The regional GEM 15km forecast system

May 13th 2004
Development and Operation Branches, CMC

Introduction

A new Canadian regional forecast system has been developed at the Canadian Meteorological Centre (CMC) in close cooperation with the Meteorological Research Branch (MRB) team. A new regional model at 15km resolution and 58 vertical levels replaces the 24km version at 28 vertical levels. The increased horizontal and vertical resolutions allow a more precise computation of the forecast and a better definition of the geophysical features. This increased resolution also enables the introduction of a more sophisticated set of physical parameterizations. These improvements were made possible by taking advantage of the increased computational power available while incorporating the most recent findings of research in meteorology.

In addition to this new forecast model, additional satellite data are incorporated into the regional system. The changes to the Regional Data Assimilation System (RDAS) are the same that were successfully implemented in June 2003 in the Canadian Global System. It is an upgrade of the Regional system in order to bring the two systems to the same level.

Extensive testing on archived summer and winter cases was necessary to achieve the final configuration of the new forecast system. This work was made with the participation of CMC operational meteorologists together with the R&D team. The new forecast system was then proposed to run in parallel mode, in real time, at the CMC in February 2004, and will be implemented into operations in May 2004.

This technical document describes the new forecast system and presents the results of the various evaluations which have led to the implementation. The changes to the forecast model are described in the first section of this document. The second and third sections provide a summary of the objective evaluation for summer-winter cases and the parallel run period respectively. Finally, highlights of the overall subjective evaluation are given in the last section.

1. Changes to the GEM model regional configuration

1.1 Dynamic configuration

1.1.1 Horizontal resolution

The far most important changes of the new model are the changes in the dynamic configuration, as summarised in Table 1 below. The changes in horizontal resolution have been well publicized, going from 24km to 15km within the uniform region of the model. But the regional model is a global model with a variable resolution and changes have been introduced in the variable grid too. Resolution decreases outside the uniform grid at a rate of 10% per grid point in each direction. In the operational set-up, there is no limit to this decrease in resolution, while in the parallel model the decrease is limited to 3° (~300 km). This has a small but beneficial effect, especially for the West Coast at 48 hours.

1.1.2 Vertical resolution

The number of levels was considerably increased (more than doubled) going from 28 to 58. The areas where this increase is mainly concentrated are the boundary layer, the upper-jet level and the stratosphere. For example,

- Number of layers below 850 hPa in the *operational* model: 7
- Number of layers below 850 hPa in the ***parallel*** model: **10**
- Number of layers between 200 and 300 hPa in the *operational* model: 2
- Number of layers between 200 and 300 hPa in the ***parallel*** model: **5**

Moreover, the number and positioning of the levels have been aligned with the next global model configuration that is presently being developed. This is quite important because of the regional and global configurations are linked in terms of data assimilation. The additional levels at the top of the model are also useful and allow the presence of a sponge[1] layer to prevent spurious heat increase at the top of the model, a phenomenon that happens from time to time. It will also ease the assimilation of satellite observations in the upper atmosphere.

1.1.3 Time step

The time step was decreased in accordance with the increase in resolution. With 450 seconds per time step, this means that there will be 8 time steps per hour (against 5 for the operational model). This increase in number of time steps was the rationale to decrease the span and period of the digital filter from 6 to 3 hours, without loss of information. The digital filter [2] is applied at the beginning of the model to filter out spurious gravity waves that could still be present in the analysis field.

The combination of the increase in the total number of grid points (Δx, Δy, $\Delta\eta$) and the decrease of time step makes the new model **8 times** more expensive to run. Fortunately, the increased power of the new supercomputer with more CPUs makes it possible to run the model in the same amount of time as the operational one.

1.1.4 Horizontal diffusion

A few changes were also introduced in the horizontal diffusion strategy. In the operational model, the diffusion is applied to all variables, not necessarily a good strategy. For instance, if one diffuses both temperature and specific humidity (as in the operational model), the resulting fields can lost some of their intrinsic coherence. This is why the parallel model applies diffusion only to momentum variables. The goal of

[1] The sponge characteristics are given in Table 1
[2] The digital filter characteristic are given in Table 1

horizontal diffusion is to damp the shortest waves and avoid spurious numerical energy accumulation at these wavelengths. Finally, the semi-Lagrangian scheme used in the GEM model is already a diffusive one, so that the diffusion coefficient does not need to be very strong.

Table 1: Summary of the dynamic configuration changes

	Operational (24 km)	**Parallel (15 km)**
Resolution: (km) Number of grid points (GP) % of GP in uniform grid	24 354 X 415 65%	15 575 X 641 66%
Levels	28	58
Time step (sec)	720	450
Horizontal diffusion	Del-2 on all variables (strong coefficient)	Del-6 on momentum variables (weak coefficient)
Digital filter: span (hours) period (hours)	6 6	3 3
Sponge	no	yes (on the top most 4 levels)

1.2. Physics configuration

The main changes in the physics configuration are summarized in Table 2 below. Note that the explicit condensation (also referred to as the stratiform condensation) and the optical properties of clouds have not changed between the operational and the parallel models (last two parameters in the Table).

1.2.1 Subgrid scale orography

The first two parameters of Table 2 are often referred to as the sub-grid scale orographic parameterization schemes and have the goal of reducing the winds when the flow encounters mountainous terrain. Even if the model resolution has increased, there is still a significant non-resolved (sub-grid) part of the mountain field that has to be taken into account. The gravity wave drag emulates the breaking of mountain waves in the stratosphere. Note that this is not too important in a regional model, since it affects the winds at relatively high levels (~100 hPa) and this is why it has been neglected until now.

The blocking term is a parameterization that was introduced in the global configuration in December 2001 and found to be of great importance in maintaining the tropospheric upper-level features in winter. This parameterization reduces the low-level winds in mountainous regions and was also found important in the regional configuration. The modified low-level wind fields result in a displacement of the precipitation patterns upstream of the mountain ranges and the temperature bias in the low troposphere is also reduced.

1.2.2 Deep convection (DC)

A lot of effort was devoted towards improving the summer precipitation forecasts and this resulted in changes in the deep and shallow convection schemes. One change in the deep convection was to get rid of the double convection strategy that is used in the operational model: one scheme in the uniform grid; another one in the variable grid. The Kain-Fritsch scheme, for which we make sure that its precipitation is coherent with the moisture tendencies it produces, can run in the variable grid without bad effects in the uniform grid.

One parameter had to be adjusted in the deep convection scheme in the so-called trigger function. The lower its value, the easier the scheme will be activated. On the other hand, the less the scheme is activated, the more precipitation is produced by the explicit scheme at the resolved scale (called stratiform scheme historically). The generation of convective precipitation by the explicit scheme often lead to an over estimation of the precipitation amounts since it is not fully resolved on a 15km grid. It is thus a fine balance that has to be found to produce the precipitation amounts that verify best overall. An additional problem comes from the fact that the data assimilation system produces humidity fields that are not necessarily coherent with the physics parameterization. A lower value of the trigger function's parameter has been included for the first 6 hours of the integration to avoid bull's eyes in the precipitation pattern, with the optimal value used afterwards. The end result of this is that the precipitation amounts are better forecast in the new system, but occasionally there will be high precipitation amounts in the first 6 hours over the USA.

1.2.3 Shallow convection

A new shallow convection scheme has been developed in the last years at RPN and was tested in the 15km regional model. Based on a Kuo scheme closure, it is called Kuo-transient (Ktrans for short). It was shown to be much better over open waters to simulate stratocumulus, instead of stratus as the former scheme used to produce. The shallow convection (SC) scheme is very important in summer to reduce the precipitation bias due to the moisture accumulation at the top of the boundary layer.

Another difference is that Ktrans can generate precipitation, which the former shallow convection scheme was not producing. This feature was judged very important in situations of streamers over open waters in winter, when the convection is not deep enough to trigger the DC scheme. The fact that now two schemes can generate implicit precipitation (in contrast to explicit precipitation) forced a revisit of the definition of some output variables. In the CMC database, the total precipitation (PR) was until now divided in two parts:

PR = AE + PC, AE = explicit part of the precipitation (from stratiform)
PC = implicit part of the precipitation (from convection).

In order to ensure back compatibility, PC still refers to the implicit precipitation, but has the following definition:

PC = PY + PZ, PY = precipitation generated by the DC scheme
PZ = precipitation generated by the SC scheme.

1.2.4 Vertical diffusion

The same way a model needs horizontal diffusion, it also needs vertical diffusion, which is performed within the physics step. The vertical diffusion is based on the turbulent kinetic energy (TKE) theory. Until now, this diffusion was dry and did not take into account the onset of condensation in the atmosphere. A new scheme, called Moistke, referring to moist TKE, has been developed in the last years to deal with this aspect. The scheme uses the relative humidity and emulates diffusion along the moist adiabat when saturated at 100%, along the dry adiabat when 0% of humidity and a proportional mixture of the two when partially saturated. The Moistke also produces implicit low level clouds that interact with the radiation scheme.

Table 2: Summary of the physics configuration changes

	Operational (24 km)	**Parallel (15 km)**
Gravity wave drag	No	yes
Blocking term	No	yes
Deep convection (DC)	Fritsch-Chappell (uniform grid) Kuosym (variable grid)	Kain-Fritsch (everywhere)
Trigger function of DC	0,07	0,05 (first 6 hours) 0,12 (rest of integration)
Shallow convection (SC)	Conres	Ktrans
Vertical diffusion	Clef (TKE)	Moistke
Implicit precipitation	PC comes from DC scheme	PC comes from both DC and SC schemes PC = PY + PZ
Explicit condensation	Sundqvist	No change
Optical properties	In house scheme	No change

2. Objective verification: winter and summer cases

2.1 Set-up

Two series of cases were used to test the model changes:

- 18 cases in summer, from Aug 13th to Sept 24th 2002;
- 15 cases in winter, from Dec 23rd 2001 to Jan 27th 2002.

Every case was separated by 60 hours, to make sure they were independent.

Three types of verification were performed, shown in Figures 1 to 6 in the following pages:

- Upper air variable verifications
- Surface parameter verifications
- Precipitation amount verifications

2.2 Upper-air verifications

The upper-air verifications are done against radiosondes over North America. The verified upper-air variables are the following 5 parameters: zonal and meridional winds, temperature, geopotential height and dew point depression. To save space, the verifications shown in this document are for the 48 hour lead time only. On the two images presented (Fig. 1 for winter cases, Fig.2 for summer cases), two set of lines are shown: **blue for the operational model and red for the parallel**. In addition, the dashed lines indicate the bias and the solid lines, the root-mean square (rms) errors. The green tags on each sub Figures indicate if the separation between the two curves is statistically significant. Tags on the right hand side relates to rms errors, on the left to bias.

<u>2.2.1 Winter verifications</u>

All the verifications curves of Fig. 1 show positive and statistically significant results for the 15 km model either for the rms or the bias. The only exception is the bias of dew point depression at levels above 500 hPa, for which there is not much humidity anyway.

The large improvements for the winds, temperatures and geopotential heights are impressive across the troposphere. In the stratosphere, improvements are also of importance, but do not have that much an impact in the regional model context.

<u>2.2.2 Summer verifications</u>

The verifications are still positive but to a lesser extent than for winter (see Fig. 2). There is still a very positive impact for the geopotential heights and for temperature.

Again the dew point depression bias is worse above 500 hPa, but this time the rms errors are better in the new model at those levels.

2.3 Surface verifications

The surface verifications are shown against synoptic stations over North America for two variables: temperature and dew point depression (see Figures 3 and 4). The graphs indicate time series from 0 to 48 hours for both bias (dashed lines) and rms errors (solid lines).

2.3.1 Winter verification

In both models, the surface temperatures in winter exhibit a cold bias of the order of ~1.5°C over all North America, but the bias is slightly colder for the 15 km model (see Fig. 3). If one stratifies the verification by region (not shown), the difference in the biases comes from the western part of the continent, while the biases are similar over the east. This situation is *preoccupying* and work is ongoing to identify the source of this bias and to correct it.

2.3.2 Summer verification

The verifications in summer are similar in both models (See Fig. 4).

2.4 Precipitation verifications

Precipitation is probably the most difficult variable to verify. The number of cases is seldom enough. In principle, thirty-three dates of verification could seem sufficient, but if one wants to stratify them between winter and summer (which is essential), then the database is reduced by a factor of two. In order to have access to a larger number of verification stations, the SHEF database is also used. It covers most part of continental USA. By doing so, however, the cases are diminished by another factor of two because SHEF observations are only taken at 12UTC and only half of the model runs are started at 12UTC (the other half started at 00UTC).

The other problem is that the verifying station information has only 24 hour accumulations. We thus verify 24 hour accumulation for three periods: 00-24 hour, 12-36 hour and 24-48 hour accumulations. In this document, we only show the 24-48 hour accumulations. In order to draw sound conclusions, we have to consider the number of observation but also the number of weather systems (number of cases), the variety of atmospheric circulations in the sample, and so on. For sure, verification indices based on less than 100 observations are not conclusive (outside of green highlighted areas on the figures 5 and 6). The number of observations in each class of precipitation is listed at the bottom of each figure.

Two sets of verifications are shown: bias and threat scores. Verifications against the North America synoptic network are presented on Fig. 5a for the winter period and on Fig. 6a for the summer period. The corresponding verifications against the SHEF network over USA are shown on Fig. 5b and 6b, respectively. On all of these graphs, blue stands for the operational model and red for the parallel one.

2.4.1 Winter verifications

First observation: the conclusions are different whether one looks at the verifications against the synoptic (Fig. 5a) or against the SHEF (Fig. 5b) networks. Using the SHEF network, one concludes that both the biases (reduced) and the threat scores (higher) are better in the new model. On the other hand, using the synoptic network, the biases are more similar in the two systems and the threat scores are worse (lower) in the higher amounts (above 5 mm of accumulation). This suggests that either the number of cases is not sufficient to conclude, or that the model response to precipitation is different depending on the area of verification. For instance, over the southern part of the USA, it is likely that there is more convective precipitation.

2.4.2 Summer verifications

The conclusion in summer is more consistent for the two verification areas (Figs. 6a and 6b). The bias is slightly higher in the new model but the threat scores are better for almost every classes of precipitation.

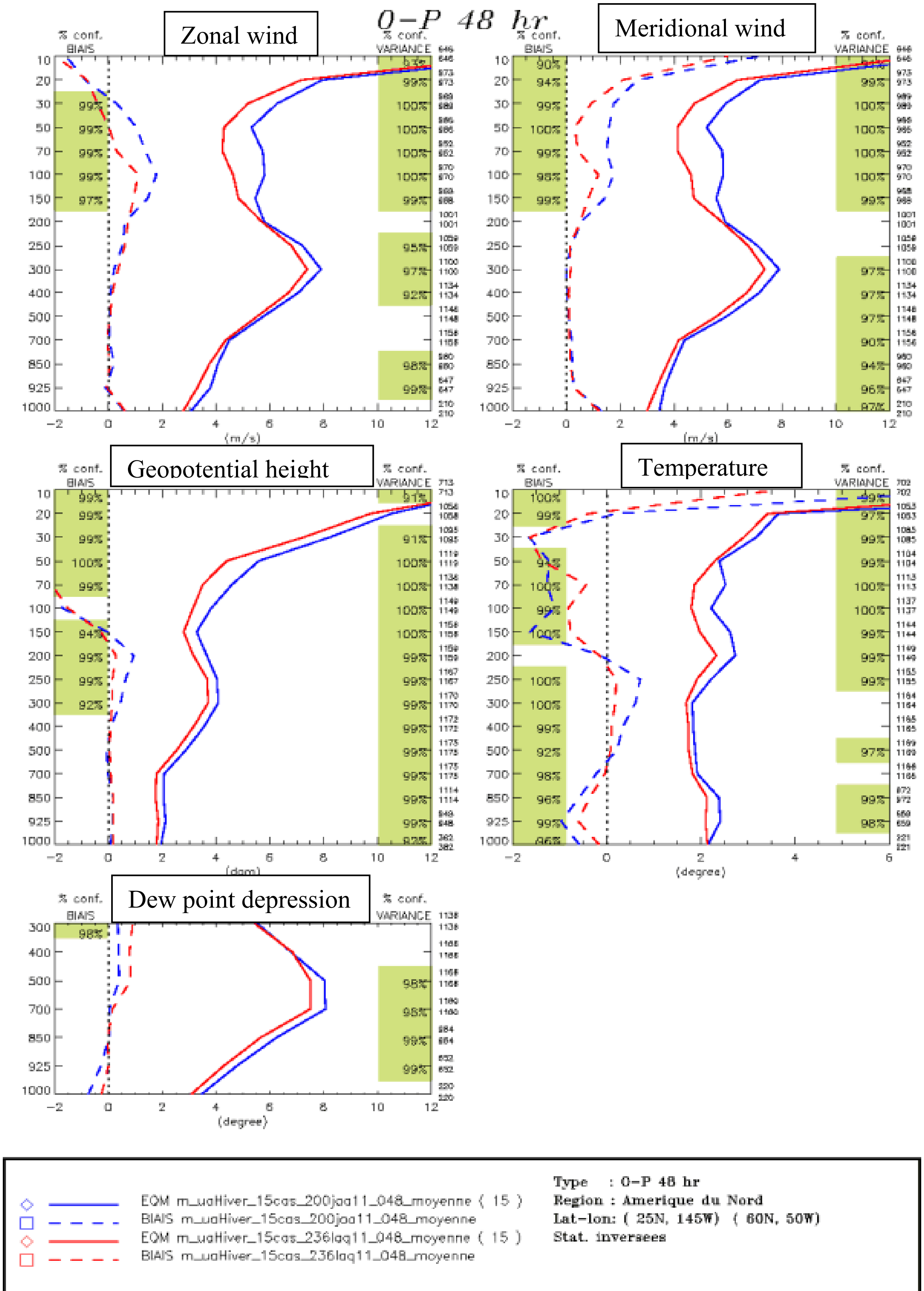


Figure 1: Upper air winter verifications (dashed lines for bias; solid lines for rms errors). Operational model is depicted in blue, parallel model in red.

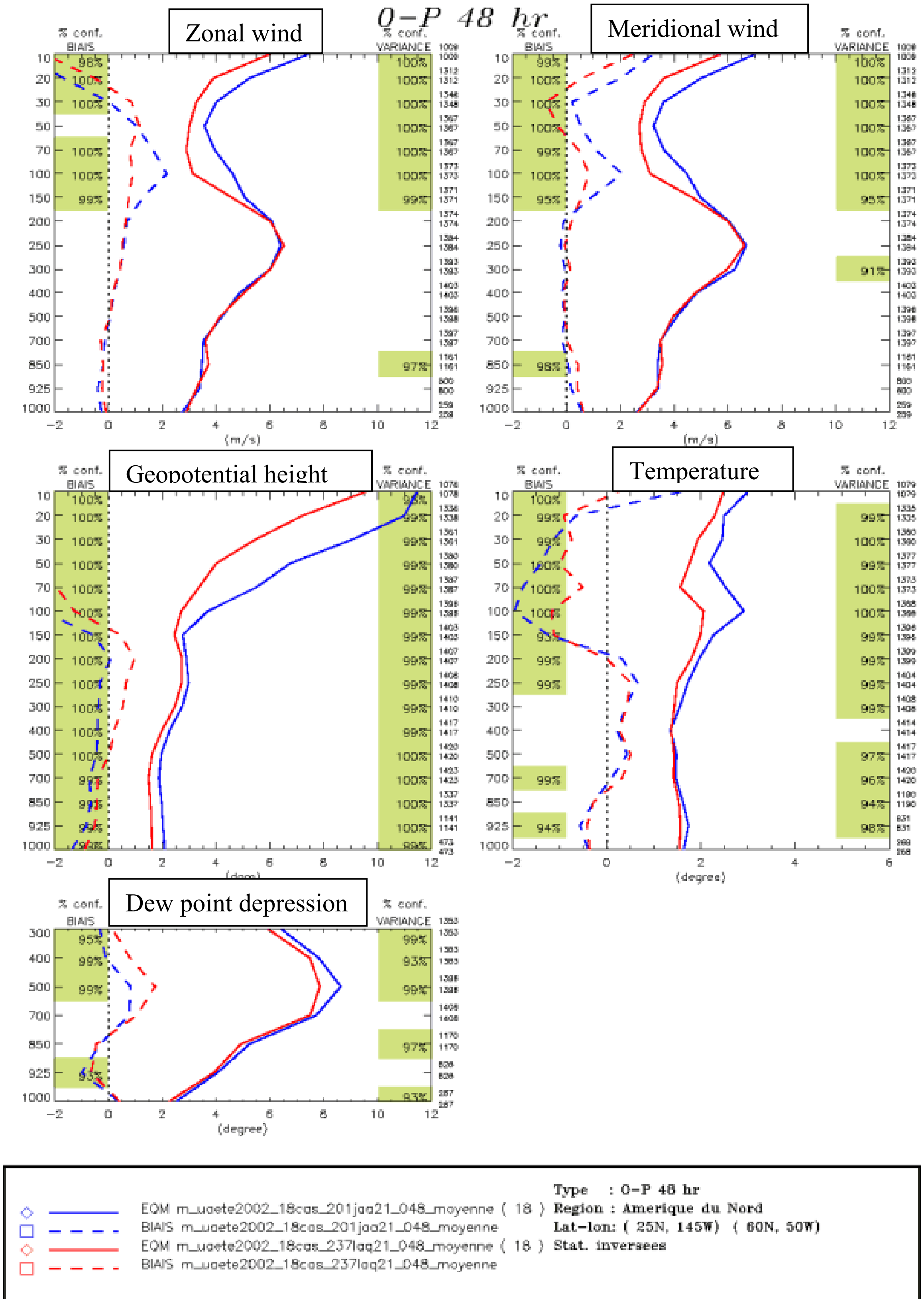


Figure 2: Upper air summer verifications (dashed lines for bias; solid lines for rms errors). Operational model is depicted in blue, parallel model in red.

Time series for surface temperature and dew point depression

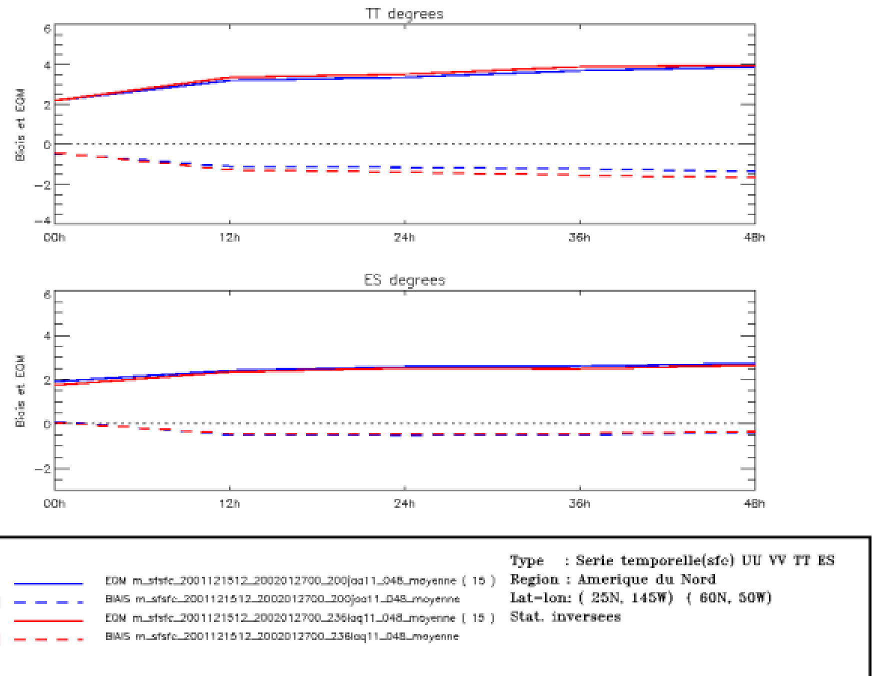


Figure 3: Surface winter verifications; red is for 15km and blue for the 24 km (dashed lines for bias; solid lines for rms errors).

Time series for surface temperature and dew point depression

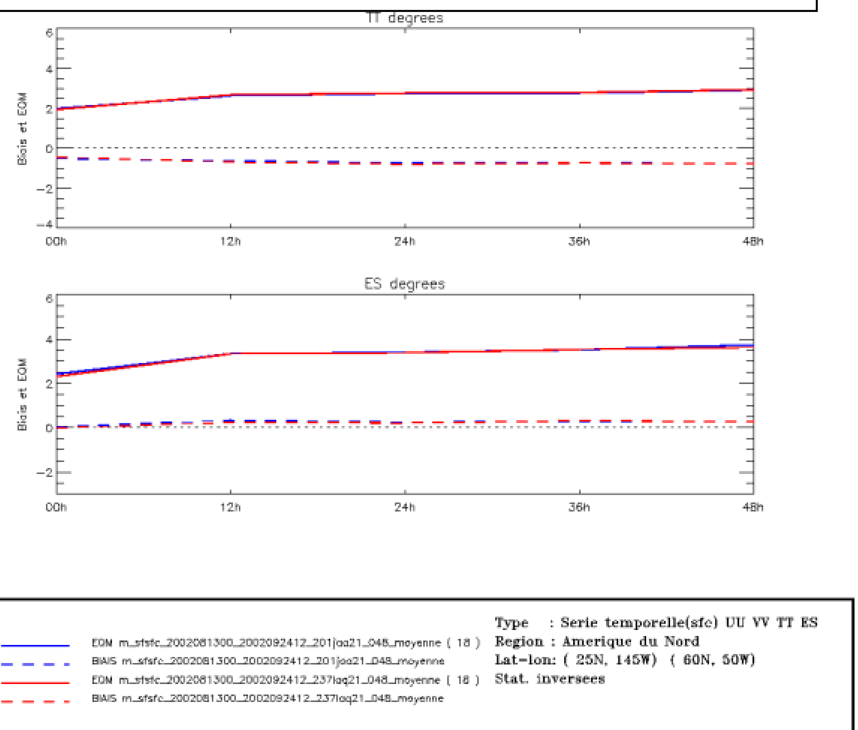


Figure 4: Surface summer verifications; red is for 15km and blue for the 24 km (dashed lines for bias; solid lines for rms errors).

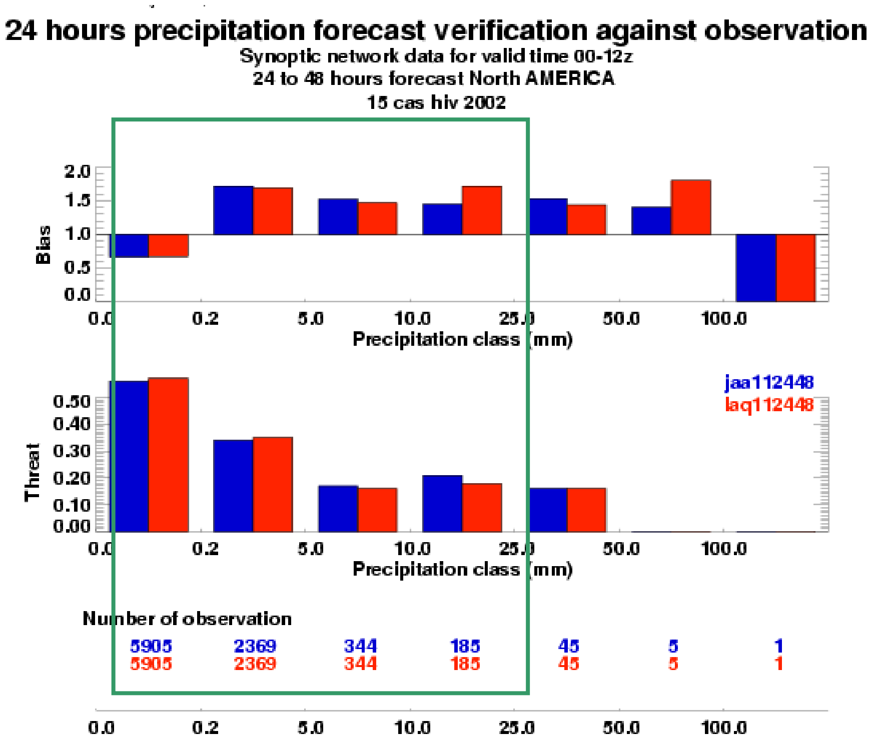


Figure 5a: Winter precipitation verification over North America (synoptic network). Framed area highlights results based on more than 100 observations. Operational model in blue (left), parallel model in red (right).

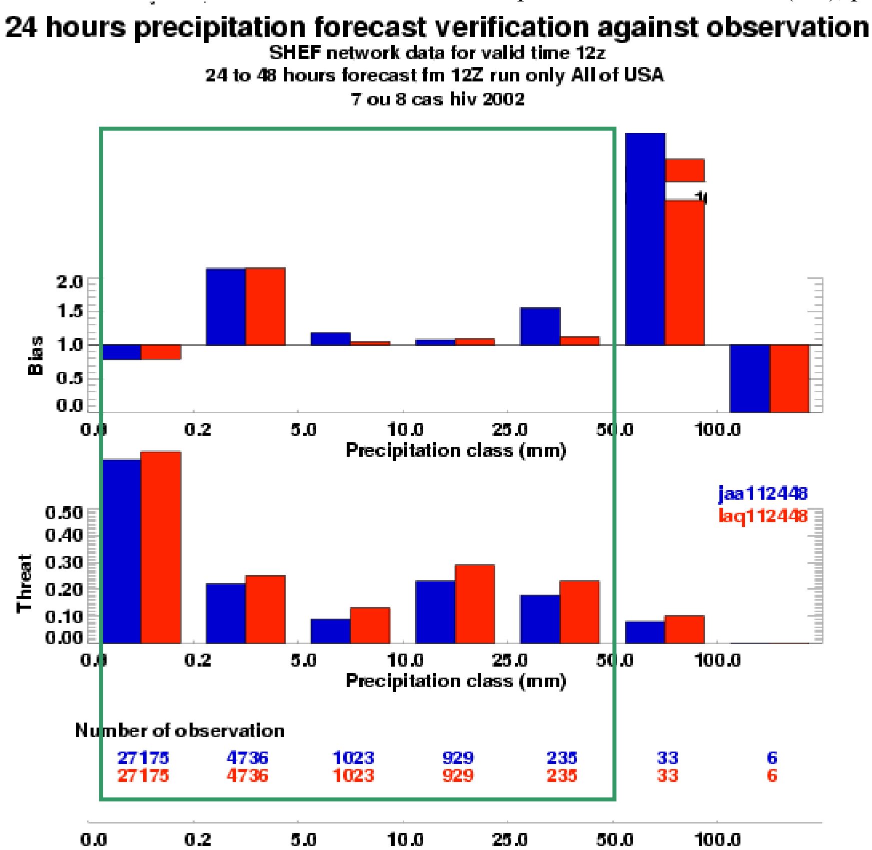


Figure 5b: Winter precipitation verification over USA (SHEF network). Framed area highlights results based on more than 100 observations. Operational model in blue (left), parallel model in red (right).

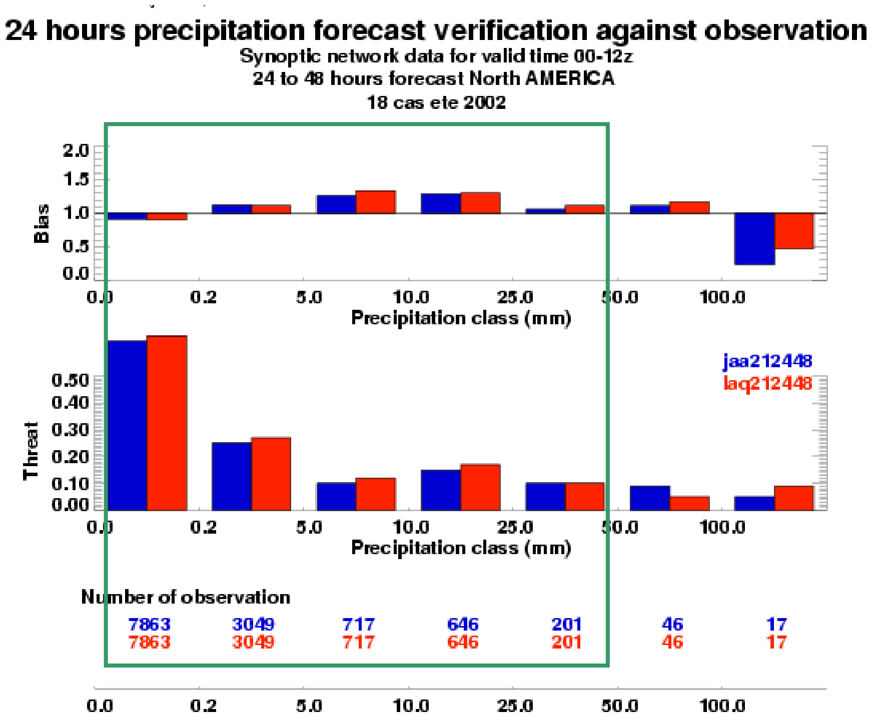


Figure 6a: Summer precipitation verification over North America (synoptic network). Framed area highlights results based on more than 100 observations. Operational model is depicted in blue (left), parallel model in red (right).

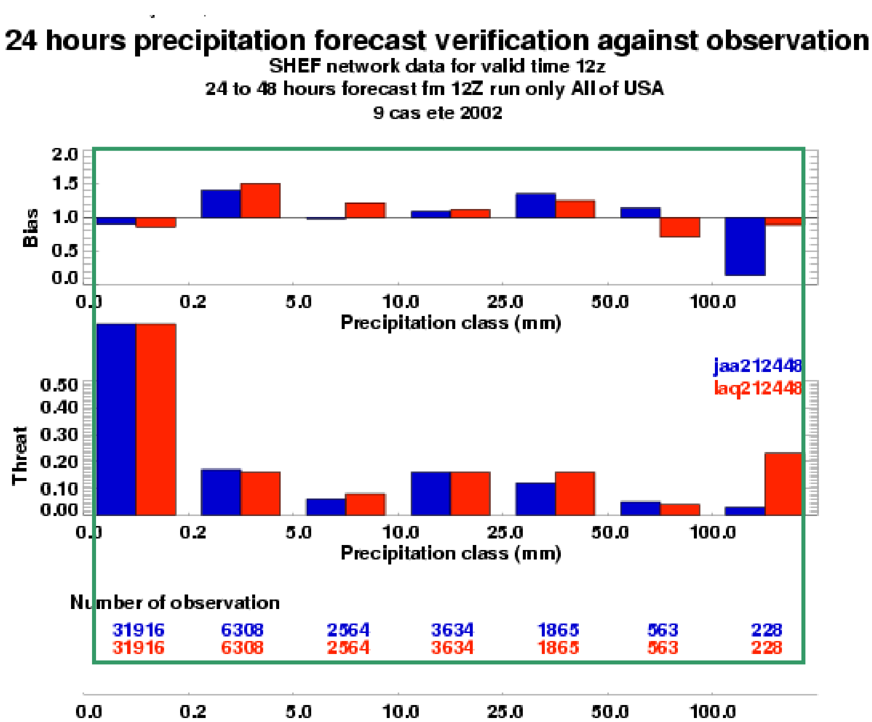


Figure 6b: Summer precipitation verification over USA (SHEF network). Framed area highlights results based on more than 100 observations. Operational model is depicted in blue (left), parallel model in red (right).

3. Objective verification: parallel run

3.1 Upper air fields

In this section, verifications scores presented are based on an international program of exchange of verification data through the World Meteorological Organization (WMO) Commission for Basic Systems. Objective verification scores against radiosonde observations are calculated for geopotential height, temperatures and winds at 850, 500 and 250 hPa. These scores were calculated over the period of the official parallel run, up to the end of April, 2004.

What the scores show is a marked decrease in RMS (root mean square) errors and a general improvement in biases. For example, RMS errors of the 48 hour forecasts of both heights and temperatures were about 10% lower than the operational model at all levels over the course of the parallel run. This represents one of the largest error reductions to the regional model in the last 10 years. Reduction in biases is also significant, but especially for the temperatures. Examples chosen below are the mid-level geopotential heights (Fig. 7) and lower level temperatures (Fig. 8), but the situation is similar at all levels for both fields.

RMS errors of the vector winds also decreased, though not as much as for heights and temperatures. The largest gains occurred at 250 hPa (Fig. 9). Meanwhile wind speed biases were also reduced, again especially at the higher levels.

3.2 Quantitative Precipitation Forecasts (QPF)

Objective verifications of QPF against both the North American synoptic network and the high density U.S. SHEF network also show a net improvement of the 15 km model over the operational 24 km model (Figs. 10-13). Equitable Threat Scores against both observation networks were generally improved in the ranges up to ~25 mm, especially in the 24-48 hour forecast period, while for amounts larger than 25mm, the scores were more equal or not quite as good. Biases were also generally decreased, though the 15 km has more of a tendency to over-forecast the higher amounts in some areas. This was noted, for example, in the subjective verifications over areas of high terrain, and scores against observations over a window which includes the mountainous areas of the western U.S. shows a somewhat higher bias (Fig. 14).

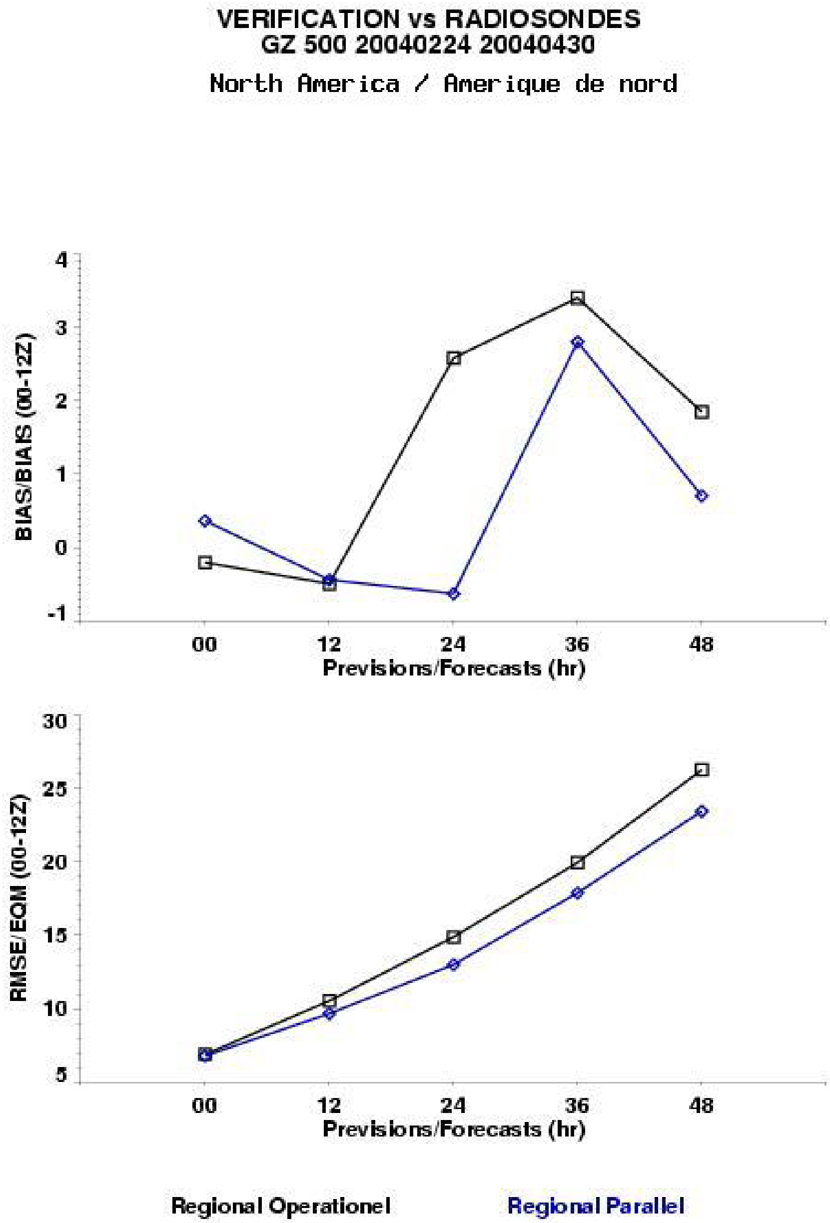


Fig 7: 500 hPa geopotential height bias and RMS (root mean square) errors for the operational (black) and parallel run (blue) GEM Regional models, against the North American radiosonde observation network, for the period Feb. 24th to April 30th

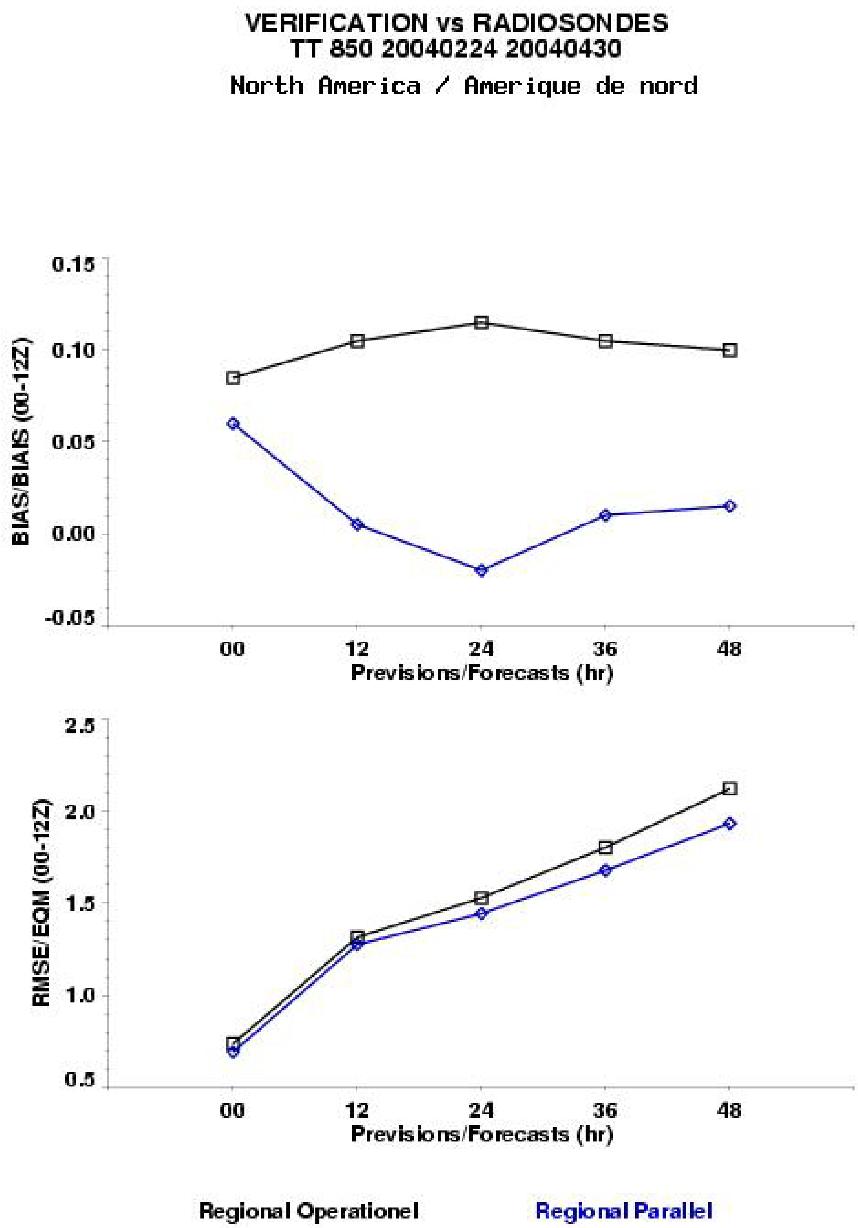


Fig 8: Same as Fig. 7 for 850 hPa temperatures.

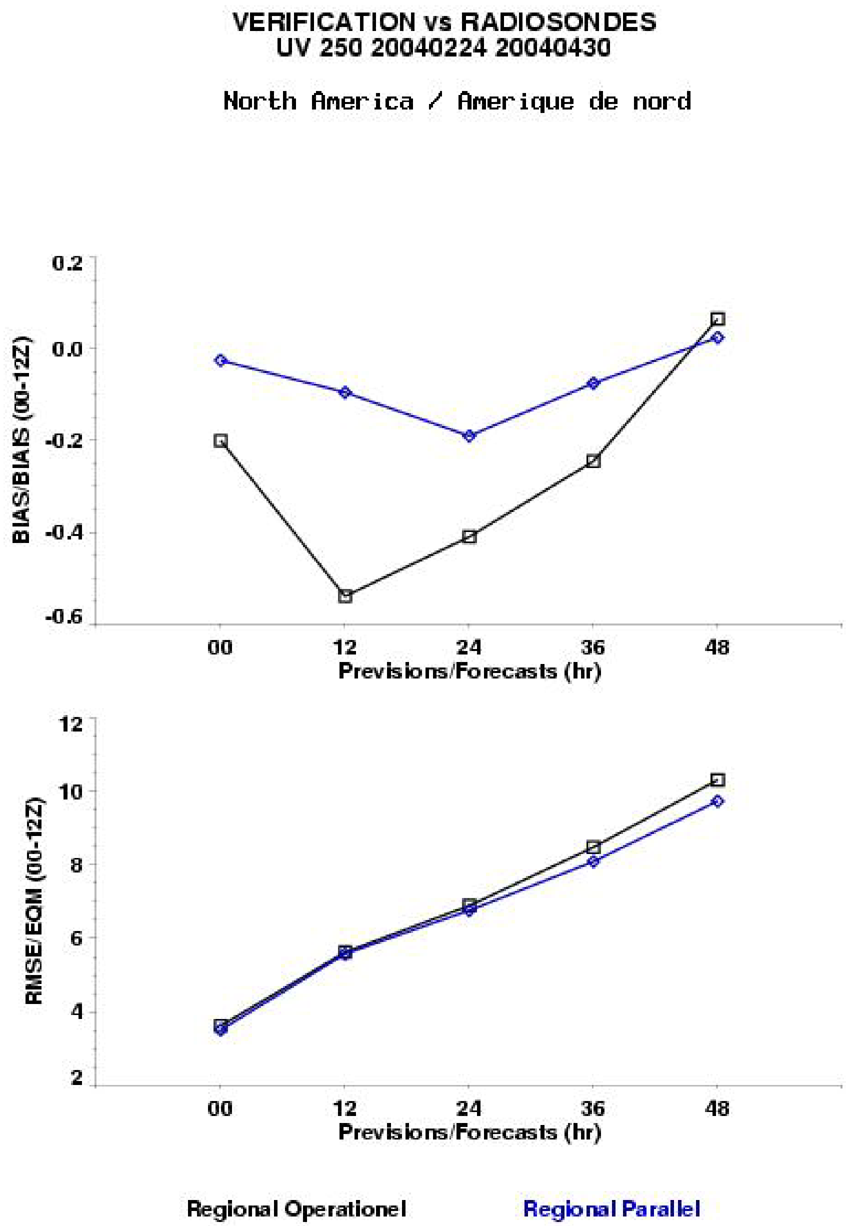


Fig 9: Same as Fig. 7 for the 250 hPa winds. Note that here the RMS errors are for the vector wind, while the bias is for the wind speed.

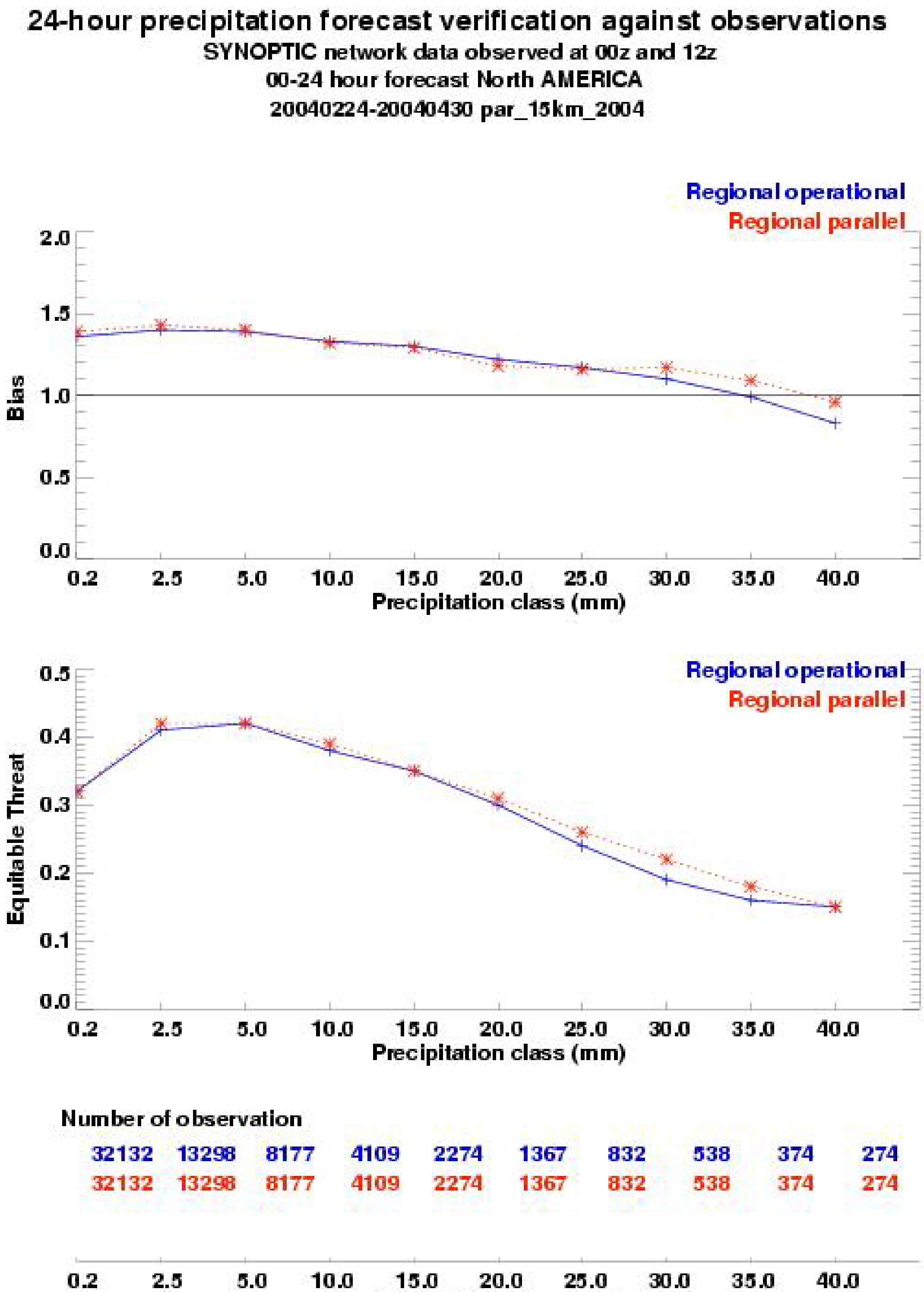


Fig. 10: Bias and Equitable Threat Scores for the operational (blue) and parallel run (red) GEM Regional models, 00-24 hour forecasts, against the North American synoptic network observations, over the period Feb 24th to April 30th.

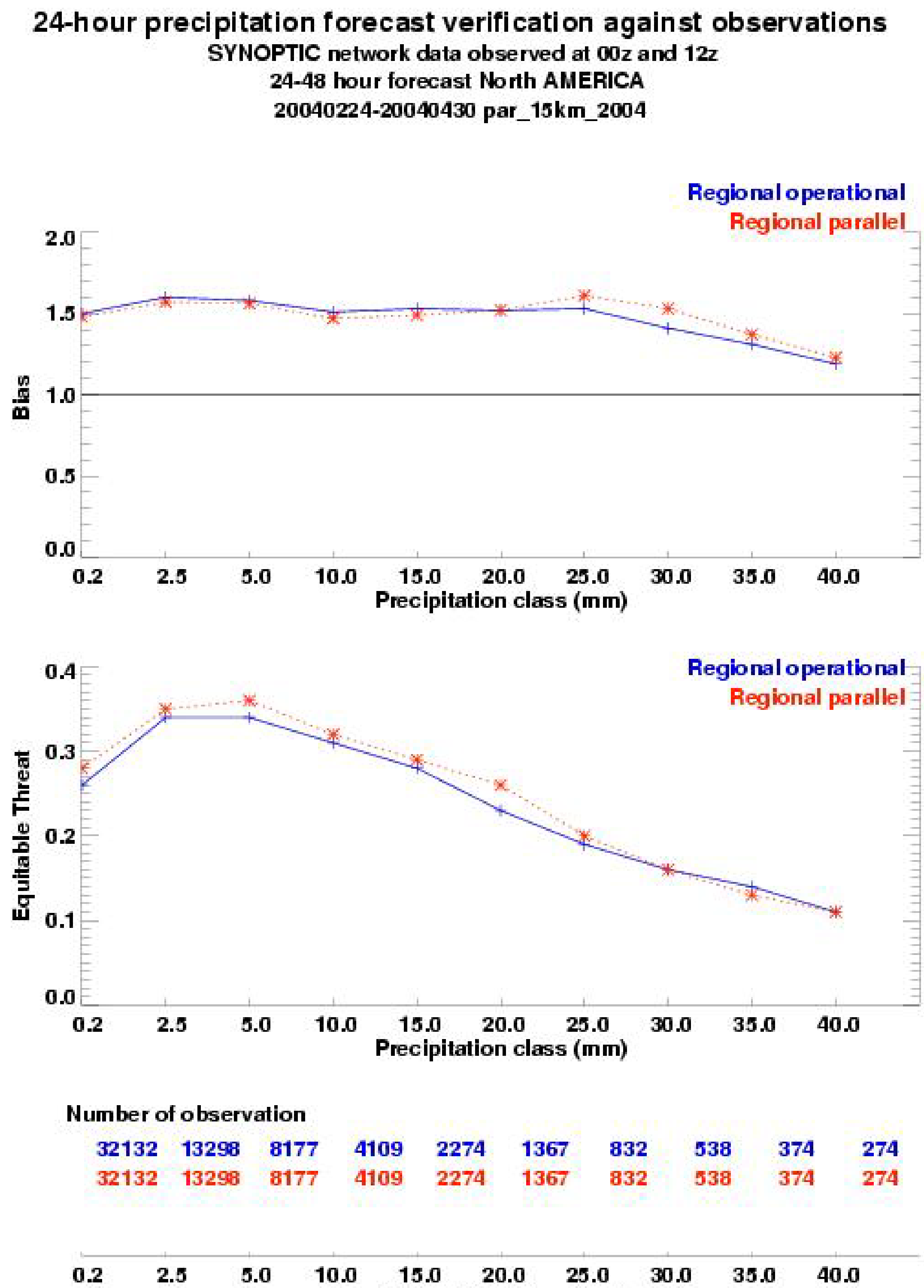


Fig 11: Same as Fig. 10, for the 24-48 hour forecasts.

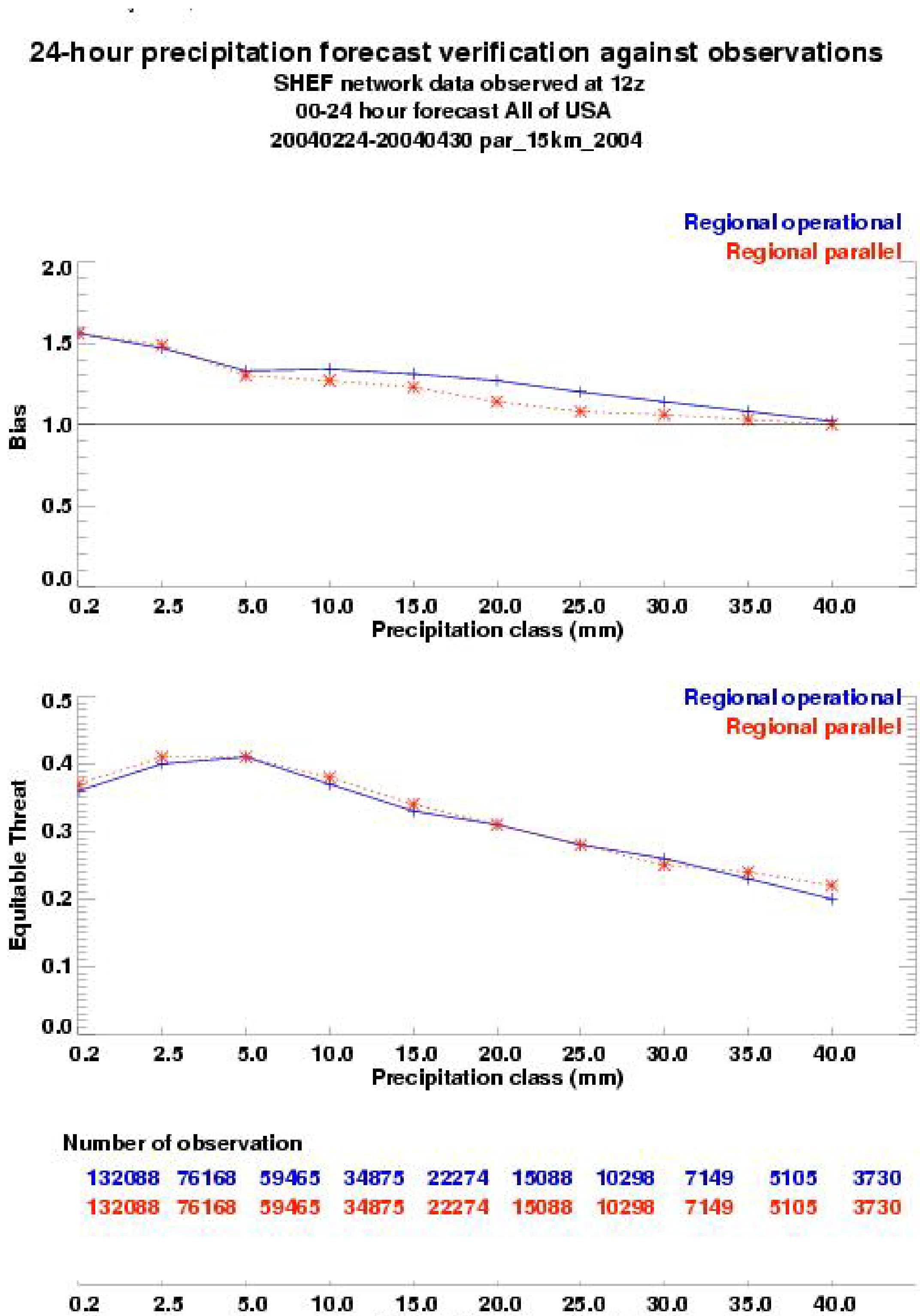


Fig. 12: Same as Fig. 10, against the high density U.S. SHEF (Standard Hydrological Exchange Format) observation network.

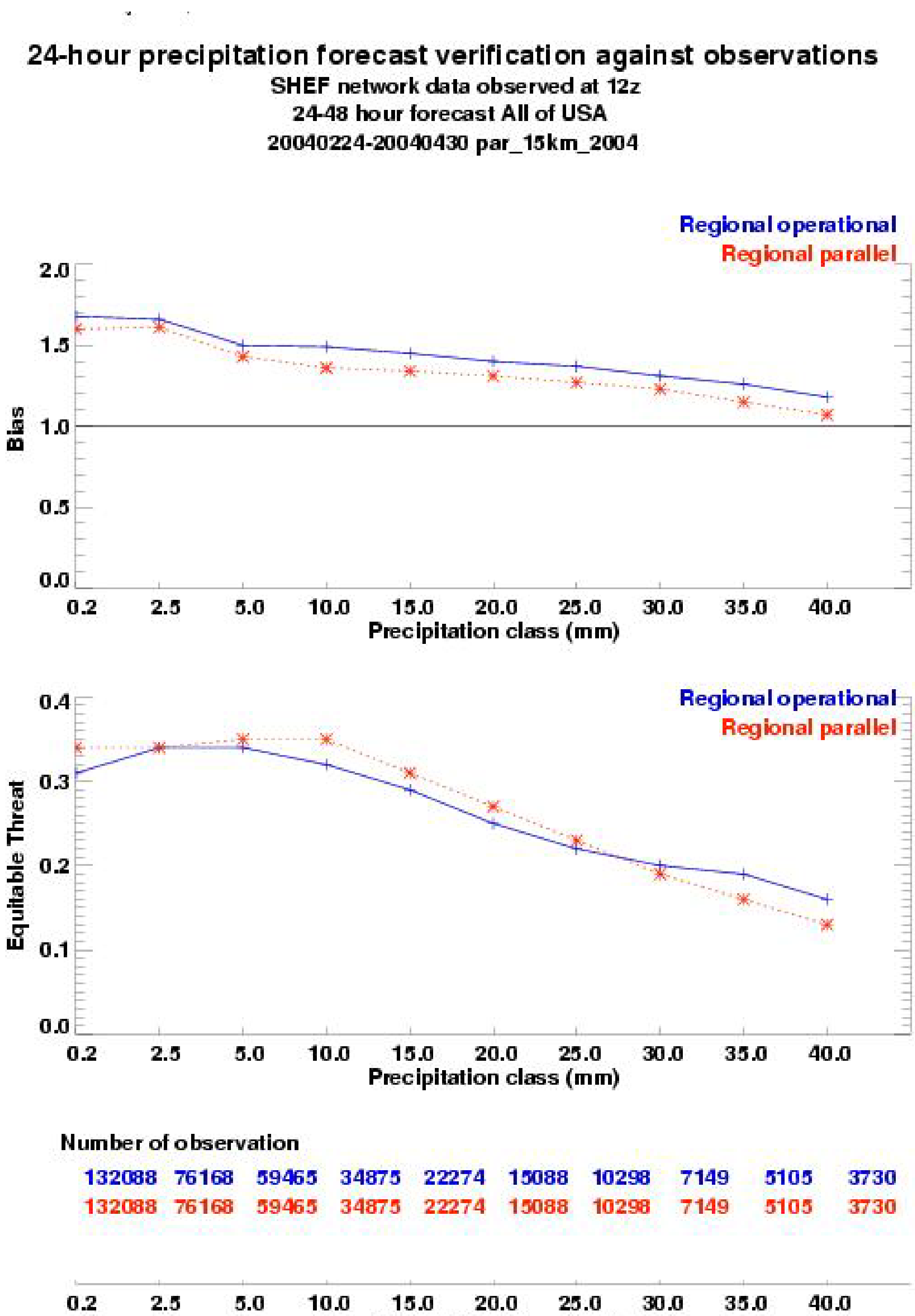


Fig. 13: Same as Fig. 12, for the 24-48 hour forecasts.

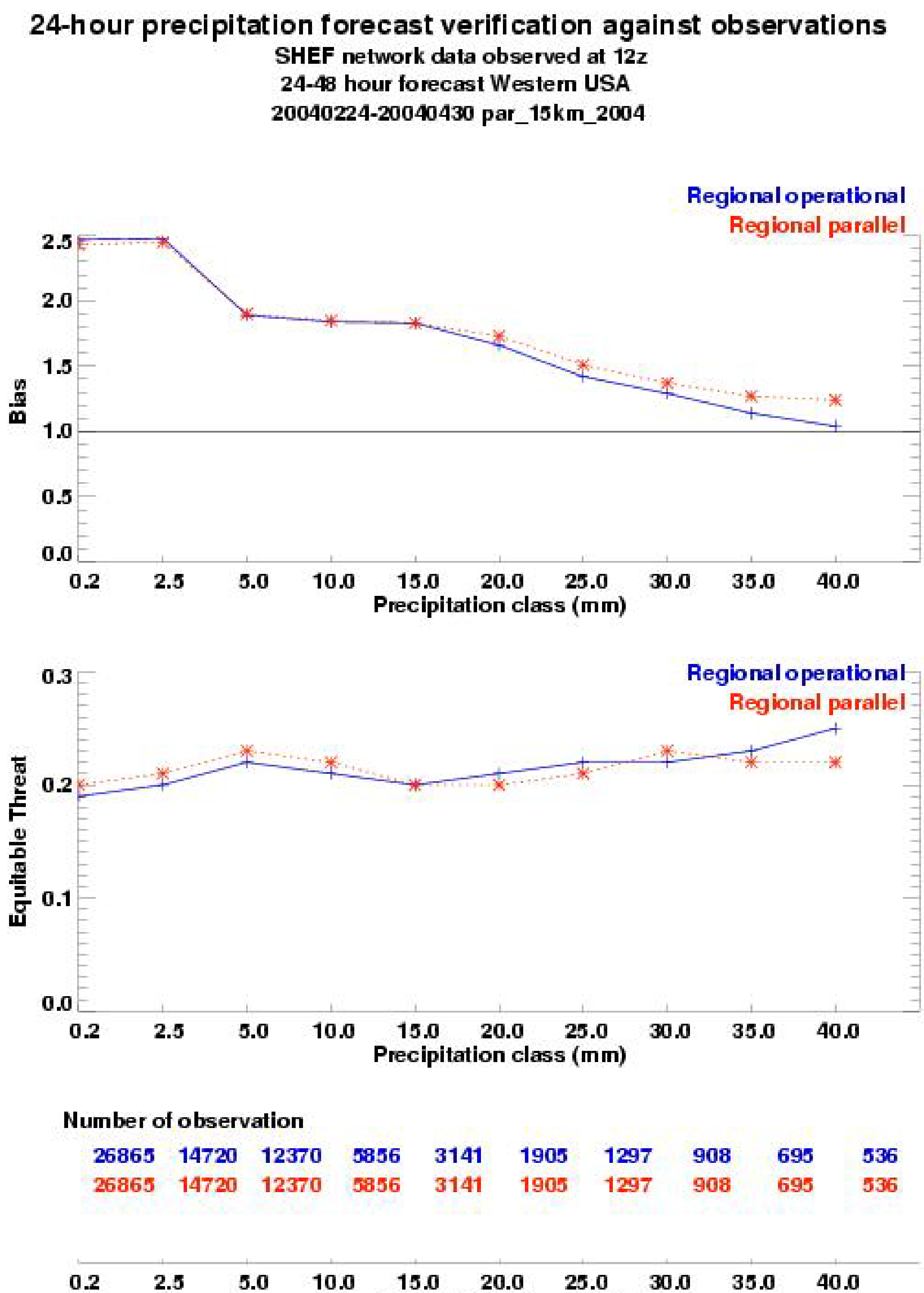


Fig. 14: Same as Fig. 13, over a Western U.S. window.

4- Highlights of subjective evaluation

During the last year or more, operational meteorologists have evaluated different versions of the new regional prediction system (referred as GEM15 in the following). This evaluation was accomplished in part through comparisons with the current operational version of the regional prediction system, driven by the GEM regional model with 24 km horizontal resolution (GEM24 in the following).

The following is a series of highlights of the subjective evaluation performed by the operational meteorologist in close cooperation with the CMC development meteorologists and Meteorological Research Branch researchers. This is an overall summary following the evaluation of archived summer and winter cases as well as real time parallel run systematic evaluation.

1- GEM15 was shown to be superior to GEM24 in its forecasts of the speed, intensity and phasing of 500 hPa short waves. When relatively large differences in the two models' short waves were found in their 48 hour forecasts, GEM15 was usually found to be better when compared with the verifying analysis. In fact, in most of these cases GEM15 was estimated to be 12 hours better than GEM24 in terms of predictability.

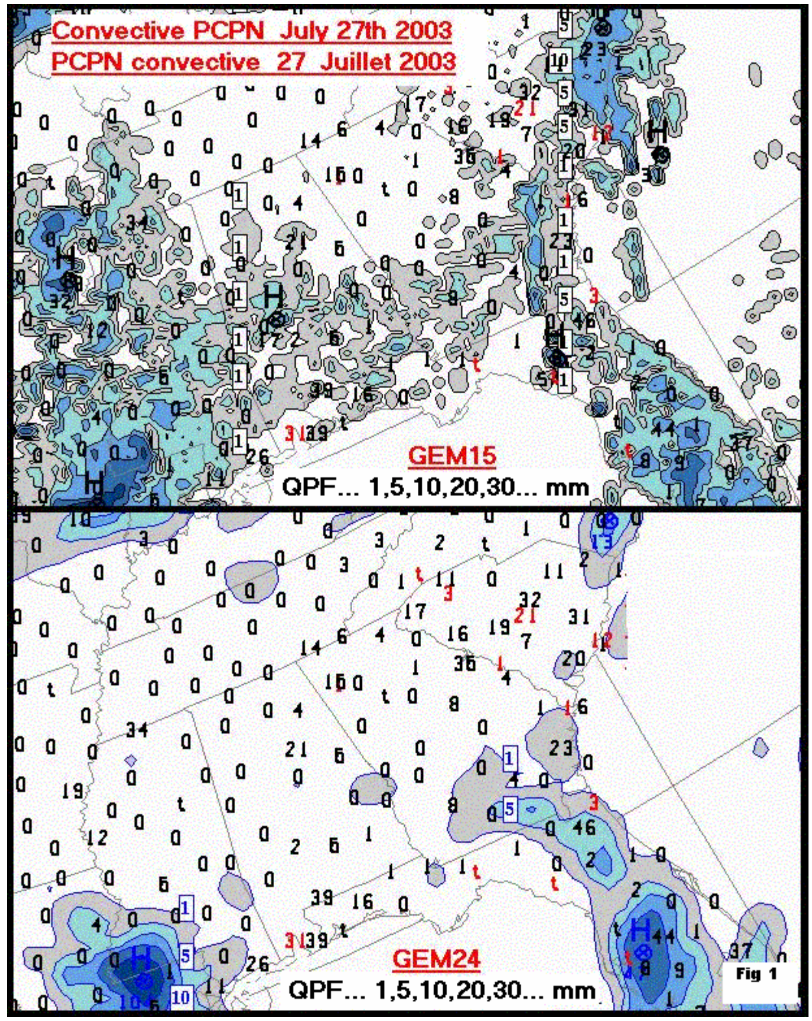
2- GEM15's mass fields were clearly superior to those of GEM24 over most of North America. However, the subjective evaluation concluded that the advantage was less clear, but still in GEM15's favour, in the Atlantic region. This was noted specifically for MSLP (Mean Sea Level Pressure) but also for precipitations amounts.

3- GEM15 exhibits the same pattern of nocturnal cold bias in surface temperature as GEM24. However, in GEM15 this bias is larger in mountainous terrain and especially in clear sky conditions. This bias is of concern and work is ongoing addressing the issue.

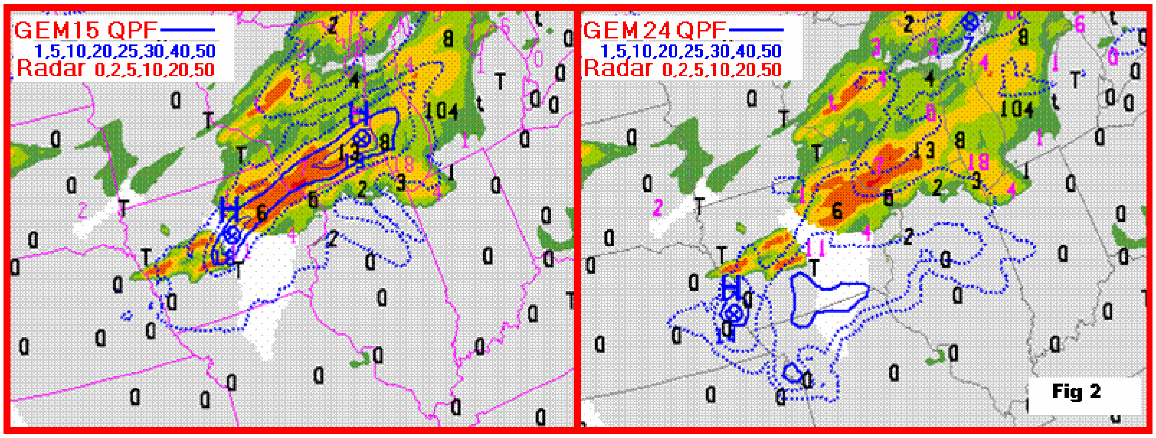
4- Chinooks in the lee of the Rockies are better-forecast by GEM15: the new model better defines the spatial variations of chinook winds descending the eastern slopes of the mountains.

5- GEM15's QPF verifies better in general than GEM24's. As a result of the higher horizontal resolution of the new model, its zones of maximum precipitation are often smaller than those of GEM24, both in winter and summer, and for both stratiform and convective precipitation. GEM15 is clearly better than GEM24 in cases where precipitation advances from the west into the BC interior. In such cases, GEM24 has too strong a tendency to push the precipitation too far east.

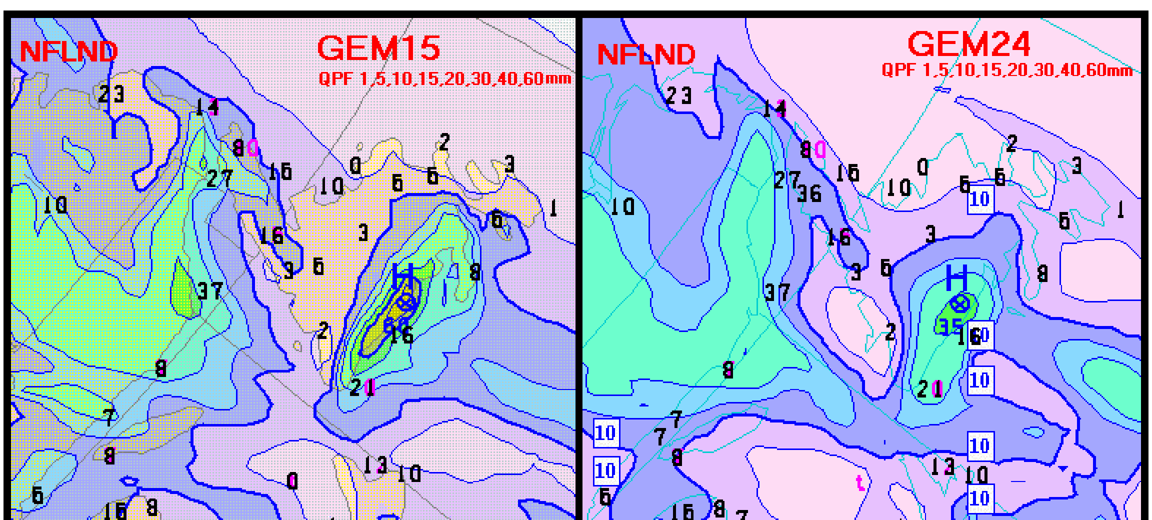
GEM15 produces larger trace areas in its QPF than GEM24 in cases of airmass convection and also in cases of light snow falling from stratocumulus. Another difference is that the GEM15 QPF amounts in cases of deep convection in a warm airmass are greater than those of GEM24. In such cases, GEM15 generally verifies better in a subjective comparison of its QPF with available observations (Fig 1).



The same comparisons also show that GEM15 performs better with respect to its positioning of the axes of convective precipitation (Fig 2). Finally, the noisier texture of GEM15's QPF in such cases of airmass convection is more realistic than GEM24's smoother pattern.



However, GEM15 can over forecast local convective precipitation amounts in the first 6 hours of model integration over southeastern USA. Furthermore, in that same forecast period occasional very local convective precipitation maxima centered on model grid points have also been noted in GEM15.



15km forecast more PCPN in southerly upslope winds along NFLND south shore.

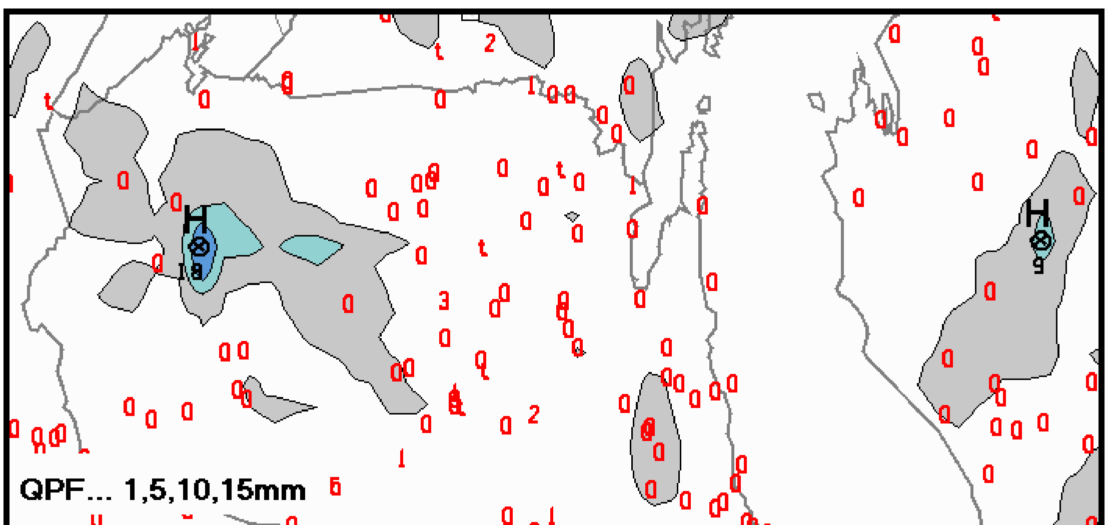
Sous les vents du sud, le 15km prevoit plus de pcpns le long de la rive sud de Terre-Neuve.

Fig 3

6- GEM15 does have a potential problem with over forecasting of precipitation amounts on the windward side of rising terrain in cases of onshore flow with orographic uplift. This is true not only of the BC coastal mountains, but also of the Torngats Mountains, and of escarpments such as found in southern Newfoundland (Fig 3 above). Using available surface-based precipitation observations, A+P has estimated that GEM15 over forecasts by a factor of two in such cases. However, in a few of these cases it has happened that further a posteriori verifications have later confirmed the higher GEM15 QPF amounts.

7- The precipitation types forecast by the two models are very similar, and neither model is clearly better than the other. GEM15's colder surface temperature bias does not seem to hurt its precipitation type forecasts. As already mentioned, this cold bias is greatest in mountainous terrain and under clear skies. In cloudy conditions with precipitation, GEM15's surface temperatures verify as well as, if not better than, those of GEM24. However, GEM15 was noted to forecast more frequent small disorganized freezing precipitation zones in the mountain valleys of BC and over the western high plains.

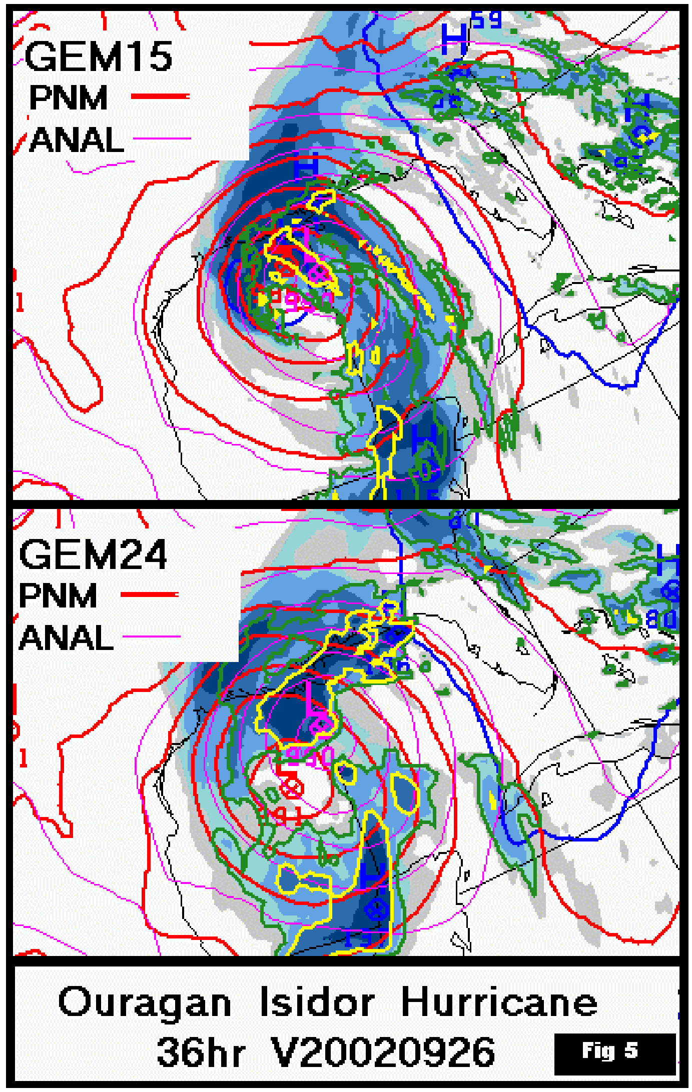
8- In cold low situations marked by the dominance of stratocumulus and cumulus clouds, it was noted that GEM15 occasionally forecasts local precipitation maxima from its explicit scheme (Fig 4). In one particular case over the USA,



The 15km creates random pcpn bull's eye under cold lo during first 12hr pd
Le 15km prédit aléatoirement des zones intenses de pcpn sous les creux froids au cours des 12 premières heures d'intégrations. Fig 4

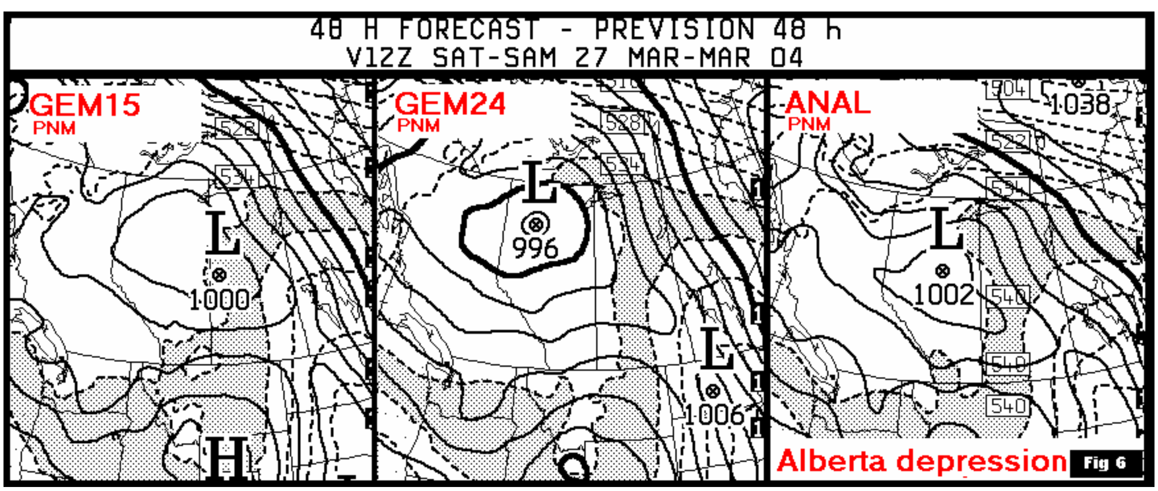
typical of this pattern, radar data and high resolution SHEF (Standard Hydrological Exchange Format) precipitation observations were available to verify GEM15's QPF maximum of 15 mm and more. *No* precipitation was observed in that case.

9- A comparison of the performance of GEM15 and GEM24 was made for some hurricane cases. In general, GEM15 verified much better for Gulf of Mexico hurricanes (Fig 5). This improvement may be related to the assimilation of AMSU-B satellite radiances in the GEM15 system. Over the Atlantic, GEM15 was still better than GEM24, though not by such a large margin.

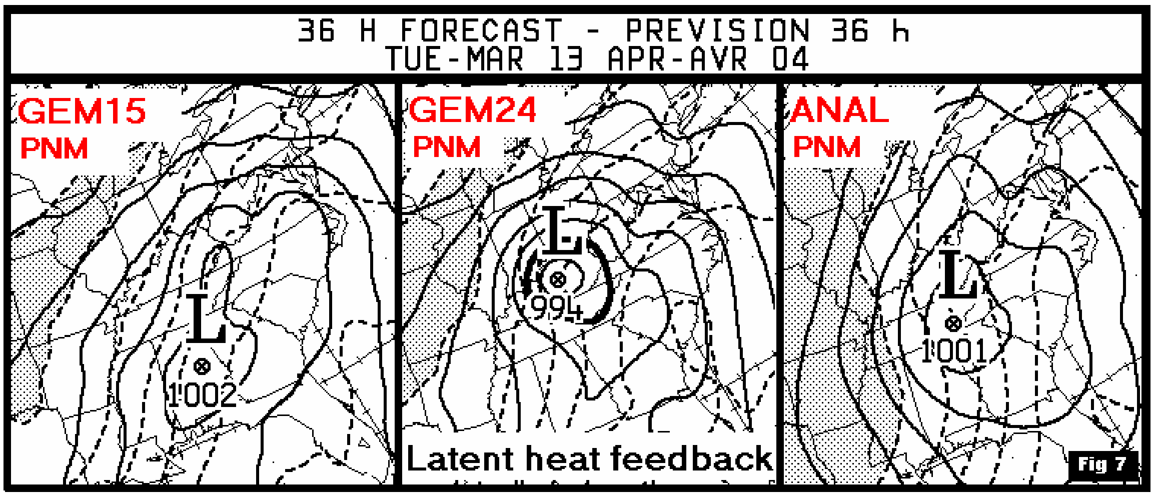


10- The negative height bias of GEM24 over the Rockies has been corrected in GEM15, as a result of the inclusion of the blocking term in the new model. In particular, upper ridges that are systematically too weak in GEM24 are forecast much better by GEM15.

11- In the case of low pressure systems forming or reforming over Alberta in the lee of the mountains, GEM24 typically places them too far north and forecasts them too deep. In such cases, GEM15 usually has a weaker low farther south, which verifies better (Fig 6).

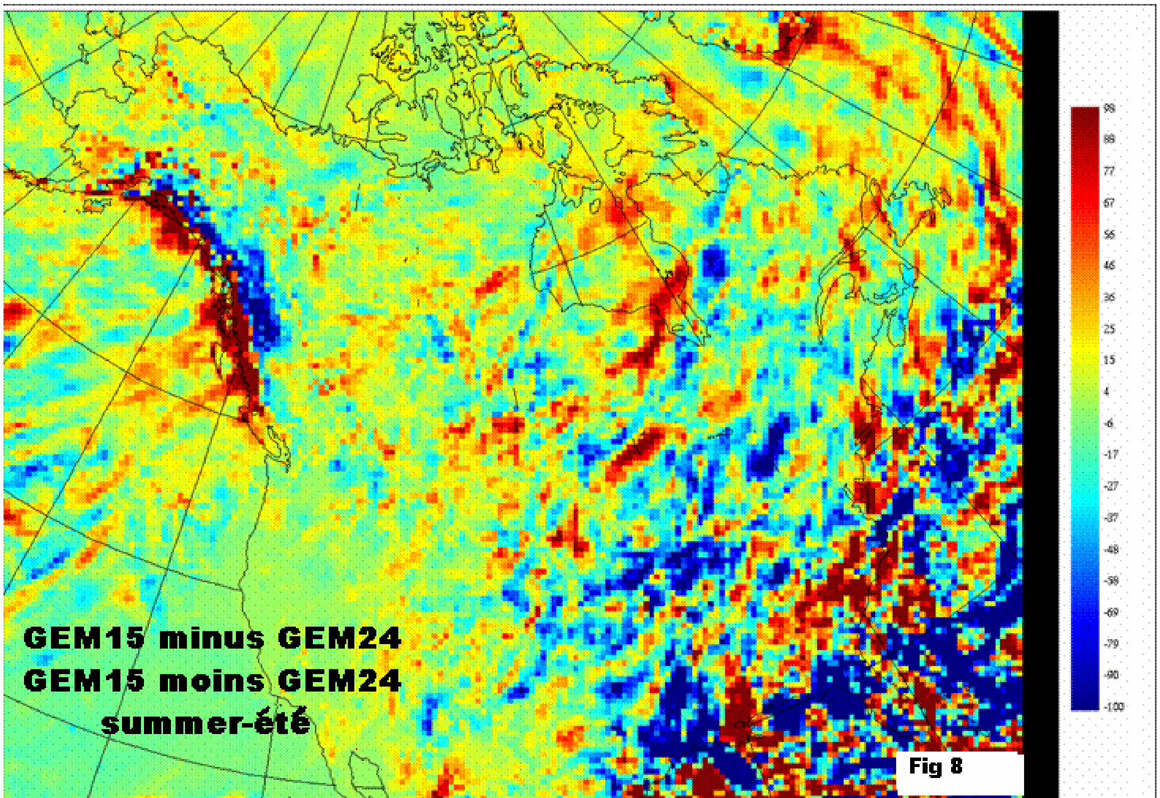


12- GEM24 has been known to liberate too much latent heat in the low levels and so to incorrectly deepen lows over the Atlantic, leading to problems in its precipitation forecast for the Maritimes and Newfoundland. GEM15 is generally better in these situations, though one problematic case was noted well offshore of Newfoundland. In a continental case of a large difference between the two models, GEM24 had clear convective feedback and as a result over deepened a low over the eastern US and forecast it too far north. This low was characterized by a warm sector with strong, active thunderstorms. In this case GEM15 verified much better in both its MSL forecast (Fig 7) and in its QPF for Ontario.

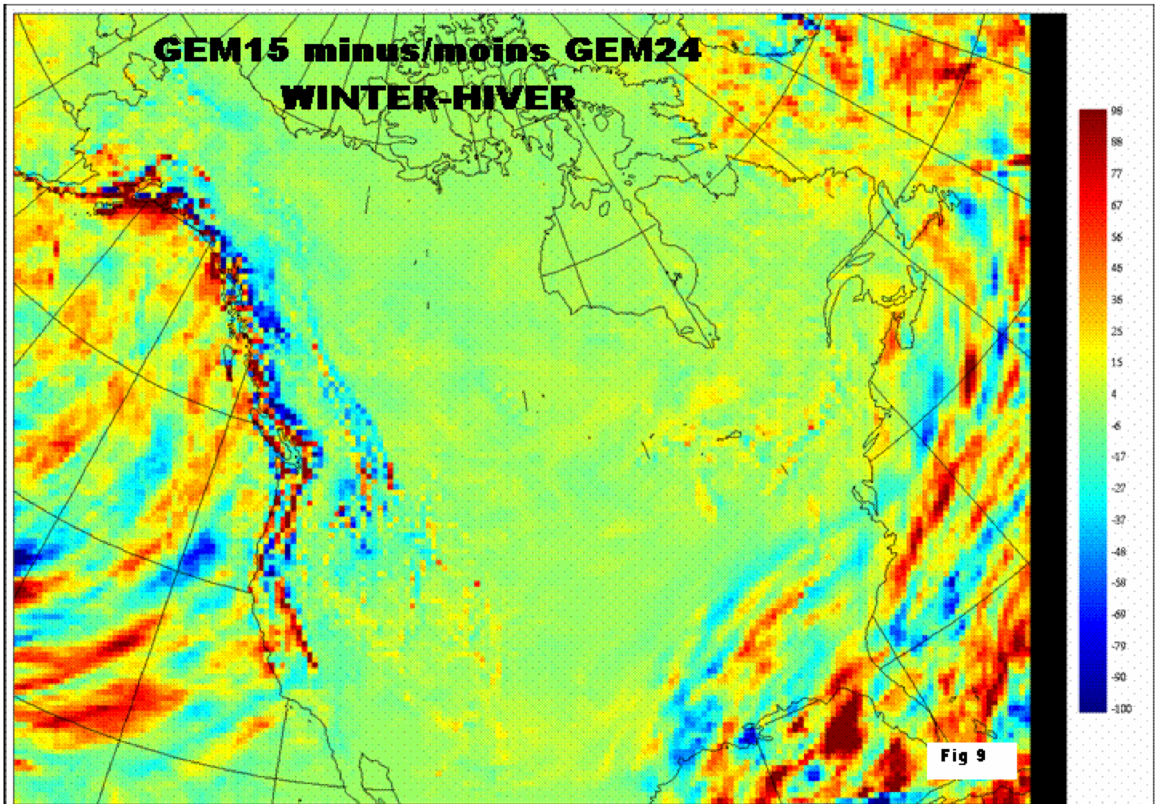


13- Despite some differences in detail, convective “streamers” coming from the Great Lakes and the Gulf of the St. Lawrence were judged to be forecast equally well by the two models. Both models often over forecast the areal coverage of clouds in these cases, especially over the American states next to the Lakes. However, the heavier snow amounts in such cases generally remain closer to the lakes in GEM15 which doesn’t verify all the time.

14- In summer, GEM15 tends to forecast less precipitation than GEM24 over southern Ontario and Québec (Fig 8). This is probably due to GEM15’s narrower axes of convective precipitation maxima. In winter, GEM15 generally produces more precipitation than GEM24 over the oceans, and especially over the Pacific and the Labrador Sea (Fig 9). The graphics also show that in both seasons GEM15 forecasts much more precipitation on the windward side of the West Coast mountains, and significantly less to their lee. The blocking term included in GEM15 acts to reduce the winds above the mountains and also a certain distance to their windward. Since the prevailing flow in the area is westerly, this results in a pattern of low level convergence to the west of the mountains, and it can be hypothesized that the heavier precipitation of GEM15 windward of the Coast mountains is related to that convergence, and therefore to the blocking term.



Difference between 18 summer cases 00-48hr total precipitation. RED ==> Gem15 forecast more precipitation than GEM24.
Différence entre 18 cas d'été des précipitations totales 00 à 48hr. Rouge ==> Le GEM15 prévoit plus de précipitations que le GEM24 .



Difference between 15 winter cases 00-48hr total precipitation. RED ==> Gem15 forecast more precipitation than GEM24.
Différence entre 15 cas d'hiver des précipitations totales 00 à 48hr. Rouge ==> Le GEM15 prévoit plus de précipitations que le GEM24