Adapting a Multi-Model Bias Correction System to Road Temperature Forecasts

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INTRODUCTION

Previous investigations and subsequent operational implementation introduced a statistical technique which substantially suppressed inherent NWP model biases in select atmospheric forecast parameters and this general approach was adapted to improve RWIS forecasts.

Experience with Road Weather Forecast Systems (RWIS) exposed model biases in forecast pavement temperatures (T_{sfc}) which varied diurnally and adversely affected performance. Using the observational data gathered in-situ by roadside RWIS environmental sensor stations (ESS) as baselines we were able to calibrate the forecast output on a hourly basis around the 24-hour clock for individual sites.

Though there are numerous techniques for tuning the forecast T_{sfc} and automatically suppress bias errors the use of a sole heat balance model (METRo) for prognostication meant that only temporally staggered runs of METRo could be used as a pseudo ensemble for blending. In our implementation then, we automatically combine information from the various staggered METRo outputs and their bias-corrected derivatives, using multiple bias correction methods and automatic assessment of each run's performance, in order to drive an optimum blended solution.

Upon applying the blended bias correction factors to T_{sfc} through the forecast time frame (24 hours) it became necessary to modify the predicted pavement condition portion of METRo's forecast output. This was done to take into account situations where the modified T_{sfc} values changed sign about 0°C, and/or rose above, or fell below, the forecast dew point compared to the original, raw, values of T_{sfc}.

Real-time results show an approximately 13% reduction in MAE (Mean Absolute Error) averaged hourly over a 24-hour lead time in pavement temperature forecasts compared to unadjusted METRo forecasts. Peak reductions were near 17% for select lead time hours.

OBJECTIVE

The objective was to improve RWIS forecasting performance, specifically for the hourly pavement temperature, T_{sfc}, by "tuning" the output of the Environment Canada's ***M****odel of the* ***E****nvironment and* ***T****emperature of* ***Ro****ads* (***METRo***) using past observations from site-specific road weather stations. Essentially, we wished to calibrate METRo forecasts in order to provide higher quality road weather forecasts to commercial clients than single-model-run deterministic forecasts could provide.

It was the second phase of a more wide-ranging application of systematic error correction methods to conventional atmospheric forecast parameters whereby comparison of previous forecasts with their verifying observations yielded statistical indices describing forecast errors used to:

1. Calibrate subsequent forecasts in order to suppress errors;
2. Calculate weight coefficients for the model blending system which are based on forecast accuracy performance (the most accurate METRo model run, as a function of lead time, gets the highest weighting in the forecast consensus blend).

This was to be done in a way which maintained logical consistency between the forecast pavement temperature and the forecast road conditions by anticipating how a bias corrected Tsfc might affect the original forecast road conditions and then altering those conditions appropriately.

FEATURES & CONSIDERATIONS

Features of our system include:

- Bias correction to be applied to all operational RWIS sites based on observations made at each roadside environmental sensor station;
- A 45-day rolling archive of forecasts and observations, fully supported and maintained 24/7/365;
- Statistical algorithms to calculate bias including simple mean, linear regression-based and Kalman filter-based biases. Mean absolute errors (MAE) for each approach were then derived to provide weighting factors for the blending part of the correction process.

As a consideration, it was anticipated that bias-correcting an original, "*raw*", forecast value of T_{sfc} such that its sign changed would necessitate that METRo's predicted road conditions would also have to be modified in logical step. E.g., a ***wet*** road prediction with a raw T_{sfc} = 1°C would have to be altered to an ***ice warning*** if the bias-corrected T_{sfc} went to -1°C.

Similarly, in cases where a raw T_{sfc} forecast was below the dew point, thus causing condensation on the road, was bias-corrected to above the dew point, METRo's forecast of a ***damp*** road would have to be altered to ***dry***.

To accomplish this, a "rules" matrix is employed for cases where a modified T_{sfc} changes its sign relative to its raw value, and/or its relative placement above or below the dew point, to logically alter the road condition forecast.

CONCLUSIONS

Calibrating heat balance model forecasts, such as those from the METRo model, by using the observational advantage which RWIS roadside weather and pavement sensor stations offer, enable us to provide improved pavement temperature forecasts averaged over time. MAE reductions varied from near zero to 17% (0.3°C) by hourly lead time to 24 hours; averaging 13% (0.2°C) over all lead times. By doing this hourly around the 24-hour clock we were able to implicitly account for any diurnal biases in METRo on a station by station basis. This helps resolve site idiosyncrasies such as shadows cast by rock cuts or other obstructions and the fact that all heat balance models have a strong sensitivity to solar input during daylight hours. It also accommodates the second/third order (urban/rural) sensitivity which roads have to traffic volumes through radiative and turbulent heat fluxes.

Specific challenges include the sensitivity of METRo and, indeed the pavement it is modelling in reality, to changes in solar inputs between cloudy and sunny days. After a period of sunny weather days, the Bias Blend System (BBS) may over-correct for dampened or non-existent biases in the model during a subsequent period of cloudy weather. This variation in the bias characteristics of METRo between bright and dull daytime weather regimes for a given site needs to be resolved prior to concluding that the BBS is offering similar gains in forecast performance in both regimes, more or less equally, rather than much more in one than the other. RWIS sites lack cloud cover sensing abilities and even if we could readily parse observations into sunny and cloudy (or more) bins we effectively reduce the number of data points available to BBS calculations per bin than if they were combined together.

The logical modification of METRo's raw forecast road condition when the modified pavement temperature changed sign about freezing, or relative to either side of the atmospheric dew point, compared to the raw pavement temperature was more than plausible. This was arguably the most successful part of the experiment despite relying on a rather elaborate, empirical-based, lookup matrix.

METHODOLOGY and RESULTS

METRo model

Temporally staggered pseudo-ensemble output of RWIS parameters

- *25 hourly forecast data points covering a 24-hour day; including endpoints.*
- *Successive 24-hour METRo runs staggered by six hours.*
- *Data stored for 180 days.*

Bias Corrector & Weight Generator [1]

Several bias correction techniques used, diurnally by hour, using up to 45 days of historical forecast-observation pairs, as available, with a minimum of 15 days required.

Blending weights are based solely on verification scores.

BIAS CORRECTION METHODS	WEIGHTING FUNCTION
• *45-day average bias;* • *45-day simple linear regression;* • *Kalman Filter (W = 0.02);* • *Kalman Filter (W = 0.1).*	• *As available, the previous 45 days of forecast-observation pairs are used to calculate mean absolute errors;* • *Weight = 1 / MAE* ^{8}

Blender [1]

Bias-corrected values optimally combined, using respective diurnal hour model weights, and applied to T_{sfc}.

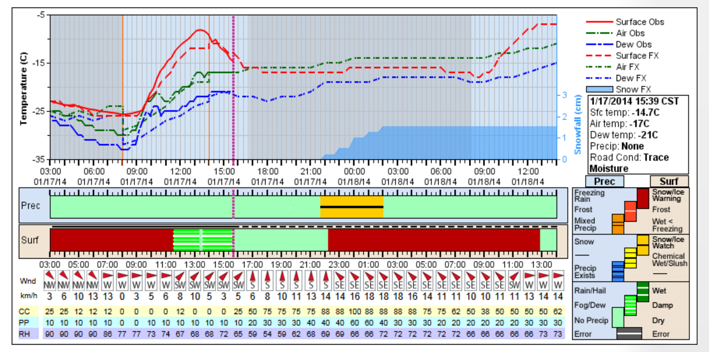
This and the previous step form the core of the Bias Blend System (BBS).

[1] *Weighted corrections, applied by location and diurnal hour to forecast pavement temperatures, embody the BBS's core role.*

Forecast Road Condition Adjustment

A 352-point 3-D decision matrix logically adjusts forecast road conditions for when T_{sfc} is altered to the opposing side of the dew point and/or 0°C.

RWIS Product



Scan Web's RWIS *Forecast Summary Page* which displays the latest forecast and observed information

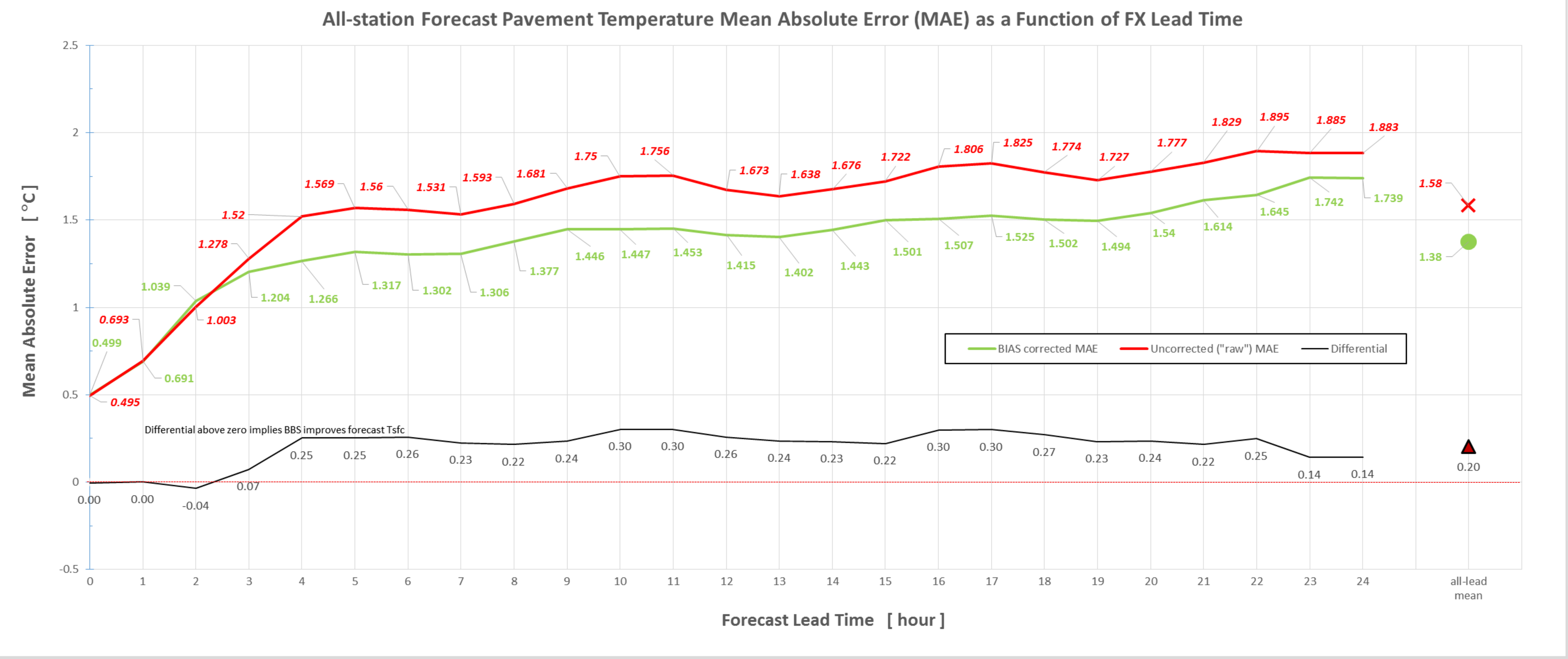
FIGURE 1: Forecast Pavement Temperature, T_{sfc}, Bias-Corrected Errors vs. METRo Model Raw Output Errors.

This plot shows hourly mean absolute errors (MAE) as a function of lead time for T_{sfc} based on approximately 15000 forecast-observation pairs for each lead time hour gathered from January 1 to 22, 2014 inclusive.

Each lead time MAE score was averaged over 180 Canadian RWIS sites, weighted by the number or forecast-observation pairs per site, and clearly show performance gains beyond lead time t=4 hours.

Differential gains in MAE between raw and corrected data varied from near 0 to 0.30°C by lead time with an average gain across all lead times of 0.20°C.

The lack of gains prior to t=4 hours can be explained by the RWIS technological advantage of having in-situ observation being fed into the model at run time. Those inputs dominate the forecast output for early lead times thus preempting bias errors growing to be a problem, which can be statistically adjusted for, until later in the nowcasting (0 to 6-hour) time frame and beyond.



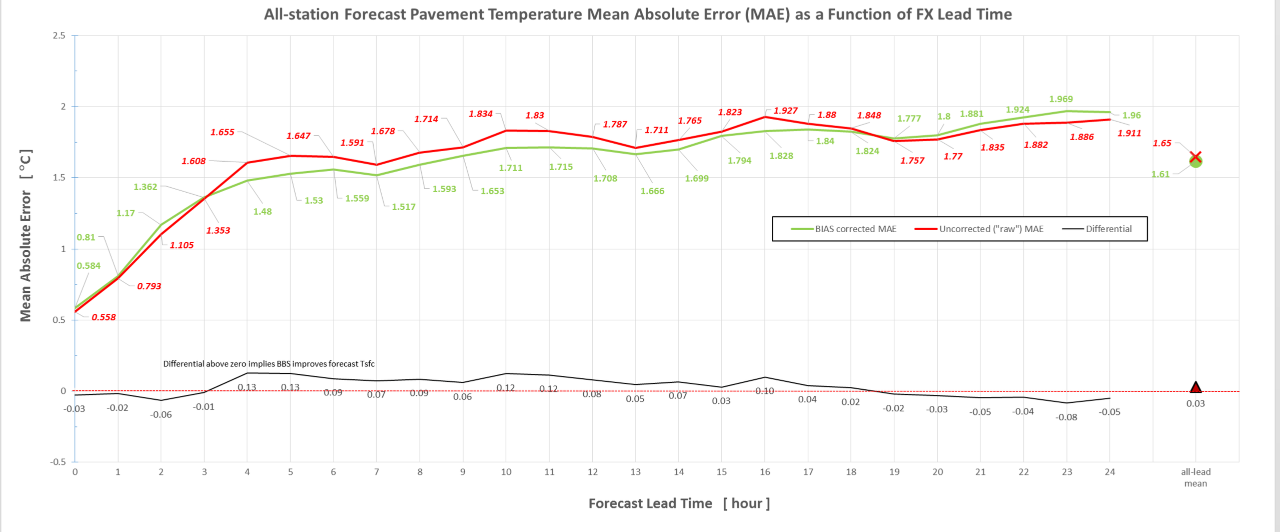


FIGURE 2: The importance of cleaning the observational data *is apparent in this chart where sporadic but isolated out-of-range pavement temperatures observations from the RWIS ESS had none-negligible impacts on the improvement in MAE compared to that shown in FIGURE 1 where such anomalies had been removed. In fact, the Bias Blend System's (BBS) advantage became a liability after t=18 hours; possibly due to the combination of bad data and systematically one less model run being available beyond that for bias calculations as METRo is typically only run every 6 hours out to 24 hours. The filter technique used was a simple out-of-range test which discarded observations below -30°C and above 15°C, including gross errors, from being incorporated in the BBS's calculations. A more sophisticated filter may offer additional gains.*

FUTURE

Some of the key areas of research & development for further exploration include:

- Calculating and applying bias correction as a function of forecast cloud cover, in lieu of actual cloud cover observations, to resolve variations in METRo's biases due to its cloud cover sensitivities.
- Review of the bias correction methods and weighting scheme approaches to best employ.
- Extension of the BBS to dew point temperature forecast values.
- Extending METRo's forecast period out to 30 hours for 24-hour products and out to 54 hours for 48-hour products such as our RWIS-driven Maintenance Decision Support System (MDSS).
- The possibility of a more sophisticated filter mechanism to eliminate various kinds of bad data, such as flat-lining data, and not just out of range data.
- Examination of METRo itself; including its new traffic volume input capabilities to explicitly account for systematic variations in traffic diurnally and by day of the week.
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