The Joint Typhoon Warning Center Tropical Cyclone Best-Tracks, 1945-2000

Jan-Hwa Chu and Charles R. Sampson

Naval Research Laboratory

Andrew S. Levine

University of Hawaii

and

Edward Fukada

Joint Typhoon Warning Center

August 2002

NRL Reference Number: NRL/MR/7540-02-16

Abstract

This report documents efforts to resolve discrepancies associated within the Joint Typhoon Warning Center (JTWC) tropical cyclone best-track archives. Corrections were limited to years for which supporting documentation was found: 1950-2000 for the western North Pacific, 1971-2000 for the North Indian Ocean and 1985-2000 for the Southern Hemisphere. The authors rate the 1985-2000 best-tracks to be of high quality and urge users to use older data with caution. The modified best-tracks are posted on JTWC Tropical Cyclone Best Track Data Site at URL: https://metoc.npmoc.navy.mil/.

1. Introduction

The Joint Typhoon Warning Center (JTWC) maintains an archive of tropical cyclone track data, commonly referred to as "best-tracks". Each best-track file contains tropical cyclone center locations and intensities (i.e., the maximum 1-minute mean sustained 10-meter wind speed) at six-hour intervals. The geographical domain of the archive is the western North Pacific (WP), North Indian Ocean (IO) and Southern Hemisphere (SH). Most of the best-track data are published in JTWC's Annual Tropical Cyclone Reports (ATCRs) (US Pacific Fleet, Air Force, Meteorological Squadron One, 1947; North Pacific Typhoon Warning Service, 1948-49 and 50-51; JTWC, 1952-58; JTWC, 1959-2000); however, these published best-tracks do not necessarily match those in the archive (hereafter referred to as the JTWC Archive). One major reason for these discrepancies is that three disparate data sources were used to construct the original JTWC Archive: (1) the National Climate Data Center (NCDC) database, (2) a Fleet Numerical Meteorology and Oceanography Center (FNMOC) database and (3) the Automated Tropical Cyclone Forecasting System (ATCF) database (Sampson and Schrader, 2000).

The purpose of this study is to identify and document the differences in data and correct as much as possible any noted discrepancies by performing a cross-validation between the ATCR documentation and the JTWC Archive. The JTWC Archive includes data from 1945, cross-validations are limited to years 1950-2000 for the western North Pacific, years 1971-2000 for the North Indian Ocean and years 1985-2000 for the Southern Hemisphere. This is mainly due to difficulties finding high quality ground truth (see Appendix 1) and best-track documentation (see Appendix 2) for earlier years. The authors defer to the ATCR data whenever possible; however, additional rules are adopted to finish the work. The body of this report discusses methods adopted to correct the JTWC Archive, outline the corrections and document the resultant best-track database.

Appendix 1 provides a concise chronology of significant events affecting JTWC historical best-tracks. Appendix 2 presents a chronology of DOD documentation for tropical cyclones in the areas of interest. Appendices 3, 4 and 5 present statistics, yearly cyclone-track charts from the resultant best-track database, and working notes for the WP, IO and SH regions, respectively. Appendix 6 is a list of acronyms used in this report.

2. Methods

Tropical cyclone best-tracks contain 6-hourly tropical cyclone positions. These positions are determined well after each tropical cyclone has dissipated, and can differ from "working best-track" positions in the TC warnings by as much as 120 nautical miles. Post-storm analysts generally have more raw data, more time and a complete storm history to produce best-tracks for the JTWC Archive. JTWC Archive data quality and supporting documentation are less reliable for older storms than more recent ones (see Appendices 1 and 2). In fact, much of the earliest data in the JTWC Archive is undocumented. Cursory inspection of the older, undocumented best-tracks was performed and typos eliminated, but the tracks were not cross-validated due to the lack of documentation. As a result, the authors have less confidence in the quality of the older tracks than they have in the newer ones.

Recent JTWC best-tracks also contain intensity estimates, although confidence in the quality of these estimates is low. The main source of intensity estimates is the Dvorak model (Dvorak, 1975, 1984 and 1995), which is considered to be less accurate than in-situ measurements, such as aircraft reconnaissance, dropsondes and surface reports. One complication with the JTWC intensity estimates is that they are one-minute mean sustained wind speeds, while other forecast agencies in the JTWC Area of Responsibility (AOR) use ten-minute mean winds. One-minute mean wind speeds are generally higher than ten-minute mean wind speeds by 14%. As a result, comparisons of JTWC best-tracks with those of other agencies must be done with extreme caution.

Keeping the concerns mentioned above in mind, the following general steps were used to correct the JTWC Archive data:

Step 1. Visually compare and document differences between the JTWC Archive and the ATCRs.

Step 2. Check differences against tracks from other sources, such as the Hurricane Risk Assessment database (Neumann, 1987 and 1999; Neumann *et. al*., 1999) and the Hong-Kong Observatory charts (Chin, 1972).

Step 3. Make recommendations for changes in the JTWC Archive.

Step 4. Include final corrections in the JTWC Archive. Post the cyclone-by-cyclone comments regarding the correction on the JTWC web site as TC notes. Additional basin and year comments are also posted.

Steps 1 through 3 formed a loop which was iterated upon many times. As these steps were performed, a set of rules for making changes in the JTWC Archive (i.e., Step 3) was developed. These rules are:

Rule 1. Typos: These are documented and corrected.

Rule 2. Storm ID: Each tropical cyclone must has a unique eight-character Storm ID that consists of a two-character basin designator, a two-digit TC number, and a four-digit year identifier (e.g., WP012000 is the first TC of the 2000 western North Pacific season). See Appendix 2 for an explanation of basin designators.

Rule 3. Period: A TC period is assigned that includes the beginning and ending date-time groups. This is not specifically included in the best-tracks file, but in a separate header file.

Rule 4. Name: Each TC is either assigned a name or the generic name "NONAME". This is not specifically included in the best-track file, but in a separate header file.

Rule 5. NONAME (TD): This indicates a tropical cyclone is a real tropical depression that had to be assigned a new Storm ID, because the same Storm ID was used by another storm. NONAME (TD) is not specifically included in the best-track file, but in a separate header file.

Rule 6. NONAME (TS): This name is adopted for the same reasons as NONAME (TD), but for a tropical storm. NONAME (TS) is not specifically included in the best-track file, but in a separate header file.

Rule 7. Combined TC names: If the JTWC Archive has two tropical cyclones and ATCR recorded them as one cyclone, we combine the two into one and delete the second cyclone from the JTWC Archive. For example, the 1956 ATR suggested that KAREN and LUCILLE are two parts of one TC, so we combined them into KAREN-LUCILLE and deleted the original LUCILLE from the JTWC Archive.

Rule 8. TC not found in ATCR: These TCs are renumbered from the original TC numbers to 50-79. This applies to years with sufficient ATCR documentation to refute the TCs in the JTWC Archive.

Rule 9. Alphanumeric data not found in ATCR: When there is no alphanumeric data in the ATCR to compare to the JTWC archive, graphical comparisons are made. For example, in the years 1950-1958, the ATCR did not contain alphanumeric data in the western North Pacific. For these years, graphical comparisons were made and noted in the TC notes.

Rule 10. Alphanumeric data not found in JTWC Archive or ATCR: When a TC track is documented in the ATCR and position data cannot be found, then the JTWC Archive is not altered. For example, the 18 hours western North Pacific TC MARY, 16 NOV 1956 is not included in the JTWC Archive.

Rule 11. Alphanumeric data reported at different times in JTWC archive and ATCR: Standard reporting times are at 00, 06, 12, and 18 Z in the JTWC archive. In some instances, the ATCR has other reporting times. In these cases alphanumeric data was compared for similarity, but the JTWC archive was not altered. Comments were made about the dissimilar times in the TC notes.

Rule 12. JTWC Archive data cannot be refuted: When the ATCR documentation is insufficient to refute the JTWC Archive tracks, keep the tracks. For example, totals for the North Indian Ocean TC (1971-76) in the JTWC Archive are significantly larger than those published in the ATCRs, but documentation is insufficient to modify the data files.

3. Results and Conclusions

Appendices 3-5 show an overview of the resultant best-track data for the JTWC Archive. Each of these appendices is for a single basin and contains the yearly totals, frequency distributions, track maps and working notes. The authors rate the quality of the 1985-2000 best-tracks to be of the highest quality. The observational network (see Appendix 1) is well established and the ATCR documentation contains alphanumeric data for the best-tracks.

The cross-validation and database correction involved a degree of subjectivity. As such, the authors have prepared detailed notes regarding changes to the JTWC Archive. Due to their length, these notes are included on the compact disk (CD) and not as part of the paper publication. They are posted with the JTWC Archive on the JTWC web site.

We expect that our efforts represent only the beginning of a continual process to update, inspect and correct the JTWC Archive. This archive also contains valuable tropical cyclone fix data and objective aid forecasts, which should also be inspected on a regular basis. Our hope is that cross-validated and corrected tracks developed in this study can be used in updated tropical cyclone climatology summaries (e.g., Lourensz, 1981; Miller *et. al.*, 1988) and other

researches.

The JTWC Archive also contains tropical cyclone fix data and objective-aid forecasts for many of the tropical cyclones. Based on cursory check, the authors recommend that a rigorous inter-comparison between the JTWC documentation and the JTWC Archive also be performed.

Acknowledgements

We would like to express our sincere gratitude to the Director and staff of JTWC for support of this work. We are particularly indebted to the many developers of the ATCF for providing the framework within which this task was performed. We also thank Captain Don Schiber, USAF of JTWC for his input during early data correction phase. The manuscript benefited from reviews by Mr. Sam Brand and Dr. Ted Tsui of NRL.

References

Air Weather Service, 1949: Report on Post Analysis of Typhoons in the western North Pacific, 1947. Technical Report 105-42, July 1949.

Anstett, R., 1998: History of the Joint Typhoon Warning Center up to 1998. The URL is http://home1.gte.net/anstett/Jthist00.htm.

Chin, P. C., 1972: Tropical cyclone climatology for the China Sea and Western Pacific from 1884 to 1970. Volume 1: Basic Data. Royal Observatory, Hong Kong. R.O. Technical Memoir No. 11, 55515.2. (265) (265.6). 1961-70. Estimated maximum surface wind, minimum sea surface pressure, maximum 700-mb wind and minimum 700-mb height for standard synoptic hours derived from eye-fix reports.

Dvorak, V., 1975: Tropical cyclone intensity analysis and forecasting from satellite imagery. *Mon. Wea. Rev.*, 103, 420-430.

_____, 1984: Tropical cyclone intensity analysis using satellite data. NOAA Tech. Report NESDIS 11. Available from NOAA/NESDIS, 5200 Auth Rd., Washington DC, 20233, 47pp.

_____, 1995: Tropical clouds and cloud systems observed in satellite imagery: Tropical cyclones. Workbook Volume 2. Available from NOAA/NESDIS, 5200 Auth Rd., Washington DC, 20233.

JTWC, 1952-58 Annual Typhoon and Tropical Storm Reports. These publications are in paper format and are available form JTWC.

_____, 1959-97 and 1998 Annual Tropical Cyclone Report (ATCR). These publications have both paper and compact disks versions, and they are available from JTWC. Web versions of 1959-2000 Annual Tropical Cyclone Reports are available from JTWC's Universal Resource Locators (URLs): http://www.npmoc.navy.mil/.

Lourensz, R. S., 1981: Tropical Cyclones in the Australian Region July 1909 to June 1980. Department of Science and Technology, Bureau of Meteorology. October 1981. Australian Government Publishing Service, Canberra. ISBN 0 642 01718 2. 99 pp.

Miller, R. J., T. L. Tsui and A. J. Schrader: 1988: Climatology of North Pacific Tropical Cyclone Tracks. NEPRF TR88-10.

Neumann, C. J., 1987: The National Hurricane Center Risk Analysis Program (HURISK), NWS NHC 38.

_____, 1999: The HURISK model: An adaptation for the Southern Hemisphere (A user's manual). 32 pp. Available form SAIC, 550 Camino El Estero, Suite 205, Monterey, CA 93940 or Naval Research Laboratory, Monterey, CA 93943.

_____, B. R. Jarvinen, C. J. McAdie, G. R. Hammer, 1999: Tropical Cyclones of The North Atlantic Ocean, 1871-1998. Prepared by National Climatic Data Center, Asheville, NC and Tropical Prediction Center/National Hurricane Center, Miami, FL. 206 pp.

North Pacific Typhoon Warning Service, 1948-49: Annual Report of Typhoon Post Analysis. Typhoon Warning Center, North Guam Weather Central, North Guam Air Force Base, Guam, Mariana Islands. No page numbers. Available from JTWC.

_____, 1950-51: Annual Report of the Typhoon Post Analysis Program. 2143D Air Weather Wing. Typhoon Post Analysis Board, Andersen Weather Central, Andersen Air Force Base (formerly North Guam Air Force Base), Guam, Mariana Islands. Available from JTWC.

Sampson, C. R. and A. J. Schrader, 2000: The automated tropical cyclone forecasting system (Version 3.2). *Bull. Amer. Meteor. Soc.*, 81, 1231-1240.

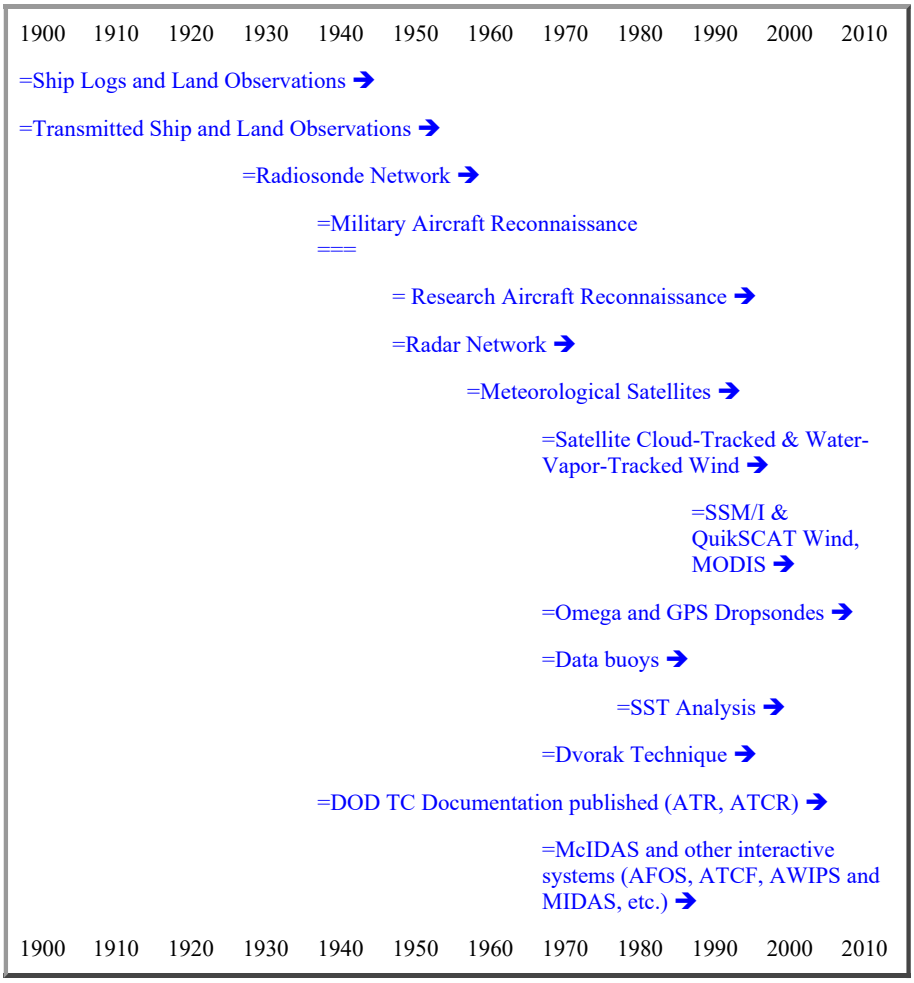
USCINCPAC (Commander in Chief, U.S. Pacific Command), 1995: Tropical cyclone operational manual. USCINCPAC Instruction 3140.1W. p. 2-4.

US Pacific Fleet, Air Force Meteorological Squadron One, 1947: 1946 Typhoon Report. QC948.U4. Guam. No page number. Available from JTWC.

Appendix 1 - Significant events affecting JTWC historical best-tracks

Systematic observations of tropical cyclones are of poor quality when compared with those of middle-latitude cyclones, especially before routine satellite imagery was made available in the early 1960s. As shown in Table 1, the instruments, observing network and tools to exploit the observations have improved dramatically in the last forty years. An added bonus is that the frequency of TC observations increased from one per day to several per hour.

Table 1. Significant events affecting tropical cyclone observations in the western North Pacific, North Indian Ocean and Southern Hemisphere regions. Thick arrows indicate that the tool is still in service. Two parallel line symbols denote the beginning and ending years of the tool in use, respectively. See Appendix 6 for acronyms.

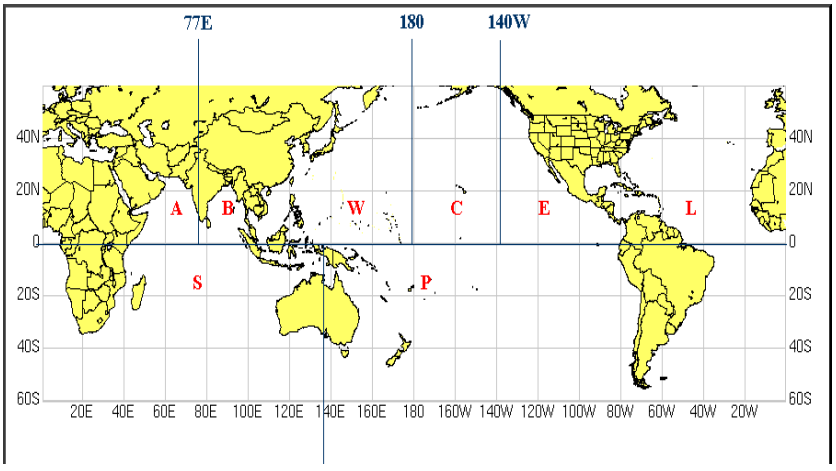


Appendix 2 - DOD TC Documentation, 1945-2000

The Area of Responsibility (AOR) for JTWC and its predecessors has changed to fit the needs of the U.S. Department of Defense (DOD). Prior to the establishment of the JTWC documents indicate that the US DOD tropical cyclone forecast AOR was only the western North Pacific Ocean. Since formation of the JTWC in 1959, the AOR has gradually increased and now includes: the western North Pacific (W), the central North Pacific (C), the eastern North Pacific (E), Bay of Bengal (B), Arabian Sea (A), South Indian Ocean (S) and South Pacific (P). Figures 1 (a) and 1 (b) show geographical domains of the DOD one-character designators for the TC regions and relationship among DOD designators, JTWC Archive regions and some other commonly used contractions, respectively.

The DOD TC documentation for the Pacific and Indian Oceans has also changed through time (Table 1). The first publication found is 1946 Typhoon Report (US Pacific Fleet, Air Force Meteorological Squadron One, 1947). The North Pacific Typhoon Warning Service prepared 1945-49 cyclone track/intensity charts (North Pacific Typhoon Warning Service, 1949). The first documentation describing a complete season for a specific basin (i.e., W) was published in 1950. Documentation for 1950-1958 included only a graphical best-track presentation of the western North Pacific TCs.

(a)



(b)

DOD Designator	Basin / Region	Other Contractions
A (Arabian Sea) **B** (Bay of Bengal)	**IO** (North Indian Ocean)	NIO
C (central North Pacific Ocean)	**CP**	CNP, CPAC, CENTPAC
E (eastern North Pacific Ocean)	**EP**	NEP, EPAC, EASTPAC
W (western North Pacific Ocean)	**WP**	WNP, NWP, WPAC, WESTPAC
L (North Atlantic Ocean)	**AL**	NA, NAT, ATL, LANT
P (South Pacific Ocean) **S** (South Indian Ocean)	**SH** (Southern Hemisphere)	SHEM, SIO (Southern Indian Ocean), AUS (Australia), SWP (South-West Pacific), SWI (South-West Indian Ocean),

Figure 1. **(a)**. Department of Defense (DOD) designators for the TC basins / regions (USCINCPAC, 1995; Anstett, 1998). The one-character designator (red) is assigned by DOD forecasters, and depends on the initial warning position of the TC. **(b)**. Relationships between DOD designators, basins used to construct Storm IDs in the JTWC Archive and some other commonly used contractions. Note that the AL Basin is not in JTWC's AOR.

Table 1. A list of DOD publishing organizations and basins covered for the entire 1945-2000 period. TC Basin designators are defined in Figure 1. See Appendix 6 for the acronyms.

Year, Organization Name and Location	Basins of TC Documentation Exists in JTWC	Year, Organization Name and Location	Basins of TC Documentation Exists in JTWC
1945: None	No Documentation	1973: FWC / JTWC, Guam	W, C, B
1946: Pacific Fleet, Guam M. I.	W	1974: FWC / JTWC, Guam	W, C, B
1947: Air Weather Service	W	1975: JTWC, Guam	W, C, A, B
1948: NPTWS, Guam	W	1976: JTWC, Guam	W, C, A, B
1949: NPTWS, Guam	W	1977: JTWC, Guam	W, C, A, B
1950: NPTWS, Guam	W	1978: JTWC, Guam	W, A, B
1951: NPTWS, Guam	W	1979: JTWC, Guam	W, A, B
1952: TTC, FWC, Guam	W	1980: JTWC, Guam	W, A, B
1953: FWC and TTC, Guam	W	1981: JTWC, Guam	W, A, B
1954: FWC, Guam	W	1982: JTWC, Guam	W, A, B
1955: FWC, Guam	W	1983: JTWC, Guam	W, A, B
1956: FWC, Guam	W	1984: JTWC, Guam	W, A, B
1957: FWC, Guam	W, C, E	1985: JTWC, Guam	W, A, B, P, S
1958: FWC, Guam	W, C, E	1986: JTWC, Guam	W, A, B, P, S
1959: FWC / JTWC, Guam	W, C	1987: JTWC, Guam	W, A, B, P, S
1960: FWC / JTWC, Guam	W, C	1988: JTWC, Guam	W, A, B, P, S

1961: FWC / JTWC, Guam	W, C	1989: JTWC, Guam	W, A, B, P, S
1962: FWC / JTWC, Guam	W, C	1990: JTWC, Guam	W, A, B, P, S
1963: FWC / JTWC, Guam	W, C	1991: JTWC, Guam	W, A, B, P, S
1964: FWC / JTWC, Guam	W, C	1992: JTWC, Guam	W, A, B, P, S
1965: FWC / JTWC, Guam	W, C, E	1993: JTWC, Guam	W, A, B, P, S
1966: FWC / JTWC, Guam	W, C, E	1994: JTWC, Guam	W, A, B, P, S
1967: FWC / JTWC, Guam	W, C, E	1995: JTWC, Guam	W, A, B, P, S
1968: FWC / JTWC, Guam	W, C, E	1996: JTWC, Guam	W, A, B, P, S
1969: FWC / JTWC, Guam	W, C, E	1997: JTWC, Guam	W, A, B, P, S
1970: FWC / JTWC, Guam	W, C, E	1998: JTWC, Pearl Harbor, HI	W, A, B, P, S
1971: FWC / JTWC, Guam	W, C, E, B	1999: JTWC, Pearl Harbor, HI	W, A, B, P, S
1972: FWC / JTWC, Guam	W, C, E, B	2000: JTWC, Pearl Harbor, HI	W, A, B, P, S

Appendix 3 - Western North Pacific Tropical Cyclones, 1945-2000

1. Number of Tropical Cyclones Per Year

Table 1 shows the total number of tropical cyclones (TCs) per year in the western North Pacific for the entire JTWC Archive (1945-2000). The AOR has included the western North Pacific since 1952, but the archive starts in 1945. The maximums are 45 (1964), 43 (1996) and 42 (1961), while the minimums are 15 (1946), 17 (1951) and 18 (1950). Incomplete documentation was found for 1945-49, and the documentation found for 1950-1958 is missing alphanumeric best-track data. It is interesting to note that the pre-1960 totals are generally less than post-1961 totals. The authors suspect that TIROS imagery made available in 1960 allowed a higher detection rate of TCs.

Table 1. Western North Pacific Number of Tropical Cyclones Per Year, 1945-2000

Year	# of TCs	Remarks	Year	# of TCs	Remarks
1945	26	No Documentation	1973	23	
1946	15	Incomplete Documentation	1974	35	
1947	27	No Documentation	1975	25	
1948	26	Incomplete Documentation	1976	25	
1949	22	No alphanumerical data	1977	21	
1950	18	No alphanumerical data	1978	32	
1951	17	No alphanumerical data	1979	28	
1952	28	No alphanumerical data	1980	28	
1953	23	No alphanumerical data	1981	29	
1954	19	No alphanumerical data	1982	28	
1955	22	No alphanumerical data	1983	24	
1956	22	No alphanumerical data	1984	30	
1957	21	No alphanumerical data	1985	27	
1958	24	No alphanumerical data	1986	28	
1959	23		1987	25	
1960	27		1988	26	

1961	38	1989	35
1962	39	1990	31
1963	28	1991	31
1964	44	1992	32
1965	41	1993	37
1966	39	1994	39
1967	41	1995	34
1968	31	1996	43
1969	23	1997	31
1970	27	1998	27
1971	37	1999	33
1972	32	2000	33

2. Frequency Distribution of TCs Per Year

Table 2 is a frequency distribution of total number of TCs per year. The distribution consists of three peaks: the dominant peak and two secondary peaks are centered around 28, 22 and 40 cyclones per year, respectively.

Table 2. Western North Pacific Frequency Distribution of TCs Per Year, 1945-2000

Number of TCs Per Year	Number of Cases	% of Total Number of Cases
14 or less	0	0
15-17	1	2
18-20	3	5
21-23	9	16
24-26	8	14
27-29	12	22
30-32	8	14
33-35	5	9
36-38	3	5
39-41	5	9
42-44	2	4
45 or more	0	0
Total	56	100

3. Yearly Track Maps

1945 1946 1947 1948 1949 1950

1951 1952 1953 1954 1955 1956 1957 1958 1959 1960

1961 1962 1963 1964 1965 1966 1967 1968 1969 1970

1971 1972 1973 1974 1975 1976 1977 1978 1979 1980

1981 1982 1983 1984 1985 1986 1987 1988 1989 1990

1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

Printable Postscript Versions Of The Track Maps

4. Working Notes

Appendix 4 - North Indian Ocean Tropical Cyclones, 1945-2000

1. Number of Tropical Cyclones Per Year

Table 1 shows the number of tropical cyclones per year for the entire 1945-2000 Indian Ocean archive. Note that post-1976 yearly totals are generally less than pre-1977 totals. The cause of this discrepancy is not clear, nor do the authors have sufficient ATCR documentation to challenge the pre-1977 data. From 1971-1974, JTWC's AOR included only the Bay of Bengal (B) and was expanded to include the Arabian Sea (A) in 1975. The 1971-1976 ATCRs contain significantly less TCs than the JTWC Archive data, but the ATCR documentation is insufficient to challenge the Archive best-tracks. The maximum for the whole 56-year period was 20 (1975); however, the maximum for the post-1977 period was 12 (1992). The minimum was 2 (1989, 1993).

Table 1. North Indian Ocean Number of Tropical Cyclones Per Year, 1945-2000

Year	# of TCs (A, B)	Remarks	Year	# of TCs (A, B)	Remarks
1945	14 (1, 13)	No Documentation	1973	16 (5, 11)	ATCR (4 B TCs only)
1946	17 (1, 16)	No Documentation	1974	12 (4, 8)	ATCR (1 B TC only)
1947	18 (2, 16)	No Documentation	1975	20 (5, 15)	ATCR 3 (1, 2)
1948	18 (5, 13)	No Documentation	1976	14 (3, 11)	ATCR 5 (2, 3)
1949	12 (1, 11)	No Documentation	1977	6 (2, 4)	ATCR 5 (1, 4)
1950	16 (0, 16)	No Documentation	1978	4 (0, 4)	
1951	15 (3, 12)	No Documentation	1979	8 (2, 6)	
1952	17 (1, 16)	No Documentation	1980	5 (1, 4)	
1953	10 (0, 10)	No Documentation	1981	3 (0, 3)	
1954	14 (3, 11)	No Documentation	1982	5 (1, 4)	
1955	13 (0, 13)	No Documentation	1983	4 (1, 3)	
1956	14 (2, 12)	No Documentation	1984	4 (1, 3)	
1957	7 (3, 4)	No Documentation	1985	6 (1, 5)	
1958	12 (0, 12)	No Documentation	1986	3 (1, 2)	
1959	16 (4, 12)	No Documentation	1987	8 (1, 7)	
1960	15 (4, 11)	No Documentation	1988	5 (1, 4)	
1961	17 (4, 13)	No Documentation	1989	2 (1, 1)	
1962	13 (2, 11)	No Documentation	1990	4 (0, 4)	
1963	16 (4, 12)	No Documentation	1991	4 (1, 3)	
1964	15 (3, 12)	No Documentation	1992	12 (3, 9)	
1965	14 (1, 13)	No Documentation	1993	2 (1, 1)	
1966	19 (2, 17)	No Documentation	1994	5 (2, 3)	
1967	15 (0, 1)	No Documentation	1995	4 (1, 3)	

1968	13 (0, 13)	No Documentation	1996	8 (3, 5)
1969	14 (1, 13)	No Documentation	1997	4 (2, 2)
1970	15 (3, 12)	No Documentation	1998	8 (4, 4)
1971	18 (3, 15)	ATCR (2 B TCs only)	1999	5 (1, 4)
1972	18 (4, 14)	ATCR (4 B TCs only)	2000	4 (0, 4)

2. Frequency Distribution of TCs Per Year

Table 2 is a frequency distribution of TCs per year. It shows a bimodal distribution with maximums centered on 4 and 13 TCs per year. The authors suspect that the bimodal distribution may be an artifact of the disparate databases used to create the JTWC Archive. The post-1977 frequency distribution is presented in Table 3 because the authors have confidence in the documentation and observing network for these years. A single peak takes place around 4 TCs per year.

Table 2. North Indian Ocean Frequency Distribution of TCs Per Year, 1945-2000

Number of TCs Per Year	Number of Cases	% of Total Number of Cases
2 or less	2	4
3-5	15	26
6-8	7	13
9-11	1	2
12-14	13	23
15-17	12	21
18-20	6	11
21 or more	0	0
Total	56	100

Table 3. North Indian Ocean Frequency Distribution of TCs Per Year, 1977-2000

Number of TCs Per Year	Number of Cases	% of Total Number of Cases
2 or less	2	8
3-5	15	63
6-8	6	25
9-11	0	0
12-14	1	4
15-17	0	0
18-20	0	0
21 or more	0	0
Total	24	100

3. Yearly Track Maps

1945 1946 1947 1948 1949 1950

1951 1952 1953 1954 1955 1956 1957 1958 1959 1960

1961 1962 1963 1964 1965 1966 1967 1968 1969 1970

1971 1972 1973 1974 1975 1976 1977 1978 1979 1980

1981 1982 1983 1984 1985 1986 1987 1988 1989 1990

1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

Printable Postscript Versions Of The Track Maps

4. Working Notes

Appendix 5 - Southern Hemisphere Tropical Cyclones, 1945-2000

1. Number of Tropical Cyclones Per Year

Table 1 shows the number of tropical cyclones per year for the entire 1945-2000 Southern Hemisphere archive. In 1985, the JTWC AOR was extended to include both the South Pacific (P) and South Indian (S) Oceans. The number of TCs per year in the South Indian Ocean is generally greater than that in the South Pacific with four exceptions (1987, 1993, 1997 and 1998) during the 16-year period (1985-2000). There is no ATCR documentation of the Southern Hemisphere for the years 1981-1984; however, the 1985 ATCR (p. 139) reports totals (24, 25, 25 and 30 TCs per year) which are different than those found in the JTWC Archive. The JTWC Archive (1981-1984) was left as is because we were unable to cross-validate individual TCs. The maximum and minimum for the whole 56-year period (1945-2000) were 55 (1963) and 13 (1945), respectively, while the maximum and minimum for the 16-year cross-validated period (1985-2000) were 38 (1997) and 21 (1988), respectively.

Table 1. Southern Hemisphere Number of Tropical Cyclones Per Year, 1945-2000

Year	# of TCs (S, P)	Remarks	Year	# of TCs (S, P)	Remarks
1945	13 (10, 3)	No Documentation	1973	36 (22, 14)	No Documentation
1946	22 (12, 10)	No Documentation	1974	34 (16, 18)	No Documentation
1947	25 (15, 10)	No Documentation	1975	32 (18, 14)	No Documentation
1948	23 (10, 13)	No Documentation	1976	27 (15, 12)	No Documentation
1949	26 (16, 10)	No Documentation	1977	25 (14, 11)	No Documentation
1950	20 (9, 11)	No Documentation	1978	32 (20, 12)	No Documentation
1951	26 (18, 8)	No Documentation	1979	27 (15, 12)	No Documentation
1952	24 (17, 7)	No Documentation	1980	28 (18, 10)	No Documentation
1953	23 (16, 7)	No Documentation	1981	29 (19, 10)	No Documentation
1954	14 (7, 7)	No Documentation	1982	28 (20, 8)	No Documentation
1955	26 (16, 10)	No Documentation	1983	24 (10, 14)	No Documentation
1956	35 (18, 17)	No Documentation	1984	32 (22, 10)	No Documentation
1957	30 (18, 12)	No Documentation	1985	35 (21, 14)	
1958	33 (19, 14)	No Documentation	1986	33 (21, 11)	
1959	30 (22, 8)	No Documentation	1987	28 (12, 16)	
1960	24 (12, 12)	No Documentation	1988	21 (14, 7)	
1961	27 (17, 10)	No Documentation	1989	28 (17,11)	
1962	26 (18, 8)	No Documentation	1990	29 (21, 8)	
1963	55 (24, 31)	No Documentation	1991	22 (16, 6)	

1964	35 (19, 16)	No Documentation	1992	30 (16, 14)
1965	42 (29, 13)	No Documentation	1993	27 (13, 14)
1966	36 (32, 4)	No Documentation	1994	30 (22, 8)
1967	30 (18, 12)	No Documentation	1995	22 (16, 6)
1968	33 (20, 13)	No Documentation	1996	28 (27, 1)
1969	35 (19, 16)	No Documentation	1997	38 (19, 19)
1970	32 (13, 19)	No Documentation	1998	37 (16, 21)
1971	26 (18, 8)	No Documentation	1999	33 (21, 12)
1972	31 (15, 16)	No Documentation	2000	27 (18, 9)

2. Frequency Distribution of TCs Per Year

Table 2 is the 46-year (1945-2000) frequency distribution of TCs per year. The distribution is nearly normal but is positively skewed. The peak is 28 TCs per year. The extremes are 13 and 55 TCs per year. Table 3 is the frequency distribution for the 16-year (1985-2000) cross-validated best-tracks. A peak still occurs at 28 TCs per year, but the extremes (i.e., 22 and 37 TCs per year) are closer to the peak.

Table 2. Southern Hemisphere Frequency Distribution of TCs Per Year, 1945-2000

Number of TCs Per Year	Number of Cases	% of Total Number of Cases
11 or less	0	0
12-14	2	4
15-17	0	0
18-20	1	2
21-23	6	10
24-26	10	18
27-29	12	21
30-32	10	18
33-35	9	16
36-38	4	7
39-41	0	0
42-44	1	2
45-47	0	0
48-50	0	0
51-53	0	0
54-56	1	2
57 or more	0	0
Total	56	100

Table 3. Southern Hemisphere Frequency Distribution of TCs Per Year, 1985-2000

Number of	Number of	% of Total

TCs Per Year	Cases	Number of Cases
11 or less	0	0
12-14	0	0
15-17	0	0
18-20	0	0
21-23	3	19
24-26	0	0
27-29	6	38
30-32	2	12
33-35	3	19
36-38	2	12
39-41	0	0
42-44	0	0
45-47	0	0
48-50	0	0
51-53	0	0
54-56	0	0
57 or more	0	0
Total	16	100

3. Yearly Track Maps

1. South Indian Ocean (S)

1945 1946 1947 1948 1949 1950
1951 1952 1953 1954 1955 1956 1957 1958 1959 1960
1961 1962 1963 1964 1965 1966 1967 1968 1969 1970
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

Printable Postscript Versions Of The Track Maps

2. South Pacific Ocean (P)

1945 1946 1947 1948 1949 1950
1951 1952 1953 1954 1955 1956 1957 1958 1959 1960
1961 1962 1963 1964 1965 1966 1967 1968 1969 1970
1971 1972 1973 1974 1975 1976 1977 1978 1979 1980
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

Printable Postscript Versions Of The Track Maps

4. Working Notes

Appendix 6 - A List of Acronyms

A - Arabian Sea Basin / region, a DOD TC basin / region designator.

AFOS - Automation of Field Operation and Services system, which was developed by Ford Aerospace Co. for U.S. National Weather Service. AFOS is an interactive system for operational weather forecasters.

AL - (Also called ATL, LANT, NA and NAT.) North Atlantic Ocean, a JTWC Archive / ATCF TC basin / region designator.

ATL - Same as AL.

AOR - the Area of Responsibility of a Navy command or a forecast center.

ARTS - Annual Report of Typhoon Season published during 1952-55. They are the predecessors of ATCR.

ATCF - Automated Tropical Cyclone Forecasting System, an interactive system for operational tropical cyclone forecasters.

ATCR - Annual Tropical Cyclone Report, published by the JTWC from 1980 to present.

ATR - Annual Typhoon Report, the FWC/JTWC 1959-73 and by the JTWC 1974-79. They are the predecessors of ATCR.

ATSR - Annual Tropical Storm Report, published by the Typhoon Tracking Center, Fleet Weather Central, Guam, Mariana Islands (M. I.), during 1956-58. They are the predecessors of ATCR.

AUS - Australia region, a TC region designator.

AVHRR - the Advanced Very High Resolution Radiometer, a broadband, four or five channel (depending on the model) scanner, sensing in the visible, near-infrared, and thermal infrared portions of the electromagnetic spectrum. This sensor is carried on NOAA's Polar Orbiting Environmental Satellites (POES), beginning with TIROS-N in 1978. Each pass of the satellite provides a 2399-km (1491 miles) wide swath. The satellite orbits the earth 14 times daily from 833 km (517 miles) above its surface.

AWIPS - Advanced Weather Interactive Processing System, which replaced the NWS AFOS during the late 1990s.

B - Bay of Bengal basin / region, a DOD TC basin / region designator.

C - central North Pacific basin / region, a DOD TC basin / region designator.

CENTPAC - Same as CP.

CNP - Same as CP.

CP - (Also called CENTPAC, CNP and CPAC.) The central North Pacific Ocean, a JTWC Archive / ATCF TC basin / region designator. CP is a JTWC Archive / ATCF TC basin / region designator.

CPAC - Same as CP.

CPHC - Central Pacific Hurricane Center in Honolulu, HI.

DOD - Department of Defense.

DMSP - Defense Meteorological Satellite Program. The 6th Space Operations Squadron, Offutt Air Force Base (AFB), Nebraska, under the 50th Space Wing at Falcon AFB, Colorado, provide command and control support for all DMSP satellites. DMSP Block 5D-3 satellites are in near polar orbiting, sun synchronous orbits at an altitude of approximately 458 nautical miles (nominal) above the earth's surface. The orbital period is 101 minutes. The weather sensor on a DMSP provides twice-daily visual and infrared imagery of cloud cover over a swath 1,600 nautical miles wide. Additional sensors measure atmospheric vertical profiles of temperature and moisture.

E - The eastern North Pacific basin / region, a DOD TC basin / region designator.

EASTPAC - Same as EP.

EP - (It is also called EASTPAC, EPAC and NEP.) The eastern North Pacific Ocean, a JTWC Archive / ATCF TC basin / region designator. EP is a JTWC Archive / ATCF TC basin / region designator.

EPAC - Same as EP.

FWC - US Navy Fleet Weather Central, Guam, Mariana Islands (M. I.), deactivated in 1999.

GPS - Global Position System.

IO - (Also called NIO.) North Indian Ocean including DOD designator A (Arabian Sea) and B (Bay of Bengal). IO is a JTWC Archive TC region designator.

JTWC - Joint Typhoon Warning Center. Prior to 1998 the JTWC was located on Guam, Mariana Islands and is now located at Pearl Harbor, Hawaii.

JTWC Archive - The JTWC Tropical Cyclone Best-tracks database. ATCF uses the same database.

L - North Atlantic Ocean, a DOD TC basin / region designator.

LANT - Same as AL.

McIDAS - Man-computer Interactive Data Access System, developed by the Space Science and Engineering Center, University of Wisconsin at Madison (SSEC/UW-Madison).

M. I. - Mariana Islands.

MIDAS - Meteorological Interactive Display and Analysis System, which was manufactured by Global Science & Technology Co. for JTWC.

MODIS - The Moderate Resolution Imaging Spectroradiometer, which is the key instrument aboard the Terra (EOS AM-1) satellite. Terra MODIS is viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands. Two bands are imaged at a nominal resolution of 250 m at nadir, five bands at 500 m and the remaining 29 bands at 1,000 m. A ± 55-degree scanning pattern at the Earth Observation Satellite orbit of 705 km achieves a 2,330-km swath.

NA - Same as AL.

NAT - Same as AL.

NCDC - National Climatic Data Center.

NEP - Same as EP.

NHC - National Hurricane Center in Miami, FL. NHC is a branch of the Tropical Prediction Center.

NIO - North Indian Ocean, a TC basin / region designator.

NOAA - National Oceanic and Atmospheric Administration.

NPMOC / JTWC - U. S. Naval Pacific Meteorology and Oceanography Center / Joint Typhoon Warning Center, since 1998. The predecessors of NPMOC / JTWC was NPMOC West / JTWC in 1997, JTWC during 1975-96, FWC / JTWC during 1959-74, FWC 1954-58, and TTC, FWC during 1952-53.

NPTWS - North Pacific Typhoon Warning Service, 2143D Air Weather Wing, Typhoon Post Analysis Board, Andersen Weather Central, Guam, M. I.

NWP - Same as WP.

NWS - U. S. National Weather Service.

NWP - Northwest Pacific tropical cyclone basin / region. See also WNP.

P - South Pacific Ocean, a DOD TC basin / region designator. South Pacific Ocean TC basin / region is also called Southwest Pacific Ocean region.

QuikSCAT - QuikSCAT is the SeaWinds scatterometer, which is a microwave radar designed specifically to measure ocean near-surface wind speed and direction. QuikSCAT is the name for about 10 km resolution, twice daily, ocean surface, instantaneous winds (speed up to about 45 knots and direction) at a 10-m height from satellite passes as processed by NOAA/NESDIS, from near real-time data collected by NASA/JPL's active SeaWinds Scatterometer instrument aboard the QuikSCAT spacecraft (year 1999+).

S - South Indian Ocean, a DOD TC basin / region designator.

SH - (Also called SHEM.) Southern Hemisphere including DOD designators S (South Indian Ocean) and (P) South Pacific. SH is a JTWC Archive basin / region designator.

SHEM - Same as SH.

SIO - Southern Indian Ocean TC basin / region designator.

SSM/I - Special Sensor Microwave Imager from DMSP system. The SSM/I is a seven-channel, four frequency, linearly-polarized, passive microwave radiometric system which measures atmospheric, ocean and terrain microwave brightness temperatures at 19.35, 22.235, 37.0 and 85.5 GHz. The 85.5-GHz footprint is the smallest with a 13 km by 15 km and the 19.35-GHz footprint is the largest at 43 km by 69 km. SSM/I provides rain rate, surface, instantaneous wind speed (up to 40 knots) and vertically integrated water vapor data over the sea regions.

SST - Sea Surface Temperature.

Storm ID - Storm Identification. In the JTWC Archive best-tracks, each tropical cyclone has a unique eight-character Storm ID that consists of a two-character basin designator, a two-digit TC number, and a four-digit year identifier.

SWP - South-West Pacific Ocean TC basin / region designator.

SWI - South-West Indian Ocean TC basin / region designator.

TC - tropical cyclone.

TCs - tropical cyclones.

TC Basin - tropical cyclone basins. Tropical cyclones form within particular oceanic regions around the world called TC basins. TC Basins are also called 'TC regions' and 'Storm Basins'. TCs vary by basin with respect to size, intensity, track, period and frequency of occurrence. Same as TC Region.

TC Region - tropical cyclone region. Same as TC Basin.

TIROS - Television Infrared Observation Satellite. TIROS-I is the first weather satellite, which was launched on 1 April 1960. TIROS-I was operational for only 78 days, and proved that meteorological satellite could be a viable tool for surveying global weather conditions from space.

TPC - Tropical Prediction Center in Miami, FL. TPC comprised of the National Hurricane Center, Tropical Analysis and Forecast Branch and Technical Support Branch.

TTC - Typhoon Tracking Center, Fleet Weather Central (FWC), U.S. Naval Air Station, Agana, Guam, Mariana Islands (M. I.).

URL - Universal Resource Locator. URL is also called Internet-web site, Web site or Home-page address.

USCINCPAC - Commander in Chief, U.S. Pacific Command.

W - The western North Pacific, a DOD TC basin / region designator.

WESTPAC - Same as WP.

WNP - The western North Pacific tropical cyclone basin / region. WNP is also referred as North-West Pacific (NWP) basin / region.

WP - (Also called NWP, WNP, WESTPAC and WPAC.) The western North Pacific Ocean, a JTWC Archive / ATCF TC basin / region designator.

WPAC - Same as WP.