A GLOBAL VIEW OF THE LANDFALL CHARACTERISTICS OF TROPICAL CYCLONES

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ABSTRACT

This report presents a climatology of the landfall characteristics of tropical cyclones (TCs) by country. Landfalling TCs can produce strong winds, storm surges and severe flooding that may result in loss of life and widespread damages. Although historically many governments have estimated the frequency of TC landfall for their own country, less work has been undertaken from a global viewpoint. This report addresses that gap by presenting a comparative assessment that may assist global efforts toward disaster risk reduction through improved understanding of the relative level of exposure of countries to TCs. The various aspects of the climatology of TC landfalls for each country are provided. Using the definition of a TC landfall as the intersection of the TC track with a coastline, eleven countries were detected as having an average of at least one landfall per year. China has the highest rate of TC landfalls. The Philippines ranks second and Japan third. A lot of countries that face the North Western Pacific were included in TC-Landfall countries, which is attributed to the high rate of TC formation over the basin.

Keywords: landfall, climatology of landfall characteristics, ranking of TC landfall country

1. Introduction

The purpose of this report is to present a climatology of the landfall characteristics of tropical cyclones (TCs) by country, for each country that experiences an average of at least one landfall a year.

Landfalling TCs can produce strong winds, storm surges and severe flooding that may result in loss of life and widespread damages. Although historically many governments have estimated the frequency of TC landfall for their own country, less work has been undertaken from a global viewpoint. This report addresses that gap by presenting a comparative assessment that may assist global efforts toward disaster risk reduction through improved understanding of the relative level of exposure of countries to TCs.

2. Data and definition

The International Best Track Archive for Climate Stewardship (IBTrACS v03r04; Knapp et al. 2010) was used in the report. While the IBTrACS compiled the best track data provided by 13 Tropical Cyclone Warning Centers (TCWCs) and Regional Specialized Meteorological Centers (RSMCs), we selected the track data from the official World Meteorological Organization (WMO) agency to identify the TC lifecycle location and intensity. The data of official WMO agency consists of track data from RSMCs and TCWCs for each basin: Japan Meteorological Agency as RSMC Tokyo for the North Western Pacific (WP), U.S. National Oceanic and Atmospheric Administration's (NOAA's) Central Pacific Hurricane Center as RSMC Honolulu for the North Eastern Pacific (EP), Australian Bureau of Meteorology (BOM) as TCWC Perth, Darwin, Brisbane, and RSMC Nadi for the South Pacific (SP), India Meteorological Department as RSMC New Delhi for the North Indian Ocean (NI), Météo-France as RSMC La Reunion and BOM for the South Indian Ocean (SI), NOAA's National Hurricane Center as RSMC Miami for the North Atlantic (NA) and the South Atlantic (SA). Due to the limitations of the track data, analysis periods were from 1971 to 2011 for EP and NA, from 1977 to 2011 for WP, and from 1990 to 2011 for NI, SI, and SP. We did not normalize for data bias caused by the different wind-averaging periods each track data, since the purpose of this report is to present a climatology of the landfall characteristics of TCs.

The TC formation location was defined as the location where a TC first reached tropical storm intensity (maximum sustained wind speeds of greater than 17 ms^{-1} or 34 knots).

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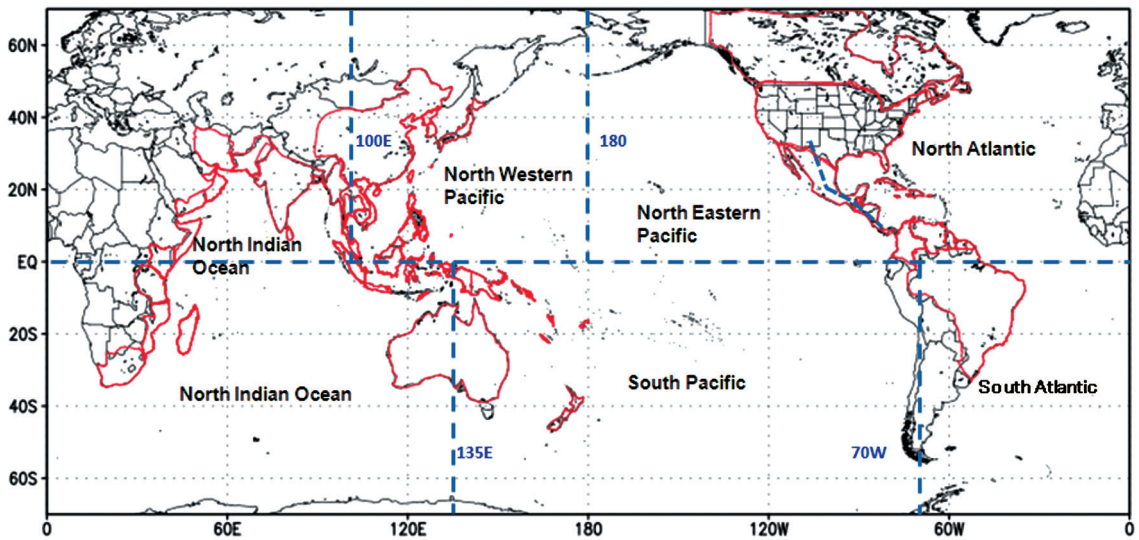

Fig. 1. Coastlines (red line) for each country in our analysis and defined borders of basins.

The location of cyclolysis was defined as the last point in the track where the TC had tropical storm intensity. The coastlines for each country were defined as shown in Fig. 1. We adopt the definition of a TC landfall as the intersection of the TC track with a coastline. The tracks were provided by the 6-hourly TC locations. We include landfalling TCs that were downgraded to a tropical depression at the first analysis point following landfall but were classified as TCs at the last analysis point prior to landfall. Inland national boundaries are treated as a coastline. For example, if a TC made landfall in Vietnam but moved across the border into Laos prior to being downgraded, we count as a landfall for Laos as well as Vietnam. It should be noted that this methodology provides a simple objective metric of the relative exposure of countries to TC impacts, but ignores the potential for significant impacts from TCs that come close to, but do not cross the coastline.

3. Results

a. Annual variation of TC formation by basin

The number of TC formations averaged from 1990 to 2011 is 77.8 with large annual variation (Fig. 2). We detected the climatological number of TC formation by basin. The seven basin regions are defined by the equator (Fig. 1). WP and EP are defined as the area bounded by 180°, and SI and SP are defined as the area bounded by 135°E.

The highest average number of TC formations for any basin is 24.1 in WP, more than 30 percent of the global number. The ranks are as follows: 15.1 in EP, 13.2 in SI, 12.6 in NA, 8.7 in SP, and 3.8 in NI. In SA, a TC formation was detected in 2004, 2010, and 2011.

b. Annual number of TC landfalls by country

We define a TC Landfall Country (TCLC) as a country for which the mean number of TC landfalls is at least one a year (≥1.0 landfalls per year). By this definition there are 11 TCLCs. The TCLCs were ranked as shown in Table 1 and graphically illustrated in Fig. 3. China has the highest rate of TC landfalls. The Philippines ranks second and Ja-

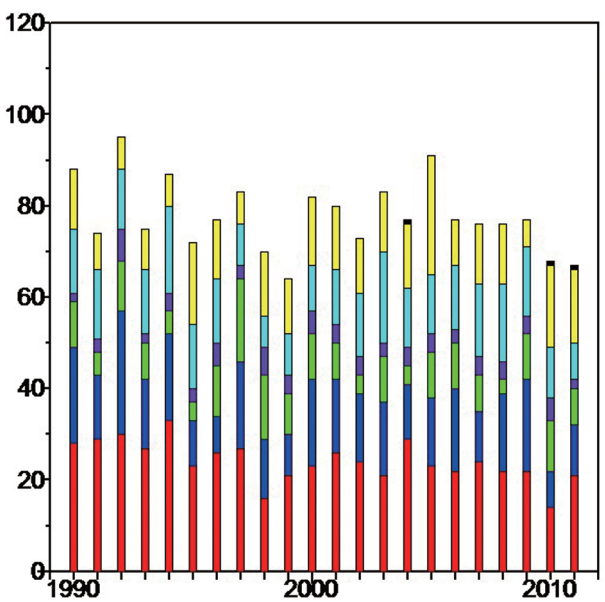

Fig. 2. Annual variation of TC formation by basin: North Western Pacific (red), North Eastern Pacific (blue),South Pacific (green), North Indian Ocean (purple),South Indian Ocean (light blue), North Atlantic (yellow), and South Atlantic (black).

TABLE 1. Ranking of TC landfall country

Rank	TLC	Yearly average No.
1	CHINA	6.714
2	PHILLIPINES	4
3	JAPAN	3.743
4	USA	3.31
5	MEXICO	3.19
6	VIETNAMA	2.943
7	AUSTRALIA	2.909
8	MADAGASCAR	1.636
9	INDIA	1.409
10	LAOS	1.343
11	CANADA	1

pan third. Five of the eleven TCLCs are countries that border the WP; which is attributed to the high number of TCs in that basin.

The following pages of the report provide graphs and figures that illustrate various aspects of the climatology of TC landfalls for each TCLC: a graph of the annual variation of TC landfalls, a graph of the distribution by month of TC landfalls, a map of the tracks of landfalling TCs, a map of formation locations for landfalling TCs, a map of landfall locations, a map of cyclolysis locations for landfalling TCs, a graph of the distribution of central pressures at the first analysis point following landfall, a graph of the distribution of maximum sustained wind speeds at the first analysis point following landfall, a graph of the distribution of TC duration from formation to landfall, and a graph of the distribution of TC duration from landfall to cyclolysis.

The climatology of TCs that made landfall on China is shown in Fig. 4. A lot of TCs form in the Philippine Sea and the South China Sea (SCS) and move westward over the southern and eastern coasts, and eastern Taiwan. If the coastlines of China do not include Taiwan, China is still ranked as the highest TCLC. The number of landfall TCs from the SCS is greater than those from the Philippine Sea.

The climatology of TC that made landfall on the Philippines is shown in Fig. 5. The intra-seasonal distribution shows a bi-modal character with peaks in July and October. It is notable that more intense (hurricane-force) TCs make landfall on the Philippines than any other country.

The climatology of TC that made landfall on Japan is shown in Fig. 6. It should be noted that Japan coastlines include the Nansei and Satsunan Islands, which is the dif-

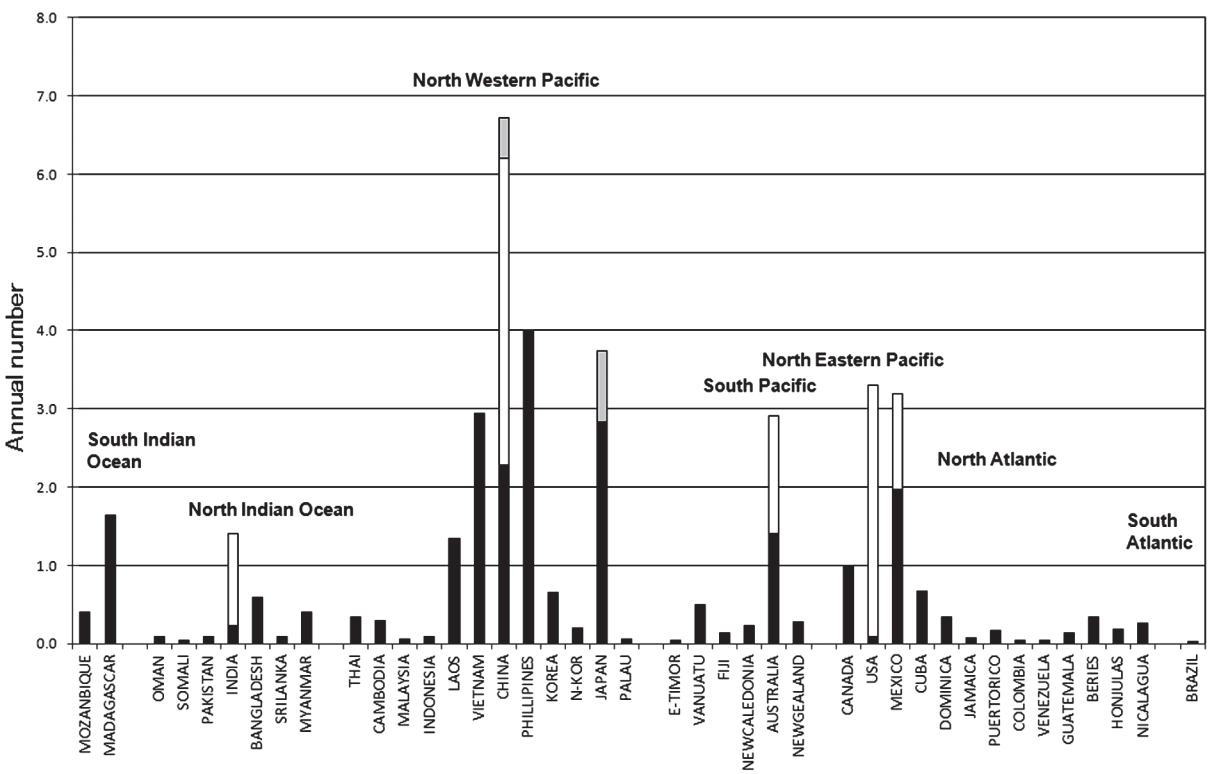

FIG. 3. Annual average number of TCs that make landfall by country. Opened bars mean the eastern coast of the countries which have the eastern and western coasts. Gray bars means Taiwan in China and Nansei and Satsunan Islands in Japan.

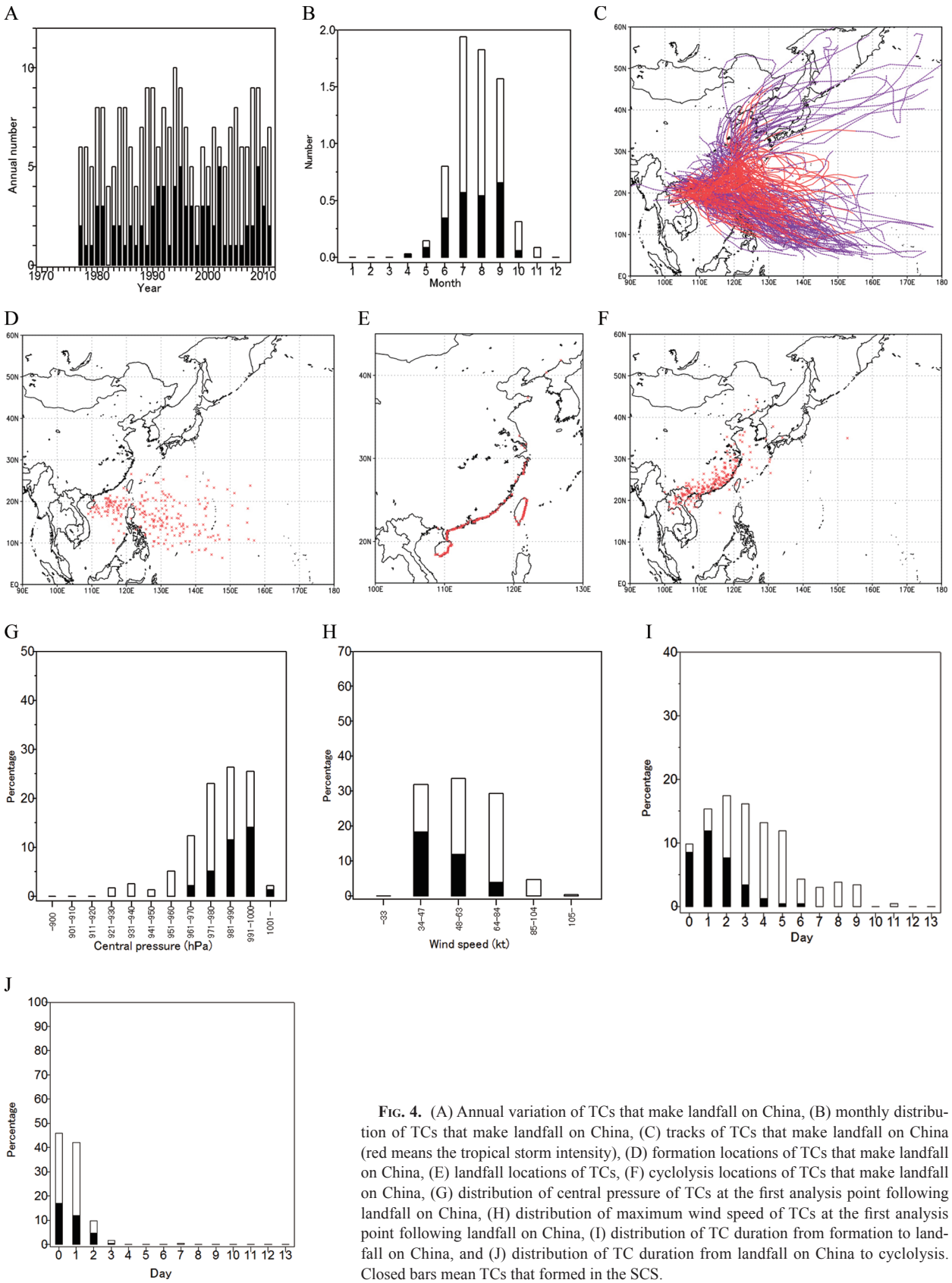

FIG. 4. (A) Annual variation of TCs that make landfall on China, (B) monthly distribution of TCs that make landfall on China, (C) tracks of TCs that make landfall on China (red means the tropical storm intensity), (D) formation locations of TCs that make landfall on China, (E) landfall locations of TCs, (F) cyclolysis locations of TCs that make landfall on China, (G) distribution of central pressure of TCs at the first analysis point following landfall on China, (H) distribution of maximum wind speed of TCs at the first analysis point following landfall on China, (I) distribution of TC duration from formation to landfall on China, and (J) distribution of TC duration from landfall on China to cyclolysis. Closed bars mean TCs that formed in the SCS.

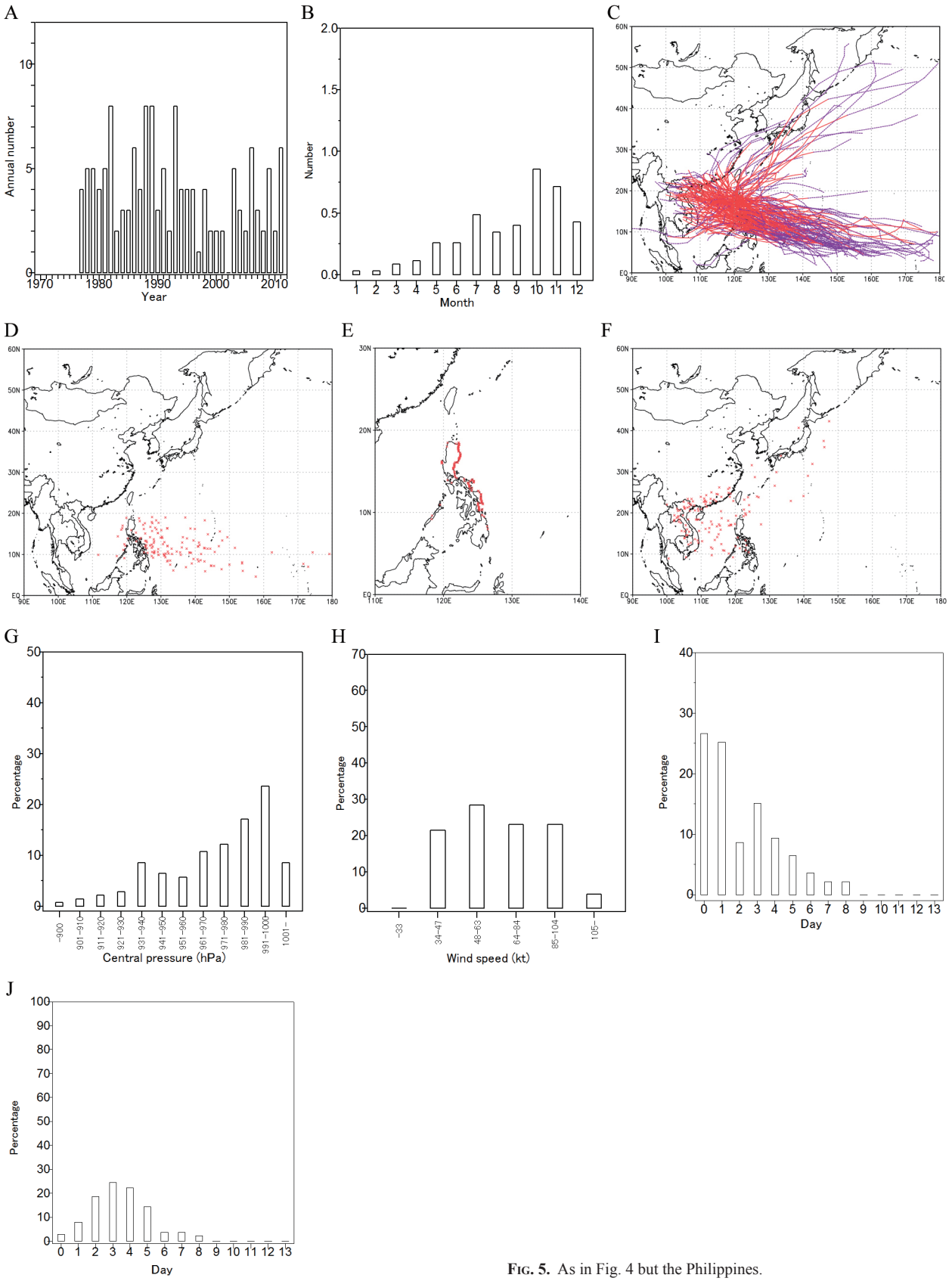

FIG. 5. As in Fig. 4 but the Philippines.

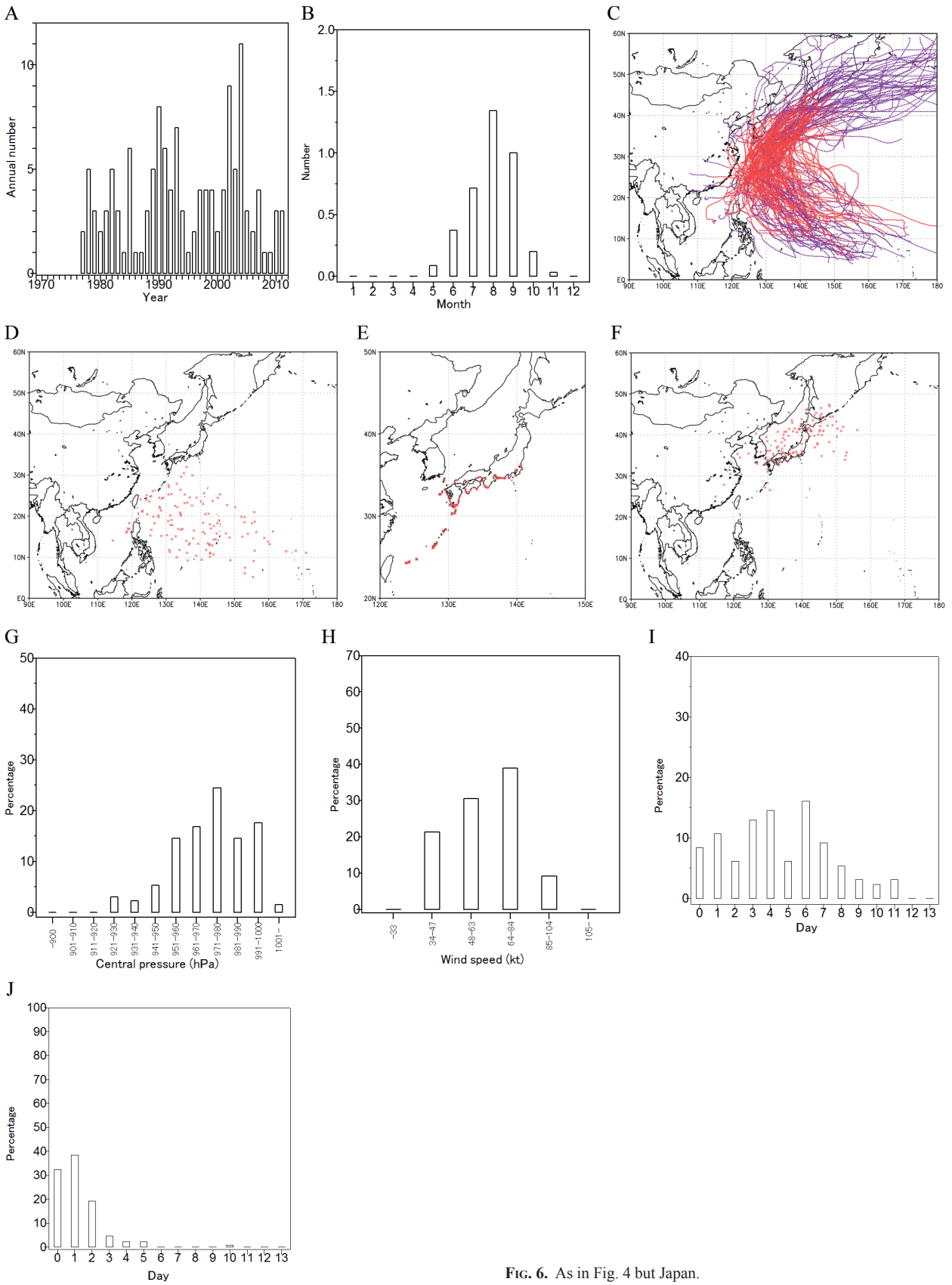

FIG. 6. As in Fig. 4 but Japan.

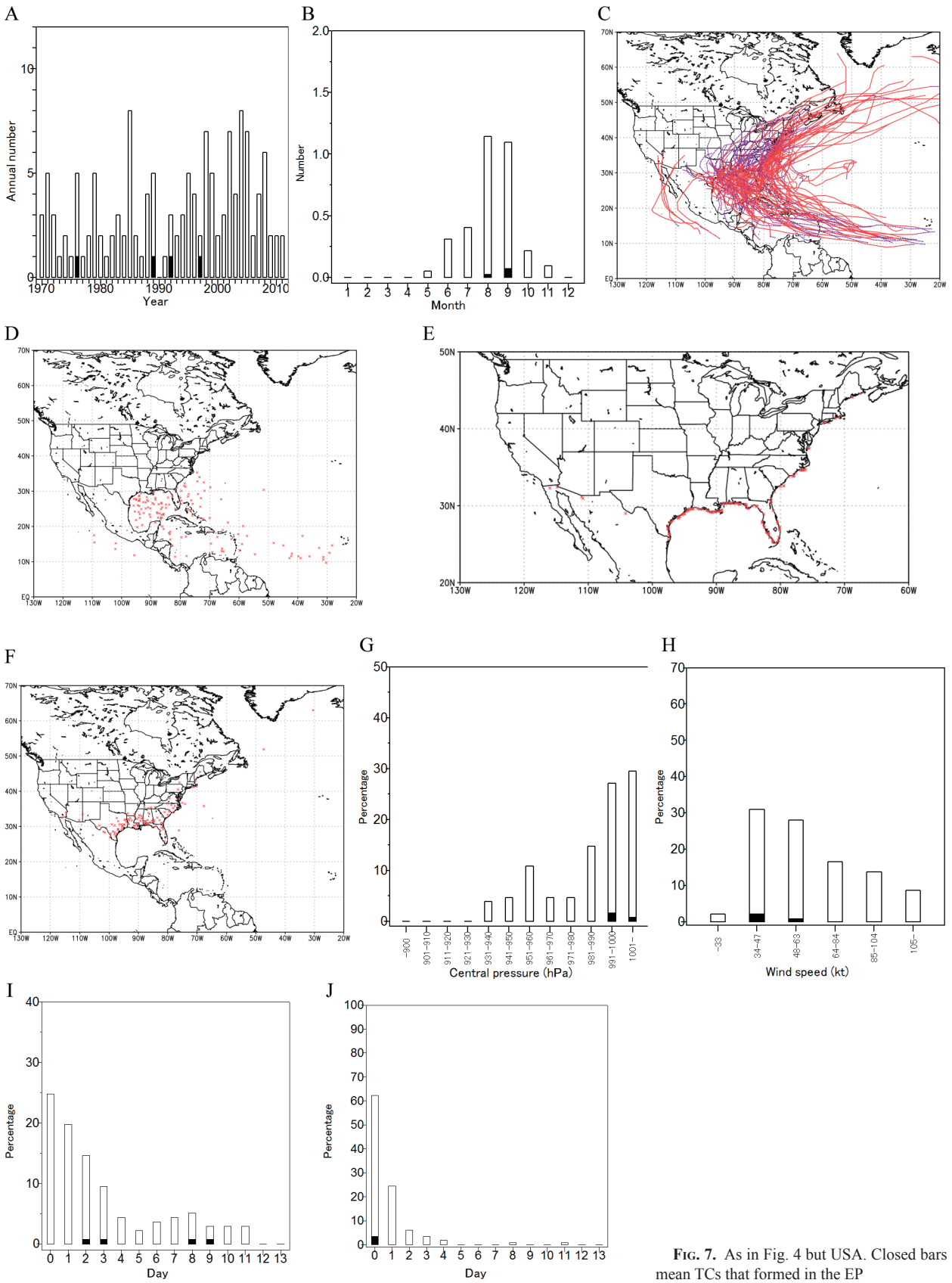

FIG. 7. As in Fig. 4 but USA. Closed bars mean TCs that formed in the EP

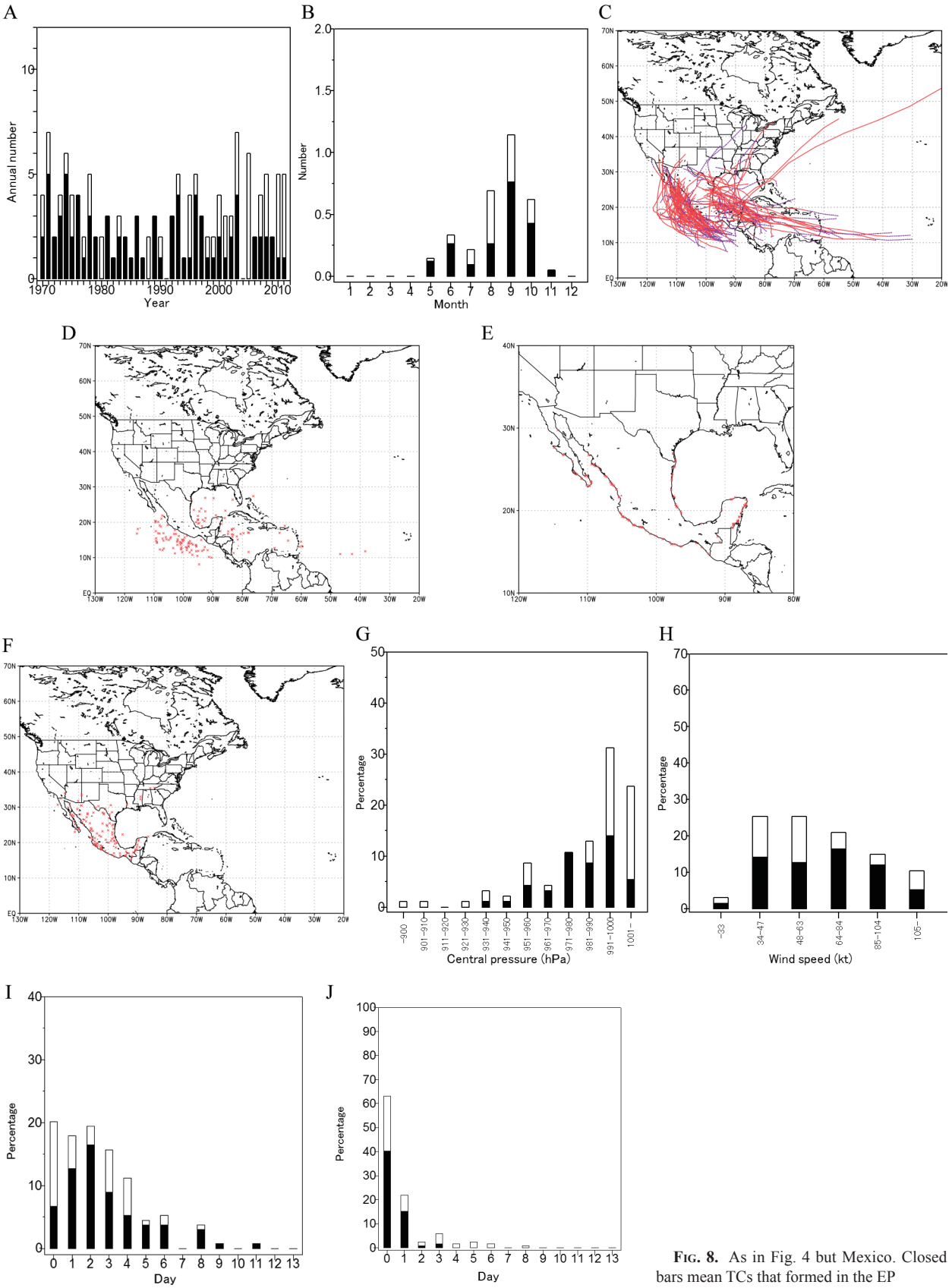

FIG. 8. As in Fig. 4 but Mexico. Closed bars mean TCs that formed in the EP

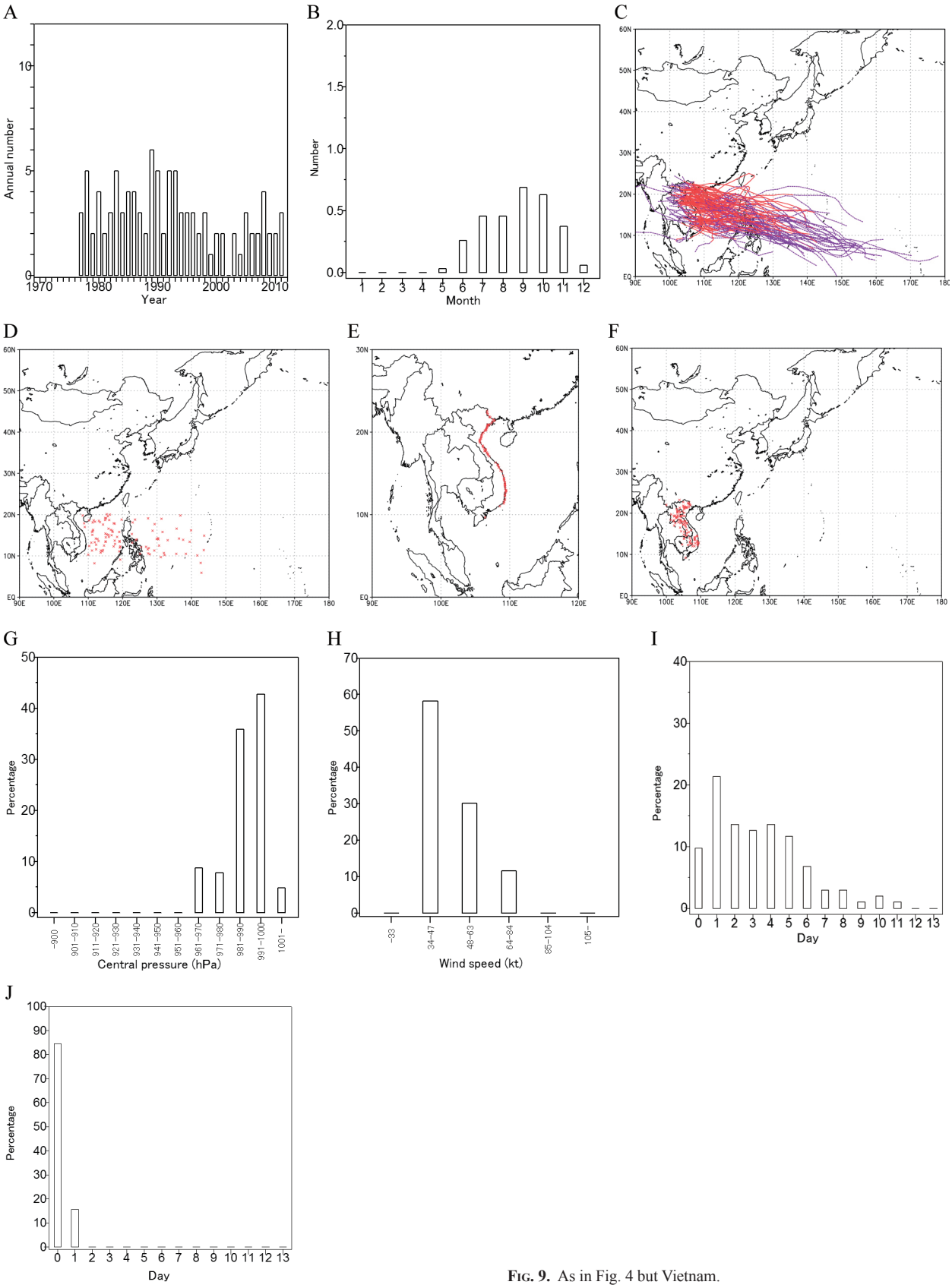

FIG. 9. As in Fig. 4 but Vietnam.

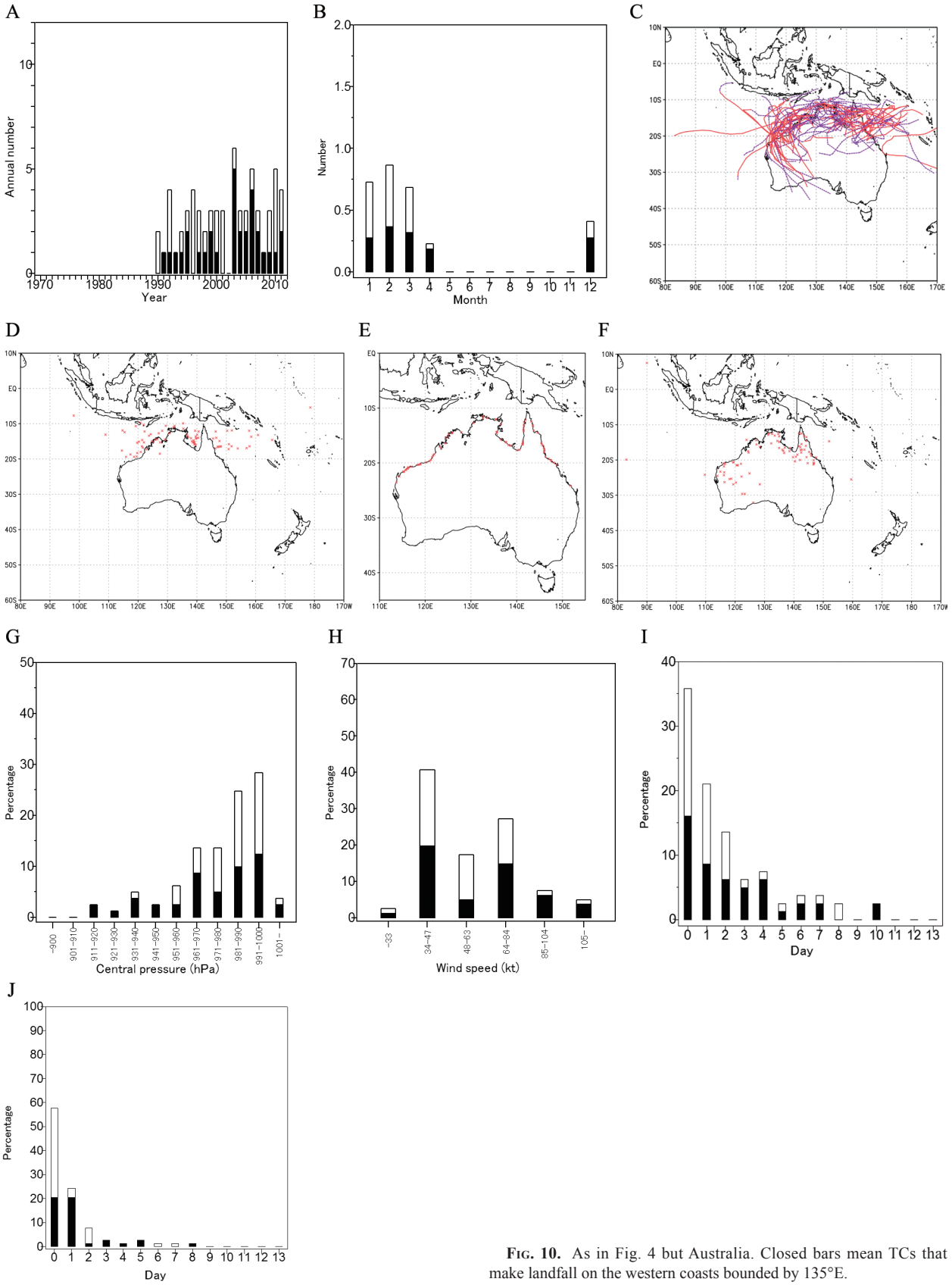

FIG. 10. As in Fig. 4 but Australia. Closed bars mean TCs that make landfall on the western coasts bounded by 135°E.

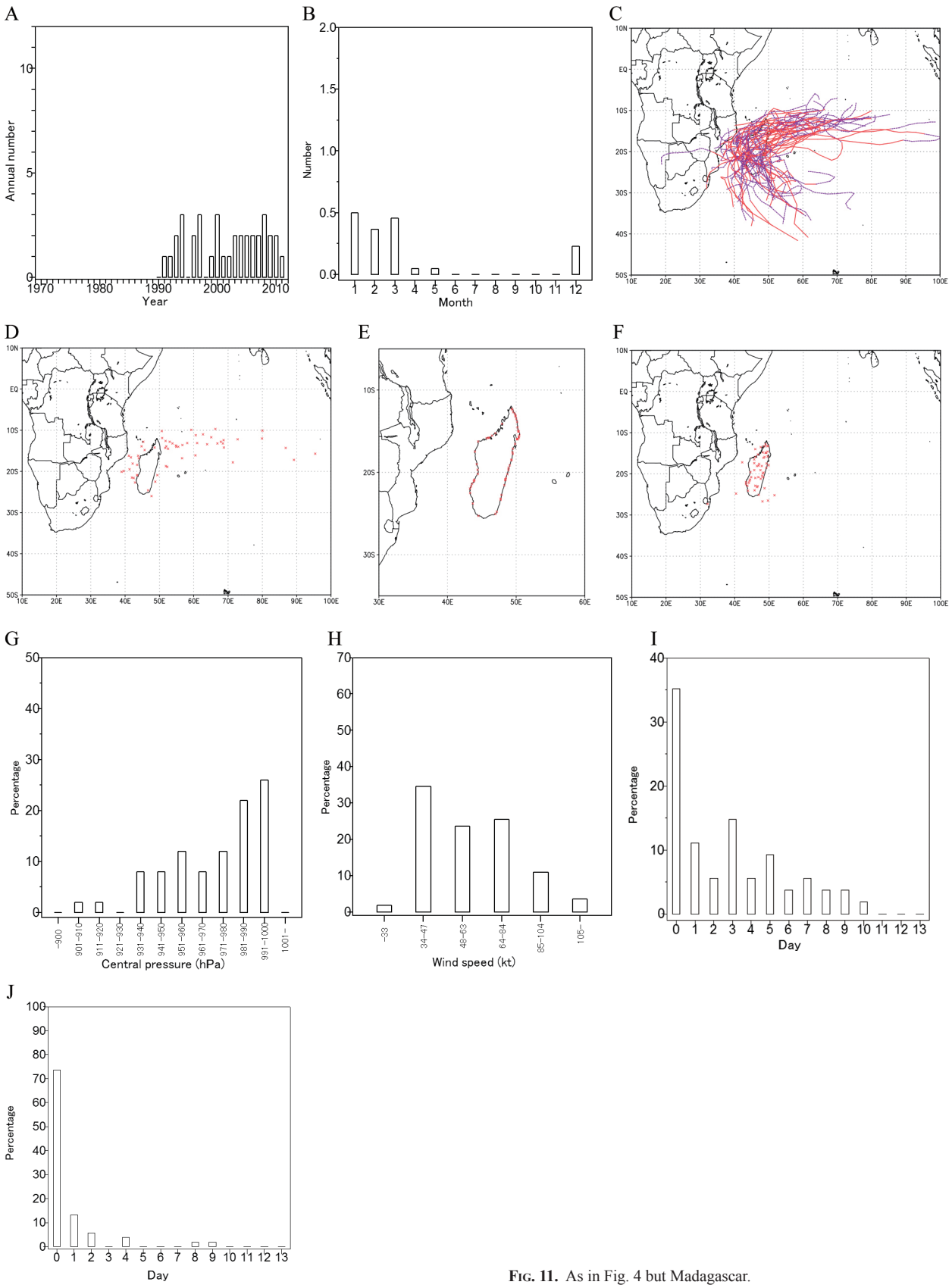

FIG. 11. As in Fig. 4 but Madagascar.

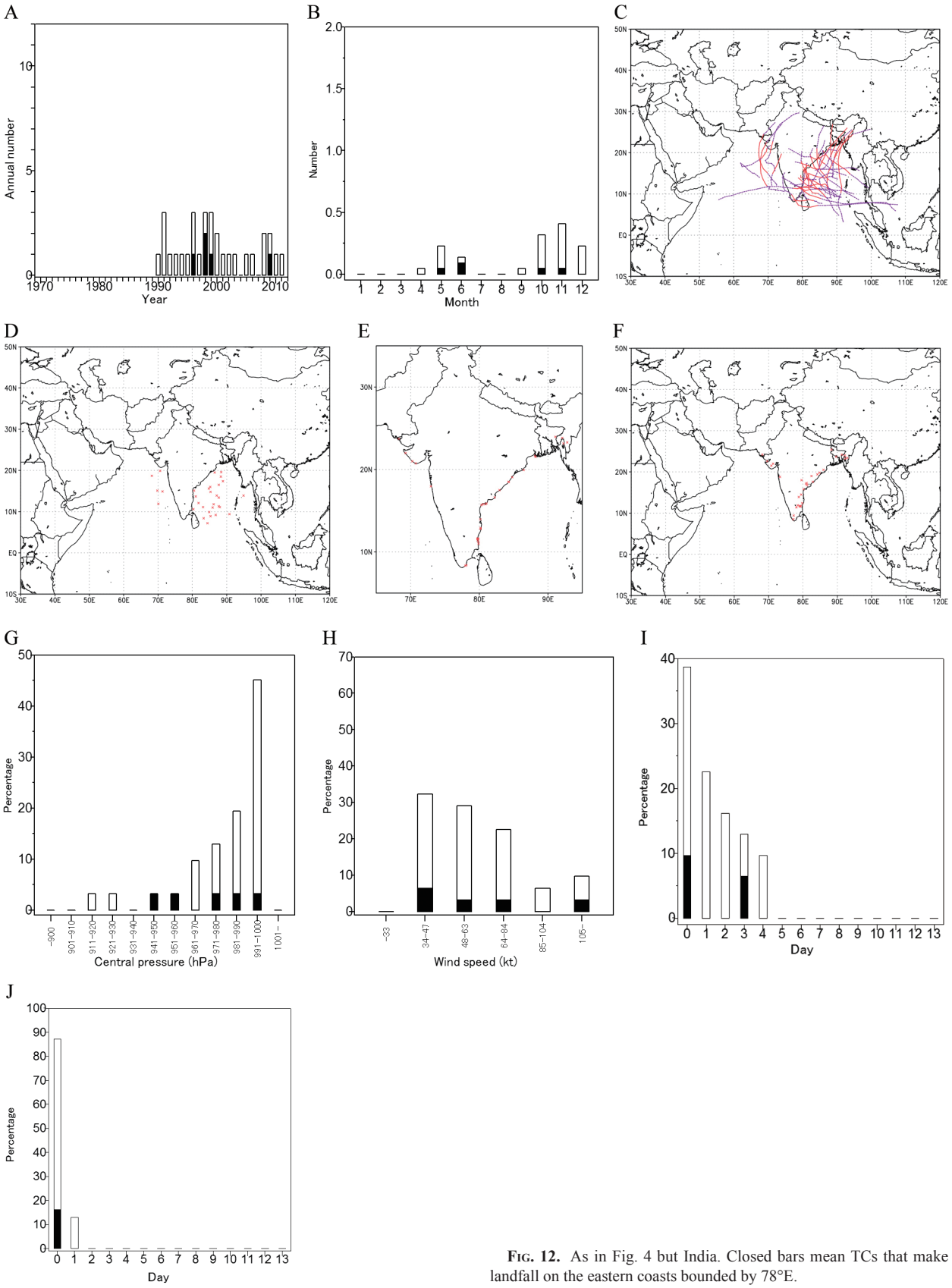

FIG. 12. As in Fig. 4 but India. Closed bars mean TCs that make landfall on the eastern coasts bounded by 78°E.

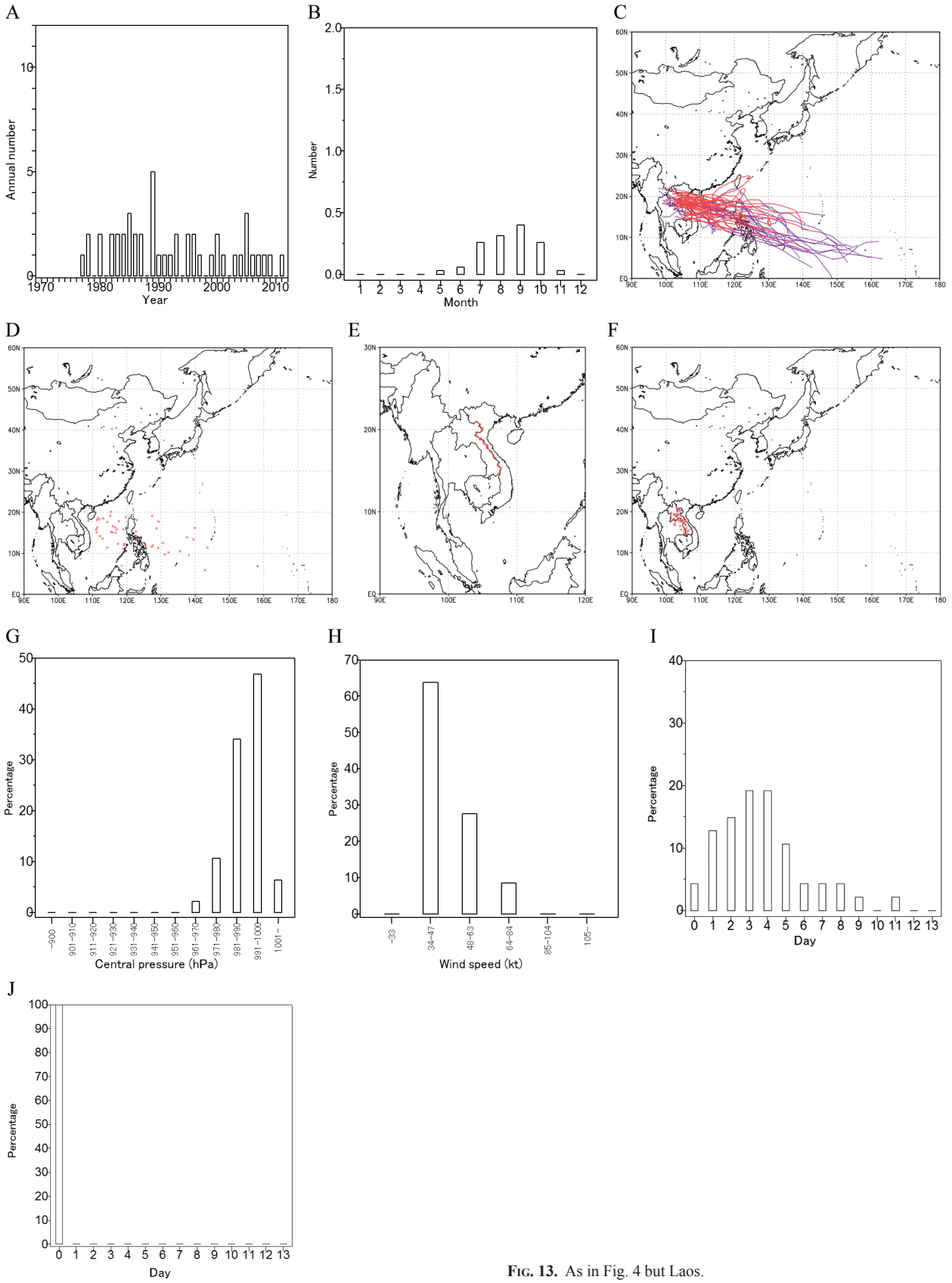

FIG. 13. As in Fig. 4 but Laos.

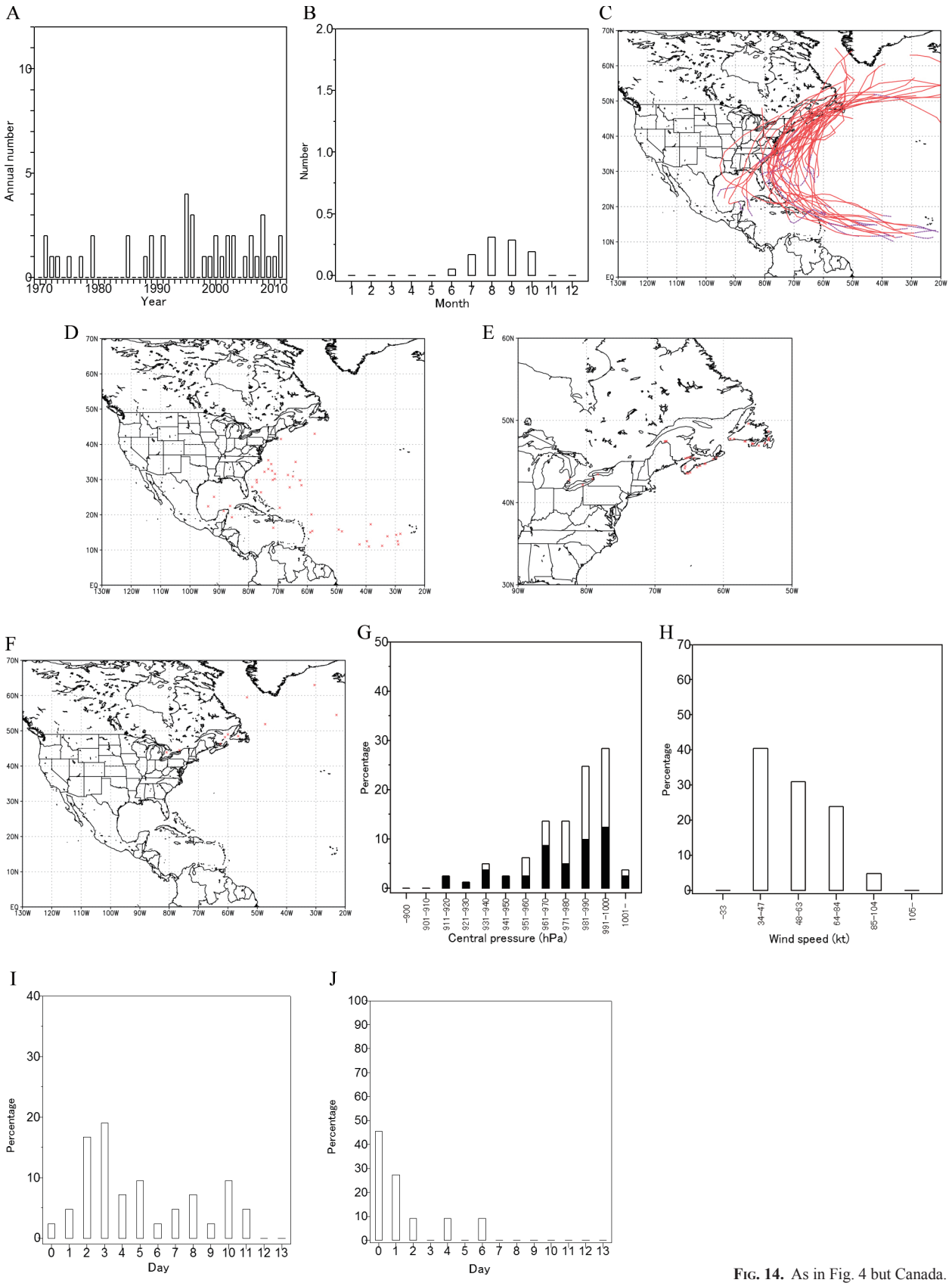

FIG. 14. As in Fig. 4 but Canada.

ferent from the definition used by the Japan Meteorological Agency. If the coastlines of Japan do not include Nansei Islands and Satsunan Islands, Japan is ranked as the seventh highest TCLC.

The climatology of TC that made landfall on the USA is shown in Fig. 7. Most TCs landfalling on the USA form in the Caribbean Sea or the Gulf of Mexico and move northwestward toward the southern and eastern coasts. TCs make landfall on both the west and east coasts of the Florida Peninsula.

The climatology of TC that made landfall on Mexico is shown in Fig. 8. In contrast to USA, the number of landfall TCs from EP is comparable to those from the Gulf of Mexico and Caribbean Sea.

The climatology of TC that made landfall on Vietnam is shown in Fig. 9. Fig. 9c illustrates that Vietnam is mainly affected by TCs that take a straight westwards track after forming in the SCS or Philippines Sea.

The climatology of TC that made landfall on Australia is shown in Fig. 10. Australia is the highest TCLC in the southern hemisphere. The number of TCs that made landfall on the north western coast from SI is comparable to the number of TCs that made landfall on the north eastern coast from SP.

The climatology of TC that made landfall on Madagascar is shown in Fig.11. A lot of TCs come from the central SI, while some TCs make landfall on the western coast of Madagascar from Mozambique Channel.

The climatology of TC that made landfall on India is shown in Fig. 12. The number of landfall TCs on the eastern coast from the Bay of Bengal is much greater than those on the western coast. The intra-seasonal distribution of TCs making landfall on India is distinctly bi-modal with the peaks in May and November.

The climatology of TC that made landfall on Laos is shown in Fig. 13. It is interesting to note that a landlocked country is ranked in the TCLC. After the passage through Vietnam, TC moved across the eastern border into Laos prior to being downgraded.

The climatology of TC that made landfall on Canada is shown in Fig. 14. Canada is the northernmost TCLCs.

4. Conclusion

This report presented a climatology of the landfall characteristics of TCs by country, in order to aid global disaster risk reduction efforts by addressing a gap in the understanding of the relative level of exposure of countries to TCs. The track data from the official WMO agency compiled in the IBTrACS was used to identify the TC lifecycle location and intensity. We adopted the definition of a TC landfall as the intersection of the TC track with a coastline. It should be noted that this methodology provides a simple objective metric of the relative exposure of countries to TC impacts.

Eleven countries were detected as a country for which the mean number of TC landfalls is at least one a year. China has the highest rate of TC landfalls. The Philippines ranks second and Japan third. A lot of countries that face the North Western Pacific were included in TCLCs, which is attributed to the high number of TC formations in that basin.

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