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DEVELOPMENT OF A THUNDERSTORM RISK ASSESSMENT CHECKLIST FOR THE PHOENIX METROPOLITAN AREA

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Introduction

Summer monsoonal thunderstorms continue to be an enigmatic forecast challenge to operational meteorologists across central and southern Arizona. Numerous factors make it difficult for forecasters to improve upon climatology across this region. These have been documented in several research studies (Dunn and Horel, 1993; Vasquez, 1993; McCollum et al., 1995; Haro and Bruce, 1997), and include, but are not limited to: 1) A lack of skill displayed by Q-G and mesoscale numerical models at forecasting precipitation across the desert southwest; 2) Arizona's proximity to the Pacific Ocean and Mexico, two data-sparse regions; and 3) a surface observation network of limited resolution over south-central Arizona.

Forecasters in central and southern Arizona have recognized and placed importance on certain forecast features, many of which are exclusive to a particular microclimate or part of the state. Time is of the essence in the operational forecast environment, and thus, forecasters find themselves trying to achieve the goal of finding clues that lead not only to more accurate forecasts, but also, forecasts that are produced in a more timely manner.

A thunderstorm risk assessment checklist for the Phoenix metropolitan area (Table 1) was developed by Phoenix NWSFO Lead Forecaster Jim Perfrement (using input from Phoenix NWS meteorologists and National Severe Storms Laboratory researchers) prior to the 1997 summer convective season in an attempt to synthesize some of these clues. This checklist was used on a daily basis every morning during the summer of 1997. This Technical Attachment summarizes what the checklist tried to accomplish, what variables were included in it, and verification problems associated with it.

Checklist Variables

The thunderstorm risk assessment checklist was an attempt to synthesize and quantify "indicators" typically associated with monsoonal thunderstorm development over south-central Arizona. The forecasting of monsoonal storms, especially severe ones, across central and southern Arizona poses many challenges, several of which are unique to the area. This can be said of countless locations across the intermountain West, where topography often adds an unnerving twist to the forecast process. It is difficult to use many "homogeneous" severe weather forecasting techniques in the intermountain West, such as those typically associated with severe weather in the Great Plains and taught in countless atmospheric science programs, with much success.

The indicators included in the checklist were monitored or measured, with a point value assigned to a particular value of that variable. For example, if the local sounding (LUF, taken at Luke Air Force Base in the western Phoenix metropolitan area and supplied by NSSL and the Salt River Project), yielded a forecast CAPE of <600 J Kg^{-1} for that afternoon, a value of "0" was assigned to that variable on the checklist. A CAPE of 600-900 J Kg^{-1} yielded a value of "10," and so on. This was done for all the variables, the values were then added to generate a total "score." This score then corresponded to an assigned threat of thunderstorms, severe and non-severe, in the Phoenix metropolitan area.

The indicators used in the checklist came to light due to experience and research. Many of these are based on upper-air data, while some are "rules of thumb." The following paragraphs explain these indicators and why they were included in the checklist.

1) Did heavy or widespread precipitation occur in the Phoenix metropolitan area yesterday?

The Phoenix metropolitan area experiences fewer afternoon and evening thunderstorms relative to other locations in central Arizona (Balling and Brazel, 1987). Additionally, 70% of all monsoonal thunderstorms in the Phoenix metropolitan area occur at night, with a precipitation maximum over south-central Arizona at about midnight. Subsequently, a detailed analysis of what happened the previous night is usually a part of every morning's briefing.

Many forecasters in the Phoenix NWSFO believe that significant convective outbreak events do not occur in the Phoenix metropolitan area two days in a row. This is a logical conclusion most of the time since a prolonged and widespread rain and/or severe weather event will typically cool and stabilize the lower troposphere.

Although widespread severe weather/heavy rain events have occurred on consecutive days in previous years, it's usually safe to assume that a day's potential is somewhat dependent on what happened the previous day. Accordingly, a value of "0" was assigned to that variable if it did rain the previous day while a value of "10" was assigned if it did not.

2) Did a "gulf surge" occur yesterday?

A "gulf surge" is a rapid increase of low-level moisture over southwest and south-central Arizona via the Gulf of California (Hales, 1974; Carleton, 1986; Stensrud et al., 1997).

Initially, the surge usually serves to inhibit convective development over the lower desert as the moist and somewhat cooler air results in a boundary layer less conducive to supporting storms (more CIN; convective temperature too high due to "marine" boundary layer). Increasing convective activity usually follows 24-36 hours after a significant gulf surge, after the lower tropospheric lapse rate increases. Observations indicate that the depth of the surge is directly related to areal coverage of thunderstorms over the south-central desert. Specifically, the deeper the gulf surge, the more widespread thunderstorms will likely be.

Recently, VAD Wind Profile (VWP) data from the KYUX (Yuma) WSR-88D has been used to measure the depth of these surges. The depth is calculated after a visual analysis of the depth of southerly winds on the KYUX VWP. Shallow gulf surges (< 3000 ft deep) were assigned a "0." Moderately deep (3000-6000 ft) surges were assigned a "10." Deep surges (>6000 ft) were assigned a value of "20."

Although deeper surges were assigned higher values, no known systematic analyses of the relationship between surge depth and thunderstorm activity across the Phoenix metropolitan area have been undertaken. Shallow surges have led to rapid storm development in the Phoenix metropolitan area, especially during the late evening hours (Dr. Robert Maddox, personal communication); however, most forecasters tend to believe that deeper gulf surges lead to more widespread thunderstorm development.

3) What was the 500 hPa temperature on the morning LUF sounding?

Very subtle changes in the mid-tropospheric air can have a profound effect on thunderstorm development. Some forecasters have drawn correlations between 500 hPa temperatures on the morning sounding and the risk of storm development in the Phoenix metropolitan area. Given the observation that maximum surface temperatures typically depart little from climatology during the monsoon, colder air aloft typically increases instability and hence the risk of thunderstorm development. Temperatures of -5°C or higher were assigned a value of "-10." Temperatures ranging from -5°C to -7°C were given a value of "10 " while temperatures of less than -7°C were assigned values of "20."

4) What was the precipitable water amount on the morning LUF sounding?

Higher precipitable water amounts relate to a greater amount of moisture in the atmosphere, especially at lower levels, and subsequently, an increased risk of thunderstorms. Additionally, these amounts are monitored very closely in order to assess flash flood potential. Precipitable water averages roughly 1 inch over south-central Arizona during July and August (Bradley and Smith, 1993). Values of less than .70 inch were assigned a "-10." Values ranging from .70 to 1.30 inches were assigned a "10" while values over 1.30 inches were assigned a "20."

5) What was the mean wind in the 500-700 hPa layer on the morning Tucson (TUS) sounding?

The Phoenix metropolitan area lies to the west and south of dramatically higher mountains and plateaus to the north and east. These mountains often serve as a focus for convective activity during summer afternoons. Significant storm development in the Phoenix metropolitan area is often dependent on the potential for storms to propagate from higher terrain toward the lower desert. That is, forecasters must ascertain the potential for cold pools/outflows to reach the Phoenix metropolitan area.

Subsequently, the mean wind in the 500-700 hPa layer plays a key role. A west-southwest flow is not favorable for the development of significant thunderstorms in the Phoenix metropolitan area, since it usually scours out monsoonal moisture from the lower and middle levels of the atmosphere over central Arizona. Also, storms which form over higher terrain north, east, and southeast of Phoenix would be advected away from the metropolitan area.

Significant thunderstorm and severe weather outbreaks have been much more frequent in the Phoenix metropolitan area when the mean 500-700 hPa flow had an easterly component (see Haro and Green, 1996; Haro et al., 1998, Wallace, 1997) and, to a lesser degree, a northerly component. Subsequently, mean flows from a northwest through east through south direction were given higher scores on the checklist than were west and southwest mean flows, ranging from 20 to 30 points. The exception was when northwest to north mean flows were less than 10 kts. Light northwest to north mean flows and all southwest to west flows rated a "0."

6) What is the forecast high temperature at Phoenix that afternoon?

High temperatures in Phoenix average around 106°F much of July and gradually decrease to 102°F by the end of August (Schmidli and Jamison, 1997). The forecast high temperature for that day can provide a clue, in a rather simplistic way, as to what kind of airmass is present and whether or not it can support thunderstorms. Forecast temperatures that are "too hot" (>115°F) are usually indicative of a very dry airmass. These temperatures were assigned a "-10."

Forecast temperatures that are "too low" (<100°F) can also signal a lack of thunderstorm development. A forecast temperature below 100°F is associated with extensive cloudiness and/or a dramatically cooled and stabilized boundary layer. These temperatures were also assigned a "-10."

Temperatures ranging between 100°F and 105°F were assigned a "0 " as they were not associated with active or inactive storm days in the Phoenix metropolitan area. Local climatology has shown that high temperatures, ranging from 106°F to 115°F, were more frequently associated with widespread thunderstorms in the Phoenix metropolitan area. Therefore, these were assigned a "10."

7) What is the forecast 2100 UTC dew point at Phoenix Sky Harbor International Airport?

Higher surface dew points are necessary in order to support long-lived and widespread convective rainfall and severe weather events in the Phoenix metropolitan area during the monsoon. In fact, a recent climatological study (Haro and Bruce, 1997) showed that measurable rainfall events at Phoenix Sky Harbor International Airport were extremely rare when 2100 UTC dew points were below 60°F. Yet, when dew point values were 60°F or higher, measurable rain events increased substantially. Therefore, scores increased with higher forecast 2100 UTC dew points, with positive scores assigned to dew points of 55°F and higher, and significantly higher scores given to dew points of 60°F or higher.

A "bonus" of 10 points was assigned if an increase in dew point was expected to occur between 2100 UTC that afternoon and 0300 UTC that evening. Dew points typically decrease during these hours due to daily atmospheric mixing. However, if the dew point increases during these hours, low-level moisture advection is occurring, which increases the likelihood of thunderstorm development in the hours to follow.

8) What are Lifted Indices (500 hPa and 300 hPa), CAPE, CIN, Cross Totals, and Vertical Totals, based on morning sounding data?

Not surprisingly, higher values were assigned to each of these indices as stability decreased. Values were assigned to forecasts of the indices for that afternoon, with the exception of the Cross and Vertical Totals, which were taken directly off the morning sounding. Vertical Totals were assigned a value solely to determine the potential for severe weather that day. Certain forecasters have noticed that when morning analyses determine the primary severe weather threat for that day to be damaging straight-line winds, this variable has proven a good indicator of the severe weather threat (increasing 850 hPa dew points and steep lapse rates improve the chances for wet microbursts).

9) Totals

All the assigned values for each variable were added to generate a total point value. Depending on what the total was, either a low, moderate, or high threat of significant/severe weather was said to exist in the Phoenix metropolitan area for the upcoming evening/night. Additionally, values assigned to the forecast high temperature for that day and the vertical totals were added in order to assess the risk of severe weather (no risk, slight risk, moderate risk).

Discussion

The checklist was a success in that it accomplished its main goal: to ensure operational forecasters took all of these factors into consideration (Jim Perfrement, personal communication). The checklist highlighted the fact that subtle changes in any of these fields can dramatically alter a thunderstorm forecast across southern Arizona. Considering that the checklist was a "first stab" at such a feat, it proved handy.

An attempt was made to do a verification study of the checklist, but this proved difficult. Part of the problem stemmed from the way certain questions were worded. Section one of the checklist inquires whether or not heavy or widespread precipitation occurred yesterday. Yet, what exactly constituted "heavy" or "widespread" precipitation was never quantified. Thus, forecasters used their own judgment when answering that question.

Another problem that made verification difficult, if not impossible, was that so much of the checklist relied on information obtained from the morning Luke Air Force Base sounding (located in the western Phoenix metropolitan area). Routine upper-air measurements are not collected at Phoenix. Technical difficulties led to several instances in which upper-air measurements were not collected and it was not deemed a high priority to repeat the run. This would then render the checklist highly ineffective, if not useless. Unfortunately, despite its metropolitan area population of over 2.5 million people, Phoenix forecasters still have to rely on upper-air data gathered over 100 miles to the southeast in Tucson, Arizona, which has proven to not be representative of lower- and mid- tropospheric conditions over central Arizona (Wallace et al., 1998).

Adding to verification difficulties was the "human equation." Completion of the checklist required forecaster modification of the morning sounding. Very rarely did any two forecasters modify a sounding exactly the same way. Thus, there was no way to "standardize" the data for a verification study, since different forecasters produced different numbers.

The general consensus was that the checklist did not do a very good job of highlighting days in which thunderstorm and/or severe weather potential was high. Despite the overall negative consensus, this doesn't reflect negatively on the checklist or its developers. Part of the problem may have simply been that certain variables were not "weighted" appropriately. All Phoenix forecasters know that the checklist variables are important. How important each variable is and how heavily it should be weighted in the checklist equation are what remains unanswered.

Recommendations

The development of a thunderstorm risk assessment checklist or "decision tree" (Colquhoun, 1987) for the Phoenix metropolitan area should remain a priority for the office. However, certain suggestions should be heeded for future iterations of such a checklist.

1) Account for kinematic features

The checklist was heavily weighted toward assessing moisture and instability, but didn't really address kinematic features. Certainly, an accurate assessment of moisture is critical to the success of any forecast for south-central Arizona during the monsoon. However, Wallace et al. (1998) showed that thunderstorms occur in the Phoenix metropolitan area on fewer than one-third of all "monsoon days" (mean dew point ≥55°F). Similarly, Haro and Bruce (1997) found that precipitation events (trace and measurable) at Sky Harbor International Airport in central Phoenix, occurred on only 23.5% of monsoon days during the period 1982-1996. These findings definitely imply that a greater emphasis on kinematic features should exist within the checklist.

2) Clearly or unambiguously define how to measure some of the "prediction" variables

Forecasters were not provided with unambiguous instructions regarding the computation of variables such as CAPE, Lifted Indices, estimation of 2 PM dew point, and "widespread" precipitation in the Phoenix metropolitan area. Thus, substantial inter-forecaster variance was introduced to the checklist results. As an example, when calculating CAPE for any afternoon, forecasters would modify the morning sounding for expected values that afternoon. But some would only modify the surface data while others would modify the lowest 100 hPa. Similar problems occurred with the calculation of other forecast variables.

The purpose of a checklist is to eliminate such "human equation" variance. Without the elimination of such, the checklist is limited in its functionality. Additionally, objective verification studies become nearly impossible to perform.

3) Carefully assess the usefulness of the checklist or "decision tree"

A careful quantitative assessment of the checklist should be made, once unambiguous instructions regarding variable estimations are provided. The person performing the assessment should determine how well the prediction variables and weighting values related to thunderstorm development in the Phoenix metropolitan area. If poor relationships existed, was it due to poor weighting, poor meteorological relationships, or improper or varying prediction procedures? Also, was the observed weather during the trial period typical or unusual? Finally, a subjective assessment of the checklist by forecasters who used it could be provided.

A thorough analysis of how well each particular variable was forecast would also prove helpful. Such an analysis could show a limited ability to forecast things such as CAPE, Lifted Indices, or afternoon dew points. This would prove helpful by showing that future efforts should center on learning how to make more accurate forecasts of critically important weather variables.

4) Account for new technology

The checklist uses many established methods to ascertain convective potential. However, many Phoenix NWSFO forecasters have recently found that new technological tools such as GOES sounder and mesoscale model data can help with the forecast process. GOES sounder precipitable water data has been found to be particularly helpful by alerting forecasters of changes in boundary layer moisture evolution over areas where no equipment exists to measure such changes.

The data-sparse nature of nearby regions such as Mexico and the eastern Pacific Ocean is one of the primary reasons that model forecasts are of such little help over these areas. Through the use of newer technologies, this problem can at least be partially alleviated.

As an example, the use of GOES sounder data in Eta model runs should lead to improved precipitation forecasts across the desert southwest. Additionally, the use of mesoscale models such as the MM5 not only helps in real-time forecast scenarios, but also during post-event analyses. Findings of such post-event research studies should be incorporated into the checklist.

Conclusions

Ultimately, the initial iteration of this checklist proved very useful by ensuring forecasters monitored variables important to the development of thunderstorms in the Phoenix metropolitan area. However, much work remains to be done before forecasters can rely on this checklist to provide an accurate assessment of convective potential. If procedural changes and careful analyses are done with respect to the checklist, it could prove to be an extremely useful forecast aid in the future.

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References

Balling, R.C. and S.W. Brazel, 1987: Diurnal variation in Arizona monsoon precipitation frequencies. *Mon. Wea. Rev.*, **115**, 342-346.

Bradley, A.A. and J.A. Smith, 1993: Extremes for precipitable water and stability indices during the warm season. Preprints, *13th Conference on Weather Analysis & Forecasting with Symposium on Flash Floods.* American Meteorological Society.

Carleton, A. M., 1986: Synoptic-dynamic character of 'bursts' and 'breaks' in the southwest U.S. summer precipitation singularity. *J. Climatol.,* **6**, 605-622.

Colquhoun, J.R., 1987: A decision tree method of forecasting thunderstorms, severe thunderstorms and tornadoes. *Wea. Forecasting,* **2,** 337-345.

Dunn, L. B. and J. D. Horel, 1994: Prediction of central Arizona convection. Part I: Evaluation of the NGM and ETA model precipitation forecasts. *Wea. Forecasting,* **9,** 495-507.

Hales, J. E. Jr., 1974: Southwestern United States summer monsoon source: Gulf of Mexico or Pacific Ocean? *J. Appl. Meteor.,* **13,** 331-342.

Haro, J. A. and M. A. Bruce, 1997: A brief climatology of the relationship between afternoon dew points and monsoonal rainfall at Phoenix Sky Harbor International Airport. National Weather Service Western Region Technical Attachment: No. 97-32.

Haro, J. A. and G. D. Green, 1997: Some radar aspects of the southern Arizona severe weather outbreak of 14 August 1996. Preprints, *28th Conference on Radar Meteorology.* Austin, TX. American Meteorological Society, 571-572.

Haro, J. A., G. D. Green, and C.L. Dempsey, 1998: Southern Arizona severe convective storms of 14 and 29 August 1996: similarities and differences. Preprints, *16th Conference on Weather Analysis and Forecasting.* Phoenix, AZ. American Meteorological Society, 335-337.

McCollum, D. M., R. A. Maddox, and K. Howard, 1995: Case study of a severe mesoscale convective system in central Arizona. *Wea. Forecasting,* **10,** 643-665.

Schmidli, R.J., and A. Jamison, 1996: Climate of Phoenix, Arizona. NOAA Technical Memorandum NWS WR-177.

Stensrud, D. J., R. L. Gall, and M.L. Nordquist, 1997: Surges over the Gulf of California during the Mexican monsoon. *Mon. Wea. Rev.,* **125,** 417-437.

Vasquez, H., 1993: Weak upper-level divergence and its role in organizing mesoscale convective storms along the Arizona monsoon moisture boundary. National Weather Service Western Region Technical Attachment No. 93-26.

Wallace, C. E. 1997. Convective storm environments in central Arizona during the summer monsoon. M.S. Thesis, School of Meteorology, University of Oklahoma.

Wallace, C.E., R.A. Maddox, and K.W. Howard, 1998. Summertime convective storm environments in central Arizona: local observations. Submitted to *Weather and Forecasting*, March 1998.

Table 1 Phoenix Metropolitan Area Thunderstorm Risk Assessment Checklist (Page 1)

PHOENIX - METROPOLITAN THUNDERSTORM CHECKLIST - '97

Date: ______________

Forecaster: __________

		Points	Today 12Z		Verification
HVY/WIDESPREAD PCPN Metropolitan AREA - YDA					
Yes		0			
No		10	____	>>	____
GULF SURGE - YESTERDAY					
No		0			
Yes - <3000' deep		0			
3000' - 6000'		10			
>6000'		20	____	>>	____
500 MB TEMPERATURE	LUF				
> -5		-10			
-5 - -7		10			
<-7		20	____	>>	____
PRECIPITABLE WATER	LUF				
< .70 inches		-10			
.70 - 1.30		10			
>1.30		20	____	>>	____
MEAN WIND (500-700mb)	TUS				
Direction	Speed				
W to SW	All	0			
NW to N	<10	0			
"	≥10	20			
NE to S	<10	20			
"	≥10	30	____	>>	____

Table 1 Phoenix Metropolitan Area Thunderstorm Risk Assessment Checklist (Page 2)

		Points	Aftn 00Z	Verification
<u>PHX MAX TEMP FCST (F)</u>				
<100		-10		
100 - 105		0		
106 - 115		10		
>115		-10	____	____
<u>DEW POINT (F) (21Z)</u>				
<50		-10		
50 - 55		0		
55 - 60		10		
60 - 65		30		
>65		40	____	____
< 3 degree decrease 21z-03z (Use only when dew pt > 59)		10	____	____
<u>LIFTED INDEX - 500 mb</u>	LUF			
>-2		0		
-2 - -4		10		
-4 - -6		20		
<-6		30	____	____
<u>LIFTED INDEX - 300mb</u>	LUF			
>-2		0		
-2 - -4		10		
-4 - -6		20		
<-6		30	____	____
<u>CAPE</u>	LUF			
<600		0		
600 - 900		10		
900 - 1200		20		
>1200		30	____	____
<u>CIN</u> (from sounding)	LUF			
If CAPE = 0		0		
>100		0		
40 - 100		10		
<40		20	____	____

Table 1 Phoenix Metropolitan Area Thunderstorm Risk Assessment Checklist (Page 3)

CROSS TOTALS	LUF		
<11	0		
11 - 19	10		
>19	20	_____	_____

VERTICAL TOTALS - 00Z	LUF	(TO DETERMINE SEVERE POTENTIAL ONLY)	
< 45	0		
45 - 50	10		
> 50	20	_____	_____

TOTALS

RANGE: _____ _____

00Z this evening	Threat
<120	Low
120 - 160	Moderate
>160	High

SEVERE: _____ _____

max temp fcst + vert totals only (point values)		
	10 or less	No Risk
	20	Slight Risk
	30	Moderate Risk

COMMENTS: