2C.4 ANNUAL ANALYSES OF BASIN AND HEMISPHERIC TROPICAL CYCLONE INDICES

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1. INTRODUCTION

Tropical cyclones have received widespread attention over the past year with the occurrence of the record activity during the Atlantic hurricane season in 2005, and new studies have addressed long-term tropical cyclone frequency and intensity. In addition, the catastrophic aftermath from hurricane Katrina in New Orleans and along the central Gulf of Mexico coast of the U.S. have greatly increased public awareness of the impacts of land-falling hurricanes and tropical storms. While recent studies (i.e., Emanuel 2005; Webster et al. 2005) have pointed to increasing trends in tropical cyclone intensity, additional analyses are necessary for fully understanding global, hemispheric and basin trends as well as inherent data problems and assumptions that must be taken into consideration.

This paper presents analyses of the annual intensities, numbers and other related indices of tropical cyclones over basin and hemispheric spatial scales. Typically, annual tropical cyclone statistics are presented as numbers of tropical storms and hurricanes, but other indices provide different perspectives on the severity of a particular year with respect to the historical record. The analyses presented herein will focus on basic statistics and integrated indices determined over each of the worlds' seven tropical cyclone basins, as well as indices determined over both the Northern and Southern Hemispheres on an annual basis.

2. DATA

The datasets used for this study were obtained from the NOAA/NESDIS/NCDC tropical cyclone archives. The archived datasets include the so-called "best track" data from the Joint Typhoon Warning Center (JTWC), covering the Pacific, Indian and Southern Hemisphere basins, as well as from the NOAA/AOML Hurricane Database (HURDAT; Landsea et al. 2004) that covers the North Atlantic basin.

The most reliable tropical cyclone data that resides in NCDC's historical archives are limited primarily to the satellite era. This limitation pertains especially to the basins of the North and South Indian Ocean, Australia and the South Pacific regions.

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Missing and incomplete data are largely the result of the fact that these storms form and spend the majority of their lifecycles over the oceans where observational data are extremely limited. The obvious exception is the North Atlantic Ocean, where routine aircraft reconnaissance since 1944 has resulted in a more complete dataset for that basin. The overall lack of reliable sustained wind and central pressure data restricts the ability to analyze a number of parameters and indices related to tropical cyclone intensity, duration, and frequency. In particular, quality-controlled sustained wind observations are required for integrated statistics, such as the Accumulated Cyclone Energy (ACE) Index (Bell et al. 2000), in order to accurately calculate an index over any period of interest.

3. TROPICAL CYCLONE INDICES

In order to put tropical cyclone activity into climatological context, a suite of parameters and indices have been developed by NCDC's Climate Monitoring Branch to encompass a broad range of characteristics related to tropical cyclones and their seasonal/annual statistics. These indices include basic parameters related to their numbers, durations, and intensities, such as the maximum 6-hr wind speed (V_{max}) as well as indices that are derived from integrated observations. These annual statistics include the following parameters and indices:

\# Tropical Storms (≥ 34 kt)
\# Hurricanes/Typhoons/Cyclones (≥ 64 kt)
\# Major Hurricanes/Typhoons/Cyclones (≥ 96 kt)
\# Super Typhoons (≥ 128 kt)
Date of first hurricane/typhoon/cyclone
Date of last hurricane day
Date of first tropical storm
Date of last tropical storm
Hurricane/typhoon/cyclone days (allows for >1/day)
Days with hurricanes/typhoons/cyclones (only 1/day)
Maximum wind speed (kt)
Minimum pressure (mb)
Hurricane wind days (∑ Days with V_{max} ≥ 64 kt)
Storm pressure days (∑ Days with 1000-press)
Accumulated Cyclone Energy (∑ V_{max}^2 ≥ 34 kt)
Mean duration of hurricanes (days)
∑ Maximum hurricane wind speeds (kt)
Mean maximum hurricane wind speed (kt)
∆ P (1000-pressure for each tropical cyclone)
Mean ∆ P (1000-pressure for each tropical cyclone)

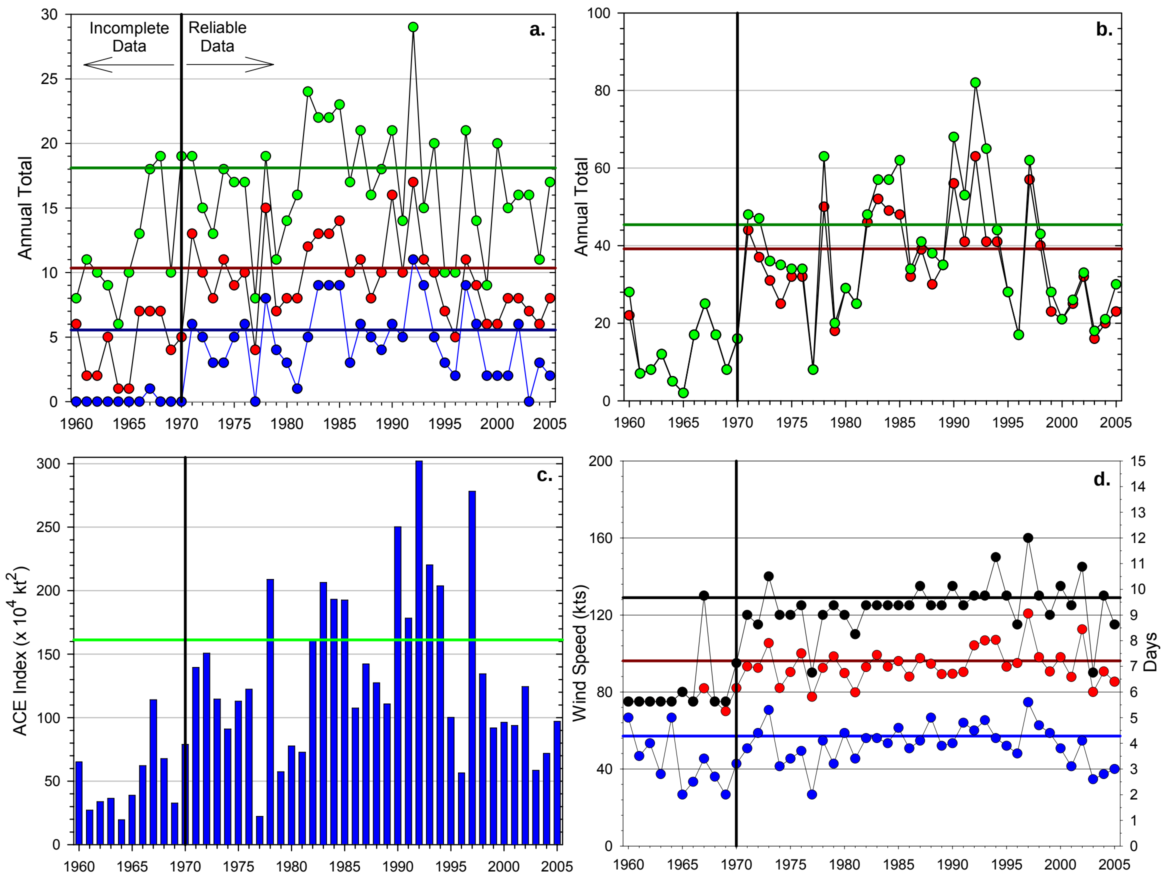

Figure 1. Annual tropical cyclone statistics for the East North Pacific (ENP) basin over the period 1960-2005: a) number of named storms (NS), hurricanes (H) and major hurricanes (MH), b) days with hurricanes (the number of days with winds >64 kt) and hurricane days (days with winds ≥64 kt x number of tropical cyclones with winds ≥64 kt), c) the Accumulated Cyclone Energy (ACE) Index (x 10^4 kt^2), and d) the maximum and mean maximum wind speed (kt), and mean hurricane duration (days). All time series include the corresponding 1981-2000 base period means.

Not all of the indices defined above will be addressed in this paper, but a subset will be presented to demonstrate the utility of analyzing multiple indices for climatological applications. Particular focus will be placed on the ACE Index as a measure of activity, given the integrated nature of this index that includes both intensity and duration information. All indices were determined over the seven tropical cyclone basins, which are defined here as: North Atlantic (NAT), East North Pacific (ENP; which includes both the eastern and central Pacific Ocean regions), West North Pacific (WNP), North Indian Ocean (NIO), South Indian Ocean (SIO; west of 105˚W), Western Australia (WAU; 105˚W to 135˚W), and the South Pacific (SPA; east of 135˚W).

Figure 1 shows a number of basic parameters derived from data in the ENP basin. Annual analyses of tropical cyclone numbers (Fig. 1-a), hurricane days and days with hurricanes (Fig. 1-b), the ACE Index (Fig. 1-c), and the maximum wind speed, mean maximum wind speed, and hurricane duration (Fig. 1-d) illustrate that there are periods in the historical record with obviously incomplete data, and periods where the completeness of the data are generally reliable. For the ENP, where routine satellite coverage began in 1966, our analysis surprisingly shows that the archived data are most clearly incomplete before 1970, and afterwards the data are generally reliable and in most cases complete.

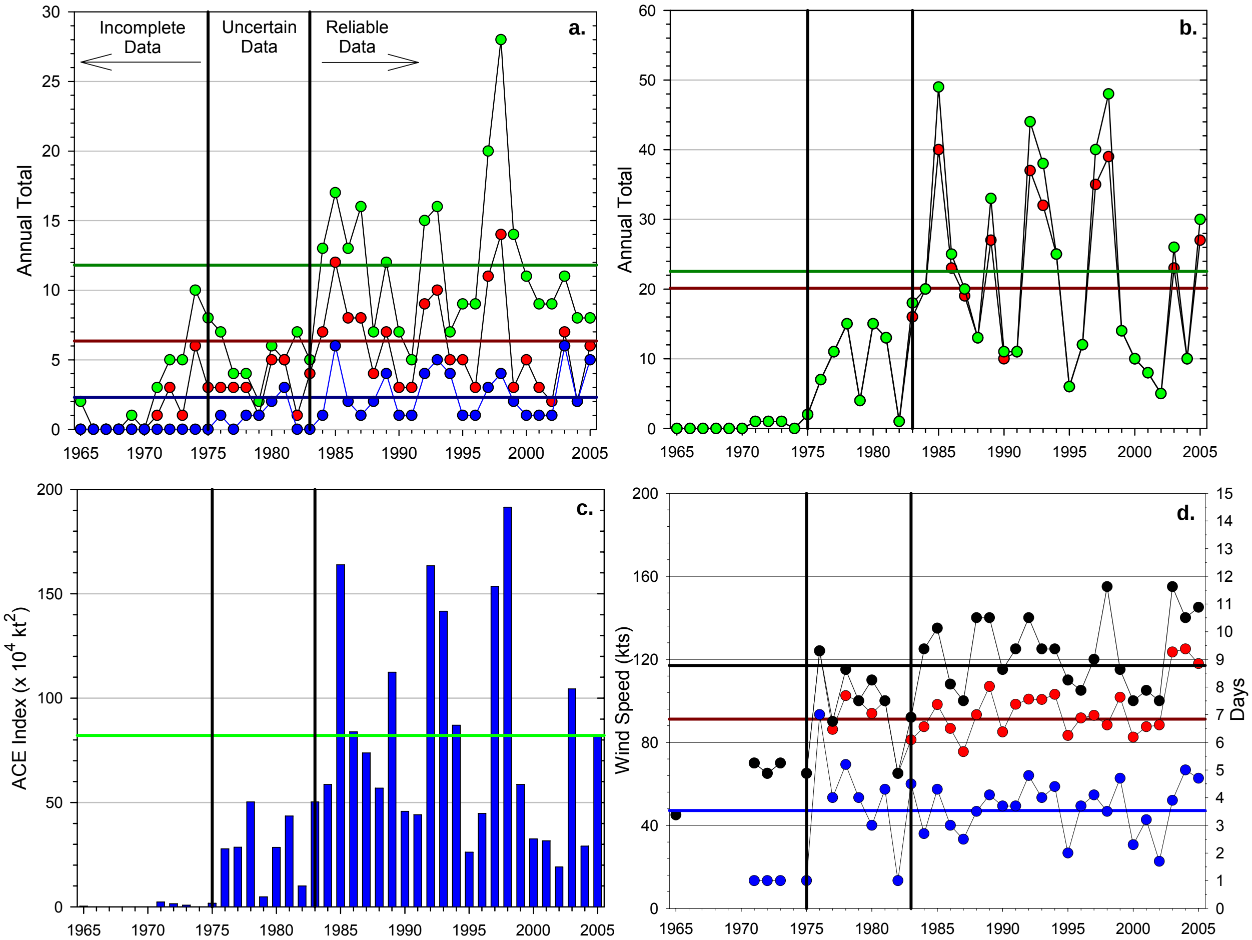

Figure 2. Same as in Fig. 1 (a-d), except the data shown are from the South Pacifc (SPA) basin and covering the period 1965-2005.

Figure 2 illustrates the same analysis, this time using data from the SPA basin. The Southern Hemisphere basins are widely known for the incompleteness of their tropical cyclone data, and this is clearly shown in Figure 2 (a-d), where the period of incomplete data extends to 1975. A period of uncertainty extends from 1975 to 1983. Despite the general completeness of the data since 1983, sustained winds are often reported only twice daily in the Southern Hemisphere and North Indian Ocean basins, versus the typical four times daily corresponding with standard synoptic reporting times that are generally routine in the other Northern Hemisphere basins. Where needed, interpolation was used to rectify missing 6-hr sustained wind speeds.

It is especially important to note that these periods of incomplete, uncertain and reliable data occur at different times in each of the seven tropical cyclogenesis regions, complicating any analysis of long-term, global tropical cyclone activity for climate-related purposes. This is especially a concern for those studies attempting to address the long-term relationship of tropical cyclones with the observed warming of sea-surface temperatures (SSTs) at the basin-, hemispheric- or global-scales.

4. BASIN-SCALE ANALYSES

As an example of the basin-scale analyses determined annually, the annual ACE Index values for all seven global tropical cyclone basins are shown in Figure 3. Each basin's annual ACE Index values are plotted along with the corresponding 1981-2000 base period means. Note that the WNP basin typically has the largest annual ACE values, as it is the region of consistently highest activity. However, there are a few years in the historical record when activity in the WNP basin was exceptionally below normal, and either the ENP or NAT were more active in terms of their annual ACE values.

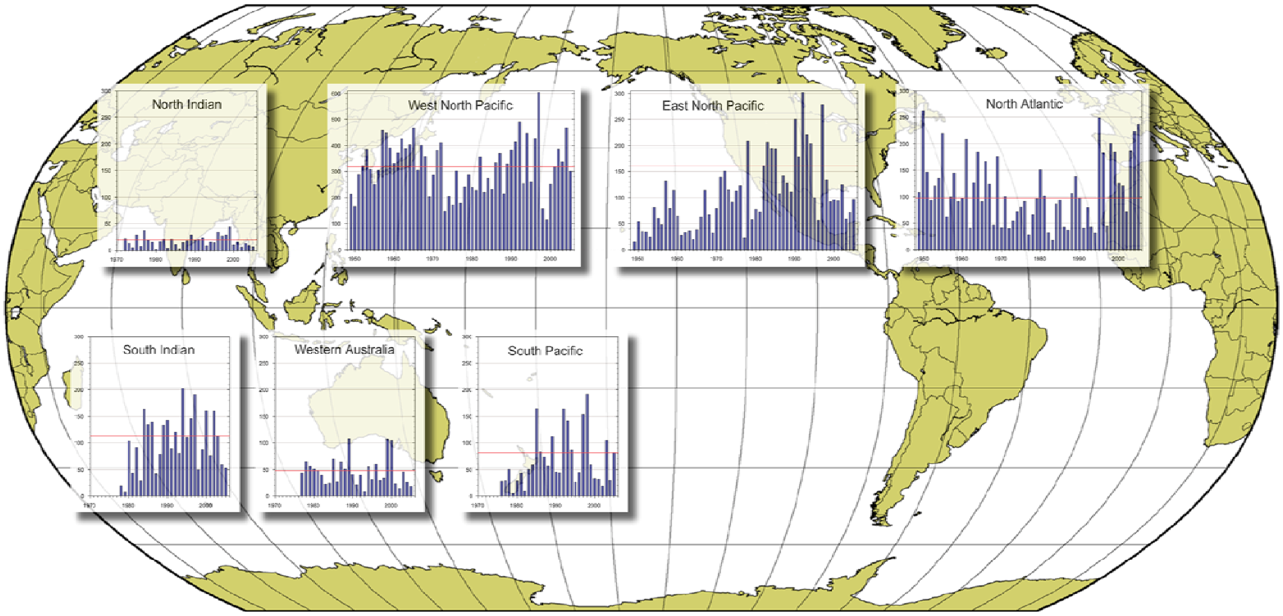

Figure 3. Annual values of the Accumulated Cyclone Energy (ACE) Index (x 10^4 kt^2) calculated for each of the seven tropical cyclone basins around the globe. The y-axis scales on all graphs are the same, except for the West North Pacific (WNP) basin, and the red lines denote the 1981-2000 base period means for each basin.

As has been reported elsewhere (i.e., Gray 1984; Henderson-Sellers et al. 1998), variability of tropical cyclone activity in each basin can occur on both inter-annual and inter-decadal time-scales. It is clear from the annual ACE Index time series that the observed long-term variability is different in each basin and in most cases is difficult to attribute to one specific climate-related event or signal.

5. HEMISPHERIC-SCALE ANALYSES

Once each basin annual value is determined, it is a simple exercise to add them together to determine hemispheric or global ACE Index values. In general, hemispheric indices are recommended over global calculations for several reasons. The primary one is that the general lack data in the Southern Hemisphere (SH) compared with the Northern Hemisphere (NH) severely limits the length of any global index, but the offset season in the SH (July to June) requires combining data from two distinct but overlapping time periods (i.e., SH data covering the period July thru June, and NH data covering each calendar year).

Figure 4 shows the annual ACE Indices for both Hemispheres since 1950. The lack of data in the SH prior to the 1980's is clearly apparent, and limits the ability of the time series to be calculated prior to the late 1970's. As noted in Figure 2, for the SPA basin, the overall reliability of the data in the SH basins is questionable before the early 1980s. Therefore, despite the inclusion of SIO data in 1978, the ACE Index values for the SH are unreliable until approximately 1983. This means that the increasing trend in SH tropical cyclone activity during the early 1980s is an artifact of the data problems, but the more recent downward trend in SH activity since about 2000 appears to be real.

For the NH, 6-hr sustained wind data from any tropical cyclones in the NIO were not available until about 1972. However, as can be seen in that basin's time series shown in Figure 3, the NIO contributes only a small fraction of the total annual ACE Index for the NH. The general increase in the annual NH ACE Index values during the 1970s was most likely due to a lack of complete data prior to that time, and specifically due to those issues already noted for the ENP basin (see Fig. 1). More recently, NH tropical cyclone activity peaked during the early- and mid-1990's, with a multi-year period of below average values from 1998-2003. The extensive activity in the NAT basin in 2004-2005 was the primary reason the NH values have been above normal these years.

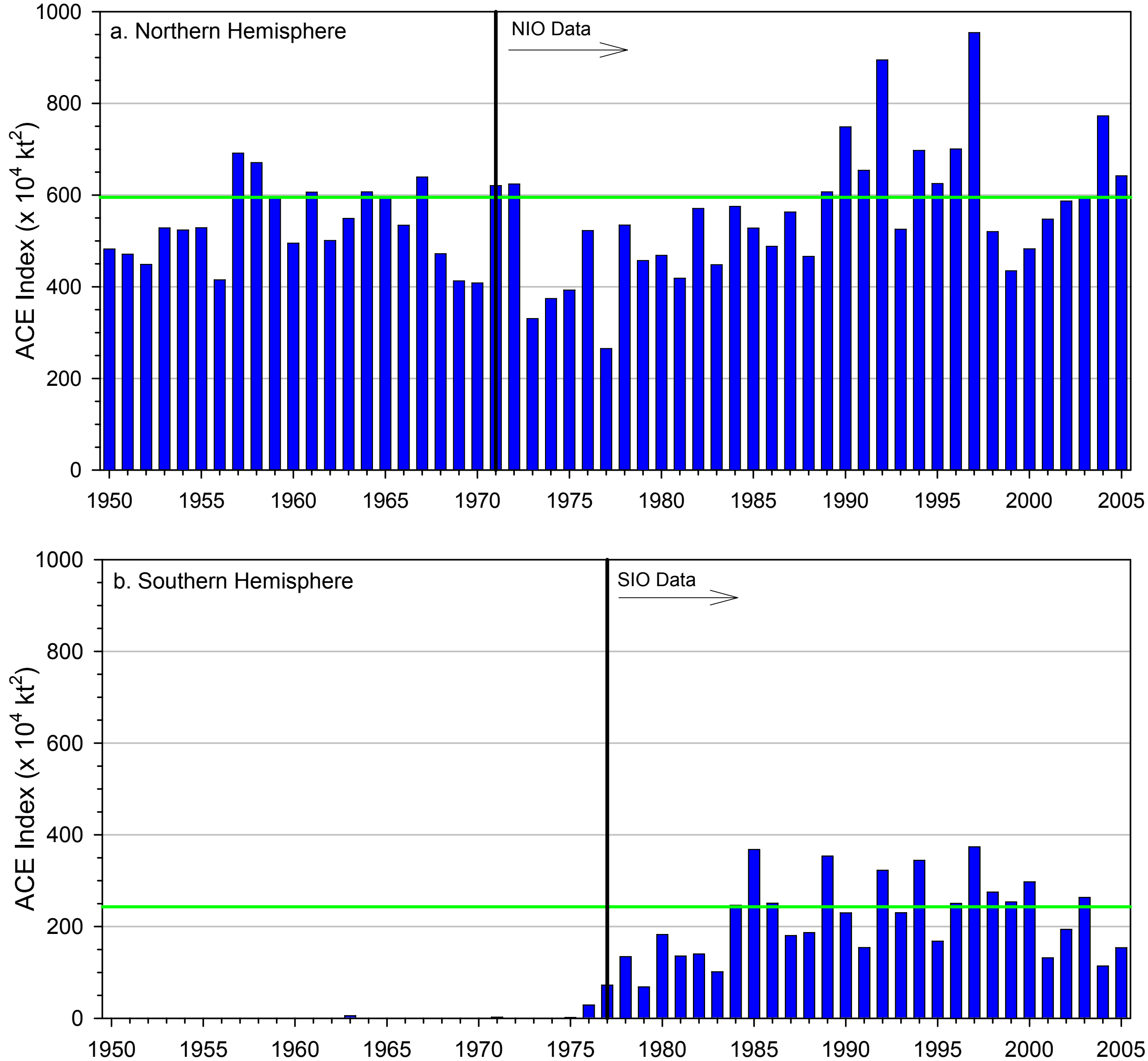

Figure 4. Annual values of the Accumulated Cyclone Energy (ACE) Index (x 10^4 kt^2), calculated for: a) the Northern Hemisphere (NH), and b) the Southern Hemisphere (SH). Green lines denote the 1981-2000 base period average for each time series.

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