# Recent historically low global tropical cyclone activity

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[1] Tropical cyclone accumulated cyclone energy (ACE) has exhibited strikingly large global interannual variability during the past 40-years. In the pentad since 2006, Northern Hemisphere and global tropical cyclone ACE has decreased dramatically to the lowest levels since the late 1970s. Additionally, the global frequency of tropical cyclones has reached a historical low. Here evidence is presented demonstrating that considerable variability in tropical cyclone ACE is associated with the evolution of the character of observed large-scale climate mechanisms including the El Niño Southern Oscillation and Pacific Decadal Oscillation. In contrast to record quiet North Pacific tropical cyclone activity in 2010, the North Atlantic basin remained very active by contributing almost one-third of the overall calendar year global ACE. **Citation:** Maue, R. N. (2011), Recent historically low global tropical cyclone activity, *Geophys. Res. Lett.*, *38*, L14803, doi:10.1029/2011GL047711.

## 1. Introduction

[2] During the past four decades, integrated and secular frequency measures of global tropical cyclone (TC) activity have undergone considerable interannual variability. Since 2006, global and Northern Hemisphere (NH) TC accumulated cyclone energy (ACE) has decreased dramatically, nearly cut in half from the previous peak in 2005 to the lowest levels since the 1970s. While the annual global frequency of tropical storm TCs has not exhibited a long-term trend (~87 per year), the calendar year total of 69 observed in 2010 represented a decades' low. Indeed while the very active North Atlantic (NATL) basin generated 19 named storms in 2010, the rest of the global tropics produced only 50 TCs including the fewest Western North Pacific (WNP) typhoons and Northeast Pacific (NEP) hurricanes counted in the reliable historical record.

[3] The strikingly large global interannual variation in TC frequency and ACE (which also includes duration and intensity) is shown here to be a function of observed large-scale low frequency modes of ocean-atmosphere climate variability mainly on interannual and longer time scales. Cursory analysis here demonstrates that low frequency variability in global TC ACE and hurricane-force (HF) TC frequency is associated with changes or evolution in the characteristics of the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). This current and most recent historical downturn in global TC ACE and frequency is consistent with similar past periods of overall colder Pacific large-scale climate conditions. However, a notable difference is the observed doubling of the NATL basin contribution of TC ACE to the global total coinciding with the onset of the so-called active era in 1995 [*Lander and Guard*, 1998; *Bell and Chelliah*, 2006].

## 2. Data and Methodology

[4] Global TC lifecycle data is obtained from the complete IBTrACS (version v03r02) database [*Knapp et al.*, 2010] with six hourly best-track positions and intensity estimates from 1970–2010 (operational center advisory estimates are used for TCs observed through the end of May 2011). Only TCs designated as in a tropical phase with one-minute maximum sustained surface wind speeds exceeding 34-knots are included in this analysis. Until a comprehensive global TC reanalysis is conducted [*Chu et al.*, 2002], considerable uncertainty will remain in interagency TC intensity estimates especially during the 1970s, prior to the satellite era [*Knapp and Kruk*, 2010]. Detailed information on the construction of the dataset used in the following analysis is provided in the auxiliary material.[1]

[5] The accumulated cyclone energy (ACE) metric [*Bell et al.*, 2000], analogous to the power dissipation index (PDI) [*Emanuel*, 2005] convolves intensity and duration information for each individual TC observed in the global tropical basins. ACE is calculated by squaring the 6-hourly intensity estimates reported in the best-track database and integrating over individual lifecycles or seasons partitioned according to basin or hemisphere. The ACE metric has an advantage of including considerable information from the entire TC lifecycle complimenting the familiar secular categorization according to the maximum lifecycle wind speed [e.g., *Webster et al.*, 2005; *Klotzbach*, 2006]. On the individual storm scale, the correlation between duration and maximum wind speed is a variable function of basin, genesis location, track, time of year, and a host of other large-scale environmental factors.

## 3. Global Tropical Cyclone ACE

[6] Twenty-four month running sums of global ACE (units of $10^4$ knots$^2$) are partitioned according to hemisphere since 1970 (Figure 1a). The top (bottom) time series represents the global (NH) ACE for the preceding 24-months, while the shaded area in between describes the SH ACE. Quantitatively, keeping in mind inherent quality issues with data prior to 1980, recent global ACE has decreased to the lowest levels since 1977 coincident with the great Pacific climate shift of 1976–1977 [*Yeh et al.*, 2011]. Preliminary data through May 2011 shows a continuation of overall global

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[1]Auxiliary materials are available in the HTML. doi:10.1029/2011GL047711.

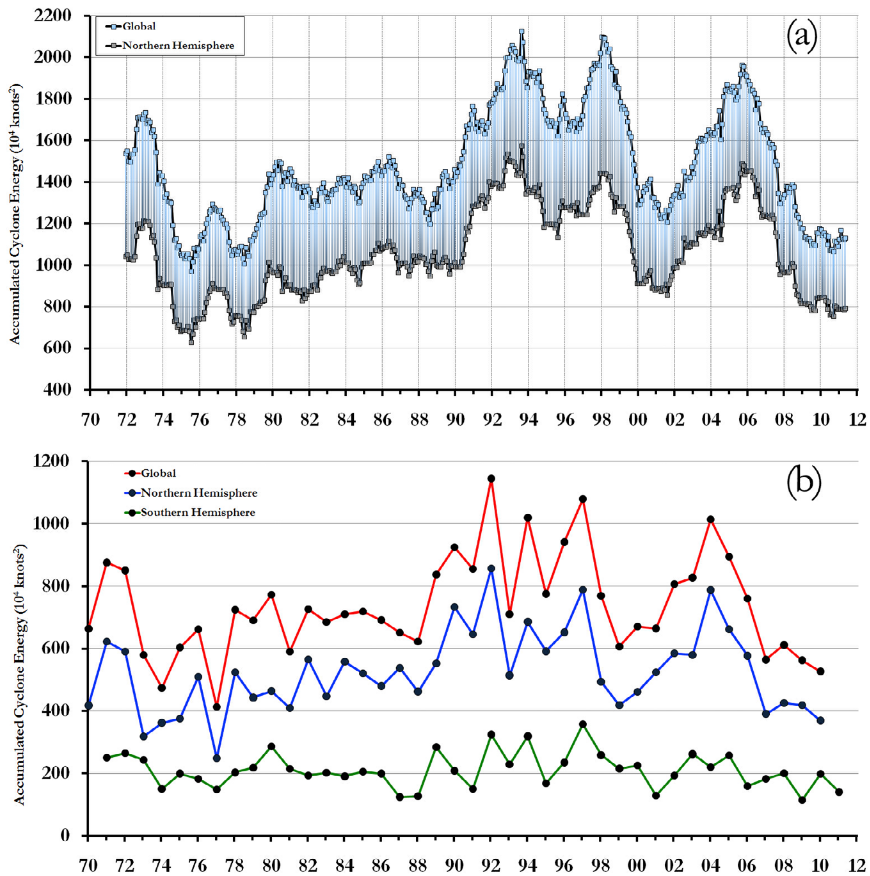


**Figure 1.** Global tropical cyclone Accumulated Cyclone Energy (ACE units $10^4$ knots$^2$) from 1970–2011. (a) 24-month running or accumulated sums, with the top time series (blue boxes) representing total global ACE, and the bottom (gray boxes) as the Northern Hemisphere ACE, with the shaded area in between corresponding to the Southern Hemisphere ACE. (b) Annual totals of global TC ACE (calendar year totals; red boxes), NH TC ACE (calendar year; blue boxes), and SH TC ACE. Note that totals defined for the SH are for July – June due to the offset tropical cyclone season straddling the calendar year change. Global ACE data is included through May 31, 2011.

and NH below average TC ACE, which initially began in 2007 [*Maue*, 2009].

[7] The most prolific calendar year totals of global ACE occurred during the 1990s peaking with the exceptional 1997–98 El Niño event, and again during 2002–2005 (Figure 1b). The recent four years of global ACE have remained near or below 600 units and are closer to values observed in 1981, 1988, and 1999–2001. From the end of the most recent peak in 2005–06, global ACE has decreased by almost half and is currently at a three decades' low. This decrease resulted from four consecutive years of below average NH ACE from 2007 to 2010 combined with average to below-average SH ACE during the same period including the most recent season ending May 2011. Similar conclusions arise when 12-month running sums of TC ACE are examined globally (Figure S1).

[8] Table 1 records the global ACE for each hemisphere and active TC basins for the 32-years inclusive between 1979 and 2010. During the entire period, the NH (SH) supplied 72% (28%) of total global ACE with the WNP contributing the largest proportion at 39%. Two separate 16-year periods are then subjectively chosen (1979–94 and 1995–2010) to coincide with the onset of the NATL active period [*Bell and Chelliah*, 2006] in 1995 typically associated with a transition to the warm phase of the Atlantic Multidecadal Oscillation (AMO). Remarkably, a comparison of each respective period's ACE for both hemispheres shows nearly identical quantities (Table 2).

[9] While the hemisphere ACE totals for each period have remained nearly the same, significant differences are observed in the contribution of the NATL to the NH and

**Table 1.** Global TC ACE Apportioned According to Basin or Hemisphere and the Percentage Compared to the Global or Northern Hemisphere Total[a]

| | Total ACE | % of Global | % of NH |
|---|---|---|---|
| Global | 24422 | 100 | - |
| North Pacific | 13694 | 56.1 | 77.8 |
| Western North Pacific | 9622 | 39.4 | 54.7 |
| Eastern North Pacific | 4072 | 16.7 | 23.1 |
| North Atlantic | 3355 | 13.7 | 19.1 |
| North Indian | 547 | 2.2 | 3.1 |
| Southern Hemisphere | 6826 | 28.0 | - |
| Northern Hemisphere | 17596 | 72.0 | 100 |

[a]Units: $10^4$ kts$^2$. ACE values are tabulated for the 32-year period of January 1979 – December 2010.

**Table 2.** Global and NH ACE Contribution (%) From the North Atlantic, Eastern North Pacific, Western North Pacific, and North Indian Ocean Basins for Two 16-Year Periods: 1979–1994 and 1995–2010[a]

| | 1979–1994 | 1995–2010 |
|---|---|---|
| NATL % of global | 9.0 | 18.6 |
| NATL % of NH | 12.5 | 25.7 |
| EPAC % of global | 20.5 | 12.7 |
| EPAC % of NH | 28.6 | 17.6 |
| WPAC % of global | 40.6 | 38.2 |
| WPAC % of NH | 56.5 | 52.8 |
| NIO % of global | 1.7 | 2.7 |
| NIO % of NH | 2.4 | 3.8 |
| Global Total | 12349 | 12073 |
| NH Total | 8872 | 8723 |

[a]The global and NH ACE quantities (units: $10^4$ $kts^2$) are provided for the two periods.

global ACE totals, which underwent an almost exact doubling in proportion. This coincides with a nearly inverse decrease in the NEP and a smaller reduction in the WNP. *Maue* [2009] discussed the observed inverse nature of TC frequency and ACE between the neighboring NEP and NATL basins positing that the large-scale influences of ENSO and the Atlantic Meridional Mode affected African easterly wave lifecycles through upper-level vertical wind shear modulation [e.g., *Kossin et al.*, 2010]. Indeed 2010 was an excellent example of a very active or prolific NATL hurricane season against an inactive or meager NEP and WNP TC year as previously observed during intense and/or prolonged La Niña events [*Lander and Guard*, 1998].

[10] While the NATL accounted for about 14% of global ACE on average from 1979–2010, the calendar year proportion was highly variable (standard deviation of 8.5%) ranging between 2% and 32% (Figure S2). Indeed, the NATL contribution during 2010 of nearly one-third of global ACE clearly beats out 1996 and 1999 for the highest percentage since at least 1979. Much of this observed dramatic increase in NATL ACE is associated with a strong upward trend in the frequency of deep tropical systems called Cape Verde hurricanes during the past two decades [*Kossin et al.*, 2010]. Cape Verde origin storms typically have long lifecycles and peak at high intensities, thus contributing considerable ACE to the seasonal totals.

## 4. Global Tropical Cyclone Frequency

[11] A total of 69 TCs were counted during calendar year 2010, the fewest observed in the past 40-years with reliable frequency data (Figure 2a). In that historical period, 12-month running-sums of the number of global TCs of at least tropical storm force has averaged 87 with an interquartile range of 82–92 (median 87). The minimum number of 64 TCs was recently tallied through May 2011, as a strong La Niña event waned. Conversely, the most recent peak of

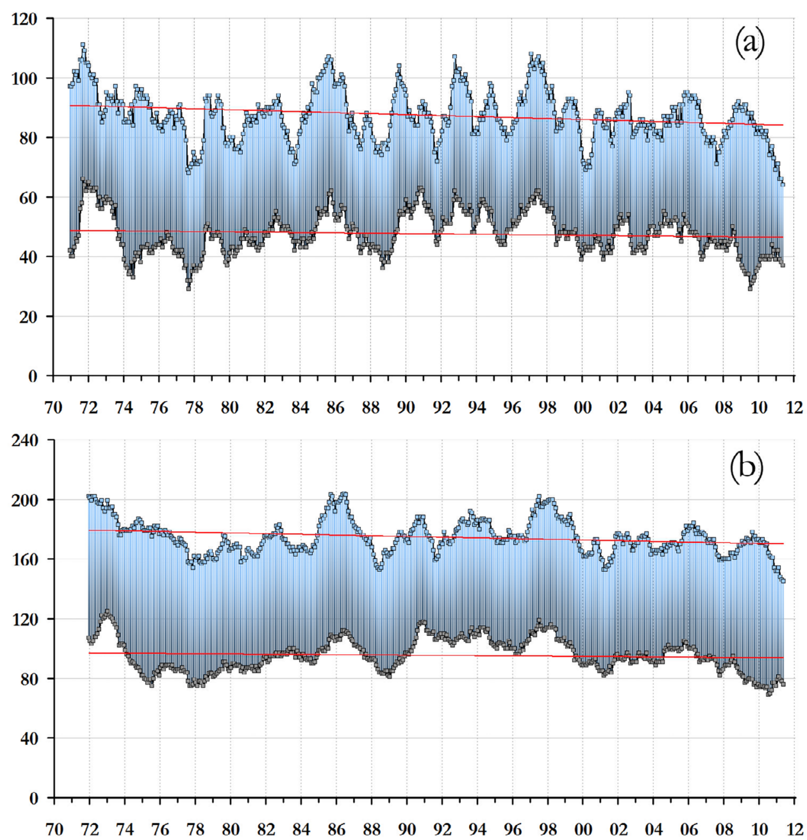


**Figure 2.** Global tropical cyclone frequency, monthly from 1970–2011: (a) 12-month running sums including all TCs (top time series), and only hurricane force TCs (bottom time series). (b) Same as Figure 2a except for 24-month running sums. Red linear trend lines are drawn on each time series. Global frequency data is included through May 31, 2011.

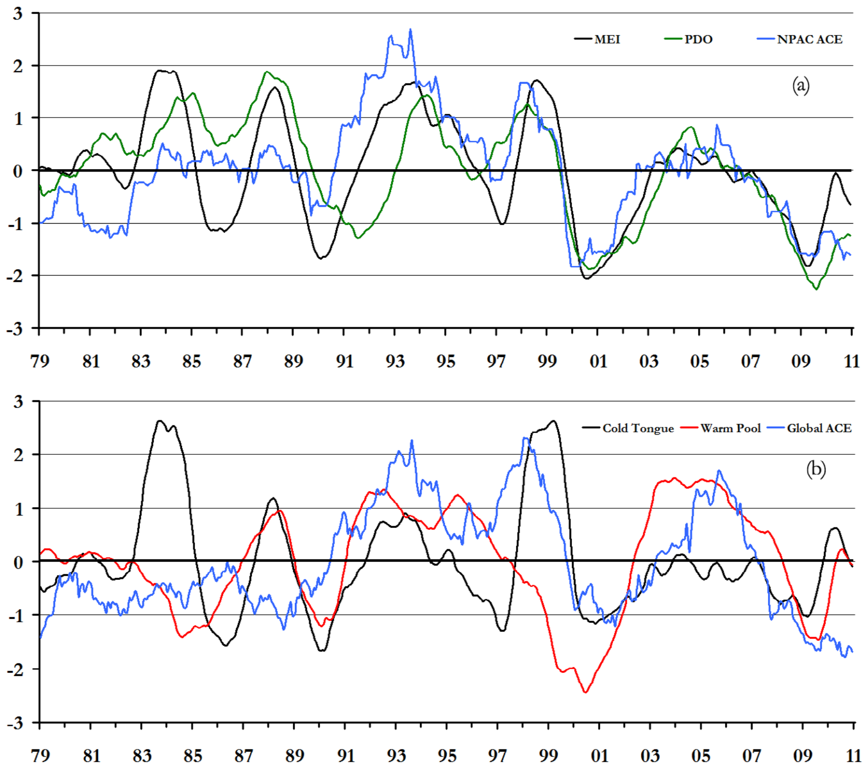


**Figure 3.** Relationship between ENSO indices and TC ACE, monthly 1979–2010. (a) Standardized 24-month running sums of North Pacific TC ACE (blue), PDO (green), and MEI (black). (b) Same as Figure 3a but for overall global TC ACE (blue), cold tongue ENSO index $N_{CT}$ (black), and the warm-pool ENSO index $N_{WP}$ (red).

108 observed during the 12-months ending February 1997 corresponded with the onset of the record El Niño event. There is no significant linear trend in the frequency of global TCs (of at least tropical storm strength), which in agreement with previous analysis [e.g., *Webster et al.*, 2005; *Wang et al.*, 2010].

[12] When only considering TCs of hurricane force (HF) and above (maximum wind speed >64 knots; Figure 2a bottom time-series) the variability is also large with a mean (standard deviation) of 48 (+7) TCs. A minimum of 29 was reached both in 12-months ending in September 1977 and more recently from August 2008 to July 2009. Using 24-month running sums (Figure 2b), a record low number of global HF TCs of 69 was recently recorded in July 2010. A 24-month running sum total of 145 TCs is the historical record low reached during the period ending May 2011.

[13] The NATL produced 19 (12) tropical storms (hurricanes) in 2010, which was a well-above average number. However, the WNP and ENP basins were both historically quiet with a combined total of 22 TCs of which 12 exceeded HF, nearly 50% below the previous 40-year average. With the inclusion of the Northern Indian Ocean basin, the NH during generated 46 TCs in 2010, the fewest since 1977.

[14] Elucidating upon aspects of the ACE metric, TCs that fail to reach HF tend to be of comparatively short duration and contribute significantly less to the global ACE total in a given year [e.g., *Villarini et al.*, 2011]. It is noteworthy that when 24-month running sums of global ACE and the frequency of HF TCs are compared (Figure S3), the two time-series are closely correlated (r = 0.90).

## 5. Large-Scale Climate Modulation

[15] The relationship between TC ACE and modes of large-scale climate variability including the PDO and ENSO is shown with standardized time series of 24-month running sums or accumulated quantities (Figure 3). The following analysis discusses the relationship between TC ACE, the PDO, and three different ENSO indices since 1979. It is reasonable to expect that the collective global distribution of TCs, their genesis locations, and tracks are temporally and spatially modulated by these large-scale climate modes, which directly relate to changes in lifecycle duration and intensity [e.g., *Gray*, 1984; *Camargo and Sobel*, 2005; *Kossin et al.*, 2010]. Moreover, global tropical storm days [*Wang et al.*, 2010] and WNP intense TC frequency fluctuations [*Chan*, 2008] have been shown to be regulated by ENSO and PDO.

[16] Considerable research has focused on the various spatiotemporal characteristics of ENSO, which has been observed to undergo variations on decadal time scales. Two distinct forms of El Niño have been described including the canonical El Niño (cold tongue, CT) warming of the eastern Pacific [*Rasmusson and Carpenter*, 1982] and a central Pacific warming with major SST anomalies shifted westward near the warm-pool (WP) edge [*Ashok et al.*, 2007; *Yeh et al.*, 2009]. During the past two decades, the occurrence of central Pacific warming episodes referred to as El

Niño Modoki events has noticeably increased beginning with the prolonged 1990–1994 El Niño event while CT events have become less frequent [*Lee and McPhaden*, 2010].

[17] To differentiate between the cold tongue (CT) and the central Pacific warm-pool (WP) flavors of El Niño, *Ren and Jin* [2011] devised a piecewise-linear combination of the familiar Niño3 and Niño4 indices. Their definitions of $N_{CT}$ and $N_{WP}$ capture the ENSO regime change of 1976–77 as well as the increasing prevalence of WP or El Niño Modoki events since 1990. $N_{CT}$ = Niño3 − $\alpha$ Niño4 and $N_{WP}$ = Niño4 − $\alpha$ Niño3, where $\alpha$ = 2/5 when Niño3*-Niño4 > 0 and $\alpha$ = 0, otherwise. The two new indices are not well correlated, and were devised to be independent (r = 0.07), an important difference between Niño3 and Niño4, which tend to conflate CT and WP events. The Multivariate ENSO Index (MEI) [*Wolter*, 1987] is well correlated with $N_{CT}$ since 1979 on monthly time scales (r = 0.83), yet poorly correlated with $N_{WP}$ (r = 0.06).

[18] The relationship between TC ACE and modes of large-scale climate variability including the PDO and ENSO indices is shown with standardized time series of 24-month running sums or accumulated quantities (Figure 3). After the observed Pacific climate shift of 1989 [*Yeh et al.*, 2011], combined North Pacific ACE (WNP+ENP), which represents on average 56% of global ACE (Table 2), is remarkably well-correlated with MEI (Figure 3a). However, during the 1980s, the correspondence is clearly less apparent with North Pacific ACE undergoing much less variation than either the PDO or the MEI.

[19] When compared to the North Pacific ACE time series (Figure 3a, blue line), the entire global TC ACE is much higher after 1999 corresponding to heightened NATL basin TC activity (Figure 3b, blue line). Indeed, the $N_{WP}$ representing the El Niño Modoki (red line) remains strongly positive as the global TC ACE most recently peaked in 2004–05. The cooling in the tropical Pacific shown in both the $N_{CT}$ and $N_{WP}$ indices has corresponded with the decrease in overall global TC ACE during the last pentad.

[20] Recent research has also identified the influence of El Niño Modoki on TC activity in the NATL [*Kim et al.*, 2009] and the entire North Pacific basin [*Chen and Tam*, 2010; *Kim et al.*, 2011], yet the observed number of WP (Modoki) events is still small due to the short data record. In related research, *Yeh et al.* [2010] found that the correlation between WNP TC frequency and tropical Pacific SST indices varied greatly between two separate time periods, 1979–89 and 1990–2000, associated with the evolving relationship between the Niño3 and Niño4 ENSO indices.

[21] On decadal time scales, the Pacific climate shifts of 1976–77 and 1988–89 have been related to the concomitant evolution of the two leading EOF modes of SST variability, the PDO and North Pacific Gyre Oscillation (NPGO) [*Yeh et al.*, 2011]. Decadal variations in the NPGO, which has been enhanced since 1989, have been linked to SST anomaly patterns that closely resemble El Niño Modoki events [*DiLorenzo et al.*, 2010]. The cursory analysis presented in Figure 3 is in accord with the aforementioned studies but includes Pacific and global ACE comparisons to the PDO, MEI, and two new ENSO indices [*Ren and Jin*, 2011], which were formulated to highlight the increasingly prevalent El Niño Modoki events.

[22] The most recent El Niño of boreal summer 2009 to spring 2010 did not foster enhanced TC activity in the North Pacific tropical basins, which remained anomalously inactive. The consequent transition to a strong La Niña in boreal summer 2010 extending through spring 2011 has also coincided with rather tepid SH TC activity and an absence of southern Indian Ocean TCs away from the Australian coast. The overall global TC activity drought has continued unabated through May 2011 in terms of both TC energy and frequency.

## 6. Discussion

[23] During the past three decades, variability in global TC ACE is shown to be related to the concomitant evolution of tropical and North Pacific interannual and interdecadal climate modes. As the PDO phase has turned decidedly more negative (colder) and two strong La Niñas have evolved since 2006, recent global TC ACE has fallen below levels associated with the previous dramatic downturn in 1999, and the lowest since at least the late 1970s. The increasing variance of NPAC climate explained by the NPGO and related El Niño Modoki events during the past two decades represents a change in overall Pacific climate [*Yeh et al.*, 2011] that has modulated overall TC activity.

[24] While many overall global and basin ACE and frequency record lows have been set, the glaring anomaly in 2010 was the extremely active NATL basin, which contributed more than 30% of the annual global ACE output. In the context of overall NH ACE variability, even with the doubling of the NATL to NH ACE proportion since 1995, the ENP + NATL proportion has remained constant since 1979 with the WNP coincidentally reacting to the observed fluctuations of ENSO and PDO [*Chan*, 2008].

[25] It is still a fundamental research question as to what are the atmosphere and ocean mechanisms responsible for the observed annual global TC frequency of ~87 storms [*Frank and Young*, 2007]. With the upcoming IPCC AR5 assessment and associated CMIP5 climate simulations, it is critical to have the best possible diagnosis of periods of global TC inactivity and incorporate the recent pentad of historical lows into the context of natural and anthropogenically forced climate variability [*Knutson et al.*, 2010]. Furthermore, research must better explain the role of tropical cyclones in the climate system especially during this current period of record inactivity.

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