Impact of combined AIRS and GPS-RO data in the new version of the Canadian global forecast model

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Introduction

Environment Canada is currently planning to raise the lid of its operational global forecast model GEM (Global Environmental Multiscale) from 10 hPa (~30 km) to 0.1 hPa (~60 km) in the first quarter of 2009. The new version is called GEM-Strato. This project has several major components: changes to the model physics, new vertical coordinate, new background error statistics, and additional data types for the assimilation system. These include AMSU-A stratospheric channels 11-14 in addition to data types recently implemented operationally: AIRS and SSM/I radiances and Quickscat oceanic winds. This paper presents results on the impact of the new model configuration, followed by that of adding the new data types mentioned above, and that from GPS-RO refractivity profiles in the variational assimilation system.

Model configuration

The essential new elements of the GEM-Strato configuration are the following:
- Model top raised from 10 hPa to 0.1 hPa
- Number of levels raised from 58 to 80
- Vertical coordinate changed from eta to hybrid
- Li and Barker (2005) radiation code implemented
- Non-orographic gravity wave drag implemented (Hines, 1997)
- New climatological ozone from Fortuin and Kelder (1998)

This model configuration, labeled baseline GEM-Strato, was tested in assimilation cycles with the data types used operationally, with the addition AMSU-A channels 11-14.

Background error covariances

With a new model configuration, an important task is the derivation of background error statistics. As for the current operational system, the background error covariances are based on the difference between 24-h and 48-h forecasts valid at the same time. With the current approach for modeling the geostrophic balance, it is not possible to filter noisy correlations of "balanced temperature" (T_{bal}) between troposphere and stratosphere. A new approach allows to explicitly compute the vertical correlations for T_{bal} so that they can be localized. This eliminated a problem of spurious stratospheric increments. The ratio of unbalanced temperature (T_{unbal}) to total temperature standard deviation from forecast differences was maintained. Variances were adjusted using radiosonde temperature and wind observations as well as MLS (microwave limb sounder) temperature retrievals. Fig. 1 shows the total standard deviation stddev T and ratios stddev T_{unbal}/stddev T for January and July. Maximum temperature errors of ~3.5 K at 1 hPa are related to the winter polar vortex. For assimilation cycles to remain stable, it was found necessary to reduce the temperature errors near the model top.

First results

First results with the Gem-Strato configuration against the current model with model top at 10 hPa (but without the new data types listed in the introduction) showed a remarkable improvement. Fig. 2 presents time series of Northern Hemisphere (NH) geopotential 120-h forecasts verified against

radiosondes and Fig. 3 presents the corresponding validation statistics for the mass, and wind profiles. Fig. 2 indicates (100 hPa panel) that the gain is dominated by two major stratospheric busts which were eliminated. These baseline GEM-Strato results correspond to a predictability gain of about 6 hours at day 5 based on 500 hPa anomaly correlation (not shown). Results for the Southern Hemisphere (SH) and Tropics as well as for the summer verification period were also clearly positive, although not as spectacular as those presented in Figs 2-3.

Adding AIRS, SSM/I and Quickscat

On 28th May 2008, Aqua AIRS (87 channels) and SSM/I (7 channels, F13 and F14 satellites) radiances as well as Quickscat ocean surface winds started to be assimilated operationally. In addition, edges of scans from AMSU-A and AMSU-B are now assimilated, increasing by 25% the volume of these data. An offline dynamical radiance bias correction system was implemented, updated at every analysis using a 15-day window. Bias predictors for microwave radiances are classical background geopotential thicknesses, with scan bias removed as a first step. AIRS uses only one predictor, the observed radiance itself. These new data were again tested in GEM-Strato and lead to a clear positive impact, similar to that noticed before their original implementation (Wagneur et al., 2007, Garand et al. 2007). AIRS is the data type providing the largest impact. An example of impact from 3D-var FGAT cycles is provided in Fig. 4 for SH 120-h forecasts.

Adding GPS-RO and more AIRS channels

The impact of GPS-RO assimilation of refractivity profiles was evaluated separately. The main characteristics are the following:
- Assimilation from 4 to 40 km
- Data from CHAMP, GRACE and COSMIC, about 500 profiles per analysis (6-h period)
- About 1 km vertical thinning (data are available at 200 m resolution)
- Background check corresponds to about 12 K limit between observed and calculated temperature. Data are assumed unbiased.
- Observation error is in the range 0.5 to 1.5%, assigned dynamically

Results in terms of 300 hPa GZ anomaly correlation are shown in Fig 5, indicating a positive impact in both hemispheres in a 70-day winter assimilation cycle. Future tests will consider using data up to 60 km near the model top. Eventually, bending angles could be assimilated instead of refractivity profiles.

The higher model top allows in principle to assimilate higher-peaking AIRS channels. Currently, the highest peaking channel is # 156 at about 150 hPa. A group of 30 additional AIRS channels is being tested on top of the current 87, the highest one being # 72 peaking at ~30 hPa. Preliminary results indicate a modest positive impact on top of all other data types. One issue is that relatively large temperature analysis increments (> 5 K) can result from weak Jacobian values near 1 hPa where the temperature background errors are largest (Fig. 1). This issue requires further study from longer cycles.

Bias correction issue

It is worth mentioning that it was judged preferable to keep the bias correction parameters fixed for AMSU-A 11-14 (after a 2-week spin-up) because the global bias for these radiances, defined as the mean value of observed radiance (O) minus the 6-h GEM forecast radiance (P), was not stable. Fig. 6 illustrates this. Over a 3-month period, the global bias increases steadily. Assimilation of GPS-RO data did not change significantly that situation. However, keeping the bias parameters fixed solves the potential problem: the global bias remains constant. Additional independent data would help to anchor the analysis within realistic climatological bounds in the stratosphere.

Conclusion

GEM-Strato is planned to become operational in early 2009. The methodology to derive background error statistics for data assimilation was substantially revised, resulting in smoother and more localized analysis increments. Northern Hemisphere winter cycles showed a major improvement against the operational model. The higher model lid allows extending the assimilation of radiances and GPS-RO in the stratosphere. The impact of GPS-RO is clearly positive despite the limited number of assimilated profiles per analysis. Based on pre-operational results presented here, a significant improvement in forecast performance scores is expected with the implementation of GEM-Strato.

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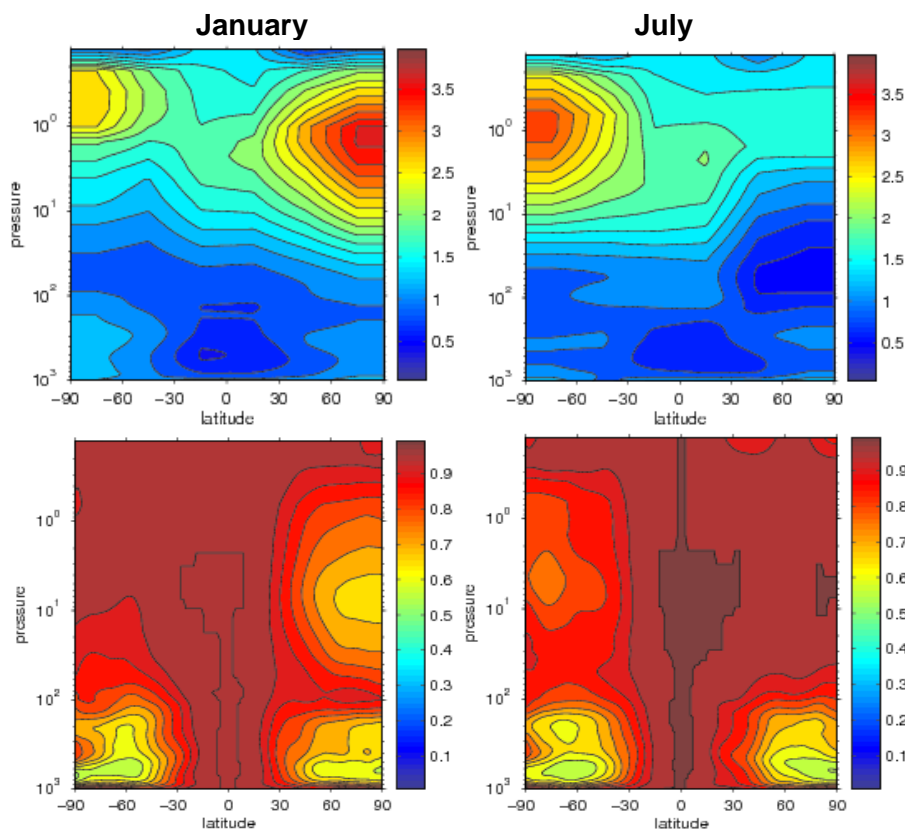
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Fig.1 Backgound standard deviation of total temperature errors stddev T (top, K) and ratio stddev T_{unbal} (stddev T)$^{-1}$ (bottom) for January (left) and July (right).
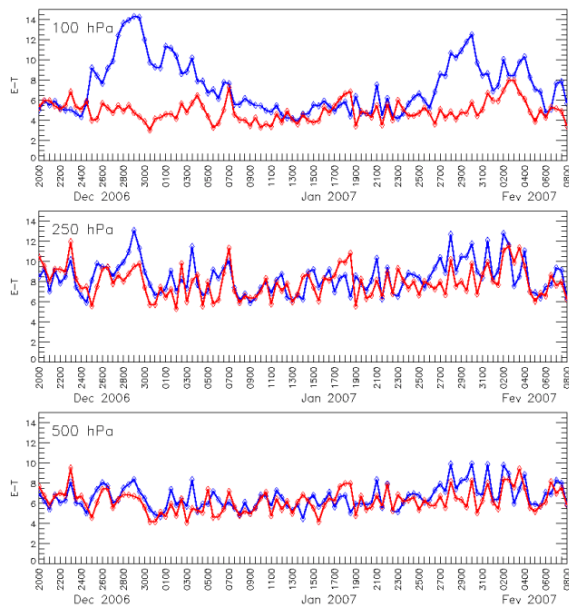
Fig. 2. Time series of stddev of radiosonde minus predicted geopotential height (dm) from NH 120-h forecasts at three pressure levels based on 4D-var cycles covering indicated period. Control (blue) is operational model with top at 10 hPa. Experiment (red) is baseline GEM-Strato.
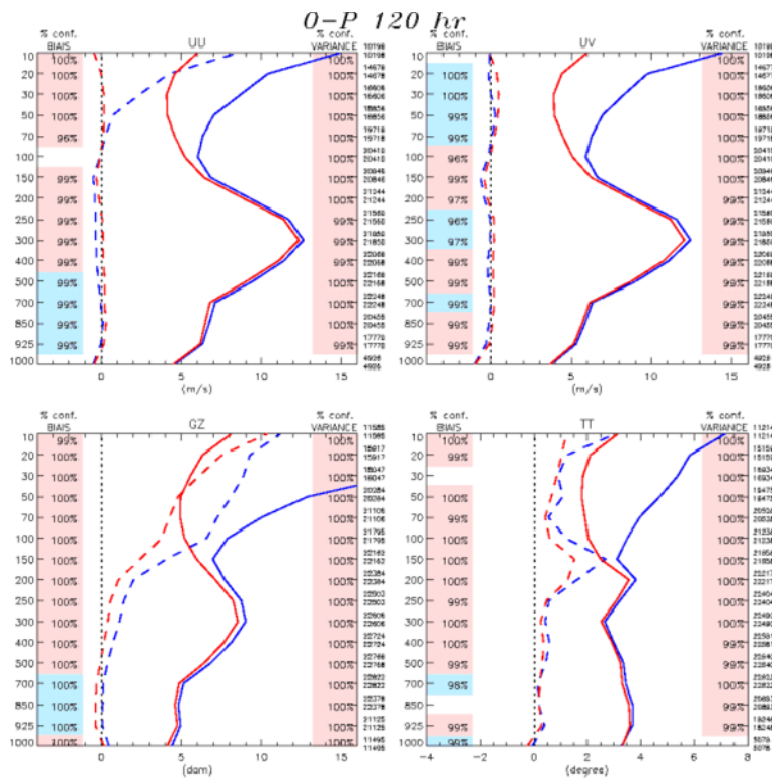

Fig. 3. Validation statistics based on 101 NH 120-h forecasts against radiosondes for the same cycles as Fig. 2. Bias (dashed) and stddev (full) for wind components UU and UV, geopotential GZ and temperature TT). Statistical significance (over 95%) of the differences between control and experiment is indicated (pink for experiment better, cyan for control better).
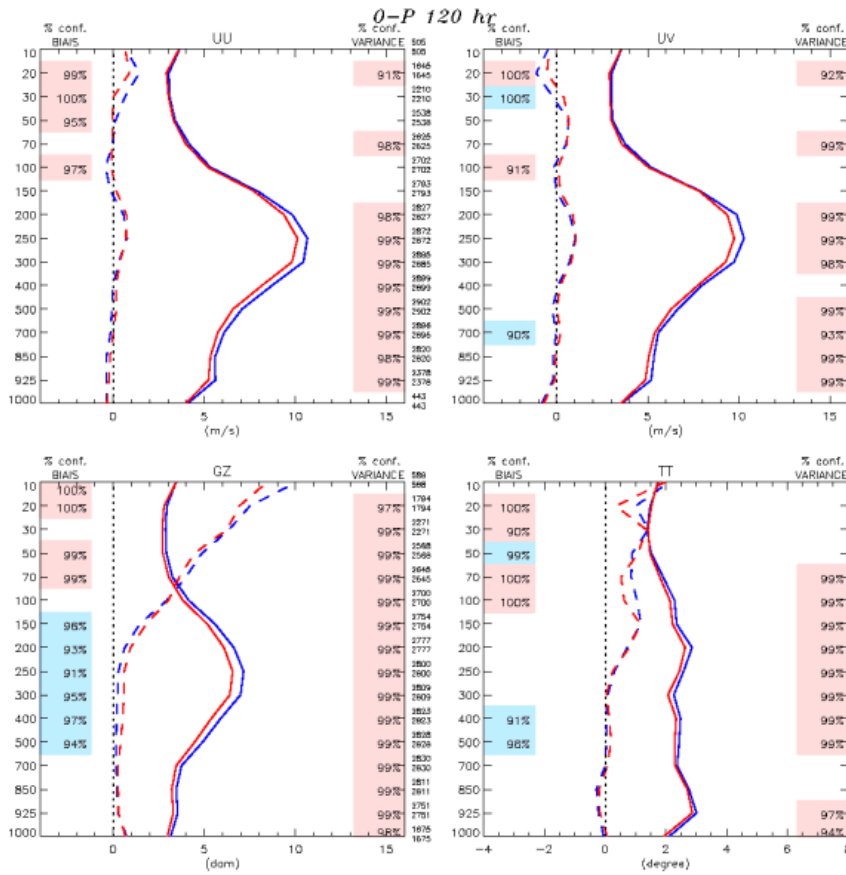
Fig. 4 Validation statistics as in Fig.3 from 3D-var cycles for 144 SH 120-h forecasts between 20 Dec 2006 and March 1 2007. Control (blue) is baseline GEM-Strato. Experiment (red) is control + new data types (AIRS, SSM/I, Quickscat).
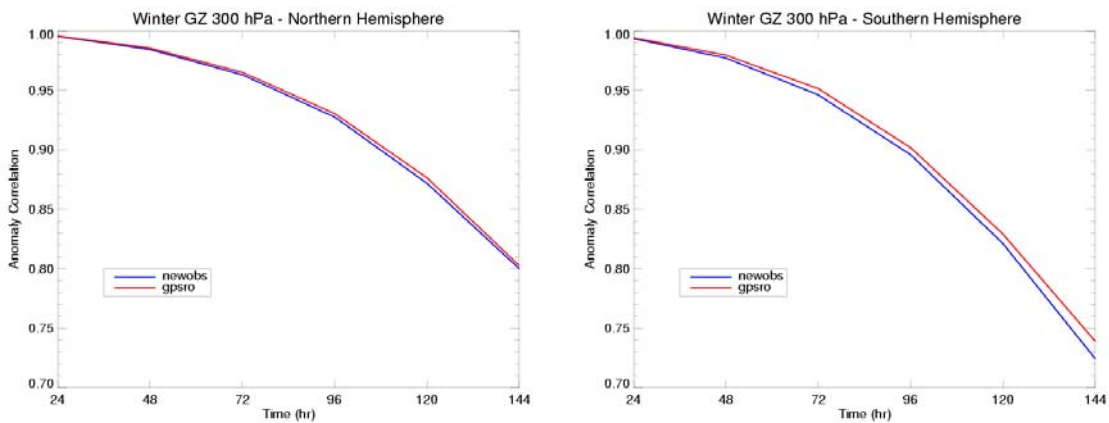

Fig. 5 300 hPa geopotential anomaly correlation for in NH (left) and SH (right) for period 20 Dec 2006 to March 1 2007. Control (blue) is baseline GEM-Strato + new obs. Experiment (red) is control + GPS-RO.
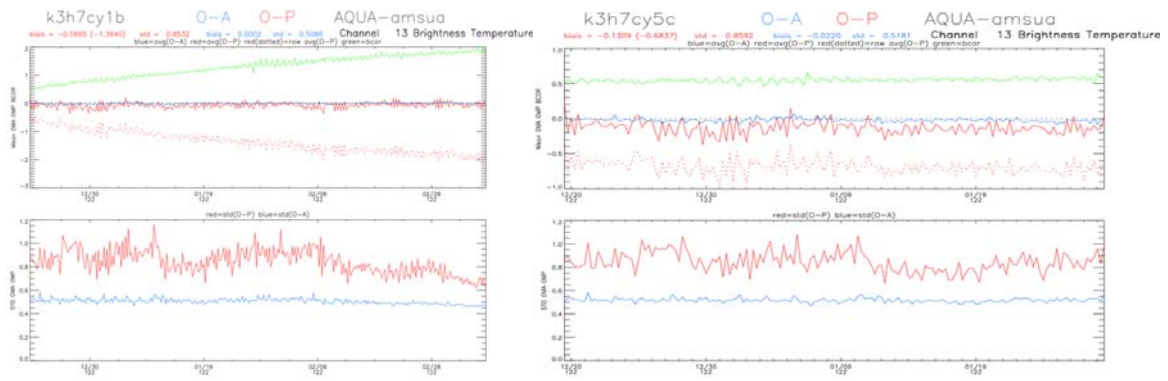
Fig. 6 Monitoring for Aqua AMSU-A channel 13; bias (top) and stddev (bottom). Statistics for (O-A) in blue and (O-P) in red, where O is the radiance observation, P is the GEM 6-h forecast radiance, and A is the analysis value. Dotted red in top panels is raw mean (O-P) (bias before correction) and green line shows the correction. Left panels show results using dynamical bias correction. Right panels show results with bias correction parameters fixed.