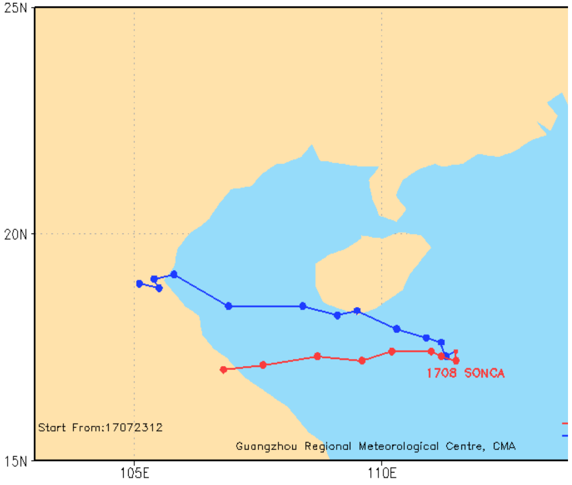


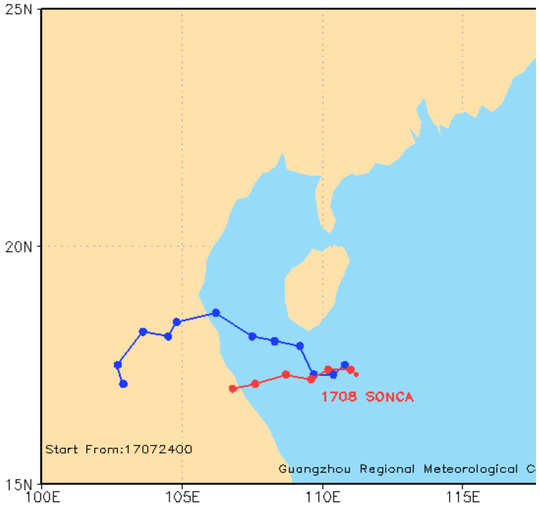


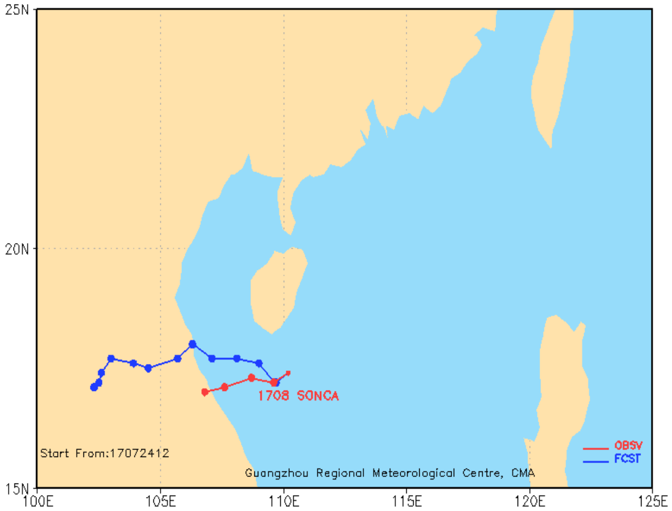


The introduction of TRAMS

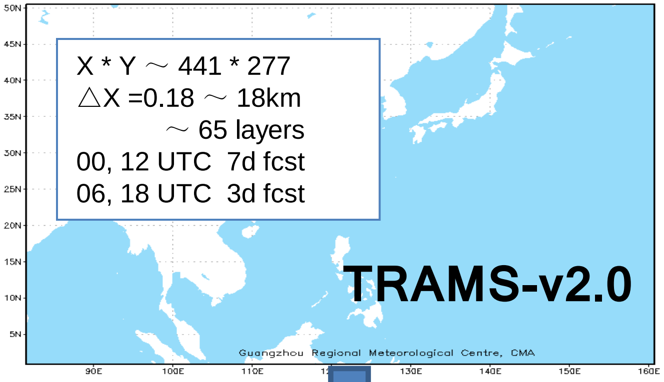
➢ **Typhoon forecast in 2017: make landfall in VietNam(SONCA)**

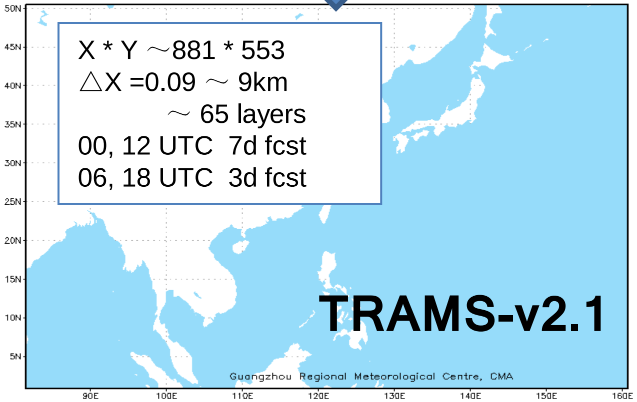






The development of high resolution model (TRAMS~ 9km)





Main feature of TRAMS-v2.1

Dynamics:

1) 3D reference (new scheme)

2) A vertical difference scheme with second order accuracy

3) W-damping

Physics:

1) shallow convection (new)

2) Multi Scale SAS Scheme

3) SMS scheme and orographic parameterization

The development of high resolution model (TRAMS~ 9km)

3D reference scheme

$$\Pi(\lambda,\varphi,z,t) = \tilde{\Pi}(\lambda,\varphi,z) + \Pi'(\lambda,\varphi,z,t)$$

$$\theta(\lambda,\varphi,z,t) = \tilde{\theta}(\lambda,\varphi,z) + \theta'(\lambda,\varphi,z,t)$$

$\tilde{\Pi},\tilde{\theta}$ represent the basic state of reference atmosphere which satisfies hydrostatic equation. Π',θ' represent the perturbation deviating from the basic state.

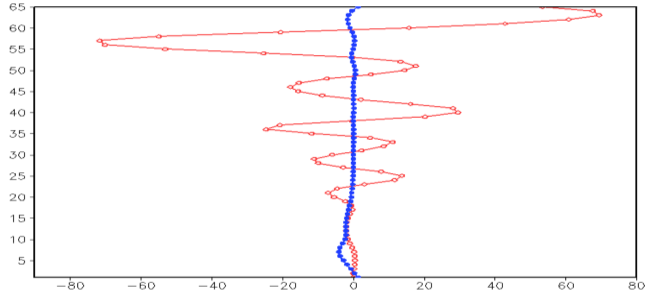
The development of high resolution model (TRAMS~ 9km)

3D reference scheme

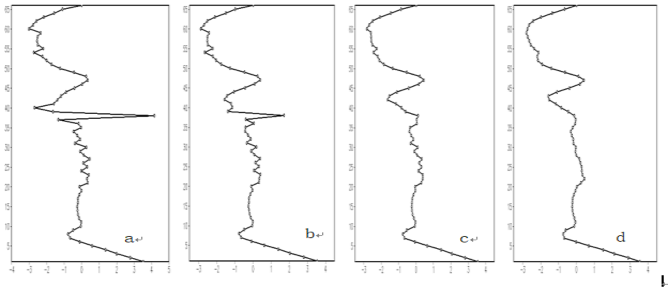
Unlike the large magnitude of the forecasted perturbation in the model derived based on 1D reference , the magnitude of the forecasted perturbation is significantly reduced with adoption of 3D reference . However, more terms such as horizontal pressure gradient and horizontal advection of reference atmosphere must be included in the new set of forecast equations

$$L_u = -C_p\tilde{\theta}\left(\frac{1}{a\cos\varphi}\frac{\partial\Pi'}{\partial\lambda} + Z_{sx}\frac{\partial\Pi'}{\partial\hat{z}}\right) + fv - \underline{C_p\tilde{\theta}\left(\frac{1}{a\cos\varphi}\frac{\partial\tilde{\Pi}}{\partial\lambda} + Z_{sx}\frac{\partial\tilde{\Pi}}{\partial\hat{z}}\right)}$$

$$L_\theta = \underline{u\frac{\partial\tilde{\theta}}{a\cos\varphi\partial\lambda} - v\frac{\partial\tilde{\theta}}{a\partial\varphi}} - \hat{w}\frac{\partial\tilde{\theta}}{\partial\hat{z}}$$

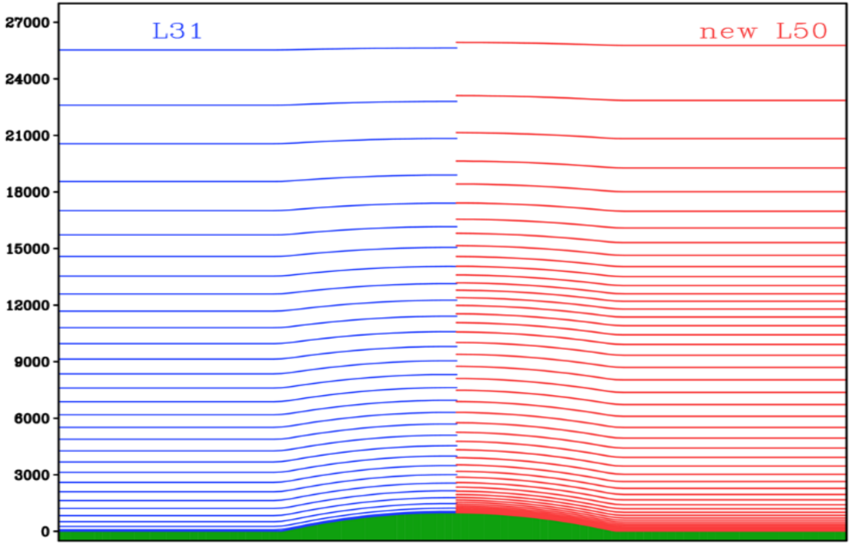


Comparison of initial potential temperature perturbation for 1D (red)and 3D (blue) reference atmosphere



Comparison of 1-hour forecasted potential temperature perturbation for; (a) 1D,(b) 20%3D,(c) 50%3D and (d) 3D reference

The development of high resolution model (TRAMS~ 9km)



A vertical difference scheme with second order accuracy under non-uniform model layers

First order accuracy:

$$f'(x) = \frac{f(x+\Delta x_1) - f(x-\Delta x_2)}{\Delta x_1 + \Delta x_2}$$

Second order accuracy:

$$f' = \frac{1}{\Delta x_2 + \Delta x_1}\left[\frac{\Delta x_2}{\Delta x_1} f(x+\Delta x_1) - \frac{\Delta x_1}{\Delta x_2} f(x-\Delta x_2)\right] - \frac{\Delta x_2 - \Delta x_1}{\Delta x_2 \Delta x_1} f(x)$$

The development of high resolution model (TRAMS~ 9km)

application of second order accuracy difference :according to the characteristics of the SISL , update implicit solving equations, second order finite difference scheme can be put into used.

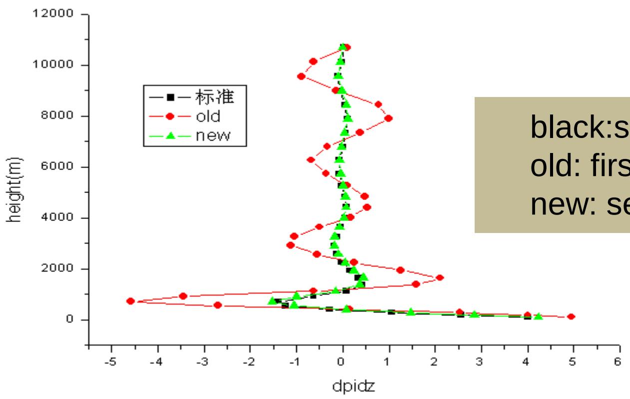
$$u = \xi_{u1}\Pi_\lambda + \xi_{u2}(\overline{\Pi}^{\varphi\lambda})_\varphi + \xi_{u3}(\overline{\Pi}^{z\lambda})_z + \xi_{u0}$$

$$v = \xi_{v1}(\overline{\Pi}^{\lambda\varphi})_\lambda + \xi_{v2}\Pi_\varphi + \xi_{v3}(\overline{\Pi}^{z\varphi})_z + \xi_{v0}$$

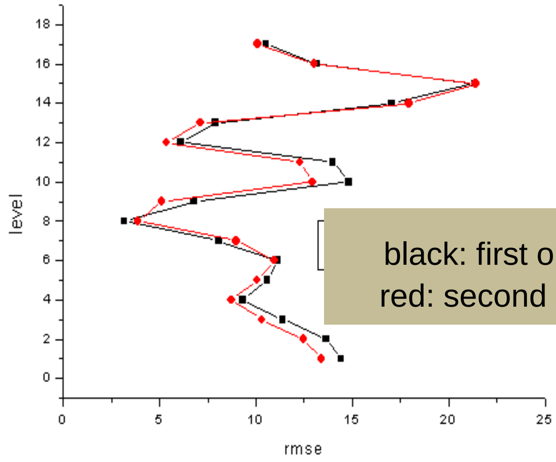
$$\hat{w} = \xi_{w1}(\overline{\Pi}^{z\lambda})_\lambda + \xi_{w2}(\overline{\Pi}^{z\varphi})_\varphi + \xi_{w3}\Pi_z + \xi_{w0}$$

$$\theta' = \xi_{\theta1}(\overline{\Pi}^{z\lambda})_\lambda + \xi_{\theta2}(\overline{\Pi}^{z\varphi})_\varphi + \xi_{\theta3}\Pi_z + \xi_{\theta0}$$

$$\Pi' = \xi_{\Pi1}\overline{u}^\lambda + \xi_{\Pi2}\overline{v}^\varphi + \xi_{\Pi3}\overline{\hat{w}}^z + \xi_{\Pi4}[u_\lambda + \cos\varphi^{-1}(\cos\varphi \cdot v)_\varphi + \hat{w}_z] + A_\Pi$$



black:standard
old: first order
new: second order



black: first order
red: second order

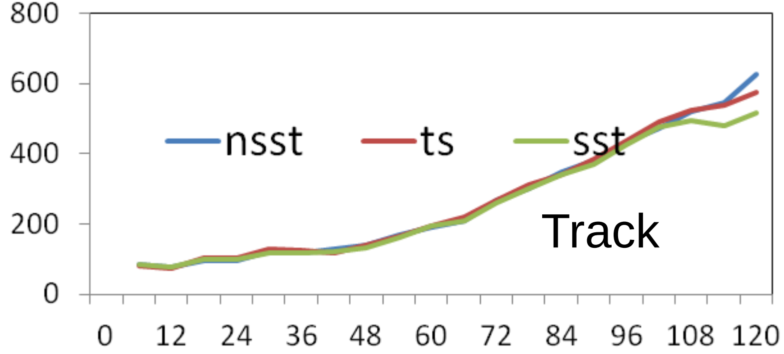
The development of high resolution model (TRAMS~ 9km)

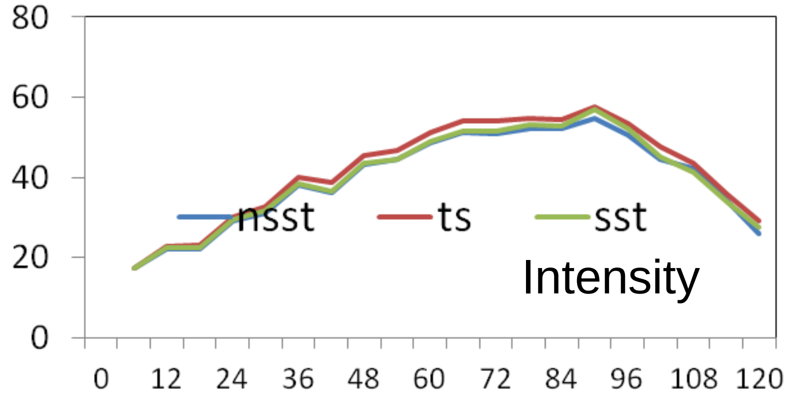
nsst-without SST schme
ts-SST schme with surface temperature
sst-with SST schme

SMS scheme (develop by our lab), includes land surface and parameterization of SST

The skin sea surface temperaturescheme based on the energy balance of the sea surface (Brunke et al, 2008 2008) was implemented:

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}(\mathrm{K}_w + \mathrm{k}_w)\frac{\partial T}{\partial z} + \frac{1}{\rho_w c_w}\frac{\partial R}{\partial z}$$

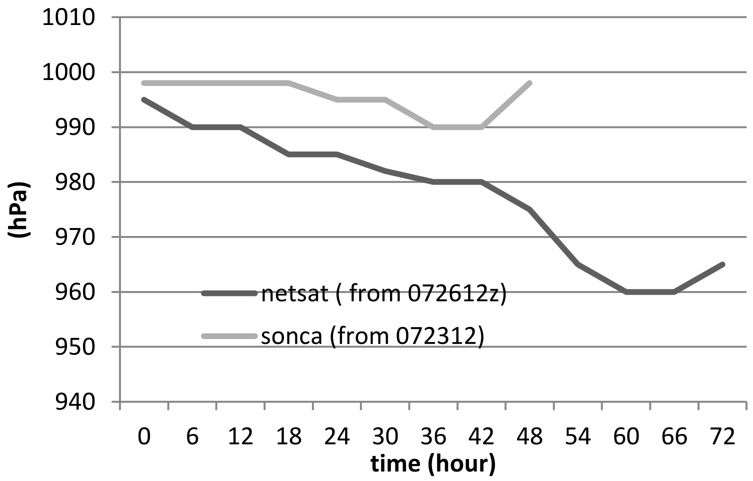


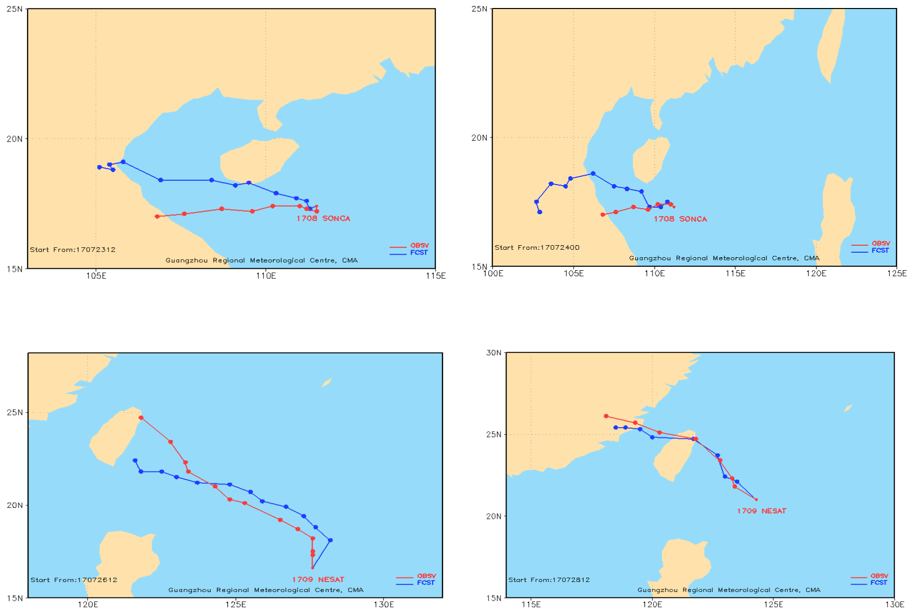


The experimental results show that the new sea temperature parameterization scheme and retrieved SST by satellite could improve the prediction of typhoon path and intensity, especially the long time forecasting.

The development of high resolution model (TRAMS~ 9km)

orographic parameterization



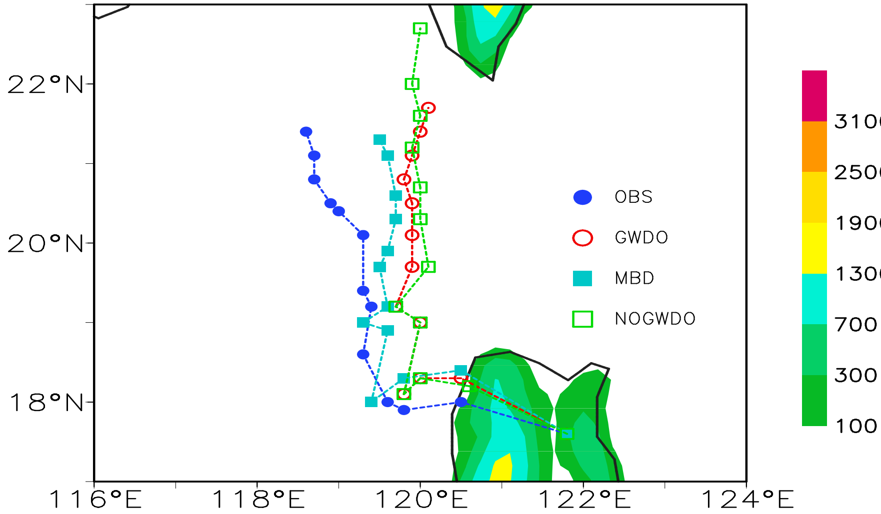


Weak typhoon is easily affected by the terrain.
orographic parameterization will be added in the new model

The development of high resolution model (TRAMS~ 9km)

orographic parameterization

The numerical simulation on typhoon "LINFA" showed that the NOGWDO exhibited a too far north path and a too fast moving speed. Though the GWD show a similar too far north path than the NOGWDO simulation, the moving speed was improved. **The MBD experiment showed a much better path simulation than that from GWDO and NOGWDO experiments.**



The sensitive simulation of the track of typhoon "LINFA" to the orographic parameterization

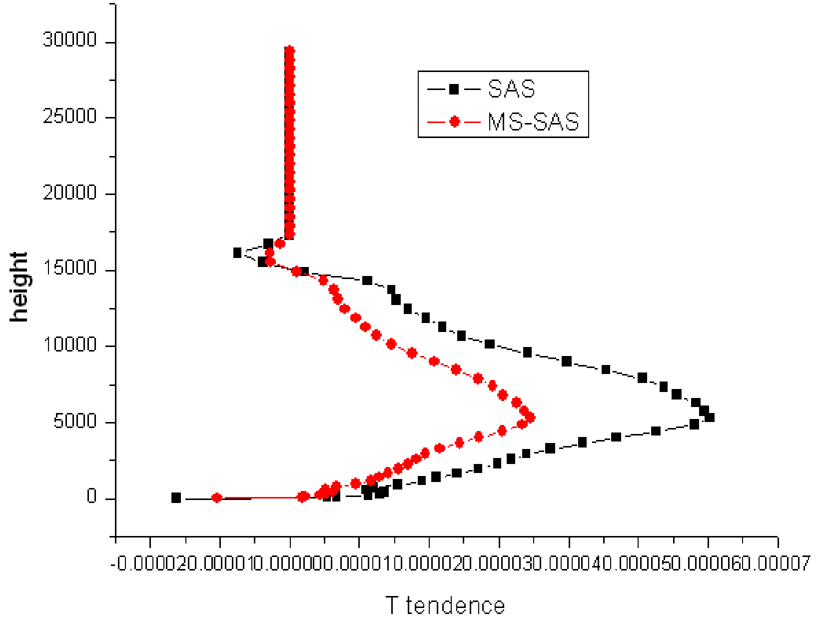
GWDO : gravity wave drag induced by sub-grid orographic effects
MBD: mountain blocking drag effects

The development of high resolution model (TRAMS~ 9km)

Multi Scale SAS Scheme based on the new SAS (Arakawa and wu 2013)

Horizontal grid spacing of the high resolution model, convective updrafts only occurs in fractional area, the key is to estimate the updraft area fraction

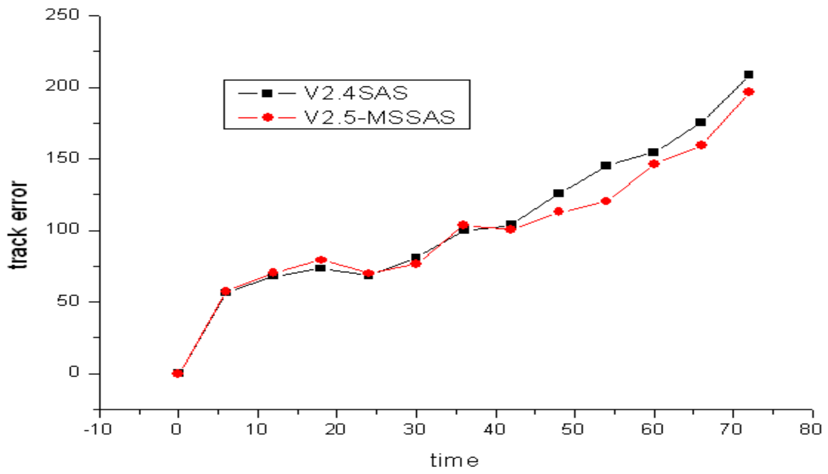
$$\sigma_u = \frac{\pi R_{conv}^2}{A_{grid}}$$



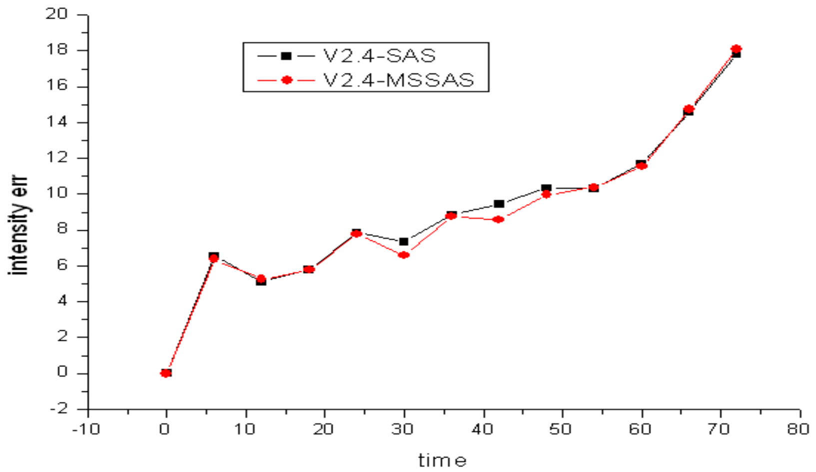
Domain average T tendency from SAS and MS-SAS scheme

The development of high resolution model (TRAMS~ 9km)

Multi Scale SAS Scheme



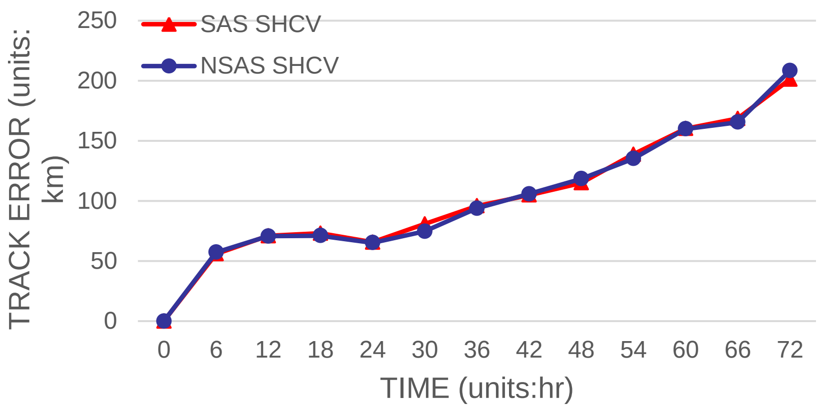
Track errors

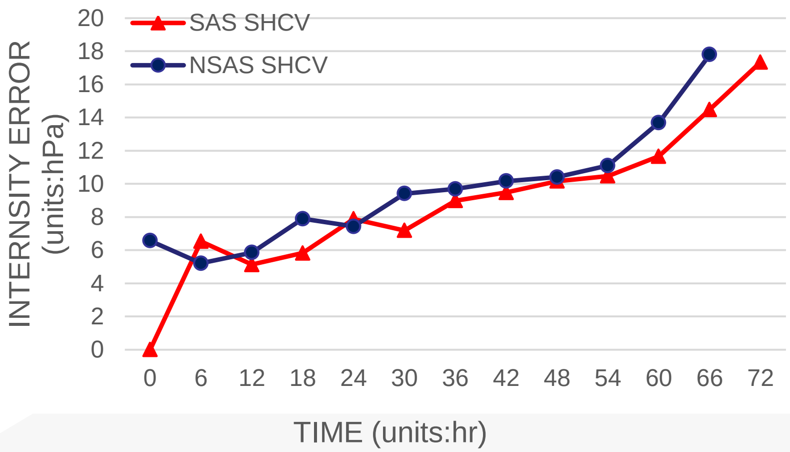


Intensity errors

Mean errors of 21 typhoon cases, Red: MSSAS Balck: SAS

The development of high resolution model (TRAMS~ 9km)



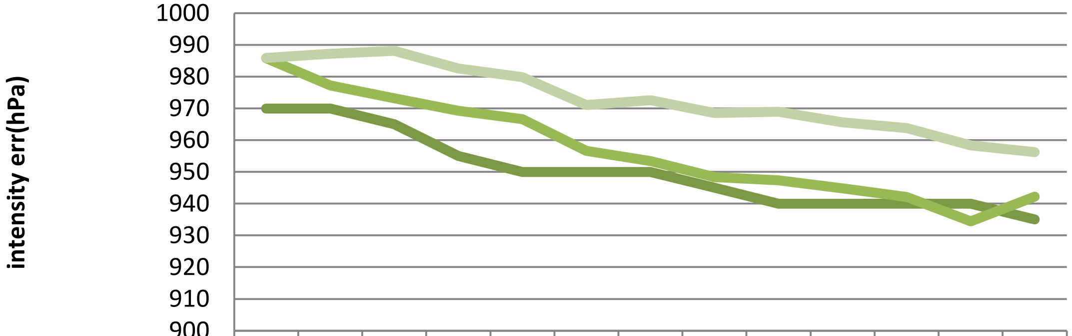


Shallow convection scheme does not work well in TRAMS , so we test two schemes:
1) mass-flux scheme(from NSAS) ;
2) turbulence diffusion scheme (From SAS).

Using 23 examples in 2017 to test these two schemes. Both schemes have similar skills on track forecast. turbulence diffusion scheme performs better on intensity forecast.

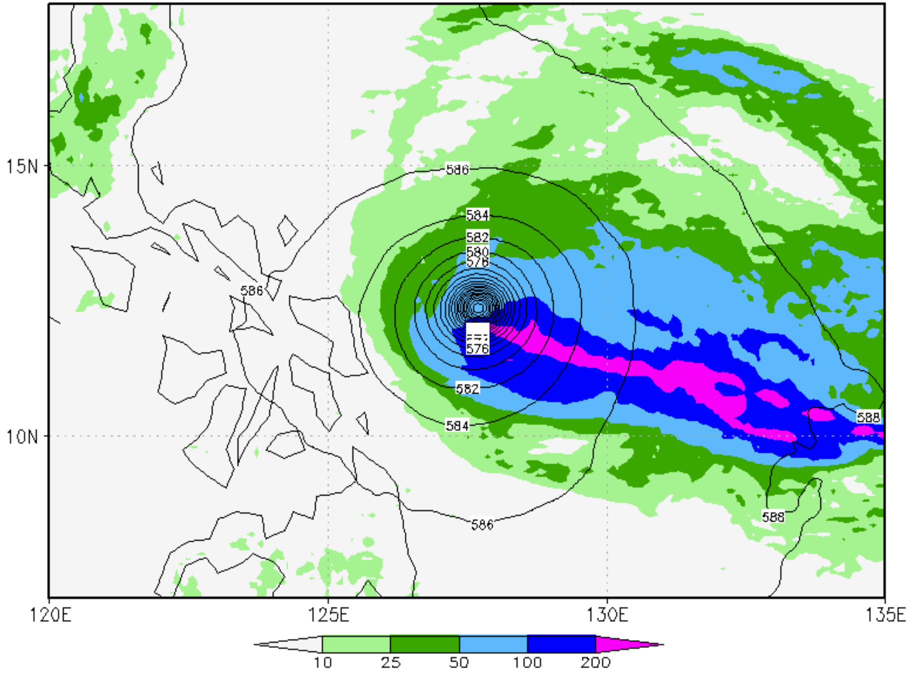
The development of high resolution model (TRAMS~ 9km)

For strong typhoon, TRAMS-18km model forecast tend to be obviously weak, and TRAMS -9km has improvement

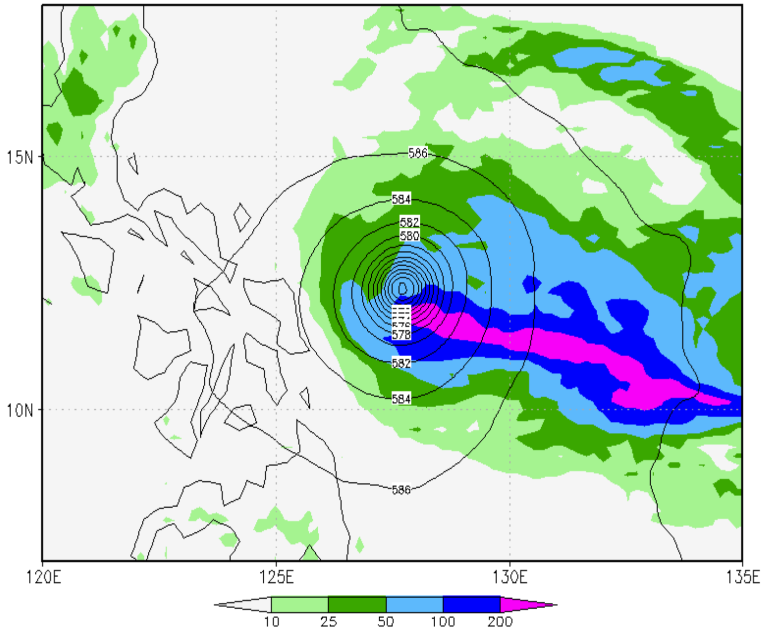


	0	6	12	18	24	30	36	42	48	54	60	66	72
OBS	970	970	965	955	950	950	950	945	940	940	940	940	935
9km model	985.8	977.2	973.2	969.3	966.6	956.6	953.4	948.4	947.3	944.8	942.1	934.4	942.2
18km model	985.9	987.2	988.1	982.6	979.8	971.1	972.6	968.5	968.9	965.6	963.8	958.3	956.2

The development of high resolution model (TRAMS~ 9km)



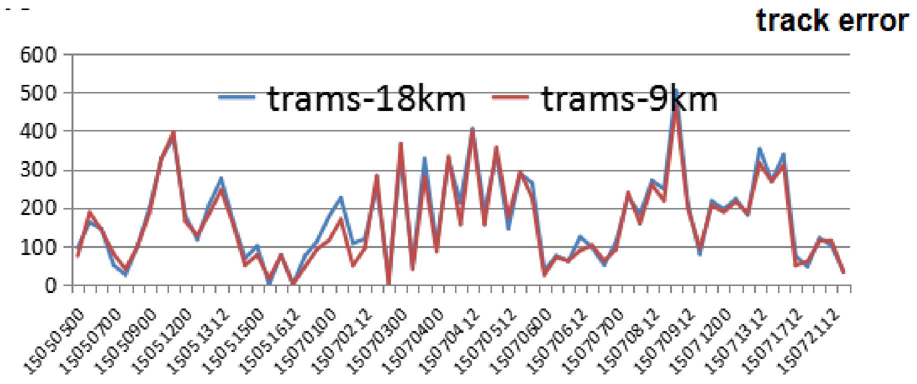
TRAMS-v2.1



TRAMS-v2.0

The development of high resolution model (TRAMS~ 9km)

TRAMS-9km shows a overall superior performances than TRAMS-18km, including the typhoon track and intensity forecasting. Not only an improvement in the intensity forecast. TRAMS-9km also has a certain decrease in the track forecast error.



72h mean track error：old-173.1km；new-163.0km

Planning and outlook

- **Establishment of TRAMS-9km,and upgrad model version**
- **Reduce the track forecast error of weak typhoon**
- **Reduce the intensity forecast error of strong typhoon**