A preliminary assessment of the biases between forecasted by ECMWF Numerical Weather Prediction model precipitation and the adjusted observed snowfall precipitation in different SPICE sites

Samuel T. Buisán[1], Craig D. Smith[2], Amber Ross[2], John Kochendorfer[3], José Luís Collado[1], Javier Alastrué[1], Mareile Wolff [4], Yves-Alain Roulet[5], Timo Laine[6], Scott Landolt[7], Roy Rasmussen[7], Michael E.Earle[8], Rodica Nitu[9]

[1] Delegación Territorial de AEMET (Spanish State Meteorological Agency) en Aragón. Paseo del Canal 17. Zaragoza, 50007, Spain

[2] Environment and Climate Change Canada 11 Innovation Blvd Saskatoon, SK, Canada

[3] National Atmospheric and Oceanic Association, Air Resources Laboratory, Atmospheric Turbulence and Diffusion Division, Oak Ridge, TN, USA

[4] Norwegian Meteorological institute, Oslo, Norway

[5] Meteoswiss, Payerne, 1530, Switzerland

[6] Finnish Meteorological Institute, Helsinki, 00101, Finland

[7] National Center for Atmospheric Research, Boulder, 80305, USA

[8] Environment and Climate Change Canada, Dartmouth, Nova Scotia, B2Y 2N6, Canada

[9] World Meteorological Organization, Geneva, 1211, Switzerland

Correspondence to: Samuel T. Buisan (sbuisans@aemet.es)

1. Introduction

The accurate prediction and verification of snowfall is encumbered by the large potential undercatch of solid precipitation (Goodison et al, 1998, Rasmussen et al, 2012) recorded in national operational networks. This undercatch can result in significant biases between the forecasted and observed precipitation, which affects model climatology, nowcasting and verification. In the framework of the WMO Solid Precipitation Inter-Comparison Experiment (SPICE), a set of transfer functions were derived for adjusting the wind-induced undercatch of solid precipitation measurements recorded by weighing gauges (Kochendorfer et al., 2017).

The objective of this work is to assess, at a set of selected sites with different climatic conditions, the biases between a Global Numerical Weather Prediction Model and the observed precipitation (adjusted and unadjusted) in order to illustrate the magnitude of the error and its relation with the forecast accuracy of the model for each site.

2. Data and methods

The data were obtained from post-SPICE precipitation observations (2015-2016 and 2016-2017 winter seasons) from various SPICE sites (CARE, Bratt's Lake, Marshall, Haukeliseter, Sodankylä and Formigal-Sarrios) (Figure 1 and Table 2)

Figure 1. Post-SPICE sites: Bratt's Lake(2), Marshall(3), CARE(4), Formigal(6), Haukelisiter(11), and Sodankyla(12)

The methodology was the following:

1. A quality control of the data was performed, cleaning the 1-min time series using range checks and a jump filter to remove outliers and a Gaussian filter to remove some high frequency noise. A noise balancing processing technique called "Brute Force" was employed for signal post-processing to identify precipitation events (Pan et al., 2016**)** for all weighing gauges (Geonor T-200B30 or Pluvio^2) in the following configurations (Figure 2):
   a. Double Fence Automated Reference (DFAR)
   b. Single-Alter shield (SA)
2. The 1-min time series was resampled to produce 30-min accumulations
3. The 30-min data for the SA precipitation gauges were adjusted using the SPICE transfer functions and procedures from Kochendorfer et al. (2017). For simplicity, we used Equation 3 because the difference in performance between Equation 3 and Equation 4 is small (Kochendorfer et al. 2017)
4. We retrieved the 24h forecasted accumulation (Day +1) at the nearest grid point of each SPICE site from the high resolution operational ECMWF model. This approximation was based on two main elements:
   a. Winter precipitation is usually not characterized by convective activity which can produce great gradients of precipitation in relative short distances

b. Thanks to the high horizontal resolution of the ECMWF model, 9 km from March 2016 (before it was 16 km), the elevation of the grid point (Table 2) is, in general, close to that of each site, with the exception of Formigal.

We also considered that larger accumulation time periods, such as 24 h, reduced the uncertainty associated with shorter forecasted periods for precipitation accumulation.

5. For daily aggregates of precipitation and comparison with the model, we used only days with a complete series of 1-minute data
6. We made the comparison for two independent winter seasons to validate the results and to assess if any differences were due to the change in horizontal resolution of the model in March 2016.

Site	Acronymous	Climate zone	Elevation (m)	Nearest grid point (m)	Pearson correlation
CARE	CAR	Humid continental subject to lake effect	251	242	0.77
Formigal-Sarrios	FOR	Alpine climate with Atlantic influence	1800	2144	0.87
Haukeliseter	HKL	Mountains, well above the tree line	991	1071	0.90
Marshall	MAR	Continental	1742	1646	0.88
Sodankyla	SOD	Northern Boreal	179	204	0.86
Bratts Lake	XBK	Continental	585	583.5	0.68

Table 1. List of sites and their elevations compared with high resolution ECMWF model nearest grid point and Pearson's correlation coefficient between daily observed and model forecasted precipitation

Figure 2. Site images. Top-left: Haukelisiter, Top-right: Sodankylä, Bottom-left: Bratt's Lake, Bottom-right: Formigal-Sarrios. The DFAR and weighing gauges in Single-Alter shields are observed.

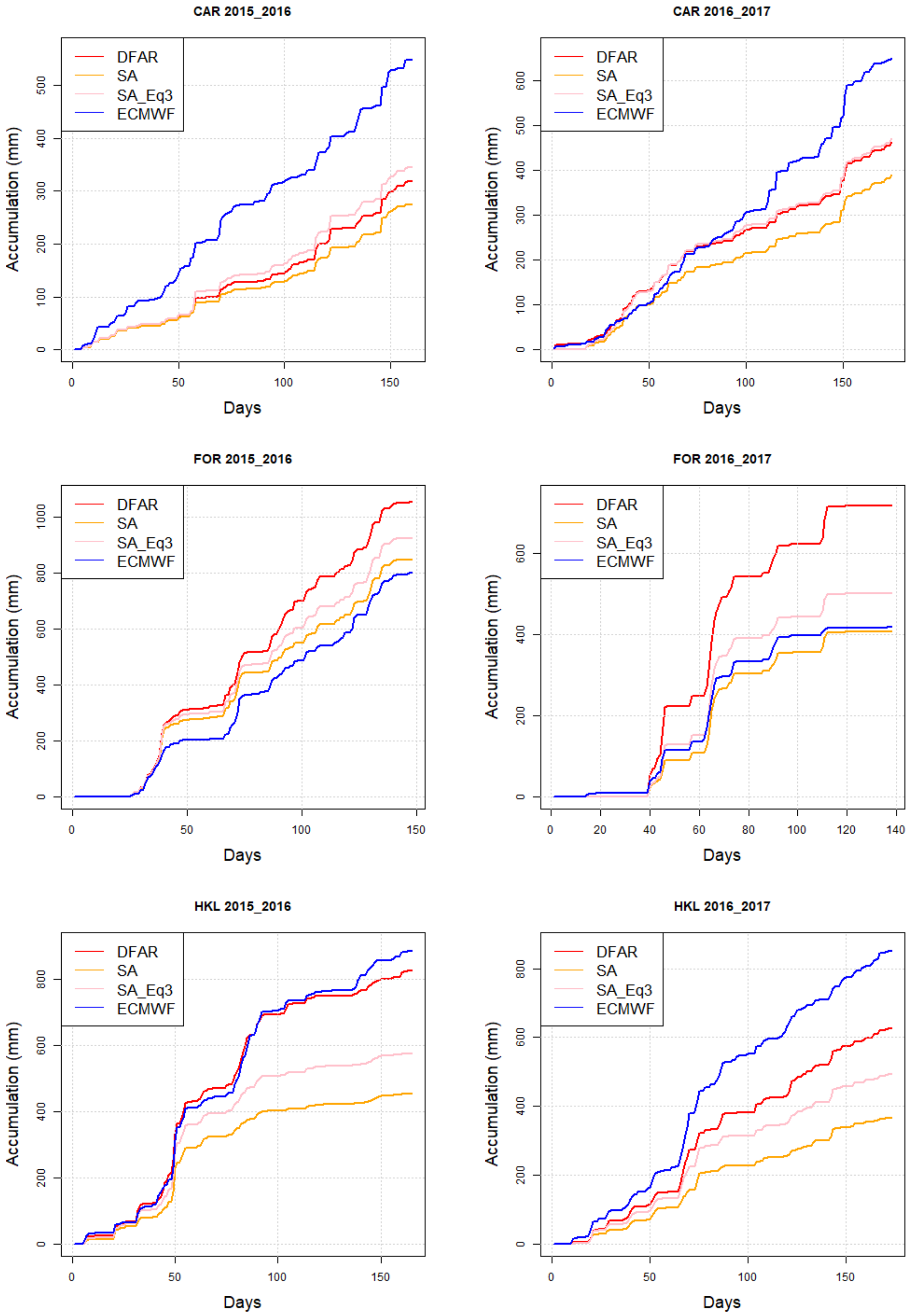
3. Results

Figure 3 shows that, overall, for all sites the significant precipitation events were captured by the model. However, the difference of precipitation for some events was high. To assess the consistency of this comparison, a Pearson correlation test was performed between the daily observed precipitation observed by the DFAR gauge configuration and the forecasted precipitation (Table 1). For all sites there was a significant statistical correlation (p-value < 0.01) with maximum values of the coefficient close to 0.9 at Haukelisiter and minimum values near 0.7 at Bratt's Lake, which in this case, was mainly due to the high model overestimation for one single episode at the beginning of each winter season. This result showed the overall quality in forecasting the occurrence and magnitude of precipitation events.

At CARE the model significantly overestimated the precipitation in both seasons. At Formigal, the model significantly underestimated the precipitation in both seasons, with better skill during 2016-2017, however, the SA and model showed a very good agreement which could lead to errors in the verification of the model for the true precipitation if the undercatch is not accounted for. At Haukeliseter, the model showed a good agreement with the DFAR during the 2015-2016, but high underestimation of the adjusted SA precipitation, using this data for intercomparison would result in high verification errors. During 2016-2017, the model clearly overestimated the precipitation as compared to the DFAR so this, combined with the potential of using an under-adjusted SA observation, would result in poor verification scores. The change from a good agreement in 2015-2016 to a model overestimate in 2016-2017 could possibly be a result of the change of resolution of the model in March 2016. This is consistent with the increase in overestimation observed starting at the end of the 2015-2016 winter season, coinciding with the model change.

At Marshall during the 2015-2016 the model showed a good agreement with DFAR and the adjustment slightly overestimated the precipitation. Unfortunately the data from 2016-2017 is still not available for the comparison. At Sodankyla, the model slightly underestimated the precipitation for the 2015-2016 winter season and showed an almost perfect agreement in 2016-2017, the adjusted SA precipitation being slightly overestimated as compared to the DFAR, but in general the agreement can be considered quite good. At Bratt's Lake, the modelled period at the beginning of both seasons produced a significant overestimation of the modelled precipitation. If this period was removed, the model overestimation would be smaller.

It is important to notice, that excepting for Haukeliseter, the model was consistent for the two independent winter seasons for all sites.


CAR 2015_2016
CAR 2016_2017
FOR 2015_2016
FOR 2016_2017
HKL 2015_2016
HKL 2016_2017
DFAR
SA
SA_Eq3
ECMWF
Accumulation (mm)
Days

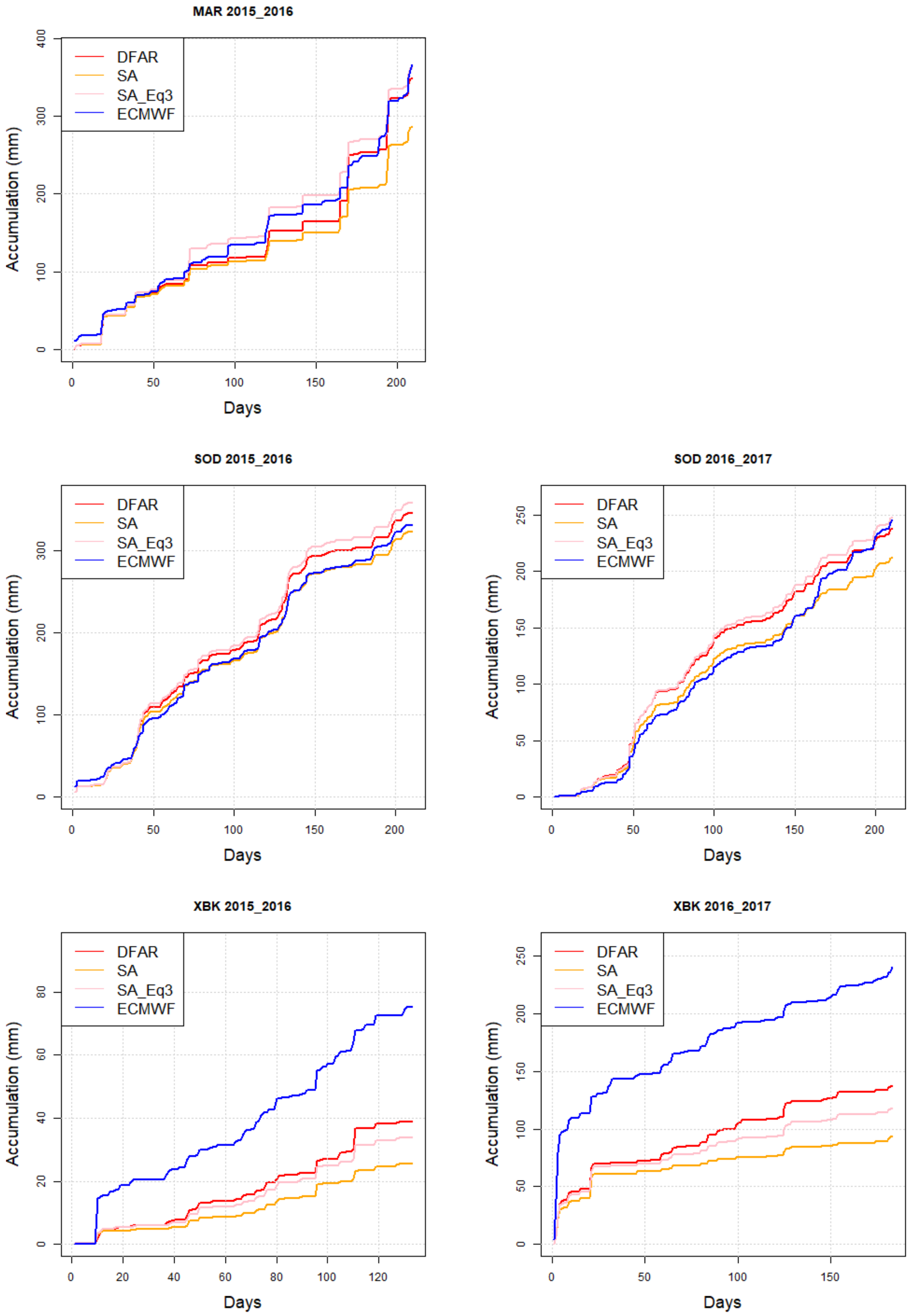


Figure 3. Seasonal accumulation of precipitation at each site as forecasted by ECMWF, DFAR, SA and adjusted precipitation for SA (SA_Eq3)

Figure 4 shows the daily bias for all sites (DFAR, SA, and adjusted SA using Eq. 3) when compared with ECMWF for days when the DFAR measured at least 1 mm of precipitation. At CARE, Haukeliseter and Bratt's Lake, the SA bias was higher than

DFAR bias, which was reduced when the precipitation was adjusted (SA_Eq3 bias), increasing the measured amount so that it compared closer to the model. At Haukelister, the difference between the DFAR and SA bias is remarkable and a result of the low catch ratio of the SA and the poor performance of the Eq3 adjustment. At Formigal and Sodankylä, the SA bias was lower than the DFAR bias, which was increased (because of the underestimation of the model) when the precipitation was adjusted (SA_Eq3 bias). This change was noticeable at Formigal but almost negligible at Sodankylä. Finally at Marshall the over adjustment produced positive bias whereas the SA bias was negative.

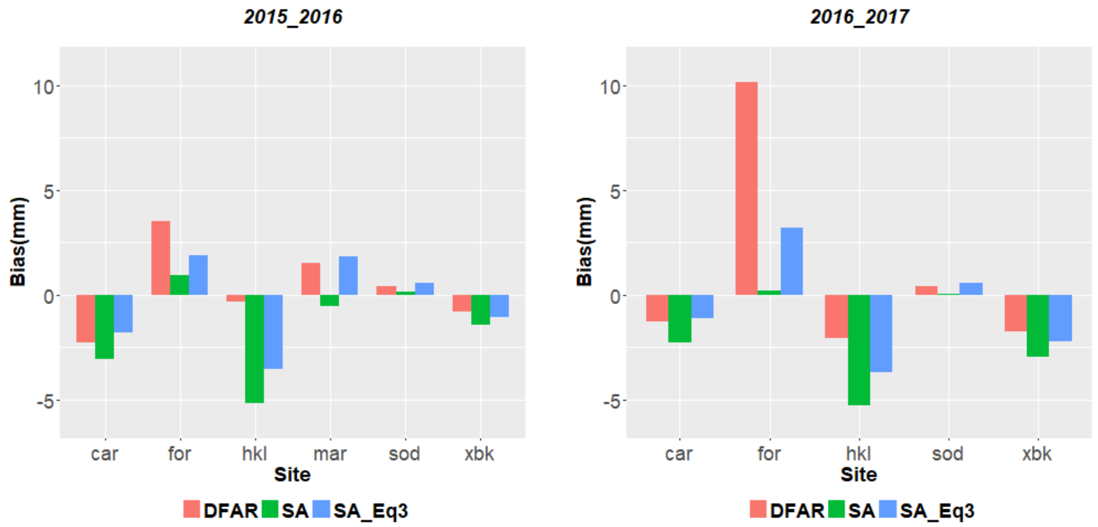


Figure 4. Daily bias (mm) between the DFAR precipitation, SA precipitation, the adjusted precipitation SA_Eq3 as compared to the ECMWF forecasted precipitation for days when the DFAR measured at least 1mm of precipitation.

Some sites are characterized by higher accumulations than others and also the seasonal relative catch ratio between the DFAR and the SA clearly differs. Figure 5 shows the relative bias. Although Figure 4 shows that the higher absolute biases were found mainly in Formigal, followed by Haukeliseter and CARE, Figure 5 shows that the highest relative biases were found at Haukeliseter and Bratt’s Lake. Since Haukeliseter is the site with highest mean 30-min wind speeds during snowfall events (6.7 m/s) with values up to 20 m/s (Kochendorfer et al. 2017), there were numerous events where the relative catch ratio between the DFAR and the SA were very low (Figure 3) and therefore the relative error was quite high. The same applies to Bratt’s Lake, which had the second highest mean wind speed (4.4 m/s), with the errors exacerbated by the period of large model overestimation at the beginning of each season. At Formigal, however, despite the high rates of precipitation the measured wind speeds during precipitation events are relatively low (2.3 m/s) which produced relatively high catch ratios (Figure 3) and therefore lower relative bias with the model.

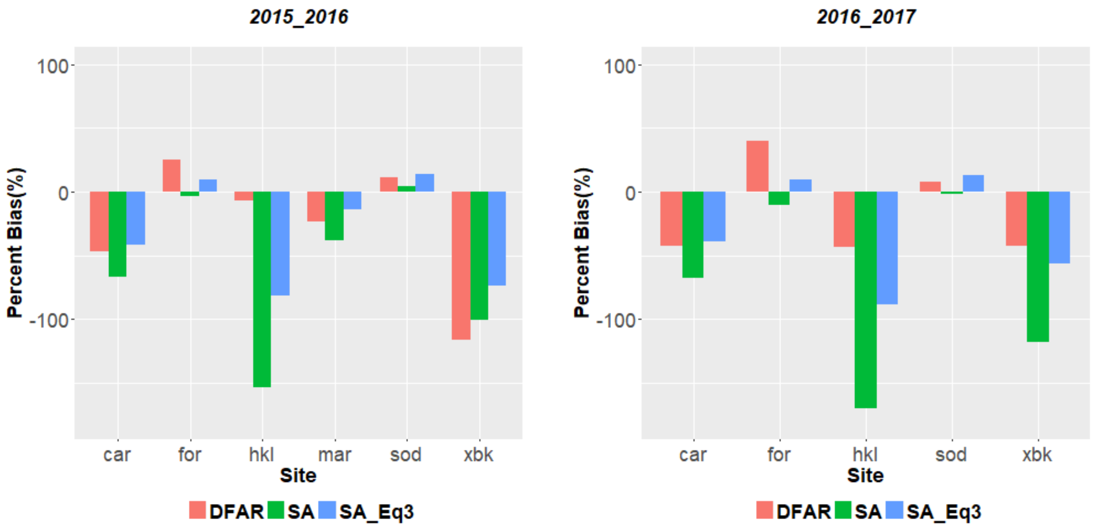


Figure 5. Daily relative_bias (%) between the DFAR precipitation, SA precipitation, the adjusted precipitation SA_Eq3 as compared to the ECMWF forecasted precipitation for days where the DFAR measured at least 1mm of precipitation.

Finally, we computed the daily root mean squared error (RMSE) to infer the magnitude of the error in terms of accumulation. Highest errors were found for Formigal, with RMSE values as high as 16 mm (between DFAR and ECMWF for 2016-2017). When comparing the adjusted SA precipitation to the ECMWF, the RMSE decreased for CARE, Haukeliseter and Bratt's Lake and increased for Sodankylä (slightly), Marshall and Formigal (significantly).

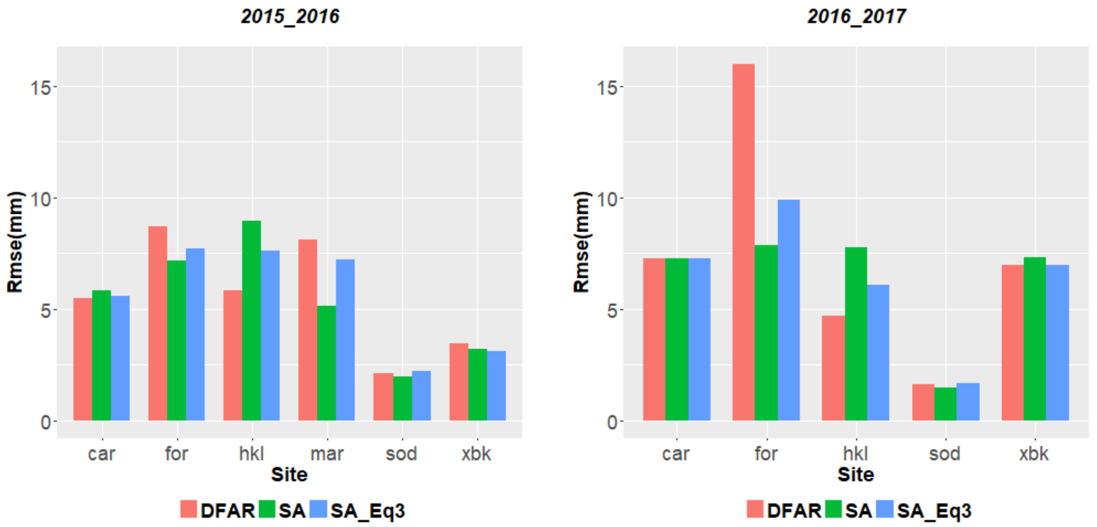


Figure 6. Daily RMSE for the DFAR precipitation, SA precipitation, the adjusted precipitation SA_Eq3 as compared to the ECMWF forecasted precipitation for days where the DFAR measured at least 1mm of precipitation.

4. Conclusions

This work aimed to illustrate the complexity of verification of the ECMWF model forecast precipitation for winter precipitation. The main conclusions were:

i. At areas where the model tends to overestimate the precipitation, the adjusted precipitation reduces the bias and the magnitude of the error.
ii. At areas where the model tends to underestimate the precipitation, the adjusted precipitation increases the bias and the magnitude of the error.
iii. DFAR observations provide ground-truthing for current versions of forecast models producing quantitative precipitation forecasts, Results could then be extrapolated to areas without DFARs but with similar climatic conditions (i.e. continental, artic, alpine continental, alpine maritime, etc) and then apply the transfer functions.
iv. In the absence of a DFAR, adjusting gauge measurements of winter precipitation is critical (understanding that there are limitations) for an assessment of modelled precipitation bias.

5. References

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WMO-SPICE website:
http://www.wmo.int/pages/prog/www/IMOP/intercomparisons/SPICE/SPICE.html