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Understanding hurricane development

The hurricane season of 2005 in the Atlantic sector was the most intense on record, with 28 recorded tropical storms and 15 of them reaching hurricane intensity. It remains controversial, however, as to whether tropical storm activity over the Atlantic has changed in a statistically significant manner One of the most commonly used indices to measure tropical storm activity is the so called Accumulated Cyclone Energy (ACE) Index which is shown for the Atlantic sector in Fig. 1a. The ACE Index takes into account the number, strength and duration of all tropical storms in a season. The ACE Index shows pronounced multidecadal variability, with enhanced tropical storm activity during the 1890s, 1950s and at present, and mostly reduced activity in between, but no sustained long-term trend. Yet, the last decade appears to be somewhat exceptional in the light of the last 155 years.

The role of tropical North Atlantic sea surface temperature (SST) in driving tropical storm activity was discussed extensively in the literature. Rather strong multidecadal variability in the SST of the Atlantic basin is observed, which is referred to as the Atlantic Multidecadal Oscillation (AMO). The AMO, which has opposite polarities in the North and South Atlantic, is most likely related to variations of the Atlantic meridional overturning circulation (MOC). It modulates the SST of the tropical North Atlantic which therefore also exhibits pronounced multidecadal variability (Fig. 1b). Interestingly, a clear warming trend is seen in the tropical North Atlantic SST which does not seem to influence the tropical storm activity. A clear warming trend is also observed in the surface temperature of the other two tropical oceans, the tropical Indian and Pacific Oceans, which is described in terms of a combined SST index (Indo-Pacific) that averages SSTs over the region 40°E-80°W, 30°N-30°S and also shown in Fig. 1b.

In order to get further insight into the relative roles of the individual ocean basins on the vertical wind shear over the tropical North Atlantic, we analysed the results of an atmospheric general circulation model (AGCM) forced by the history of observed global monthly (Hadley Centre) SSTs for the period 1870-2003. The simulated vertical wind shear over the Tropical Atlantic (not shown) is in rather good agreement among the five realisations, indicating a strong role of the boundary forcing. The ensemble mean, a measure of the SST-forced signal, compares well with observations. Furthermore, the variations of the vertical wind shear correspond nicely to those of the ACE Index: Reduced wind shear goes along with enhanced tropical storm activity and vice versa. This indicates the important roles of the vertical wind shear in controlling tropical storm activity in the Atlantic sector during the last 130 years and of the global SSTs in driving the wind shear.

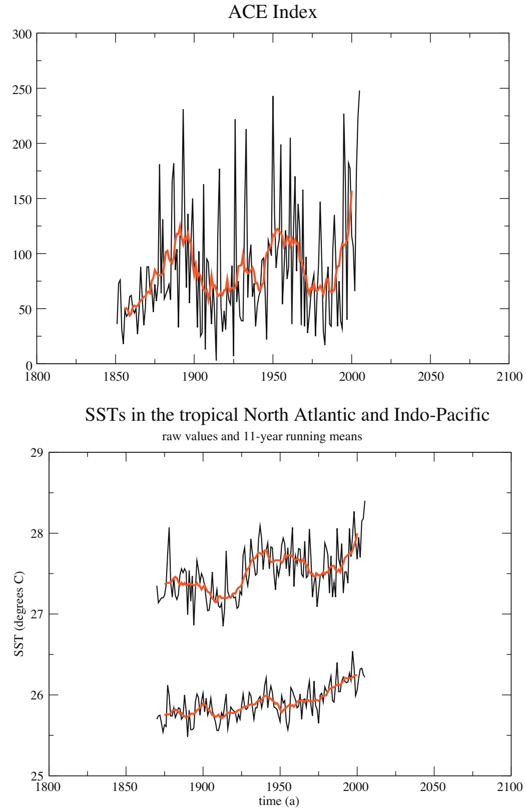

Figure 1: a) Accumulated Cyclone Energy (ACE) Index for the Atlantic basin 1851-2005. The red curve shows the low-pass filtered time series (applying an 11-year running mean).

b) Upper curve: SSTs in the tropical North Atlantic averaged over the region 10-14°N and 20-70°W. Lower curve: SSTs in the Indo-Pacific region (40°E-80°W, 30°N-30°S). The SSTs are computed for the hurricane season (JJASON). The black lines denote the raw values, while the red lines depict the low-pass filtered (applying an 11-year running mean) time series which highlight the multidecadal variations. Units: °C.

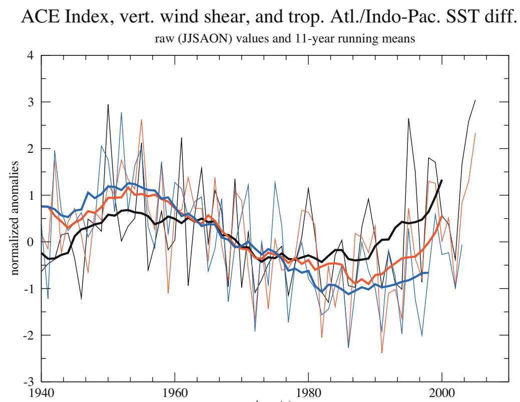

Figure 2: ACE Index (black), inverted simulated vertical wind shear (blue), and tropical North Atlantic/Indo-Pacific SST difference (red). The data were normalized with respect to their individual long-term standard deviations to ease comparison. The thin lines are the raw JASON values. The thick lines denote the low-pass filtered (applying an 11-year running mean) values.

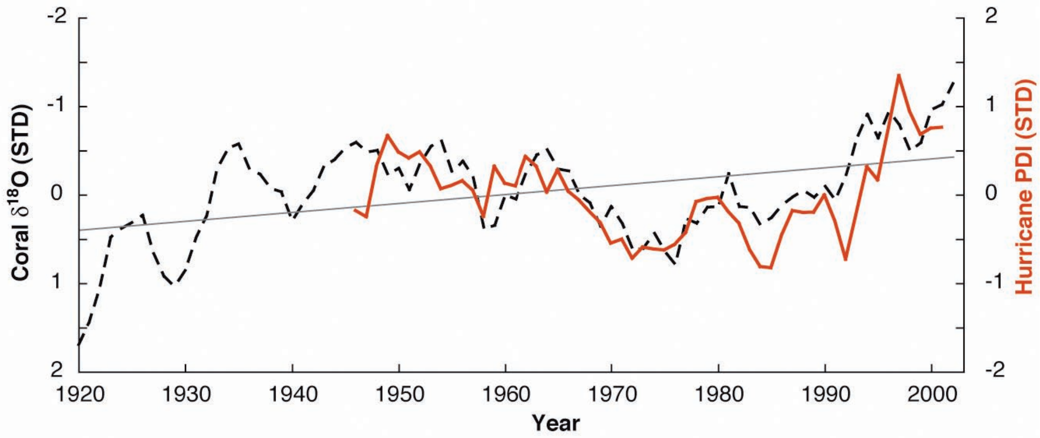

Figure 3: Reconstruction of hurricane activity as measured by the Power Dissipation Index (PDI) using a Caribbean coral (black) and the observed PDI (red). Both time series were normalized to ease comparison.

The question arises, however, why the obvious upward trend in tropical North Atlantic SST (Fig. 1b) is neither reflected in the simulated vertical wind shear nor in the record of observed tropical storm activity (Fig. 1a). It was shown that the Tropical Indian Ocean exhibited a strong warming trend during the last decades which forced global atmospheric anomalies. In particular, it drove enhanced vertical wind shear over the tropical North Atlantic, so that the warming of the Indian Ocean acted to compensate, at least partly, the tendency of the tropical North Atlantic warming to reduce the wind shear. Furthermore, it is known that anomalously high Tropical Pacific SST (El Niño conditions) also drives enhanced vertical wind shear over the tropical Atlantic. The inverted SST difference, tropical North Atlantic minus Indo-Pacific, is plotted in Figure 2 together with the inverted ensemble mean wind shear from the model simulation and the ACE Index. The time series are shown only from 1940 onwards, which is the period of most reliable observations. All three indices show a remarkable correspondence at decadal and longer time-scales. Apparently, the warming trends of the three tropical oceans cancel with respect to their effects on the vertical wind shear over the tropical North Atlantic, so that the tropical cyclone activity remained rather stable and mostly within the range of the natural multidecadal variability. The most recent period is characterized by an increased tropical North Atlantic / Indo-Pacific SST difference indicating that the tropical North Atlantic warmed more rapidly than the Indo-Pacific. This led to reduced vertical wind shear and thus to enhanced tropical storm activity. In contrast, summer and fall of 2006 were characterized by El Niño conditions in the Indo-Pacific, leading to a rather small temperature difference between the tropical North Atlantic and the tropical Indian and Pacific Oceans, and this explains the weak tropical storm activity.

Overall, however, there seems to be an increase in hurricane destructiveness over the last century, as measured by the so called PDI (Power Dissipation Index). This is seen somewhat in the observations (Fig. 3), but the observational record is rather short. Reconstruction of PDI using a Caribbean coral offers a possibility to extend the record. An example of this work is also shown in Fig. 3 in terms of the $\delta^{18}O$. The coral signal which depends on both temperature and salinity tracks nicely the observational record during the last 50 years. We could extend the PDI record back to 1920 with the coral, and the reconstruction from this coral shows a much clearer upward trend, which is consistent with the evolution of the ACE Index. The latter, however, extends further back in time than the coral-based PDI, and the time period 1875-1900 is characterized by anomalously strong hurricane activity, so that the obvious trend in the coral time series may be due to a sampling problem. We shall use therefore corals that allow reconstructions even further back in time to uniquely answer the question as to whether the statistics of hurricane activity have changed in a statistically significant way.

References

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