Developmental Testbed Center (DTC) Project for the Air Force Weather Agency (AFWA)

Final Report of GSI Testing and Evaluation (3.3.2)

February 2014

Index

1. Introduction

The Grid Point Statistical Interpolation (GSI) Data Assimilation System is a three dimensional (3D-Var) and hybrid data assimilation (DA) system currently used by various agencies as part of operational systems for both regional and global applications, including NCEP's Global Forecast System (GFS), North American Mesoscale Forecast System (NAM), and Hurricane WRF Forecast System (HWRF), NASA's Global Forecast System as well as NOAA's Rapid Refresh System (RAP). The GSI is also a community research model with public access. The DTC provides code management and user support and facilitates code transitions from research to operations. The DTC releases an updated GSI code annually.

Baseline experiments conducted by the DTC last year were designed to assist AFWA in determining an appropriate initial configuration for the impending GSI operational implementation. With the global coverage domains fully transitioned to GSI in summer 2013, baseline GSI testing for FY2013 is taking place during AFWA's phased implementation of GSI on all of their regional theaters. The baseline experiments were performed using a functionally-similar operational environment and complement the AFWA real-time pre-operational parallel GSI runs. The AFWA parallel runs bring in updates and changes periodically and focus on evaluating the overall performance of GSI. The DTC performs both real-time and retrospective GSI runs and focuses on testing incremental changes. The real-time runs are used to sync the test configurations with AFWA's, uncover issues in the existing configurations, and collect forecasts for background error (BE) covariance generation, while the retrospective runs are set up to isolate an incremental change. For more specific tests that are sensitive to having AFWA's exact system, DTC collected a full case including observations, background, lateral boundary conditions, etc.

This report is split into two separate sub-tasks. In order to investigate the GSI performance over regional domains, AFWA steered DTC to focus on two particularly important areas:

- Mitigation of Sea Level Pressure (SLP) analysis errors
- Impact study of domain-specific background error covariance (BE) using NCAR's GEN-BE v2.0

Section 2 covers the SLP efforts. The motivation for the study is covered in section a, followed by experimental design in section b. Description of the DTC testing and evaluation results is covered in section c. Section 3 discusses the domain-specific BE testing and evaluation. Experimental design is covered in section a, details of the usage and configuration of GEN-BE v2.0 is outlined in section b, followed by results from the retrospective testing environment in section c. A brief summary and concluding remarks are included in section 4. Finally, five appendices are included. Appendix A includes details on improving the GSI analysis for MU based on WRFDA, followed by the GSI, WRF-ARW and GEN-BE namelists in Appendix B-D, respectively. Appendix E describes code changes due to the pre-processing procedure difference between NCEP and AFWA.

2. Mitigation of SLP Analysis Errors

a. Motivation

AFWA discovered problems in the SLP field when implementing GSI on their SW Asia (T4) domain. Figure 2.a-1 is the time series of bias and root-mean-square error (RMSE) of SLP provided by AFWA in July, 2013. A large root-mean-square error (RMSE) was shown at the analysis time, as well as the whole forecast period, in the SLP field derived from GSI, relative to the RMSE for the current operational production system (WRFDA). Similar behavior was reported by AFWA for all other verification time periods. This issue was restated in October, 2013 due to a critical bug fix made to the AFWA pre-processing system. Figure 2.a-2 shows SLP fields for both the background (6 hr forecast from previous 06 Z cycle) and analysis using GSI for 20131114 at 12 Z. Areas of high SLP biases in the analysis are circled in yellow. The circled areas are not present in the background, and also do not occur in the WRFDA analysis (not shown). This indicates this is an issue that is specific to the calculation of SLP and/or associated components of the testing system including GSI. Similar behavior was visible in the verification for all other verification time periods provided by AFWA to DTC.

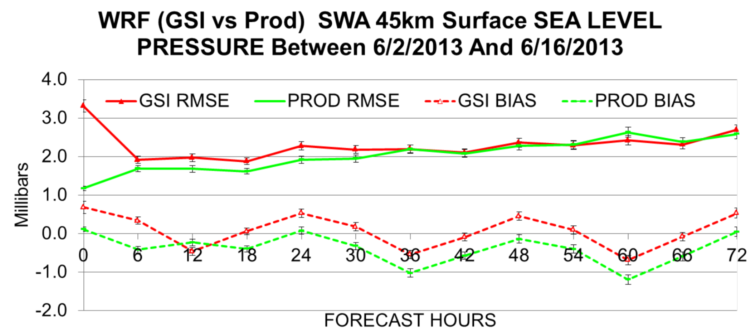


Figure 2.a-1: Surface Sea Level Pressure for SW Asia domain for two week forecast period in June, 2013. Red lines indicate GSI RMSE (solid) and Bias (dashed) and green lines indicate WRFDA RMSE (solid) and Bias (dashed).

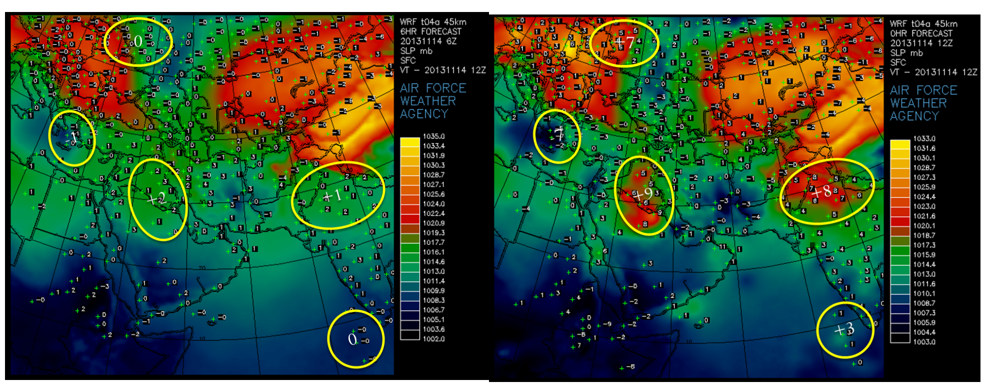


Figure 2.a-2: SLP fields for the background (left) and generated from the GSI experiment (right). SLP values are contoured, with fit to observations (Analysis-observation) values overlaid. Yellow circles indicate areas of high bias.

b. Experimental design

The DTC worked interactively with AFWA on this issue since the first time the issue was reported. Various suggestions, revisions and/or new additions to the GSI code or the system configurations, were provided to AFWA. Both sides conducted multiple trial experiments to solicit potential error sources and therefore, tackle the issues. All these suggestions and recommendations were made based on the following acknowledgement:

- SLP is not an analysis variable, nor a forecast variable, and, therefore, is not directly updated by GSI (or WRFDA) or by the forecast model, here ARW.

Instead, the derivation of SLP is dependent on which and how analysis/forecast variables are adopted in the computational formula and, consequently, results could differ (slightly) from model to model. The consistency of update/computation of the associated variables among the specific data assimilation, forecast and post-processing procedures might be important as well for the SLP derivation.

- In general, SLP is associated with pressure, temperature, and moisture near the surface. These variables are analysis variables and, therefore, updated at each analysis cycle by either GSI or WRFDA. Undesired assimilation of associated observations could contribute to anomalous SLP errors.
- Since GSI and WRFDA have their own quality control (QC) steps, either performed in the pre-processing procedure and/or inside the data assimilation process, types, locations and numbers of the data assimilated by the two systems are different. Therefore, verifying SLP against certain data sets (especially those considered as bad data in one of the data assimilation systems) might bring up false alarms.

Request for access to the verification procedure or the post-processing procedure was made to AFWA and is still an ongoing effort. Therefore, the reported effort from the DTC in this fiscal period focuses on the data assimilation side only, associated with surface observation analysis in the GSI.

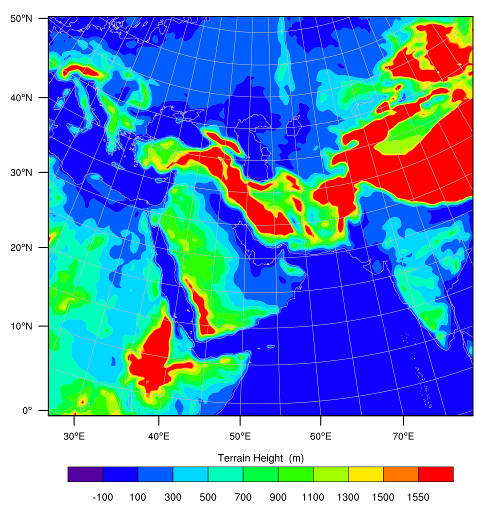


Figure 2.b-1: AFWA SW Asia domain used for SLP tests. Color bars show the height of terrain in the domain.

During the process, the DTC collected files from AFWA, including the background, observations and boundary conditions, to fully reproduce the GSI analysis and therefore perform tests to isolate and tackle error sources for the SLP issues. Then, recommendations from DTC were provided to AFWA for their further tests and verification. Since AFWA performed their tests in their real-time parallel setup, the test cases were varying with time. Time periods for these test cases are listed as follows:

- 20130602-20130616
- 20130620-20130626
- 20130730
- 20130819
- 20130826
- 20130829
- 20130905
- 20130912
- 20131030
- 20131114

The testing domain is the same as for the AFWA cases shown in Figure 2.b-1. The 162x152 model grid is configured at 45 km horizontal resolution and 57 full vertical sigma levels with a 10 hPa model top.

The DTC tests used the same configurations as the AFWA tests for comparison purposes. Since the DTC couldn't reproduce the verification results from AFWA by using UPP (software) and MET (verification), all tests conducted by the DTC were post-processed and verified by AFWA.

c. DTC testing and evaluation

i. Initial tests (July- Oct, 2013)

The initial stage tests were mostly based on the cases received before and around the time the pre-processing bug was fixed. Therefore the emphasis of the efforts was a bit different from that of the other stage efforts, which will be described in the following sections.

Upon close examination of the AFWA test case and a few trials conducted by the DTC and AFWA, it was noticed that

- GSI analysis did not fit to the surface observations well (7-10% compared to the background).
- Limited observation impacts on the GSI surface analysis
- Surface temperature fit showed a similar pattern to SLP fit to observations

Based on these findings, the DTC decided to focus on two areas, data availability and surface temperature data assimilation, which were identified as two potential error sources. Table 2.c.i-1 outlines many of the "trial and error" tests between AFWA and DTC, which lead to progress in resolving this issue.

Table 2.c.i-1: Iterations of initial-stage testing and investigation for T4 SLP issues

Requested Test or Recommended Change	Result of Test/Recommendation
DTC recommended tests: • Run GSI case with pre-operational configuration • Turn off all observations • Run GSI with 181 observation type turned off (surface land w/ station pressure.	The use of GSI caused big SLP RMSE (negative bias) at analysis time. Still large RMSE with 181 turned off

<table>
<tr><td>Recommended due to suspicion of terrain issues with surface land observations in this domain).</td><td></td></tr>
<tr><td>• AFWA delivered new code with updates to include all wind observations</td><td>Found T only fits observations 10% compared to bkgd</td></tr>
<tr><td>• DTC sent new anavinfo file to test (changed ‘as/tsfc_sdv’ column to follow NAM settings, rather than GFS settings)
DTC recommended tests:
• Test all surface obs off (but others on)
• Test with all surface obs on (180,181,183,187)
• No data assimilation</td><td>Tests showed GSI surface observations did not impact analysis results (very few observations & observations in wrong location leading to little/no impact on analysis)

DTC reran the testing case to investigate why GSI could not fit to surface observations</td></tr>
<tr><td>• Full case for testing purposes delivered to DTC</td><td>Found the fit to temperature observations extremely small (O-B RMSE = 2.10, O-A RMSE = 2.05)
Possible reasons: GSI inflated observation error (by default) based on vertical location of the observation and the first model level. Complex terrain may contribute to issues as well.</td></tr>
<tr><td>DTC recommended test:
• Test using RAP fix for surface T (terrain adjustment for T, GSI currently only has terrain adjustment for pressure).</td><td>RAP fix for T did not help in the T4 domain.</td></tr>
<tr><td>DTC recommended test:
• Test using DTC modified setup.f90 to loosen strict observation error inflation for surface observations</td><td>DTC tests showed the updated code improved the analysis fit to surface T observations by increasing the fitting percentage from 7.1% to 19.5%</td></tr>
<tr><td>DTC recommended test:
• Test using DTC modified code and new namelist, which removed RAP surface T fix, but added two RAP options to loosen restrictions of using surface obs under model surface.</td><td>AFWA test showed that high RMSE was still present.</td></tr>
<tr><td colspan="2">AFWA uncovered errors in prepbufr QC process and had a critical bug fix to the pre-processing system</td></tr>
<tr><td>• AFWA sent a new test case with new preprocessed data</td><td>Results showed GSI assimilated many more observations:

<table>
<tr><th></th><th>Data Type</th><th>Before</th><th>After</th></tr>
<tr><td rowspan="3">q_s</td><td>187</td><td>128</td><td>839</td></tr>
<tr><td>287</td><td>118</td><td>748</td></tr>
<tr><td>281</td><td>182</td><td>2035</td></tr>
<tr><td rowspan="2">T_s</td><td>181</td><td>191</td><td>2212</td></tr>
<tr><td>187</td><td>126</td><td>874</td></tr>
</table>
</td></tr>
</table>

	Noticed all surface T observations were monitored and moisture/wind were assimilated in the current AFWA setup, due to degradation of surface T data assimilation
• DTC sent code to AFWA for improved usage of temperature under model surface	Results showed T discrepancy was comparable with WRFDA results. However, SLP problem was still present.
• Recommendation to turn on 180 T observations because they contains important surface pressure information	180 turned on in AFWA tests

ii. Investigation of surface moisture data assimilation

Since the pre-processing bug fix enables many more surface observations to be fed to GSI, potential error sources in GSI were re-examined by the DTC with new testing cases, provided by AFWA. Figure 2.c.ii-1 shows the moisture (1st level water vapor mixing ratio) analysis increments (analysis-background) of GSI compared to those of WRFDA. The GSI increments have much larger magnitude than those for WRFDA, having a maximum analysis increment of 9 g/kg with many points greater than 3 g/kg. Most increments are positive and also appear to match spatially to many of the areas circled in Figure 2.c.ii-1. Finally, relative to WRFDA, the GSI analysis increments are smooth and cover a large area, indicating a larger horizontal scale from GSI background error statistics.

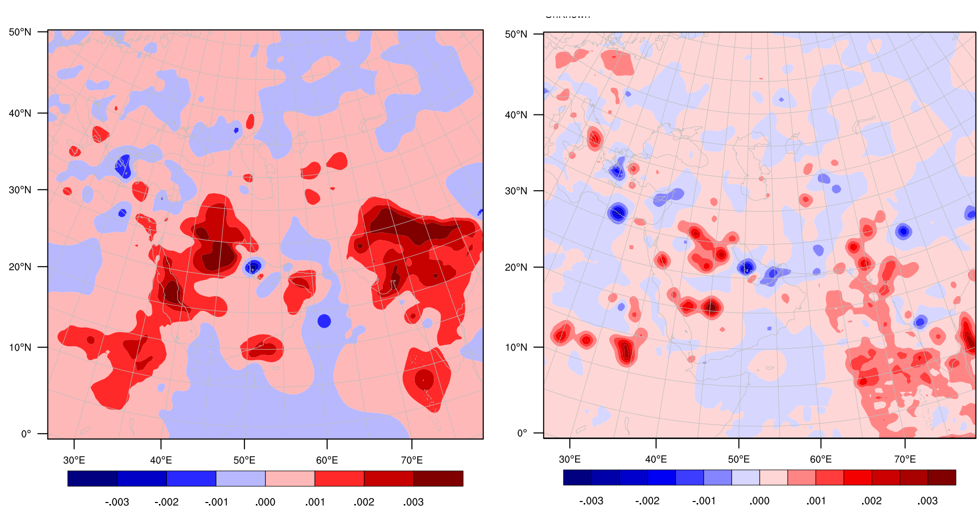


Figure 2.c.ii-1: Analysis increments for 1st level water vapor mixing ratio (kg/kg) for GSI (left) and WRFDA (right).

The observation of large positive increments matching the location of the high SLP biases led to the DTC recommendation for AFWA to run two more tests

- GSI with conventional data only
- GSI with surface moisture data turned off (with 180 T turned on by default)

The results, shown in Figure 2.c.ii-2, indicate that surface moisture observations were negatively impacting the SLP field in the GSI analysis.

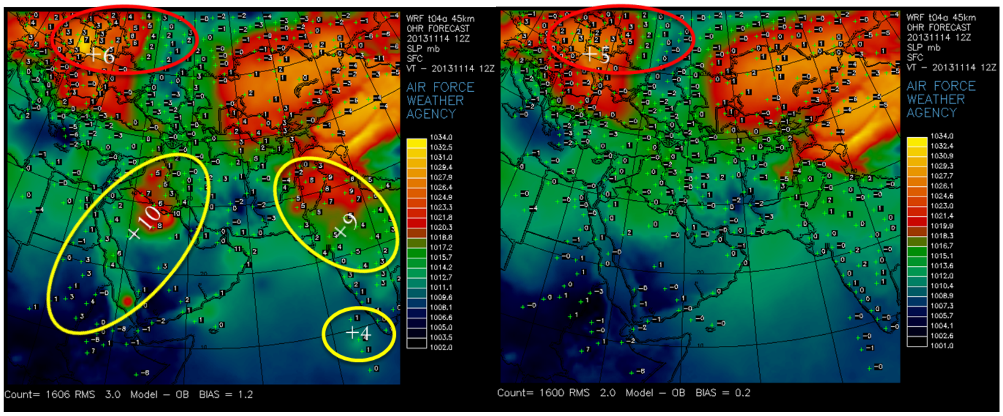


Figure 2.c.ii-2: SLP fields for the GSI analysis with only conventional observations turned on (left) and the GSI analysis with moisture observations turned off (right). SLP values are contoured, with bias values overlaid.

The DTC then compared the GDAS PrepBUFR file with the one from AFWA. All surface observations in the GDAS PrepBUFR were marked with a QC flag "9", which is a rejection flag for GSI. After forcing the flag value to "2" (in order for GSI to assimilate these observations), a similar result to Figure 2.c.ii-2 for the moisture analysis increments was produced, indicating the surface moisture issue might come from the QC procedure inside GSI. In fact, it was discovered that all surface moisture observations passed the GSI gross QC check (no surface moisture observations were rejected by GSI).

Table 2.c.ii-1 shows diagnostics associated with the surface moisture QC procedure from GSI for the 2013111412 case:

Table 2.c.ii-1: QC diagnostics from the GSI test case for 2013111412

ddiff	qsges	ratio	residual	obserrlm	qcgross	ratio_errors
7.388	16.473	1.861	44.846	24.096	7.000	0.245
6.327	16.864	5.077	37.517	7.390	7.000	0.800
5.865	17.038	1.710	34.420	20.134	7.000	0.294

The variables shown in Table 2.c.ii-1 are those used for the surface moisture QC:

- residual=ddiff/qsges *100, ddiff is innovation (O-B), and qsges is saturated background
- obserrlm is inflated obs error (mostly inflated to 2 or 5 times larger)
- qcgoss is QC threshold (qcgross=7)
- ratio=residual/obserrlm

For this particular test case, the values shown in the table illustrate the following issues

1. The moisture innovation value (ddiff), defined as a relative value to saturated background, was relatively small compared with qsges. Consequently, residual was relatively small as well (mostly ~30%)
2. The inflate error (obserrlm) was used in the gross check, 2 to 5 times larger than the original value

3. The threshold (qcgross) was too big

In order to ensure the gross check for moisture observations works, the DTC changed the GSI code to use the original observation error instead of the inflated error for obserrlm. Also, after sensitivity testing, the gross check threshold was reduced from 7 to 2 for the surface observation types 180, 181, 183, 187. Results showed the maximum Q analysis increment was reduced from 9g/kg to 4.5g/kg. However, rejected data were added back during the 2nd outer loop (number of assimilated surface q increased with increasing iteration numbers) as shown in the following diagnostics generated by GSI (last column indicates number of background and assimilated observations in loop 1 and 2):

```
o-g 01 q 181 0000 count 815 638 210 100 61 37 6 4 0 0 0 1871
o-g 02 q 181 0000 count 863 665 217 102 60 36 5 4 0 0 0 1952
o-g 03 q 181 0000 count 866 671 217 102 60 36 5 4 0 0 0 1961
```

Many observations with large initial innovations came back into the analysis after the 1st outer loop. The reasons were likely to be:

1. Most of the moisture innovations were positive (forecast was too dry), forcing the analysis results positive to reduce the innovation in the 2nd outer loop
2. The horizontal impact scale in BE for surface observations might be too large
3. Some surface observations were under the model surface. The model 1st level moisture is used in GSI as the background to calculate O-B. GSI has no vertical elevation adjustment for moisture.

We cannot reduce the surface observation impact radius in the BE file at this time, so we made changes to force 1st loop observation rejection to be retained for the 2nd loop. This resulted in the following diagnostics:

```
o-g 01 q 181 0000 count 815 638 210 100 61 37 6 4 0 0 0 1871
o-g 02 q 181 0000 count 811 636 208 100 58 35 5 4 0 0 0 1857
o-g 03 q 181 0000 count 811 634 208 100 58 35 5 4 0 0 0 1855
```

The DTC applied the new QC procedure and fix to the observation rejection and reran the previous test case. Figure 2.c.ii-3 shows the comparison of the results before and after the code changes. It shows magnitude and spatial extent of positive moisture increments were reduced significantly.

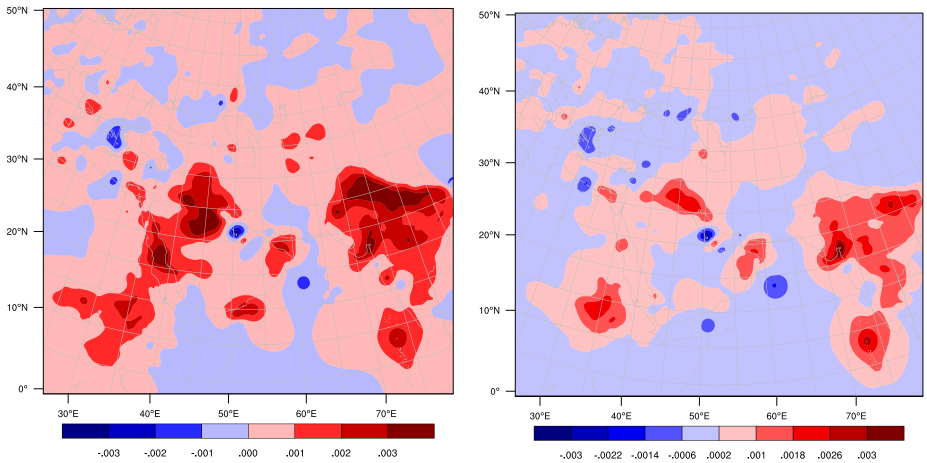


Figure 2.c.ii-3: Analysis – Background increments for 1st level water vapor mixing ratio (kg/kg) for GSI before gross check threshold reduction (left) and GSI after gross check threshold reduction (right).

Table 2.c.ii-2 shows the number of surface moisture observations assimilated and rejected after the code changes were made to the QC procedure. After data assimilation, about 30% of surface observations were rejected.

Table 2.c.ii-2: Moisture Observations Assimilated vs. Rejected

Q Data type	Number kept	Number Rejected
180	25	4
181	1682	516
183	81	51
187	645	228

Figure 2.c.ii-4 shows the updated SLP field for the test case with all of the changes described above. It shows much better RMSE and Bias compared to Figure 2.c.ii-1, but still worse than values from the operational system (WRFDA). The DTC recommendation for moisture is to investigate the impact scale BE at the low levels, where it should be reduced to further improve the moisture analysis in terms of the derived SLP field.

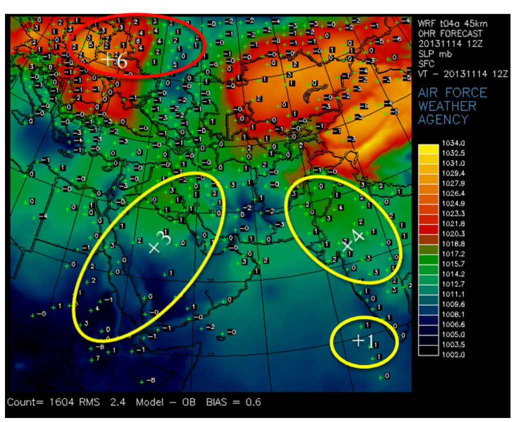


Figure 2.c.ii-4: SLP fields for the GSI analysis with updated moisture observations assimilated. SLP values are contoured, with bias values overlaid.

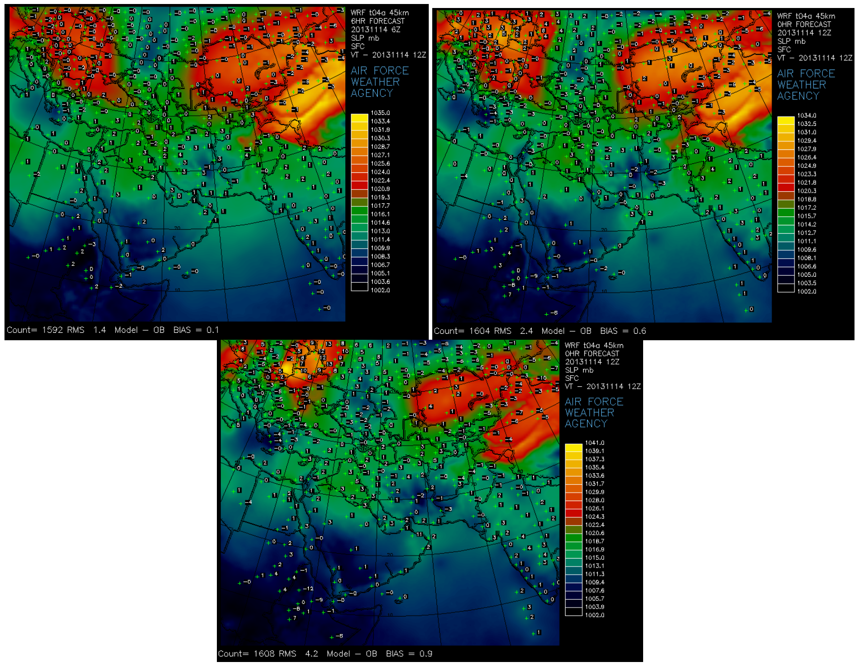


Figure 2.c.iii-1: SLP fields for the background (upper left), the SLP analysis with only pressure observations turned on (upper right), and the SLP analysis with all temperature surface types turned on (lower). SLP values are contoured, with bias values overlaid.

iii. Investigation of other surface data assimilation

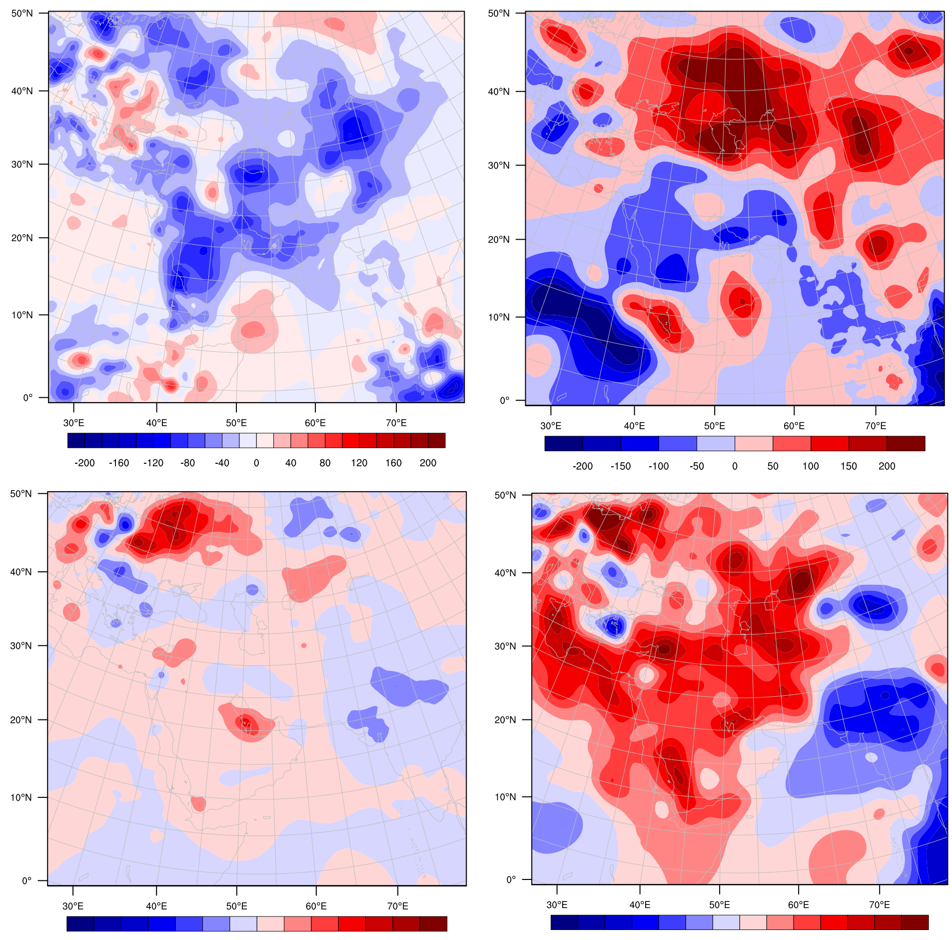
In addition to surface moisture, additional tests were performed to examine impacts of other surface observations on the SLP field. Figure 2.c.iii-1 shows the GSI background, the SLP fields derived from the GSI experiments with surface pressure observations "only" (180 T was turned on following the control experiment) and with all surface temperature observations turned on. Please note since AFWA currently has type 180 surface T turned on by default in their real time parallel runs (due to reported performance degradation when other surface temperature observations are turned on), all the experiments here and as follows had 180 surface T assimilated as well, in addition to other testing data. Table 2.c.iii-1 shows the verification results of the SLP fields from these experiments. Unfortunately, assimilation of any surface observations seems to negatively influence the derived SLP field at this point.

Table 2.c.iii-1 Bias and RMSE of SLP background and analysis derived from the GSI experiments with surface T and p assimilated

	Background	**With surface T**	**With surface P**
Bias	0.1	0.9	0.2
RMSE	1.4	4.2	2.0

iv. GSI-ARW pressure update and beyond

Additional diagnostics were performed at the DTC to further examine the relationship among the surface analysis updates. Figure 2.c.iv-1 shows analysis increments of the 1st level of MU, T and surface pressure for GSI and WRFDA. MU is dry air mass in a column. It is shown GSI updates to MU and T are relatively smaller compared with WRFDA and there is no update from GSI on surface pressure. As a prognostic variable, MV is a very important variable for the WRF model forecast, while surface pressure is only a diagnostic variable (which might be the reason for GSI not updating it). However, it really depends on how the post-processing procedure computes the SLP values. Therefore, the differences shown here between GSI and WRFDA might show potential error sources of the SLP issues. The DTC is investigating the impact of computation of MU on the SLP analysis. Appendix A outlines the code differences between WRFDA and GSI on calculation of MU and the code changes that are being implemented into GSI to follow the WRF formula. AFWA tests are pending further investigation.



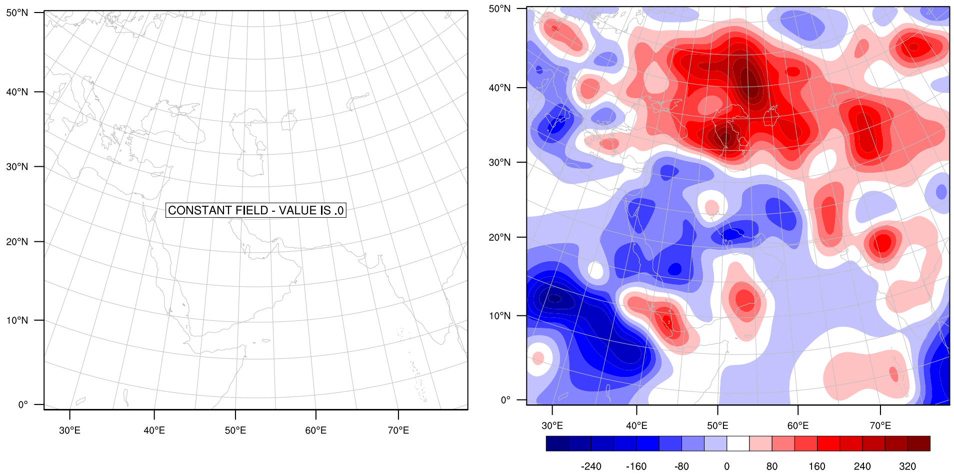


Figure 2.c.iv-1: Analysis increments for 1st level dry air mass in column (Pa; upper), 1st level temperature (K; middle), and surface pressure (Pa; lower) for GSI (left) and WRFDA (right).

3. Impacts of Domain-Specific Background Error (BE)

a. Experimental design

i. Grid and Domain

Due to specific interest in the regional domains, the Caribbean (also known as T8) domain was chosen for the FY2013 DTC testing. The domain is pictured in Figure 3.a.i-1. The 212x122 grid is configured with a 15 km horizontal resolution and 57 full vertical sigma levels with a 10 hPa model top.

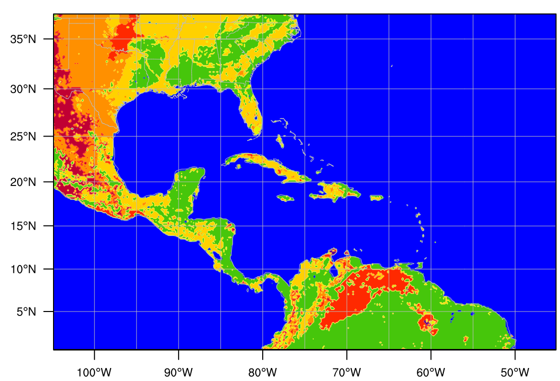


Figure 3.a.i-1: AFWA Caribbean domain used for DTC GSI baselines tests for domain-specific background error (BE) generation testing.

ii. GSI-ARW system setup and data

The setup of the DTC end-to-end data assimilation and forecast system followed the cycling scheme provided by AFWA. The only differences between the current AFWA system and the DTC system were input fields and changes to the BE for testing purposes.

The DTC used the NCEP GFS analyses and forecasts and real-time SST data as background and boundary conditions, while AFWA uses UKMET files and AGRMET and TAVGSFC SST data. The DTC used the NCEP GFS prepbufr observations, instead of the AFWA prepbufr files.

The DTC system, shown in Figure 3.a.ii-1, includes two cycles: a 06Z cold start cycle and a 12Z continuous cycle. The 06Z cold start cycle starts with collecting background files, GFS 0-56 hour forecasts initiated at 06Z (GRIB2 files, 0.5° horizontal resolution) and real-time SST data from NCEP. The WRF preprocessing system (WPS and *real*) is then run to decode and interpolate data into the testing domain and grids. *real* is run twice; first to generate a background file for GSI, wrf_input, valid at 06Z (GFS analysis) and boundary conditions valid from 06-12Z, and a second time to generate the boundary files covering 48 hour forecasts starting from 12Z. Next, GSI is run to generate an analysis using the background from the 06Z GFS analysis and the observations within a ±3 hour time window from the GFS PrepBUFR (for conventional observations) and BUFR files (for satellite observations). For satellite data assimilation, GSI cycles the radiance bias correction by reading the radiance bias correction coefficients from the previous GSI cycle. The bias correction coefficients are then updated for angular bias correction. The boundary conditions are then updated by *update_BC* using the GSI analyses and GFS forecasts. Finally, Advanced Research WRF (ARW) is run to generate 6 hour model forecasts. Unlike the 06Z cycle, the 12Z continuous cycle uses the 6 hour forecasts generated by the 06Z cycle as the background. Following the GSI run, the ARW is run to produce 48 hour forecasts for verification. The forecasts are processed by the Unified Post-Processing (UPP) system and verified by the Model Evaluation Tools (MET) against GFS PrepBUFR conventional data. Finally, AFWA GO-index statistics are generated based on MET statistics.

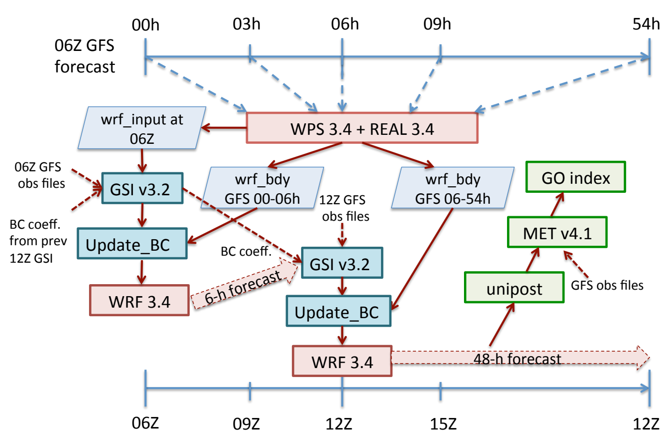


Figure 3.a.ii-1: Schematic of DTC real-time system following the AFWA pre-operational configuration.

The versions of model components of the system are listed as follows:

- GSI: v3.2
- update_BC: 2012 version
- WRF: v3.4
- UPP: v1.0

- MET: v4.1

Appendix B provides relevant portions of the GSI namelist used in the DTC system. Appendix C provides relevant portions of the WRF-ARW namelist used in the DTC system.

Table 3.a.ii-1 summarizes the data linked, read into, and used in the analysis for both the DTC and AFWA systems. When building the DTC GSI configuration, channels and prepBUFR observation types followed those of the AFWA system by matching convinfo and satinfo files.

Table 3.a.ii-1: Data linked, read in, and used in the GSI analysis for both the AFWA and DTC systems.

Data file linked	Data type read in	Used in analysis
PREPBUFR	Read in: ps, t, q, uv	All
AIRS	Read in data from AQUA	used
AMSU-A	From N18, AQUA, N19, METOP-A	All used
HIR3	No N17 data read in; N16 turned off	
HIR4	From N19, METOP-A	Both used
SBUV/2	sbuv2 from n16, n17, n18, n19	None of data used
MHS	n18, N19, METOP-A	
IASI	METOP-A	
GPSRO	Reads in: gps_ref	Used

b. GEN-BE v2.0 code testing and configuration

i. Testing of new GEN-BE code

Per guidance of AFWA, the DTC began testing the GEN-BE v2.0 code developed by NCAR's Mesoscale and Microscale Meteorology (MMM) division and delivered to the DTC in August, 2013. The package includes:

- Users' Guide (draft)
- GEN-BE v2.0 code
- Converter (transfer GEN-BE code to GSI required format)

Considerable testing and communication with code developers was required to run the code and obtain the proper configuration for AFWA applications. Table 3.b.i-1 outlines the DTC testing and evaluation process in order to get GEN-BE v2.0 running for AFWA applications using the NMC method.

Table 3.b.i-1: Testing and Evaluation process for GEN-BE v2.0

Test/code update	Note
Original code release tested on multiple compliers	Would not compile using intel or gfortran (fixed by developers), able to compile using pgi compilers
Linked missing libraries	Need to link grib libraries from WRF code, not included with source code
Small scripting changes made	Script changes needed to properly link display date for stage 0 perturbations
GSI converter code issues/code update (Sept, 2013)	Worked with developers to identify issues in converter code to convert netCDF output to binary file readable by GSI
Namelist option sensitivity tests	• Tested various namelist options to identify options that worked and produced most reasonable results (relative to NAM BE and code used for FY2012 BE tests). A working version of namelist is provided in the final report
Latitudinal variation issues/bin_bype=3 test (Sept-Oct, 2013)	• BE diagnostics of sensitivity tests revealed no latitudinal variation in horizontal lengthscale, standard deviation and streamfunction regression coefficients Developers recommended bin_type=3 (rather than 5) to gain latitude dependence. Test run failed due to memory deallocation error
Real definition work-around	Tested suggested work-around to fix memory deallocation error when using bin_type =3. This option did not work due to missing stage 2 output. Cannot use this option without bug fix.
Bug fix code testing	Developers provided bug fixed code, however bin_type =3 still had no latitudinal variation present. A bug in the code (da_gen_be.f90) was identified
2nd bug fix code testing	Test showed latitudinal variation in the netCDF file, but would not run using the GSI converter code
Converter code fix testing	DTC met with developers to discuss converter code issues and went through how GSI reads file to ensure proper reading of the BE by GSI
New code (v2.1) delivered with bug fix for real definition and updated converter code (Dec, 2014)	• Code included updates to fix memory deallocation error issues, as well as converter code reworked to handle the bin_type =3 option for GSI Tests with new code showed values that were not in the appropriate range for GSI
Update to v2.1 delivered (Dec, 2014)	• Tests showed code now readable by GSI, but only working for GSI moisture analysis option ‘qoption=1’. AFWA system uses ‘qoption=2’ Due to magnitude of changes, developers recommended proceeding with qoption=1 until updates to the code to use qoption=2 can be added to GEN-BE

ii. AFWA configuration

Through testing and evaluation, as well as discussions with developers, the DTC has established a GEN-BE v2.0 namelist to be used for AFWA applications. This namelist is provided in Appendix D.

iii. Remaining issues

The testing and evaluation process provided a suggested namelist and a working code base for domain-specific BE generation. However, there are remaining issues that need to be investigated or updated based on DTC feedback to GEN-BE v2.0 developers:

1. GEN-BE v2.1 code still does not work for GSI qoption=2. This update requires code fixes to update the GSI control variables for moisture. The issue was reported to GEN-BE developers. Figure 3.b.iii-1 shows the GO index time series over 1 month testing period for the NAM BE control run with qoption=1 vs. the NAM BE control run using qoption=2, demonstrating differences stemming from changing this moisture analysis variable option. The majority of GO index points fall below the 1.0 line, indicating the NAM BE using qoption=2 may provide better forecast skill relative to using the NAM BE using qoption=1.
2. Output of streamfunction regression coefficients might have issues. Figure 3.b.iii-2 shows diagnostics from GEN-BE v2.1 for streamfunction regression coefficient compared to code used for FY2012 testing. It appears the field may be read into GSI incorrectly. Issue was reported to developers.

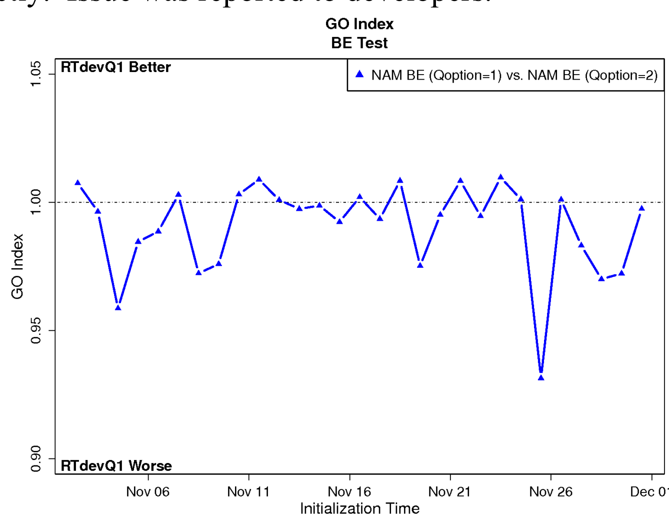


Figure 3.b.iii-1: Go Index scores for NAM BE using qoption=1 vs. the NAM BE using qoption=2 over a 1 month forecast period from Nov 1 –Nov 30, 2013.

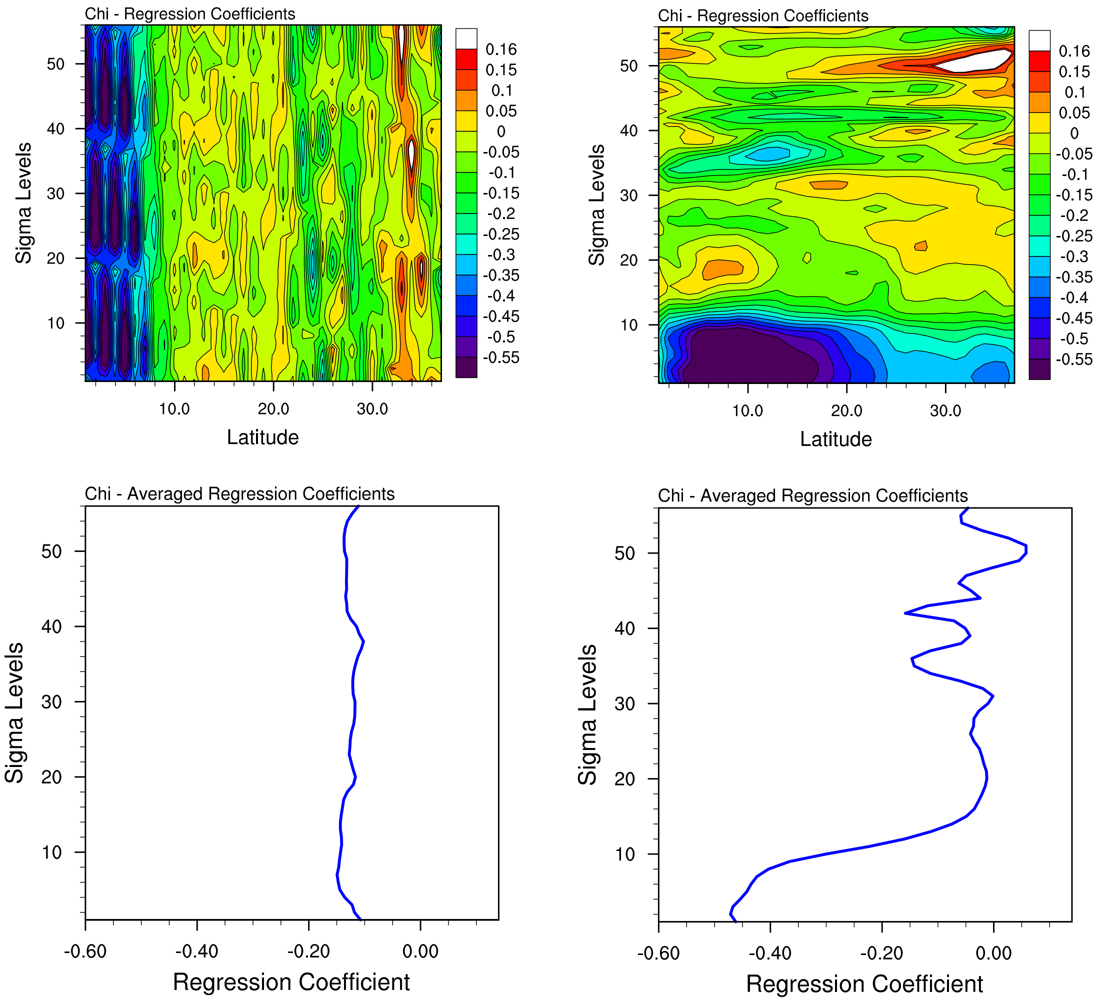


Figure 3.b.iii-2 : Streamfunction (Chi) Regression coefficient diagnostics from GEN-BE 2.0 (left) and previous GEN-BE code (right).

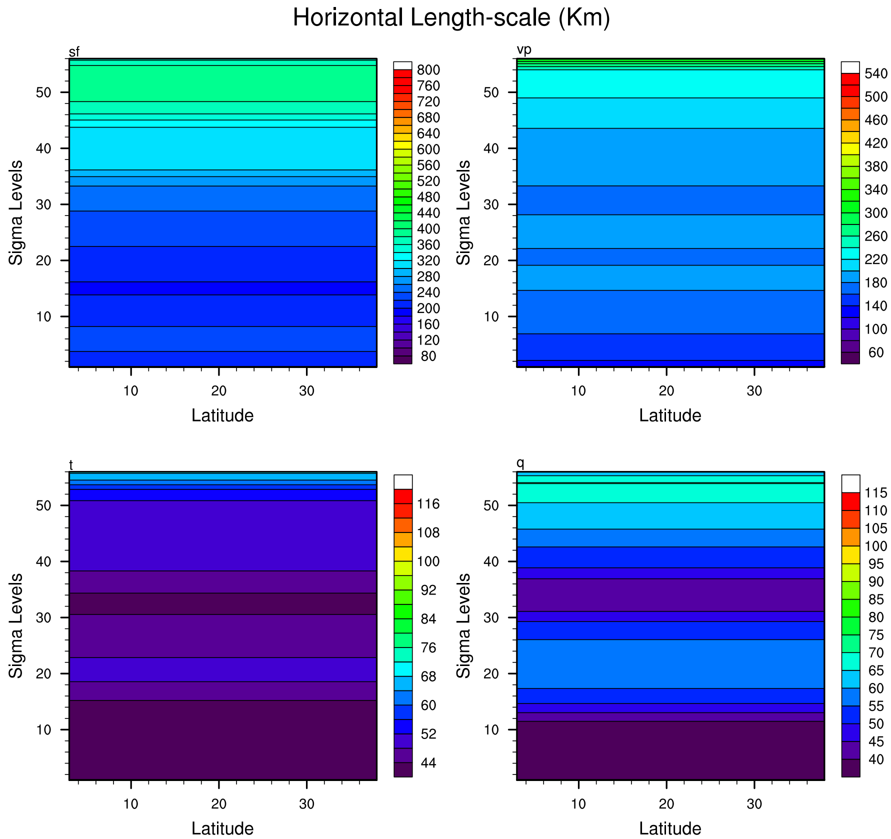
c. Experiments and Results

In order to proceed with testing during code updates, the DTC ran retrospective tests using both the non-latitude dependent code (using qoption=2) as well as the latitude dependent code (using qoption=1). In order to eliminate differences stemming from the qoption used in GSI, control runs using the NAM BE were run using each q option in order to have a consistent baseline for comparison.

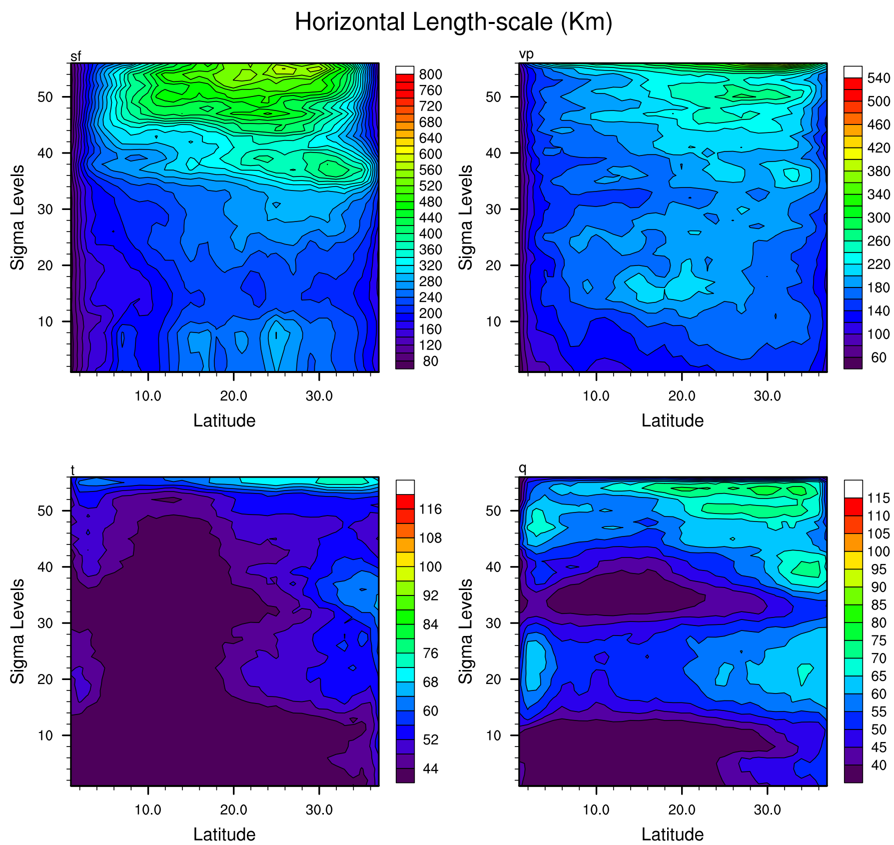
Both domain-specific BEs were generated using the NMC method over one month of deterministic forecasts generated from the DTC real-time runs using a functionally-similar testing environment. The one month period was from 01 October 2013 12 Z – 31 October 2013 12Z. The Retrospective testing period was the following one month period from 01 November 2013 12Z – 30 November 2013 12Z. Both BEs were tuned only using the tuning factors in the 'avavinfo' file following those of the NAM BE.

i. Non-latitude dependence code tests (with qoption=2)

The non-latitude dependent code (GEN-BE v2.0) was tested because this is the only working code with qoption=2 turned on (AFWA configuration). Figure 3.c.i-1 shows the latitude dependence not present for the horizontal lengthscale field as mentioned, compared with results from FY2012 GEN-BE code.



(a)



(b)

Figure 3.c.i-1: Horizontal lengthscale for control variables streamfunction (upper left), velocity potential (upper right), temperature (lower left), and moisture (lower right) for (a) GEN-BE v2.0 and (b) FY2012 GEN-BE code (lower panels).

Forecast verification resulted in GO Index scores indicating the domain-specific BE failed to beat the forecast performance of the NAM BE for the testing period over the T8 domain (see Figure 3.c.i-2).

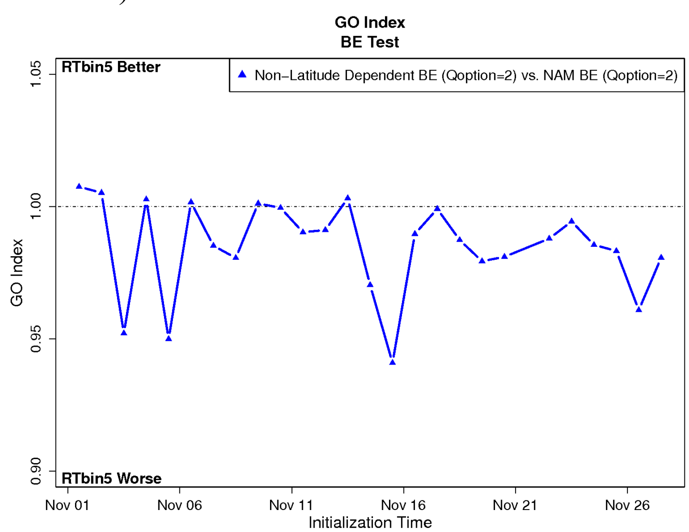


Figure 3.c.i-2: Go Index scores for non-latitude dependent BE vs. the NAM BE over a 1 month forecast period from Nov 1 –Nov 30, 2013.

ii. Latitude dependent code tests (with qoption=1)

The GEN-BE v2.1 was able to generate latitude dependent BE statistics only when using qoption=1 in GSI. Therefore, both the domain-specific BE as well as the NAM BE tests were run using this option for consistency. Initial BE diagnostics indicate that the domain-specific BE has a significantly smaller horizontal length, as shown in Figure 3.c.ii-1.

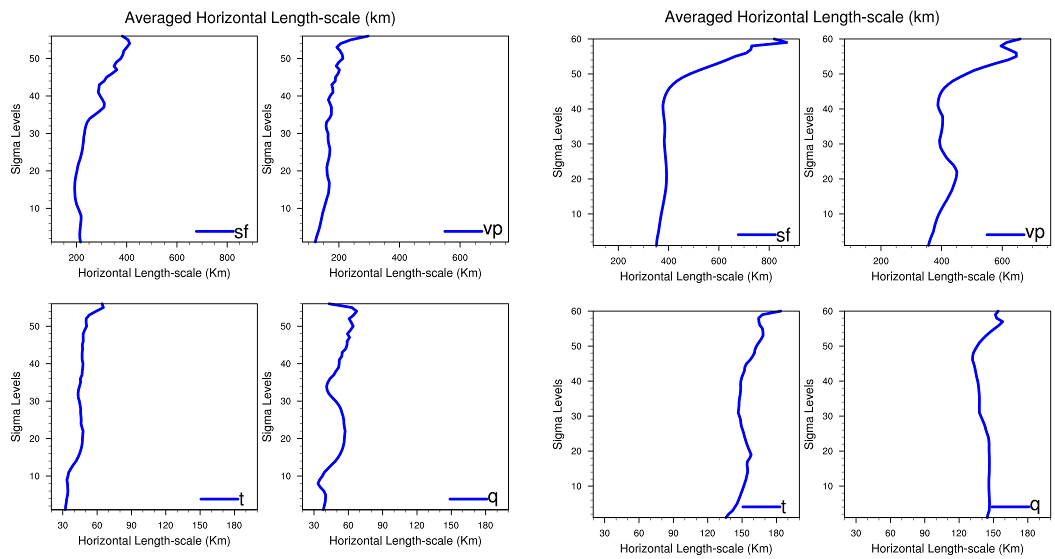


Figure 3.c.ii-1: Average horizontal lengthscale for GSI control variables streamfunction (upper left), velocity potential (upper right), temperature (lower left), and moisture (lower right) for GEN-BE v2.0 domain-specific BE (left panels) vs. Control NAM BE (right panels).

Another difference between this domain-specific BE and the NAM BE is the Psfc regression coefficients for the GEN-BE v2.1 now have a latitude dependence, whereas FY2012 domain-specific BE (not shown) and the NAM BE do not have a latitude dependence for this field. Averaged Psfc regression coefficients show similar magnitude between the domain-specific BE and the NAM BE (see Figure 3.c.ii-2).

Both BE statistics were tested by performing a pseudo-single observation test (PSOT), shown in Figure 3.c.ii-3. It can be seen that the domain-specific BE has a much smaller influence spatially than the NAM BE. The moisture field problems probably stem from the usage of qoption=1 for the tests. The response in the wind field is very similar both in magnitude and spatial extent for both the domain-specific BE and the NAM BE.

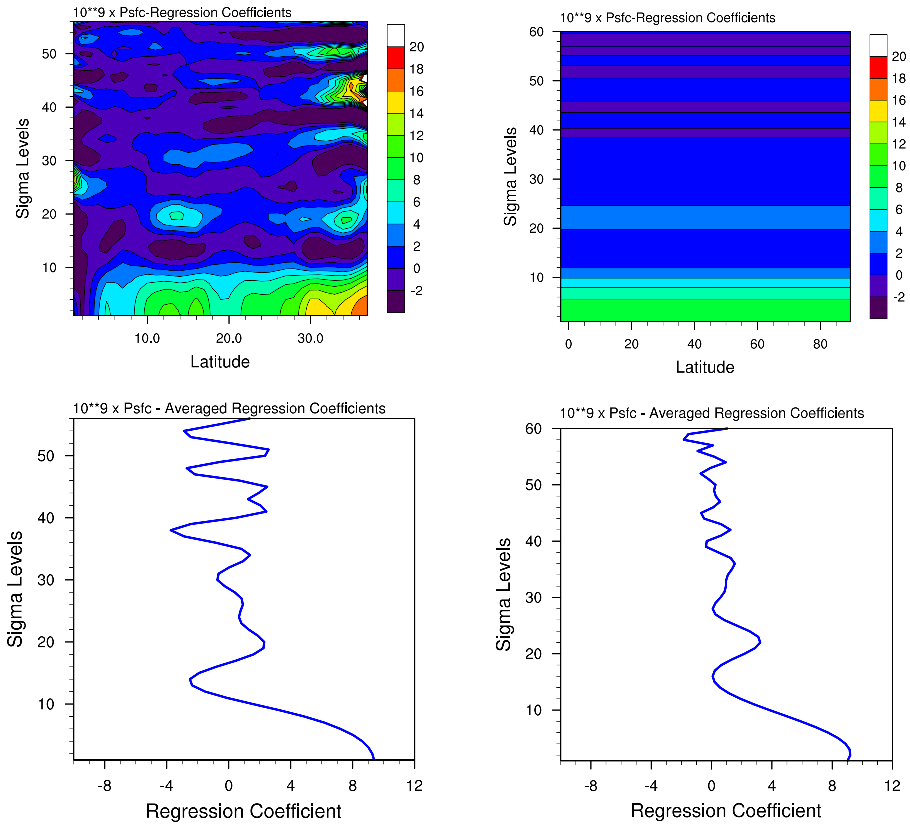


Figure 3.c.ii-2: Psfc regression coefficent (top) and averaged Psfc regression coefficents (bottom) for GEN-BE v2.1 domain-specifc BE (left) and control NAM BE (right).

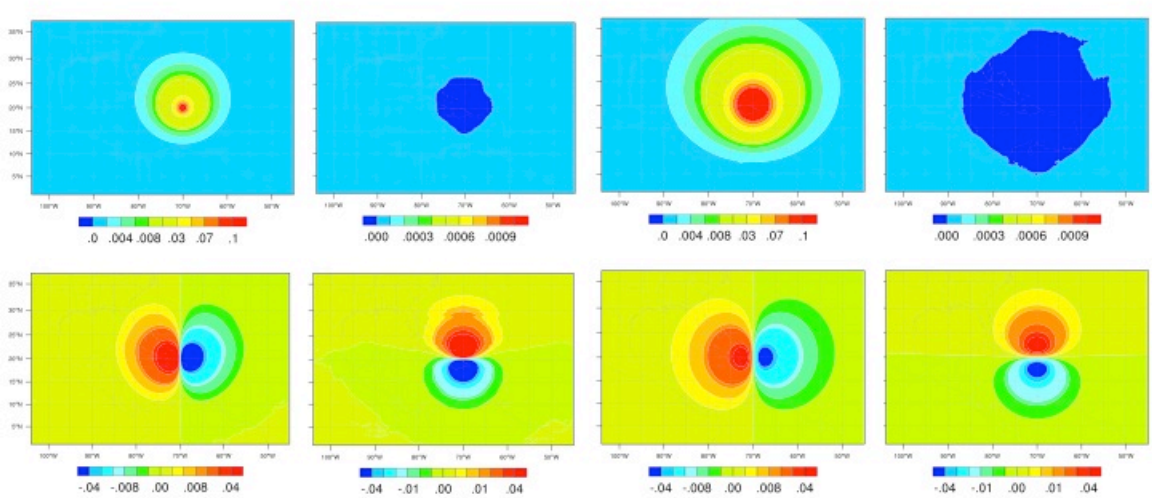


Figure 3.c.ii-3: PSOT of temperature observation at 500 mb for T (upper left), Q (upper right), V (lower left), and U (lower right) for GEN-BE v2.0 domain specific BE (left) and control NAM BE (right).

Forecast impact of both BE statistics was evaluated using the GO Index, shown in Figure 3.c.ii-4. The results once again point to the domain-specific BE unable to beat the forecast performance of the NAM BE in the T8 domain for this testing period. Further tuning may be necessary to improve the scores using the domain-specific BE. The box-plot in Figure 3.c.ii-4 indicates that these results are statistically significant in favor of the NAM BE configuration.

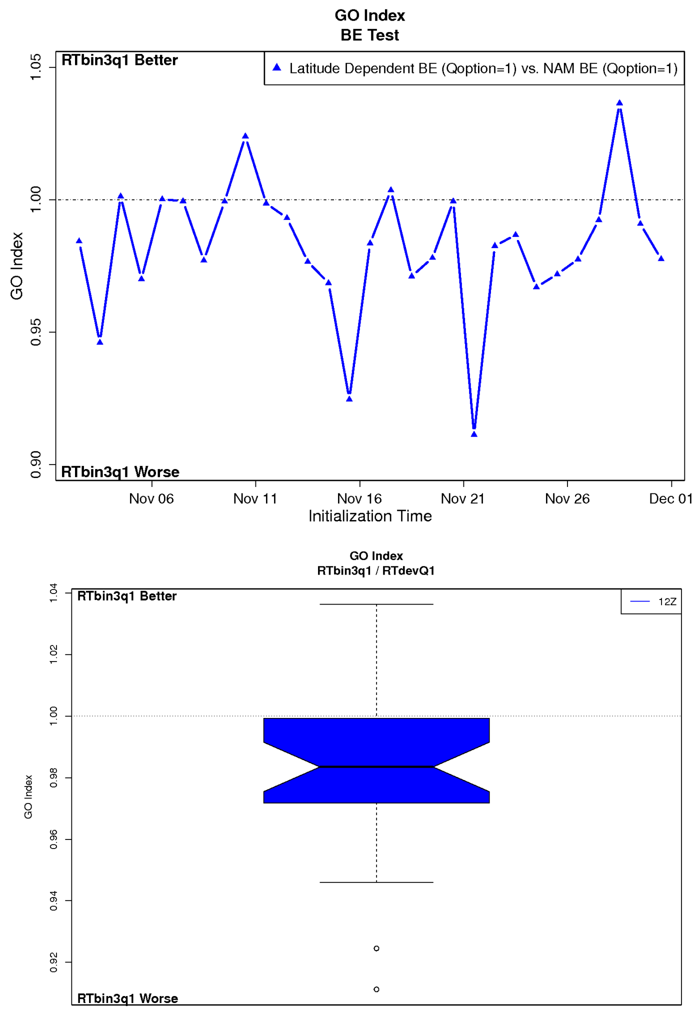


Figure 3.c.ii-4: Go Index scores for domain-specific (latitude dependent) BE vs. the NAM BE over a 1 month forecast period from Nov 1 –Nov 30, 2013. Upper panel show timeseries of GO Index scores, where lower panel shows boxplot aggregation of scores over the one-month period.

In addition to the GO index metrics, Figure 3.c.ii-5 shows the vertical RMSE profile for temperature, wind speed and height for the GEN-BE configuration vs. the NAM BE configuration. It can be seen that the analysis has statistically significantly (SS) smaller errors associated with the NAM BE for temperature and wind speed above 850 hPa. Conversely, the GEN-BE configuration has SS differences in its favor for 1000 hPa for wind speed and above 850 hPa for height.

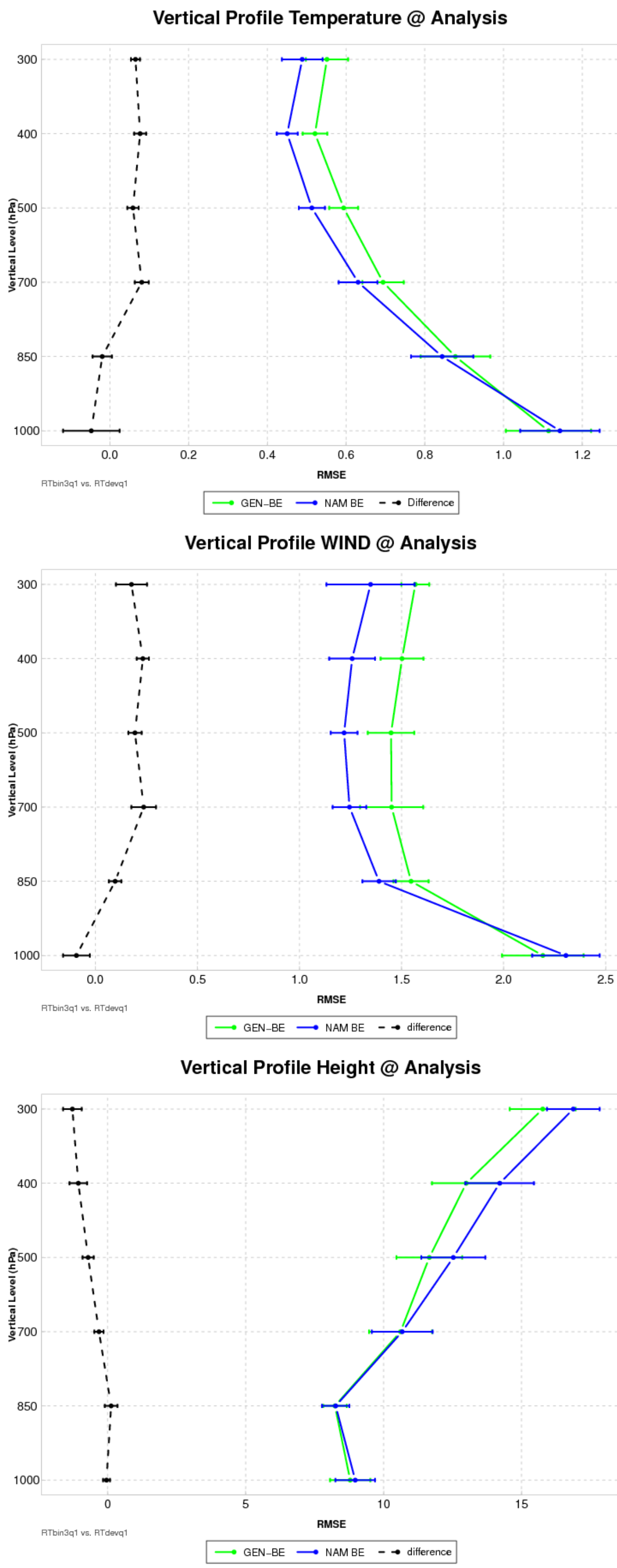


Figure 3.c.ii-5: Vertical RMSE profiles for temperature (upper), wind speed (middle) and height (lower) for forecast generated using the domain-specific BE generated using GEN-BE (green) vs. the forecasts generated using the pre-computed NAM BE (blue). The pair-wise differences are shown in black, with SS

differences where the black line does not encompass zero. The forecasts were using over a 1-month period from Nov 1 – Nov 30, 2013 at 12 Z.

In order to synthesize the forecast results better, a SS table is shown in Table 3.c.ii-1. The results for temperature, wind speed, U-component wind, V-component wind, dew point temperature, and height are shown for significant levels from 1000 – 300 hPa. Boxes that are shaded blue (and marked NAM) indicate the parameter and level have SS differences favoring the forecasts using the NAM BE, whereas boxes shaded green (and marked GEN-BE) indicate SS differences favoring the forecasts using the domain-specific BE generated using GEN-BE. Boxes with no shading indicate there are no SS differences between the two configurations. Table 3.c.ii-1 shows a strong signal of SS differences favoring the forecasts generated using the NAM BE for temperature and wind fields, particularly for forecast lead times within 24 hours, and above 700 hPa. The forecasts generated using the GEN-BE domain-specific BE show a signal of improvement for wind fields at the analysis time in the lowest level, as well as some scattered SS impact in the dew point temperature and height fields.

Table 3.c.ii-1: Statistical Significance Table for forecasts generated using GEN-BE BE vs. NAM BE

Parameter/		RMSE					
Forecast Hr		1000	850	700	500	400	300
Temperature	0			NAM	NAM	NAM	NAM
	12	NAM	NAM	NAM			
	24	NAM		NAM			
	36					NAM	NAM
	48				NAM		
Dewpoint Temp	0	NAM			GEN_BE		GEN_BE
	12				GEN_BE		
	24						
	36						
	48	NAM		NAM			GEN_BE
Wind Speed	0	GEN_BE	NAM	NAM	NAM	NAM	NAM
	12			NAM			NAM
	24			NAM			
	36						
	48			NAM		NAM	
V-comp Wind	0	GEN-BE	NAM	NAM	NAM	NAM	NAM
	12				NAM		
	24			NAM	NAM	NAM	NAM
	36						
	48						NAM
U-comp Wind	0	GEN_BE		NAM	NAM	NAM	NAM
	12			NAM	NAM	NAM	NAM
	24				NAM		
	36						
	48	GEN_BE					NAM
Height	0			GEN_BE	GEN_BE	GEN_BE	GEN_BE
	12	NAM	GEN_BE	GEN_BE			NAM
	24						
	36						
	48						

iii. GFS BE investigation

Although the NAM BE is recommended for use for northern hemisphere domains, the pre-computed global GFS BE is still used in the Southern Hemisphere domains. An additional 1-month retrospective test was run using the GFS BE as an additional control experiment. Figure 3.c.iii-1 shows the GO index scores for the domain-specific BE compared to the GFS BE. Results show that the domain-specific BE is not beating the forecast performance of the GFS BE either, with the boxplot indicating this result is SS.

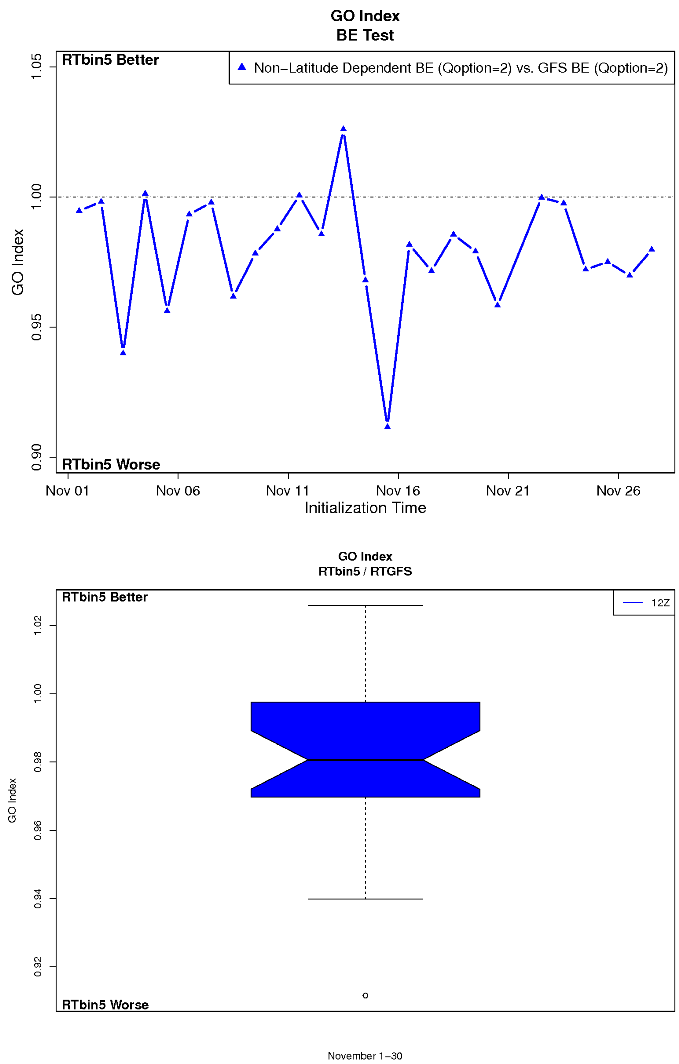


Figure 3.c.iii-1: Go Index scores for domain-specific (latitude dependent) BE vs. the GFS BE over a 1 month forecast period from Nov 1 –Nov 30, 2013. Upper panel show timeseries of GO Index scores, where lower panel shows boxplot aggregation of scores over the one-month period.

An additional comparison between the two operational BEs (GFS and NAM) was performed as a reference here. Figure 3.c.iii-2 shows the GO index scores for the NAM BE vs. the GFS BE for the same 1-month period. Results show that the NAM BE has SS better forecast performance, by a small margin. The NAM BE is currently being used operationally in the T8 domain. Figure 3.c.iii-3 shows the vertical RMSE profiles for the NAM BE vs. the GFS BE for temperature and wind fields. The results show SS differences at the analysis time favoring the GFS BE for temperature and the NAM BE for wind. These results are consistent with findings over the Northern Hemispheric domain tests in FY2012.

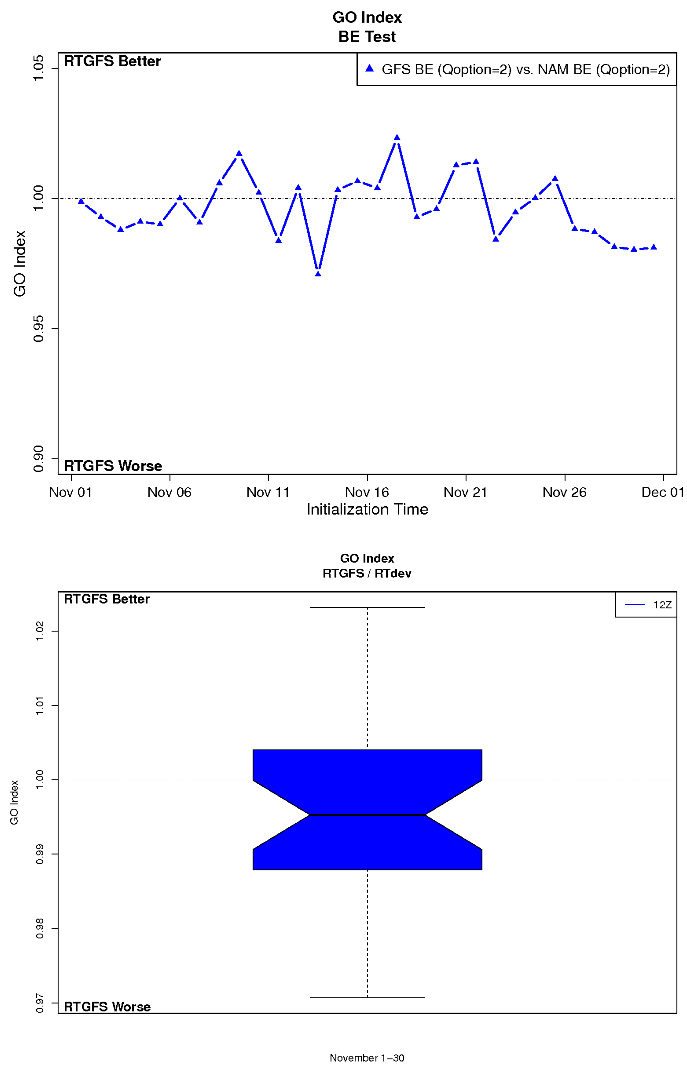
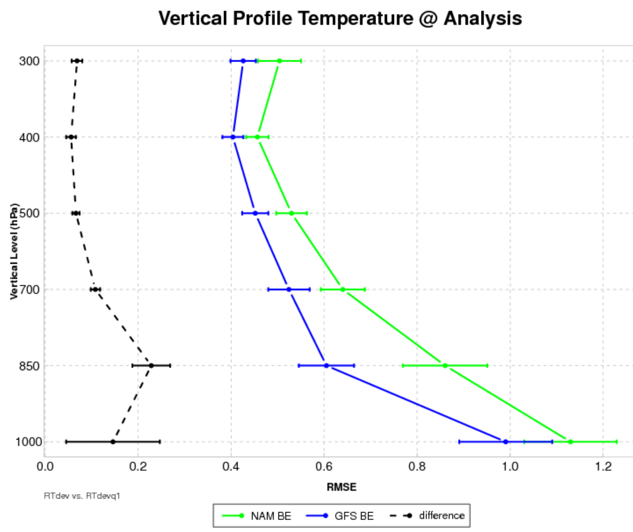


Figure 3.c.iii-2: Go Index scores for GFS BE vs. the NAM BE over a 1 month forecast period from Nov 1 – Nov 30, 2013. Upper panel show timeseries of GO Index scores, where lower panel shows boxplot aggregation of scores over the one-month period.



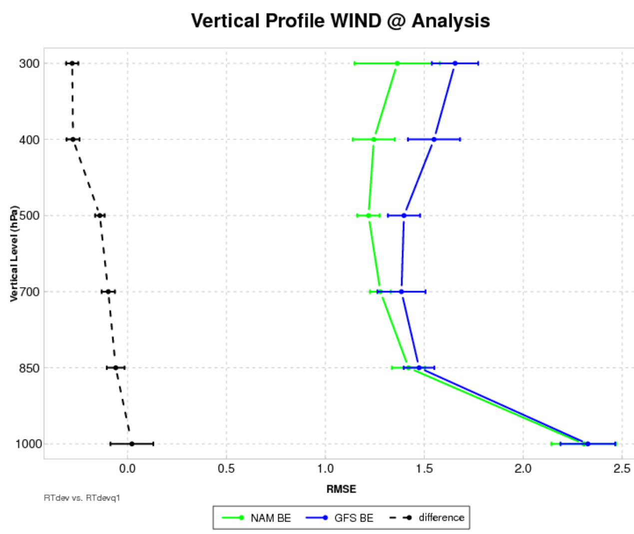


Figure 3.c.iii-3: Vertical RMSE profiles for temperature (upper) and wind speed (lower) for forecast generated using the NAM BE (green) vs. the forecasts generated using the GFS BE (blue). The pair-wise differences are shown in black, with SS differences where the black line does not encompass zero. The forecasts were using over a 1-month period from Nov 1 – Nov 30, 2013 at 12 Z.

4. Conclusions

The DTC performed testing and evaluation concentrated on the performance of GSI over the regional domains. Two focus areas were mitigation of SLP analysis errors and domain-specific BE generation and testing.

The SLP study focused on debugging a large RMSE and Bias in the derived SLP field from the AFWA end-to-end system. DTC worked closely with AFWA to identify the issue and provide solutions. Efforts were made to investigate surface observation assimilation and associated fields update, including surface moisture, surface temperature and dry air mass fields, which contribute to the SLP analysis issues. The DTC provided suggested configurations and testing components. Further tests and verification are pending.

The domain-specific BE impact study required a large amount of discussion and testing involving the developers of GEN-BE v2.0 in order to get the code working for AFWA applications. The DTC has provided a suggested namelist for AFWA applications, and identified remaining issues that should be addressed before further tests can be done. Domain-specific BE's using the NMC method over the T8 domain were generated and tested using the DTC functionally-similar real-time testing system. The test results show the domain-specific BE cannot beat the forecast performance of the NAM BE for this forecast period and domain. Further tuning may be necessary to gain better forecast scores using the domain-specific BE once the full capability of the GEN-BE code is available.

5. Appendix

Appendix A: Improving GSI analysis for MU Based on WRFDA

The GSI analysis Sea level pressure has big bias and RMS comparing to WRFDA one.

The definition of MU in WRF is: "perturbation dry air mass in column".

In GSI, MU is updated as through the surface pressure analysis. The guess Ps is formulated as:

ges_ps=(MU+MUB)* q_integral+P_top
q_integral= vertical sum of ges_q weighted by Delta Sigma

After analysis Ps (ges_ps) and Q (ges_q), the MU is modified as

MU=(ges_ps–P_top)/q_integral-MUB

In WRFDA, surface analysis results are saved as PSFC and MU is "perturbation dry air mass in column". So we will follow WRFDA method to calculate "perturbation dry air mass" from surface pressure analysis increment and moisture analysis increment and save this value as "MU".

In WRFDA:

The increments of the dry air mass in a column are obtained from the increments of the surface pressure and mixing ratio of water vapor based on the equation:

$$\underline{\mu'} = \frac{p'_{sfc} - (\mu+\mu')\times\int_0^{1.0} q'_k \, d\eta w}{1+\int_0^{1.0} q_k \, d\eta w} = -\frac{p'_{sfc} + (\mu+\mu')\times\int_{1.0}^{0} q'_k \, d\eta w}{\int_{1.0}^{0} (1+q_k) d\eta w}$$

$q'_k = \dfrac{qv'_k}{(1-qv_k)^2}$ is the mixing ratio of water vapor

$q_k = \dfrac{qv_k}{1-qv_k}$ is the mixing ratio of water vapor

qv'_k is the specific humidity analysis increment at levels h_k

p'_{sfc} is the surface pressure analysis increment

$\mu+\mu'$ is dry air mass in column

In the WRFDA code, μ' is calculated in the subroutine da_transfer_xatowrf (da_transfer_model.f):

```
!------------- -----------------------------------------------------
! [2.0] compute increments of dry-column air mass per unit area
!-----------------------------------------------------------------

do j=jts,jte
  do i=its,ite
    sdmd=0.0
    s1md=0.0
    do k=kts,kte
      sdmd=sdmd+q_cgrid(i,j,k)*grid%dnw(k)
      s1md=s1md+(1.0+grid%moist(i,j,k,P_QV))*grid%dnw(k)
    end do

    mu_cgrid(i,j)=-(grid%xa%psfc(i,j)+grid%xb%psac(i,j)*sdmd)/s1md
  end do
end do

do j=jts,jte
  do i=its,ite
    grid%mu_2(i,j) = grid%mu_2(i,j) + mu_cgrid(i,j)
    grid%psfc(i,j) = grid%psfc(i,j) + grid%xa%psfc(i,j)
  end do
end do
```

Here, μ' is mu_cgrid, grid%mu_2 is the background/analysis dry air mass and grid%psfc is the background/background surface pressure. The following fields are used in the calculation:

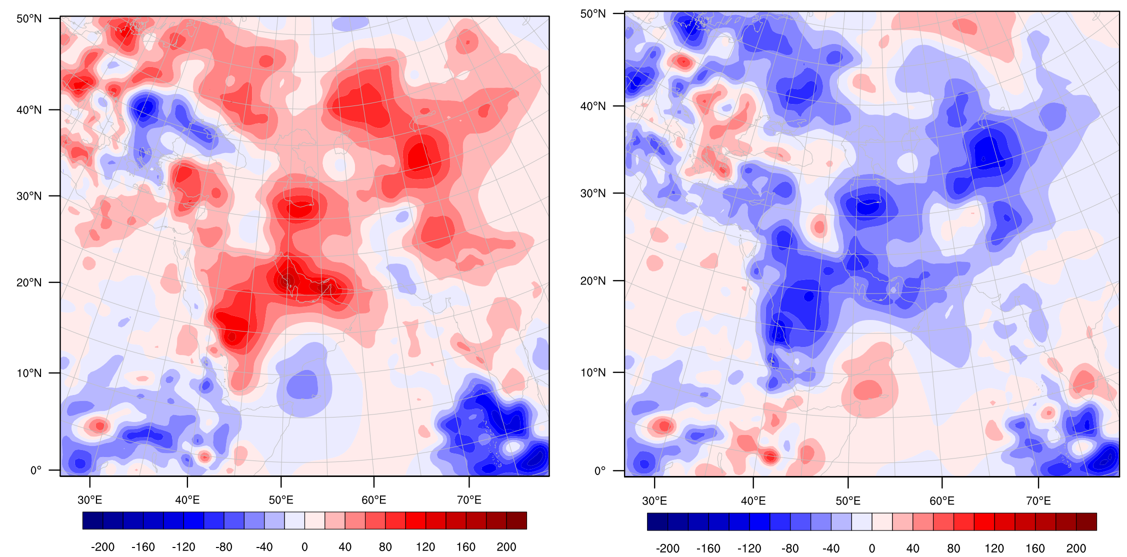
Background water vapor mixing ratio:
grid%xb%q(i,j,k) = grid%moist(i,j,k,P_QV)

Analysis increment of water vapor mixing ratio:

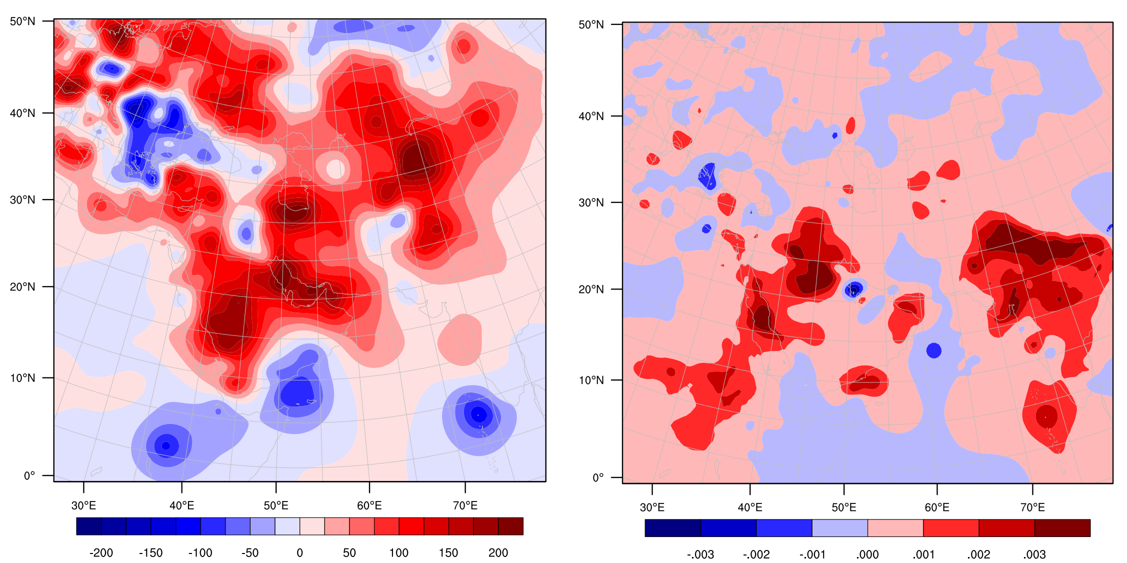
```
do k=kts,kte
  do j=jts,jte
    do i=its,ite
      if ((grid%xb%q(i,j,k)+grid%xa%q(i,j,k)) < 0.0) then
        q_cgrid(i,j,k) =-grid%xb%q(i,j,k)/(1.0 - grid%xb%q(i,j,k))**2
      else
        q_cgrid(i,j,k) = grid%xa%q(i,j,k)/(1.0 - grid%xb%q(i,j,k))**2
      end if
    end do
  end do
end do
```

background dry air mass:
grid%xb%psac(i,j) = grid%mub(i,j)+grid%mu_2(i,j)

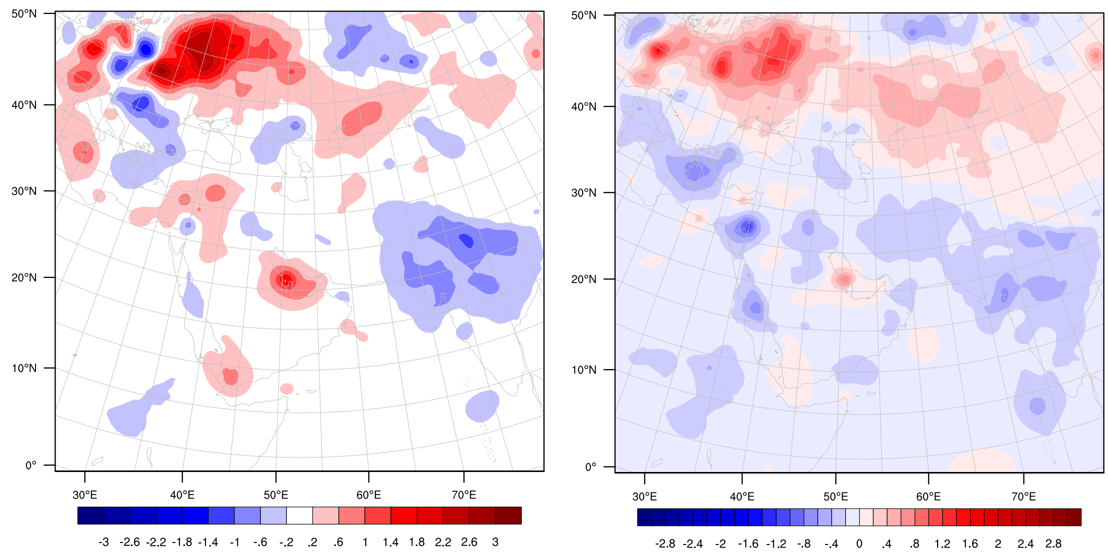
In GSI, a new subroutine is added in update_guess.f90 to calculate analyzed MU based on the above process.



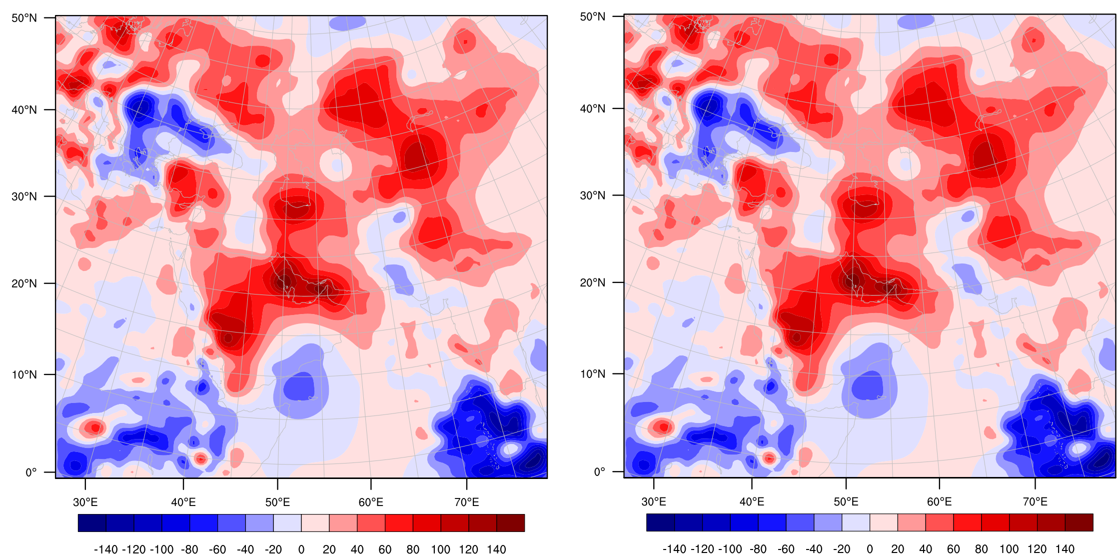
The above figure shows the MU analysis increment with new method (left) and old method (right). The analysis increment changed significantly. The increments are mainly positive in new method instead of negative in old method.



The above figure shows the MU difference between new method and old method (left) and 1st level moisture analysis increment (right) with the new method. The moisture analysis increments show no difference between new and old methods. The changes of MU in the new method originate from vertical integration of q analysis.



The above figure shows the 1st level T analysis increments with surface observations (left) and without surface observations(right).



The above figure shows the MU analysis increments with surface observations (left) and without surface observations (right).

Because our test from AFWA has surface T observations turned off, the test when turning on surface T observations with the new calculation of MU should also be investigated.

Appendix B: GSI namelist

```
&SETUP
  miter=2,niter(1)=50,niter(2)=50,
  write_diag(1)=.true.,write_diag(2)=.false.,write_diag(3)=.true.,
  gencode=78,qoption=2,
  factqmin=0.0,factqmax=0.0,deltim=1200,
  ndat=77,iguess=-1,
  oneobtest=.false.,retrieval=.false.,
  nhr_assimilation=3,l_foto=.false.,
  use_pbl=.false.,
 /
 &GRIDOPTS
  JCAP=62,JCAP_B=62,NLAT=,NLON=,nsig=60,regional=.true.,
  wrf_nmm_regional=.false.,wrf_mass_regional=.true.,
  diagnostic_reg=.false.,
  filled_grid=.false.,half_grid=.true.,netcdf=.true.,
 /
 &BKGERR
  vs=1.0,
  hzscl=0.373,0.746,1.50,
  bw=0.,fstat=.true.,
 /
 &ANBKGERR
  anisotropic=.false.
 /
&OBSQC
  dfact=0.75,dfact1=3.0,noiqc=.false.,c_varqc=0.02,vadfile='prepbufr',
/
```

Appendix C: WRF-ARW namelist

```
&domains
 time_step                = 90,
 time_step_fract_num      = 0,
 time_step_fract_den      = 1,
 max_dom                  = 1,
 s_we                     = 1,     1,     1,
 e_we                     = 418, 321, 157,
 s_sn                     = 1,     1,     1,
 e_sn                     = 280, 301, 154,
 s_vert                   = 1,     1,     1,
 e_vert                   = 57,    51,    51,
 num_metgrid_levels       = 27,
 num_metgrid_soil_levels  = 4,
 dx                       = 15000.0, 3000.0, 1000.0,
 dy                       = 15000.0, 3000.0, 1000.0,
 grid_id                  = 1,     2,     3,
 parent_id                = 0,     1,     2,
 i_parent_start           = 0,  153,  166,
 j_parent_start           = 0,  159,  141,
 parent_grid_ratio        = 1,  4,3,
 parent_time_step_ratio   = 1,  3,3,
 feedback                 = 0,
 smooth_option            = 0
 p_top_requested          = 1000
 interp_type              = 1
 lowest_lev_from_sfc      = .false.
 lagrange_order           = 1
 force_sfc_in_vinterp     = 6
 zap_close_levels         = 500
 eta_levels = 1.000, 0.997, 0.992, 0.985, 0.978, 0.969, 0.960, 0.950,
        0.938, 0.925, 0.910, 0.894, 0.876, 0.857, 0.835, 0.812,
        0.787, 0.760, 0.731, 0.700, 0.668, 0.635, 0.600, 0.565,
        0.530, 0.494, 0.458, 0.423, 0.388, 0.355, 0.323, 0.293,
        0.264, 0.237, 0.212, 0.188, 0.167, 0.147, 0.130, 0.114,
        0.099, 0.086, 0.074, 0.064, 0.054, 0.046, 0.039, 0.032,
        0.027, 0.022, 0.017, 0.013, 0.010, 0.007, 0.004, 0.002,
        0.000,
/

&physics
 mp_physics               = 4,     6,     6,
```

```
ra_lw_physics                      = 1,     1,     1,
ra_sw_physics                      = 1,     1,     1,
radt                               = 30,    30,    30,
sf_sfclay_physics                  = 1,     1,     1,
sf_surface_physics                 = 2,     3,     3,
bl_pbl_physics                     = 1,     1,     1,
bldt                               = 0,     0,     0,
cu_physics                         = 1,     1,     0,
cudt                               = 5,
isfflx                             = 1,
ifsnow                             = 0,
icloud                             = 1,
surface_input_source               = 1,
num_soil_layers                    = 4,
mp_zero_out                        = 2,
maxiens                            = 1,
maxens                             = 3,
maxens2                            = 3,
maxens3                            = 16,
ensdim                             = 144,
num_land_cat                       = 28,
fractional_seaice                  = 1,
seaice_threshold                   = 271,
tice2tsk_if2cold                   = .true.,
/
&dynamics
rk_ord                             = 3,
diff_6th_opt                       = 2,
diff_6th_factor                    = 0.10,
w_damping                          = 1,
diff_opt                           = 1,
km_opt                             = 4,
damp_opt                           = 3,
base_temp                          = 283.,
iso_temp                           = 210.,
zdamp                              = 5000.,  5000.,  5000.,
dampcoef                           = 0.05,    0.02,   0.01
khdif                              = 0,      0,      0,
kvdif                              = 0,      0,      0,
SMDIV                              = 0.1,    0.1,    0.1,
EMDIV                              = 0.01,   0.01,   0.01,
EPSSM                              = 0.1,    0.1,    0.1
non_hydrostatic                    = .true., .true., .true.,
TIME_STEP_SOUND                    = 0,      4,      4,
H_MOM_ADV_ORDER                    = 5,      5,      5,
V_MOM_ADV_ORDER                    = 3,      3,      3,
```

```
H_SCA_ADV_ORDER                 = 5,      5,      5,
V_SCA_ADV_ORDER                 = 3,      3,      3,
moist_adv_opt                   = 1,      2,      2,
scalar_adv_opt                  = 0,      2,      2,
chem_adv_opt                    = 0,
tke_adv_opt                     = 0,
use_baseparam_fr_nml            = .true.,
/

&bdy_control
spec_bdy_width                  = 5,
spec_zone                       = 1,
relax_zone                      = 4,
specified                       = .true.,
periodic_x                      = .false.,
symmetric_xs                    = .false.,
symmetric_xe                    = .false.,
open_xs                         = .false.,
open_xe                         = .false.,
periodic_y                      = .false.,
symmetric_ys                    = .false.,
symmetric_ye                    = .false.,
open_ys                         = .false.,
open_ye                         = .false.,
nested                          = .false.,
/
```

Appendix D: GEN-BE v2.0 Namelist

```
&gen_be_info
model = 'WRF'
application = 'GSI'
be_method = 'NMC',
ne = 5,
cut = 0, 0, 0, 0, 0, 0,
use_mean_ens=.false.
start_date = '2013100212',
end_date = '2013103112',
interval = 24,
testing_eofs = .false.
/

&Gen_be_cv
nb_cv = 5,
cv_list = 'psi','chi','t','rh','ps',
fft_method = 2,
covar1  = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
covar2  = 1, 0, 0, 0, 0, 0, 0, 0, 0, 0,
covar3  = 1, 0, 0, 0, 0, 0, 0, 0, 0, 0,
covar4  = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
covar5  = 1, 0, 0, 0, 0, 0, 0, 0, 0, 0,
covar6  = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
covar7  = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
covar8  = 0, 0, 0, 0, 0 ,0, 0, 0, 0, 0,
covar9  = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
covar10 = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
use_chol_reg = .true.
/

&gen_be_bin
bin_type = 3,
lat_min = 25.0,
lat_max = 50.0,
binwidth_lat = 1.0,
hgt_min = 1000.0,
hgt_max = 2000.0,
binwidth_hgt = 1000.0,
/

&gen_be_lenscale
```

```
data_on_levels = .true.
vert_ls_method = 1,
ls_method = 2,
use_med_ls = .true.
horizvar = 'correl',
horizfunct = 'GAUS',
stride = 1,
n_smth_ls = 2,
use_global_bin = .false.
/
```

Appendix E: GSI code changes contributed from the pre-processing procedure

It was found GSI code has to be changed in order to read AFWA prepBUFR files during the FY13 DTC tests. As shown in Figure E-1, analysis differences were shown for the wind fields, due to the data missing from the DTC test. Table E-1 lists the observation types and associated numbers used in Figure E-1. The reason for such differences is the discrepancy between the NCEP and AFWA pre-processing procedures in handling observation records.

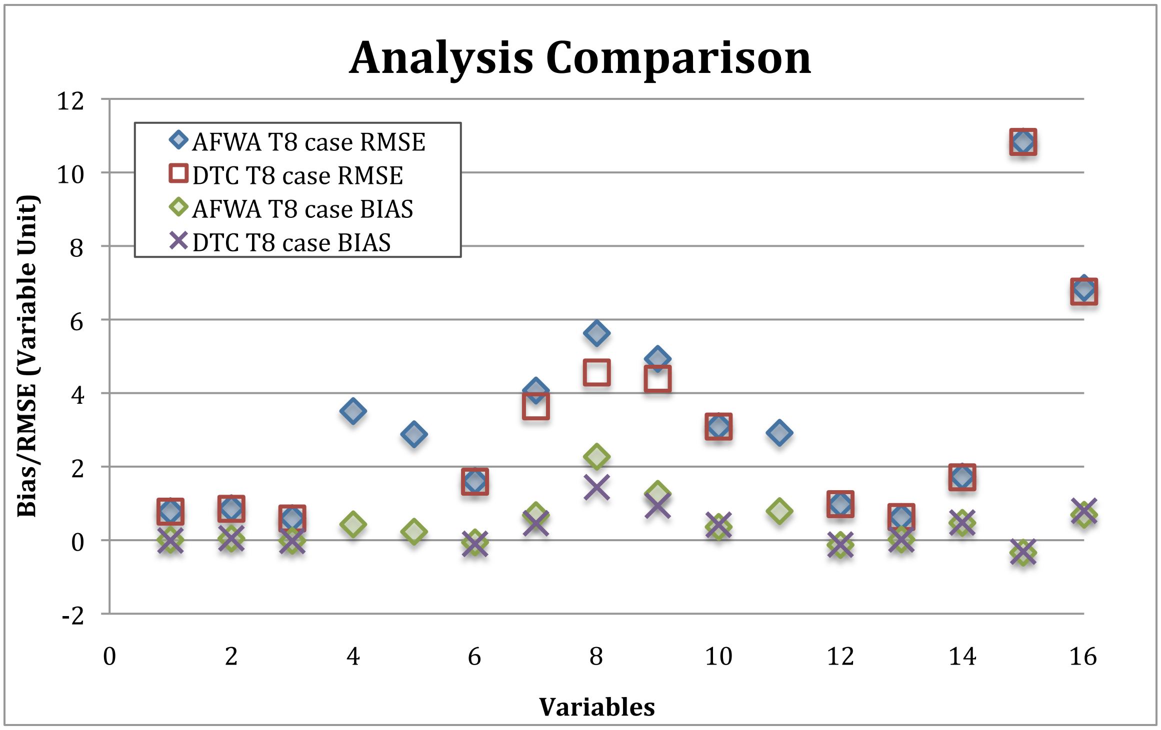


Figure E-1: Analysis comparison between AFWA supplied case and DTC test case. Variable numbers correspond to conventional observation types listed in table 6.

Table E-1: Conventional observations types associated with variable numbers in Figure 13

Variable no.	1-3	4-11	12-14	15-16
Variable name	Ps 180,181,187	UV 220,321,243,245,245,246,253,280	T 120,131,180	Q 120,180

Both BE statistics were tested by performing a pseudo-single observation test (PSOT), shown in Figure 3.c.ii-3. It can be seen that the domain-specific BE has a much smaller influence spatially than the NAM BE. The moisture field problems probably stem from the usage of qoption=1 for the tests. The response in the wind field is very similar both in magnitude and spatial extent for both the domain-specific BE and the NAM BE.