A Look at Global Tropical Cyclone Activity during 1995: Contrasting High Atlantic Activity with Low Activity in Other Basins

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ABSTRACT

During 1995, there was a near-record number of named tropical cyclones in the North Atlantic basin. This unusual event fueled speculation that it marked a tangible signal of global climate change, or that it marked a return to a period of higher tropical cyclone activity in the Atlantic, such as that which has been documented to have occurred during the decades of the 1940s through the 1960s. Less publicized, the tropical cyclone activity in other basins during 1995 was almost everywhere below normal. The concept of global and basin ‘‘prolific’’ years and ‘‘meager’’ years is introduced. During the past 30 years, the Atlantic has had two prolific years: 1969 and 1995. Although the annual number of tropical cyclones in each of the other basins is uncorrelated with the annual number of tropical cyclones in the Atlantic, the two Atlantic prolific years of 1969 and 1995 were meager years in some of the other major basins, and below normal years in all of them. In the time series of the annual number of tropical cyclones in all basins except the Atlantic, 1969 and 1995 rank lowest and third lowest, respectively. The known relationships of the annual number of tropical cyclones in the Atlantic with ENSO and with the quasi-biennial ossilation are insufficient to explain the unusual global distribution of tropical cyclones during 1995.

1. Introduction

The time series of the annual numbers of tropical cyclones (TCs) in the various ocean basins (and possible modifications to the regional and global TC distribution by climate change) have become a high-profile topic of scientific and popular interest (e.g., see Lighthill et al. 1994). The near-record number of named TCs in the Atlantic during 1995 was well publicized and fueled speculation that it marked a tangible signal of global climate change. Others (e.g., Gray 1990; Goldenberg et al. 1996) are concerned that, while not a harbinger of global climate change, we may be returning to a period of higher Atlantic TC activity, such as that which has been documented to have occurred during the decades of the 1940s–1960s (Gray 1990; Neumann et al. 1993) when many more intense TCs made landfall on the North American coastline than in the decades to follow.

Less publicized, the TC activity in other basins during 1995 was almost everywhere below normal, resulting in a global number well below normal. This paper explores the global distribution of TCs during 1995. The historical record of TC distribution within several of the world’s major TC basins is examined. The concept of ‘‘prolific’’ years and ‘‘meager’’ years is introduced as a characteristic of the time series of the global and basin TC distribution. Factors that purportedly affect global and basin TC distributions, such as the El Niño–Southern Oscillation (ENSO) and the quasi-biennial oscillation (QBO), are examined with respect to the historical record of global and basin TC distribution; the possible role of these factors in the unusual global and basin distribution of TCs during 1995 is also examined. A strikingly similar global distribution of TCs during 1969 (i.e., an Atlantic prolific year associated with low numbers of TCs in most other basins) raises unanswered questions concerning the large-scale mechanisms responsible for Atlantic prolific years.

2. Data and method

The historical record of TC activity in the western North Pacific, North Indian Ocean, and Southern Hemisphere was obtained from the best track archives[1] of the Joint Typhoon Warning Center (JTWC), Guam (see the appendix for a brief description of the JTWC). The historical record of TC activity in the eastern North Pacific was obtained from the best track archives that are pub-

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[1] The best track archives of the JTWC are contained in the Global Tropical/Extratropical Cyclone Climate Atlas (GTECCA) compact disc, which may be obtained from the National Climatic Data Center, Asheville, North Carolina.

TABLE 1. Annual tropical cyclone distribution using JTWC and NHC best track archives. Annual numbers of tropical cyclones in the NAT through 1989, and the annual numbers of tropical cyclones in parentheses are from Neumann (1993). Values highlighted with one asterisk indicate meager years, and values highlighted with two asterisks indicate prolific years (as defined in section 4).

Year	WNP	NAT	ENP	NIO	SH	Global	Global − NAT
1966	30	11	13	—	—	—	—
1967	35**	8	17	—	—	—	—
1968	27	8	19	—	—	—	—
1969	19*	18**	10*	(6)	(19)*	(72)	(54)*
1970	24	10	18	(7)	(24)	(83)	(73)
1971	35**	13	18	(7)	(29)	(102)**	(89)
1972	30	7	12	(7)	(30)	(86)	(79)
1973	21	8	12	(6)	(31)	(78)	(70)
1974	32	11	17	(7)	(30)	(97)	(86)
1975	20*	9	16	6	(24)	(75)	(66)
1976	25	10	14	5	(27)	(81)	(71)
1977	19*	6	8*	5	(28)	(66)*	(60)
1978	28	12	18	4	(30)	(92)	(80)
1979	23	9	10*	7	(24)	(73)	(64)
1980	24	11	14	2*	(30)	(81)	(70)
1981	28	12	15	3	24	82	70
1982	26	6	19	5	25	81	75
1983	23	4*	21	3	25	76	72
1984	27	13	18	4	30	92	79
1985	26	11	22	6	35**	100	89
1986	27	6	17	3	33**	86	80
1987	24	7	18	8	28	84	77
1988	26	12	13	5	21	78	66
1989	31	11	17	3	28	90	79
1990	30	14	20	4	29	97	83
1991	30	8	14	4	22	78	70
1992	32	6	24**	13**	30	105**	99**
1993	30	8	14	2*	27	81	73
1994	36**	7	17	5	30	95	88
1995	26	19**	10*	4	22	81	62
Mean	27.1	9.8	15.8	4.8	27.2	84.9	75.0
σ	4.5	3.4	3.8	2.4	3.8	9.8	9.9

lished yearly in *Monthly Weather Review* by the Tropical Prediction Center [TPC, formerly the National Hurricane Center (NHC)], Miami (e.g., Pasch and Mayfield 1996). The time series of the annual number of TCs in the Atlantic was obtained from Neumann (1993) and supplemented by statistics from the TPC (e.g., Rappaport et al. 1998) for the years since 1990 (the last year in Neumann's summary). The TC activity of the Southern Hemisphere was obtained from the archives of the JTWC. Southern Hemisphere statistics, prior to the inauguration of JTWC warning responsibility there, were obtained from Neumann (1993) (Table 2).

Statistics of TC activity were compiled and examined for five basins (Table 1): 1) the western North Pacific (WNP), 2) the North Indian Ocean (NIO), 3) the North Atlantic (NAT), 4) the eastern North Pacific (ENP), and 5) the Southern Hemisphere (SH). Numbers of TCs in the ENP are examined for only the years of reliable satellite coverage (i.e., beginning circa 1966). Annual numbers of TCs in the SH begin during 1969 in Neumann's record and are available since 1981 in the JTWC archives (1981 was the year during which the JTWC was tasked with producing warnings there—see the appendix). To analyze the global distribution of TCs during 1995 (and the historical global distribution of TCs), only the named TCs (i.e., those TCs that possess 1-min sustained surface wind of 35 kt or greater) are included in the tabulations for the WNP, ENP, and the NAT. In the NIO and the SH, all TCs for which the JTWC issued TC warnings are counted regardless of their peak intensity. This is done since for several years in the early part of the best track data archives for these basins, the peak intensities of the TCs are not recorded. Also, the threshold sensitivity for the JTWC to go into warning status for TCs in these basins (especially the SH) is higher than for those in the WNP.

The global number of TCs during a given year is tabulated according to the way that the JTWC compiles this statistic: the number of TCs in the Northern Hemisphere (NH) are accrued during the calendar year (e.g., 1 January 1995–31 December 1995); then, the SH TCs that occurred during the period 1 July of the prior year through 30 June of the indicated calendar year are added to the NH totals to arrive at the annual global number of TCs (e.g., the global number of TCs during 1995 include the NH TCs during the calendar year of 1995 plus the TCs of the SH during the yearlong period 1 July 1994–30 June 1995). The World Meteorological Organization (WMO) tabulates its global number of TCs by coupling the NH number of TCs of a given calendar

TABLE 2. Annual tropical cyclone distribution (after Neumann 1993).

Year	WNP	NAT	ENP	NIO	SH	Global
1968	27	8	18	7	19	79
1969	19	18	10	6	24	77
1970	24	10	19	7	29	89
1971	35	13	18	7	30	103
1972	30	7	14	7	31	89
1973	21	8	12	6	30	77
1974	32	11	18	7	24	92
1975	20	9	17	7	27	80
1976	25	10	15	10	28	88
1977	19	6	8	6	30	69
1978	28	12	19	6	24	89
1979	23	9	10	5	30	77
1980	24	11	14	3	32	86
1981	28	12	15	6	24	85
1982	26	6	23	5	22	82
1983	23	4	21	3	25	76
1984	27	13	21	3	26	90
1985	26	11	23	7	28	95
1986	27	6	17	1	25	75
1987	24	7	20	5	22	79
1988	26	12	15	3	29	85
1989	31	11	17	3	21	80

year with the SH TCs that occurred during the period 1 July of the calendar year in question through 30 June of the following year (Table 3). Herein, the annual global number of TCs is compiled according to the method of the JTWC. The JTWC global accounting is favored based simply on the fact that approximately 80% of the SH TCs occur between 1 January and 30 June of any given calendar year. In addition, there is a statistically significant positive cross correlation between the annual SH totals and the WNP annual TC totals when these two time series are compared as per the JTWC accounting. When the SH annual totals are cross correlated with the WNP (as per the WMO convention), the two time series are uncorrelated. Basin interrelationships are discussed in more detail in section 4.

Tropical cyclones are a rare outcome of atmospheric processes operating in the Tropics and subtropics. Approximately 85 TCs reach tropical storm intensity throughout the world during each calendar year (Gray 1975). Given the relative rarity of the formation of TCs, it would seem that some very special conditions must be present in order for them to form. Gray (1968, 1975, 1979) found that the climatological frequency of TC genesis was related to six factors:

1) above-average low-level vorticity;
2) above-average middle-level moisture;
3) conditional instability through a deep layer;
4) a warm and deep oceanic mixed layer;
5) weak vertical shear of the horizontal wind; and
6) an initial disturbance located at least a few degrees poleward of the equator.

Although these criteria exist over large portions of the tropical oceans for extended periods of time, TC genesis remains relatively infrequent. In studies of individual TCs (e.g., McBride 1981a,b; Zehr 1992), one common feature emerged as the most important factor in the genesis of a TC: a preexisting disturbance containing abundant deep convection. Now, there are lots of such disturbances in the Tropics and subtropics and it remains largely unknown why some produce TCs and others do not (Frank 1987). Speculations on the causes of the distribution of TCs during 1995 are largely based on examinations of the large-scale flow patterns with respect to the aforementioned factors influencing TC genesis.

3. The tropical cyclones of 1995

a. *A busy year in the Atlantic*

The busy NAT hurricane season of 1995 was well publicized by the national news media, and has been the subject of many articles and talks in meteorological journals and conferences. The annual total of 19 named TCs in the NAT basin during 1995 was nine above the long-term average. The NAT annual total has not been this high since 1933 when there were 21 TCs of at least tropical storm intensity. The most recent year of comparable activity was 1969 when there were 18 TCs of at least tropical storm intensity. An in-depth analysis of the 1995 NAT hurricane season is described by Lawrence et al. (1998).

b. *The TC distribution in other basins during 1995*

1) WESTERN NORTH PACIFIC

For the WNP, 1995 included 15 typhoons, 11 tropical storms, and 8 tropical depressions. The calendar-year total of 34 significant TCs in the WNP was 3 above the long-term (36-yr) average. The year's total of 26 TCs of at least tropical storm intensity was two below the long-term average (Fig. 1). The year of 1995 was the first since 1988 during which the number of TCs of at least tropical-storm intensity was below normal. Likewise, the total of 15 typhoons was below the long-term average of 18. Since 1959, 12 years (1969, 1970, 1973–1980, 1983, and 1988) have had 15 or less typhoons (JTWC 1995). Most of the years with a low number of

TABLE 3. Comparison of JTWC SH totals vs WMO SH totals for comparable years.

Year	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
JTWC	0	0	0	0	0	0	0	0	0	0	0	0	24	25	25	30	35	33	28	21	28	29	22	30	27	30	22
WMO	19	24	29	30	31	30	24	27	28	30	24	30	32	24	22	25	26	28	25	22	28	21	0	0	0	0	0

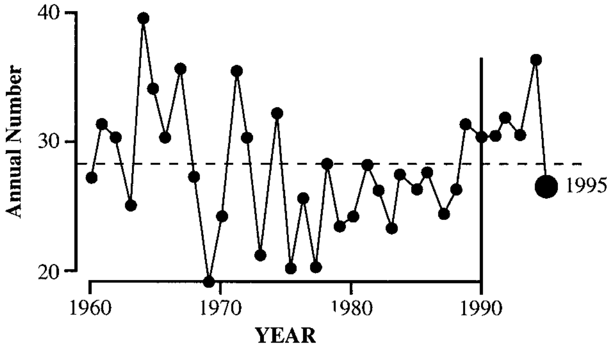

FIG. 1. Tropical cyclones of tropical storm or greater intensity in the western North Pacific (1960–95). Dashed line indicates the long-term annual average.

typhoons occurred during an 8-yr run from 1973 to 1980. The average intensity of all the 1995 TCs was the second lowest during the 21-yr period 1975–95 (Fig. 2).

The annual mean genesis location (Fig. 3) was west of normal—the first such occurrence since 1990. The annual mean genesis location of TCs that form in the WNP is highly dependent upon the status of ENSO, and tends to be to the east of normal during El Niño years and west of normal during La Niña years (Li 1988; Dong 1988; Lander 1994). During 1995, six TCs formed east of 160°E, but most formed in the Philippine Sea (west of 140°E) and eight formed in the South China Sea, resulting in the westward displacement of the annual mean genesis location. With few exceptions, TC formation was confined to the South China Sea and the Philippine Sea from May through the end of the year. The low-level wind of the tropical Pacific in 1995 was dominated by easterly flow. As a consequence, the summer monsoon circulation of the WNP was weak—in stark contrast to the very active summer monsoon of 1994. During June, July, and August of 1995, low-level easterly wind flow was unusually persistent in the low latitudes of the WNP (Fig. 4a), and the normal southwest monsoon of the Philippine Sea (with its episodic extensions further eastward) was replaced by mean monthly easterly flow [Climate Prediction Center (CPC) 1995]. Also, during these months, the axis of the low-level subtropical ridge was displaced approximately 5° equatorward of normal. With the monsoon trough weakened or absent during much of 1995, a ready source of above-average low-level vorticity (one of Gray's six factors related to TC genesis) was missing. Corresponding

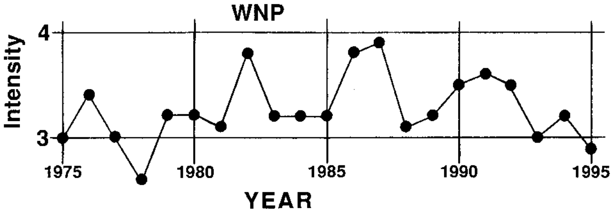

FIG. 2. Average intensity of TCs in the WNP for each year from 1975 to 1995. Intensity units are based upon the following ranges of 1-min sustained surface winds: 1 = 25–44 kt; 2 = 45–63 kt; 3 = 64–80 kt; 4 = 81–95 kt; 5 = 96–115 kt; 6 = 116–135 kt; and 7 > 135 kt. Ranges 3–7 correspond to categories 1–5 on the Saffir–Simpson hurricane scale (Simpson 1974).

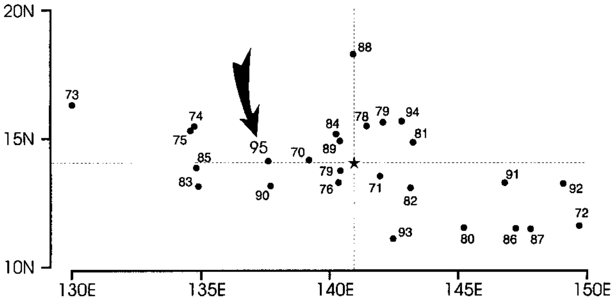

FIG. 3. Mean annual genesis locations of significant tropical cyclones in the WNP for the period 1970–95. The 1995 mean annual genesis location is indicated by the arrow. The star lies at the intersection of the 26-yr average latitude and longitude of genesis. For statistical purposes, genesis is defined as the first 1-min sustained surface 25 kt (13 m s^{-1}) wind based on the JTWC best track.

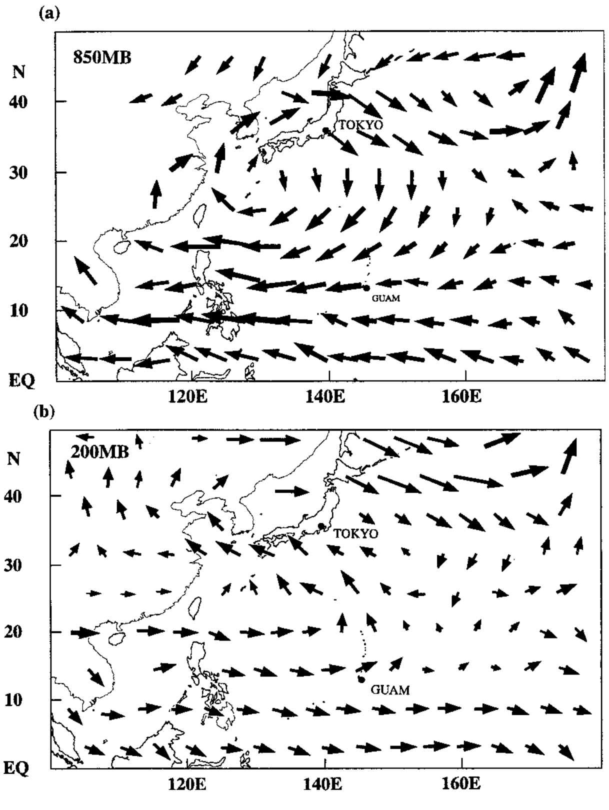

FIG. 4. Wind anomalies over the WNP: (a) August 1995 mean 850 mb and (b) August 1995 mean 200 mb. Arrows indicate wind direction and arrow length is proportional to wind speed. The low-latitude westerly wind anomalies at 200 mb and the low-latitude easterly wind anomalies at 850 mb are both approximately 10 kt (5 m s^{-1})—the discrepancy of arrow length is due to the fact that the 200-mb arrows are scaled at approximately one-third the length of the 850-mb wind arrows. [Wind anomalies are adapted from the CPC (1995).]

anomalies in the upper troposphere consisted of westerly wind anomalies over the low latitudes of the WNP (Fig. 4b). Low-level easterly anomalies coupled with upper-tropospheric westerly anomalies resulted in above-average westerly shear over most of the deep Tropics of the WNP. The vertical shear of the horizontal wind is another of Gray's six factors related to TC genesis: too much, and TC genesis is inhibited.

Thus, excessive westerly vertical shear over much of the WNP during 1995 and a weakened monsoon trough may be related to the below normal number of named TCs, the reduction in the average intensity of TCs for the year, and the westward displacement of TC genesis.

2) EASTERN NORTH PACIFIC

During 1995, the ENP experienced a near-record low number of TCs. The annual total of 10 was only two above the record low of eight named TCs that occurred during 1977. It was six below the long-term average and 14 below the number of named TCs that occurred in this basin during the very active year of 1992. Since 1966, only four years (1969, 1977, 1979, and 1995) have had 10 or fewer named TCs (Table 1). An in-depth analysis of the 1995 ENP hurricane season is described by Rappaport et al. (1998).

3) NORTH INDIAN OCEAN

Tropical cyclones in the NIO (especially in the Bay of Bengal) have been some of the deadliest in history. In terms of storm surge, the Bay of Bengal is the most dangerous TC basin in the world. Particularly sensitive is the low-lying Ganges River delta region of Bangladesh. One of the world's greatest TC-related disasters occurred in 1970 when an estimated 300 000 lives were lost as a result of a powerful TC that made landfall there. A similar TC struck the coastal regions of Bangladesh during April 1991 and devastated the coastal city of Chittagong with surface winds in excess of 130 kt (67 m s^{-1}). The accompanying storm surge was measured at 20 ft (6 m). The official death toll of the 1991 TC was 138 000 and the damage was estimated at $1.5 billion (US) (JTWC 1991).

The NIO is a marginal basin with a long-term annual average of 5 TCs, ranging from a high of 13 TCs during 1992 to a low of 2 TCs in 1980 and 1993. The year of 1995 included four numbered TCs in the NIO: one in the Arabian Sea, and three in the Bay of Bengal. Two of these—TC 03B (B for Bay of Bengal) and TC 04B—exceeded hurricane intensity; the other two—TC 01B and TC 02A (A for Arabian Sea)—reached peak intensities of 45 kt (23 m s^{-1}) and 55 kt (29 m s^{-1}), respectively. Three of the four TCs in the NIO during 1995 formed in the monsoon trough. TC 01B can be traced to the remnants of Tropical Depression 16W, which, after making landfall in Vietnam, passed across southeast Asia and regenerated in the Bay of Bengal.

The NIO has one of the world's most unusual annual distributions of TCs: of the mean annual total of five, approximately two occur in the spring and three occur in the fall (there is an unusual midsummer minimum when the monsoon trough has moved to its northernmost position, mostly over land). During 1995, there were no significant TCs in the NIO during the spring. All four of the 1995 significant TCs in the NIO occurred in the two-month period 16 September–18 November. The lack of significant TCs in the NIO during the spring of 1995 may be the result of excessive vertical wind shear. During April 1995 (as in the WNP for most of 1995) the low-level winds were anomalously easterly and the upper-level winds were anomalously westerly (CPC 1995), resulting in excessive westerly shear over much of the NIO. During May, the low-level southwesterlies were slightly stronger than normal and the upper-level flow was anomalously easterly resulting in unusually high easterly shear over the NIO. During the fall, when the monsoon trough moved back over water, the low-level and upper-level wind patterns were near normal, with the exception of November when the two TCs of hurricane intensity occurred. The low-level monsoon trough was stronger than normal during November as manifested by enhanced low-level westerlies in equatorial latitudes, and lower than normal sea level pressure (SLP) along the trough axis.

4) SOUTHERN HEMISPHERE

The number of TCs in the SH during 1995 (i.e., 1 July 1994–30 June 1995) was well below normal (in stark contrast to the prolific year in the Atlantic). Getting off to a slow start with 22 TCs in the SH, 1995 was only one TC shy of being a meager year in the SH as defined in section 4. Only one year, 1988, had fewer, with only 21 significant TCs. The 22 significant TCs in the SH included 12 of hurricane intensity, seven tropical storms, and two tropical depressions.

During 1995, there were four significant TCs east of 165°E in the SH (one below normal), consistent with the demise of the warm phase of ENSO during 1995. The only TC of hurricane intensity east of 165°E occurred at the end of 1994 when low-latitude low-level wind anomalies were still westerly there. The remainder of the SH TC activity during 1995 was weighted toward the South Indian Ocean (west of 105°E), where 11 (50%) of the TCs occurred; and in the Australian region (between 105° and 165°E) where 7 (33%) occurred (these numbers were one and three below normal, respectively). A persistent large-scale anomaly in the SH during November of 1994 through April of 1995 was higher than normal SLP over northeastern Australia and the Tropics of the western South Pacific (Fig. 5a). Though not explicitly one of Gray's factors, which influence TC genesis, higher than normal SLP indicates that perhaps there was increased subsidence over the region of elevated pressure. This would lead to drying of the at-

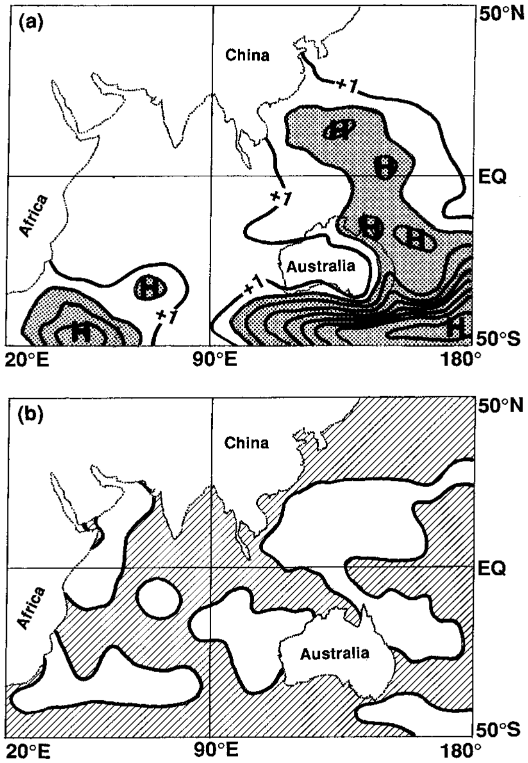

FIG. 5. (a) January 1995 SLP anomalies. Shaded regions are 2 hPa or greater above normal. (b) January 1995 OLR anomalies. Within the open regions, over water, the OLR is above normal, indicating less cloudiness [figures adapted from CPC (1995)].

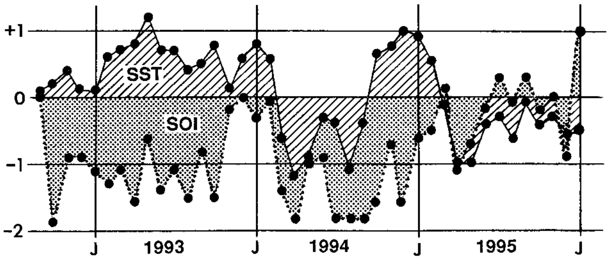

FIG. 6. Anomalies from the monthly mean for (a) eastern equatorial Pacific Ocean SST (shaded) in degrees Celsius and (b) the SOI (cross-hatched) for the period 1993 through 1995. The "J" indicates January. [Adapted from CPC (1994, 1995).]

mospheric column and a reduction of deep convection. Indeed, anomalies of outgoing longwave radiation (OLR) (Fig. 5b) support this idea. The SLP and OLR anomalies (CPC 1995) are consistent with the greatest reduction of TCs in the SH during 1995 occurring in the western South Pacific and in the Australian region.

A more complete description of the SH TC statistics during 1995 can be found in summaries prepared by the respective regional specialized meteorological centers (RSMC) (e.g., the Australian Bureau of Meteorology, Fiji, and La Reunion), and also in the 1995 JTWC Annual Tropical Cyclone Report (JTWC 1995).

4. Discussion

a. The global atmosphere during 1995

During 1995, a prolonged period of the warm phase of the El Niño–Southern Oscillation (ENSO) came to an end. Large-scale atmospheric and oceanic circulation anomalies indicative of the warm phase of ENSO [e.g., consistently warmer than normal sea surface temperature (SST) over much of the eastern equatorial Pacific (i.e., El Niño conditions), a strongly negative Southern Oscillation index (SOI), and a penetration of monsoon westerlies in the WNP far to the east of normal] rapidly returned to near normal, or even reversed during the first half of 1995. By June of 1995, the SST along the equator in the "Niño 3" region of the central and eastern Pacific had become colder than normal (Fig. 6), the SOI had risen to near zero (Fig. 6), and low-level easterly wind anomalies replaced westerly wind anomalies in the low latitudes of the WNP. Based on these Pacific basin SST patterns and the distribution of wind and surface pressure in the Tropics of the Pacific basin, the CPC—along with other international meteorological centers—officially declared that the warm phase of ENSO was over. In some respects (e.g., the cooling of the equatorial sea surface and unusually strong low-level easterly winds in low latitudes of the WNP), the climatic anomalies of the Pacific basin during most of 1995 were consistent with those expected of a cold phase of ENSO, often referred to as La Niña (Philander 1990).

Other persistent global climatic anomalies during 1995 included a west-wind phase of the QBO (Fig. 7), warmer than normal 500-hPa temperatures in the Tropics, and a warmer than normal global average temperature (CPC 1995).

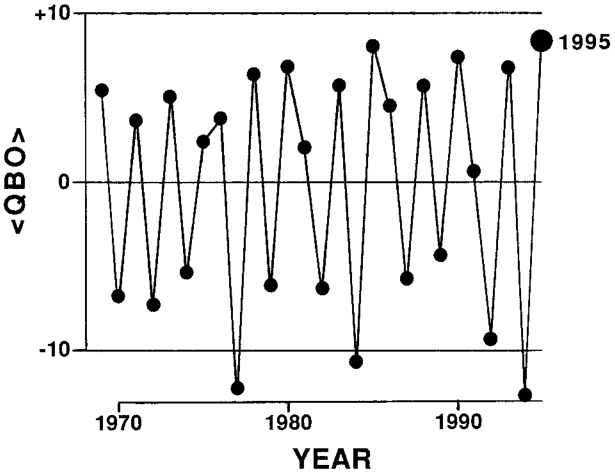

FIG. 7. Time series of the ⟨QBO⟩ (which is the average value of the equatorial anomaly of the 50-hPa wind during the 6-month period June–November of each year). Units are meters per second. Adapted from Gray (1984) and CPC (1995).

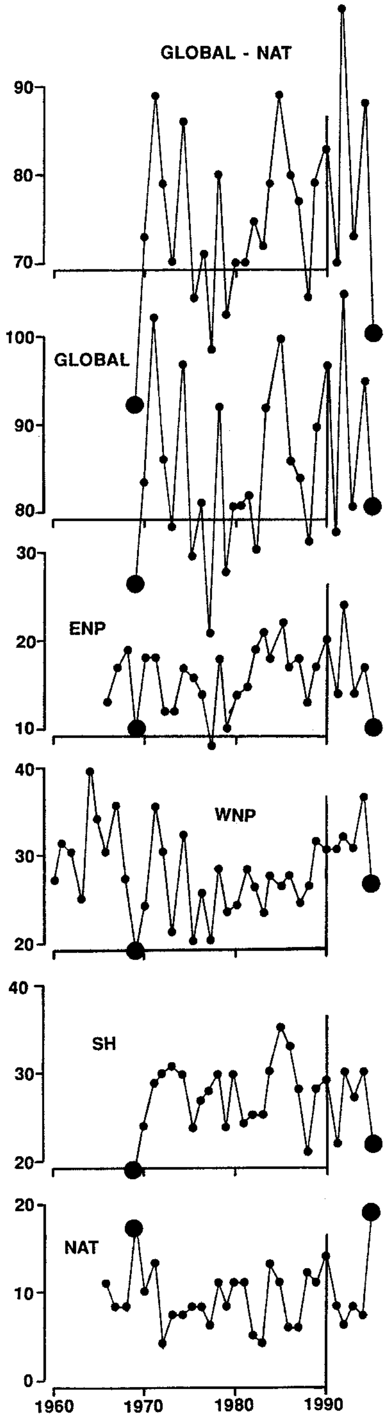

Fig. 8. Time series of the annual global number of TCs, and the annual number of TCs in each of the indicated TC basins. The number of TCs during 1969 and 1995 are highlighted by the large-sized dots. The annual global number of TCs minus those in the NAT (GLOBAL − NAT) is also shown.

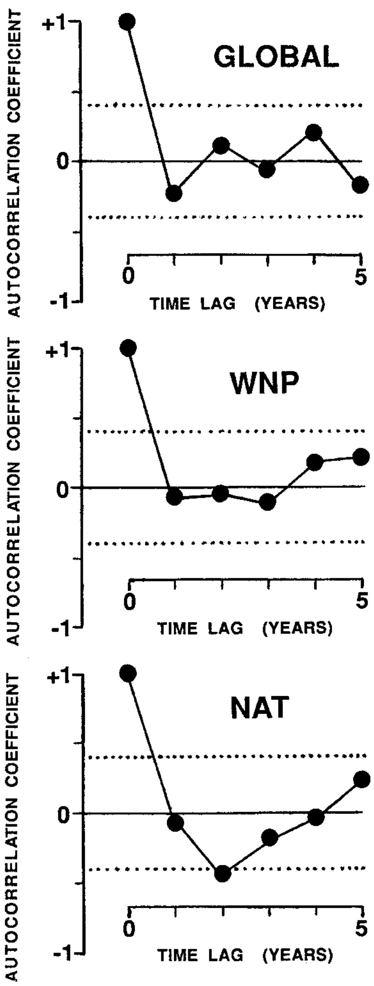

Fig. 9. Time-lag autocorrelations for the global TC time series and for the indicated basins. Dotted lines indicate the 95% confidence level.

b. Prolific years and meager years

All of the time series of annual tabulations of TC numbers (from the annual global total, to the annual totals within individual ocean basins) (Fig. 8) appear highly erratic (i.e., there is no persistence, and the values seem to jump substantially from one year to the next). Time-lag autocorrelations of these time series (Fig. 9) confirm this aspect: all have small negative values at a 1-yr time lag. Also, most of the time series have prominent spikes of both exceptionally low and high values.

In a normal distribution, 90% of the realizations fall within 1.645σ of the mean value, leaving 5% above and 5% below this threshold. Using the values of the standard deviations computed for each of the time series, the following annual numbers of TCs (rounded to the nearest whole) are computed for values at the $\pm1.645\sigma$ thresholds: WNP (20 and 35); NAT (4 and 15); ENP (10 and 22); NIO (2 and 9); SH (21 and 33); Global (69 and 101); and Global − NAT (59 and 91). The high years will hereafter be referred to as prolific years, and the low years as meager years. The following prolific years and meager years are identified for the global and basin distributions (bold years indicate the extreme):

1) Global prolific years = 1971 and **1992**; global ''meager'' years = **1977**.
2) Global − NAT prolific years = **1992**; Global − NAT meager years = **1969**.
3) WNP prolific years = 1967, 1971, and **1994**; WNP meager years = **1969**, 1975, and **1977**.
4) NAT prolific years = 1969 and **1995**; NAT meager years = **1983**.
5) ENP prolific years = 1985 and **1992**; ENP meager years = 1969, **1977**, 1979, and 1995.
6) NIO prolific years = **1992**; NIO meager years = **1980** and **1993**.
7) SH prolific years = **1985** and 1986; SH meager years = **1969** and 1988.

The range in the annual numbers of TCs in every basin is remarkably large. The global annual average[2] is 85 with a range of 66–105; the WNP annual average is 27 with a range of 19–36; the NAT annual average is 10 with a range of 4–19; the ENP annual average is 16 with a range of 8–24; the NIO annual average is 5 with a range of 2–13; and the SH annual average is 27 with a range of 19–35. Interestingly, the difference between the maximum annual number of TCs and the minimum annual number of TCs in all basins is approximately 15. The difference of 39 between the maximum and minimum annual global number of TCs is more than twice that of any individual basin.

c. Basin interrelationships

Given the relative rarity of TC formation (as a global atmospheric phenomenon) coupled with the aforementioned phenomenon of basin prolific and meager years, a natural question arises as to whether there are compensations among the annual number of TCs within the several TC basins that act so as to stabilize the annual global number of TCs (i.e., negative correlations among some or all of the TC basins); or whether the annual global number of TCs is destabilized by positive correlations among some or all of the TC basins.

The latter appears to be true. The variance of the annual global number of TCs is about twice that of the highest variation in any TC basin—in fact, the standard deviation of the annual number of TCs is approximately four within all of the TC basins (σWNP = 4.5; σENP = 3.8; σNAT = 3.4; σSH = 3.8) with the exception of the NIO (σNIO = 2.3). The standard deviation of the annual global number of TCs is approximately 10. Cross correlations among the basins (Fig. 10) reveal three statistically significant values (and each of these is a weak positive correlation): the annual number of TCs in the WNP is positively correlated with the annual number of TCs in the ENP, and the annual number of TCs in the SH is positively correlated with both the annual number of TCs in the ENP and the annual number of TCs in the WNP. The higher variance of the annual global number of TCs is consistent with weak positive correlations among some of the major TC basins, coupled with no statistically significant negative correlations among any of the basins.

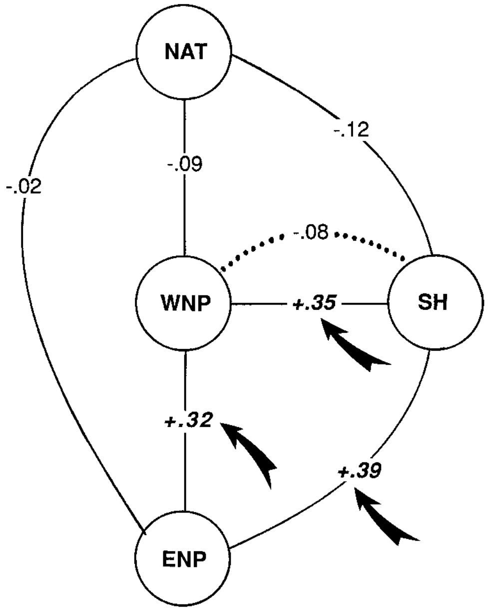

FIG. 10. Rank cross correlations between the major TC basins of the annual number of TCs within each basin. Arrows show cross correlations that are significant at the 90% level. The cross correlation of −0.08 between the WNP and the SH (shown by the dotted line) is the value obtained as per the WMO tabulation of SH TCs.

During the 27-yr period 1969–95 there were 14 years with at least one basin experiencing a prolific or a meager year. Five of these years had two, or more, prolific and/or meager years. Only two of the years (1969 and 1995) had both prolific and meager years occurring simultaneously in different basins; the prolific years during these two years were those of the NAT.

d. The Atlantic prolific years of 1969 and 1995

During the 30-yr period 1966 to 1995, the NAT experienced two prolific years: 1969 and 1995. What is astonishing about these two years is the fact that they were both below normal years for all major basins and meager for some basins (Fig. 8); they are the lowest and third lowest years of record for the Global − NAT

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[2] The average annual global number of TCs recorded herein does not include those few TCs that form in the Hawaiian region. Such TCs, forming between 140°W and the international data line, are incorporated into Neumann's totals for the ENP, but are not tabulated in the TPC record of ENP TCs. Approximately one TC per year forms in the Hawaiian region, and would thus raise the annual global number of TCs to approximately 86.

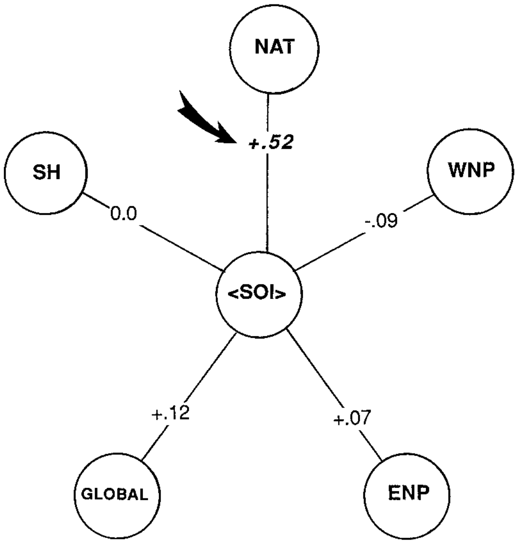

FIG. 11. Rank cross correlations between the major TC basins and an ENSO index. The selected ENSO index is the average value of the monthly SOI during the boreal spring through the boreal autumn. Arrow shows the NAT cross correlation that is significant at the 99% level. (The time series of monthly values of the SOI were obtained from the CPC.)

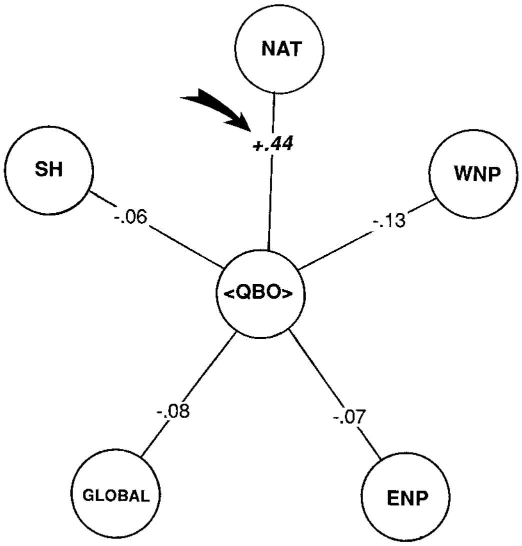

FIG. 12. Rank cross correlations between the major TC basins and the QBO. The selected QBO index is the average value of the monthly 50-hPa equatorial wind anomaly during the period June–November, designated as ⟨QBO⟩. Arrow shows the NAT cross correlation, which is significant at the 98% level. [The time series of the QBO was obtained from Gray (1984) and CPC (1995).]

time series (Table 1), and they were the only two years during which a prolific year in one basin was accompanied by a meager year in one or more of the other basins (Table 1). During 1969, three of the other major basins (WNP, ENP, and SH)—and the Global − NAT—had annual TC numbers that were meager years. Assuming a normal distribution for the annual number of TCs within each basin, the random odds of any one basin being 1.645σ away from its mean is approximately 10%. During 1969, the WNP, NAT, ENP, and the SH (compiled as per the JTWC convention) were all at least 1.52σ away from their respective means. The odds that, by chance, four basins were simultaneously 1.52σ from their respective means are only 2.7 in 10 000. During 1995, the annual number of TCs in the NAT was more than 1.645σ above its mean, the ENP was 1.52σ below its mean, the SH was 1.37σ below normal, and the WNP, though below normal, was within one sigma of its mean. The odds that three major basins would be simultaneously at least 1.37σ away from their respective means, by chance, is 5 in 1000. Clearly, the association of the NAT prolific years of 1969 and 1995 with meager years for some (and below normal years for most) of the other major TC basins is not a chance occurrence. There must be a large-scale physical mechanism acting to generate NAT prolific years, while at the same time suppressing the development of TCs in the other major basins.

Only two major global quasi-periodic atmospheric cycles have been shown to affect the global distribution (i.e., annual numbers and formation locations) of TCs: ENSO (e.g., Gray 1984; Chan 1985; Lander 1994) and QBO (Gray 1984; Chan 1995). A case can be made that neither of these influences is a primary cause for the global distribution of TCs during 1969 and 1995. For example, the year 1969 has been listed as an El Niño year (Quinn et al. 1978), and the year 1995 has been designated by some as a weak La Niña year (CPC 1995; JTWC 1995). The QBO was in a westerly phase during both 1969 and 1995; however, other than in the NAT, the QBO seems to have little effect upon the numbers of TCs.

e. The ENSO and QBO connections

It has been documented by Gray (1984) that the annual number of NAT TCs is affected by ENSO and the QBO (among other regional climatic anomalies): during El Niño years, the annual number of NAT TCs is reduced, an effect also associated with the easterly phase of the QBO. Of all the major TC basins, only the annual number of TCs in the NAT exhibits a statistically significant relationship with an ENSO index (Fig. 11) and with the QBO (Fig. 12). This is at variance with findings by Chan (1985, 1995)—who used techniques of statistical analysis more sophisticated than those used herein—that the annual number of TCs in the WNP exhibits statistically significant relationships with both ENSO and the QBO. Lander (1994), using simple rank cross correlations, showed that the annual number of TCs in the WNP was not significantly correlated with any ENSO index. The magnitudes of these correlations were so small that, at best, they could explain only about 7% of the variance. The correlation coefficients for the relationships between ENSO indices and the annual number of TCs in the WNP were, however, all of the appropriate sign to support Chan's finding of a reduction of the number of TCs there during El Niño years. The same cannot be said of the QBO. Concerning the QBO, simple rank cross correlations show that only the annual number of TCs in the NAT is significantly correlated with the QBO (Fig. 12). The magnitudes of the correlation coefficients between the QBO and the annual number of TCs in all the other major basins are quite small, and the variance explained is only a few percent. The signs of the correlations, however, are negative for all basins (except the NAT) and lend no support to Chan's claim of a statistically significant increase of TCs in the WNP during the westerly phase of the QBO.

5. Summary and conclusions

The 19 named TCs in the NAT during 1995 were nearly a record for that basin. During the past three decades, only the year 1969—with its 18 TCs of at least tropical storm intensity—was nearly as prolific. During 1995 and 1969 (two years that have been designated herein as prolific years in the NAT), the annual number of TCs in most of the other TC basins was well below normal (to such an extent that even the annual global number of TCs during these two years was below normal). Despite the strong reduction of the annual number of TCs in most basins during the aforementioned NAT prolific years, there is no overall correlation between the annual number of TCs in the NAT and the annual number of TCs in any other major TC basin (i.e., the WNP, ENP, and SH). In fact, the only statistically significant correlations of annual numbers of TCs are weak positive correlations between the WNP and the ENP, between the SH and the WNP, and between the SH and the ENP. These weak positive correlations act to increase the variance of the annual global number of TCs.

There are only two large-scale atmospheric phenomena (i.e., ENSO and the QBO) that have been documented to have an effect on the annual number of TCs in the NAT and within the other TC basins. It has been shown herein that only within the NAT are the magnitude of these relationships strong. In all other major basins, the ENSO and the QBO have little, if any, effect on the annual number of TCs [although the formation regions of TCs within the WNP and the SH (Basher and Zheng 1995) are shifted quite markedly by ENSO]. The global distribution of TCs during the Atlantic prolific years of 1969 and 1995 stands quite apart from the long-term relationships noted between the annual number of TCs in the NAT with the annual number of TCs in the other major TC basins. The ENSO and QBO cannot alone account for the unusual distribution of TCs during 1969 and 1995. In fact, 1969 is considered by some to have been an El Niño year, while the global climatic anomalies during 1995 were considered by some to be representative of the cold phase of ENSO (i.e., La Niña). The only apparent commonality between 1969 and 1995 was that the QBO was in a westerly phase, a large-scale atmospheric condition experienced approximately once every two years.

The NAT prolific year of 1995 need not be considered to be a herald of a return to a higher number of NAT TCs such as has been documented to have occurred during the decades of the 1940s through 1960s. In fact, the NAT prolific year of 1969 was, in retrospect, a ''herald'' of lower NAT TC activity during the 1970s–80s. It is hypothesized that NAT prolific years such as 1995 and 1969 will always be a characteristic of the NAT time series, regardless of interdecadal changes in the average annual number of TCs in the NAT.

That the NAT prolific year of 1995 was a signal of global climate change is unlikely, considering that the phenomenon has occurred in the past, and that the global distribution of TCs during the previous NAT prolific year—1969—was so strikingly similar. Based on the peculiar similarities between the global TC distribution of 1969 and 1995, it is hypothesized that the phenomenon of NAT prolific years (accompanying meager years in other basins) has its roots in a specific (but infrequent) state of the global atmosphere, which does not appear to be related to ENSO, the QBO, interdecadal changes in the annual number of TCs in the NAT, or long-term global climate change. Its mechanism remains a mystery.

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APPENDIX

A Brief Description and History of the JTWC

The Naval Pacific Meteorology and Oceanography Command Center West (NPMOCW) Joint Typhoon Warning Center (JTWC), Guam, was activated on 1 May 1959 as the Fleet Weather Central/Joint Typhoon Warning Center. It is a joint navy–air force activity. Located at Nimitz Hill, Guam, the JTWC has a forecast area of responsibility (AOR) that extends from the international date line westward to the coast of Africa, in both hemispheres. Seventy percent of the world's TCs develop in this AOR.

The United States Commander-in-Chief, Pacific (USCINCPAC) Command Instruction 3140.1 (series), tasks the JTWC to provide TC warning support to all United States government agencies within the assigned AOR. This instruction is, for the JTWC's AOR, the equivalent of the U.S. National Hurricane Operations Plan (e.g., NHOP 1990). JTWC warnings and reconnaissance information are made available to all nations in or near the specific ocean basins, as well as to national meteorological centers around the world. The Japan Meteorological Agency (JMA) [the civilian meteorological center designated by the World Meteorological Organization (WMO) to be the regional specialized meteorological center (RSMC) for the issuance of TC warnings in the WNP] uses JTWC's naming convention for tropical storms and typhoons. In addition to the JMA, the JTWC AOR contains numerous local and regional warning centers, including other WMO-designated RSMCs (e.g., Fiji, New Delhi, La Reunion, etc.). Outside of the WNP, the JTWC applies numbers to the TCs, but uses the names given to them by the respective RSMC.

Although there is no official collaboration between the JTWC and the RSMCs within its AOR, there is exchange of data, open dissemination of warnings and numerical guidance, and occasionally some personal communication.

Initially, JTWC issued warnings from the 180° meridian to 100°E in the Northern Hemisphere. During and following the Vietnam conflict, JTWC's AOR was expanded. On 4 June 1971, the Bay of Bengal was added, and in 1975 the Arabian Sea was added. The final expansion occurred in 1981 when the JTWC assumed TC forecast responsibility for the western South Pacific Ocean and the entire South Indian Ocean. For more details on the JTWC, its history, its structure, and its organization, see Guard et al. (1992).

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