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Application of Numerical Weather Prediction Prognoses
to Operational Weather Forecasting in Hong Kong

Mrs. Hilda Lam

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Hilda Lam
Hong Kong Observatory
Hong Kong, China

1. Introduction

In the past few decades, there have been tremendous advances in the field of numerical weather prediction, contributing to significant improvements in operational weather forecasting and weather services. This paper traces the use of NWP in Hong Kong since the 1980’s and the positive impacts on forecast performance in general. However, there are still recent occasions in which numerical models fail to capture changes in weather systems. A few examples are presented below, illustrating difficulties forecasters still face. The paper concludes with some suggestions to bring about more effective utilization of NWP for operational forecasting.

2. Past and current application of NWP prognoses at the Hong Kong Observatory (HKO)

In the early 80’s, forecasters got by with a couple of faxed numerical prognostic charts for the next 48 to 72 hours at the 500hPa level and at the surface. In 1985, model output in the form of grid point values were received from the global models of ECMWF and the UK Met Office via GTS and HKO began generating prognostic weather charts in-house for forecasters’ reference (Lam 1989).

A more complete suite of model output (2.5 degree resolution) from ECMWF was made available in 1989. Finer model (GSM) output at 1.25 degree resolution up to T+120 hours was routinely acquired from JMA in 1996. Besides generating prognostic charts and time series products (Figure 1) from direct model output, HKO applied post-processing techniques on the model maximum and minimum temperature forecasts, including Kalman filtering and linear regression techniques to reduce model bias (Figure 2). Algorithms were developed to generate automatic weather forecasts (Figure 3) based on model output without human intervention to assist forecasters in utilizing increasing amount of model output in an efficient manner (Lam 2005). The extended forecast range of model output also allowed the forecast to cover up to 5 days in 2000.
HKO obtained global model output for the first time from the NCEP via FTP over the internet in 2002. Forecasters at the HKO routinely scrutinize global model output from the above sources in formulating the medium range forecast which covered up to 7 days in 2003.

In 2004, HKO began to acquire EPSgrams from ECMWF at four grids in the vicinity of the territory (Figure 4), providing forecasts of various weather parameters at 6-hourly intervals up to T+240 hours based on its global deterministic models as well as its ensemble prediction system. This product has become an essential tool for forecasters as it has the benefit of the full resolution of the global model and prediction in finer temporal steps (every 6 hours), resulting in more precise guidance on the changes in weather parameters, e.g. temperature fall associated with the arrival of cold front or onset or cessation of rain with the passage of a monsoon trough.

In 2009, we saw even higher resolution global model output from JMA and ECMWF, with 0.5 degree and 0.25 degree for the former up to T+216 hours and 1 degree resolution for the latter up to T+ 168 hour.

Besides utilizing global model output from other centres, HKO has also operated its regional spectral model (ORSM) since 1999. Adapted from JMA’s RSM, the ORSM has an outer domain of 60 km resolution, one way nesting into an inner domain of 20km resolution (Figure 5). It runs once very three hours, producing forecasts up to T+48 hours originally and later extended to T+72 hours. The model output has the benefit of incorporating latest local data such as wind profilers and radar reflectivity as well as better temporal and spatial resolution for capturing and forecasting mesoscale systems. It provides high spatial resolution products such as temperature forecasts for various parts of Hong Kong (Figure 6). To take advantage of the rapid update cycle, time-lagged ensemble products for various parameters are also produced for forecasters’ reference (Figure 7). To enhance our short-range forecasting, the HKO started experimenting in 2004 the operation of a non-hydrostatic model (NHM) adapted from JMA. Currently it is operated at 5 km resolution with a forecast period of 12 hours. The NHM model, with hourly run cycle, is coupled with our radar/raingauge based nowcasting system, SWIRLS (Yeung et al 2008), to extend quantitative rainfall forecast from 6 hours to 12 hours ahead.

A summary of models used in weather forecasting in Hong Kong since the 1980’s is given in Table 1. Details of the current NWP models used
at the HKO are given in Table 2.

3. Forecast performance

With the support of NWP guidance, the HKO provides weather service in Hong Kong, including the issue of public weather forecast for the next day and 7-day medium range forecast. The HKO also operates severe weather warnings including tropical cyclone warning for the local community as well as serving the shipping and aviation sectors over the western North Pacific and South China Sea.

To gauge our public forecast performance, the HKO has routinely performed forecast verification since 1980’s using objective verification schemes (Li 1997). The current scheme was set up in 1987, assigning success scores for each of the parameters in a daily weather forecast, namely, wind, maximum and minimum temperature, precipitation, state of sky and visibility. A final score for the weather forecast is obtained by taking the weighted average of parameter scores, the weighting being different in different seasons to reflect the importance of the parameters perceived by the public in different times of the year.

Figure 8 shows the monthly mean verification score of the local weather forecasts for the next day in the past 30 years or so. A gradual increasing trend is observed which can be attributed predominantly to improvement in the skill of NWP and the availability of model output of increasingly higher resolution for operational use. The rather prominent rise in the scores around 1989 and the sustained improvement after 2004 can be related to the availability of 2.5 degree ECMWF prognoses and EPSigrams respectively.

Figure 9 gives the monthly mean verification score of 7-day forecasts, showing definite improvement in the scores over the years. It can be observed that the current day-five forecast score is higher than the day-one score in 1990 and higher than the three-day forecasts in 2000. However, the performance of 6-day and 7-day forecasts which were introduced after late 2003, does not show very marked improvement over the past few years.

The HKO has been issuing tropical cyclone (TC) forecasts for the area 10-30 °N 105-120 °E for years. Figure 10 depicts the HKO TC forecast track error since the 1970’s. The decreasing track error, e.g. the 48-hour track error, again reflects the advancement in the NWP skills since the 1990’s. The reduction in track error in recent years may also be
attributed to the adoption of multiple-model ensemble technique (Wu and Lam 2007) in TC forecasting since 2002. The example of Typhoon Chanchu in 2006 epitomizes the power of NWP. The 90-degree turn of the storm around 15 May was correctly predicted by global models 3 days before, i.e. from 12 May onwards (Figure 11).

Under the WMO framework and through cooperation with main numerical prediction centres, NWP model prognoses are made available to HKO, resulting in the general improvement in forecast performance in the short to medium range. The public also finds our forecast service increasingly satisfactory. In regular public surveys, the score given to the HKO services increased from around 70% in early 1990’s to about 80% in recent years.

4. Cases of unsatisfactory forecasts

Despite the tremendous progress in model skills, there were still occasions when model prognoses gave consistently unsatisfactory forecasts. Some recent examples in our region are described below:

a) A prolonged cold spell in early 2008 over south China

Hong Kong experienced the longest cold spell from 24 January to 16 February in 40 years with the mean minimum temperature staying below 12 degrees Celsius throughout that period. The mean minimum temperature recorded at the Hong Kong Observatory during 24 January - 13 February was 9.9 degrees, the second lowest during the same period since record began in 1885.

This exceptionally long cold spell was a result of the cold air from Siberia moving south to reach central and southern China incessantly, while moist air was transported from the South China Sea and even as far as the Indian Ocean. The rendezvous of the cold and moist air brought continuous cloudy, rainy and cold weather to the region.

Tong et al (2008) analysed the forecast aspect of this cold spell and pointed out that global models predicted reasonably well the outbreaks of cold air in southern China, associated with the passages of high- and low-latitude (the southern branch) westerly troughs in the medium term. This can be illustrated by the reasonable agreement between the actual and forecast 24-hour pressure change in Hong Kong (Figure 12). However, the intensity of the cold spell was severely underestimated. An average warm bias of 2 to 4 degrees in the model 72-hour forecast surface
temperature was observed over most of south China during that period. Besides exhibiting significant warm bias, the forecast temperature was sometimes even out of step with the actual one, particularly in the early part of the episode (Figure 13), impacting on the accuracy of our public weather forecasts.

b) Typhoon Fengshan in 18-26 June 2008

Fengshan developed into a tropical depression over the western North Pacific to the east of the Philippines on 18 June. Moving in a west-northwest direction, it intensified into a typhoon on 20 June before crossing the Philippines. Fengshan entered the South China Sea along a northwest track on 22 June and weakened into a severe tropical storm. Fengshan turned gradually to the north and made landfall just to the east of Hong Kong on 25 June. The post analysed track of Fengshan is given in Figure 14.

All global models continuously predicted recurvature of Fengshan to the north and then north-northeast from 19 June to 23 June, for most of Fengshan’s life time, although Fengshen actually moved along a west-northwest to north-westward track (Figure 15). Post-analysis indicated that it was due to models continuously over-weakening the 500 hPa subtropical ridge to the north of the TC (Figure 16), resulting in great uncertainty over Fengshan’s track throughout the period (Chan and Chan 2008). Large forecast errors were incurred in both short and medium term forecasts. The Philippines was severely hit with over 200 deaths and around 800 missing in a capsized passenger ship. Fengshan spared Taiwan but brought havoc to Hong Kong and cities in the vicinity.

c) The combination of Typhoon Ketsana and the northeast monsoon over the south China coast, September - October 2009

From 27 to 29 September 2009, a continental anticyclone prevailed over south China while Ketsana moved westwards across the northern part of the South China Sea, roughly along the 15 degree latitude, attaining typhoon intensity on 28 September. At the same time, an upper-level trough moved from west to east over south China on 27 and 28 September. Figure 17 shows the surface analysis and satellite imageries of selected days during the period.

The NWP models captured the evolution of these systems in general and predicted that the undercutting of warm and moist air mass brought by Ketsana by the cooler continental air mass, coupled with the moisture
laden upper-air westerly trough would produce precipitation in Hong Kong on 28 and 29 September with showers easing off the next couple of days. The 12-hourly rainfall forecast taken from the ECMWF model grid closest to Hong Kong and the actual rainfall recorded at the HKO are plotted in Figure 18. It can be seen that while rainfall forecast for the 28th and 29th was satisfactory, the heavy rain amounting to some 60 mm in 2 hours which occurred on the latter part of 30 September, was not forecast by the model. The prognostic chart valid for 12 UTC on 30 September in Figure 19 indicated the same. Radar imageries in Figure 20 show that the heavy rain developed over waters to the south and moved northwards to affect Hong Kong.

When forecasters are confronted with situations in which the actual differs substantially from the model forecast, they have to resort to their synoptic reasoning, past experience and other legacy rule of thumbs to decide on their forecast for the next day. Luckily, our forecasters made the right decision and provided a reasonable weather forecast for 1 October which is the national day with many ceremominal and celebration functions held outdoor.

5. Conclusion

In the past few decades, advancement in NWP undoubtedly has enabled meteorological services to provide more accurate forecasts for longer forecast periods, enhancing the standing of the meteorological services and raising public expectation about weather forecasts. Forecasters nowadays work differently, having to assimilate and interpret a large amount of model output from different sources of NWP models and ensemble forecasting systems. Occasional inaccurate model forecasts become more difficult to handle: forecasters who have relied so much on NWP, suddenly find themselves on their own and have to rely on their synoptic reasoning, physical and dynamical understanding of the atmospheric processes, statistical tools and rule of thumbs to come up with a weather forecast; and public’s generally high expectation has to be managed.

In order to further improve NWP model performance, it may be beneficial to foster closer cooperation between operational forecasters and model developers. Systematic verification results of model performance by operational weather services for their location of interest, as well as cases of inaccurate forecasts may be referred to model developers to help improve model skills. In cases in which models persistently produce inaccurate forecasts, advice from model developer
on how best to make use of the model output may be useful to operational forecasting. Careful review of cases involving inaccurate model forecasts by operational forecasters may yield lessons to be learnt for the benefit of future applications.

Acknowledgement:

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References


Li, S.W., 1997: Royal Observatory’s Objective Forecast Verification Schemes. *Hong Kong Observatory Technical Note (Local) No. 70*, Hong Kong Observatory.


Table 1: A summary of models used in weather forecasting in Hong Kong Observatory since the 1980’s

(a) Global models

<table>
<thead>
<tr>
<th>Year</th>
<th>Model Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early 1980's</td>
<td>Mufax JMA 500 mbar circum-polar forecast charts</td>
</tr>
<tr>
<td>since 1985</td>
<td>Grid point value model outputs from ECMWF and UKMO via Global Telecommunication System (GTS) in range of 5 to 2.5 degrees for T+72 hours</td>
</tr>
<tr>
<td>1989</td>
<td>ECMWF 2.5 degrees model output via GTS for T+72 hours</td>
</tr>
<tr>
<td>1996</td>
<td>JMA's GSM 2.5 degrees products, up to T + 120 hours and 1.25 degrees products</td>
</tr>
<tr>
<td>1999</td>
<td>additional ECMWF 2.5 degrees GPV products, up to T + 120 hours via GTS</td>
</tr>
<tr>
<td>2002</td>
<td>global model products from the US NCEP 1 degree products, up to T + 96hrs, via Internet</td>
</tr>
<tr>
<td>2004</td>
<td>● ECMWF EPSgrams for 4 grids around Hong Kong acquired through contract in April</td>
</tr>
<tr>
<td></td>
<td>● ECMWF 00UTC prognostic charts since July 2004 via GTS</td>
</tr>
<tr>
<td>2006</td>
<td>ECMWF products were extended to T + 240hrs</td>
</tr>
<tr>
<td>2007</td>
<td>NCEP products were extended to T + 240hrs</td>
</tr>
<tr>
<td>2009</td>
<td>● JMA 0.5 degree resolution products and 0.25 degree, up to T + 216hrs</td>
</tr>
<tr>
<td></td>
<td>● ECMWF 1 degree resolution products, up to T + 168hrs, 0.25 degree for surface only</td>
</tr>
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</table>

(b) Regional models

<table>
<thead>
<tr>
<th>Year</th>
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</tr>
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<tr>
<td>1988</td>
<td>The very fine mesh limited area model of the JMA was adapted to Hong Kong as OLAM. The model was run once a day at 1 degree horizontal resolution to produce 6-hourly forecasts up to 72 hours</td>
</tr>
<tr>
<td>1999</td>
<td>The Operational Regional Spectral Model (ORSM) was adapted from JMA’s RSM, with an outer domain at 60 km resolution up to T+48hours, nested into an inner domain at 20 km resolution up to T+24 hours</td>
</tr>
<tr>
<td>2003</td>
<td>The forecast ranges of the outer domain and inner domain of ORSM were extended to 72 hours and 42 hours respectively</td>
</tr>
<tr>
<td>2004</td>
<td>The Non-hydrostatic Model (NHM) adapted from JMA began to run at 5 km horizontal resolution up to T+12hour</td>
</tr>
<tr>
<td>model</td>
<td>grid</td>
</tr>
<tr>
<td>--------------</td>
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</tr>
<tr>
<td>ECMWF</td>
<td>2.5 deg</td>
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<tr>
<td></td>
<td>1 deg</td>
</tr>
<tr>
<td></td>
<td>0.25 deg</td>
</tr>
<tr>
<td>JMA</td>
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<td></td>
<td>0.25 deg</td>
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<tr>
<td>UKMO(EGRR)</td>
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<tr>
<td>NCEP</td>
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</tr>
<tr>
<td>ORSM</td>
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<tr>
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<tr>
<td>NHM</td>
<td>5km</td>
</tr>
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</table>
Figure 1 Prognostic charts and time series charts generated from direct model output from global NWP models.
Figure 2  JMA temperature forecast product showing direct model forecast, Kalman-filtered and regression post-processed forecasts

Figure 3  Automatic weather forecast covering the weather for the next 7 days
Figure 4  EPSgram from ECMWF

Figure 5  Domain of ORSM – regional forecast model operated by HKO: inner domain for 20km model run; the outer domain for 60km model run.
Figure 6  Regional temperature forecast by 20-km ORSM

Figure 7  Time-lagged ensemble for temperature and rainfall
Figure 8  Monthly mean verification score and 12-month running average of the local weather forecasts for the next day.

Figure 9  Monthly mean verification score of 7-day forecasts. Forecast advanced from 3-day in 1983, to 4-day in 1998, became 5-day in 2000 and currently a week long since late 2003.
Figure 10  HKO tropical cyclone forecast track error

Figure 11  Displayed in the HKO’s Tropical Cyclone Information Processing System (TIPS) are the forecast tracks by various models and multi-model ensemble (green) forecast track of Chanchu with base time at 12 UTC on 12 May 2006 when Chanchu was crossing the Philippines. HKO warning positions for shipping is also shown in black.
Figure 12 72-hour forecast pressure change in 24 hours (PC24). Initial time at 12 UTC daily from 24 January to 17 February 2008. Purple and red lines denote forecast and actual PC24 respectively.
Figure 13 ECMWF EPSgram for Hong Kong SE grid showing the temperature forecast (blue) and the corresponding observed temperature at HKO (magenta). Orange line marked the forecast initial temperature.
Figure 14  Post-analysed track of Typhoon Fengshan

(a) 00 UTC on 19 June 2008  
(b) 00 UTC on 22 June 2008  
(c) 00 UTC on 23 June 2008  
(d) 00 UTC on 24 June 2008

Figure 15  Forecast tracks of Fengshan predicted by global models
Figure 16 ECMWF 500hPa geopotential heights charts at 12 UTC on 24 June 2008.
Figure 17  (a) to (c) Surface analysis and (d) to (f) satellite imageries around 00 UTC on 26, 29 September, 1 October 2009.
Figure 18  12-hourly rainfall forecast taken from the ECMWF model grid closest to Hong Kong and the actual rainfall recorded at the HKO. A “missing” bar means a 0 mm forecast.

(a) 26 September  
(b) 27 September  
(c) 28 September  
(d) 29 September

Figure 19  The surface prognostic charts valid for 12 UTC on 30 September with base time at 12 UTC on 26-29 September 2009
Figure 20  Radar echoes moving in from the south to affect Hong Kong on 30 September 2009.