

Supplementary Methods

Here I described adjustments to the raw tropical cyclone intensity data made necessary by changing measurement and estimation techniques.

Tropical cyclone detection rates have been close to 100% globally since around 1970, when global satellite coverage became nearly complete ¹. In densely travelled oceans, such as the North Atlantic, detection rates were probably reasonably high well back into the 19th century. But reliable estimation of storm intensity depends almost entirely on in situ aircraft measurements and, for the last 30 years or so, on satellite-based techniques. Airborne reconnaissance missions were undertaken in the western North Pacific and North Atlantic regions beginning around 1945. These missions continue in the North Atlantic region, but were discontinued in the western North Pacific in 1987. Techniques for estimating tropical cyclone intensity from satellite imagery and other satellite-based measurements were developed during the 1970s ². In both the western North Pacific and North Atlantic regions, these techniques were refined and calibrated against aircraft measurements and today constitute the primary means of estimating peak surface winds in all locations except the North Atlantic, where they are supplemented by reconnaissance aircraft measurements.

For the first decade or so of airborne reconnaissance, surface winds were estimated mostly by visual inspection of the sea surface. Beginning in the early 1950s, radar altimeters aboard the aircraft made possible an accurate determination of the aircraft's absolute altitude. When combined with direct pressure measurements, this gives a good estimate of geopotential height at flight level. Surface pressure can then be estimated using empirical relationships between surface and flight level pressure. This technique, developed during the 1950s, was used without significant modification through the end of aircraft reconnaissance in the western North Pacific and until the advent of accurate

dropwindsondes in the North Atlantic. Minimum surface pressure estimates were converted to maximum sustained surface wind using semi-empirical wind-pressure relations which, however, have evolved with time. For the North Atlantic, Landsea³ has documented a change in that took place in 1970, leading to lower wind speed estimates. Emanuel⁴ fit a polynomial curve to Landsea's corrections and used it to convert pre-1970 to post-1970 wind speeds:

$$V_{max}' = V_{max} [1 - 2 \times 10^{-5} V_{max}^2], \quad (1)$$

where V_{max}' is the adjusted velocity and V_{max} is the original velocity, both in meters per second. We applied this correction to pre-1970 wind speeds in the North Atlantic. For the western North Pacific, the wind-pressure relationship used until 1973 was

$$V_{max} = 16\sqrt{1010 - p_c}, \quad (2)$$

where in this case V_{max} is given in knots and p_c is the central surface pressure in hPa. In 1973, JTWC adopted a revised wind-pressure relationship given by

$$V_{max} = 6.7(1010 - p_c)^{.644}, \quad (3)$$

where V_{max} is again given in knots. Eliminating p_c between (2) and (3) gives a formula for correcting the pre-1973 JTWC wind speeds:

$$V_{max}' = 0.228 V_{max}^{1.288}, \quad (4)$$

where in this case V_{max} and V_{max}' are given in meters per second. This yields a substantial reduction in pre-1973 wind speeds, amounting to an average of around 10 ms^{-1} over the observed range of hurricane-force winds.

Although the JTWC best track data does not record estimates of central pressure, the latter was tabulated as part of the Annual Tropical Cyclone Reports available from JTWC. To test whether the wind-pressure relations given by (3) and (4) are indeed valid in the best track data, we tabulated the maximum sustained surface wind and minimum

surface pressure for each storm between 1959 and 2003, covering the whole period of time that the Annual Tropical Cyclone Reports are available. This shows that (4) is very closely followed in the interval 1973-1987, and maintains exactly thereafter, when the Dvorak method was used to estimate surface winds, while minimum pressure was calculated directly from (3).

In principle, applying correction (4) to the pre-1973 JTWC best track winds should result in their satisfying (3) closely, but this does not turn out to be the case. Supplementary Figure 1 shows that while, as expected, the unadjusted winds are much too strong relative to the recorded pressures, the correction introduced by (4) goes too far, and the adjusted winds are somewhat too weak. A better fit is obtained by compromising between the raw winds and the adjusted winds given by (4):

$$V_{max}'' \equiv wV_{max}' + (1-w)V_{max}, \quad (5)$$

where V_{max}' is given by (4) and w is a weight. For the period 1959-1966, a good fit is obtained by choosing $w = 0.3$ (see Supplementary Figure 1), while for 1967-1972, a better fit is obtained by taking $w = 0.8$. (The winds during and after 1973 are unadjusted, equivalent to taking $w = 1$.) Having no pressure data before 1959, we use the same adjustment as for the period 1959-1966.

While wind speeds records are reasonably complete for all recorded tropical cyclones in the North Atlantic and North Pacific basins during and after 1949, they are elsewhere spotty before the advent of satellite-based storm estimation techniques.

The power dissipation index (*PDI*) given by (2) in the main text and accumulated annually over ocean basins will depend on the history of maximum sustained winds, the lifetime of the storm, and the frequency of events. The frequency itself depends to some extent on the working definition of what constitutes a tropical cyclone, and this differs

among the reporting agencies and, within a given agency, in time. Ambiguity arises in connection with so-called subtropical storms, which have some of the characteristics of baroclinic systems. But almost all of such systems are comparatively weak and so will not have much influence on the *PDI* statistics. By the same token, different conventions have been applied to the definition of storm birth and death, and this affects the total storm lifetime. But since, by definition, storms are weak at the beginning and end of their lives, this will have only a small effect on *PDI*. (Occasionally, a storm undergoing extratropical transition may be moderately intense at the time of transition.) Indeed, one would expect measurements of tropical cyclone maximum winds to focus on relatively intense storms near the peak of their intensity, which will constitute to dominant contributions to the *PDI*.

In summary, one may expect estimates of the power dissipation index given by (2) in the main text to be robust in all regions after about 1980 and in the North Atlantic and western North Pacific regions from the late 1950's onward. Estimates in these latter two regions should be moderately accurate from the late 1940s to the late 1950s.

References

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