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FORECASTING SUMMERTIME CONVECTION IN WESTERN NORTH DAKOTA USING RAOB

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1. INTRODUCTION

The North Dakota Atmospheric Resource Board (NDARB) conducts the North Dakota Cloud Modification Project (NDCMP) every summer in western ND with the goals of suppressing hail damage and increasing rainfall. The NDCMP operates from June 1st through August 31st each year, with the possibility of extensions into September. The NDCMP area is composed of two “districts” in western ND (Figure 1). District I is made up of Bowman County and portions of Slope County in the southwest corner of ND. District II contains McKenzie, Mountrail, Ward, and Williams counties in the northwest part of ND (ARB, 2005).

The accurate forecasting of potential convection is important to the success of the NDCMP, since early response to developing storms is critical. NDCMP meteorologists usually lack extensive experience in forecasting convection so a guide is especially useful while they gain that experience. Two of the main requirements for convective initiation are the presence of moisture and instability in the atmosphere, and rawinsonde observations provide a variety of data to measure these characteristics.

1.1 Previous Work

The NDARB and Andrew Clausen performed an unpublished study in 2003 comparing the values from eight different indices based on rawinsonde observations. The values used for each index would be the mean value

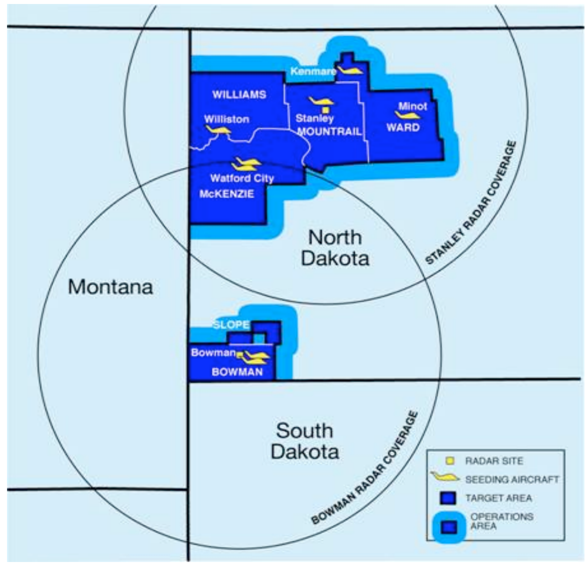

Figure 1: NDCMP Operations Area

from the two nearest rawinsonde sites adjacent to the forecast area. For District II, data from Glasgow, MT and Rapid City, SD were used, while data from Bismarck, ND and Rapid City, SD were used for District I.

NDCMP forecasts are issued at 17 UTC, so all rawinsonde data were taken from 12 UTC balloon launches. A set of thresholds was compiled to serve as a guide for future forecasters on the NDCMP. This work showed that a forecast based on these thresholds could be accurate 80% of the time. Forecasts would indicate that a day would have “significant weather” for the NDCMP on any day that at least one index exceeded its threshold. Significant weather was defined as any day a project flight occurred, or weather was close enough to the project area that the meteorologist would have to monitor the radar for potential operations. These conditions were met on 69% of the days studied between 2000 and 2002.

This system of forecasting resulted in a forecast accuracy 11% better than if the forecast

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was always for significant weather. However, this research said nothing about the weather on days when the thresholds were not met. For example, the research showed that 92% of days with a K index greater than or equal to 30 were significant weather days. It does not say how many days had significant weather when the K index was below 30. Further, it was difficult to recreate the work with additional data since the definition of a significant weather day was ambiguous. Finally, it is likely that data gathered @ 12 UTC and averaged between two sites a significant distance from the forecast area would not be representative of the atmosphere around the most likely time of convective initiation (~ 00 UTC).

1.2 RAOB

The Rawinsonde Observation Program (RAOB) plots rawinsonde data and computes a large variety of indices for the user, including the eight indices used in the previous research. The indices typically associated in some way with convection are displayed in RAOB's severe weather table. RAOB allows thresholds to be set for each index in the severe weather table so the program can quickly display which indices indicate a good chance for convection and which indicate a low chance of convection. An adjustable threshold is important because it allows for the differences in various climate regions. Also, RAOB can plot data from a large variety of different file types, which can be obtained over the Internet from any number of sources (ERS, 2006).

2. DATA

2.1 Rawinsonde Data

In order to improve the reliability of the rawinsonde data, using a location closer to the forecast area is ideal. However, there are no locations closer to the NDCMP areas that collect daily rawinsonde data, so this research uses forecast model data from the ETA model. This gives the advantage of selecting a more likely time for convective initiation. All model data used are from 00 UTC, because a majority of convective events in ND occur in the afternoon and evening. While using model data helps alleviate the temporal and spatial challenges from the previous work, a new challenge associated with the accuracy of the model used is introduced. This is considered to be a more acceptable issue than the previous method.

2.2 Radar Data

To determine the actual weather that developed for each day, NDCMP WSR-74C radar data was reviewed. The NDCMP operates radars in Stanley and Bowman, ND during the months of NDCMP operations. The data is displayed using the Thunderstorm Identification, Tracking, Analysis, and Nowcasting (TITAN) software (Dixon and Weiner, 1993).

3. METHODOLOGY

Model rawinsonde data were acquired during 2007 and 2008 NDCMP operations when possible for Bowman, Minot, and Williston, ND. The data were then displayed in RAOB and the values for each available index were saved.

Strict criteria were determined for what would constitute a significant weather day versus a no significant weather (no sig) day. To simplify the criteria to a basic yes or no question, it was decided that the presence of a thunderstorm in or near the district would be considered a weather day, and if no thunderstorms were present it would be considered a no sig day. Thunderstorms were considered near the district if they passed within 20 nm. A storm was considered a thunderstorm if its maximum reflectivity was at least 45 dBZ.

Each district of the NDCMP was evaluated separately using data from the appropriate location. For District I, only model data for Bowman were used. District II was evaluated using model data from Minot and Williston individually, as well as examining an average of the data from those two locations. All indices were calculated using a parcel lifted from a mean layer of the lowest 150 hPa.

When evaluating the weather for an individual day only the period between the time the forecast was issued (17 UTC) and 06 UTC were considered. A meteorologist forecasting weather after this time period would want to consider model data from a more appropriate time period such as 12 UTC.

Once the appropriate weather had been assigned to each day and all the rawinsonde data were entered into a spreadsheet, thresholds were calculated. A macro was written to step through every possible value for each index and calculate the accuracy of a forecast using that threshold. The value that produced the best results was determined to be the ideal threshold for that index.

4. RESULTS

When the actual weather was assessed for each day it was discovered that about two-thirds (68%) of the days in District I were no sig days. In District II the ratio of no sig days to weather days was almost 1:1 at 70-72. This means that a simple forecast of no sig would have 68% accuracy in District I while only 49% in District II. This disparity is attributed to the size difference between the districts.

Due to the number of no sig days in District I as well as the district's small size, no indices showed a significant improvement in forecast accuracy. In District II, results were much more promising. While data from Williston and the average of Williston and Minot produced limited results, the data from Minot had the best results. Viewing only 2007 data, there were eleven different indices that each had a threshold produce 75% or greater accuracy (Table 1).

Index	Threshold	Accuracy
CAP Strength	0 - 2.65 °C	83%
Jefferson Index	>= 26.5	83%
K Index	>= 25.55	83%
Cross Totals	>= 20.35	82%
Thompson Index	>= 28.5	81%
Lifted Index	<= 0	79%
S Index	>= 38.35	79%
LFC-LCL	0 – 839 m	78%
LFC	>= 497.5 hPa	78%
CAPE	>= 5 J/kg	77%
Showalter Index	<= 0.20	77%

Table 1: 2007 indices that had an accuracy of at least 75% based on Minot data in District II.

A new threshold was found based on the number of these indices that met their respective threshold. A threshold was set such that six or more of these indices exceeding their threshold indicated thunderstorms were likely, and less than six indices exceeding their threshold indicated no significant weather. Forecast accuracy increased to 88% based on this method of evaluation.

Due to questionable performance in 2007, model data from Bowman and Williston was not reviewed for 2008. Minot data were slightly less accurate for 2008, but there were still nine indices with over 70% accuracy (Table 2).

Index	Threshold	Accuracy
Total Totals	>= 46.25	80%
Jefferson Index	>= 28.5	75%
K Index	>= 27.75	75%
Cross Totals	>= 16.95	74%
Vorticity Generation Parameter	> 0	73%
Lifted Index	<= 1.6	72%
S Index	>= 35.45	72%
Showalter Index	<= 2.5	72%
Thompson Index	>= 46.25	72%

Table 2: 2008 indices that showed a forecast accuracy of at least 70% based on Minot data in District II.

Seven of these indices were shown to be accurate for both 2007 and 2008. These seven, as well as CAP strength and Total Totals, were evaluated over the two-year span and a single threshold was found for each. CAP strength and Total Totals were included due to the fact that in 2007 and 2008, respectively, they proved to be among the most accurate (Table 3). A new threshold was found based on these nine indices, similar to the eleven indices for 2007, and it was found the forecast accuracy was 80%

based on at least 7 of these indices meeting their respective thresholds.

Index	Threshold	Accuracy
Jefferson Index	>= 28.5	78%
K Index	>= 27.95	77%
Cross Totals	>= 18.65	76%
Thompson Index	>= 28.5	76%
Total Totals	>= 47.55	76%
S Index	>= 35.8	75%
Lifted Index	<= 0.8	73%
Showalter Index	<= 0.5	73%
CAP Strength	0 – 2.65°C	73%

Table 3: Indices that showed a forecast accuracy over 70% for Minot data in District II for 2007-2008.

5. CONCLUSIONS

The most encouraging result was the development of a procedure that forecasts thunderstorms if seven or more indices exceed their threshold, and it forecasts no thunderstorms if less then seven indices exceed their threshold. This method shows which days have the best potential for thunderstorms. Since many aspects of the atmosphere are included, the results are not affected as much by one or two indices. When only one or two indices exceed their threshold it could indicate that only one requirement for convection, such as moisture, is present while other elements, such as instability, are not.

Several individual indices can be quite useful as well. While this is not a surprise for some indices since they have been widely used for years, it was helpful to establish thresholds that can be used for this specific region. Also, some less common indices proved to be equally helpful. In particular, the Jefferson Index was among the most accurate in both 2007 and 2008. The Jefferson Index is used to predict non-frontal thunderstorms and has been tested in a variety of areas (Jefferson, 1963, 1966). It is interesting that in this research no distinction was made based on the forcing for convection on the weather days and yet an index designed for a specific type of forcing performed the best.

None of these indices showed significant improvement in forecast accuracy over a generic no sig forecast for District I. This is likely due to the relatively small area used in assessing that district. This had the effect of excluding weather from days where a larger area would have experienced thunderstorms, thereby increasing the number of no sig days (68% vs 52%). District II covers a much larger area and therefore had an increased chance of experiencing weather at some point in or near the district.

Model data from Williston also performed poorly compared to Minot data, which could be explained by the typical weather patterns in the region. A majority of weather systems moving through the region move in an easterly direction and Williston is on the western edge of District II. A site located on the western border could not be expected to show an accurate assessment of the atmosphere 150 miles to the east. Minot is located on the eastern end of District II and would not necessarily show an accurate assessment of the atmosphere 150 miles to the west, but weather systems developing in the west would move into the Minot area. Weather systems that first develop convection in the eastern part of District II would not generally move towards Williston. The model data would reflect this tendency so Williston data would not predict storms to the east, but Minot data would predict storms moving into the area from the west.

6. FUTURE WORK

Future work may include the option to look at model data for an area specified by a certain radius around each location. This would eliminate area related biases. In District I, this would increase the study area and consequently increase the number of weather days.

In District II, the Williston data would no longer be used to forecast weather on the eastern end of the district where storms could be developing in a very different atmosphere from the one over the western edge of the district. Minot data would no longer be used to forecast weather in the western part of the district either, and accuracy may decrease with some indices.

Another focus of future work would be to study the relationship of various indices to each other. Convection is not likely to develop in a strongly capped environment regardless of the amount of instability present, nor is convection likely in an environment with very little capping if there is no instability or moisture present. Each index measures different aspects of the environment, and the chances for convection are affected by all characteristics of the atmosphere.

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Index	Equation
CAP Strength	Max Temp Diff Between Environmental and Lifted Parcel Profiles
Convective Available Potential Energy (CAPE)	$\int_{LFC}^{EL} g\left(\frac{Tv_{parcel} - Tv_{env}}{Tv_{env}}\right)dz$
Cross Totals (CT)	Td_{850}-T_{500}
Jefferson Index (JI)	1.6 * $WBPT_{850}$ – T_{500} – 0.5 * $T\_Depression_{700}$ - 8
K Index (KI)	T_{850} – T_{500} + Td_{850} – Td_{700} – $T\_Depression_{700}$
Level of Free Convection (LFC)	Level at which a parcel first becomes warmer than the environmental temperature
LFC – Lifted Condensation Level (LCL)	LFC - LCL
Lifted Index (LI)	Te_{500} – Tp_{500}
S Index	TT – T_{700} – Td_{700} – K where K = 0 when VT >= 25 2 when VT > 22 and < 25 6 when VT <= 22
Showalter Index (SI)	Te_{500} – Tp_{500} using a parcel lifted from 850 hPa
Thompson Index (TI)	KI - LI
Total Totals (TT)	T_{850} + Td_{850} – 2 * T_{500}
Vorticity Generation Parameter	Mean 0-6 km shear * $\sqrt{CAPE}$

Table 4: Equations for indices used. (ERS, 2006)