Worldwide Tropical Cyclone Activity Measured Using the Actuaries Climate Index® Methodology

Douglas J. Collins, FCAS, MAAA

Abstract: Accumulated cyclone energy (ACE) has been used by the National Oceanic and Atmospheric Administration, and others, as a measure of the strength and duration of tropical cyclones and their seasonal activity. The Actuaries Climate Index (ACI) was launched in 2016 for the U.S. and Canada, as a measure of changes in climate and coastal sea level in those countries. A component measuring tropical cyclone activity is not included in the ACI, since the low frequency of landfalling events is not suitable for a regional index. On a global basis, however, an index measuring tropical cyclone activity over land and water could be particularly useful to actuaries and those in the insurance industry with an interest in monitoring changes in tropical cyclone activity as it relates to climate change. Using the ACI methodology, this paper shows the results of a global index of tropical cyclone activity based on ACE data. Based on the index, trends in worldwide tropical cyclone activity over the period with good data (1985 – 2017) have been flat to downward, but this time period is not sufficiently long for a credible conclusion. This result is consistent with previous research by others, but no such analysis has been previously published based on the ACI methodology, in index form.

Keywords. Accumulated cyclone energy, Actuaries Climate Index®

INTRODUCTION

Accumulated Cyclone Energy is a measure of the strength and duration of tropical cyclones. ACE is calculated from the maximum estimated wind speed of a storm at 6-hour intervals over its lifetime. Specifically, accumulated cyclone energy can be calculated for any storm using the following formula,

$$\text{ACE} = 10^{-4} \Sigma\, v^2_{\max}$$

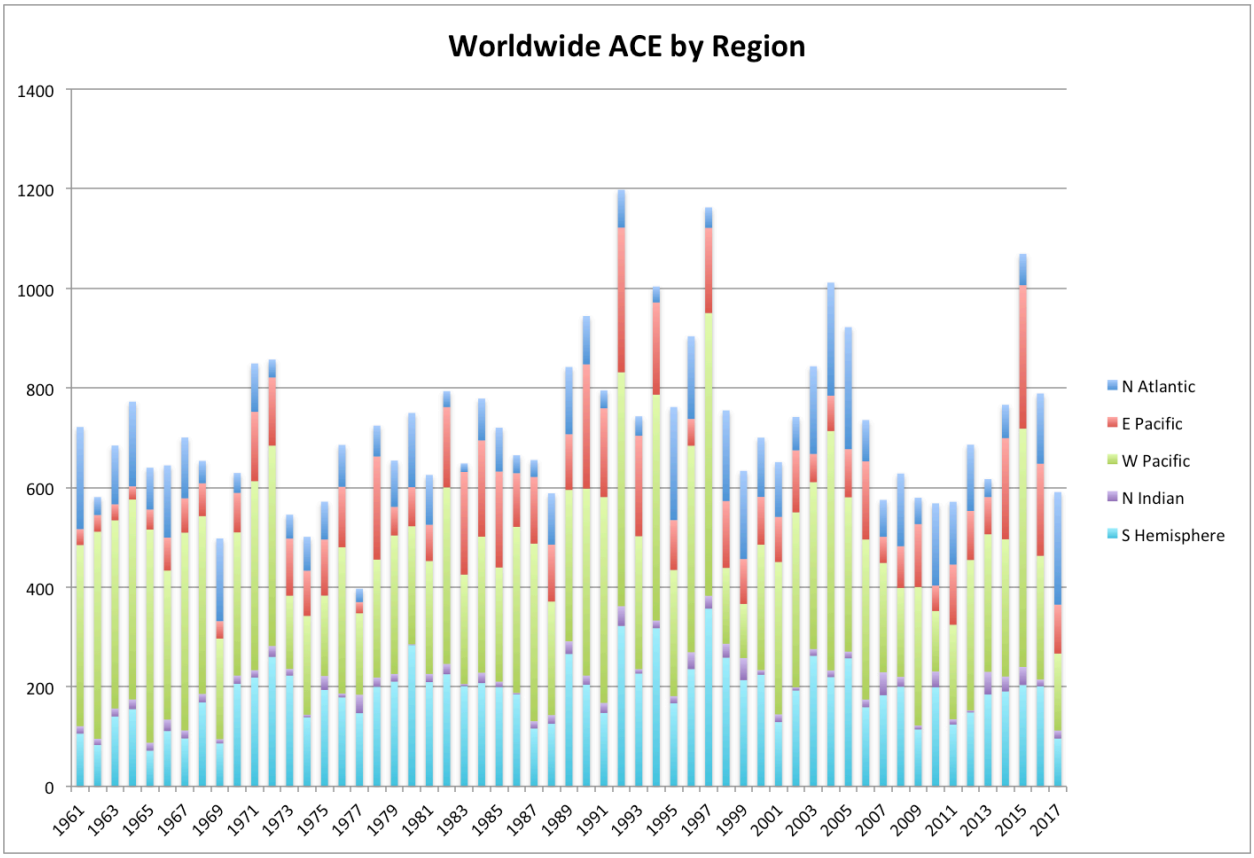
where $v_{\max}$ is the estimated maximum sustained wind speed in knots at six-hour intervals and the sum of wind speeds squared is divided by 10,000 for convenience. ACE is a more comprehensive measure than the commonly used Saffir-Simpson scale. After determining the ACE for each storm, values can be accumulated by season to provide a measure of seasonal tropical storm activity and intensity for any region of the world. A worldwide database of ACE values has been constructed by Phil Klotzbach[1],[2] of the Colorado State University Tropical Meteorology Project.

ACE data is available worldwide for most ocean basins starting in 1961 and for the Atlantic back to 1851, though tropical cyclone records are generally less reliable prior to tracking satellites, which began in the 1970s and were dependent on visible light images until the early 1980s[1]. The Actuaries Climate Index (ACI), which is documented and updated on a web site[3] sponsored by four actuarial organizations in North America (American Academy of Actuaries, Canadian Institute of Actuaries,

Casualty Actuarial Society and Society of Actuaries), is calculated using a reference period of 1961-1990. As the quality of satellite data prior to the mid-1980s likely led to significant underestimates in tropical cyclone intensity[4],[5],[6], a reference period of 1985-2014 is used in this paper. While a much longer period would probably be required to measure average tropical cyclone activity, this 30-year period marks the beginning of good satellite-based data and is long enough to serve as a useful baseline.

Figure 1 shows annual ACE by region since 1961. One can see that the West Pacific is the most active basin followed by the Southern Hemisphere. In 2017, the North Atlantic basin was the largest contributor to worldwide tropical cyclone activity for the first time since at least 1961.

Figure 1 – Worldwide ACE by Region



The Actuaries Climate Index measures changes in extreme temperatures, rainfall and wind, as well as changes in sea level. The wind component in the ACI is based on average daily wind speeds and therefore does not reflect the most damaging winds found in tropical cyclones or other strong windstorms. The ACI is calculated for three-month meteorological seasons (and by month) for 12 large land regions in the United States and Canada. At this temporal and geographical scale, tropical cyclones are relatively brief occurrences that occur rarely in most of these regions and not at all in some. In order to produce a meaningful index of tropical cyclone activity, a broad geographic measure by ocean basin (including surrounding land areas) and worldwide is required. This paper summarizes such an index with annual data through 2017.

Figure 2 shows worldwide ACE as a standardized anomaly (ACE_{std}) compared to the reference period 1985-2014. The standardized anomaly, which is the metric used in the Actuaries Climate Index, is the difference between the mean ACE for each year and the reference period mean, divided by the standard deviation of ACE during the reference period. The standardized anomaly is a common tool for comparing different statistics, and measures ACE on a basis comparable to the Actuaries Climate Index. Also shown in Figure 2 are moving averages of ACE_{std} over five, ten, and twenty years. The Actuaries Climate Index is commonly presented with a five-year moving average as a means of smoothing out the random variations in the index so that trends can be more easily seen. For tropical cyclone statistics, even on a worldwide basis, five years is not long enough to accomplish similar smoothing. The ten-year average better balances stability and responsiveness and is selected as the key metric for this paper. As noted, data prior to the mid 1980s is likely understated. Over the subsequent time period, ten-year averages have been generally declining since 1998 and twenty-year averages since 2006. Research by Klotzbach[1],[5] and Maue[7],[8] has previously discussed these trends. The 21st century projections in the Fifth Assessment Report of the IPCC[9] are that the global frequency of tropical cyclones will likely decrease or remain essentially unchanged, while the global mean maximum wind speed in cyclones will likely increase.

Figure 2 – Worldwide ACE_{std} using 1985-2014 Reference Period

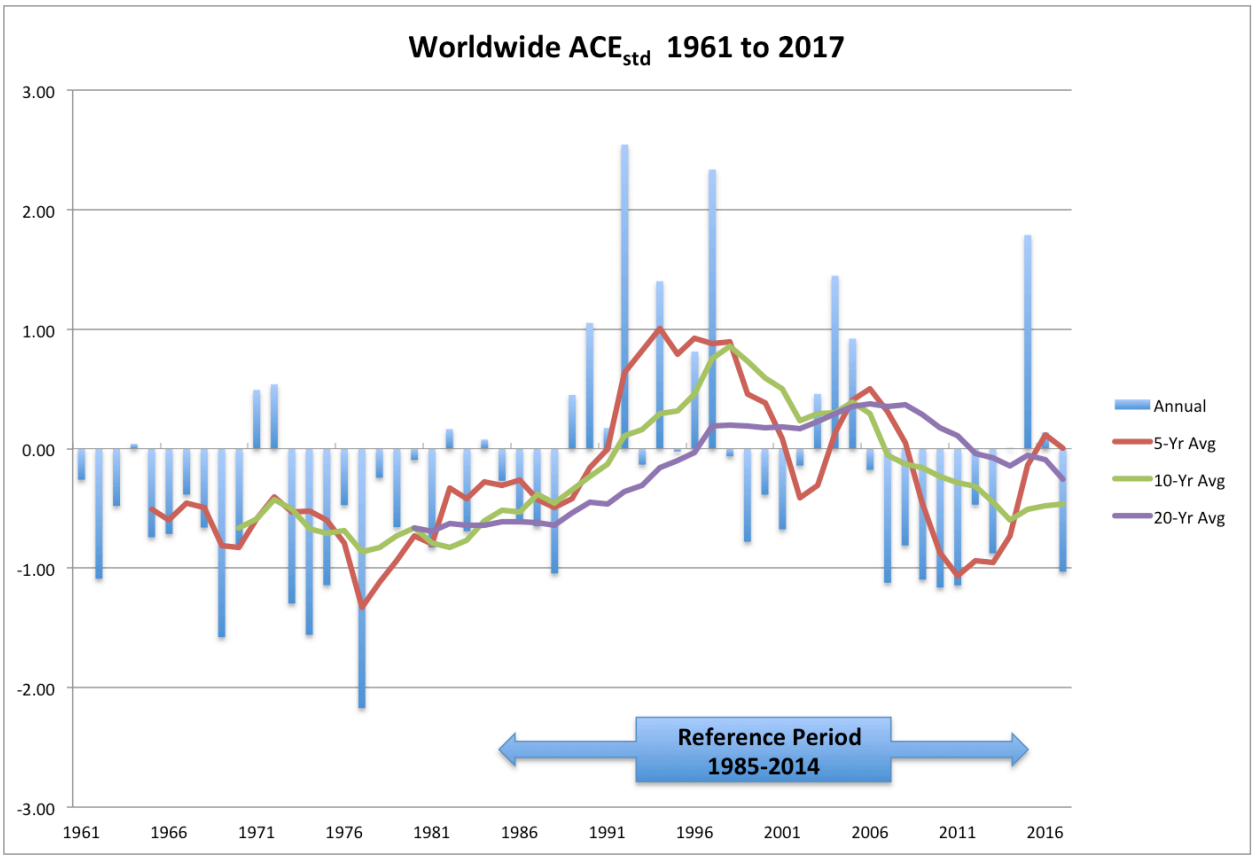
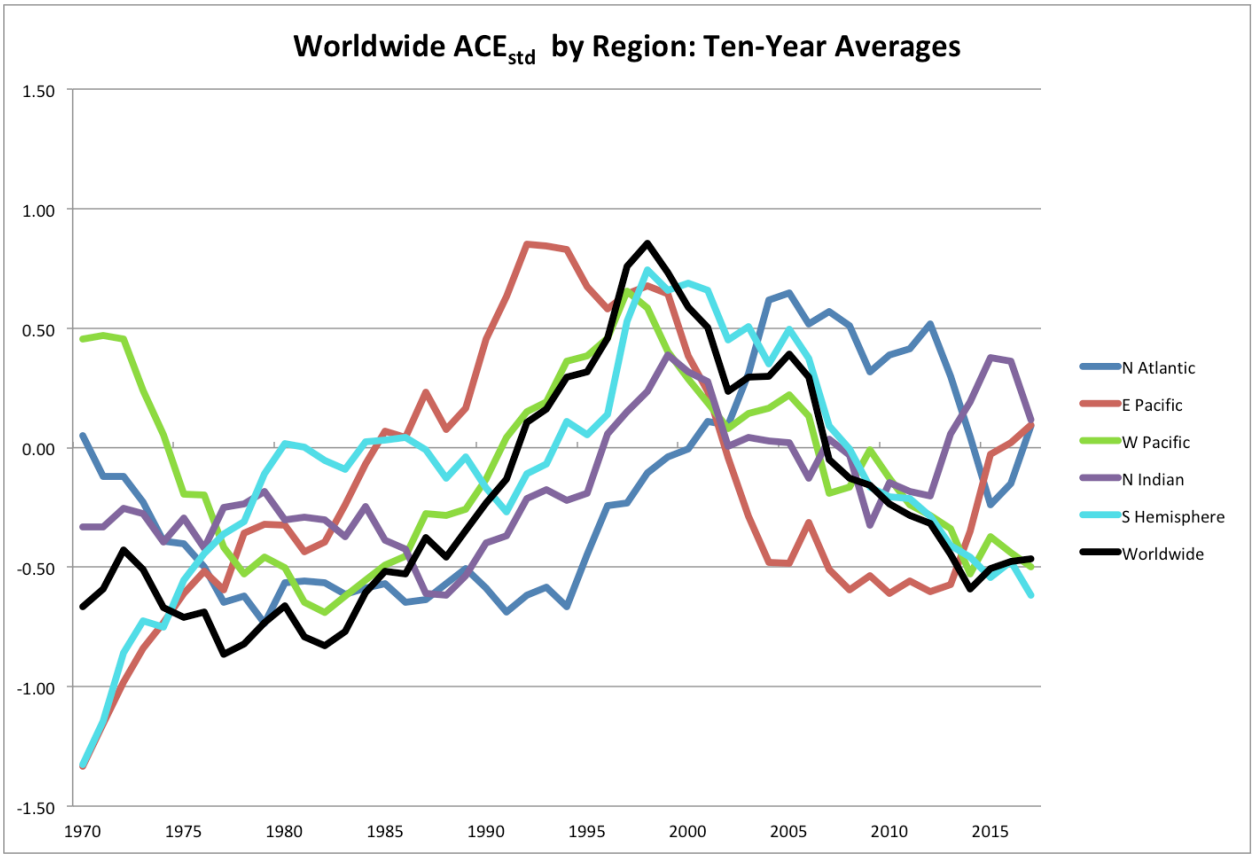


Figure 3 focuses on the ten-year moving average and compares ACE_{std} by region through 2017. One can see that activity in different regions is often offsetting. Only for the ten-year periods ending 1996-2005 have four or more of the five regions been above the reference period average. In recent years, the worldwide average has been pulled down by well-below average tropical cyclone activity in the Western Pacific and the Southern Hemisphere. Ryan Maue has noted[7] that activity in the North Atlantic and East Pacific basins has been inversely correlated and this can be clearly seen in Figure 3 (red versus dark blue lines).

Figure 3 – Comparison of regional ACE_{std} using ten-year averages



1.1 Research Context

This paper primarily focuses on the following areas from the Research Taxonomy:

- Actuarial Applications and Methodologies - Data Management and Information,

Enterprise Risk Management Processes (Analyzing/Quantifying Risks), Ratemaking (Large Loss and Extreme Event Loading)

- Financial and Statistical Methods – Natural Peril Modeling
- Business Areas – Fire & Allied Lines, Homeowners, Reinsurance

A search of the Database of Actuarial Research Enquiry does not show any mention of the use of ACE to analyze hurricane activity, or any actuarial paper on global tropical cyclone or hurricane activity.

Other scientific papers on the use of ACE or analyzing global hurricane activity are:

1. Increasing destructiveness of tropical cyclones over the past 30 years, Emanuel, 2005[10]
2. Hurricanes and Global Warming, Pielke Jr., Landsea, Mayfield, Laver and Pasch, 2005[11]
3. Trends in global tropical cyclone activity over the past twenty years (1986 – 2005), Klotzbach, 2006[1]
4. A globally consistent reanalysis of hurricane variability and trends – Kossin, Knapp, Vimont, Murnane and Harper, 2007[12]
5. Northern Hemisphere tropical cyclone activity – Maue, 2009[7]
6. Recent historically low global tropical cyclone activity – Maue, 2011[8]
7. Historical Global Tropical Cyclone Landfalls – Weinkle, Maue & Pielke Jr., 2012[13]
8. Extremely intense hurricanes: revisiting Webster et al. (2005) after 10 years – Klotzbach & Landsea, 2015[5]

1.2 Objective

Given the lack of actuarial literature on the subject, and the launch in November 2016 of the Actuaries Climate Index, this paper will provide background information and data on Accumulated Cyclone Energy, in the form of an index using the ACI methodology.

1.3 Outline

In the remainder of the paper, Section 2 will discuss background and methods used, Section 3 summarizes and discusses results, and Section 4 describes results and conclusions in more detail.

2. BACKGROUND AND METHODS

2.1 ACE data

Sums of ACE statistics for all storms in a season or year provide a measure of the combined cyclone energy in that season or year. This paper is based on summaries of ACE, worldwide and by ocean basin, constructed by Phil Klotzbach and available on the Colorado State University Meteorological Project website[2]. Similar data, available on a website[14] constructed by Ryan Maue at Weather.us, was also reviewed in researching this paper and was used to fill a few gaps in the Klotzbach database.

ACE provides a more comprehensive measure of cyclone activity that the commonly used Saffir-Simpson measure of hurricane strength, which is usually cited based on the maximum wind speed over the life of a storm. Another measure, track integrated kinetic energy (TIKE), introduced by Misra et al[15], accounts for the size of the wind field, in addition to intensity and duration, making it a slightly better statistic than ACE but TIKE data is not generally available historically on a worldwide basis.

2.2 ACE statistics and values for notable storms

Exhibit 1 displays ACE statistics from 1961 through 2017 by region and worldwide. Regions are defined as follows: North Atlantic, East Pacific (north of the equator and east of 180 degrees longitude), West Pacific (north of the equator and west of 180 degrees longitude), North Indian and Southern Hemisphere. Southern Hemisphere data includes the South Indian and South Pacific and is for each year ending June 30th. Tropical cyclones are rare in the South Atlantic and are excluded from the ACE statistics. Data for each region includes the entire time that each storm is classified as either tropical or sub-tropical, whether over the ocean or surrounding land areas, bays and seas. ACE data for storms that cross regions are assigned to the region in which they first became named[2].

As noted in the footnotes on Exhibit 1, Sheet 2, the Klotzbach data goes back to 1961 or earlier (to 1851 in the North Atlantic) except in the East Pacific (EPAC) and the North Indian (NIO) regions. To fill in the early years in EPAC and NIO, which represent only 19% of worldwide ACE across all years, two sources were used:

- Maue[11] provides ACE for 1970 EPAC and 1970-1971 NIO
- Wikipedia provides ACE for EPAC in 1963, 1965 and 1966 on pages:

https://en.wikipedia.org/wiki/196n_Pacific_hurricane_season, where n is 3, 5 or 6.

- Otherwise, the author estimated 1960s ACE in these two regions based on the number and maximum intensity of storms

The largest worldwide annual value of ACE was 1,198, which occurred in 1992. On average, ACE is distributed by region as follows:

- West Pacific 41%
- Southern Hemisphere 26% (about two-thirds of which is from the South Indian, based on the Klotzbach data)
- East Pacific 16%
- North Atlantic 14%
- North Indian 3%

The largest ACE for an individual storm during the satellite era is 82 for Hurricane Ioke in 2006, which started in the East Pacific before crossing into the West Pacific and spent 9 days as a category 4 or 5 storm on the Saffir-Simpson scale. The largest ACE in the North Atlantic is 70.4 for Hurricane Ivan in 2004, which spent 8.25 days as a category 4 or 5 storm. These statistics are from Wikipedia. More recently, Hurricane Irma in 2017 generated the second highest ACE in the North Atlantic during the satellite era with a value of 67.5, spending 5.5 days as a category 4 or 5 storm according to preliminary information from the National Oceanic & Atmospheric Administration.

2.3 Applying the ACI method to ACE

The standardized anomalies of annual ACE compared to the 1985-2014 reference period are calculated based on the following formula:

$$ACE_{std} = (\text{ACE for Year N} - \text{Reference period mean ACE}) /$$

$$(\text{Reference Period ACE standard deviation})$$

Exhibit 2, Sheets 1-6, show ACE_{std} worldwide and by region graphically. The underlying data for ACE_{std} worldwide is shown on Exhibit 3, Sheets 1-2 and ACE_{std} by region is shown on Exhibit 4, Sheets 1-2.

A key consideration in determining ACE_{std} is the choice of reference period. As noted, the Actuaries Climate Index uses a reference period of 1961-1990 but the more recent period was

chosen for ACE_{std} due to concerns about the completeness of tropical cyclone data prior to the advent of good satellite data.

3. RESULTS AND DISCUSSION

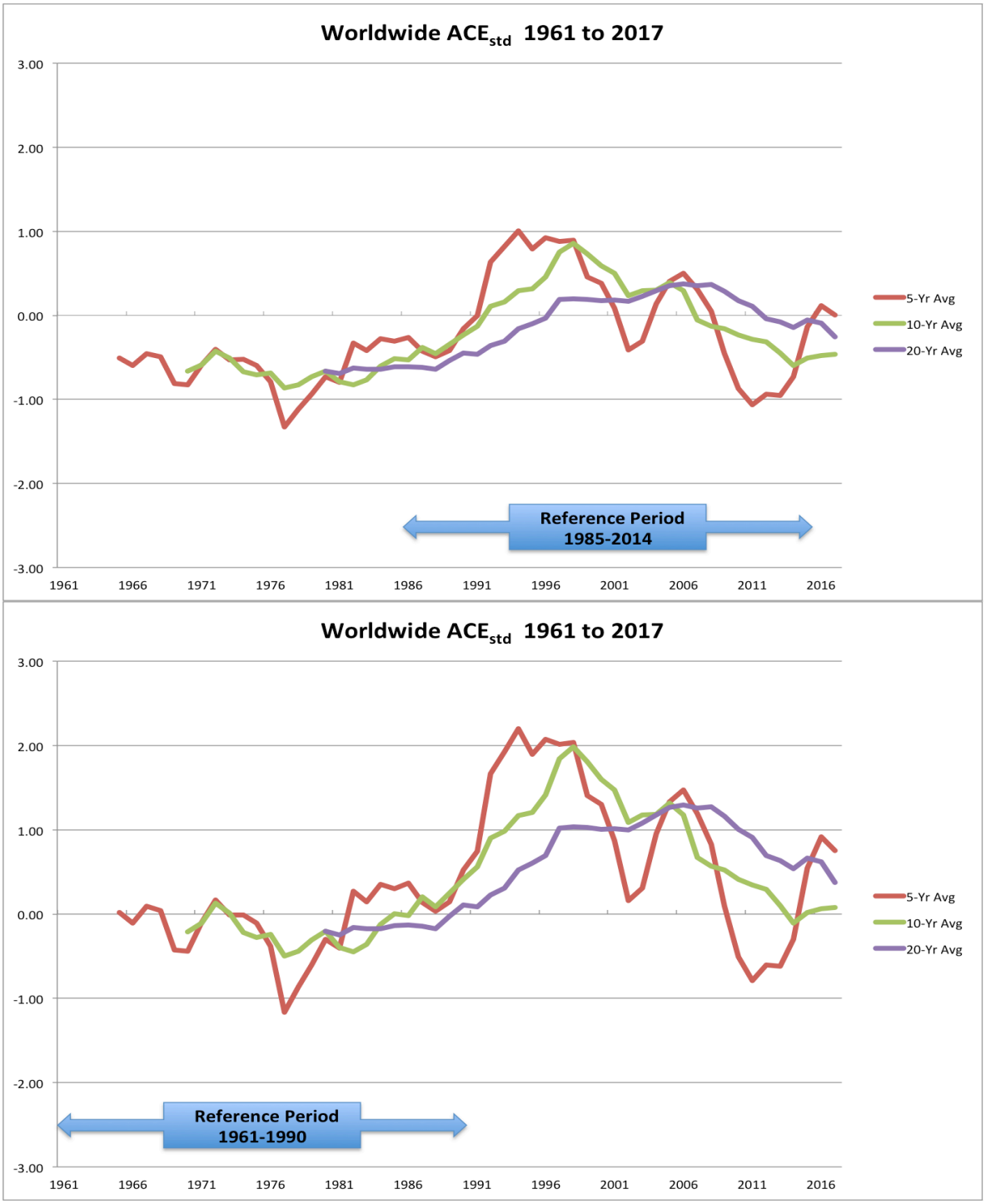
Exhibit 2, Sheets 1-6 display worldwide and regional ACE_{std}, each on a y-axis scale measuring anomalies relative to the reference period standard deviations, e.g., a value of 1.00 is a year one standard deviation above the reference period mean. Standardized anomalies are a useful way of comparing different quantities on a similar scale.

On a worldwide basis (Exhibit 2, Sheet 1), seven of the last ten years have had significantly below normal tropical cyclone activity, and only one of the last ten has had significantly above normal activity. In the North Atlantic, 2017 was one of the most active and intense years for hurricanes, but the other four ocean basins all had below normal activity bringing the worldwide total to a well-below average level.

Figure 2 shows worldwide ACE_{std} with the 1985-2014 reference period and various rolling averages. Figure 4 below compares the rolling averages in Figure 2 with rolling averages calculated with the same reference period as the Actuaries Climate Index, i.e. 1961-1990. The underlying annual ACE data is the same in each graph but the standardized anomalies are different and can be found in Exhibit 3, Sheets 1-2. The reference period mean is lower for 1961-1990 than for 1985-2014 and the standard deviation is much lower in the earlier period. As a result, the standardized anomalies are much higher, peaking at around two in the graph based on the earlier reference period.

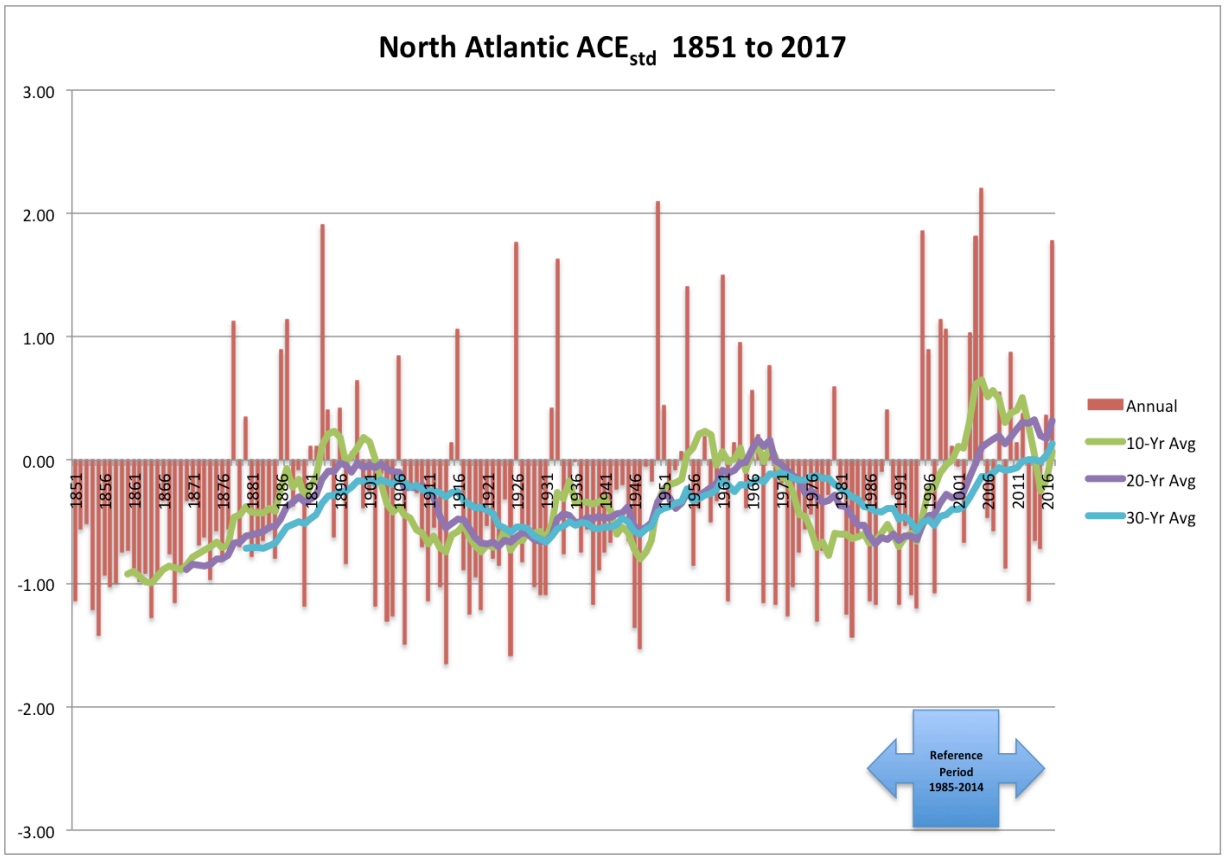
Whereas in Figure 2 (and the top graph in Figure 4) all three rolling averages ending 2017 were at or below the 1985-2014 reference period mean, the ten-year average ending 2017 is virtually the same as the 1961-1990 reference period mean in the lower graph in Figure 4 and the five- and twenty-year averages finish above the reference period mean. Taking the ten-year average as the best metric for measuring trends in global cyclone activity implies that even with the 1961-1990 reference period the recent rolling averages indicate no significant trend. An averaging period longer than ten years may be more appropriate for determining trends. Until much more data becomes available with good satellite measurements of tropical cyclone intensity in the coming decades, the appropriate averaging period and the existence of trends will remain uncertain given the natural variability in these statistics.

Figure 4 – Worldwide ACE_{std} Comparing Reference Periods



A longer historical time series is provided by NOAA[16] for the North Atlantic, which is probably the most-studied region but still only has high quality data back to 1966 per Klotzbach[2]. Standardized anomalies of this ACE data are plotted below in Figure 5. Note that the thirty-year averages never reached zero, i.e., the average during 1985-2014 reference period, in the pre-satellite era.

Figure 5 – North Atlantic ACE with 1985-2014 Reference Period



It has been noted by some researchers[1],[7],[8],[9],[10],[11] that although the number of global tropical cyclones has not increased with climate change, the number of intense storms has been trending upward. Data from Klotzbach[2] on storm counts is displayed in Exhibit 6, Sheets 1-5 and summarized in graphs on Exhibit 5, Sheets 1-2. This data shows that the number of named storms worldwide have been fairly stable since the 1970s in the 83-90 range per year. Ten-year averages of major storms (category 3-5) have been stable since about the mid-1990s at 23.5-25.5 per year but at a higher level than the 1970s and 1980s, consistent with research[5],[6] indicating that pre-satellite data likely led to significant underestimates in intensity, especially for the most intense systems. Exhibit 5, Sheet 2 shows a decline in the number of non-major tropical cyclones (tropical storms and category 1-2 cyclones/hurricanes/typhoons) from around 70 per year in the 1970s to 10-year averages around 60 since 2010.

4. CONCLUSIONS

The methodology presented in this paper produces an index of tropical cyclone activity worldwide and by region, consistent with the methodology used for the Actuaries Climate Index. Such an index can be easily updated and analyzed periodically.

Worldwide ACE_{std} since 1985, the period with good satellite data, is probably not long enough to credibly measure the effects of climate change on tropical cyclone activity. The two most unusual years for worldwide ACE_{std} were 1992 and 1997, the only years more than two standard deviations above the reference period mean. In the 20 years since then, there have been 14 below average years and only 6 above average years. The warm temperature component of the Actuaries Climate Index[3], and global temperature studies, have shown rapidly increasing anomalies since the late 1970s. Evidence that these warmer temperatures, along with warmer oceans, have increased the frequency and intensity of tropical cyclones remains to be seen.

Acknowledgment

The author acknowledges and appreciates the public availability of data from Ryan Maue and Phil Klotzbach, and the valuable contributions of the reviewers, Jess Geller and Alp Can.

5. REFERENCES

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Abbreviations and notations

ACE, Accumulated Cyclone Energy
ACI, Actuaries Climate Index
DFA, dynamic financial analysis
GLM, generalized linear models
OLS, ordinary least squares
ERM, enterprise risk management

Biography of the Author

Douglas J. Collins retired from Towers Watson in 2010 following a 30-year consulting career at TW and its predecessor firms. He began his career and completed his actuarial exams at the Travelers Insurance Company. He has a B.S. in Mathematics from Rensselaer Polytechnic Institute. He is a Fellow of the CAS and a Member of the American Academy of Actuaries. He has been a member of the Climate Change Committee since its inception and was its chair from 2014 to 2017.

Accumulated Cyclone Energy (ACE)
Source: http://tropical.atmos.colostate.edu/Realtime/ (except as noted)

	North Atlantic (NATL)	East Pacific (EPAC*)	West Pacific (WPAC)	North Indian (NIO**)	Southern Hemisphere (SH***)	Worldwide (WW)
1961	205	32	364	15	106	722
1962	36	34	416	13	83	581
1963	118	32	378	16	140	684
1964	170	27	401	20	155	772
1965	84	40	428	16	72	640
1966	145	66	299	23	111	644
1967	122	69	397	16	96	700
1968	45	66	357	17	169	654
1969	166	35	202	9	86	498
1970	40	79	288	16	206	629
1971	97	139	380	15	219	849
1972	36	137	402	22	260	857
1973	48	115	147	13	222	546
1974	68	91	198	5	139	501
1975	76	113	161	28	194	572
1976	84	122	294	8	179	686
1977	27	22	164	37	147	397
1978	62	207	237	19	200	724
1979	93	57	278	15	210	654
1980	149	79	237	2	284	750
1981	100	73	227	16	209	625
1982	32	161	355	21	225	794
1983	17	206	220	4	201	648
1984	84	193	273	21	207	779
1985	88	193	229	11	199	720
1986	36	108	333	3	185	665
1987	34	134	357	15	116	655
1988	103	114	228	17	126	588
1989	135	112	304	25	266	842
1990	97	250	375	18	204	944
1991	36	178	413	20	147	795
1992	76	291	470	40	322	1,198
1993	39	202	267	9	227	743
1994	32	185	454	15	318	1,004
1995	227	100	253	14	167	762
1996	166	54	415	34	235	904
1997	41	171	568	26	357	1,162
1998	182	134	152	28	258	755
1999	177	90	109	44	213	633
2000	119	96	252	9	224	700
2001	110	91	306	15	129	651
2002	67	125	351	6	193	742
2003	176	57	335	14	262	843
2004	227	71	481	13	219	1,011
2005	245	97	310	13	257	922
2006	83	157	321	15	159	736

Accumulated Cyclone Energy (ACE)

Source: http://tropical.atmos.colostate.edu/Realtime/ (except as noted)

	North Atlantic (NATL)	East Pacific (EPAC*)	West Pacific (WPAC)	North Indian (NIO**)	Southern Hemisphere (SH***)	Worldwide (WW)
2007	74	53	220	46	183	575
2008	146	84	178	20	200	628
2009	53	126	278	8	114	580
2010	165	51	121	32	199	568
2011	126	121	190	11	124	571
2012	133	99	302	4	148	686
2013	36	75	276	46	184	617
2014	67	203	276	30	191	766
2015	63	288	479	36	204	1,069
2016	141	185	248	14	201	789
2017	226	98	155	16	96	591
Total	5,830	6,585	17,105	1,054	10,747	41,320
Average	102	116	300	18	189	725
% of WW	14%	16%	41%	3%	26%	

Notes:

** For EPAC, 1961-2, 1964, 1967-1969 estimated by author based on Wikipedia season summaries: 196x Pacific Hurricane Season; 1963, 1965-66 from similar Wikipedia pages, which show ACE. 1970 from Maue: (http://wx.graphics/tropical/)

*** For NIO, 1961-1969 estimated by author, 1970-71 from Maue (http://wx.graphics/tropical/)

**** SH Data for 12 months ending June 30th. Excludes South Atlantic.

Exhibit 2
Sheet 1

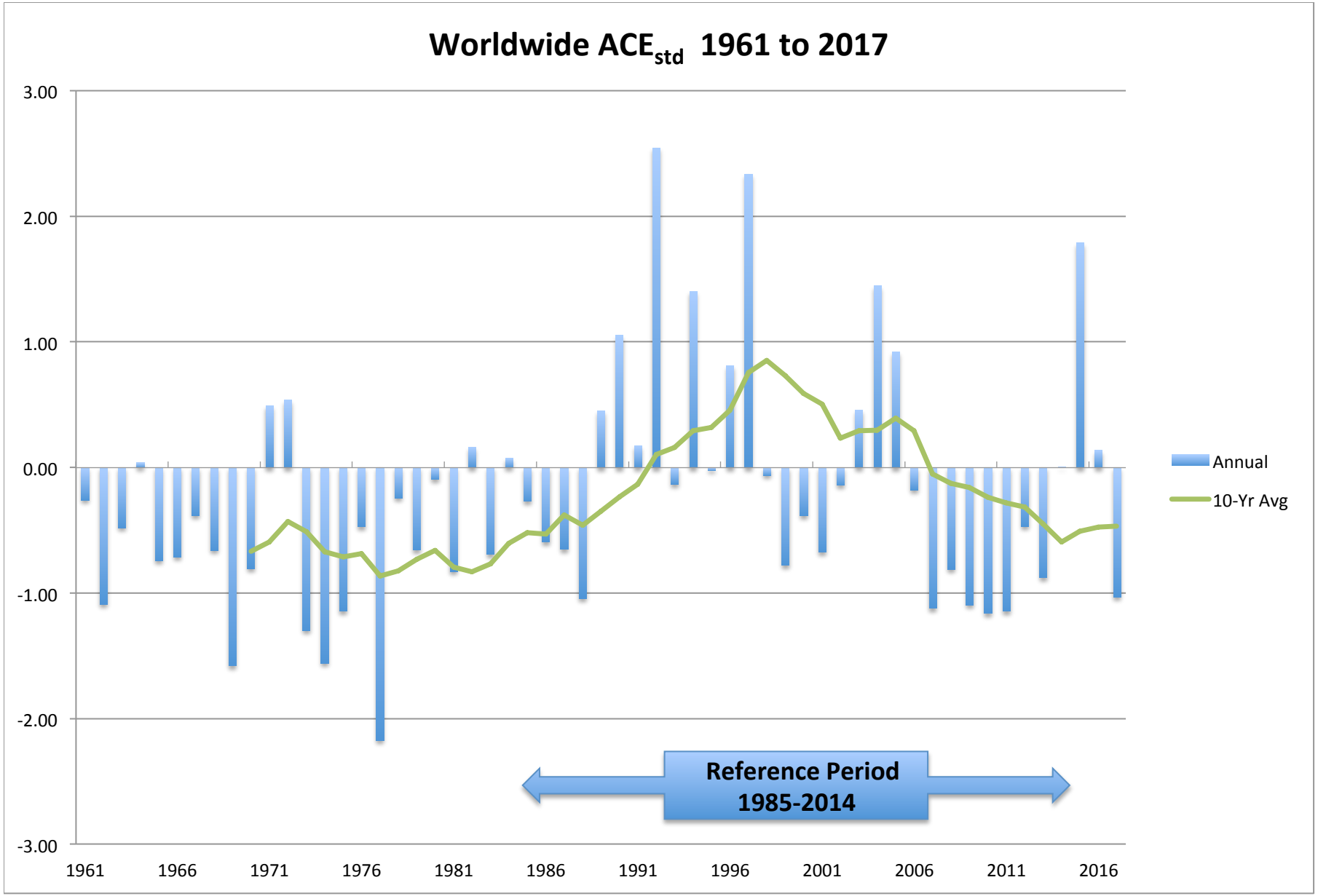


Exhibit 2
Sheet 2

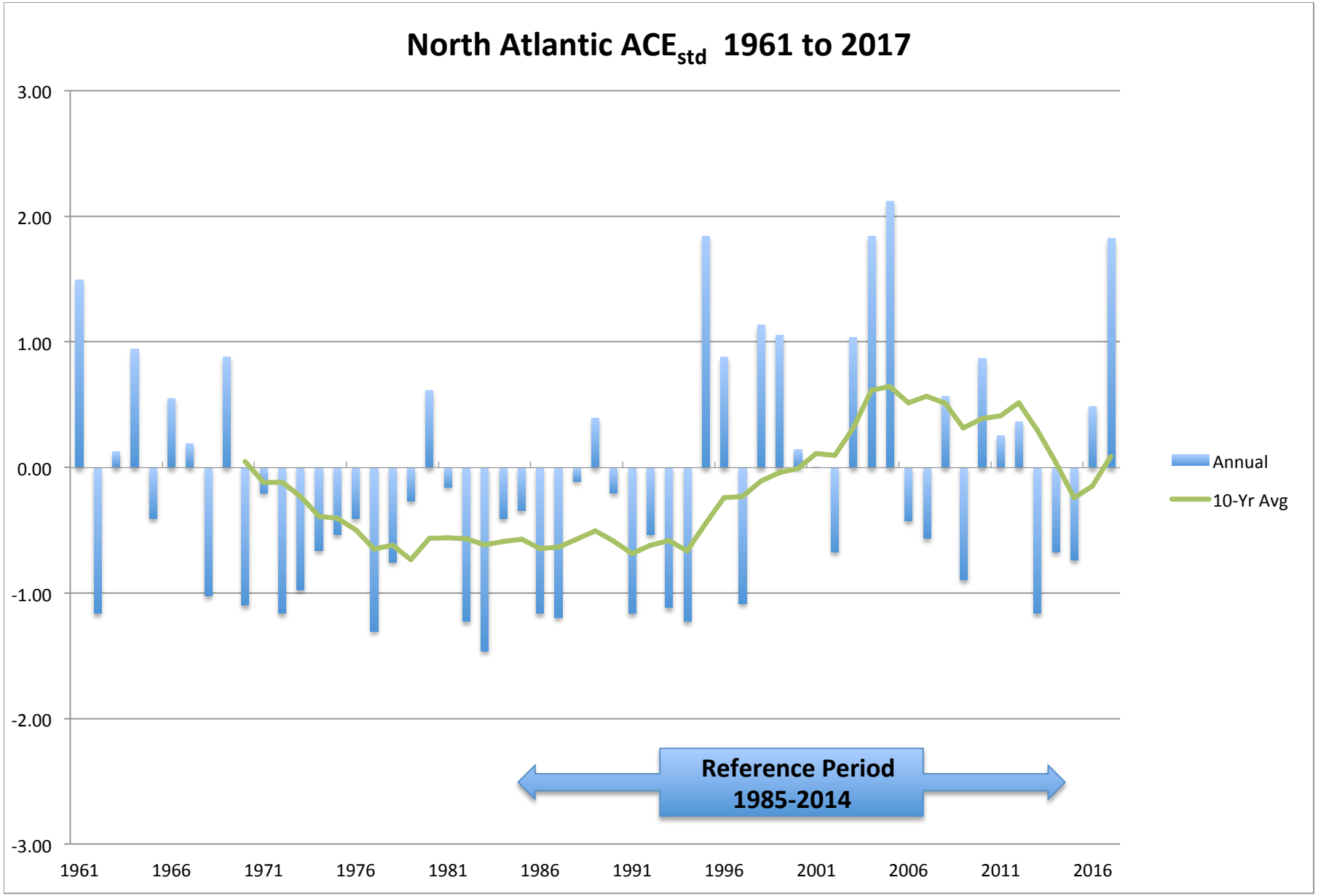


Exhibit 2
Sheet 3

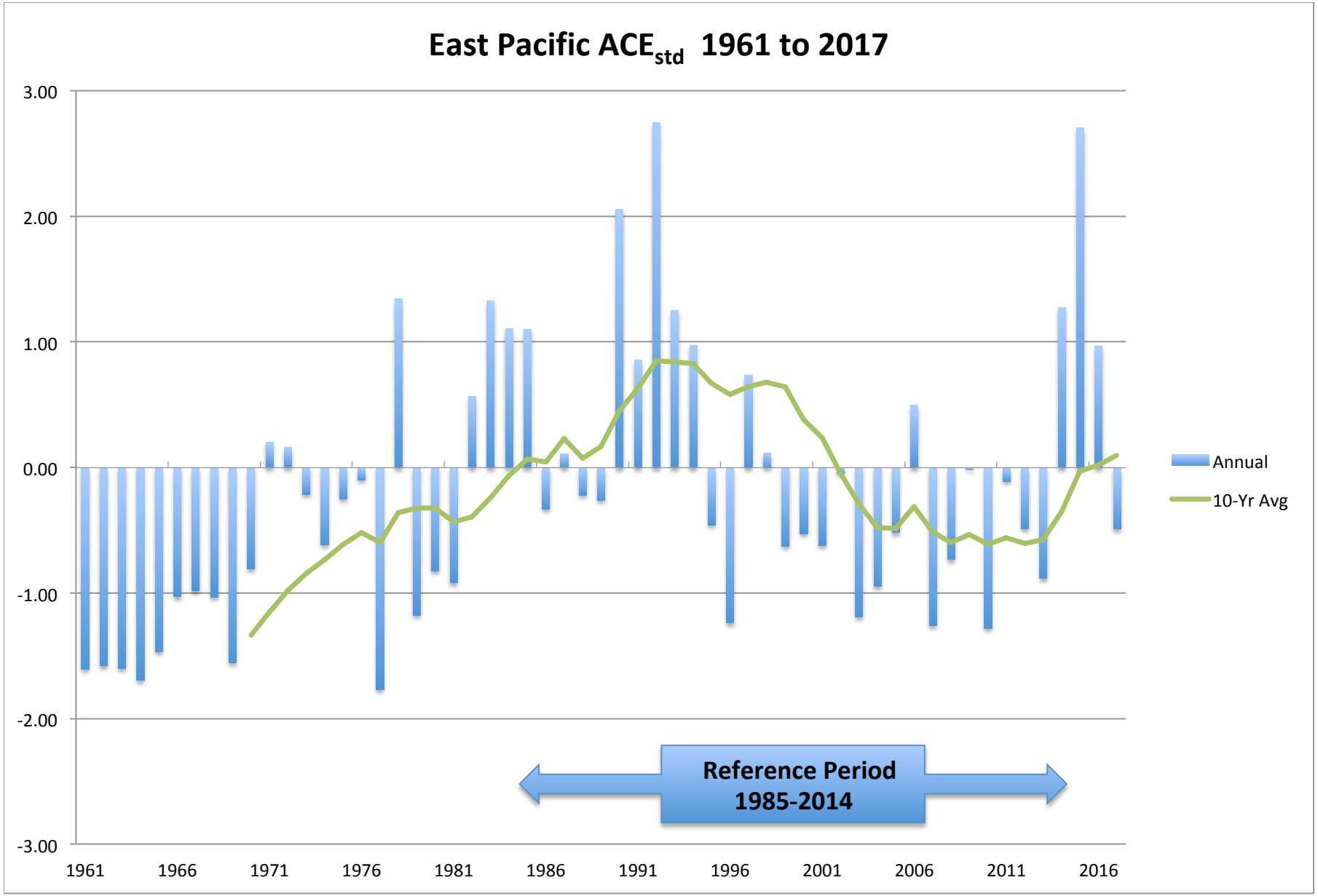
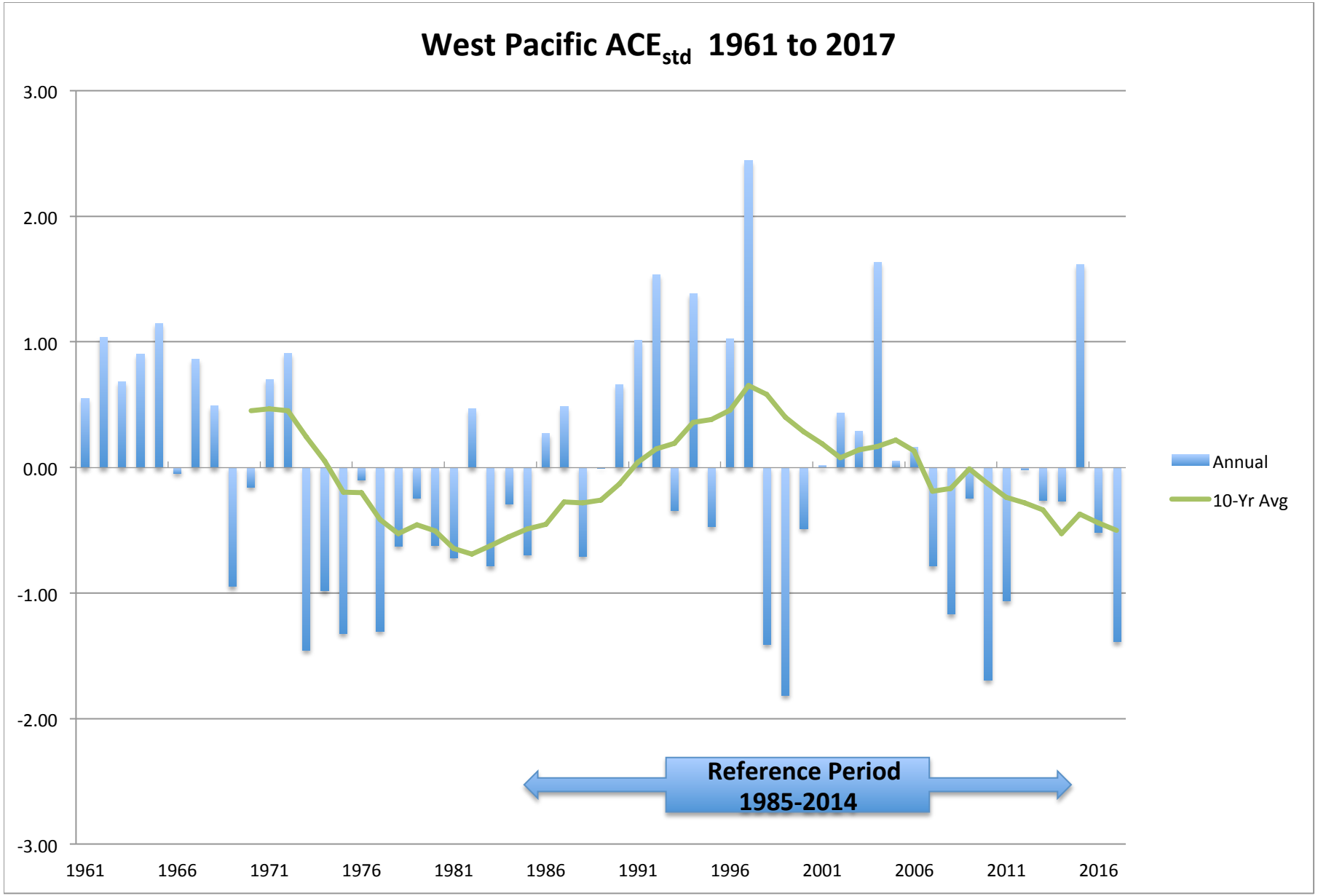


Exhibit 2
Sheet 4



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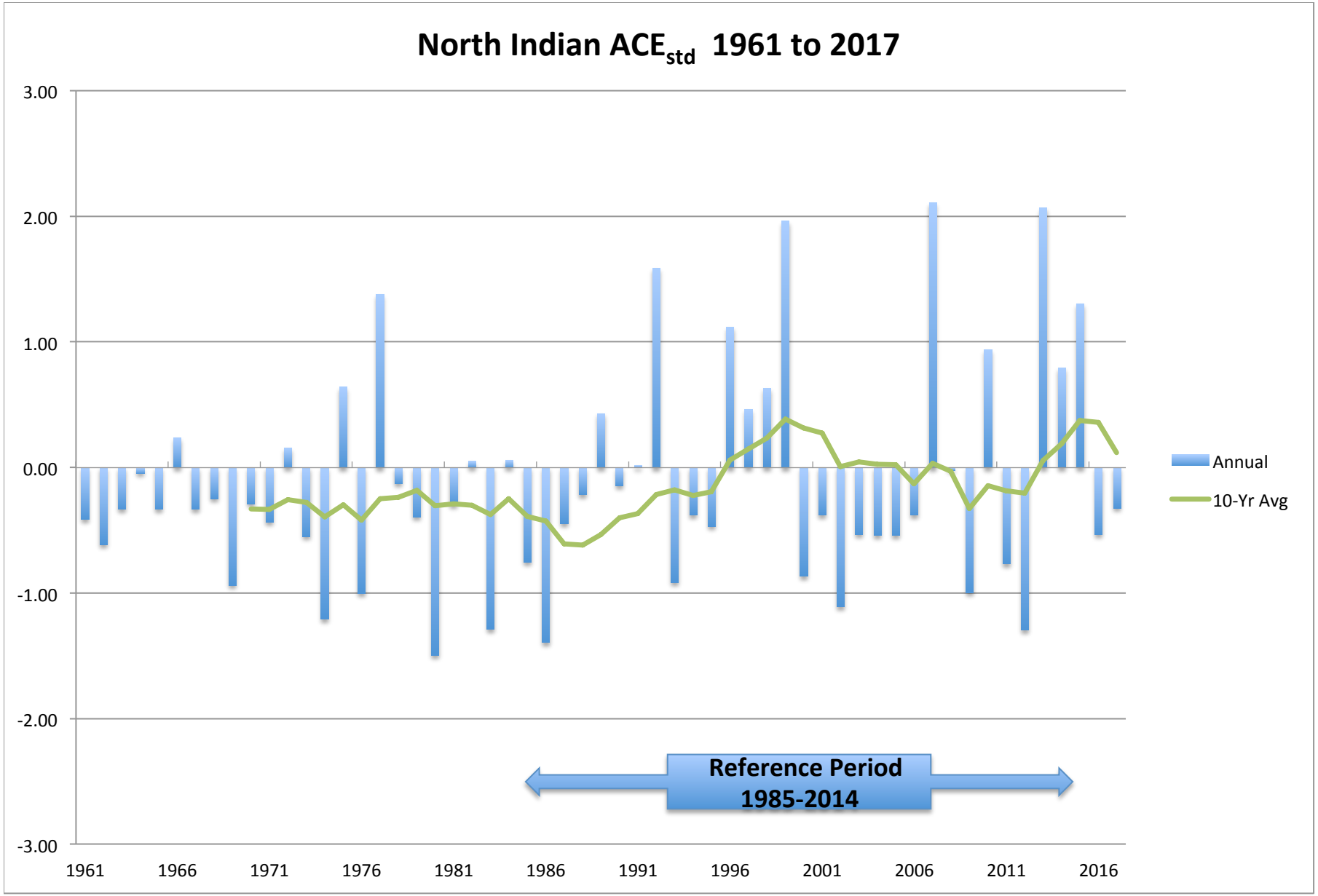
Sheet 5



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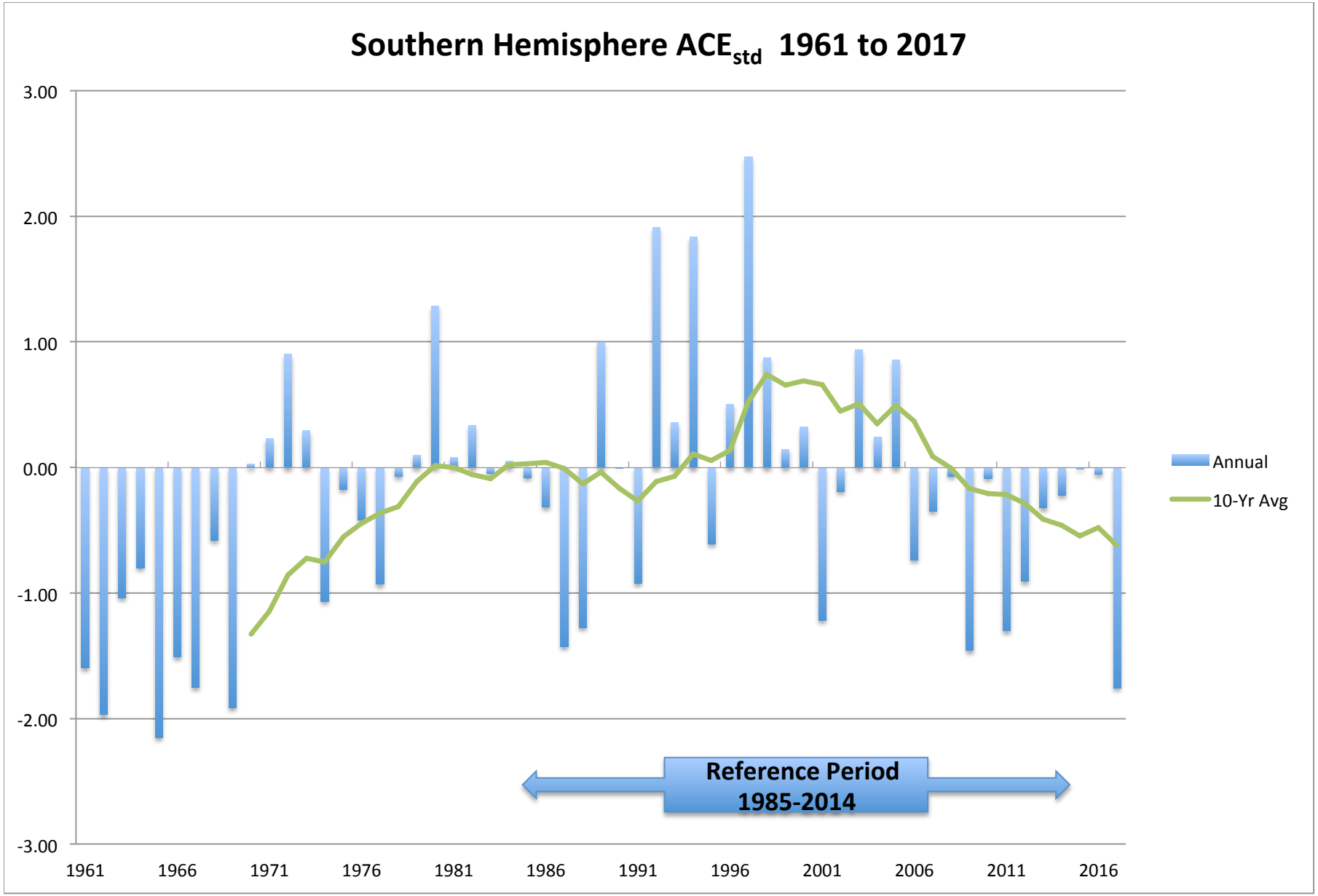
Sheet 6



Worldwide Accumulated Cyclone Energy as Standardized Anomaly (ACEstd)

	Reference Period 1961 - 1990				Reference Period 1985 - 2014			
	Worldwide ACEstd	5-Year Average	10-Year Average	20-Year Average	Worldwide ACEstd	5-Year Average	10-Year Average	20-Year Average
1961	0.38				-0.26			
1962	-0.82				-1.09			
1963	0.06				-0.48			
1964	0.81				0.04			
1965	-0.32	0.02			-0.74	-0.50		
1966	-0.28	-0.11			-0.71	-0.60		
1967	0.20	0.09			-0.38	-0.45		
1968	-0.20	0.04			-0.66	-0.49		
1969	-1.52	-0.43			-1.58	-0.81		
1970	-0.41	-0.44	-0.21		-0.80	-0.83	-0.67	
1971	1.46	-0.10	-0.10		0.49	-0.59	-0.59	
1972	1.52	0.17	0.13		0.54	-0.40	-0.43	
1973	-1.12	-0.01	0.01		-1.29	-0.53	-0.51	
1974	-1.50	-0.01	-0.22		-1.56	-0.52	-0.67	
1975	-0.90	-0.11	-0.27		-1.14	-0.59	-0.71	
1976	0.07	-0.38	-0.24		-0.47	-0.79	-0.69	
1977	-2.38	-1.16	-0.50		-2.17	-1.33	-0.86	
1978	0.40	-0.86	-0.44		-0.24	-1.12	-0.82	
1979	-0.20	-0.60	-0.30		-0.66	-0.94	-0.73	
1980	0.61	-0.30	-0.20	-0.21	-0.09	-0.73	-0.66	-0.66
1981	-0.44	-0.40	-0.39	-0.25	-0.83	-0.80	-0.79	-0.69
1982	0.99	0.27	-0.45	-0.16	0.16	-0.33	-0.83	-0.63
1983	-0.25	0.14	-0.36	-0.17	-0.69	-0.42	-0.77	-0.64
1984	0.86	0.35	-0.12	-0.17	0.08	-0.27	-0.60	-0.64
1985	0.36	0.30	0.00	-0.14	-0.27	-0.31	-0.52	-0.61
1986	-0.11	0.37	-0.01	-0.13	-0.59	-0.26	-0.53	-0.61
1987	-0.19	0.14	0.20	-0.15	-0.65	-0.42	-0.38	-0.62
1988	-0.76	0.03	0.09	-0.17	-1.04	-0.50	-0.46	-0.64
1989	1.40	0.14	0.25	-0.03	0.45	-0.42	-0.35	-0.54
1990	2.27	0.52	0.41	0.11	1.05	-0.16	-0.23	-0.45
1991	1.00	0.74	0.56	0.08	0.17	0.00	-0.13	-0.46
1992	4.42	1.67	0.90	0.23	2.54	0.64	0.11	-0.36
1993	0.56	1.93	0.98	0.31	-0.13	0.82	0.16	-0.30
1994	2.77	2.20	1.17	0.52	1.40	1.01	0.29	-0.16
1995	0.72	1.89	1.21	0.61	-0.02	0.79	0.32	-0.10
1996	1.92	2.08	1.41	0.70	0.81	0.92	0.46	-0.04
1997	4.12	2.02	1.84	1.02	2.34	0.88	0.76	0.19
1998	0.66	2.04	1.98	1.04	-0.06	0.89	0.85	0.20
1999	-0.37	1.41	1.80	1.03	-0.78	0.46	0.73	0.19
2000	0.19	1.30	1.60	1.01	-0.38	0.38	0.59	0.18
2001	-0.22	0.87	1.48	1.02	-0.67	0.09	0.50	0.19
2002	0.55	0.16	1.09	0.99	-0.14	-0.41	0.24	0.17
2003	1.41	0.31	1.17	1.08	0.46	-0.30	0.29	0.23
2004	2.84	0.95	1.18	1.18	1.45	0.14	0.30	0.30
2005	2.08	1.33	1.32	1.26	0.92	0.40	0.39	0.36
2006	0.49	1.47	1.17	1.29	-0.18	0.50	0.29	0.38

Worldwide Accumulated Cyclone Energy as Standardized Anomaly (ACEstd)

	Reference Period 1961 - 1990				Reference Period 1985 - 2014			
	Worldwide ACEstd	5-Year Average	10-Year Average	20-Year Average	Worldwide ACEstd	5-Year Average	10-Year Average	20-Year Average
2007	-0.87	1.19	0.68	1.26	-1.12	0.31	-0.05	0.35
2008	-0.42	0.82	0.57	1.27	-0.81	0.05	-0.13	0.36
2009	-0.83	0.09	0.52	1.16	-1.09	-0.46	-0.16	0.29
2010	-0.93	-0.51	0.41	1.00	-1.16	-0.87	-0.24	0.18
2011	-0.90	-0.79	0.34	0.91	-1.14	-1.07	-0.28	0.11
2012	0.07	-0.60	0.29	0.69	-0.47	-0.94	-0.31	-0.04
2013	-0.51	-0.62	0.10	0.64	-0.87	-0.95	-0.45	-0.08
2014	0.75	-0.30	-0.11	0.54	0.00	-0.73	-0.59	-0.15
2015	3.33	0.55	0.02	0.67	1.79	-0.14	-0.51	-0.06
2016	0.95	0.92	0.06	0.62	0.14	0.12	-0.47	-0.09
2017	-0.73	0.76	0.08	0.38	-1.03	0.00	-0.47	-0.26

	1961-1990	1985-2014
Mean	677.3	765.6
Standard Dev.	117.8	169.9

ACEstd = (ACE for Year N - Reference Period Mean) / (Reference Period Standard deviation)

Worldwide Accumulated Cyclone Energy as Standardized Anomaly (ACEstd) - By Region

	ACEstd - Reference Period 1985 - 2014									
	North Atlantic		East Pacific		West Pacific		North Indian		Southern Hemisphere	
	ACEstd	10-Year Average	ACEstd	10-Year Average	ACEstd	10-Year Average	ACEstd	10-Year Average	ACEstd	10-Year Average
1961	1.49		-1.60		0.55		-0.41		-1.59	
1962	-1.16		-1.58		1.04		-0.61		-1.97	
1963	0.13		-1.60		0.68		-0.33		-1.04	
1964	0.94		-1.69		0.90		-0.05		-0.80	
1965	-0.41		-1.46		1.15		-0.33		-2.15	
1966	0.55		-1.03		-0.05		0.24		-1.51	
1967	0.19		-0.98		0.86		-0.33		-1.75	
1968	-1.02		-1.03		0.49		-0.25		-0.58	
1969	0.88		-1.55		-0.95		-0.94		-1.91	
1970	-1.10	0.05	-0.81	-1.33	-0.15	0.45	-0.29	-0.33	0.03	-1.33
1971	-0.20	-0.12	0.20	-1.15	0.70	0.47	-0.43	-0.33	0.23	-1.14
1972	-1.16	-0.12	0.16	-0.98	0.91	0.45	0.16	-0.26	0.90	-0.86
1973	-0.97	-0.23	-0.21	-0.84	-1.45	0.24	-0.55	-0.28	0.29	-0.72
1974	-0.66	-0.39	-0.61	-0.73	-0.98	0.05	-1.20	-0.39	-1.06	-0.75
1975	-0.53	-0.40	-0.25	-0.61	-1.32	-0.19	0.64	-0.30	-0.17	-0.55
1976	-0.41	-0.50	-0.10	-0.52	-0.10	-0.20	-1.00	-0.42	-0.42	-0.44
1977	-1.30	-0.65	-1.76	-0.60	-1.30	-0.42	1.38	-0.25	-0.93	-0.36
1978	-0.75	-0.62	1.34	-0.36	-0.62	-0.53	-0.13	-0.24	-0.07	-0.31
1979	-0.26	-0.73	-1.17	-0.32	-0.24	-0.46	-0.39	-0.18	0.10	-0.11
1980	0.61	-0.56	-0.82	-0.32	-0.62	-0.50	-1.50	-0.30	1.29	0.02
1981	-0.16	-0.56	-0.92	-0.43	-0.72	-0.64	-0.30	-0.29	0.08	0.00
1982	-1.22	-0.57	0.57	-0.39	0.47	-0.69	0.05	-0.30	0.34	-0.05
1983	-1.46	-0.61	1.33	-0.24	-0.78	-0.62	-1.29	-0.37	-0.05	-0.09
1984	-0.41	-0.59	1.11	-0.07	-0.29	-0.55	0.06	-0.25	0.05	0.02
1985	-0.34	-0.57	1.10	0.07	-0.69	-0.49	-0.75	-0.39	-0.08	0.03
1986	-1.16	-0.65	-0.33	0.04	0.27	-0.45	-1.39	-0.43	-0.31	0.04
1987	-1.19	-0.63	0.11	0.23	0.49	-0.27	-0.44	-0.61	-1.43	-0.01
1988	-0.11	-0.57	-0.22	0.08	-0.71	-0.28	-0.22	-0.62	-1.27	-0.13
1989	0.39	-0.50	-0.26	0.17	0.00	-0.26	0.43	-0.53	1.00	-0.04
1990	-0.20	-0.59	2.05	0.45	0.66	-0.13	-0.14	-0.40	0.00	-0.17
1991	-1.16	-0.69	0.86	0.63	1.01	0.04	0.02	-0.37	-0.92	-0.27
1992	-0.53	-0.62	2.74	0.85	1.53	0.15	1.59	-0.21	1.91	-0.11
1993	-1.11	-0.58	1.25	0.84	-0.34	0.19	-0.91	-0.18	0.36	-0.07
1994	-1.22	-0.66	0.97	0.83	1.38	0.36	-0.38	-0.22	1.83	0.11
1995	1.84	-0.45	-0.46	0.67	-0.47	0.38	-0.47	-0.19	-0.61	0.06
1996	0.88	-0.24	-1.24	0.58	1.02	0.46	1.12	0.06	0.50	0.14
1997	-1.08	-0.23	0.74	0.64	2.44	0.65	0.46	0.15	2.47	0.53
1998	1.13	-0.11	0.12	0.68	-1.41	0.58	0.63	0.24	0.88	0.74
1999	1.05	-0.04	-0.62	0.64	-1.81	0.40	1.96	0.39	0.15	0.66
2000	0.14	-0.01	-0.53	0.38	-0.49	0.29	-0.86	0.32	0.32	0.69
2001	0.00	0.11	-0.62	0.24	0.02	0.19	-0.38	0.28	-1.22	0.66
2002	-0.67	0.10	-0.05	-0.04	0.44	0.08	-1.11	0.01	-0.19	0.45
2003	1.04	0.31	-1.19	-0.29	0.29	0.14	-0.53	0.04	0.94	0.51
2004	1.84	0.62	-0.94	-0.48	1.63	0.17	-0.54	0.03	0.25	0.35
2005	2.12	0.65	-0.52	-0.48	0.05	0.22	-0.54	0.02	0.86	0.50
2006	-0.42	0.52	0.50	-0.31	0.16	0.13	-0.38	-0.13	-0.73	0.37

Worldwide Accumulated Cyclone Energy as Standardized Anomaly (ACEstd) - By Region

	ACEstd - Reference Period 1985 - 2014									
	North Atlantic		East Pacific		West Pacific		North Indian		Southern Hemisphere	
	ACEstd	10-Year Average	ACEstd	10-Year Average	ACEstd	10-Year Average	ACEstd	10-Year Average	ACEstd	10-Year Average
2007	-0.56	0.57	-1.26	-0.51	-0.78	-0.19	2.11	0.04	-0.35	0.09
2008	0.57	0.51	-0.73	-0.60	-1.16	-0.17	-0.02	-0.03	-0.07	0.00
2009	-0.89	0.32	-0.02	-0.53	-0.24	-0.01	-0.99	-0.33	-1.46	-0.16
2010	0.87	0.39	-1.28	-0.61	-1.69	-0.13	0.94	-0.14	-0.09	-0.21
2011	0.25	0.41	-0.11	-0.56	-1.06	-0.24	-0.77	-0.18	-1.30	-0.21
2012	0.36	0.52	-0.48	-0.60	-0.02	-0.28	-1.29	-0.20	-0.90	-0.29
2013	-1.16	0.30	-0.88	-0.57	-0.26	-0.34	2.07	0.06	-0.32	-0.41
2014	-0.67	0.05	1.28	-0.35	-0.26	-0.53	0.80	0.19	-0.22	-0.46
2015	-0.74	-0.24	2.70	-0.03	1.62	-0.37	1.31	0.38	-0.01	-0.54
2016	0.49	-0.15	0.97	0.02	-0.52	-0.44	-0.53	0.36	-0.05	-0.48
2017	1.82	0.09	-0.49	0.10	-1.39	-0.50	-0.32	0.12	-1.75	-0.62
1985-2014										
Mean ACE	109.9		127.3		304.1		20.1		204.2	
Standard Dev.	63.7		59.5		107.9		12.3		61.7	

ACEstd = (ACE for Year N - Reference Period Mean) / (Reference Period Standard deviation)

Exhibit 5
Sheet 1

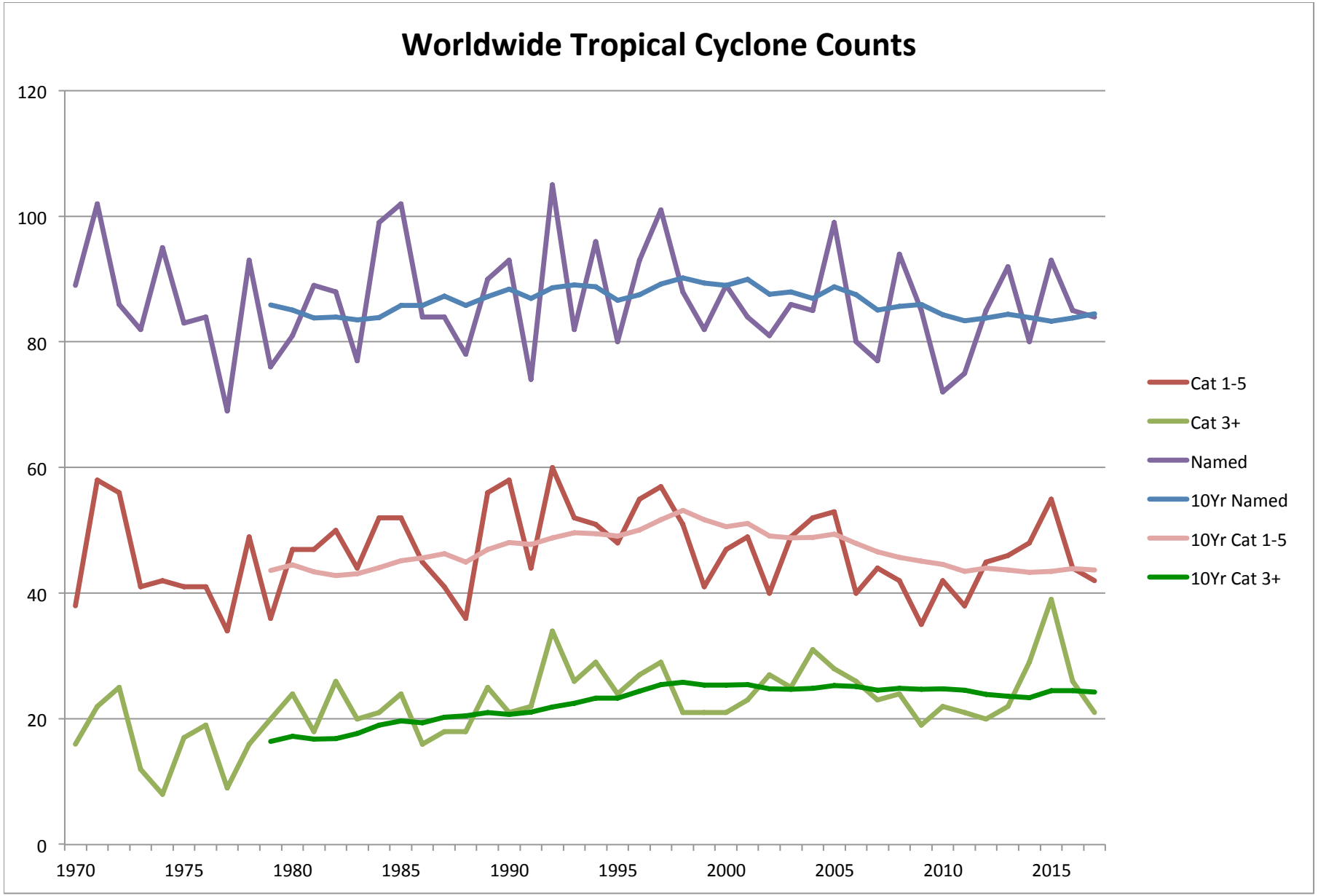
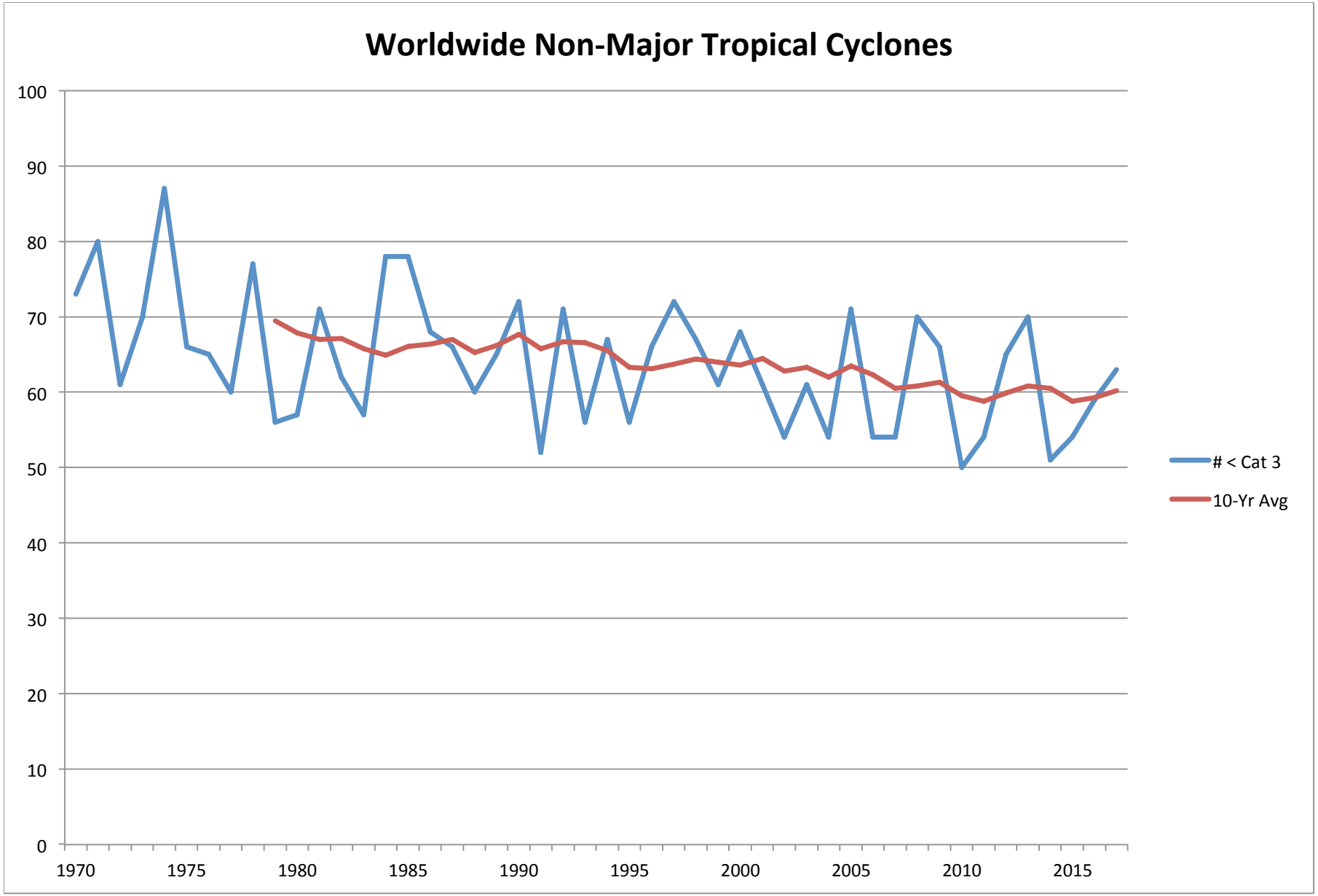


Exhibit 5
Sheet 2



Number of Tropical Cyclones

	Worldwide				Worldwide 10-Year Averages			
Year	Named Storms	Tropical Storms	Hurricanes, Cycl. & Typh.	Category 3+	Named Storms	Tropical Storms	Hurricanes, Cycl. & Typh.	Category 3+
1970	89	51	38	16				
1971	102	44	58	22				
1972	86	30	56	25				
1973	82	41	41	12				
1974	95	53	42	8				
1975	83	42	41	17				
1976	84	43	41	19				
1977	69	35	34	9				
1978	93	44	49	16				
1979	76	40	36	20	85.9	42.3	43.6	16.4
1980	81	34	47	24	85.1	40.6	44.5	17.2
1981	89	42	47	18	83.8	40.4	43.4	16.8
1982	88	38	50	26	84.0	41.2	42.8	16.9
1983	77	33	44	20	83.5	40.4	43.1	17.7
1984	99	47	52	21	83.9	39.8	44.1	19.0
1985	102	50	52	24	85.8	40.6	45.2	19.7
1986	84	39	45	16	85.8	40.2	45.6	19.4
1987	84	43	41	18	87.3	41.0	46.3	20.3
1988	78	42	36	18	85.8	40.8	45.0	20.5
1989	90	34	56	25	87.2	40.2	47.0	21.0
1990	93	35	58	21	88.4	40.3	48.1	20.7
1991	74	30	44	22	86.9	39.1	47.8	21.1
1992	105	45	60	34	88.6	39.8	48.8	21.9
1993	82	30	52	26	89.1	39.5	49.6	22.5
1994	96	45	51	29	88.8	39.3	49.5	23.3
1995	80	32	48	24	86.6	37.5	49.1	23.3
1996	93	38	55	27	87.5	37.4	50.1	24.4
1997	101	44	57	29	89.2	37.5	51.7	25.5
1998	88	37	51	21	90.2	37.0	53.2	25.8
1999	82	41	41	21	89.4	37.7	51.7	25.4
2000	89	42	47	21	89.0	38.4	50.6	25.4
2001	84	35	49	23	90.0	38.9	51.1	25.5
2002	81	41	40	27	87.6	38.5	49.1	24.8
2003	86	37	49	25	88.0	39.2	48.8	24.7
2004	85	33	52	31	86.9	38.0	48.9	24.9
2005	99	46	53	28	88.8	39.4	49.4	25.3
2006	80	40	40	26	87.5	39.6	47.9	25.2
2007	77	33	44	23	85.1	38.5	46.6	24.6
2008	94	52	42	24	85.7	40.0	45.7	24.9
2009	85	50	35	19	86.0	40.9	45.1	24.7
2010	72	30	42	22	84.3	39.7	44.6	24.8
2011	75	37	38	21	83.4	39.9	43.5	24.6
2012	85	40	45	20	83.8	39.8	44.0	23.9
2013	92	46	46	22	84.4	40.7	43.7	23.6
2014	80	32	48	29	83.9	40.6	43.3	23.4
2015	93	38	55	39	83.3	39.8	43.5	24.5
2016	85	41	44	26	83.8	39.9	43.9	24.5
2017	84	42	42	21	84.5	40.8	43.7	24.3
Total	4151	1917	2234	1075				
Average	86.5	39.9	46.5	22.4				
Total 1985-2014	2596	1179	1417	716				
Average	86.5	39.3	47.2	23.9				

Sources: http://tropical.atmos.colostate.edu/Realtime/
(except for East Pacific 1970 and North Indian 1970-1971 and South Atlantic: https://en.wikipedia.org/wiki/)

Number of Tropical Cyclones

	North Atlantic				East Pacific			
Year	Named Storms	Tropical Storms	Hurricanes	Category 3+	Named Storms	Tropical Storms	Hurricanes	Category 3+
1970	10	5	5	2	18	14	4	0
1971	13	7	6	1	18	6	12	6
1972	7	4	3	0	14	6	8	4
1973	8	4	4	1	12	5	7	3
1974	11	7	4	2	18	7	11	3
1975	9	3	6	3	17	8	9	4
1976	10	4	6	2	15	6	9	5
1977	7	2	5	1	8	4	4	0
1978	11	6	5	2	19	5	14	7
1979	9	3	6	2	10	4	6	4
1980	11	2	9	2	15	8	7	3
1981	12	5	7	3	15	7	8	1
1982	6	4	2	1	23	11	12	5
1983	4	1	3	1	21	9	12	8
1984	13	8	5	1	21	8	13	7
1985	11	4	7	3	24	11	13	8
1986	6	2	4	0	17	8	9	3
1987	7	4	3	1	20	10	10	4
1988	12	7	5	3	15	8	7	3
1989	11	4	7	2	18	9	9	4
1990	14	6	8	1	21	5	16	6
1991	8	4	4	2	14	4	10	5
1992	7	3	4	1	27	11	16	10
1993	8	4	4	1	15	4	11	9
1994	7	4	3	0	20	10	10	5
1995	19	8	11	5	10	3	7	3
1996	13	4	9	6	9	4	5	2
1997	8	5	3	1	19	10	9	7
1998	14	4	10	3	13	4	9	6
1999	12	4	8	5	9	3	6	2
2000	15	7	8	3	19	13	6	2
2001	15	6	9	4	16	8	8	2
2002	12	8	4	2	15	7	8	6
2003	16	9	7	3	16	9	7	0
2004	15	6	9	6	12	6	6	3
2005	28	13	15	7	15	8	7	2
2006	10	5	5	2	19	8	11	6
2007	15	9	6	2	11	7	4	1
2008	16	8	8	5	17	10	7	2
2009	9	6	3	2	20	12	8	5
2010	19	7	12	5	8	5	3	2
2011	19	12	7	4	11	1	10	6
2012	19	9	10	2	17	7	10	5
2013	14	12	2	0	20	11	9	1
2014	8	2	6	2	22	6	16	9
2015	11	7	4	2	26	10	16	11
2016	15	8	7	4	21	8	13	6
2017	17	7	10	6	18	9	9	4
Total	571	273	298	119	798	357	441	210
Average	11.9	5.7	6.2	2.5	16.6	7.4	9.2	4.4
Total 1985-2014	387	186	201	83	489	222	267	129
Average	12.9	6.2	6.7	2.8	16.3	7.4	8.9	4.3

Number of Tropical Cyclones

	West Pacific				North Indian			
Year	Named Storms	Tropical Storms	Typhoons	Category 3+	Named Storms	Tropical Storms	Cyclones	Category 3+
1970	24	12	12	11	7	4	3	1
1971	35	11	24	11	7	5	2	1
1972	30	8	22	14	4	0	4	0
1973	21	9	12	4	4	4	0	0
1974	32	17	15	3	1	0	1	0
1975	20	6	14	5	5	2	3	0
1976	25	11	14	9	5	5	0	0
1977	19	8	11	4	5	3	2	2
1978	28	13	15	3	4	2	2	0
1979	23	9	14	8	5	4	1	0
1980	24	9	15	9	3	3	0	0
1981	28	12	16	6	3	1	2	0
1982	25	6	19	12	5	3	2	1
1983	23	11	12	6	3	3	0	0
1984	27	11	16	9	4	2	2	0
1985	26	9	17	6	6	6	0	0
1986	27	8	19	8	3	3	0	0
1987	24	7	17	12	8	8	0	0
1988	26	13	13	7	5	4	1	1
1989	31	10	21	8	2	2	0	1
1990	32	11	21	8	2	1	1	1
1991	29	9	20	11	4	3	1	1
1992	32	11	21	11	10	7	3	1
1993	30	10	20	9	3	0	3	0
1994	36	16	20	12	5	4	1	1
1995	27	12	15	7	4	2	2	1
1996	36	15	21	10	8	4	4	1
1997	32	10	22	12	4	2	2	1
1998	18	9	9	5	8	3	5	1
1999	24	13	11	4	5	2	3	3
2000	25	10	15	8	4	2	2	0
2001	29	9	20	11	3	2	1	1
2002	24	8	16	11	5	5	0	0
2003	22	5	17	11	4	3	1	0
2004	31	11	20	14	5	3	2	0
2005	24	6	18	10	6	6	0	0
2006	22	9	13	10	6	5	1	1
2007	22	6	16	9	6	3	3	2
2008	27	15	12	8	6	5	1	1
2009	24	9	15	7	5	4	1	0
2010	15	6	9	4	5	2	3	2
2011	18	8	10	7	6	5	1	0
2012	25	10	15	10	4	4	0	0
2013	28	12	16	11	6	2	4	1
2014	21	9	12	7	5	3	2	2
2015	26	6	20	16	5	3	2	2
2016	24	11	13	11	5	4	1	0
2017	26	14	12	6	4	2	2	1
Total	1247	480	767	415	232	155	77	31
Average	26.0	10.0	16.0	8.6	4.8	3.2	1.6	0.6
Total 1985-2014	787	296	491	268	153	105	48	23
Average	26.2	9.9	16.4	8.9	5.1	3.5	1.6	0.8

Number of Tropical Cyclones

	Southern Hemisphere				South Indian			
Year	Named Storms	Tropical Storms	Cyclones	Category 3+	Named Storms	Tropical Storms	Cyclones	Category 3+
1970	30	16	14	2	17	6	11	2
1971	29	15	14	3	20	7	13	3
1972	31	12	19	7	15	7	8	2
1973	37	19	18	4	23	9	14	3
1974	33	22	11	0	18	10	8	0
1975	32	23	9	5	20	14	6	3
1976	29	17	12	3	16	9	7	3
1977	30	18	12	2	15	7	8	1
1978	31	18	13	4	20	11	9	4
1979	29	20	9	6	17	12	5	4
1980	28	12	16	10	16	4	12	9
1981	31	17	14	8	21	11	10	8
1982	29	14	15	7	19	10	9	2
1983	26	9	17	5	11	5	6	0
1984	34	18	16	4	24	13	11	3
1985	35	20	15	7	20	12	8	2
1986	31	18	13	5	21	12	9	5
1987	25	14	11	1	11	7	4	0
1988	20	10	10	4	13	7	6	2
1989	28	9	19	10	17	4	13	6
1990	24	12	12	5	17	8	9	4
1991	19	10	9	3	14	8	6	2
1992	29	13	16	11	14	7	7	7
1993	26	12	14	7	12	6	6	2
1994	28	11	17	11	22	9	13	7
1995	20	7	13	8	14	4	10	7
1996	27	11	16	8	18	5	13	7
1997	38	17	21	8	20	8	12	5
1998	35	17	18	6	15	9	6	2
1999	32	19	13	7	20	10	10	6
2000	26	10	16	8	17	5	12	7
2001	21	10	11	5	14	5	9	4
2002	25	13	12	8	17	7	10	7
2003	28	11	17	11	18	8	10	5
2004	22	7	15	8	15	3	12	6
2005	26	13	13	9	18	11	7	4
2006	23	13	10	7	15	10	5	5
2007	23	8	15	9	14	3	11	8
2008	28	14	14	8	21	11	10	5
2009	27	19	8	5	18	11	7	4
2010	25	10	15	9	14	6	8	5
2011	21	11	10	4	12	7	5	1
2012	20	10	10	3	16	7	9	2
2013	24	9	15	9	16	6	10	6
2014	24	12	12	9	14	5	9	7
2015	25	12	13	8	16	8	8	5
2016	20	10	10	5	9	4	5	3
2017	19	10	9	4	11	6	5	2
Total	1303	652	651	300	795	374	421	197
Average	27.1	13.6	13.6	6.3	16.6	7.8	8.8	4.1
Total 1985-2014	780	370	410	213	487	221	266	140
Average	26.0	12.3	13.7	7.1	16.2	7.4	8.9	4.7

Number of Tropical Cyclones

	South Pacific				South Atlantic			
Year	Named Storms	Tropical Storms	Cyclones	Category 3+	Named Storms	Tropical Storms	Hurricanes	Category 3+
1970	13	10	3	0	0	0	0	0
1971	9	8	1	0	0	0	0	0
1972	16	5	11	5	0	0	0	0
1973	14	10	4	1	0	0	0	0
1974	15	12	3	0	0	0	0	0
1975	12	9	3	2	0	0	0	0
1976	13	8	5	0	0	0	0	0
1977	15	11	4	1	0	0	0	0
1978	11	7	4	0	0	0	0	0
1979	12	8	4	2	0	0	0	0
1980	12	8	4	1	0	0	0	0
1981	10	6	4	0	0	0	0	0
1982	10	4	6	5	0	0	0	0
1983	15	4	11	5	0	0	0	0
1984	10	5	5	1	0	0	0	0
1985	15	8	7	5	0	0	0	0
1986	10	6	4	0	0	0	0	0
1987	14	7	7	1	0	0	0	0
1988	7	3	4	2	0	0	0	0
1989	11	5	6	4	0	0	0	0
1990	7	4	3	1	0	0	0	0
1991	4	1	3	1	1	1	0	0
1992	15	6	9	4	0	0	0	0
1993	14	6	8	5	0	0	0	0
1994	6	2	4	4	0	0	0	0
1995	6	3	3	1	0	0	0	0
1996	9	6	3	1	0	0	0	0
1997	18	9	9	3	0	0	0	0
1998	20	8	12	4	0	0	0	0
1999	12	9	3	1	0	0	0	0
2000	9	5	4	1	0	0	0	0
2001	7	5	2	1	0	0	0	0
2002	8	6	2	1	0	0	0	0
2003	10	3	7	6	0	0	0	0
2004	6	4	2	2	1	0	1	0
2005	8	2	6	5	0	0	0	0
2006	8	3	5	2	0	0	0	0
2007	9	5	4	1	0	0	0	0
2008	7	3	4	3	0	0	0	0
2009	9	8	1	1	0	0	0	0
2010	10	3	7	4	1	1	0	0
2011	9	4	5	3	0	0	0	0
2012	4	3	1	1	0	0	0	0
2013	8	3	5	3	0	0	0	0
2014	10	7	3	2	0	0	0	0
2015	9	4	5	3	0	0	0	0
2016	11	6	5	2	0	0	0	0
2017	8	4	4	2	0	0	0	0
Total	505	276	229	103	3	2	1	0
Average	10.5	5.8	4.8	2.1	0.1	0.0	0.0	0.0
Total 1985-2014	290	147	143	73	3	2	1	0
Average	9.7	4.9	4.8	2.4	0.1	0.1	0.0	0.0