What constitutes drought alleviation?

Palmer Drought Severity Index (Palmer 1965)

$PDSI \leq -4.0$	extreme
$-4.0 < PDSI \leq -3.0$	severe
$-3.0 < PDSI \leq -2.0$	moderate
$-2.0 < PDSI \leq -1.0$	mild
$-1.0 < PDSI \leq -0.5$	incipient
$PDSI \geq -0.5$	normal or wet conditions

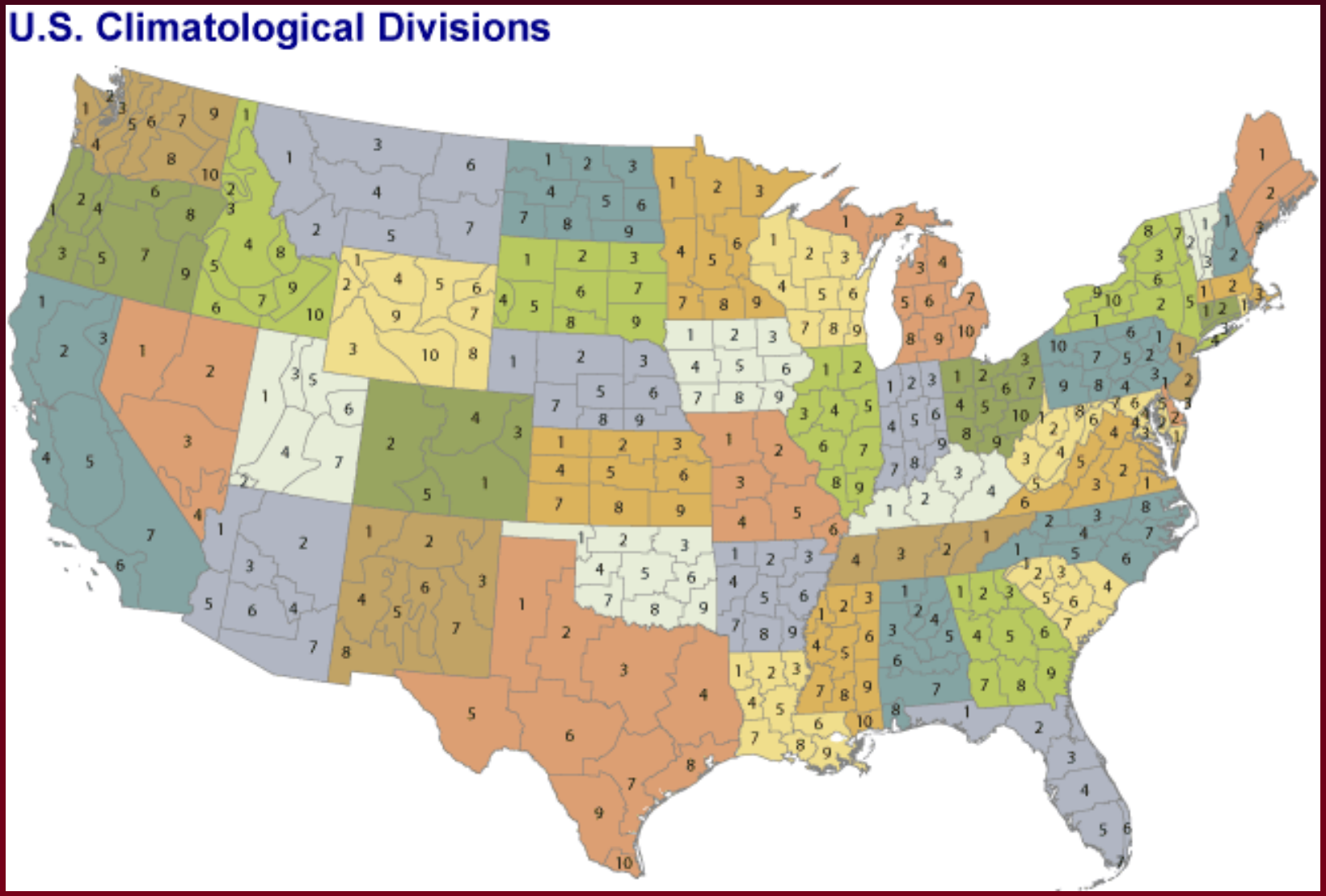
PDSI is calculated monthly at each state climate division

An alleviated drought event (ADE) is defined here as:

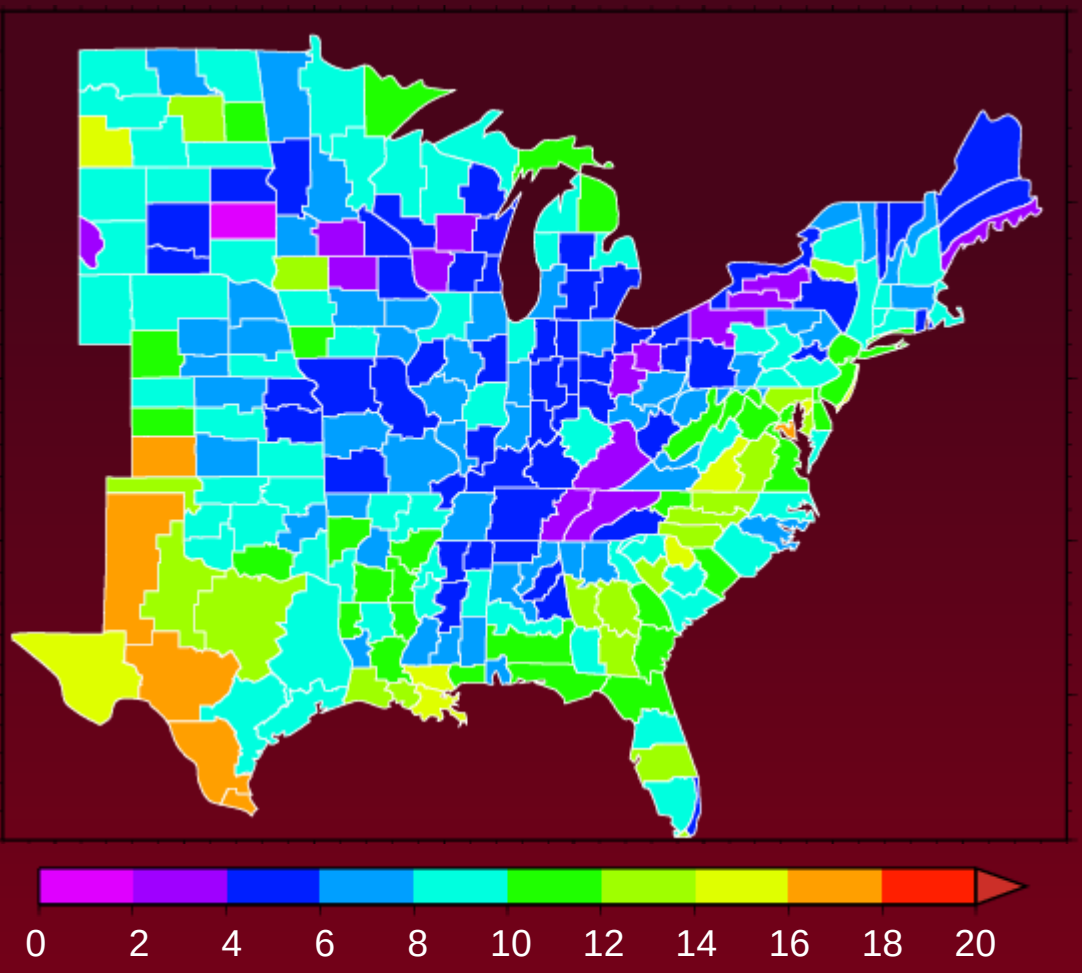
initial PDSI < -2.0 (moderate drought or worse)
increasing by +1.0 or more (one or more categories)
over the course of one month

Climatological Divisions for Contiguous U.S.

source: National Climatic Data Center



Summer / Autumn (June-November) ADEs for the eastern part of the U.S. 1960 - 2010



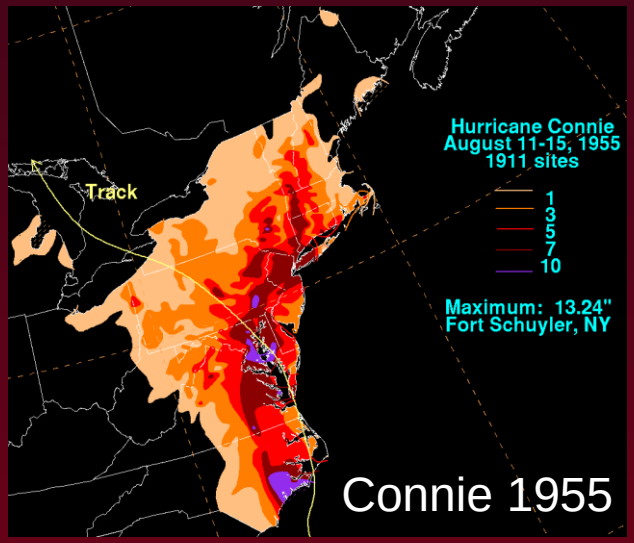
The ADE count represents number of occasions within a climate division in which the PDSI has increased by 1 or more units over one month from an original value of -2 or less.

Drought events vs Tropical Cyclones

Sugg (1968) analyzed the impact of precipitation from 9 tropical cyclones to drought events.

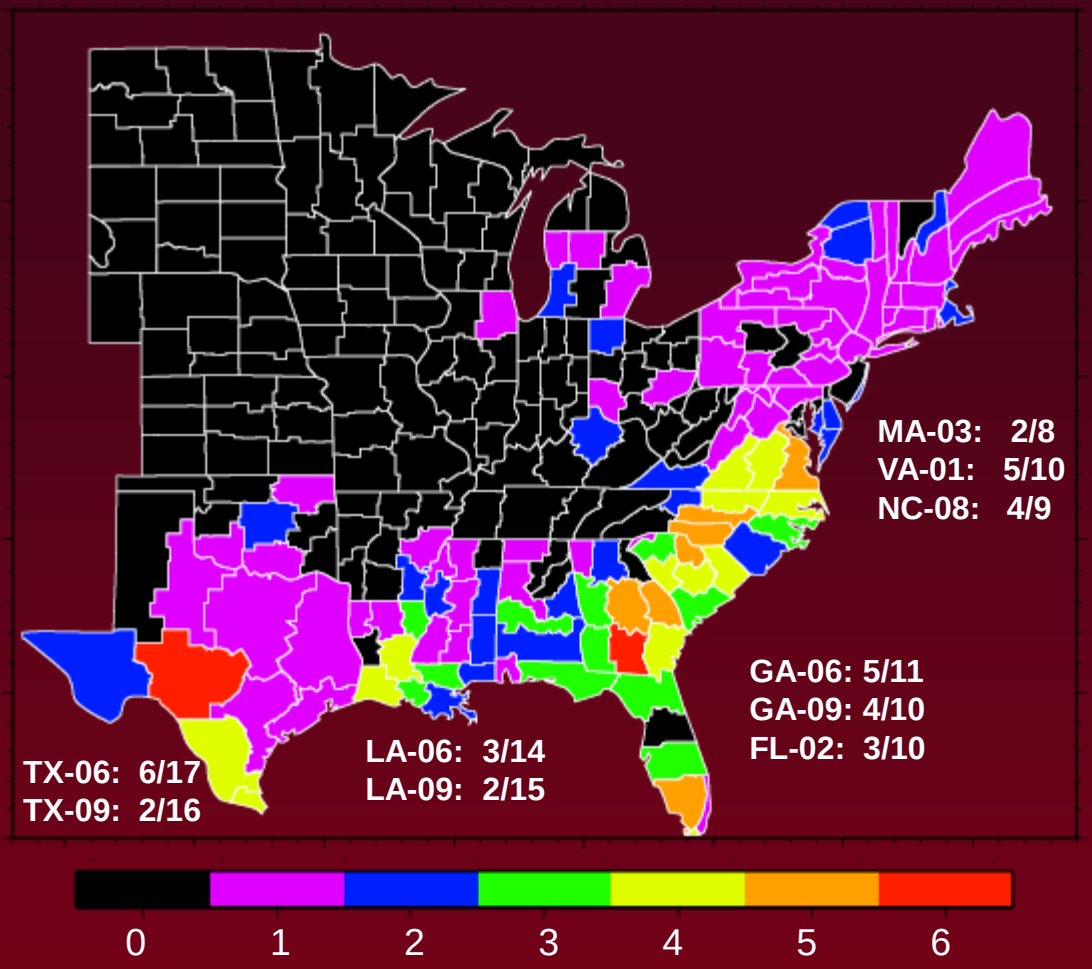
Most analyzed cyclones singly contributed to drought alleviation in one or more climate divisions, such that the PDSI became positive during the month.

Information on quantified cyclone contribution to monthly rainfall, and to the monthly PDSI value, was not presented.



tropical cyclone rainfall data compiled by NOAA/NCEP/HPC

ADEs with tropical cyclone within 150 km
1960 - 2010



tropical cyclone center distance determined from HURDAT

CD-00: # / #

# of TC-affected ADEs / # of total ADEs

This ADE count represents the number of occasions in which the center of a TC was located within 150 km (assumed small) of the climate division during an ADE. The presence of a TC is simply associated with drought alleviating monthly rainfall, and represents a first step toward attributing TC impacts to ADEs.

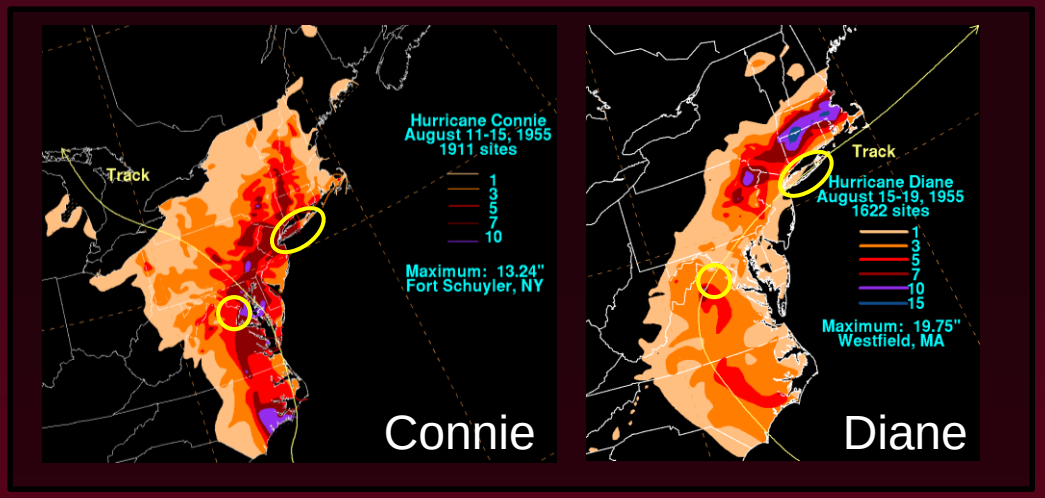
Examples of significant drought alleviation by tropical cyclones

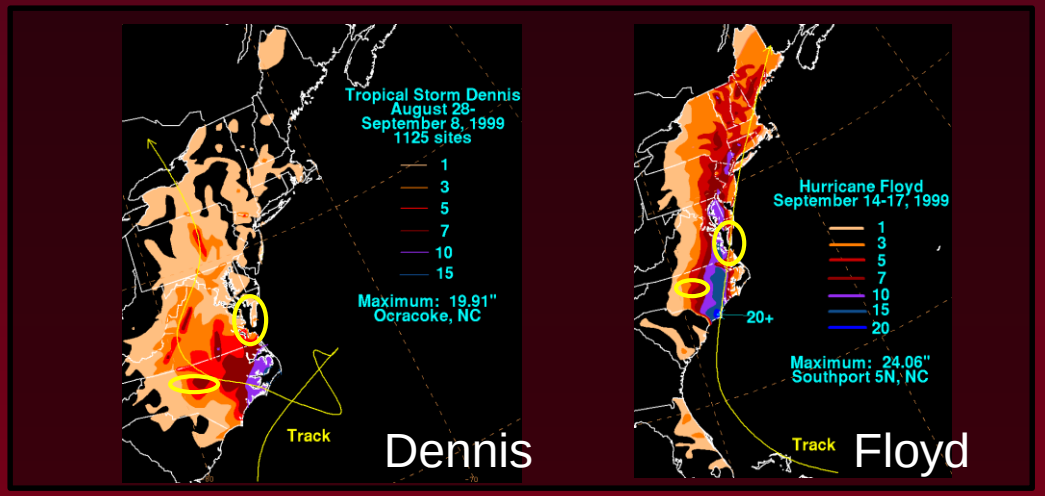
Connie was followed one week later by Diane during August 1955.

PDSI	VA-04	NY-04
July	-2.53	-3.27
August	2.69	2.06
change	**+5.22**	**+5.33**

Dennis was followed within two weeks by Floyd during September 1999.

PDSI	VA-01	NC-04
August	-2.34	-3.77
September	3.95	2.24
change	**+6.29**	**+6.01**





tropical cyclone rainfall data compiled by NOAA/NCEP/HPC

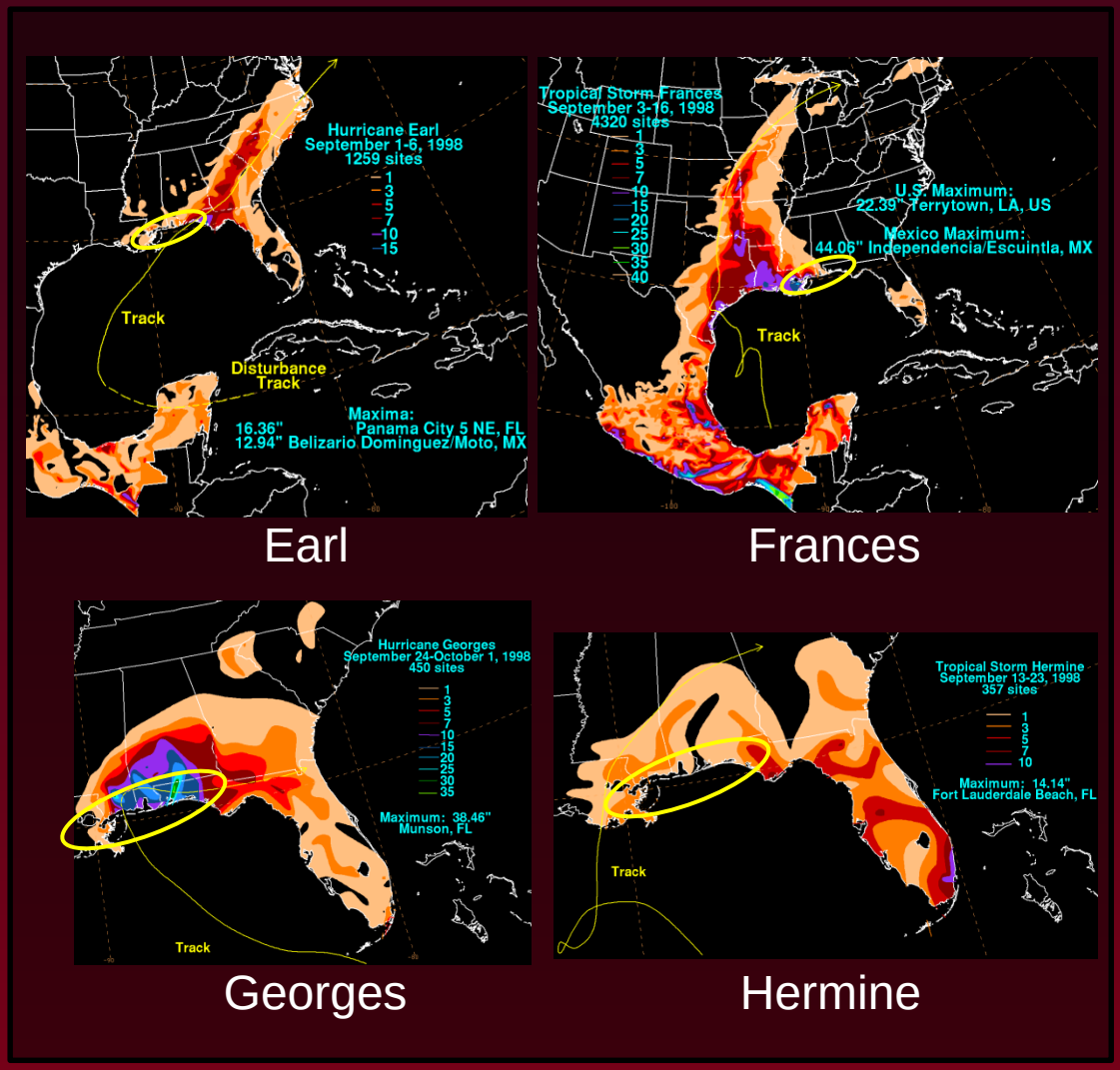
Examples of signficant drought alleviation by tropical cyclones

September 1998

Four tropical cyclones contributed to the alleviation of a wide ranging drought along the Gulf Coast.

PDSI	LA-09	MS-10
August	-2.42	-2.17
September	2.51	2.81
change	**+4.93**	**+4.98**

PDSI	FL-01	AL-08
August	-3.38	-2.14
September	2.94	2.61
change	**+6.32**	**+4.75**

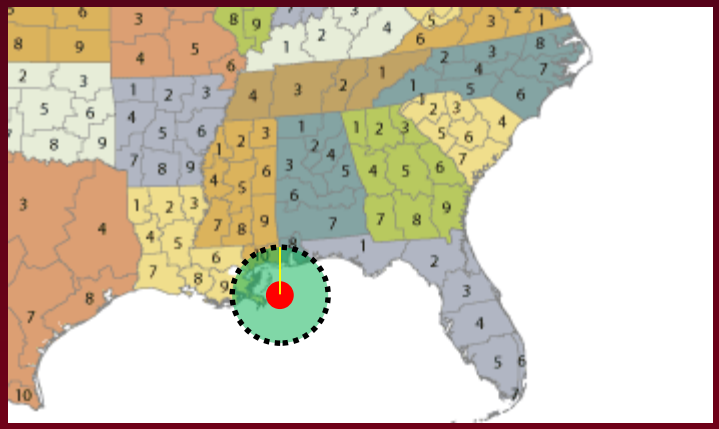


tropical cyclone rainfall data compiled by NOAA/NCEP/HPC

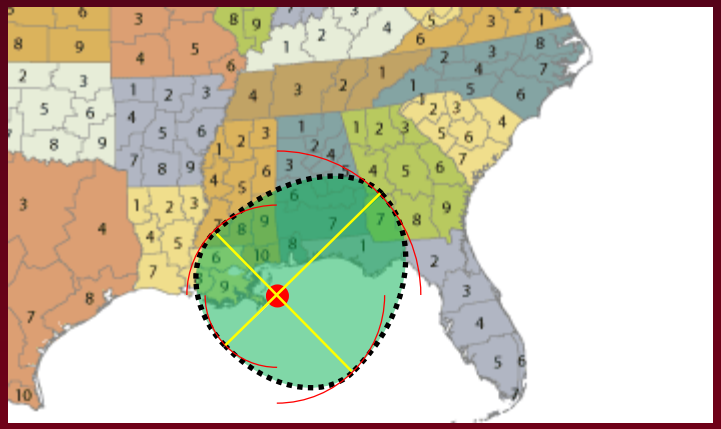
Attributing Tropical Cyclone impact to ADEs

- Establish a radius of influence specific to each tropical cyclone
- From the Extended Best Track dataset, the 34-kt wind field radius (R34) is used
  - specific to the size and shape of the tropical cyclone circulation
  - assumes field of precipitation is mostly enclosed in the 34-kt circulation area

R = 150 km

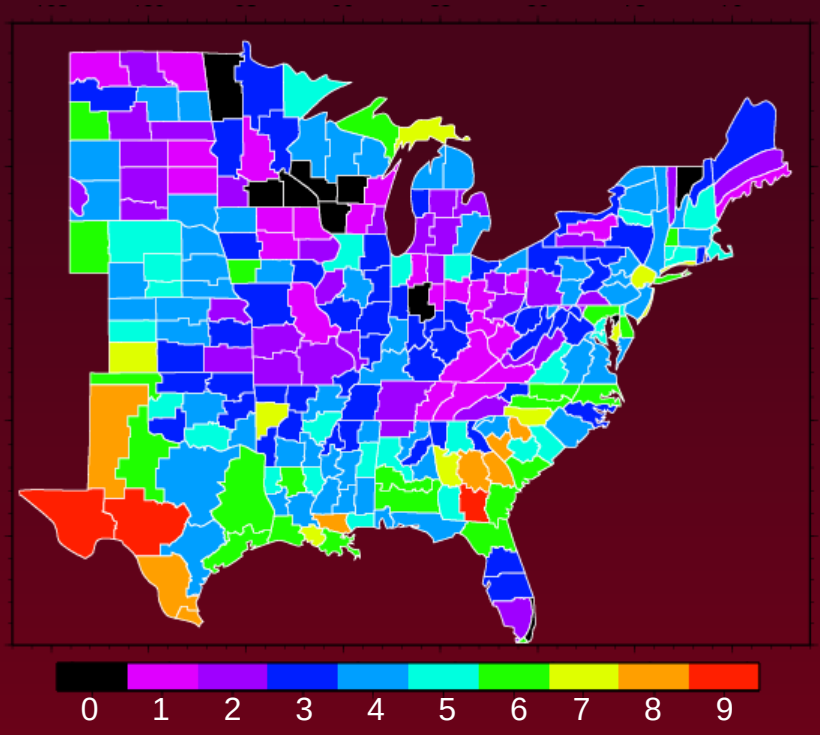


R = R34



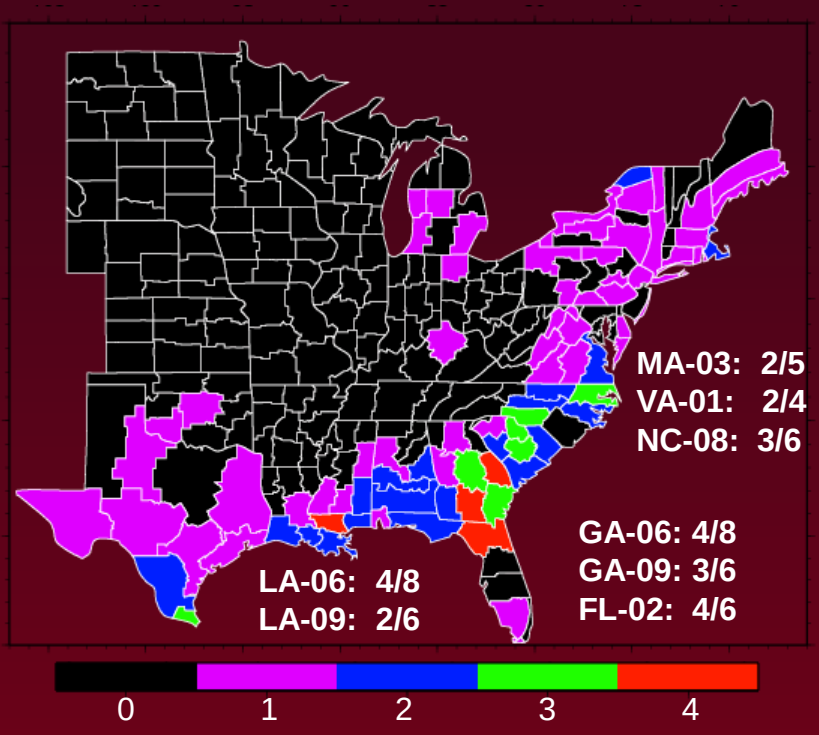
The initially fixed radius of influence of 150 km is expanded to the R34 of individual TCs. Once again, the presence of the TC is simply associated with drought alleviating monthly rainfall, but more precisely represents the influence of a TC on a given climate division.

Summer / Autumn ADEs 1988 - 2010



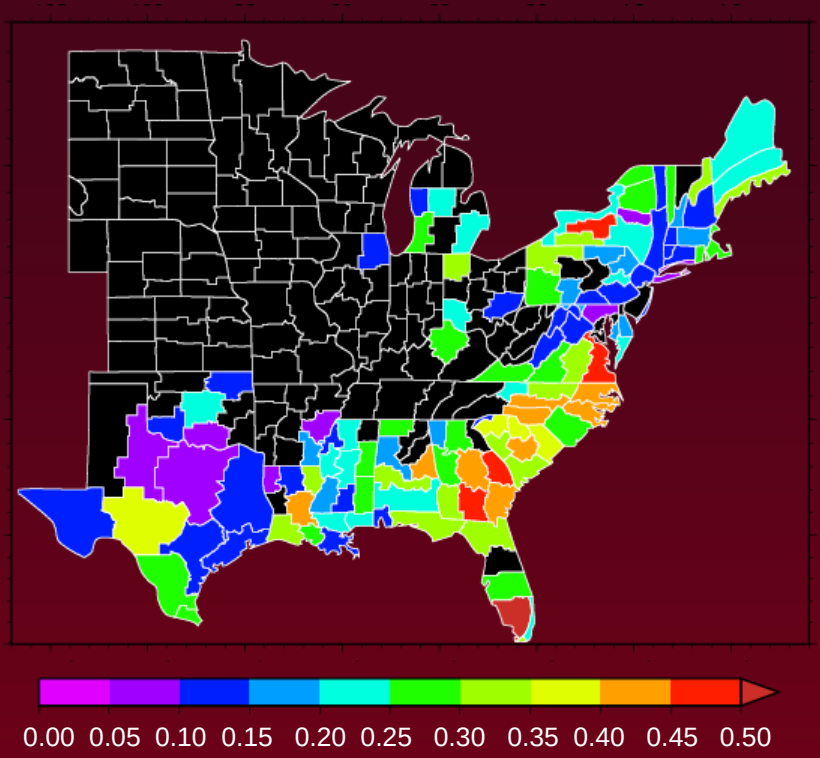
The ADE count for 1960 – 2010 is reduced to the EXBT subset of 1988 – 2010.

TC-affected ADEs within R34 range 1988 - 2010



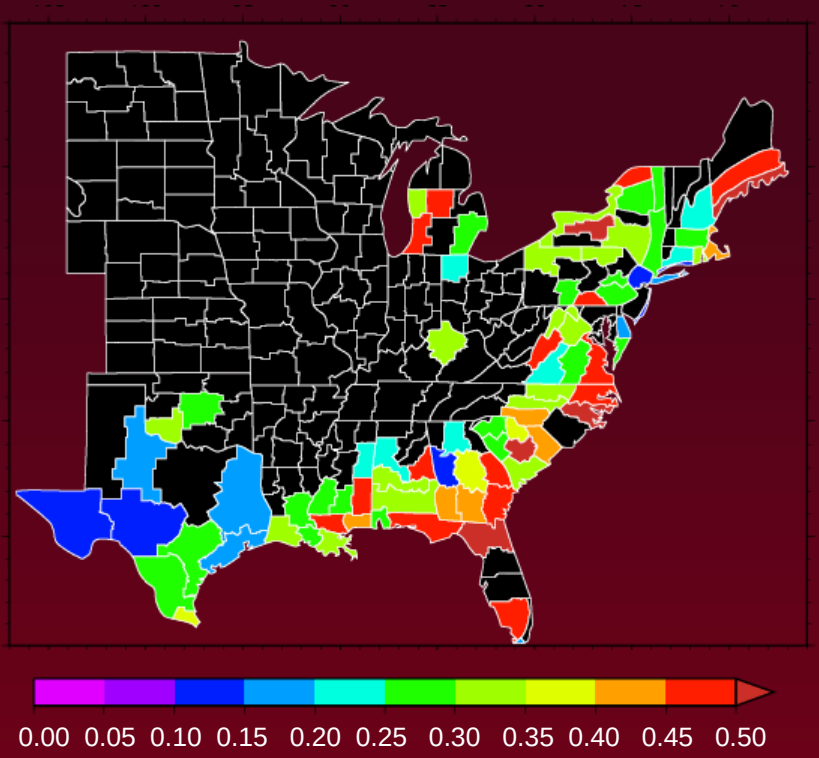
The number of ADEs contained within the R34 circulation area of TCs.

TC-affected ADE frequency (150 km range) 1960 - 2010



The frequency of ADEs contained within the {R = 150 km} circulation area of TC.

TC-affected ADE frequency (R34 range) 1988 - 2010



The frequency of ADEs contained within the R34 circulation area of TCs.

Differences in frequency stem from both the radius setting and the exclusion of 1960-1987 TCs and ADEs.

Attributing Tropical Cyclone rainfall to ADEs

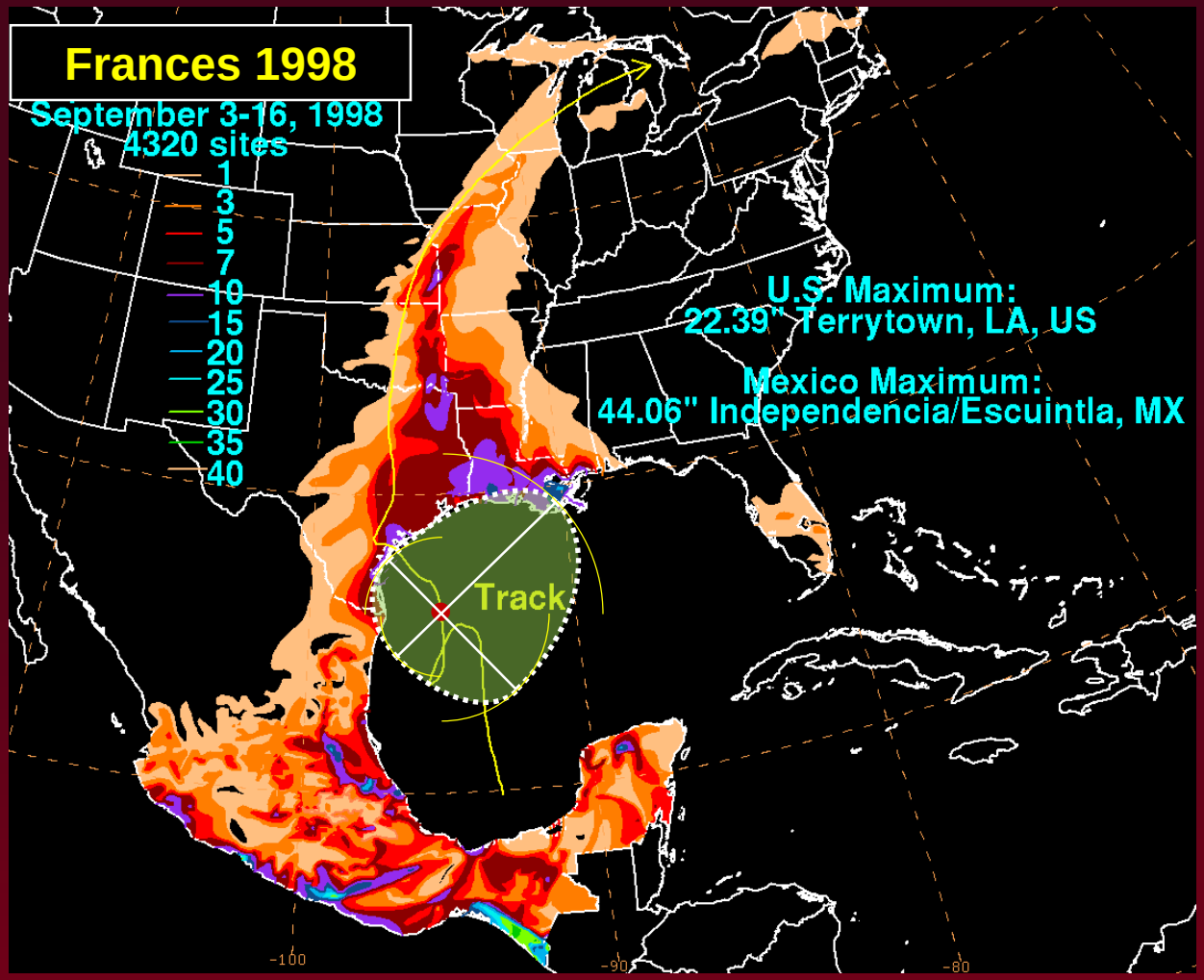
- Within R34 range, more rainfall output is attributable to the cyclone
- How much of the TC rainfall actually contributes to drought alleviation in a month?
  - compared against total monthly rainfall to determine TC rainfall "efficiency" in alleviating drought conditions:

$$\text{efficiency} = \frac{\text{TC rainfall during ADE}}{\text{monthly rainfall during ADE}}$$

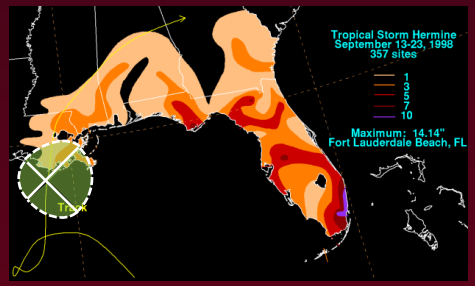
  - comparable against monthly change of PDSI, which in part reflects total rainfall in a climate division throughout the month

Rainfall data are tabulated for the time period in which the R34 area of one or more TC envelopes a climate division. The TC rainfall is compared against (divided by) the monthly rainfall of the ADE to obtain TC rainfall efficiency in alleviating a drought event during a month.

** R34 envelope vs HPC-tabulated TC rainfall **



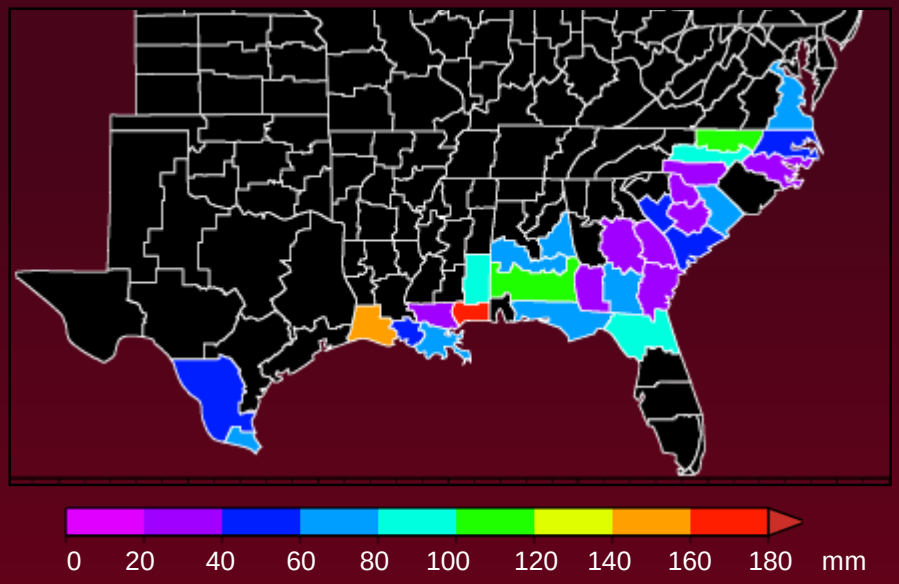
Hermine 1998



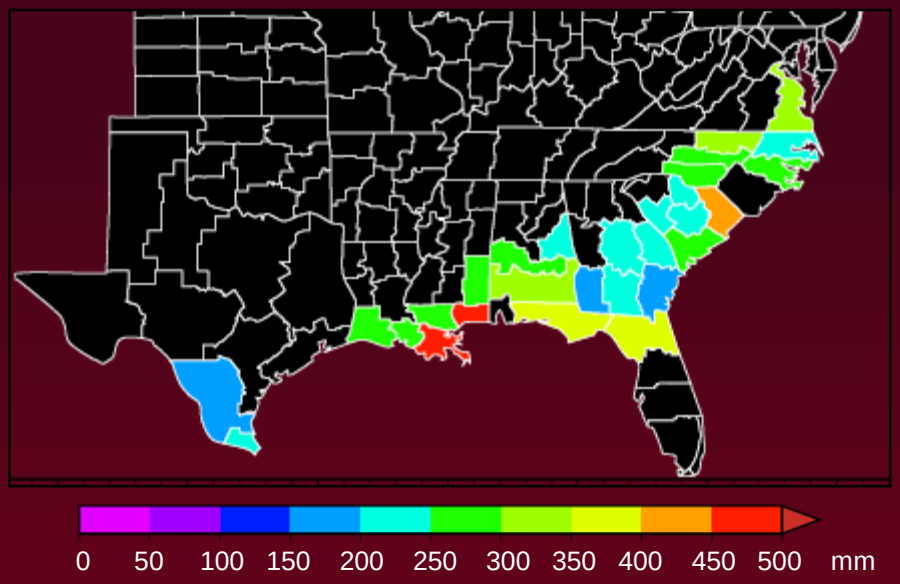
R34 areas drawn to scale for one time for each TC

NOAA/NCEP/HPC TC rainfall products incorporate all rainfall observations over a large area in proximity to a TC. However, the outlying rainfall may be a result of other phenomena (e.g. sea breeze, monsoon). Application of the R34 envelope more precisely associates rainfall observations to a TC, and allows for more manageable attribution of TC precipitation to an ADE.

rainfall attributed to TCs within R34 range
(averaged for all TC-affected ADEs)
1988 - 2010



monthly rainfall in ADEs
(averaged for all TC-affected ADEs)
1988 - 2010



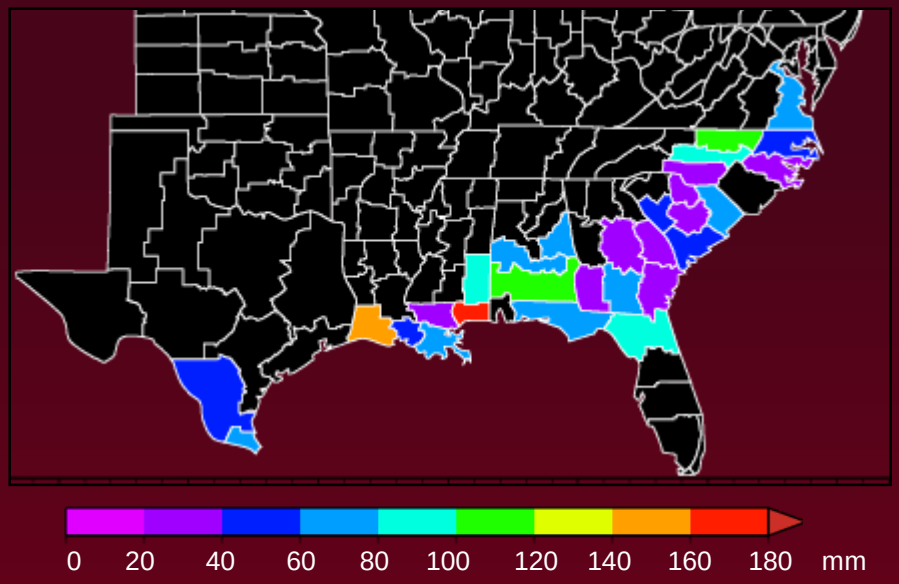
results shown where a TC-affected ADE occurs 2, 3, or 4 times in a climate division

Rainfall tabulated while the R34 circulation area of one or more TCs enveloped a climate division experiencing an ADE.

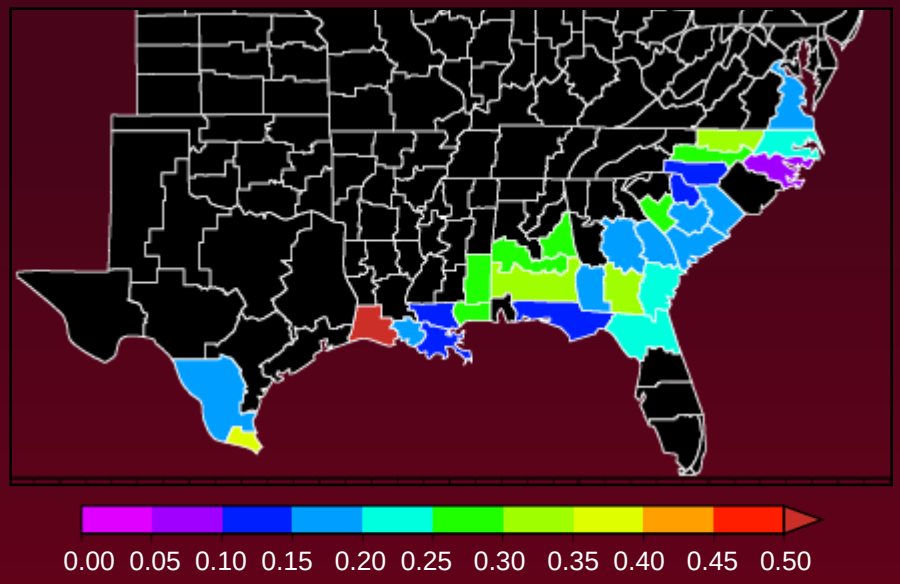
Monthly rainfall observed during all TC-affected ADEs.

Following climate record convention, TC rainfall and monthly rainfall data are averaged throughout the climate division for each TC-affected ADE. At least 3 reporting stations are used in the climate division average. Climate division rainfall data are then averaged for all TC-affected ADEs during 1988-2010, with the results are depicted above.

rainfall attributed to TCs within R34 range
(averaged for all TC-affected ADEs)
1988 - 2010



TC rainfall efficiency in ADEs within R34 range
(averaged for all TC-affected ADEs)
1988 - 2010



results shown where a TC-affected ADE occurs 2, 3, or 4 times in a climate division

Rainfall tabulated while the R34 circulation area of one or more TCs enveloped a climate division experiencing an ADE.

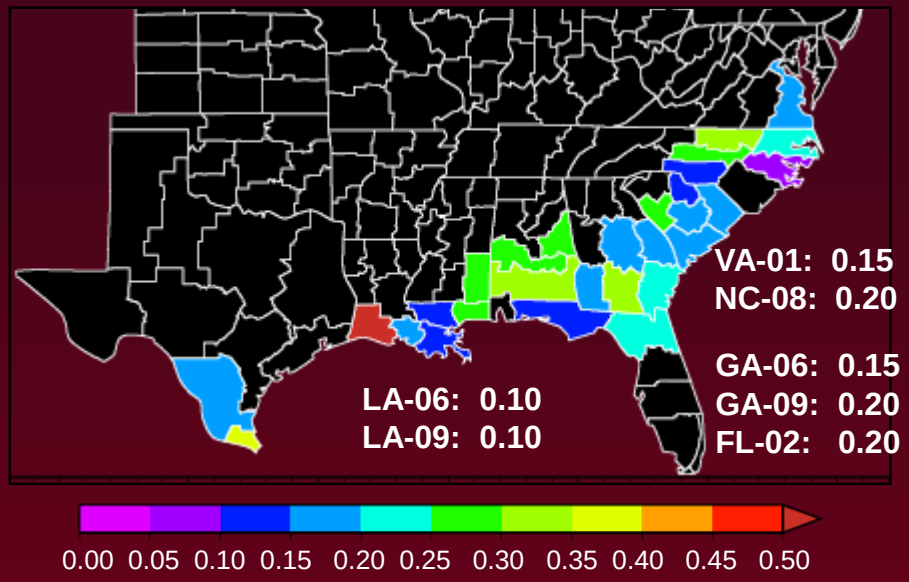
$$\text{efficiency} = \frac{\text{TC rainfall during ADE}}{\text{monthly rainfall during ADE}}$$

The TC rainfall efficiency values are first calculated from the TC rainfall and monthly rainfall data corresponding to each TC-affected ADE before they are averaged for all TC-affected ADEs of 1988-2010. The values of the TC rainfall efficiency depicted above do not necessarily reflect a direct correspondence between the two figures in the previous slide.

TC rainfall efficiency in ADEs within R34 range

(averaged for all TC-affected ADEs)

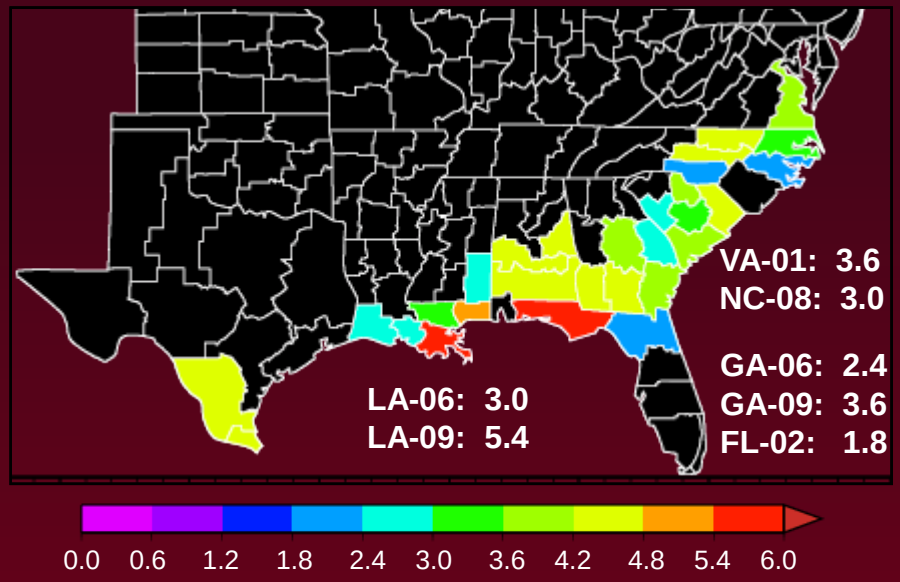
1988 - 2010



monthly change of PDSI during TC-affected ADEs

(averaged for all TC-affected ADEs)

1988 - 2010



results shown where a TC-affected ADE occurs 2, 3, or 4 times in a climate division

$$\text{efficiency} = \frac{\text{TC rainfall during ADE}}{\text{monthly rainfall during ADE}}$$

Monthly PDSI change (> 1.0) for all TC-affected ADEs

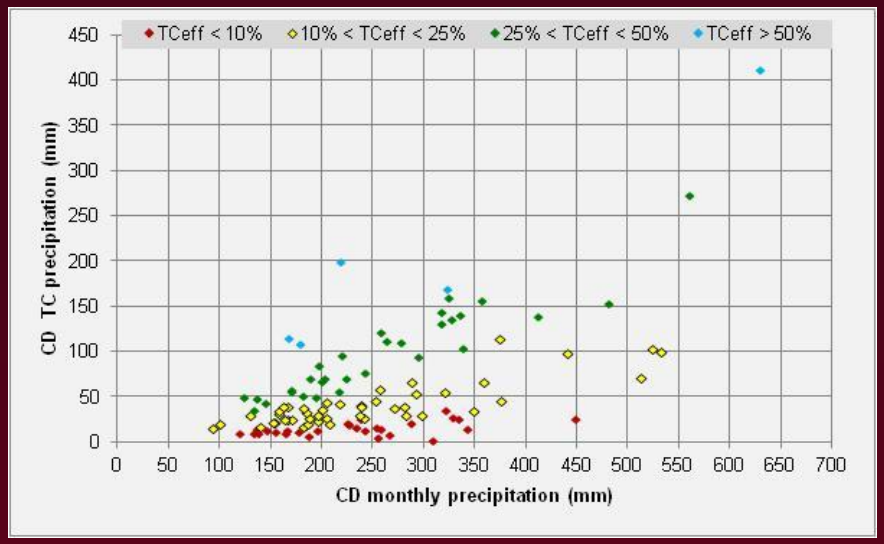
The TC rainfall efficiency values from each TC-affected ADE are averaged over the period of 1988-2010. The values of the TC rainfall efficiency depicted above do not necessarily correspond to the figures in the previous slide.

All ADEs within R34 range of one or more TCs 1988-2010

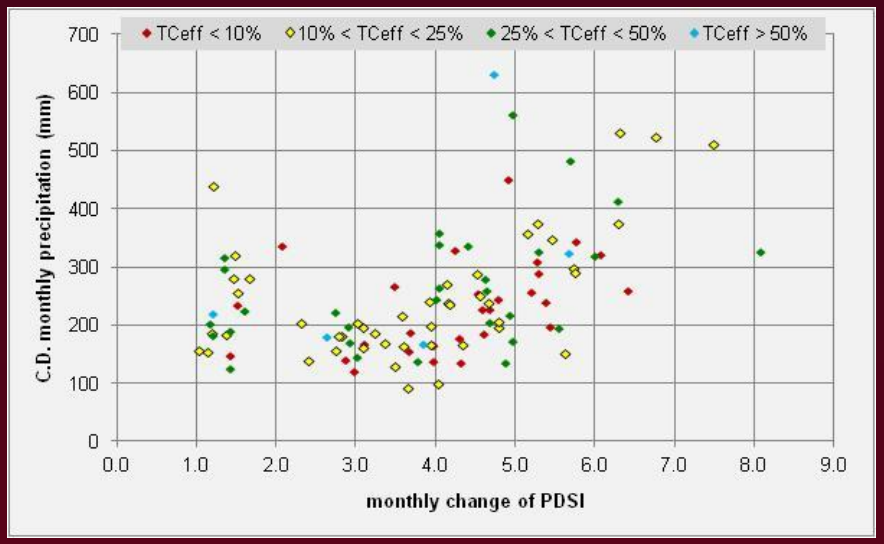
Y	M	CD	TCprcp	Mprcp	TC-eff	dPDSI
1988	8	GA06	17	182	0.104	2.83
1988	8	NC04	37	183	0.217	2.78
1988	9	MI05	14	137	0.099	3.98
1988	9	MI08	10	156	0.073	3.68
1988	9	OK05	40	162	0.223	3.10
1990	10	GA05	19	208	0.113	4.79
1990	10	GA06	46	376	0.139	6.29
1990	10	GA08	34	134	0.312	4.89
1990	10	GA09	49	196	0.257	5.55
1990	10	SC03	34	349	0.115	5.46
1990	10	SC05	37	272	0.128	4.15
1990	10	SC06	14	343	0.040	5.78
1990	10	SC07	1	310	0.005	5.28
1991	8	MA03	16	140	0.112	2.40
1995	10	AL05	120	259	0.462	4.65
1995	10	AL06	111	264	0.404	4.06
1995	10	NY09	25	164	0.153	3.60
1995	10	NY10	8	165	0.051	3.98
1995	10	PA10	30	130	0.232	3.49
1996	10	GA08	108	180	0.620	2.65
1996	10	GA09	55	170	0.366	2.94
1998	8	TX06	134	327	0.355	5.31
1998	8	TX07	39	167	0.204	3.94
1998	8	TX08	42	145	0.296	3.02
1998	8	TX09	24	166	0.117	4.34
1998	9	AL07	153	482	0.297	5.70
1998	9	AL08	411	630	0.642	4.75
1998	9	FL02	98	440	0.225	1.21
1998	9	GA05	57	257	0.219	1.52
1998	9	GA06	31	158	0.201	1.03
1998	9	GA08	109	278	0.339	4.63
1998	9	LA05	46	253	0.166	4.56
1998	9	LA06	29	283	0.130	1.67
1998	9	LA07	102	339	0.304	4.05
1998	9	LA08	94	295	0.333	1.35
1998	9	LA09	24	450	0.049	4.93
1998	9	MS09	130	317	0.371	1.36
1998	9	MS10	272	561	0.402	4.98
1998	9	TX04	69	204	0.324	4.68
1998	9	TX10	30	238	0.173	4.18
1998	10	FL01	99	532	0.160	6.32
1998	11	FL05	114	168	0.608	3.86
1999	9	CT02	65	288	0.232	4.52
1999	9	CT03	13	243	0.039	4.80
1999	9	ME02	16	254	0.063	4.54
1999	9	ME03	20	227	0.085	4.59
1999	9	MD01	55	217	0.259	4.94
1999	9	MA02	76	243	0.317	4.02
1999	9	MA03	20	187	0.105	3.24
1999	9	NH02	38	239	0.169	4.16
1999	9	NJ01	168	324	0.502	5.68
1999	9	NY03	10	178	0.054	4.31
1999	9	NY04	23	196	0.110	4.80
1999	9	NY08	12	167	0.082	3.12
1999	9	NC03	114	375	0.249	5.29
1999	9	NC04	143	318	0.361	6.01
1999	9	NC05	56	320	0.171	1.48
1999	9	PA03	53	293	0.174	5.76
1999	9	PA04	16	185	0.086	4.62
1999	9	PA06	36	201	0.158	3.94
1999	9	RI01	5	188	0.035	3.70
1999	9	SC04	140	336	0.358	4.42
1999	9	SC07	96	221	0.365	2.75
1999	9	VA01	138	412	0.336	6.29
1999	9	VA02	34	322	0.088	6.08
1999	9	VA03	30	298	0.104	5.74
1999	9	VA04	14	258	0.056	6.43
1999	9	VA05	12	197	0.065	5.44
1999	9	WV06	11	147	0.076	1.44
2000	9	FL01	25	238	0.091	5.39
2000	9	FL02	40	281	0.155	1.47
2000	9	GA05	21	153	0.136	5.62
2000	9	GA06	33	185	0.169	1.37
2000	9	GA08	4	256	0.014	5.22
2000	9	NC05	26	188	0.142	1.19
2000	9	SC05	70	190	0.387	1.43
2000	9	SC06	51	182	0.288	1.21
2001	6	LA06	71	513	0.134	7.50
2001	6	LA09	103	524	0.202	6.77
2001	6	MS10	65	358	0.186	5.16
2001	6	NC08	69	224	0.263	1.61
2002	9	AL07	84	197	0.351	2.92
2002	9	GA04	8	134	0.071	4.32
2002	9	NC07	27	205	0.108	2.32
2002	9	PA08	15	93	0.161	3.65
2002	10	GA09	9	121	0.081	2.99
2002	10	NC08	47	137	0.345	3.78
2004	10	LA08	7	267	0.028	3.50
2005	7	MI10	21	155	0.135	1.14
2005	7	OH01	9	139	0.059	2.88
2005	7	TX10	49	125	0.419	1.44
2005	9	LA07	198	219	0.749	1.22
2006	6	SC03	26	241	0.118	3.93
2006	6	SC06	43	205	0.191	3.03
2008	7	TX05	20	101	0.219	4.04
2008	7	TX09	56	171	0.269	4.98
2008	7	TX10	159	325	0.483	8.08
2008	8	AL03	25	171	0.146	3.37
2008	8	AL06	41	239	0.167	4.67
2008	8	FL02	155	357	0.432	4.05
2008	8	FL07	66	201	0.330	1.17
2008	8	MS06	18	228	0.075	4.69
2008	8	MS07	20	289	0.070	5.31
2008	8	MS08	29	196	0.146	3.09
2008	8	MS09	43	217	0.196	3.58
2008	9	NJ03	34	159	0.218	2.76
2010	9	NC07	25	335	0.085	2.08
2010	9	NC08	26	329	0.083	4.25
2010	9	VA01	15	234	0.056	1.53

Due to a relatively low sample size per climate division, a table depicting TC rainfall efficiency values for each TC-affected ADE is provided. Efficiency values are calculated for each station for each ADE before they are averaged within each climate division. Shading indicates alternating ADEs.

TC rainfall vs monthly rainfall for all ADEs 1988 - 2010



monthly rainfall vs dPDSI for all ADEs 1988 - 2010



results shown for all climate divisions within R34 range during a TC-affected ADE

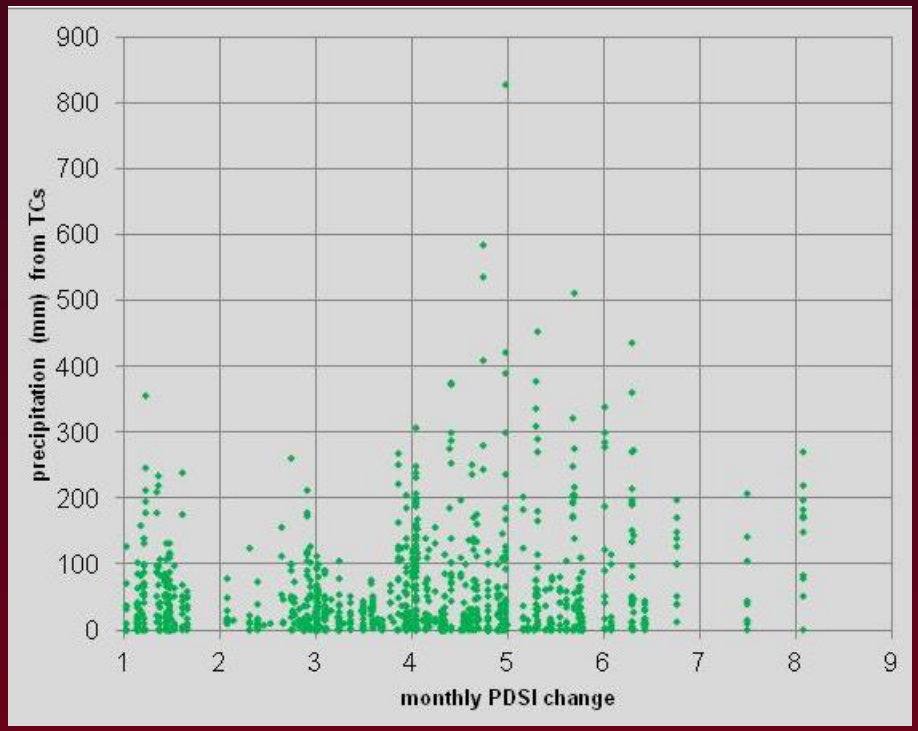
Cumulative frequency of TC efficiency values for all TC-affected ADEs 1988-2010

TCeff	> 0.10	> 0.15	> 0.20	> 0.25	> 0.30	> 0.35	> 0.40	> 0.45	> 0.50
ADEs	81	62	47	35	28	19	11	7	5
Freq.	0.743	0.569	0.431	0.321	0.257	0.174	0.101	0.064	0.046

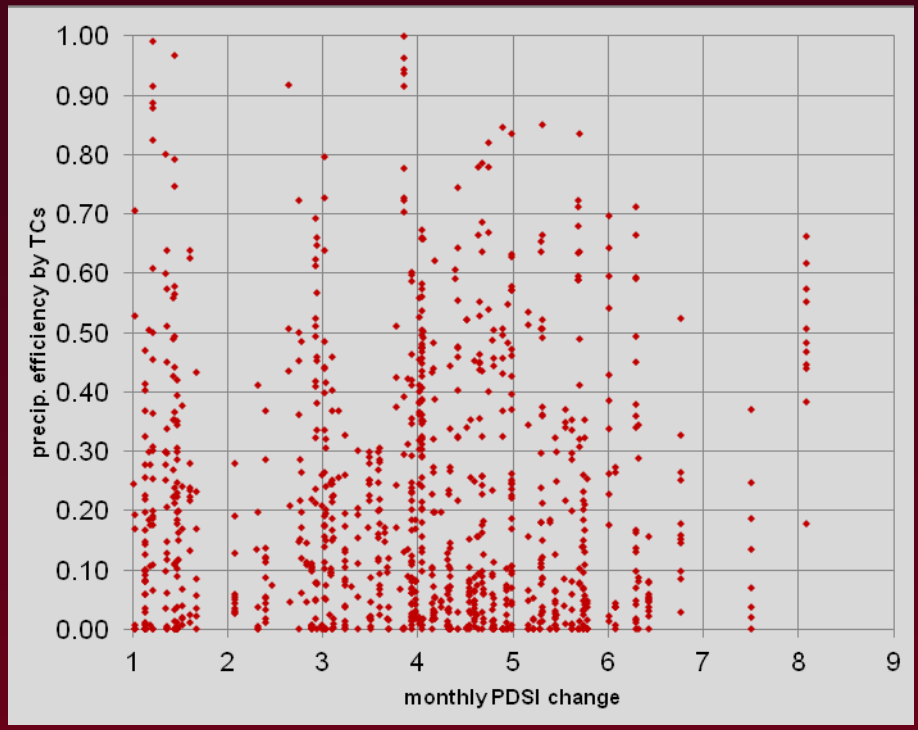
Rainfall values are averaged throughout a climate division with 3 or more reporting stations during each TC-affected ADE. A value of monthly PDSI change is representative of the climate division.

Approximately one-third of TC “efficiency” values calculated for 1988-2010 are 25% or higher. (Threshold for TC drought alleviation?)

rainfall attributed to TCs within R34 range 1988 - 2010



TC rainfall efficiency in ADEs within R34 range 1988 - 2010



results shown for all individual stations within R34 range during a TC-affected ADE

TC rainfall values depicted above (left figure) are provided from each station within each TC-affected ADE.

The TC rainfall efficiency values may be affected by disparities in the reporting of rainfall from some stations, resulting in a wide range of efficiency values amongst the reporting stations (right figure). Averaging a sufficiently high number of stations within a climate division helps to resolve the reporting disparity.

Preliminary conclusions

- ***Alleviated drought events (ADEs) are concentrated in the southeastern U.S., from VA to FL to TX
- Tropical cyclones pass within their 34-kt radius of climate divisions in the southeastern U.S. during about 30-50% of ADEs
  - Radius of influence for cyclones < 1988 would increase sample size
- The most TC-affected ADEs have occurred in Georgia, where precipitation from Atlantic- and Gulf-based cyclones can occur
- One-third of TC alleviation efficiency (TCeff) values > 25%
- Southern Florida has experienced 2-3 total ADEs since 1988

***According to NCDC, a 5-km-spaced grid is gradually being phased into climatological record keeping in place of variably-shaped climate divisions; this would allow more precise assessment of potential drought conditions for clustered stations.

Future Work Planned

- Examine other indices depicting drought events and their alleviation
  - including the Standardized Precipitation Index (SPI) and others
- Determine drought alleviation by tropical cyclones using the TRMM Cloud and Precipitation Feature (TCPF) product
  - Would help to attribute (drought alleviating) rainfall to a tropical cyclone
  - Would provide rainfall data where ground-truth observations are scarce
- Projecting the potential for drought alleviation by way of seasonal tropical cyclone forecasts

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