The Regional Tropical Cyclone Numerical Prediction Model (GRAPES-TCM) in China

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• STI: Huang Wei, Liang Xudong, Wang Dongliang, Li Yongping, et al.
• NMC: Shen Minghua, Ma Suhong, Zhang Jin, et al.
Outline

- Introduction to GRAPES-TCM
- Development of GRAPES-TCM
  (1) Vortex Initialization
  (2) Model Physics
  (3) Coupling with Ocean Model
- Performance of GRAPES-TCM
- Summary and Future Plan
GRAPES

*(Global/Regional Assimilation PrEdiction System)*

Two families: **GRAPES-GFS** and **GRAPES-MESO**

**GRAPES–TCM**

A **Tropical Cyclone Model** based on the **GRAPES-MESO**
Dynamics of GRAPES

Fully-compressible

Non-hydrostatic

Navier-Stokes Equations

Terrain-following coordinate (Gal-Chen and Somerville, 1975)

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

A finite difference semi-Lagrangian semi-implicit scheme (Robert 1982)

\[ \frac{\psi^{t+\Delta t} - \psi_t}{\Delta t} = \frac{1}{2} [\alpha \cdot (L \psi_t + N \psi_t) + \beta \cdot (L \psi_t + N \psi_t)] \]

vector discretization
The History of GRAPES–TCM

Resolution:
- 2004-2008: Movable Domain
- 2006: 48h forecast, 00, 12 UTC
- 2007: Fixed Model Domain (Enlarged)
- 2008: Extended to 72h forecast, 00, 06, 12, 18 UTC
- 2009
- 2010-2013: 0.15º

Initialization:
- 2004-2008: Bogus
- 2006: Vortex Relocation
- 2007: Cycled Vortex Relocation
- 2008: Cycled Vortex assimilation

Assimilation:
- 2004-2008: 3DVAR
- 2006
- 2007: MC-3DVAR
- 2008: VIRV

Physics:
- 2004-2008: KF-ETA cumulus, MRF PBL, RRTM, NCEP-cloud3
- 2006: PBL, Surface Parameterization
- 2007: Cumulus Parameterization
- 2008: Verification on CPs
- 2009: Modified KF Trigger
- 2010-2013: Modified Drag Coefficient

PC-Cluster Systems
IBM HPC
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Development of GRAPES-TCM

Vortex Initialization

Vortex Relocation

Cycled Vortex Relocation

Cycled Vortex Assimilation

Radiation Scheme

KF Trigger Scheme

Verificaton on CP schemes

Roughness Parameterization

Physics

Vortex + Satellite data Assimilation

GRAPES

GRAPES-TCM
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Vortex initialization in GRAPES-TCM

Operation

Bogus

Cycled Vortex Relocation

Bogus data assimilation

Cycled vortex Data Assimilation with MC-3DVAR

Pilot

Cycled data assimilation with vortex retrieved from SCAT winds, radars, and TBB……

Cycled data assimilation with vortex retrieved from SCAT winds and radars

Cycled data assimilation with vortex retrieved from SCAT winds (VIRV)
CDA（Cycled vortex Data Assimilation）

CDA: Cycled vortex Data Assimilation with MC-3DVAR by Liang (2007)*

• MC-3DVAR:
  Based on the 3DVAR, a filter is introduced to the cost function to consider the effect of full constraint of model

\[
J = [x(t_0) - x_b(t_0)]^T B^{-1} [x(t_0) - x_b(t_0)] + [H(x(t_0)) - y_o(t_o)]^T O^{-1} [H(x(t_0)) - y_o(t_0)] + \left[ \frac{\Delta x(t_0)}{\Delta t} \right]^T R^{-1} \left[ \frac{\Delta x(t_0)}{\Delta t} \right]
\]

*(Liang X. et al. 2007a,b, Quart. J. Roy. Meteor. Soc.)*
Schematic of the CDA in GRAPES-TCM

- Observation Data
- Bogus

- Forecast Field
- MC_3dvar
- Vortex

- Regional Analysis
- Global Analysis

- Final Analysis

Previous Run

Current Run

Schematic of cycling data assimilation for GRAPES_TCM
Flow Chart of CDA: four times a day

- Environment fields
- GFS
- 1st run
- model
- Vortex fields
- Bogus Vortex
- 2nd run
- model
- Vortex fields
- 3rd run
- model
- Vortex fields
- 4th run
- model
- Environment fields
- GFS
- Environment fields
- GFS
- Environment fields
- GFS
Impacts of CDA on TC structure

Simulated Radar reflectivity

Rainfall accumulation

CTL

BDA

CDA

TRMM

CDA
Impacts of CDA on the Intensity Prediction
Typhoon Jangmi (2007)

Evolution of Minimum SLP (hPa)
TC Track Errors (km) CDA vs. Relocation

(Liang X. et al. 2007a,b, 
*Quart. J. Roy. Meteor. Soc.*)
VIRV for TC Initialization
(Vortex Initialization with Retrieved Variables from SCAT winds)
VIRV for Rainfall Prediction of TC Morakot (2009)

CTL (GFS only) vs VIRV + Radar reflectivity

VIRV

00 UTC 8 - 00 UTC 9 August

OBS
TC initialization with TBB Nudging


Cloud Top Temperature

Initial Analysis with TBB

Initial Analysis from NCEP/GFS
Modification of Asymmetric Structure

CTRL (GFS)

BDA

TBB

Nudging

12h 15h 18h 21h
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Improvement of Convective Parameterization

• Issue: A common criticism of the earlier version of the Kain-Fritsch scheme was that it sometimes produced widespread light precipitation in marginally unstable environments (Warner and Hsu, 2000; Colle et al., 2003).

• Motivation: The definition of convection trigger function of Kain-Fritsch scheme is very crucial in determining the prerequisite for a parcel to move upward and to trigger convection.

Improvement: The trigger function is redefined with moisture advection instead of environmental vertical motion that is related to moisture convergence. This significantly reduces the false alarm of rainfall under marginally unstable environments.
The false alarm of rainfall over the region with weak environmental forcing is reduced with the new convection trigger scheme.

GRAPES-TCM
Rainfall Prediction

Typhoon Morakot (2009) 1200UTC 6-1200UTC 7 Aug. 24h rainfall accumulation
Convection Trigger based on Moisture Advection
(Ma and Tan 2009, Atmos. Res.) NCAR/WRF V3.3

WRF Model Version 3.3: Updates

**WRF Model Update**

WRF model tar file has been updated to Version 3.3 on April 6, 2011. For known problems in V3.3, please click [here](#).

WRF Pre-Processing System (WPS) has been updated to [Version 3.3](#).

**Note:** The V3.3 WRF can use V3.2 (and V3.1) wrfinput and wrfbdy files. However there are fixes in V3.3 program real (see below), and one may benefit from the change if wrfinput and wrfbdy files are regenerated.

As always, be cautious when using new options.

If you are interested in seeing how V3 has been tested, click [here](#).

**New in Version 3.3:**

**Physics:**

- Cumulus and shallow convection parameterization options:
Cd: Surface Drag Coefficient change under strong sea surface winds
The intensity prediction of Saomai (2006) is improved by reducing the surface drag for strong winds.
Improvement of Radiative Transfer Parameterizations

- **Delta-Four-Stream Doubling–Adding Method**: more accurate to compute the radiative transfer in complicated TC clouds *(Zhang F. et al., 2013a,b, JAS)*

<table>
<thead>
<tr>
<th>Two-stream</th>
<th>Four-stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>For single-layer cloud</td>
<td>For multi-layer clouds</td>
</tr>
<tr>
<td>Inapplicable to TC forecasting</td>
<td>Applicable to TC forecasting</td>
</tr>
<tr>
<td>Low calculation accuracy</td>
<td>High calculation accuracy</td>
</tr>
<tr>
<td>Huge computation complexity</td>
<td>Reduced computation complexity</td>
</tr>
</tbody>
</table>
Use of the Delta-Four-Stream Doubling–Adding Radiative Transfer Parameterization

Composite reflectivity (dBZ); landfall time: $T = 45$ hr
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Coupling with Ocean Model

**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;
GRAPES-TCM - Ocean Coupled model

- GRAPES-TCM
- ECOM
- WW3
- SST
- Surface flux
- oasis3
- Stress from wave
- Surface wind
- Velocity of Ocean Current
- Stress from wave
SST forecasted by the coupled model
---Typhoon Muifa

NCEP AVHRR + AMSR-E SST analysis at 08/08/11, 00UTC

72 hour forecasted SST by the coupled model Initialized at 00UTC 05 AUGUST, 2011

➢ The coupled model reproduces the sea surface cooling
The weaken of the warm core structure

48 h distribution of equivalent potential temperature
Initialized at 00UTC 05 AUGUST, 2011

The 48 h distribution of the vertical temperature anomaly across the center of “Muifa”
Initialized at 00UTC 05 AUGUST, 2011
Typhoon Muifa – impact of coupling

- Too strong in GRAPES_TCM
- Coupling weaken the intensity

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

Black – observation
Red – Uncoupled model
Green – Coupled model
Forecast verification for MUIFA

Number of cases (21, 21, 19, 17)
Typhoon MUIIFA intensity forecast

Minimum sea level pressure forecast
GRAPES_TCM

Minimum sea level pressure forecast
Coupled model

Maximum wind forecast
GRAPES_TCM

Maximum wind forecast
Coupled model
Typhoon SINLAKU – impact of coupling

NCEP AVHRR + AMSR-E SST analysis at 15/09/08, 00UTC

- Too strong in GRAPES_TCM model
- Coupling weaken the intensity

Tropical Cyclone SINLAKU (2008)
INITIAL TIME 12:00 UTC, 12 September 2008
Forecast verification of Nine TCs in 2011

Number of cases (72,72,56,56,49,44,44)
Intensity forecast of Nine TC in 2011

Number of cases (72, 72, 56, 44)
24-h Prediction Error of TC intensity by GRAPES-TCM coupled model (2011-2012)

<table>
<thead>
<tr>
<th>Cases</th>
<th>Pre-landfall Error</th>
<th>Post-landfall Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Coupled (hPa)</td>
<td>Coupled (hPa)</td>
</tr>
<tr>
<td>75</td>
<td>8.37</td>
<td>8.1</td>
</tr>
</tbody>
</table>
Sensitivity test on the effects of wave and ocean

Design of numerical experiments

✓ CTR: Atmospheric model
    (No coupling with Ocean)
✓ AS: Ocean–Atmos Coupled
✓ AW: Atmos–Wave Coupled
✓ ASW: Ocean–Atmos–Wave Coupled
The Impacts of Ocean on TC Inflow

(Inflow is enhanced by sea waves)
Impacts on Typhoon Intensity Predictions

(a) 

(b) 

CTR, AS, AW, ASW
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GRPAES-TCM

Operation run

Basic configuration
Horizontal resolution: 0.25°x0.25°
Grid size: 161×101
Zone: movable with the initial TC position

Physical parameterization
Convective parameter scheme: KF +convection trigger (Ma and Tan, 2009, Atmos. Research)
Drag coefficient for strong wind (Moon et al., 2007, Mon. Wea. Rev.)
PBL scheme: MRF
Microphysics: NCEP cloud3
Land-air Flux: bulk scheme
Long wave radiation scheme: RRTM scheme

First guess
NCEP/AVN 12-h forecasts

Initial vortex
CDA (Liang et al., 2007a,b, Quart. J. Roy. Meteor. Soc.)
24-h Prediction Errors (km) of NW Pacific TC tracks in recent five years
24-h Prediction Errors (km) of NW Pacific TC tracks

24h Position Error Trend

Position Error (km)

UKMO-MetUM
CMA-T639
JMA-GSM
GRAPES-TCM

2007 2008 2009 2010 2011 2012 2013
Intensity error for GRAPES-TCM

Intensity error (m/s)

lead times

2010
2011
2012
2013

24h
48h
72h
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Summary

- GRAPES_TCM has been established and put into operation since 2006.
- The development of vortex initialization, convective parameterization, and PBL parameterization schemes has a positive effect on the improvement of GRAPES_TCM.
- The verification of coupled model shows that it could improve the intensity prediction as compared with the uncoupled GRAPES_TCM.
Future Plan

To focus on further improving the forecast of intensity change and the distribution of wind and rainfall in high resolution by

- Increasing the model resolution (1 or 3km)
- Improving the vortex initialization with the technique of data assimilation
- Improving the PBL scheme
- Improving the cloud micro-physical scheme
Thanks for your attention!

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Future Developments

TC Observations

Initialization of GRAPES-TCM
(Appropriate use of TC observations)

Further Understanding of TC structure

Model Constraints
(Appropriate for TC)

Deterministic + Ensemble Forecasts

Coupling
Initialization and Dynamics/Physics
Evaluation in Taiwan CWB (TWRF)

**Problem:**

Two typhoons Fanapi and Megi hit Taiwan in 2010:
1) too active cyclone genesis,
2) warm anomaly under 500hPa had found in TWRF.

**Improvement:**

Overall, not only the track forecast skill but also the bias that mentioned above had been improved.
Improvement in GRAPES-TCM

- Physical schemes
- Radiation
- Vortex initialization
- Cumulus convection
- PBL
- Air-sea interaction
Intensity bias for GRAPES-TCM