

**WWW TECHNICAL PROGRESS REPORT ON THE GLOBAL
DATA-PROCESSING AND FORECASTING SYSTEM (GDPFS),
AND THE ANNUAL NUMERICAL WEATHER PREDICTION (NWP)
PROGRESS REPORT FOR THE YEAR 2005**

Hong Kong, China

Centre: Hong Kong Observatory

1. Summary of highlights

- (i) Since April 2005, Hong Kong Observatory (HKO) has started providing Tropical Cyclone (TC) track forecast guidance, based on her 60-km Operational Regional Spectral Model (ORSM), to other Members via the Global Telecommunication System (GTS).
- (ii) Rainstorm Analysis and Prediction Integrated Data-processing System (RAPIDS), a very-short-range forecasting system for rainstorm prediction guidance, was put into trial operation in April 2005. RAPIDS blends the quantitative precipitation forecast from the non-hydrostatic model (NHM) adapted from Japan Meteorological Agency (JMA) and the nowcasting system - Short-range Warning of Intense Rainstorms in Localized Systems (SWIRLS) to provide precipitation prediction up to 6 hours ahead. In support of RAPIDS, NHM has been upgraded to run at 5 km horizontal resolution, providing forecasts up to 12 hours ahead.
- (iii) The IBM p690 server was upgraded to support provision of regional rainfall products and upper-air forecast weather maps, based on 60-km ORSM, in the HKO web site.
- (iv) Prototype products utilizing TC information from the Ensemble Prediction System (EPS) of the Japan Meteorological Agency (JMA) were developed for forecasters' reference.

2. Equipment in use at the centre

The current computer systems at HKO are listed below:

Machine	Quantity	Peak performance	No. of CPU	Memory	Year of Installation
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	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, hosted in Kings Park outside HKO Headquarters, is used to support research and development activities in Numerical Weather Prediction (NWP) and acts as the backup computing facility for forecasting and information processing.

The IBM p690 server is primarily used for running SWIRLS and RAPIDS. It also supports the generation of NWP products for use in HKO web sites.

The IBM SP server cluster is used to support meteorological data processing, generation of forecast products as well as development and trial operation of various NWP components, including the MPI version of ORSM (MPI ORSM).

The CRAY SV1-1A computer is used for running ORSM.

The Origin 2000 computer acts as a backup facility for the pre-processing and product generation of ORSM.

The SUN E450 computer is used for the post-processing and forecast verification of ORSM.

The two SGI O2 workstations serve as the web server for hosting ORSM's products and a suite for visualization of model outputs.

3. Data and products from GTS in use

Since the start of the AMDAR programme in 2000, HKO has been receiving, via GTS, AMDAR bulletins from US and Australian aircraft landing or departing the Hong Kong International Airport.

In 2005, with the assistance of Civil Aviation Department of Hong Kong, China, and the Cathay Pacific Airways (CPA), a trial of AMDAR data collection from one Cathay B747 aircraft commenced. After evaluation of the data quality, HKO started the operational dissemination of the AMDAR weather reports via GTS, making available the data to all WMO members. Since September 2005, the Hong Kong AMDAR programme was expanded to provide additional AMDAR reports from a total of six CPA aircraft. At present, HKO receives about 1,000 AMDAR weather reports daily

directly from these aircraft. From December 2005 onwards, HKO began to disseminate AMDAR reports from Hong Kong aircraft in BUFR format through GTS in accordance with WMO code migration plan.

The approximate number of observation reports received from GTS on a typical day in 2005 is given below:

SYNOP/SHIP	90,000
TEMP/PILOT	2,900
AIREP	3,400
AMDAR	7,300
SATEM/SATOB	2,100
TOVS/ATOVS	30,000

Other observations, such as RADOB, are also gathered through 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 2005 is given below:

<u>Centre</u>	<u>Type</u>	<u>Number</u>
Deutscher Wetterdienst	GRIB	5,300
European Centre for Medium Range Weather Forecasts	GRIB	250
Japan Meteorological Agency	GRIB	3,550
US National Centers for Environmental Prediction	GRIB	18,500
United Kingdom Meteorological Office	GRID	370

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 is 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 RSM is also adapted from JMA and runs in a similar fashion as ORSM.

NHM was upgraded in April 2005 to provide hourly forecasts up to 12 hours ahead, with a horizontal resolution of 5 km. The model's boundary conditions come from the 20-km MPI RSM. For initializing the hydrometeors in cloud microphysics, moisture analysis output from LAPS adapted from NOAA/FSL is used.

7.1 System run schedule and forecast ranges

The forecast ranges of the 60-km ORSM and 20-km ORSM are 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 is the area 19.5-25.0 °N, 111.2 – 117.1 °E. To support the operation of RAPIDS, NHM is scheduled to run hourly and provide 12 hour forecasts for model guidance on severe weather.

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, ECMWF

and JMA EPS data sets for four grid points nearest to Hong Kong are also acquired for forecasters' reference.

An automated medium-range forecasting system (AMFS) has been put into 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 (up to 10 July 2005)
GOES-9 IR1 brightness temperature data (S-VISSR format)

- (C) MTSAT-1R geostationary satellite of JMA (from 11 July 2005)
IR1 brightness temperature data (HIRID format)

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

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

- (F) 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/MTSAT-1R 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 MPI RSM analysis into the model grid at 5-km resolution. The domain of NHM composes of 121x121 model grids in Mercator projection and 45 vertical levels.

Specific humidity of hydrometeors (cloud liquid water, cloud ice, rain water, snow and graupel) on model levels in the initial condition are interpolated vertically from LAPS output on pressure levels.

(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/MTSAT-1R 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.

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	In (surface pressure), horizontal wind components, virtual temperature, specific humidity.
Initialization	Non-linear normal mode initialization
Physical processes	
Radiation scheme	Sugi <i>et al.</i> (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

General features of NHM are 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	Mercator 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 MPI RSM 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 Saito et al. (2005).

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 (975, 925, 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 graphical 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.

Starting from April 2005, the 60-km ORSM TC track forecast guidance has been disseminated via GTS. The guidance is issued and updated twice a day based on the 00 and 12 UTC model runs whenever a TC with at least TD strength appears in the area of responsibility of HKO (10-30N, 105-125E). The information provided in the guidance includes forecast TC positions and intensity changes at 6-hourly intervals out to 72 hours. The HKO TC warning position and intensity at 00 and 12 UTC are also included as initial values.

The 60-km ORSM Internet forecast products for the public were enhanced on 2 June 2005 to include upper-air weather charts. The enhanced product suite is summarized in Appendix I. The ORSM weather maps are updated twice a day based on the 00 and 12 UTC model runs at 12-hour forecast intervals out to 72 hours.

(ii) MPI ORSM

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 have been added to the product suites.

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 has been 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 EPS meteograms. An option is also provided to automatically remove any bias in the ensemble mean.

(iii)NHM

A new very-short-range forecasting system for rainstorm prediction guidance called RAPIDS (Rainstorm Analysis and Prediction Integrated Data-processing System) was developed and put into trial operation in late April 2005. The essence of RAPIDS is to blend the quantitative precipitation forecasts from NHM and the nowcasting system SWIRLS to provide precipitation prediction up to 6 hours ahead. The horizontal resolution of RAPIDS output is 2 km and the update frequency is 1 hour. The weighting of NHM and SWIRLS forecasts in RAPIDS are adjusted dynamically according to the real-time verification results of precipitation predictions from NHM and SWIRLS.

(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 Harbour in 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 was presented to forecasters in tabular form via an intranet web page.

Under a collaborative research project with JMA, a study on the verification and utilization of the JMA EPS TC data was performed. Automated techniques, including clustering, Bayesian learning and artificial neural network, were employed to process the ensemble track and intensity data with a view to enhancing forecast accuracy and reducing model bias. Forecast verifications with raw and processed ensemble forecasts were performed. Prototype products including clustered TC track diagram, weighted ensemble mean track, conditional strike probability map and calibrated TC intensity were developed.

8. Verification of prognostic products

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 for the area 10 - 40°N, 95 – 135 °E. The monthly verification results of 60-km ORSM 12 UTC runs for 2005 are presented in Appendix II.

9. Plans for the future

9.1 Development of the GDPFS

- (i) Two Intel-based SuperBlade servers, with a total peak performance of about 390 GFLOPS, will be commissioned in early 2006 for running an enhanced version of SWIRLS.
- (ii) A technical study on high performance computing requirements is being conducted and will be completed in early 2006. Preparation for the acquisition of the next generation computing platform of HKO will commence after the study.

9.2 Research activities in NWP

- (i) Study on running NHM at higher horizontal resolution (e.g. 2 km) in support of RAPIDS will continue. The development of NHM applications to provide guidance on severe weather prediction in the very-short-range (1-6 hours) will be explored.
- (ii) The development of a 4DVAR DAS for future operation will continue. Effectiveness of assimilating remote-sensing data by 4DVAR DAS will be assessed using impact studies.
- (iii) Results from the study on JMA EPS TC data will be reported. New forecasting tools and products based on the study will be developed for operational use.

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Appendix I — HKO Computer Model Forecast Weather Maps on the Internet

Level	Weather Map	Display Format
Surface	Weather	Cartoons at major cities
	Air Temperature	Colour filled contour maps
	Mean Sea Level Pressure	Contour lines
	Wind Speed & Wind Direction	Wind bards with colours to indicate wind strength
850hPa	Wind Speed & Wind Direction	Wind bards with colours to indicate wind strength
	Relative Vorticity & Streamline	Colour filled contour maps and arrow lines
700hPa	Wind Speed & Wind Direction	Wind bards with colours to indicate wind strength
	Relative Humidity & Streamline	Colour filled contour maps and arrow lines
500hPa	Wind Speed & Wind Direction	Wind bards with colours to indicate wind strength
	Geopotential Height	Colour filled contour maps
200hPa	Wind Speed & Wind Direction	Wind bards with colours to indicate wind strength
	Jet Stream & Streamline	Colour filled isotachs and arrow lines

Other Specifications:

1. Weather maps are provided with a forecast interval of 12 hours out to 72 hours.
2. Updated twice a day based on the 00 and 12 UTC 60-km ORSM model runs.
3. Animation option is also provided in the web interface.
4. Area of coverage: 8.5-41.7 N, 92.1-143.8 E
5. URL: <http://www.weather.gov.hk/nwp/nwpe.htm>

Appendix II — Summary of Verification of Prognostic Products Generated by 60-km ORSM 12 UTC Runs for 2005 (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	11.8	12.8	11.0	10.1	10.2	10.4	10.1	11.0	11.4	9.7	9.8	11.1	10.8
72	22.7	23.2	19.9	18.5	20.0	16.6	18.3	20.1	20.5	17.2	18.1	20.9	19.7

Table 2. RMS error of u-component wind at 200 hPa against analysis (in m/s)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
24	4.2	4.1	4.4	4.8	5.6	4.9	4.9	5.1	4.8	4.4	4.0	4.1	4.6
72	6.6	6.7	7.0	8.6	9.0	7.9	7.9	8.1	8.1	7.5	6.4	6.9	7.6

Table 3. RMS error of v-component wind at 200 hPa against analysis (in m/s)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
24	4.6	4.2	5.2	5.2	6.0	5.0	5.0	5.3	5.4	5.0	4.6	4.9	5.0
72	7.2	6.6	7.8	8.6	8.9	8.3	8.2	8.4	8.7	7.8	7.3	8.0	8.0

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

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
24	3.0	3.3	3.2	2.9	3.1	3.4	3.5	3.4	3.5	2.9	3.3	3.3	3.2
72	4.4	4.3	4.4	4.1	5.1	5.4	5.7	6.0	6.1	4.7	4.9	5.3	5.0

Table 5. RMS error of v-component wind at 850 hPa against analysis (in m/s)

Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
24	3.0	3.3	3.1	3.0	3.2	3.5	3.5	3.4	3.6	2.8	3.1	3.0	3.2
72	4.3	4.5	4.4	4.3	5.4	6.0	6.4	6.6	6.5	4.8	4.9	5.1	5.3