United States Drought of 2007: Historical Perspectives

By: **Peter T. Soulé** & Justin T. Maxwell

Abstract

The impacts of the United States drought of 2007 to both society and ecosystems were substantive and included multi-billion dollar agricultural losses and the second worst wildfire season on record. The purpose of this paper is to place the 2007 drought in historical perspective relative to the climate record from 1895–2007 to increase our understanding of this hazard and contribute to improvements of drought mitigation plans. We compared the 2007 drought historically against the climatic record (1895–2007) using the Palmer Drought Severity Index (PDSI). We then examined the temporal progression of the 2007 drought and placed the peak month of drought severity (November) in historical perspective using rankings of severity and statistical recurrence intervals. Moreover, we examined the climatic factors (e.g. geopotential height anomalies) that contributed to both abnormally dry and wet conditions recorded within the continental United States. While there were regions that experienced the worst drought on record both annually and in November during the calendar year 2007, this year was not as severe as other notable drought years. November 2007 ties (with 5 other years) for the 12th worst on record in terms of the number of climatic divisions experiencing the worst November drought. Statistically, drought/wetness conditions in November 2007 were not exceptionally extreme, with almost all of the calculated statistical recurrence intervals being much less than the 113 year period of record.

Peter T. Soulé & Justin T. Maxwell (2009) "United States Drought of 2007: Historical Perspectives" *Climate Research* Volume 38 pp. 95-104 (open access) Version of Record Available From (www.researchgate.net)

1. INTRODUCTION

The 2007 drought in the southeastern and southwestern United States attracted considerable media attention. Reports in the southeast claimed that the drought of 2007 was the worst in a century (New York Times, www.nytimes.com/2007/10/16/us/16drought.html; Time Magazine, www.time.com/time/magazine/article/0,9171,1684513,00.html). In addition, reports of damaged crops, diminishing water supplies, and large wildfires extended from early summer into late fall. The drought affected pasture and hay production most severely, making it so difficult and expensive to feed livestock that the USDA allowed farmers to apply for national disaster relief (USDA 2007). In Georgia, the drought caused an estimated $787.2 million in agricultural production losses and $1.3 billion in total economic losses (Flanders et al. 2007). Numerous counties throughout the southeast, southwest, mountain west, and northern Minnesota were considered 'primary natural disaster areas' due to losses from extreme drought (USDA 2007). In addition, the drought of 2007 severely reduced water levels in many reservoirs, thereby affecting water supplies for municipalities, industry, and hydroelectric and nuclear power generation (P. O'Driscoll & L. Copeland, USA Today, www.usatoday.com/weather/news/2007-10-19-drought_N.htm; Duke Energy, www.duke-energy.com/news/releases/2007103001.asp). In the southwest, water levels in Lake Mead were 54% below maximum capacity at the end of October (K. Dewey, www.hprcc.unl.edu/nebraska/Lake-Mead-2007.html), and the southeastern states of Georgia, Florida, and Alabama were involved in federal lawsuits over control of water releases from Lake Lanier (NBC 11 Alive, www.11alive.com/news/article_news.aspx?storyid=110717). The reduced supply of water forced many southeastern states to implement restrictions on watering lawns, washing automobiles, and other non-critical uses of water (CBS News; www.cbsnews.com/stories/2007/05/29/national/main2861151.shtml?source=search_story). Further, drought conditions helped produce one of the worst wildfire seasons on record, with 3.8×10^6 ha burned nationwide in 2007, which is the second largest amount in recorded history (NOAA 2007a). Wahlquist (2003) found that media coverage of drought influences public perceptions and community mitigation plans. She argues that most of the public receives information about drought conditions through the media; thus, the way the media reports on a current drought will influence how the public prepares for future droughts.

Drought occurs throughout the entire United States and can potentially be severe anywhere (Cook et al. 1999). Research on drought in the United States is diverse and includes examinations of intensity, frequency, causes, and spatial and temporal patterns (Oglesby & Erickson III 1989, Soulé 1990, Knapp et al. 2002, Hoerling & Kumar 2003, Salas et al. 2005). When severe, drought is a natural hazard that can cause billions of dollars in damages (Wilhite 2000). Continued research on the causes and patterns of drought will increase our understanding of this hazard and contribute to improvements of drought mitigation plans. For example, the Carolinas Dynamic Drought Index (Carbone et al. 2008) uses a combination of indices at different temporal scales to help decision makers understand the behavior and patterns of drought, which is needed to improve mitigation plans in North and South Carolina.

Analyzing drought from a historical perspective has been a frequent topic in drought research (Karl & Quayle 1981, Cook et al. 1988, Pielke et al. 2005, Herweijer et al. 2006). Various techniques have been used to characterize drought conditions, including principal components analysis (Karl & Koscielny 1982, Cook et al. 1999, Knapp et al. 2002), tree-ring analysis (Cook et al. 1988, Cook et al. 1999, Timilsena et al. 2007), synoptic analyses (Trenberth et al. 1988, Palmer & Branković 1989, McCabe et al. 2004), and analyses of frequency, duration, and drought rank / recurrence intervals (RI) (Diaz 1983, Karl & Young 1987, Soulé 1992, González & Valdés 2006). Pielke et al. (2005) argue that the spatial scale of the study is important in determining the historical rank. At finer scales (e.g. county level), a drought can be historically significant relative to a broader scale (e.g. state level). For this study, we chose to use climatic divisions because they are small enough to show intrastate variations but large enough to easily interpret.

The purpose of this paper is to place the 2007 drought in historical perspective relative to the climate record from 1895–2007. We discuss the progression of the 2007 drought by determining the month when the drought peaked, and further examined that month by comparing it historically. In addition, we examined the climatic factors (e.g. geopotential height anomalies) that contributed to extreme drought (or wet) conditions in many regions of the United States.

2. DATA AND METHODS

We obtained monthly data of the Palmer Drought Severity Index (PDSI; Palmer 1965) for the period 1895–2007 for each of the 344 climatic divisions in the contiguous United States (NOAA 2007b). This PDSI data set is updated monthly and calibrated using the 1931–1990 period (NOAA 2007c), and we obtained the data in January 2008. The PDSI data are frequently used to characterize drought conditions in the United States (Soulé 1990, Hidalgo 2004, Bordi et al. 2006, Goodrich & Ellis 2006, Easterling et al. 2007), and have been used in historical comparisons (Soulé 1993, Cook et al. 1999, Herweijer et al. 2006, Timilsena et al. 2007). The PDSI is water balance-based and provides a measurement centered on zero that characterizes the moisture conditions of the current month relative to the climatic normals of the location (i.e. the climatic division). The index for any given month considers the moisture climate of the current and preceding months, making the index moderate in response to changing moisture conditions. Because the index is based on a 'moisture departure from normal' within a given climatic division (Karl 1983; p. 1357), a month recording PDSI values of –3.0 (severe drought) in southwestern Arizona can be compared to a similar magnitude drought in southeastern Georgia, since the magnitude of moisture severity relative to long-term climatic normals is similar for both locations.

To place the drought of 2007 in historic context, we determined and mapped the spatial pattern of the rank of average annual drought severity based on PDSI values using the full period of record (1895–2007) for each climatic division. Thus, the driest year on record received a rank of 1, while the wettest year received a rank of 113. We used choropleth maps of drought severity based on PDSI paired with 500 hPa geopotential height anomaly maps obtained from the NCEP/NCAR reanalysis (NCEP/NCAR 2008a) to examine the temporal progression of the 2007 drought in the United States. To determine the month of maximum drought severity in 2007, we calculated the average monthly value of drought severity across all climatic divisions (n = 344). To aid our interpretation of the temporal patterns of drought severity, we examined monthly mean anomaly composite maps of columnar precipitable water, 1000 mb temperature, 1000 mb vector wind, and 1000 mb outgoing longwave radiation (NCEP/NCAR 2008b) (data not shown).

After determining that drought conditions peaked in November, we placed this month in historical perspective in 2 ways. First, we used the same procedures as for the annual drought conditions and determined the rank of drought severity in November for each climatic division. Second, we calculated the statistical RI for this month for each climatic division using Kite's (1988) methodology, which allows an assessment of the statistical rarity of events based on standardized Z scores. We first tested the monthly PDSI data from each climatic division for normality using the Shapiro-Wilk test (Shapiro & Wilk 1965), a null hypothesis of no significant difference from a normal probability distribution, and $\alpha = 0.01$. Of the 4128 months tested (n = 12 mo for n = 344 climatic divisions), the majority (87%) were normally distributed, allowing us to use the data directly without transformation. We separated these recurrence intervals based on whether an individual climatic division had positive or negative moisture anomalies for the month, and present the recurrence intervals as a choropleth map.

3. RESULTS

While the drought of 2007 in the contiguous United States received most of the media attention, record-setting moisture conditions were experienced on both ends of the spectrum (Fig. 1). In the 113 year study period, 2% of the climatic divisions (7/344) across the country recorded their worst annual average drought conditions in 2007, and 10.2% of the divisions had drought conditions that were among the 5 worst years ever. In contrast, 3 climatic divisions (0.9%) recorded their wettest year on record, and 5.5% had moisture conditions ranked in the top 5.

The spatial pattern of moisture conditions in 2007 was consistent throughout the year, especially from May to November. Although drought intensity increased during the year, areas that began the year in drought (wetness) generally ended it in drought (wetness) (Fig. 2). Perhaps most intriguing is that the consistency of moisture patterns was not matched by consistency of geopotential height anomaly patterns. In January (Fig. 2a), the flow was conducive for cyclogenesis in the southern Great Plains, with the area being between a western trough and an eastern ridge. In March (Fig. 2b), virtually the entire country experienced positive geopotential height anomalies and above normal temperatures (not shown), and drought conditions worsened in both the mountain west and southeast. In May, most of the country again experienced positive geopotential height anomalies (Fig. 2c),

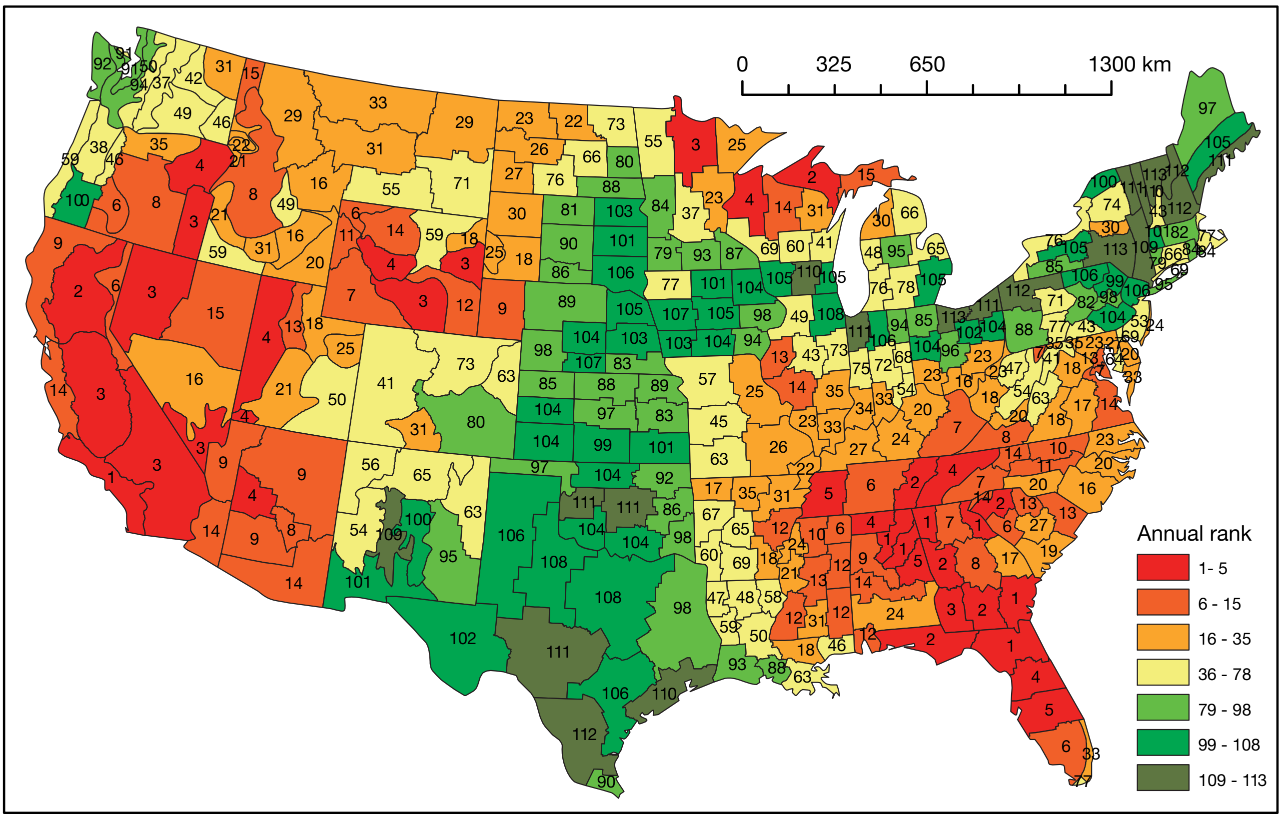

Fig. 1. Drought ranks (1 = driest, 113 = wettest) based on annual average Palmer Drought Severity Index (PDSI) values for 2007. Map created using ArcGIS 9.2 (ESRI 2006)

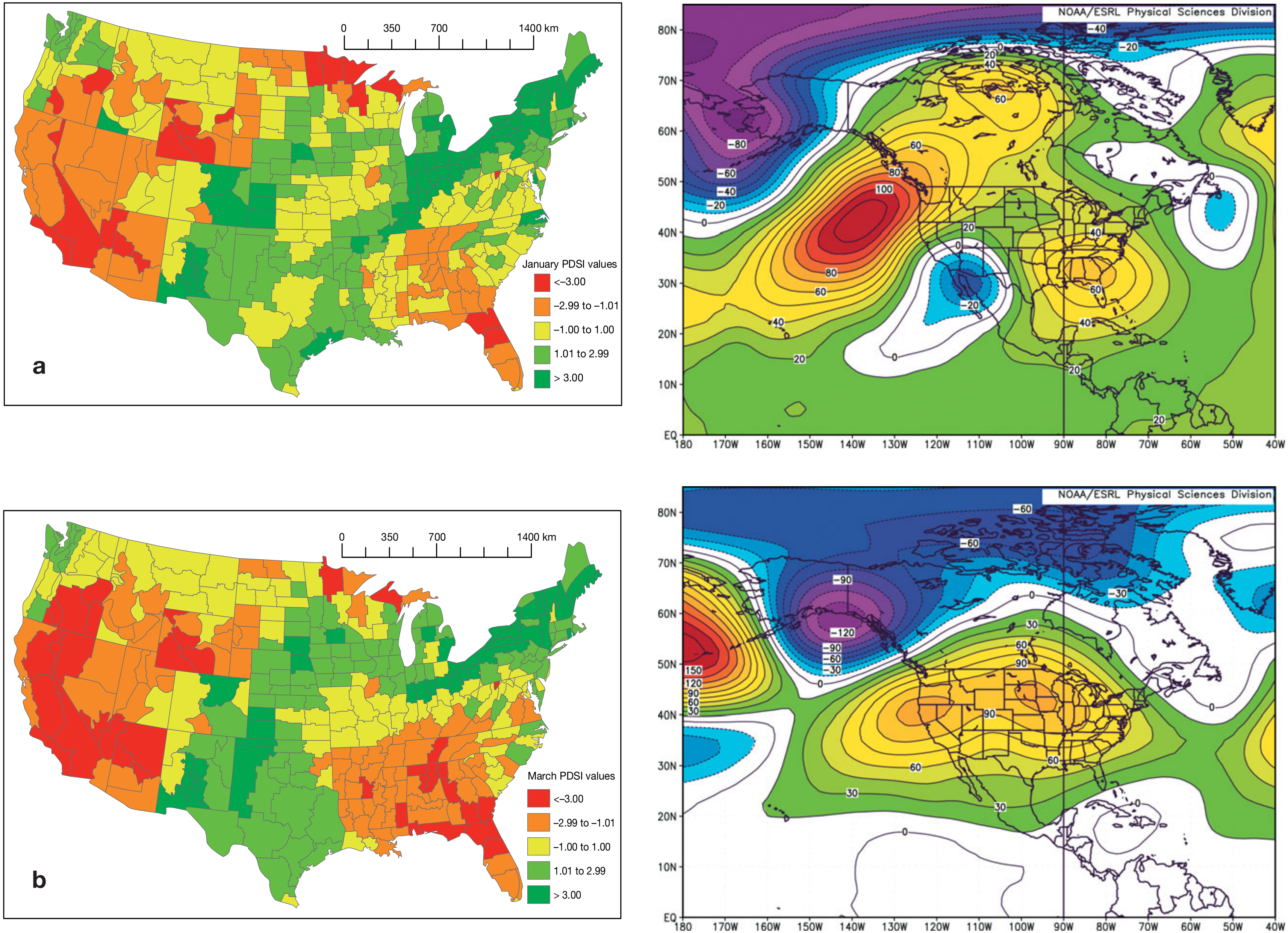

Fig. 2 (above and following 2 pages). 2007 monthly PDSI values by climatic division (left panels) and 500 hPa geopotential height anomalies (right panels) for (a) January, (b) March, (c) May, (d) July, (e) September, and (f) November. Map created using ArcGIS 9.2 (ESRI 2006)

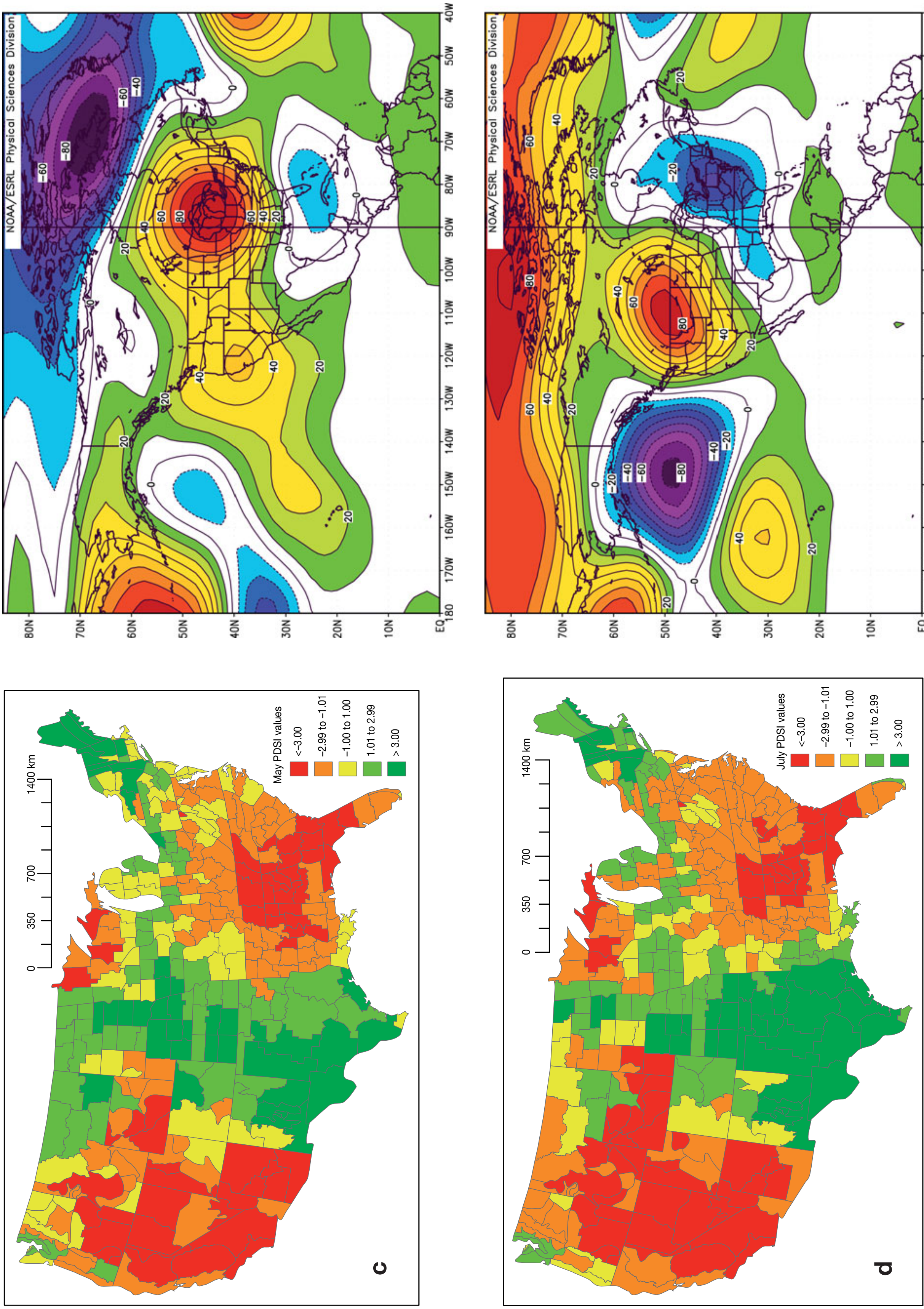

Fig. 2 (continued)

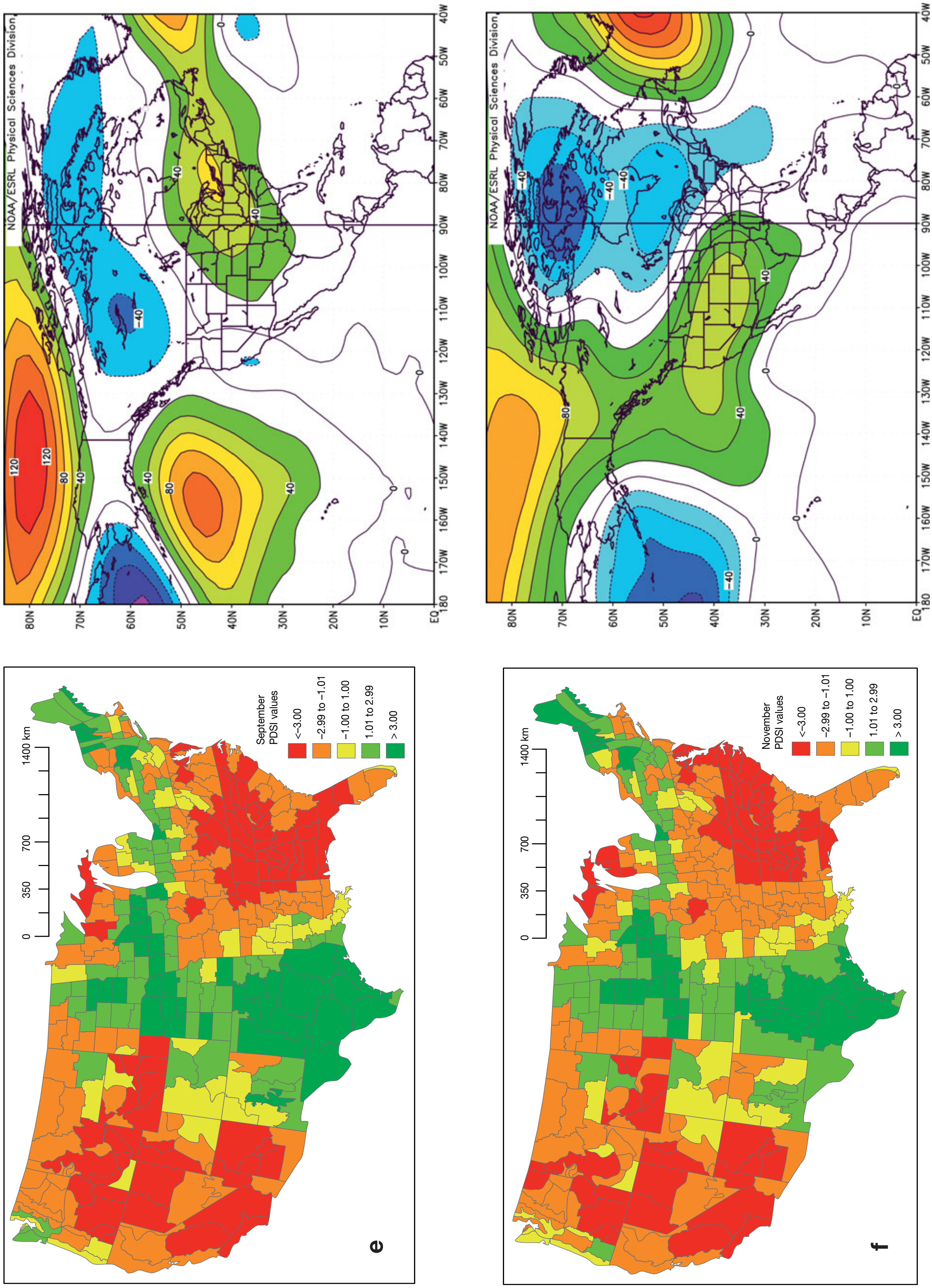

Fig. 2 (continued)

with the position of the strongest ridge axis over the Great Lakes causing a contraction of the abnormally wet pattern in the northeast, an expansion of the drought conditions in the southeast, and an intensification of wetness throughout the Great Plains. This occurred in association with south and southeasterly flow from the Gulf of Mexico that decreased rates of evapotranspiration due to increased cloud cover and precipitation (NCEP/NCAR 2008c). The Great Plains experienced abnormal amounts of cold, wet and cloudy conditions because the 1000 mb vector winds from the south continued strongly throughout the summer months, expanding the area of wetness. In addition, tropical storm Erin moved well inland into the southern Great Plains in mid-August, further enhancing the wetness in this region (especially Texas). In July, an enhanced western ridge was prominent (Fig. 2d), and drought conditions intensified in the northern intermountain region in association with significantly above normal temperatures. Despite below normal 500 mb heights in the east in July, surface temperatures remained near normal and there was very little change in drought conditions. In both August (not shown) and September (Fig 2e), weakly anomalous ridging occurred throughout most of the east, resulting in above normal temperatures and an expansion of drought conditions. Moreover, the lack of land-falling tropical systems in the United States in 2007 (Unisys 2008) reduced chances of any synoptic-scale drought-busting system modifying the pattern.

The area affected by drought conditions peaked in September, with more climatic divisions experiencing severe drought conditions (≤−3.0 PDSI) in this month (Table 1). However, drought intensity for the entire United States peaked in November following a month (October, not shown) when geopotential height anomalies were positive everywhere except in the coastal northwest Pacific. Positive height anomalies persisted through November in the western states (Fig. 2f), resulting in some moderation of the extreme wetness in the Great Plains.

Table 1. Average monthly Palmer Drought Severity Index (PDSI) values (2007) across contiguous United States (n = 344) climatic divisions and number of climatic divisions recording PDSI values ≤−3.0 (severe drought)

Month	Average PDSI	No. divisions ≤−3.0 PDSI
January	0.66	21
February	0.34	19
March	0.06	37
April	0.19	35
May	−0.37	57
June	−0.43	60
July	−0.44	61
August	−0.45	74
September	−0.69	79
October	−0.51	59
November	−0.84	71
December	−0.43	61

Table 2. Comparison of years with all-time November low PDSI values

Rank	Year	No. climatic divisions
1	1930	43
2	1934	40
3	1956	39
4	1954	25
5	1936	19
6.5	1953	11
6.5	1964	11
8.5	1965	10
8.5	2002	10
12	1897	8
12	1924	8
12	1976	8
12	1988	8
12	2007	8

November 2007 ties (with 5 other years) for the 12th worst on record, in terms of the number of climatic divisions experiencing severe drought conditions (Table 2). In comparison, 1930 was far worse, with over 5 times the number of climatic divisions recording the worst November drought conditions and displaying a substantially more contiguous spatial pattern of drought than in 2007 (Figs. 3 & 4). Regionally, the spatial pattern of drought ranks in November 2007 shows that the southeastern states and California experienced the worst drought conditions in terms of contiguous climatic divisions with top 5 rankings. Statistically, drought/wetness conditions in November 2007 were not exceptionally extreme, as only 2 climatic divisions recorded a recurrence interval extending beyond the 113 year period of record for drought and 1 division for wetness (Fig. 5). The resulting spatial pattern of the recurrence intervals reinforces the consistency of drought (or wetness) conditions throughout the year.

4. CONCLUSIONS

In 2007, some regions within the United States experienced their worst drought conditions since 1895. The reductions in soil moisture had multiple impacts for society, including reduced agricultural yields, increased wildfire occurrence, and reduced supply in reservoirs that service municipalities, industry, and power generation. Despite these substantive impacts, the 2007 drought was not exceptionally severe climatologically and statistically, in comparison to other droughts that have occurred within the era of instrumental records (e.g. the drought of 1930). Further, moisture conditions

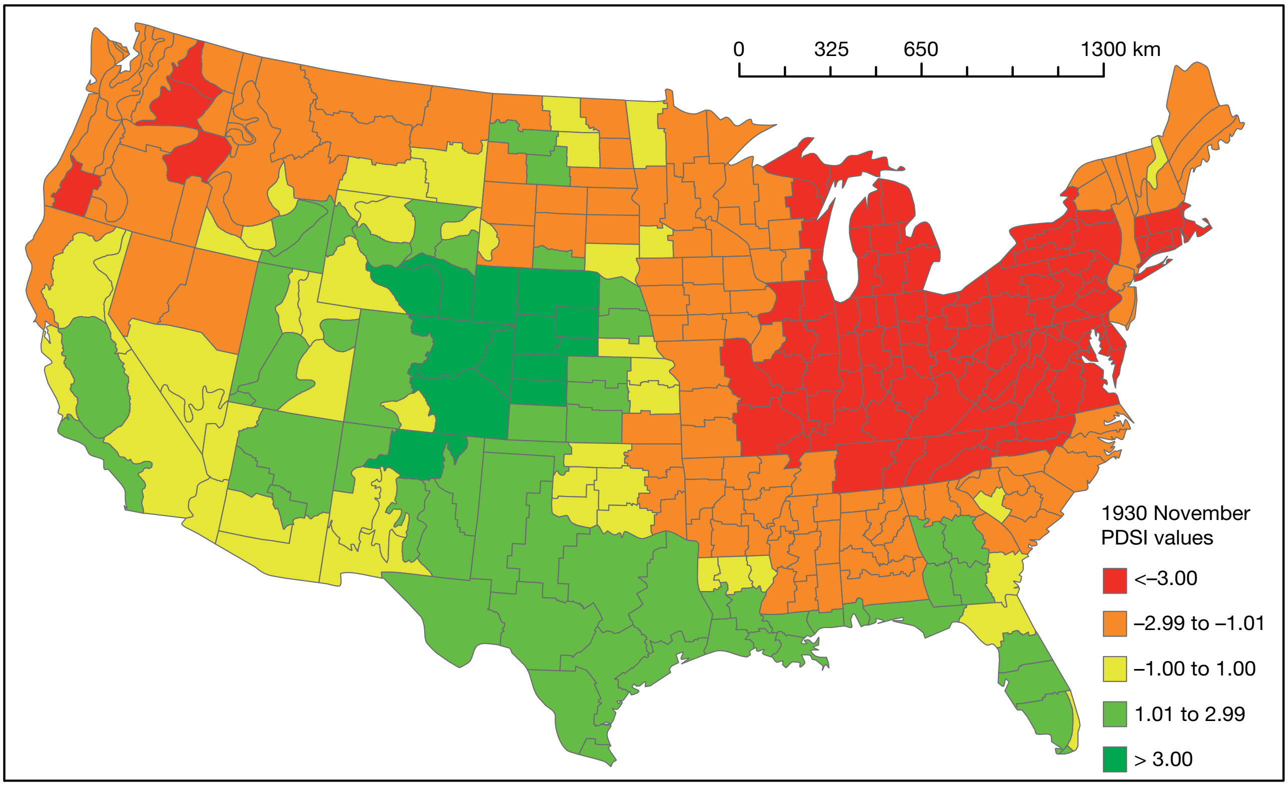

Fig. 3. Drought conditions in November 1930. Map created using ArcGIS 9.2 (ESRI 2006)

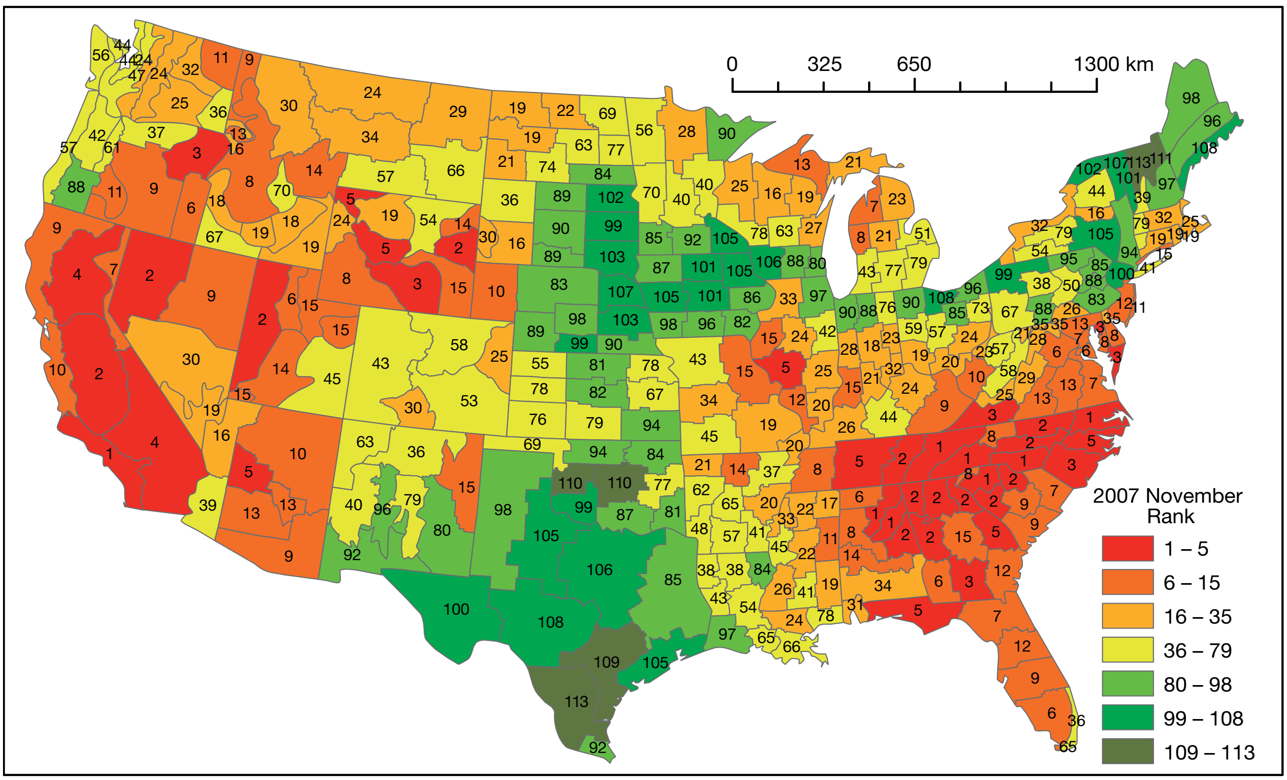

Fig. 4. Drought ranks (1 = driest, 113 = wettest) based on average PDSI values for November 2007. Map created using ArcGIS 9.2 (ESRI 2006)

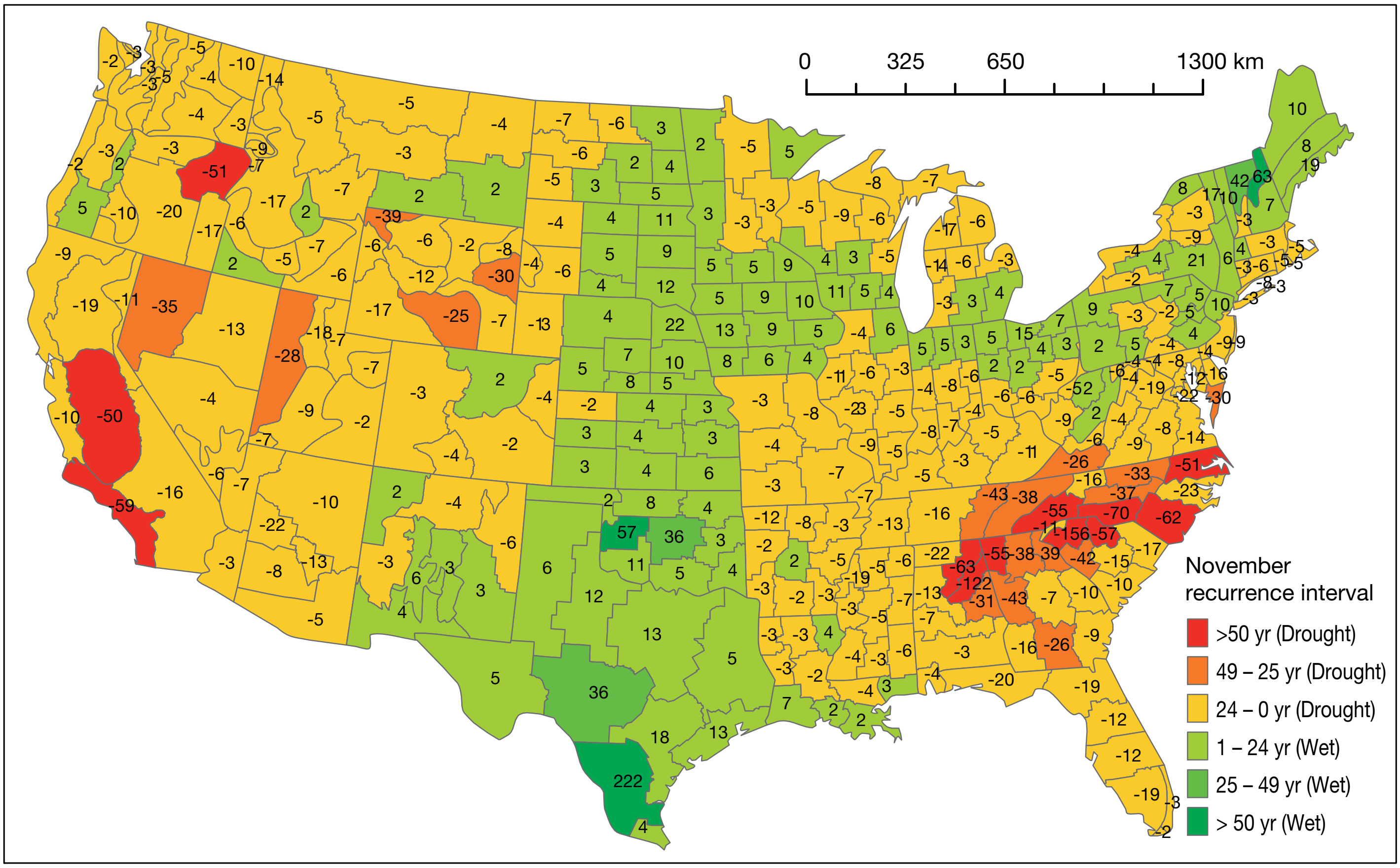

Fig. 5. Statistical recurrence intervals for November 2007 calculated from 1895–2007 PDSI records. Map created using ArcGIS 9.2 (ESRI 2006)

across the United States were highly variable in 2007, with a large portion of the country (e.g. southern Great Plains) experiencing extreme wetness. Drought has always been a challenge for humans, and with the population increases that have occurred in the United States since the worst drought years of the 1930s, even less severe droughts have significant and long-lasting impacts on humans and human activities. Thus, the media attention received by the drought of 2007 is partly a result of stresses placed on water resources by our increasing population. Further, the extensive press coverage reinforced the need for enhanced water conservation and drought mitigation plans at the local and regional level, and heightened the awareness of Americans of our most precious natural resource.

LITERATURE CITED

Bordi I, Fraedrich K, Petitta M, Sutera A (2006) Extreme drought events comparison using PDSI and SPI indexes. Geophys Res Abstr 8:06020

Carbone G, Rhee J, Mizzell H, Boyles R (2008) A regional-scale drought monitoring tool for the Carolinas. Bull Am Meteorol Soc 89:20–28

Cook E, Kablack M, Jacoby G (1988) The 1986 drought in the southeastern United States: How rare an event was it? J Geophys Res B 93:14.257–14.260

Cook E, Meko D, Stahle D, Cleaveland M (1999) Drought reconstructions for the continental United States. J Clim 12:1145–1162

Diaz H (1983) Some aspects of major dry and wet periods in the contiguous United States, 1895–1981. J Clim Appl Meteorol 22:3–16

Easterling D, Wallis T, Heim R, Lawrimore J (2007) The effects of temperature and precipitation trends on US drought. Geophys Res Lett 34:L20709, doi: 10.1029/2007GL031541

ESRI (Environmental Systems Research Institute) (2006) ArcGIS 9.2. Redlands, CA. Available at www.esri.com/

Flanders A, McKissick J, Shepherd T (2007) Georgia economic losses due to 2007 drought. The University of Georgia Center for Agribusiness and Economic Development. Center Report: CR-07-10 July 2007, p 1–8

González J, Valdés J (2006) New drought frequency index: definition and comparative performance analysis. Water Resour Res 42:W11421, doi: 10.1029/2005WR004308

Goodrich G, Ellis A (2006) Climatological drought in Arizona: an analysis of indicators for guiding the governor's drought task force. Prof Geogr 58:460–469

Herweijer C, Seager R, Cook E (2006) North American droughts of the mid to late nineteenth century: a history, simulation and implication for mediaeval drought. Holocene 16:159–171

Hidalgo H (2004) Climate precursors of multidecadal drought

variability in the western United States. Water Resour Res 40:W12504, doi: 10.1029/2004WR003350
Hoerling M, Kumar A (2003) The perfect ocean for drought. Science 299:691–694
Karl T (1983) Some spatial characteristics of drought duration in the United States. J Clim Appl Meteorol 22:1356–1366
Karl T, Koscielny A (1982) Drought in the United States: 1895–1981. J Climatol 2:313–329
Karl T, Quayle R (1981) The 1980 heat wave and drought in historical perspective. Mon Weather Rev 109:2055–2073
Karl T, Young P (1987) The 1986 southeast drought in historical perspective. Bull Am Meteorol Soc 68:773–778
Kite G (1988) Frequency and risk analysis in hydrology. Water Resources Publications, Colorado
Knapp P, Grissino-Mayer H, Soulé P (2002) Climatic regionalization and the spatio-temporal occurrence of extreme single-year drought events (1500–1998) in the interior Pacific northwest, USA. Quat Res 58:226–233
McCabe G, Palecki M, Betancourt J (2004) Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States. Proc Natl Acad Sci USA 101: 4136–4141
NCEP/NCAR (National Centers for Environmental Prediction/National Corporation for Atmospheric Research) (2008a) 500 mb geopotential height anomaly maps. Accessed 14 Feb 2008. www.cdc.noaa.gov/Composites/Day/
NCEP/NCAR (2008b) Monthly mean anomaly composite maps of columnar precipitable water, 1000 mb temperature, 1000 mb vector wind, and 1000 mb outgoing longwave radiation. Accessed 14 Feb 2008. www.cdc.noaa.gov/Composites/Day/
NCEP/NCAR (2008c) Monthly precipitation anomaly and NOAA interpolated OLR monthly mean and climatology maps. Accessed 14 Feb 2008. www.cdc.noaa.gov/Composites/Day/
NOAA (National Oceanic and Atmospheric Administration) (2007a) Climate of 2007. Wildfire season summary. National Climatic Data Center. Accessed 15 Jan 2008. www.ncdc.noaa.gov/oa/climate/research/2007/fire07.html
NOAA (2007b) drd964x.pdsi.txt Accessed 15 Jan 2008. ftp://ftp.ncdc.noaa.gov/pub/data/cirs/drd964x.pdsi.txt
NOAA (2007c) Time bias corrected divisional temperature-precipitation-drought index. Accessed 15 Jan 2008. ftp://ftp.ncdc.noaa.gov/pub/data/cirs/divisional.README
Oglesby R, Erickson D III (1989) Soil moisture and the persistence of North American drought. J Clim 2:1362–1380
Palmer W (1965) Metrologic drought. Research Paper No. 45. US Department of Commerce, Weather Bureau, Washington, DC
Palmer T, Branković Ĉ (1989) The 1988 US drought linked to anomalous sea surface temperature. Nature 338:54–57
Pielke R, Doesken N, Bliss O, Green T and 5 others (2005) Drought 2002 in Colorado: An unprecedented drought or a routine drought? Pure Appl Geophys 162:1455–1479
Salas J, Fu C, Cancelliere A, Dustin D, Bode D, Pineda A, Vincent E (2005) Characterizing the severity and risk of drought in the Poudre River, Colorado. J Water Res Pl-ASCE 131:383–393
Shapiro S, Wilk M (1965) An analysis of variance for normality (complete samples). Biometrika 52:591–611
Soulé P (1990) Spatial patterns of multiple drought types in the contiguous United States: a seasonal comparison. Clim Res 1:13–21
Soulé P (1992) Spatial patterns of drought frequency and duration in the contiguous USA based on multiple drought event definitions. Int J Climatol 12:11–24
Soulé P (1993) Hydrologic drought in the contiguous United States, 1900–1989: spatial patterns and multiple comparison of means. Geophys Res Lett 20:2367–2370
Timilsena J, Piechota T, Hidalgo H, Tootle G (2007) Five hundred years of hydrological drought in the Upper Colorado River Basin. J Am Water Resour Assoc 43:798–812
Trenberth K, Branstator G, Arkin P (1988) Origins of the 1988 North American drought. Science 242:1640–1645
Unisys (2008) Unisys weather. Accessed 14 Feb 2008 www.weather.unisys.com/
USDA (United States Department of Agriculture) (2007) USDA accepts applications for crop, feed and livestock losses suffered Feb. 28 up to Dec. 31, 2007. Accessed 14 Feb 2008 www.fsa.usda.gov/FSA/printapp?fileName=nr_20080125_rel_0020.html&newsType=newsrel
Wahlquist A (2003) Media representation and public perceptions of drought. In: Botterill L, Fisher M (eds) Beyond drought: people, policy, and perspectives. CSIRO Publishing, Collingwood Victoria, Australia, p 67–86
Wilhite D (2000) Drought as a natural hazard: concepts and definitions. In: Wilhite D (ed) Drought: a global assessment 1:3–18. Routledge, New York

Editorial responsibility: Bryson Bates, Wembley, WA, Australia

Submitted: March 4, 2008; Accepted: August 5, 2008
Proofs received from author(s): December 1, 2008