Verification of Sounding Parameters from the RAP and the RAP-Based and RUC-Based SFCOA Products

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I. Introduction

Forecasters depend in part on numerical weather models to generate timely and accurate forecasts. Last spring, the NOAA/NWS Storm Prediction Center (SPC) switched from using the Rapid Update Cycle model (RUC, Benjamin et al. 2004) to the Rapid Refresh model (RAP, Benjamin et al. 2007) in their day to day operations (Laflin, 2013). Consequently, the SPC switched the basis for their surface objective analysis (SFCOA, Bothwell et al. 2002) products over from the RUC to the RAP, although the RUC based products were kept for backup and quality checks.

Laflin (2013) averaged data from May to the middle of July for six stations in the Southern Great Plains and found that the RAP consistently under-forecasted parameters of convective available potential energy (CAPE). Laflin also observed a dry bias in the boundary layer, which would contribute to lower values of CAPE.

A study completed by Coniglio (2011) examined the differences between 0-and-1 hour RUC forecasts of severe weather parameters to corresponding VORTEX2 sounding data. This study found that, in contrast to the Laflin's findings for the RAP, the RUC had a positive bias for low-level moisture, and thus a resultant negative bias for the planetary boundary layer height, lifted condensation level, and the level of free convection. This study also noted a positive bias for CAPE, convective inhibition (CIN), and dew point temperature. Positive biases were also found for composite severe parameters, including the supercell composite parameter (SCP, Thompson et al. 2003), significant tornado parameter (STP, Thompson et al. 2003), as well as effective bulk wind difference (EWBD, Thompson et al. 2007), and effective storm-relative helicity (ESRH, Thompson et al. 2007). The SFCOA products take in the RUC forecasts and use surface observations, METARS, and soundings to improve the time scale resolution of the data, adding new observations every few hours or even every hour as opposed to every twelve hours or six hours (Bothwell et al. 2002). As a result, the biases for the SFCOA products should be smaller in magnitude than those for the same severe weather parameters forecasted by the RUC, and Coniglio found that this was indeed the case.

This study intends to extend the results found by Laflin and Coniglio by comparing observed soundings from July 2012 to July 2013 to forecast data from the RAP as well as RAP-based and RUC-based SFCOA output.

II. Methods

The study was conducted in two phases. The first phase consisted of replicating the Laflin (2013) results. The same six sounding locations were used: Rapid City, South Dakota (KRAP), Dodge City, KS (KDDC), Omaha, Nebraska (KOAX), Topeka, KS

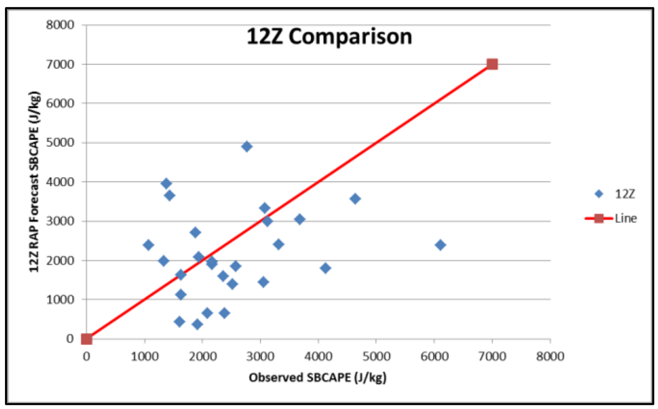
(KTOP), Norman, OK (KOUN), and North Platte, Nebraska (KLBF). A time frame of roughly the same length and during the late spring and early summer of 2012 was also adhered to. The soundings sampled were taken from a preconvective environment, where moist layer (parcel properties obtained by averaging data from the lowest 100 mb) CAPE (hereafter, MLCAPE) was sampled to be 500 J kg^{-1} or greater and which was located within an SPC Convective Outlook for thunderstorms. There were 56 soundings in total that qualified, and 26 of these were used for the purposes of this study. As with the Laflin study, these soundings were then compared to the previous 1200 UTC and 1800 UTC RAP model runs. Raw RAP files were converted to GRIB-2 (Dey 1998) files and then on to GEMPAK files (desJardins 1985). A nearest grid point method was used to retrieve sounding data for each sounding site. The N-SHARP sounding software (Hart et al. 1999) was then used to calculate various forecast parameters. A statistical analysis was performed for SBCAPE, most unstable CAPE (i.e. most unstable parcel in the lowest 300 mb; MUCAPE), and MLCAPE.

The second phase of the study took a much broader look at data from the RAP, SFCOA, a RUC based SFCOA (hereafter, SFCOAb), and an experimental RAP based SFCOA (hereafter, SFCOAp) from June of 2012 to August of 2013. This data was processed in a similar way as the RAP data used to replicate the Laflin study (i.e. using a nearest grid point method and then calculating various parameters using N-SHARP. A statistical analysis for the entire time period was performed on each parameter. Any seasonality was explored by performing additional analysis in three month periods: June, July, and August (JJA), September, October, and November (SON), December, January, and February (DJF) and March, April, and May (MAM). The study period overlapped into a second JJA 2013 sub-period, but the data for this period was excluded since availability of RAP data was inconstant. However, it was included for the SFCOA, SFCOAb, and SFCOAp. The objective was to determine the difference, if any, between the RAP and SFCOA products from the observed atmosphere. Note that all box and whisker plots used to display data include the 95th and 10th percentiles for the whiskers. This helped offset the skewness toward smaller values for CAPE.

III. Verification Results

A. Phase I: Confirmation of Laflin (2013) Observations

SBCAPE, MLCAPE, and MUCAPE were examined from the 26 soundings selected from May 9th, 2012 to July 15th. 1200 UTC and 1800 UTC SBCAPE as forecast by the RAP model were plotted against 0000 UTC observed soundings. Each specific case is included in Fig. 1, with a one-to-one line plotted on the same graph, indicating where the forecast value was equal to the observed value.



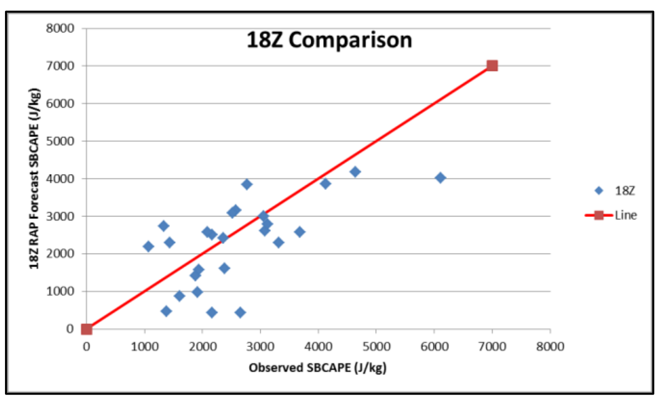


Figure 1: A comparison of the 12-hour 1200 UTC RAP forecast SBCAPE to the 0000 UTC observed SBCAPE with a one-to-one

line (above), and a comparison of the 6-hour 1800 UTC RAP forecast SBCAPE to the 0000 UTC observed SBCAPE.

In Fig. 2, the individual case values for SBCAPE, MUCAPE, and MLCAPE were averaged and plotted for comparison. The results of this study mostly agreed with those of Laflin (2013). The 1200 UTC forecast was about 500 J/kg lower than the observed values for SBCAPE and MUCAPE, and was about 250 J/kg lower for MLCAPE. Some improvement was made with the 1800 UTC forecasts. There was still a negative bias present for SBCAPE and MUCAPE, but forecast and observed MLCAPE were almost identical.

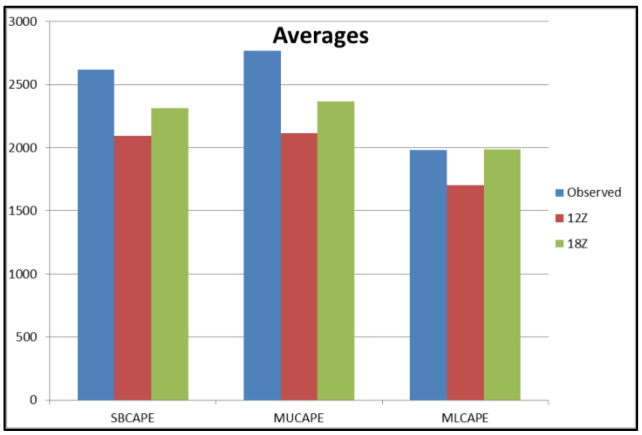


Figure 2: 12-hour (1200 UTC) and 6-hour (1800 UTC) RAP forecast SBCAPE, MUCAPE, and MLCAPE averaged over the late spring and early summer months of 2012 compared to the 0000 UTC observed SBCAPE, MUCAPE, and MLCAPE averaged over the same time period.

Fig. 3 includes box and whisker plots for the mean statistics over the Phase I study period for observed data at 0000 UTC, 12-hour forecast data from the 1200 UTC initialized RAP, and 6-hour forecast data from the 1800 UTC initialized RAP. The median for the observed SBCAPE was around 2400 J/kg, and the median for the 1200 UTC forecast SBCAPE was around 1900 J/kg. There was a slight positive bias (~100 J/kg) for the 1800 UTC forecasted SBCAPE, and the median was at about 2500 J/kg. A strong negative bias was seen for the 1200 UTC MUCAPE and MLCAPE forecasts with a similar rebound and little positive or negative bias for the 1800 UTC runs. MUCAPE forecasts were the best overall, and SBCAPE forecasts were the worst overall. Also, the spread of the data between the 1st and 3rd quartiles for SBCAPE and MUCAPE were greater for the RAP than for the observed soundings.

B. Phase II: Extension to SFCOA Products Throughout the Year.

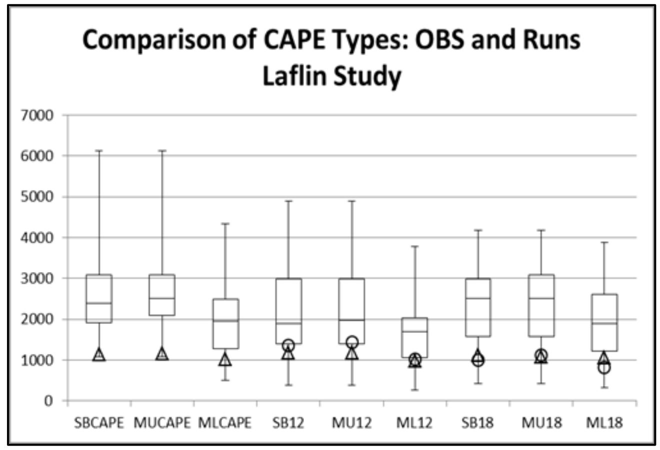


Figure 3: Box and whisker plots of the spring/summer values for CAPE parameters for Phase I. The whiskers represent the 95th and 10th percentiles. Open circles represent root mean square errors, and the open triangles represent standard deviation. SB12, MU12, and ML12 indicate the plots for 12-hour 1200 UTC RAP forecasts statistics for SBCAPE, MUCAPE, and MLCAPE. SB18, MU18, and ML18 represent 6-hour 1800 UTC RAP forecast SBCAPE, MUCAPE, and MLCAPE.

Phase II expanded the investigation over a period of one year and two months (June 1st, 2012 to August 31st, 2013) and included observed soundings from 83 stations (see Table 1 in the Appendix) all over the United States. Figs. 4 – 6 (see Appendix for all remaining figures) are box and whisker plots for the mean statistics of the observed, RAP, SFCOA, SFCOAb, and SFCOAp parameter values. This study focused primarily on thermodynamic parameters which play some role in the forecasting of severe weather events. According to a study completed by Rasmussen and Blanchard (1998), CAPE is a good discriminator between non-severe thunderstorms and supercell thunderstorms that produce tornadoes, so determining CAPE errors for the RAP and various SFCOA products is beneficial for forecasting such events accurately. Various types of CAPE were examined alongside other thermodynamic variables, since these can have local effects on the severity and duration of severe storms (Bunkers et al. 2006, Grams et al. 2012). The yearly statistical averages were calculated, along with seasonally averaged bias statistics.

Figs 4 – 6 display the statistics for the yearly averages for the eight parameters examined: SBCAPE, MUCAPE, MLCAPE, 3K CAPE, surface temperature, dewpoint temperature, mixing ratio (hereafter MMXR), and precipitable water (hereafter PWAT). For SBCAPE, MUCAPE, and MLCAPE, data less than 100 J/kg was excluded to make the statistics more representative of an environment characterized by instability. The figures show that while most of the parameters examined were under forecast, the degree to which they were under forecast varied.

For the CAPE parameters, SBCAPE showed the largest amount of difference in means between the observed value and the RAP forecast value, with the 3rd quartile for SBCAPE being almost 1000 J/kg lower than the 3rd quartile for the 0000 UTC observed SBCAPE. The difference in medians for SBCAPE was much less significant, and the RAP actually performed fairly well for MUCAPE. The RAP also did not have as large of a spread of values between the 1st and 3rd quartiles. The SFCOA, SFCOAb, and SFCOAp more accurately represented the CAPE parameters in both the medians and spreads, and the RUC-based SFCOAb was the most statistically favorable of all the models. The data is heavily skewed towards small values in all the plots, and this is because the averages included data from the winter and from states in which large values of CAPE are seldom seen.

The plots for surface temperature and dewpoint show that there is a slight low bias for both between the RAP and observed soundings, though the low bias for surface temperature was greater (about 4 ºC). The SFCOA, SFCOAb, and SFCOAp products were very close to the observed data. All four products were very similar on the spread of the data between the 1st and the 3rd quartiles with smaller error bars than those seen with CAPE. This is simply because surface temperature and dewpoint do not vary as widely in magnitude as CAPE does across the country.

Finally, the box and whisker plots for PWAT and MMXR show low biases for the RAP as well. All three SFCOA-type products have a slight positive bias for precipitable water, though the SFCOAp had greater outliers.

Figs. 7-14 display the box and whisker plots for mean difference between observed data and the RAP, SFCOA, SFCOAb, and SFCOAp, as well as the root mean square error (RMSE) and the standard deviations of the mean differences. These plots show that the majority of the errors for CAPE parameters for all four products tended to be negative. Mean differences for the RAP and SFCOAb tended to be the most negative. There was also a trend for the RMSE to become large in the spring and summer and to diminish in the fall and winter months. Standard deviations of the mean differences followed the same trend. The winter plots for mean difference tended to more closely resemble the mean difference averaged over the whole year.

The surface temperature plots showed a tendency for the bias to be between zero and negative two for all four products with a reasonable overall spread. Standard deviations of the mean difference and RMSE were fairly close in magnitude. In contrast, errors for dewpoint for all four products tended to be centered around zero; however, SFCOAb and SFCOAp products consistently had a very large overall spread of mean difference. Consequently, RMSE and standard deviation of the mean differences were much larger for the SFCOAb and SFCOAp. The seasonal tendency towards negative mean difference seen in the CAPE parameters was not present for surface temperature or dewpoint. There was little difference in seasonality compared to the yearly mean difference for the Sfc D (except for the afore-mentioned issues with the SFCOAb and SFCOAp products), but surface temperature mean difference became more positive in the summer, deviating from the yearly statistics.

MMXR mean difference was slightly positive but near zero for the whole year. The RAP mean difference was the closest to zero. The spread of mean difference was generally small between the 1st and 3rd quartiles, except again there is a large spread for the SFCOAb and SFCOAp in the summer and fall months. PWAT mean differences were predominantly positive, with spread in the mean difference showing a seasonal tendency to increase in the summer months and decrease in the winter months. MMXR showed little seasonal variation in comparison to the yearly statistics, but mean difference for PWAT became more positive in the summer and then became more negative in the fall and winter months, more closely resembling the yearly statistics.

IV. Conclusions

Over the course of this study, the results of Laflin (2013) were supported, not only for the late spring and early summer months, but also over the entire year. The RAP consistently under-forecast lower level CAPE but represented MUCAPE rather well. The objective analysis products examined herein did eliminate some of the negative bias (mean difference) for thermodynamic sounding parameters, though when mean differences were plotted and examined, they struggled with precision, as seen in the large spread of mean differences over the summer months. Where there was seasonality present, the effects appeared to be weakened over the second JJA period. It might be worthwhile in the future to examine whether or not this had anything to do with relatively hot and dry summer conditions experienced in the summer of 2012 contrasting with the relatively cooler and wetter conditions during the summer of 2013 in the United States.

Overall, the summer seasonality and the decreased variance of mean difference for the winter from the yearly averaged statistics suggests that the RAP and RAP-based SFCOA products do not handle dry conditions as well as the RUC and RUC based products do.

Acknowledgements: The authors would like to thank numerous people at the Storm Prediction Center including Andy Dean, who developed some of the scripts to query data from the GEMPAK files, Phillip Bothwell, who provided information regarding SFCOA, and Jay Liang and Gregory Grosshans who helped set up the space needed to store all the files. Additionally, we also thank Peggy Stogsdill and Brenda Gomez for accomplishing several administrative tasks. Finally, we thank Jaret Rogers for facilitating the OU/SPC Career Experience Program.

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V. References

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VI. Appendix

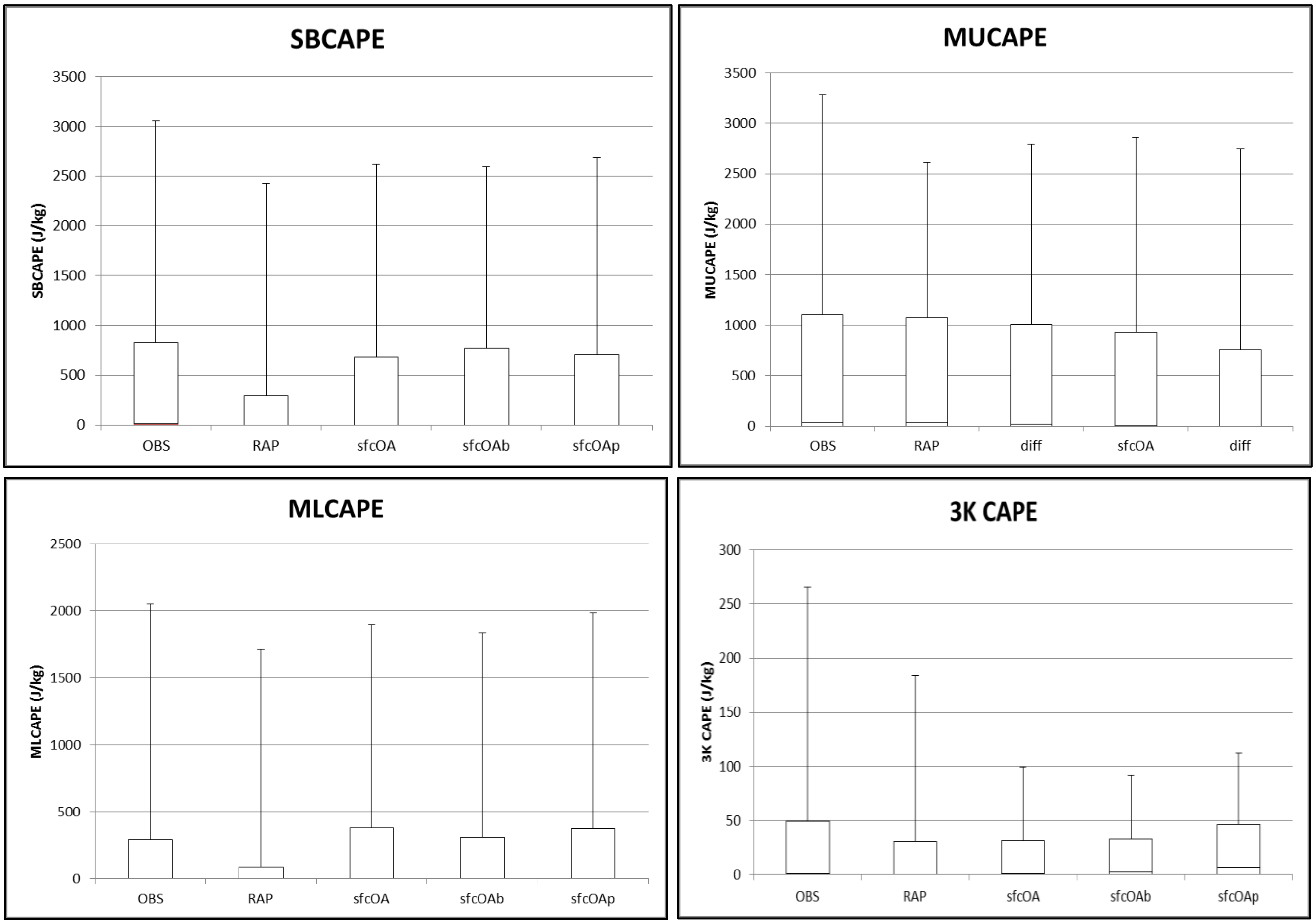

Figure 4: Box and whisker plots displaying statistics for the yearly averaged CAPE parameters from Phase II of the study. The whiskers represent the 95th and 10th percentiles.

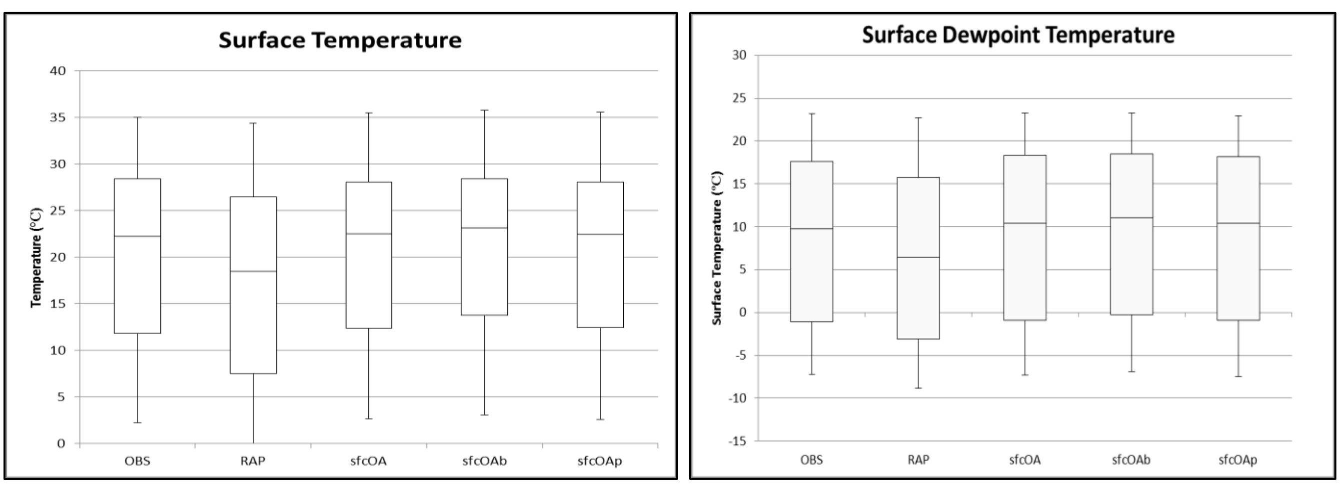

Figure 5: Box and whisker plots displaying the yearly averaged surface temperature and dewpoint for Phase II of the study. The whiskers represent the 95th and 10th percentiles of the data.

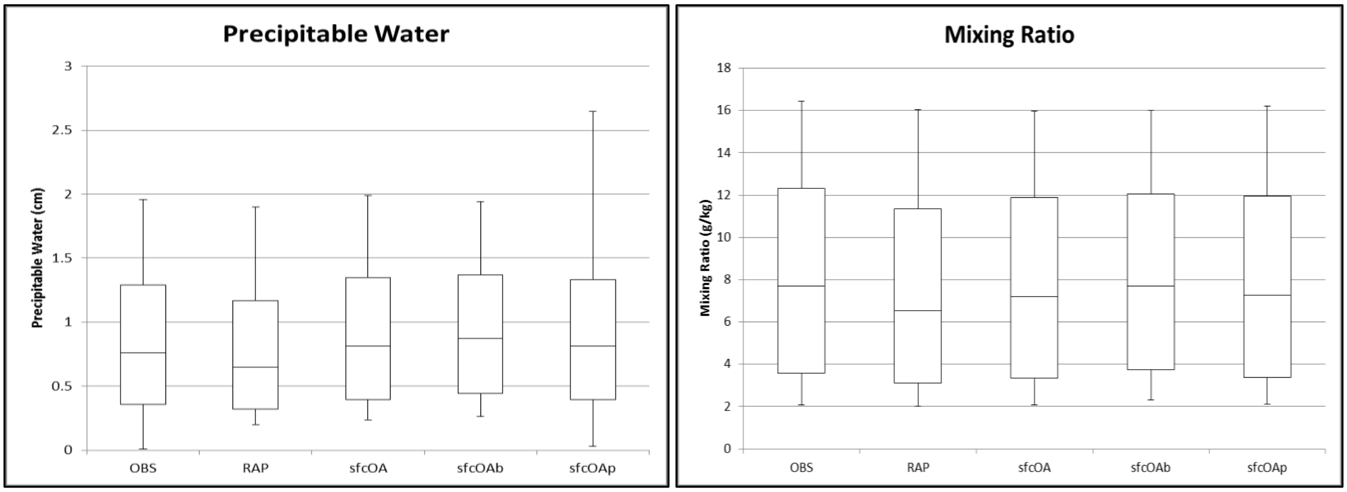

Figure 6: Box and whisker plots displaying the yearly averaged precipitable water amounts and mixing ratio for Phase II of the study.

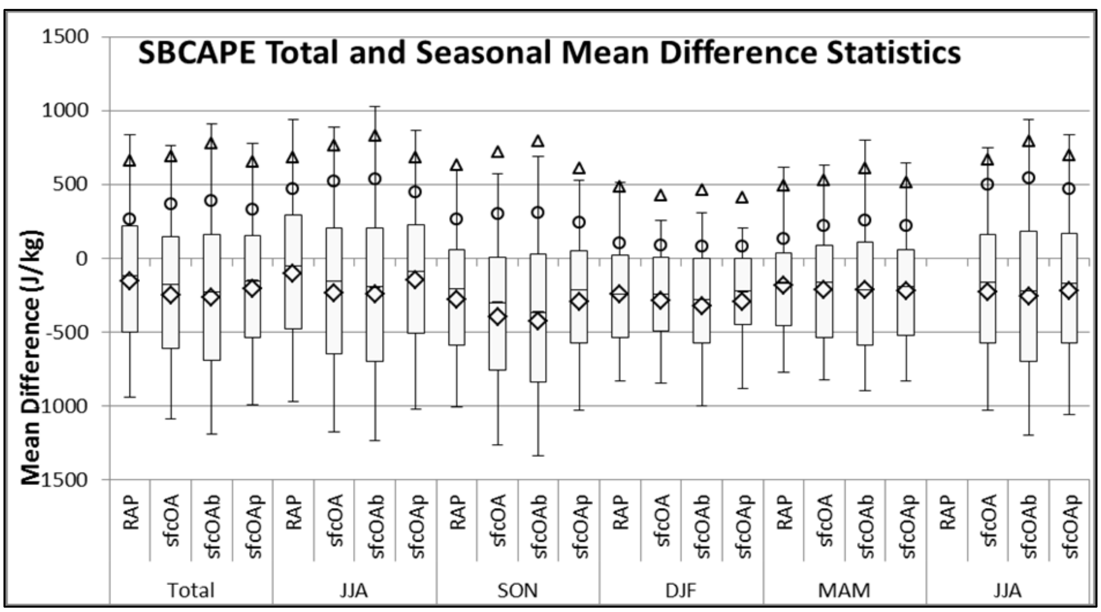

Figure 7: A box and whisker plot displaying both the yearly and seasonal statistics for mean difference for SBCAPE The open diamonds indicate the mean of the mean difference; the open circles represent the RMSE; the open triangles represent standard deviation of the mean difference. Data less than 100 J/kg was excluded from the calculations. The whiskers represent the 95th and 10th percentiles.

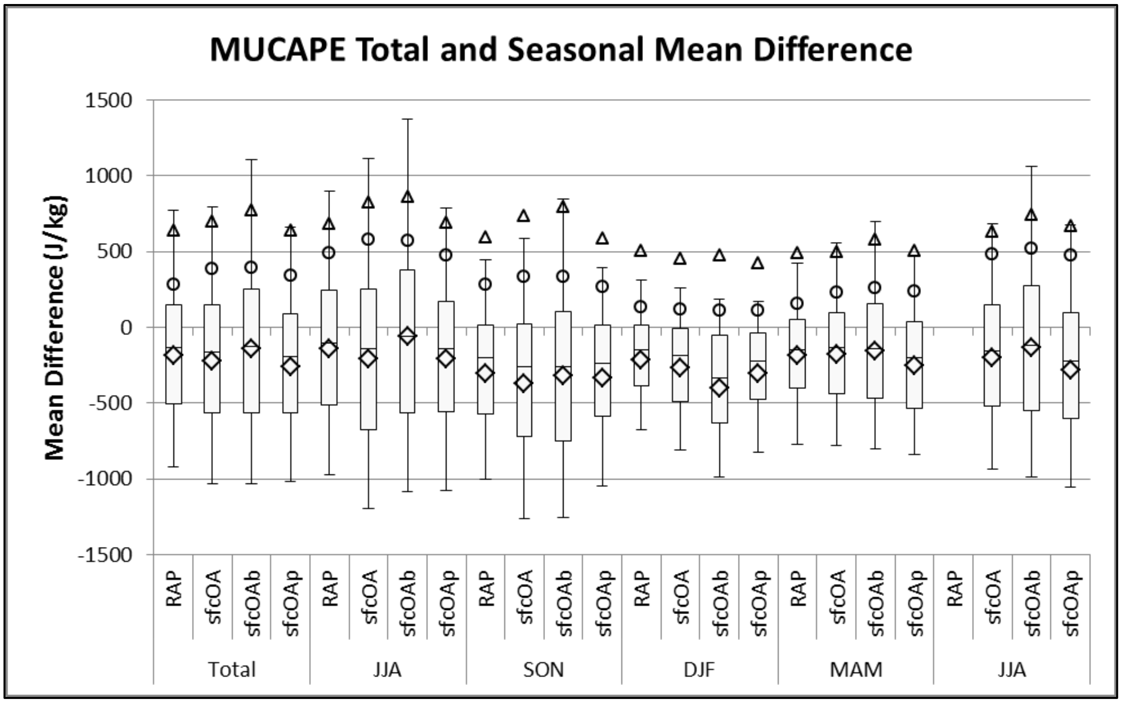

Figure 8: Same as Figure 7, only displaying MUCAPE data.

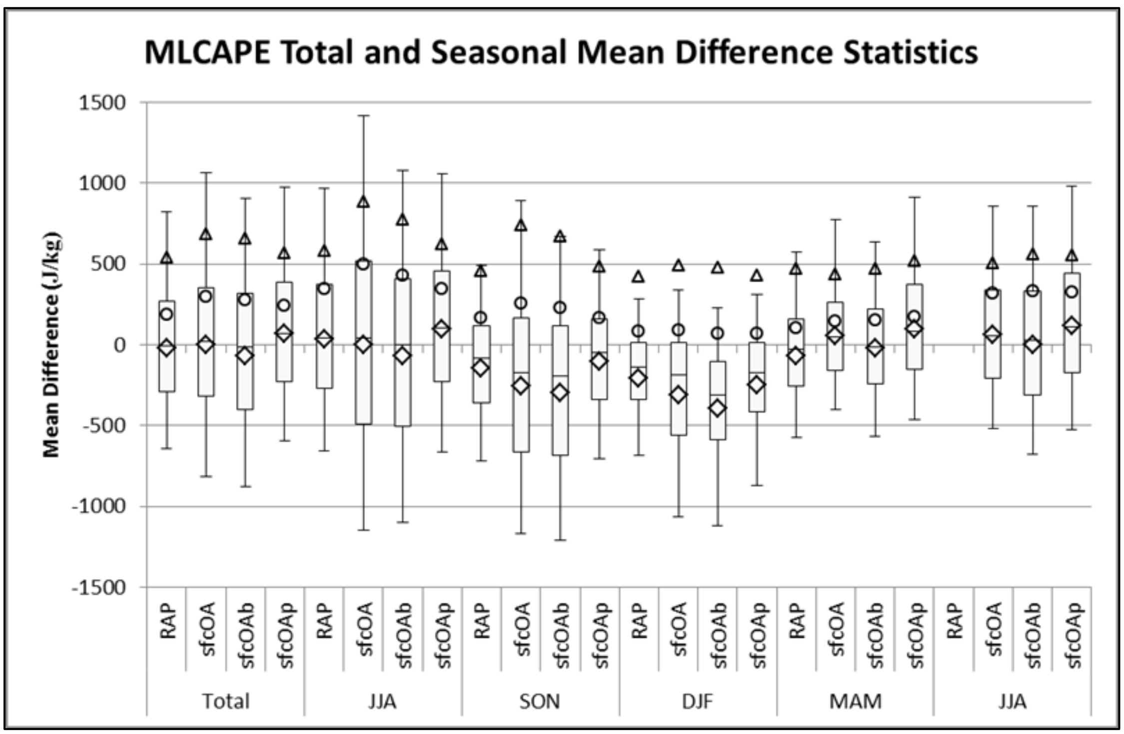

Figure 9: Same as Figure 7, on displaying MLCAPE data.

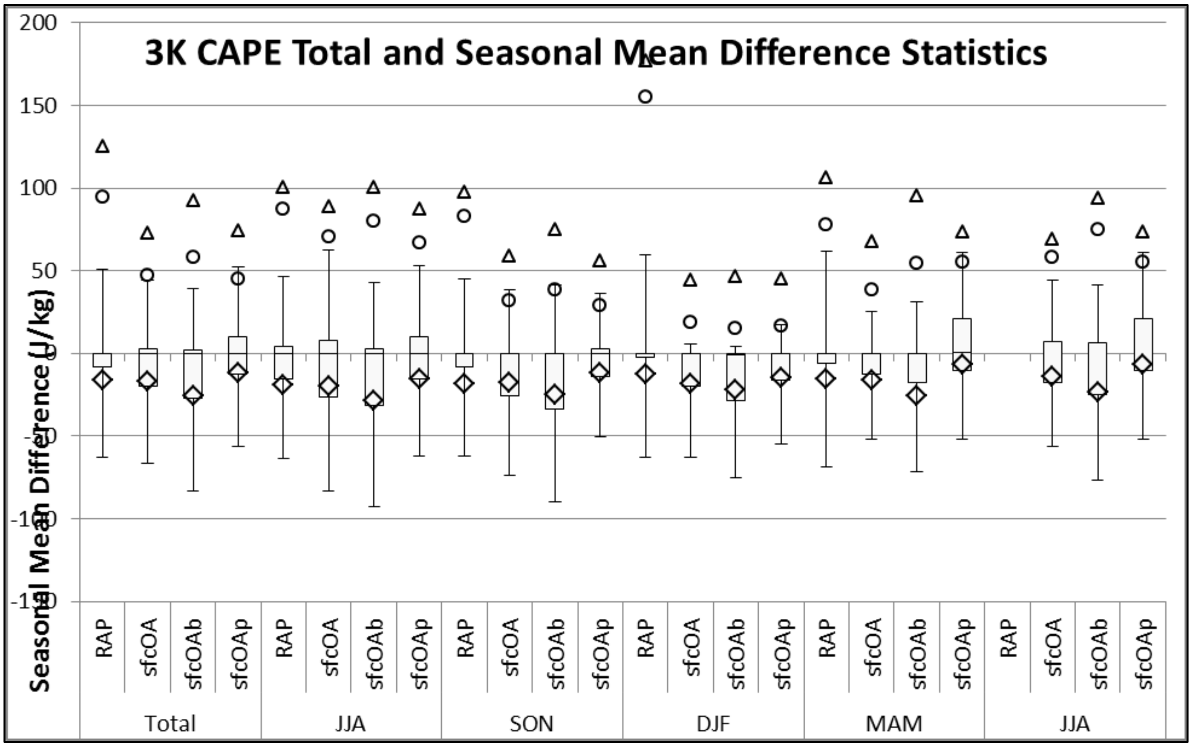

Figure 10: Same as Figure 7, only displaying 3K CAPE data.

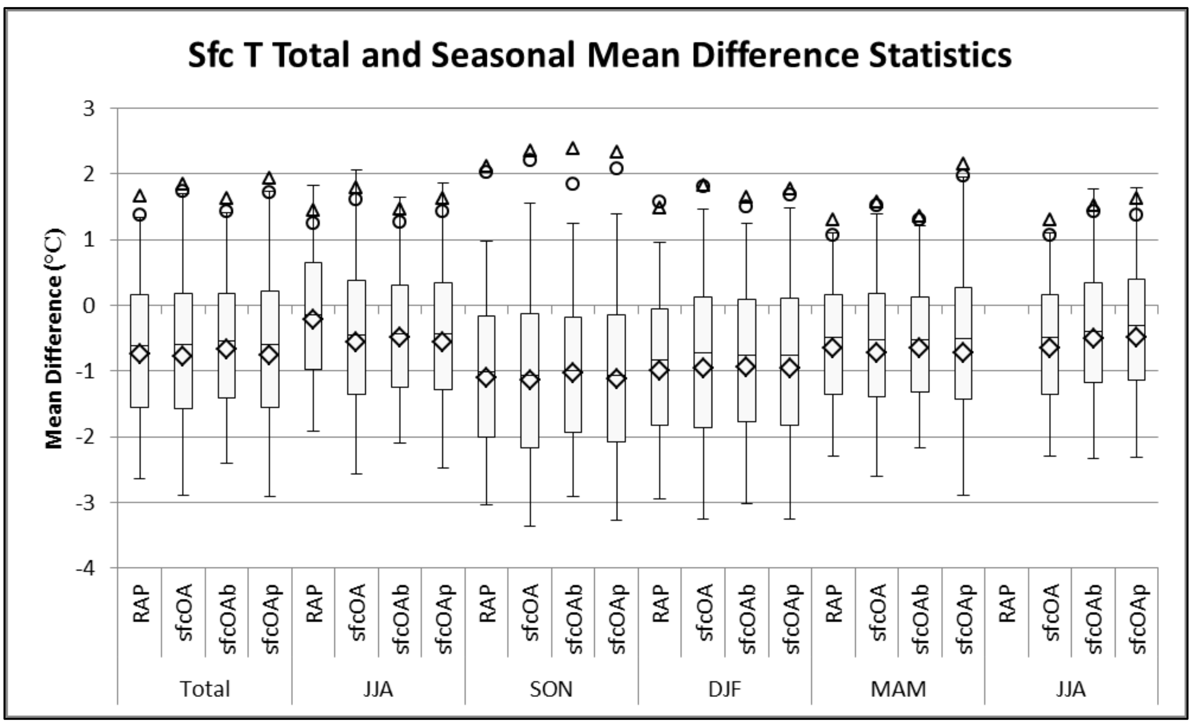

Figure 11: Same as Figure 7, only displaying surface temperature data.

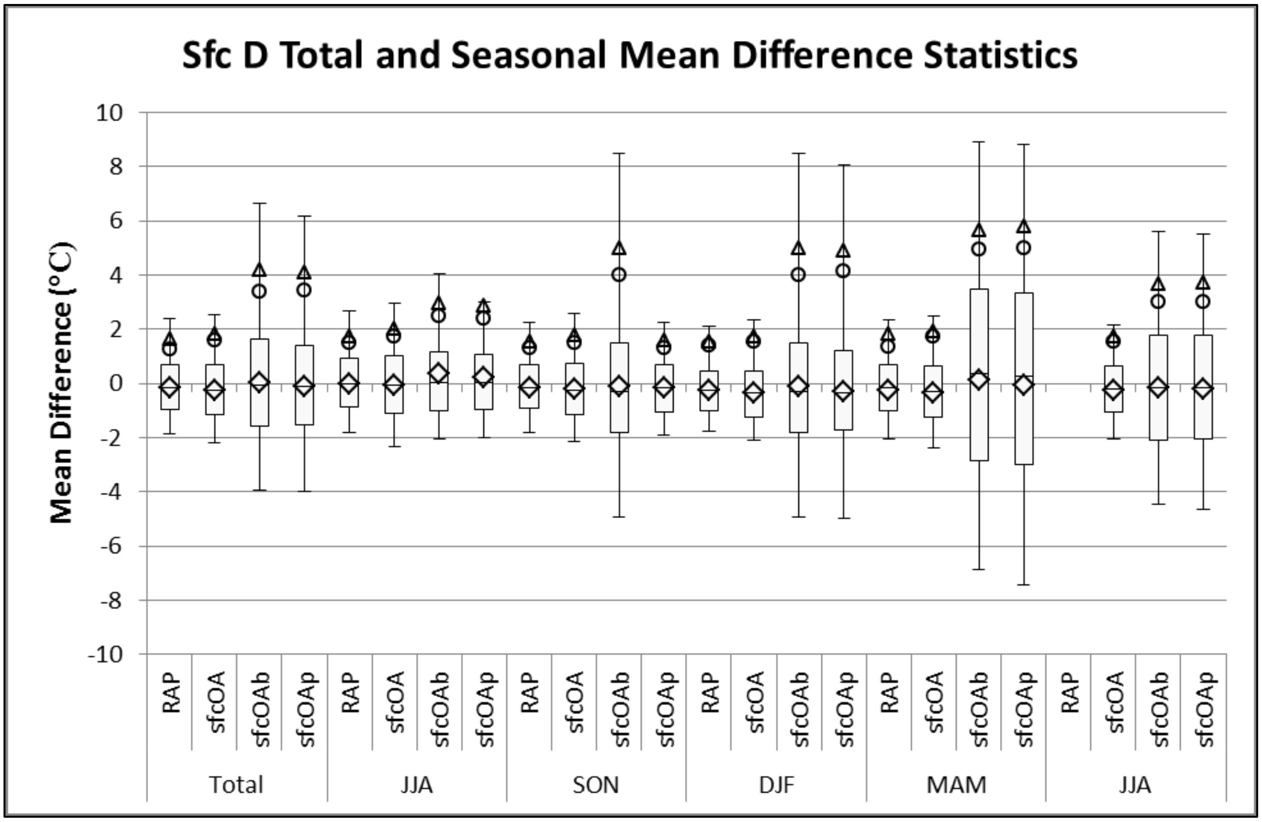

Figure 12: Same as Figure 7, only displaying dewpoint temperature data.

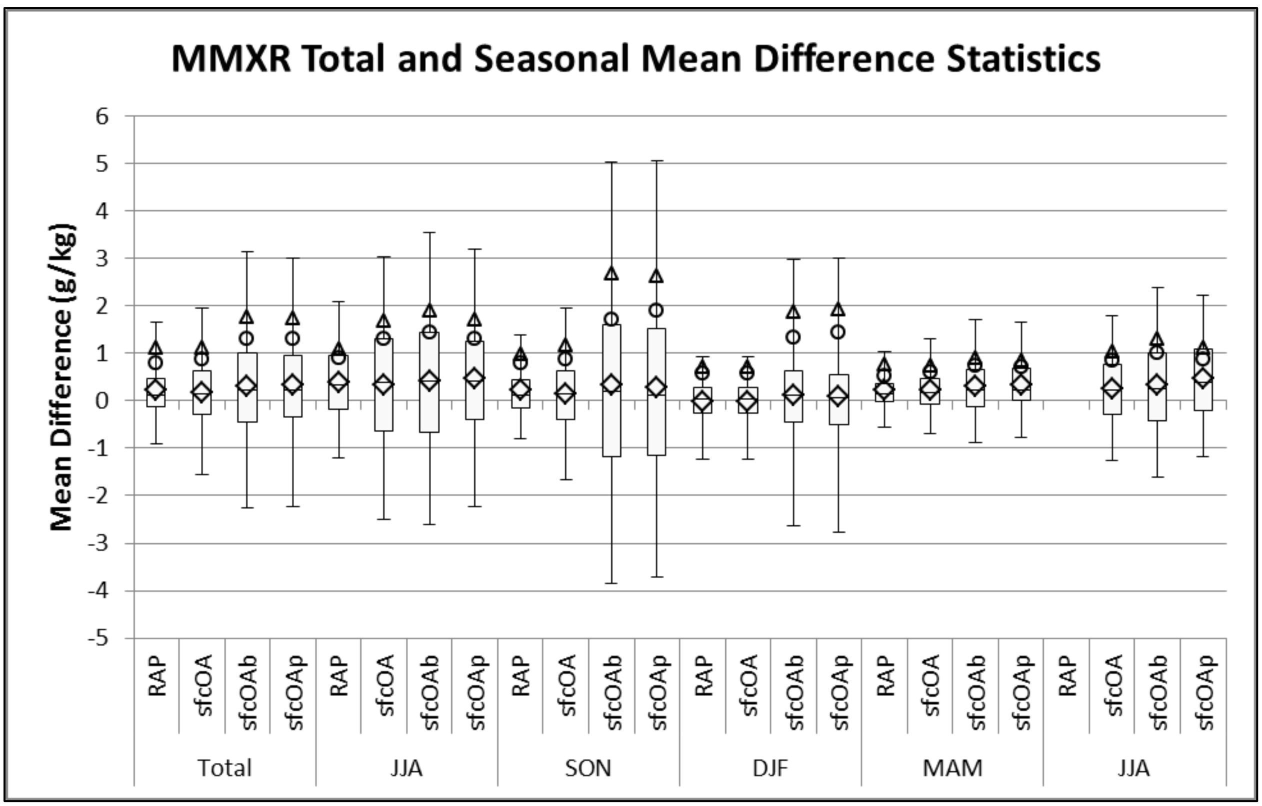

Figure 13: Same as Figure 7, only displaying mixing ratio data.

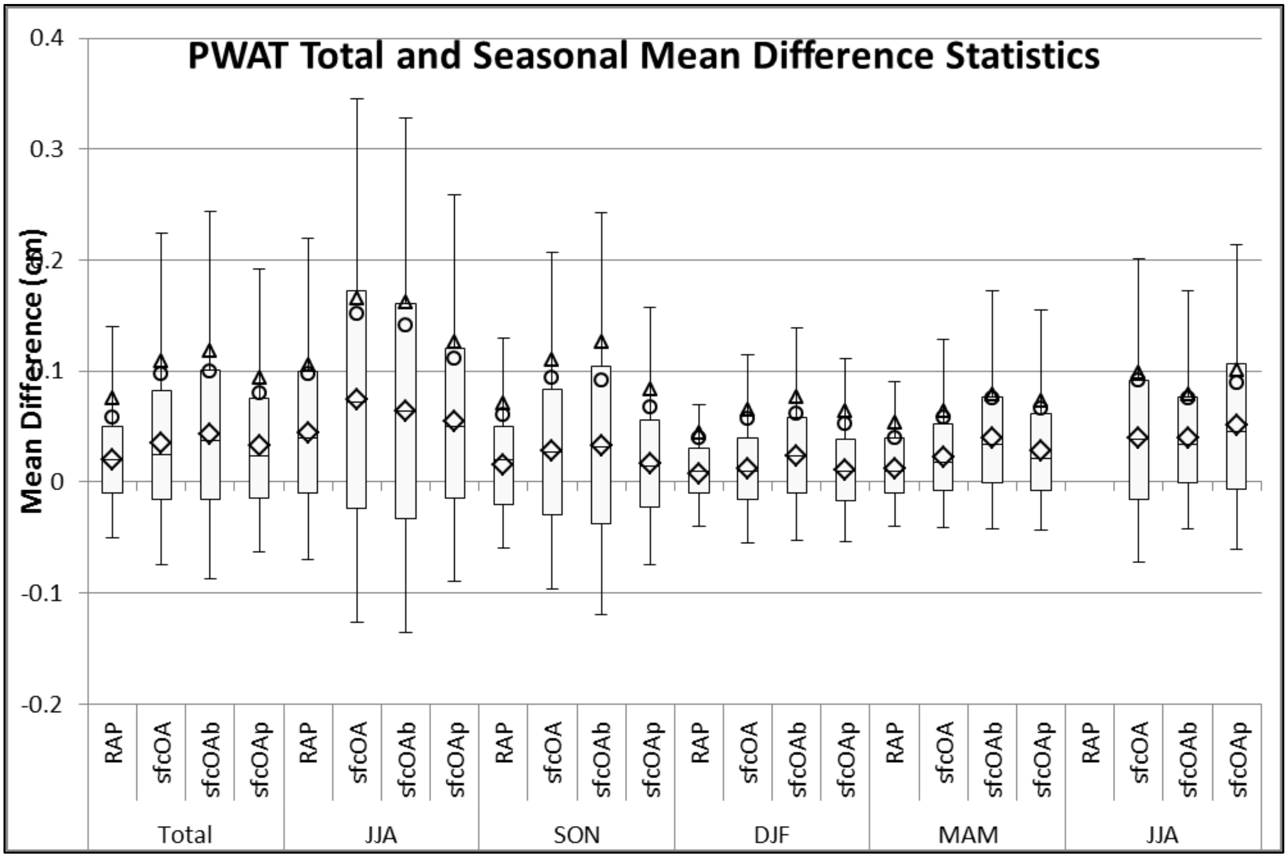

Figure 14: Same as Figure 7, only displaying precipitable water data.

List of Stations IDs								
1Y7	BMX	DNR	FSI	JAN	MAF	OKX	TBW	YOY
ABQ	BNA	DRA	FTK	JAX	MFL	OUN	TLH	YQI
ABR	BOI	DRT	FWD	KEY	MHX	PIT	TOP	YUM
ADG	BRO	DTX	GJT	KREE	MMMD	QAG	TUS	
ADN	BUF	DVN	GRB	LBF	MPX	RAP	VEF	
ALB	CAR	EDW	GSO	LCH	MUGM	RIW	VPS	
AMA	CHH	EPZ	GYX	LIX	MWCR	RNK	WAL	
APG	CHS	EYW	IAD	LKN	MYNN	SGF	WMW	
APX	CRP	FFC	ILN	LMN	NKX	SHV	XMR	
BIS	DDC	FGZ	ILX	LZK	OAX	SLC	YCX	

Table 1: A list of all the stations from which data was taken for Phase II of the study.