Analysis of Cobb-Predicted Snow for Winters 2008-2010 at Six Locations

RACHAEL A. WITTER

Meteorology Program, Iowa State University, Ames, IA

Mentors: William A. Gallus Jr., Christopher D. Karstens, Logan R. Karsten

Department of Geological and Atmospheric Sciences
Iowa State University, Ames, IA

ABSTRACT

Forecasting snowfall totals remains a difficult challenge to forecasters. Though there are many techniques of snowfall forecasting, the Cobb method uses average snow liquid ratios (SLRs) taken through snow events. These SLRs account for various physical aspects of snow production such as snow crystal density, vertical motion and temperature to create these ratios. This study analyzes snowfall projections using the Cobb method generated at six stations representative of three geographical groups during 2008-2009 and 2009-2010 winter seasons. Contingency tables for each site were calculated to determine forecast hits and misses.

1. Introduction

Snowfall totals are a difficult phenomena to forecast. Snowfall amounts depends on a variety of factors, including geographical location in which the event takes place, track of a mid-latitude cyclone or orientation of winds for lake effect. A way of forecasting snowfall is by using snow liquid ratios (SLRs). SLRs are the ratio of precipitable water to snowfall. A traditional snowfall forecast might assume that 10 inches of snow would melt down to 1 inch of water (10:1). More recently, several snowfall algorithms have been developed to take the average SLR through the duration of a storm to forecast storm totals. Research has been done on how different types of snow events are handled using SLRs.

A study done by Cobb and Waldstreicher et al (2005) examined the microphysics that affect snowfall accumulation. These factors include snow crystal shape and snow density. Dendritic snow crystals yield the highest of SLRs due to their light nature, while rimed crystals yield low SLRs due to their heavy, wet nature. This study also examined the role of vertical motion in the snow creation process. A snow production zone, or SPZ, is defined as a region of increased efficiency of snow production. If a vertical motion maximum occurs directly below the SPZ, maximum snowfall totals will occur.

Using this information, the Cobb The algorithm was developed. This algorithm is an extension of the Cross-Hair approach (Waldstreicher et al. 2001) as well as the snow ratio flow-chart. (Dubè et al 2003.). Dubè et al. (2003) looked at the disadvantages of many widely used SLR techniques, such as the National Weather Service's temperature conversion table and Scofield/Spayd diagrams (Scofield and Spayd et al 1984). All of these techniques look at the effect of temperature on SLRs. Dubè et al. (2003) also further proves that the 10:1 ratio is not a good SLR to be used as base ratio for forecasting. Out of 60% of verified cases, only 25% fell within the 10:1 ratio, while 41% worked with the NWS conversion table. The main problem with these techniques of forecasting is that they do not take vertical motion into account, Cobb and Waldstreicher et al (2005) mention is key in forecasting snowfall.

The purpose of this study is to determine how well the Cobb method performs under several different situations. These situations include variability in geography, winter seasons, models, and seasonal snowfall totals. *It is hypothesized that the North American Mesoscale model (NAM) Cobb snowfall projections near the Great Lakes region will perform the best owing to the NAM's higher resolution.*

2. Data and Method

Hourly (NAM) and 3-hourly (GFS) forecast data for six city locations (Table 1) were examined from two winter seasons (November-March, 2008-2009 and 2009-2010). These data were obtained from Pennsylvania State University's extensive BUFKIT (Mahoney et al 1996) archives. All BUFKIT data were post-processed to obtain forecasted quantities of SLR and snow accumulation, using the Cobb method (Cobb et al 2005). The six stations are representative of three different geographical regions (Table 1).

Local COOP observations of total preciptation and snow for each site were obtained from the NCDC for verification. These data are provided in 24-hour summaries (midnight to midnight, LST). Hourly METAR observations from the Automated Surface Observation System (ASOS) were used to eliminate any precipitation in the NCDC precipitation totals that fell in a form other than snow. Thus, the corrected precipitation totals attempt to better represent the total SLR for each day. A daily mean snow ratio was then calculated using the corrected SLR and the total observed snowfall (in inches).

Table 1. *Geographic distribution of stations by region. Regions included Eastern coastal cities, cities near the Great Lakes and the Midwest.*

Station	Location
KALB	Albany, New York
KBOS	Boston, Massachusetts
KBUF	Buffalo, New York
KDSM	Des Moines, Iowa
KERI	Erie, Pennsylvania
KJFK	New York City, NewYork

The hourly and three-hourly snowfall totals and SLRs from the NAM and GFS, respectively, were summed into the same 24-hour periods corresponding to the observed data. In addition, an average daily snow ratio was calculated by summing the forecast snow-ratio only when snow was forecasted, and dividing this total by the number of hours when snow was forecast to fall.

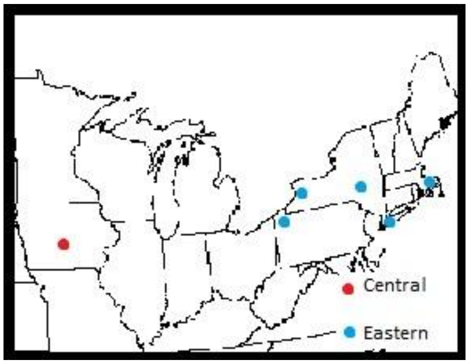

***Figure 1**. Map of stations by time zone*

To account for one of the stations (KDSM) being in the Central time zone, as seen in Fig. 1, 06Z-06Z forecasts were utilized for the Central time zone, while 05Z-05Z forecasts were used for the Eastern time zone. NAM forecasts could easily be scaled back one hour to satisfy the restrictions set by the NCDC data. For the GFS, forecasted snowfall and QPF were multiplied by 1/3 at the beginning of the forecast period, and

2/3 at the end to interpolate the forecast to hourly.

3. Statistical Analysis

Data analysis for this study were comprised of three parts. The data were examined by separate models, GFS and NAM, and then an cumulative total of the two models was taken to see where Cobb output performed well. Differences in SLR and snowfall amounts were calculated using the mean absolute error (MAE) via

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |f_i - y_i| \ , \qquad (1)$$

which is the summation of the forecasted quantity minus the true value(verification), divided by the number of model runs in the season. The mean absolute error for SLR and snowfall amounts were calculated for the NAM and GFS and the average between the two models. This error accounted for the models predicting either too heavy or too light by yielding an absolute value.

In addition to MAE, the error for NAM, GFS and the cumulative of the two models' predicted snowfall totals was found using the verified snowfall amounts minus the models' predicted snowfall.

Forecast statistics were computed using contingency tables. Seen below, contingency tables are a measure of forecast hits and misses.

		Forecast	
		yes	no
Observed	yes	a	b
	no	c	d

a = hit
b = miss
c = false alarm
d = correct null

Probability of Detection (POD) was computed via

$$POD = \frac{a}{a+b} \ , \qquad (2)$$

where a is the number of correct warnings over the number of total observed events (a + b).
The False Alarm Ratio (FAR) was found using

$$FAR = \frac{c}{a+c} \ , \qquad (3)$$

where c is the number of falsely warned events over the total warnings issued (a + c).
The critical success index (CSI), also referred to as Threat Score, was calculated using

$$CSI = \frac{a}{a+b+c} \ , \qquad (4)$$

where a is the number of correct warnings over total warnings issued and missed (a + b + c).

The Equitable Threat Score (ETS), also referred to as skill score, was computed via

$$ETS = \frac{a - ch}{a+b+c-ch} \ , \qquad (5)$$

where

$$ch = \frac{(a+b)(a+c)}{n} \ , \qquad (6)$$

a is the number of correct warnings minus ch, which is the number of correct forecasts due to chance (Equation 6), over (a + b + c), the total number of warnings issued in addition to forecast misses.

The contingency tables were constructed for the six sites using three snowfall thresholds (Table 2) and the NAM and GFS for winter 2008-2009 and 2009-2010, respectively. The zero inch threshold represents the models' ability to capture a snowfall event. The four inch and eight inch thresholds represent the models' ability to capture medium- and high-end events.

Table 2. *Snowfall event thresholds for contingency tables.*

Snowfall Thresholds
Events greater than 0 inches
Events greater than 4 inches
Events greater than 8 inches

Figure 2. Forecast statistics for all sites, winter seasons 2008-2009 and 2009-2010, and NAM and GFS models for (a) POD, (b) CSI, (c) FAR, and (d) ETS, with a zero inch snowfall threshold.

4. Results

a) Zero Inch Snowfall Threshold

Statistics for the zero inch threshold are displayed in Figure 2. It is shown that two of the six locations, KBUF and KERI have substantially higher values of POD (0.5-0.75), CSI (0.45-0.6) and ETS (0.15-0.35), and lower FAR (0.1-0.4) values, compared to the other four locations. It is important to note that KBUF and KERI are the only two locations that receive lake-effect snow in addition to other synoptic-scale snow events. At these two locations, snow events were correctly predicted approximately half of the time, while falsely alarming only approximately 25% of the time. Thus, it seems the Cobb method performs rather well for these two lake effect snow locations.

Additionally, Fig. 2 shows that KJFK and KBOS have the lowest vales of POD (0.2-0.3), CSI (0.1-0.2) and ETS (0.05-0.15) and the highest values of FAR (0.4-0.7) compared to the other four locations. Interestingly, these two locations are situated along the northeastern coast of the U.S. At these two locations, snow events were correctly predicted only 25% of the time, while falsely alarming at least 50-70% of the time. Thus, it seems that the Cobb method may not perform as well for locations situated along the northeastern coast of the U.S.

The remaining two locations, KALB, KDSM, have similar values of POD, FAR and CSI, ranging from 0.2-0.4, and ETS values ranging from 0.1-0.2. These two locations could be considered inland locations not influenced by lake effect snow or a major body of water, however, it is noted that KALB and KDSM are separated by a considerable distance. At these

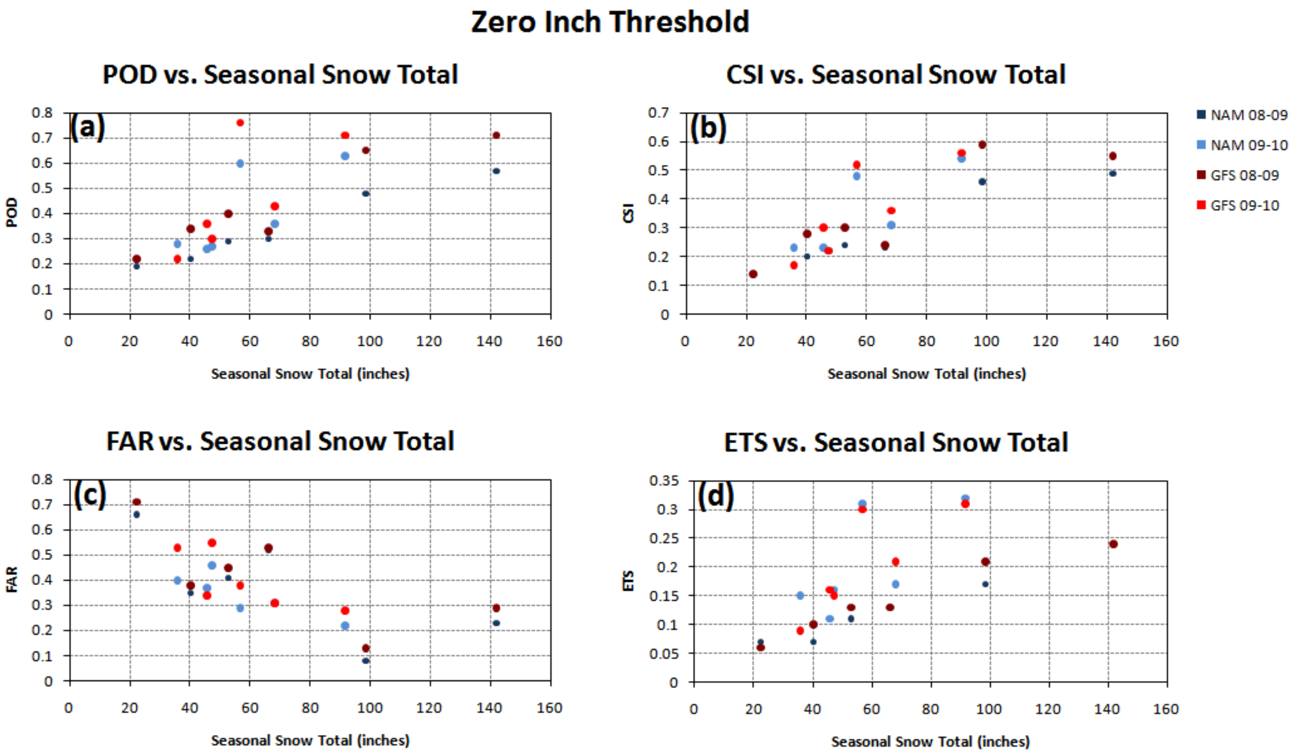

Figure 3. Sensitivity of (a) POD, (b) CSI, (c) FAR and (d) ETS values with increasing seasonal snowfall totals for both winter seasons and both models at all six locations.

two locations, snow events were correctly predicted and falsely alarmed approximately 33% of the time. Additionally, the statistics faired marginally better than KBOS and KJFK. Thus it is difficult to determine whether or not the Cobb method performs well at these two locations. It is important to note that other factors, such as annual variability in the meso- and synoptic-scale weather patterns, differences between the NAM (mesoscale) and GFS (global) models, and differences in seasonal snowfall totals.

In addition to the geographic variability that is apparent in Fig. 2, the statistics show that variability exists between the two seasons and the two models. A majority of the locations had higher values of POD (2/3 of locations), CSI (2/3), and ETS (11/12), and lower values of FAR (3/4), for the 2009-2010 winter season compared to the 2008-2009 winter season.Thus, it appears snow events during the 2009-2010 winter season were handled better by the models than during the 2008-2009 winter season. On a per-year basis, the GFS has higher FAR values than the NAM, however, the GFS also has higher values of POD, CSI and ETS in nearly all cases. Thus, even though the GFS tends to capture snow events better than the NAM, it also “cries wolf” more frequently.

Lastly, the sensitivity of the statistics to the seasonal snow total was investigated. Interestingly, Fig. 3 shows a positive correlation between POD, CSI and ETS, and the total amount of snow that fell at each location during each season. Additionally, a negative correlation exists between FAR and seasonal snow total. Note, these inferences from Fig. 3 are independent of model type and season, with the exception of panel d. (ETS vs Seasonal Snow Total) On this panel, the correlation is more positive for the 2009-2010 season compared to the 2008-2009 season, supporting statements previously made regarding the improved performance during the 2009-2010 season.

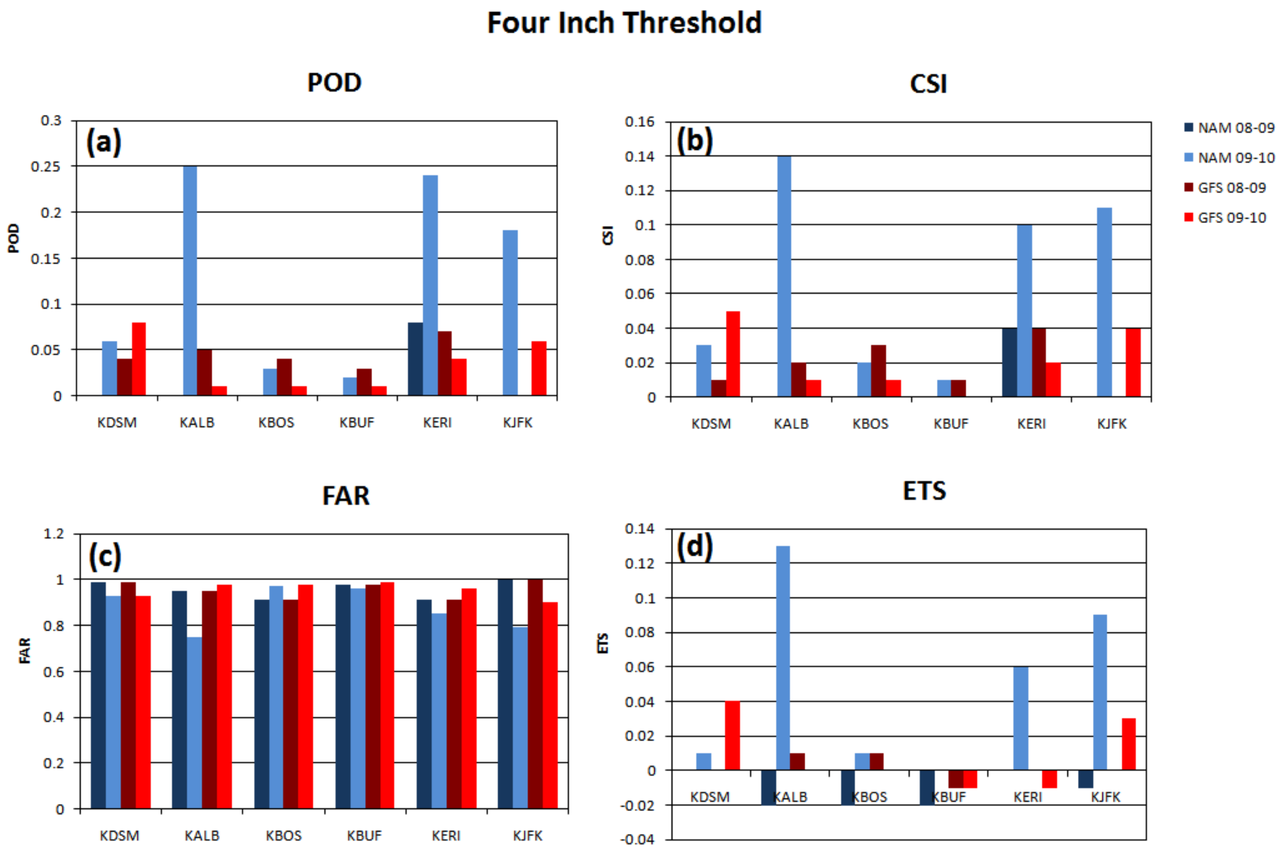

Figure 4. As in Fig. 2, except for a four inch snowfall threshold.

b) Four and Eight Inch Thresholds

The statistics, and the discussion, for these two thresholds have been combined into one section, owing to a lack of notable differences between the four and eight inch thresholds. In general, values for POD, CSI and ETS were relatively low (< 0.1) and FAR (~ 0.9-1.0) values were rather high at all locations for both seasons and both models. Thus, it seems the models have a difficult time accurately predicting medium- and high-end snow events. When analyzing several of these observed medium- and high-end cases, this was indeed the case. For example, two of the 37 available runs from the NAM and the GFS predicted at least four inches of snow in one such case. The question, which models runs captured the event, was also briefly investigated. However, due to time limitations, this is left to further research.

In looking more closely at Fig. 4, it appears that some runs of the GFS are capturing the four inch threshold events at all locations. This is evidenced by consistenly low values of POD, CSI and ETS and consistenly high values of FAR in Fig. 4. Additionally, several more of the NAM runs during the 2009-2010 winter season at KALB, KERI and KJFK were capturing these events, but for the other three locations these runs of the NAM were not. However, POD, CSI and ETS values are still relatively low (< 0.25) and FAR values are consistenly above 0.9. Thus, in general the models had a difficult time capturing these medium- and high-end snow events.

5. Conclusions

BUFKIT profiles from the winter seasons of 2008-2009 and 2009-2010 were post-processed using the Cobb method to analyze how well this technique performed at six locations in the U.S. Contingency tables were constructed using thresholds of zero, four and eight inches. From

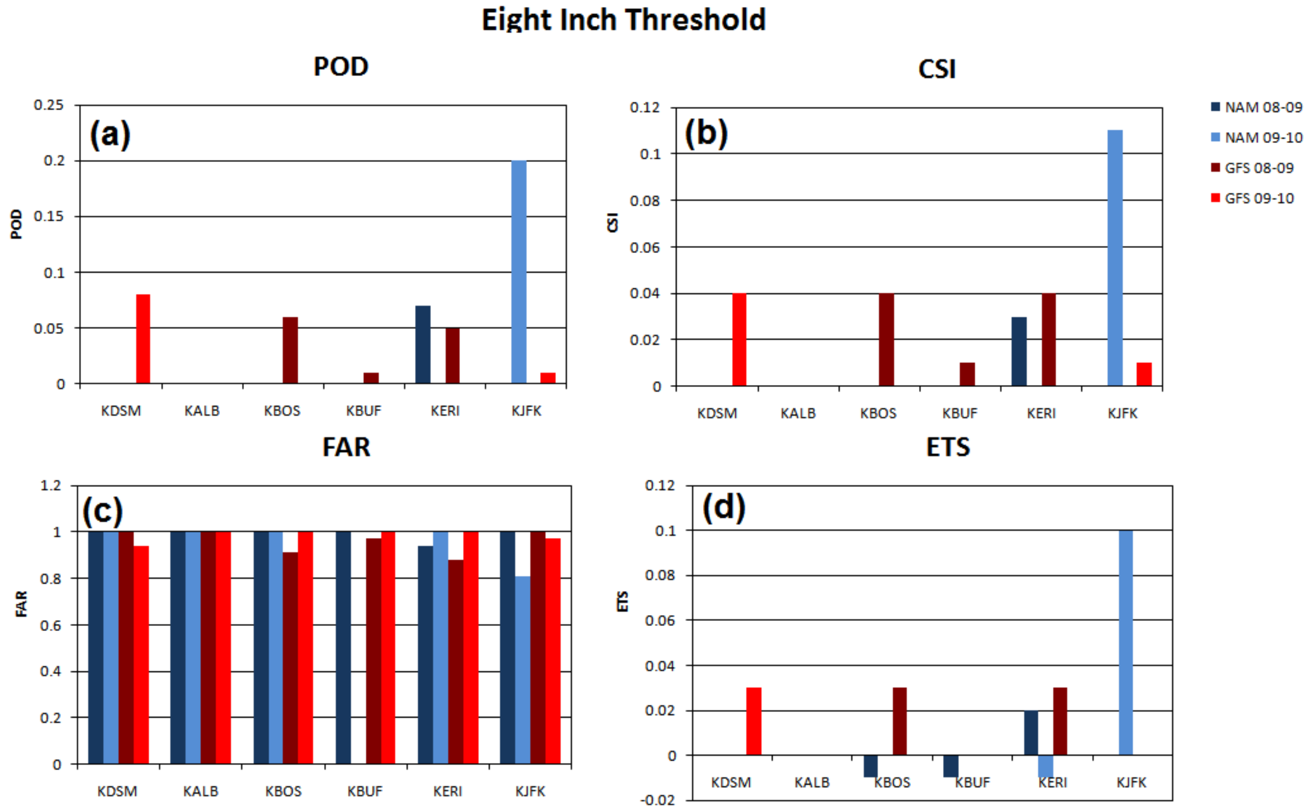

Figure 5. As in Fig. 2, except for a eight inch snowfall threshold.

these tables, four statistical variables, POD, CSI, FAR and ETS, were computed, which represent how well these forecasts verified.

It was shown that the statistics for the locations influenced by lake-effect snow were the highest. Additionally, the GFS performed better than the NAM for both seasons, and the 2009-2010 winter season performed better than the 2008-2009 winter season for both models. Although these results could be attributal to the Cobb method alone, it is possible that one or both of the models perform exceptionally well in the aforementioned situations. Perhaps future work could involve analyzing what differences in the statistics come about by using several different methods of forecasting snowfall. In any event, from this study, a forecaster should give slightly more weight to the GFS snowfall predictions compared to the NAM when making a snowfall forecast, contrary to the initial hypothesis stated earlier. Additionally, forecasters tasked with forecasting lake effect snow are encouraged to use the Cobb method.

The sensitivity of the statistics to the seasonal snowfall totals was also examined. It was shown that a positive correlation exists for POD, CSI and ETS as the seasonal snow totals increase, and a negative correlation exists for FAR as seasonal snow totals increase. Thus, the more snow that a particular location receives in a winter season, the better chance the models do at predicting the event.

It is important to point out a few limitations to this study. First, snowfall is a challenging quantity to accurately measure. In this study, it is assumed that the COOP snowfall observations accurately represent the amount of snow that fell at the six locations. In reality, there are several factors such as strong winds or above-freezing temperatures, for example, hamper the COOP observer’s ability to make accurate snowfall measurements. Another limitation is the use of only six locations in this study.

Although these six locations provided a sufficient amount of data for this study, it is recommended that future studies incorporate a larger sample size, perhaps in a well-confined geographic area, such as a county warning area (CWA). This type of information could perhaps better assist the forecaster while preparing snowfall forecasts for their area.

6. Acknowledgements

I would like to thank Dr. Bill Gallus for his mentorship on this project. I would also like to thank Chris Karstens for his guidance with this project and help with coding and data analysis, and Logan Karsten for his help with coding.

7. References

Baxter, Martin A., Charles E. Graves, James T. Moore, 2005: A Climatology of Snow-to-Liquid Ratio for the Contiguous United States. *Wea, Forecasting,* **20,** 729–744.

Cobb, D. K. and J. S. Waldstreicher, 2005: A simple physically based snowfall algorithm. *21st Conf. on Weather Analysis and Forecasting and 17th Conf. on Numerical Weather Prediction, Washington, DC,* Amer. Meteor. Soc., CD-ROM, 2A.2.

Dubè, I., 2003: From mm to cm... Study of snow/liquid water ratios in Quebec. [Available online at: http://meted.ucar.edu/norlat/snowdensity/from_mm_to_cm.pdf].

Mahoney, E. A., and T. A. Niziol: BUFKIT: A software application toolkit for predicting lake effect snow. *13th Intl. Conf. On Interactive Info. and Processing Sys. (IIPS) for Meteorology, Oceanography, and Hydrology,* Long Beach, CA, Amer. Meteor. Soc.

Scofield, R.A., L.E. Spayd Jr., 1984: A technique that uses satellite, radar, and conventional data for analyzing and short-range forecasting of precipitation from extratropical systems. NOAA Tech Memo, NESS **86**, 44.

Waldstreicher, J. S., 2001: The importance of snow microphysics for large snowfalls. [Available online at: http://www.erh.noaa.gov/er/hq/ssd/snowmicro/].

Ware E.C., Schultz D.M., Brooks H.E., Roebber P.J., Bruening S.L., 2006: Improving Snowfall Forecasting by Accounting for the Climatological Variability of Snow Density. *Weather and Forecasting* **21**:1, 94-103.