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Eastern Atlantic tropical cyclone frequency from 1851–1898 is comparable to satellite era frequency

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Abstract

Trend in North Atlantic tropical cyclone frequency is subject to uncertainties related mainly to observational deficiencies. These uncertainties make assessments of anthropogenic effects on present and future trends problematic. Here we document that, contrary to received opinion, ship numbers actually peaked in the mid-nineteenth century and reached a minimum in the early twentieth century. The greater opportunities for ship encounters with tropical cyclones is demonstrated in re-analysis of Eastern Atlantic tropical cyclones from 1851–1898. Our results suggest that nineteenth century frequency is comparable to that for the same area during the entire satellite era from 1965–2012.

S Online supplementary data available from stacks.iop.org/ERL/9/114023/mmedia

Keywords: tropical cyclones, North Atlantic Ocean, trend analysis

Introduction

The long-term increase in North Atlantic tropical cyclone (TC) numbers since the late 19th century is considered to be largely due to observational deficiencies (Landsea 2007, Vecchi and Knutson 2008, 2010, Landsea *et al* 2010). These uncertainties make the assessment of anthropogenic effects on North Atlantic TC frequency uncertain and open to debate (Knutson *et al* 2010).

Estimates of missing TCs have focused on both insufficient spatial coverage in remote ocean areas (Landsea 2007, Vecchi and Knutson 2008, 2010) and under-counting of very short duration storms (Landsea *et al* 2010). Vecchi and Knutson (2008) produced under-count estimates suggesting that TC numbers in the late 19th century may be only slightly lower than recent decades. How reliable is this estimation since we are told that 'as one goes back further in time, the numbers of ships and shipping lanes decreases and fewer people live' (on the coast) (Landsea 2007)? The answer is actually straight-forward but one that has not been demonstrated until now. Despite lower coastal populations in the 19th century, there were actually more registered ships at sea than in the first half of the 20th century. We demonstrate the effect by comparing newly-compiled North Atlantic TC tracks in the Eastern Atlantic from 1851–1898 with two other equal-length periods (1899–1946 and 1965–2012).

Data from ship registry numbers and ship types

Global shipping registries date back to 1870 with the *Répertoire Générale* compiled by Bureau Veritas of Paris. This was followed in 1886 by *Lloyd's Register of Shipping*. Differences in counts between the two global series are due to different tonnage requirements for inclusion in each registry for steamers and sailing vessels. For further details see http://homepages.ihug.co.nz/~j_lowe/C16ComparisonBVLL.htm. Annual figures are not complete for either category with the main gaps being in both World War I and II, and for sailing vessels after 1920. Our estimate of the long-term variation in

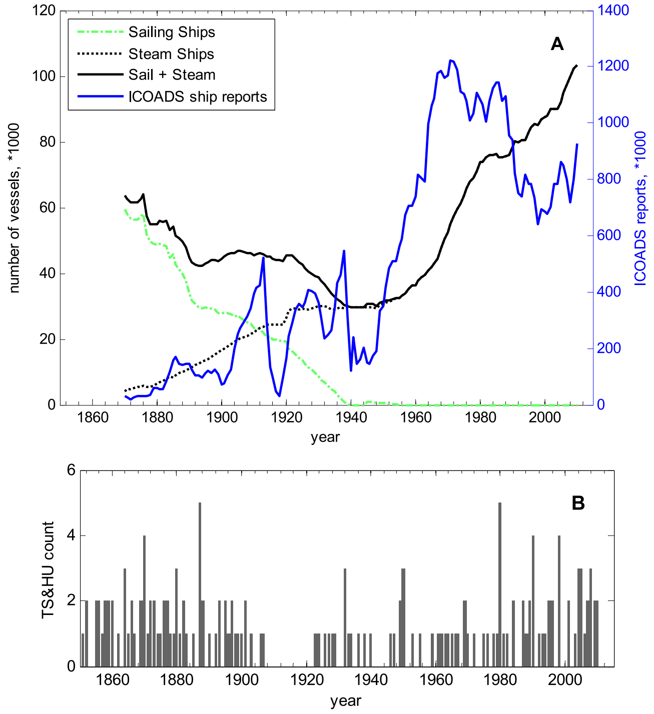

Figure 1. Panel A: time series of the number of world shipping fleets along with the number of North Atlantic weather observations recorded in the International Comprehensive Ocean-Atmosphere Database (ICOADS) from 1870–2010, limited to ship reports only for region 1 above 10N as defined in figures 3–2 in Slutz *et al* (1985). Sailing ships (green dashed line), steamships (black dashed line) and the total of both (solid black line) while the ICOADS observations are given in blue. Panel B: time series of detected tropical cyclones in the eastern North Atlantic that remained east of 50 W longitude their entire lifetime (tropical storm or hurricane intensity only) from 1851–2012. The sharp fall in sailing ships coincides with the minimum in tropical cyclone detection east of 50 W in the first half of the twentieth century. Better sampling by ICOADS of global shipping and improved recruitment of volunteer ship observers after 1950 accounts for much of the post-World War II, pre-satellite era improvement in storm detection.

the numbers from 1870–2010 (figure 1(a)) includes data from *Lloyd's Register of Shipping* available at http://people.hofstra.edu/geotrans/eng/ch3en/conc3en/worldregisteredfleet.html. Although these are global totals, the numbers should be representative of the North Atlantic, especially in the pre-World War II era because of the dominance of Europe and North America in ship production and registration (Konvitz 1994) and commercial trade links between Europe and the US with Argentina and the West Indies (Marnot 2012).

Sailing ships were in decline from the beginning of the record shown (having likely peaked about 1860) and falling almost 50% by 1892 but then stabilizing to a much slower decline to 1920. American ship production never recovered from the US Civil War and it was only by the 1890s that production again rose (Kinghorn 2012). Additionally, the American whaling fleet active in the eastern Atlantic during the hurricane season shrank in numbers during the same time and all whaling out of New England ceased after 1922 (Lund *et al* 2010). As both merchant and whaling sailing vessels fell in number, the opportunities to encounter TCs in the eastern Atlantic fell dramatically from 1870 to 1940 and did not completely recover until after 1950. The post-1920 estimated totals for sailing ships are gradually taken down to effectively zero by 1940. We allow for a slight recovery immediately after 1945 falling again to zero by 1955, by which time cheap motor fuel had removed any remaining incentives to maintain sailing ships for long-haul transport (www.deldot.gov/archaeology/3_bridges/pdf/hist_bg.pdf; see pp 53–54). By the 1950s participation in the Voluntary Observing Ships program (Kistler *et al* 2001) became high enough to offset the still low total number of ships.

Steamships increased in number from about 4000 in 1870 to over 24 000 by 1914. Steamship numbers rose only gradually, in part due to high production costs relative to sail, but also because fewer ships were needed due to increased ship size and capacity driven by innovations in merchant shipping (Stopford 2009). Together, the overall number of ships on the world's oceans actually fell from 1870 to about the mid-1890s and had a second decline after 1920 reaching a low point about 1945. Since that time there has been an increase in global registered ship numbers.

The number of ship weather reports in marine databases such as ICOADS (Worley *et al* 2005, Woodruff *et al* 2011) (figure 1(a)) indicate a gradual rise in numbers from the 1850s to present. Notable declines occur in both World Wars and in recent years following a peak in the late 1980s. The ICOADS figures are, however, unrepresentative both in number and spatial distribution to the actual number of ships at sea before the 1950s. We would expect that the actual number of detected TCs would be lower in the early 20th century than in the late 19th century (figure 1(a)). This would be especially the case in the Eastern Atlantic due to the declining number of sailing ships and reduced use of the trade wind routes.

Results

The number of TCs which remained east of 50 W throughout their entire lifetimes at tropical storm and hurricane intensity are depicted (figure 1(b)). TC tracks between three equal length 48-year periods for TCs remaining east of 50 W are shown (figure 2). The years 1851–1898 (figure 2(a)) are from a new compilation using ship logbooks, newspaper accounts and other sources not previously used before (Chenoweth 2014). The years 1899–1946 (figure 2(b)) covers the era of declining and lowest ship numbers while 1965–2012 (figure 2(c)) covers the satellite era (complete daytime satellite coverage from 1966).

The latter two panels are populated from the HURDAT2 database (Landsea *et al* 2004, Landsea and Franklin 2013) as of August 2014, which includes re-analysis updates through 1950. The frequency of TCs (figure 1(b)) is just as high in the 19th century as in the satellite era and the lower numbers in 1899–1946 indicates the real effect that the decline in ship numbers had on the ability to detect TCs even after recent re-analysis (Landsea *et al* 2008, 2012). Pre-satellite era Eastern Atlantic TCs were either ignored or never searched for since they generally do not affect land areas. Meteorologists

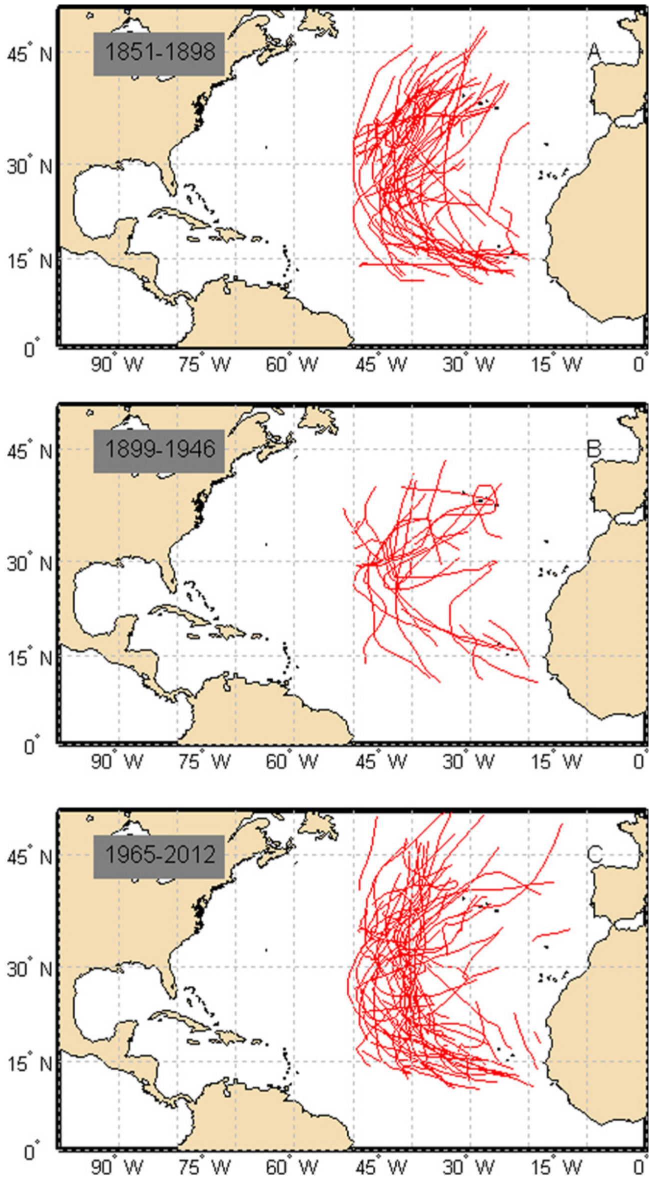

Figure 2. Tracks of tropical cyclones that remained east of 50 W through their entire life cycle as a tropical cyclone (tropical depression, sub-tropical and extratropical status are not shown) for (a) 1851–1898, based on new re-analysis work by the first author; (b) 1899–1946 and (c) 1965–2012, satellite era. There were 66 such storms detected from 1851–1898 and 63 from 1965–2012 but only 22 from 1899–1946. Fewer ships and poor ICOADS sampling account for the low detection rate in 1899–1946.

working at the National Hurricane Center and its predecessor agencies in the 1940s and 1950s used synoptic maps that extended only as far east as 55 W (Hagen *et al* 2012). Newspapers read by Fernandez-Partagas (Partagas and Diaz 1996) revealed no new tropical cyclones that remained east of 50 W their entire lifetimes. Other newspapers, hydrographical and meteorological archives, and logbooks contain this information and it is abundant in the 19th century. However, the first half of the 20th century is clearly less reliably sampled and not just due to the outbreak of two world wars.

Discussion

Vecchi and Knutson (2008, 2011) have demonstrated that undercounts of TCs in the North Atlantic prior to the satellite era probably accounts for much of the apparent increase in numbers from 1878 to present. By 1900, only a handful of whaling vessels fished in the North Atlantic greatly reducing an important source for TC detection in the eastern Atlantic. Not only were ship numbers of all types at their lowest in the early decades of the 20th century, this was also a period of reduced TC activity (Goldenberg *et al* 2001). The low numbers of storms from 1902–1930 is a combination of a real climate fluctuation (e.g., fewer and weaker storms detected in well-sampled regions such as the Lesser Antilles (Chenoweth and Divine 2008) and reduced detection capability. Any time series using a start point around 1900 will inadvertently maximize the upward trend in storm numbers due to both effects. Even following re-analysis efforts (Landsea *et al* 2008, 2012), there is likely a severe under-count of storms in the eastern Atlantic. The sudden surge in TCs after 1930 in the western North Atlantic is partly due to technological and observational improvements by American commercial and government entities (Chenoweth and Divine 2008). We also observe that from 1944–1953, new re-analysis (Hagen *et al* 2012) adds ten more storms that remained east of 50 W that are not all in HURDAT2, the successor to HURDAT (Landsea and Franklin 2013) and such a high occurrence rate before 1944–1953 is not matched until the 1880s and earlier. This indicates that increasing ship numbers in ICOADS following WWII and before continuous satellite monitoring also played a role in improving detection of TCs east of 50 W.

Conclusions

The number of TCs passing through the Lesser Antilles region has been essentially constant for over 300 years (Chenoweth and Divine 2008) and US land-falling TCs are constant since the late 19th century (Landsea 2007). Together, these two areas account for about 50% of all the detected TCs in the North Atlantic. The likelihood of the eastern Atlantic having a different occurrence rate is not supported by the new compilation of 1851–1898 and the likely impact of the actual number of ships available to make weather observations on storm detection. Until additional observations for the early 20th century are located and incorporated into data sets, adjustments will be needed to perform long-term trend analysis in the North Atlantic. This highlights issues with other global TC basins that are less complete in observational coverage and limits the ability to produce long-term global TC counts that are not similarly affected. We concur with Vecchi and Knutson (2011) in their conclusion that data problems with both raw and adjusted Atlantic TC data from HURDAT2 prevent the ability to use such data to confidently compare it with computer model projections of anthropogenic effects.

Our results indicate that TC under-count methodologies should consider using ship registry numbers along with ICOADS weather reports to better estimate missing storms in the pre-satellite era. The improved 1851–1898 TC record in the North Atlantic is entirely driven by use of abundant new source records. Some of these records extend into the 20th century. Our results indicate that basin-wide TC frequency is likely to be little changed over the entire record from 1851–1965. In the satellite era, there are new data-related issues associated with post-1999 instrumentation and methodologies that affect interpretation of long-term trends in TC frequency (Landsea 2007, Knutson *et al* 2010).

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