NLDAS Drought Monitors: Precipitation Deciles and the Palmer Drought Severity Index

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Abstract

The creation and initiation of effective drought monitoring system can be the first pivotal step toward successful drought prediction. The NLDAS drought research project's goal is create such a monitor have it be fully-operational and real-time. To lay the foundation for such a drought monitor, the existing monitors must be a examined for the efficiency. The two existing indices looked at this paper are the Precipitation Deciles and the Palmer Drought Severity Index. Due to time constraints, only the Precipitation Deciles made it all the way through to execution. The North American Drought Monitor was used as the "truth" to validate this index. It was found that the Deciles index is a good indicator of short-term droughts since it currently only takes into account one-month precipitation values.

1. Introduction

Throughout history droughts have been one of the most feared natural disasters. The amount of damage that is caused by these events have devastated many areas, even collapsed many strong communities. There is not much we can do to prevent these events but predicting them could prove to be a very powerful tool. By being able to predict when these events might occur, populations can take steps to prevent some of the damage that can be done and more efficient drought relief programs can be initiated.

In this paper, we will explore two drought analysis methods. The first method we will look at will be Rainfall Deciles. This method aims to characterize meteorological droughts based on climatological precipitation amounts. Next, we will discuss the Palmer Drought Severity Index. This index's main goal is to characterize meteorological drought intensity by observing several crucial hydrometeorological fluxes.

2. What is a Drought?

The definition of a drought sometimes varies based on the person doing the defining. There are several types of droughts, so it can prove a little difficult to form a concise, unifying definition that will cover all of the areas. The main types of droughts that are usually of the most interest are meteorological, agricultural, and hydrological droughts. In its most elemental form, a drought is a temporary, natural event in which the lack of precipitation over an extended period, in comparison to some long-term mean, brings on some sort of hydrological deficit (Morid et al. 2005).

Drought analysis is a big step in progress toward the prediction of future droughts. The purpose of this analysis is to identify the magnitude, duration, and severity of a drought. To conduct a significant drought analysis there are some things that one needs to keep in mind. The type of drought that is being looked at needs to be determined because each type of drought has its own separate characteristics and warning sign.

The averaging period is also very important since there are certain tradeoffs when choosing these series. The longer the averaging period that is chosen the fewer events that will be observed. This is because the smaller drought or wet spell events that occur within this long period of time disappear in the averaging process thus several drought events are observed, which cuts down on the sample size. The other thing to watch is autocorrelation. Due to the averaging effects of longer averaging periods, serial correlation tends to be smaller. With those two aspects in mind, it is clear that the averaging period should be chosen so that it is large enough that statistical analysis of the sample is still meaningful but small enough such that it avoids the misleading smoothing effects of large averaging periods. For this fact, we have chosen a relatively short averaging period for this project, one month (Dracup et al. 1980).

Dracup et al suggests the need for a truncation level. A truncation level represents, quantitatively, what exactly is considered a drought (Dingman 2002). Dracup specifically defines X_0 as the truncation value. This value will divide the number line in various place, the distance between each divide can be defined as having some sort of relationship to the drought severity, drought intensity, and drought duration. More specifically, when using drought indices, the truncation level explains what each range of index value represents, in terms of drought. We will not have to directly deal with this concept because it is almost entirely accounted for by the developer of the drought indices we will be utilizing. In a nutshell, truncation levels are the means by which we define a drought or a wet spell (Dracup et al. 1980).

3. Palmer Drought Severity Index

One of the most utilized and useful drought indices today is the Palmer Drought Severity Index (referred to hereafter as PDSI) created by Wayne C. Palmer in 1965. This particular index is a meteorological drought index. This means that it takes into account precipitation dominated fluxes. The main strengths of this method are that it has been used for such a long time and is already in operation. The cons, however, are a little more numerous and vary based on need. The main disadvantages are that values between different climatological regions are incomparable, the index is calibrated by the Midwestern climate divisions, and it completely ignores, and currently, cannot handle mountainous regions and regions that experience climatological extremes. Although it seems as though, unless your main interest is Midwestern climate, then the PDSI is ineffective, it is used nationally to trigger drought relief programs. Much research has been done on the effectiveness of the PDSI and even ways to improve on it.

Some of these findings will be discussed later on in this paper. For now, we will discuss the foundation of this index.

a. Computations

The PDSI is based on a simple two-level soil model; composed of the two layers: surface layer and underlying soil. In order to compute this index, one must have observed values of several fluxes: precipitation, evapotranspiration, loss, runoff, and recharge. Also the potential values of these fluxes (except for precipitation) must be computed so that it can be gauged as to what is the "normal". All of the values will be calculated using monthly mean values.

The potential values are computed based on equations from Palmer's "Meteorological Drought". Potential loss is computed by accounting for the departure of moisture from both the surface layer and underlying soil.

$$PL = PL_S + PL_U$$

where PL_S is equivalent to the potential evapotranspiration (PE) or the amount of soil moisture available in the surface layer at the beginning of the month (S'_S), whichever value is smaller. The last term of the equation, potential loss of the underlying soil (PL_U), is calculated using the equation: $PL_U = (PE – PL_S)\ S'_U/AWC$; available water capacity (AWC). Potential recharge is computed by taking the difference of the available water capacity and the total available soil moisture at the beginning of the month (S'). Although, potential runoff does not have an exact definition, in this paper, the value of the (S') is assigned to this parameter.

The next step in the computational process is to calculate the coefficients of these fluxes. This is simply done by finding the ratio of the long term mean of the observed value to the long term mean of the potential value for every month. These coefficients estimate the "normal-ness" of the moisture state and are used to compute the CAFEC (Climatically Appropriate For Existing Conditions).

$$\hat{P} = \alpha PE + \beta PR + \gamma PRO + \delta PL$$

Where α, β, γ, and δ stand for the coefficients of potential evapotranspiration, potential recharge, potential runoff and potential loss, respectively. This equation serves to calculate the normal precipitation for the given station. Next, we find the departure from normal which is simply the difference of the CAFEC precipitation and observed precipitation. Then, we utilize the following equations in the given order to reach the PDSI index value.

$$K' = 1.5\ log10\left(\frac{\frac{\overline{PE} + \bar{R} + \overline{RO}}{\bar{P} + \bar{L}} + 2.80}{\bar{D}}\right) + 0.50$$

Here, $\overline{D}$ is the mean of the absolute values of d.

$$K = \frac{17.67}{\sum_{1}^{12} \overline{D}K} K'$$

$$Z = dK$$

$$X = X_{i-1} + Z_i/3 - 0.103X_{i-1}$$

Table 1: Palmer Drought Severity Index Categories

Value	Category	Value	Category
4.00 or more	Extremely Wet	-0.50 to -0.99	Incipient drought
3.00 to 3.99	Very Wet	-1.00 to -1.99	Mild Drought
2.00 to 2.99	Moderately Wet	-2.00 to -2.99	Moderate Drought
1.00 to 1.99	Slightly Wet	-3.00 to -3.99	Severe Drought
0.50 to 0.99	Incipient Wet Spell	-4.00 or less	Extreme Drought
0.49 to -0.49	Near Normal		

From here we are able to compute the three values (X_1, X_2, and X_3) that allow us to reach the final PDSI index value. The values represent the probability for the onset of a wet spell, the probability for the onset of a drought, the severity of the present spell. The final PDSI value is chosen based on a series of logical steps that choose which value best represents the current state. Above, in Table 1, are the categories and truncation levels of the PDSI; -4.00 being the most severe drought and 4.00 being the wettest period (Palmer 1965).

4. Precipitation Deciles

This method is a rather under-utilized drought indices but its simplicity makes it the most reasonable place to start. The Precipitation Deciles method was created by Gibbs and Maher in 1967 to obtain a consistent assessment of the meteorological situation for regions where precipitation averages were inadequate. This index is favorable because it is easy and relatively quick to compute. Also, the only data it requires as an input is long term precipitation values, which is not difficult to come across. The simplicity of this index contributes to its downfalls, however, since there are a lot of variations that this index ignores. Some of these deficiencies include the inability for the decile ranges to accurately represent the drought situations in areas where precipitation patterns depend heavily on seasonality and difficult to understand patterns when constructed as a time series.

Gibbs and Maher proposed that these decile values be computed on an annual basis. By nature, droughts do not usually last this long of a time scale, typically their duration is on the order of months. Also, as mentioned before, some of the drought events will be lost or smoothed out when the averaging period is so long. Therefore, for this project, we will use monthly averages because they allow for the analysis of a greater number of drought events and we avoid the smoothing error. This simple index could not be used for drought prediction because of its dependence on observed data but it does a very good job at giving a general idea about the current hydrometeorological state of the regions.

a. *Computations*

As promised, the computations for this index are very basic and thus do not require the use of extensive lists of equations. First, the long term precipitation data set must be sorted, starting with the wettest amount and decreasing to the driest. Next, this sorted set needs to be dividing into ten deciles. Lastly, rank the time period of interest against the ranked data to see which decile it falls within.

Table 2: Precipitation Deciles Category

Decile Range	Category
10	Much Above Normal
6-7	Above Normal
4-5	Near Normal
2-3	Below Normal
1	Much Below Normal

In table 2, the categories and truncation levels of the Precipitation Deciles is represented. According to this method, a drought ends when: 1) the previous month's precipitation puts the three month total in or above the fourth decile, 2) the summed precipitation for the previous three month period is in or above the eighth decile (Kinninmonth et al. 2002), or ,as a supplemental rule suggested by Keyantash and Dracup, if the summed precipitation surpasses the first decile for every month in the drought then the drought can be considered concluded. This last rule was formed because this index makes it possible for the first rule to be prompted quite easily by receiving insignificant amounts of precipitation during a period where that area receives little to no precipitation.

5. NLDAS

To run these monthly, drought indices we will be utilizing datasets from the North American Land Data Assimilation System (NLDAS). This section will serve to provide some background information on NLDAS; it will not go into great depth, however - since that is beyond the scope of this paper. NLDAS is a multi-institutional project that works to provide the most accurate and precise land-surface meteorology forcing data possible. This data is used for initializing North American meteorological and hydrological cycle models. Another similar project, with a different spatial scale, is GLDAS. Currently, the project is in its second phase, referred to as NLDAS-2.

These datasets are available on a 1/8° grid and is based on NARR data, along with observed precipitation and radiation measurements. NLDAS data has an hourly temporal resolution and is available for over 30 years starting in January 1979. It covers the entire contiguous United States as well as southern Canada and northern Mexico; latitudinally, 25.0625°N to 52.9375°N. NLDAS land-surface meteorology in the forcing datasets are used to drive several different land-surface models, which provide outputs such as soil moisture, energy and water fluxes, and snow cover. The two drought indices that are being discussed in this paper are being forced by NLDAS's Mosaic and Forcing-A. The data is outputted in GRIB-1 format (Mitchell et al. 2004).

Some of this project's drought research goals are to construct and validate the forcing dataset and use the land-surface models (LSM) to examine the optimal NLDAS forcing methods. The stage in this project that this paper is picking up from is constructing and carrying out drought monitor systems using meteorological forcing data and several LSM outputs. After these systems are completed they will need to be validated using observed drought conditions. Finally, the system will be used to for real-time operations and data distribution.

6. Method

The method used for initiation, as well as the entire stage, of the project's current stage is rather abstract; primarily program coding. Fortran-95 programs were written to compute the drought indices. These two particular indices were chosen for very specific reasons. Although, there are various drought indices that can be chosen, Rainfall Deciles was chosen for an especially simple reason: its simplicity. It seems like the best approach to finish the easiest operation first. On the other hand, the Palmer Drought Severity Index was not as simple. This drought index was chosen because it is the basis of several other indices. Therefore, to "crack to code" for those we needed to lay the foundation, which turned out to be PDSI.

Thus far, we have constructed and executed the Rainfall Deciles program. Due to time constraints, the Palmer Drought Severity Index is still in the process of construction. Also, time constraints prevented us from making the Rainfall Deciles program exactly how its makers intended for it to be. Both programs will be run based on thirty years of data. Like discussed previously, to decipher the end of the drought in the Rainfall Deciles program, the preceding three months of rainfall data needs to be ranked against the ordered list. Currently, only one month's precipitation is being ranked and characterized. Also, the drought starting and stopping mechanism have not been fully programmed in.

In this study, the North American Drought Monitor will be treated as the truth. This is the closest to actual observed data that is available at this point. These maps are a fusion of a variety of sources. The situation represented on these maps takes into account five drought indices and chooses which one does the best job depicting drought severity. Since some of the indices perform better than others in different regions, the index that best represents any specific region is chosen to do so. To make sure that this information is as accurate as possible the information garnered by the index blends are verified and fine-tuned by observations taken by experts in many of the geographical regions depicted on the map. The majority of government agencies concerned with droughts are involved with the creation of these maps, so this is a fully functional source.

7. Results

The first map that was generated by the Precipitation Deciles program is shown in Figure 1a. Although this is only one month's ranking, instead of the preferred three-month sum, it is generally consistent with the U.S. Drought Monitor map. The NDMC's map shows a more widespread area of drought where as the Deciles map shows less drought stricken areas, but with greater magnitudes. The two maps correspond best over eastern Texas, Oklahoma, Louisiana, and southern Mississippi.

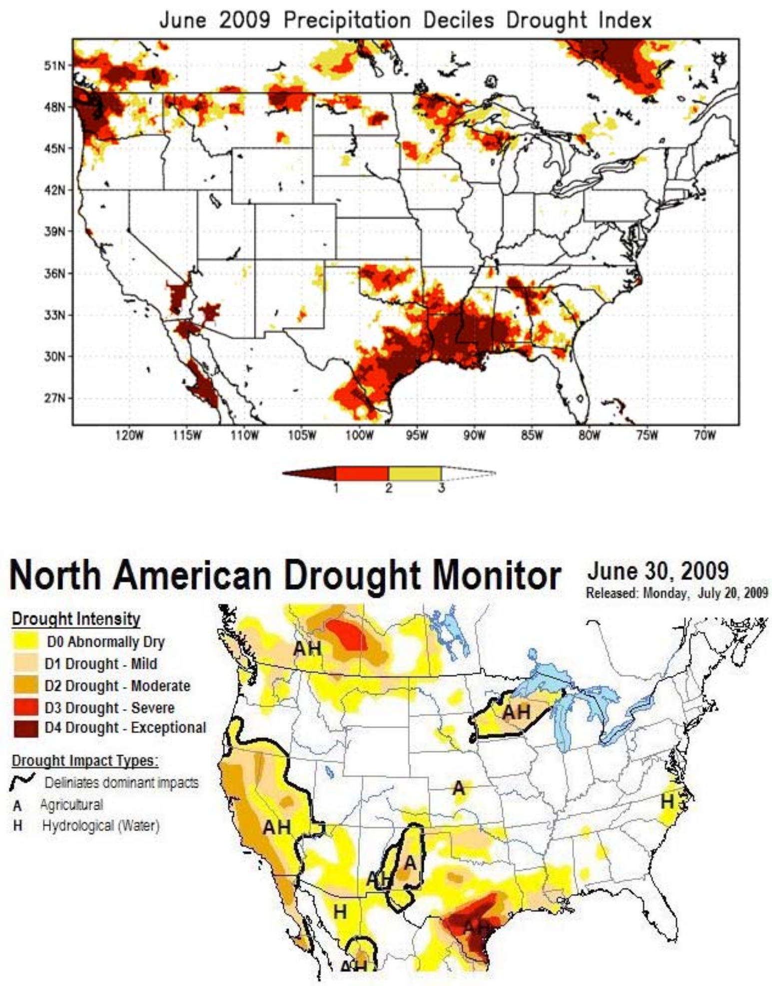

FIGURE 1: a)June 2009 Precipitation Deciles; b) June 2009 NADM

Some other areas where correspondence is rather high are the northern border of the U.S., particularly Oregon, northern Montana, northern Wisconsin and especially well in North Dakota. The Deciles map was even sensitive enough to pick up on some of the dryness in North Carolina. Although a small amount of the dryness in California is represented in the Deciles map, it is only a fraction of the actual dryness. These inconsistencies are most likely due to the sub-optimal timescale that the Deciles map is generated from.

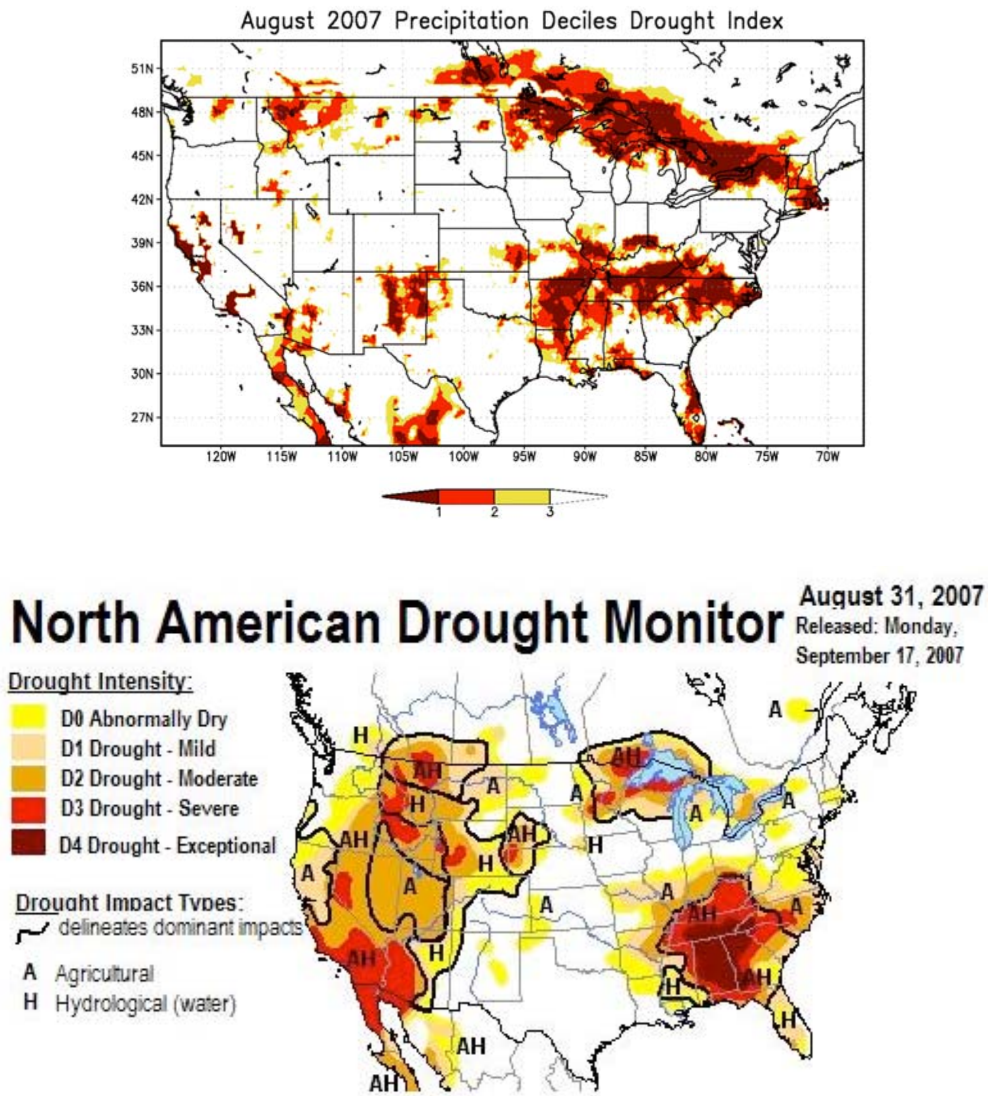

FIGURE 2: a) Precipitation Deciles August 2007; b) NADM August 2007

The two maps in Figure 2 generally correlate rather well. The two major drought areas during this month are the midwest and the south. The drought in the midwest looks enhanced on the Deciles map because the NLDAS dataset covers the southern portion of Canada, which the NDMC does not take into account. The drought severity in these areas also correspond well. The drought in the south corresponds well also, although not as well that the midwestern drought. The main regions in the south that differs from what is represented on the NDMC's map are southern Georgia, northwestern Florida, and central Alabama. This may be an example of the drought's end triggered by trivial amounts of precipitation when the area would not normally receive any precipitation. A major reason that these maps seem to correspond poorly is that the NADM is taking into account agricultural parameters whereas the Deciles are taking into account purely meteorological factors, more specifically precipitation.

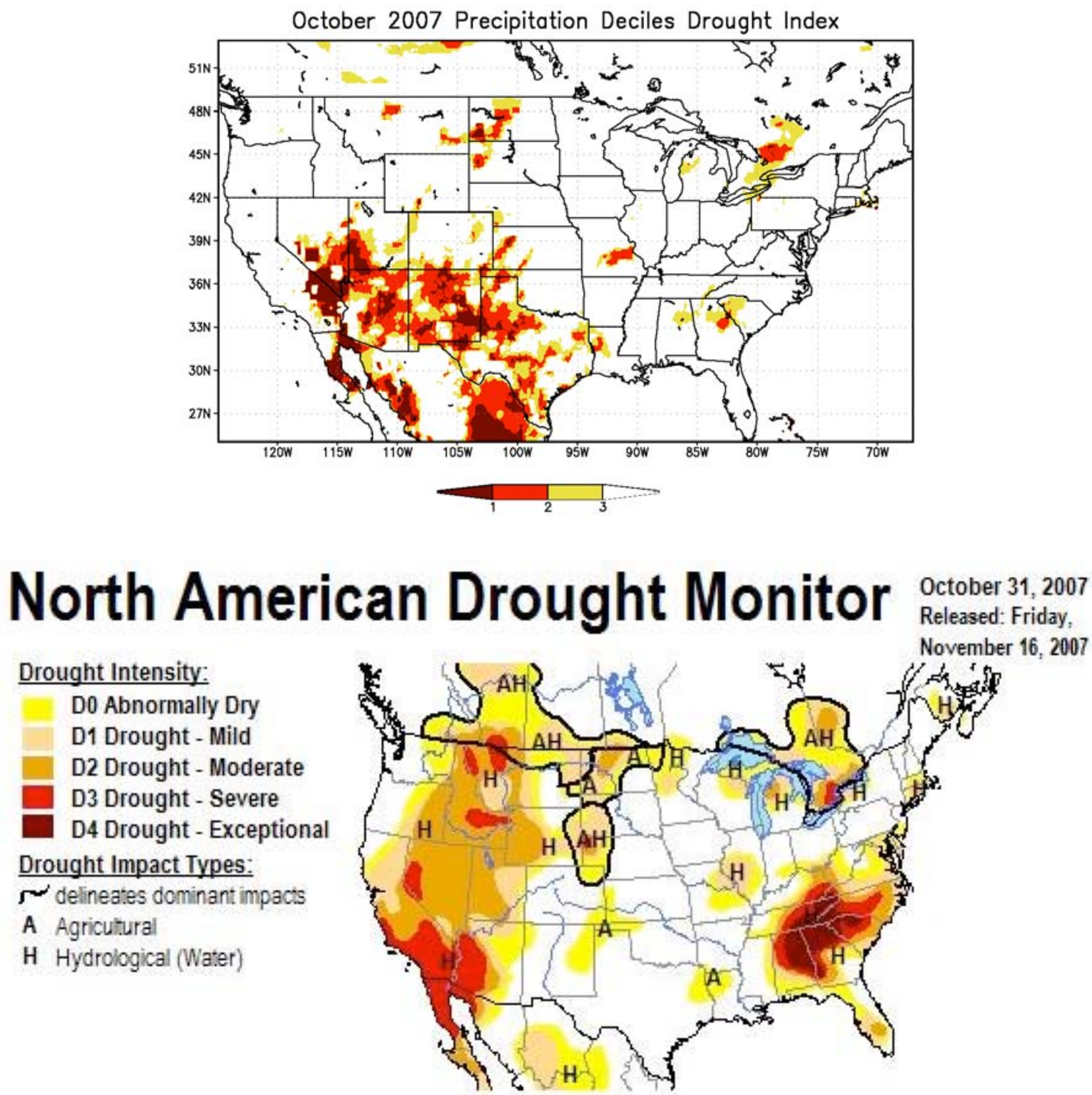

Figure 3: **a) Precipitation Deciles October 2007; b) NADM October 2007**

This is an example of a month when the Deciles render a map that is almost completely opposite to the NDMC's map. The Precipitation Deciles show that the rainfall for this month is relatively normal. However, the observed conditions show that there is a big drought in the south and as well as in the west. The Deciles map completely misses the southern drought and is very patchy in the southwest. The only place where the correspondence is relatively high is in the Great

Lakes region and section of the south west. The large areas of drought seem to be due to long-term effect which the Deciles map is not programmed to incorporate.

8. Discussion

a. Shortcomings of Rainfall Deciles and PDSI

Drought information is essential for various reasons, thus the inability to formulate an all-encompassing definition. Reflecting the diverse needs for drought information, there are almost as many drought indices to accommodate. It is often the case that a drought index works well in one region but poorly in others. Keyantash and Dracup (2002) carried out a study comparing a handful of drought indices based on a certain criteria. Precipitation Deciles and the PDSI were both included in the meteorological drought indices part of their study. Unexpectedly, the rather simple Precipitation Deciles topped the list off as the best meteorological drought index while the PDSI fell in seventh place as the worse in the group.

The downfalls of the PDSI stem from its empirical roots. This index was developed for agricultural regions, mainly in the Midwest and thus all of the equations are calibrated to those areas. This makes the utilization in areas outside these, less applicable as well as less accurate. Many of the critics of this index complain that the use of the Thornthwaite method to calculate evapotranspiration inhibits the PDSI from being more accurate. By utilizing the NLDAS dataset, this problem can be eliminated. Additionally, PDSI’s primitive water-balance model makes several assumptions that effects that index values. For example, Palmer’s assumption that runoff does not occur until both layers have been completely saturated often results in underestimations of recharge in the summer and early fall months. These are just two examples of what makes the PDSI poorly formed; since there are several other similar assumptions made in the formation of this index it is easy to see why it is such a bad judge of the any current hydrometeorological situation.

On the other hand, the Precipitation Deciles are much less criticized. The one main complaint about this index is that the stopping rules are too easily activated, thus making it difficult to use in regions with highly seasonal climates; this is the main reason the third stopping rule was implemented. Other than this rather significant downfall, according to Keyantash and Dracup, the Precipitation Deciles receives perfect scores in robustness, the significant application over a range of conditions, and extendibility, its ability to be used across a long time period. The Precipitation Deciles seem to be such a consistently good drought indicator because it makes so few assumptions, which is the mistake that other indices make. It is based on the fact that the median is a better indicator of the central tendency of a system than the mean.

b. Future Work

Work will be continued on completing the Precipitation Deciles programs as well as executing the PDSI program. The drought triggering and stopping mechanisms will need to be programmed into the Deciles program. Also, three-month sums will be used to create the maps instead of the current one-month values. This will allow it to take into account more long-termed events, in which it is currently incapable of doing.

Researchers have worked to solve the calibration problems in Palmer's method. The Self-Calibrating Palmer Drought Severity Index (SC-PDSI) has been created in response to this problem. The SC-PDSI has taken some of the constants in the PDSI equations, reworked the duration factor, and fine-tuned the climatic characteristic. In collaboration, these changes calibrate the PDSI to every individual climate region. This will allow the index to perform more consistently over different geographical regions, despite the area's climate.

The NLDAS drought research project will continue to work with drought indices, similarly to what has been done for this paper. The goal is to create a drought monitor, comparable to the North American Drought Monitor, using entirely NLDAS forcing and LSM outputs. The outputs of the new drought monitor will need to be investigated to determine what effects the models, climatology length, and ensemble construction have on drought characterization. The final goal of the project is transition to a fully-operational, real-time drought monitor.

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