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

CANADA

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1 Summary of highlights

On March 15th 2005, the three dimensional variational data assimilation (3D-Var) system of the global forecasting system has been replaced by a 4D-Var formulation. The new upgraded system allows for a better usage of data and permits a 60% increase in the number of data element assimilated by the global assimilation system. This is a significant upgrade to the global data assimilation system and it has shown a clear improvement in the meteorological performance of the global forecasting system.

The automated computer worded forecast, SCRIBE, became the main tool for public forecast preparation in the Meteorological Service of Canada.

On July 6th 2005, a new version of the chemical transport model, CHRONOS, became operational. Years 2000-2001 emission inventories replaced the year 1995 inventory and biogenic emissions were modified according to BEIS3 (Biogenic Emissions Inventory System) and BELD3 (Biogenic Emissions Land use Data). With these changes, CHRONOS has improved ability to forecast tropospheric ozone and PM2.5 (Particulate Matter of 2.5 microns or less).

On July 21st 2005, we implemented version 4.5 of the WAM model for our wave forecast program. Taking advantage of this new version of the wave model, we increased the resolution to 0.5 degree for the Northern domains of the Atlantic and Pacific Oceans. We also introduced 4 new windows of wave forecast at a resolution of 0.05 degree to cover the following Great Lakes: Lake Ontario, Lake Erie, Lake Huron and Lake Superior.

An experimental high resolution version of the GEM model at 2.5 km has been installed over two windows over Canada.

On December 7th 2005, the AMSU-A and MHS data from NOAA-18 were incorporated in the Global 4D-Var and Regional 3D-Var data assimilation systems. On the same date, cloud derived winds (Air Motion Vectors or AMV’s) from METEOSAT-7 were replaced by the METEOSAT-8 AMV’s data.

On December 13th 2005, an upgrade to the global Ensemble Prediction System (EPS) was implemented. New observation types are now being used by an improved ensemble Kalman filter data-assimilation system. The physical parameterizations of the EPS models have also been revised to better simulate the diurnal cycle and to reduce model biases. The EPS is now run twice daily and the forecast period has been extended from 10 days to 16 days.

The UMOS set of guidance for the regional system has been expanded to include probability of precipitation forecast.

2 Equipment in use at the Centre

Summary of equipment in use at the Canadian Meteorological Centre (memory and disk space in Gbytes)		
Computer	**Memory**	**Disk**
IBM P Series 690, 960 cpu	2126	10000 (SAN)
IBM P Series 575, 256 cpu	1024	700 (SAN)
2 SGI ORIGIN 3000, 20 cpu each	40	14000
1 SGI ORIGIN 300, 8 cpu	8	4500
1 TANDEM Himalaya, S7400, 2 cpu	1	64
5 Compaq DL580 (4 cpus each)	20	5176
28 Compaq DL380 (2 cpu each)	92.5	17564
28 Compaq DL 360 (2 cpu each)	43	648
42 Dell Power-Edge 1650/1850 (2 cpu each)	162	2916
10 Dell Power-Edge 2850 (2 cpu each)	40	13548
3 Dell Power-Edge 6850 (4 cpu each)	24	2016

3 Data and products from GTS in use

3.1 Data

The following types of observations are presently used at the Centre. For these types, we use all observations that are available from the GTS, on the global scale. The numbers indicate typical amounts received during a 24-hour period:

SYNOP/SHIP	47,000
TEMP (500 hPa GZ)	1,180
TEMP/PILOT (300 hPa UV)	1,250
DRIFTER/BUOYS	35,000

AIREP/ADS	4,500
SATOB (including BUFR)	1,210,000
MCSST (US Navy)	600,000
SA/METAR	175,500
AMDAR/ACARS	190,000
PIREP	900[1]
PROFILER	1700
GOES radiances	180,000[2]
ATOVS (AMSU-A)	1,700,000[3]
ATOVS (AMSU-B/MHS)	12,000,000[3]
SSM/I	1,400,000[4]
A/ATSR	80,000[5]

3.2 Products

GRIB ECMF
GRIB KWBC
GRIB EGRR
FDCN KWBC
FDUS KWBC
U.S. Difax products
Significant weather forecasts
Winds/Temperature forecasts for various flight levels

4 Data input system

Fully automated.

5 Quality control system

Various real-time quality control checks are performed for each observation received from the GTS. In particular:

- all reports are checked for gross errors;
- values for main items, such as height, pressure, temperature, dew-point and wind are checked to be inside physical and climatological limits;
- temperature profile check;
- hydrostatic check;
- horizontal check (spatial consistency with neighbours and first guess fields done using variational quality control in addition to background check)

These checks are done at, or after the decoding phase of the bulletins. Canadian observations are put on the GTS before such quality control is performed. However, Canadian observations are subject to quality control at the observing site, before transmission to the national centre.

The information generated by the quality control system inside the objective analysis is fed back into the observations database in order for non real-time monitoring and quality control

[1] Not assimilated
[2] Locally processed GOES imagery, clear sky radiances
[3] Four NOAA satellites now assimilated, AMSUA on AQUA, obtained by ftp
[4] A third of these are used for ice analyses, obtained by ftp
[5] This instrument flies on ENVISAT

activities to be performed. This monitoring is done on the global scale. Nationally, we also monitor the bursting altitude of upper-air soundings and results are distributed to data producers on a daily basis and monthly reports are distributed.

Each Canadian synoptic report (manned stations only) is also monitored in real time for completeness and timeliness. Requests to individual stations are made if certain criteria are met. Observing stations send corrections if time permits. These corrections are sent to the GTS for transmission. A monthly summary of errors is produced and distributed to data producers.

6 Monitoring of the observing system

Monitoring the availability of observations on the global scale is an inherent portion of operations at the CMC. Information on the current content of the observational databases is available in real time, by observation types and by geographical areas. A chart showing the geographical distribution of observations, by types, used in the analysis for the numerical models is distributed to forecast centres across the country in real-time. A monthly report describing the availability of upper air observations is produced and distributed to data producers.

The information on the availability and quality of observations available for use in the final global analyses is assembled each month into the "CMC Global Data Monitoring Report". The statistics presented in the report are prepared in accordance to the WMO/CBS approved procedures. The reports are no longer distributed but, with additional information, are available in pdf format via a data monitoring web site (http://www.cmc.ec.gc.ca/~cmcdev/data_monitoring).

In 1993, CMC was designated by CBS as the lead centre for the monitoring of the quality of land surface observations in WMO RA-IV (North and Central America). In 1994, the CMC began to fulfil its role and since then has regularly produced its 6-monthly reports entitled "Report on the Quality of Land Surface Observations in Region IV". Two such reports were distributed in 2005. Monitoring results are distributed directly to national focal points for most countries within RA-IV.

7 Forecasting system

7.1 System Run Schedule

Assimilation and final analysis run schedule (all times in UTC)			
Description	**Name**	**Time**	**Remarks**
Global assimilation	G2	00, 06, 12, 18	Details section 7.2.1.1.
Regional assimilation	R2	00, 06, 12, 18	Details section 7.3.1.1.
Regional final analysis	R3	00, 12	Cut-off: T+7:00.
Global ensemble assimilation	E2	00, 06, 12, 18	Details section 7.2.5.

Forecast run schedule (all times in UTC)				
Description	**Name**	**Time**	**Forecast period**	**Remarks**
Global	G1	00, 12	240 hours at 00 360 hours at 00 on Saturdays 144 hours at 12	Details section 7.2.1.1. All products available at T+5:00.
Regional	R1	00, 12	48 hours	Details section 7.3.1.1. All products available at T+3:00.
Local high resolution	LE, LW	12	24 hours	Details section 7.3.5.
Global ensemble	E1	00, 12	16 days	Details section 7.2.5.
Air quality	C1	00	48 hours	Details section 7.4.4.
Monthly	M1	00	35 days	Details section 7.5. Launched at the beginning and middle of every month.
Seasonal	M1	00	100 days	Details section 7.5. Launched at the beginning of every month.

7.2 Medium range forecasting systems (3-10 days)

7.2.1 Data assimilation and objective analysis

7.2.1.1 **Upper air**

Method	Four-dimensional multivariate variational analysis of observations misfits, at the appropriate time, to the 9-hour forecast of a 28-level 0.9° uniform resolution GEM (Laroche et al., 2005). The incremental approach is used for 4D-Var. (Gauthier et al., 1999). The GEM tangent-linear model and its adjoint with simplified physics are used to propagate the analysis increments and the gradient of the cost function over the assimilation window. The length of the assimilation window is 6 hours with a time step of 45 min.

Variables	T, Ps, U, V and log q (specific humidity).
Levels	28 η levels of GEM model.
Domain	Global
Grid	$0{,}9^{o}$ resolution for the outer loops and $1{,}5^{o}$ for inner loops.
Simplified Physics	Vertical diffusion Subgrid scale orographic effects[6] Large-scale precipitation[6] Deep moist convection[6]
Frequency	Every 6 hours using data ±3 hours from 00 UTC, 06 UTC, 12 UTC and 18 UTC.
Cut-off time	3 hours for forecast runs. 9 hours for final analyses at 00/12 UTC and 6 hours at 06/18 UTC.
Processing time	54 minutes plus 3 minutes for trial field model integration on the IBM.
Data used	GTS data : TEMP, PILOT, SYNOP/SHIP, SATOB, ATOVS level 1b (AMSU-A; AMSU-B/MHS), BUOY/DRIFTER, PROFILER, AIREP/AMDAR/ACARS/ADS, and locally processed GOES radiances data.

7.2.1.2 **Surface**

Fields	**Analysis Grid(s)**	**Method**	**Trial Field**	**Frequency**	**Data Source**
Surface air temperature	400 x 200 gaussian	Optimum interpolation	Model forecast of temperature at eta=1.0	6 hours	Land Synops, SAs, Ships, Buoys, Drifters
Surface dew point depresssion	400 x 200 gaussian	Optimum interpolation	Model forecast of dew point depression at eta=1.0	6 hours	Land Synops, Metars, SAS, ships, buoys, drifters
Sea surface temperature anomaly	a)400 x 200 gaussian b)1080 x 540 gaussian	Optimum interpolation	Previous analysis	24 hours (at 00z)	Ships,buoys, drifters, AVHRR satellite data (Brasnett, 1997) Plus A/ATSR for b)
Snow depth	1080 x 540 gaussian	Optimum interpolation	Previous analysis with estimates of snowfall and snowmelt	6 hours	Land Synops, Metars, Sas (Brasnett, 1999)

[6] Used in second outer loop only.

Ice cover	1080 x 540 gaussian	Data averaging with a return to climatology in areas where data are not available.	24 hours	SSM/I, Ice Centre Data
Deep soil temperature	400 x 200 gaussian	Derived from climatology and a running mean of the surface air temperature analysis	6 hours	No direct measurements available
Soil moisture	400 x 200 gaussian	Derived from climatology		No measurements available
Albedo	400 x 200 gaussian	Derived from albedo climatology, vegetation type, the snow depth analysis and the ice cover analysis	6 hours	No direct measurements available

7.2.2 Model

Initialization	Diabatic digital Filter (Fillion et al., 1995).
Formulation	Hydrostatic primitive equations.
Domain	Global.
Numerical technique	Finite differences: Arakawa C grid in the horizontal and A grid in the vertical (Côté, 1997).
Grid	Uniform 400 x 200 latitude-longitude grid of 0.9 degree (~100 km) horizontal resolution.
Levels	28 hybrid levels (0., 0.011, 0.027, 0.051, 0.075, 0.101, 0.127, 0.155, 0.185, 0.219, 0.258, 0.302, 0.351, 0.405, 0.460, 0.516, 0.574, 0.631, 0.688, 0.744, 0.796, 0.842, 0.884, 0.922, 0.955, 0.980, 0.993, 1.000). Hybrid coordinate, η, is defined as η=p-p_T/p_S-p_T, where p_T is 10 hPa and p_S is the surface pressure.
Time integration	Implicit, semi-Lagrangian (3-D), 2 time-level, 2700 seconds per time step (Côté et al., 1998a and 1998b).
Independent variables	x, y, η and time.
Prognostic variables	E-W and N-S winds, temperature, specific humidity and logarithm of surface pressure, liquid water content.
Derived variables	MSL pressure, relative humidity, QPF, precipitation rate, omega, cloud amount, boundary layer height and many others.

Geophysical variables: derived from analyses at initial time, predictive derived from analyses, fixed in time derived from climatology, fixed in time	 Surface temperature and humidity, force-restore method (Deardorff, 1978). Sea surface temperature, snow depth, albedo, deep soil temperature, ice cover. Soil humidity, surface roughness length (except variable over water), soil volume thermal capacity, soil thermal diffusivity.
Horizontal diffusion	Del-6 on momentum variables only, except del-2 applied on momentum variables at the top (last level) of the model.
Vertical diffusion	Fully implicit scheme based on turbulent kinetic energy (Benoît et al., 1989).
Orography	Extracted from USGS, US Navy, NCAR and GLOBE data bases using in house software.
Gravity wave drag	Parameterized (McFarlane, 1987; McFarlane et al., 1987).
Low level blocking	Parameterized (Lott and Miller, 1997; Zadra et al., 2003).
Radiation	Solar and infrared modulated by clouds (Garand, 1983; Garand and J. Mailhot, 1990).
Surface fluxes	Momentum, heat and moisture based on similarity theory.
Boundary layer fluxes	Based on turbulent kinetic energy (Benoît et al., 1989; Delage, 1988a and 1988b).
Shallow convection	Turbulent fluxes in partially saturated air (Girard, personal communication).
Stable precipitation	Sundqvist scheme (Sundqvist et al., 1989).
Convective precipitation	Kuo-type scheme (Kuo, 1974).

7.2.3 Numerical Weather Prediction products

7.2.3.1 **Analysis**

A series of classic analysis products are available in electronic or chart form (snow depth and snow cover, sea surface temperature, surface MSLP and fronts, upper-air geopotential, winds and temperature at 1000, 850, 700, 500, 250 hPa, etc.).

7.2.3.2 **Forecasts**

A series of classic forecast products are available in electronic or chart form (MSLP and 1000-500 hPa thickness, 500 hPa geopotential height and absolute vorticity, cumulative precipitation over given periods and vertical velocity, 700 hPa geopotential height and relative humidity). A wide range of bulletins containing spot forecasts for many locations are produced. As well, other specialized products such as precipitation type and probability of precipitation forecasts, temperature and temperature anomaly forecasts are produced.

7.2.4 Operational techniques for application of NWP products

Perfect Prog	6- and 12-h probability of precipitation forecasts at the 0.2, 2 and 10 mm thresholds, at all projection times between 0 and 144 hours (Verret, 1987). An error feedback system is applied on the probability of precipitation forecasts to remove the biases (Verret, 1989). Consistency is forced between the 6-hour and the 12-h probability of precipitation forecasts using a rule based system, which inflates the forecasts. This guidance is also run experimentally out to 240 hours. Spot time total cloud opacity at three-hour intervals between 0 and 144 hour projection times (Verret, 1987). An error feedback system is applied on the forecasts to remove the biases and to force the forecasts to show the typical U-shaped frequency distribution like the one observed (Verret, 1989). This guidance is also run experimentally out to 240 hours. Spot time surface temperatures at three-hour intervals between 0 and 144 hour projection times (Brunet, 1987). An anomaly reduction scheme is applied on the forecasts so that they converge toward climatology at the longer projection times. This guidance is also run experimentally out to 240 hours. All weather element guidance mentioned above is also produced off each member of the Ensemble Prediction System at all projection times between 0 and 240 hours. Maximum/minimum temperatures forecasts out to day 15 once a week (Brunet and Yacowar, 1982). The predictand is the maximum/minimum temperatures observed over the climatological day (06-06 UTC). Five-, seven- and ten-day temperature anomaly forecasts in three equiprobable categories are generated every day, based on simple linear regression of the temperature anomalies on the thickness anomalies. Fifteen-day temperature anomaly forecasts are generated once a week. (Verret et al., 1998). Stratospheric ozone used to calculate the Canadian UV Index (Burrows et al., 1994).
Model Output Statistics (MOS)	An Updateable MOS system (Wilson and Vallée, 2001 and 2002) has been developed for temperatures. Spot time surface temperatures at three-hour intervals between 0 and 144 hour projection times.
Analog technique	24-h probability of precipitation at the 0.2 mm threshold for the day 3-4-5 ranges (Yacowar, 1975; Soucy 1991). An anomaly reduction scheme is applied on the forecasts. Sky cover forecasts for the daylight part of the day at the day 3-4-5 ranges (Soucy, 1991). Wind forecasts for days 3-4-5 (Yacowar and Soucy, 1990). Day 3-4-5 period based on 00 UTC NWP output and for day 3 based on 12 UTC NWP (Soucy, 1991).
Automated computer worded forecasts	A system has been developed and installed at all the Regional Weather Centres in Canada to generate a set of automated plain language forecast products, including public, agricultural, forestry, snow and marine forecasts from a set of weather element matrices for days 1, 2 and 3 (Verret et al., 1993; 1995; 1997). The public forecast type of products can be generated out to day 5. See the following section Weather element matrices. SCRIBE is now the main tool for operational public forecast preparation.

Weather element matrices	An ensemble of weather element matrices including statistical weather element guidance, direct model output parameters and climatological values are prepared at a 3-hour time resolution at approximately 1145 points in Canada and over adjacent waters. The data is valid at the projection times between 0- and 144-hour. Included in the weather element matrices are: climatological maximum / minimum temperatures on a local time window; statistical spot time temperature forecasts; maximum / minimum temperature forecasts calculated from the spot temperatures on a local time window; climatological frequencies of a trace or more of precipitation over 6- and 12-h periods; climatological frequencies of 10 mm or more of precipitation over 12-h periods; statistical spot cloud opacity; statistical forecasts of probability of precipitation over 6- and 12-h periods at the trace and 10 mm thresholds; model precipitation amounts; model cloud height in three categories high, middle and low, Showalter index; vertical motion at 850 hPa; conditional precipitation type; various thicknesses; wind direction and wind speed at surface; model surface dew-point depression; Canadian UV index; model total clouds; 6- and 12-h diagnostic probability of precipitation; model surface temperature, model temperature and dew-point depression near η-level 0.97; sea surface temperature; ice cover; snow depth; wave height forecasts and freezing spray accumulation forecasts. These matrices are disseminated to the Regional Weather Offices where they are used to feed an interactive system for composition of meteorological forecasts called SCRIBE (Verret et al., 1993; 1995 and 1997).

7.2.5 Ensemble Prediction System

Since December 13, 2005, the 16 member Ensemble Prediction System (EPS) runs twice a day up to 16 days. Previously, the EPS would run only once a day and only up to forecast day 10. The more frequent and longer EPS runs became possible with the Canadian participation in the North American Ensemble Forecast System (NAEFS). Combining the Canadian and American ensemble forecasts, due to the improved sampling of the model error component, should extend the range of usefulness of the ensemble forecast well into week two.

Since December 13, 2005, the ensemble Kalman filter (EnKF) of CMC uses four ensembles of 24 members. The EnKF thus still uses a total of 96 members. The previous configuration, known as a double ensemble Kalman filter (Houtekamer et al., 2005), used two ensembles of 48 members. Other modifications are the inclusion of a digital filter finalization in the ensemble of 96 6-h integrations that is required by the EnKF and the addition of model error before rather than after the model integrations. These modifications lead to an improved balance in the guess fields and are in preparation for the implementation of time interpolation in the EnKF.

The trial fields are obtained using a configuration of the GEM model with a horizontal resolution of 1.2 degree and with 28 eta levels. The model top is at 10 hPa.

In principle, the EnKF can assimilate each observation for which a forward interpolation operator has been made available. The EnKF can thus, at least in principle and after testing, assimilate all data that are currently assimilated in the deterministic 4D-variational assimilation system of CMC. With the current system, we do, for instance, directly assimilate the AMSU A and B radiance observations. At this point, however, time interpolation in the 6-h assimilation window has not yet been implemented in the operational EnKF and it is consequently necessary to impose an additional data selection to discard some of the data that are outside the central 3-h window.

The 16 initial conditions for the medium-range ensemble forecasts are obtained in the following manner:

i) Twice a day, at 00 and 12 UTC, sixteen representative members are chosen among the 96 analyses of the EnKF.

ii) The ensemble spread, of the 16-member ensemble of initial conditions, is inflated by a factor 1.8 to arrive at sufficient spread in the medium range.

Two separate models are subsequently used to produce the 16-day forecasts: the SEF spectral model and the GEM grid point model (resolution of 1.2 degree, Cote et al., 1998a and 1998b). Each model uses different configurations of the physical parameterizations.

Ensemble outputs of the following products are available on the web: spaghetti plots of the 500 hPa heights; composite MSLP highs and lows; cumulative precipitation amounts; forecast charts of precipitation amounts probability for various thresholds (http://www.weatheroffice.ec.gc.ca/ensemble/index_e.html).

A set of new products are under development on the EPS outputs. Bayesian Model Averaging (Raftery et al., 2005) is used to generate probability density function for temperatures. Results with Bayesian Model Averaging are available in Wilson et al. (2005). Charts of probabilities of exceeding different thresholds for different variables are also under development. A new updated Perfect Prog statistical post-processing system has been implemented in the EPS to provide statistical surface temperature forecasts from each member model outputs.

7.3 Short range forecasting system (0-48 hours)

7.3.1 Data assimilation and objective analysis

7.3.1.1 **Upper air**

Method	The short-range forecasting system is driven using the analysis produced by the Regional Data Assimilation System (RDAS). This system consists of a 12 hour spin-up period during which 6-hour trial fields are produced by the Regional Global Environmental Multiscale (GEM) model (58 levels). The RDAS is initiated from the analysis of the Global 4D-Var Data Assimilation System. The three-dimensional multivariate variational (3D-Var) method is used in the RDAS and it is performed twice during the spin-up period. The computation of innovations for the regional analysis is performed using the high resolution grid of the GEM model. The 3DVar analyses are done in spectral space using the incremental approach. The analysis fields are then supplied to the short-range forecasting model directly on its eta coordinates and variable resolution working grid. (Laroche et al., 1999)
Variables	T, Ps, U, V and log q (specific humidity).

Levels	28 η levels of GEM global model.
Domain	Global.
Grid	The analysis is done spectrally at T108 using a 400x200 gaussian grid. Analysis increments are interpolated on the GEM model's global variable resolution grid: 15 km in the uniform core area with decreasing resolution outside North America.
Frequency and cut-off time	Two 12-hour spin-ups are produced each day (00 UTC to 12 UTC and 12 UTC to 24 UTC). They are initiated from global analyses at 00 UTC or 12 UTC, followed by a regional analysis at 06 UTC or 18 UTC with a cut-off time of 5h30. The final analysis of each spin-up (00 UTC and 12 UTC) has a cut-off of 1h40. Data within +/- 3 hours of analysis time are used.
Processing time	15 minutes for the analysis and 6 minutes for the 6-hour GEM integration on IBM.
Data used	GTS data: TEMP, PILOT, SYNOP/SHIP, SATOB, ATOVS level 1b (AMSU-A, AMSU-B/MHS), BUOY/DRIFTER, AIREP/AMDAR/ACARS/ADS, PROFILER, and locally processed GOES radiances data.
Bogus	Subjective bogus, as required.

7.3.1.2 **Surface**

The medium-range forecasting system for the surface analyses of ice, snow depth and SST are used (see section 7.2.1). The surface temperature and soil moisture are deduced from a sequential assimilation method based on model error feedback to generate analyses of temperatures and moisture in two soil layers (Bouttier et al., 1993). These analyses are produced once a day, with increments added at 00 UTC.

7.3.2 Model

Initialization	Diabatic digital Filter (Fillion et al., 1995).
Formulation	Hydrostatic primitive equations.
Domain	Global.
Numerical technique	Finite differences: variable resolution Arakawa C grid in the horizontal and Arakawa A grid in the vertical (Côté, 1997).
Grid	575 x 641 variable resolution on latitude-longitude grid having a uniform .1375 degree (~15 km) window covering North America and adjacent oceans.
Levels	58 hybrid levels: 0.0000, 0.0102, 0.0233, 0.0374, 0.0508, 0.0625, 0.0720, 0.0795, 0.0852, 0.0897, 0.0941, 0.0990, 0.1044, 0.1104, 0.1172, 0.1248, 0.1334, 0.1431, 0.1541, 0.1667, 0.1812, 0.1976, 0.2149, 0.2331, 0.2522, 0.2721, 0.2928, 0.3144, 0.3369, 0.3602, 0.3843, 0.4091, 0.4348, 0.4612, 0.4883, 0.5161, 0.5446, 0.5737, 0.6034, 0.6337, 0.6646, 0.6959, 0.7272, 0.7567, 0.7845, 0.8104, 0.8346, 0.8571, 0.8780, 0.8973, 0.9151, 0.9316, 0.9467, 0.9606, 0.9733, 0.9850, 0.9950, 1.0000. The hybrid coordinate, η, is defined as η=p-p_T/p_S-p_T, where p_T is 10 hPa and p_S is the surface pressure

Time integration	Implicit, semi-Lagrangian (3-D), 2 time-level, 450 second per time step (Côté et al., 1998a and 1998b).
Independent variables	x, y, η and time.
Prognostic variables	East-west and north-south winds, temperature, specific humidity and logarithm of surface pressure, cloudwater content, turbulent kinetic energy (TKE).
Derived variables	MSL pressure, relative humidity, QPF, precipitation rate, omega, cloud amount, boundary layer height and many others.
Geophysical variables: derived from analyses at initial time, predictive derived from climatology at initial time, predictive derived from analyses, fixed in time derived from climatology, fixed in time	 Surface and deep soil temperatures, surface and deep soil humidity ISBA scheme (Noilhan and Planton, 1989); snow depth, snow albedo Sea ice thickness Sea surface temperature, ice cover Surface roughness length (except variable over water); soil volume thermal capacity; soil thermal diffusivity.
Horizontal diffusion	Del-6 on momentum variables only, except for top sponge layer (del-2 applied on momentum variables at the 4 uppermost levels of the model).
Vertical diffusion	Fully implicit scheme based on turbulent kinetic energy (Benoît et al., 1989).
Orography	Extracted from USGS, US Navy, NCAR and GLOBE data bases using in house software.
Gravity wave drag	Parameterized (McFarlane, 1987; McFarlane et al., 1987).
Low level blocking	Parameterized (Lott and Miller, 1997; Zadra et al., 2003).
Radiation	Solar and infrared modulated by clouds (Garand, 1983; Garand and Mailhot, 1990; Yu et al., 1996).
Surface scheme	Mosaic approach with 4 types: land, water, sea ice and glacier (Bélair et al., 2003a and 2003b).
Boundary-layer turbulence	Based on turbulent kinetic energy (Benoît et al., 1989; Delage, 1988a and 1988b), with statistical representation of subgrid-scale clouds (Mailhot and Bélair, 2002; Bélair et al., 2005)
Shallow convection	Kuo Transient scheme (Bélair et al., 2005)
Stable precipitation	Sundqvist scheme (Sundqvist et al., 1989; Pudykiewicz et al., 1992).
Deep convection	Kain & Fritsch scheme. (Kain and Fritsch, 1990 and 1993)

7.3.3 Numerical Weather Prediction products

7.3.3.1 **Analysis**

A series of standard analysis products are available in electronic or chart form (snow cover and snow depth, sea surface temperature, surface MSLP and fronts, upper-air geopotential, winds and temperature at 1000, 850, 700, 500, 250 hPa, etc.).

7.3.3.2 **Forecasts**

A wide variety of forecast products are available in electronic or chart form. These include the classic charts such as MSLP and 1000-500 hPa thickness, 500 hPa geopotential height and absolute vorticity, cumulative precipitation and vertical velocity, 700 hPa geopotential height and relative humidity. Series of special charts are produced in the context of the summer or winter severe weather (tropopause, stability indices, wind shear, helicity, wind chill, liquid water content, streamlines, low-level maximum wind, vertical motion, etc.) or in the specific support for aviation forecasting (icing, freezing level, height of cloud ceiling, momentum flux, turbulence, etc.). A wide range of bulletins containing spot forecasts are produced for many locations over North America.

7.3.4 Operational techniques for application of NWP products

Perfect Prog	6- and 12-h probability of precipitation forecasts at the 0.2, 2 and 10 mm thresholds, at all projection times between 0 and 48 hours for a 264 Canadian station set (Verret, 1987). Consistency is forced between the 6-hour and the 12-hour probability of precipitation forecasts using a rule based system, with emphasis on inflation of the forecasts. Spot time total cloud opacity at three-hour intervals between 0 and 48 hour projection times (Verret, 1987). Consistency between the cloud and the probability of precipitation forecasts is forced using a rule based system. Emphasis is put on inflating the cloud forecasts so that they show a frequency distribution similar to that observed (Verret, 1988). Spot time surface temperatures at three-hour intervals between 0 and 48 hour projection times (Brunet, 1987). Maximum/minimum temperature forecasts for day 1 and day 2 (Brunet and Yacowar, 1982). The predictand is the maximum/minimum temperatures observed over the climatological day (06-06 UTC). Surface wind forecasts at 6-h intervals out to 48 hours. The forecasts are tuned based on a calibration technique.
Model Output Statistics (MOS)	An Updateable MOS system (Wilson and Vallée, 2001 and 2002) has been developed and implemented. The system currently provides forecasts for : Spot time surface temperatures at three-hour intervals between 0 and 48 hour projection times. Surface wind speed and wind direction at three-hour intervals between 0 and 48 h projection times. 6- and 12-h probability of precipitation at the -0.2 mm threshold between 0 and 48 h projection times.. Spot time total sky cover at three-hour intervals in four categories. The system is based on Multiple Discriminant Analysis (MDA)
Diagnostic techniques on	Charts of forecast icing (Tremblay et al., 1995), turbulence (Ellrod, 1989), cloud amounts with bases and tops, freezing levels and tropopause

direct model output fields	heights. The charts are produced at 6-h intervals out to 24 hours. These charts constitute the Aviation Package. Forecast charts of buoyant energy, helicity, convective storm severity index, low level wind shear, precipitable water, low and high level wind maximum, surface temperature and dew points, heights and contours at 250 hPa and tropopause heights. The charts are produced at 6-h intervals out to 24 hours. These charts constitute the Summer Severe Weather Package. Forecast charts of precipitation type (Bourgouin, 2000), 250 hPa contour heights and vorticity, precipitable water, 6-h precipitation amounts, wind chill, surface temperature, thickness values and warm or above freezing layers with bases and tops. The charts are produced at 6-h intervals out to 24 hours. These charts constitute the Winter Severe Weather Package. Forecast charts of the mean sea level pressure at 21 UTC with the forecast precipitation amounts between 12 and 00 UTC; charts of the streamlines at 21 UTC with the wind mileage (time integration of the wind speed) between 12 and 00 UTC; charts of the forecast minimum and maximum boundary layer height and the ventilation coefficient. These charts, valid for Today and Tomorrow, constitute the Air Quality Package. Direct model outputs are used to forecast upper air winds and temperatures for aviation purposes. Several parameters interpolated at stations, formatted and transmitted operationally to Regional Offices.
Automated computer worded forecast: Scribe	A system has been developed and installed at all the Regional Weather Centres in Canada to generate a set of automated plain language forecast products from a set of weather element matrices for days 1, 2 and 3 (Verret et al., 1993; 1995 and 1997). See the following section Weather element matrices. The system called SCRIBE has been implemented in all offices and is now the main tool for operational forecast preparation. Scribe for marine forecasts is presently being tested.
Weather element matrices	Same as section 7.2.4, except the data is valid at projection times between 0 and 48 hours and UMOS guidance is used instead of Perfect Prog one. Supplementary weather element matrices have been developed and implemented in quasi-operational mode. The content of these matrices include mean sea level pressure, surface pressure, lifted index, highest freezing level, mean wind direction and speed over the four lowest η level of the driving model, boundary layer height and ventilation coefficients at time of minimum and maximum temperatures, instantaneous and accumulated downward infra-red and visible radiation fluxes. The time resolution of these matrices is 3 hours, with projection times out to 48 hours.

7.3.5 High resolution model for short range forecasts

In 2005, the outdated HIMAP system was replaced by a LAM (limited area model) version of the GEM model at high resolution (2.5 km). It runs once a day for 24 hours over 2 sub-areas of Canada: southern British-Columbia and southern Ontario-Quebec. The model used is similar to the unified model described in section 7.3.2; the main differences are:

- grid resolution of 2.5 km;
- non-hydrostatic formulation;
- stable precipitation parameterized with Kong and Yau scheme (Kong et al., 1997);
- no parameterization of deep convection.

The model starts from the 12-hour forecast of the regional model following the 00 UTC run and the boundary conditions are provided by the same model run at every hour.

Outputs are transmitted in GRIB formats to Canadian Regions. Series of coloured images (including animation) are also made available through the internal Web.
As computer resources become available, it is planned to implement more windows of the model to allow a more complete coverage of Canada

7.4 Specialized forecasts

7.4.1 Environmental Emergency Response model

The CMC is able to provide in real-time air concentrations and surface deposition estimates of airborne pollutants. These fields are obtained from either an Eulerian 3-D long range atmospheric transport/dispersion/deposition model, named the "Canadian Emergency Response Model" or "CANERM", or from short/long range Lagrangian Particle Models: MLDP0, MLCD and MLDP1. Important applications from these models are the estimation of the concentrations of radionuclides and volcanic ash. Based on this operational capability, the CMC is designated by the WMO as a Regional Specialised Meteorological Centre (RSMC) with specialization in Atmospheric Transport Modelling Products for Environmental Emergency Response. In addition, CMC is designated by the International Civil Aviation Organisation as a Volcanic Ash Advisory Centre (VAAC).

7.4.1.1 **Data assimilation, objective analysis and initialization**

CANERM and the Lagrangian Particle Models are "off-line" models. Therefore fields of wind, moisture, temperature and geopotential heights must be provided to them. These are obtained either from the Global or Regional forecasts and objective analysis systems. Please refer to the above sections 7.2 and 7.3 for more information on these NWP products.
Latitude, longitude and time of the release are necessary input parameters. Estimates of intensity and duration of the release are also required. In the case of a nuclear accident and in the absence of actual source data, the standard default values adopted at the WMO's First International Workshop on Users' Requirements for the Provision of Atmospheric Transport Model Products for Environmental Emergency Response (September 1993) would be used. These are:

- uniform vertical distribution up to 500 m above the ground;
- uniform emission rate during the first 6 hours;
- total pollutant release of 1 arbitrary unit;
- type of radionuclide is Caesium 137.

7.4.1.2 **Models**

CANERM is described in Pudykiewicz, 1989. The horizontal and vertical advections in the model are performed using the semi-Lagrangian algorithm of Ritchie, 1987. Diffusion is modelled according to K-theory. The diffusivities are constant in the free atmosphere but have a vertical profile in the boundary layer which is dependent on the state of the surface layer; the vertical diffusivity within the surface layer is approximated using the relations provided by the analytical theory of the surface layer. CANERM simulates wet and dry scavenging, wet and dry deposition and radioactive decay for selected tracers. Wet scavenging is modelled by a simplified statistical parameterization based on the relative humidity. The source term is modelled by a narrow gaussian distribution to simulate both the release and subgrid scale mixing.

CANERM can be executed in forecast mode up to day 10, using the operational Global forecast model, and up to 2 days using the operational Regional forecast model. CANERM can also be executed in hindcast mode using Global or Regional objective analyses. Presently, three horizontal resolutions are available: a resolution of 150 km on a quasi-hemispheric domain, a movable continental domain with a resolution of 50 km and a mesoscale domain with a resolution of 25 km. CANERM can be run for both the Northern and Southern Hemispheres.

MLDP0 is a Lagrangian Particle Model described in D'Amours & Malo, 2004. In this model, dispersion is estimated by calculating the trajectories of a very large number of air particles (or parcels). The trajectory calculations are done in two parts : 3-D displacements due to the transport by the synoptic component of the wind, then 3-D displacements due to unresolved turbulent motions. Vertical mixing caused by turbulence is handled through a random displacement equation based on a diffusion coefficient. This coefficient is calculated in terms of a mixing length, stability function, and vertical wind shear.

Lateral mixing is modeled according to a first order Langevin stochastic equation for the unresolved components of the horizontal wind. Dry deposition is modeled in term of a deposition velocity. The deposition rate is calculated by assuming that a particle contributes to the total surface deposition flux in proportion to the tracer material it carries when it is found in a layer adjacent to the ground surface. Wet deposition will occur when a particle is presumed to be in a cloud. The tracer removal rate is proportional to the local cloud fraction.

In MLDP0, tracer concentrations at a given time and location are obtained by assuming that particles carry a certain amount of tracer material. The concentrations are then obtained by calculating the average residence time of the particles, during a given time period, within a given sampling volume, and weighing it according to the material amount carried by the particle.

MLDP0 can be executed in configurations similar to those of CANERM; a global configuration also exists. MLDP0 can be executed in inverse (adjoint) mode. The model has been used extensively in this configuration in the context of the WMO-CTBTO cooperation.

MLCD is a Lagrangian Particle Model described in details in Flesch, et al. 2002, and was developed in collaboration with the Department of Earth and Atmospheric Sciences of University of Alberta. It is designed to estimate air concentrations and surface depositions of pollutants for very short range (less than ~10 km from the source) emergency problems at the Canadian Meteorological Centre. As in MLDP0, this 3-D Lagrangian dispersion model calculates the trajectories of a very large number of air particles. MLCD is a first order Lagrangian Particle Dispersion Model because the trajectories of the particles are calculated from the velocities increments, while MLDP0 is a zeroth order Lagrangian Particle Dispersion Model since the trajectories of the parcels are updated from the displacements increments.

The Langevin Stochastic Equation is based on the turbulent components of the wind (Turbulent Kinetic Energy). Vertical wind and TKE profiles are generated from a "user provided" set of wind observations (velocity + direction) time dependant through a "two-layer" model (Flesch and Wilson, 2004). For example, these wind observations can be obtained from a meteorological tower or from detailed real-time forecasts from NWP Global and Regional operational models. Wind profiles can change over time and vary in the vertical, but is horizontally uniform, which represents an important difference with MLDP0 that uses full 3-D meteorological fields.

MLCD can take into account the horizontal diffusion for unresolved scales operating at time scales longer than those associated to TKE (meanders). The removal processes of radioactive decay, wet scavenging and dry deposition can also be simulated by the model. MLCD can be run in forward or inverse mode. Air concentrations and surface depositions can be calculated over five different types of grids (time-fixed or time-variable, constant or variable horizontal resolution, polar stereographic or cylindrical equidistant) and for specific layers in the atmosphere through a user specified list of vertical levels.

A new Lagrangian Particle Model called MLDP1 is currently under development at the Canadian Meteorological Centre. This stochastic dispersion model is well described in Flesch, et al. 2004, and combines the advantages of both MLDP0 (full 3-D meteorological fields) and MLCD (first order model) models described previously. MLDP1 is parallelized to run on several nodes on the IBM supercomputer at CMC. It uses both distributed- and shared-memory standards.

7.4.1.3 **Numerical Weather Prediction (atmospheric transport/dispersion/deposition) products**

Upon receiving a request for a nuclear or radiological support from an appropriate WMO Member Country Delegated Authority, the CMC will provide the following standard set of basic products:

- three dimensional trajectories starting at 500, 1500 and 3000 m above the ground, with particle locations indicated at synoptic hours;
- time integrated pollutant concentration within the 500 m layer above the ground, in units/m3, for each of the three time periods. The duration of the first time period is between 12 and 24 hours starting at release time. For a release before 12 UTC, it ends at 00 UTC; for a release after 12 UTC, it ends at 12 UTC the next day. The second time period is the 24 hours following the first time period. The third time period is the 24 hours following the second time period;
- total deposition (wet and dry) in units/m2 from the release time to the end of the third time period.

The standard set of products was agreed upon at the First International Workshop on Users' Requirements for the Provision of Atmospheric Transport Model Products for Environmental Emergency Response. The CMC can also provide charts of air concentration estimates for many levels in the atmosphere as well as total surface deposition estimates at various time intervals. All the products can be transmitted in real time during environmental emergencies.

7.4.2 Ozone and UV index forecasting

The Canadian Global model is used to prepare ozone and UV Index forecast at the 18 hour projection time based on 00 UTC data and at the 30 hour projection time based on 12 UTC data (Burrows et al., 1994). A Perfect Prog statistical method is used for forecasting total ozone, which is then supplemented with an error-feedback procedure. UV Index is calculated from the corrected ozone forecast. Charts of the total ozone forecast and of the UV Index forecast are prepared and transmitted to the Regional Offices. Bulletins giving the forecast UV Index at an ensemble of stations across Canada are also generated. Correction factors have been added to take into account the snow albedo, elevation and Brewer angle response.

7.4.3 Wave forecasting

Sea-state forecasts of 48 hours over Eastern Pacific, Western Atlantic and 4 Great Lakes (Ontario, Erie, Huron and Superior) are generated twice a day (00 UTC and 12 UTC) by the WAM (WAve Modeling) model (version 4.5). The model is run at a resolution of 0.5 degree over the Pacific and the Atlantic while a resolution of 0.05 degree is used over the Great Lakes. The Pacific version of the wave model uses the surface level winds from the global model while the Atlantic and Great Lakes versions use the regional model wind outputs. Various parameters are plotted on the wave forecast charts (wave height, swell period, swell height, direction, etc.).

7.4.4 Air Quality forecasting

CHRONOS (Canadian Hemispheric and Regional Ozone and NOx System) is a chemical transport model integrated daily over a domain covering the bulk of North America and adjacent waters (Pudykiewicz et al., 1997). The model is run from 00 UTC every day of the year to 48 hours. It has a horizontal resolution of 21 km and 24 vertical Gal-Chen levels up to 6 km. The chemical mechanisms used in the simulation include 114 chemical reactions involving 47 chemical species. The advection-diffusion equation in the model is solved using a semi-Lagrangian algorithm. The model simulates dry deposition and wet scavenging of the chemical tracers. The meteorological inputs used in the simulation of atmospheric chemistry are provided by the Canadian operational regional GEM model. The emissions inventory of chemical species is based on 2000-2001 data and the SMOKE processing system. The emission inventory takes into consideration the day of the week, the season and the various types of emissions which are mobile, non-mobile, major and minor point sources and the biogenic sources. The emissions follow a diurnal cycle. The initial conditions for the different chemical compounds are given by the previous 24 hr forecast.

The current operational outputs from CHRONOS consist of hourly concentrations of tropospheric ozone, $PM_{2.5}$ and $PM_{10.}$ Only emissions of sulphate and secondary organic aerosols are presently considered in the forecasting of PMs. Post-processing is performed on these outputs to provide users with maximum, mean and 3-hourly running mean forecast of tropospheric ozone per 6 hr forecast period. The outputs are available on the web as alphanumerical point forecasts for a selection of cities across Canada. Also on the web (http://www.msc-smc.ec.gc.ca/aq_smog/chronos_e.cfm), maps of maximum values for aerosol and PMs are available, providing a better spatial representation of the different chemical variables predicted by CHRONOS. The maps are also available internally on vizaweb.

7.5 Extended range forecasts (10-30 days)

Ten-day temperature anomaly forecasts (Verret et al., 1998) are generated once a day and fifteen-day temperature anomaly forecasts are generated once a week using a perfect prog approach from the medium-range model described in section 7.2.2.

Monthly temperature forecasts based on numerical weather prediction techniques are issued at the beginning and mid-month of every month. Two ensembles of 6 runs, obtained from 24-hour time lag, are produced: 6 from the Global Environmental Multiscale (GEM) model (Côté

et al., 1998a and 1998b) (1.875 degree with 50 levels in the vertical) and 6 from the atmospheric general circulation model second generation (AGCM2) of the Canadian Climate Centre for modelling and analysis (CCCma) (McFarlane et al., 1992) (T32 L10). Both models use the same initial operational analyses. SST anomalies observed over the previous 30 days are added to climatological values over the period; snow is relaxed towards climatology at the end of the first month, except for the AGCM2, where it is a prognostic variable.
Direct model surface temperature outputs ensemble means are averaged over the 30-day period and subtracted from model climatology obtained from a 26-year hindcast period (see section 7.6). The final deterministic forecasts are generated from the normalized average of both model ensemble means. These temperature anomalies are then normalised by the model standard deviation multiplied by 0.43 (to get equiprobable classes) and categorised in above, below and normal categories. Charts are produced, showing above normal, below normal and near normal temperature categories. Monthly forecast products are available on the Internet (Web address http://weatheroffice.ec.gc.ca/saisons/index_e.html).

7.6 Long range forecasts (seasonal forecasts)

7.6.1 Season 1 forecasts (zero lead time)

Season 1 forecasts are produced using a numerical approach (Derome et al., 2001). The approach is identical to the monthly forecast one described in section 7.5 . Maps are similar to those used in monthly forecasts: 3 categories, separated using the 0.43 standard deviation of observed climatology. The temperature and precipitation forecasts are produced using direct model outputs. The two ensemble means of forecasts are subtracted from their respective models' climatologies, and normalised by models' standard deviations. These normalised forecasts are then added, divided by two and used to produce a map, categorised in 3 categories, using the 0.43 value for separation. Skill maps of temperature and precipitation, as obtained over the 26 years of historical runs, are shown for each of the 4 seasonal forecasts periods.

The probabilistic forecasts are done by counting members in each of the three possible forecast categories: below normal, near normal and above normal. The probabilistic forecasts are not calibrated but a reliability diagram with error bars is provided with each forecast.

The model outputs for the season 1 are now available in real time on Internet via the CCCma web site. The monthly and seasonal means for 7 fields for the 2 operational models (CCCma AGCM2 and GEM) can be downloaded. Data from both the operational and the hindcast runs are available. The operational forecast data can be accessed at http://www.cccma.bc.gc.ca/data/cmc/cmc.shtml while the hindcast data are located at http://www.cccma.bc.ec.gc.ca/data/hfp/hfp.shtml

Seasonal forecasts are now generated for twelve three month seasons and are issued on the first day of each month, the forecasts being valid for the following three months.

7.6.2 Season 2, 3 and 4 forecasts

Seasonal forecasts with lead times of 3, 6 and 9 months are produced, using a Canonical Correlation Analysis technique (Shabbar and Barnston, 1996). The technique uses the SST anomalies observed over the last year to predict temperature and precipitation anomalies at Canadian stations (51 for temperatures, 69 for precipitation) for the following 3 seasons. Maps of above, normal and below temperature and precipitation are produced. These are accompanied by skill maps, as obtained from cross-validation over a 40-year period. Seasonal forecast for seasons 2, 3 and 4 are available for the main four seasons of the year (winter: December, January, February; spring: March, April, May; summer: June, July, August and fall: September, October, November).

8 Verification of prognostic products

Objective verification of the operational numerical models is carried out continuously at the CMC. S1 skill scores, biases and root mean square errors are produced for the Canadian verification area. A monthly verification summary is produced and distributed to our clients.

A verification system following the WMO/CBS recommendations was implemented in 1987. Results are routinely exchanged with the other participating NWP centres. The table on the following page is a summary of the CMC verification scores for 2005 according to the recommended format. Since 1994, CMC has exchanged these verification scores electronically with other NWP centres, which has allowed a more comprehensive comparison of NWP models from the various centres.

Verification summary - 2005
Canadian Meteorological Centre
Global Environmental Multiscale (GEM) Model (0.9 deg. L28)
Verification against analysis

Area	Parameters	T+24h		T+72h		T+120h	
		00UTC	12UTC	00UTC	12UTC	00UTC	12UTC
N. Hemisphere	RMSE (m) GZ 500 hPa	11.0	11.6	29.4	29.8	54.7	55.1
	RMSVE (m/s) Wind 250 hPa	5.9	5.0	10.2	10.2	15.6	15.6
Tropics	RMSVE (m/s) Wind 850 hPa	2.8	2.8	4.2	4.2	5.1	5.1
	RMSVE (m/s) Wind 250 hPa	5.1	5.1	8.3	8.3	10.5	10.5
S. Hemisphere	RMSE (m) GZ 500 hPa	15.8	16.0	40.7	40.9	71.9	71.9
	RMSVE (m/s) Wind 250 hPa	5.3	5.3	11.3	11.4	17.3	17.3

Verification against radiosondes

Network	Parameters	T+24h		T+72h		T+120 h	
		00UTC	12UTC	00UTC	12UTC	00UTC	12UTC
N. America	RMSE (m) GZ 500 hPa	11.8	11.9	30.0	30.2	54.9	55.1
	RMSVE (m/s) Wind 250 hPa	6.6	6.5	12.0	12.0	17.8	17.5
Europe	RMSE (m) GZ 500 hPa	13.9	12.9	30.9	29.7	60.2	59.6
	RMSVE (m/s) Wind 250 hPa	5.9	5.6	11.1	10.8	17.7	17.6
Asia	RMSE (m) GZ 500 hPa	14.2	14.1	27.4	27.2	45.9	45.1
	RMSVE (m/s) Wind 250 hPa	6.3	6.5	10.7	10.9	14.6	14.6
Australia - N.Z.	RMSE (m) GZ 500 hPa	13.9	14.5	24.3	28.7	41.6	49.9
	RMSVE (m/s) Wind 250 hPa	6.5	6.7	10.8	11.0	15.7	16.0
Tropics	RMSVE (m/s) Wind 850 hPa	4.3	4.1	5.4	5.1	6.2	5.8
	RMSVE (m/s) Wind 250 hPa	6.3	6.3	8.6	8.9	10.4	10.0
N. Hemisphere	RMSE (m) GZ 500 hPa	13.9	13.5	31.7	31.4	58.7	58.5
	RMSVE (m/s) Wind 250 hPa	6.2	6.1	11.3	11.3	17.0	16.9
S. Hemisphere	RMSE (m) GZ 500 hPa	16.2	17.8	31.2	36.7	52.9	61.1
	RMSVE (m/s) Wind 250 hPa	6.6	7.1	11.3	11.9	16.6	17.4

9 Plans for the future

- The global model horizontal resolution will be increased to 33 km with improved physics schemes.

- New observation datasets will be added to the assimilation systems. These datasets will include radiances data from SSMI, SSMI/S and AIRS instruments as well as an extended coverage of radiances from geostationary satellites (Clear Sky Radiances, CSR).

- SCRIBE will become the main tool for marine forecast preparation in MSC.

- Work to expand the UMOS set of guidance to include dew point temperature, probability of precipitation amounts and probability of precipitation types will be initiated.

- Development work on a new updated version of perfect prog will continue. This new perfect prog system is meant to become part of the Ensemble Prediction System.

- Canada, in collaboration with USA and Mexico, will implement the North American Ensemble Forecast System (NAEFS). Canada and USA will start developing joint ensemble products over North America. More products, such as the extension of the public forecast to day 7, will be issued out of the ensemble prediction system suite.

- 2 new models (SEF and GCM-3) will be added to the seasonal forecast system which already uses GEM and GCM-2.

- A regional atmospheric forecast model coupled to an ocean-ice model over the Golf of St-Lawrence will be developed.

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