Highlights of the Operational WRF-Based Numerical Prediction System at Central Weather Bureau of Taiwan

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1897 1937 1996
Outline

- Introduction to the CWB WRF DA system
- Recent improvements
- Summary
About the History

- CWB began to develop its own NWP system since 1984.
- WRF model was implemented in CWB’s operational environment since 2004 and went through comprehensive evaluations.
- By cooperating with NCAR scientists, WRF was operational to be the 3rd generation regional forecast system since Nov 2007.
  - Both deterministic and ensemble prediction system
Domains of CWB WRF

- D1: 45-km resolution  
  222 X 128
- D2: 15-km resolution  
  184 X 196
- D3: 5-km resolution  
  151 X 181
- 45 levels in vertical

Highest terrain in Domain 3 over CMR/Taiwan ≈ 3,271 m  
True elevation is 3,952 m
Configuration of DA system

- 4 times per day.
- Partial cycle was constructed by WRF 3D-VAR and WRF model
  - Background error covariance from NCEP GFS statistics (CV3) with length scale and variance tuning was used in 3DVAR
  - Assimilate all the GTS observations and GPSRO/ZTD
  - Typhoon initialization: vortex relocation and bogus synthetic sounding
- Model physics
  - Microphysic: Goddard MPS
  - Cumulus: Kain-Fritch scheme with new trigger function
  - PBL: YSU scheme
  - Surface layer: Monin-Obukhov scheme
  - Land process: NOAH
  - Long wave: RRTM
  - Short wave: Goddard
Performance of the CWB WRF in 2008~2011
Track forecast errors in 2008 ~ 2011

w: CWB issued warnings
QPF verification at 5-km resolution over Taiwan island
Important issues to improve the forecast performance

- To configure a robust DA system
- Assimilate the ZTD to improve model QPF
- Apply the GWDO parameterization to improve the wintertime forecast
- Remove the warm bias in KF scheme
Configure a robust DA system
The DA strategy

- Applying the partial cycle strategy
  - Cold start from NCEP GFS at the previous-12 hr, and cycling in every 6-hr interval

Take the advantage from the GFS analysis to avoid the bias drift in the data void area.

The 12-hr model forecast improve the spin-up problems from the cold-start initial condition.
Impact of the partial cycle strategy

The mean error of the composite analysis of full cycle (left) and partial cycle (right) experiment from 78 cases for 700 hPa temperature

Full cycling accumulated systematic bias over data sparse area.
Impact of the outer-loop

- To include the nonlinearities in the observation operators
- More use of the observations, in particular for GPSRO.
- Produce better model initial state.

More use of the observations (GPSRO)
RMSE from 78 forecasts
Mean typhoon track errors from 78 typhoon forecasts

![Graph showing mean typhoon track errors from 78 typhoon forecasts. The graph compares different cycling scenarios: Full cycling with OL, Partial cycling with OL, Partial cycling without OL, and Full cycling without OL. The y-axis represents track errors in km, and the x-axis represents forecast hours (hr). The graph includes bars and lines indicating improvements in track accuracy over time.](image-url)
ZTD DA to improve QPF
Impact of assimilating GPS ZTD

12 hr Accu. rainfall
QPF verification: 2008060100~2008061512

impact of assimilating ZTD during Meiyu season
Accu. rainfall from 08060100 to 08061212

OP24 00–12 hour Accumulated rainfall

OP23 00–12 hour Accumulated rainfall

OBS

With ZTD

W/O ZTD
GWDO parameterization to improve the wintertime forecast
Impact of the GWDO parameterization

RMSE of 72-hr forecast T and H for December 2008
New trigger function

The default KF trigger function that the temperature anomalies are correlated with vertical velocity only, i.e. related the KF temperature perturbation, $\Delta T$, to moisture advection.

The default KF trigger has undesirable characteristics especially in weakly-forced situations as those found in the tropics.

Ma and Tan (2009) proposed a new KF trigger which they tested in MM5.
\[ \delta T_{vv} = R_h \delta T_{vvh} + R_v \delta T_{vvv} \]

Where
- \( T_{vv} \) = temperature perturbation (DTLCL),
- \( R_h \) = normalized horizontal moisture advection,
- \( T_{vvh} \) = horizontal temperature anomaly from the surrounding 9 grid points,
- \( R_v \) = normalized vertical moisture advection, and
- \( T_{vvv} \) = vertical temperature anomaly from the adjacent 3 levels.

The convection was easier to be triggered as the RH > 75%.
Warm bias in KF

Warm bias

72-hr fcst

T MEAN ERROR

warm bias

Kain-Fritsch

Grell - Devenyi

72+hr fcst
Reducing areas of light rainfall without altering location of stronger systems.
Heating rate from KF

![Graph showing heating rate comparison between original and new trigger.](image)

*Average profile over x = 150.214, y = 7.71*
ECMWF analysis, K-F, K-F with new trigger function

Mean Temperature(K) at 850hPa

Initial from 00UTC 01 Jun 2008 to 12UTC 15 Jun 2008

0072-hr forecast

CONTOUR FROM 280 TO 308 BY 4
WRF

Standard KF

Sea Level Pressure (hPa)
Accumulated Rainfall (mm)

Sea Level Pressure Contours: 952 to 1020 by 4

New-trigger KF

Sea Level Pressure (hPa)
Accumulated Rainfall (mm)

Sea Level Pressure Contours: 952 to 1020 by 4

OUTPUT FROM WRF V3.1.1: MODEL
WE = 222 ; SN = 128 ; Levels = 45 ; Dts = 45km ; Phys Opt = 7 ; PB

Phys Opt = 7 ; PBL Opt = 1 ; Ox Opt = 1

TYPHOON – MORAKOT
Mean Error

RMSE

KF

KF with New trigger
<table>
<thead>
<tr>
<th>TWRF</th>
<th>0hr</th>
<th>12hr</th>
<th>24hr</th>
<th>36hr</th>
<th>48hr</th>
<th>60hr</th>
<th>72hr</th>
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<tr>
<td>KF scheme (km)</td>
<td>8</td>
<td>124</td>
<td>193</td>
<td>256</td>
<td>306</td>
<td>374</td>
<td>444</td>
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<tr>
<td>new KF scheme (km)</td>
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<td>103</td>
<td>152</td>
<td>186</td>
<td>189</td>
<td>225</td>
<td>284</td>
</tr>
</tbody>
</table>
Summary

- Continuous improvement on the forecast skill year after year in CWB WRF
  - Related to many efforts in the aspects of model process and data assimilation
  - To demonstrate a successful migration of the data assimilation system from the community to operation
    - Close cooperation between CWB and NCAR scientist