CORRESPONDENCE:

Stormiest winter on record for Ireland and UK

To the Editor — Meteorological agencies of Ireland and the UK have confirmed that winter (December to February) 2013–2014 (W2013–14) set records for precipitation totals and the occurrence of extreme wind speeds[1–3]. Less clear is whether storminess (characterized as the frequency and intensity of cyclones) during W2013–14 was equally unprecedented. We assessed multidecadal variations in storminess by considering frequency and intensity together and found that in the context of these large-scale cyclone characteristics, W2013–14 was indeed exceptional. Given the potential societal impacts, there is clearly a need to better understand the processes driving extreme cyclonic activity in the North Atlantic.

We applied an automated detection routine[4] (see Supplementary Information) to the National Centers for Environmental Prediction and National Center for Atmospheric Research Reanalysis 1 (NCEP1)[5] and the 20th Century Reanalysis (20CR)[6] datasets to determine cyclone frequency and intensity over four domains (Fig. 1a). Storminess (I) was calculated[7] as $I_y = C_y L_y$, where C is the number of cyclones observed during each winter in year y and L is their mean local Laplacian (intensity). Based on the NCEP1 dataset, we found that W2013–14 was the stormiest in the 66-year record (1948–1949 to 2013–2014) across the North Atlantic, due to unprecedented cyclone intensity and frequency for the mid- and high-latitude North Atlantic, respectively (Fig. 1b). Cyclone intensity has increased over the North Atlantic, consistent with trends in NCEP1 near-surface wind speeds (see Supplementary Information) and with previous investigations into cold-season cyclone activity over the North Atlantic[8,9]. W2013–14 is also ranked as the stormiest on record for the Ireland–UK domain, where the combination of high cyclone frequency and above average cyclone intensity resulted in exceptional storminess.

The 20CR dataset was used to gain a longer-term perspective of storminess. The accuracy of the 20CR dataset depends on the number of observations assimilated and is reduced in data-sparse regions and periods[9]. Therefore, we only identified

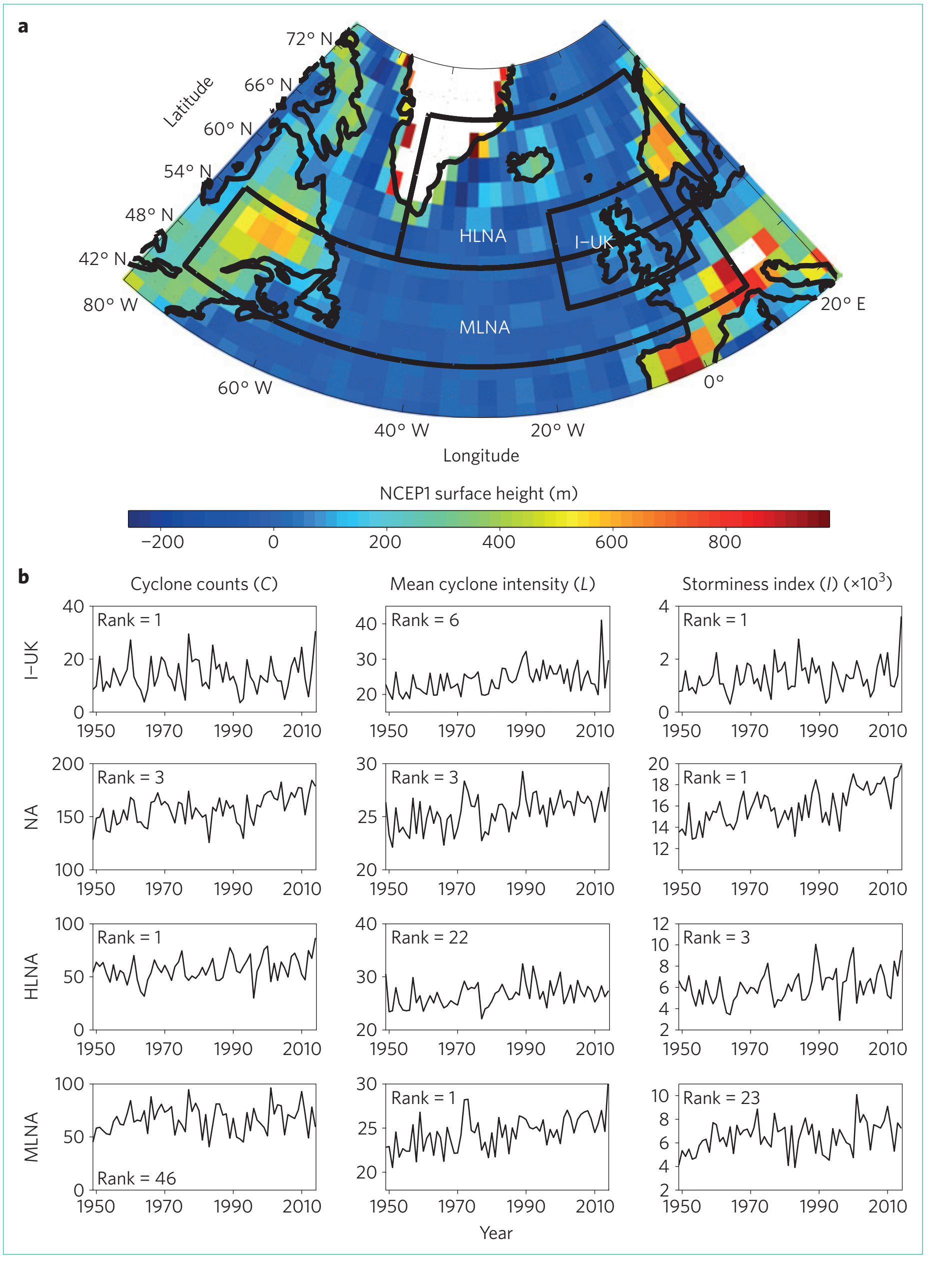

Figure 1 | Domains analysed and NCEP1 cyclone metrics. **a**, The North Atlantic (NA) region analysed with the domains differentiated as: Ireland and UK (I-UK), high-latitude North Atlantic (HLNA) and mid-latitude North Atlantic (MLNA). **b**, Winter (December–February) cyclone metrics for each domain (from top I-UK, NA, HLNA, MLNA) derived from the NCEP1 dataset with the associated rank for winter 2013–2014. Units for cyclone counts are 'cyclone days', defined as the number of cyclones detected in six-hourly sea-level pressure fields, divided by four. The units for cyclone intensity and storminess are Laplacians of sea-level pressure (∇^2_p: hPa 10^{-5} km^{-2}). See main text for definition of the dataset.

20CR cyclones for the Ireland–UK domain, where the observational network is dense and early 20CR storminess has been corroborated[10]. Ensemble mean cyclone metrics were derived from the 56 20CR constituent ensemble members (20CR-CMs) for the years 1871–1872 to 2011–2012 and bridged to the NCEP1 dataset via linear regression for the overlapping years (see Supplementary Information). The regression-adjusted ensemble-mean cyclone metrics are hereafter referred to as RA-20CR-EM (same for RA-20CR-CMs). Reconstructed metrics for the full 143-year period were derived by appending NCEP1 W2012–13 and W2013–14. The resulting storminess series suggest that for the Ireland–UK domain, W2013/14 was unprecedented in the full 143-year record (Fig. 2a). Following assessment of the spread in storminess across all RA-20CR-CMs and sampling uncertainty in individual regression adjustments, we found that it is very unlikely ($P = 0.0137$) that storminess in any year exceeded that in W2013–14 (see Supplementary Information).

We compared the reanalysis metrics with other climate series. First, we examined correspondence with December–February counts of cyclonic Lamb weather types (LWTs), also derived from NCEP1 and 20CR[11]. This revealed statistically significant (two-tailed t-test: $P < 0.05$) correlations between our December–February cyclone counts and concurrent winter totals of hybrid and pure cyclonic LWTs (NCEP1, 1948–2014: $r_{hybrid} = 0.88$, $r_{pure} = 0.86$; RA-20CR-EM, 1872–2012: $r_{hybrid} = 0.90$, $r_{pure} = 0.87$; where r is the coefficient of correlation). Our cyclone counts are less than the number of hybrid LWTs by 12% (NCEP1) and 11% (RA-20CR-EM), whereas our counts of pure cyclonic days are 23% and 24% higher in NCEP1 and RA-20CR-EM, respectively. Underestimation is probably due to our algorithm requiring a closed isobaric pattern for detection; a more stringent criterion than used to define hybrid cyclonic LWTs. Overestimation of pure cyclonic LWTs could be due to more frequent sampling (six hourly in NCEP1 rather than daily for the LWT analysis), which would capture more systems with sub-daily residency over the Ireland–UK domain. Second, we assessed the correspondence between RA-20CR-EM cyclone metrics and observed precipitation. Correlation with precipitation from the Climatic Research Unit Time-Series Version 3.21 (CRU TS3.21) dataset[12] (Fig. 2b) revealed that our cyclone metrics capture regional-scale precipitation variability in the vicinity of the Ireland–UK domain, with the strongest correlations found between storminess and precipitation across England and Wales.

The ability of the reconstructed storminess series to detect years of extreme precipitation totals is tested by examining the top-ranked years. The three stormiest winters W2013–14, W1914–15 and W1983–84 correspond well with regional rainfall totals: W2013–14 and W1914–15 rank first and second, respectively, for England and Wales in the Met Office Hadley Centre UK Regional Precipitation Series (HadUKP), whereas W1983-84 registers as the fourth wettest in Northern Ireland (where records begin in 1910[14]). There is also a match between the occurrence of extreme wind speeds and storminess: W2013–14 ranks first by counts of very severe gales[11]; W1909–10 and W1979–80 rank second and third, respectively, and feature sixth and eleventh in our analysis. For both precipitation and wind, the storminess metric is a more useful indicator of seasonal extremes than cyclone counts alone.

As the quality of the 20CR dataset is lower during the early part of the record, we

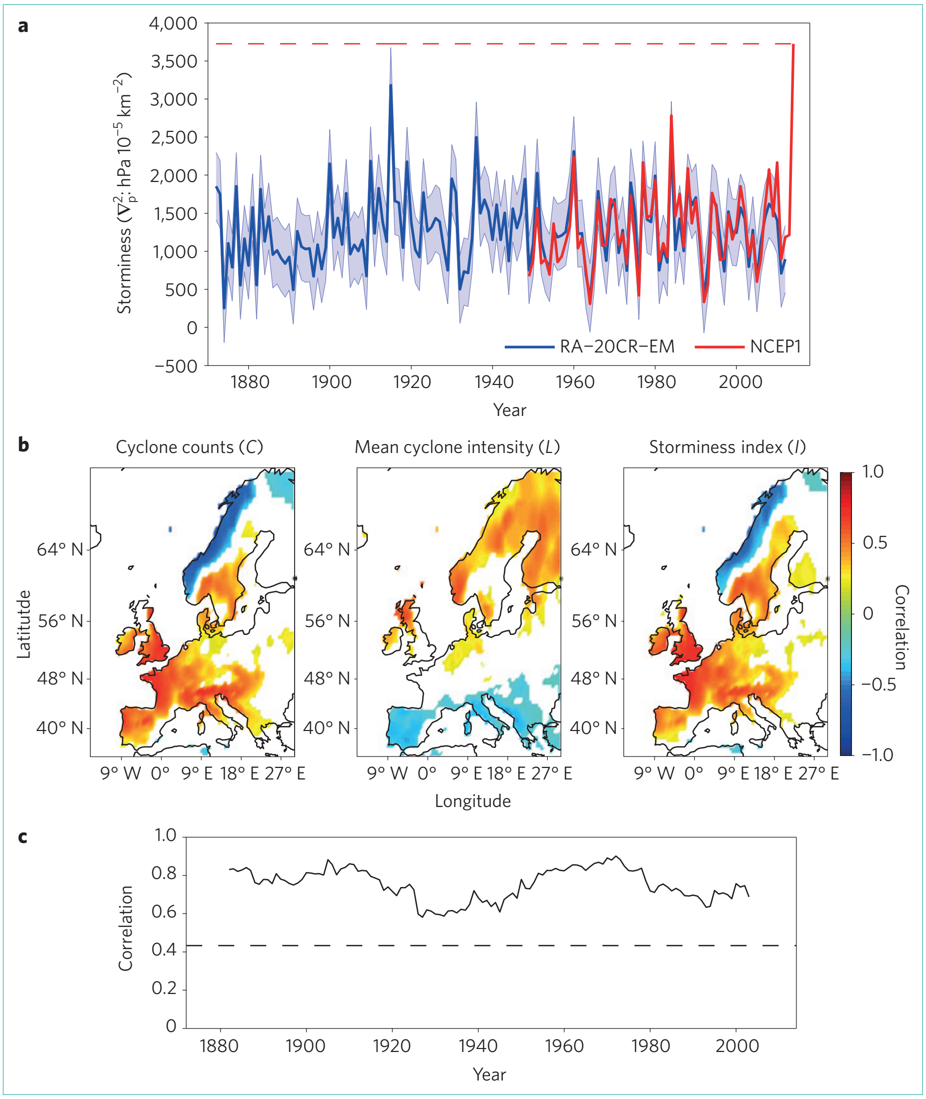

Figure 2 | Extended cyclone metrics from the 20CR dataset. **a**, Ireland and UK storminess for RA-20CR-EM (blue) and NCEP1 (red) series. The shaded region is the 95% prediction bound of the function used to bridge 20CR-EM to NCEP1 (see Supplementary Information). The dashed line highlights the exceptional winter 2013–2014 storminess. **b**, Correlation between CRU TS3.21 precipitation and cyclone metrics from RA-20CR-EM. White cells over land denote locations where correlation is non-significant (0.05 level). **c**, A 21-year moving average of the correlation between England–Wales precipitation and reconstructed RA-20CR-EM storminess. The dashed line indicates the critical coefficient of correlation (r) value (according to t-test) for rejection of the null hypothesis ($r = 0$) at the 0.05 level. See main text for definitions of the datasets.

tested the reconstructed storminess series for inhomogeneities. We found no statistically significant (0.05 level) change point using the RA-20CR-EM series and weak evidence for a change point across RA-20CR-CMs in 1909. Even if all pre-1909 reconstructed storminess indices are revised upward by an amount equal to the maximum difference in means between all ensemble members (pre- and post-1909), W2013–14 remains the stormiest on record (see Supplementary Information). Furthermore, using the long-running England and Wales Precipitation series (for the winters 1872–2014), we find no evidence that correspondence with reconstructed RA-20CR-EM storminess is weaker in the early years of the 20CR dataset (Fig. 2c), thus bolstering confidence in a part of the 20CR record where data quality has been questioned[9].

We conclude that W2013–14 experienced the most severe storminess for at least 143 years when cyclone frequency and intensity are considered together. This finding is supported by independent measures of precipitation, atmospheric circulation and gales (see Supplementary Information on gales). Given the severe impacts of storminess experienced in the Ireland–UK domain during W2013–14, as well as climate model projections showing enhanced cyclone activity for this part of the North Atlantic[15], further research is needed into the key processes driving extreme storminess over the region. ❐

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Additional information

Supplementary information is available in the online version of the paper.

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Ever-wet tropical forests as biodiversity refuges

To the Editor — Species assemblages are exceptionally rich in ever-wet tropical forests[1], here broadly defined as tropical forests that experience high annual rainfall (≥2,000 mm yr^{-1}) and are aseasonal (that is, zero months with ≤60 mm precipitation). Protecting as many of the remaining ever-wet tropical forests as we can stands to yield a double dividend through providing refugia for large numbers of tropical forest species that may be particularly vulnerable to the drier conditions presently occurring[2] and predicted to occur over coming decades[3,4], and helping to mitigate climate change impacts overall[5]. We estimate that ever-wet zones currently cover 30% of the tropical forest biome[6,7], with 50% of this area remaining as intact natural forest[8], of which only 6% is formally protected[9] (Supplementary Information). A standard set of global climate models[3,7] generally agree that tropical ever-wet zones will contract by at least 20% (Supplementary Fig. S1), potentially drying out one-fifth of extant intact ever-wet tropical forest and one-quarter of the protected ever-wet tropical forests by 2050 (Fig. 1 and Supplementary Tables S1–S3).

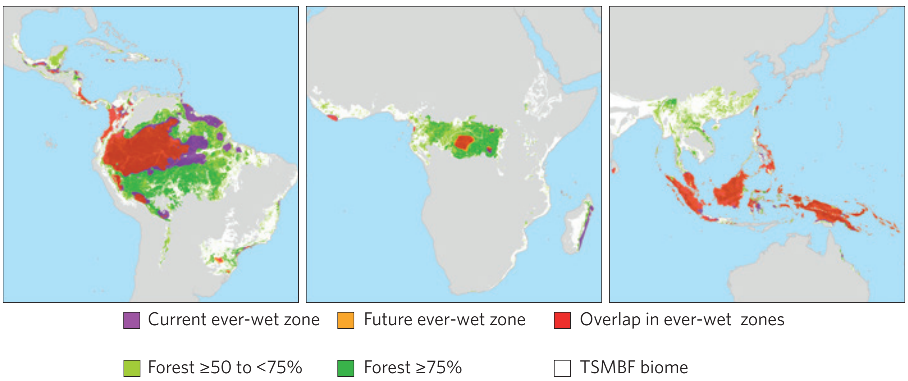

Figure 1 | Ever-wet zones within the tropical and subtropical moist broadleaf forest (TSMBF) biome[6] defined using current climate and future climates[3,7] in 2050 under representative concentration pathway 8.5 (where ≥75% of 17 global climate models agree). Ever-wet zones are underlain with remaining forest data[8] consisting of two classes of tree cover (also see Supplementary Fig. S2).

The footprint of ever-wet zones is projected to largely contract throughout the tropics rather than expand or shift to new areas, attributable in our analysis to increasing seasonal variability in rainfall rather than pronounced decreases in areas that receive high (≥2,000 mm) annual precipitation. Extensive areas of the central Amazon Basin and the Guianas, however, will no longer qualify as ever-wet zones due to both longer dry spells and less annual rainfall (Supplementary Fig. S2). The projected loss of ever-wet zones in these two regions dominate global losses, with a marked trend of contraction westward, resulting in an estimated loss of one-third of the Neotropical ever-wet zone (Supplementary Table S1).