Reconstruction of droughts in India using multiple land surface models (1951-2015)

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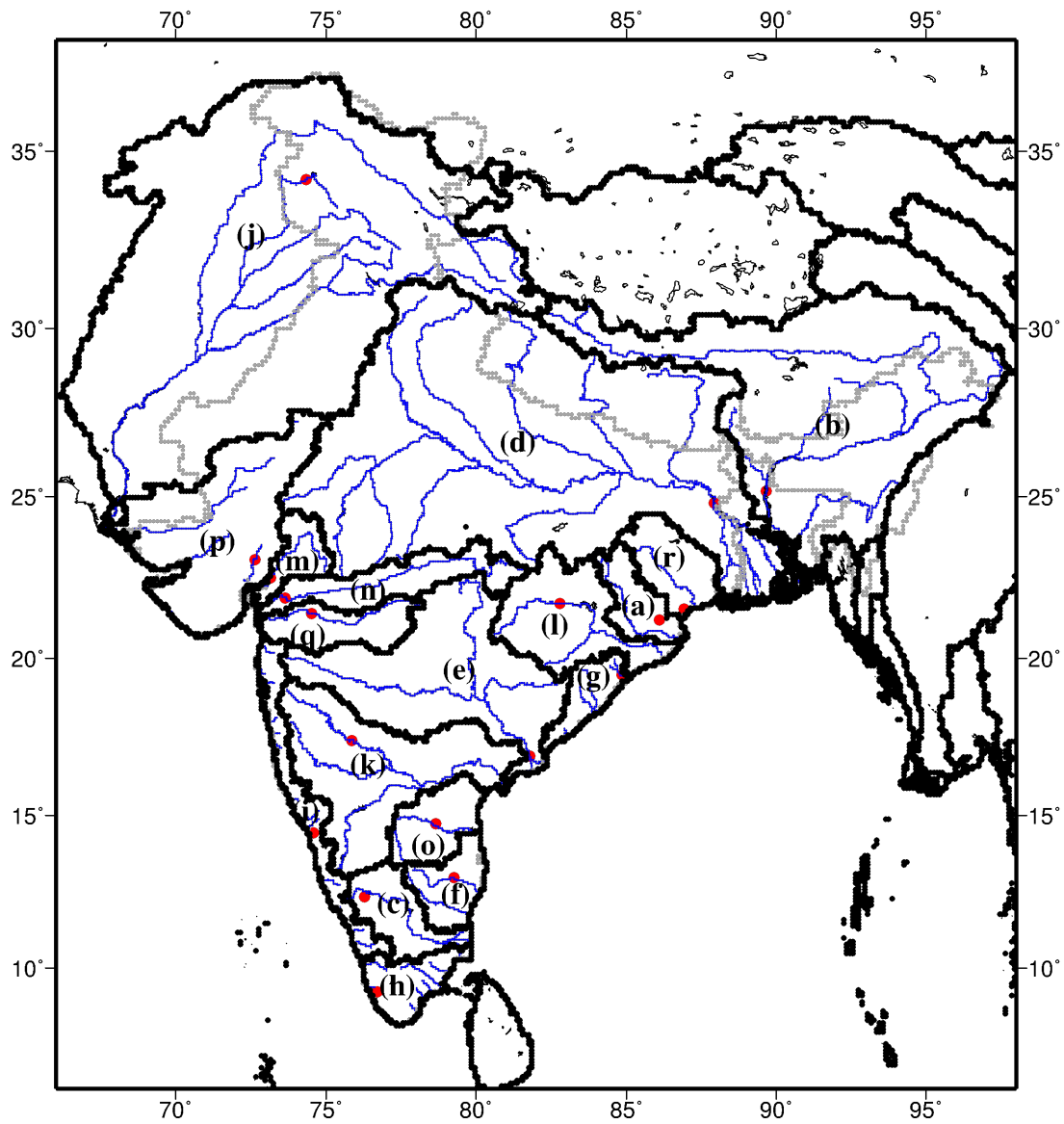
Figure S1: Map of gauge stations used for calibration and validations of models (shown with red color filled circle), river network (shown with blue color line) and basins (bordered with black color line, Refer basins name in Table 2) of India. Boundary of India is shown with grey color.
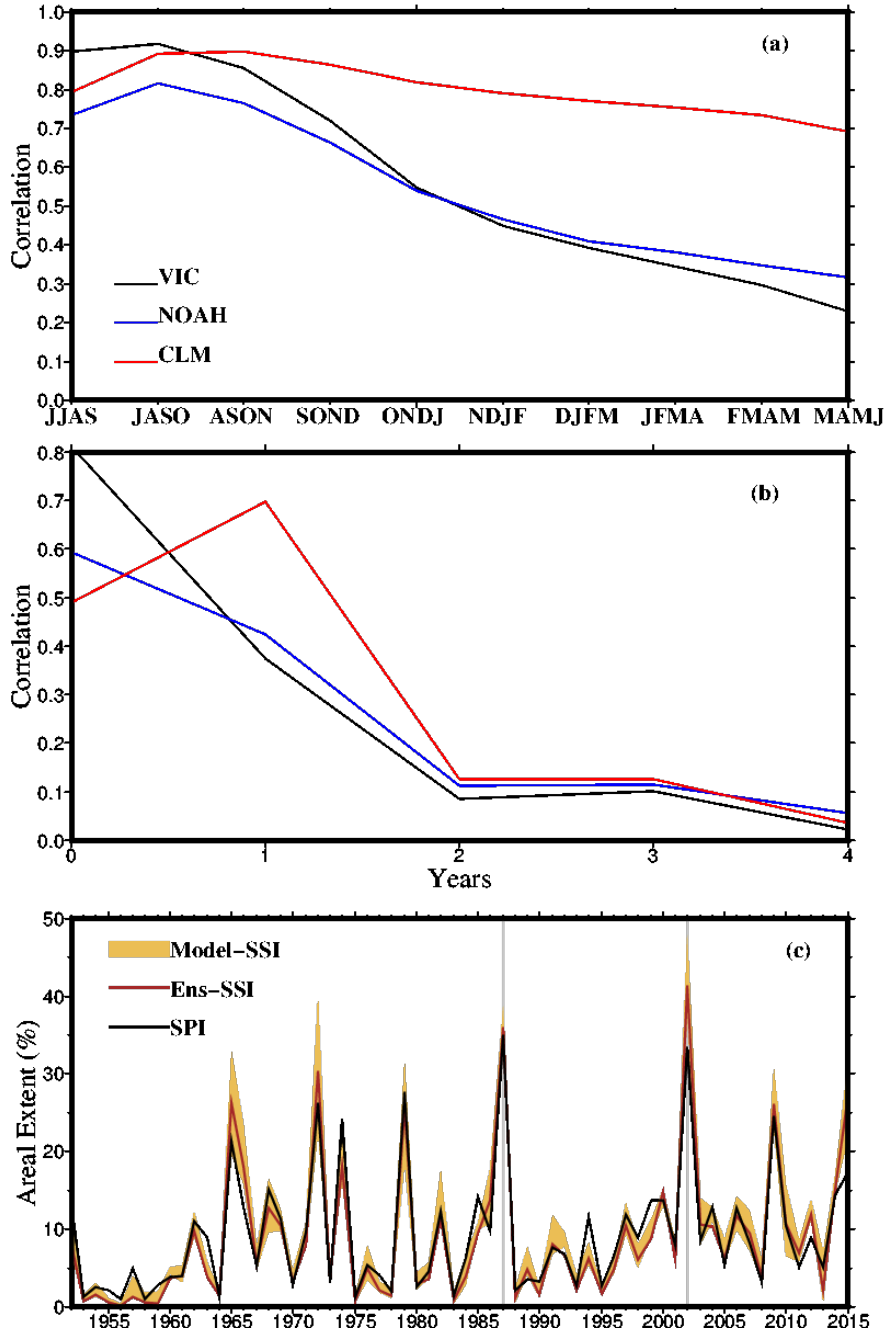
Figure S2: (a) Correlation between 4-month SPI at the end of the monsoon season (JJAS) and 4-month SSI (root-zone soil moisture) at different leads. (b) Correlation of 12-month SPI at the end of December with 12-month SSI at lead varying from 0-48 months. (c) uncertainty in areal extent of root-zone soil moisture drought based on the lead time for which 4-month SSI shows the highest correlation with the 4-month SPI at the end of the monsoon season. Black line in (c) shows 4-month SPI at the end of the monsoon season. Shaded area shows indermodel uncertainty estimated using one standard deviation. Gray lines show major drought events.
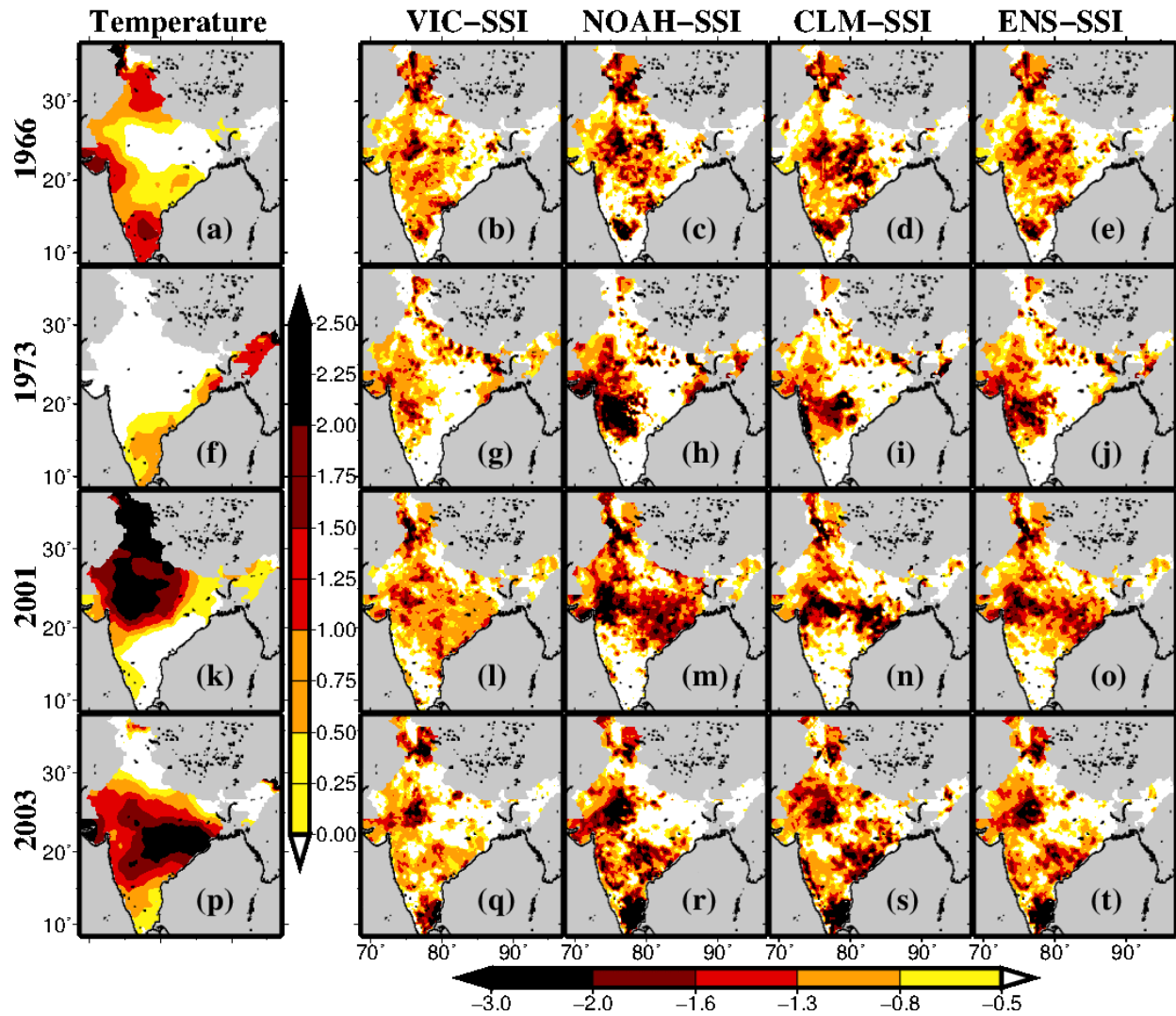
Figure S3: Reconstruction of the Rabi season (NDJF) drought events of (a-e) 1966, (f-j) 1973, (k-o) 2001, and (p-t) 2003 estimated based on (b,g,l,q) 4-month SSI at the end of February estimated using root-zone soil moisture from the VIC model, (c,h,m,r) 4-month SSI simulated using the Noah model, (d,i,n,s) 4-month SSI simulated using the CLM and (e,j,o,t) ensemble mean of 4-month SSI simulated using the VIC, Noah and CLM. (a,f,k,p) Air temperature anomaly during the Rabi season for the respective years.
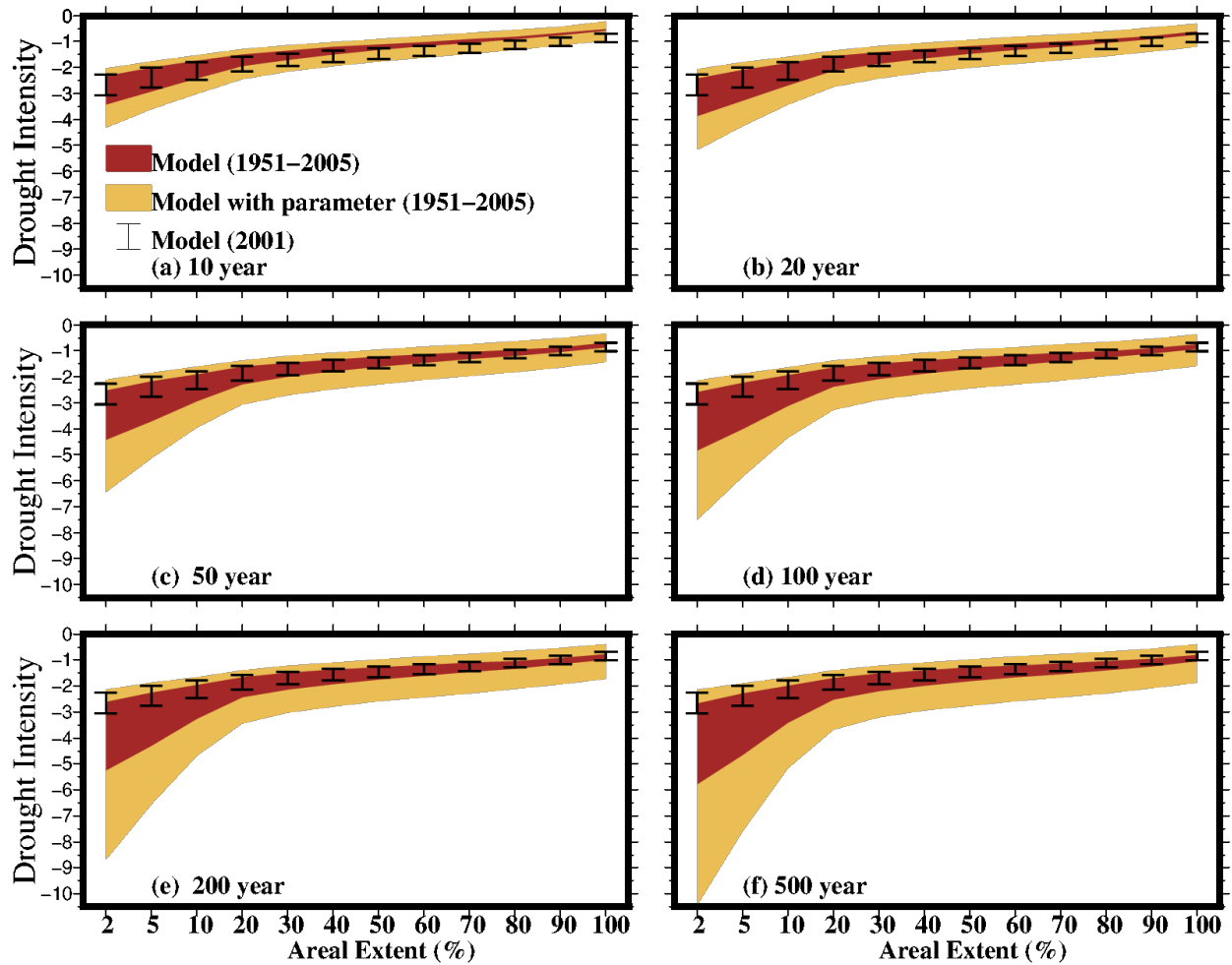
Figure S4: Uncertainty in Intensity-Areal Extent [%]-Frequency [IAF] curve of drought during Rabi season (November through January) estimated using three LSMs [Dark brown color shade shows uncertainty in models without considering distribution uncertainty while light brown color with considering distribution uncertainty] for all-India with return periods (a) 10, (b) 20, (c) 50, (d) 100, (e) 200, and (f) 500 years. Black error-bars indicate uncertainty Intensity-Areal Extent [%] for 2001 Rabi season drought using three LSMs.
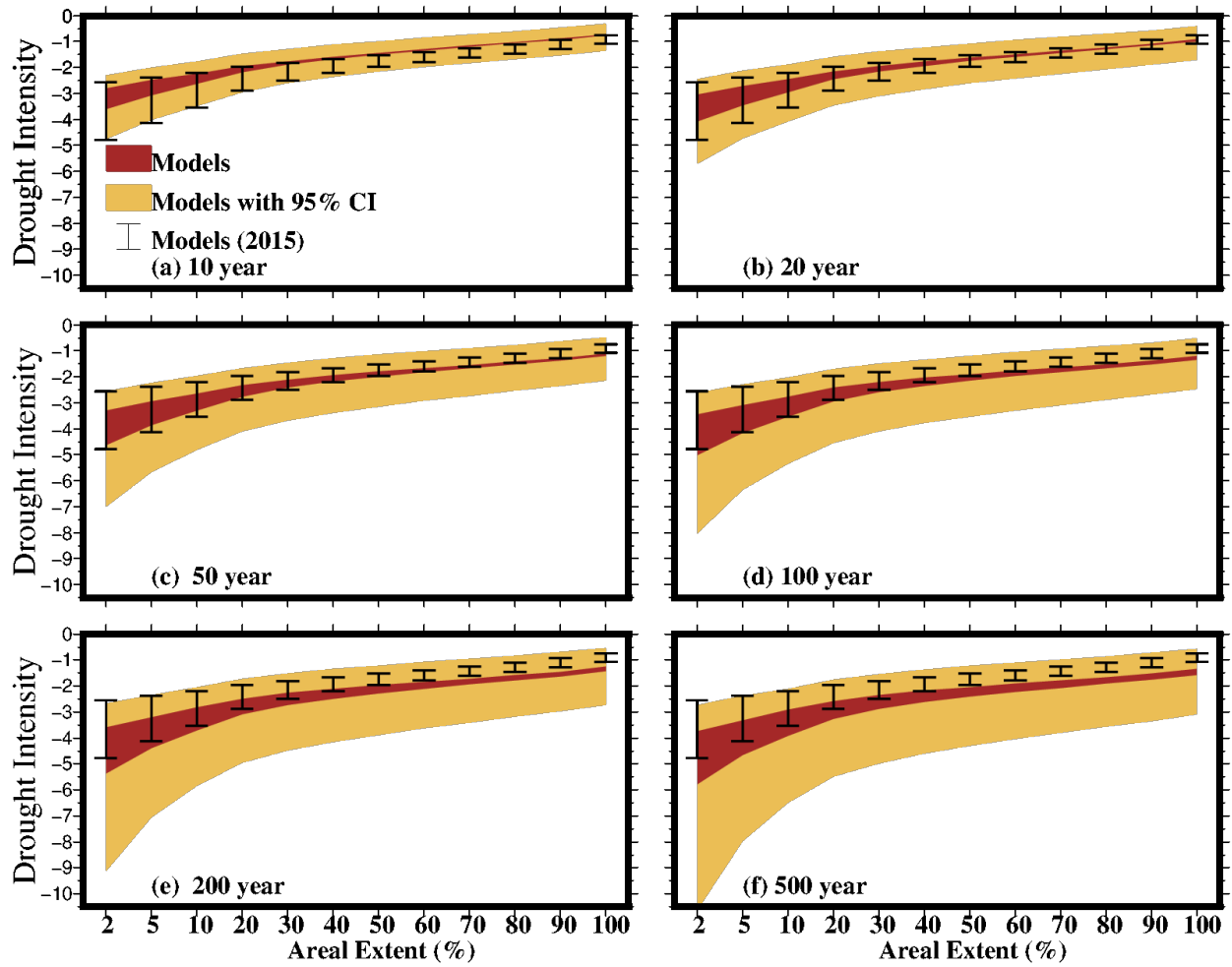
Figure S5: Same as Fig. 4 but for 12-month SSI at the end of December for the Indo-Gangetic Plain.
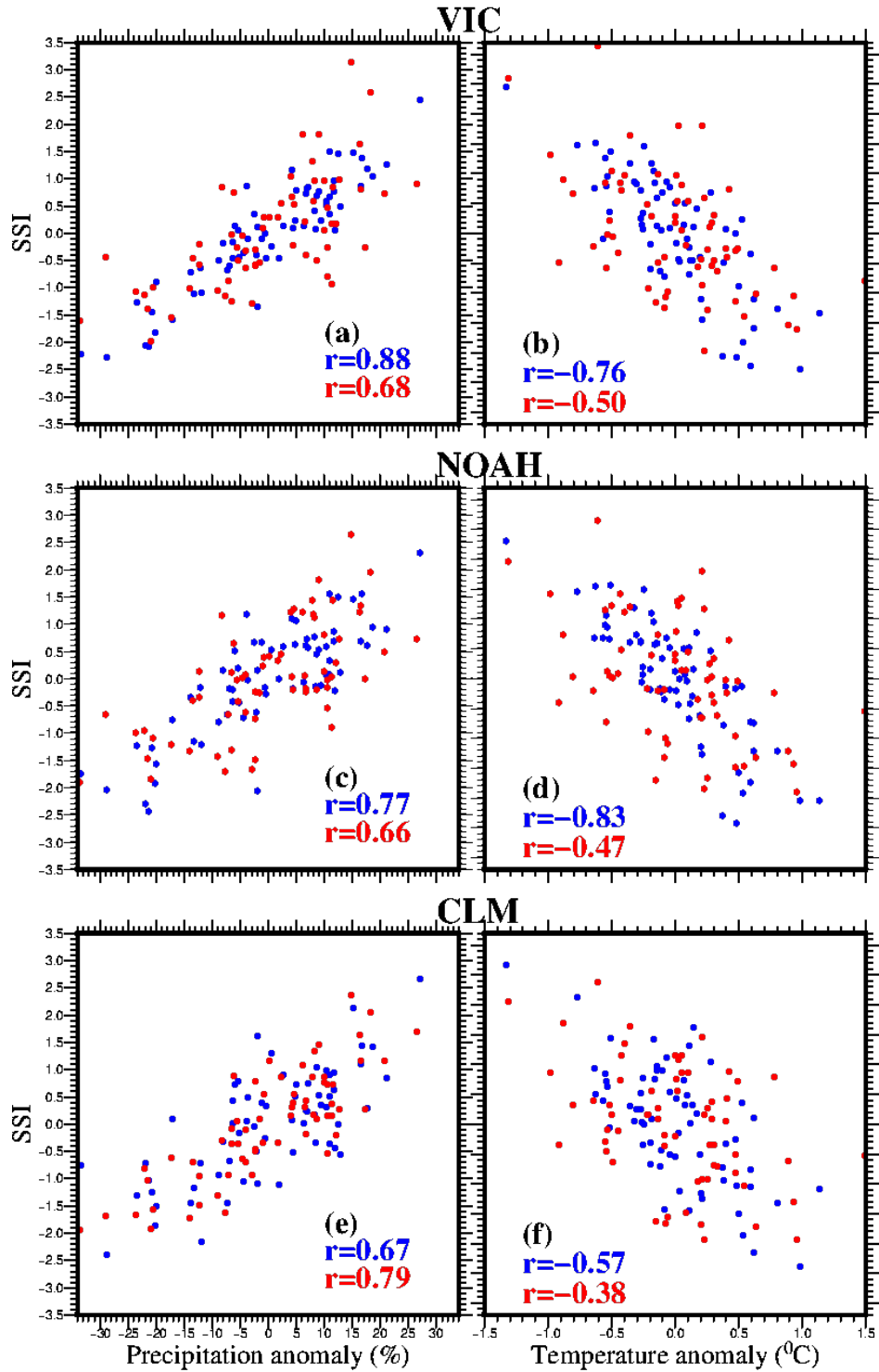
Figure S6. (a,c,e)Relationship between monsoon season precipitation anomaly (%) and 4-month SSI at the end of the Rabi season and (b,d,f) same as (a,c,e) but for the relationship between 4-month SSI and air temperature anomaly of the Rabi season. Correlation coefficients are shown for all-India SSI (blue) and 4-month SSI of the Indo-Gengatic Plain (red).
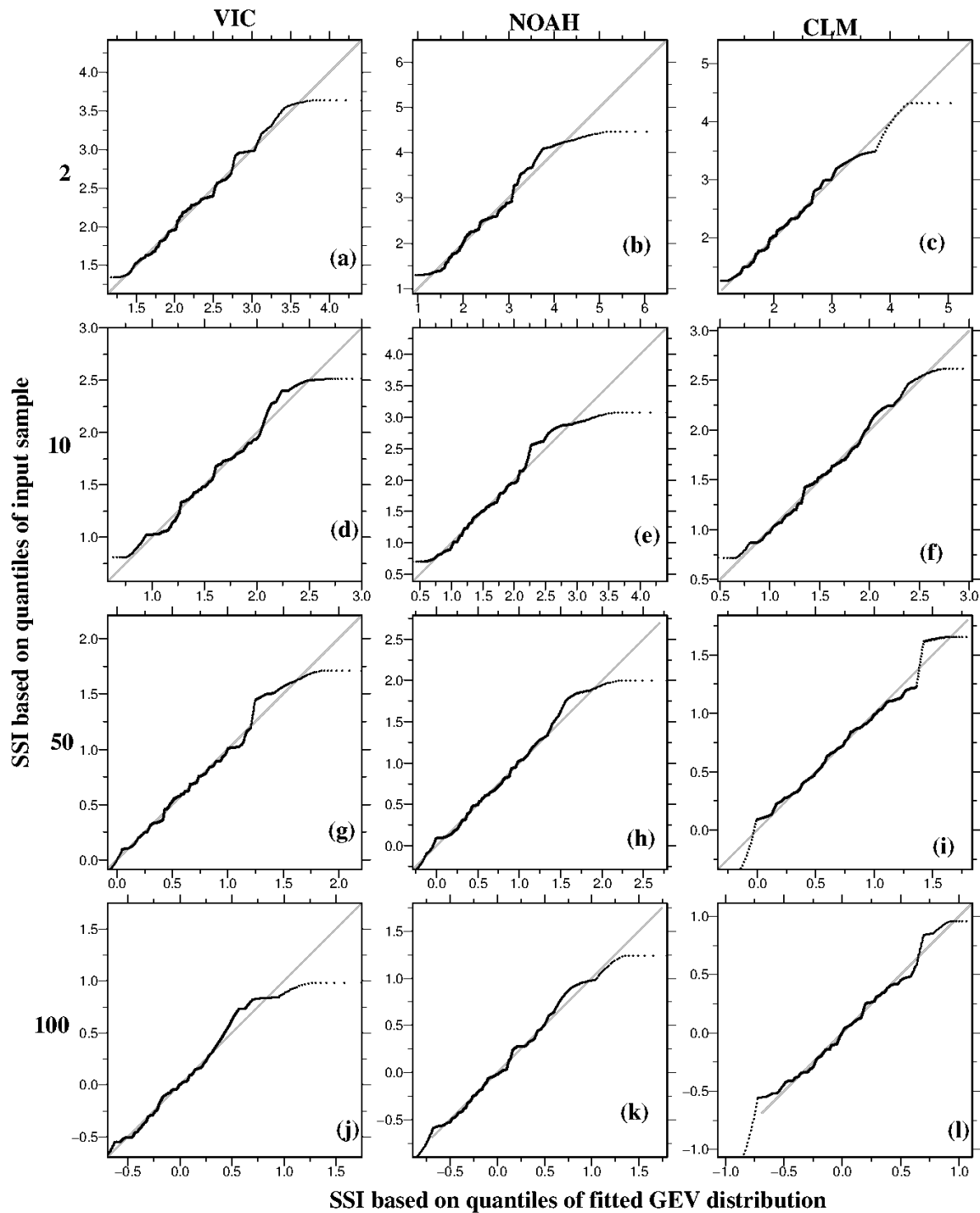
Figure S7: Quantile-quantile plot of the monsoon season SSI for different areal extent (%, written in left) of whole India from the VIC (a,d,g,j), NOAH (b,e,h,k), and CLM (c,f,i,l) and corresponding SSI estimated by fitting GEV distribution to the monsoon season SSI.
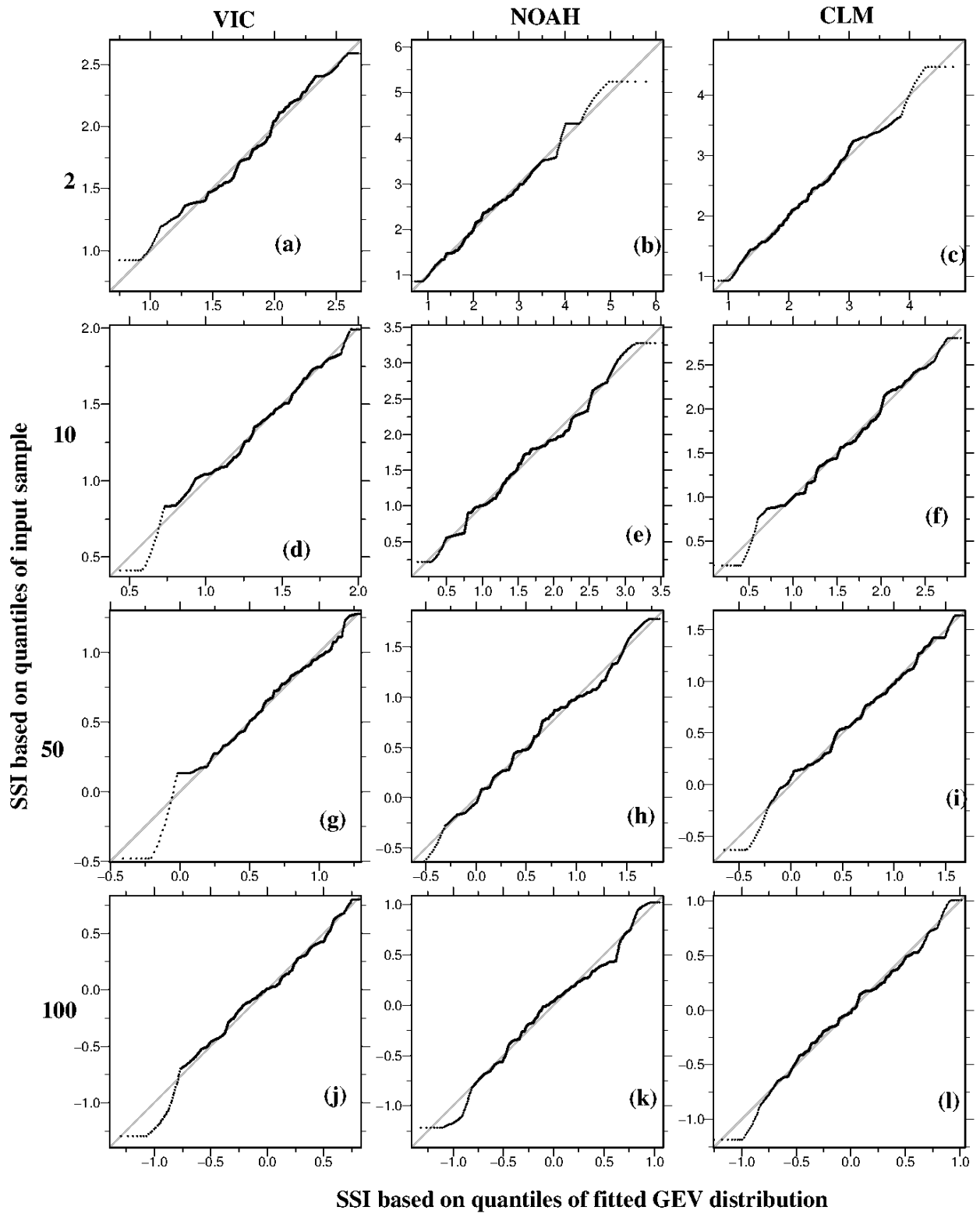
Figure S8: same as Figure S7 but for the Rabi season.
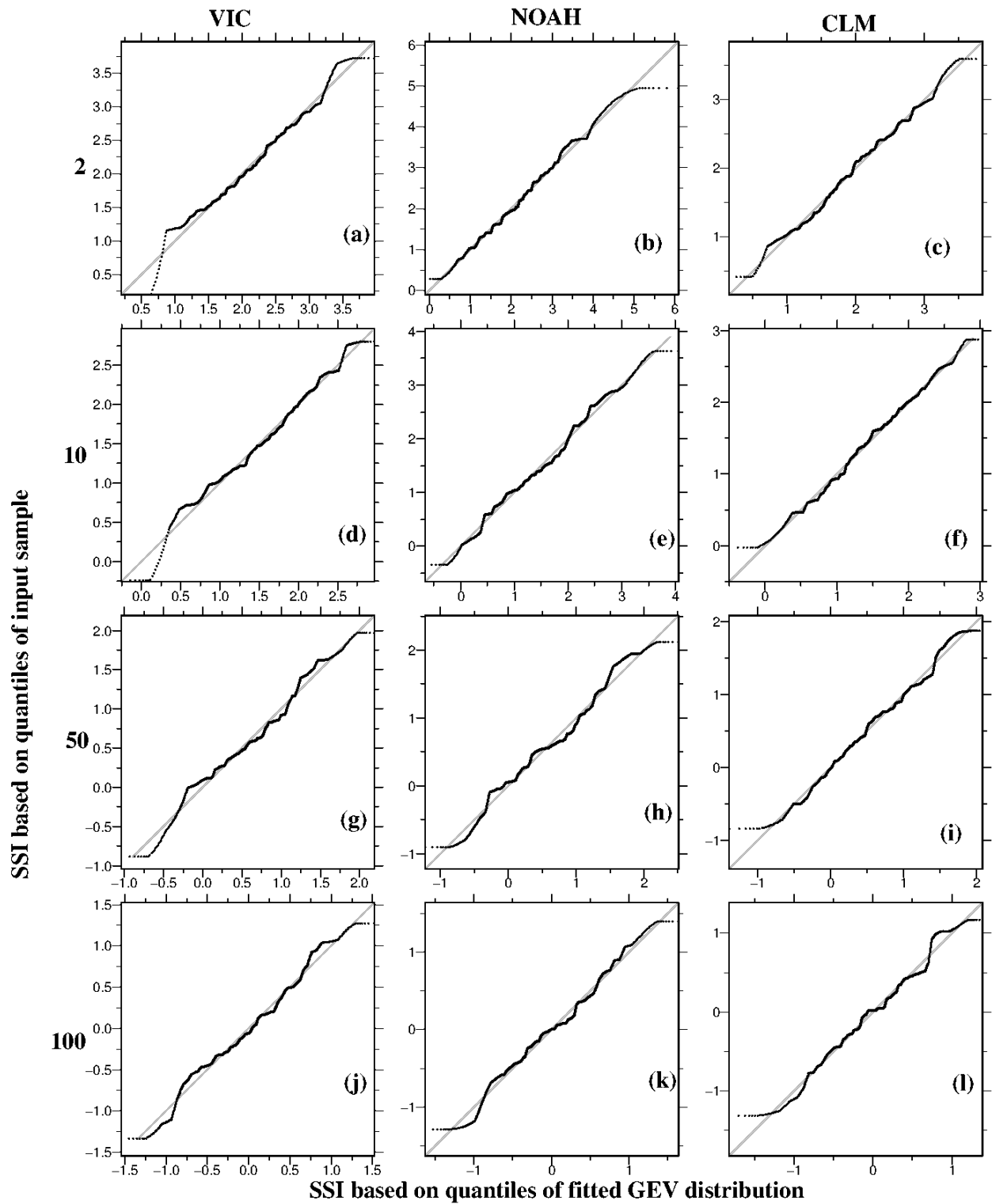
Figure S9: same as Figure S8 but for annual SSI estimated for areal extent of Indo-Gangetic plain.

Table S1: Description of hydrological process and parameters use in all three models.

LSM	Hydrology	Soil Layers	Soil/ vegetation parameters	Input Parameters
VIC v4.2.1.a	Variable Infiltration Capacity curve for runoff, Arno model for Base flow, drainage driven by gravity, Penman-Monteith equation for evapotranspiration (ET)	Three layers	Vegetation parameter based on 1km Advanced Very High Resolution Radiometer (AVHRR), Soil parameter from Harmonized world soil database (HWSD)	Four parameters, Precipitation, Maximum and Minimum air temperatures, and Wind speed
NOAH v3.1	Exponential distribution of infiltration capacity for runoff, baseflow proportional to storage, drainage driven by gravity, Penman-Monteith equation for ET estimation,	Four layers	Modified IGBP MODIS 20-category vegetation, vegetation fraction derived based on Normalized Difference Vegetation Index (NDVI) from AVHRR, Soil parameters derived from FAO.	Precipitation, air temperature, wind speed, surface pressure, humidity, surface downward and longwave radiations.
CLM v3.0	TOPMODEL for surface runoff, groundwater scheme, , Penman-Monteith equation for ET	10 Layers	Vegetation parameters represented for 17 plant functional types (Bonan et al. 2002), soil parameters based on IGBP.	Precipitation, air temperature, specific humidity, incident solar radiation, and surface pressure.

Table S2: Performance of three LSMs (VIC, NOAH, and CLM) in terms of Nash Sutcliffe Efficiency (NS) and correlation coefficient (R) for monthly streamflow simulations compared against observations across 19 gauging stations across India (see Figure S1 for locations of these basins) for calibration and validation periods. Additionally the skill of the ensemble mean streamflow (ENS) from the three LSMs is also provided in this Table.

No.	Basins	Station	Lon (°)	Lat (°)	Drainage Area (km^2)	Period		VIC		Noah		CLM		ENS	
								R	NS	R	NS	R	NS	R	NS
a	Brahmani	Anandpur	86.12	21.21	10,000	Calibration	1974-1982	0.93	0.86	0.89	0.63	0.92	0.59	0.95	0.78
						Validation	1985-1990	0.95	0.74	0.90	0.48	0.94	0.64	0.96	0.74
b	Brahmaputra	Bahadpur	89.66	25.18	444,375	Calibration	1969-1971	0.88	0.66	0.96	0.90	0.90	0.76	0.94	0.85
						Validation	1973-1975	0.94	0.85	0.98	0.94	0.92	0.82	0.96	0.89
c	Cauvery	KMVadi	76.29	12.34	3125	Calibration	1991-1995	0.85	0.36	0.92	-6.14	0.36	-0.46	0.85	-4.34
						Validation	1996-2000	0.93	-10.78	0.90	-20.2	0.38	-1.40	0.89	-7.92
d	Ganga	Farakka	87.92	24.83	865,000	Calibration	1952-1960	0.98	0.89	0.98	0.93	0.88	0.73	0.98	0.92
						Validation	1965-1973	0.98	0.78	0.98	0.91	0.87	0.66	0.98	0.88
e	Godavari	Polavaram	81.78	16.92	260,000	Calibration	1952-1960	0.98	0.95	0.97	0.74	0.96	0.90	0.98	0.92
						Validation	1965-1973	0.95	0.81	0.94	0.72	0.93	0.85	0.97	0.88
f	East coast	Tiruk	79.26	12.98	10,625	Calibration	1976-1979	0.79	0.30	0.85	-2.20	0.69	-2.31	0.80	-2.24
						Validation	1978-1979	0.83	-1.43	0.87	0.61	0.73	-0.72	0.85	-0.13
g	North east coast	Purus	84.87	19.51	6250	Calibration	1997-2000	0.87	0.75	0.81	0.17	0.81	-0.09	0.86	0.36
						Validation	2001-2005	0.94	0.78	0.93	0.70	0.87	0.45	0.95	0.78
h	South coast	Thump	76.70	9.23	1875	Calibration	1980-1990	0.79	0.58	0.83	0.62	0.88	0.52	0.91	0.82
						Validation	1991-1995	0.89	0.53	0.94	0.01	0.65	0.39	0.91	0.67
i	West coast	Sante	74.59	14.43	2500	Calibration	1989-1999	0.98	0.90	0.98	0.90	0.97	0.93	0.98	0.94

						Validation	2000-2005	0.87	0.55	0.89	0.50	0.88	0.59	0.88	0.57
j	Indus	Baram	74.33	34.22	13,125	Calibration	1968-1974	0.9	0.68	0.87	0.73	0.79	0.53	0.86	0.62
						Validation	1976-1979	0.90	0.80	0.84	0.68	0.88	0.71	0.84	0.69
k	Krishna	Takli	75.85	17.41	37,500	Calibration	1969-1974	0.88	0.76	0.90	0.77	0.82	0.67	0.91	0.81
						Validation	1976-1979	0.82	0.64	0.90	0.74	0.74	0.53	0.88	0.74
l	Mahanadi	Basantpur	82.79	21.72	48,750	Calibration	1972-1980	0.92	0.80	0.94	0.75	0.95	0.90	0.96	088
						Validation	1976-1980	0.95	0.88	0.94	0.84	0.96	0.88	0.97	0.93
m	Mahi	Khanpur	73.14	22.53	30,625	Calibration	1980-1995	0.96	0.93	0.97	0.93	0.85	0.68	0.94	0.84
						Validation	1996-2005	0.92	0.71	0.96	0.93	0.84	0.58	0.96	0.77
n	Narmada	Garudeshwar	73.65	21.89	76,250	Calibration	1973-1987	0.97	0.93	0.97	0.93	0.97	0.93	0.98	0.97
						Validation	1996-2005	0.95	0.66	0.96	0.79	0.92	0.64	0.96	0.77
o	Pennar	Alladupalli	78.67	14.72	9375	Calibration	1988-1989	0.93	0.85	0.85	0.72	0.92	0.84	0.93	0.87
						Validation	1990-1991	0.89	0.70	0.83	0.65	0.84	0.62	0.91	0.83
p	Sabarmati	Ahmedabad	72.63	23.08	10,000	Calibration	1968-1969	0.90	0.69	0.96	0.93	0.95	0.43	0.95	0.87
						Validation	1970-1972	0.89	0.22	0.89	0.75	0.95	0.57	0.94	0.69
q	Tapi	Sarangpur	74.53	21.43	46,250	Calibration	1980-1986	0.97	0.93	0.97	0.92	0.92	0.84	0.97	0.93
						Validation	1990-2005	0.93	0.81	0.91	0.83	0.88	0.76	0.93	0.85
r	Subarnarekha	Govindpur	86.92	21.55	4375	Calibration	1994-2000	0.88	0.76	0.86	0.70	0.87	0.47	0.92	0.79
						Validation	1990-2005	0.94	0.83	0.92	0.84	0.81	0.35	0.92	0.81

Table S3: Uncertainty in areal extent (%) of area under severe to exceptional drought based on models simulated SSI during JJAS (shown in Figure 1a) and based on lagged 4-month SSI (shown in Figure 4) during major JJAS drought based on SPI

Major JJAS drought (based on SPI)	JJAS SSI (Figure 1)				Lagged 4-month SSI (Figure 4)			
	VIC	NOAH	CLM	Ensemble	JASO VIC	JASO NOAH	ASON CLM	Ensemble
1987	37.74	39.16	33.05	36.73	35.70	38.93	32.45	35.92
2002	34.11	38.73	37.65	35.95	38.98	48.54	37.97	41.42
1979	26.61	26.25	13.19	19.87	30.31	27.28	21.15	25.49
1972	32.54	47.44	19.21	29.81	32.71	39.03	24.43	30.27
2009	29.05	34.20	33.56	31.46	22.45	27.70	29.03	26.13
2015	14.01	21.21	18.13	16.51	24.33	32.82	29.07	27.51

Table S4: Uncertainty in areal extent (%) of area under severe to exceptional drought based on models simulated SSI during Rabi season (NDJF; shown in Figure 5) during major Rabi season drought based on Ensemble SSI.

Major Rabi season drought (based on Ensemble SSI)	Rabi season SSI (Figure 5)			
	VIC	NOAH	CLM	Ensemble
1966	16.93	25.21	25.79	21.90
1973	12.40	30.11	19.61	20.68
2001	17.25	40.75	24.75	26.17
2003	19.02	36.27	34.85	28.84

Table S5: Shows JJAS drought intensity (SSI) for different areal-extent (%, of India) and return period (in years) for different models. GEV distribution was fitted to JJAS SSI for different areal-extent for the period 1901-2015.

Return period	10			20			50			100			200			500		
Areal Extent	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM
2	-2.89	-3.52	-3.00	-3.16	-3.98	-3.36	-3.48	-4.57	-3.83	-3.72	-5.02	-4.19	-3.94	-5.46	-4.55	-4.22	-6.05	-5.04
5	-2.46	-2.93	-2.51	-2.66	-3.31	-2.77	-2.89	-3.79	-3.09	-3.04	-4.15	-3.31	-3.18	-4.50	-3.52	-3.34	-4.96	-3.79
10	-2.15	-2.47	-2.14	-2.32	-2.79	-2.32	-2.53	-3.20	-2.54	-2.66	-3.50	-2.67	-2.78	-3.78	-2.80	-2.91	-4.15	-2.94
20	-1.81	-2.01	-1.78	-1.98	-2.29	-1.93	-2.18	-2.64	-2.09	-2.31	-2.90	-2.20	-2.43	-3.14	-2.29	-2.57	-3.44	-2.38
30	-1.58	-1.73	-1.55	-1.76	-2.00	-1.70	-1.97	-2.33	-1.85	-2.10	-2.56	-1.95	-2.22	-2.78	-2.03	-2.37	-3.06	-2.12
40	-1.41	-1.52	-1.38	-1.59	-1.78	-1.53	-1.80	-2.10	-1.68	-1.94	-2.32	-1.77	-2.07	-2.54	-1.85	-2.22	-2.80	-1.94
50	-1.25	-1.35	-1.23	-1.44	-1.60	-1.38	-1.66	-1.91	-1.53	-1.80	-2.13	-1.62	-1.94	-2.34	-1.70	-2.10	-2.60	-1.78
60	-1.11	-1.19	-1.10	-1.30	-1.44	-1.24	-1.53	-1.75	-1.39	-1.68	-1.96	-1.49	-1.82	-2.16	-1.57	-1.99	-2.42	-1.65
70	-0.98	-1.05	-0.97	-1.17	-1.30	-1.11	-1.40	-1.59	-1.27	-1.56	-1.80	-1.36	-1.72	-2.00	-1.44	-1.90	-2.25	-1.53
80	-0.84	-0.91	-0.83	-1.04	-1.15	-0.98	-1.28	-1.44	-1.13	-1.45	-1.64	-1.23	-1.61	-1.83	-1.31	-1.81	-2.07	-1.40
90	-0.70	-0.77	-0.69	-0.90	-1.00	-0.84	-1.15	-1.28	-0.99	-1.33	-1.47	-1.08	-1.50	-1.65	-1.16	-1.71	-1.88	-1.25
100	-0.52	-0.60	-0.51	-0.73	-0.82	-0.65	-0.99	-1.08	-0.80	-1.18	-1.27	-0.90	-1.35	-1.44	-0.97	-1.58	-1.65	-1.06

Table S6: Parameters and confidence interval for GEV distribution fitted to JJAS 1951-2015 SSI estimated using different models for different areal extent (%, of India).

areal extent	parameter	VIC			NOAH			CLM		
		value	Lowe r CI	Higher CI	value	Lower CI	Higher CI	value	Lower CI	Higher CI
2	shape	-0.06	-0.25	0.14	0.00	-0.22	0.22	0.02	-0.18	0.23
	scale	0.42	0.35	0.52	0.63	0.51	0.78	0.47	0.38	0.58
	location	2.00	1.88	2.12	2.10	1.92	2.28	1.92	1.79	2.05
5	shape	-0.14	-0.35	0.06	-0.02	-0.25	0.21	-0.06	-0.26	0.13
	scale	0.40	0.32	0.49	0.55	0.45	0.68	0.42	0.35	0.52
	location	1.70	1.58	1.81	1.71	1.55	1.87	1.63	1.51	1.74
10	shape	-0.16	-0.36	0.04	-0.04	-0.26	0.19	-0.17	-0.36	0.03
	scale	0.38	0.31	0.46	0.50	0.40	0.62	0.40	0.33	0.49
	location	1.43	1.33	1.54	1.39	1.25	1.53	1.39	1.28	1.50
20	shape	-0.15	-0.34	0.03	-0.06	-0.27	0.15	-0.22	-0.38	-0.07
	scale	0.36	0.30	0.44	0.46	0.37	0.56	0.38	0.31	0.46
	location	1.12	1.02	1.22	1.04	0.91	1.16	1.10	1.00	1.21
30	shape	-0.14	-0.32	0.04	-0.07	-0.26	0.13	-0.24	-0.38	-0.10
	scale	0.36	0.29	0.43	0.44	0.36	0.54	0.38	0.31	0.45
	location	0.90	0.80	0.99	0.80	0.68	0.93	0.90	0.80	1.00
40	shape	-0.13	-0.31	0.04	-0.07	-0.26	0.12	-0.24	-0.38	-0.11
	scale	0.36	0.29	0.43	0.43	0.35	0.53	0.38	0.31	0.45
	location	0.72	0.62	0.81	0.62	0.50	0.74	0.73	0.63	0.83
50	shape	-0.12	-0.30	0.06	-0.07	-0.26	0.12	-0.24	-0.38	-0.11
	scale	0.35	0.29	0.43	0.42	0.35	0.52	0.38	0.31	0.45
	location	0.56	0.46	0.65	0.47	0.35	0.58	0.58	0.48	0.68
60	shape	-0.11	-0.30	0.08	-0.07	-0.26	0.11	-0.24	-0.37	-0.11
	scale	0.35	0.29	0.43	0.42	0.34	0.51	0.38	0.31	0.45
	location	0.41	0.32	0.51	0.33	0.21	0.44	0.44	0.34	0.54
70	shape	-0.09	-0.29	0.10	-0.07	-0.26	0.11	-0.24	-0.37	-0.11
	scale	0.35	0.28	0.42	0.41	0.34	0.50	0.38	0.31	0.45
	location	0.27	0.18	0.37	0.20	0.09	0.32	0.31	0.21	0.41
80	shape	-0.08	-0.28	0.12	-0.08	-0.26	0.11	-0.24	-0.37	-0.10
	scale	0.34	0.28	0.42	0.40	0.33	0.49	0.38	0.31	0.45
	location	0.14	0.04	0.23	0.08	-0.03	0.19	0.18	0.08	0.28
90	shape	-0.06	-0.27	0.14	-0.08	-0.27	0.10	-0.24	-0.38	-0.11
	scale	0.33	0.27	0.41	0.40	0.33	0.48	0.38	0.31	0.45
	location	0.00	-0.10	0.09	-0.04	-0.15	0.07	0.04	-0.06	0.14
100	shape	-0.05	-0.26	0.17	-0.09	-0.28	0.10	-0.24	-0.38	-0.11
	scale	0.33	0.27	0.40	0.39	0.32	0.48	0.37	0.31	0.45
	location	-0.18	-0.27	-0.08	-0.19	-0.30	-0.09	-0.14	-0.24	-0.04

Table S7: Shows NDJF drought intensity (SSI) corresponding to different areal-extent (%, of India) and return period (in years) for different models. GEV distribution was fitted to NDJF SSI for different areal extent and for the period 1901-2015.

Return period	10			20			50			100			200			500		
Areal extent	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM
2	-2.31	-3.42	-3.21	-2.42	-3.87	-3.53	-2.52	-4.43	-3.92	-2.58	-4.85	-4.18	-2.63	-5.25	-4.42	-2.68	-5.78	-4.71
5	-1.99	-2.90	-2.71	-2.08	-3.26	-2.96	-2.17	-3.71	-3.25	-2.23	-4.02	-3.44	-2.27	-4.31	-3.60	-2.31	-4.68	-3.80
10	-1.74	-2.42	-2.28	-1.82	-2.66	-2.45	-1.90	-2.94	-2.63	-1.94	-3.11	-2.73	-1.97	-3.26	-2.81	-2.00	-3.43	-2.90
20	-1.48	-1.94	-1.85	-1.55	-2.11	-1.97	-1.62	-2.28	-2.07	-1.65	-2.37	-2.13	-1.68	-2.45	-2.17	-1.70	-2.52	-2.22
30	-1.33	-1.68	-1.61	-1.40	-1.84	-1.72	-1.45	-1.99	-1.83	-1.48	-2.07	-1.88	-1.51	-2.14	-1.93	-1.53	-2.20	-1.97
40	-1.21	-1.49	-1.42	-1.27	-1.64	-1.54	-1.33	-1.78	-1.65	-1.36	-1.87	-1.71	-1.38	-1.93	-1.76	-1.40	-1.99	-1.80
50	-1.10	-1.33	-1.27	-1.17	-1.48	-1.39	-1.23	-1.62	-1.50	-1.26	-1.70	-1.57	-1.28	-1.76	-1.61	-1.29	-1.83	-1.66
60	-1.01	-1.18	-1.13	-1.08	-1.33	-1.25	-1.14	-1.47	-1.37	-1.17	-1.55	-1.44	-1.19	-1.62	-1.49	-1.21	-1.68	-1.54
70	-0.90	-1.04	-0.99	-0.98	-1.18	-1.12	-1.05	-1.33	-1.25	-1.09	-1.41	-1.32	-1.12	-1.47	-1.37	-1.14	-1.54	-1.42
80	-0.80	-0.90	-0.86	-0.88	-1.04	-0.99	-0.96	-1.18	-1.12	-1.00	-1.27	-1.19	-1.03	-1.33	-1.25	-1.06	-1.39	-1.31
90	-0.67	-0.75	-0.72	-0.77	-0.90	-0.85	-0.86	-1.04	-0.98	-0.90	-1.12	-1.06	-0.93	-1.18	-1.12	-0.97	-1.24	-1.18
100	-0.51	-0.59	-0.54	-0.61	-0.72	-0.68	-0.70	-0.86	-0.81	-0.75	-0.94	-0.89	-0.78	-1.00	-0.95	-0.82	-1.06	-1.01

Table S8: Parameters and confidence interval for GEV distribution fitted to NDJF 1951-2015 SSI estimated for different areal-extent (%, of India) using different models.

Areal extent	Parameter	VIC			NOAH			CLM		
		Value	Lower CI	Higher CI	Value	Lower CI	Higher CI	Value	Lower CI	Higher CI
2	Shape	-0.35	-0.55	-0.15	-0.03	-0.20	0.15	-0.11	-0.27	0.06
	Scale	0.38	0.31	0.47	0.67	0.55	0.81	0.59	0.49	0.72
	Location	1.72	1.62	1.82	1.96	1.78	2.15	2.03	1.86	2.19
5	Shape	-0.36	-0.51	-0.21	-0.08	-0.22	0.07	-0.17	-0.32	-0.02
	Scale	0.34	0.28	0.41	0.62	0.51	0.74	0.54	0.45	0.66
	Location	1.47	1.38	1.56	1.63	1.46	1.79	1.69	1.54	1.84
10	Shape	-0.39	-0.52	-0.26	-0.20	-0.34	-0.06	-0.29	-0.45	-0.14
	Scale	0.31	0.26	0.38	0.58	0.48	0.69	0.51	0.43	0.62
	Location	1.27	1.19	1.35	1.37	1.21	1.53	1.43	1.29	1.57
20	Shape	-0.43	-0.55	-0.31	-0.33	-0.47	-0.18	-0.42	-0.61	-0.23
	Scale	0.30	0.25	0.37	0.54	0.45	0.66	0.49	0.40	0.60
	Location	1.05	0.97	1.13	1.08	0.93	1.22	1.13	1.00	1.27
30	Shape	-0.47	-0.59	-0.35	-0.35	-0.48	-0.21	-0.42	-0.57	-0.26
	Scale	0.31	0.26	0.38	0.53	0.44	0.63	0.47	0.39	0.58
	Location	0.89	0.81	0.98	0.86	0.72	1.00	0.91	0.79	1.04
40	Shape	-0.50	-0.63	-0.37	-0.35	-0.48	-0.21	-0.40	-0.55	-0.26
	Scale	0.33	0.27	0.40	0.51	0.43	0.62	0.47	0.39	0.57
	Location	0.76	0.68	0.85	0.69	0.55	0.83	0.73	0.61	0.86
50	Shape	-0.51	-0.65	-0.37	-0.35	-0.48	-0.21	-0.39	-0.52	-0.25
	Scale	0.35	0.29	0.42	0.50	0.42	0.61	0.46	0.38	0.56
	Location	0.64	0.54	0.73	0.54	0.41	0.67	0.58	0.46	0.70
60	Shape	-0.49	-0.63	-0.36	-0.34	-0.47	-0.21	-0.37	-0.50	-0.24
	Scale	0.37	0.30	0.44	0.49	0.41	0.59	0.45	0.38	0.55
	Location	0.51	0.41	0.61	0.40	0.27	0.53	0.44	0.32	0.56
70	Shape	-0.47	-0.61	-0.34	-0.33	-0.46	-0.21	-0.35	-0.48	-0.23
	Scale	0.38	0.31	0.46	0.48	0.40	0.58	0.45	0.37	0.54
	Location	0.38	0.28	0.48	0.27	0.14	0.40	0.30	0.18	0.42
80	Shape	-0.45	-0.58	-0.32	-0.33	-0.46	-0.21	-0.34	-0.46	-0.22
	Scale	0.40	0.33	0.48	0.48	0.40	0.57	0.44	0.37	0.53
	Location	0.24	0.13	0.34	0.14	0.02	0.27	0.17	0.05	0.28
90	Shape	-0.44	-0.56	-0.31	-0.33	-0.46	-0.21	-0.33	-0.44	-0.21
	Scale	0.41	0.34	0.50	0.47	0.39	0.56	0.43	0.36	0.52
	Location	0.09	-0.02	0.19	0.01	-0.11	0.14	0.03	-0.08	0.15
100	Shape	-0.43	-0.55	-0.30	-0.34	-0.46	-0.22	-0.31	-0.43	-0.20
	Scale	0.43	0.35	0.51	0.46	0.39	0.56	0.42	0.35	0.50
	Location	-0.11	-0.22	0.00	-0.14	-0.27	-0.02	-0.14	-0.25	-0.03

Table S9: Shows 12-month drought intensity (SSI) at the end of December corresponding to different areal-extent (%, of Ganga region) and return period (in years) for different models. GEV distribution was fitted to 12-month SSI at the end of December for different areal extent and for the period 1901-2015.

Return period	10			20			50			100			200			500		
Areal extent	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM	VIC	NOAH	CLM
2	-2.96	-3.60	-2.79	-3.20	-4.07	-3.04	-3.45	-4.64	-3.30	-3.61	-5.02	-3.46	-3.74	-5.37	-3.60	-3.88	-5.80	-3.75
5	-2.59	-3.06	-2.48	-2.80	-3.44	-2.71	-3.01	-3.87	-2.95	-3.13	-4.15	-3.10	-3.23	-4.39	-3.22	-3.34	-4.68	-3.35
10	-2.28	-2.63	-2.24	-2.46	-2.95	-2.44	-2.65	-3.31	-2.65	-2.75	-3.53	-2.77	-2.83	-3.71	-2.87	-2.92	-3.92	-2.97
20	-1.96	-2.17	-1.95	-2.14	-2.45	-2.14	-2.32	-2.75	-2.32	-2.43	-2.93	-2.42	-2.51	-3.09	-2.50	-2.59	-3.26	-2.57
30	-1.75	-1.88	-1.75	-1.94	-2.15	-1.93	-2.13	-2.42	-2.10	-2.24	-2.59	-2.20	-2.32	-2.74	-2.27	-2.42	-2.89	-2.34
40	-1.58	-1.67	-1.59	-1.77	-1.92	-1.77	-1.97	-2.19	-1.94	-2.08	-2.35	-2.04	-2.17	-2.48	-2.11	-2.27	-2.63	-2.18
50	-1.42	-1.49	-1.45	-1.62	-1.74	-1.63	-1.82	-1.99	-1.80	-1.94	-2.15	-1.90	-2.03	-2.28	-1.97	-2.13	-2.42	-2.04
60	-1.28	-1.34	-1.32	-1.48	-1.57	-1.50	-1.68	-1.82	-1.67	-1.80	-1.97	-1.77	-1.90	-2.10	-1.84	-2.00	-2.24	-1.92
70	-1.15	-1.19	-1.19	-1.34	-1.42	-1.37	-1.55	-1.67	-1.54	-1.67	-1.82	-1.64	-1.77	-1.94	-1.72	-1.88	-2.08	-1.80
80	-1.01	-1.06	-1.06	-1.21	-1.28	-1.24	-1.42	-1.52	-1.42	-1.54	-1.66	-1.52	-1.64	-1.78	-1.59	-1.75	-1.92	-1.67
90	-0.88	-0.92	-0.92	-1.07	-1.14	-1.10	-1.28	-1.37	-1.28	-1.40	-1.51	-1.38	-1.51	-1.63	-1.45	-1.62	-1.75	-1.53
100	-0.72	-0.76	-0.75	-0.91	-0.98	-0.92	-1.12	-1.20	-1.10	-1.24	-1.33	-1.19	-1.35	-1.45	-1.27	-1.46	-1.57	-1.34

Table S10: Parameters and confidence interval for GEV distribution fitted to 12-month SSI at the end of December for different areal-extent (%, of Indo-Gangetic plain) for the period 1901-2015 simulated using different models.

Areal extent	Parameter	VIC			NOAH			CLM		
		Value	Lower CI	Higher CI	Value	Lower CI	Higher CI	Value	Lower CI	Higher CI
2	shape	-0.24	-0.37	-0.11	-0.11	-0.30	0.07	-0.23	-0.39	-0.07
	scale	0.63	0.53	0.76	0.89	0.73	1.09	0.63	0.52	0.76
	location	1.86	1.69	2.03	1.83	1.58	2.07	1.69	1.52	1.86
5	shape	-0.29	-0.42	-0.16	-0.17	-0.35	0.00	-0.26	-0.42	-0.10
	scale	0.61	0.51	0.73	0.84	0.69	1.01	0.62	0.52	0.76
	location	1.59	1.43	1.75	1.51	1.28	1.74	1.42	1.25	1.59
10	shape	-0.32	-0.47	-0.18	-0.22	-0.38	-0.05	-0.31	-0.46	-0.15
	scale	0.59	0.49	0.71	0.79	0.65	0.95	0.64	0.53	0.78
	location	1.33	1.17	1.49	1.23	1.01	1.44	1.19	1.02	1.37
20	shape	-0.32	-0.48	-0.17	-0.24	-0.41	-0.08	-0.36	-0.52	-0.20
	scale	0.59	0.49	0.71	0.73	0.60	0.88	0.66	0.54	0.80
	location	1.02	0.86	1.18	0.90	0.71	1.10	0.93	0.75	1.11
30	shape	-0.31	-0.47	-0.15	-0.25	-0.41	-0.08	-0.37	-0.54	-0.21
	scale	0.59	0.49	0.71	0.69	0.57	0.84	0.66	0.55	0.81
	location	0.79	0.64	0.95	0.69	0.50	0.88	0.74	0.56	0.92
40	shape	-0.30	-0.46	-0.14	-0.25	-0.41	-0.08	-0.37	-0.54	-0.21
	scale	0.59	0.48	0.71	0.67	0.55	0.81	0.66	0.54	0.80
	location	0.62	0.46	0.77	0.52	0.34	0.70	0.59	0.41	0.77
50	shape	-0.29	-0.45	-0.13	-0.25	-0.41	-0.09	-0.37	-0.54	-0.20
	scale	0.58	0.48	0.70	0.65	0.54	0.78	0.65	0.54	0.79
	location	0.46	0.31	0.62	0.38	0.20	0.55	0.45	0.27	0.63
60	shape	-0.28	-0.44	-0.12	-0.25	-0.41	-0.09	-0.36	-0.53	-0.19
	scale	0.57	0.47	0.69	0.63	0.52	0.76	0.64	0.53	0.78
	location	0.33	0.17	0.48	0.25	0.08	0.42	0.32	0.15	0.50
70	shape	-0.28	-0.44	-0.12	-0.25	-0.41	-0.09	-0.35	-0.52	-0.18
	scale	0.57	0.47	0.68	0.61	0.51	0.74	0.63	0.52	0.77
	location	0.20	0.04	0.35	0.14	-0.03	0.30	0.20	0.03	0.37
80	shape	-0.27	-0.43	-0.11	-0.25	-0.40	-0.09	-0.35	-0.52	-0.18
	scale	0.56	0.46	0.67	0.60	0.49	0.72	0.62	0.51	0.76
	location	0.07	-0.08	0.22	0.03	-0.13	0.19	0.08	-0.09	0.25
90	shape	-0.26	-0.42	-0.11	-0.25	-0.40	-0.10	-0.34	-0.52	-0.17
	scale	0.55	0.45	0.66	0.58	0.48	0.70	0.61	0.50	0.74
	location	-0.05	-0.20	0.10	-0.08	-0.24	0.08	-0.04	-0.21	0.13
100	shape	-0.26	-0.42	-0.10	-0.25	-0.41	-0.10	-0.34	-0.52	-0.17
	scale	0.54	0.44	0.65	0.57	0.47	0.69	0.60	0.49	0.73
	location	-0.20	-0.34	-0.05	-0.21	-0.36	-0.06	-0.19	-0.35	-0.03

Table S11: P (at 5% significance level) and h value for goodness of fit-test (chi-square test) performed to test fit of GEV distribution fitted to monsoon season SSI for selected areal extents (%) of drought in whole India. P > 0.05 and h = 0 indicates that fit-test do not reject the null hypothesis that GEV distribution fits the monsoon season SSI for selected areal extent of drought in India.

Areal Extents (%)	VIC		NOAH		CLM	
	p	h	p	h	p	h
2	0.4561	0	0.1224	0	0.2017	0
5	0.5614	0	0.0193	1	0.1253	0
10	0.0039	1	0.1075	0	0.2826	0
20	0.0895	0	0.4278	0	0.5560	0
30	0.8090	0	0.4843	0	0.7565	0
40	0.8653	0	0.6782	0	0.4341	0
50	0.6169	0	0.9178	0	0.2901	0
60	0.6535	0	0.8591	0	0.1416	0
70	0.6797	0	0.9521	0	0.4647	0
80	0.7765	0	0.6975	0	0.5668	0
90	0.7715	0	0.8193	0	0.7120	0
100	0.6236	0	0.5412	0	0.3994	0

Table S12: P (at 5% significance level) and h value for goodness of fit-test (chi-square test) performed to test fit of GEV distribution fitted to Rabi season SSI for selected areal extents (%) of drought in whole India. P > 0.05 and h = 0 indicates that fit-test do not reject the null hypothesis that GEV distribution fits the Rabi season SSI for selected areal extent of drought in India.

Areal Extents (%)	VIC		NOAH		CLM	
	p	h	p	h	p	h
2	0.0734	0	0.3150	0	0.5683	0
5	0.5521	0	0.2178	0	0.2678	0
10	0.1061	0	0.0437	1	0.8159	0
20	0.5601	0	0.1862	0	0.0359	1
30	0.0650	0	0.1159	0	0.4452	0
40	0.3063	0	0.2194	0	0.2711	0
50	0.4567	0	0.0423	1	0.2256	0
60	0.7388	0	0.0592	0	0.2453	0
70	0.8595	0	0.1084	0	0.7286	0
80	0.6454	0	0.1711	0	0.6279	0
90	0.1219	0	0.3509	0	0.5686	0
100	0.5028	0	0.2988	0	0.4191	0

Table S13: P (at 5% significance level) and h value for goodness of fit-test (chi-square test) performed to test fit of GEV distribution fitted to annual SSI for selected areal extents (%) of drought in Indo-Gangetic plain region. P > 0.05 and h = 0 indicates that fit-test do not reject the null hypothesis that GEV distribution fits the annual SSI for selected areal extent of drought in Indo-Gangetic plain region.

Areal Extents (%)	VIC		NOAH		CLM	
	p	h	p	h	p	h
2	0.4525	0	0.5415	0	0.3826	0
5	0.7838	0	0.3348	0	0.7478	0
10	0.0929	0	0.6391	0	0.9476	0
20	0.1229	0	0.2932	0	0.8235	0
30	0.1277	0	0.0367	1	0.6543	0
40	0.0596	0	0.3943	0	0.6637	0
50	0.0947	0	0.5460	0	0.7185	0
60	0.0715	0	0.4994	0	0.6978	0
70	0.2186	0	0.5070	0	0.5262	0
80	0.1146	0	0.4389	0	0.6752	0
90	0.0532	0	0.2795	0	0.6849	0
100	0.1506	0	0.9097	0	0.8758	0