Canada

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1 Summary of highlights

Major changes were implemented, in year 2006, to the operational global forecast system using the Global Environmental Multiscale (GEM) model.

The forecast model horizontal resolution has significantly increased from about 100 km (400 × 200 grid points) to nearly 33 km at mid latitudes (800 × 600 grid points). The number of vertical levels has increased from 28 to 58, the top of the model remaining at 10 hPa.

The physical parameterization of the forecast model has been substantially modified compared to the old operational version. The condensation and precipitation packages, in particular, were changed quite drastically. The Kain-Fritsch (1990, 1993) scheme has replaced the Kuo (1974) scheme for the deep convection. The Sundquist (1989) grid scale condensation scheme was modified mostly with respect to the evaporation of the precipitation below the cloud base, which is done over several levels in the new version. Another change to the condensation suite is the inclusion of a shallow convection scheme, based on a Kuo scheme closure, called Kuo transient. The surface modeling scheme known as ISBA (Interaction Soil Biosphere, and Atmosphere) has replaced the so-called `force- restore` module. Together with ISBA, a land-surface 6-h data assimilation system has been implemented in order to provide initial conditions of surface temperatures and moisture. Another model physics modification is the use of the Bougeault and Lacarrère (Bougeault and Lacarrère, 1989, Bélair et al, 1999) mixing length for vertical diffusion due to turbulence, providing a clear improvement over the one previously used, especially for convective, well mixed, boundary layers.

Several modifications and improvements have been brought to the global data assimilation system to provide analyses to the new model version (see Gauthier *et al.,* 2006 and Laroche *et al.,* 2006, for a comprehensive description of the operational 4D-Var data assimilation system). A new set of background error statistics on the 58 model levels has been computed using the so-called NMC method. The set of physical parameterizations for this model has been changed to those now used in the new forecast model described above. However, the corresponding simplified physical parameterizations used in the tangent linear model and its adjoint model remains the same as before.

The computational efficiency of the 4D-Var data assimilation system has been improved by 40% overall.

The Canadian ensemble outputs are used operationally in the North American Ensemble System (NAEFS) project since July 2006. NAEFS is a joint initiative involving the MSC, the United Sates National Weather Service (NWS) and the National Meteorological Service of Mexico (NMSM). The following products based on the NAEFS joint ensemble forecasts are available on the WEB since October 31 2006: EPSgrams for cities in Canada, Mexico and United States, charts of Ensemble means and standard deviation and maps of probabilities occurrence of several weather.

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)
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)	1,175
TEMP/PILOT (300 hPa UV)	1,250
DRIFTER/BUOYS	5,200
SATOB (including BUFR)	1,450,000
MCSST (US Navy)	600,000
SA/METAR	345,000
AMDAR/ACARS	224,000
PIREP	900[1]
PROFILER	800
GOES radiances	180,000[2]
ATOVS (AMSU-A)	1,675,000[3]
ATOVS (AMSU-B/MHS)	12,250,000[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

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[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

4 Forecasting system

4.1 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.

4.2 Medium range forecasting systems (3-10 days)

4.2.1 Data assimilation and objective analysis

4.2.1.1 Upper air

Method	Four-dimensional multivariate variational analysis of observations misfits, at the appropriate time, to the 9 h forecast of a 58 level, 0.45^o longitude and 0.33^o latitude resolution GEM model (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 h with a time step of 45 min.
Variables	T, Ps, U, V and log q (specific humidity).
Levels	58 η levels of GEM model.
Domain	Global
Grid	For the outer loops: Uniform 800 × 600 latitude-longitude horizontal grid. Horizontal resolution is 0.45^o in longitude and 0.33^o in latitude. For the outer loops: lat-lon uniform 1.5^o resolution.
Simplified Physics	Vertical diffusion Subgrid scale orographic effects[6] Large-scale precipitation[6] Deep moist convection[6]
Frequency	Every 6 h using data ±3 hours from 00 UTC, 06 UTC, 12 UTC and 18 UTC.
Cut-off time	3 h for forecast runs. 9 h for final analyses at 00/12 UTC and 6 h at 06/18 UTC.
Processing time	110 min plus 5 min for trial field model integration on the IBM.
Data used	TEMP, PILOT, SYNOP/SHIP, AWV's, ATOVS level 1b (AMSU-A; AMSU-B/MHS), BUOY/DRIFTER, PROFILER, AIREP/AMDAR/ACARS/ADS, and locally processed GOES radiances data.

[6] Used in second outer loop only.

4.2.1.2 Surface

Fields	**Analysis Grid(s)**	**Method**	**Trial Field**	**Frequency**	**Data Source**
Surface air temperature	1080 × 540 gaussian	Optimum interpolation	Model forecast of temperature at η=1.0	6 h	Land Synops, SAs, Ships, Buoys, Drifters
Surface dew point depresssion	1080 × 540 gaussian	Optimum interpolation	Model forecast of dew point depression at η=1.0	6 h	Land Synops, Metars, SAS, ships, buoys, drifters
Sea surface temperature anomaly	a) 400 × 200 gaussian b) 1080 × 540 gaussian	Optimum interpolation	Previous analysis	24 h (at 00z)	Ships,buoys, drifters, AVHRR satellite data (Brasnett, 1997) Plus A/ATSR for b)
Snow depth	1080 × 540 gaussian	Optimum interpolation	Previous analysis with estimates of snowfall and snowmelt	6 h	Land Synops, Metars, Sas (Brasnett, 1999)
Ice cover	1080 × 540 gaussian	Data averaging with a return to climatology in areas where data are not available.		24 h	SSM/I, Ice Centre Data
Deep soil temperature	1080 × 540 gaussian 800 × 600 lat-lon	Derived from climatology and a running mean of the surface air temperature analysis 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).		6 h 6 h	No direct measurements available No direct measurements available
Soil moisture	400 × 200 gaussian 800 × 600 lat-lon	Derived from climatology 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).		- 6 h	No measurements available No direct measurement available
Albedo	400 × 200 gaussian	Derived from albedo climatology, vegetation type, the snow depth analysis and the ice cover analysis		6 h	No direct measurements available

4.2.2 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 800 × 600 latitude-longitude horizontal grid. Horizontal resolution is 0.45° in longitude and 0.33° in latitude.
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. Hybrid coordinate, η, is defined as $\eta=(p-p_T)/(p_S-p_T)$, where p_T is 10 hPa and p_S is the surface pressure.
Time integration	Implicit, semi-Lagrangian (3-D), 2 time-level, 900 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 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 moisture ISBA scheme (Noilhan and Planton, 1989; Bélair et al. 2003a, b); snow depth, snow albedo, snow density. Sea ice thickness Sea surface temperature, ice cover Surface roughness length (except over water), subgrid-scale orographic parameters for gravity wave drag and low-level blocking, vegetation characteristics, soil thermal and hydraulic coefficients, glaciers fraction.
Horizontal diffusion	Del-6 on momentum variables only, except del-2 applied on momentum variables at the lid (top 4 levels) of the model.
Orography	Extracted from USGS, 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 scheme	Mosaic approach with 4 types: land, water, sea ice and glacier (Bélair et al., 2003a and 2003b).
Surface roughness length over water	Charnock formulation except constant in the Tropics.
Turbulent mixing (vertical diffusion).	Based on turbulent kinetic energy (Benoît et al., 1989; Delage, 1988a and 1988b) with mixing length from Bougeault-Lacarrère (1989; see also Bélair et al, 1999) except near the surface and in the upper-troposphere.
Shallow convection	1) Turbulent fluxes in partially saturated air (Girard, personal communication). 2) 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)

4.2.3 Numerical Weather Prediction products

4.2.3.1 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.).

4.2.3.2 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.

4.2.4 Operational techniques for application of NWP products

Perfect Prog	6 h and 12 h probability of precipitation forecasts at the 0.2, 2 and 10 mm thresholds, at all projection times between 0 h 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 h 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 h. Spot time total cloud opacity at three-hour intervals between 0 and 144 h 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 h. 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 h. All weather element guidance mentioned above is also produced off each member of the Ensemble Prediction System at all projection times between 0 h and 240 h. 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)	The UMOS (Wilson and Vallée, 2001 and 2002) set of guidance for the regional system includes three-hour intervals 2-m temperature, surface winds, cloud cover and probability of precipitation forecast (6 h and 12 h) and the surface temperature for the global system at three-hour intervals between 0 h and 144 h projection times.
Automated computer worded forecasts	A system is running 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 the main tool for operational public forecast preparation. Human has an interface to add value to the automated forecast as required. Once the meteorologist has reviewed, the Scribe system generate the forecast products automatically.
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-h time resolution at approximately 1145 points in Canada and over adjacent waters. The data is valid at the projection times between 0 h and 144 h. 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-h 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-h 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-h 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).

4.2.5 Ensemble Prediction System

The 16 member Ensemble Prediction System (EPS) runs twice a day up to 16 days. The more frequent and longer EPS runs became a necessity within 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.

The ensemble Kalman filter (EnKF) of CMC uses four ensembles of 24 members for data assimilation. The EnKF thus still uses a total of 96 members. The trial fields are obtained using a configuration of the GEM model with a horizontal resolution of 1.2º and with 28 η 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:

- Twice a day, at 00 and 12 UTC, sixteen representative members are chosen among the 96 analyses of the EnKF.
- 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 1.2º, Côté 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: 10 days mean temperature anomaly , 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.

The Canadian ensemble outputs are used in the North American Ensemble System (NAEFS) project, a joint initiative involving the MSC, the United States National Weather Service (NWS) and the National Meteorological Service of Mexico (NMSM). The following products based on the NAEFS joint ensemble forecasts are available on the WEB since October 31 2006: EPSgrams for cities in Canada, Mexico and United States, charts of Ensemble means and standard deviation and maps of probabilities occurrence of several weather.

The web site is located on the official MSC server: http://weatheroffice.ec.gc.ca/ensemble/index_naefs_e.html

A common product will be available soon. This product will be a NCEP/MSC chart of the temperature anomaly for day 8 to 14.

4.3 Short range forecasting system (0-48 hours)

4.3.1 Data assimilation and objective analysis (see Mailhot *et al*, 2006)

4.3.1.1 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 h spin-up period during which 6 h 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 η 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 previous GEM global model.
Domain	Global.
Grid	The analysis is done spectrally at T108 using a 400 × 200 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 h 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 min for the analysis and 6 min for the 6 h 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.

4.3.1.2 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.

4.3.2 Model (see Mailhot *et al*, 2006)

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 × 641 variable resolution on latitude-longitude grid having a uniform 0.1375 º (~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 $\eta=p-p_T/p_S-p_T$, 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 moisture ISBA scheme (Noilhan and Planton, 1989); snow depth, snow albedo Sea ice thickness Sea surface temperature, ice cover Surface roughness length (except 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).
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).
Surface roughness length over water	Charnock formulation
Boundary-layer turbulent mixing (vertical diffusion)	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)). Mixing length from Blackadar.
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)

4.3.3 Numerical Weather Prediction products

4.3.3.1 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.).

4.3.3.2 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.

4.3.4 Operational techniques for application of NWP products

Perfect Prog	Same as in 4.2.4 except based on the regional model and for lead time within 48 hours
Model Output Statistics (MOS)	An Updateable MOS system (Wilson and Vallée, 2001 and 2002) is implemented. The regional 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. 6h and 12h 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 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 6h 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 6h 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 6h 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 is 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 4.2.4, 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.

4.3.5 High resolution model for short range forecasts

A LAM (limited area model) version of the GEM model at high resolution (2.5 km) is ran 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 4.3.2; 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.

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

4.4.1 Nowcasting systems

4.4.1.1 In Operation

The SCRIBE Weather Forecast Product Expert System is now capable of ingesting the latest observations and nowcasting model data to update in real time the Scribe weather elements. This sub-system has been developed to minimize the necessary manual adjustments done by the forecaster to merge the current weather conditions with the forecast.

Version 1.0 of the Scribe Nowcasting is currently using surface observations, North American radar mosaic data and lighting data from the Lighting Detection Network. These observations are used to feed short term forecast models. A statistical model called “PubTools” uses the surface observations to forecast the probabilities of occurrences of weather elements. The observed radar reflectivities are projected during the next 6 hours with a vector motion calculated from observed imageries 20 minutes apart. Finally, an algorithm has been developed at CMC to predict the probabilities of thunderstorm occurrences based on the forecast position of the lightning clusters. All these observed and forecast data are processed by a rules base system to determine the best sequence of weather elements representing the current observation and short term tendencies.

The first 6 to 9 hours of the Scribe weather elements will thus be influenced by the nowcasting data. Depending on the weather conditions and on how well the model handles these conditions, significant changes can be done to the regular Scribe weather elements. To assess whether these changes contribute to improve the first hours of the forecast or not, objective verifications was perforemed. For some weather elements preliminary results show that in the first 6 hours of the forecast the Probablily of Detection has increased and the related False Alarm Ratio has decreased. Other verification scores also indicate an improvement of the short term forecast performance.

4.4.1.2 In development

A nowcasting module to analyse and extrapolate clouds, convection, precipitation occurrence and precipitation types has been running hourly in development mode at Canadian Meteorological Centre since July 2006. The system starts by extracting surface observations over Canada, northern U.S. and western Greenland. These observations are transformed into analyses using a krigging technique. Although only cloud, convection, and precipitation analyses are extrapolated, analyses for several other surface parameters are produced, including temperature (dry and dew-point), winds, pressure, etc. A rule-based consistency module uses those parameters to produce hourly consistent analyses. As an example, no freezing precipitation will be analyzed with above-freezing temperatures. The blending module incorporates data from radars, satellites and lightning detectors and the previous analyses as a trial field to produce the best possible analyses at initial time. These analyses are then blended with NWP data from our regional forecast system over adjacent waters, were there are no surface observations. Nowcasts are obtained by extrapolating these final analyses using the wind field at 1 hour intervals from the NWP model up to To+6h. Values from these extrapolated fields are interpolated at the stations.

4.5 Specialized forecasts

4.5.1 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). There has been an increase application of these operational atmospheric transport modeling tools to the dispersion of chemical and biological agents in the context of the response to local environmental emergencies.

4.5.1.1 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 4.2 and 4.3 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.

4.5.1.2 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.

4.5.1.3 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.

4.5.2 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.

4.5.3 Wave forecasting

Sea-state forecasts of 48 to 120 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 0.5º over the Pacific and the Atlantic while a resolution of 0.05º is used over the Great Lakes.

The Pacific version of the wave model which uses the surface level winds from the global model produces forecast up to 120 hours. Two Atlantic versions are in operations. The former uses the regional model wind outputs producing forecast to 48 hours while the later uses the global model winds producing forecast to 120 hour. Finally, wave forecasts up to 48 hour are produced for Lake Superior, Lake Huron, Lake Erie and Lake Ontario. Various parameters are plotted on the wave forecast charts (wave height, swell period, swell height, direction, etc.).

4.5.4 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 and 12 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 12 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.

4.6 Extended range forecasts (10-30 days)

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) (1.875º 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 4.7). 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).

4.7 Long range forecasts (seasonal forecasts)

4.7.1 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 4.6. 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 available in real time on Internet at the following site (username and password available on demand):

http://collaboration.cmc.ec.gc.ca/cmc/saison/glb/cmc_seasonal_fcst_global.html.

The forecast digital data are on a 2.5 degrees grid in GRIB1 format. Monthly means of surface air temperature, precipitation, 500 hPb heights, 850 hPa temperature and mean sea level pressure are available for each of the 12 models runs used to prepare the official forecast. Also, hindcast data are available for both models as well as climatological fields. Please read the information file named README.txt in the directories to get more detailed information.

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.

4.7.2 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).

5 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 2006 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 - 2006

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 RMSVE (m/s) Wind 250 hPa	10.5 4.8	11.0 4.9	29.0 10.1	29.4 10.1	54.4 15.5	55.0 15.6
Tropics	RMSVE (m/s) Wind 850 hPa RMSVE (m/s) Wind 250 hPa	3.0 5.0	2.9 5.0	4.3 8.0	4.3 8.0	5.1 10.0	5.1 10.0
S. Hemisphere	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	14.7 5.1	14.8 5.1	38.7 11.0	38.9 11.0	69.3 17.0	69.4 17.1

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 RMSVE (m/s) Wind 250 hPa	11.8 6.4	11.8 6.5	30.0 11.7	29.4 11.8	53.3 17.4	54.3 17.7
Europe	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	13.2 5.9	11.7 5.6	29.3 11.0	28.0 10.8	55.3 17.0	53.7 16.9
Asia	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	14.0 6.4	13.8 6.7	28.4 11.1	28.1 11.3	48.1 15.1	47.7 15.3
Australia - N.Z.	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	13.0 6.3	15.2 6.5	24.0 10.4	28.2 10.6	40.8 15.2	49.9 15.7
Tropics	RMSVE (m/s) Wind 850 hPa RMSVE (m/s) Wind 250 hPa	4.3 6.1	4.1 6.0	5.2 8.3	5.0 8.5	6.2 10.0	5.8 10.6
N. Hemisphere	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	13.7 6.2	13.1 6.1	31.3 11.3	31.0 11.3	57.3 17.0	57.3 16.9
S. Hemisphere	RMSE (m) GZ 500 hPa RMSVE (m/s) Wind 250 hPa	15.6 6.5	18.3 7.0	30.1 10.9	36.8 11.6	51.6 16.2	62.1 17.2

6 Plans for the future

6.1 Development of the GDPFS (in the next year)

Considerable effort has been put into increasing the volume of satellite measurements in the operational data assimilation systems. Parallel runs will be proposed in view of adding the following data types in both the operational 4D-Var data assimilation system within the medium range forecasting system, and the 3D-Var data assimilation system within the short range forecasting system.

6.1.1 Assimilation of satellite measurements

6.1.1.1 AIRS infrared radiances

The operational assimilation of AIRS radiances is foreseen for mid 2007 along with other data types such as Quickscat winds and SSM/I radiances. The final configuration will use about 70 AIRS channels. A dynamic bias correction has been implemented. The traditional way of using only clear ocean data for the bias correction was found inadequate because it lacked dynamic range (extremes observed only over polar regions). The new system uses all data judged suitable for data assimilation. A clear positive impact is obtained in the SH and Tropics despite the use of AMSU data from the same platform (AQUA). The impact in the NH is closer to neutral. The model top at 10 hPa imposes limitations on the channel selection which will be overcome by raising the top to 0.1 hPa in 2008.

6.1.1.2 GPS (radio-occultation and ground-based)

Test runs are underway to assimilate GPS radio-occultation observations from the CHAMP, GRACE and COSMIC satellites. When available, data from METOP GRAS will also be included. The largest impact is expected to be on the 50 hPa temperature fields. GPS ground-based observations contain information on column integrated water vapor (high temporal resolution). A project for a prototype ground-based GPS meteorological network in Canada (for about 100 sites) has been proposed. So far, capital funds have been obtained to purchase processing software and data servers for data processing. This project would also need staff but the financial resources currently have not been identified within Environment Canada. In the mean time, GPS antenna observations at about 30 stations in Canada are being processed in an ad-hoc manner. Assimilation tests (for a summer and winter test period) of the NOAA ground-based GPS meteorological network have been completed in the regional MSC weather forecasting model. The largest impact has been found to be in the summer over the central US where 24-48 h forecasts of precipitation are improved.

6.1.1.3 Passive microwave

Observations from the SSMIS satellite (temperature and humidity sounder) are now being tested at MSC in the new 4D-Var system in view of being added to the operational dataset.

6.1.1.4 QuikScat surface winds

Data assimilation experiments with scatterometer data from Quikscat conducted recently at the Canadian Meteorological Center with the global forecast system show a small but systematic positive impact on short- to medium-range forecasts, especially over the Southern Hemisphere. The operational assimilation of Quikscat is foreseen for mid 2007.

6.1.2 Development of the long range forecast system (seasonal)

In 2007, we plan to add new models into the seasonal forecast system. The GCM-3 model developed by the Canadian Climate group (CCCma) will be added to the existing GCM-2 and GEM models. Original plans aim to add also the Canadian SEF model to this Ensemble. The inclusion of this latter model will depend on the analysis to be made in early 2007.

6.1.3 Development of the global ensemble forecast system (EPS)

In 2007, we plan to implement a new configuration of the EPS in which only the GEM model is used in both the data-assimilation and the forecast components. It has a higher resolution 400 × 200 uniform global grid and 28 levels. To account for model error, different physical parameterizations are used in the EPS. In the medium-range forecast component of the EPS, algorithms for stochastic physics and for the backscatter of kinetic energy are used as well. In the data-assimilation component, random approximately balanced fields are added to account for the unexplained part of the model error.

Within the EPS Data Assimilation System, the EnKF will use time interpolation of the model trajectory towards the observation times. This will permit the accurate assimilation of all observations that are available in the 6-h data-assimilation window. Development work on a new updated version of perfect prog for EPS will continue. Canada, in collaboration with USA and Mexico, will continue to develop the North American Ensemble Forecast System (NAEFS). A week-2 temperature forecast will be issued early in 2007.

6.1.4 Development of the Global GEM Model (medium range forecast system)

The next major upgrade to the global GEM model, called GEM-strato, is planned for early 2008. This will include an increase of the model top from 10 to 0.1 hPa, an increase in the number of vertical levels from 58 to 80, a new radiative transfer code based on the correlated K distribution (CKD) approach, a new parameterization for non orographic gravity wave drag, and an improved method to calculate subgrid-scale orographic geophysical fields. Furthermore, this stratospheric version of GEM will allow the assimilation of new data. Work is under way in the data assimilation division that will lead to significant improvements in the quality of our stratospheric and upper troposphere analysis.

6.1.5 Development of the Regional forecast system (short range forecast system)

Due to the recent increase in resolution of the global model, the gap in resolution between the two models, and consequently the need for a spin-up period has been greatly reduced. It is planned that the spin-up period for the operational regional model will be reduced to 6 hours as of April 2007. In addition, the regional 3D-Var analysis will consider the First Guess at Appropriate Time (FGAT) with an updated set of background-error statistics (based on the so-called *NMC* method). Several other modifications will accompany this implementation:, improved ice thickness climatology, improved lake water temperature in transition seasons, improved snow cover analysis.

The regional forecast system will then be running 4-times per day (instead of two), later in 2007 as 06Z and 18Z runs will be tested, and implemented.

6.1.6 Development of the local forecast systems

A LAM (limited area model) version of the GEM model at high resolution (2.5 km) is currently running, once per day, in experimental mode providing 24 h forecasts over 2 sub-areas of Canada: southern British-Columbia and southern Ontario-Quebec (see section 4.3.5).

As more computer resources become available in 2007, it is planned to implement more windows of the model to allow the coverage of other parts of Canada. Two additional windows will be installed in the spring of 2007. The first one will cover the Baffin Island in the Canadian Arctic as part of the TAWEPI (Thorpex Arctic Weather and Environmental Prediction Initiative). The second window will cover Atlantic Canada in support of local environmental projects. The model will be used as well for weather forecasting of the 2010 Vancouver winter Olympics.

An update of the micro physics scheme is expected to occur in the fall 2007, as the Milbrandt & Yau scheme (Mibrandt 2005 a, b) should replace the Kong & Yau scheme (Kong & Yau 1997). This update is aiming at improving the precipitation typing (snow vs rain) and precipitation amounts especially in mountainous environment. An improved method to calculate subgrid-scale orographic geophysical fields will also be tested in 2007.

6.1.7 Development of the statistical products and other products

Work to expend the UMOS set of guidance to include dew point temperature, probability of precipitation amounts, and types, as well as marine winds will be continued. UMOS will also be tested on a LAM model. UMOS will also be adapted to the forecast of ground level ozone (O_3) and particulate matter (PM 2.5). The development of an upgraded Perfect Prog to forecast the probability of precipitation will continue. SCRIBE will generate public forecasts with a 1-hour temporal resolution from 0 to 48 hours based on the regional system. Experimental public forecasts out to 10 days based on the ensemble forecast system will be developed.

6.1.8 Canadian Precipitation Analysis (CaPA)

In collaboration with the Meteorological Service of Canada, the Meteorological Recherche Division of Environment Canada is developing a North-American precipitation analysis at the resolution of its regional NWP system (15 km) to provide better forcing for the Canadian Land Data Assimilation System (CaLDAS). This analysis uses optimal interpolation to combine six-hourly observed accumulations of precipitation with a first guess obtained from the regional NWP system. At the moment, the observations are obtained from the synoptic weather station network as well as from stations operated by other organizations in Canada, including other governmental agencies and hydropower companies. In the coming year, we plan to make this version of the system into an operational product as well as to work on a second version of the system which would include other sources of information, such as cloud fraction from GOES imagery, precipitation occurrence from synoptic station hourly messages and radar observations, convection type from lightning data and the atmospheric model's lifting index, and finally topography.

6.1.9 Coupled atmosphere-ocean-ice modelling

At regional scales, we already have clear evidence that interactions with the ocean and sea ice can have important impacts on weather forecasts even in the short-term. This has previously been demonstrated in a two-way interactive coupled system involving the regional configuration of the GEM model and a DFO ocean-ice model for the Gulf of St. Lawrence. This system has been undergoing technology transfer and a parallel run is in progress for operational implementation at CMC in the near future.

6.1.10 Development of an on-line air quality forecast model

Development is underway to replace the current air quality forecast model CHRONOS with a more scientifically and technically advanced model. The new model, GEM-MACH, is based on the GEM weather forecast model and will integrate, on-line, all the processes related to the formation of ground-level smog. The model will take advantage of the direct 1-way coupling of the between the meteorological and the chemical processes, and will also benefit from an improved aerosol representation. GEM-MACH is expected to start being tested in late 2007.

6.2 Research Activities in NWP

6.2.1 Remote sensing: Limb sounding wind measurement for the Stratospheric Wind Interferometer For Transport Studies (SWIFT) instrument

A fast forward operator for the CSA CHINOOK SWIFT instrument (provides stratospheric winds and ozone) is being developed to enable assimilation of observations in near real time in the event that these will indeed be made available in near real time by either the CSA and/or ESA.

6.2.2 Data assimilation for the short range forecasting: the Limited Area Model 4D-Var assimilation (*LAM4D*).

At Environment Canada (EC), a Limited-Area 4D-Var analysis system has been developed in order to enable the analysis of synoptic and mesoscale weather. This system in its North American continent extension is referred to as *LAM4D*. The main objective of this new analysis system being the improved forecast of precipitation up to 48h (more emphasis on the first 24h), with a replacement of the Canadian Regional analysis system currently operational at CMC within the short-range forecast system. Tangent-linear (TL) and adjoint (AD) versions of GEM-LAM were developed as an extension of the work by Tanguay and Polavarapu (1999). The TL/AD GEM-LAM code was successfully coupled in 2005 to the limited-area version of the LAM4D variational analysis code.

LAM4D uses bi-Fourier spectral representation on a rotated limited area domain rather than spherical harmonics on the sphere. Otherwise, the two configurations of the code were designed to be mostly transparent to the user. Helmholtz's functions are being used in the two analysis systems with non-separable background error correlations in their respective spectral spaces.

The horizontal resolution of the nonlinear GEM-LAM NA-Continental model is 15 km (the current operational regional model being at 15 km). However, the inner-loop resolution of the incremental LAM4D is currently tested at 40 and 80 km (6h time assimilation window). This represents about a factor of 5 increase in horizontal resolution as compared to the current inner loop of the global operational incremental 4D-Var system which is currently at T108. There is a factor 12 between the current regional forecast model and the inner loop global 4D-Var analysis system. This is the current operational setup. This factor is reduced to 3.5 between the nonlinear model and the inner loop of LAM4D at 40 km. Remarkably, this can be achieved by only a factor 2 increase in the dimension of the analysis problem, whereas this type of inner loop resolution would totally be impracticable within the current operational context with the global analysis code where a factor around 20 would be required. The LAM4D is currently in a mature stage where pre-operational testing (tuning) is extensively done with a large sample of summer and winter cases in collaboration with CMC staff.

In addition, one can define small analysis domains for even higher resolutions at 2.5 km for instance, designed to improve short-range weather forecasting in the 0-12h range. The analysis code (3D-Var mode) for such high-resolution local grid was tested under simple observation assimilation experiments but there remains more work to introduce background-error correlations representative of errors at these small scales together with new types of high spatial and temporal observations.

6.2.3 Short range forecasting model:

The current Regional forecast system uses the GEM model with a variable resolution global grid configuration. The uniform resolution portion of the domain covers North-America (north of Mexico) and adjacent oceans. The performance of a Limited Area Model configuration of the GEM model will be compared to this variable grid configuration over this same domain. The success of the replacement of the variable grid by the LAM configuration would greatly ease the implementation of a 4D-Var regional assimilation (See section 9.2.2 above).

This new regional forecast system would be running at a resolution of 10 km, using a new radiative transfer code based on the correlated K distribution (CKD) approach, a new parameterization for non orographic gravity wave drag, and an improved method to calculate subgrid-scale orographic geophysical fields.

6.2.4 Background-error statistics for the 4D-Var assimilation

With the goal of replacing the "NMC method" to compute the background-error covariances, a system simulation approach has been applied to the global variational data assimilation system. The perfect model assumption is used and therefore random perturbations are only applied to the observations. Consequently, the variances computed from the ensemble spread are underestimated and must be inflated. The same approach for modelling the background error covariances as in the operational system is maintained (i.e. correlations are homogeneous/isotropic, variances are zonally constant). While positive forecast impacts, relative to using the operational statistics, have been obtained in the context of the 100 km, 28-level model version (Buehner et al., 2005) experiments to date using the operational 35 km, 58-level model have produced mixed results.

Two new dynamical constraints are being introduced in the 3D-Var assimilation system, based on the Charney nonlinear balance and the quasigeostrophic omega equation. The first of these balances will make covariances flow-dependent, a feature that has been shown to improve the quality of analyses at ECMWF. The second balance is expected to attenuate spurious vertical motions which are believed to cause unrealistic mixing of chemical species.

6.2.5 Estimation of observation impact through sensitivities with respect to observations

The analysis code has been re-implemented recently in research mode as a collection of basic transformation operators acting on objects defined in various spaces. This modular approach enabled the development of various assimilation formulations and tools that help diagnose the impact of the different components of our data assimilation system. We have recently implemented the Observation Impact (OI) algorithm proposed by Langland and Baker (2004). This algorithm has been used to assess the value of observations assimilated by our 3D-FGAT and 4D-Var schemes. We also investigated the usefulness of observations with respect to their time distribution over the assimilation window. We clearly showed the increasing impact of observations valid later in the assimilation window in 4D-Var as compared to 3D-FGAT.

6.2.6 Sea-ice analysis

A prototype variational data assimilation system is being developed for sea-ice analysis and forecasting. The prototype system employs a multicategory sea ice model coupled to the Princeton ocean model to model the ice conditions in the Labrador Sea. The background-error statistics are obtained from an ensemble approach to data assimilation that uses output from the operational ensemble prediction system to supply an ensemble of atmospheric forcing fields. Research to date has focused on assimilation of passive microwave data and manual analyses of RadarSAT data to estimate ice concentration. The use of the estimated multi-variate background-error statistics to correct near-surface ocean temperature and salinity has been shown to improve 24-hour sea-ice forecasts. It is expected that, once sufficiently developed, the assimilation system will be applied to other regions and models currently being used or developed in Canada.

6.2.7 Stratospheric data assimilation and chemical data assimilation

The vertical extension of the GEM global model will raise the upper lid from its current 10 hPa level to 0.1 hPa. This is expected to provide a better framework for the assimilation of radiance measurements from instruments like AIRS and IASI. A number of changes have been brought to the model to include Hines gravity-wave drag, a new parameterization for radiation from Li and Barker (2005) that allows interaction of ozone. This project was also developed within the framework of a coupled dynamical-chemical data assimilation system. The assimilation can use either a 3D-Var or 4D-Var assimilation which was built by extending the system used operationally at the MSC. Stratospheric chemistry has been introduced in the model and the assimilation and experiments with the fully coupled system are being undertaken. The objective of this project is to better understand the chemical and dynamical couplings by using a coupled dynamical-chemical model in data assimilation using observations of chemical species obtained from the MIPAS instrument on ENVISAT. This study is expected to shed some light on the requirements for observations of chemical species that would be needed to get a good overview of the atmospheric chemistry and its evolution.

Research continues into data assimilation for climate applications. While the ultimate goal is to understand climate model deficiencies, improvements to data assimilation schemes arise incidentally. 3D-variational assimilation with a climate model which includes interactive chemistry, radiation and dynamics, the Canadian Middle Atmosphere Model, has shown that the large variability of the mesosphere renders assimilation schemes extremely sensitive to covariance specification (Polavarapu et al. 2005). The digital filter was found detrimental to mesosphere because it altered the amplitude of the diurnal tide and was thus replaced by an Incremental Analysis Updating procedure. Because gravity waves are an important component of mesospheric dynamics, a new diagnostic was developed to assess the level of filtering needed to separate real from spurious gravity waves. Experiments with ensemble perturbation methods of estimating covariances demonstrate the impact of observations from the troposphere and stratosphere on the mesosphere. There is also preliminary evidence of the vertical transfer of information through wave propagation during the forecast step of assimilation cycles. Such evidence would indicate the value of performing data assimilation with a forecast model that has realistic mesospheric dynamics even when mesospheric observations are not assimilated.

6.2.8 Canadian Land Surface Data Assimilation System (CaLDAS)

Surface fluxes of heat and evaporation are of crucial importance in numerical weather prediction. They influence atmospheric circulations at both small and large scales, and have an impact on short, medium, and extended range forecasts. Initial conditions of surface variables such as soil moisture and snow mass greatly determine the partition of surface available energy into latent and sensible heat fluxes. With the objective of improving the representation of surface fluxes in Canadian NWP systems, a new Canadian Land surface Data Assimilation System (CaLDAS) has been developed. In the first version of CaLDAS, the assimilation of surface temperatures and of soil moisture is done using external integrations of surface processes forced by our best estimates of atmospheric forcing for air temperature and humidity, winds, radiation, and precipitation (from the Canadian Precipitation Analysis – CaPA). In this first version, only observations of low-level air temperature and relative humidity are assimilated in this system. Assimilation snow water content will be examined in a subsequent version of CaLDAS, together with the inclusion of remote sensing data. Finally, the impact of the new surface assimilation system on regional short-range forecasts is currently being examined.

6.2.9 External land surface modeling

Because surface characteristics are often known with fairly good resolution, sometimes on the order of 100 m or even less, it is possible to run land surface schemes at much higher resolution than what is currently possible with atmospheric models. Running GEM with a 100-m grid size for the entire Canada, for several days, is out of reach for some time, even when considering future increase in computing power. It is possible, however, to run the land surface models separately from the atmospheric models (in an “external” or “off-line” fashion) at a much lower computational cost. Using atmospheric forcing adapted to the higher-resolution surface characteristics (e.g., orography) and high-resolution surface characteristics, it is possible to represent the small-scale effects of cities and other local features (e.g., valleys and peaks in mountainous regions). The tool that is used to run the surface in an external manner is called MEC, i.e., Modeling Environmental Community system. Work is currently done by RPN’s numerical group to improve this tool, which will become even more important in the next few years with applications in other domains such as oceanography. This external surface system is expected to revolutionize how surface processes are represented in all the forecasting systems at MSC (even in climate).

6.2.10 Improvement in the representation of grid-scale and subgrid-scale orography, together with improved representation of subgrid-scale roughness and low-level blocking effect of mountains

In the Canadian GEM model, currently used for regional and global weather forecast, the effects of subgrid-scale topography are represented by the physical parametrizations of gravity-wave drag, orographic blocking and surface fluxes. These parametrizations depend on estimates of various parameters related to the subgrid topography variance, slope covariances and roughness length. The method used to estimate these parameters is currently under revision. The objective of this revision is to improve the partition and the balance between the ensemble of tendencies generated by surface-flux schemes.

6.2.11 Research into numerical methods

Vertical staggering is introduced in the GEM model: the chosen staggering is the Charney-Phillips arrangement. It is expected to improve the circulation near the top of the model.

Iterative solvers are being developed in place of the direct solvers of GEM for limited-area modeling. The absence of polar regions in that case insures a better convergence of the iterative methods.

A shallow-water model on the Yin-Yang grid is being developed as a possible cure to the convergence of meridians near the poles. This approach keeps the simplicity of the latitude-longitude grid. A special attention will be given to the conservation properties of this approach. Triangular discretization is also being studied in the contexts of the global and limited-area modeling. It is particularly suited for adaptativity. Both the Yin-Yang and the triangular discretizations of the shallow-water equations will be compared the spectral shallow-water model at high-resolution to determine the future direction of global modeling.

6.2.12 Polar-GEM & TAWEPI

TAWEPI (Thorpex Arctic Weather and Environmental Prediction Initiative) is an initiative led by researchers of the Meteorological Research Division of Environment Canada (EC). It includes modeling projects and data assimilation studies aiming to enhance weather forecasting capabilities in polar regions, and to improve our understanding of the Arctic and its influence on world weather. The primary objective of the TAWEPI initiative is to develop and validate a regional Numerical Weather Prediction (NWP) model in support of IPY projects. The proposed model, called Polar-GEM, will have a 15-km resolution focused over the Arctic basin and surrounding regions. Particular emphasis will be put on improving the representation of snow processes, air-sea interactions, high-latitude clouds, and sea-ice modeling in the Arctic. The CMC data assimilation system will be used to study the sensitivity of weather forecast over polar regions to lower-latitude influences and vice-versa; to validate and assimilate satellite data from polar orbiting satellites; and to produce stratospheric analyses, including evolution of the ozone layer.

6.2.13 Urban meteorology modeling system

The Meteorological Service of Canada (MSC) has recently launched a project to improve the representation of cities in the Canadian meteorological models, as part of a larger program funded by the Canadian CBRN (Chemical, Biological, Radiological, and Nuclear) Research and Technology Initiative (CRTI). The project aims at developing an advanced emergency response system based on an integrated, multi-scale modeling system for the accurate and efficient prediction of urban flows and atmospheric dispersion over populated North American cities (Mailhot et al., 2006). A prototype version of this system is planned for quasi-operational runs at the Environmental Emergency Response Division of the Canadian Meteorological Centre in summer 2007.

The development of such a prototype (with grid-size resolutions going down to about 250m) involves several aspects: 1) extension of turbulent diffusion scheme to 3D turbulence, 2) inclusion of urban processes with the Town Energy Balance (TEB) urban canopy scheme, 3) generation of new land covers characterizing urban types (Lemonsu et al., 2007b), and 4) specification of anthropogenic heat fluxes for use in TEB. Two urban field campaigns were held in Montreal (MUSE - Montréal Urban Snow Experiments - Bélair et al., 2006; Lemonsu et al., 2007a) to examine urban surface energy budgets during Canadian winters. Validation of the urban modeling system is underway using detailed observations from the Oklahoma City Joint Urban 2003 and MUSE urban field campaigns.

6.2.14 Hydrological modeling at RPN

To better represent water movement on the surface and in the soil, modeling efforts are under way to take into account in its land-surface models the lateral surface and subsurface flows generated by the effect of the sub-grid slope, using a parameterization first proposed by Soulis et al. (2000) for the land-surface model CLASS. These flows are then routed through the lake and river system using an off-line kinematics wave model proposed by Kouwen (2006). Leakage from the groundwater is represented by a linear reservoir fed by the bottom drainage of the soil column and calibrated on observed stream flow during low flow periods. Numerical experiments will be conducted in the coming year to assess the impact of these changes on surface fluxes and eventually on numerical weather predictions. In the longer term, we also expect to be able to use this hydrological model to assimilate stream flow observations in the CaLDAS land data assimilation system under development at RPN.

6.2.15 Wave modeling

The updated version of WAM, a MPI implementation of WAM 4.5, has been running operationally at CMC on three domains for a year now: North Pacific, using winds from GEM global, North Atlantic and 4 of the 5 Great Lakes, using winds from GEM regional. The last version of the model uses a 5 km grid while the two ocean versions have a resolution of 0.5º. Work is underway to set up a Gulf of St. Lawrence domain, incorporating the results of some development work done in the Quebec regional office.

Wave modeling research is focused towards the next version of WAM, which will include a high resolution nested component for nearshore and shallow water wave forecasting. A second, equally important focus is improving the wind input to the wave model. To that end, storm insertion methods are being tested to improve the wave model's ability to predict extreme wave events associated with hurricanes and other small scale storms. Preliminary results for hurricane Juan, given realistic wind input, indicate overforecasting of the maximum wave heights, calling into question the parameterizations in the wave model itself. This is currently being further investigated.

Tests of the wave model on L. Erie with statistical wind forecasts (Model output statistics) demonstrated that wave forecasts can be improved slightly compared to forecasts using the direct model output winds. This work is being extended to the Atlantic ocean domain. A project to develop an ensemble wave prediction system is beginning. It is planned to first run the existing operational wave model using winds from the operational 16 member ensemble system, then later on, to build a regional ensemble wave forecast capability using the regional ensemble system when it is available.

6.2.16 Verification

Verification research efforts in Canada currently focus on two main areas: development of spatially-oriented and scale separation techniques for use in the evaluation of high resolution model forecasts, and development of a comprehensive verification system for the ensemble system.

Following validation of a wavelet-based scale-separation technique using the Canadian lightning forecasts, this method is being applied to the analysis of high resolution precipitation observations. This new development is expected to allow the verification of precipitation forecasts as against analyzed precipitation fields, where the scales that are verified are allowed to vary according to spatial variations in the observation density. This new verification method is being applied to forecasts from the high resolution GEM-LAM at 2.5 km. Other newer verification methods are also being used to verify the GEM-LAM, including the contiguous rain area verification method of Ebert and McBride.

The verification of ensemble forecasts requires a major data management capability. We have been developing a user-friendly data management structure for ensemble verification which will be used to verify both the Canadian ensemble system, and the combined Canadian-US ensembles which are part of NAEFS. Eventually, it is hoped the system will work well also for verification of the combined ensembles of the TIGGE project. The data management has been set up and the verification tools are now being interfaced with the system.

We have finally added bootstrapped confidence intervals to many of our verification efforts, in order to be able to make more defendable decisions on the implementation of new models. Bootstrapping has been applied to diagnostic verification both for the full resolution models and for the EPS. In the latter case, tests of block bootstrapping have been undertaken to ensure sufficient statistical independence in the bootstrap samples. In future, the use of non-parametric estimation of confidence intervals will be applied to all verification measures involving intercomparisons.

Research and development continues on methods for verifying extreme events forecasts from the EPS. These include verification with respect to quantiles of the long term climatological distribution of precipitation accumulation, and methods of fitting distributions to ensemble forecasts.

6.2.17 Environmental Prediction

The objective of our research and development in Emerging Numerical Environmental Prediction (ENEP) for water aspects is to produce forecasts, on time scales from minutes to seasons, of future states of environmental systems such as oceans, the water cycle, ice and ecosystems using appropriate numerical models coupled to Environment Canada’s (EC) numerical weather prediction system. This is being achieved by working in a close inter-disciplinary collaboration with other scientists at Recherche en prevision numérique, the Canadian Meteorological Centre (CMC), the National Water Research Institute, the Canadian Ice Service, the Climate Research Directorate, the National Laboratories of the Meteorological Service of Canada, the Water Survey of Canada, Fisheries and Oceans Canada (DFO), and many Canadian Universities

6.2.17.1 Atmosphere-Ocean-Ice modeling

.In global atmosphere-ocean-ice coupling, a new interagency initiative referred to as the Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS) has been initiated as a scientific and technical cooperation amongst EC, DFO and the Department of National Defence (DND), in partnership with the French Mercator Océan Consortium together with whom we will be further enhancing the ocean data assimilation and prediction component and coupling it with the EC Global Environmental Multiscale (GEM) atmospheric model . The objective is to take advantage of improvements in ocean models and the new, real time global oceanographic data sets in order to produce new ocean products and improved weather and climate predictions. A complementary academic research and development network on “Prediction and Predictability of the Global Atmosphere-Ocean System from Days to Decades” has been approved by the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) and is being established. At regional scales, we already have clear evidence that interactions with the ocean and sea ice can have important impacts on weather forecasts even in the short-term. This has previously been demonstrated in a two-way interactive coupled system involving the regional configuration of the GEM model and a DFO ocean-ice model for the Gulf of St. Lawrence. This system has been undergoing technology transfer and a parallel run is in progress for operational implementation at CMC in the near future. Significant research is in progress in another CFCAS funded integrated modelling program at Dalhousie University entitled "Interdisciplinary Marine Environmental Prediction in the Atlantic Coastal Region". This program is making heavy use of an atmosphere-ocean observing system in Lunenburg Bay Nova Scotia and is developing an advanced coupled atmosphere-ocean-ecosystem modelling capability to study how ecological processes can be incorporated into realistic physical models, the predictive skill of interdisciplinary coupled models, and the consequences of episodic phenomena including extreme weather events. EC is particularly involved in diagnosing the performance of the GEM model for predicting marine fog events, and leading the preparation of the integrated modelling system for an observing and modelling demonstration project in 2007. A project on probabilistic forecast tools for search and rescue has begun under the Search and Rescue New Initiatives Fund. Its objectives are to enhance the marine weather and wave forecast information for predicting target location, to improve the forecast information available for high impact weather, and to quantify the uncertainty in forecasts of important marine elements such as wind and waves so that the relevant products can be expressed in probabilistic terms.

6.2.17.2 SAR winds

The Canadian Space Agency is funding a collaborative project at Dalhousie University on the validation of wind fields from high-resolution NWP models using synthetic aperture radar (SAR). It involves using NWP surface wind outputs together with available algorithms to produce simulated backscatter fields to compare with SAR and in situ observations for cases of interest. A two-dimensional variational technique is being used to combine the SAR data and model output, and the improvement that the SAR data adds to the model fields has been documented.

6.2.17.3 Storm surge modeling

Improvements to storm surge modelling are emerging from a recent Climate Change Action Fund project entitled "Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of south eastern New Brunswick. As an element in this project, the an advanced version of operational Storm Surge and Water Level Alert System for Atlantic Canada was used conduct a 40-year sea-level rerun for the Atlantic region which was validated with observations, diagnosed for trends and projected for climate change scenarios using the statistical theory of extremes in an award winning Ph.D. thesis study.

6.2.17.4 Water cycle modeling

In terms of water cycle modelling, progress has been made on the development and testing of a framework to predict available water supplies in watersheds, building on previous work coupling a distributed hydrological model and EC atmospheric models. A generalized modelling approach is being followed to enable prediction of all important components of the water cycle at fine resolution with a coupled numerical-weather-hydrological modelling system, Modélisation Environnementale de la Surface et de l'Hydrologie (MESH). This is being achieved by adding the hydrological component to the MEC (Modélisation Environnementale Communautaire) system that enables the use of a variety of our environmental prediction models in off-line, in-line, or coupled mode. A recent addition to the MEC system is a common sea-ice model that hence becomes readily available for use the regional and global atmosphere-ocean-ice projects mentioned earlier.

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