1999-2009: Has the intensity and frequency of hurricanes increased ?

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Abstract

One of the often quoted side-effects of global warming is an increase in the frequency and intensity of severe weather events such as hurricanes. This hypothesis is tested here against hurricane data from the National Hurricane Center, a branch of the National Oceanic and Atmospheric Administration, and also the Joint Typhoon Warning Centre.

Data for the years 1999-2009 are analysed and tested against long term data for the North Atlantic, Eastern Pacific, Western Pacific, Northern and Southern Indian oceans. It is concluded that Hurricane intensity and frequency is significantly higher in this period in the North Atlantic. However in the Eastern Pacific, Western Pacific, Northern and Southern Indian oceans, there is no evidence of significant change. *Taken together, there appears to be no significant difference in either frequency or intensity of hurricanes globally. Repeating the analysis for 1999-2007 gives the same result and this conflicts with statements made in the IPCC 2007 report.*

This study takes no position about the amount or causes of global warming. It simply analyses relevant quoted data and publishes the data in such a way that it can be easily checked by others.

`Keywords: Severe weather event frequency, Hurricanes, global warming`

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1 Document revision history

Web publication allows the easy privilege of updating papers quickly to respond to feedback. This is an active project in view of the interesting patterns apparent in these data so the revision history so far in reverse temporal order is as follows:-

- 18-Feb-2010v1. Following considerable feedback thanking me for collating the raw data, I have added three other datasets, Northern Hemisphere, Southern Hemisphere and Worldwide. These of course include no new information but have collated the existing data into additional hemispheric plots and also a worldwide plot for convenience. The updated spreadsheet contains the same revision name. The analysis is unchanged but I reworded the comparison with the first IPCC statement.

- 16-Feb-2010v1. Following feedback, the spreadsheet, (which was a total mess having grown organically during the project), was completely redone to make it easier to work with and for other people to understand what I did and repeat it. I am also now explicit about the t-test (two-tailed), which was sloppy of me and even worse, the wrong spreadsheet got put up on the web-site which didn't match this paper. Mea culpa and thanks to people for pointing out the confusion. The matching spreadsheet has the above version number on it. Finally I noticed that somebody had questioned whether the datasets should overlap or not. Interesting question, so I did both and there is very little difference.

- 12-Feb-2010v1. Updated version using a t-test and data from as much of the world as is available, (somewhere between 90-95%).

- 02-Feb-2010v1. Initial version using a z-test and data from the northern hemisphere only.

2 Overview

It is frequently quoted that global warming will lead to more violent weather events. For example, Henson notes on p. 2 of [5]

> "As the world warms, the intensity of hurricanes - such as Katrina, which ravaged New Orleans in 2005 - is steadily rising, see p. 128."

Such quotations are underpinned by theoretical work with complex computer models such as that by [6]. However, complex computer models are beset by unquantifiable errors [4], [3], so it is difficult to make convincing predictions and no further discussion will be made here. Instead, openly available raw data will be analysed for simple statistical significance.

All northern hemisphere data is analysed along with some data from the southern hemisphere, (the southern Indian ocean). The only published data area which is omitted is the southern Pacific ocean for which only 10 years of data are available however, these suggest that the total contribution is only between 5-10% of the rest of the world combined, so this should have no significant effect on the results reported here.

The IPCC in its 2007 report [7] has this to say on hurricanes

1. There has been an increase in hurricane intensity in the North Atlantic since the 1970s, and that the increase correlates with increases in sea surface temperature.

2. The observed increase in hurricane intensity is larger than climate models predict for the sea surface temperature changes we have experienced.

3. There is no clear trend in the number of hurricanes.

4. Other regions appear to have experienced increased hurricane intensity as well, but there are concerns about the quality of data in these other regions.

5. It is more likely than not ($> 50\%$) that there has been some human contribution to the increases in hurricane intensity.

6. It is likely ($> 66\%$) that we will see increases in hurricane intensity during the 21st century.

Initially the period 1999-2009 will be analysed comparing it against worldwide data for the period 1946-2009. Following this, the data is re-analysed against the IPCC report for the period 1999-2007 to see how well the claims agree. Individual areas will be shown as well as collective data as the individual areas show interesting patterns.

3 Worldwide Analysis 1999-2009

Raw hurricane data is taken from the National Hurricane Center [2] for the years 1999-2009 (although November 2009 is not yet formally complete in the records at the time of writing) and the Joint Typhoon Data Center [1] for the years 1946-2009. These data show the following:-

Year	Tropical Storms	Hurricanes	Major Hurricanes
2009	8	2	2
2008	16	8	5
2007	14	6	2
2006	9	5	2
2005	28	15	7
2004	15	9	6
2003	16	7	3
2002	12	4	2
2001	15	9	4
2000	15	8	3
1999	12	8	5
Long Term Averages	10.66 (10)	6.08 (6)	2.66 (2)

Table 1: Hurricane numbers and intensity for 1999-2009 and the long term averages in the North Atlantic computed from 1945-2009 data. Figures in parentheses are the long term averages quoted by [2].

Note that the columns are inclusive in the sense that the 2009 year should be read as 8 tropical storms of which 2 developed into hurricanes and both of which were major hurricanes, (3 or above on the widely-used Saffir-Simpson scale).

Year	Tropical Storms	Hurricanes	Major Hurricanes
2009	18	7	4
2008	16	7	2
2007	11	4	1
2006	18	10	5
2005	15	7	1
2004	12	6	3
2003	16	7	0
2002	12	6	5
2001	15	8	2
2000	17	6	2
1999	9	6	2
Long Term Averages	13.95 (16)	7.23 (9)	2.82 (4)

Table 2: Hurricane numbers and intensity for 1999-2009 and the long term averages in the eastern Pacific computed from 1948-2009 data. Figures in parentheses are the long term averages quoted by [2].

Year	Tropical Storms	Hurricanes	Major Hurricanes
2009	37	14	7
2008	32	12	5
2007	26	16	9
2006	26	13	10
2005	25	18	10
2004	32	20	14
2003	27	17	11
2002	31	16	10
2001	33	20	11
2000	35	15	8
1999	35	12	4
Long Term Averages	29.23	17.06	9.34

Table 3: Hurricane numbers and intensity for 1999-2009 and the long term averages in the western Pacific computed from 1946-2009 data.

Year	Tropical Storms	Hurricanes	Major Hurricanes
2009	5	1	0
2008	7	1	1
2007	6	3	2
2006	5	1	1
2005	7	1	0
2004	4	1	0
2003	3	1	0
2002	4	0	0
2001	4	1	1
2000	4	2	0
1999	7	3	3
Long Term Averages	5.15	1.42	0.61

Table 4: Hurricane numbers and intensity for 1999-2009 and the long term averages in the northern Indian ocean computed from 1977-2009 data.

Year	Tropical Storms	Hurricanes	Major Hurricanes
2009	19	8	6
2008	22	10	5
2007	19	11	5
2006	14	7	6
2005	17	6	4
2004	26	12	6
2003	21	11	6
2002	25	12	8
2001	21	11	5
2000	27	16	8
1999	35	14	7
Long Term Averages	26.76	12.3	5.79

Table 5: Hurricane numbers and intensity for 1999-2009 and the long term averages in the southern Indian ocean computed from 1977-2009 data.

The combined data is simply the sum of these five tables using data up to 2009. Note that historically, the western Pacific has been the most active followed by the southern Indian, eastern Pacific and then the North Atlantic.

3.1 Methodology

A very simple methodology will be used. A two-tailed t-test [8] will be used to assess whether there are any significant changes in the means of these five populations compared with their historical averages, whether there are any significant changes in the combined population compared with the historical averages and whether the percentage of hurricanes which become major hurricanes has changed with respect to the historical averages. Finally, the datasets are combined and tested again. Threats to this approach will be considered later. The t-test is appropriate when sample sizes may be small, (in this case of the order of 10) although there is little difference between a t-test and a z-test on these data.

One of the comparison datasets will be the most recent decade and the other, an appropriate version of the historical data depending on how much is available. It is a moot point whether these should be allowed to overlap so I did both to check. The t-parameters are quoted in each case as (non-overlapping t; degrees of freedom) / (overlapping t; degrees of freedom), so (3.93;62)/(2.84;73) means a non-overlapping t value of 3.93 with 62 degrees of freedom and an overlapping t value of 2.84 with 73 degrees of freedom.

In each case, the null hypothesis is that the mean in the years 1999-2009 individually or collectively is the same as the relevant historical mean.

The t-test for the difference of means taken from the same population, states that the following statistic is approximately distributed as N(0,1).

$$t(N_1 + N_2 - 2) = \frac{\overline{X_1} - \overline{X_2}}{\hat{\sigma}(\frac{1}{N_1} + \frac{1}{N_2})^{\frac{1}{2}}} \quad (1)$$

where

$$\hat{\sigma} = \frac{N_1 s_1^2 + N_2 s_2^2}{N_1 + N_2 - 2} \quad (2)$$

and $\overline{X_i}, s_i$ and N_i are respectively the sample means, sample variances and number of samples for each of the populations.

3.2 Analysis of Atlantic data

These data show the following[1]:-

[1] http://www.leshatton.org/index_DA.html

- Hypothesis A1: There is no change in the average number of tropical storms: *t = (3.93;62)/(2.84;73), rejected at the 1% level. Average number has* ***increased****.*

- Hypothesis A2: There is no change in the average number of hurricanes: *t = (1.81;62)/(1.43;73), no evidence to dispute this.*

- Hypothesis A3: There is no change in the average number of major hurricanes: *t = (2.05;62)/(1.7;73), rejected at the 5% level. Average number has* ***increased****.*

- Hypothesis A4: There is no change in the proportion of hurricanes which mature into major hurricanes: *t = (1.94;62)/(1.33;73), no evidence to dispute this.*

It can be concluded that the Atlantic is significantly more active in the last 11 years compared with long term averages. Note that if the quoted long term means shown in parentheses in Table 1 are used along with an estimate of the standard deviation from 1946-2009 data, then these trends are more accentuated.

3.3 Analysis of Eastern Pacific data

The results of this show the following:-

- Hypothesis P1: There is no change in the average number of tropical storms: *t = (0.36;59)/(0.31;70), no evidence to dispute this.*

- Hypothesis P2: There is no change in the average number of hurricanes: *t = (-0.5;59)/(-0.45;70), no evidence to dispute this.*

- Hypothesis P3: There is no change in the average number of major hurricanes: *t = (-0.47;59)/(-0.41;70), no evidence to dispute this.*

- Hypothesis P4: There is no change in the proportion of hurricanes which mature into major hurricanes: *t = (0.81;59)/(-0.31;70), no evidence to dispute this.*

It can be concluded that the Eastern Pacific has shown no significant change in the last 11 years compared with long term averages. Note that if the quoted long term means shown in parentheses in Table 2 is used along with an estimate of the standard deviation from 1946-2009 data, then a highly significant reducing trend appears for the total number of hurricanes and the total number of major hurricanes appears. (See the accompanying Excel dataset for this analysis[2]).

3.4 Analysis of Western Pacific data

The results of this show the following:-

- Hypothesis P1: There is no change in the average number of tropical storms: t = *(0.83;62)/(0.73;73), no evidence to dispute this.*
- Hypothesis P2: There is no change in the average number of hurricanes: t = *(-1.28;62)/(-1.11;73), no evidence to dispute this.*
- Hypothesis P3: There is no change in the average number of major hurricanes: t = *(-0.38;62)/(-0.33;73), no evidence to dispute this.*
- Hypothesis P4: There is no change in the proportion of hurricanes which mature into major hurricanes: t = *(0.41;62)/(0.32;73), no evidence to dispute this.*

It can be concluded that the Western Pacific has shown no significant change in the last 11 years compared with long term averages.

3.5 Analysis of Northern Indian data

The results of this show the following:-

- Hypothesis P1: There is no change in the average number of tropical storms: t = *(-0.11;31)/(-0.09;42), no evidence to dispute this.*
- Hypothesis P2: There is no change in the average number of hurricanes: t = *(-0.2;31)/(-0.15;42), no evidence to dispute this.*
- Hypothesis P3: There is no change in the average number of major hurricanes: t = *(0.63;31)/(0.41;42), no evidence to dispute this.*
- Hypothesis P4: There is no change in the proportion of hurricanes which mature into major hurricanes: t = *(-0.15;31)/(0.23;42), no evidence to dispute this.*

It can be concluded that the Northern Indian ocean has shown no significant change in the last 11 years compared with its long term averages.

[2]http://www.leshatton.org/Documents/Data_Hurricanes_1946-2009.zip

3.6 Analysis of Southern Indian data

The results of this show the following:-

- Hypothesis P1: There is no change in the average number of tropical storms: *t = (-3.35;31)/(-2.09;42), rejected at the 1% level. Average number has **decreased**.*

- Hypothesis P2: There is no change in the average number of hurricanes: *t = (-1.63;31)/(-1.19;42), no evidence to dispute this.*

- Hypothesis P3: There is no change in the average number of major hurricanes: *t = (0.34;31)/(0.27;42), no evidence to dispute this.*

- Hypothesis P4: There is no change in the proportion of hurricanes which mature into major hurricanes: *t = (2.71;31)/(1.96;42), rejected at the 5% level. Average proportion has **increased***

It can be concluded that the Southern Indian ocean has shown no significant change in the number of hurricanes in the last 11 years compared with long term averages, although there is evidence that the proportion which mature into major hurricanes has increased whilst simultaneously there is evidence to suggest that the total number of storms has decreased.

Taking the five datasets together gives a combined worldwide result as follows

3.7 Analysis of Northern and Southern hemispheres combined

The results of this show the following:-

- Hypothesis C1: There is no change in the average number of tropical storms: *t = (0.17;205)/(0.48;264), no evidence to dispute this.*

- Hypothesis C2: There is no change in the average number of hurricanes: *t = (-1.58;205)/(-1.15;264), no evidence to dispute this.*

- Hypothesis C3: There is no change in the average number of major hurricanes: *t = (0.74;205)/(0.57;264), no evidence to dispute this.*

- Hypothesis C4: There is no change in the proportion of hurricanes which mature into major hurricanes: *t = (0.29;205)/(0.21;264), no evidence to dispute this.*

It can be concluded that there has been no significant change in the last 11 years compared with long term averages.

4 Repeat analysis, worldwide 1999-2007

In order to match the IPCC 2007 analysis, the above was repeated for the period 1999-2007. The results of significance are essentially the same as the 1999-2009 period giving values for C1-4 as (-0.02;205)/(0.26;264), (-0.73;205)/(-0.31;264), (1.21;205)/(1.08;264) and (0.25;205)/(0.19;264) respectively. The conclusions are unaffected.

4.1 Threats and notes

In the Atlantic Ocean, 2005 was a terrible year and it has been implied that this in itself may herald increasing storm activity. However in statistical terms, it is simply an outlier and no special treatment is necessary.

The Northern and Southern Indian Oceans are effectively incomplete before 1977 with little or no reliable data associated with them, (the phrase "Unknown storm" often appears for example). Data before 1977 for both these datasets was therefore ignored. This was the only data manipulation which took place.

The combined analysis thereafter treats each dataset with equal weight. This seems reasonable as they come from comparable sources.

Small departures from the averages quoted at [2] were noted as can be seen in Tables 1 and 2 where the quoted averages are shown in parentheses. An attempt was made to remodel the conclusions using the quoted means but with standard deviations calculated from the main data, (as matching standard deviations were not quoted). This did not change the results for the North Atlantic but did change the results for the eastern Pacific leading to the conclusion that the *total number of hurricanes and major hurricanes was reducing*. This result was significant at the 1% level. It is unclear however why the quoted averages at [2] do not tally with the raw data displayed at [1] so the conclusions of this paper are drawn from the raw data only and are as correct as the data.

5 Some comments on the raw data

Although the main thrust of this analysis is to test the conclusions of the IPCC 2007 report wherever possible, the raw data appears to contain some subtle interesting aspects over and above this. Figures 1, 2, 3, 4 and 5 contain the North Atlantic, East Pacific, West Pacific, North Indian and South Indian datasets respectively for the number of hurricanes and the number of major hurricanes respectively over the measurement periods covered here.

In the North Atlantic dataset Figure 1, hints of two peaks of activity 1947-1965 and 1995-2009 can be seen with a relatively inactive period 1965-1995. In the Eastern Pacific dataset, Figure 2, there are hints of an interesting anti-correlation with a relative peak of activity 1970-2000 with a decline in activity since. In Figure 3, the West Pacific dataset, there appears to be a slight decline for about 10 years from 1972-1982. In the North Indian dataset, Figure 4, there appears to be a peak of activity in the decade surrounding 1995 with apparent decline afterwards. Finally, in the South Indian dataset, Figure 5, there are signs that the number and intensity of hurricanes appears to have had a relatively active period in the range 1975-2000 followed by a decline in activity, which is similar to the trend observed in the Eastern Pacific data. Finally Figures 6 and 7 show the collected data for each hemisphere and Figure 8 shows the collected worldwide data since 1977 including tropical storms, (the earliest year here for which all datasets are complete and apparently of consistent quality). Figure 7 is therefore identical with Figure 5 but will differ as data from the South Pacific becomes available.

For anybody interested in data analysis, Figure 8 is fascinating. Visually, the dataset shows the number of Tropical Storms roughly constant in the last 10 years and the number of hurricanes and major hurricanes in decline from a peak in the early 1990s although the apparent decline of the last 10 years is not statistically significant as shown in the text. This Figure also puts the unprecedented North Atlantic storm season of 2005 into global context where it doesn't particularly stand out.

These observations are only hints but might be worth pursuing further as they suggest coupling. The next stage taken here will be to investigate any significant micro-patterns present.

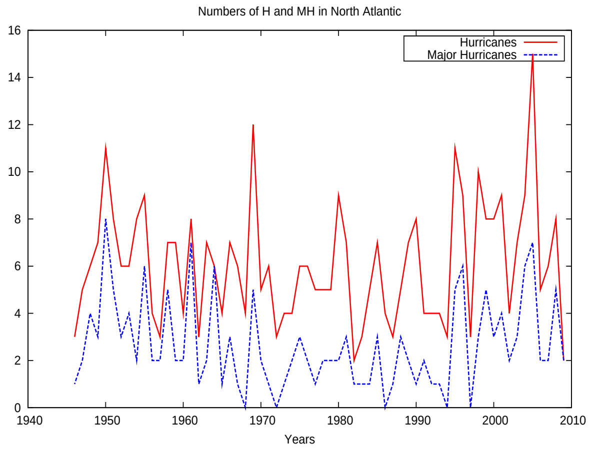

Figure 1: Northern Atlantic hurricanes and major hurricanes in the last 50 years.

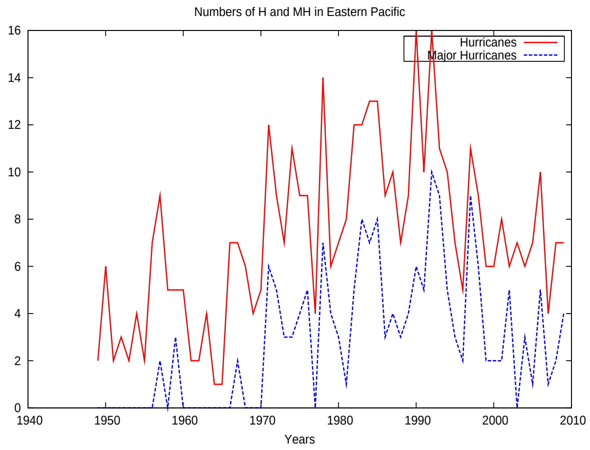

Figure 2: Eastern Pacific hurricanes and major hurricanes in the last 50 years.

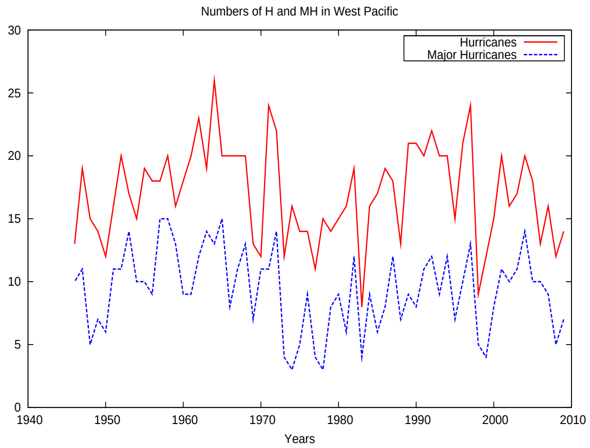

Figure 3: West Pacific hurricanes and major hurricanes in the last 60 years.

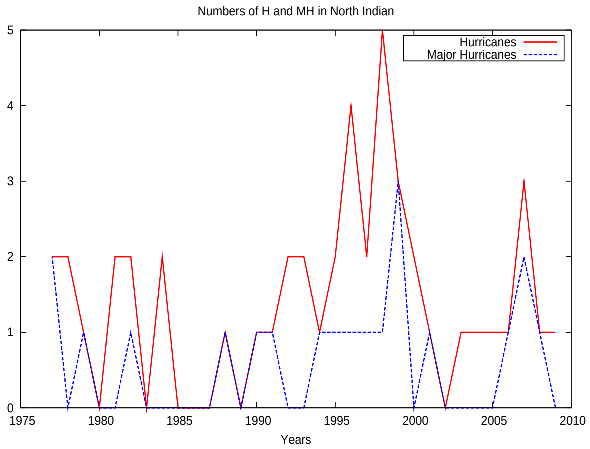

Figure 4: North Indian hurricanes and major hurricanes in the last 30 years.

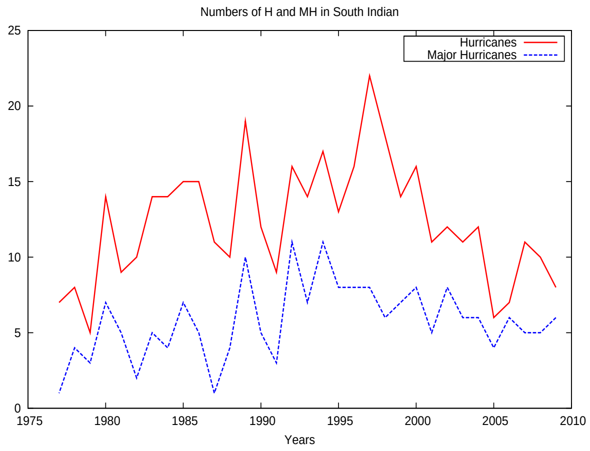

Figure 5: South Indian hurricanes and major hurricanes in the last 30 years.

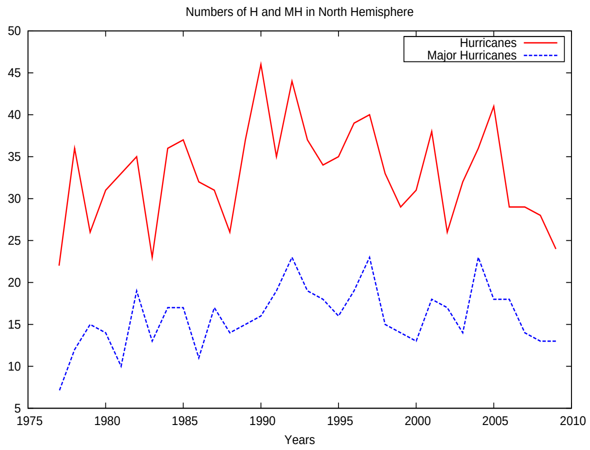

Figure 6: Northern Hemisphere hurricanes and major hurricanes in the last 30 years.

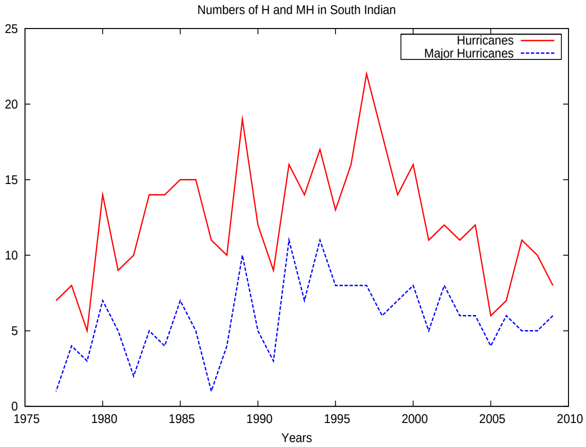

Figure 7: Southern Hemisphere hurricanes and major hurricanes in the last 30 years. This is currently identical to the South Indian data but as more South Pacific data is added, it will change.

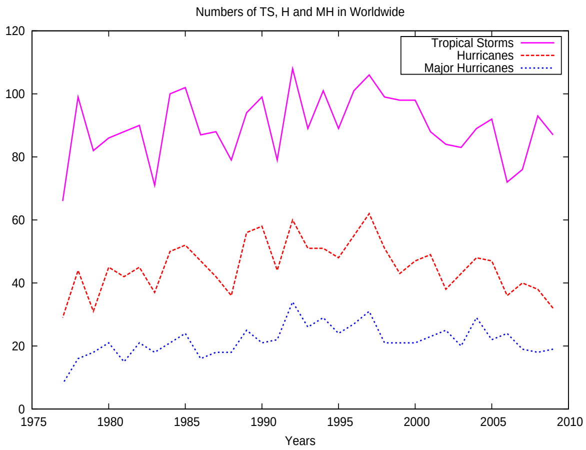

Figure 8: Worldwide tropical storms, hurricanes and major hurricanes in the last 30 years. This currently excludes South Pacific data which is incomplete so this is estimated to represent 90-95% of the total activity.

6 Conclusions

Over the periods 1999-2007 or 1999-2009, it can be concluded that, worldwide, *there is no evidence to support that the average number of tropical storms, hurricanes, major hurricanes or proportion of hurricanes which mature into major hurricanes has increased compared with the historical data available at [1].*

Taken separately, there is strong evidence that the Atlantic is becoming more active in both number of hurricanes and number of major hurricanes (these are defined to be ≥ 3 on the Saffir-Simpson scale), but there is no equivalent evidence in any of the published data areas that this is true elsewhere. Indeed there is weak evidence (at around the 10% level that the total number of hurricanes worldwide has decreased but this may simply because 2008-2009 were relatively quiet years). This will be analysed further as more data becomes available.

The difference between the quoted means on [2] and those calculated from the data here can be explained for the North Atlantic because data for that area is available going back into the 19th century. However, there is little difference between the mean calculated here for 1946-2009 and the quoted mean for this area. The Eastern Pacific remains problematic. The difference between the mean calculated from the 1946-2009 data here and the quoted value is relatively large. If the quoted mean uses data unavailable here and is correct, then activity in the eastern Pacific is unquestionably declining. This is speculative however as the intention here was to use *only* the data so that this analysis can be checked by others.

Relating the 1999-2007 period analysis carried out here to the IPCC points enumerated earlier in this paper, leads to the following annotated conclusions, (with my annotations in italic):-

1. There has been an increase in hurricane intensity in the North Atlantic since the 1970s and that the increase correlates with increases in sea surface temperature. (*There has certainly been an increase in the last decade however looking at the raw data in Figure 1, this is only a return to the level of activity it had in the 1950s and 1960s after a 25 year period of relatively low activity from around 1970. The relationship between intensity and sea surface temperature could not be tested.*)

2. The observed increase in hurricane intensity is larger than climate models predict for the sea surface temperature changes we have experienced. (*Climate models are corrupted by unquantifiable errors. This could be due to inadequate physics, software error or both.*)

3. There is no clear trend in the number of hurricanes, (*corroborated*).

4. Other regions appear to have experienced increased hurricane intensity as well, but there are concerns about the quality of data in these other regions. (*Only the Atlantic has experienced a statistically significant increased number of major hurricanes in this period. All other datasets show no significant change. This is a worryingly incorrect statement.*)

5. It is more likely than not (> 50%) that there has been some human contribution to the increases in hurricane intensity. (*Since there hasn't been any significant increase in hurricane intensity, its hard to see what human contribution has got to do with it. Statements like this do not enhance confidence in the quality of the IPCC reporting.*)

6. It is likely (> 66%) that we will see increases in hurricane intensity during the 21st century, (*Pure speculation of a similar quality to the previous point.*)

It is concluded that the match between the data and the IPCC 2007 analysis is not good with the last two points being particularly wayward. It would be intriguing to know if the quoted climate models predict the subtler features indicated in the raw data.

7 Pedagogical note

In order to allow easy open access to the data and analysis for this paper, a matching zip file is available[3]). The zip file contains an Excel spreadsheet with the same version number as this document containing the main analysis and data and also .dat files and a .gnu file which, with the excellent *gnuplot*, can be used to re-generate all the figures in this paper.

It is hoped that this may help to convince other climate data owners to release all their data and software used to generate results into the public domain to achieve the same benefits as we enjoy with open source software. If you have a Linux system, all you need to do is unzip the archive and then issue the command

[3]http://www.leshatton.org/Documents/Data_Hurricanes_1946-2009.zip

```
% gnuplot hurricanes.gnu
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This will generate all the figures shown above. You will be able to read the Excel file with *Open Office*, (which is how I created it).

8 Acknowledgements

This is a brief thank you to United States government bodies such as NOAA and NASA as well as the Unisys corporation who by their enlightened attitude to the promotion of science for the public good, make data such as this freely available.

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