Annual WWW Technical Progress Report

On the Global Data Processing and Forecasting System 2004

HONG KONG, CHINA

Member: Hong Kong, China **Centre: Hong Kong Observatory**

1. Summary of highlights

The IBM p690 server was upgraded to support the development and future operation of the Hong Kong Observatory's (HKO) Rainstorm Analysis and Prediction Integration Data-processing System (RAPIDS), a very short range rainstorm forecasting system. In April 2004, the non-hydrostatic model (NHM) component of RAPIDS started its operational trial the Observatory.

The Message Passing Interface (MPI) version of the HKO's Operational Regional Spectral Model (ORSM) was put into trial operations, running in parallel with the shared memory version. Forecast times series from both models are consolidated and presented in a time-lagged ensemble manner.

A four-dimensional variational (4DVAR) data assimilation system (DAS) for the MPI version of ORSM (MPI ORSM) was adapted from the Japan Meteorological Agency (JMA). (Hereafter, "ORSM**"** refers to the original shared memory version of the Operational Regional Spectral Model. For the MPI version of the Operational Regional Spectral Model, it is abbreviated as "MPI ORSM".) Impact studies had been performed under the Typhoon Committee Research Fellowship Scheme.

A cluster consisting of eight IBM p630 servers was acquired to support data processing and forecasting operation in emergency situation as well as numerical model development and testing.

2. Equipment in use at the centre

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
IBM p630 cluster	1	76.8 GFLOPS	16	32 GB	2004
IBM p690	1	88.0 GFLOPS	20	32 GB	2003
IBM SP	1	66.0 GFLOPS	44	25 GB	2001
CRAY SV1-1A	1	19.2 GFLOPS	16	8 GB	1999
SGI Origin 2000	1	4.0 GFLOPS	8	2.5 GB	1998
SUN E450	2	2.4 GFLOPS	4	1 GB	1998
SGI O2	2	0.4 GFLOPS	1	1 GB	1998

The IBM p630 server cluster is used to support the following activities:

(i) Backup forecasting operation, including data acquisition and processing, information dissemination, nowcasting and Numerical Weather Prediction (NWP) activities during contingencies;

(ii) Development of NWP systems, including new DAS and model testing.

The IBM p690 server is used to support the following activities:

(i) Operation of the Short-range Warning of Intense Rainstorms in Localized Systems (SWIRLS);

(ii) Trial operation of NHM and development for RAPIDS;

The IBM SP cluster is used for the following purposes:

(i) to generate diagnostic products;

(ii) to plot weather charts;

(iii) to produce graphics displays for supporting the operations of the Central Forecasting Office (CFO) and the Airport Meteorological Office (AMO);

(iv) to run a database for keeping climatological records;

(v) to support climatological research ;

(vi) to support the data pre-processing and graphical product generation of the ORSM;

(viii) to support the trial operations of:

- MPI ORSM;
- the Local Analysis and Prediction System (LAPS);

(vii) to support development and test runs of

- 4DVAR DAS for MPI ORSM
- the Weather Research and Forecasting (WRF) model.

(viii) to support development and operations of various NWP post-processing applications:

- automated medium-range forecast systems (AMFS)
- Kalman-filtered temperature forecast
- time-lagged ensemble forecast
- probability of strong and gale force winds during tropical cyclone situations

- tropical intensity forecast guidance

The CRAY SV1-1A is used to run the analysis and forecast system of the ORSM.

The SGI Origin 2000 serves as a backup for data pre-processing and graphic product generation of the ORSM.

The SUN E450 servers are used for the generation of ORSM products to support aviation operations, prepare verification for model products and other development uses.

Two SGI O2 are used as graphics display workstations for the visualization of nowcasting products and the Intranet web server for ORSM products.

3. Data and products from GTS in use

Since the start of the AMDAR programme in 2000, HKO has been receiving AMDAR bulletins from US and Australian aircraft landing or departing the Hong Kong International Airport via the GTS. In 2004, about 850 AMDAR bulletins were received daily. This represented a 10% increase as compared with the figure in 2003. The AMDAR observations were used for real-time monitoring of low-altitude windshear and turbulence and ingested into ORSM's analysis. From April 2004 onwards, HKO began to disseminate hourly AMDAR bulletins of data from Hong Kong aircraft through GTS. On average, about 7,000 AMDAR reports were compiled monthly.

The approximate number of bulletins of observations received from GTS on a typical day in 2004 is given below:

SYNOP/SHIP	90,000
TEMP/PILOT	2300
AIREP	3600
AMDAR	850
SATEM/SATOB	2300
TOVS/ATOVS	30,000

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 2004 is given below:

Centre	Type	Number
Deutscher Wetterdienst (since December 2004)	GRIB	700
European Centre for Medium Range Weather Forecasts	GRIB	250
JMA	GRIB	3,550
US National Centers for Environmental Prediction	GRIB	18,500
United Kingdom Meteorological Office	GRID	350

4. Data input system

Automated.

5. Quality control system

Incoming data are checked automatically for adherence to prescribed coding formats, internal consistency, and physical and climatological limits. Then, the data are checked against the first guess field generated by the ORSM (external consistency check).

Quality control of outgoing observational data originating from Hong Kong is implemented to ensure conformity to WMO coding formats and to enforce checking against internal consistency, time consistency as well as physical and climatological limits.

6. Monitoring of observing system

The monitoring was carried out at the territorial level.

7. Forecasting system

ORSM operates at 20 km and 60 km resolutions for an inner and an outer domain respectively. The model was originally developed by 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 ORSM is also adapted from JMA and runs in a similar fashion as ORSM.

NHM configured at 5 km horizontal resolution with 45 vertical levels has been put into trial operation since April 2004. It was originally developed by JMA and is adapted for the development and future operations of RAPIDS. In trial operational mode, NHM is scheduled to run twice daily (initialized at 03 and 15 UTC) and provide 12 hour forecasts for model guidance on severe weather. The initial and boundary conditions are both obtained from the 20-km resolution ORSM.

7.1 System run schedule

The forecast ranges of the 60-km ORSM and 20-km ORSM have been extended to 72 hours and 42 hours respectively since mid 2003. 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 schedules and domain settings for MPI ORSM are identical to those of ORSM.

The domain of NHM covers the area 19.5-25.0 ^{o}N, 111.2 – 117.1 ^{o}E. It is initialized by interpolating the 20-km ORSM analysis into the 5-km resolution model grid. The boundary conditions in hourly interval are also obtained from 20-km ORSM. To use the latest ORSM analysis, the model is configured to run with a cut-off time of about 3 hours

7.2 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, selected ECMWF Ensemble Prediction System (EPS) data sets for four grid points nearest to Hong Kong are also acquired for forecasters' reference since April 2004.

An automated medium-range forecasting system (AMFS) has been put into trial operations to provide 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.

7.3 Short-range forecasting systems (0-72 hours)

7.3.1 Data assimilation, objective analysis and initialization

(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) From RSMC Data Serving System (DSS) of JMA
GOES-9 IR1 brightness temperature data (S-VISSR format)

(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 horizontal domains of both inner and outer models compose of 151×145 model grids in Mercator projection. 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 GOES-9 IR1 brightness temperature data, are 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. An nonlinear normal mode initialization is performed before the forecast model is run.

(ii) MPI ORSM

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

NHM is initialized by interpolating the 20-km ORSM analysis into the model grid at 5-km resolution

(iv) LAPS

Experiments are also carried out with a view to implement a rapidly updated local analysis system for the nowcasting of rainstorms in Hong Kong and the generation of alternative initial conditions for NHMs. LAPS (Albers 1995 and Albers *et al.* 1996), originally developed by the Forecast Systems Laboratory of NOAA, is adapted for this purpose.

LAPS is configured to use 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. There are totally 21 vertical levels in the configuration. The objective analysis employed in LAPS is a combination of successive correction and 3-dimensional variational techniques.

LAPS assimilates SYNOP, METAR, SHIP, TEMP, PILOT, AIREP, AMDAR, SATEM, TOVS, ATOVS, SATOB, QuikSCAT sea surface winds, GOES-9 brightness temperature and albedo, data from automatic weather stations over the south China coastal region, local wind profiler data, local GPS data, as well as Doppler radar reflectivity and velocity data from the local radars in Hong Kong. In addition, derived wind products such as the multi-level TREC (Tracking Radar Echoes by Correction) winds obtained from SWIRLS (Li and Lai 2003) are also assimilated. These additional wind data are especially useful in defining the wind structure of tropical cyclones approaching southern China.

An initialization package to generate initial conditions for NHM from LAPS outputs has also been developed. LAPS analysis on dynamical and physical fields, as well as the analysis output for various hydrometeors (cloud liquid water, cloud ice, rain water, hail and graupel) can be used to initialize the NHM for reducing model spin-up.

7.3.2 Model

(i) ORSM

The characteristics of ORSM are shown as follows:

Basic equations	Primitive hydrostatic equations
Vertical	Sigma-P hybrid coordinate, model top at 10 hPa.
Forecast parameters	ln (surface pressure), horizontal wind components, virtual temperature, specific humidity.
Initialization	Non-linear normal mode initialization
Physical processes	
Radiation scheme	Sugi *et al.*(1990)
Short wave	Calculated every hour
Long wave	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 methods	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 ORSM are identical to those of ORSM. Further details on the formulation of MPI ORSM is given in JMA (2002)

(iii) NHM

A general description of NHM is summarized as follows:

Governing Equations	fully compressible non-hydrostatic system, no approximation
Prognostic variables	momentum, pressure, potential temperature, turbulent kinetic energy, mixing ratio of water vapour, cloud water, cloud ice, rain water, snow
Horizontal coordinate	Conformal projection
Vertical coordinate	terrain following height coordinates
Horizontal grid	Arakawa-C grid
Vertical grid	Lorenz grid
Time integration	semi-implicit (HI-VI), split-explicit (HE-VI)
Horizontal differencing	2nd to 5th order
Turbulence closure	level 2.5 TKE
Precipitation processes	bulk cloud microphysics, cumulus parametrization (moist convective adjustment, Arakawa Schubert, Kain-Fritsch)
Boundary layer processes	Non-local boundary layer (Sun and Chang, 1986)

	Computation of PBL height by vertical profile of virtual potential temperature or using scheme by Hong and Pan (1996), 6 options in computation of bulk coefficients: Kondo, Sommeria, Businger, Kada and Yaglom, Louis, Beljaars and Holtslag
Radiation processes	two options: schemes employed in RSM, and cloud radiation scheme
Upper boundary condition	fixed wall with Rayleigh damping
Lateral boundary condition	hourly boundary conditions from 20-km ORSM forecasts
Diffusion	fourth order linear diffusion or non-linear diffusion
Topography	derived from global 30 second topography (GTOPO 30)

For further details on NHM, please see Fujita et al. (2002).

7.3.3 Numerical weather prediction 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 ORSM

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

(iii) NHM

Hourly prognostic charts on surface (hourly accumulated rainfall with MSLP and wind) and upper levels (850, 700, 500, 200 hPa), time series and time cross section for HKO grid are generated.

7.3.4 Operational techniques for application of NWP products

(i) ORSM

2D and 3D graphical model products are made available to the forecasters for reference through a web-based display. These products include forecast time cross-section and tephigrams as well as forecast rainfall distribution charts for Hong

Kong. Local text forecasts based on ORSM prognostic data with warnings of thunderstorms and rainstorms are generated automatically.

Post-processing of the model prognostic data, such as application of Kalman Filtering technique and regression method, are employed to generate instantaneous temperature as well as 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. The technique of pattern recognition is employed in rainfall verification with a view to identifying systematic bias of rainstorm locations and providing better interpretation guidance.

Tropical cyclone (TC) track forecasts from consecutive runs of 60-km ORSM and 20-km ORSM are generated to facilitate forecaster's interpretation of model forecasts. Ensemble forecast of TC track derived from global model outputs is also compiled. Forecasters can modify the weightings for various model outputs and generate the ensemble forecast interactively.

Since June 2004, the 60-km ORSM forecast information has been disseminated to the public in form of weather maps (mean-sea-level pressure, surface winds and temperature, and weather) via the HKO Internet web page. The ORSM weather maps are update twice a day based on the 00 and 12 UTC model runs with a 12-hour forecast interval out to 72 hours.

(ii) MPI ORSM

MPI ORSM produces the same set of ORSM products for forecaster's reference. In addition, forecast satellite imageries (infrared channel) using a radiative transfer model and forecast time series based on a time-lagged ensemble approach were added to the product suites.

(iii) WRF

During the Athens Olympic Games 2004, the WRF model was run once a day out to 24 hours to provide real-time forecast support to the Hong Kong Windsurfing Team. The model is configured with a grid at 5-km resolution, size 105x105, 45 vertical levels and centred at the Olympic Sailing Centre of Athens. The initial and boundary conditions were interpolated from the 18-UTC GFS forecast data of NCEP. The characteristics of sea breeze and northerlies in the region were successfully captured by the surface wind forecasts. Tailor-made forecast time-series products were delivered to the sailors via

mobile communication devices and the Internet.

(iv) LAPS

Based on the LAPS system, a tropical cyclone specific application called TC-LAPS has been put into trial operation. The purpose of the TC-LAPS is to provide local forecasters rapidly updated analysis of 3-dimensional wind structure of approaching tropical cyclones. It also aims to help forecaster to estimate the probability of the occurrence of strong/gale 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) Others

A forecasting tool for probability of strong and gale force wind inside the Victoria Habour in tropical cyclone (TC) situations has been developed and put into operation. The probability is basically determined by regression of the spread of forecast movements from various NWP model output 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 inside the harbour.

A TC forecast guidance tool is also developed and put into trial-operation to facilitate the estimation of TC intensity 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 in TC situations to calculate the probability of particular class of intensity, maximum wind and central pressure.

The ECMWF EPS 10-metre wind and 6-hourly rainfall data for selected data sets in 2003 were verified against wind and rainfall measurements in Hong Kong. Based on the verification results, an experimental extreme wind forecast product was developed using the ensemble maxima of the ECMWF EPS 10-metre wind data. The possibility of high winds occurring locally in Hong Kong was assessed by tracking the highest ensemble maximum among all valid forecasts. The forecast information would be presented to forecasters in tabular form via an intranet web page.

8. Plans for the future

The implementation of the RAPIDS for operation will be accomplished. A very short range forecast for precipitation up to six hours ahead will be generated by combining nowcasting products with the NHM forecasts. The latter will be configured to run at 5-km resolution in hourly update, using LAPS analysis as the initial condition.

The development and research on using NHM with higher horizontal resolution (e.g. 2 km) will continue.

The development of a 4DVAR DAS for future operation will continue. The effectiveness of assimilating remote-sensing data by 4DVAR DAS will be assessed using impact studies.

The use and performance of EPS data will be further explored.

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