Supplementary Materials

**Supplementary Text S1 –Bayesian version of Dynamic Factor Analysis and Hidden Markov Model**

The Bayesian implementations of DFA can optionally model the deviations of the latent trends with Student-t, which makes the modeling of extremes is better comparing to Gaussian distribution (Ward et al. 2019; Litzow et al., 2020). In addition, this approach provided posterior distributions that contribute to evaluating the reliability of each time series loading and share trends.

We set 3 parallel estimation chains with 2000 warm-up and sampling iterations respectively in Stan (Stan Development Team, 2018) as well as two latent trends in advance with two types of error structure (equal or unequal) for each trend. The best-fitted shared trend was determined by the joint information of three conditions, including the Bayesian Leave-One-Out Information Criterion (LOOIC), the posterior distribution of loading of each biology time series (95% or above as a threshold), and the convergence of model structures (Vehtari et al., 2017). The best-fitted model from the Bayesian DFA in our study is a one shared trend with time series-specific observation error variances. The best-fitted shared trend is next conducted to identify latent state shifts by using a Hidden Markov Model (HMM). When fitted to the trend posterior estimates, the HMM can treat the process that dividing total variance into a process and observation error component as discrete rather than continuous as other state-space models. Similarly, LOOIC is also used to determine the best-fitted number of alternative states in 3 states. Analyses were conducted using the 'bayesdfa' R package (R Core Team, 2018; Ward et al. 2019).
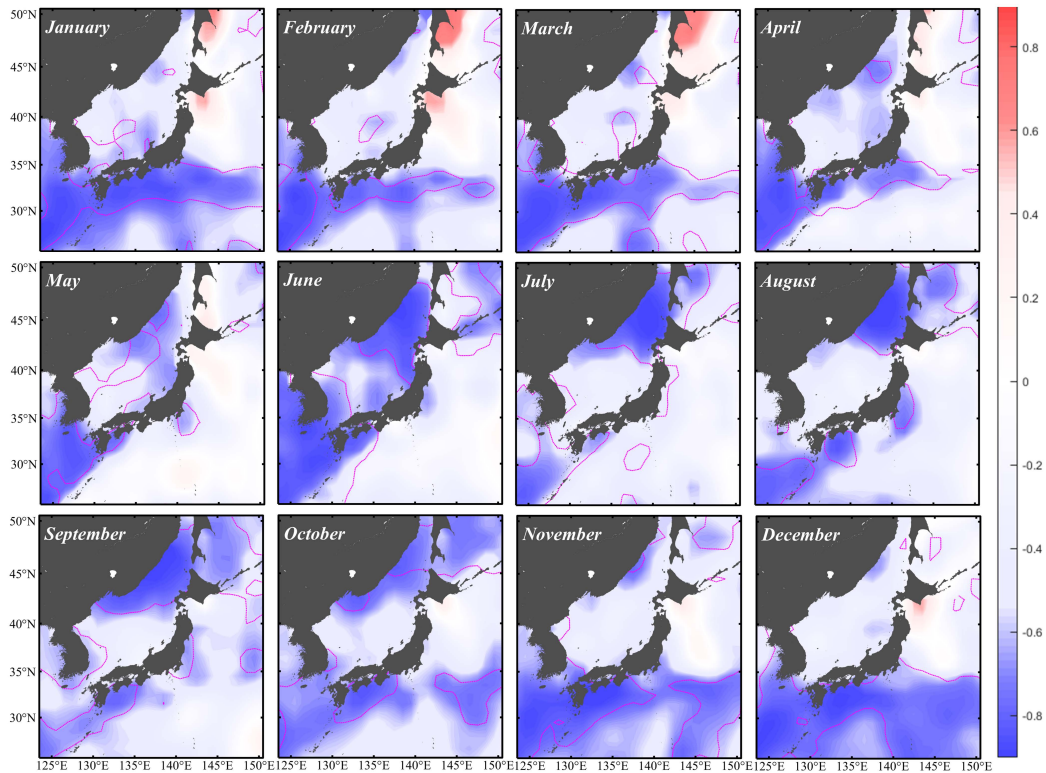
Figure S1. Maps of correlation coefficients between the shared trend out from the Bayesian DFA and monthly sea surface temperature (SST) fields. Purple dotted lines enclose area with significant correlations (*p*<0.05).
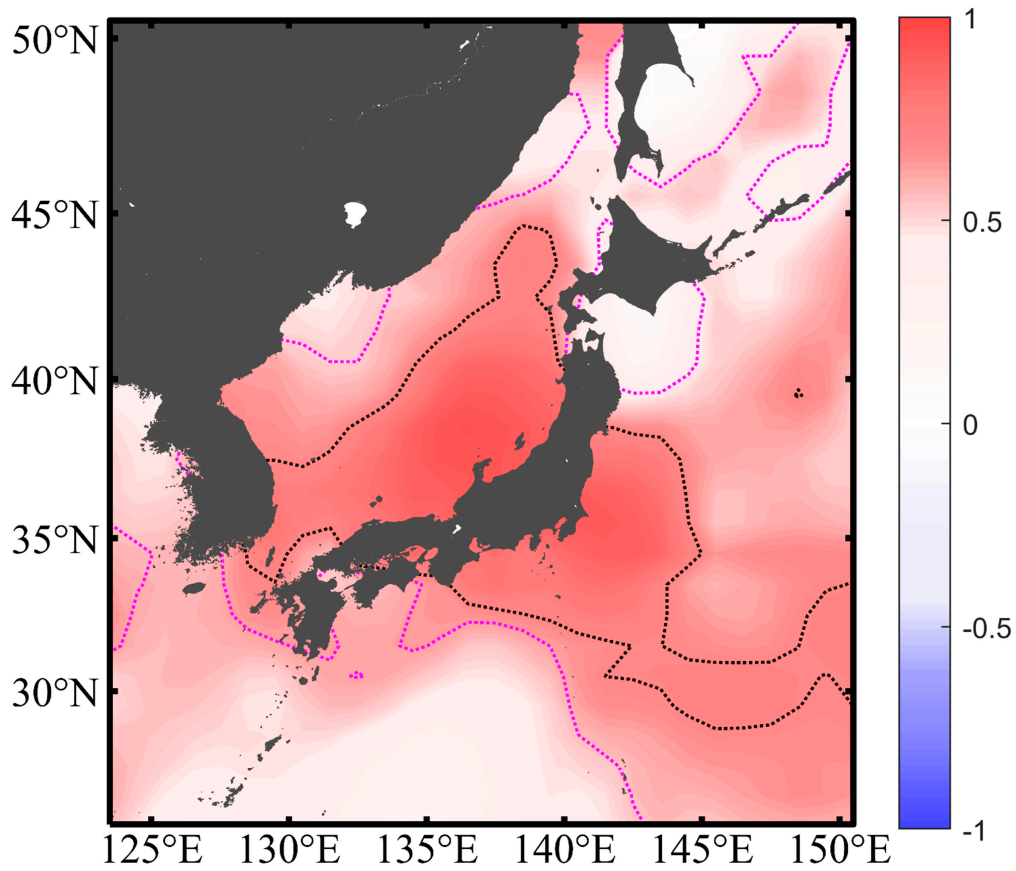
Figure S2. Maps of correlation coefficients between the time series of mean bottom water temperature(depth=317m,1956-2010) and winter(NDJFM) sea surface temperature (SST) field. Purple dotted lines enclose area with significant correlations (*p*<0.05). Black dotted lines enclose area with high correlations (r > 0.7).
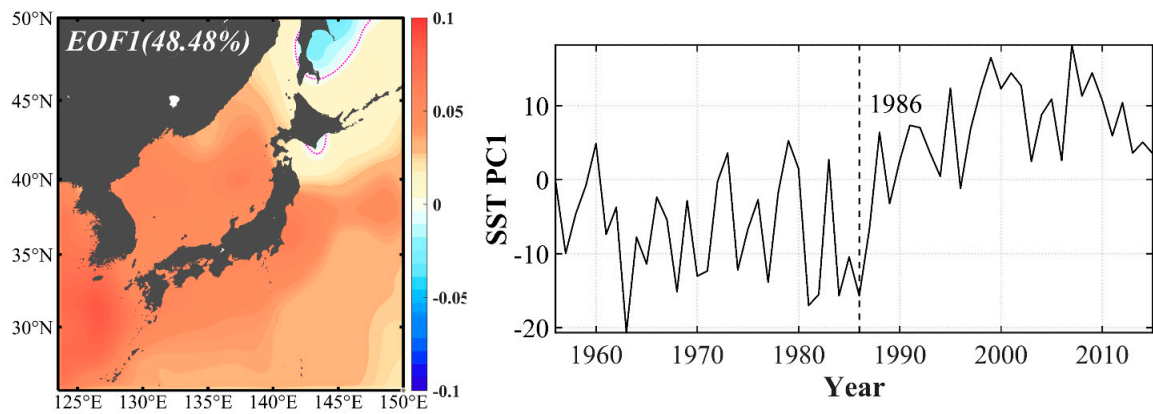
Figure S3. EOF analysis for winter（NDJFM）SST field in temperate waters of the NWP: The leading spatial pattern (eigen vector) (left) and the time series of SST PC1 (right).
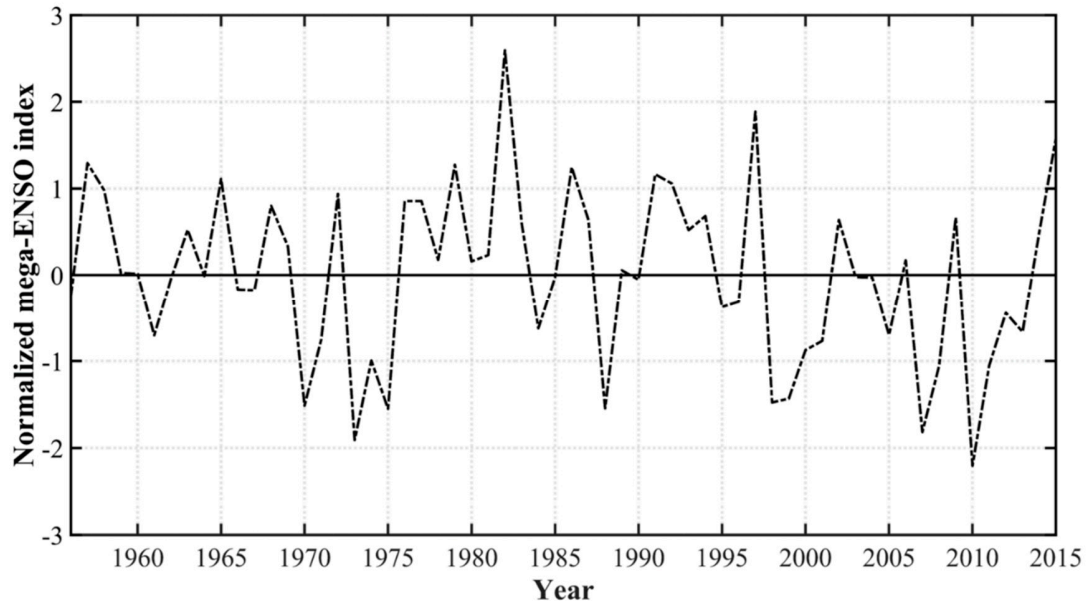
Figure S4. The time series of normalized mega-ENSO index (1956-2015).
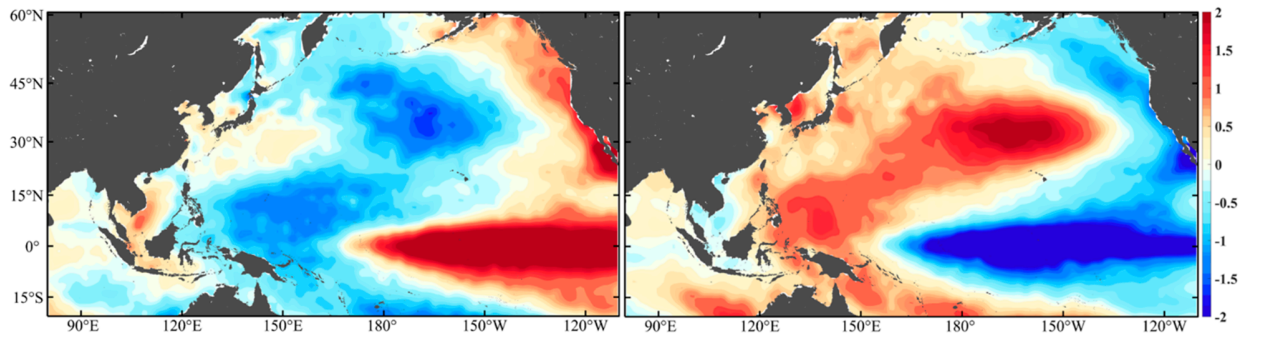
Figure S5. Maps of DJF sea surface temperature (SST) normalized anomalies in mega- El Niño (left) and mega-La Niña (right) during era2(1987–2015).
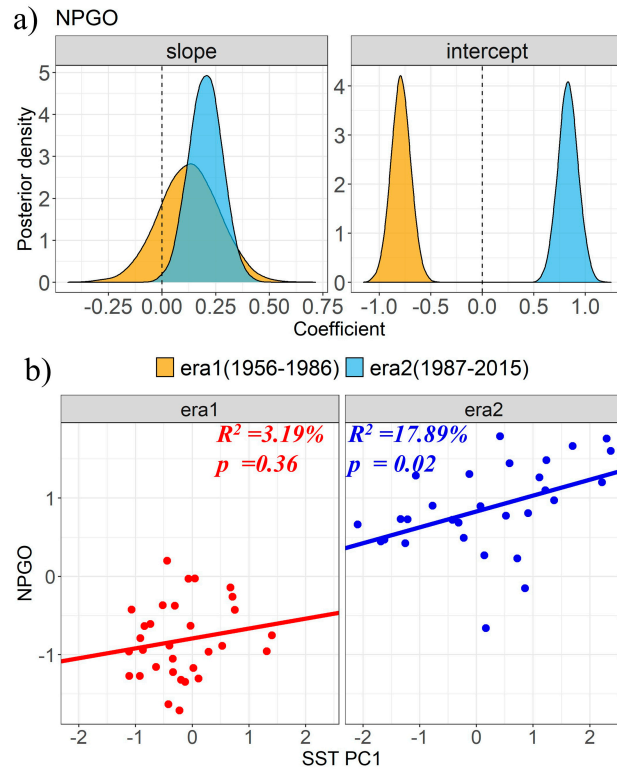
Figure S6. Non-stationary temporal relationships between NPGO and winter SST: (a) era-specific posteriors distribution for the slope and intercept of NPGO on winter SST PC1. (b) era-specific Scatter plots and best linear fits with corresponding R^2 and p values to NPGO and winter SST PC1 estimated by Bayesian regression models.
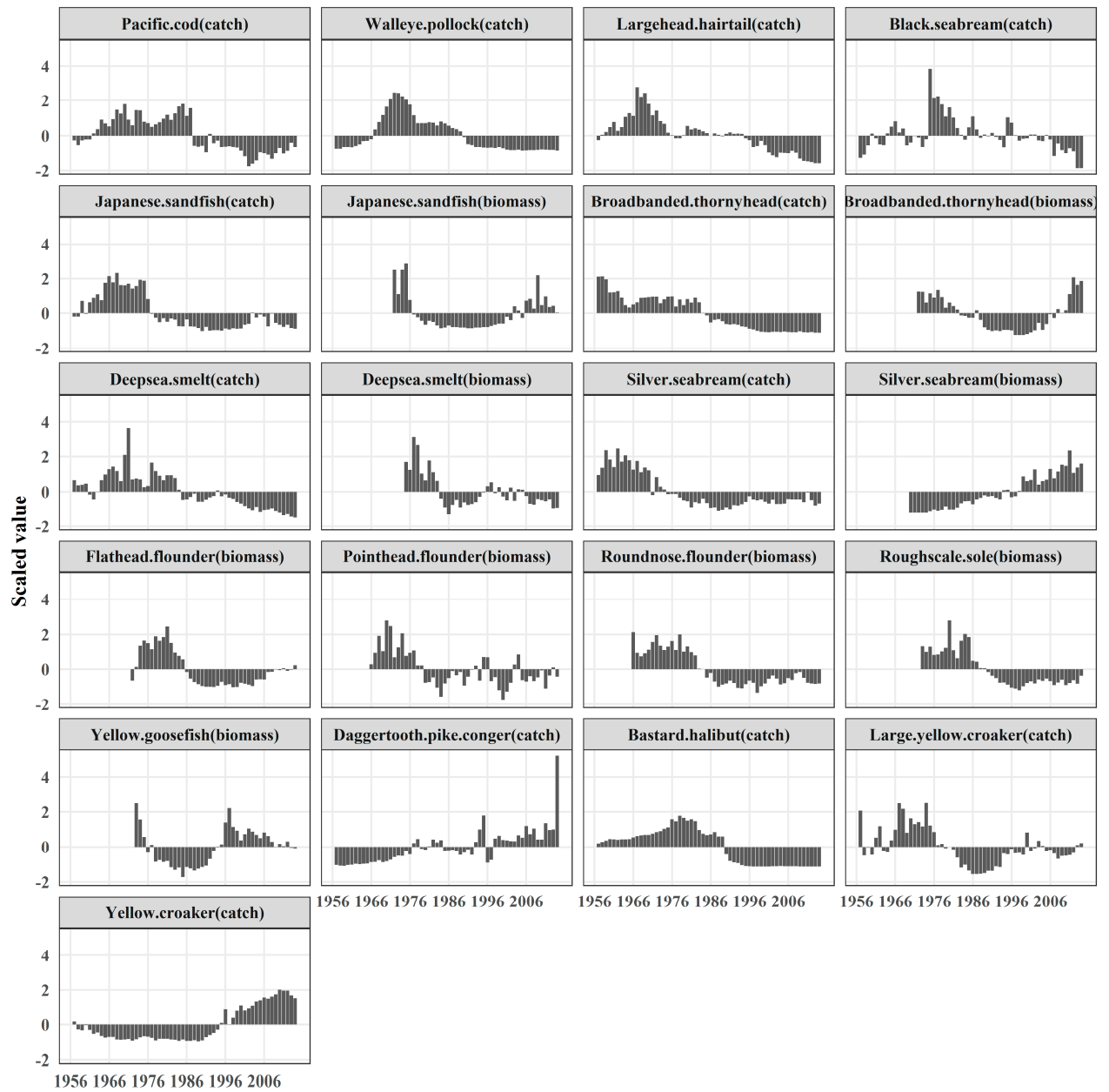
Figure S7. Time series data of demersal fishes (scaled).

Table S1. Large-scale climate indices used in our research. DJF = December-January-February.

Climate Indices	Source	Years	Season	Descriptions
North Pacific Gyre Oscillation (NPGO)	http://www.o3d.org/npgo/npgo.php	1956-2015	DJF	The second axis of North Pacific SSH anomalies
Arctic Oscillation Index (AOI)	https://www.ncdc.noaa.gov/teleconnections/ao/	1956-2015	DJF	The AO is a climate pattern characterized by winds circulating counterclockwise around the Arctic at around 55°N latitude
Siberian High Index(SHI)	http://rda.ucar.edu/datasets/ds010.1/	1956-2015	DJF	The mean sea level pressure over the region 40°N-60°N, 70°E-120°E.
East Asian Monsoon (MOI)	http://www.esrl.noaa.gov/psd/data/timeseries/	1956-2015	DJF	The MOI is the difference in the zonal wind speed (field at 300hPa) between 27.5°N-37.5°N, 110°E-170°E and 50°N-60°N, 80°E- 140°E.
Southern Oscillation Index (SOI)	https://www.esrl.noaa.gov/psd/enso/dashboard.html	1956-2015	DJF	The SOI is a standardized index based on the observed sea level pressure differences between Tahiti and Darwin, Australia.
mega-ENSO Index	B. Wang et al., 2013	1956-2015	DJF	The difference of averaged West Pacific K-shape SST and East Pacific triangle SST

Table S2. Time series data of demersal fishes (scaled).

year	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	TS13	TS14	TS15	TS16	TS17	TS18	TS19	TS20	TS21
1956	-1.53	-0.83	-0.33	-1.35	0.14		1.95	0.23	1.04									-1.04	0.07	0.01	-0.04
1957	-0.26	-0.77	-0.24	-1.29	-0.20		2.12	0.66	0.95									-1.04	0.20	2.06	0.17
1958	-0.52	-0.77	0.06	-1.10	-0.20		2.14	0.38	1.36									-1.07	0.29	-0.49	-0.28
1959	-0.26	-0.66	0.21	-0.54	0.69		1.96	0.40	2.35									-1.08	0.37	-0.02	-0.33
1960	-0.21	-0.66	0.50	0.13	-0.05		1.21	0.46	1.82									-1.03	0.45	-0.45	-0.04
1961	-0.21	-0.69	0.78	-0.14	0.60		1.22	-0.15	1.40									-1.03	0.44	0.53	-0.31
1962	0.13	-0.57	0.28	-0.49	0.86		1.30	-0.45	2.50									-0.97	0.42	1.18	-0.52
1963	0.38	-0.48	0.50	-0.52	1.11		0.86	0.02	1.70									-0.99	0.44	-0.21	-0.45
1964	0.91	-0.30	1.07	0.14	0.72		0.45	0.67	2.06									-0.97	0.44	-0.31	-0.64
1965	0.70	-0.29	1.28	0.52	1.76		0.31	0.98	1.78									-0.96	0.45	0.37	-0.73
1966	0.53	-0.19	1.12	0.83	2.15		0.49	1.28	1.26					0.28	2.14			-0.88	0.54	0.99	-0.70
1967	0.94	0.36	2.79	0.18	1.79		0.60	1.43	1.74					0.92	0.92			-0.86	0.62	2.48	-0.70
1968	1.49	0.78	2.18	0.41	2.33		0.85	1.18	1.11					1.93	0.72			-0.78	0.66	2.17	-0.85
1969	1.25	1.18	2.44	-0.54	1.63		0.89	0.61	1.37					1.01	0.89			-0.87	0.69	0.81	-0.86
1970	1.80	1.65	1.81	-0.38	1.62		0.95	2.08	1.22			-1.22		2.79	1.14			-0.83	0.68	1.63	-0.84
1971	0.91	2.08	1.16	-0.01	1.71		0.97	3.64	-0.18			-1.22		2.48	1.58			-0.73	0.76	1.30	-0.81
1972	0.60	2.46	1.43	-0.10	1.44	2.52	0.98	1.27	0.71		0.84	-1.21	-0.65	0.68	1.96	-0.01		-0.58	0.85	1.42	-0.92
1973	1.45	2.45	0.84	-0.63	1.57	1.12	0.54	1.25	0.75		0.30	-1.21	0.13	1.27	1.37	1.35	2.48	-0.51	0.90	1.16	-0.83
1974	1.44	2.25	0.67	-0.19	1.93	2.52	0.77	0.60	0.70		0.14	-1.21	1.37	2.06	1.10	0.97	1.56	-0.52	1.03	2.50	-0.72
1975	0.79	2.04	0.17	3.84	1.88	2.87	0.98	1.16	0.27	1.70	-0.13	-1.14	1.66	0.74	1.31	1.32	0.58	-0.21	1.11	1.21	-0.65
1976	0.71	1.77	0.03	2.12	0.79	0.73	0.99	0.89	0.33	1.25	-0.12	-1.05	1.51	0.92	1.63	0.81	-0.32	-0.42	1.57	0.84	-0.69
1977	0.50	1.17	-0.15	2.26	-0.05	-0.08	0.36	1.35	1.65	3.14	-0.11	-1.11	1.18	1.06	1.11	0.82	0.12	0.22	1.46	0.12	-0.75
1978	0.65	0.71	-0.15	1.78	-0.27	-0.24	0.76	0.95	1.18	2.70	-0.33	-1.06	1.90	0.21	2.00	1.00	-0.86	0.45	1.77	0.17	-0.89
1979	0.77	0.72	0.03	1.10	-0.52	-0.44	0.45	0.30	0.91	1.03	-0.52	-0.88	1.64	0.21	0.99	1.24	-0.76	-0.10	1.66	-0.07	-0.80
1980	0.97	0.72	0.56	1.61	-0.29	-0.66	0.79	0.60	0.66	0.65	-0.57	-1.05	1.86	-0.77	1.33	2.79	-0.86	-0.16	1.50	0.01	-0.80
1981	1.19	0.77	0.37	1.03	-0.50	-0.44	0.58	0.39	0.94	1.77	-0.93	-1.05	2.45	-0.73	0.96	1.07	-0.82	0.05	1.58	-0.14	-0.80
1982	0.90	0.74	0.43	0.44	-0.31	-0.50	0.91	0.20	0.94	1.11	-0.62	-0.95	1.53	-0.46	0.77	0.62	-1.17	0.42	1.47	-0.62	-0.84
1983	1.27	0.58	0.35	0.06	-0.37	-0.70	0.60	-0.14	0.79	0.62	-0.69	-0.70	0.93	-1.04	0.03	1.65	-1.31	0.26	0.96	-1.18	-0.86
1984	1.67	0.80	0.26	-0.23	-0.74	-0.86	-0.01	-0.16	0.12	-0.38	-0.38	-0.57	0.74	-1.55	0.00	2.03	-1.18	0.39	0.75	-1.02	-0.92

Year																					
1985	1.81	0.70	0.14	0.47	-0.76	-0.83	-0.13	-0.26	-0.49	-0.93	-0.68	-0.57	0.56	-0.80	-0.48	1.86	-1.72	-0.21	0.68	-1.35	-0.84
1986	1.12	0.57	0.01	1.09	-0.36	-0.70	-0.53	-0.26	-0.43	-1.31	-0.96	-0.74	-0.16	-0.50	-0.21	0.47	-1.16	-0.19	0.72	-1.55	-0.92
1987	1.58	0.44	0.13	0.36	-0.76	-0.79	-0.39	0.16	-0.28	-0.79	-0.93	-0.44	-0.53	-0.10	-0.70	0.41	-1.24	-0.17	0.85	-1.55	-0.92
1988	-0.56	0.38	0.06	-0.12	-0.76	-0.79	-0.35	-0.39	-0.11	-0.50	-1.11	-0.34	-0.73	-0.35	-0.99	0.07	-1.35	-0.25	0.59	-1.53	-0.89
1989	-0.62	0.25	-0.02	0.07	-0.84	-0.83	-0.47	-0.81	-0.60	-0.93	-1.06	-0.20	-0.84	-0.16	-0.87	0.05	-1.25	-0.45	0.60	-1.50	-0.94
1990	-0.56	-0.08	0.10	-0.03	-1.01	-0.83	-0.62	-0.95	-0.60	-0.64	-0.93	-0.26	-0.96	-0.92	-0.80	-0.15	-1.16	-0.32	-0.43	-1.36	-0.89
1991	-0.97	-0.47	0.19	0.16	-0.78	-0.86	-0.65	-1.02	-0.49	-0.78	-1.04	-0.23	-0.99	-0.42	-0.64	-0.37	-1.07	-0.14	-0.81	-1.37	-0.71
1992	0.11	-0.52	0.11	-0.06	-0.99	-0.86	-0.62	-0.97	-0.31	-0.73	-0.80	-0.34	-1.00	-0.02	-0.78	-0.50	-0.69	-0.45	-0.90	-1.12	-0.59
1993	-0.42	-0.66	0.12	-0.23	-0.97	-0.83	-0.66	-1.02	-0.23	-0.63	-0.82	-0.41	-1.00	0.19	-1.06	-0.76	-0.20	0.29	-0.93	-1.15	-0.48
1994	-0.28	-0.66	0.11	-0.69	-0.96	-0.83	-0.75	-0.95	0.09	-0.28	-0.75	0.09	-0.94	-0.65	-1.08	-0.75	0.03	1.00	-1.05	-0.38	-0.29
1995	-0.66	-0.71	-0.14	1.04	-1.00	-0.79	-0.78	-0.95	-0.25	-0.03	-0.61	0.12	-0.72	0.69	-0.85	-0.87	0.15	1.78	-1.10	-0.43	0.09
1996	-0.62	-0.72	-0.25	0.74	-0.87	-0.79	-0.88	-0.97	-0.13	0.32	-0.25	-0.30	-0.90	0.68	-0.65	-1.04	1.38	-0.91	-1.11	-0.11	0.85
1997	-0.58	-0.71	-0.67	0.02	-0.92	-0.73	-0.92	-1.25	-0.32	0.54	-0.46	-0.25	-0.84	-0.68	-0.77	-1.10	2.21	-0.75	-1.12	-0.36	0.01
1998	-0.63	-0.73	-0.57	-0.27	-0.86	-0.66	-1.00	-1.25	-0.40	-0.07	-0.52	0.05	-1.01	-0.45	-1.33	-1.19	1.14	0.47	-1.12	-0.34	0.38
1999	-0.71	-0.66	-0.28	-0.17	-0.88	-0.60	-1.06	-1.25	-0.62	0.27	-0.43	0.87	-1.01	-1.18	-0.97	-0.97	0.93	0.63	-1.12	-0.46	0.77
2000	-0.88	-0.75	-0.52	-0.14	-0.88	-0.60	-1.07	-1.18	-0.71	-0.26	-0.60	0.62	-0.77	-1.72	-0.81	-0.78	0.38	0.41	-1.12	0.83	1.07
2001	-1.19	-0.82	-0.98	0.08	-0.66	-0.21	-1.09	-1.10	-0.85	-0.52	-0.70	0.68	-0.82	-1.26	-0.54	-0.69	0.73	0.37	-1.12	-0.22	0.79
2002	-1.76	-0.85	-1.14	0.06	-0.61	-0.40	-1.05	-0.97	-0.98	0.25	-0.48	1.27	-0.88	-0.77	-0.35	-0.81	1.05	0.34	-1.12	-0.07	0.90
2003	-1.61	-0.85	-1.25	-0.26	0.02	0.38	-1.05	-0.55	-1.10	-0.54	-0.73	0.41	-0.95	0.26	-0.53	-0.58	0.88	0.33	-1.12	0.35	1.05
2004	-1.43	-0.82	-1.00	-0.30	-0.25	0.15	-1.07	-0.95	-0.90	0.15	-0.73	0.62	-0.57	0.82	-0.86	-0.66	0.69	0.67	-1.10	0.07	1.31
2005	-0.97	-0.88	-1.00	0.04	-0.09	-0.27	-1.04	-0.62	-1.18	0.12	-0.70	0.69	-0.56	-0.62	-0.79	-0.53	0.50	0.53	-1.11	-0.24	1.41
2006	-1.03	-0.86	-1.02	-0.20	-0.20	0.70	-1.06	-0.07	-1.08	-0.23	-0.41	1.30	-0.58	-0.70	-0.50	-0.68	0.82	1.19	-1.11	-0.17	1.57
2007	-1.10	-0.85	-0.89	-1.19	-0.76	0.80	-1.09	-0.28	-1.04	-0.72	-0.46	0.76	-0.16	-0.39	-0.61	-0.90	0.63	0.73	-1.12	-0.38	1.50
2008	-1.35	-0.86	-1.00	-0.43	-0.02	0.25	-1.08	0.22	-0.98	-0.77	-0.43	1.15	-0.14	-0.68	-0.23	-0.75	0.29	1.04	-1.12	-0.68	1.62
2009	-1.02	-0.84	-1.33	-0.85	-0.56	2.19	-1.03	-0.01	-1.13	-0.40	-0.43	1.54	-0.02	-0.46	-0.15	-0.59	0.02	0.42	-1.12	-0.52	1.76
2010	-0.74	-0.81	-1.46	-1.02	-0.66	0.44	-1.08	0.16	-1.22	-0.51	-0.62	1.47	-0.05	-0.07	-0.49	-0.90	0.18	0.43	-1.12	-0.51	2.01
2011	-1.04	-0.82	-1.49	-0.75	-0.78	0.99	-1.10	1.12	-1.36	-0.57	-0.04	2.34	0.06	-1.09	-0.76	-0.78	0.06	1.35	-1.12	-0.47	1.96
2012	-0.90	-0.83	-1.53	-0.92	-0.65	0.34	-1.07	2.08	-1.29	-0.41	-0.51	1.07	-0.10	-0.36	-0.81	-0.62	0.30	0.97	-1.12	-0.34	1.97
2013	-0.39	-0.83	-1.58	-1.87	-0.84	0.41	-1.10	1.64	-1.44	-0.98	-0.82	1.38	-0.02	0.10	-0.83	-0.82	-0.03	1.00	-1.12	0.11	1.69
2014	-0.64	-0.88	-1.59	-1.87	-0.89	0.02	-1.11	1.87	-1.50	-0.96	-0.70	1.60	0.23	-0.42	-0.80	-0.37	-0.07	5.19	-1.12	0.21	1.53
2015	-0.93	-0.89	-1.69	-1.73	-0.67	0.67	-1.09	2.13	-1.42	-0.73	-0.62	1.70	0.12		-0.73	-0.36	0.09	0.59	-1.12	0.14	1.63

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