Examining the Accuracy of CAPE and CIN in 20th Century Reanalysis Version 2

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Abstract

The impact of climate change on severe thunderstorms is unknown. Previous work has used data from reanalysis to derive variables that do not suffer from a large bias, which makes counts of severe thunderstorm occurrences difficult to assess. How well the new 20th Century Reanalysis Version 2 captures key stability indices used in severe weather forecasting is unclear. This paper compares two key indices, CAPE and CIN, to weather balloon data over the central United States. "Errors" in reanalysis were computed by subtracting the weather balloon observations from the estimates in reanalysis at Dodge City, Kansas, Topeka, Kansas, and Norman, Oklahoma. Given that CAPE and CIN can be highly variable in space and time, the mean and median errors in reanalysis were found to be relatively accurate. Future work could involve exploring the differences between reanalysis and weather balloons over a larger area of the eastern United States, and include the use of additional variables.

Introduction

There has been limited research into significant severe storms (i.e., those that produce the largest hail, highest winds, and largest tornadoes), and their relationship to climate (Brooks 2013).

There have been issues with observations of severe storms due to the increase in technology and the number of people involved in detecting severe storms, there is a much higher count of severe storms. This need for more accurate data from the past led to the creation of reanalysis, the process of taking previously known data and using a computer model to create a more spatially balanced set of meteorological variables throughout our recent history (Compo et al. 2011).

Brooks et al. (2003) used key severe storm indices in reanalysis to assess variability of significant severe storm environments through time [i.e., those storms that produce 2+ inch diameter hail, 74+ mph winds, or EF2+ tornadoes.

Twentieth Century Reanalysis Version 2, is the newest reanalysis and runs from 1871 to 2012 (Compo et al. 2011). Convectively Available Potential Energy (CAPE) and Convective Inhibition (CIN), which measure the positive and negative buoyancy of an air parcel respectively (Figure 1), are calculated in reanalysis. However, it is not clear how well reanalysis captures these two key indices.

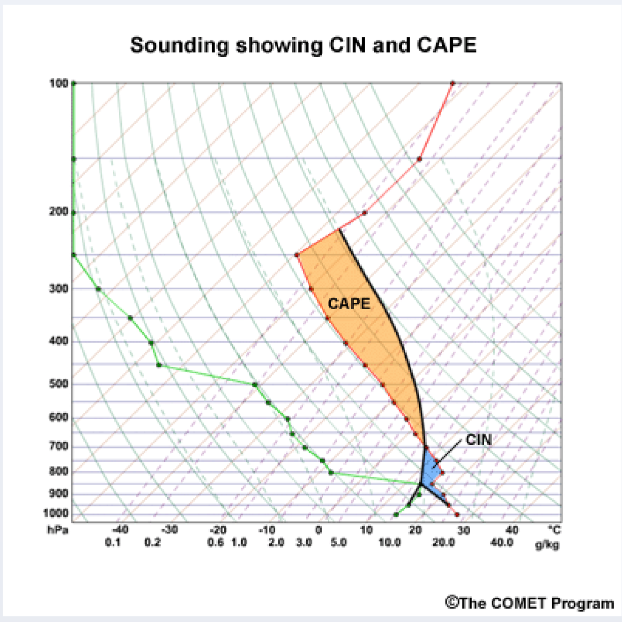

Figure 1: Weather Balloon sounding illustrating the calculation of CAPE and CIN (Red=Temperature, Green=Dew Point, Black=Path of Air Parcel)

Methodology

The decision was made to concentrate on new reanalysis data using the indices of CAPE and CIN in the South-Central United States.

After creating and running a program in R, values of CAPE and CIN were output from 1900-2011 in 12 different locations in the central United States seen in Figure 2.

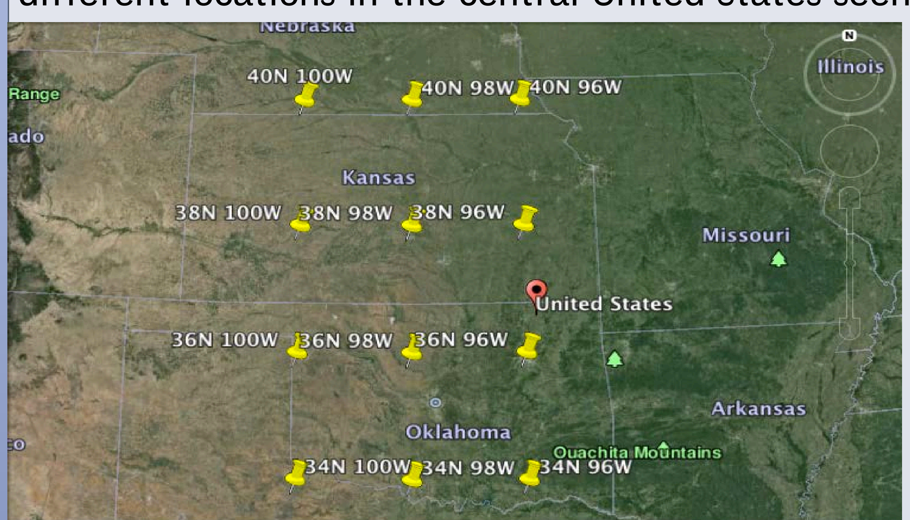

***Figure 2:** Coordinates of 20th Century Reanalysis Version 2 Data*

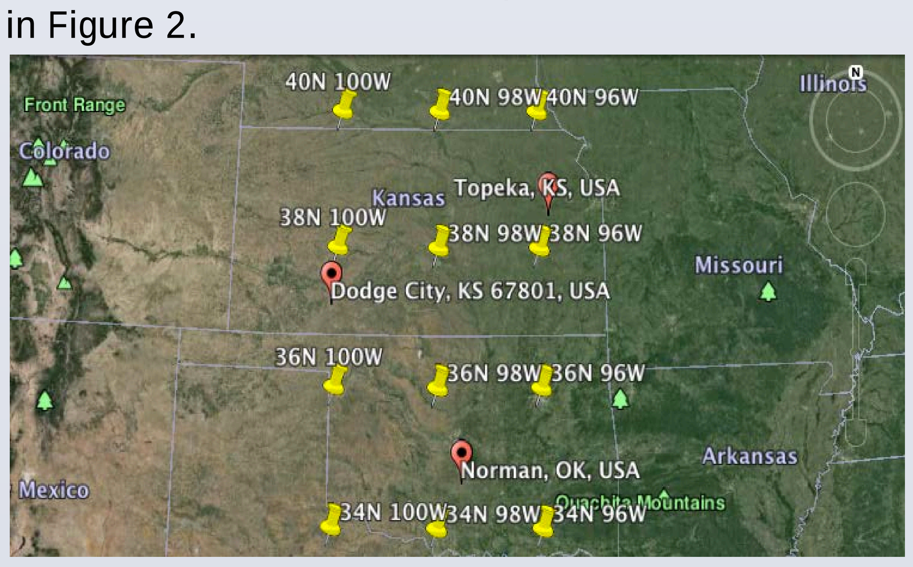

***Figure 3:** Cities used for 20th Century Reanalysis Version 2 Data Comparisons*

Three stations that launch weather balloons were selected for comparison: Dodge City, Kansas, Topeka, Kansas, and Norman, Oklahoma (Figure 3). The decision to compare Dodge City and 38N 100W was easily made.

Our solution for Norman and Topeka's data, was to average the two data points that the cities were set between.

The next step was to average the two data sets for each city by creating a program in R.

After creating the R code in which to combine all reanalysis CAPE and CIN data in all three cities by outputting it into one file, it was now time for the final comparison.

After preparing the output file, the decision was made to compare these data by computing error, which is solved using the equation, estimated value minus the actual value.

The final step was to create a code, similar to the previously created descriptive statistics code for reanalysis CAPE and CIN data, with the intention of gaining the knowledge of descriptive statistics specifically regarding the error calculated.

After editing the previous descriptive statistics code in terms of error, the final R program was finally ready to run.

Results

An analysis of the descriptive statistics for Dodge City, Topeka, and Norman shows higher instability at Dodge City than the other stations on average, but if outliers are taken into account, Norman has higher instability (Table 1)

This shows there is a large number of high CAPE values at Dodge City that bring up its average. Essentially, these results illustrate how instability has high variability. On the other hand, convective inhibition, determined through both mean and median, is consistently higher in Norman than in Dodge City, with Topeka having the least.

	Dodge City		Topeka		Norman	
	CAPE	CIN	CAPE	CIN	CAPE	CIN
Min	0	-800	0	-671	0	-716
25%ile	1	-46	1	-40	1	-59
Mean	630	-36	445	-31	569	-42
Median	33	-13	13	-8	78	-20
75%ile	942	-2	516	-1	906	-2
Max	7758	0	5709	0	6218	0
Std. Dev.	1024	56	818	53	851	59
Variance	1049152	3131	668928	2835	724965	3438

Table 1: *Descriptive statistics for CAPE and CIN at Dodge City, Topeka, and Norman, 25%ile = 25th Percentile, 75%ile = 75th Percentile, Std. Dev.= Standard Deviation.*

The error in CAPE between 20th Century Reanalysis Version 2 and the weather balloon data in the cities of Dodge City, Topeka, and Norman show different features (Figure 4). Reanalysis does better at capturing CAPE over Dodge City than at Topeka or Norman. Dodge City also had a larger number of positive outliers than Topeka and Norman.

The boxes in the box plot represent 50% of the error data points, and those for Topeka and Norman seem to be almost identical, but the median lines were clearly different. Dodge City's median line was located much closer to zero with a median error of only -4 J/kg.

In the case of CIN, all three box plots were approximately the same size visually, and mean errors were all near -40 J/kg (Figure 5). When looking at median, errors were very close to or at zero. Like CAPE, CIN is also highly variable in space and time, so these mean and median errors are encouraging.

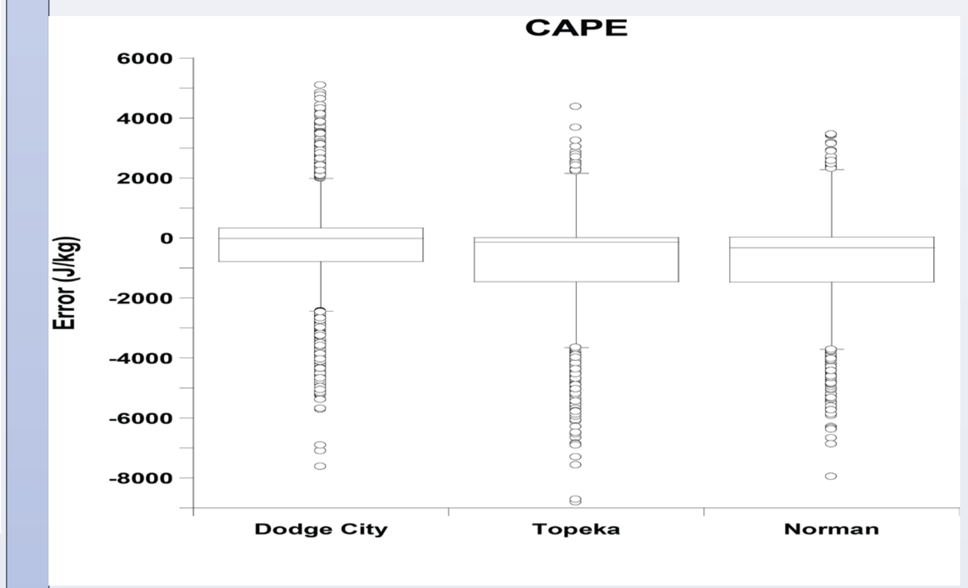

Figure 4. Box plot diagrams summarizing the error in CAPE between 20th Century Reanalysis Version 2 and weather balloon data for Dodge City, Topeka, and Norman.

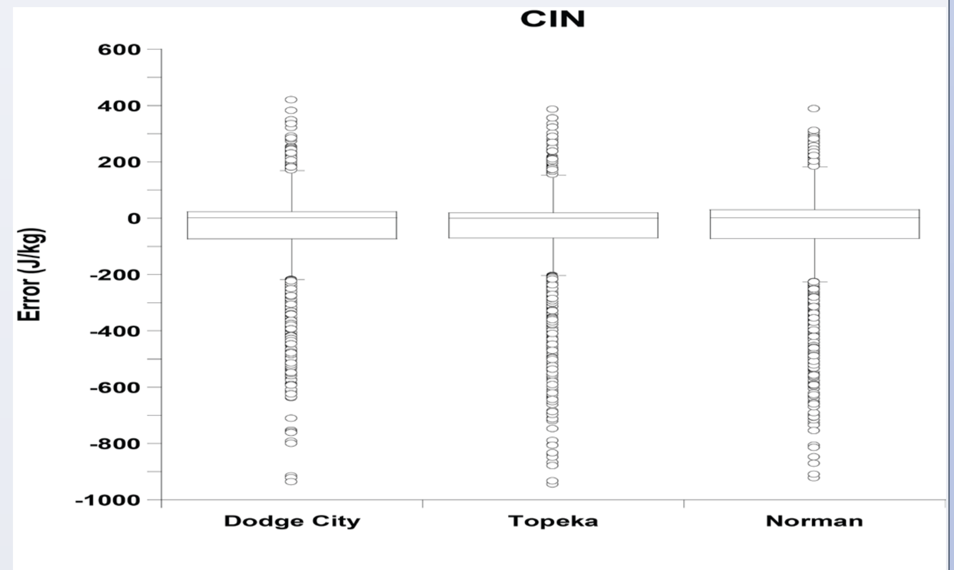

Figure 5. Box plot diagrams summarizing the error in CIN between 20th Century Reanalysis Version 2 and weather balloon data for Dodge City, Topeka, and Norman.

Discussion and Conclusion

The importance and purpose of this research is not just simply to validate two stability indices computed in 20th century Reanalysis Version 2, but also to help narrow down key stability indices within reanalysis that could potentially be used as a proxy to extend the history of severe thunderstorm environmental conditions backward in time. This allows climatologists to have a wider range of data in which to detect patterns, and to truly see if severe storms are increasing. Currently, there is not enough data for climatologists to determine the impact of anthropogenic climate change on severe thunderstorms. With these new validated data, and eventual data collected farther back than just 1871, the ability to adequately assess severe thunderstorms in the context of anthropogenic climate change could increase.

An analysis of the descriptive statistics for Dodge City, Topeka, and Norman shows there is a large number of high CAPE values at Dodge City that bring up its average. Essentially, these results illustrate how CAPE and CIN both have high variability. On the other hand, convective inhibition, determined through both mean and median, is consistently higher in Norman than in Dodge City, with Topeka having the least. When looking at the error between reanalysis data and weather balloon data, in terms of CAPE and CIN, it was obvious that reanalysis does better at capturing CAPE over Dodge City than at Topeka or Norman. Also, in terms of CAPE, Dodge City's median line was located much closer to zero with a median error of only -4 J/kg. In the case of CIN, all three box plots were approximately the same size visually, with relatively precise mean errors, and when looking at median, errors were very close to or at zero. Given that CAPE and CIN can be highly variable in space and time, the mean and median errors are relatively accurate.

These data still leave a great deal to be desired though, especially when it comes to minimum and maximum errors depicted in Figures 3 and 4. There are several reasons why such large errors occurred. First, erroneous values were noted in the CAPE and CIN weather balloon observations (e.g., 10,000 J/kg CAPE and -1000 J/kg CIN). This leads to the question of whether the weather balloon data contain additional errors. Reanalysis can only capture certain levels of the atmosphere vertically too, and because CAPE and CIN are vertically integrated (i.e., capturing the area underneath the curve, Figure 1), reanalysis might miss key locations in the upper atmosphere and underestimate the amount of CAPE and CIN. Lastly, there is a question of location and consistency with the patterns found in these data. This is just a small sample size looking specifically at three cities in the central plains of the United States, and results may be different in other locations.

Future work could involve exploring the differences between 20th Century Reanalysis Version 2 and weather balloons over a larger area of the eastern United States. In addition to CAPE and CIN, other variables could also be explored, which would help assess which variables used in severe thunderstorm forecasting are best resolved in 20th Century Reanalysis Version 2. Once this is known, the best suite of variables can be used to reconstruct severe thunderstorm environments back into the 19th Century.

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References

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