TOWARD A 30 YEARS NORTH AMERICAN PRECIPITATION AND GROUND SURFACE ANALYSIS

PROJECT ADVANCEMENT UPDATE – SPRING 2016

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INTRODUCTION

In a previous report [1], the methodology and agenda to develop a 30 Years North American Precipitation and Ground Surface Analysis was introduced. As a summary, it was underlined that a reforecast downscaling approach based on GEM[1] and that uses ERA Interim reanalysis[2] as initial fields needed to be designed in order to obtain background fields for CaPA[3] and CaLDAS[4] and produce a 30 analysis. This approach is referred to as the Global and Regional Deterministic Reforecast System (GDRS and RDRS).

In the present report, the project advancement and preliminary results are presented. In a first section, the improvements to the system concerning the required computational time are presented. A second section is dedicated to the preliminary evaluation of the method at both the global and the regional levels, and in comparison to observations and to the Global and Regional Deterministic Prediction Systems (GDPS and RDPS, which are operational forecast systems). Finally, the forthcoming refinements are discussed considering the preliminary results.

PRELIMINARY REFINEMENTS OF THE METHOD

Forecast and assimilation systems from CMC are now operated based on a task sequencer called Maestro. A sequencer is an application that submits sets of tasks (job scripts) in a user-defined order. Maestro is the unified task sequencer currently under joint development and used operationally between Operations, Research and Development at CMC[5].

As discussed in a previous report [1], the present study follows a similar reforecast methodology as the Global and Regional Ensemble Prediction System (GEPS, REPS, without the ensemble component). These systems and their associated Maestro task flow (also referred to as Maestro suites) were selected as starting points for this study. However, after a detailed evaluation of the various components of these

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[1] The Global Environmental Multiscale (GEM) model is used by ECCC for weather forecasting.

[2] The European Centre for Medium Range Weather Forecasts (ECMWF) has developed an upper-air reanalysis named ERA Interim which can be used, among other things, to initialize atmospheric models such as GEM.

[3] The Canadian Precipitation Analysis (CaPA) produces gridded estimates of precipitation.

[4] Canadian Land Data Assimilation System (CaLDAS) produces gridded estimates of soil moisture, soil temperature and snowpack properties.

[5] Maestro has become a standard to a point that it is now almost impossible to operate atmospheric models without its use.

systems, it became evident that several operation required in the context of ensemble forecasting, were not useful in the context of the present study. In other words, the suites could be simplified in order to reduce their complexity and required computational time while keeping their results unchanged.

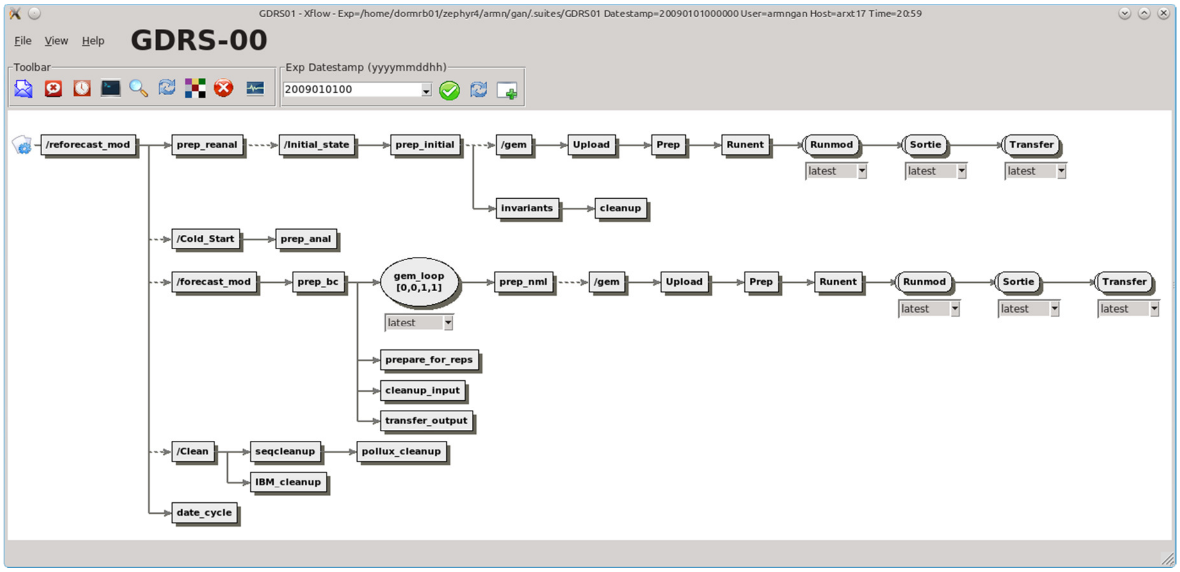

Figure 1: Illustration of the original Maestro suite of the GDRS

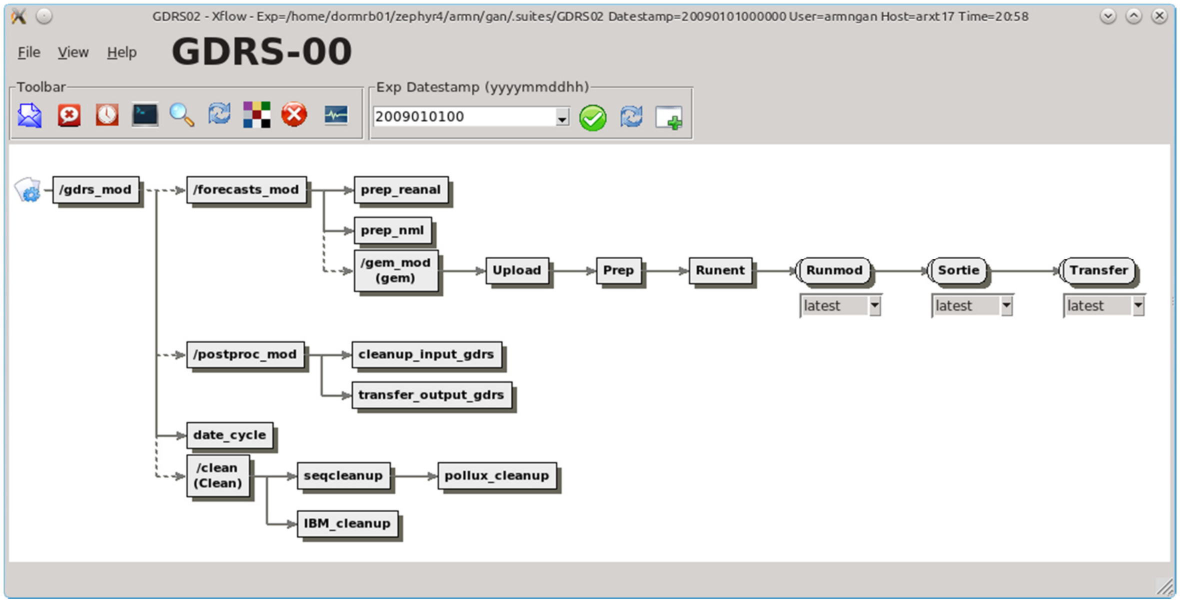

Figure 2: Illustration of the new Maestro suite of the GDRS

Figure 1 and Figure 2 illustrate the Maestro suites of the original and refined GDRS, while Figure 3 and Figure 4 illustrate the equivalent for the RDRS. As seen on these figures, tasks flows have been simplified and many tasks have been removed, notably for the global system, which results in a much more streamlined flow. These changes mainly consisted in the removal of a one iteration call to GEM model which was aimed to interpolate the various variables from ERA Interim vertical grid (pressure levels) to GEM vertical grid (hybrid levels). This step is required in the GEPS approach so that perturbation of the main variables of the model can be added directly on the model grid. Removing that step in the GDRS allows starting reforecast directly from ERA Interim (avoiding a double application of model initialization procedure at iteration zero). Removing that step also required some adaptation of the RDRS.

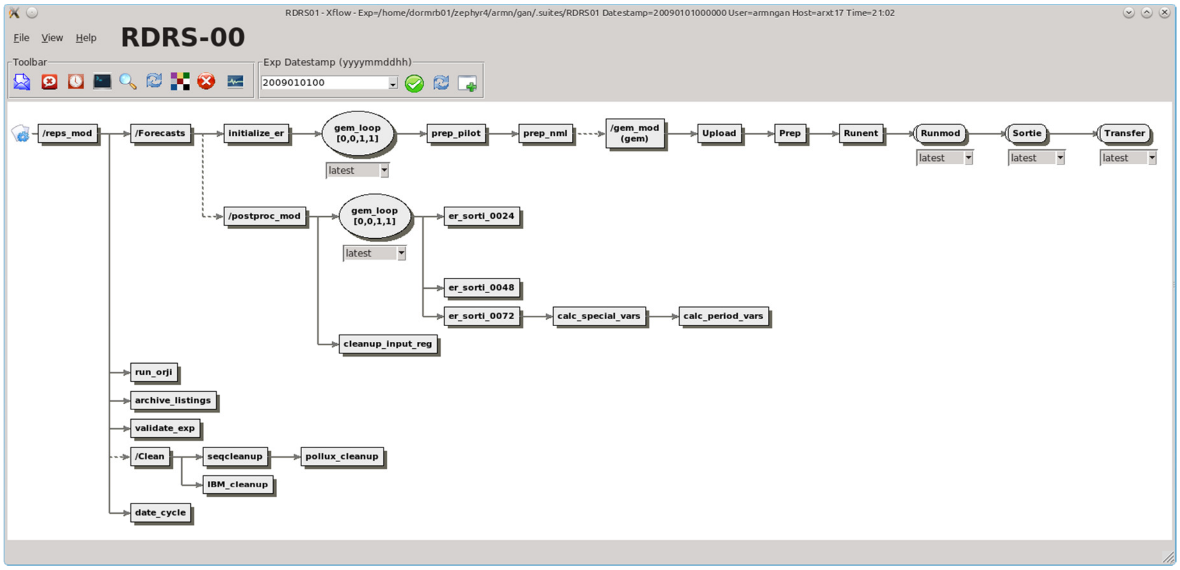

Figure 3: Illustration of the original Maestro suite of the RDRS

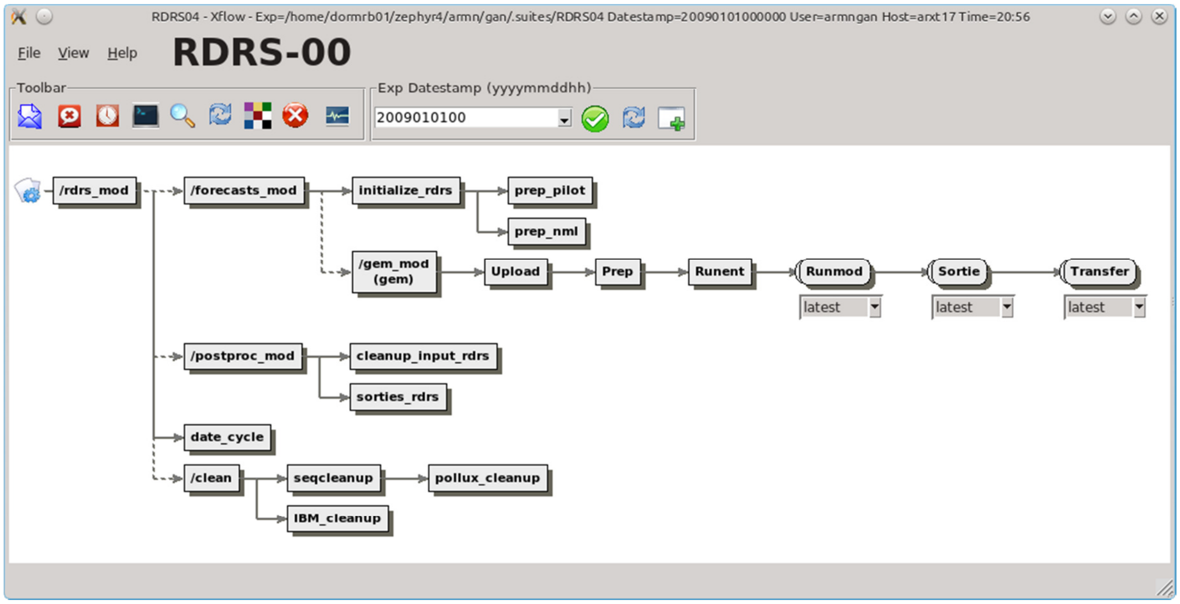

Figure 4: Illustration of the new Maestro suite of the RDRS

To make sure these changes did not affect results, we have evaluated the original and new approaches based on standard CMC verification tools ARCAD and EMET (c.f. next section for more details on ARCAD and EMET). ARCAD scores (verification against radiosonde, i.e. troposphere to stratosphere) of the new versus original approaches for the global and regional are identical: bias and standard deviations of the two approaches superpose (not shown here). At the surface, EMET scores (c.f. next section for more details on EMET) show statistically significant but very marginal differences mostly at the start of the reforecast. These differences are due to the fact that iteration zero is done only once in the new approach, while it was done twice originally.

However, these modifications of the suites have an important influence on the execution time of both the GDRS and RDRS. Before these refinements, a 24 h reforecast cycle of the GDRS and RDRS were requiring at best slightly more than 30 min to be completed on 128 and 160 CPU cores respectively. The new suites require only 17 min for the GDRS and 22 min for the RDRS to complete a 24 h cycle both on 128 CPU cores. Thus, a 30 years sequential reforecast would now require a total of ~600 computational days to complete (30*365*2*(17+22)/60/24), while it required more than 1000 days with 10 % more CPU cores before. This is a huge improvement. In addition, the resources required to execute each task have been fine-tuned, which allowed to significantly lower the queue waiting time.

PRELIMINARY EVALUATION OF THE REFORECAST APPROACH

In order to evaluate results of the reforecast system at the global and regional scales, standard CMC tools and methodology were used, i.e. ARCAD and EMET. The evaluation of models using these tools is mandatory to obtain approval for model modifications by the CPOP (the joint MRD/CMC committee responsible for authorizing changes to both the operational and pre-implementation parallel runs at CMC). Both tools compare model outputs directly to observations, providing a realistic view of the approach's capabilities.

For this first evaluation of the reforecast system, the official evaluation time windows of the 2011 winter (2011/02/01 to 2011/03/31) and summer (2011/07/01 to 2011/08/28) have been selected. These two periods have previously been used to score several operational systems to satisfy the CPOP requirements. It is thus considered as a good reference. In this study, results from the reforecast approach are compared to the GDPS and RDPS v4.0 (first version of operational systems to rely on the EnVAR). It is noteworthy that the GDPS has a resolution almost twice as fine as the GDRS in the three directions. For their part, regional systems feature similar horizontal resolutions and domains but the RDPS features more vertical levels than the RDRS.

In the following sections, ARCAD and EMET scores are discussed for both the global and regional reforecast systems and for both the 2011 winter and summer seasons. We focus on the so-called "North America Plus" geographic sub-domain for both the global and the regional verifications. Surface scores for the so-called "Great Lake Watersheds" sub–domain are also included for illustration purpose at the end of the Appendix but not discussed (as the authors think that is it too early in the process to draw sensible conclusions with this domain). This domain is identical to the one currently used to evaluate CaPA above Great Lakes basin.

In all figures, blue curves indicate the reference (they generally show the results from the operational CMC model), while the red curves show the results from the approach that is being evaluated. With the exception of time evolution, results are shown after 24 h of forecast. Finally, due to the large amount of figures already included in this report, results for all variables, lead hour, run hour and evaluation sub-domains are not shown here. The latter can be provided to the reader on demand. In addition, for the readability of the report, it was decided not to integrate most figures within the text. They are thus included in the Appendix.

Finally, it is noteworthy that the preliminary results presented in this report are not fully representative of the final product results. First, the introduction of precipitation and surface assimilation will greatly influence surface scores, and, as a consequence, atmospheric scores. We also expect some improvement by further refining the approach, notably by recycling quantities such as surface and soil variables and clouds and TKE as well as surface variables. Finally, it is also to be underlined that the final product will be the combination of various reforecast started every 12 h (one at 0 UTC and the other at 12 UTC). As a result, 24 h time evolution of variables will be based on the output of two different reforecasts. Similarly, 24 h precipitation accumulation will be the sum of 12 h accumulations from two distinct reforecasts. The configuration of this combination depends on the results of reforecast system. In the present report, we decided to strictly follow the official verification methodology to properly compare results and not to combine distinct forecasts started a different hours. This aspect will be further evaluated as we settle to a definitive configuration of the reforecast system.

EVALUATION OF RESULTS IN THE ATMOSPHERE (ARCAD)

ARCAD is dedicated to the verification of atmospheric model outputs against radiosondes. It thus evaluates model results from the earth surface to the upper atmosphere (i.e. troposphere to stratosphere). Variables evaluated in ARCAD[6] are absolute temperature T, zonal wind velocity U, the modulus of wind velocity|U|, geopotential Z and dew point depression (T – Td). In the figures produced by ARCAD, biases are shown with dash lines and standard errors with plain lines. The number of observations is shown on the right of the figures. Finally, color boxes on the sides of ARCAD figures indicate which model version is better, and with which confidence (the absence of this box indicates that there are no significant differences between models).

ARCAD scores of the GDRS for both the winter, Figure 5, and the summer, Figure 8, are generally in good agreement with GDPS scores. Indeed, after 24 h of forecast, biases and standard errors profiles are very similar in both approaches (with the exception of the absolute temperature errors close to the surface which we will discuss later). The GDRS generally features errors equal or slightly larger than the GDPS, notably in summer. These differences are for a part caused by initial fields of the operational and reforecast approaches. In addition, GEM configuration differs between the GDPS and the GDRS and a notably coarser grid is used in the later.

The GDPS uses CMC analysis as initial fields, which was generated based on GEM and designed to be used as input of the latter. At the opposite, the global reforecast approach relies on ERA-Interim, which was generated based on a different approach and observation datasets. Thus, while both analyses intend to get close to the truth, CMC analysis and ERA-Interim can notably differ (such as for the dew point depression, not shown here). In addition, dynamic balance is less consistent with GEM during the first hours of forecast in the context of an initialization with ERA-Interim. However, this imbalance quickly disappears[2] and a clear convergence between the operational model and the reforecast system scores is already observed after 12 h of forecast (not shown here).

Concerning absolute temperature in the lower part of the atmosphere (i.e. the lowest pressure levels: 1000 mb, 925 mb and 850 mb), important differences can be observed notably during the summer, Figure 8. The GDRS presents a higher standard error at 925 mb and 850 mb. This also translates in a larger error for the dew point depression at these levels. This error is currently being investigated, but it is suspected

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[6] Note that in ARCAD figures, T is referred to as TT, U as UU, |U| as UV, Z as GZ and (T – Td) as ES. This nomenclature follows CMC variables names dictionary.

to be caused by erroneous initial surface fields. Results after 12 h of forecast are similar and feature an analog departure of the temperature at the surface.

A comparison of ARCAD scores of the regional approaches, i.e. the RDPS and RDRS, is presented in Figure 11 for the winter and Figure 14 for the summer. Regional system results are in line with the ones of the global systems, albeit both RDPS and RDRS results are better than the one from GDPS and GDRS (not shown here). This comparison is thus very similar to Figure 5 and Figure 8. Absolute temperature (and thus dew point depression) also presents a larger departure from the observations in the bottom of the atmosphere for the reforecast approach.

As a result of the above, it can be considered that, besides the absolute temperature departure at the surface (which is being investigated), results in the atmosphere from this preliminary evaluation of both the global and regional reforecast approaches are promising. Furthermore, it is confirmed that RDRS results are generally better than the one from GDRS.

EVALUATION OF SURFACE RESULTS (EMET)

EMET is dedicated to the evaluation of surface results. Currently, SYNOP, METAR and SA surface stations databases along with the observations used in the operational CaPA are available for comparisons. Variables that can be evaluated with EMET are among other the absolute and dew point temperatures (2 m), wind velocity and direction (10 m), cloud cover, 6 h and 24 h precipitation accumulations, and surface pressure.

In the figures produced by EMET and presented in this report, the upper part shows either time evolution of bias/standard error, or Frequency Bias Index (FBI)/Equitable Threat Score (ETS) as a function of thresholds and for a given lead time. The observation number is shown on the curves. The smaller bottom figure indicates which version of the model is better, by what amount, and grayed region shows the confidence interval of the difference.

EMET verifications presented in this report are preliminary and final results will be significantly different due to the introduction of clouds, atmospheric boundary layer and surface variables recycling as well as data assimilation. In addition, evaluation of 24 h precipitation accumulation requires the combination of results from two reforecast started at 12 h interval, which we did not implement yet. We thus focus on ETS and FBI of 6 h precipitation accumulation after 24 h lead-time for reforecasts started at 0 UTC. Similarly, surface temperature evolution presented here is based on the results from reforecasts started at 0 UTC. Final results will rely on both output from reforecasts started at 0 UTC and 12 UTC. Finally, all EMET scores are based on same domain as used to produce ARCAD scores, i.e. “North America Plus”.

Precipitation evaluation for the global approach is shown in Figure 6 for the winter and in Figure 9 for the summer. GDPS and GDRS precipitation threat scores are identical for both seasons. They are notably better in the winter than in the summer. GDRS bias is however higher than the GDPS (which already shows too frequent precipitation event at almost all thresholds). This difference might be due to the coarser horizontal resolution of the reforecast system. Concerning regional reforecast systems, as shown in Figure 12 for the winter and Figure 15 for the summer, threat scores are generally slightly better for the RDPS for both seasons, while biases are similar in winter and much better in summer for the RDRS. In fact, differences between the RDRS and the RDPS are not in line with the global systems’ differences (due to differing configuration of the GDPS and RDPS). Indeed, comparing the GDRS with the RDRS (not shown here), RDRS precipitation threat score tend to be marginally better and biases are generally improved in the regional approach.

Considering some clouds take up to a week to fully develop, it is strongly believed that recycling quantities related to clouds and their water content will improve precipitation scores (even if some adaptation of these fields are required during the initialization of the reforecast). Furthermore, this should improve surface temperature prediction notably during the first hours of the reforecast considering radiation fluxes may be more realistic.

Concerning surface temperature errors, it can be readily seen that global, Figure 7 (winter) and Figure 10 (summer), and regional approaches, Figure 13 (winter) and Figure 16 (summer), present great similarities. As for precipitation, differences between the GDRS and RDRS are smaller than differences between GDPS and RDPS, which can be explained by the fact that global and regional reforecast systems use a much more similar configuration of the physical processes in GEM than the GDPS and RDPS.

In winter, there is an almost constant bias between the operational and reforecast approaches along the whole integration. It turn out that the GDRS/RDRS almost always have a warm bias compared to observations while the GDPS/RDPS is almost always colder (much colder for the RDPS). Due to the diurnal cycle of surface temperature error, GDRS/RDRS results are better during the first two third of the computation, and GDPS/RDPS are better after. Winter standard deviation error is generally lower for the GDPS/RDPS, but this difference tends to decrease with lead time. In summer, bias differences of surface temperature between approaches are less important as the GDPS is now slightly warmer than observations. Concerning summer standard deviation error, GDPS/RDPS are generally lower notably at the beginning and end of the integration.

Surface temperature bias and standard deviation errors from the GDRS and the RDRS only feature marginal differences (not shown here). Both approaches are warmer than observations notably in the first hours of the integration. These errors tend to be in agreement with ARCAD scores in the lower atmosphere. Given the discrepancies observed with the GDPS/RDPS scores as well as scores from other surface quantities (not shown here), this point to notable differences in the earth surface variables between the operational and reforecast approaches. These fields are coming from an SPS open loop driven by ERA-Interim in the case of the reforecast systems. While this represents a sensible first approximation to provide GEM with realistic initial surface fields, it is not optimum since such a dataset never directly sees observations though assimilation. The inclusion of clouds, atmospheric boundary layer and surface data recycling as well as data assimilation should allow mitigating this problem, as well as predicting more consistent energy transfers between the earth surface and the atmosphere.

SUMMARY AND AGENDA

This report presents the preliminary refinements and evaluations of the systems that will produce a background field for CaPA and CaLDAS, i.e. the global/regional deterministic reforecast system (GDRS/RDRS). Preliminary refinements have allowed cutting the execution time of the whole approach by almost half (without changing its results). Preliminary results (upper atmosphere and surface) have been compared to observations and operational Global and Regional Prediction Systems (namely GDPS/RDPS version 4) for the 2011 winter and summer seasons following the official scoring methodology (ARCAD and EMET). Results from the GDRS/RDRS are generally in good agreement with the GDPS/RDPS featuring a similar (or slightly larger) error compared to observations. This is promising, notably considering that the

GDRS has a twice as coarse resolution as the GDPS. Only the absolute temperature in the lowest part of the atmosphere shows a different shape with a substantial departure from the GDPS/RDPS. This difference is currently investigated, but it is strongly believed that it is caused by differences in the ground surface fields.

In this perspective, it becomes more and more clear that a recycling of clouds, atmospheric boundary layer and ground surface variables is required. Indeed, recycling ground surface variables will alleviate the need to use precomputed fields coming from an SPS open loop driven by ERA-Interim. Recycling will further improve precipitation scores and surface temperature prediction during the first hours of the reforecast considering radiation fluxes may be more realistic. Finally, recycling surface and boundary layer quantities may also help minimize the impact of a cold start with ERA-Interim, as well as improve consistency between surface and atmospheric variables (allowing more representative energy transfers between the earth surface and the atmosphere). Thus, the refinement of the initialization procedure of the GDRS/RDRS and the implementation of variables recycling are the next development step. In addition, we can now rely on the latest version of GEM (v4.8) since it very recently gained the operational status. Both of these changes should improve results and computational efficiency before incorporating the precipitation and surface data assimilation components to the methodology (CaPA and CaLDAS).

Finally, concerning observations, we have gathered a few more datasets. Their processing did not start yet, but we plan to work on this aspect soon. Summer student that will assist us with this task (May to August) have already been selected (we have received a huge interest for this training period: 87 candidates!). It is also noteworthy that we have been accepted to present the project and its preliminary results (oral presentation) at the Conference of the Canadian Water Resources Association (CWRA), May 25 to 27, Montreal.

BIBLIOGRAPHY

[1] N. Gasset and V. Fortin, "Toward a 30 Years North American Precipitation and Ground Surface Analysis," Montréal, 2015.

[2] K. Chikhar and P. Gauthier, "Impact of analyses on the dynamical balance of global and limited-area atmospheric models," *Quarterly Journal of the Royal Meteorological Society,* vol. 140, p. 2535–2545, 2014.

APPENDIX I: ACRONYM LIST

GENERAL ACRONYM:

MRB/MRD: Meteorological Research Board/Division
CPOP: “Comité des Passes Opérationnelles et Parallèles”
CMC: Canadian Meteorological Centre
RPN: “Recherche en prévision numérique” (Numerical Weather Prediction Research)

MODELSAND PREVISION SYSTEMS:

GEM: Global Environmental Multiscale Model
GEPS: Global Ensemble Prediction System
REPS: Regional Ensemble Prediction System
GDPS: Global Deterministic Prediction System
RDPS: Global Deterministic Prediction System
SPS: Surface Prediction System, formerly known as GEM-Surf
GDRS: Global Deterministic Reforecast System
RDRS: Global Deterministic Reforecast System

ASSIMILATION SYSTEMS:

EnKF: Ensemble Kalman Filter
EnVAR: Ensemble-Variational data assimilation
CaPA: Canadian Precipitation Analysis system
CaLDAS: Canadian Land Surface Data Assimilation System

OBSERVATION DATASETS:

AHCCD: Adjusted and Homogenized Canadian Climate Data (daily)
ISD: Integrate Surface Data (hourly), formerly known as Integrate Surface Hourly (ISH)
GHCN-D: Global Historical Climate Network – Daily (daily)
DAI Portal: Data Access and Integration Portal (hourly)

VERIFICATION PACKAGE:

ARCAD: “Analyse de Résultats de Cycles d'Assimilation de Données” (comparison of forecast and analysis results against radiosondes)

EMET: Surface verification system at observation points

APPENDIX II: ARCAD AND EMET VERIFICATIONS

GDRS/GDPS WINTER 2011

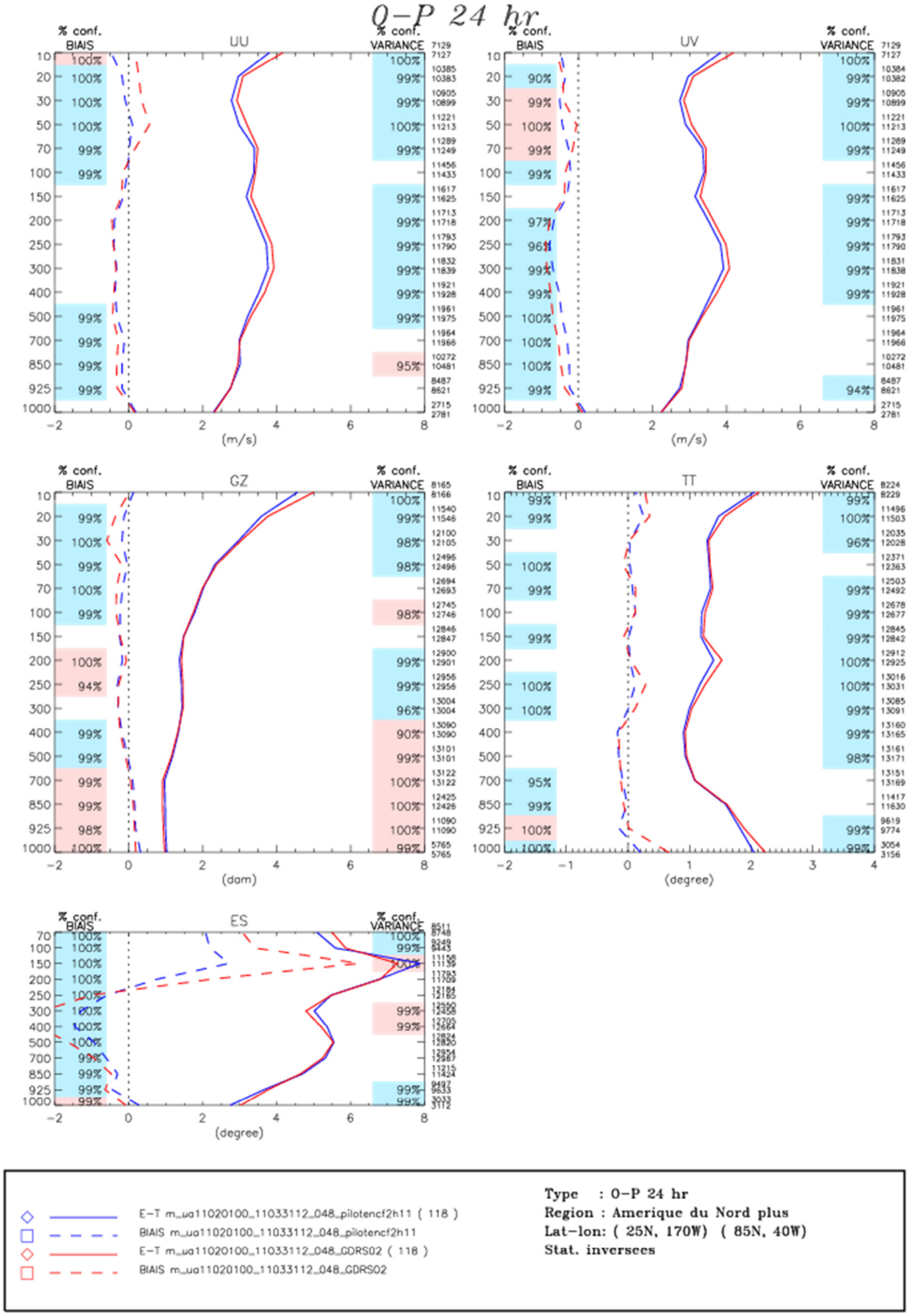


Figure 5: Winter 2011 ARCAD scores from the GDPS (blue) and the GDRS (red), namely pilotencf2h11 and GDRS02, for the North America Plus sub-domain

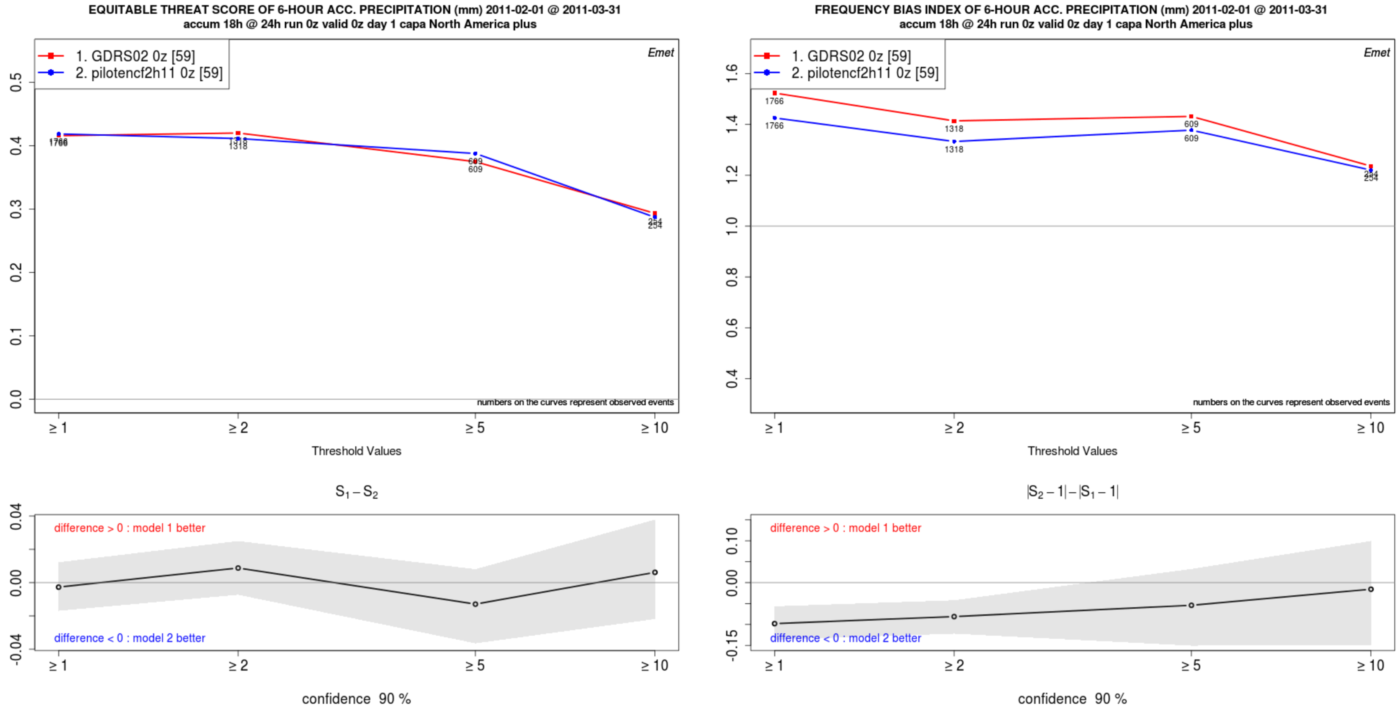


Figure 6: Winter 2011 6 h precipitation accumulation verification after 24 h lead time (0 UTC) for the GDPS (blue) and the GDRS (red), namely pilotencf2h11 and GDRS02, for the North America Plus sub-domain : equitable threat score (left), and frequency bias index (right)

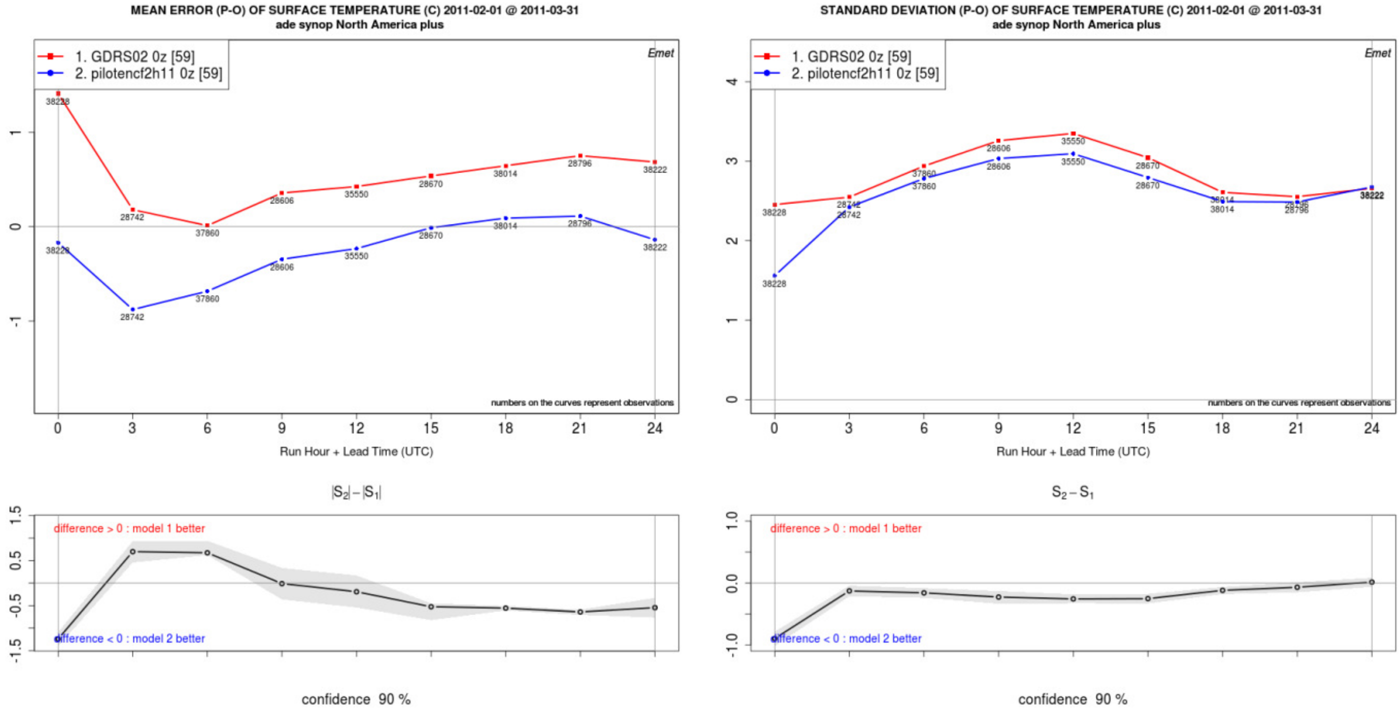


Figure 7: Winter 2011 EMET scores for surface temperature (2 m) time evolution for the GDPS (bleu) and the GDRS (red), namely pilotencf2h11 and GDRS02, for the North America Plus sub-domain: bias (left), standard error (right)

GDRS/GDPS Summer 2011

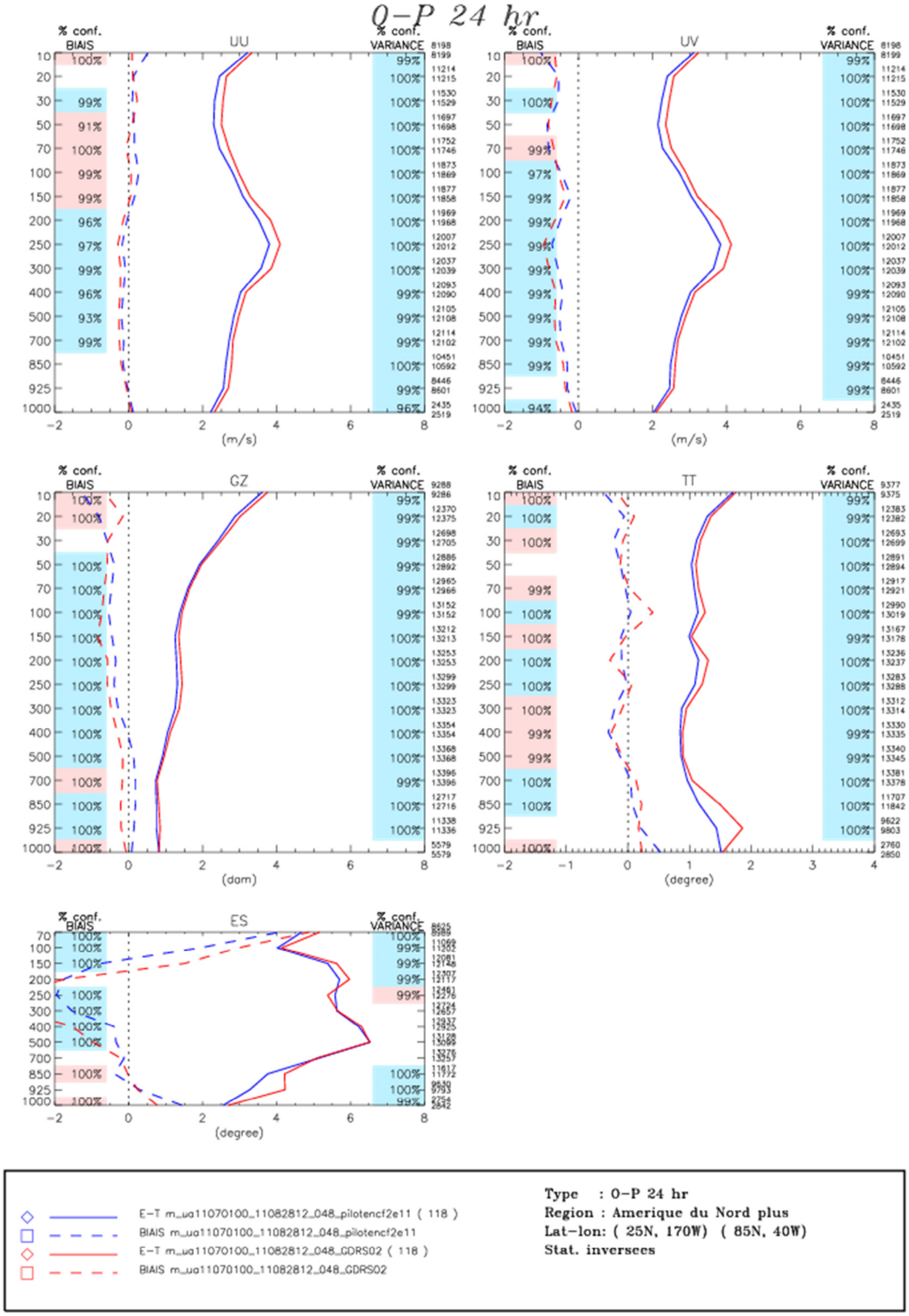


Figure 8: Same as Figure 5 for the summer 2011

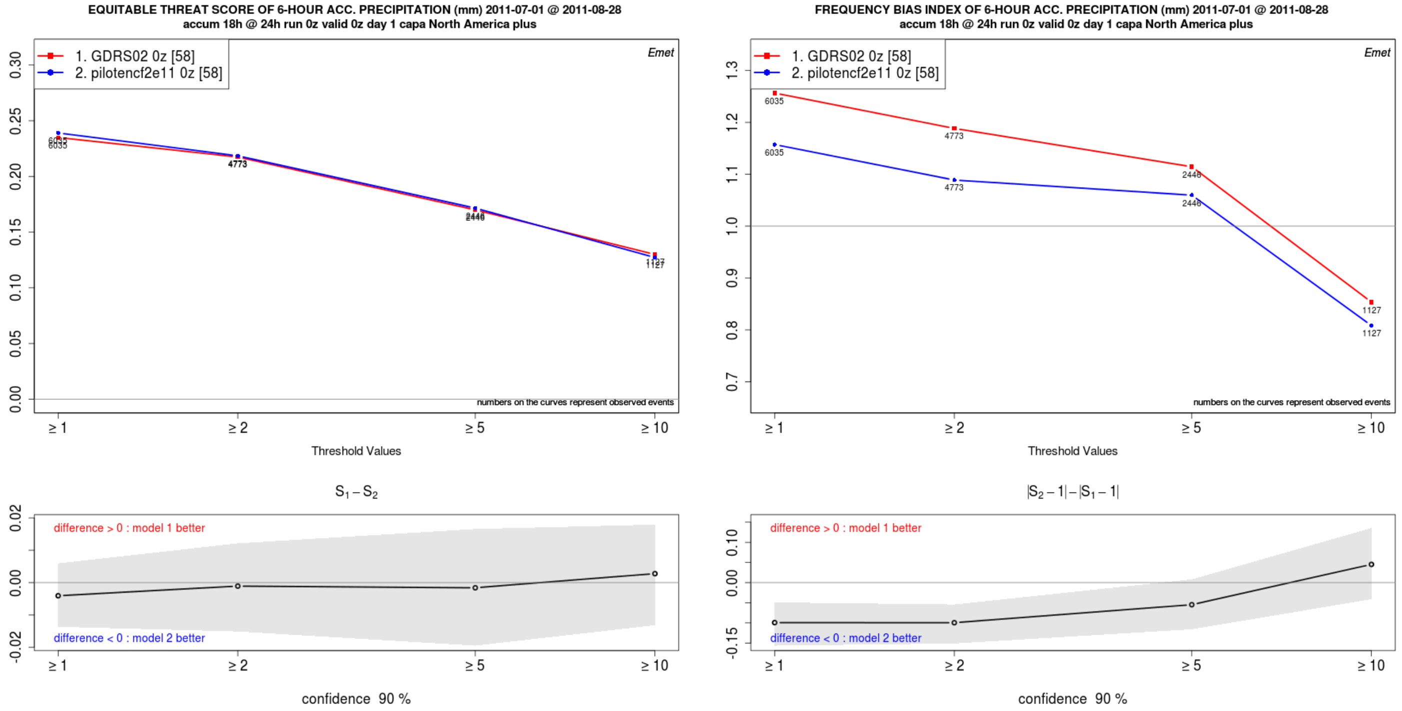


Figure 9: Same as Figure 6 for the summer 2011

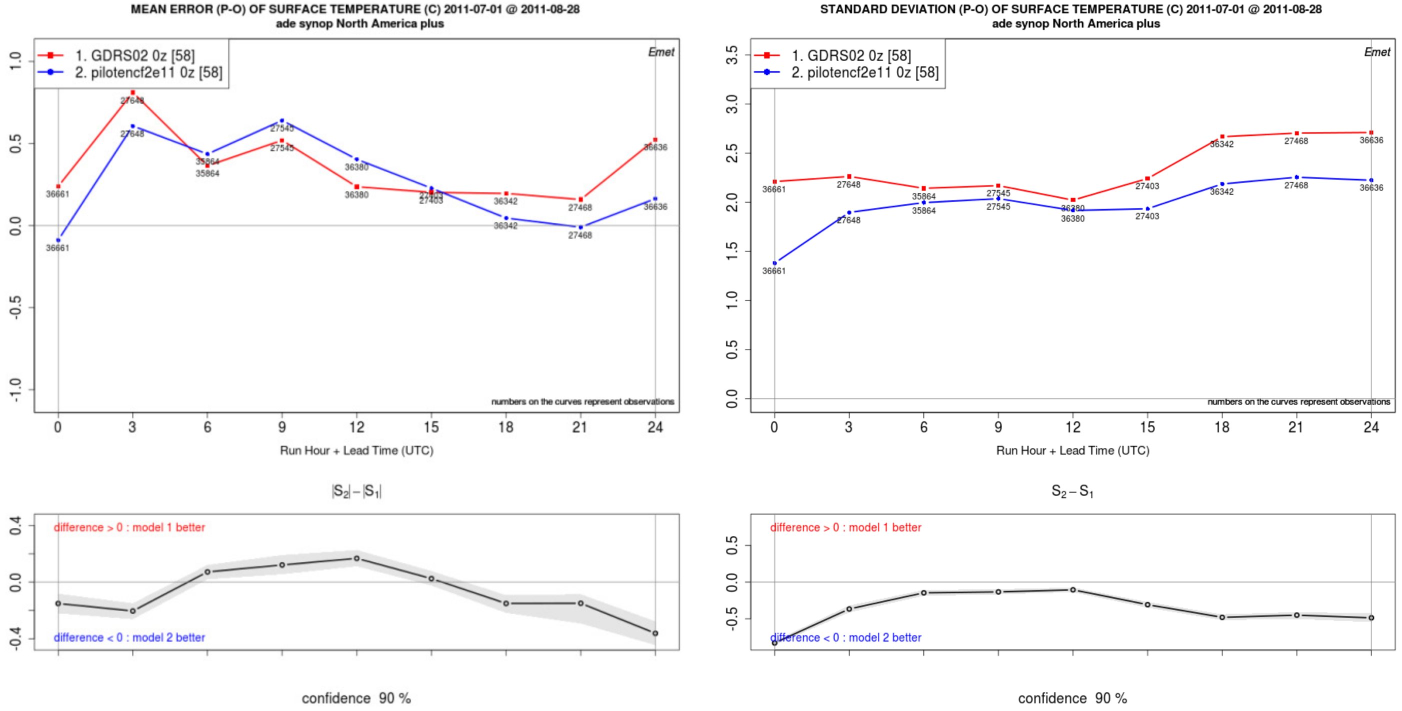


Figure 10: Same as Figure 7 for the summer 2011

RDRS/RDPS WINTER 2011

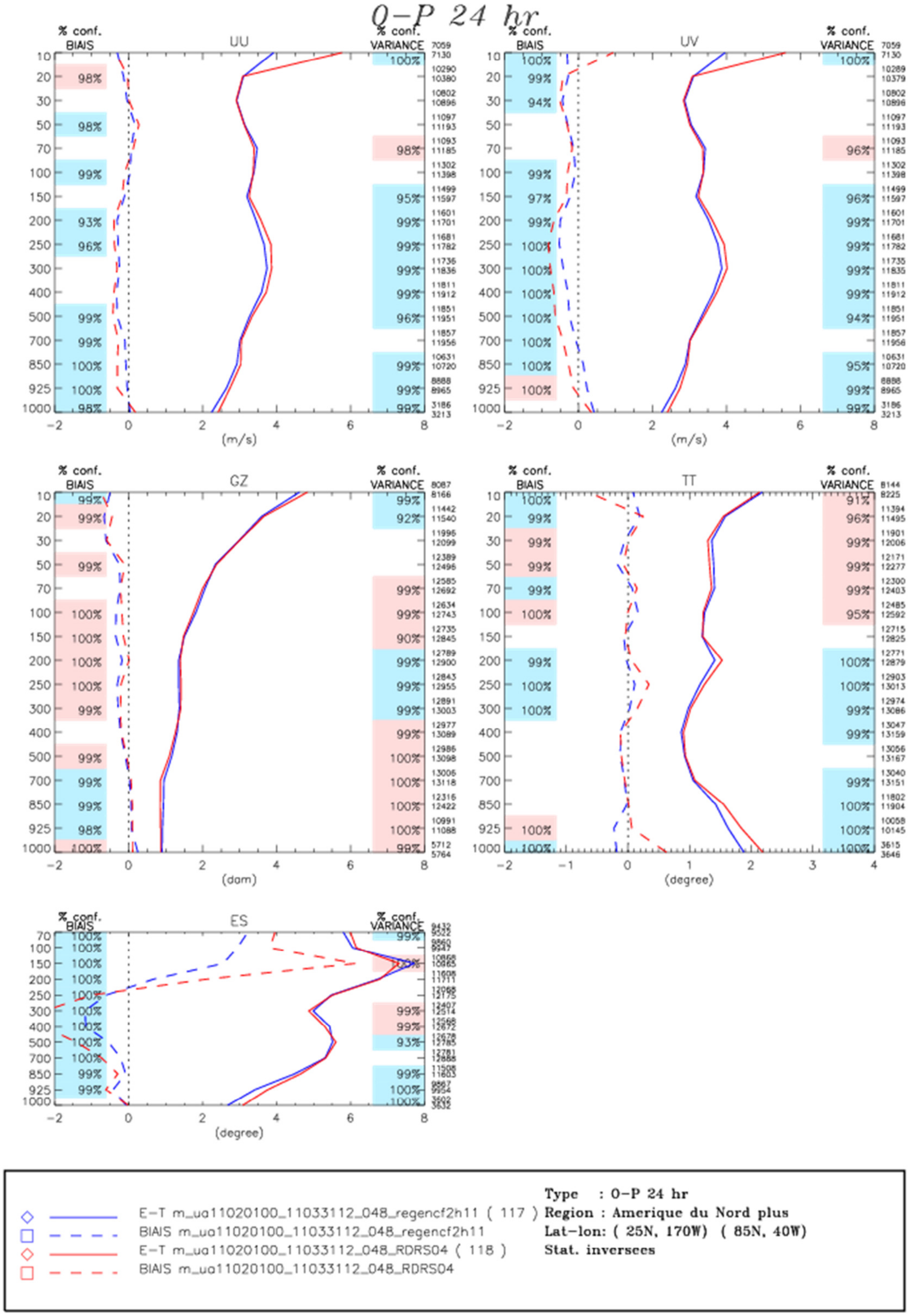


Figure 11: Same as Figure 5 for the RDPS (blue) and the RDRS (red), namely regencf2h11 and RDRS04, during the winter 2011

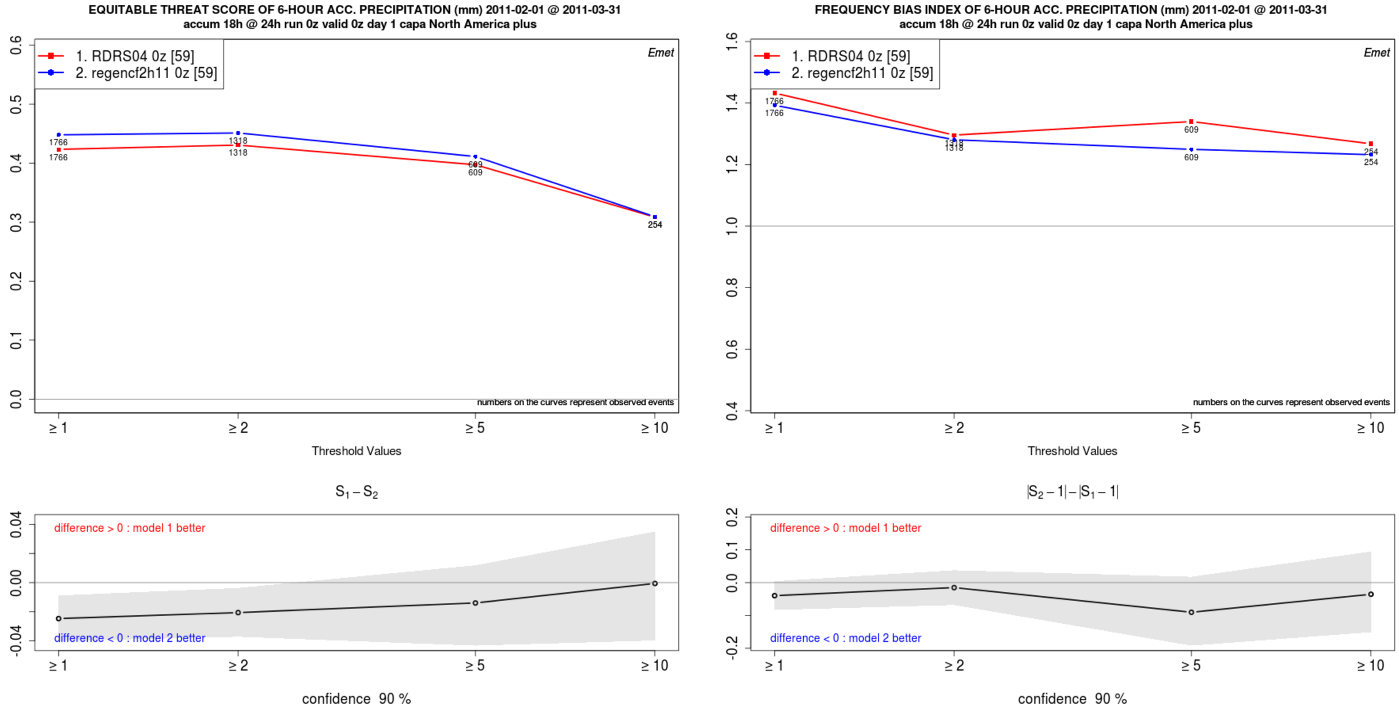


Figure 12: Same as Figure 6 for the RDPS (blue) and the RDRS (red), namely regencf2h11 and RDRS04, during the winter 2011

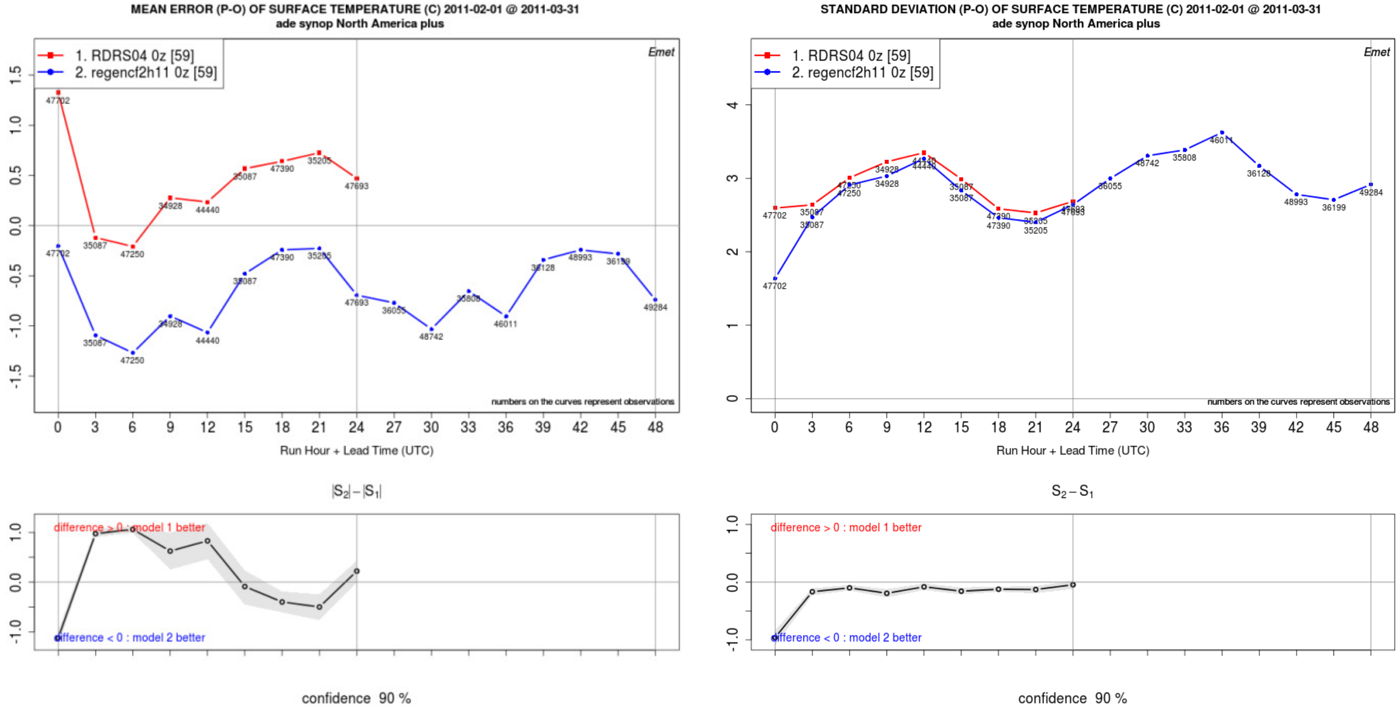


Figure 13: Same as Figure 7 for the RDPS (blue) and the RDRS (red), namely regencf2h11 and RDRS04, during the winter 2011

RDRS/RDPS Summer 2011

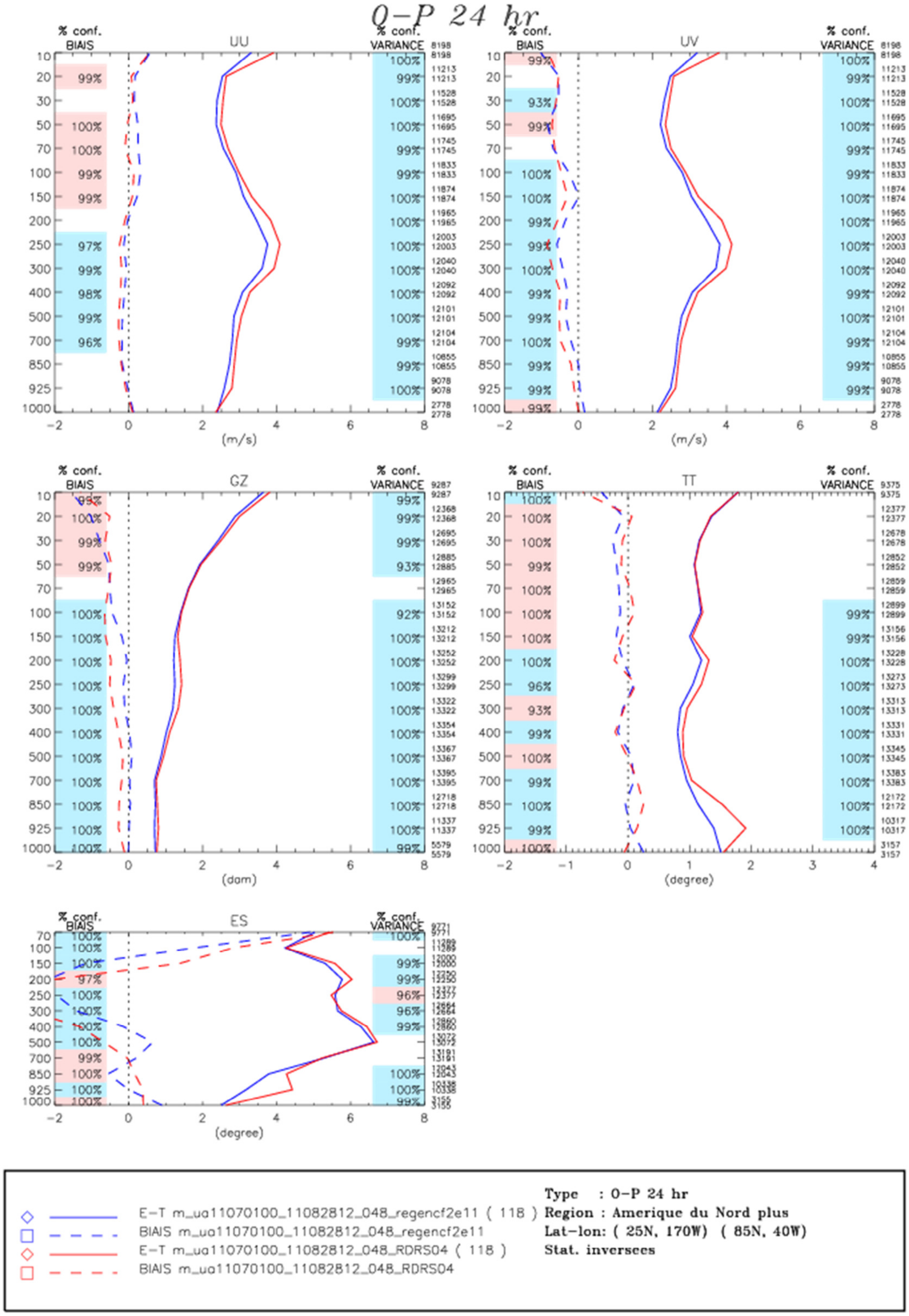


Figure 14: Same as Figure 5 for the RDPS (blue) and the RDRS (red), namely regencf2e11 and RDRS04, during the summer 2011

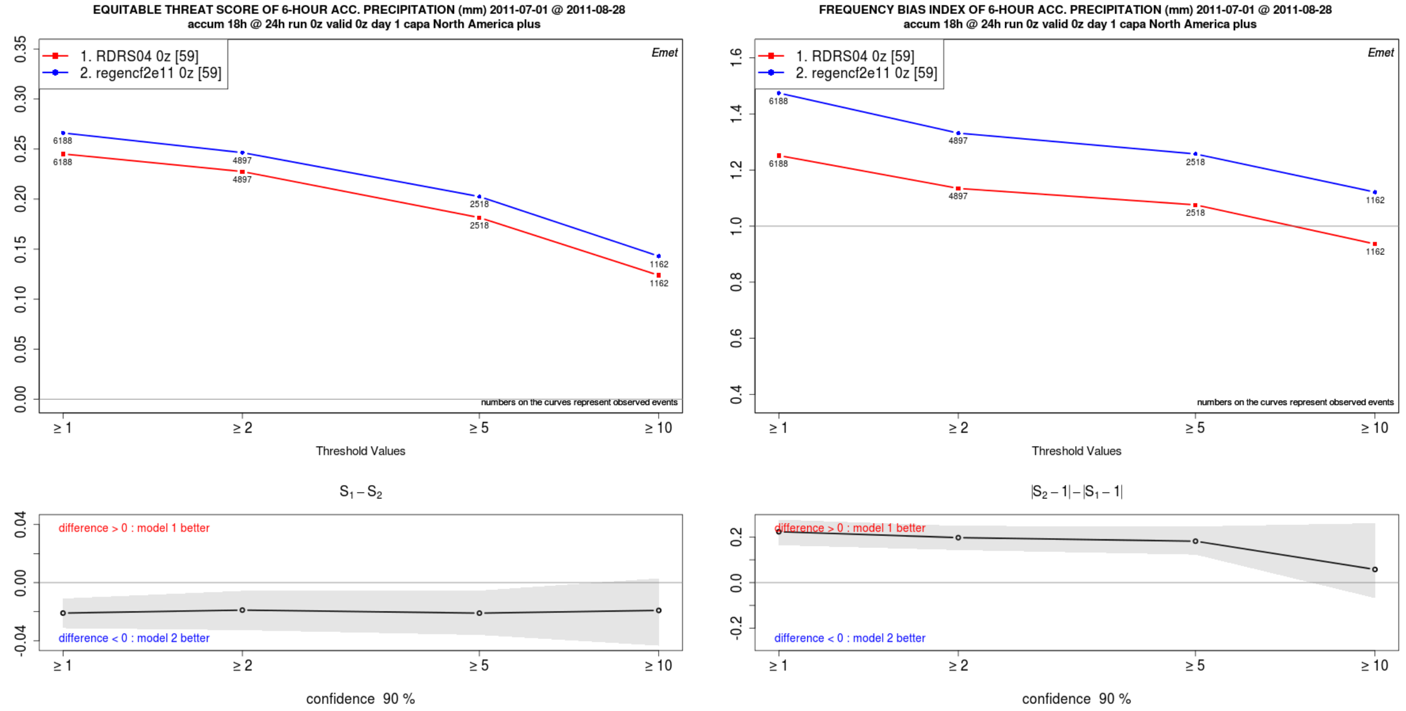


Figure 15: Same as Figure 6 for the RDPS (blue) and the RDRS (red), namely regencf2e11 and RDRS04, during the summer 2011

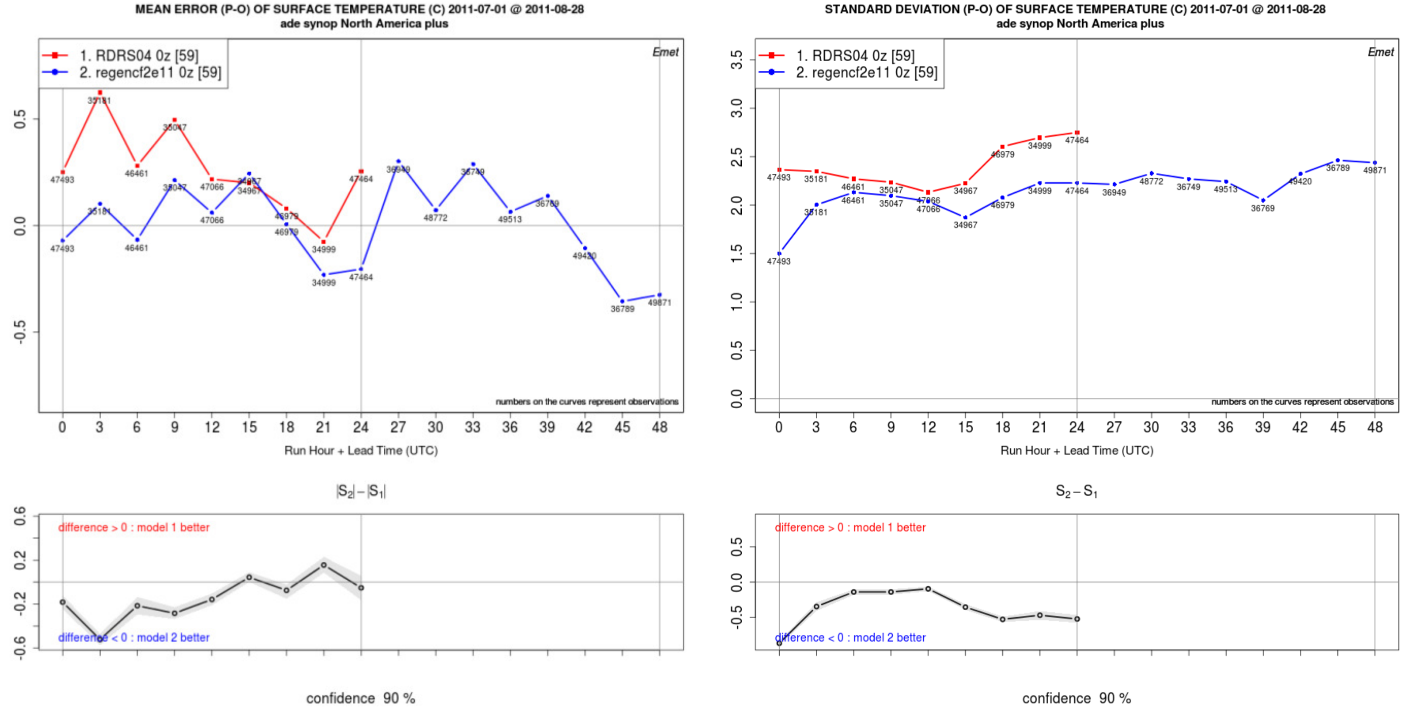
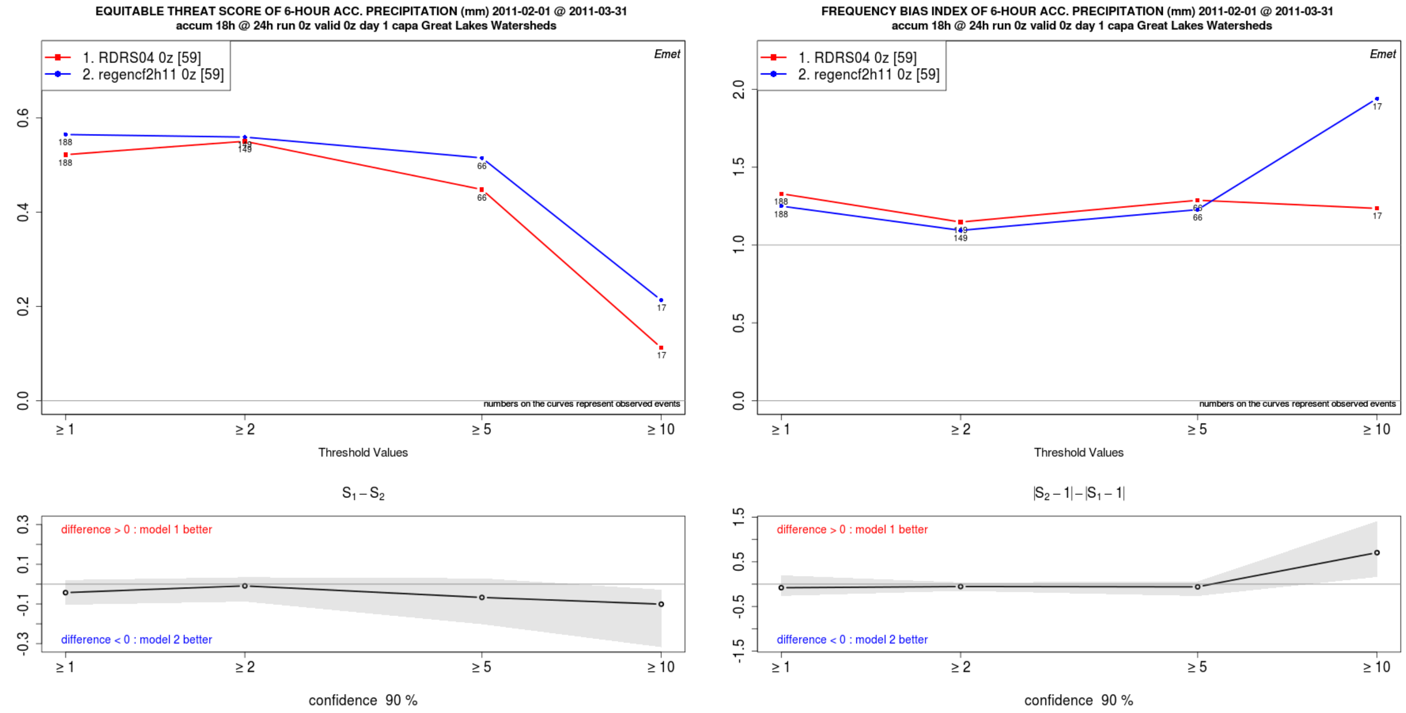


Figure 16: Same as Figure 7 for the RDPS (blue) and the RDRS (red), namely regencf2e11 and RDRS04, during the summer 2011

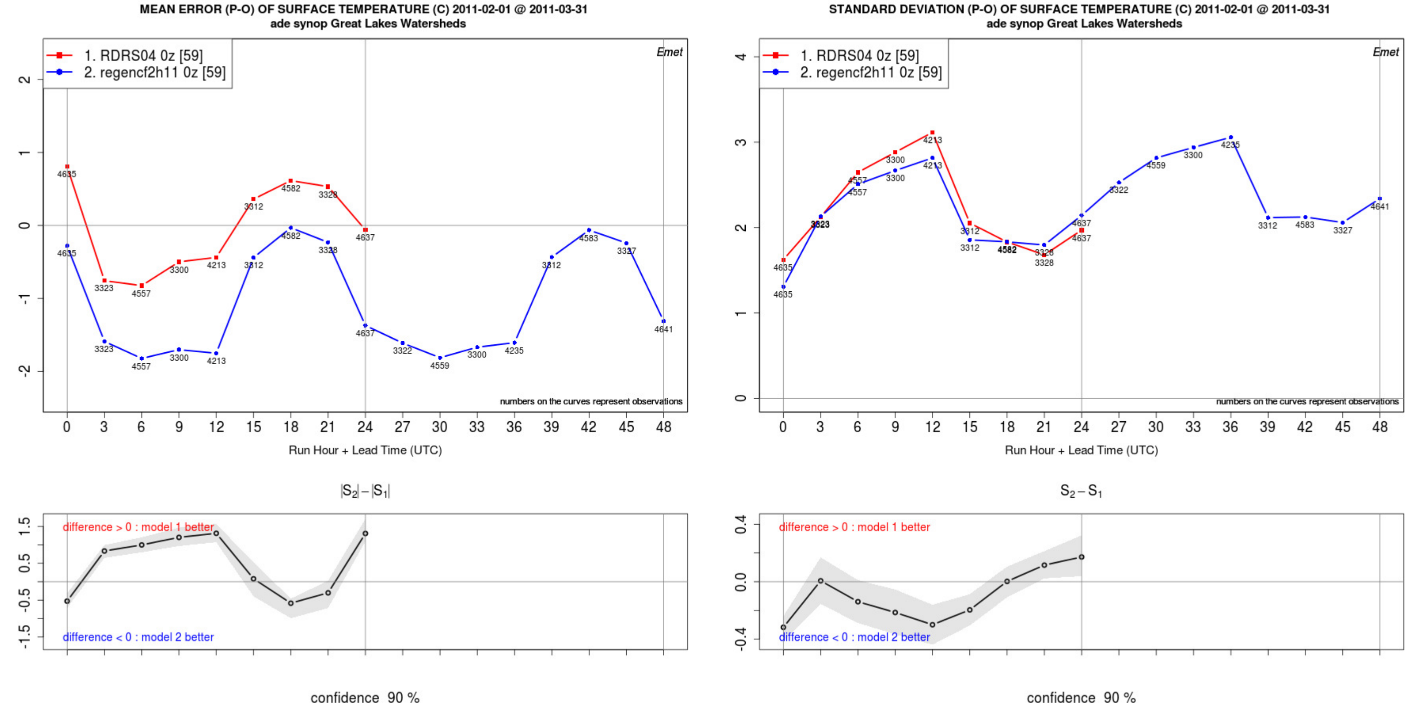
GREAT LAKES WATERSHEDS SUB-DOMAIN

WINTER 2011


EQUITABLE THREAT SCORE OF 6-HOUR ACC. PRECIPITATION (mm) 2011-02-01 @ 2011-03-31
accum 18h @ 24h run 0z valid 0z day 1 capa Great Lakes Watersheds

FREQUENCY BIAS INDEX OF 6-HOUR ACC. PRECIPITATION (mm) 2011-02-01 @ 2011-03-31
accum 18h @ 24h run 0z valid 0z day 1 capa Great Lakes Watersheds

Figure 17: Same as Figure 6 for the RDPS (blue) and the RDRS (red) during the winter 2011 for the Great Lakes Watersheds Sub-Domain


MEAN ERROR (P-O) OF SURFACE TEMPERATURE (C) 2011-02-01 @ 2011-03-31
ade synop Great Lakes Watersheds

STANDARD DEVIATION (P-O) OF SURFACE TEMPERATURE (C) 2011-02-01 @ 2011-03-31
ade synop Great Lakes Watersheds

Figure 18: Same as Figure 7 for the RDPS (blue) and the RDRS (red) during the winter 2011 for the Great Lakes Watersheds Sub-Domain

SUMMER 2011

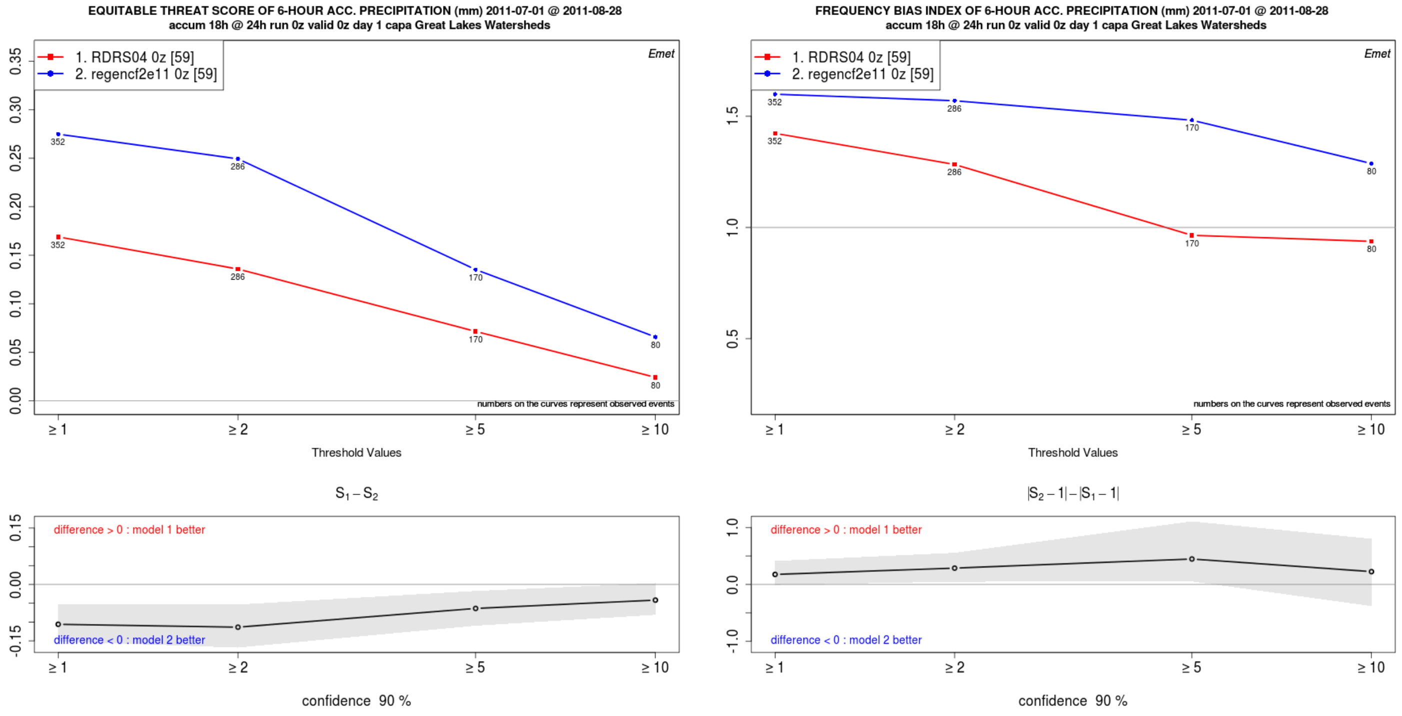


Figure 19: Same as Figure 6 for the RDPS (blue) and the RDRS (red) during the summer 2011 for the Great Lakes Watersheds Sub-Domain

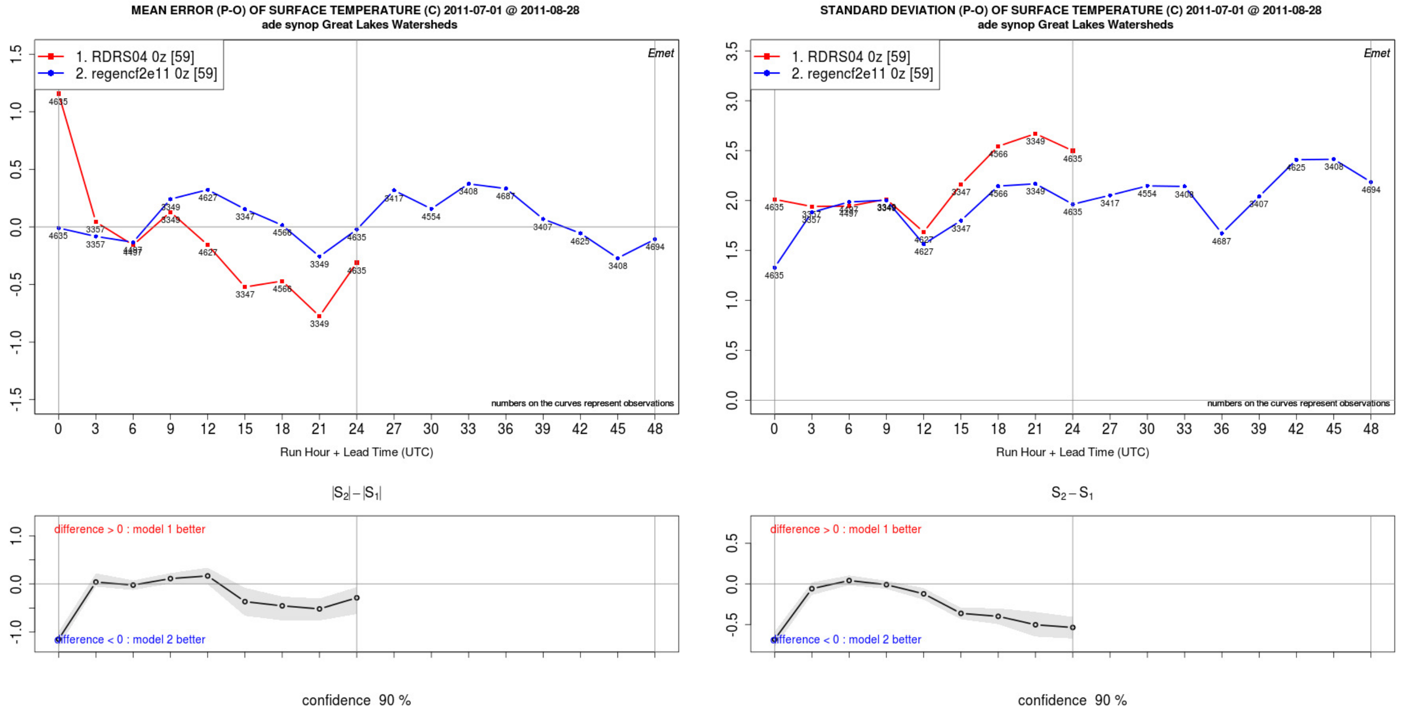


Figure 20: Same as Figure 7 for the RDPS (blue) and the RDRS (red) during the summer 2011 for the Great Lakes Watersheds Sub-Domain