Coupled Atmosphere-Ice-Ocean Forecast System in the Gulf of St-Lawrence

Technical note

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Novembre 18, 2014
Version 3.0.0

Version	Date	Auteur	Modification
1.0	10/09/2014	S. Dyck	• Creation of Document, based on the first technote of the RDPS-CGSL (Manon Faucher)
1.1	10/10/2014	G. Smith, V. Vu, S. Dyck	• Various edits to content and grammar • Corrected computational requirements • Included precipitation scores for summer
1.2	10/14/2014	S. Dyck	• Reformatted the document and removed upper air scores and resources sections
1.3	10/17/2014	A. Mahidjiba	• Adjustments according to the Technical Note template (text, titles, margins, layout, header and foorter, …) • Some other text suggestions + Table of contents • Adjustment of figures (etikets and labels of the axes in the figures are very small. Tiles will be added to these figures) • Some comments about figures and table

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Major Update to the Coupled Atmosphere-Ice-Ocean Forecast System

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Abstract

The Regional Deterministic Prediction System, Coupled in the Gulf of St. Lawrence was updated with the newest version of the GEM atmospheric model, a new state of the art multiprocessor ocean model NEMO, and a more consistent coupling method in preparation for the migration towards a newer supercomputer architecture. We also updated the task manager of the system to MAESTRO to make the migration easier still. The validation results of these changes, although not anticipated to be a major improvement, show that the updated system does perform better than the original system.

Nomenclature

Acronyms :

- CMC : Canadian Meteorological Centre
- RDPS-CGSL : Regional Deterministic Prediction System, Coupled in the GSL
- HRDPS : High Resolution Deterministic Prediction System
- CPOP : "Comité des passes opérationnelles et parallèles"
- GEM : Global Environment Multi-Scale
- CICE Community Ice CodE
- NEMO : Nucleus for European Modeling of the Ocean
- RMPS-GSL : Regional Marin Prediction System for the GSL

- NLMCM : National Laboratory for Marine and Coastal Meteorology
- MoGSL: Model of the Gulf of St. Lawrence

1. Introduction

The Canadian Meteorological Centre (CMC) has been running a coupled atmosphere-ice-ocean forecasting system for the Gulf of St. Lawrence (GSL) in experimental mode since December 2007 and in fully operational mode starting prior to the ice season in 2011. It has been named the Regional Deterministic Prediction System, Coupled in the GSL (RDPS-CGSL). The system provides meteorological forecasting over the GSL and surrounding coastal regions. It also provides sea-ice forecasts for the Gulf that includes ice extent, fraction, thickness and internal pressure. Model output from this system is used by the operational Regional Deterministic Wave Prediction System (RDWPS) over the GSL and the experimental High Resolution Deterministic Prediction System (HRDPS) for the maritime domain. It is initialized with 3D ocean pseudo-analysis from the Regional Marine Prediction System in the GSL, as well as surface and boundary conditions produced by the RDPS.

In preparation for the upcoming super computer migration a proposal to update the operational RDPS-CGSL was accepted by the "Comité des passes opérationnelles et parallèles (CPOP)" for a parallel run in May 2014. This update includes:

- a general update to the atmosphere model,
- a replacement of the ice-ocean component,
- a change to the task sequencer used (Maestro)
- an improved coupling method.

These changes will be reviewed in the following sections.

The main goal of this update was to deliver a system that would be easily transferred to the new supercomputer and in so doing, unify the ocean component of the RDPS-CGSL with other coupled and uncoupled ocean and ice systems currently being implemented within the CMC. The original intent was not to improve the quality of the ocean, ice or meteorology forecasts; however a significant improvement in many surface scores compared to the previous version of the RDPS-CGSL are found. The winter and summer verification scores will be presented in section 7.

This project is a realization of the joint effort between several Research, Development and Operational departments of Environment Canada and Fisheries & Oceans Canada. It follows from the work of Pellerin *et al*. (2004) showing the role of two-way coupling between an atmospheric and an ocean-ice model in a case of rapid ice movement over the CGSL and the impact on coastal weather forecasts.

2. Model Configurations

2.1. GEM

The CMC atmospheric Global Environment Multi-Scale (GEM) model (Côté *et al.,* 1998, Mailhot et al. 2006) is used in a limited area model configuration at a 10km (0.09 degree) resolution and 80 staggered vertical levels. The version of GEM was upgraded from v4.0.7 to v4.6.0-rc8 with RPN physics v5.6.3. As soon as the experimental version is closed, an upgrade will be made to the final 4.6.0 version of GEM. The domain is a 360 by 400 rectangular latitude-longitude projection that have grid point collocated with the grid points of the operational RDPS, at the same resolution. The timestep for the model was reduced to 225 seconds for compatibility with the coupling methodology. Meteorological variables are output hourly. The namelist parameters for our configuration were based on the operational RDPS. One parameter is of particular note is Z0TRDPS300. This parameter changes the way heat and humidity fluxes vary with respect to increasing wind speed at the air-sea interface, and must be set to true, which was not the case for the original RDPS-CGSL.

2.2. NEMO-CICE

The ice and ocean components are run together in a seamless coupled simulation. The Community Ice CodE (CICE) sea-ice model (Hunk *et al*., 2010) was updated from version 1.0 to 4.0 and the Saucier *et al* ocean model MoGSL was completely replaced with NEMO (Nucleus for European Modeling of the Ocean, Madec 2008) version 3.1. Indeed, NEMO and CICE are supported by a large scientific community and are based on more efficient computing technologies than the current system and thus will facilitate future advances toward increases in resolution and the introduction of new scientific developments.

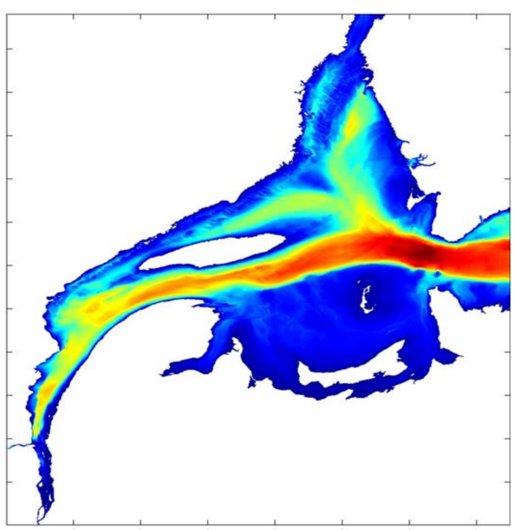

Figure 1: Gulf of St Lawrence grid with colour contours denoting relative bottom bathymetry.

NEMO-CICE is a three dimensional ocean circulation model driven by tides and observed river runoffs at lateral boundaries with a multi-category ice model with 4 layer thermodynamics. It has a resolution of 5km on a 149 by 236 rotated-Mercator grid. The timestep for the ice-ocean model is the same as the atmospheric model at 225 seconds. It is initialized by the Regional Marine Prediction System for the GSL (RMPS-GSL), an analysis that assimilates, via a direct insertion technique, RADARsat image analyses of sea-ice when available.

Information from the St. Lawrence River is provided by a one-dimensional hydrological model extending from Québec city to Montreal.

A more complete description, evaluation and comparison with the old MoGSL ocean model are provided in a separate technical note for the RMPS-GSL which also includes an evaluation of simulated sea-ice. Readers wishing more details can refer to Roy et al. [2014] .

3. Coupling Strategy

At each timestep, coupling of GEM and NEMO-CICE is done via an exchange of surface and radiation fluxes through a common GOSSIP server (Bouhemhem 2004). **Figure *2*** shows a schematic of the coupling strategy used between the ocean, atmosphere and sea-ice models. The higher resolution model, in this case NEMO-CICE, calculates the surface momentum, heat and fresh water fluxes based on variables and fluxes received by GEM and then passes the information back to GEM through an aggregation process onto the coarser resolution grid. Consistency is maintained by the fact that both models use identical physics subroutines to calculate the fluxes.

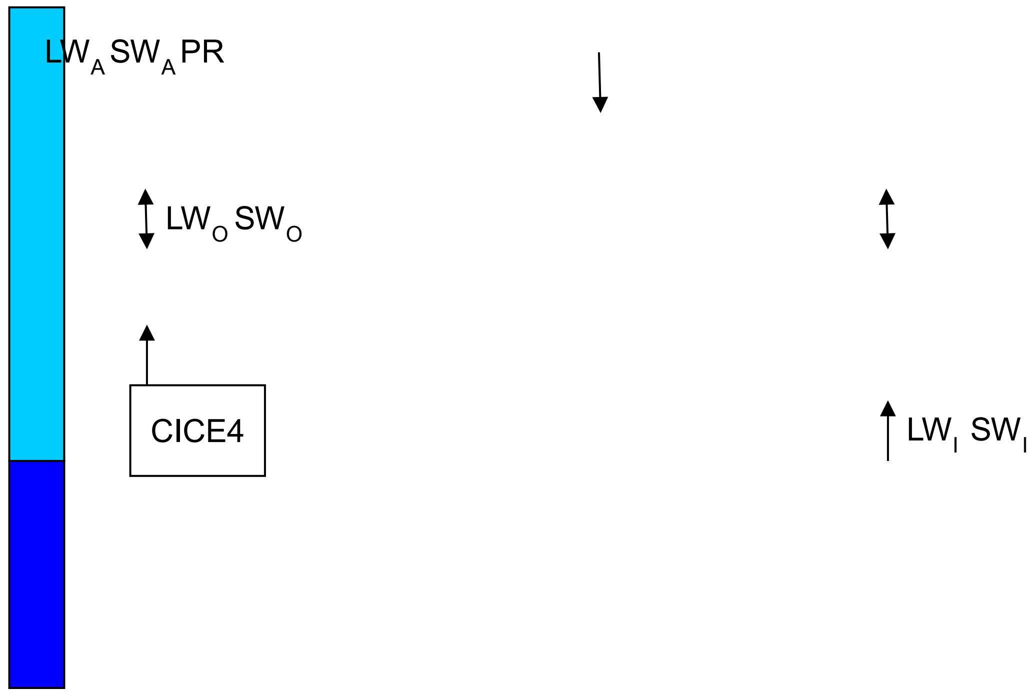

Figure 2: Coupling Schematic. The abbreviations used are as follows: LW (long wave), SW (short wave), SH (sensible), LH (latent), PR (precipitation), SB (sublimation), EV (evaporation), Tau (wind stress)

This technique differs from the original coupling method used by the first version of the coupled GSL model because the atmosphere and ocean models would use their own subroutines to calculate the fluxes based on the transfer of variables alone. In addition, for every one ocean timestep in the original setup the atmospheric model made two atmospheric timesteps. As the timestep had to be decreased due to an increased vertical resolution of the GEM model, this led to a coupling exchange at each timestep for both models. The comprehensive list of fluxes, and variables used to calculate those fluxes can be found in the following table.

Table 1: Calculation of Surface Fluxes

Fluxes (Air-A, Ocean-O, Ice-I)	**Variables used in calculation**
Sensible Heat (SH_{AO})	Ocean Temperature (T_O) Air Temperature of the first thermodynamic model level (T_A) Height of the first thermodynamic model level (Z_H) Wind at the first momentum model level (U_A) Height of the first momentum model level (Z_M)
Evaporation (EV_{AO})	Specific Humidity of the first thermodynamic model level

	(q_A,) Saturation Specific Humidity at the ocean surface (q_O) T_A, T_O, U_A, Z_M, Z_H
Latent Heat (LH_{AO})	EV_{AO}
Momentum (Tau_{AO})	Wind at the ocean surface (U_O) U_A, T_A, T_O, Z_M, Z_H
Sensible Heat (SH_{AI})	Ice Temperature (T_I) T_A, U_A, Z_M, Z_H
Sublimation (SB_{AI})	Saturation Specific Humidity at the ice surface (q_I) q_A, T_A, T_I, U_A, Z_M, Z_H
Latent Heat (LH_{AI})	SB_{AI}
Momentum (Tau_{AI})	U_A, T_A, T_I, U_I, Z_M, Z_H

4. Operational Forecast Setup

The RDPS-CGSL is run four times a day for 00z, 06z, 12z and 18z initialization times for a forecast horizon of 48 hours. It relies on the completion of the operational RDPS and the RMPS-GSL as the analyses produced by these systems are used to initialize GEM and NEMO-CICE respectively. The hourly RDPS output is also used to force the lateral boundaries throughout the 48 hour forecast.

The unified task sequencer that is used to control the submission of pre-processing jobs, post-processing jobs and the coupled model runs is MAESTRO. It is the official sequencer for the new supercomputer, and as such will facilitate the migration of the system.

5. Results

5.1 Winter 2014

The system was run once daily initialized at 00z during the winter months of 2014. It was monitored by CMC, the National Laboratory for Marine and Coastal Meteorology (NLMCM), and the Canadian Ice Services to provide user feedback. Following the documented CPOP standards for the RDPS-CGSL we evaluated the system and were able to see a marked improvement in the overall surface scores and upper air scores. The precipitation scores show no significant improvement or degradation in the forecast between models. The details will be discussed in the Objective Evaluation section which immediately follows.

A subjective evaluation of the RDPS-CGSL was conducted at the same time by Mark Pilon and Serge Desjardins at the NLMCM and will be summarized in the Subjective Evaluation section.

Objective Evaluation:

For this evaluation we used the period from January 1st 2014 to March 31st 2014 inclusive. The period starts with very cold temperatures, combined with rapid formation of sea-ice. Although mild conditions were seen during mid January, the following weeks produced consistently cold temperatures and a substantive ice cover that persisted until the end of the period.

In order to produce the surface scores used in the evaluation of the RDPS-CGSL, we used the EMET verification package. With this software we examined the bias, standard deviation, root mean square error and the correlation of the following variables: Air temperature (TT), dew point temperature (TD), surface pressure (P0), and wind speed (UV). Only the standard deviation and bias are presented here. For the precipitation we used the Heidke Skill Score and the Proportion Correct to evaluate the forecasts. A summary for the most commonly evaluated variables are provided in Figure 3.

TT	Bias			Correlation			Standard Deviation			Root Mean Square		
	R110K80N	GF1058GN	ALSIPS	R110K80N	GF1058GN	ALSIPS	R110K80N	GF1058GN	ALSIPS	R110K80N	GF1058GN	ALSIPS
HR18	−0.24	0.19	0.13	96.4%	96.0%	96.7%	1.98	2.01	1.83	2.00	2.02	1.83
HR30	−1.23	−0.14	−0.49	93.6%	94.0%	94.4%	3.05	2.87	2.76	3.29	2.87	2.80
TOTAL	−0.87	−0.11	−0.33	94.6%	94.7%	95.2%	2.65	2.56	2.43	2.81	2.57	2.46

UV	Bias			Correlation			Standard Deviation			Root Mean Square		
	R110K80N	GF1058GN	ALSIPS	R110K80N	GF1058GN	ALSIPS	R110K80N	GF1058GN	ALSIPS	R110K80N	GF1058GN	ALSIPS
HR18	−0.24	−0.24	−0.23	71.5%	71.0%	72.1%	5.39	5.42	5.33	5.39	5.42	5.34
HR30	0.80	0.82	0.72	73.7%	73.7%	74.1%	5.31	5.33	5.29	5.37	5.39	5.34
TOTAL	0.46	0.45	0.40	73.3%	73.0%	73.7%	5.30	5.33	5.28	5.34	5.37	5.31

TD	Bias			Correlation			Standard Deviation			Root Mean Square		
	R110K80N	GF1058GN	ALSIPS	R110K80N	GF1058GN	ALSIPS	R110K80N	GF1058GN	ALSIPS	R110K80N	GF1058GN	ALSIPS
HR18	0.15	0.71	0.38	95.5%	95.9%	95.8%	2.55	2.43	2.44	2.56	2.53	2.47
HR30	−1.20	−0.17	−0.74	94.5%	94.9%	95.3%	3.09	2.94	2.81	3.32	2.95	2.90
TOTAL	−0.68	0.10	−0.32	95.0%	95.2%	95.5%	2.85	2.74	2.67	2.96	2.77	2.73

Figure 3: A summary of score values for TT, TD and UV for the RDPS(R110K80N), the original RDPS-CGSL(GF1058GN) and the new RDPS-CGSL(ALSIPS) for hours 18 and 30 of the forecast and overall. For clarity score values highlighted in green are the best of the three models, values highlighted in orange are the worst.

Overall the updated RDPS-CGSL performs better than either the RDPS or the original RDPS-CGSL for this period where surface variables are concerned.

Subjective Evaluation:

Throughout the evaluation period, from December 8th to March 28th 2014, the NLMCM was assessing various aspects of the RDPS-CGSL including coupling indices, predicted air temperatures, forecasted precipitation, ice conditions and air-sea heat fluxes both over the entire period as a whole and multiple case studies. Details can be found in a document produced in support of the original CPOP proposal (Pilon and Desjardins, 2014). We take here an excerpt from the document to illustrate the main conclusions from the report:

"1. The NEMO-CICE coupled model [regl_NC] demonstrated a significant reduction in MAE over the current operational coupled model [regl_OC], particularly during the period from 18 Dec., 2013 until 8 Jan., 2014.

2. The bias of the regl_NC was essentially the same as that of the regl_OC although opposite in sign. The largest improvement of the bias of the regl_NC over the regl_OC occurred in the early season when the Gulf still had minimal ice cover. The bias of the regl_NC is negative just as it is for the RDPS [regl_A] while that of the regl_OC is positive.

3. The regl_NC forecast performance is more consistent for larger ACI values showing less scatter in the MAE of forecast 1.5 m temperature. This means that the larger the effect of coupling the more reliably the regl_NC forecasts more accurate screen temperature forecasts than the regl_OC or the regl_A.

4. The regl_OC model had the lowest MAE when forecasting 48 hr QPF amounts for the cases studied when compared to observed 48 hr observed precipitation accumulations. The regl_NC model had the lowest bias when forecasting 48 hr QPF amounts for the cases studied when compared to the observed 48 hr observed precipitation accumulations. Overall the differences between the regl_NC and regl_A model are not operationally significant. However the differences between the regl_OC and regl_A appear to be more substantial particularly where the air mass holds more heat and moisture. Furthermore this does not seem to be associated with the effects of coupling as this bias is most noticeable upstream in the warm waters south of NS and NL.

5. In the five cases studied the regl_NC showed varying degrees of skill in ice concentration and coverage forecasts but generally performed better than the regl_OC *particularly with ice concentration. Neither model seemed to do well forecasting ice in the northern waters, southwest of the Strait of Belle Isle.*

6. Regarding forecasting the movement of the ice field in two cases studied, in one the regl_NC appeared to give a the best forecast (Feb. 12) while in the second case neither model was clearly better than the other (Mar. 26 case)

7. A subjective evaluation of the initialization of the ice field in the regl_NC was considered to be as good if not better than the regl_OC in the cases studied. However, at times both models did not appear to initialize the ice fields well - so that they were similar to the CIS analysis. (eg case 1 regl_OC, case 3 regl_NC,)

Conclusion: It is recommended that the new coupled system be implemented as it has demonstrated improved skill in handling ice fields and forecast screen level temperatures and demonstrated similar skill in the cumulative 48 QPF forecasts when compared to the current operational coupled model."

5.2. Summer 2014

The updated RDPS-CGSL was put into parallel August 5, 2014. At the end of September we evaluated the major surface variables, precipitation and upper air scores. The conclusions drawn from the winter verification period do not change. Overall we either see a slight improvement or no significant change in surface scores and precipitation scores (**Error! Reference source not found.**).

6. Conclusion

The main objective of this implementation was to update the atmospheric model version and to replace the existing ice-ocean model by NEMO-CICE (along with the new flux-coupling methodology). The evaluation of this system over the winter 2014 showed a significant improvement in surface atmospheric scores as compared to the operational coupled system, with the elimination of numerous forecast busts. The important improvement found here is due in part to the use of an improvement in the roughness length scales used for momentum, heat and moisture. These results will be further elaborated and studied as part of a scientific publication currently in preparation.

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Appendix A: Winter Surface Scores

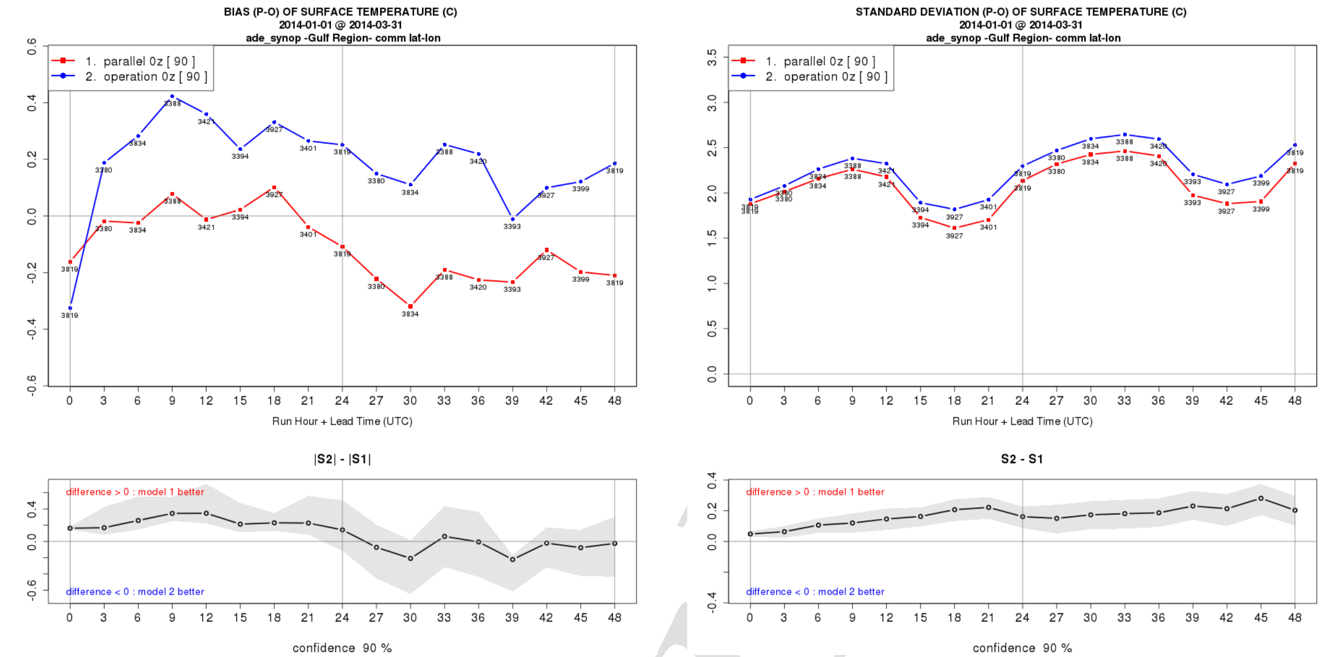

Figure 3 : EMET generated surface scores for air temperature

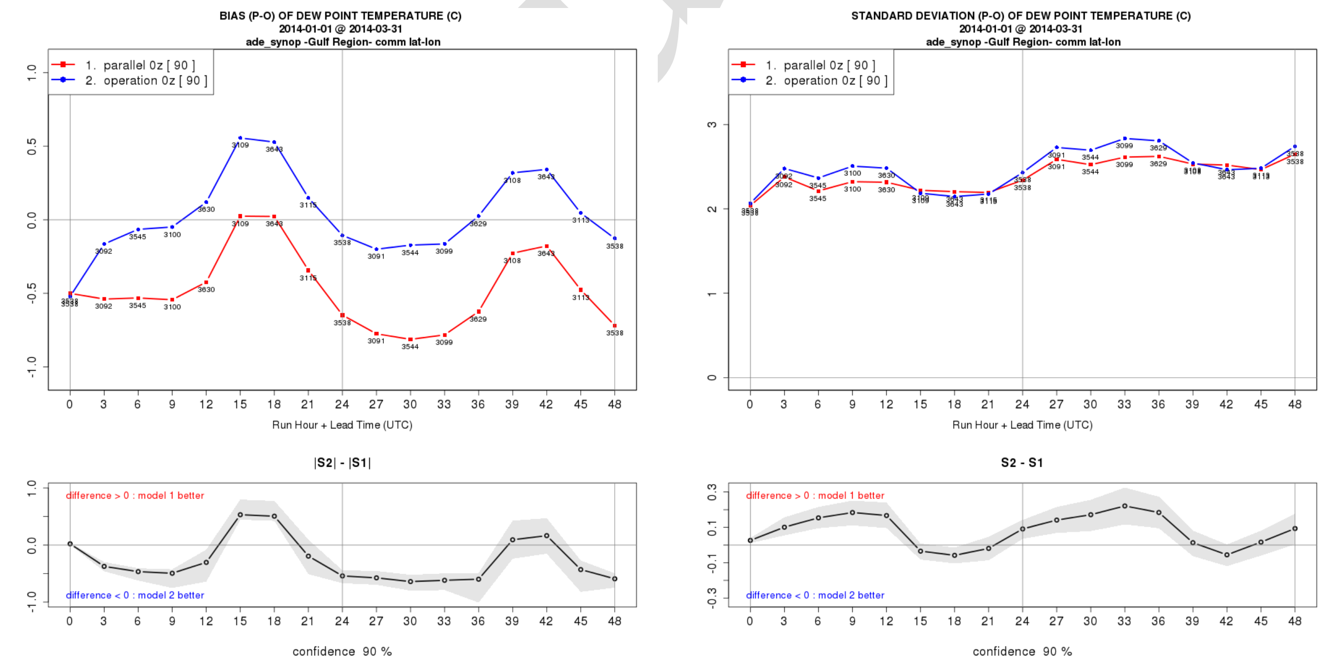

Figure 4 : EMET generated surface scores for dew point temperature

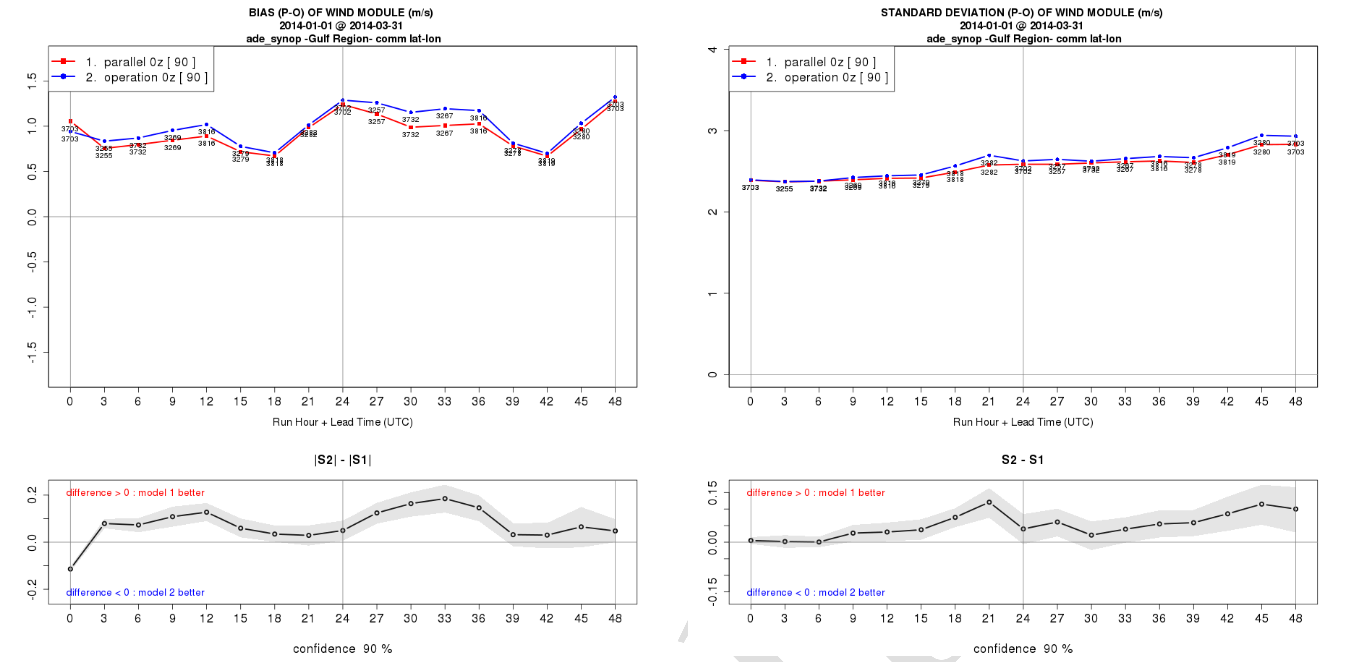

Figure 5 : EMET generated surface scores for wind modulus

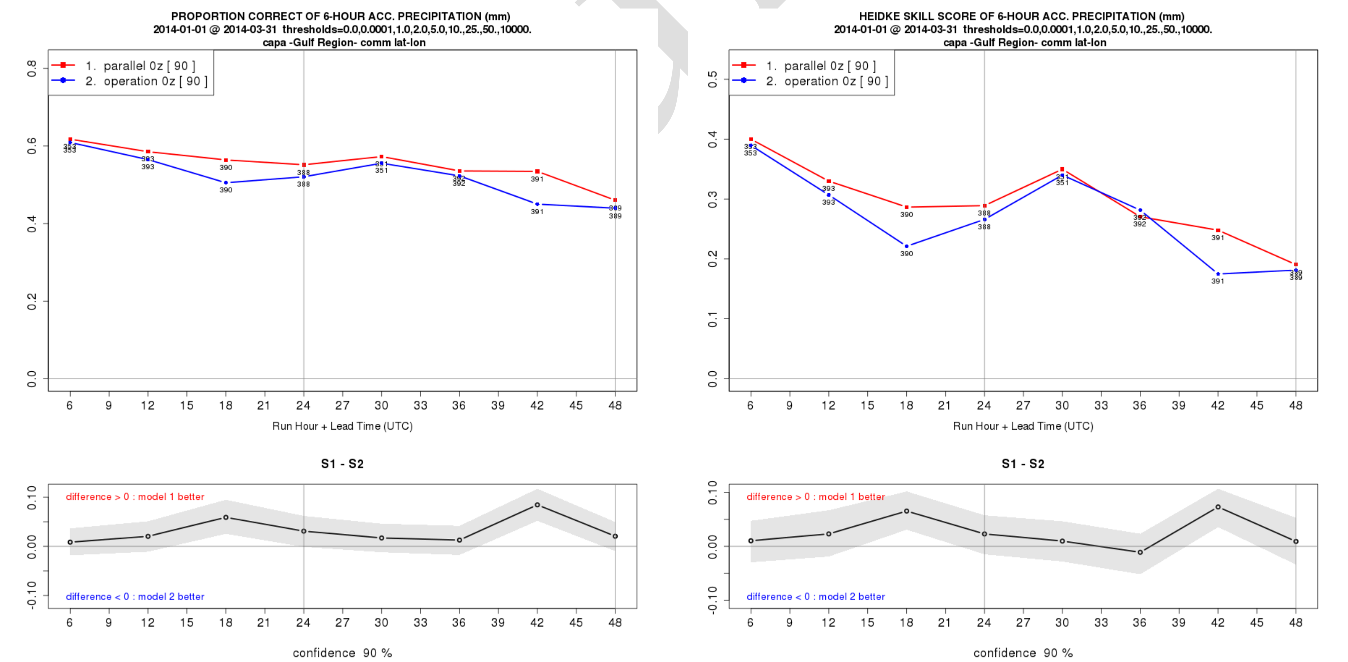

Figure 6 : EMET generated surface scores for precipitation

Appendix B : Summer Surface Score

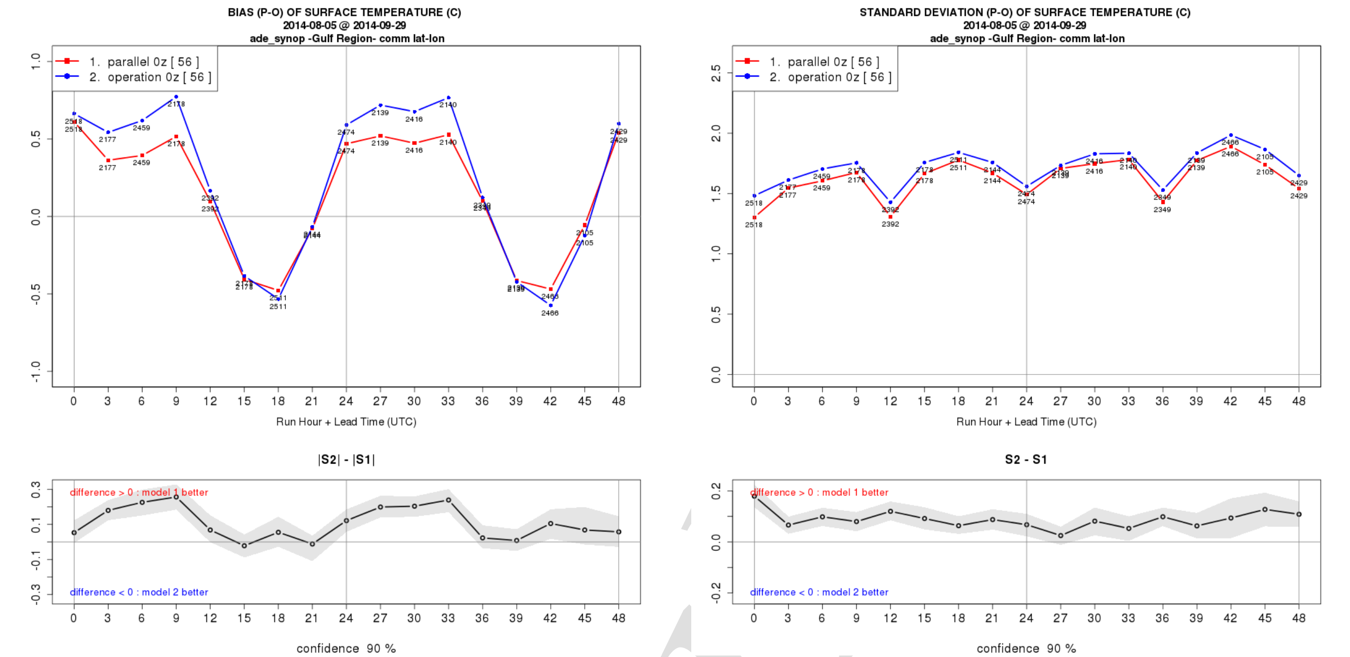

Figure 7 : EMET generated surface scores for air temperature

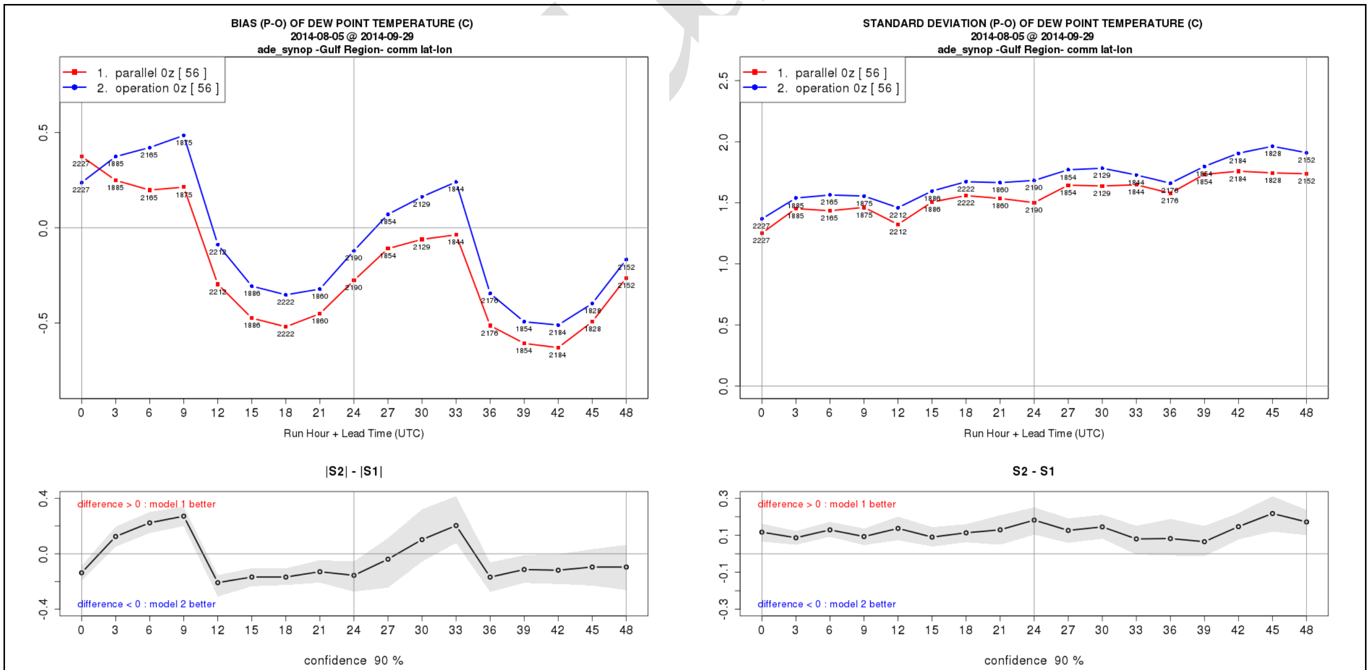

Figure 8 : EMET generated surface scores for dew point temperature

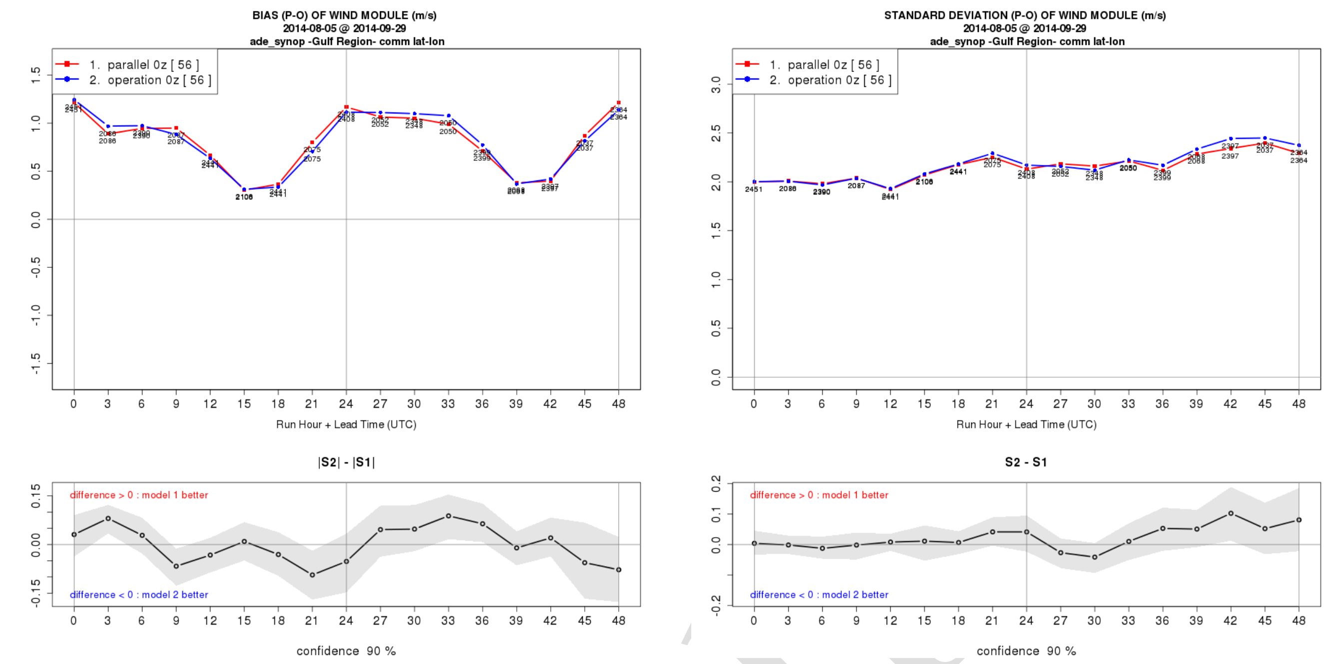

Figure 9 : EMET generated surface scores for wind modulus

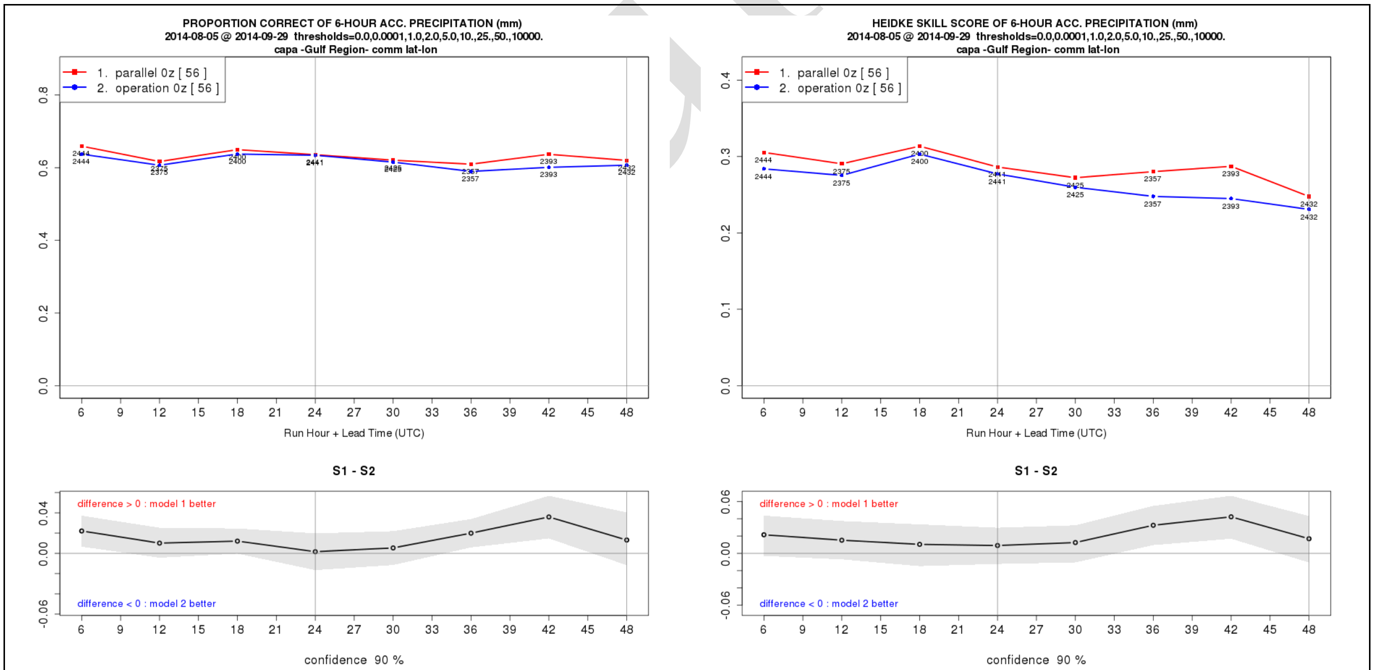

Figure 10 : EMET generated surface scores for precipitation