An Impact Study of COSMIC Refractivity Data on the CWB Global Forecast System

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Objective

To investigate the added values of GPS RO data by evaluating the impacts of GPS observations upon Taiwan’s CWB/GFS analyses and forecasts in various seasons, in order to justify the operational usage.
Introduction

- GPS/RO measurements have been assimilated into the analysis and forecast system at many operational weather centers and have demonstrated positive impacts on daily forecasts.

- The local refractivity operator has been built into the CWB/GFS three-dimensional variational system (SSI) and performed positive-to-neutral impacts to weather forecasts in low resolution (T179/L30) in last year.

- In this year, we upgrade the CWB/GFS resolution to T239/L30 and would like to see whether the positive-to-neutral impacts can still be found.
Local Refractivity Operator

\[ N = 77.6 \frac{p}{T} + 3.73 \times 10^5 \frac{e}{T^2} \]

3DVAR (SSI) technique to minimize the cost function

\[ J(x) = \frac{1}{2} (x - x_b)^T B^{-1} (x - x_b) + \frac{1}{2} (H(x) - y)^T (O + F)^{-1} (H(x) - y) + J_c \]

- \( x \) is the desired analysis, \( x_b \) is the first guess
- \( y \) represents the available observation (\( N^{GPS} \)), and \( H \) is the observational operator
- \( B, O \) and \( F \) are background, observational and representative error covariance matrices
Quality Check Algorithm

QC Algorithm for GPS data:

- BAD flag data from the TACC removed
- Observational outliers with the Z-scores > 4 removed (5% soundings discarded)
- Data clustering (<1 grid size or < 5 min) removed (3% soundings discarded)
- Large fractional increments (greater than 7% at each vertical level) removed (19% sounding discarded)
- Large bias (>1.5% or < -1% after vertical average) removed (2% sounding discarded)
Observation weighting function

\[ O^{-1} = w_2(H) = \frac{1}{RMS(N_{\text{mod}}(H) - N_{\text{obs}}(H))^2} \cdot \left[ \exp\left(-\frac{H}{7.7}\right) \right]^2 \]
Assimilation Procedure of GPS RO data

**Step I**
- Initial 1st guess (6-hr model forecast)
- All other available observations, except COSMIC GPS data.

**T239/L30**

**No GPS**
- 3DVAR (200/100)

**Step II**
- No-GPS analysis as 1st guess
- COSMIC GPS observation

**With GPS**
- 3DVAR (20 → 100)
- Final Analysis
Post-run: providing the first guess for the update cycle

7 days forecast

- 6hr fcst
- GFS
- 3DVAR
- Analysis
- First guess
- Observations

00UTC

- 6hr fcst
- GFS
- 3DVAR
- Analysis
- First guess
- Observations

06UTC

- 6hr fcst
- GFS
- 3DVAR
- Analysis
- First guess
- Observations

12UTC

- 6hr fcst
- GFS
- 3DVAR
- Analysis
- First guess
- Observations

18UTC

Time
Result

2007/07 (summer) 2008/01 (winter)

~70% of received data used  ~74% of received data used
Global Assimilation of GPS/RO Local Refractivity Data

2008/01 500-hPa H over Southern Hemisphere

→ Positive impact (higher AC score) as GPS data are assimilated
Better performance with increased model resolution

T179 results: dashed line  T239 results: solid line

North Hemisphere  
(20 N - 80 N)

South Hemisphere  
(20 S - 80 S)

The Tropics  
(20 S - 20 N)

2008/01 500-hPa AC Score
2007/07
RMSE H
Result

2007/07
RMSE U

2007 JUL
mean fru score
area--SA

[(nogps-gps)/nogps] * 100 & 95% confidence interval

2007 JUL
mean fru score
area--NA

[(nogps-gps)/nogps] * 100 & 95% confidence interval

2007 JUL
mean fru score
area--TP

[(nogps-gps)/nogps] * 100 & 95% confidence interval
SH winter (2008/01)

RMSE H

RMSE T

RMSE U
Anomaly Correlation Fractional Improvement Rate

Summer Month

2007 JUL  mean ach score  area--SA

Winter Month

2008 JAN  mean ach score  area--SA
### Positive: fractional improvement > 0.5%

### Neutral: fractional improvement < 0.5% and > -0.5%

### Negative: fractional improvement < -0.5%

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Temperature adjustment

Warmer temperature in the lower-to-middle troposphere over the SH is found as the GPS RO refractivity is assimilated into the CWB/GFS.
Moisture adjustment

Drier moisture in the lower and middle troposphere is found as the GPS RO refractivity is assimilated into the CWB/GFS.
Improvement of Track Forecast
---Typhoon Jangmi (2008)

Track Error of Typhoon JANGMI

- CTRL
- GPSRO

Track error (km)

Forecasting time (hr)

- GPS
- NOGPS
Improvement of Track Forecast
--- Typhoon Morakot(2009)

Track Error of Typhoon MORAKOT

![Map showing track forecast comparison between GPS and NOGPS](image)

Graph showing track error over forecasting time for Typhoon MORAKOT with GPS and NOGPS data.
After statistical evaluation of the GPS data impact for all variables at all levels on the CWB/GFS, it is clear that the positive impacts (or improvements) are mostly evident over the Southern Hemisphere.

Positive impacts can be still found over the Northern Hemisphere and Tropics, although their tendencies are not as clear as those over the Southern Hemisphere.

There are warmer temperature and drier moisture in the lower-to-middle troposphere as the GPS data is assimilated into the CWB/GFS.

Based of these systematic positive-to-neutral impacts, the CWB has officially included the COSMIC GPS data in the assimilation system for operational forecasts since 5 July 2009.