Analysis of Inferred Cyclogenesis Frequency in ERA-40 Reanalysis and in an Ensemble of Models

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Introduction

Predictions regarding future tropical cyclone (TC) activity would ideally be done using a Coupled Global Climate Models (CGCMs) capable of resolving TCs, where TCs statistics in two different simulations, one using present-day level of greenhouse gases and one using projected level of greenhouse gases, would be compared. However, due to their coarse resolution, CGCMs are unable to resolve TCs. Hence, the results of studies based on what has been coined Tropical Cyclone-Like Vortices (TCLVs)) remain inconclusive since they are not based on realistic TCs. To circumvent this problem, a different approach can be used where the frequency of TCs is inferred from the temporal evolution of the main large-scale climatic fields we believe to control their frequency of occurence and distribution.

Methodology

To infer seasonal TCs frequency, Gray (1975) proposed the use of an index, the Seasonal Genesis Parameter (SGP), which was found to be a good predictor of the number of TCs formed in a three months period per 5° × 5° latitude-longitude square per 20 years. The SGP is the product of a dynamical potential and a thermal potential, each of which is based on the product of three factors, such that:

$$\text{SGP} = \underbrace{(|f| \times I_\zeta \times I_{WS})}_{\text{Dynamic potential}} \times \underbrace{(E \times I_\theta \times I_{RH})}_{\text{Thermal potential}}$$

where

- f is the Coriolis parameter at a given latitude.
- $I_\zeta = \zeta \frac{f}{|f|} + 5$ with ζ being the low level relative vorticity at 925 hPa.
- $I_{WS} = \left(\left| \frac{\delta V}{\delta P} + 3 \right| \right)^{-1}$ is the inverse of the vertical wind shear of the horizontal wind (V) between pressure (P) levels 925 hPa and 200 hPa.
- $E = \int_0^{60} \rho_w c_w (T - 26)\ dz$ measures the thermal energy of the ocean between the surface and 60 m depth (ρ_w and c_w are density and specific heat capacity of sea water).
- $I_\theta = \left(\frac{\delta\theta}{\delta P} + 5 \right)$ is the moist static stability defined as the vertical gradient of the equivalent potential temperature θ_e between the surface and 500 hPa.
- $I_{RH} = Max\left(\frac{RH-40}{30}, 1 \right)$, where RH is the average relative humidity in percent between 500 hPa and 700 hPa.

These components summarize the main dynamical and thermodynamic large scale variables that are believed to determine whether the atmosphere-ocean system can support TC development. If any of the components of the SGP is less than or equal to zero, the SGP is set to zero. The SGP is usually divided between the winter (JFM), spring (AMJ), summer (JAS) and fall (OND). The Yearly Genesis Parameter (YGP) is calculated as the sum of the four SGPs. By comparion, the Convective SGP (CSGP) (Royer et. al., 1998), another index to estimate TC frequency, replaces the thermal potential of the SGP by a convective potential defined as

$$\text{convective potential} = k \times P_c \text{ over the oceans}$$

where P_C is the seasonal mean convective precipitation computed by a given model. The CSGPs can also be summed over all seasons to give a CYGP. The proportionality factor k was defined such that the total number of cyclones over the globe given by the CYGP be the same as the original YGP for the present climate using ERA-40 reanalysis.

In this study, we first validate the use of both indices by comparing the inferred number of TCs using ERA-40 reanalysis data for the period 1983-2002 to the actual number of TCs for the same period. We then analyze the YGP and CYGP in the present climate for an ensemble of six CGCMs and compare the quality of their predictions to both observations and ERA-40 reanalysis data.

Observations were taken from Joint Typhoon Warning Center (JTWC) best track data set for the Southern Hemisphere, West North Pacific and Northern Indian Ocean and from the National Hurricane Center (NHC) best track data set for the Atlantic and Eastern North Pacific. A storm was considered a tropical cyclone whenever the surface sustained winds reached 17 m/s.

Results

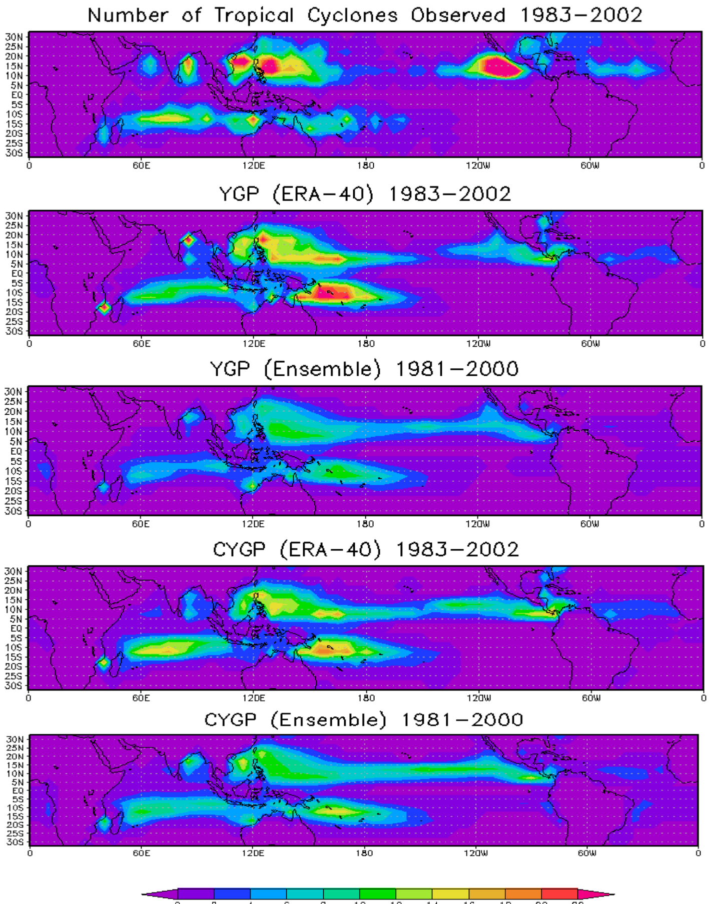

Figure 1: Tropical cyclone genesis per 20 years as given by a) observation and predicted by b) d) ERA-40 reanalysis data and c) e) an ensemble of IPCC models.

Figure 1 shows the YGP and CYGP calculated from ERA-40 reanalysis and the ensemble mean of 6 CGCMs simulations for the same nominal period. The YGP and CYGP as computed using the ERA-40 reanalysis data for the period 1983-2002 compare favorably to the actual number of tropical cyclones for the same period: the mean annual number of cyclones during that 20 years period was 86 while the number predicted by ERA-40 for YGP and CYGP is 83. However, the proportion of cyclones is too high in the Southern Hemisphere (SH) and too low in the Northern Hemisphere (NH). More specifically, TC genesis is underestimated in the NE Pacific and Atlantic while it is overestimated in the SW Pacific. Also, the YGP fails to predict TC activity in the Arabian Sea. By opposition, especially in the case of the CYGP, the genesis parameters predict the frequent formation of TCs in the Central Pacific where in fact few actually occur.

We then performed a similar analysis on an ensemble of six CGCMs (CGCM 3.1, ECHAM 5, GFDL-CM 2.0, GFDL-CM 2.1, MIROC 3.2 (hi-resolution) and HadGEM 1) whose simulations were submitted to the IPCC for the 4th assessment report. The analysis was done for the period 1981-2000 in the scenario of the 20th Century. In this case, the number of TCs is clearly underestimated by the YGP, which predicts an average of 58 $TCs/year$, while the CYGP, if using the same proportionality factor k as with ERA-40, predicts 85 $TCs/year$. There is a large variability between individual models, with respect to both YGP and CYGP: using the YGP, the predictions varied from 29 $TCs/year$ (CGCM 3.1) to 121 $TCs/year$ (ECHAM 5) while the CYGP varied from 48 $TCs/year$ (MIROC 3.2) to 120 $TCs/year$ (ECHAM 5). Again, the geographical distribution of predicted TCs shows some discrepancies. Most noticeable is the almost complete absence of TC formation in the Atlantic. This was caused by the vorticity factor which is found to be 0 over large portion of that basin. Similarly to ERA-40, the models also underestimate TC genesis in the NE Pacific and in the Arabian Sea and predict frequent TC formation in Central Pacific, contrary to observations. The CYGP also predict unrealistic TC activity off the coasts of South America in the SH.

Having validated the use of the parameters on both ERA-40 and an ensemble of CGCMs, future research will look at the time evolution of those same parameters to detect the possible emergence of a trend in the inferred TC statistics when CO_2 levels are increased in the models.

References:

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