Reprint 579

Impact of Remote Sensing Data and Data Assimilation Strategies in the Mesoscale Modelling of Landfalling Tropical Cyclones

W.K.Wong, P.W. Li & Y.F. Tong

WMO International Workshop on Tropical Cyclone Landfall Processes, Macao, China, 21-25 March 2005

Impact of remote sensing data and data assimilation strategies in the mesoscale modelling of landfalling tropical cyclones

Wai-kin Wong*, Ping-wah Li and Yu-fai Tong
Hong Kong Observatory,
134 A Nathan Road, Hong Kong, China

Introduction

Mesoscale numerical weather prediction (NWP) models are useful in the study of complex physical processes of tropical cyclones (TCs) and their associated severe weather phenomena. Many mesoscale convective activities are embedded inside a TC circulation, and their predictabilities greatly depend on the initial states. In this connection, the assimilation of observations, especially remote sensing observations such as radar and satellite data, has significant impact on the performance of NWP models in giving guidance on heavy rain and high winds for landfalling TCs. In this paper, we shall discuss various NWP methodologies employed to improve the analysis and forecast of landfalling TCs utilizing remote sensing data.

Assimilation of radar data

At the Hong Kong Observatory (HKO), rainfall analyses (R-A) are generated by calibrating reflectivity data from two S-band Doppler radars against local raingauge network observations. The coefficients in the Z-R relationship are updated in real-time. The rainfall analysis is then employed to initialize the Operational Regional Spectral Model (ORSM) through physical initialization. The inclusion of additional radar and rain-gauge data from Guangdong is found to improve the calibration of Z-R relation (Li et al 2004). Furthermore, the composite radar imagery can be utilized to provide a wider and more detailed coverage. This facilitates the computation of circulation around approaching TCs using TREC (Tracking Radar Echoes by Correlation) employed in HKO's nowcasting system (Li and Lai 2004). In the simulation of landfalling TCs such as Hagupit (0218) and Dujuan (0313), the assimilation of the aforementioned rainfall estimate and TREC wind derived from composite radar imageries improves the 24-hour forecast track error using ORSM (Table 1). Other aspects such as improvement in the short-term TC intensity prediction and the enhancement of forecast convective activities around TC centres are also observed.

Experiment	A	B	C	D
Error (km)	91	112	113	129

Table 1. Summary of 24-hour forecast position errors in simulation for Hagupit and Dujuan. The statistics are calculated from 4 sets of simulation results for the two TCs. The data settings of the experiments are shown in Table 2.

Experiment	A	B	C	D
R-A using raingauges in HK and Guangdong	Y	Y	N	N
R-A using raingauges in HK only	N	N	Y	Y
TREC wind included	Y	N	Y	N

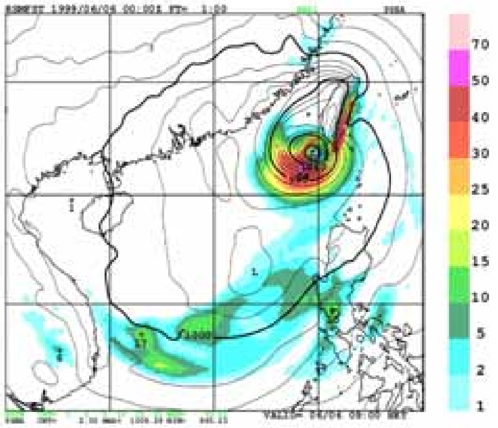
Table 2 Data setting in Experiments A to D.

Impact of data assimilation techniques

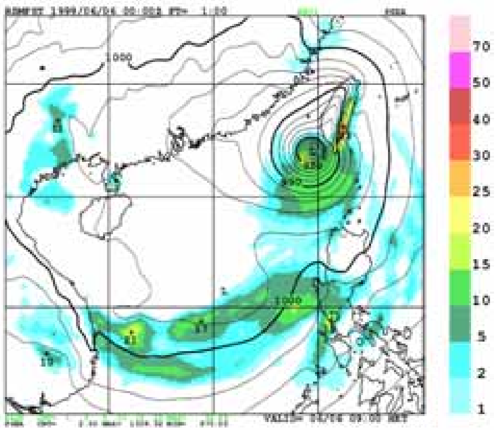
With the advent of more sophisticated data assimilation scheme such as 4DVAR, remote sensing data can be used more effectively to derive the best estimate of analysis by capturing the atmospheric evolution. The rainfall data from

*E-mail address: waikwong@hko.gov.hk

remote-sensing observations and the bogus TC vortices can be assimilated into the NWP model consistent with the model dynamics and physics. Numerical experiments are conducted at the HKO to investigate the use of satellite precipitation in 4DVAR (Koizumi et al 2003) to forecast the landfall of Typhoon Maggie (9903). In the experiments, rain rate estimates from TRMM microwave imager (TMI) and precipitation radar (PR) are assimilated. TC bogus vortices are ingested in each hourly-bin within the 3-hour assimilation time-window. Compared to the operational 3-dimensional optimal interpolation (3D-OI) scheme, 4DVAR can produce a more enhanced asymmetric distribution of moisture and precipitation around the TC centre (Figure 1). The subsequent intensity and precipitation predictions during landfall are also improved.



(a)

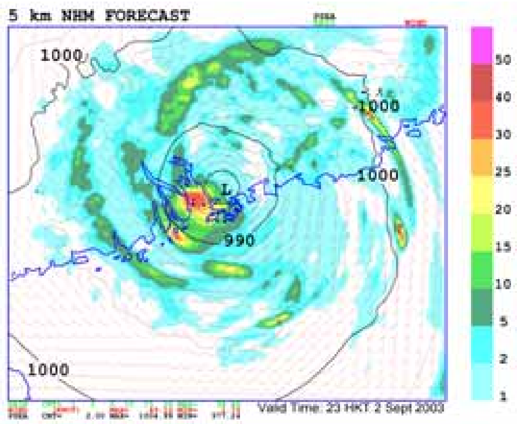


(b)

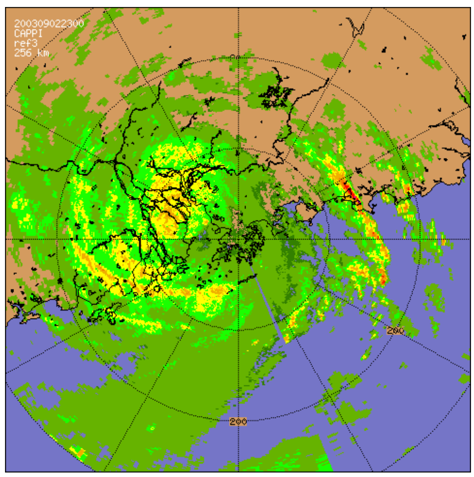
Figure 1. One hour forecast of MSLP and hourly precipitation by ORSM initialized at 00 UTC 6 June 1999 by (a) 4DVAR, and (b) 3D-OI.

Non-hydrostatic model

To further improve the modelling of cloud microphysical processes and vertical motion within TCs, numerical experiments using a non-hydrostatic model (NHM) (Fujita et al 2002) are also conducted. NHM has been put into trial operation at the HKO since April 2004. This model has horizontal resolution of 5 km with 45 vertical levels. In the current trial set-up, NHM is initialised by interpolating 20-km resolution ORSM analysis. Using the 3D-OI data analysis, improved with additional radar and rain-gauge data from Guangdong, positive impact on NHM to spin up various hydrometeors in microphysical processes is obtained. As shown in the simulation of Typhoon Dujuan (0313), the model can successfully simulate mesoscale rain bands around Dujuan (Figure 2) and local high winds during its passage in the vicinity of HK.



(a)



(b)

Figure 2. (a) Nine hour surface forecast of precipitation, and MSLP using 5-km resolution

NHM during the passage of T Dujuan (0313) in the vicinity of HK. NHM is initialised at 06 UTC 2 September 2003, (b) actual radar imagery at 15 UTC 2 September 2003.

Concluding remarks

The above studies on several landfalling TCs illustrate that by using more remote sensing data in model analysis, the analysed circulation and physical parameters of TCs can be improved, leading to better forecasts in precipitation and intensity. New techniques in the effective usage of these data through 4DVAR or high-resolution NHM with explicit cloud microphysics show promises of further improving short-range forecasting of TCs and related severe weather during landfall. In this connection, the ingestion of radial winds from Doppler radars and GPS precipitable water vapour measurements in operational mesoscale NWP applications at the HKO will be investigated in the future.

Acknowledgements

The authors would like to thank Mr. C.Y. Lam and Mrs. Hilda Lam for their valuable comments and suggestions. ORSM, 4DVAR and NHM are developed based on JMA's RSM, Meso-4DVAR and NHM systems respectively.

References

Fujita T., K. Saito, Y. Yamada, J. Ishida, M. Narita, S. Goto, C. Muroi, T. Kato and H. Eito, 2002: Development of a nonhydrostatic model for very short-range forecasting at JMA. Proceedings, 15th AMS Conf. Numerical Weather Prediction, 355-356.

K. Koizumi, Y. Ishikawa, T. Tsuyuki, S. Murakami and Y Sato: Precipitation assimilation to JMA mesoscale model using 4D-Var method, *GEWEX-GCPC Workshop on Objective Analysis of Precipitation 11-13 March 2003, ECMWF, Shinfield Park, Reading, UK*.

Li, P.W., C.K. Chow and H.Y. Yeung, 2004: Using the real-time data of the Guangdong automatic weather station network to improve rainstorm nowcasting in Hong Kong. *18th Guangdong-Hong Kong-Macao Seminar on Meteorological Science and Technology, 16-18 February 2004, Hong Kong, China (in Chinese).*

Li, P.W. and E.S.T. Lai, 2004: Applications of radar-based nowcasting techniques for mesoscale weather forecasting in Hong Kong. *Met. Appl.*,**11**, 253-264.

NPD/JMA 1997: Outline of the Operational Numerical Weather Prediction at the Japan Meteorological Agency, Japan Meteorological Agency, March 1997.