5B.4

DOWNSCALING HURRICANE CLIMATOLOGIES FROM GLOBAL MODELS AND RE-ANALYSES

Kerry Emanuel*, Ragoth Sundararajan, and John WIlliams
Massachusetts Institute of Technology, Cambridge, Massachusetts

1. INTRODUCTION

Predicting the response of global tropical cyclone activity to climate change is of obvious interest and practical utility. Yet the primary tools for quantifying climate change, global climate models, currently have horizontal grids that are far too coarse to resolve tropical cyclones, though they often produce facsimiles of such storms. Here we present a new technique for downscaling tropical cyclone climatologies from coarse output of global climate models and re-analyses that circumvents the resolution problem by applying a specialized tropical cyclone model that fully resolves the critical core region.

This technique begins with the method described in detail in Emanuel et al. (2006). In that method, very large (O 10^4) numbers of synthetic hurricane tracks are generated by first drawing randomly from an historically determined space-time genesis probability distribution, carrying the tracks forward using either a Markov Chain or a Beta-and-Advection model (Marks, 1992), and finding the intensity evolution by integrating a specialized, very high resolution, coupled atmosphere-ocean hurricane model, the Coupled Hurricane Intensity Prediction System (CHIPS; (Emanuel et al., 2004). Winds needed to determine the tracks using the Beta-and-Advection model and to deduce vertical wind shear for the intensity model, are derived from synthetic time series of winds that conform to key statistical characteristics of winds from the global models or re-analyses. It was found that the statistical characteristics of the synthetic storms, including their tracks and intensities, match those of historical storms quite well. Details of this technique can be found in Emanuel et al. (2006).

The new technique, described in detail in Emanuel et al. (2008), dispenses with genesis from historically derived genesis distributions in favor of a new technique based on random seeding of the climate state, using the intensity model to determine the survival of the seeds, as described presently. The results presented in this extended abstract differ from those of Emanuel et al. (2008) in that the seeds are configured differently.

2. GENESIS BY NATURAL SELECTION

Rather than drawing randomly from an historically based genesis distribution, here we simply put down hurricane “seeds” randomly in space and time and allow the intensity model to determine their fate. The seeding rate is slightly weighted by the resolved, 850 hPa relative vorticity multiplied by the Coriolis parameter. These seeds consist of weak, warm-core vortices. In Emanuel et al. (2008), we used seeds with dry cores and maximum winds of 12 ms^{-1}, while here we instead use seeds with saturated cores but maximum winds of only 6 ms^{-1}. This allows us to partially assess the sensitivity of the technique to the exact form of the initial seeds. When run using re-analysis data, the new seeds produce results that are slightly improved over those of Emanuel et al. (2008).

The random seeding technique, used in conjunction with the Beta-and-Advection and CHIPS models, is completely independent of historical hurricane data, allowing us to make assessments that do not in any way depend on best-track data, except that we perform a one-time, universal calibration of the seeding rate to give global genesis rates in accord with observed genesis rates. There is no spatial or temporal variation in this seeding rate; it is just a universal constant. When applying the technique to global climate models, we also slightly calibrate the global model-derived potential intensities (again by single, universal multiplicative factors) for each model to obtain reasonable intensity distributions in the current climate.

3. RESULTS

Here we focus on results that differ in significant and/or interesting ways from those presented in Emanuel et al. (2008). When run with the new seeds that have weaker winds but saturated cores, the technique does at least as well in simulating the seasonal cycle of events in all ocean basins, and does an even better job with interannual variability, as shown in Figure 1, explaining about 65% of the interannual variability in Atlantic tropical cyclone frequency. Given that the technique does not in any way account for the climatology of pre-existing disturbances, such as African easterly waves, it is surprising that so much interannual variance is captured, suggesting that no more than about 35% of the interannual variability of storm counts

---

**Corresponding author address*: Kerry Emanuel, Rm. 54-1620 MIT, 77 Mass. Ave., Cambridge, MA 02139; e-mail: emanuel@texmex.mit.edu

is attributable to interannual variability of initiating disturbances, such as easterly waves, or to purely random variability. This paints an optimistic picture for seasonal forecasting of Atlantic storms.

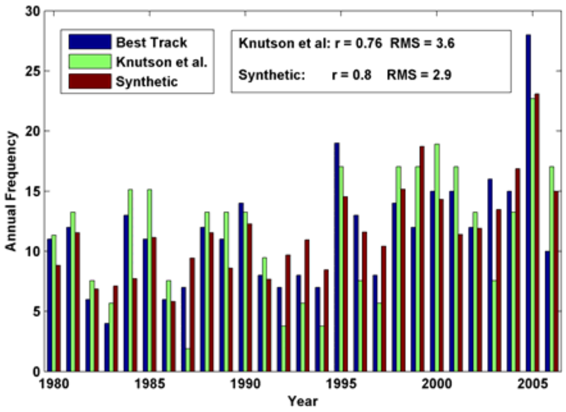

Figure 1: Number of Atlantic storms in each year from 1980 to 2006 in best track data (blue), the regional simulations of Knutson et al. (2007, green), and the current synthetic track technique (red). Regression coefficients and root-mean-square differences between the two downscaled techniques and best-track data are shown in upper right.

When the years in the interval 1980-2006 are stratified by the phases of El Niño/Southern Oscillation (ENSO) and the Atlantic Meridional Mode (AMM; Kossin and Vimont, 2007), the synthetic technique does exceptionally well in distinguishing active from inactive phases (Figure 2).

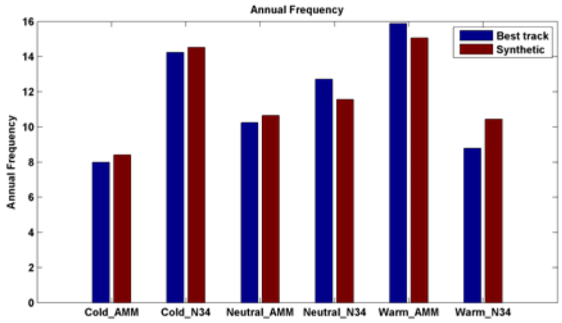

Figure 2: Frequency of Atlantic tropical cyclones during the interval 1980-2006 by phase of ENSO and the AMM according to best-track data (blue) and the present synthetic technique (red). The terms on the x axis refer first to the ENSO phase and second to the AMM phase.

In general, using the weak, core-saturated seeds leads to enhanced sensitivity to climate change, from interannual to multidecadal time scales. The correlation between interannual variations of predicted and observed frequency in the Atlantic from 1980 to 2006 improved from 0.69 with the more intense but unsaturated seeds to 0.80 with the weaker, saturated seeds. On the other hand, the basin-to-basin variability becomes too large with the new seeds. When the technique is run, as before, using the output of seven global climate models and the last twenty years of the 22nd century under IPCC scenario A1b are compared to the last twenty years of the 20th century (Figure 3), the increase in power dissipation is greater than with the stronger seeds. But the overall conclusions remain the same: expected changes are, while substantial, much more modest than a simple extrapolation from the end of the 20th century would suggest, and there is much model-to-model and basin-to-basin variability in the results.

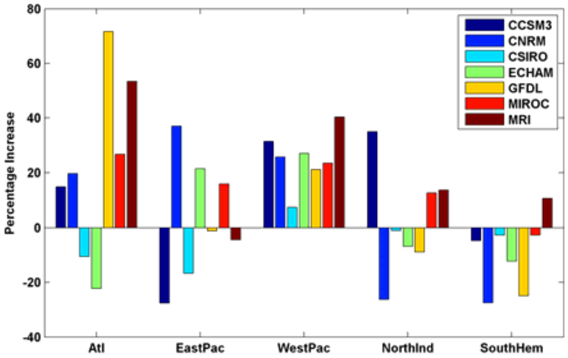

Figure 3: Percentage change in tropical cyclone power dissipation between the last 20 years of the 20th century and the last 20 years of the 22nd century under IPCC Scenario A1b, in which CO_2 reaches 720 ppm by the end of the 21st century and is constant thereafter. Results are shown for 7 climate models (different colors) and 5 ocean basins.

4. SUMMARY

The technique described herein enables one to estimate hurricane climatology from coarse-grained climate data sets, including re-analyses and climate models, and is entirely independent of historical hurricane data, except that a one-time, universal calibration constant for the seeding rate is chosen to match historical global genesis rates. The seeding is mostly random in space and time, but the seeding rate is slightly weighted by the resolved, 850 hPa relative vorticity multiplied by the Coriolis parameter. In this abstract, the seeds have maximum velocities of only 6 ms^{-1} but are saturated in their cores, in contrast to those used previously by Emanuel et al. (2008), which had twice the maximum wind speed but whose cores were unsaturated. The genesis distributions in space and time are produced by natural selection of the weak initial seeds; most of these die a natural death from having been placed in unfavorable environments, but a few survive to become tropical cyclones with maximum winds of at least 20 ms^{-1} (by choice). These survivors are regarded as constituting the tropical cyclone climatology downscaled from the model or re-analysis data set.

In view of the particulars of this method, it is somewhat surprising that it captures so much of the observed interannual variability of Atlantic storms (Figure 1). It makes no account of the presence or strength of potential initiating disturbances, such as African easterly waves, (although there is some weighting of the seeding rate with monthly mean low-level vorticity) and so one concludes that at least 65% of the interannual variance in the Atlantic is owing to large-scale factors, with the rest coming from some combination of random variability and the variability of initiating disturbances. This paints an optimistic view of seasonal forecasting, and Figure 2 in particular suggests that much skill can be attained in the Atlantic if the phases of ENSO and the AMM can be skillfully predicted. On the other hand, the absence of a distinct climatology of potential initiating disturbances almost certainly leads to biases in the location of genesis events, with Atlantic genesis generally weighted too far to the west (Emanuel et al., 2008). We speculate that the serious underprediction of eastern North Pacific genesis rates evident in our published paper may be owing to the absence of strong initiating disturbances in our technique; by the time our weak disturbances begin to develop, they are too far to the west and in thermodynamically unfavorable environments.

Perhaps the most interesting issue raised in this study is the disparity between what this technique hindcasts for the period 1980-2006, driven by NCAR/NCEP reanalysis data, and what it forecasts for the next 200 years driven by climate models subjected to a doubling of CO_2 from its current value. Whereas global tropical cyclone power dissipation (*PDI*) nearly doubles from 1980 to 2006, using the new, saturated seeds, the global increase over the next 100-200 years is only a few percent, though with much larger changes of either sign in individual models and in individual ocean basins. There are several possible interpretations of this disparity. It may be that the big increases over the past 25 years are not largely attributable to global warming but to some other phenomenon or combination of phenomena. Alternatively, there might be some systematic problem with our technique or with the global climate models that is not allowing them to capture the detailed nature of the earth's response to increasing greenhouse gases, and thereby leading to a systematic underprediction of the tropical cyclone response. Finally, it may be that the equilibration of the earth's climate to increased CO_2 , which is what happens under IPCC scenario A1b by the end of the 22nd century, differs in important ways from the transient response we are witnessing at present. We are currently undertaking analyses designed to resolve these questions.

5. REFERENCES

Emanuel, K., C. DesAutels, C. Holloway and R. Korty, 2004: Environmental control of tropical cyclone intensity. *J. Atmos. Sci.*, **61**, 843-858

Emanuel , K., R. Sundararajan and J. Williams, 2008: Hurricanes and global warming: Results from downscaling IPCC AR4 simulations. *Bull. Amer. Meteor. Soc.*, **89**, 347-367

Emanuel, K. A., S. Ravela, E. Vivant and C. Risi, 2006: A statistical-deterministic approach to hurricane risk assessment. *Bull. Amer. Meteor. Soc.*, **19**, 299-314

Knutson, T. R., J. J. Sirutis, S. T. Garner, I. M. Held and R. E. Tuleya, 2007: Simulation of the recent multi-decadal increase of Atlantic hurricane activity using an 18-km grid regional model. *Bull. Amer. Meteor. Soc.*, **88**, 1549-1565

Kossin, J. P. and D. J. Vimont, 2007: A more general framework for understanding Atlantic hurricane variability and trends. *Bull. Amer. Meteor. Soc.*, **88**, 1767-1781

Marks, D. G., 1992: The beta and advection model for hurricane track forecasting. Natl. Meteor. Center, Camp Springs, Maryland, 89 pp.