Climate Change Impacts on Tropical Cyclones: the current state of knowledge

John L McBride

Centre for Australian Weather and Climate Research, Bureau of Meteorology, Melbourne, Australia, j.mcbride@bom.gov.au

1 INTRODUCTION

The question "Have there been observed changes in tropical cyclone activity that can be attributed to global warming?" remains an area of active research. There is also much research on projections of tropical cyclone activity under various warming scenarios. The results of international modelling studies consistently find fewer Southern Hemisphere tropical cyclones in a warmer climate. Balanced against this they consistently find a higher proportion of more intense cyclones. [1]. Despite the consistency of these results, confidence in the projections is only moderate, as in the absence of detectable observed changes, the projections rely totally on modelling and theoretical studies

The purpose of the current paper is twofold:

(1) *To present the results of a recent global assessment of the state of the science* [1];
This assessment was made by a World Meteorological Organization (WMO) Expert Team on the topic, of which the author is co-chair.

(2) *To summarise recent important contributions to the topic, specific to the Australian region*.

2. A GLOBAL ASSESSMENT

Quoting from the Abstract of the WMO assessment, we obtain the following summary assessment:

Detection: Large amplitude fluctuations in the frequency and intensity of tropical cyclones greatly complicate both the detection of long-term trends and their attribution to rising levels of atmospheric greenhouse gases. Trend detection is further impeded by substantial limitations in the availability and quality of global historical records of tropical cyclones. Therefore, it remains uncertain whether past changes in tropical cyclone activity have exceeded the variability expected from natural causes.

Projections of cyclone intensity: Projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100.

Projections of cyclone frequency: Existing modelling studies consistently project decreases in the globally averaged frequency of tropical cyclones, by 6–34%.

Projections of most intense cyclones and of precipitation: Higher resolution modelling studies typically project substantial increases in the frequency of the most intense cyclones, and increases of the order of 20% in the precipitation rate within 100 km of the storm centre.

Regional Projections: For all cyclone parameters, projected changes for individual basins show large variations between different modelling studies.

3 RESEARCH ON CLIMATE CHANGE IMPACTS IN THE AUSTRALIAN REGION

For the detection of trends, Knutson et al [1] use the criterion that the observed change must exceed that expected through natural causes. In the Australian region large interannual changes occur associated with the El Nino Southern Oscillation (ENSO) phenomenon [2]. This variability makes it difficult to demonstrate the statistical significance of trends when non-parametric monte carlo tests are used. A recent major study has also demonstrated the presence of large variability on multi-decadal timescales in tropical cyclone landfalls along the Eastern Australian coastline [3]. The presence of the multi-decadal variations, combined with the fact that reliable measurements of cyclone numbers and intensity over the open ocean go back only to the 1960's for frequency and the 1980's for intensity [4], also adds to the difficulty of distinguishing any observed trends from those that would result from natural variations.

The second factor making it difficult to determine trends is the continuing change in observational techniques and data platforms used to measure cyclones numbers, length of cyclone lifetime and cyclone intensity. A major cause of homogeneity has been the introduction of advanced infra-red satellite-based techniques to determine cyclone intensity. These techniques became standard practice in the Australian region during the mid 1980's. Most recent studies consider this period as the effective beginning of the reliable cyclone intensity data set in our region. An industry-funded study has been performed to reanalyse satellite-based estimates of cyclone intensity in the Western Australia region [5]. That study found intensity estimates were too weak (less intense) in the early years of satellite availability, hence positive trends in intensity are likely due to changes in observing methods.

The importance of the official cyclone tracks has led to a critical examination of the official Australian data set and the subsequent release of a new temporally-homogeneous data set by the National Climate Centre [4]. The National Climate Centre has also compiled an official best track data set for the Southern hemisphere and is a partner in the international official tropical cyclone tracks initiative IbTracs [6] aimed at global archival and distribution of all official and modified tropical cyclone tracks. Resulting from this, trends have been examined in the official tracks for the Southern hemisphere and for the Australian region. Significances were tested by non-parametric Monte Carlo methods simulations (10,000 iterations) involving re-sampling the time series with and without replacement and forming a sampling distribution of the linear trend from which significance levels were obtained. The linear trend significances were calculated in the two-tailed form, with the overall significance of the trend being the larger of the two assessments.

The results are shown in Fig.1 in the form of the logarithm of the significances being plotted along the ordinate. Results are shown for the Southern hemisphere (SH) and several subregions. As can be seen, the line for the Australian region remains between +1 (positive trend at 10% significance level) and -1 (negative trend at 10% level) for all intensity categories, meaning there are no significant trends in the Australian region over the past 26 years. Significant positive trends are observed for the most intense cyclones (945 and 950 hPa) in the South Indian Ocean, and consequently in the Southern Hemisphere. A breakpoint analysis [7] and the qualitative discussion of changes in data availability and in operational procedures in reference [7] would suggest that these trends are influenced to some extent by changes in data quality.

The large body of recent work on cyclone tracks in the Australian region bears results consistent with the global picture. That is: "it remains uncertain whether observed trends in tropical cyclones in exceed those expected from natural variability".

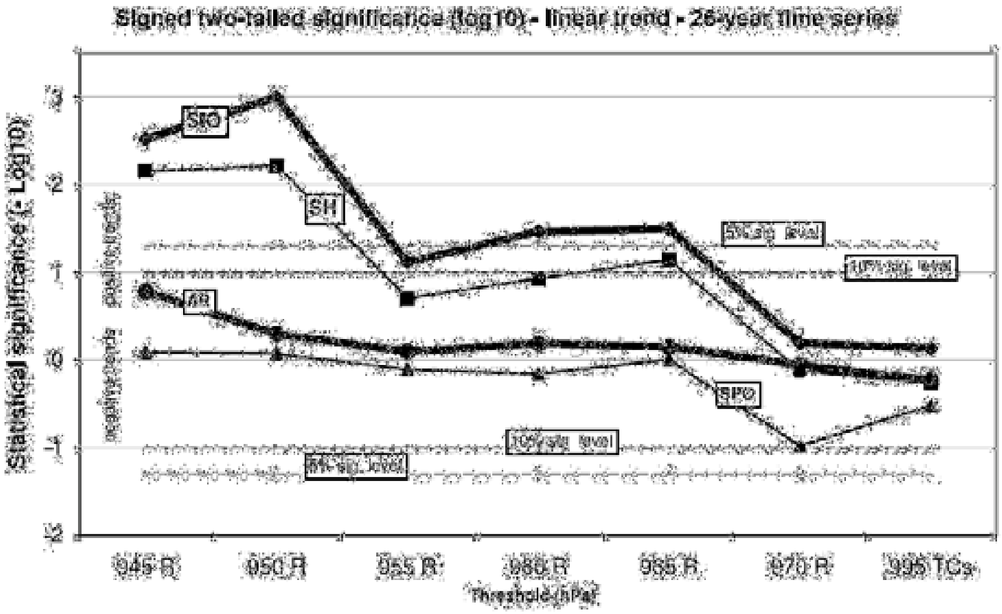

Fig.1 Significance values of the linear trends of tropical cyclones in the Southern Hemisphere over the 26 year period ending 2006–2007 for four regions: Southern Hemisphere (SH), South Indian Ocean (SIO), South Pacific Ocean (SPO), and Australian (AR). Significances are shown for the trends in TC numbers (995 hPa TCs) and trends in the proportions of TCs reaching higher intensities (945, 950, . . ., 970 hPa, indicated by ''R'' on the horizontal axis). The significances are plotted logarithmically (base 10), signed according to the sign of the trend. Points closer to (farther away from) the zero line indicate less (more) significant trends. Also plotted are the 5% and 10% (two-tailed) significance levels. From Reference [7]

For tropical cyclone projections there have been two major modelling studies specifically addressing Australian Region cyclones under warming scenarios [8], [9]. Both studies found a significant increase in the proportion of cyclones at higher intensities with no significant change in numbers. However, a survey of the results of global modelling studies at horizontal resolutions of 120Km or better found a consistent signal of decreasing tropical cyclone numbers in the two Southern Hemisphere basins (Southern Indian Ocean, Southern Pacific Ocean), and obtained differing results for intensity from model to model, with some models giving increases and some decreases in mean intensity in a warmer climate.

From international global modelling studies the projection of fewer cyclones in the Southern Hemisphere has become a robust result, being obtained in almost all studies. To date, however, the result is not well understood physically. In addition the studies do not subdivide the large Pacific and Indian Ocean basins into sub-regions, so at this stage there are no robust projections for the Australian region.

4 SUMMARY AND DISCUSSION

There has been substantial progress towards development of a complete and homogeneous set of historic tracks for the Australian region. There is still much to do, however. The replacement tracks data set developed by the National Climate Centre has involved addition and deletion of cyclone numbers only, and in some cases length of track. Intensities have not yet been modified. There are procedures under investigation to re-analyse intensities, including possibly reanalyisis of satellite data, and probably a reverse engineering of the wind-pressure relationship used across the three Warning Centres over the period of record.

For cyclone projections, to date there are very few studies addressing the question in the region. The reasons for this are a) that the computer resources required are large, and b) both dynamical and statistical downscaling techniques must be developed as the cyclone eye wall and maximum wind structures are not resolved by the climate models. Current downscaling techniques do not well reproduce interannual variability of cyclones in the current climate. In addition, there is little agreement between climate models on projections for the large scale atmospheric structures known to influence tropical cyclone activity such as the structure and behaviour of ENSO, the monsoon trough and fields of vertical shear.

There is a large amount of innovative work taking place at various institutions around the country addressing these problems.

5 REFERENCES

[1] Knutson, Thomas R., J McBride, J Chan, K A Emanuel, G Holland, C Landsea, Isaac Held, J Kossin, A K Srivastava, and M Sugi. (2010). "Tropical cyclones and climate change". Nature Geoscience, 3, doi:doi:10.1038/ngeo779

[2] Ramsay, H.A., L.M.Leslie, P.J.Lamb, M.J.Richman, and M.Lepastrier. (2008). "Interannual Variability of Tropical Cyclones in the Australian Region: Role of Large-Scale Environment". J.Clim., 21, 1083-1102.

[3] Callaghan, J. and S. Power. (2010). " Variability and decline in the number of severe tropical cyclones making land-fall over eastern Australia since the late 19th Century". Climate Dynamics. (In Press).

[4] Trewin, B. (2008). "An Enhanced tropical Cyclone Data Set for the Australian Region". American Meteorological Society 20th Confer. On Climate Variability and Change. Extended Abstract. http://ams.confex.com/ams/pdfpapers/128054.pdf

[5] Harper, H.A., S. A. Stroud, M.McCormack and S. West. (2008). "A review of historical tropical cyclone intensity in northwestern Australia and implications for climate change trend analysis. Aust Meteor. Mag., 57, 121-141.

[6] Knapp, K. R., M. C. Kruk, D. H. Levinson, H. J. Diamond, and C. J. Neumann. (2010) "The International Best Track Archive for Climate Stewardship (IBTrACS): Unifying tropical cyclone best track data". Bulletin of the American Meteor. Society, In press..

[7] Y. Kuleshov, R. Fawcett, L. Qi, B. Trewin, D. Jones, J. McBride and H. Ramsay. (2010). "Trends in tropical cyclones in the South Indian Ocean and the South Pacific Ocean". J. Geophys. Res. 115, D1, D01101, 0148-0227

[8] Leslie, L. M., Karoly, D.J., Leplastrier, M. and B.W. Buckley. (2007). "Variability of tropical cyclones over the southwest Pacific Ocean using a high-resolution climate model". Meteorol. Atmos. Phys., 97, 171-180.

[9] Walsh, K.J.E., Nguyen, K.-C. & McGregor, J.L. (2004). "Fine-resolution regional climate model simulations of the impact of climate change on tropical cyclones near Australia". Clim. Dyn., 22, 47-56.