Recent Developments in Assimilation of Satellite Data in the MSC 4D-Var Analysis and Forecast System

S. Macpherson, L. Garand, J. Aparicio, M.Buehner, G. Deblonde, M. Charron, M. Roch, C. Charette, A. Beaulne

Data Assimilation and Satellite Meteorology Section,
Meteorological Research Division, Environment Canada

Stephen.Macpherson@ec.gc.ca

Abstract

In May 2008, several important changes with respect to satellite data assimilation were made to the Meteorological Service of Canada (MSC) operational global 4D-Var Data Assimilation and Forecast System (DAFS). At the same time, a new version of the MSC DAFS has been developed which uses a new version of the MSC Global Environmental Multiscale (GEM) model called GEM-Strato. The GEM-Strato model incorporates several significant changes to the current version of the model, including a lid raised from 10 hPa (~30 km) to 0.1 hPa (~65 km). The new system, scheduled to replace the current system in 2009, allows for assimilation of additional radiance data from higher-peaking microwave and infrared instrument channels as well as GPS radio-occultation data up to 40 km (~3 hPa).

This paper describes the recent changes in satellite data assimilation in the operational DAFS, and presents results of satellite data impact experiments with the new GEM-Strato system. In addition, the performance of the operational DAFS and the new GEM-Strato system are compared. Finally, future plans for satellite data assimilation are presented, which include assimilation of data from the EUMETSAT satellites METOP (AMSU-A, MHS, IASI, GRAS, ASCAT) and METEOSAT.

INTRODUCTION

Prior to May 2008, the only satellite radiance data assimilated in the MSC 4D-Var Data Assimilation and Forecast System (DAFS) were from NOAA/AQUA AMSU-A (channels 3-10), NOAA AMSU-B/MHS (channels 2-5) and GOES (water vapour channel) instruments. In addition, AMSU/MHS data from extreme viewing angles or field-of-view (FOV) were not assimilated.

The following changes were made to the MSC DAFS in May 2008:

- removal of AMSU-A channel 3 data
- addition of AMSU/MHS data from extreme FOV (~25% more data)
- addition of clear-sky SSM/I radiances over water from DMSP satellites F13 and F14
- addition of AQUA AIRS data (87 channels, cloud-free radiances)
- addition of QuickScat ocean winds

By the end of 2008, GPS radio-occultation (GPS-RO) refractivity data up to 30 km will be added to the operational system.

Along with these changes, a new dynamic bias correction system was introduced to replace the old static system. In the new system, bias corrections for satellite radiances are updated every analysis time (i.e., every 6 hours) using the average of observed minus first-guess radiance differences accumulated over a 15-day sliding window. FOV-dependent biases and two airmass (thickness) predictors are applied in the bias correction of AMSU/MHS and SSM/I data, while correction of GOES and AIRS data is done with the observed brightness temperature as a predictor.

The operational MSC 4D-Var Meso-global DAFS uses the 58-level GEM forecast model with a lid at 10 hPa. A new version of the DAFS, based on an 80-level version of GEM with a higher lid at 0.1 hPa, is scheduled to replace the current system in early 2009. As the entire stratosphere is now represented in the forecast model, it is referred to as GEM Meso-Strato or simply GEM-Strato. The two models are compared in Table 1 and Figure 1. Note that the new GEM-Strato model allows for assimilation of the four highest peaking AMSU-A channels (11-14).

	Operational GEM (Meso-global)	**New GEM-Strato (Meso-Strato)**
Grid (horizontal)	800 x 600 (33 km)	800 x 600 (33 km)
Vertical coordinate	Eta (normalized sigma)	Hybrid (eta transitioning to pressure in stratosphere)
Number of levels	58	80
Top	10 hPa	0.1 hPa
Sponge layer (wind, temperature)	4 highest levels (to 50 hPa)	6 highest levels (to 1 hPa)
Tropical sponge layer	Same as above	8 levels to 3 hPa
Radiation	VIS :Fouquart and Bonnel (1980) IR : Garand (1983)	Li and Barker (2005) Correlated-k Distribution
Non-orographic gravity wave drag	No	Hines (1997)
Methane oxidation	No	Yes
Ozone	Climatology (Kita and Sumi (1986))	Climatology (Fortuin and Kelder (1998)) Haloe data above 0.3hPa Mix at 0.3 hPa
AMSU-A Data	Channels 4-10	Channels 4-14

***Table 1*: Comparison of operational GEM and new strato version of GEM.**

Tests with the new GEM-Strato system involved data impact experiments with the data added recently to the operational system (SSM/I, AIRS and QuickScat) as well as data from 35 additional higher-peaking AIRS channels and GPS-RO refractivity profiles up to 40 km. The results of these data impact experiments are presented in this paper. A comparison of forecast verifications for the current operational system (10 hPa top) with the new GEM-Strato system (0.1 hPa top) is also presented. The radiative transfer model (RTM) in the MSC DAFS is RTTOV version 8.7. This RTM is also used in all the experiments described in this paper.

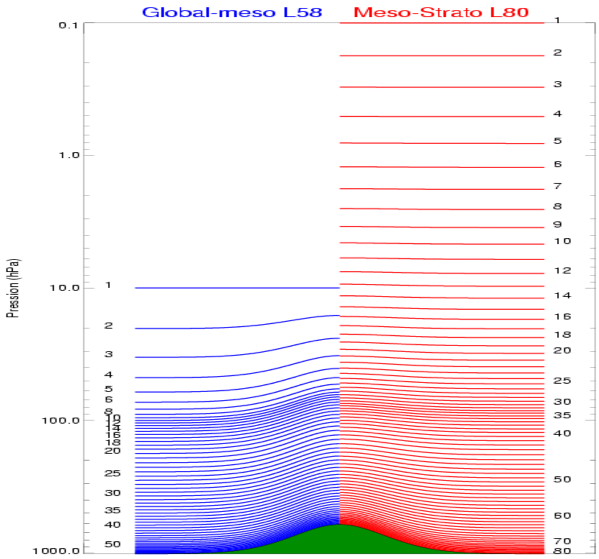

***Figure 1*: Operational Meso-global GEM (58 level, blue) and new Meso-Strato GEM (80 level, red) model vertical levels.**

DATA IMPACT EXPERIMENTS WITH GEM-STRATO DAFS

Addition of new satellite data (SSM/I, AIRS and QuickScat)

Figure 2 shows the verification of 76 GEM-Strato day 5 (120 h) forecasts of wind (U,V), geopotential height (GZ), temperature (T) and dewpoint depression (T-Td) for the Southern Hemisphere (SH) summer against radiosonde observations for a baseline system (control) compared to an experiment where SSM/I, AIRS (87 channels) and QuickScat data are added. Satellite data assimilated in both control and experiment include AMSU-A channels 4-14, AMSU-B/MHS channels 2-5, and GOES water-vapour channel radiances. AMSU-A channel 3 data are assimilated in the control but not in the experiment. Forecasts are initialized with 4D-Var analyses at 00 and 12 UTC.

The old static satellite data bias correction system is applied in the control, while the new dynamic scheme is used in the experiment with the new data. The new dynamic scheme in GEM-Strato adds two new thickness predictors above 10 hPa for correction of AMSU-A and AMSU-B/MHS data. AMSU-A channels 11-14 are assimilated without bias correction in the control.

The new data have a clear positive impact on the standard deviation (Std) of the differences between forecast and observation for winds (U,V), GZ and T. This impact is most evident in the day 4 and 5 forecasts for the SH summer, but is still significant for other seasons and regions. Impact on biases is more neutral or mixed, with mainly positive impact observed for T, U and GZ above 150 hPa. Details on the AIRS implementation and its separate impact in assimilation cycles were presented by Garand et al. (2007).

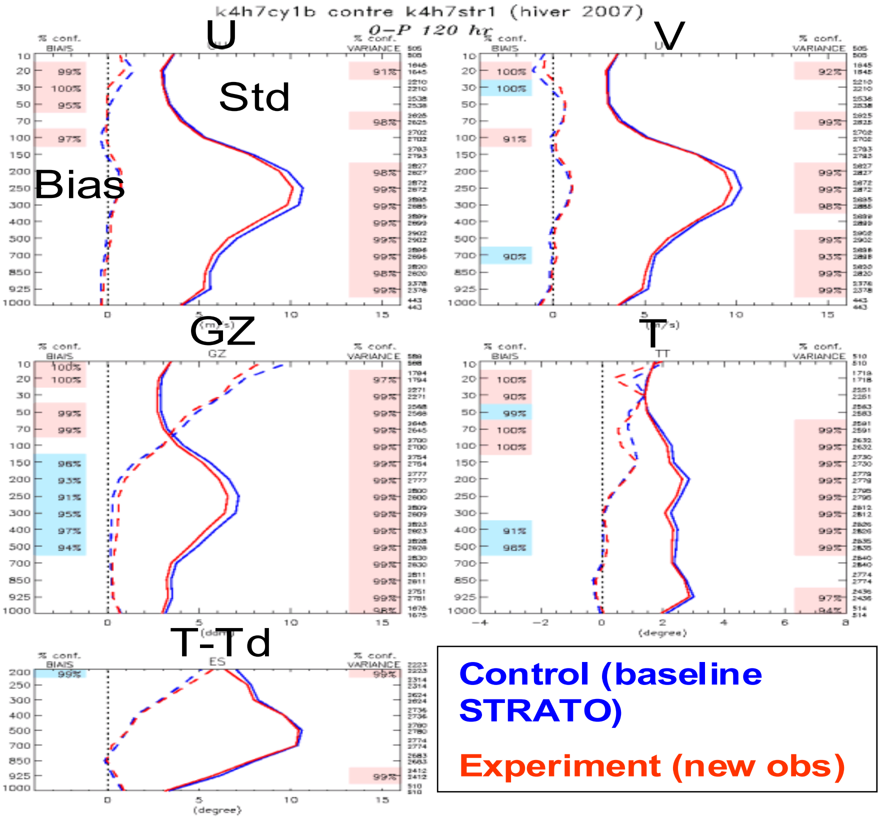

Figure 2**: Verification of day 5 forecasts in Southern Hemisphere (summer) against radiosonde observations for a baseline GEM-Strato (control) and experiment (new obs) with new satellite data and dynamic bias correction scheme. Differences with significance above 95% are shaded, where red (blue) shading signifies better Std or Bias results for the experiment (control). Verification is done at standard pressure levels from 1000 to 10 hPa.**

Addition of GPS-RO data

GPS-RO refractivity profiles, assimilated from 4 to 40 km (~3 hPa), are added to the new observation data assimilated in the GEM-Strato experiment above (SSM/I, AIRS, QuickScat). The GPS-RO satellites at the time of the tests included CHAMP (1 satellite, ~150 profiles/day), GRACE (1 satellite, ~150 profiles/day), and COSMIC (6 satellites, two antennae, ~1500 profiles/day).

The profiles are distributed quasi-randomly and uniformly over the globe, with each profile contributing ~40 data vertically (vertical thinning at 1 km). The data are assumed non-biased (based on accurate clocks, 10^{-14} seconds) and the observation error assigned is small: 0.7% (10-20 km) to 3-4% at 40 km, assigned dynamically.

Verification of day 1-6 forecasts against analyses over a period of 70 days in NH and SH winter seasons are presented in Figure 3 in terms of anomaly correlation (AC) scores for 300 hPa geopotential height (GZ) for experiments with and without GPS-RO data. The baseline (control) for the experiment is the "new observation" experiment of the previous section. In this case, however, the forecasts are based on 3D-Var FGAT analyses rather than 4D-Var. A positive impact of GPS-RO data is evident in the figure, with higher (better) AC values for the experiment with GPS-RO giving forecast skill gains at days 3-6 of ~2 hours in the Northern Hemisphere (NH) and ~3-4 hours in the Southern Hemisphere (SH).

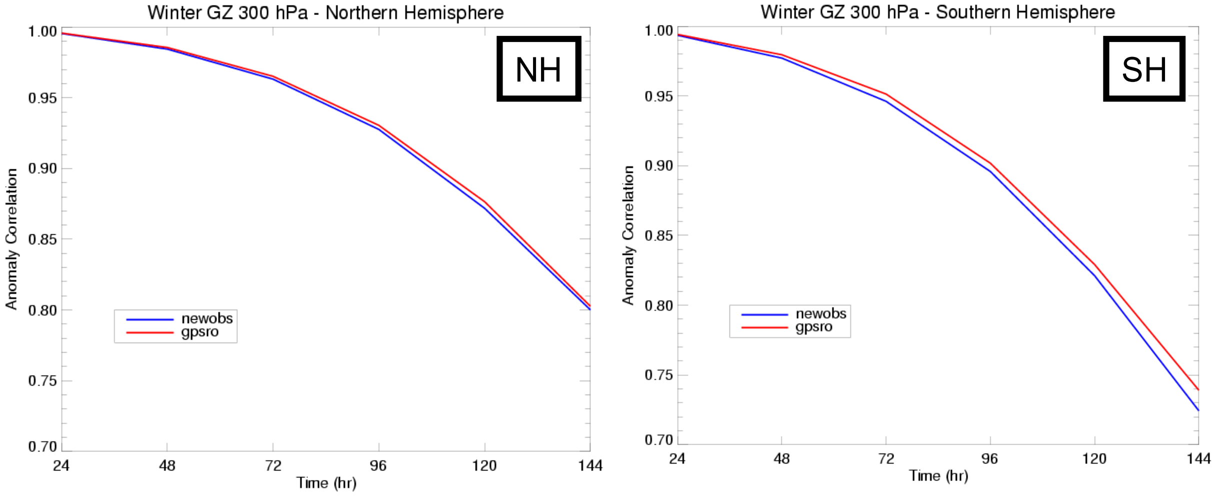

Figure 3**: Day 1-6 Anomaly Correlation scores for 300 hPa GZ forecasts for experiments with GPS-RO (red, labeled gpsro) and without GPS-RO (blue, labeled newobs).**

At the time of writing, a parallel 4D-Var Meso-global (operational 10 hPa top GEM model) DAFS run is underway with GPS-RO data assimilated up to 30 km. The GPS-RO data are expected to be assimilated operationally by the end of 2008. Additional details on the impact GPS-RO in combination with AIRS were presented by Garand et al., 2008.

Addition of 35 additional higher-peaking AIRS channels

AIRS channels whose weighting function profiles (Jacobians) have significant tails above the model top are not assimilated, as the RTM in the DAFS cannot in this case provide reasonable simulated radiances from model data. The raising of the GEM model top from 10 hPa to 0.1 hPa in the new GEM-Strato system allows additional AIRS channels to be assimilated. A set of 35 additional AIRS channels is selected and added to the 87 channels already assimilated in the operational system and in the GEM-Strato experiments described so far. The maximum height of the Jacobian peak values for the additional 35 channels is ~70 hPa compared to ~150 hPa for the original 87 AIRS channels. Verifications of forecasts from GEM-Strato 3D-Var FGAT DAFS experiments with and without the additional AIRS channels were compared to assess the impact of the additional radiance data.

While positive impacts, essentially reduced biases at upper levels, are noted in the analysis and 6h forecasts, the impact becomes mostly neutral by day 3 and eventually slightly negative for the North America region by day 5. Investigation is currently underway to better understand these results. It is planned to include these channels with the IASI implementation in 2009.

VERIFICATION OF GEM-STRATO DAFS FORECASTS COMPARED WITH OPERATIONAL MESO-GLOBAL SYSTEM

A series of 0-5 day forecasts were produced with a final configuration of the 80 level (0.1 hPa top) GEM-Strato model based system and an operational configuration system equivalent to the operational 58 level (10 hPa top) Meso-global model based system but with GPS-RO data (to 30 km) added. The main differences between the operational Meso-global GEM and new Meso-Strato GEM models are given in Table 1. The final configuration of the GEM-Strato DAFS includes:

- assimilation of GSP-RO data to 40 km;
- static bias correction for AMSU-A channels 11-14, to avoid significant drift in time of 6h forecast radiances away from the observations when dynamic correction is applied

- improved model background error statistics, with new variances based on microwave limb sounder (MLS) data, and localizations applied to vertical error correlations to avoid unrealistic analysis increments at levels far removed from observation innovations.

4D-Var analyses are used to initialize the forecasts in both systems.

A comparison of winter season day 5 forecast verifications against radiosondes in both hemispheres for the operational and new Strato systems is shown in Figure 4. A dramatic improvement in the verification results is noted for the new Meso-Strato system, primarily in winds (U,V), temperature (T) and geopotential height (GZ) above 500 hPa. This degree of improvement is observed over the entire 5 day forecast period. The improvement is slightly less dramatic for the NH and SH summer seasons (not shown).

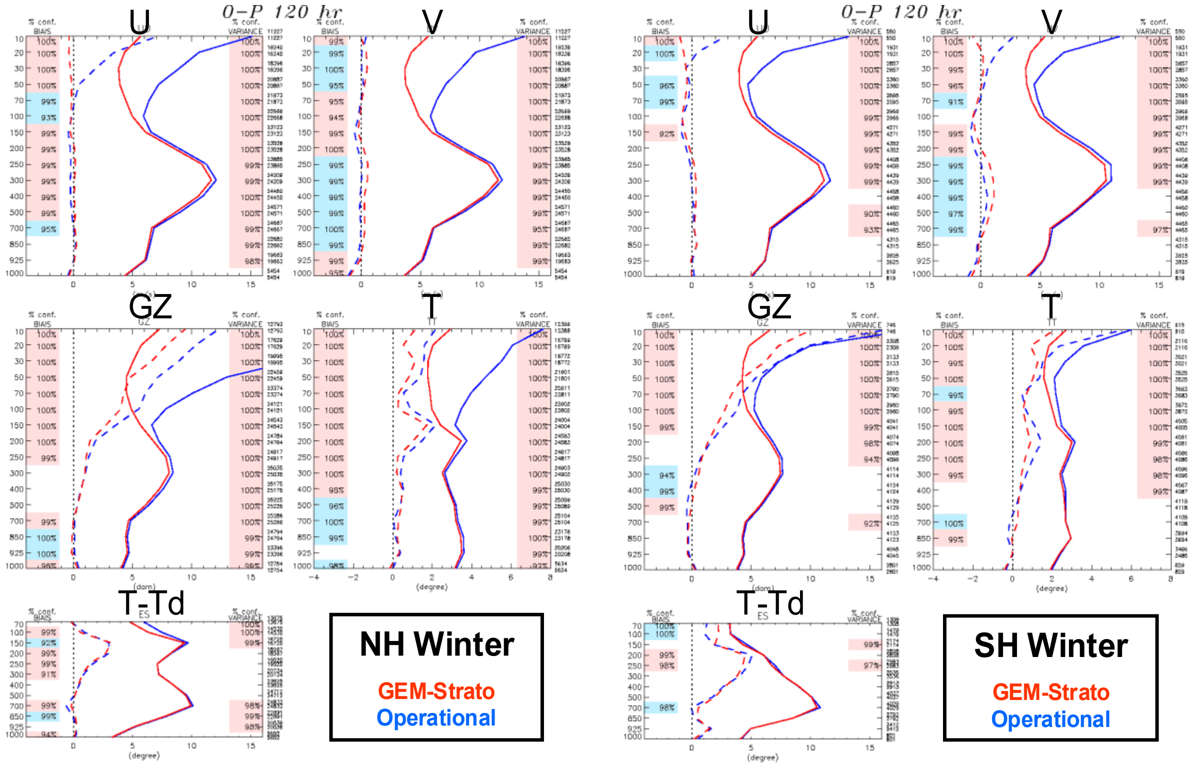

Figure 4: **As Fig. 2, but for NH and SH day 5 forecasts from the GEM-Strato (red) and GEM Meso-global (blue) DAFS**

RESEARCH AND FUTURE PLANS

Pre-assimilation monitoring and research activities are underway for the following satellite instruments:

Microwave radiances (polar orbiting satellites)

- METOP AMSU-A, MHS
- DMSP F16 SSMIS (7 SSM/I-like imager channels initially)

Infrared radiances (polar orbiting satellites)

- METOP IASI (~100 channels)

Infrared radiances (geostationary satellites, water vapour channels initially)

- METEOSAT
- MT-SAT

GPS-RO

- METOP GRAS

Scatterometer Ocean Winds

- METOP ASCAT

Research is also being carried out in assimilation of cloudy radiance data (see paper in this volume by S. Heillette entitled “Progress toward the assimilation of AIRS cloudy infrared radiances at CMC”).

CONCLUSIONS

Important changes to the MSC operational 4D-Var global data assimilation and forecast system (DAFS) were made in May 2008, involving a significant increase in the amount of satellite data assimilated. Radiance data from the AQUA AIRS and DMSP SSM/I instruments were added, and the amount of AMSU-A, AMSU-B, and MHS data was increased by ~25% due to inclusion of extreme viewing angle data. Quickscat ocean winds were also added. At the same time, a new dynamic satellite data bias correction scheme was implemented, replacing the old static system. GPS-RO refractivity profile data to 30 km height will be added soon. The positive impact from these changes is illustrated in experiments with a new Strato version of the DAFS, described below.

A new version of the MSC GEM forecast model called GEM-Strato has been under development for several years and is scheduled to replace the current GEM (Meso-global) model in the near future. The new model features a much higher top (0.1 hPa compared to 10 hPa), as well as a new radiation scheme, and will allow for stratospheric modeling, including chemistry, while improving forecasts for the troposphere. The dramatic positive impact on tropospheric forecasts has been shown. A new Strato version of the MSC DAFS based on the new GEM-Strato model allows assimilation of satellite radiance data from channels with sensitivity at higher levels in the atmosphere, such as AMSU-A channels 11-14 and selected AIRS channels. In addition, GPS-RO data up to 40 km or more can be assimilated, as well as radiances from some of the upper atmosphere sounding channels of the SSMIS instrument onboard the most recent DMSP satellites.

Assimilation of data from EUMETSAT satellites at MSC is currently limited to satellite atmospheric motion vectors (AMVs) from the METEOSAT satellites. This will change soon, as plans are underway for the assimilation of AMSU-A, MHS, IASI, GRAS, and ASCAT data from the METOP-A satellite as well as radiances from the geostationary METEOSAT satellites.

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