STATION-BASED INDICES FOR DROUGHT MONITORING IN THE U.S.

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1. INTRODUCTION

The North America Drought Monitor (NADM) is the result of a trilateral partnership between the U.S., Mexico, and Canada to improve drought monitoring on the North American continent and provide decision makers with information essential to planning, mitigation, and response activities. The NADM consists of a map and narrative discussion summarizing drought conditions across the continent on a monthly basis. The drought conditions in each of the three countries are assessed independently based on different data, indices, and analyses within each country, and the results are combined by the lead author into the NADM.

Since the national depictions are produced separately by scientists within each country, the drought conditions along the international borders may be inconsistent. In order to provide guidance for a consistent depiction across the international boundaries, continental-scale drought indicators are generated using data from all three countries, using the same analysis period and same methodologies. In situ-based continental-scale indicators include station Palmer Drought Indices, Standardized Precipitation Indices (SPI), and Percent of Average Precipitation (PCTPCP); satellite-based continental indicators include the NOAA/NESDIS (National Oceanic and Atmospheric Administration/National Environmental Satellite, Data, and Information Service) Vegetation Health Index (VHI); and continental-scale modeled indicators include the Leaky Model soil moisture computed by the NOAA/NWS (NOAA/National Weather Service) Climate Prediction Center (CPC).

In the United States, drought monitoring on a local scale has been based on station data, but climate divisions provide the basis for drought monitoring on a regional or national scale. Divisional data have been used because spatial drought analyses require data which are spatially and temporally complete. Station data frequently have missing months and the period of record varies from station to station, whereas the climate division data base is spatially and temporally complete from 1895 to present. Unfortunately, since divisional data are themselves area-averages and provide a large-scale picture of the climate, they cannot be used to assess conditions on a spatial scale smaller than the size of the division. Station data are point measurements and, therefore, provide a finer spatial resolution.

For the NADM continental-scale in situ indicators, station data are used for Canada, Mexico, and Alaska, but climate division data are used for the contiguous U.S. This results in a discontinuity in scale (station data are point measurements, divisional data are area-averages) along the U.S.-Canadian and U.S.-Mexican borders. In order to compute consistent cross-border in situ indicators, station data for the contiguous U.S. need to be used in place of, or in addition to, the climate division data.

This paper presents an analysis of one of the NADM indicators -- Palmer Drought Indices -- computed for station data and climate division data for the contiguous U.S. The station values are compared to the divisional values for the divisions the stations are in, and U.S.-Mexico contoured maps based on all station data are compared to contoured maps based on a mix of station and divisional data.

2. DATA AND METHODOLOGY

Monthly temperature and precipitation data were available for the U.S. climate divisions for the period January 1895-September 2006. Monthly temperature and precipitation data were available for U.S., Mexican, and Canadian stations through September 2006, but the beginning period varied from station to station. The period common to most stations was 1951-present.

The source of the station data for the contiguous U.S. was the Cooperative Network (COOP) Summary of the Day dataset (TD-3200). Data for a subset of the approximately 6000 currently open COOP stations are transmitted on an operational near-real time basis, and the station availability varies from month to month. For example, 2159 COOP stations had both daily temperature and precipitation for August 2006 that were complete enough (no more than one day missing for precipitation and no more than ten days missing for temperature) to compute monthly values. Only 1039 of them had monthly data for August 2006, had at least 43 years of monthly data, and were at least 85% complete for both temperature and precipitation from 1951-present. Only 863 stations had data for September 2006, had at least 43 years of monthly data, and were at least 85% complete for both temperature and precipitation from 1951-present.

SPI and PCTPCP indicators were examined in addition to the Palmer indices, but missing data limited their utility. Missing months from the period October 2004-August 2006 for SPI, and from October 2001-

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August 2006 for PCTPCP, resulted in a missing September 2006 SPI or PCTPCP value for the timescale(s) affected by the missing month for many stations, as many as half of the stations at the longer timescales (see Table 1).

Table 1. Number of stations with non-missing data for SPI and PCTPCP for September 2006.

Timescale	Number of Stations
1-month	865
2-month	865
3-month	760
6-month	591
9-month	524
12-month	522
24-month	482
36-month	461
48-month	446
60-month	428

Long-term averages (1951-2001 means) were used to estimate temperature and precipitation values for the missing months in the Palmer drought index computations. This estimation methodology was not used for the SPI or PCTPCP computations because it would seriously impact the resulting index values for the short timescales. The SPI and PCTPCP indicators were not analyzed in this study because of the resulting large variation in number of stations for the different timescales due to missing data.

The comparison methodology used in this study consisted of visual comparison of maps of the station and corresponding divisional Palmer index values for September 2006, and the computation of correlation coefficients and differences (mean, mean of absolute value, greatest positive, greatest negative, and greatest absolute value) between the station and corresponding divisional values over the period 1951-2006.

3. RESULTS

The Palmer index consists of a backstepping procedure involving a probability analysis which can result in an unstable value for operational drought monitoring (Heim, 2002). Heddinghaus and Sabol (1991) developed a modified version of the index that minimizes this instability. This modified version of the Palmer index (referred to as the PMDI, or more simply as the PDI) was used in this analysis.

3.1 *Maps of September 2006 Palmer Index*

Figure 1 shows the location of the 863 stations in the 50 States having sufficient data for September 2006 and their September 2006 PDI values. The spatial distribution of the stations is irregular with the West having a sparser station density and most climate divisions having stations. Only a few divisions did not have collocated stations (for example, northeast Wyoming and northern Idaho).

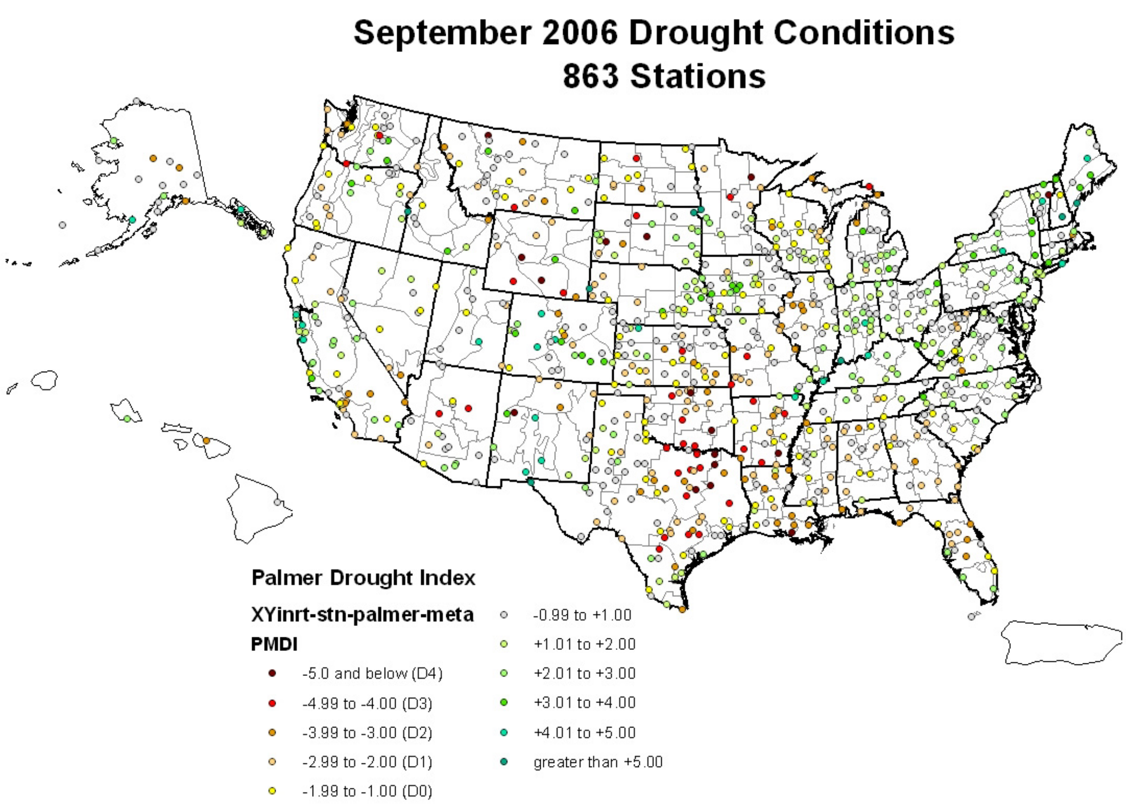

Figure 1. September 2006 PDI values for U.S. stations.

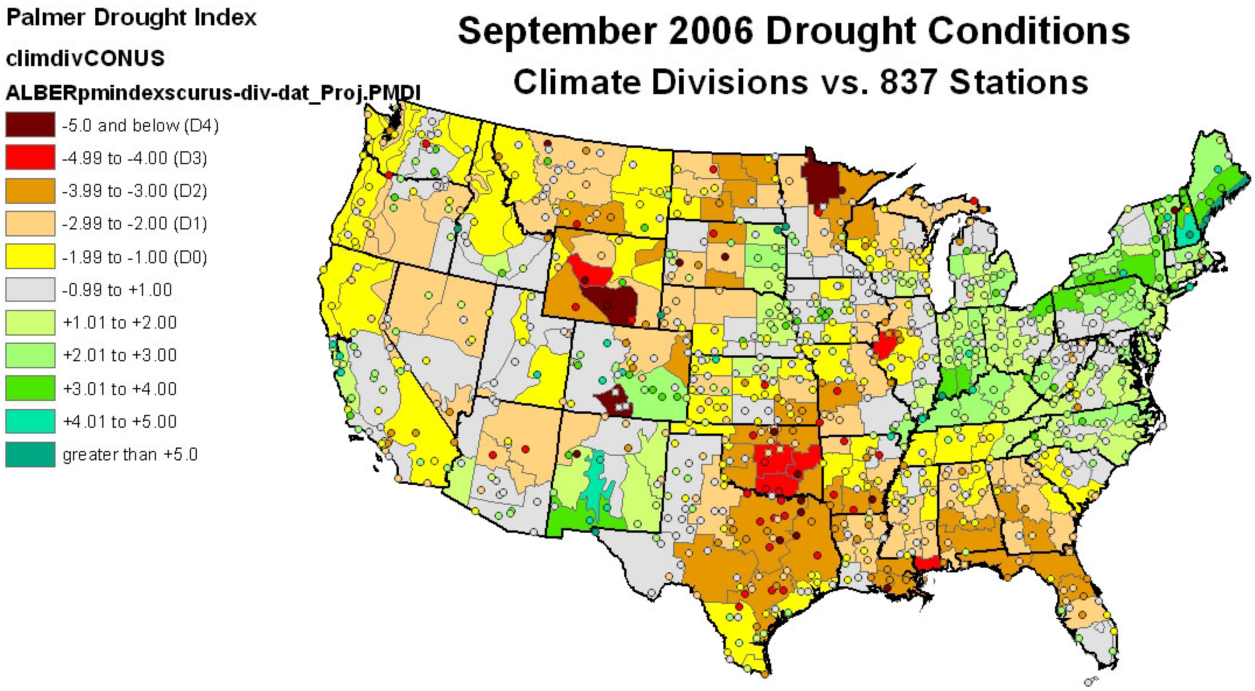

Figure 2. September 2006 PDI values for the climate divisions and the 837 stations in the contiguous U.S.

Of the 863 stations in the 50 States that had sufficient data for September 2006, 837 of them were located in the Lower 48 States. The September 2006 PDI values for these stations and the climate divisions in the contiguous U.S. are plotted in Figure 2. In many instances, the station PDI values are consistent with the divisional values, but in many other instances the two values are different, sometimes significantly different. This could be due to the fact that local drought conditions (represented by the station values) can vary considerably across small distances, whereas the divisional values are area averages. The climate divisions in Texas, for example, are quite large. The differences also could be due to the fact that some climate divisions may cover climatically inhomogeneous regions. The divisions in Colorado, for example, represent mountainous river basins which have a variety of diverse climatic regimes.

Two sets of NADM continental indicator maps are produced for each drought index: dot maps for North America showing the station and climate division values and contoured maps for the U.S. and Mexico based on the station and divisional values. The climate division values are plotted at the division's center point (centroid). Both sets of maps provide useful guidance for the NADM author in determining the NADM drought depiction along the international borders. Contoured maps are not produced for the entire North American continent because of insufficient station density for the Canadian stations.

Figures 3 and 4 show the differences in September 2006 PDI contours for the contiguous U.S. based on the climate division values and the station values. The dots on each map show the location of the divisional center point (Figure 3) and station location (Figure 4). As expected, since the divisional data are themselves area averages, contours based on the divisional values show large areas of homogeneous drought conditions (Figure 3). The station-based contours show considerably more spatial variability (Figure 4). The maps are consistent in showing the major (severe) drought and wet spell areas, but there are differences along the edges of the main drought areas and in the mild to moderate drought areas.

There are 344 climate divisions and 3028 counties (which includes some "town" governments in some Northeastern States, according to the 1993 Statistical Abstract of the United States) in the contiguous U.S., or on average approximately ten counties per division. This makes climate division data unusable for depicting drought conditions on a county scale. Station data are better suited for determining county-scale drought conditions, as illustrated in Figure 5.

The NADM author uses the U.S. Drought Monitor (USDM) depiction for the week closest to the end of the month for the U.S. depiction on the NADM. Several dozen drought indicators are used to prepare the USDM depiction. Figure 6 shows how the September 2006 station PDI values compare to the September 26, 2006 USDM depiction.

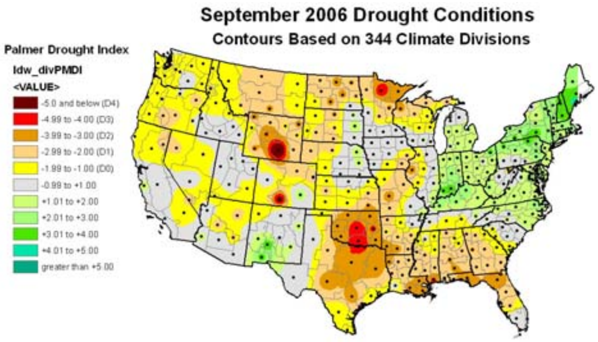

Figure 3. Contours of September 2006 PDI based on climate division values (dots are divisional centroid).

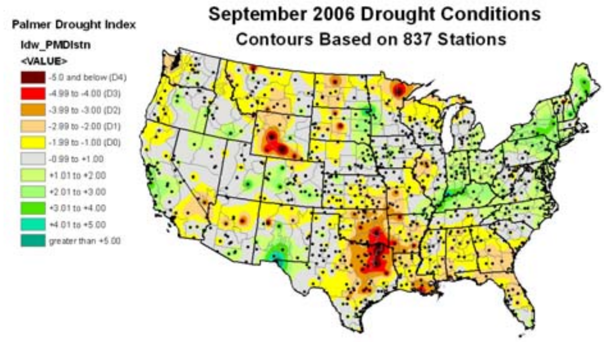

Figure 4. Contours of September 2006 PDI based on station values (shown as dots).

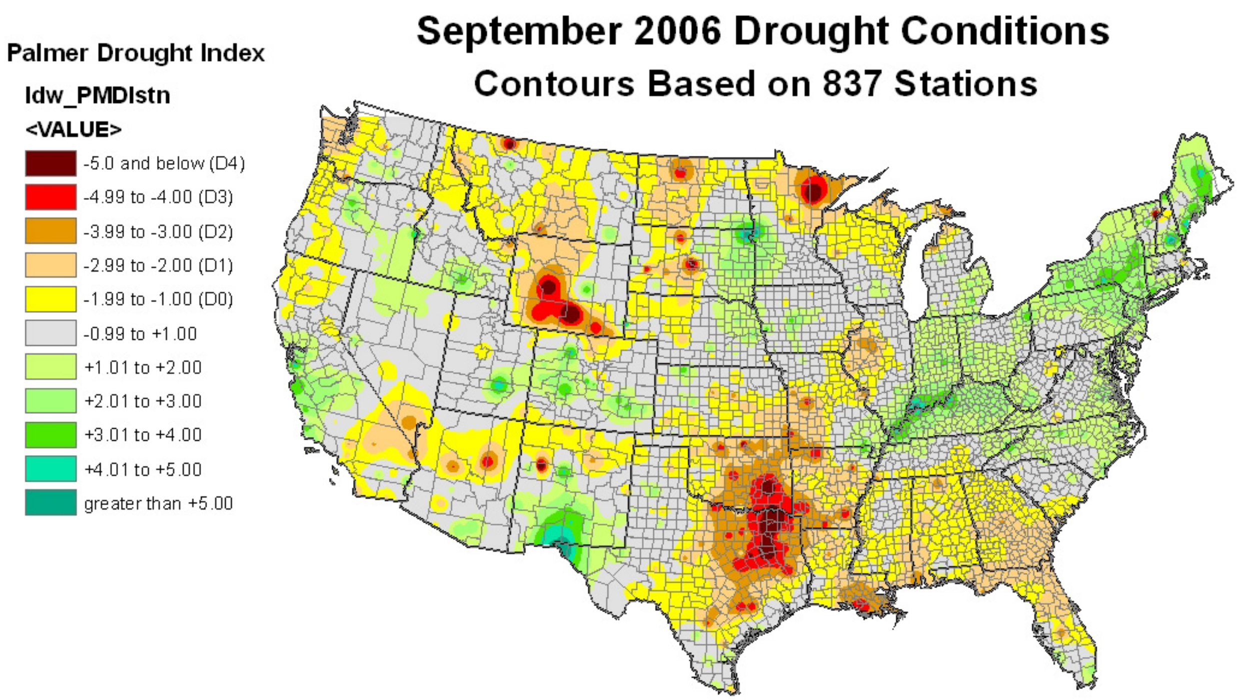

Figure 5. Contours of September 2006 PDI based on station values, plotted with county boundaries.

3.2 *Period of Record Comparison*

Correlation coefficients were used to assess how well the station PDI values track compared to the climate division values over the period January 1951-September 2006. Figure 7 shows that the correlations are positive everywhere, highest in the central and eastern parts of the country, and lower in the West, with the lowest values generally occurring in parts of the Rocky Mountains. A few stations had low correlations in the midst of high correlation stations east of the Rockies, with the most notable example located in southeast Iowa along the Mississippi River.

Figure 8 shows the mean difference in the station and divisional PDI values over the 1951-2006 period. The mean difference generally is between -0.25 and +0.25, with a few stations having more extreme differences, mostly in the southern Plains, Southwest, and central Rockies.

A different spatial pattern emerges when the differences are examined regardless of their sign. A map of the average of the absolute value of the differences (Figure 9) shows the greatest differences over the western U.S., and the smallest differences over the eastern half of the country, which is consistent with the correlation map (Figure 7). The greatest mean absolute differences occur in the Rockies, southern California desert, and at that errant station in southeast Iowa. Similar patterns are found in maps of the greatest negative difference (Figure 10), greatest positive difference (Figure 11), and greatest absolute difference (Figure 12).

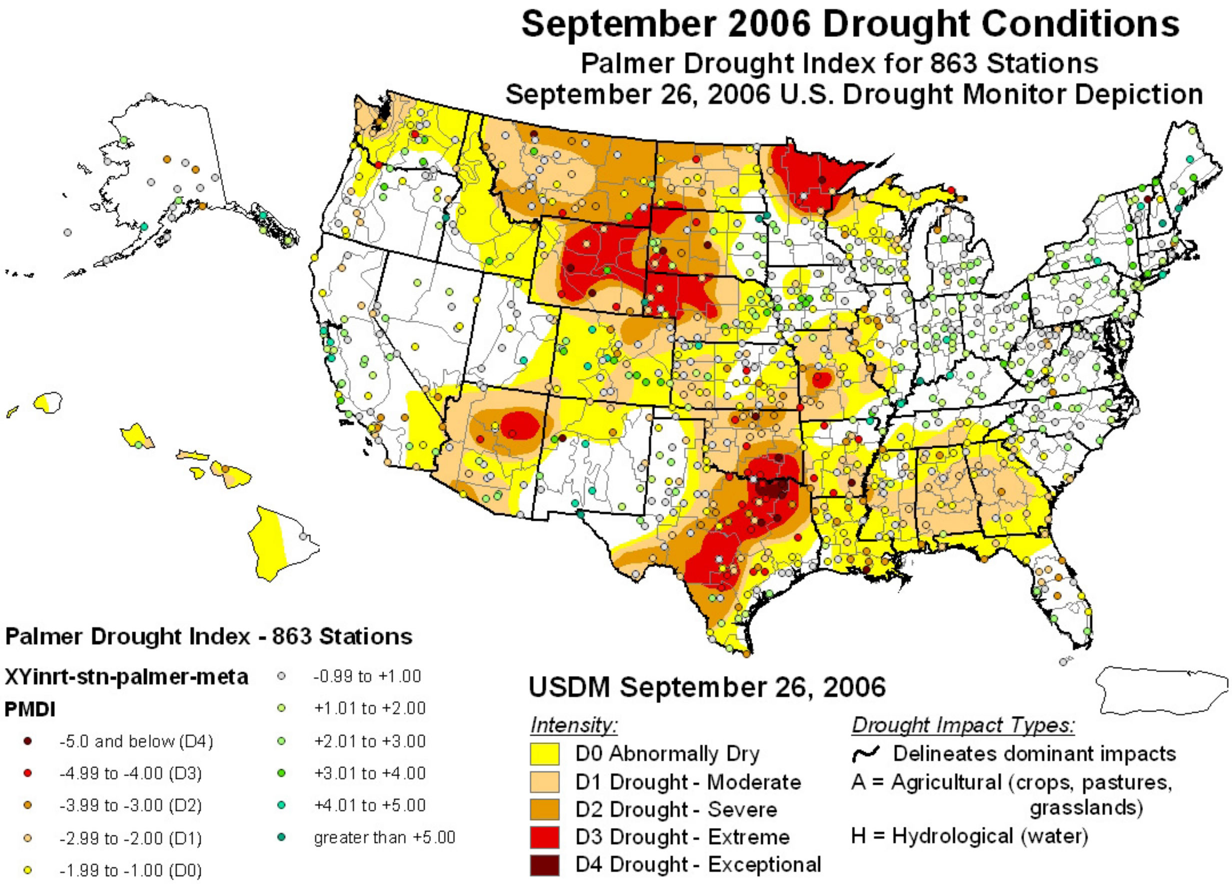

Figure 6. September 2006 station PDI compared to the September 26, 2006 USDM depiction.

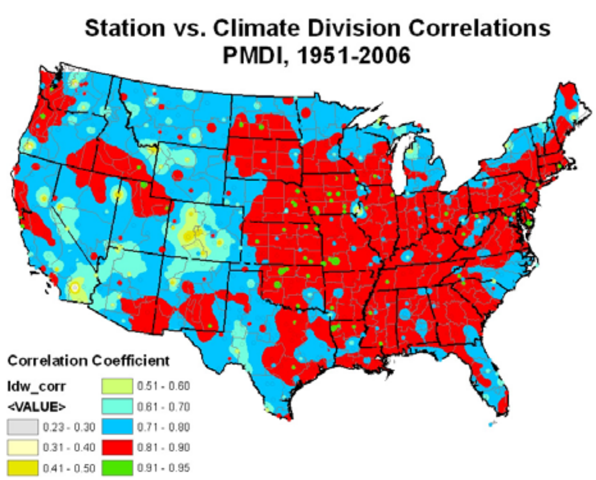

Figure 7. Correlation coefficients for station vs. climate division PDI (PMDI) from January 1951-September 2006.

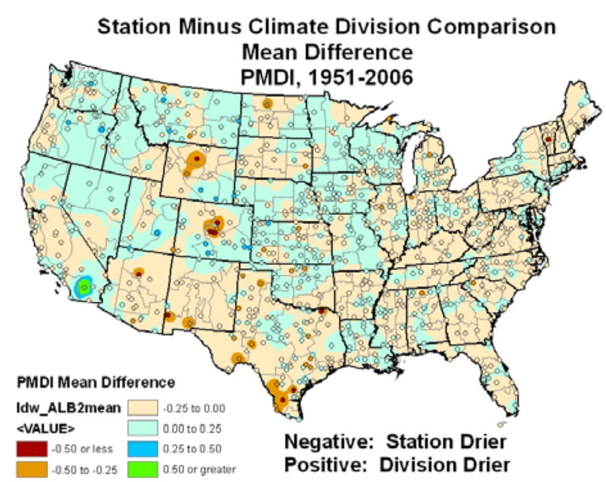

Figure 8. Mean difference between station and climate division PDI (PMDI) from January 1951-September 2006.

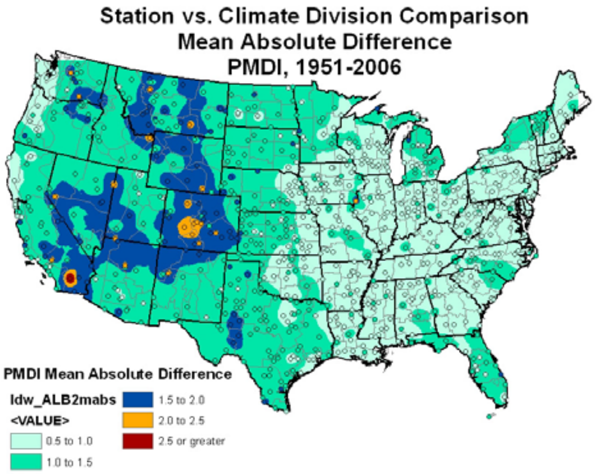

Figure 9. Mean absolute difference between station and climate division PDI (PMDI) from January 1951-September 2006.

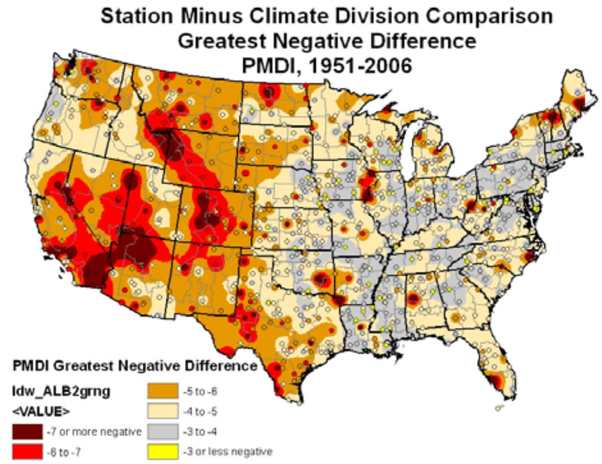

Figure 10. Greatest negative difference between station and climate division PDI (PMDI) from January 1951-September 2006.

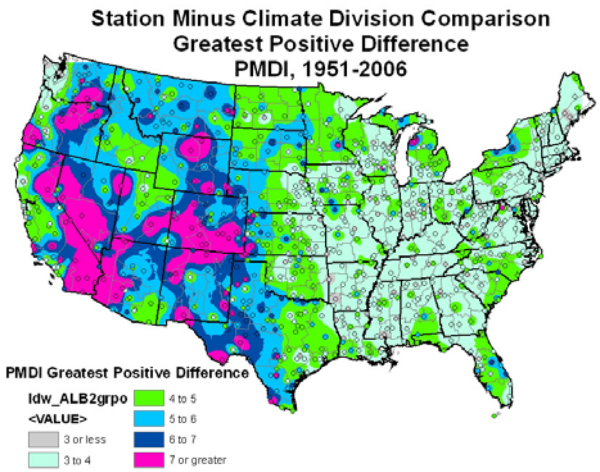

Figure 11. Greatest positive difference between station and climate division PDI (PMDI) from January 1951-September 2006.

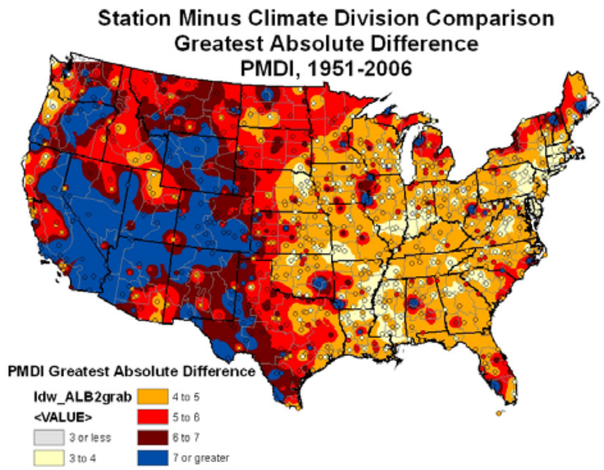

Figure 12. Greatest absolute difference between station and climate division PDI (PMDI) from January 1951-September 2006.

One possible explanation for these differences may lie in the definition of the climate divisions. The divisions east of the Rockies are smaller and represent areas that are more climatologically homogeneous, whereas the western divisions are larger and represent more heterogeneous climate regions.

3.3 *Comparison of Operational NADM Indicator Maps: All Stations vs. Station-Division Mix*

Monthly contoured maps of drought indicators across the U.S. and Mexico are produced on a routine basis as part of the NADM analysis. Figure 13 shows the PDI contoured map for September 2006 created using the traditional mix of stations for Mexico and climate divisions for the contiguous U.S. The drought regions in the U.S. appear as large, smoothly-rounded areas. Figure 14 is the same map, except station data were used instead of climate divisions in the contiguous U.S. The drought regions are generally smaller and have sharper edges. Some drought regions have more severe conditions in their core areas on the station map. Differences in the shape of the drought areas along the U.S.-Mexican border are also noticeable.

The PDI is a long-term drought index. The Palmer model also computes a short-term drought index, the Palmer Z Index. Figures 15 and 16 compare the Palmer Z Index computed using the traditional station-division mix (Figure 15) and using only stations (Figure 16). As for the PDI, the Z Index drought areas are rounder and more homogeneous for the divisions and more sharply defined for the stations. Also, the station-based map shows more fine-scale drought areas.

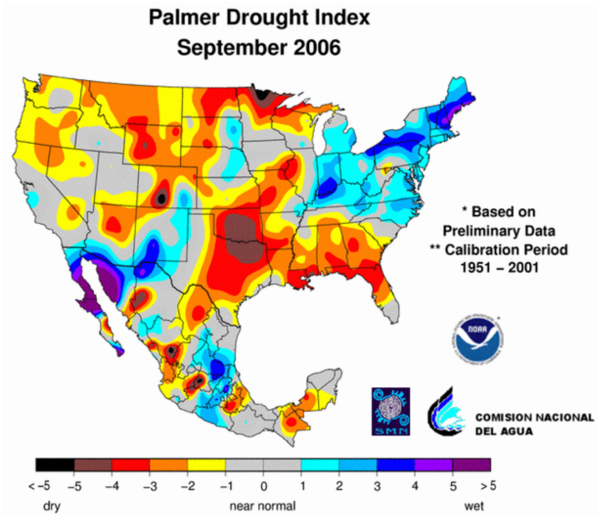

Figure 13. September 2006 PDI map created using stations for Mexico and climate divisions for the U.S.

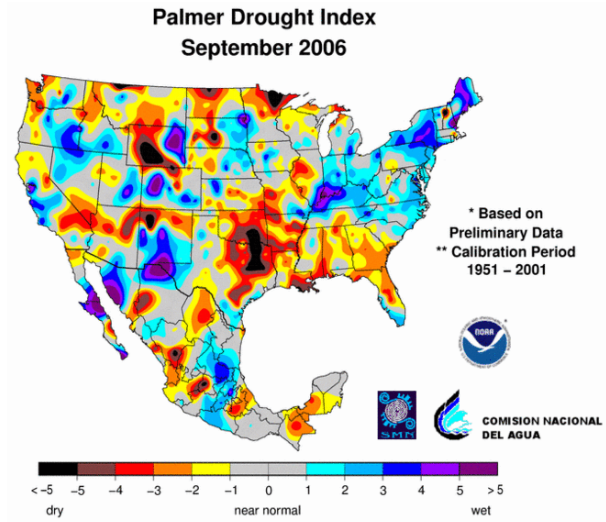

Figure 14. September 2006 PDI map created using stations for Mexico and stations for the U.S.

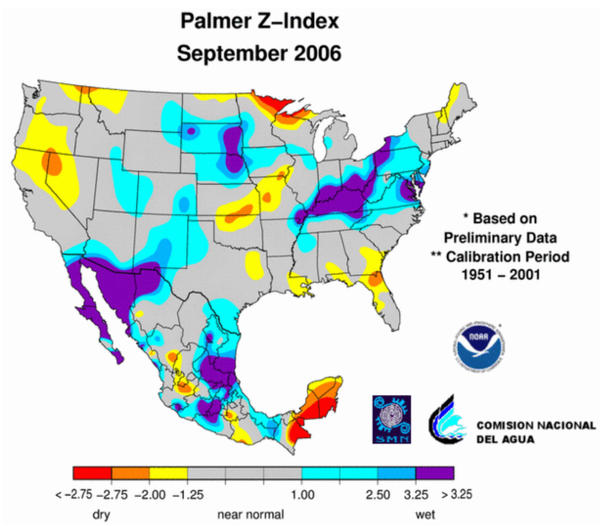

Figure 15. September 2006 Palmer Z Index map created using stations for Mexico and climate divisions for the U.S.

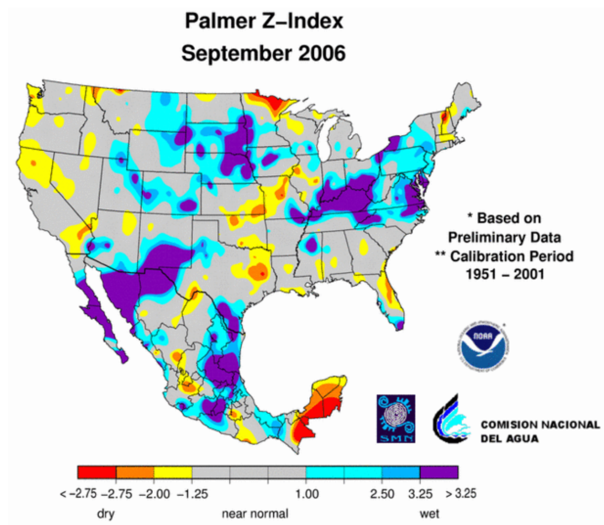

Figure 16. September 2006 Palmer Z Index map created using stations for Mexico and stations for the U.S.

4. DISCUSSION AND CONCLUSIONS

It is clear from this analysis that the point measurements from station data provide a finer spatial resolution on drought maps than area-averaged climate division data. However, missing data, differing periods of record, and spatial gaps in station coverage limit the utility of station data for some drought monitoring applications, and it is intuitively obvious that spatial analyses (e.g., the creation of contoured maps) are highly dependent on the number of stations available and their specific locations. If the number of operationally-available stations changes from month to month, this could negatively impact analyses made from the contoured maps. Climate division data do not provide the spatial detail required to assess drought conditions on a fine spatial detail (e.g., at the county level), but the serially and spatially complete and consistent data base is a significant strength. The station and climate division drought indices (PDI) track fairly close to each other for climatically homogeneous parts of the country, but significant differences occur for inhomogeneous areas such as the mountainous West.

It would be advantageous to develop a data base that combines the strengths of both station and climate division data. A serially-complete gridded data base at a spatial scale fine enough to assess drought conditions at the county level would be sufficient. Such a gridded data base is being developed for the Living Blended Paleo Drought project and it could have application here for the USDM and NADM.

In conclusion, I recommend that we use both divisional data and station data for the operational NADM drought indicators, specifically:

1) Continue using climate division-based drought indicators. Develop equivalent climate division data bases for Mexico and Canada to enable the computation of a consistent set of continental climate division drought indicators.

2) Compute NADM drought indicators based on station data to assess drought conditions on a fine (i.e., county level) spatial scale.

3) Develop a gridded data base of monthly temperature, precipitation, and drought indices to complement the station and climate division analyses.

5. REFERENCES

Heddinghaus, T.R. and P. Sabol, 1991: A review of the Palmer Drought Severity Index and where do we go from here? *Proceedings, 7th Conf. on Appl. Climatol.,* 10-13 September 1991, Boston: American Meteorological Society, 242-246.

Heim, R.R., Jr., 2002: A review of Twentieth-Century drought indices used in the United States. *Bull. Amer. Meteor. Soc.*, **83**, 1149-1165.