Is recent major hurricane activity normal?

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The anomaly of the recent increase in Atlantic major hurricane activity (MHA) is controversial. From a reconstruction of past MHA, Nyberg *et al.*[1] conclude that the present activity is not unusual by comparison with that of the past 270 years. However, here I estimate the uncertainty of average MHA in the hurricane record[2] before 1945 and show that the reconstruction of Nyberg *et al.*[1] differs strongly from that record, and probably overestimates past MHA. Owing to this and further reasons, I question whether their reconstruction provides an accurate basis for conclusions about past MHA.

Nyberg *et al.*[1] reconstruct MHA for the past 270 years using data sets from coral and sediment cores as well as sea surface temperature (SST) data. Their reconstruction shows a huge difference compared to the hurricane record[2] before 1944. The authors explain this by the unreliability of that record. However, uncertainties in the record, owing to possible underreporting of tropical storms, are not unlimited. Relative to 1966–2002, the highest estimates of underreporting are about two tropical storms per year from 1900 to 1965, and two to three tropical storms in the 19th century[3,4].

To estimate the possible underreporting of MHA, I used the ratio of the number of major hurricanes to the total number of tropical storms, assuming a constant ratio over the long term. I adjusted the number of tropical storms for the estimations given in refs 3 and 4, which for 1851–1885 is a range from zero to six tropical storms for a single year (three per year on average), for 1885–1900 is a range from zero to four (two on average), and for 1900–1965 is two tropical storms (Fig. 1, black line). The average major hurricane/tropical storm ratio for 1966–2006 and the average corrected ratio for 1910–1965 are both 0.21. Therefore, no MHA correction is indicated for 1910–1965. To adjust the considerably lower ratio for 1851–1910, a correction of plus one major hurricane per year on average is needed (Fig. 1, red line). Figure 1 (blue line) shows that the ratio is strongly correlated to the number of major hurricanes. This is also true for 1851–1910 after the correction, and shows that the correction seems reasonable and should provide an upper limit of past MHA. This upper limit yields almost exactly two major hurricanes per year on average between 1851 and 1940. The Nyberg *et al.*[1] reconstruction, which produces clearly more than three (about 3.3) major hurricanes on average over that period, overestimates major hurricane frequency before 1940 by at least ~60%. Even an extreme adjustment of plus five tropical storms before 1900 and a MHA correction according to the plus-two-tropical-storm-adjustment from 1900–1944 would still show an overestimation of about 35%.

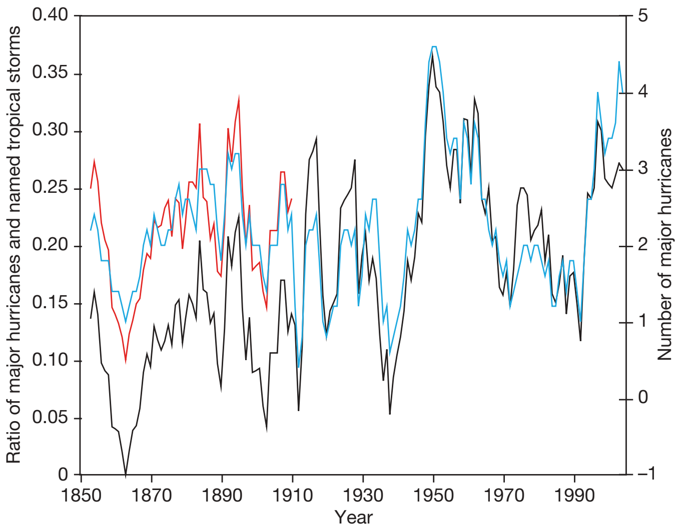

Figure 1 | Annual number of major hurricanes compared to the total number of tropical storms. The black line shows the five-year moving average of the ratio between major hurricanes and the total number of tropical storms[2] after correction of the observational bias of tropical storm number proposed by refs 3 and 4. The red line and the blue line show the ratio and the number of major hurricanes, respectively, after correction for a possible observational bias of major hurricanes before 1910.

Another important problem of the reconstruction is that the two basic data sets show an inverse long-term trend regarding their relationship to MHA, at least for 1730–1950. According to the coral data, there would have been a positive MHA trend over the reconstruction period, but, according to the sediment data, there would have been a negative trend. Thus, at least one of the two data sets must produce a wrong long-term trend of MHA.

Moreover, one of the data sets shows an inverse spatial correlation to wind shear north and south of about 22° N latitude, respectively[1] (that is, when wind shear is relatively high in the south, it is low in the north). Since 1944, about 50% of major hurricanes have reached major hurricane strength only north of 22° N where mainly an inverse wind shear anomaly is observed. Thus, the influences of the inverse wind shear anomalies north and south of 22° N on MHA might cancel each other out, at least to some degree.

The reconstruction probably overestimates the influence of wind shear and underestimates the influence of SSTs, because over the calibration period there is a clear multi-year trend of wind shear but only a small trend of SSTs. Therefore, the relationship to SSTs might not be well calibrated. A calibration over the periods before or after the calibration period adopted in the paper (1946–1990), where multi-year SST trends are more pronounced than wind shear trends, would probably produce a considerably different reconstruction, especially regarding the long term. The dominant influence of SSTs in the recent activity increase, for example, has been shown in other studies[5,6].

These problems seriously undermine the reliability of the reconstruction, especially before 1940, and therefore the main conclusions of Nyberg *et al.*[1]

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Neu[1] suggests that the reconstruction of Atlantic major hurricane activity (MHA) (that is, frequency) in Nyberg *et al.*[2] overestimates past MHA because it differs significantly from the known observational records of tropical storms and MHA[3] before 1945 and overestimates the influence of vertical windshear $|V_z|$.

Neu[1] claims that the variability of the historical tropical storm record[3] is accurate and provides an alternative reconstruction of MHA from 1851 to 1910 based on assumptions of low numbers (according to refs 4 and 5) of non-observed tropical storms, and a stable ratio between total number of tropical storms and MHA over the long term. However, Neu's record shows a sudden rise in MHA around 1944, coincident with the start of aircraft reconnaissance, which allowed much better monitoring of tropical cyclones. Also, according to ref. 4, the undercount bias is up to six tropical cyclones per year between 1851 and 1885, and up to four per year between 1886 and 1910. These biases are higher than the ones Neu[1] uses in his record of major hurricane numbers. Furthermore, to quote from ref. 4, "conclusions from this paper on the number of missed tropical cyclones are likely conservative". Moreover, MHA shows a stronger variability, closely correlated to $|V_z|$ (ref. 2), than tropical storms and non-major hurricanes in the reliable record[1–3], indicating a varying MHA/tropical storm ratio back in time.

The reconstruction in ref. 2 is based on proxies of $|V_z|$ (also, for example, sea-level pressures, lower atmospheric stability and moisture) and independent sea-surface temperature (SST) records. In contrast to Neu's[1] claims, no significant trends are apparent during the calibration period[2] between ~1969 and the late 1980s, either in the observed number of major hurricanes[1–3] or in the measured $|V_z|$, whereas there is a significant trend of increasing SSTs in and around the main development region (MDR). This lack of a direct response of an increase in MHA from the increases in SSTs indicates the strong influence of $|V_z|$, and interactively caused SST anomalies in MDR relative to tropical mean SSTs, on MHA. Moreover, the MHA record[1–3] shows no appreciable difference in numbers of major hurricanes between the periods 1948–1952 (average of 3.8 major hurricanes) and 1995–2006 (average of 3.9 major hurricanes), despite the fact that SSTs were more than ~0.4 °C higher in and around the MDR during the latter period. The ~1.5 m s^{-1} higher vertical wind shear in MDR during this period[2] indicates the dampening effect of $|V_z|$ on MHA.

A conclusion in ref. 2 is that the average number of major hurricanes in the Atlantic during the period from 1995 to 2005 is not unusual when compared to previous high-activity phases, also supported by Fig. 1 in Neu[1] and by refs 6 and 7. Reference 2 does not say that the recent increases in SSTs have no influence on MHA. A comparison of present values of $|V_z|$ with reconstructed values back to 1730 shows that the $|V_z|$ was high from 1995 to 2005, but that although it decreased from the late 1980s it should still have dampened MHA. Thus, high MHA suggests the net result of higher SSTs overcoming the effect of high $|V_z|$.

The trade wind strength ($|V_z|$) in MDR is affected by the Atlantic subtropical high through an equatorward meridional pressure gradient[8–11]. Thus, the combined proxies may reflect a trend since the mid–late 18th century of an intensified and poleward Hadley cell circulation, where the proxies from the northern Caribbean reflect the strengthening of the subtropical high and trade winds[12] (which from the late 1960s to the late 1980s were anomalously strong[13]) and the associated increasing subsidence caused by a faster warming of the atmosphere than ocean[2], which together may have suppressed MHA. Also, these seasonal precipitation proxies reflect warm-phase El Niño Southern Oscillation (ENSO) events, which cause upper westerly winds, additional wind shear in MDR, and an equatorward shift of the subtropical jet stream that suppress MHA[9] and precipitation[10,11] during the hurricane season. These events were frequent from the mid 1970s to the early 1990s.

The proxies used in ref. 2 reflect the region where almost all Atlantic major hurricanes form (see Fig. 2 of ref. 2), and the non-linear solution[2] allows for varying MHA in response to $|V_z|$ and other influences such as SSTs. Absolute MHA values may change slightly given different model calibrations, but the proxies[2] still indicate a declining trend in MHA until the early 1990s superimposed on decadal and multi-decadal variability and that the conclusions in Nyberg *et al*[2] remain.

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