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High-Resolution Surface Modelling for extended-range downscaling of near-surface atmospheric fields over Canada

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Abstract

The Government of Canada has commissioned a project carried out by Environment Canada (EC) to generate high-resolution 2008-2012 database of near-surface winds over the entire country. Time series of wind will be generated with the limited-area configuration of the Global Environmental Multiscale (GEM-LAM) model. The final results are required to have a horizontal grid spacing of 2 km and output frequency of 10 min.

The approach adopted is to perform a single continuous multi-year GEM-LAM simulation over a continental-scale mesh, as blending of results obtained from multiple simulations conducted over smaller domains and time frames may lead to significant spatiotemporal discontinuities. However, due to the accumulation of errors, simulations performed over extended time frames are prone to drifts of atmospheric and surface variables that can be detrimental to the quality of the simulated fields, including winds.

In order to prevent drifts in surface fields, grid nudging of relevant land-surface variables towards a high-resolution surface analysis is devised. The surface analysis is generated with a high-resolution offline Surface Prediction System (SPS). The atmospheric forcing for SPS simulations is derived by assimilating EC's operational regional weather forecasts, Canadian Precipitation Analysis (CaPA), observed near-surface temperatures and humidity, and regional analysis of soil moisture. The results show that the grid nudging of land surface fields towards the expected values obtained from the SPS simulations has potential to considerably improve the GEM-LAM skill in reproducing surface-layer meteorological fields.

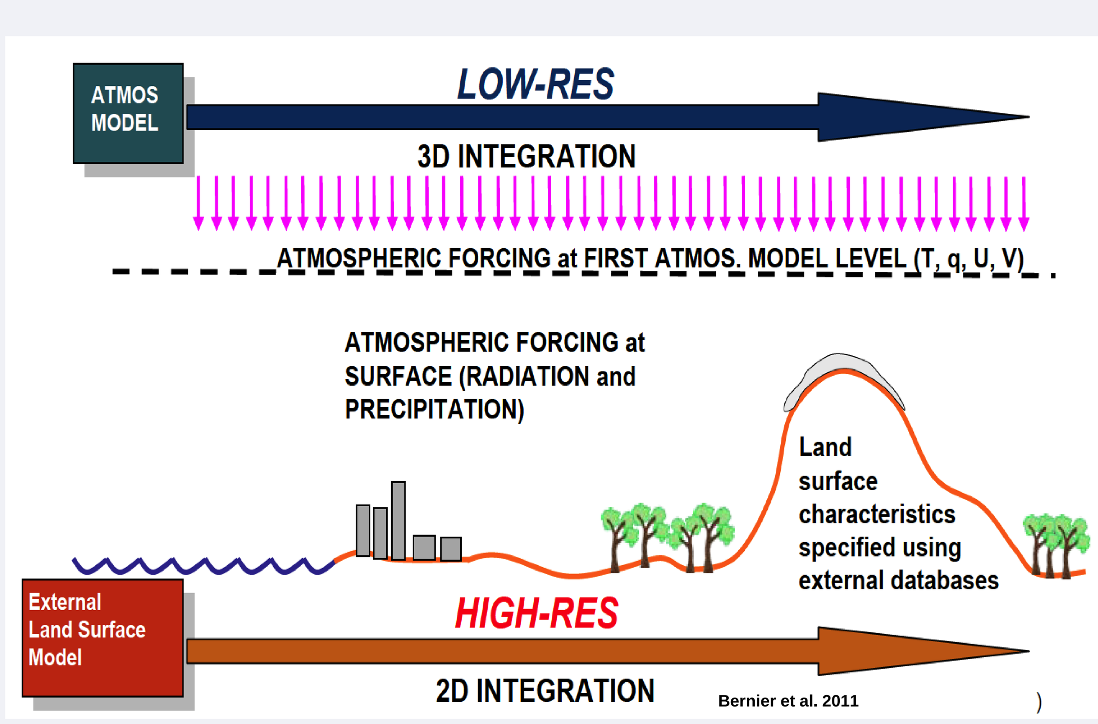
The project is part of the Pan Canadian Wind Integration Study aimed to improve large-scale wind energy integration within Canadian power grids.

Objectives

The principal objective is to generate high-resolution time series of surface variables, such as soil temperature, soil moisture, snow depth and others, to serve as a reference for the relaxation of GEM-LAM prognostically evolving surface fields.

EC's operational regional analysis is not suitable for this purpose due to its insufficient resolution. Thus the surface time series will be generated using the SPS. This approach permits high-resolution surface integrations with limited computational effort.

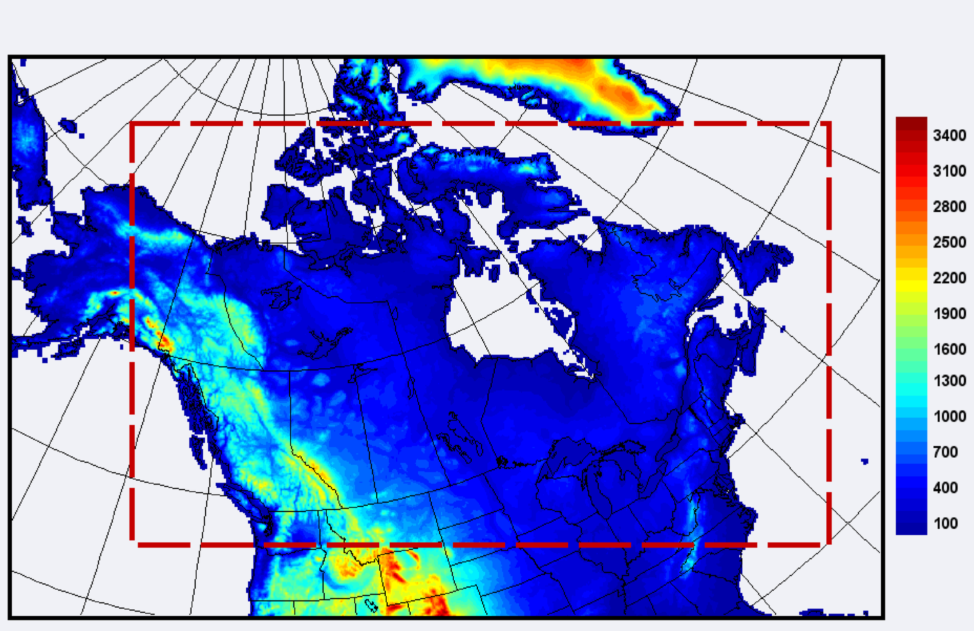
SPS is a two-layer surface model with land, water, glaciers and sea ice schemes and uses a detailed representation of surface characteristics: topography, soil type, vegetation type and coverage (1, 2).



SPS requires hourly updates of atmospheric forcing: temperature, humidity, wind, incoming radiation and precipitation accumulations. Forcing temperature, specific humidity and precipitation type are vertically adjusted according to a higher-resolution terrain elevation (3).

The SPS integrations will be performed in two continental-scale domains:

- 480x300 points domain with a 15-km grid spacing,
- 3000x1800 points domain with a 2-km grid spacing (red square) :

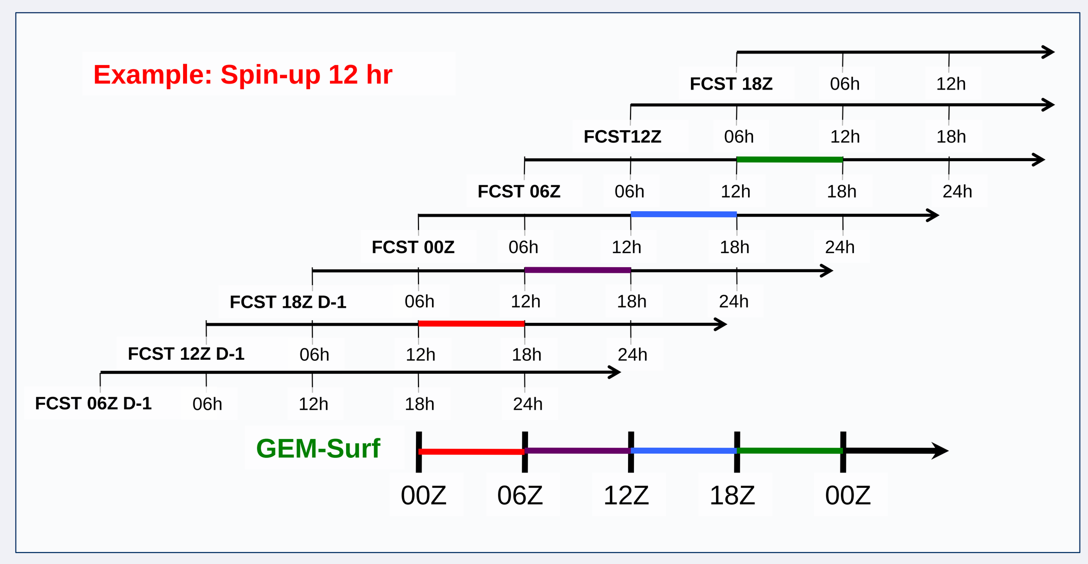


Methods

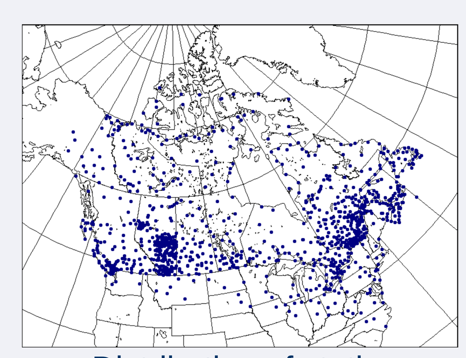
Downscaling of surface fields is performed in three main steps.

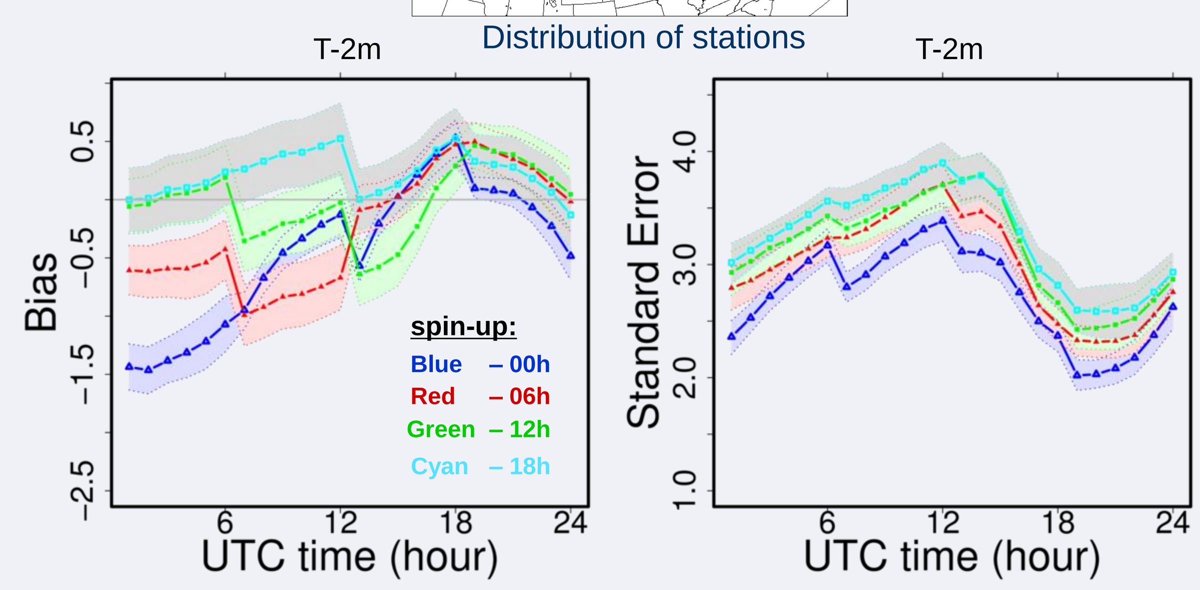
In the first step a lower-resolution SPS simulation (with a 15-km grid spacing) is driven with the atmospheric temperature, humidity, wind and radiation taken from the first prognostic level of the operational regional 15-km forecasts. Forecasts of hourly precipitation accumulations are readjusted to the Canadian Precipitation Analysis (CaPA).

Regional forecasts are issued four times per day at 00, 06, 12, 18Z. Hence, multiple forecasts are available to serve as forcing in the SPS:



The SPS skill in reproducing diagnostic level fields depends on the the forecasts' spin-up, as illustrated by 2-m temperature scores over Canadian Prairies for the test period Jan 20 – Mar 20, 2011.


Distribution of stations



In the second step Optimal Interpolation (OI) is employed to assimilate hourly observations of 2-m temperature and humidity observed at land-based stations spread across the 15-km computational domain. The SPS-simulated hourly values provide the first guess (background) field for OI.

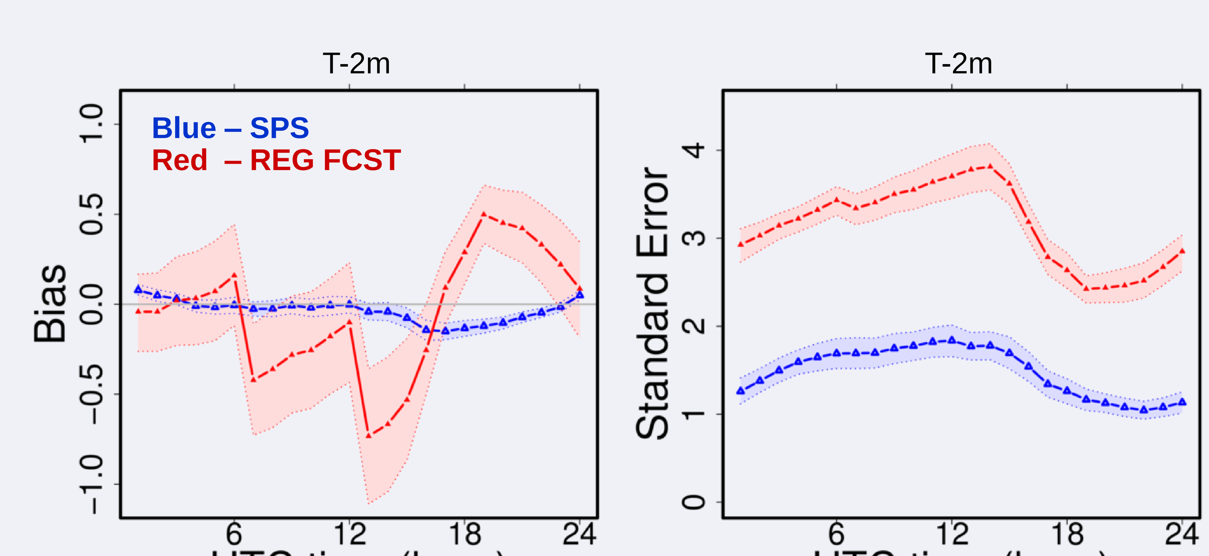
In the third step, the OI 2-m temperatures and humidity are used as the atmospheric forcing in a high-resolution 2-km SPS simulation. In this simulation 10-m wind (as well as radiation and CaPA-adjusted precipitation) is again taken from the regional forecasts. The SPS has a lower skill in simulating 10-m wind speed than the regional forecasts.

In order to prevent deviations of SPS-simulated soil moisture from observed values, large-scale components of the SPS soil moisture I_{SPS} are relaxed towards their counterparts in the EC's operational regional analyses I_{ANA} as follows:

$$I_{SPS} = I_{SPS} + R\,[\,(I_{ANA})_{LS} - (I_{SPS})_{LS}\,],$$

where *LS* denotes large-scale components obtained by filtering out the spatial scales smaller than approximately 50 km and *R* is the relaxation coefficient.

The following graphs show the 2-km SPS 2-m temperature bias and standard error for Canadian Prairies for Jan 20 – Mar 20, 2011:



Finally, the SPS-derived analysis of soil temperature, soil moisture, snow depth and snow density are then used to readjust the GEM-LAM corresponding fields as follows:

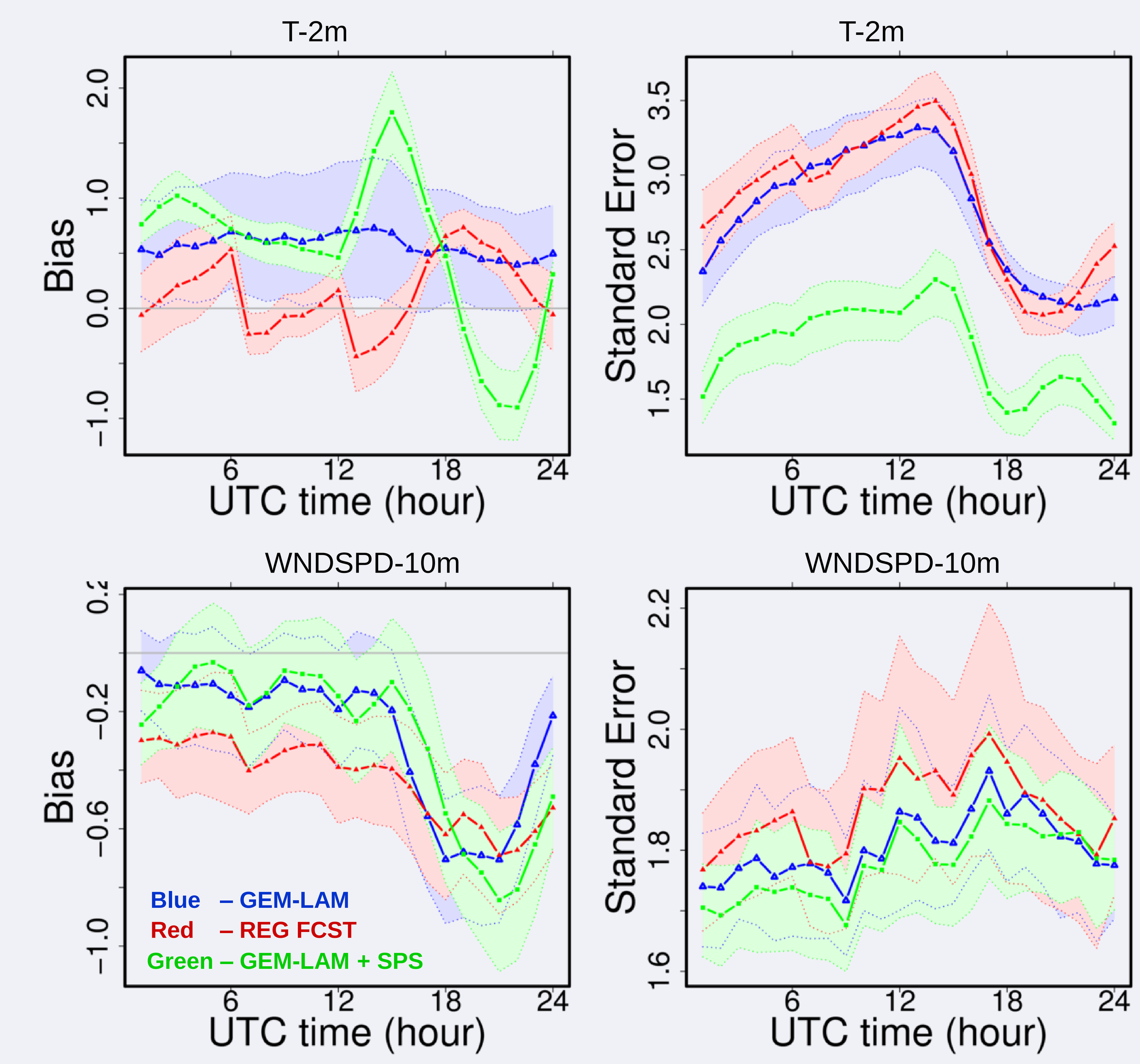
$$\Psi_{GEM} = \Psi_{GEM} + R\,(\,\Psi_{SPS} - \Psi_{GEM}\,),$$

where Ψ_{GEM} is a prognostically evolving GEM-LAM surface field, Ψ_{SPS} is is the corresponding SPS value and *R* is a relaxation factor.

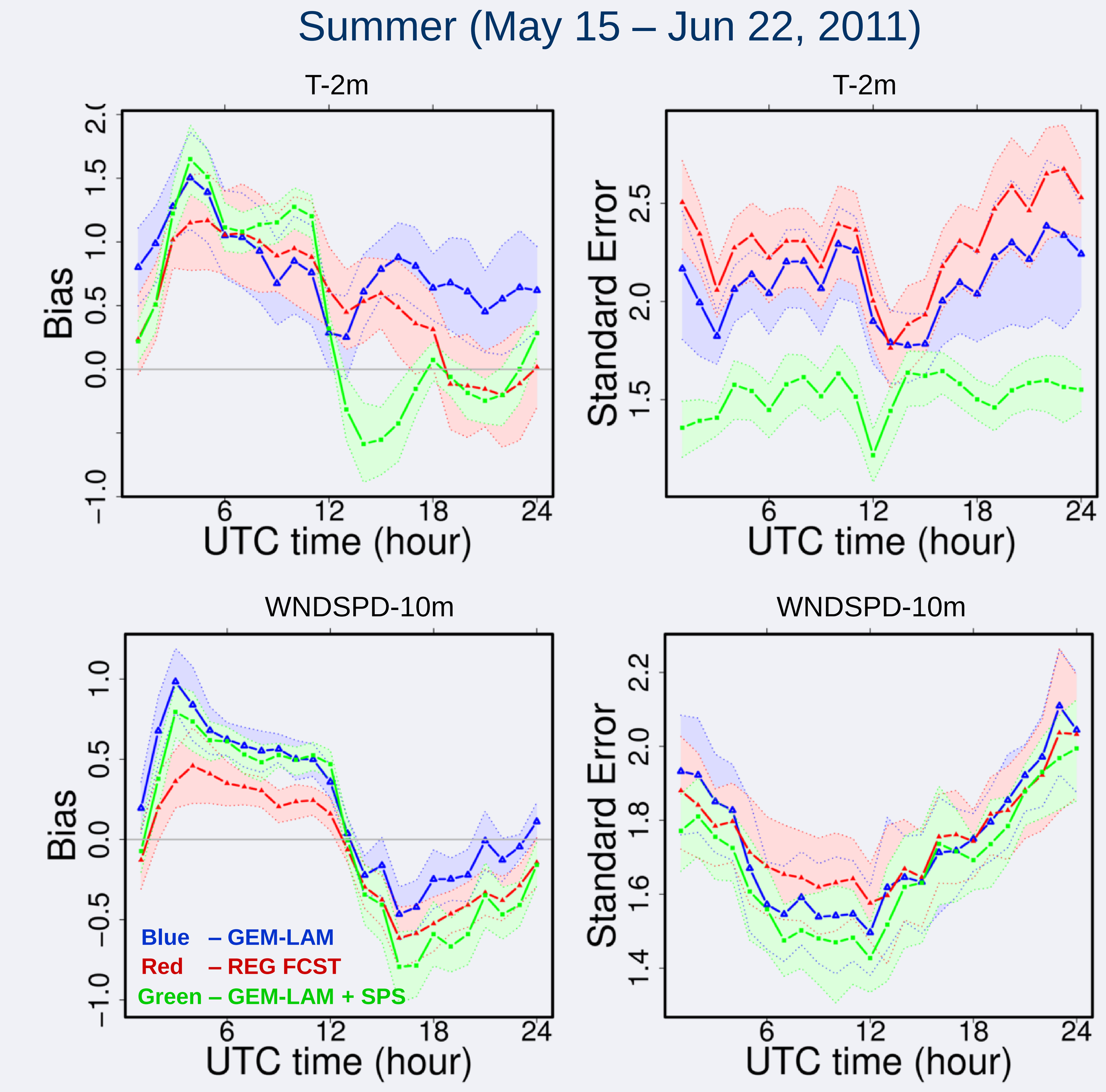
Results

In order to validate the strategy, common 2-km GEM-LAM simulations with and without the surface nudging towards SPS fields are carried over a small domain centred over Canadian Prairies and compared against the observations of 2-m temperature and 10-m wind speed.

Winter (Jan 20 – Feb 27, 2011)



Summer (May 15 – Jun 22, 2011)



Conclusions

- Preliminary tests show that the implementation of grid nudging in GEM-LAM simulations considerably improves 2-m temperatures, particularly in terms of standard error. The improvement is less significant for 10-m wind speed.
- A stronger diurnal cycle is present in the 2m-temperature bias in the SPS-nudged GEM-LAM simulations (green lines). This is found to be a result of a time shift due to non-centred interpolation of forcing fields in SPS runs. Reduction of SPS time step significantly improved the diurnal variation of the bias of SPS temperatures and is expected to improve the GEM-LAM results.
- Besides the principal objective of providing reference for surface grid nudging in GEM-LAM simulations, extended SPS simulations over a continental-scale domain will allow for an extensive validation of SPS performance over regions with different surface properties.

References

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