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The US summer of 1993:
A sharp contrast in weather extremes

J. N. Lott
US National Climatic Data Center

During the summer of 1993, the upper Mid-west of the USA was devastated by severe flooding, while much of the south-east and nearby areas suffered from a heatwave and drought. This article provides a review of the details gathered from numerous sources about these events. See Fig. 1 for a map of the states mentioned in the text.

The combined flooding/drought losses for the summer of 1993 exceeded $16000 million. The US government allocated over $5800 million in disaster relief funds for the flood- and drought-ravaged areas, and seven federal agencies were involved in this disaster relief effort.

To add insult to injury, the summer of 1993 June-August) produced an estimated 648 tornadoes across the country - about twice the number normally expected. There were also several reports of softball-size hail in the areas hit by severe flooding, thus adding to the destruction. Some of the thunderstorm radar echo tops reached over 21km, being fueled by surface dew points that exceeded 25°C. These 'supercell' storms generated some of the tornadoes mentioned above and, in some cases, produced non-tornadic microburst winds exceeding 90kn.

Synoptic conditions

It appears that the prolonged El Nino event of 1992-93 may have played a role in the unusual pattern of weather that occurred during the

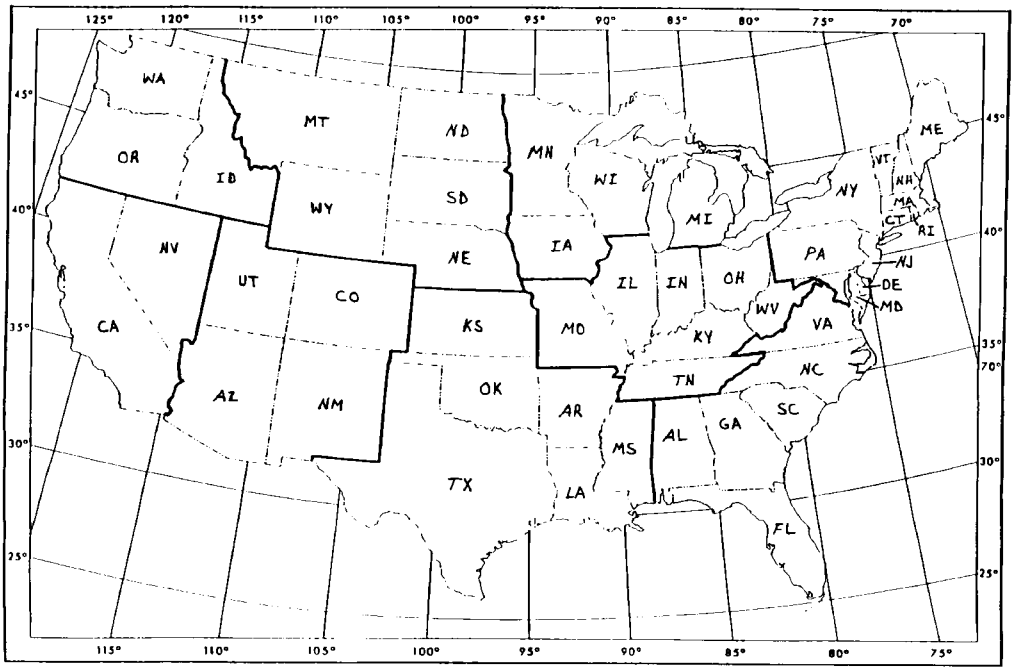

Fig. 1 State map of the USA, indicating states mentioned in the text. AL – Alabama, GA – Georgia, IA – Iowa, IL – Illinois, KS – Kansas, MO – Missouri, MN – Minnesota, MT – Montana, NC – North Carolina, ND – North Dakota, NE – Nebraska, SC – South Carolina, SD – South Dakota, TN – Tennessee, VA – Virginia, WI – Wisconsin.

first half of 1993. However, it is very difficult to establish a direct correlation. Recent studies have indicated a positive correlation between El Nino and winter spring rainfall in the 'deep south' from Texas to the Carolinas, while other relationships have been difficult to establish.

Figures 2 and 3 illustrate the polarity of the conditions experienced across the USA during the summer of 1993. Due to the persistent west-east trough-ridge pattern (Fig. 2), a large portion of the country was either unusually wet or unusually dry. During the summer months the jet stream was also much stronger than usual, reminiscent more of spring than summer, over the Rockies and the Plains. A very strong Bermuda high pressure system combined with the persistent upper-level trough over the Midwest during most of the summer. These anticyclonic conditions led to the generation of a hot and rather stagnant airmass, which suppressed the formation of thunderstorms over the south-east; the low-level air was abnormally dry and the vertical stability was enhanced by warm, anticyclonic conditions aloft. On the western edge of the anticyclone there was a 'moisture pump' into a region of very unstable air over the Midwest (Fig. 3), where heavy thunderstorms were prevalent. Also, a quasistationary front was often present over the upper Midwest, thus aiding in the development of thunderstorms.

By the end of August, about one third of the country was unusually moist (denoting an unusual to extreme moist spell - see Fig. 4), and about one third of the country was unusually dry (moderate to extreme drought), thus leaving only about a third of the country with near normal conditions. For example, from April through to August, Des Moines, IA, received 1021mm of rain (compared to a normal of 513mm) while Greenville-Spartanburg, SC, received only 191mm (compared to a normal of 550mm). Similarly, Salina, KS received 1081mm for the same 5-month period, while only 245mm fell on Charlotte, NC.

Midwest flooding

River flooding

The stage was set for severe flooding when the

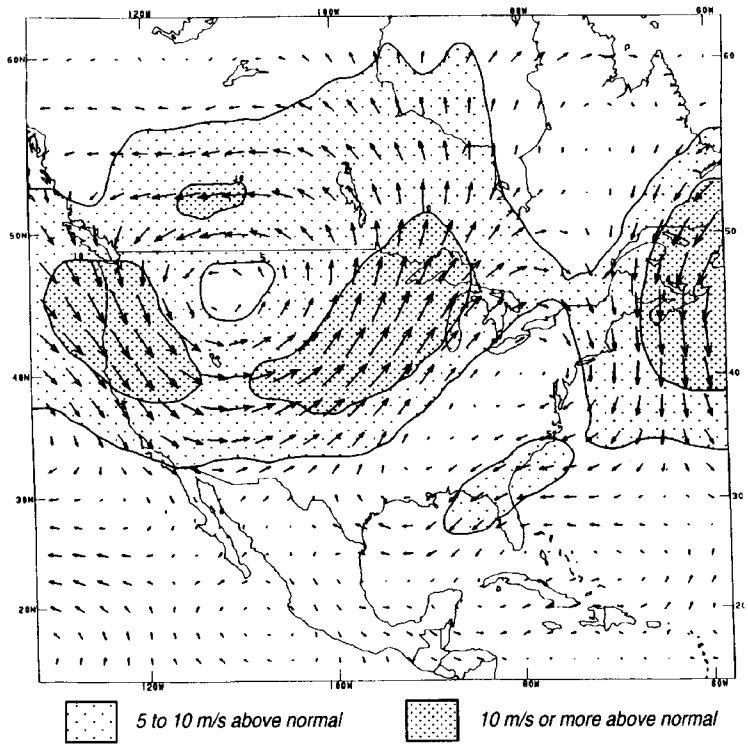

Fig. 2 Departure of the observed flow at 250mbar (approximately 10km above the surface) from the 1979–88 normal during the period 5 June–24 July 1993. The arrows represent the magnitude and direction of the flow anomaly. (Prepared by the US Climate Analysis Center.)

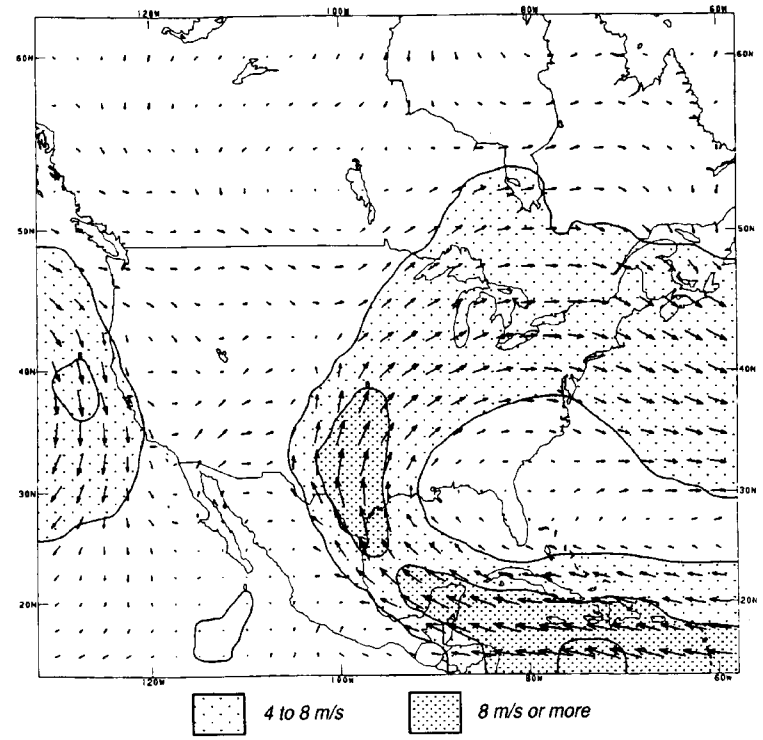

Fig. 3 Average 850mbar flow (approximately 1500m above the surface) during the period 5 June–19 July 1993. The arrows represent the magnitude and direction of the observed wind. (Prepared by the US Climate Analysis Center.)

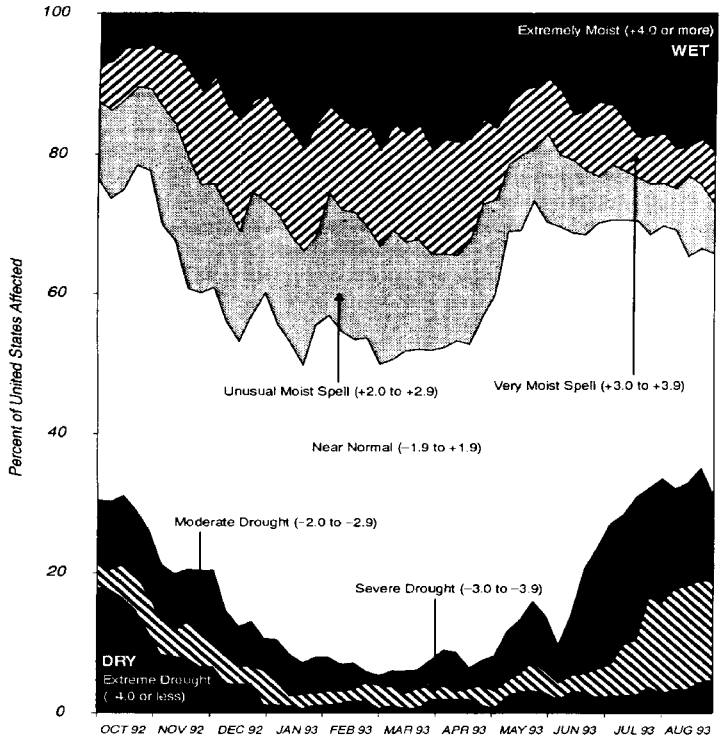

Fig. 4 Percentage of the USA affected by a wet spell or drought, based on the preliminary Palmer Index, as computed by the US Climate Analysis Center for the period October 1992 to August 1993. On this graph, the 'wet area' percentages are inverted such that the true percentage is estimated by subtracting the per cent figure on the vertical axis from 100 per cent.

upper drainage basin of the Mississippi River experienced a wet autumn in 1992 followed by heavy winter snowfall and ensuing spring snowmelt. Iowa reported its greatest snowpack since the spring of 1979. Severe flooding began in May on the Redwood River in Minnesota, and in June on the Black River in Wisconsin. Then came the record flooding of the Mississippi, Missouri, and Kansas Rivers. The most severe flooding was concentrated along an 800km stretch of the Mississippi River between Cairo, IL, and Minneapolis, MN; and along a 640km length of the Missouri River from Omaha, NE, to St. Louis, MO. Some sections of the Mississippi River were above flood stage from late March through to most of August. Also, some areas were flooded which were outside the 100-year flood plain charts (for previous flooding). Figure 5 illustrates the locations of the rivers which experienced flooding and the severity of their flooding.

The Missouri River crested in St. Charles, MO, at 12.0m, and in Kansas City at 14.9m (0.8m above the previous record set in 1951) - 5.3m above flood stage. The Mississippi River at St. Louis crested at 15.1m (1.9m above the previous record set in 1973) - 6.0m above flood stage. This previous record at St. Louis was exceeded in 1993 for a period of over three weeks. The Kansas River at Kansas City crested at 16.7m - 6.7m above flood stage, and 1.2m above the old record. The Red River in North Dakota reached a level of 9.8m - 6.4m above flood stage.

The Missouri River, normally no more than 800m wide, expanded to 8-10km in width north of St. Joseph, MO, and 13-16km in width east of Kansas City. Just north of St. Louis, it reached a width of 32km near its confluence with the Mississippi, as the merging

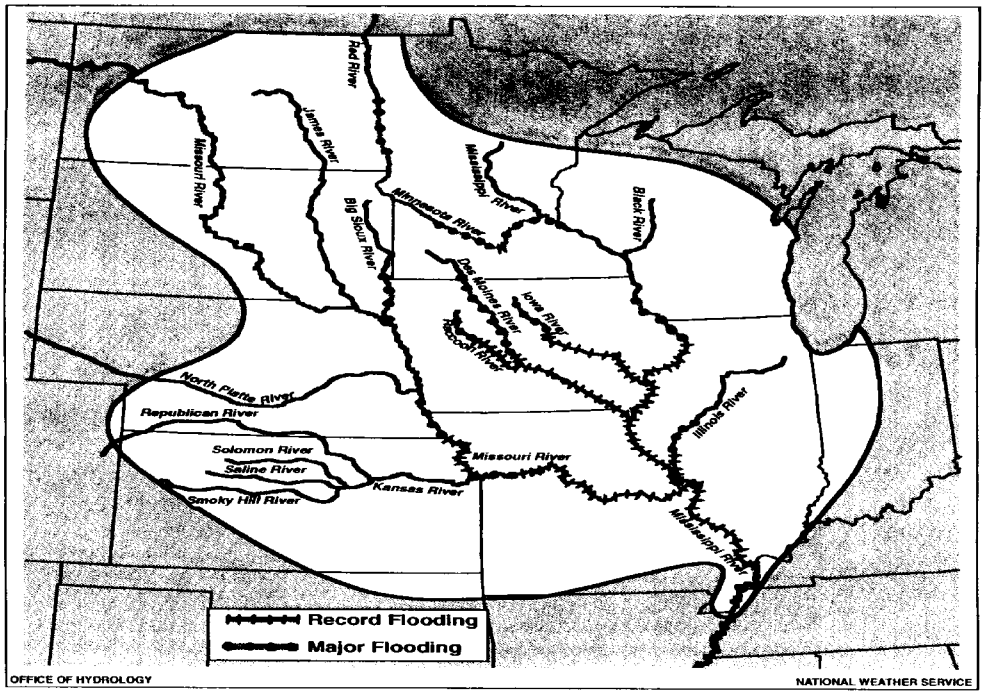

Fig. 5 Degree of flooding observed along various rivers throughout the Midwest during July and August 1993 (courtesy of the Office of Hydrology, US National Weather Service)

of the two rivers occurred 32km north of their normal point of confluence. As a result, almost half of the 1606km^2 of St. Charles County, MO, were under water. The Mississippi River reached nearly 12km in width at some points.

In Des Moines, IA, residents were without potable water for 12 days due to flooding of their water-supply facilities. This is the largest US city (250000 population) to go without water for such an extended period. (The Raccoon River in Des Moines crested at 2.1 m over its previous all-time record crest.) Also, 85000 people were without water in St. Joseph, MO, along with 77000 in Alton, IL.

Many of the bridges crossing the Mississippi were destroyed or damaged by the flooding.

From 16 to 20 July, there were no bridge crossings over a 341 km span between Burlington, IA, and St. Louis, MO. The flood halted Mississippi River traffic over a 940km stretch from Cairo, IL, to St. Paul, MN, from late June to early August. This resulted in over 5000 loaded barges being stranded, and an estimated $3million per day being lost in revenue. Similarly, the Missouri River was closed from late June to early August over an 860km span stretching from its confluence with the Mississippi River to near Sioux City, IA. Eleven commercial airports were closed at one time or another due to the flooding. Railway traffic was devastated, with over 6400km of track either flooded or made idle, and over $200million in estimated losses.

Agricultural economy

Well over 7 million hectares were flooded, covering parts of nine states. At least 50000

homes were damaged or destroyed, over 85,000 residents had to evacuate their homes, and at least 77 small towns near the rivers were completely flooded. Some of the flooding occurred as levees collapsed after being weakened by constant pressure from rising water levels. However, some levees, such as the 15.9m 'wall' protecting St. Louis, held back the rising waters. It is interesting to note that the St. Louis levee was built to a level 2.7m higher than the previous record crest for the Mississippi River, but less than l m higher than the 15.1m crest recorded on 1 August. Approximately 58 per cent of the nearly 1400 levees on the Mississippi and Missouri Rivers were overrun or breached by the water.

Over 4 million hectares of farmland were flooded, and crop losses exceeded $5000million. Many farm animals, such as cattle, perished in the rising waters. Total crop losses due to flooding or saturated fields exceeded 14million hectares. The national soybean yield was 17 per cent below the 1992 level, while the national corn yield was down by 33 per cent.

Overall damage estimates exceed $15000 million - by far the greatest loss in US history attributed to flooding. The 'economic' cost of lost business revenue adds to the overall cost of the event. Local power plants were damaged in many cities, with electrical service lost as a result (including 45 000 people without power in Des Moines). The overall death toll from the flooding was 48.

Federal disaster areas included all of Iowa, 62 per cent of Missouri, 58 per cent of Wisconsin and North Dakota, 52 per cent of South Dakota, 46 per cent of Nebraska, 40 per cent of Minnesota, 25 per cent of Illinois and 22 per cent of Kansas. In Alexandria, MO, flood waters reached depths of 2-3m, while Kansas City residents found water 2m deep in places. In Eden Prairie, WI, many people were stranded in floating cars (including police officers), and manhole covers were 'blown' into the air by the water pressure. Near Bismarck, ND, a severe thunderstorm with very large hail stranded three girls in the Missouri River - all three were injured by the hail but survived the ordeal. In Iowa, measurable rainfall fell somewhere in the state for 33 consecutive days from 22 June to 25 July, and the state endured ten consecutive months (until August 1993 inclusive) of above normal rainfall.

Precipitation records

The waters in some areas remained above flood stage for many weeks, and receded rather slowly. Many locations experienced not one, but two record crests during the flooding. Continuation of heavy rainfall in some areas during August further delayed the river levels' fall.

Mississippi River watershed 1993 precipitation was the greatest since 1895 for the following periods: July, June-July, May-July, and April-July. Rainfall totals were phenomenal. For example, Papillion, NE (just south of Omaha), reported 25mm of rain in 6 minutes during a thunderstorm. Several locations in Nebraska and other states reported 300 mm of rain in 48-hour periods. In Adrian, MN, after 178mm of rain in a little over an hour, a lm wall of water rushed through the town causing severe damage. There was even an unofficial report from New London, IA, of 165mm of rain during a 15-minute cloudburst!

The combined totals for June-July are equally impressive. Wisconsin, Iowa, and Illinois had their wettest June-July period on record (since 1895), while Minnesota had its second wettest. Iowa, the Dakotas, and Montana had their wettest July on record, while Iowa also had its wettest August on record. Cedar Rapids, IA, recorded 875mm for the period April to July and Salina, KS, received 945mm for the same period - both exceeding their annual average in just 4 months.

North-west and north-central Missouri generally received between 380 and 635mm of rainfall for July, with some stations receiving 1.5 to 2.5 times the previous record total for July. (This contrasts with some locations in the south-east 'boot heel' of Missouri receiving less than 25mm for July.)

Record monthly totals of greater than 250mm in June or July were recorded at eight National Weather Service (NWS) offices. There were many other notable falls varying from 51mm in 12 minutes in Montgomery County, IA, to 305mm in 3 hours near Baraboo, WI. During July, 770mm of precipitation fell in

Table 1 Record June–July 1993 combined rainfall totals for NWS offices in the Midwest USA

Location	New record (mm)	Old record (mm)	Old record (year)	Normal (mm)	1993 value (% of normal)
Bismarck, ND	467	208	1963	124	376
Concordia, KS	597	478	1967	206	290
Omaha, NE	450	361	1967	183	246
Springfield, IL	427	422	1981	175	243
Sioux Falls, SD	363	343	1948	155	234
Grand Island, NE	396	378	1967	170	233
Aberdeen, SD	345	287	1939	150	231
Huron, SD	351	338	1984	152	230
Waterloo, IA	544	447	1990	236	230
Williston, ND	257	234	1963	112	230
Fargo, ND	305	300	1975	140	218
Green Bay, WI	345	335	1990	165	209
Moline, IL	483	467	1969	234	207
Grand Forks, ND	295	290	1968	142	207
Dubuque, IA	419	404	1969	208	201
Norfolk, NE	391	340	1950	196	200
Chicago, IL	366	284	1970	188	195

Worth County, MO (90 per cent of the mean annual precipitation).

State-wide mean precipitation was the highest on record (since 1895) for June through to August combined in seven states and in the Missouri River basin, upper Mississippi River basin and the Souris-Red-Rainy basin. State-wide average precipitation was also a record for January to August in five states (Idaho, Illinois, Iowa, Minnesota and North Dakota). Record June to July combined totals for NWS offices are shown in Table 1.

Figure 6 illustrates the widespread unusual nature of this event, with large areas experiencing more than double the normal rainfall for June to August. In fact, many locations received between 750 and 1000mm of rainfall during this period. Figure 7 shows calculated return periods using data from the Historical Climate Network (Karl et al. 1990) dataset Precipitation probabilities calculated for the National drought atlas using L-moment techniques (Guttman et al. 1994; Hosking 1990) were the basis for the calculation of these return periods. The June to July combined period was selected for illustration here since it produced the largest anomalies for the event. The return periods shown are based on sample sizes that average about 90 years. Confidence in the long recurrence intervals (greater than about 200 years) is therefore low. However, the values can be used in a qualitative and comparative sense. For example, a location with a calculated recurrence interval of 1000 years experienced a more extreme event than a place with an interval of 100 years.

Severe flooding in the upper Midwest during the summer of 1947 was similar to 1993 in several respects. These similarities include cool spring weather east of the Rockies, wet conditions from the central Plains to the Great Lakes states, and the development of major flooding in the upper Mississippi valley in late June. However, during 1993 (unlike 1947), heavy rainfall in the upper Mississippi area continued through July - a month longer than in 1947. The only other time this century that widespread summer flooding occurred in these same areas was during June-July of 1951.

South-east drought and heatwave

The heatwave and drought in the south-east, although less costly than the flooding, was devastating for many of the area's farmers. During June to July, much of the area received less than 50 per cent of normal rainfall along with temperatures 1.5 to 3.5degC above normal. (See Fig. 6 for a map of summer rainfall as a percentage of normal.) The south-east as a whole recorded the second driest July on record

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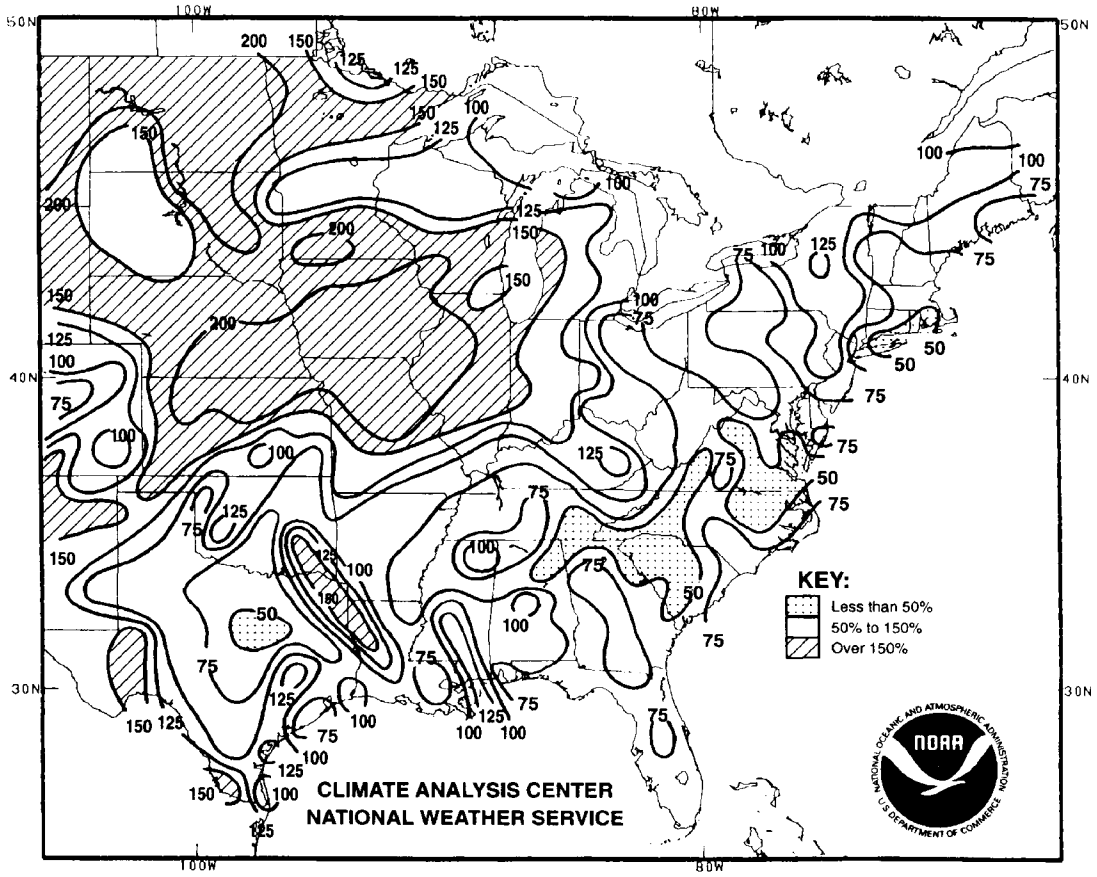

Fig. 6 Summer rainfall (for the period June–August 1993) expressed as a percentage of the climatological average (prepared by the US Climate Analysis Center)

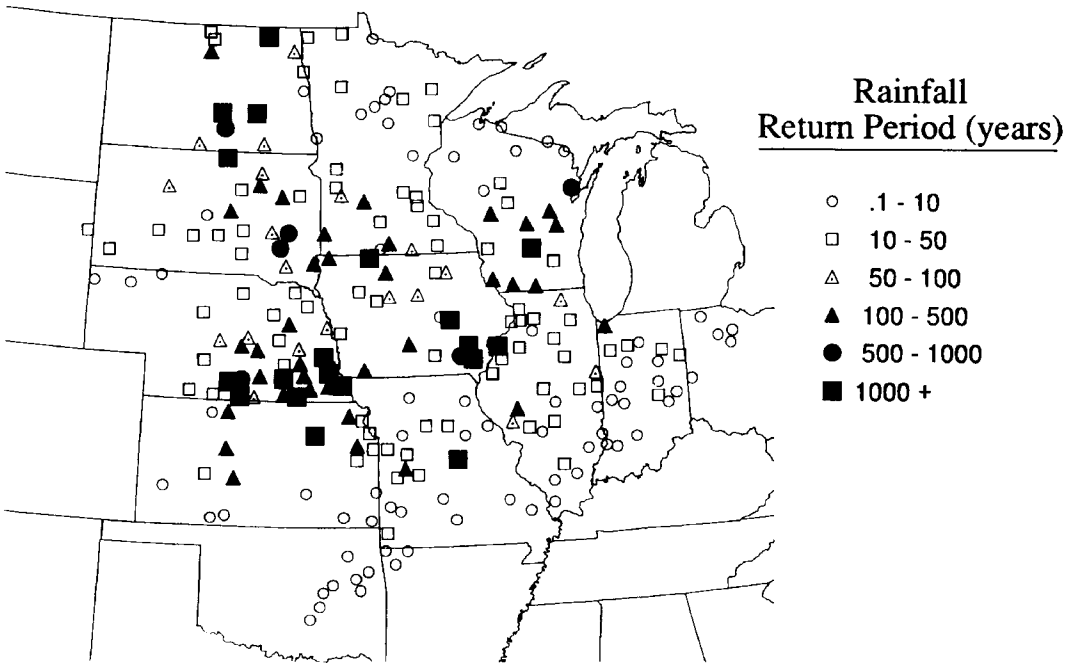

Fig. 7 Rainfall return period (years) for rainfall amounts that fell during June–July 1993, for the upper Midwest area

(since 1895, the driest was 1983). Also, the states of Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia had their hottest July on record (also since 1895). South Carolina was one of the hardest-hit states, having its driest June and sixth driest July on record, resulting in the following losses:

(i) Over 95 percent of corn crop.
(ii) Over 70 percent of soybean crop
(iii) Over 50 percent of wheat crop.
(iv) Over 25 percent of tobacco crop.
(v) Peach crop production reduced significantly in volume and market value.
(vi) 1.8million chickens killed by the heat.

Much of South Carolina, North Carolina, Georgia, and Tennessee were placed in the severe to extreme drought category according to the Palmer Drought Severity Index (PDSI). (The PDSI uses mathematical formulae to quantify each region's wet or dry spell.) However, due to unusually wet conditions during the autumn of 1992 through to the early spring of 1993, hydrological impacts were generally not severe.

The death toll from a heatwave is very hard to calculate due to the occasional inability to determine if a death was truly caused by the heat. Deaths that are attributed to 'heat stress' are often included in evaluations. Preliminary reports indicate that the death toll exceeded 100 for the south-east and north-east regions combined.

The monetary values of crop losses were estimated at $264 million for South Carolina, $165 million for North Carolina, and $500 million for Georgia. The overall losses for the south-east probably exceeded $1000 million. Federal disaster areas were declared for all of South Carolina, in 89 (of 100) counties in North Carolina and in 154 (of 159) counties in Georgia, thereby allowing emergency funding and assistance to be provided.

Temperature and rainfall records

Several locations in the south-east reported 32°C or higher every day in July, including Greenville-Spartanburg, SC, Chattanooga, TN, and Atlanta, GA. In Columbia, SC, there were 17 days in July with maxima of 38°C or higher, while in Augusta, GA, 47 days in a 61-day period experienced temperatures of 35°C or more.

It was the hottest summer (June-August) on record at Chattanooga, TN (average temperature 27.8°C, with 29.6°C being the mean temperature for July), Newark, NJ (average temperature 26.2°C), and across Florida where the state-wide mean temperature was 27.9°C. In addition, it was the second hottest summer on record (since 1895) in the states of New Jersey, North Carolina and South Carolina, and in the south-east region as a whole. July was the hottest on record at places as far apart as Chattanooga, TN (3.7degC above average), Philadelphia, PA (+3.6degC), and Tallahassee, FL (+l.ldegC). Table 2 provides a list of NWS stations with temperature anomaIies of at least 3 degC above normal, and which experienced their hottest July on record.

Table 2 Locations where the temperature anomaly reached +3 degC for July 1993, and where it was also the hottest July on record

Location	Temperature anomaly (degC)
Chattanooga, TN	+3.7
Atlanta, GA	+3.7
Philadelphia, PA	+3.6
Knoxville, TN	+3.5
Charlotte, NC	+3.4
Athens, GA	+3.3
Augusta, GA	+3.1
Norfolk, VA	+3.0
Columbia, SC	+3.0

In Texas, San Antonio, Austin, and Corpus Christi all recorded no measurable precipitation for at least 60 consecutive days. It was the driest June on record at Charlotte, NC (3.8mm), Greenville-Spartanburg, SC (4.3mm), and at Raleigh-Durham, NC (8.4mm). July was the driest on record at Charleston, WV (50mm) Beckley, WV (42mm), Greenville-Spartanburg, SC (19mm), and Norfolk, VA (9.1mm); while in Texas, San Antonio, Dallas, Austin and Waco all recorded no precipitation. The summer June to August) was the driest on record (since 1895), in South Carolina (203mm mean), and

in the south-east region as a whole (263mm mean). It was the second driest summer on record in Florida, New Hampshire, North Carolina and Virginia.

Acknowledgments and sources of further information

The data and information contained in this report were provided by the Climate Analysis Center, the National Climatic Data Center, the National Weather Service, the Midwestern Climate Center, and various media reports.

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