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Winter 2013-14: Stormiest on Record

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To the Editor –

Meteorological agencies of Ireland and the UK have confirmed that winter (December to February) 2013-14 (W2013/14) set records for precipitation totals and the occurrence of extreme wind speeds[1,2,3]. Less clear is whether storminess (characterised as the frequency and intensity of cyclones) during W2013/14 was equally unprecedented. We assess multi-decadal variations in storminess by considering frequency and intensity together and find that 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 (NA).

We applied an automated detection routine[4] (see Supplementary Information) to the NCEP1[5] and 20CR[6] reanalysis 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 NCEP1 we find that W2013/14 was the stormiest in the 66-year record (1948/49 to 2013/14) across the NA, due to unprecedented cyclone intensity and frequency for the mid- and high-latitude NA, respectively (Fig. 1b). Intensity has increased over the NA consistent with trends in NCEP1 near-surface wind speeds (see Supplementary Information) and with previous investigations into cold season cyclone activity over the NA[8, 9]. W2013/14 is also ranked stormiest on record for the I-UK domain, where the combination of high cyclone frequency, together with above average intensity results in exceptional storminess.

The 20CR was employed to gain a longer-term perspective of storminess. The accuracy of 20CR depends on the number of observations assimilated and is reduced in data-sparse regions and periods[9]. Therefore, we only identified 20CR cyclones for I-UK, 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 1871/72 to 2011/12 and bridged to NCEP1 via linear regression for the overlapping years (see Supplementary Information). The regression adjusted (RA) ensemble mean (EM) 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 I-UK, 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 find that it is very unlikely (p=0.0137) that storminess in any year exceeded W2013/14 (see Supplementary Information).

We compared the reanalysis metrics with other climate series. First, we examined correspondence with DJF counts of cyclonic Lamb Weather Types (LWTs), also derived from NCEP1 and 20CR[11]. This reveals statistically significant (p<0.05) correlations between our DJF 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). 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 likely 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 NCEP rather than daily for Lamb) which would capture more systems with sub-daily residency over I-UK. Second, we assessed correspondence between RA-20CR-EM cyclone metrics and observed precipitation. Correlation with the CRU TS3.21 precipitation[12] (Fig. 2b) reveals that our cyclone metrics capture regional-scale precipitation variability in the vicinity of I-UK with strongest correlations found between storminess (I) 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 in the HadUKP England-Wales precipitation (EWP) series[13] (which dates from winter 1767), whereas W1983/84 registers as 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 is lower during the early part of the record we tested the reconstructed storminess series for in-homogeneities. 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, utilising the long-running EWP 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 20CR (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 latter). Given the severe impacts of storminess experienced in I-UK during W2013/14, as well as climate model projections showing enhanced cyclone activity for this part of the NA[15], further research is needed into the key processes driving extreme storminess over the region.

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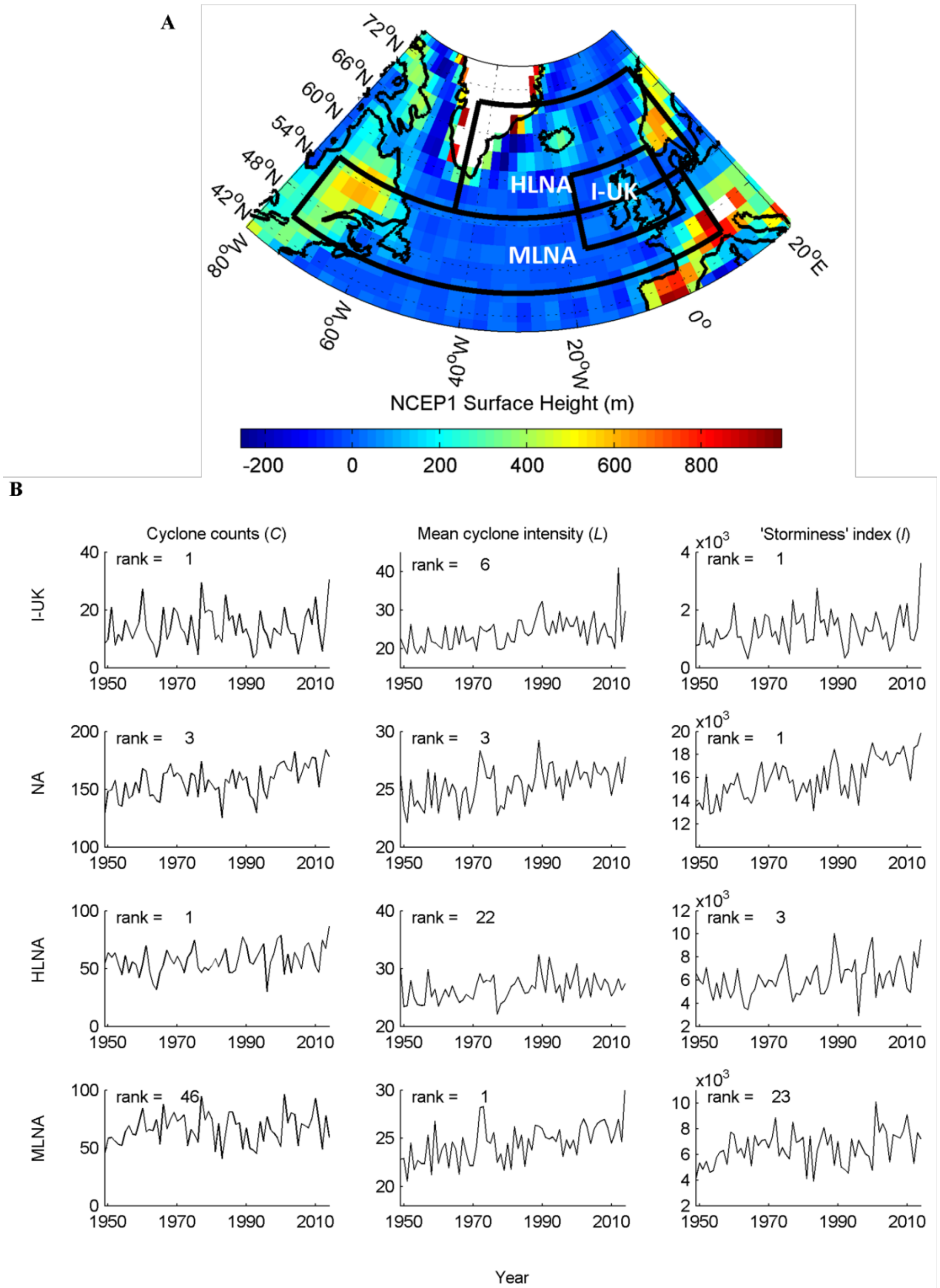

Figure 1|Domains Analysed and NCEP1 Cyclone Metrics. A, The North Atlantic (NA) region analysed with the domains differentiated as: I-UK (Ireland and UK), HLNA (High-Latitude North Atlantic) and the MLNA (Mid-Latitude North Atlantic). **B,** Winter (December - February) cyclone metrics for each domain (from top I-UK, NA, HLNA, MLNA) derived from NCEP1 with associated rank for W2013/14. Units for cyclone counts are 'cyclone days', defined as the number of cyclones detected in 6-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}).

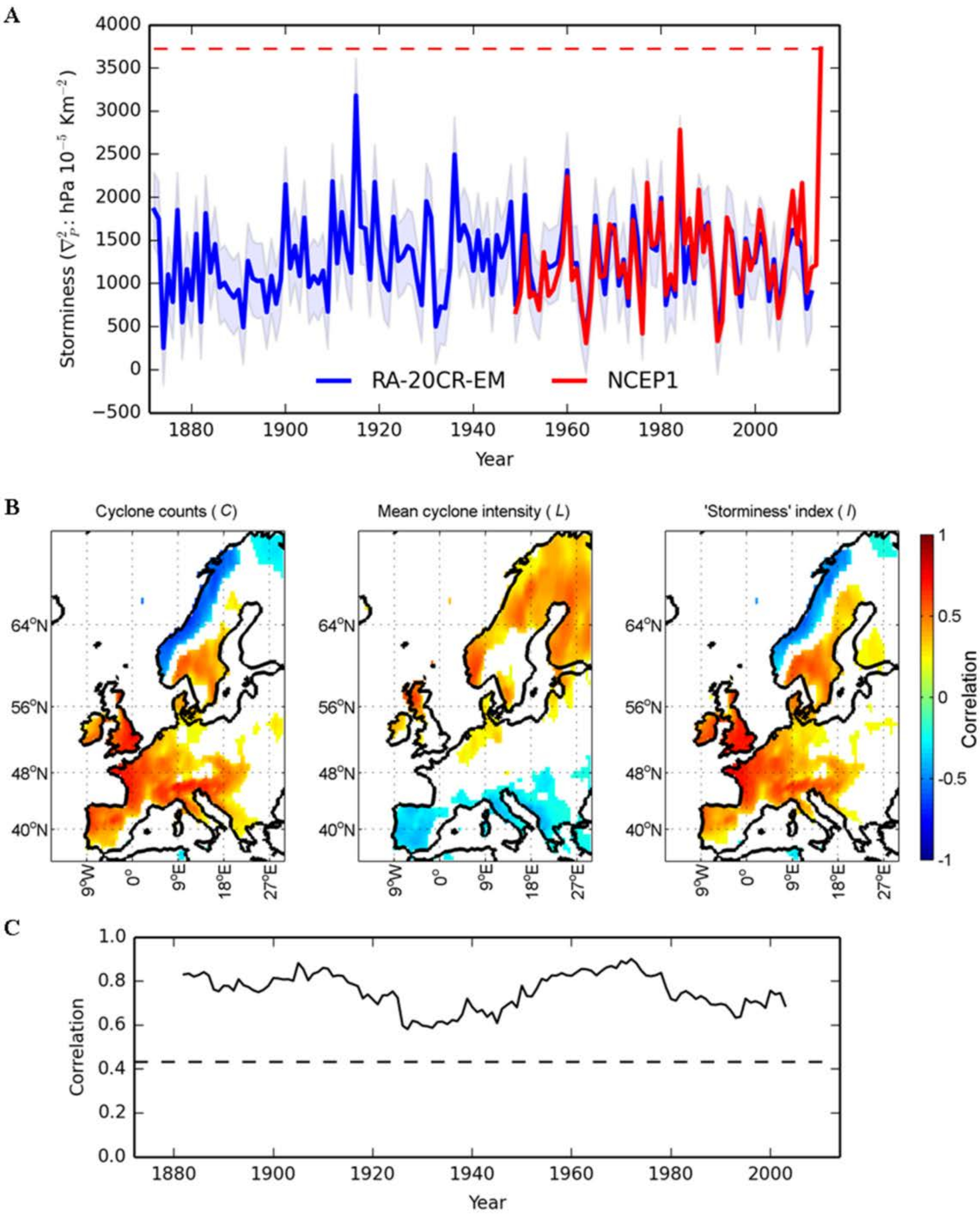

Figure 2|Extended Cyclone Metrics from 20CR. **A,** I-UK storminess for RA-20CR-EM (blue) and NCEP1 (red) series. The shaded region is the 95% prediction bound of the transfer function used to bridge 20CR-EM to NCEP1 (see Supplementary Information). The red horizontal line shows the unprecedented nature of W2013/14 storminess. **B,** Correlation between CRUTS3.21 precipitation and cyclone metrics derived from RA-20CR-EM. White grid cells over land denote grid cells where the correlation is not significantly different from zero at the 0.05 level. **C,** 21-year moving average of the correlation between EWP and reconstructed RA-20CR-EM storminess (*I*). The dotted grey line indicates the critical *r* value (according to a *t*-test) for rejection of the null hypothesis (*r* = 0) at the 0.05 level.