Canada

Canadian Meteorological Centre
2121 Trans-Canada Highway
Dorval, Québec H9P 1J3

1. Summary of highlights

The mesoscale short range model (HIMAP), running at 10 km resolution, was upgraded in February 2002 to use the ISBA surface module.

A modification of Satwinds thinning rules was introduced in March 2002.

The global medium range Ensemble Prediction System was improved in March 2002 by the introduction of a blocking term in the subgrid orography parameterization and by the introduction of high density Satwinds.

NOAA17 radiances were added to the observational data base in December 2002.

The transition to the NEC SX-6 computer system of all the operational suite started in December 2002.

2. Equipment in use at the Centre

Computer	Memory	Disk (Gbytes)
10 SX-6/8M, 8 cpu	64*10GB	2176
2 NEC SX-5/16, 16 cpu	128GB	1108
1 NEC SX-4/32 , 32 cpu	8GB (16GB ssd)	800
4 SGI ORIGIN 2000, 4-4-12-16 cpu	1GB-2GB-3GB-4GB	1000-800-1000-2300
1 TANDEM Himalaya, S7400, 2 cpu	1024MB	64
10 SGI ORIGIN 200, 1-3 cpu	512MB	29-225
27 HP 9000 C110-C180-C360	256MB-512MB	6-22
9 HP K200 - K370	256MB -512MB	8-108
4 SGI-Indigo 2XS	64MB-256MB	3-20
35 SGI 230 -330	256MB-512MB	8-20
30 NCD Xterminals	32MB - 128MB	-
1 SGI OCTANE	256MB	72

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	38,000
- TEMP (500 hPa GZ)	1,150

- TEMP/PILOT (300 hPa UV)	1,260
- DRIFTER/BUOYS	15,500
- AIREP/ADS	3,250
- SATEM	15,300[1]
- SATOB (including BUFR)	465,000
- SATOB-SST	2,000
- SA/METAR	175,500
- AMDAR/ACARS	131,600
- PIREP	900[1]
- PROFILER	760[1]
- HUMSAT	12,500[2]
- ATOVS (AMSU-A)	985,000[4]
- SSM/I	1,000,000[3]

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, now 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 activities to be performed. This monitoring is done on the global scale.

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[1] Not assimilated yet, or no longer assimilated
[2] Locally produced GOES moisture profiles
[3] A third of these are used for ice analyses
[4] Three NOAA satellites now assimilated

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 reports are prepared in accordance to the WMO/CBS approved procedures. The reports are sent to the WMO Secretariat as well as other major GDPS centres.

Similar information is also available in near real-time 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 2002. Monitoring results are distributed directly to national focal points for most countries within RA-IV.

7. Forecasting system

7.1 System run schedule

The following table summarizes the operational runs at CMC. The core of the operational runs executes in batch on the NEC SX-6 cluster. Most of the postprocessing jobs, including those generating CMC products, execute on the front end computer (SGI Origin 2000).

CMC model and upper-air objective analysis run schedule		
R1 (00,12)	Regional GEM model run Regional objective analysis Regional forecast model (24 km) All products available by	00 or 12 UTC data Cut-off time T+1:50 To 48 h T+3:00
R1 (06, 18)	Regional early objective analysis	06 or 18 UTC data Cut-off time T+1:20
R2 (00, 12)	Regional assimilation system Start-up of spin-up Regional objective analysis Regional forecast model	00 or 12 UTC data (from global cycle) Cut-off time T+6:00 6-h forecast

R2 (06, 18)	Regional assimilation system Regional objective analysis Regional forecast model	06 or 18 UTC data Cut-off time T+5:30 6-h forecast
R3 (00, 12)	Regional final objective analysis	00 or 12 UTC data Cut-off time T+7:00
RW (06,18) West window	Regional high resolution (HIMAP) 10 km	30-h forecast (initial conditions from the 6-h forecast of R1 (00,12))
RE (06,18) East window	Regional high resolution (HIMAP) 10 km	30-h forecast (initial conditions from the 6-h forecast of R1 (00,12))
G1 (00, 12)	Global GEM model run Global objective analysis Global GEM model forecast All products available by	00 or 12 UTC data Cut-off time T+3:00 To 120 h 12 UTC To 240 h 00 UTC To 360 h 00 UTC - Saturday only T+6:30
G1 (06, 18)	Global early objective analysis	06 or 18 UTC data Cut-off time T+2:00
G2 (00, 06, 12, 18)	Global assimilation cycle Global objective analysis Global GEM model forecast	00, 06, 12, 18 UTC data Cut-off time: T+6:00 (06, 18), T+9:00 (00, 12) 6-h forecast
E2, E1 (00, 06, 12,18)	Ensemble prediction system runs (16 members)	Continuous data assimilation system for 16 members. 10-day forecasts at 150km resolution issued once a day for each members
C1 (00)	CHRONOS model for air quality prediction	48-h forecast
M1 (00)	Global model run (T63)	To 840 h (monthly forecast) for 5 consecutive days before end and middle of month. To 2400 h (seasonal forecast, 3 months) for 6 consecutive days before end of February, May, August and November

Note: There are also runs (not described here) that perform surface objective analyses and update geophysical fields; these are runs G3, G4, G5, G6 and R6.

7.2 Medium range forecasting systems (3-10 days)

7.2.1 Data assimilation and objective analysis

7.2.1.1 Upper air

Method	Fully three-dimensional multivariate variational analysis of deviations of observations from 6-hour forecast of a 28-level 0.9° uniform resolution GEM. The incremental approach is used for 3D-Var. (Gauthier *et al.*, 1997, Gauthier *et al.*, 1999). A digital filter is used to initialize the forecast model.
Variables	T, Ps, U, V and log (specific humidity).
Levels	28 η levels of GEM model.
Domain	Global

Grid	400 x 200. Spectral analyses at T108.
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	15 minutes plus 3 minutes for trial field model integration on the NEC SX-5.
Data used	GTS data : TEMP, PILOT, SYNOP/SHIP, SATOB, ATOVS level 1b (amsu-a), BUOY/DRIFTER, AIREP/AMDAR/ACARS/ADS, and locally derived humidity profiles from GOES (HUMSAT).
Bogus	Subjective bogus, as required.

7.2.1.2 Surface

Analyzed surface fields for the medium range forecasting system

Fields	**Analysis Grid(s)**	**Method**	**Trial Field**	**Frequency**	**Data Source**
Surface air temperature	0.9° x 0.9° global	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	400 x 200 gaussian	Optimum interpolation	Previous analysis	24 hours	Ships,buoys, drifters, AVHRR satellite data (Brasnett, 1997)
Snow depth	1080 x 540 gaussian	Optimum interpolation	Previous analysis with estimates of snowfall and snowmelt	6 hours	Land Synops, Metars, Sas (Brasnett, 1999)
Ice cover	1080 x 540 gaussian	Data averaging with a return to climatology in areas where data are not available.		24 hours	SSM/I, Canadian Ice Service 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) 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, 2700 second

	per time step (Côté *et al.* 1998*a*; Côté *et al.* 1998*b*).
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	Surface temperature and humidity, force-restore method (Deardorff, 1978).
- derived from analyses, fixed in time	Sea surface temperature, snow depth, albedo, deep soil temperature, ice cover.
- derived from climatology, fixed in time	Soil humidity, surface roughness length (except variable over water); soil volume thermal capacity; soil thermal diffusivity.
Horizontal diffusion	None, except del-2 applied near the calculation poles and 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* 2002)
Radiation	Solar and infrared modulated by clouds (Garand, 1983; Garand and 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, 1988*a*; Delage, 1988*b*).
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 (*i.e*. surface analysis of snow and 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 (i.e. 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). A wide range of bulletins containing spot forecasts for many locations are produced . As well, other specialized products such as precipitation and probability of precipitation forecasts, temperature and temperature anomaly forecasts, etc., 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 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 biases and to force the forecasts to show the typical U-shaped frequency distribution similar to that 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 to 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 elements 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 10 on a daily basis and 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)
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 elements 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 elements matrices". The system, called SCRIBE is currently being implemented as the main tool for public forecast production.
Weather elements matrices	An ensemble of weather elements matrices including statistical weather elements guidance, direct model output parameters and climatological values are prepared at a 3-hour time resolution at approximately 800 points in Canada and over adjacent waters. The data is valid at the projection times between 0- and 144-hour. Included in the weather elements 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; thicknesses for various atmospheric layers; wind direction and speed at the 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 at 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; 1997).

7.2.5 Ensemble Prediction System

The 16 member Ensemble Prediction System (EPS) runs once a day up to 10 days (Houtekamer *et al.,* 1996; Lefaivre *et al.,* 1997; Plante *et al.* 1999). Eight perturbed analyses are obtained by running independent assimilation cycles that use perturbed sets of observations and are driven by eight different versions of the spectral global model (SEF model T150, Ritchie, 1991). The number of perturbed analyses is doubled as follows: the mean of the analyses is subtracted to the operational analysis and a fraction of this difference is added to the original perturbed analyses. Every day, at 00 UTC, two separate models are used to produce the 10-day forecasts: the SEF model and the GEM model (resolution of 1.2°, Côté *et al.,* 1998*a* and 1998*b*). Each model uses different versions of their physical parameterizations.

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

7.3 Short range forecasting system (0-48 hours)

7.3.1 Data assimilation and objective analysis

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 (28 levels). The spin-up is initiated from the 6-hour trial fields of the Global Data Assimilation System. The type of analysis, which is performed three times during the spin-up period, is similar to that of the global analysis (c.f. section 7.2.1). However the computation of innovations for the regional analysis are performed using the high resolution grid of the GEM model in its regional configuration. The 3D-Var 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.*, 1998, Laroche *et al.*, 1999)
Variables	T, Ps, U, V and log (specific humidity).
Levels	28 η levels of GEM model.
Domain	Global.
Grid	Analysis is done spectrally at T108 using a 400x200 gaussian grid. Results are interpolated on the GEM model's global variable resolution grid: 24 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). The first two analyses of each spin-up (00 UTC, 06 UTC and 12 UTC, 18 UTC) have a cut-off time of 5h30. The final analysis of each spin-up (00 UTC and 12 UTC) has a data cut-off time of 1h50. 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 NEC SX-5.
Data used	GTS data : TEMP, PILOT, SYNOP/SHIP, SATOB, ATOVS level 1b (amsu-a), BUOY/DRIFTER, AIREP/AMDAR/ACARS/ADS, and locally derived humidity profiles from GOES (HUMSAT).
Bogus	Subjective bogus, as required.

Surface

Method	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	353 x 415 variable resolution on latitude-longitude grid having a uniform .22 degree (~24 km) window covering North America and adjacent oceans.
Levels	28 hybrid levels (0, .010, .020, .040, .061, .091, .131, .177, .222, .273, .328, .384, .444, .500, .555, .611, .666, .722, .773, .818, .859, .894, .925, .950, .970, .985, .995, 1.00); 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, 720 second per time step (Côté *et al.*, 1998*a*; Côté *et al.*, 1998*b*).
Independent variables	x, y, η and time.
Prognostic variables	East-west and north-south 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	Surface and deep soil temperatures, surface and deep soil humidity ISBA scheme (Noilhan and Planton 1989); sea ice thickness, snow depth, snow albedo

- derived from analyses, fixed in time	Sea surface temperature, ice cover
- derived from climatology, fixed in time	Surface roughness length (except variable over water); soil volume thermal capacity; soil thermal diffusivity.
Horizontal diffusion	del-2 applied to all history carrying variables.
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	Nil.
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* 2002a and Bélair *et al* 2002b)
Boundary layer fluxes	Based on turbulent kinetic energy (Benoît *et al.*, 1989; Delage, 1988*a*; Delage, 1988*b*).
Shallow convection	Turbulent fluxes in partially saturated air (Girard, personal communication).
Stable precipitation	Sundqvist scheme (Sundqvist *et al.*, 1989).
Convective precipitation	Fritsch-Chappell scheme (Fritsch and Chappell, 1980; Bélair *et al.,* 2000) in the uniform grid, mass flux type (Wagneur, 1991) in the variable grid.

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 (i.e. surface analysis of snow and cover, 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. A myriad 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 stations 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 (UMOS)	An Updateable MOS system (Wilson and Vallée., 2002) has been developed and implemented. The system currently provides forecasts at 674 Canadian locations for : - 6-h and 12-h probability of precipitation forecasts at all projection times between 0 and 48 hours. - 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. Development work is being done to expand the set of weather elements guidance to include sky cover.
Diagnostic techniques on direct model output fields	Charts of forecast icing (Tremblay *et al.*, 1995), turbulence (Ellrod, 1989), cloud amounts with bases and tops, freezing levels and tropopause 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 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 surface 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 output 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

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 elements matrices for days 1, 2 and 3 (Verret *et al*., 1993; 1995; 1997). See the following section "Weather elements matrices". The system called SCRIBE is currently being implemented as the main tools for public forecast generation.

Weather elements 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 elements 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 infrared 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 (HIMAP)

A high resolution model runs twice a day for 30 hours over two sub-areas of Canada: western Canada and upstream waters; Great Lakes and eastern Canada. This strategy was given the name of High Resolution Model Applications Project (HIMAP, Pellerin *et al*., 1998). The model used is the same unified model described in section 7.3.2, except for the following differences:

- the window of uniform grid has a resolution of .09 degrees (~10 km);
- the number of vertical levels are 35 with top of the model at 10 hPa;
- the convection scheme is the Kain-Fritsch scheme (Kain and Fritsch, 1990, Kain and Fritsch, 1993);
- the stable precipitation scheme is the mixed-phase scheme (Tremblay *et al* 1996) with the Bourgouin method for precipitation types (Bourgouin, 2000).

The model starts from the 6-hour forecast of the regional model following the 00 UTC and 12 UTC runs. Outputs of surface fields covering the uniform grid area are transmitted in GRIB formats to Canadian Regions. Series of coloured images (including animation) are also made available through the internal Web.

7.4 Specialised 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 a 3-D long range atmospheric transport/dispersion/deposition model, named the "Canadian Emergency Response Model" or "CANERM". The main applications for this model have been for estimating concentrations of radionuclides and volcanic ash. Based on this operational capability, the CMC has been designed by the WMO as a Regional Specialised Meteorological Centre (RSMC) with specialization in Atmospheric Transport Modelling Products for Environmental Emergency Response. In addition, CMC has been designed by the ICAO as a Volcanic Ash Advisory Centre (VAAC).

7.4.1.1 Data assimilation, objective analysis and initialization

Fields of wind, moisture, temperature and geopotential heights must be provided to CANERM. These are obtained either from the Global or the Regional forecast and objective analysis systems. Please refer to the above section 7.2 for more information on these NWP products.

Latitude, longitude and time of the release are necessary input parameters for CANERM. Estimates of intensity and duration of the release are also required. 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 Model

CANERM ,developed by Janusz Pudykiewicz of Environment Canada, 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.

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

Upon request from the appropriate WMO Member Countries Delegated Authorities, 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/m^3, 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/m^2 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 the surface, 850, 700, 500, 300 and 250 hPa levels as well as total surface deposition estimates, at 3 or 6-hour intervals, if required. All the products can be transmitted by facsimile, in real time, during environmental emergencies. In addition, CMC is designated by the ICAO as a Volcanic Ash Advisory Centre (VAAC).

7.4.2 Ozone and UV index forecasting

The Canadian Global model is used to prepare ozone and UV Index forecasts 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 providing the forecast UV Index for an ensemble of stations across Canada are also generated.

7.4.3 Wave forecasting

Sea-state forecasts valid for the next 48 hours over the Eastern Pacific and Western Atlantic are generated twice a day (00 UTC and 12 UTC) by the WAM (WAve Modeling) model. The Pacific version of the wave model uses the surface level winds from the global model while the Atlantic version uses the regional model wind outputs. Various parameters are plotted on the wave forecast chart (wave height, swell period, swell height and 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 surrounding waters (Pudykiewicz et al., 1997). The model is run from 00 UTC every day up to 48 hours. It has a horizontal resolution of 21 km and 20 levels in the vertical up to 4 km. The chemical mechanisms used in the simulation include 114 chemical reactions and 47 species. The advection-diffusion equation in the model is solved using semi-Lagrangian algorithm. The model simulates the dry deposition and wet scavenging of 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 1990 data and has 21 km resolution for surface emission fields. The emission inventory system takes into consideration the day of the week and the various source types such as mobile, non-mobile, major and minor point sources and biogenic. The initial conditions for the different chemical species are given by the previous 24 hr forecast.

The current operational output of CHRONOS consists of hourly concentrations of ozone and aerosol species. The current version of the system considers only sulphate and secondary organic aerosols. Post-processing is performed on these outputs to provide users with maximum, mean and 3-hourly running mean data of tropospheric ozone per 6 hours slice. The outputs are available on the world wide 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 ozone and aerosol species are available, providing a better spatial representation of the different chemical variables predicted.

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. An ensemble of 5 runs, obtained from 24-hour time lag, is produced. The model used is very similar to the former operational spectral global model (Ritchie, 1991), except it has lower resolution (T63 L23) and has evolving geophysical forcing: the anomalies (analysis-climatology) of sea surface temperature (SST) and snow, observed during the previous 30 days, are added to the daily climatology during the integration. 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). 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)

Seasonal forecasts are issued 4 times a year (at the beginning of March, June, September and December). Seasonal products are distributed internationally and nationally through Internet (address http://weatheroffice.ec.gc.ca/saisons/index_e.html on the Web). The charts are accompanied by verification charts of the performance of the forecast over the hindcast period. Verification charts of the previous season's prediction and a preliminary analysis of the observed anomalies are also provided.

7.6.1 Season 1 forecasts (zero lead time)

Season 1 forecasts are produced using a numerical approach (Derome *et al.,* 2001). Two ensembles of 6 runs, obtained from 24-hour time lag, are produced: 6 from the T63 L23 model described in section 7.5, 6 from a general circulation model (GCM) (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 GCM, where it is a prognostic variable. A simple statistical linear regression equation relates the 1000-500 hPa thickness anomalies (forecast minus model climatology) to surface temperature anomalies, using regression coefficients for 90-day forecasts. Maps are similar to those used in monthly forecasts: 3 categories, separated using the 0.43 standard deviation of observed climatology. The precipitation forecast is produced using a more direct approach: the two ensemble means of forecast precipitation 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.

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.

8. Verification of prognostic products

Objective verification of the operational NWP models is done continuously at 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 2002 along 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 - 2002
Canadian Meteorological Centre
Global Environmental Multiscale (GEM) Model (0.9 deg. L28)

Verification against analysis

Area	Parameters	T+24h 00UTC	T+24h 12UTC	T+72h 00UTC	T+72h 12UTC	T+120h 00UTC	T+120h 12UTC
N. Hemisphere	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	12.4 3.7	12.2 3.7	32.7 7.8	32.6 7.7	60.2 11.5	59.7 11.4
Tropics	RMSVE (m/s) Wind 850 hPa RMSVE (m/s) Wind 250 hPa	2.8 5.2	2.8 5.2	4.3 8.8	4.4 8.9	5.2 10.9	5.3 11.0
S. Hemisphere	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	19.5 5.9	19.5 6.0	46.5 12.2	46.3 12.2	76.8 18.0	75.8 17.9

Verification against radiosondes

Network	Parameters	T+24h 00UTC	T+24h 12UTC	T+72h 00UTC	T+72h 12UTC	T+120 h 00UTC	T+120 h 12UTC
N. America	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	12.8 6.8	12.7 6.7	33.7 12.8	34.1 12.7	58.3 18.5	59.6 18.4
Europe	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	13.9 6.5	13.4 6.2	32.4 12.1	33.2 11.9	60.4 19.0	60.3 18.6
Asia	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	13.9 6.6	14.1 6.7	28.9 11.5	30.8 11.9	50.0 15.9	51.7 16.2
Australia - N.Z.	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	14.4 6.6	14.8 6.8	26.6 11.2	28.5 11.3	43.7 16.2	46.9 16.1
Tropics	RMSVE (m/s) Wind 850 hPa RMSVE (m/s) Wind 250 hPa	4.2 6.3	4.2 6.4	5.4 8.9	5.2 9.3	6.2 10.7	6.1 11.1
N. Hemisphere	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	14.3 6.5	14.1 6.4	34.4 12.1	35.1 12.0	62.3 18.0	62.7 17.8
S. Hemisphere	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	17.2 6.9	19.0 7.3	34.6 12.1	38.3 12.3	56.2 17.4	60.9 17.6

9. Plans for the future

The regional model resolution will be increased to 15 km resolution with improved physics schemes.

Additional type of observations (additional AMSU-A channels above 10 hPa, some AMSU-B channels, radiances for IR channels: HIRS, GOES) will be incorporated into both assimilation systems.

A major conversion effort towards the new IBM supercomputer system will take place.

The UMOS guidance will be completed for clouds. Development work will continue to update the Perfect Prog statistical guidance system.

A first version of the marine SCRIBE system will be delivered.

The Ensemble Kalman Filter will replace the OI analysis scheme in the Ensemble Prediction System.

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