JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2007

Hong Kong Observatory, Hong Kong, China

1. Summary of highlights

(i) Post-processed model guidance based on the 60-km Operational Regional Spectral Model (ORSM) was developed to support the Pre-Olympic equestrian events held in Hong Kong (see 4.3.4.1(i)).

(ii) A suite of new model ensemble products for tropical cyclone (TC) forecasting was launched for the TC season of 2007 (see 4.3.4.1(vii)).

(iii) Several new modules for severe weather nowcasting, namely lightning, downburst / wind gust and hail, were implemented on the operational nowcasting system SWIRLS and put under trial in support of thunderstorm warning operation in Hong Kong (see 4.4.1.1).

(iv) To participate in the WMO/WWRP Beijing 2008 Forecast Demonstration Project, the upgraded nowcasting system SWIRLS-2 was successfully put into real-time trial in Beijing in the summer of 2007 (see 4.4.1.2).

(v) A suite of global-regional spectral climate models was put into operation in mid-2007 (see 4.7.1).

2. Equipment in use

The current computer systems at the HKO with their major characteristics are listed below:

Machine	Quantity	Peak performance	No. of CPU	Memory	Year of Installation
Galactic SuperBlade	1	432.0 GFLOPS	60	124 GB	2006
IBM p630 cluster	1	96.0 GFLOPS	20	40 GB	2004
IBM p690	1	140.8 GFLOPS	32	48 GB	2003
IBM SP	1	66.0 GFLOPS	44	31 GB	2001
CRAY SV1-1A	1	19.2 GFLOPS	16	8 GB	1999

The Galactic SuperBlade server cluster is used to support the R&D of nowcasting and NWP systems, including the Non-Hydrostatic Model (NHM), 4DVAR Data Assimilation System (DAS) and Weather Research and Forecasting (WRF) model.

The IBM p630 server cluster is used to provide backup computing resources during contingencies, to operate a global-regional climate model suite and to support development of NWP systems.

The IBM p690 server is used to support the operation of the HKO nowcasting system, the trial operation of NHM and the Rainstorm Analysis and Prediction Integrated Data-processing System (RAPIDS) as well as their related R&D activities.

The IBM SP cluster is used to conduct various data acquisition and processing activities in support of operations of the forecasting office. Besides, it also provides a platform for the trial operations of the Message Passing Interface version of the Regional Spectral Model (MPI-RSM) and the Local Analysis and Prediction System (LAPS).

The CRAY SV1-1A is used to run the analysis and forecast system of the Operational Regional Spectral Model (ORSM).

3. Data and Products from GTS in use

The approximate number of bulletins of observations received from GTS on a typical day in 2007 is given below:

SYNOP/SHIP	12,000
TEMP/PILOT	900
AIREP	600
AMDAR	1,800
SATEM/SATOB	200
TOVS/ATOVS	1,100

Other observations, such as RADOB, are also gathered through the GTS during the passage of tropical cyclones.

The approximate number of bulletins of NWP products received from GTS and through the Internet on a typical day in 2007 is given below:

Centre	Type	Number
Deutscher Wetterdienst	GRIB	6,500
European Centre for Medium Range Weather Forecasts	GRIB	4,000
Japan Meteorological Agency	GRIB	3,000
US National Centers for Environmental Prediction	GRIB	18,500
United Kingdom Meteorological Office	GRIB	2,000

4. Forecasting system

4.1 System run schedule and forecast ranges

ORSM operates at 20 km and 60 km resolutions for an inner and an outer domain respectively. The model was originally developed by Japan Meteorological Agency (JMA) and was adapted for short-range weather forecasting in Hong Kong. The 60-km model is run in a 6-hourly analysis-forecast cycle with boundary data extracted from JMA's Global Spectral Model (GSM) forecasts. The 20-km

model is run in a 3-hourly analysis-forecast cycle and is one-way nested into the 60-km model. MPI RSM was also adapted from JMA and runs in a similar fashion as ORSM.

The forecast range of the 60-km ORSM and 20-km ORSM are 72 hours and 42 hours respectively. The outer 60-km ORSM is run 4 times a day for the area 9 °S – 59 °N, 65 – 152 °E based on 00, 06, 12 and 18 UTC analysis data, with an observation cut-off time of 3 hours. The inner 20-km ORSM is run 8 times a day for the area 10 – 35 °N, 100 – 128 °E based on 00, 03, 06, 09, 12, 15, 18 and 21 UTC analyses, with an observation cut-off time of 2 hours. The run schedule and domain setting for MPI RSM are identical to those of ORSM.

NHM (Saito et al. 2006) operates on an hourly basis on IBM p690 server at 5 km horizontal resolution. Model computation with initial time at T hour is started at T+50 minutes. The domain covers the area 19.5-25.0 ^{o}N, 111.2 – 117.1 ^{o}E and 12 hour forecasts are produced to give model guidance on severe weather and to support the operation of RAPIDS. The initial field of NHM is from the 20-km MPI RSM while the mixing ratios of the hydrometeors in the model cloud processes are initialised by moisture analysis output from LAPS (Albers 1995 and Albers et al. 1996) at 5 km horizontal resolution. The model boundary conditions are extracted from 20-km MPI RSM.

4.2 Medium range forecasting system (4-10 days)

Operationally, forecasts up to 7 days ahead are formulated by forecasters based on a subjective assessment of the prognostic forecast products from the European Centre for Medium-range Weather Forecasts (ECMWF), JMA, the United Kingdom Meteorological Office (UKMO) and the National Centers for Environmental Prediction (NCEP) of the United States. Besides the above deterministic NWP models, ECMWF and JMA Ensemble Prediction System (EPS) data sets for four grid points nearest to Hong Kong are also acquired for forecasters' reference.

An automated medium-range forecasting system (AMFS) provides objective forecast guidance on local winds, state of sky, weather, as well as temperature and relative humidity ranges up to 7 days ahead. AMFS is run twice a day based on the 00- and 12-UTC model outputs primarily from JMA and ECMWF, supplemented with those from ORSM and the global model of NCEP. Besides the use of direct model outputs, key post-processing techniques employed in AMFS include linear regression, Kalman–filtering and poor-man ensemble averaging. The AMFS also incorporates some of the local forecasting rules used by forecasters.

An extreme wind forecast product alerts the forecasters of the possibility of occurrence of high winds in Hong Kong. The product makes reference to the ensemble maxima of the ECMWF EPS 10-metre wind data from the current and latest model runs. The possibility of high winds is assessed by tracking the highest ensemble maximum among all valid forecasts. The forecast information is presented to the forecasters in tabular form via an intranet web page.

4.3 Short-range forecasting system (0-72 hrs)

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

(i) ORSM

Meteorological data assimilated by the analysis scheme of ORSM are as follows:

(A) From GTS

SYNOP, SHIP	surface data and ship data
TEMP, PILOT	radiosonde and pilot data
AIREP, AMDAR	aircraft data
SATEM	satellite thickness data
TOVS, ATOVS	virtual temperature profiles
SATOB	satellite wind data

(B) FY-2C geostationary satellite of CMA
IR1 brightness temperature data

(C) From NCEP data server
Daily sea surface temperature analysis at 1-degree resolution

(D) Through regional data exchange
Data from automatic weather stations over southern China

(E) Local data
Tropical cyclone bogus data during tropical cyclone situations
Automatic weather station data
Wind profiler data
Doppler weather radar data

A three-dimensional multivariate optimal interpolation is performed four times a day based on 00, 06, 12 and 18 UTC data for the 60-km outer domain. For the inner domain, the same analysis scheme is performed 8 times a day based on 00, 03, 06, 09, 12, 15, 18, and 21 UTC. All analyses are applied to the 36 model levels. The first guess fields of the model analyses are provided by their respective latest forecasts.

The hourly rainfall information, derived from the real-time calibration of radar reflectivity with rain gauge data as well as from the FY-2C IR1 brightness temperature data, is incorporated into the model through a physical initialization process. In this process, the moisture of the initial field (between the lifting condensation level and the cloud top inferred from the cloud top temperature) at the point where rain is observed is adjusted to allow precipitation process to be switched on. The heating rate of the precipitation process is also adjusted to correspond to the rainfall amount observed. Rainfall

information in the past hour and three hours are used in the outer and inner models' analysis respectively. A nonlinear normal mode initialization is performed before the forecast model is run.

(ii) MPI-RSM

The data ingestion, objective analysis and initialization processes are identical to those of ORSM, except that the number of model levels is increased to 40.

(iii) NHM

The initial condition of NHM is obtained from interpolation of 20-km MPI RSM forecast output to the model grid at 5-km resolution.

The mixing ratios of hydrometeors (cloud liquid water, cloud ice, rain water, snow and graupel) on model levels in the initial condition are interpolated vertically from LAPS analysis on pressure levels.

(iv) LAPS

LAPS was originally developed by the Forecast Applications Branch in NOAA. The data assimilation system of LAPS is configured to ingest the 20-km ORSM output as background field. Hourly analyses are produced for a 125×105 horizontal grid of 10, 5 and 1 km resolution and on 21 constant pressure levels in vertical direction. Another domain with 121x121 horizontal grids and 37 vertical levels is set up to provide the initial condition of hydrometeors for NHM and to support operation of lightning nowcast in SWIRLS. The objective analysis in LAPS is based on successive correction augmented by a moisture balance computation using three-dimensional variational technique.

Observation data within one-hour assimilation time-window are ingested in LAPS. They include conventional surface observations (SYNOP, METAR and SHIP), upper level data (TEMP, PILOT, AMDAR and AIREP) and automatic weather stations in Hong Kong and Guangdong. Remote sensing observations like radar reflectivity and Doppler velocity from the two local weather radars, upper level winds from wind profiler network, FY2C albedo and IR brightness temperature are also ingested. LAPS can also assimilate the QuikSCAT sea surface winds, satellite sounding (SATEM and ATOVS) cloud motion winds (SATOB), GPS precipitable water and TREC (Tracking Radar Echoes by Correlation) motion vectors obtained from the SWIRLS nowcasting system. The data cut-off time for hourly LAPS analysis at hour T for all the domains are set at T+35 minutes.

4.3.1.2 Research performed in this field

A more recent version of LAPS has been adapted for mesoscale data assimilation in supporting nowcast operation locally (at about 1 km horizontal resolution and higher) and in WMO/WWRP B08FDP (Beijing 2008 Forecast Demonstration Project). Model background using NHM output on model levels was developed to provide first guess fields at higher horizontal resolution.

4.3.2 Model

4.3.2.1 In operation

(i) ORSM

The characteristics of ORSM are shown as follows:

Governing equations	Primitive hydrostatic equations
Prognostic variables	Natural log of surface pressure, horizontal wind components, virtual temperature, specific humidity
Horizontal coordinate, resolution, and number of grid points	Mercator projection, 20 km resolution for the inner model and 60 km for the outer, 151x145 grid points
Vertical coordinate and grid configuration	Sigma-P hybrid coordinate, 36 levels with model top at 10 hPa
Initialization	Non-linear normal mode initialization
Radiation scheme	Short wave and long wave (Sugi et al.,1990). Calculated every hour
Moisture processes	
Cumulus convection	Arakawa-Schubert (1974)
Mid-level convection	Moist convective adjustment proposed by Benwell and Bushby (1970) and Gadd and Keers (1970)
Large-scale condensation	Included
Grid-scale evaporation and Condensation	Included
Planetary boundary layer	Scheme proposed by Troen and Mahrt (1986) in which non-local specification of turbulent diffusion and counter-gradient transport in unstable boundary layer are considered
Surface	4-layer soil model
	Daily sea-surface temperature analysis (fixed in forecast)
	Climatological snow and sea ice distribution
	Climatological evaporation rate, roughness length and albedo
Numerical technique	Horizontal: Double Fourier
	Vertical : Finite difference
	Time: Euler semi-implicit time integration
Topography	Envelope topography, derived from 30-second latitude/longitude resolution grid point topography data
Horizontal diffusion	Linear, second-order Laplacian
Boundary conditions	For the outer model, 6-hourly boundary data including mean sea level pressure, wind components, temperature and dew point depression at 16 pressure levels (1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 hPa) and the surface, are provided by JMA's GSM. For the inner model, hourly boundary data are provided by the outer 60km model

For further details on ORSM, please see JMA (1997).

(ii) MPI-RSM

The characteristics of MPI-RSM are identical to those of ORSM, except that the number of model levels is increased to 40. Further details on the formulation of MPI-RSM is given in JMA (2002).

(iii) NHM

A general description of NHM is summarized as follows:

Governing Equations	Fully compressible non-hydrostatic equations
Prognostic variables	Momentum in x, y and z directions, pressure, potential temperature, turbulent kinetic energy, mixing ratio of water vapour, cloud water, cloud ice, rain water, snow and graupel
Numerical technique	Finite difference method on the Arakawa-C type staggered coordinate grid system. Fourth-order horizontal finite difference operator in flux form with modified advection treatment for improved monotonicity
Horizontal coordinate, resolution, and number of grid points	Mercator projection, 5 km resolution, 121x121 grid points
Vertical coordinate and grid configuration	Terrain following height coordinates, 45 levels on Lorenz grid with model top at 27 km
Time integration and time step	Horizontal explicit and vertical implicit (HE-VI) with acoustic filter, 24 seconds
Planetary boundary layer process	Diffusion processes based on diagnosed turbulent kinetic energy using a 1.5 order turbulent closure model, non-local effect considered by adjusting mixing lengths, similarity theory adopted for surface boundary layer.
Precipitation processes	Three-ice bulk cloud microphysics + Kain-Fritsch convective parameterization. Lagrangian treatment for fall of rain and graupel
Diffusion processes	Linear, fourth-order Laplacian with non-linear damper. Targeted moisture diffusion applied to grid-points with excessive updrafts
Radiation processes	Short wave and long wave (Sugi et al, 1990); radiation scheme incorporating cloud optical properties determined by cloud water/ice contents
Upper boundary condition	Fixed wall with Rayleigh damping
Lateral boundary condition	Hourly boundary conditions from 20-km MPI RSM forecasts
Topography and land-surface characteristics	USGS global 30 second topography (GTOPO30) and (Global Land Cover Characterization) (GLCC)

Further details on NHM can be found in Saito et al. (2006).

4.3.2.2 Research performed in this field

Development to apply NHM output as first-guess in LAPS was performed. Research on post-processing NHM output to support short-range forecast of severe thunderstorms was underway. Furthermore, NHM was adapted to provide numerical guidance in supporting Observatory's forecast

operation in specialized events including severe weather nowcast in B08FDP as well as wind and weather guidance in the 2008 Olympic Regatta to be held in Qingdao.

4.3.3 Operationally available NWP products

(i) ORSM

The products of the 60-km ORSM include sea level pressure / geopotential heights, wind, temperature, dew point depression at 15 pressure levels (1000, 925, 850, 700, 500, 400, 300, 250, 200, 100, 70, 50, 30, 20, 10 hPa) and the surface as well as accumulated rainfall at 3-hourly intervals. For the inner 20-km domain, the forecast elements are the same as above but the products are generated at hourly intervals.

(ii) MPI-RSM

The model outputs from MPI-RSM are the same as those from ORSM.

(iii) NHM

Hourly prognostic charts on surface (hourly accumulated rainfall with sea level pressure and wind) and upper levels (975, 925, 850, 700, 500, 200 hPa), time series and time cross section for grid points at the HKO and near the Hong Kong International Airport are generated.

The 60-km ORSM TC track forecast guidance is routinely generated and disseminated via the GTS. The guidance is issued and updated twice a day based on the 00 and 12 UTC model runs whenever a TC reaching tropical depression strength appears in the area of responsibility of the HKO (10-30 ^{o}N, 105-125 ^{o}E). The information provided in the guidance includes forecast TC positions and intensity changes at 6-hourly intervals out to 72 hours. The HKO analysed TC warning position and intensity at 00 and 12 UTC are also included as initial values.

The following 60-km ORSM products in GRIB format are made available twice a day on the HKO's Server for International Exchange for access by registered national meteorological services.

Table 4.3.3.1 List of 60-km ORSM model products on the HKO's Server for International Exchange

Level	Content	Initial Time	Forecast Hours	Area	Resolution
Surface	Sea level pressure	00 and 12 UTC	12, 24, 36, 48, 60 and 72	5-45 °N, 90-140 °E	0.5x0.5 Degree
	Temperature				
	Relative humidity				
	Wind				
925, 850, 700, 500 and 400hPa	Geopotential height				
	Temperature				
	Relative humidity				
	Wind				

300, 250, 200, 150 and 100hPa	Geopotential height				
	Temperature				
	Wind				

Under a WMO pilot project in Region II, the HKO has been generating city-specific NWP products based on 60-km ORSM in the form of time series of weather parameters for reference by Members in the Region since 2006. The products, based on the direct model output of 60-km ORSM at the model land grid nearest to the corresponding cities, are made available on a password-protected web site maintained by the HKO. By the end of 2007, forecasts of 120 cities are being provided by the HKO. To facilitate the project participants' adaptation of the model outputs for their own specific applications, a software application in the form of spreadsheet was developed to assist the users in carrying out post-processing and verification of the NWP products.

Table 4.3.3.2 Forecast of meteorological elements provided in the city-specific forecast time series

Content	Initial Time	Forecast Hours	Display format
Sea level pressure	00 and 12 UTC	3-hourly intervals from 3 to 72 hours	In both graphical and tabulated data formats
Surface air temperature			
Surface dew point temperature			
Surface relative humidity			
Surface wind direction and speed			
Total cloud amount			
3-hourly precipitation			

Selected model products derived from ORSM are also disseminated in graphical format via the Internet for public consumption (URL: http://www.weather.gov.hk/nwp/nwpe.htm).

Table 4.3.3.3 60-km ORSM-based model forecast charts available on the Internet

Level	Content	Initial Time	Forecast Hours	Area
Surface	Weather depicting fine, cloudy and rain areas	00 and 12 UTC	12, 24, 36, 48, 60 and 72	8.5-41.7 °N, 92.1-143.8 °E
	Air temperature		00, 12, 24, 36, 48, 60 and 72	
	Sea level pressure			
	Wind			
850hPa	Wind			
	Relative vorticity and streamline			
700hPa	Wind			

	Relative humidity and streamline			
500hPa	Wind			
	Geopotential height			
200hPa	Wind			
	Jet stream and streamline			

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation

(i) ORSM

Local text forecasts based on ORSM prognostic data with warnings of thunderstorms and rainstorms are generated automatically. ORSM model outputs are also used to derive automatic wind forecasts for preparation of forecast bulletins for the South China Coastal Waters. Post-processing techniques, including Kalman filter and linear regression, are employed to adjust the temperature forecasts, including the daily minimum and maximum temperature forecasts in Hong Kong.

A weather map algorithm is employed to produce hourly weather map (fine and cloudy areas, accumulated rainfall contours) based on ORSM prognostic data. Rainstorm risk maps based on model-forecast rainfall rates are compiled from the latest five 20-km ORSM runs, akin to the ensemble approach. Near real-time rainfall verification results are provided to the forecasters.

TC track forecasts from consecutive runs of 60-km ORSM and 20-km ORSM are generated to facilitate forecaster's interpretation of model forecasts. The TC positions, determined as the point of minimum sea level pressure, are identified with the fitting method of overlapping parabolic interpolation (Manning & Haagenson, 1992).

Model guidance based on the 60-km ORSM was also developed in support of the forecast operation for the Pre-Olympic equestrian events held in Hong Kong in August 2007. Post-processing techniques (including Kalman filter and linear regression) are applied to provide site-specific weather forecasts at 3-hourly intervals for the two race venues up to 72 hours ahead.

(ii) MPI-RSM

MPI-RSM produces the same set of ORSM products for forecaster's reference. In addition, forecast satellite imageries (infrared channel) using a radiative transfer model were introduced to the product suite.

To take advantage of the vast amount of forecast information available from the two independent cycle runs of ORSM and MPI-RSM, an ensemble forecasting system based on the current and time-lagged forecasts was set up. A maximum of 28 member forecasts can be obtained at any grid point in the neighbourhood of Hong Kong and the forecast information is presented in the form of standard EPS

meteograms. An interactive web interface is provided for forecaster's easy control over which elements, grid points, model runs, valid times, etc., are to be included in the meteograms. An option is also provided to automatically remove any bias in the ensemble mean.

(iii) NHM

The precipitation forecast from NHM is used in the RAPIDS to blend with rainfall nowcast products generated by SWIRLS to provide quantitative precipitation forecast up to 6 hours ahead. Please refer to Section 4.4.2 below for more details.

(iv) LAPS

Based on the LAPS system, a tropical cyclone specific application called TC-LAPS is in operation. The purpose of the TC-LAPS is to provide the forecasters with rapidly updated analysis of 3-dimensional wind structure of approaching tropical cyclones. It also aims to help forecasters estimate the probability of the occurrence of strong/gale force winds over the territory. Wind field of horizontal resolution of 10, 5 and 1 km at standard pressure levels, plus vertical cross-section across the TC centre are generated hourly.

(v) TIPS

The Tropical Cyclone Information Processing System (TIPS) has been in operation since 2005, integrating various information and data, including a) NWP products from the Observatory's ORSM, as well as ECMWF, JMA, UKMO and NCEP models, b) subjective forecasts and warning positions from meteorological centres, and c) satellite and radar imageries, for use by forecasters in the preparation of tropical cyclone forecasts. TIPS can also generate ensemble tracks from model forecast positions for reference by the forecasters, who can modify interactively the weightings for individual model outputs in order to re-calculate the ensemble track

(vi) WRF

During the 2007 Qingdao International Regatta, the WRF model was run twice a day out to 24 hours to provide real-time forecast support to the Hong Kong Windsurfing Team. The model was configured with the finest grid at 3-km resolution, size 100x100, 45 vertical levels and centred at the Olympic Sailing Centre of Qingdao. Tailor-made forecast time-series products were delivered to the windsurfing team via the Internet during the Regatta.

(vii) Others

A forecasting tool for estimating the probability of strong and gale force winds in Hong Kong during TC situations is in operation. The probability is basically determined by regression of the spread of forecast movements from various deterministic models against a Gaussian distribution. The resulting probability is then obtained from the spread and the climatological probability isopleths for occurrence of strong and gale force winds. The tool also allows users to conduct "what-if" analyses based on their input of alternative forecast positions of the TC. The tool was further enhanced in 2007 to make use of

the uncertainty information given by the ECMWF EPS in terms of movement and intensity of the TC for generation of the probabilities.

A TC forecast guidance tool is also in use to forecast the TC intensity up to 72 hours ahead using JMA global model output. Based on regression of model forecast on central pressure against the best-track data in the past few years, a set of best-estimated parameters is derived and then applied to the real-time NWP forecasts to calculate the probability of particular class of intensity, maximum wind and central pressure of the TCs. In 2007, the TC forecast guidance tool was enhanced to include JMA EPS data. Deterministic forecasts of TC intensity derived from JMA EPS data are calibrated using an artificial neural network.

Starting from the TC season of 2007, three more new forecast products utilizing the JMA and ECMWF EPS TC data, namely the clustered TC track diagram, conditioned strike probability map and time-series of strike probability for various distance thresholds are generated in real-time for reference by the forecasters.

4.3.4.2 Research performed in this field

An evaluation study was conducted on the calibration of probability of precipitation derived from ECMWF EPS using the logistic regression technique. The method has proved to be particularly effective for improving the reliability of the probability forecasts and reducing the over-forecast biases as evident in the point forecasts from the direct model output.

Another study was conducted on the use of EPS information in TC track forecasting. Based on a homogeneous dataset from 2005-2006, it was found that the simple ensemble mean tracks from JMA or ECMWF EPS were highly correlated with the corresponding tracks from the deterministic models. As such, inclusion of the EPS mean tracks in the multi-model consensus would not significantly improve the forecast skill. The study also revealed that both multi-model consensus and EPS display a common tendency of an increasingly slow bias in the motion of the model TC vortices.

Research was conducted on a vector motion consensus method to generate TC consensus forecast tracks based on motion vectors calculated from NWP forecast positions. Verification results suggested that the consensus tracks generated using this method would be more skillful. The method would be incorporated in TIPS for reference by the forecasters.

4.4 Nowcasting and Very Short-range Forecasting Systems (0-6 hrs)

4.4.1 Nowcasting system

4.4.1.1 In operation

SWIRLS is a radar-based nowcasting system with output updated every 6 minutes. It has been put into operation since 1999, with an original objective for short-range rainfall forecasting in support of rainstorm warning operation in Hong Kong. It has since evolved into a multi-function system with a wide spectrum of applications, including flood warning and landslip warning. Major components of

SWIRLS include: (i) TREC which derives the multi-scale "wind" fields at multi-altitude levels by tracking the movement of individual radar reflectivity cells using the TREC technique; (ii) GTrack which tracks and predicts the movement of clusters of radar echoes using an object-oriented approach; (iii) Dynamic radar-raingauge analysis which updates the Z-R relation dynamically using radar reflectivity and rain-gauge data in order to re-calibrate the radar rainfall in real-time; (iv) QPF which extrapolates the rainfall re-calibrated radar echoes along the TREC wind direction using a semi-Lagrangian advection scheme to produce rainfall accumulations out to 6 hours over Hong Kong and nearby areas; (v) Landslip Alert which predicts the number of landslides in the next 3 hours based on a rainfall-landslide correlation model developed by geotechnical engineers; (vi) Flood Alert which predicts flash floods over low-lying areas based on the 1-hour QPF of SWIRLS; and (vii) TephiViewer which calculates a number of thermodynamical instability indices based on upper-air observations and various NWP model outputs to alert forecasters of the potential of severe weather.

In 2007, a graphical rainfall nowcast product with GIS information was developed and made available to government and selected users for trial. The nowcast data was based on the actual radar-rainfall analyses and the 1-hour predictions from SWIRLS. The product is presented as an animated sequence of rainfall maps updated every 30 min. The underlying GIS platform is Google Earth.

Since mid-2007, several new modules for severe weather nowcasting, namely lightning, downburst / wind gust and hail, were put into operational trial in support of thunderstorm warning operation in Hong Kong. The lightning algorithm (Yeung at al., 2007) focuses on the initiation and intensity of cloud-to-ground lightning based on isothermal reflectivity data with reference to the 3-dimensional temperature analyses by LAPS. The downburst/wind gust algorithm is a physically-based scheme to predict the maximum possible wind gust due to downburst associated with severe thunderstorms. Major inputs include radar-estimated vertically integrated liquid (VIL) water and ascent data. The hail algorithm predicts the occurrence of hail associated with severe thunderstorms, with the 60-dBZ contour and the VIL in the lowest 2 km as the major inputs. Besides detection, the above nowcasting modules also extrapolate the severe weather tracks out to 30 min using the TREC motion vectors.

4.4.1.2 Research performed in this field

Two computationally intensive modules of SWIRLS, respectively for semi-Lagrangian advection and TREC calculations, were parallelized based on the MPI standards with significant speed-up achieved on multi-CPU/node computers. The optimized software was put into operation in April 2007. Furthermore, parallelization on graphics processing units (GPU) was attempted and the execution bottlenecks were being investigated.

SWIRLS was adapted to the Beijing domain to participate in B08FDP. Significant R&D for upgrading the system was also initiated with the major enhancement areas including: (i) severe weather nowcasts; (ii) probabilistic nowcasts; and (iii) graphical products with GIS information. The upgraded system, referred to as SWIRLS-2, was successfully put into real-time trial in Beijing in 2007 summer. The lightning algorithm was further enhanced to include cloud-to-cloud lightning data as an additional predictor.

A new algorithm to retrieve echo motion based on optical-flow formulation and variational technique has been developed. Echo motion at different spatial scales can be obtained to track individual radar pixels and storm entities.

A project on thunderstorm lifecycle was conducted to study the distribution of lifetime with respect to the radar parameters associated with a storm cell. Case study results indicated that cells with different lifetime distribution in general correspond to different radar signatures. Further work is being conducted for the development of an automatic algorithm to objectively analyze the radar parameters of storm cells and classify them into different life cycle groups based on clustering techniques.

A feasibility study was conducted to investigate if SWIRLS 1-hour rainfall nowcast data could be applied to flood forecast over a very small catchment area (order of a few square kilometres). Preliminary results based on 8 rainstorm cases indicated that while the rainfall onset times were reasonably well predicted, the spatial variability of the actual rainfall distributions coupled with the forecast location and intensity errors severely limited the overall prediction skill.

4.4.2 Models for Very Short-range Forecasting Systems

4.4.2.1 In operation

RAPIDS

RAPIDS has been put in trial operation since April 2005 to provide quantitative precipitation forecasts for 1-6 hour forecasts at 2 km resolution on an hourly update basis (Li et al. 2005, Wong and Lai 2006). The system blends the output from SWIRLS and NHM with their respective weightings based on real-time verification results of precipitation predictions. Regional phase correction to correct spatial errors in the forecast precipitation field in NHM in difference regions was introduced in 2007. To correct the positive biases in rainfall intensity occasionally found in NHM forecast, an intensity correction scheme, which is based on comparing cumulative distribution of rainfall intensity from SWIRLS rainfall analysis and NHM short-term forecast, was also implemented.

4.4.2.2 Research performed in this field

Studies on the performance of RAPIDS in heavy rain and tropical cyclone cases showed that the blending technique could produce improved precipitation predictions. Studies on incorporation of uncertainties of phase correction in blending process are underway.

4.5 Specialized numerical predictions

No specialized numerical model is being operated at the moment.

4.6 Extended range forecasts (ERF) *(10 days to 30 days)*

No ERF model is being operated at the moment.

4.7 Long range forecasts (LRF) *(30 days up to two years)*

4.7.1 In operation

The suite of global-regional spectral climate models adapted from the Experimental Climate Prediction Center (ECPC) of the University California at San Diego, USA was put into operation since mid 2007. The model suite generates seasonal temperature and rainfall forecasts for Hong Kong and its neighbouring areas. Products are made available to the general public via the Observatory's Internet website.

4.7.2 Research performed in this field

The current operational regional climate model covers a small area over southern China. In an attempt to improve forecast generated by the model suite, a regional model with a much larger domain but coarser resolution was constructed and tested. It was found that the tested model produced more reasonable rainfall forecast for southern China. Systematic verification will be carried out to compare its skill with the existing model.

4.7.3 Operationally available EPS LRF products

No EPS LRF system is being operated at the moment.

5. Verification of prognostic products

5.1 Verification of forecasts generated by ORSM is conducted on a routine basis. Forecast parameters including zonal and meridional winds, temperature, pressure/geopotential heights and relative humidity at a number of model levels are verified against ORSM analysis and rawinsonde observations for the area 10 – 40 °N, 95 – 135 °E. The monthly verification results of the 60-km ORSM 12 UTC runs for 2007 are presented in Appendix I.

6. Plans for the future *(next 4 years)*

6.1 Development of the GDPFS

6.1.1 NHM will be upgraded in 2008 with (i) a new turbulent closure model in the planetary boundary layer scheme; (ii) a new partial condensation scheme and (iii) an improved short-wave radiation scheme.

6.1.2 The CRAY SV1-1A will be replaced by an enhanced high performance computing system with a peak performance of around 5 TFLOPS in 2008 to support the development and operation of a new suite of high resolution NWP models. The new model suite, comprising meso-scale models with horizontal resolutions ranging from 20 to 2 km, is expected to be fully commissioned in mid-2009.

6.2 Planned research Activities in NWP, Nowcasting and Long-range Forecasting

6.2.1 Planned Research Activities in NWP

(i) A 3-dimensional variational data assimilation system for NHM will be developed and tested;

(ii) Research will continue on applying NHM at higher horizontal resolution (e.g. 2 km) in support of RAPIDS and providing guidance on severe weather prediction in the very-short-range. Improvements to correct phase and intensity errors of NHM to blend rainfall nowcast in RAPIDS will carry on;

(iii) A multi-model ensemble-based NWP guidance will be implemented to facilitate the preparation of site-specific forecasts for the 2008 Olympic equestrian events.

6.2.2 Planned Research Activities in Nowcasting

(i) Fine tuning and further testing of SWIRLS-2;

(ii) Continue research and development on thunderstorm lifecycles;

(iii) Continue development and testing GPU-based optimization for the SWIRLS software;

(iv) Continue development and evaluation of optical-flow technique to retrieve echo motion to support both quantitative precipitation and storm-based related nowcasts.

6.2.3 Planned Research Activities in Long-range Forecasting

The possibility of generating monthly forecast using the long-range model suite will be explored. The technique of lagged ensemble averaging will also be looked into.

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Appendix I — Summary of Verification of Prognostic Products Generated by 60-km ORSM 12 UTC Runs for 2007 (Verification Area: 10 – 40 °N, 95 – 135 °E)

Table 1. RMS error of geopotential height at 500 hPa against analysis (in m)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
24	11.9	13.3	12.8	10.6	9.7	9.3	12.2	11.2	11.4	10.8	11.1	10.4	11.2
72	20.9	23.5	19.2	19.8	19.0	16.7	18.8	18.5	18.3	20.2	19.5	18.8	19.4

Table 2. RMS error of geopotential height at 500 hPa against observations (in m)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
24	14.7	17.7	17.3	14.0	12.7	12.8	13.7	15.2	12.4	12.5	13.0	13.1	14.1
72	24.0	28.1	23.0	23.5	21.5	20.9	21.0	23.3	19.9	20.8	21.5	21.8	22.4

Table 3. RMS of vector wind errors at 250 hPa against analysis (in m/s)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
24	6.2	6.4	6.6	7.6	7.3	7.1	6.8	6.7	6.7	6.0	6.2	5.6	6.6
72	9.7	10.2	10.0	13.6	12.2	12.5	11.5	10.8	10.7	9.6	10.7	9.3	10.9

Table 4. RMS of vector wind error at 850 hPa against analysis (in m/s)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
24	4.4	4.3	4.6	4.3	4.5	4.3	4.6	4.8	4.7	4.7	4.8	4.4	4.5
72	6.2	6.3	6.2	6.6	7.2	7.0	7.7	8.4	8.5	7.5	7.0	6.6	7.1

Table 5. RMS of vector wind errors at 850 hPa against observations (in m/s)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
24	5.0	4.9	5.1	4.8	4.7	4.9	4.7	4.9	4.3	4.8	4.8	5.0	4.8
72	6.0	6.2	6.4	6.4	6.1	6.4	6.1	6.4	6.0	6.0	5.8	5.9	6.1