5.3 DEVELOPMENT OF AN ADVANCED AVIATION NOWCASTING SYSTEM BY INCLUDING RAPIDLY UPDATED NWP MODEL IN SUPPORT OF AIR TRAFFIC MANAGEMENT

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INTRODUCTION

Aircraft operations are dependent on weather. Many studies have pointed out that severe convective weather could bring adverse effects to flight safety and airport ground operations (e.g. Evans 2008). To help Air Traffic Management (ATM) better manage the flight traffic over the Hong Kong Flight Information Region (HK FIR), an Aviation Thunderstorm Nowcasting System (ATNS) is being developed by the Hong Kong Observatory (HKO) to predict the movement of thunderstorms near the Hong Kong International Airport (HKIA) and its neighbouring airspace in the next few hours. The prototype ATNS based on the HKO's nowcasting system, viz. the SWIRLS (Short-range Warnings of Intensity Rainstorm in Localized System), has been described in Li (2009). This prototype is based on automatic tracking and prediction of the future movement of thunderstorms using Doppler weather radar information and artificial intelligence methods.

Owing to the nature of the extrapolation technique, SWIRLS can only provide reliable forecast up to, say, one or two hours ahead. In order to extend the forecast range and to cover the development and dissipation of thunderstorms, the concept of blending nowcasting technology with Numerical Weather Prediction (NWP) model output is being explored in order to improve forecasts in the next 1-6 hours. The NWP model in use is a high resolution non-hydrostatic model with horizontal resolution of 5 km. The extended nowcasting system is named Advanced Aviation Nowcasting System (AANS).

This paper illustrates the concept of the AANS under development and provides some preliminary assessment of its performance.

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1. RADAR-BASED AVIATION NOWCASTING SYSTEM

The Aviation Thunderstorm Nowcasting System (ATNS) was based on the technology of HKO's nowcasting system SWIRLS (Li 2009). SWIRLS automatically tracks and predicts the future movement of radar echoes based on Doppler weather radar information. The system uses artificial intelligence methods, especially the pattern recognition technique, to automatically track the past movements of thunderstorms. Projection of the future position of the thunderstorm is based on semi-Lagrangian advection scheme. SWIRLS participated in the Forecast Demonstration Project under the World Weather Research Programme (WWRP) of World Meteorological Organization (WMO) during the Beijing 2008 Olympics Games and was demonstrated to be one of the most advanced nowcasting systems (Ebert et al. 2009).

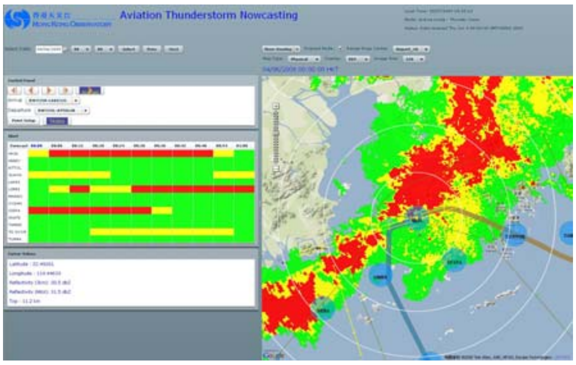
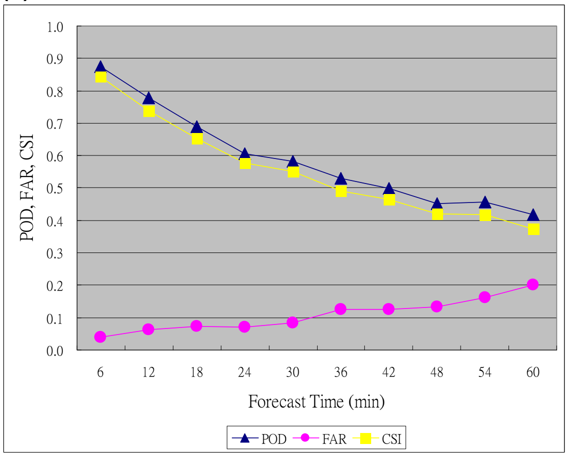


Figure 1 – Sample display of the GIS-based ATNS. The blue dots indicate the locations of the ATM way-points. The time series on the left show the severity of the forecast radar reflectivity at the way-points in the next hour in 6-minute intervals. Amber and red represent dBZ ≥33 and ≥41.respectively.

A prototype of the ATNS has been introduced to local ATM and airlines since 2008 with positive user feedback. Based on the feedback, the previous version of the prototype has been enhanced with a number of new features.

(a) HKO ATNS



(b) TITAN

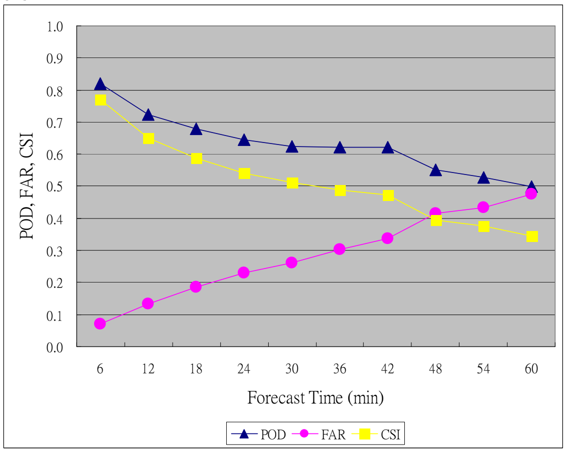


Figure 2 – (a) Sample display of the skill scores of the ATNS; (b) the corresponding skill scores of TITAN.

In particular, the previous version of the prototype provides 1-hour forecast radar reflectivity of thunderstorm at some prescribed altitudes within about 120 km of HKIA. The latest ATNS has been enhanced by including the actual and forecast heights of cloud top as well as the actual and forecast intensities of the vertically integrated liquid water amounts. Meanwhile, to facilitate the users to appreciate the weather with reference to geographical information, ATNS has been enhanced to utilize the Google Map / Geographical Information System (GIS) technology (Figure 1). Apart from the usual GIS information such as the latitude/longitude, terrain height and boundary information, users can also add/delete way-points of their choices, read out the storm intensity (radar reflectivity value), cloud top as well as maximum reflectivity value of a vertical column of the atmosphere at any particular location. Such information would be useful to ATM operations. A trial website has been developed for evaluation and familiarization by the users.

Figure 2a shows verification results of ATNS during a severe thunderstorm case on 4 June 2009. The thunderstorms on that day moved from southwest to northeast and brought heavy downpour and active lightning to the airport. Forecast reflectivity values at the way-points as illustrated in Figure1 were extracted for calculating the performance indices, including POD (Probability of Detection), FAR (False Alarm Ratio) and CSI (Critical Success Index). The actual reflectivity values of the radar echoes at the way-points at the respective time were used to calculate the above mentioned performance indices. The reflectivity threshold of 33 dBZ is considered.

To further study the performance of the ATNS in comparison with other available nowcasting systems, the version 5 of the TITAN nowcasting system (Thunderstorm Identification, Tracking, Analysis and Nowcasting) (Dixon et al. 1993) was setup as a comparison. Polygon objects of the actual/forecast radar reflectivity identified in TITAN were used to determine the performance indices. Comparing Figures 2a and 2b, it can be seen that though the POD of TITAN was higher than that of the ATNS within the 60 minute forecast period, the FAR of ATNS, in contrary, was much smaller than that of TITAN. Overall speaking, the CSI showed that ATNS outperformed TITAN slightly for that particular case. More cases are being conducted in order to come up with more comprehensive comparison results.

2. DEVELOPMENT OF THE ADVANCED AVIATION THUNDERSTORM NOWCASTING SYSTEM

A number of studies are being carried out at HKO to further improve the quality and enhance the reliability of the ATNS. One area which requires further study is the growth and dissipation of thunderstorm. The extrapolation approach to predict the thunderstorm location and intensity in the ATNS is limited in providing information about the rapid development of a thunderstorm. This is recognized within the meteorological community worldwide as one of the most difficult and challenging subjects, requiring the inputs of more sophisticated forecasting techniques such as numerical weather prediction (NWP) models.

At HKO, the SWIRLS-NWP blending technology has been developed and put into operational trial since 2005 (Li et al. 2005 and

Wong et al. 2009). The idea is as follows: SWIRLS provides skilful thunderstorm nowcast in the next one to two hours, especially in the situations where the advection of precipitation system is dominant. However, when the thunderstorm motion is erratic or when radar echoes develop or dissipate rapidly, advection methods are less reliable. More sophisticated forecasting techniques such as high resolution NWP models would be necessary, especially in the forecast range beyond 3 hours. On the other hand, NWP models usually suffer from the intrinsic "spin-up" problem, hence hindering reliability of numerical prognoses in the first couple of hours. To achieve an optimal performance in the 1 to 6 hour forecast range, blending SWIRLS with NWP forecasts is adopted to generate an optimal solution.

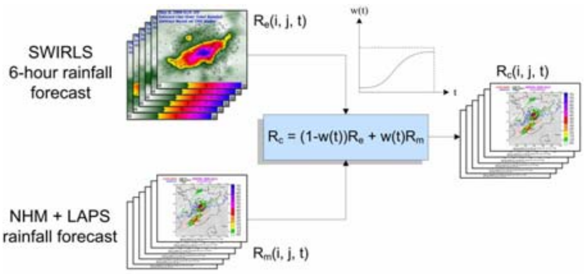


Figure 3 – Schematic diagram showing the components of the Advanced Aviation Nowcasting System adopting the SWIRLS-NWP blending approach.

The NWP model used is based on the Non-hydrostatic Model (NHM) developed by the Japan Meteorological Agency (JMA) (Saito et al. (2007)). Currently, NHM is configured with a horizontal resolution of 5 km covering about 600x600 km^2 around Hong Kong. The model configuration, dynamics and physical schemes are summarized in Table 1. The initial condition of NHM is based on the forecast from the HKO's Operational Regional Spectral Model (ORSM) with horizontal resolution of 20 km, with moisture analysis from LAPS (NOAA/GSD Local Analysis and Prediction System) (Albers et al., 1996). Local observations, including radar (reflectivity and Doppler velocity volumes), geostationary satellite (visible albedo, brightness temperature from infrared and water vapour channels), automatic weather stations (AWS) and radiosondes are ingested into LAPS to generate a three dimensional analysis of humidity and hydrometeors. The background fields in LAPS analysis are obtained from the forecasts of NHM.

The algorithm in AANS consists of the following procedures: (i) SWIRLS radar forecast reflectivity, converted into surface precipitation using dynamic reflectivity-rainfall (Z-R) relation; (ii) precipitation forecast from the NHM; and (iii) blending process (Figure 3). The whole blending involves sophisticated procedures which are described in the following:

(i) phase correction: to tackle the problem of spatio-temporal errors in the model precipitation forecast, phase correction is applied to the direct model output Location departure in the forecast precipitation patterns from NHM is estimated with respect to the actual radar-rainfall distribution (i.e. radar-estimated rainfall calibrated against rain-gauges). Variational technique is adopted which minimizes the root mean square error of the forecast rainfall field from a previous model run (usually initialized at 1-2 hours before) and the actual precipitation distribution (Wong et al. 2009).

(ii) calibration of intensity of model QPF: correction of the intensity of model precipitation based on radar-based quantitative precipitation estimate (QPE), and

(iii) blending of calibrated model QPF with the radar nowcast, with larger weighting assigned to the nowcast component at short lead times and increasing weighting to the NWP component as lead time increases to 6 hours.

The blended forecast precipitation is then converted back to forecast radar reflectivity at the way-points. In the dynamic Z-R conversion, the actual rainfall amounts recorded at rain gauges are correlated with the reflectivity values at some prescribed altitude via the $Z=aR^b$ formula. The parameters a and b could change from time to time as the storm progress.

Figure 4 shows the comparison between the effects of ATNS using SWIRLS simple extrapolation (1-6 hours forecasts) and AANS using SWIRLS-NHM blended forecasts for the case of 4 Jun 2009 (1-6 hour forecasts). The right panels of the figure are radar-based QPE at the respective forecast hours. It appears that the rainfall forecasts produced by simple extrapolation over-estimate the rainfall beyond 2 hours. The blended approach, however, produces forecast precipitation field resembling that based on the radar echoes. This experiment demonstrates that the SWIRLS-NHM blending method could produce rather reasonable forecasts, making it a feasible approach to extend the skill of the thunderstorm nowcast beyond the first couple of hours.

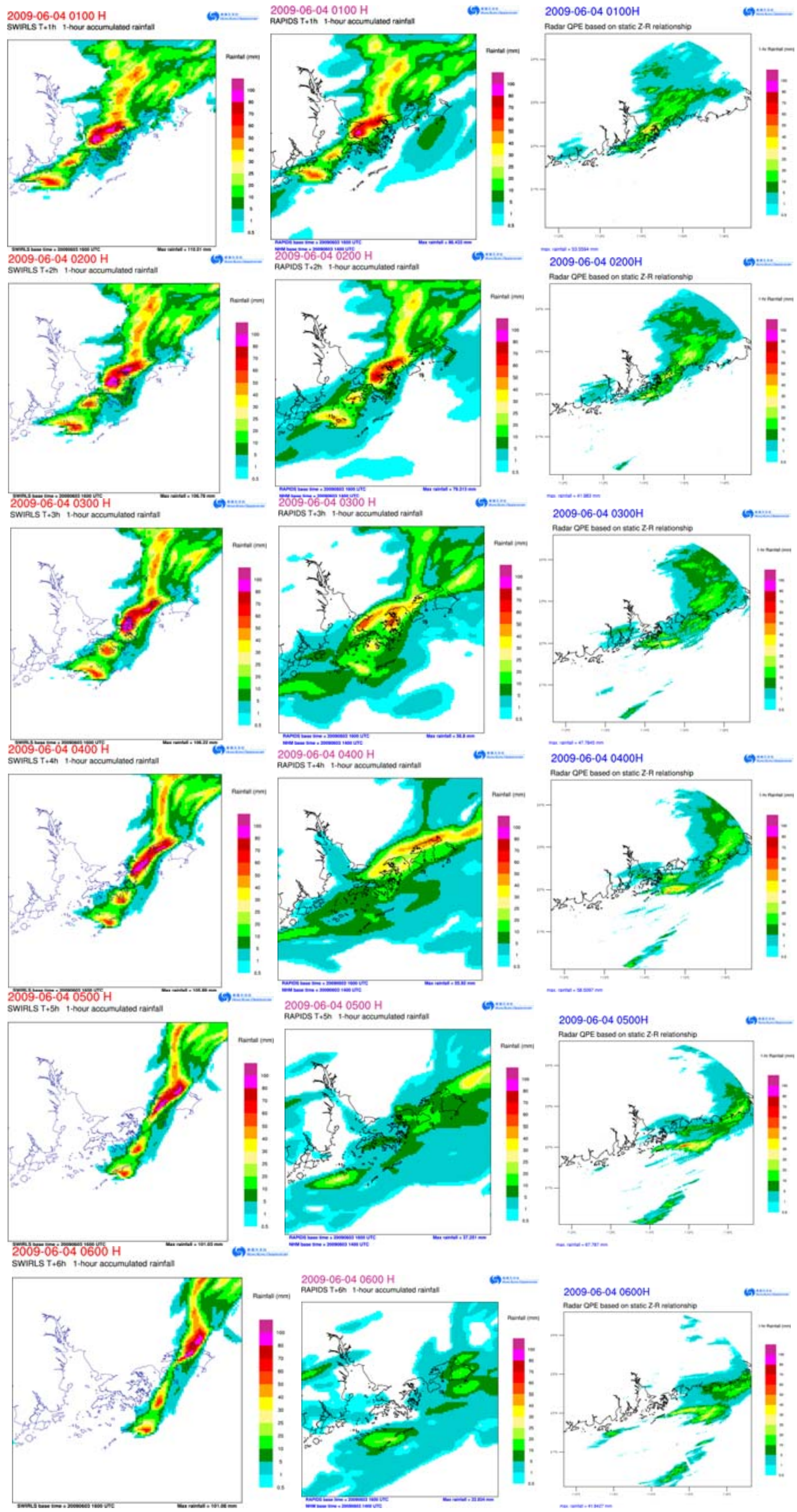


Figure 4 – An example showing the comparison between the effects of SWIRLS simple extrapolation and blending of SWIRLS and NHM rainfall forecast under development. Figures from top to bottom are 1-hr, 2-hr, …, 6hr simple extrapolation (left column) and AANS blended precipitation (middle column) forecasts. Figures on the right show the corresponding radar-based QPE (different scale).

Figure 5 shows the verification results of the performance of ATNS (only with simple extrapolation up to 6 hours ahead) and AANS for the 4 Jun 2009 case. The same set of way-points and radar reflectivity threshold as in Sec. 1 above are used in the verification. It can be observed that the AANS has a higher probability of detection (POD) than ATNS through the blending of the two forecasts beginning from the 1-hr forecast time. While the POD of the simple extrapolation in the ATNS drops rapidly with time after 1-hr forecast time, the POD of AANS maintains at rather stable level at around 0.5 between 2-hr and 4-hr until it drops below 0.4 after 5 hours. These demonstrate that the blending approach produces improved results in comparison with the simple extrapolation approach of the ATNS, especially beyond 1 hour ahead.

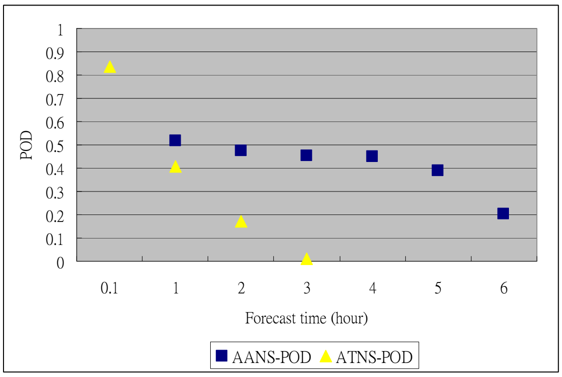


Figure 5 – POD of the extended ATNS (simple extrapolation up to 3 hours ahead) and AANS (blended SWIRLS-NHM) forecasts upto 6 hours ahead.

3. ON-GOING DEVELOPMENT

Examples shown in Sec. 2 above indicate that the blended SWIRLS-NWP approach can produce reasonable results. A number of further development works are required to further enhance and improve the quality and the reliability of the aviation thunderstorm nowcasting products. These include the upgrading of the extrapolation method from the current TREC (Tracking Radar Echo by Correlation) method to more advanced tracking method such as MOVA (Multiscale Optical flow by Variational Analysis) (Wong and Lai, 2009) which takes into account the movements of the radar echoes at different spatial scales simultaneously. Meanwhile, HKO's NHM will be upgraded in 2010 to increase the horizontal resolution from the existing 5 km to 2 km. In connection with that, a 3-dimensional variational data analysis (3DVAR) will be implemented with a view to ingesting more types of local observations including LIDAR, microwave radiometer, Terminal Doppler Weather Radar, etc. Furthermore, more experiments will be carried out to further increase the horizontal resolution of the NHM model down to sub-km scale, as well as tuning the data assimilation scheme.

In summary, the AANS under development is designed to provide ATM and airline users an overall picture at a glance of the anticipated impact of thunderstorms to flight routes and significant ATC points. It is hoped that this development could meet the users' needs to further enhance aviation safety and efficiency required by the future ATM systems. Meanwhile, the AANS could also be used for the development of the new terminal forecast (NTF) products now being collaboratively developed by WMO and ICAO for providing forecasts of weather elements critical to aviation in the terminal area with much finer resolution in space and time.

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Model version	JMA-NHM (ver. 0902)
Horizontal resolution	5 km
Number of grid points	121x121x45
Forecast Range	12 hours
Update cycle	1 hour
Horizontal grid	Arakawa-C
Vertical coordinates	Terrain following height coordinates on Lorenz grid
Initial condition	20km ORSM forecast Specific humidity of water vapour, cloud liquid water, cloud ice, snow and graupel can be initialized by LAPS (ver. 0-32-15) cloud moisture analysis
Observations assimilated in LAPS	- SYNOP, HK AWS, GD AWS - radiosonde data, wind profiler - MTSAT-1R IR brightness temperature and visible albedo - Radar reflectivity and Doppler velocity
Boundary condition	20 km ORSM
Map projection	Mercator
Dynamics	Fully compressible non-hydrostatic governing equations, solved by time-splitting horizontal-explicit-vertical-implicit (HEVI) scheme and 4th order spatial centred finite differencing in flux form
Physical processes	- Kain-Fritsch convective parameterization scheme - Three ice bulk cloud microphysics scheme - Surface flux based on Beljaars and Holtslag (1991) - Mellor-Yamada-Nakanishi-Niino Level 3 (MYNN-3) turbulence closure model with partial condensation scheme (PCS) - Long wave radiation process follows Kitagawa (2000) - Short wave radiation process using Yabu et al. (2005)

Table 1. Model configuration of NHM in HKO.