15C.2 ENSO AND GENESIS POTENTIAL INDEX IN REANALYSIS AND AGCMS

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1. Introduction

The impact of environmental factors on tropical cyclone (TC) genesis is analysed using a using the genesis potential index of Emanuel and Nolan (2004). We focus specifically on the environmental factors responsible for El Niño-Southern Oscillation (ENSO) impacts on TC activity (Landsea, 2000; Chu, 2004). Although the genesis potential index was developed by a statistical fitting procedure based only on the mean genesis climatology of the reanalysis, composites of the anomalous genesis potential index for El Niño and La Niña years well describe observed interannual variations of genesis frequency and location in several basins.

Four factors contribute to the genesis potential index: vorticity at 850hPa, relative humidity at 700hPa, vertical wind shear from 850 to 200hPa and potential intensity (PI). To determine the relative contributions of the environmental factors to interannual variations of genesis frequency, we examine modified indices in which only one of the factors varies interannually and the others are set to their climatological values. This procedure allows us to indentify the dominent factors in each region. For example, in El Niño years, vertical shear is important to the reduction in genesis frequency seen in the Atlantic basin, and both relative humidity and vorticity are important to the eastward shift in the mean genesis location in the western North Pacific.

We compare the genesis potential index computed using monthly data from the NCEP/NCAR reanalysis with that computed using data from three atmospheric general circulation models (AGCMs) forced by observed SST. We find that the AGCMs are able to reproduce both the genesis potential index climatology and ENSO respones, with slight differences in the strength, location and extent of the genesis potential pattern.

2. Definition of Genesis Potential Index

Based on Gray's TC genesis index, Emanuel and Nolan (2004) empirically used reanalysis data to relate spatial and temporal variability of genesis with a limited number of environmental predictors and developed the following index :

$$GP = \left|10^5\eta\right|^{3/2}\left(\frac{\mathcal{H}}{50}\right)^3\left(\frac{V_{\rm pot}}{70}\right)^3(1+0.1V_{shear})^{-2},$$

where η is the absolute vorticity at 850hPa in s^{-1}, $\mathcal{H}$ is the relative humidity at 700hPa in percent, $V_{\rm pot}$ is the potential intensity in ms^{-1}, and $V\rm{shear}$ is the magnitude of the vertical wind shear between 850hPa and 200hPa in ms^{-1}.

The technique to obtain potential intensity $V_{\rm pot}$ is a generalization of the one described in Emanuel (1995) and takes into account dissipative heating (Bister and Emanuel, 1998), in addition to sea surface temperature (SST), sea level pressure (SLP),and atmospheric temperature and mixing ratio at various pressure levels. The climatological, low-frequency variability of the potential intensity was presented in Bister and Emanuel (2002a,b).

3. Climatology of Genesis Potential Index

The maximum, over months of the year, of the climatological genesis potential index at each grid point computed from NCEP/NCAR reanalysis (Kalnay et al., 1996) monthly data for the period 1950-2004 is shown in in Fig. 1; regions prone to tropical cyclones appear as maxima.

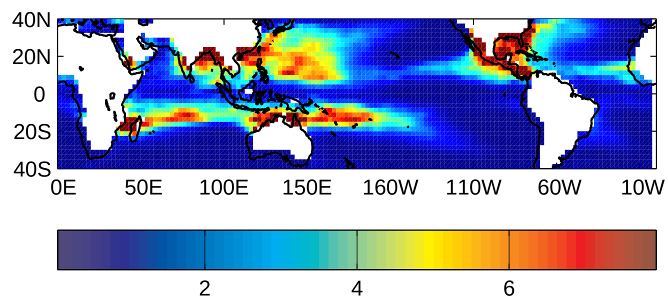

Figure 1: Genesis potential index climatology annual maximum.

The per basin annual cycle of genesis potential index and observed number of tropical cyclones is shown in Fig. 2 for South Pacific, North Indian, western North Pacific and North Atlantic basins. There is good agreement between the climatogical genesis potential index and the observed number of tropical cyclones.

4. ENSO Impact on the Genesis Potential Index

Using monthly genesis potential index anomalies for the period 1950-2004, seasonal composites for warm and

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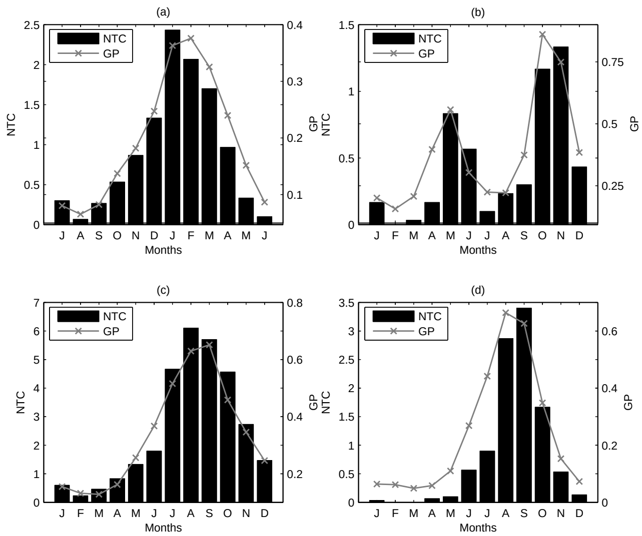

Figure 2: Genesis potential index and number of tropical cyclones climatology in the (a) South Pacifi c, (b) North Indian, (c) western North Pacifi c and (d) North Atlantic basins.

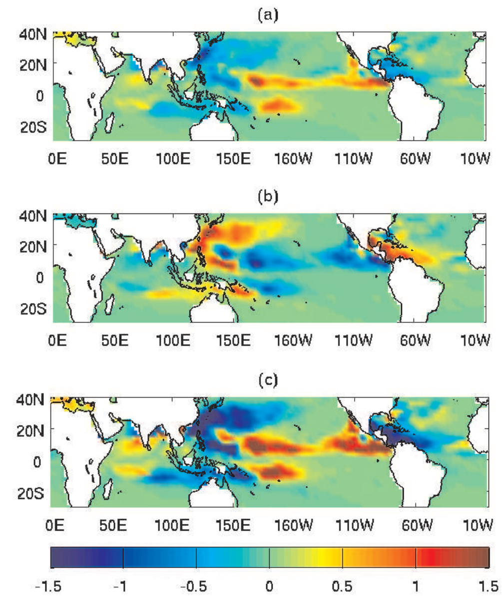

Figure 3: Genesis potential anomalies in ASO (August-October) for (a) El Niño and (b) La Niña years. Difference of the anomalies in El Niño and La Niña years for the genesis potential index (c).

cold ENSO events were computed. ENSO events were defined using the Nino3.4 index with the 13 years (25% of the cases) with the highest (lowest) seasonal Nino3.4 values defined as El Niño (La Niña) years and the remaining years defined as neutral years, as in Goddard and Dilley (2005); Camargo and Sobel (2005). Fig. 3 shows the ENSO composites for ASO (August-October), the peak season for tropical cyclone activity in the North Atlantic and Western North Pacific.

The ASO warm-event genesis potential index composites reflect the well-known decrease of cyclone activity in the North Atlantic and eastern part of the western North Pacific (horse shoe pattern), and increase in the Eastern and Central Pacific in El Niño years (Fig. 3a). An almost mirror image appears in the La Niña years (Fig. 3(b)), which is emphasized in the difference between El Niño and La Niña years (Fig. 3(c)).

The observed genesis density is calculated by counting the number of tropical cyclones with genesis (first position) in each $2.5° \times 2.5°$ latitude and longitude square. Similarly, for the track density, we use six hourly data to count the number of times a tropical cyclone is over each $2.5° \times 2.5°$ latitude and longitude square, normalized such that 24 hours in a particular location for one TC is counted as one.

The difference of the observed ASO El Niño and La Niña genesis and track density composites is shown in Fig. 4. Though noisier, the observed composites have a similar pattern as the genesis potential index composites.

It is important to notice that it is not the southern hemisphere tropical cyclone season in ASO, and that the anomalies in the southern hemisphere are relative to very small climatological values.

The JFM (January-March) ENSO anomalies in the genesis potential and genesis density are also analyzed (not shown). One important difference between the northern and southern hemisphere is that the shift due to ENSO is more zonal in the former and more meridional in the latter. There is also a longitudinal shift in the South Pacific, with a positive genesis potential anomaly in El Niño years to the east of Australia and a negative anomaly near the Australian continent.

The genesis potential ENSO composites shown for ASO and JFM are in agreement with the known effects of ENSO on TCs, such as a decrease of TC activity in the Atlantic in El Niño years accompanied increase in the eastern and central Pacific, with a southeastern shift in the western North Pacific.

5. Factors Influencing ENSO Impact on Genesis Potential Index

We want to measure the importance of the four variables in the genesis potential index (vorticity, vertical wind shear, potential intensity and humidity) in determining the ENSO composites. To do that, we calculated the genesis potential index using climatological values of three of the variables and interannually varying values of the fourth variable. The resulting anomalies and ENSO composites were then calculated in the four cases.

Fig. 5 shows the difference of the genesis potential anomalies in the northern hemisphere in JFM, when only

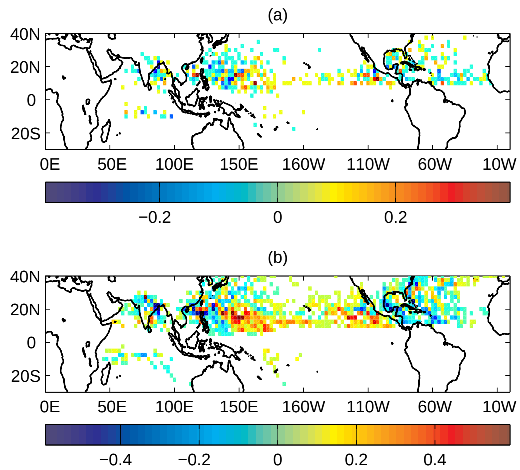

Figure 4: Difference of the anomalies in El Niño and La Niña years for the genesis density (a) and track density (b) in ASO.

interannually varying values of (a) vorticity, (b) vertical wind shear, (c) potential intensity, and (d) relative humidity are used. Comparing with these patterns to the one in Fig. 3(c), we see that the relative importance of the four factors in setting the genesis potential index response to ENSO depends on the region.

For the Atlantic and eastern North Pacific the main contributor for the ENSO genesis potential anomalies is the vertical wind shear, with additional contibution of the relative humidity for the Atlantic and the potential intensity for the eastern North Pacific. In the case of the western North Pacific, the negative anomaly near the Asian continent is mainly due to the relative humidity, with additional contibution from the potential intensity. The increase near the date line is mainly due to the vorticity, with some additional contribution from the vertical wind shear and relative humidity. In the Indian Ocean, there is a shift of the genesis potential from the northern to the southern part of the Bay of Bengal, mainly due to vertical wind shear, which is also mainly responsible for the anomalous positive genesis potential in the Arabian Sea. Though the peak of tropical cyclone activity in the eastern North Pacific and and North Indian Ocean occur in JAS and OND, respectively, and these results are not shown here, the ASO figures are in agreement.

In the southern hemisphere (not shown) the increase in the genesis potential anomalies around 10°S is mainly due to vertical wind shear and vorticity (South Pacific) or localized patches of PI (South Indian). The decrease of the genesis potential anomalies in the South Indian Ocean around 15°S and at the Mozambique channel is mainly due to vertical wind shear and relative humidity changes. In the South Pacific, from the eastern Australian coast to east of the date line, the main influencing factor on the genesis potential negative anomaly is the relative humidity, while east of the date line the vertical wind shear and the potential intensity have a large impact in changing the genesis potential. Pattern correlations (not shown) of the genesis potential anomaly with all factors varying and only one varying confirm these findings.

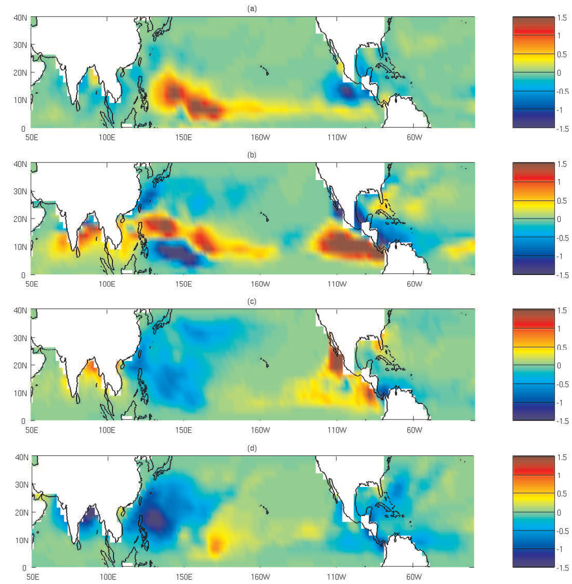

Figure 5: Difference of El Niño and La Niña genesis potential anomalies composites in the northern hemisphere in ASO for varying (a) vorticity, (b) vertical wind shear, (c) potential intensity, (d) relative humidity, respectively, with the other variables as climatology.

6. Genesis Potential in AGCMs

We calculated the genesis potential index in 3 AGCMs: ECHAM3.6 (here denoted ECHAM3), ECHAM4.5 (denoted ECHAM4), and CCM3.6 (denoted CCM). The first two models were developed at the Max-Planck Institute for Meteorology, Hamburg, Germany (Model User Support Group, 1992; Roeckner et al., 1996) and the third model was developed at NCAR - National Center for Atmospheric Research, Boulder, Colorado (Kiehl et al., 1998). The three models are forced with monthly mean observed sea surface temperatures and have the same horizontal resolution (T42, or approximately 300km). Both Echam4 and CCM have 24 ensemble members, while Echam3 has 10 ensemble members. Echam4 has data available in the period 1950-2004, Echam3 for 1949-2000 and CCM 1950-2001.

Figure 6 shows the maximum annual values of the genesis potential in the models' climatology and reanalysis. Figure 7 shows the models warm and cold anomalous genesis potential composites in warm ENSO events, similar to Fig. 3(a) for the reanalysis. While the models are able to reproduce the basic pattern characteristics of the genesis potential climatology and anomalies, details of these patterns differ among the models, with the maxima (minima) values in locations different from Renalysis, and varying size and extent of the patterns.

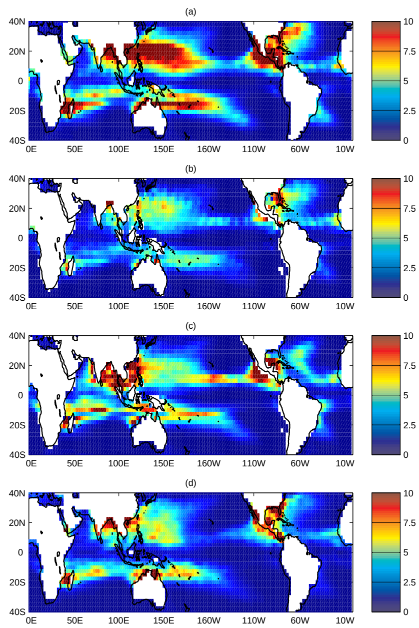

Figure 6: Genesis potential index climatology annual maximum in models (a) Echam4, (b) Echam3, (c) CCM, and reanalysis (d).

7. Conclusions

The genesis potential index patterns were analyzed in reanalysis and SST-forced AGCMs. There is good agreement between the climatogical genesis potential index from reanalysis and the observed number of tropical cyclones. The observed ENSO composites for genesis and track density have a pattern similar to those of the genesis potential index ENSO composites.

In most basins, the primary factor responsible for the changes in the genesis potential due to ENSO is the vertical wind shear. The relative humidity is also important in many basins, especially the western North Pacific near the Asian continent and the southern Hemisphere. The vorticity has contributions only in the central Pacific (North and South), when in El Niño events the tropical cyclones tend to form nearer the equatorial region. The potential intensity is the factor with least influence on the genesis potential anomalies in ENSO events.

The genesis potential index climatology in the models is similar to the reanalysis, with maxima in the locations where tropical cyclones occur in observations. However, the models have different magnitudes for the genesis potential index compared to reanalysis. In general, the shifts in tropical cyclone activity due to ENSO are reproduced in the reanalysis and the models. The models' detailed location of the anomalies are similar to observations, with some differences, especially in the central Pacific, where the models are more active than the reanalysis.

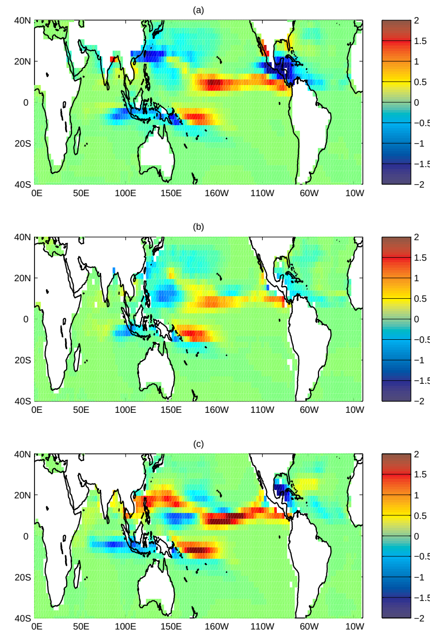

Figure 7: Genesis potential index anomalies composites for ASO El Niño in models (a) Echam4, (b) Echam3, (c) CCM.

References

Bister, M. and K. A. Emanuel, 1998: Dissipative heating and hurricane intensity. *Meteor. Atm. Phys.*, **52**, 233–240.

—, 2002a: Low frequency variability of tropical cyclone potential intensity, 1, interannual to interdecadal variability. *J. Geophys. Res.*, **107**, 4801, doi:10.1029/2001JD000776.

—, 2002b: Low frequency variability of tropical cyclone potential intensity, 2, climatology for 1982-1995. *J. Geophys. Res.*, **107**, 4621, doi:10.1029/2001JD000780.

Camargo, S. J. and A. H. Sobel, 2005: Western North Pacific tropical cyclone intensity and ENSO. *J. Climate*, **18**, 2996–3006.

Chu, P. S., 2004: *Hurricanes and typhoons, past, present and future*, Columbia University Press, New York, chapter ENSO and tropical cyclone activity. 297–332, edited by R. J. Murnane and K.-B. Liu.

Emanuel, K. A., 1995: Sensitivity of tropical cyclones to surface exchange coefficients and a revised steady-state model incorporating eye dynamics. *J. Atmos. Sci.*, **52**, 3969–3976.

Emanuel, K. A. and D. Nolan, 2004: Tropical cyclone activity and global climate. *26th Conference on Hurricanes and Tropical Meteorology*, Amer. Meteor. Soc., Miami, FL, 240–241.

Goddard, L. and M. Dilley, 2005: El Niño: Catastrophe or opportunity? *J. Climate*, **18**, 651–665.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph, 1996: The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteor. Soc.*, **77**, 437–441.

Kiehl, J. T., J. J. Hack, G. B. Bonan, B. A. Boville, D. L. Williamson, and P. J. Rasch, 1998: The national center for atmospheric research community climate model: Ccm3. *J. Climate*, **11**, 1131–1149.

Landsea, C. W., 2000: *El Niño: Impacts of multiscale variability on natural ecosystems and society*, Cambridge University Press, chapter El Niño-Southern Oscillation and the seasonal predictability of tropical cyclones. 149–181, edited by H. F. Díaz and V. Markgraf.

Model User Support Group, 1992: Echam3 - atmospheric general circulation model. Technical Report 6, Das Deutshes Klimarechnenzentrum, Hamburg, Germany, 184pp.

Roeckner, E., K. Arpe, L. Bengtsson, M. Christoph, M. Claussen, L. Dümenil, M. Esch, M. Giorgetta, U. Schlese, and U. Schulzweida, 1996: The atmospheric general circulation model ECHAM-4: Model description and simulation of present-day climate. Technical Report 218, Max-Planck Institute for Meteorology, Hamburg, Germany, 90 pp.