PROJECT 2.2: TROPICAL CYCLONES IN THE NORTH-WEST

Milestone Report 2: (to end December 2010)

Principal Investigators

Dr John Leonard McBride, Bureau of Meteorology, Centre for Australian Weather and Climate Research, PO Box 1289, Melbourne, Victoria, 3001 (Ph: 03 9669 4421; Email: j.mcbride@bom.gov.au)

Dr Richard Dare, Employed on the IOCI project since June 2009 - . Bureau of Meteorology, Centre for Australian Weather and Climate Research, PO Box 1289, Melbourne, Victoria, 3001 (Ph: 03 9669 4649; Email: r.dare@bom.gov.au)

Dr Hamish Ramsay, Employed for six months on the IOCI project. October 2008 –March 2009 Located at Bureau of Meteorology, Centre for Australian Weather and Climate Research, PO Box 1289, Melbourne, Victoria, 3001

Ms Anne Leroy, Employed on the IOCI project as a consultant on Intraseasonal Forecasting of tropical cyclone activity. Météo France, Nouméa, New Caledonia

Milestone 2.2.1: Research paper submitted on the climatology and interannual variability of tropical cyclones in the Indian Ocean that affect the Western Australian coastline

Completed 31/12/2009

This milestone has been completed and was reported on in the IOCI3 Report 1.

Milestone 2.2.2: A statistical forecast model for tropical cyclone activity along the Western Australian coastline (2-week lead time)

Completed 31/12/2009

This milestone has been completed and was reported on in the IOCI3 Report 1.

Milestone 2.2.3: Research paper on theoretical framework for understanding interannual variability of tropical cyclone behaviour in the southern Indian Ocean.

Completed 31/12/2010

The scientific findings associated with this milestone concerned the impact of tropical cyclones on ocean temperatures and the subsequent large impact played by cyclones on the seasonal cycle of sea surface temperature. These findings were discussed in detail in IOCI Report II and so will not be repeated here. The paper from this milestone has been submitted to the international journal Monthly Weather Review. It is currently undergoing revision following comments from the journal referees.

Milestone 2.2.4 Report on extreme tropical cyclone behaviour in Western Australia and their economic impacts

Interviews and investigations were completed 31/12/2010, however, the results will be drawn together into a formal report by about mid 2011.

Data on damage and rebuilding costs associated with tropical cyclone events is relatively easily obtainable though government resources (mainly the Bureau of

Transport Economics) from the Insurance Industry (e.g Munich Re) and from the University Sector (e.g Risk Frontiers), all of whom keep and publish such data.

The secondary or indirect costs to primary and secondary industry in terms of cyclone impact on operating costs is much more difficult to document. It has become clear there are no industry-wide published figures on this. Extensive discussions were held with representatives of off-shore industry who listed a number of costs:

1. down time when ports are closed,
2. design costs such that offshore and onshore exploration platforms can withstand the cyclone-level winds,
3. de-manning of platforms several days before cyclones occur,
4. closure of ports,
5. closure of roads,
6. the down time due to closed roads and ports,
7. costs associated with scheduling changes and movement of operating staff.

Unfortunately this lack of information on these secondary costs has meant that this milestone has not provided the depth of information we had hoped. A synthesis of the primary costs (damage and rebuilding costs) and suggested possible solutions to obtaining the secondary costs in the future will be produced for mid-2011.

Milestone 2.2.5 State of Knowledge Report on tropical cyclone dynamics, databases and current practices relevant to Western Australia

Completed 31/12/2011

Databases and current practices

As discussed in our papers with Kuleshov and co-authors and our papers with Knutson and co-authors, there is disagreement among scientists worldwide as to whether there is any trend in the official records of tropical cyclone numbers and tropical cyclone intensities. The prime reason for the uncertainty and for the disagreement is that observations of tropical cyclone numbers and estimates of intensity depend fundamentally on remote sensing instruments carried on meteorological satellites. The technology of these instruments has changed continuously during the era of satellite data. Hence trends in the time series of cyclone intensity may be "apparent" due to instrument changes rather than real, due to global warming or other influences.

A number of important international studies have been carried out to determine whether there have been trends by constructing a temporally-consistent or homogenous satellite data set for tropical cyclones. This technique degrades recent satellite data to the temporal and spatial resolution of the earlier data. Cyclone intensity is then determined by applying intensity algorithms across the consistent data set. The most recent conclusion by a paper in nature (Elsner and co-authors 2008) is that trends in the upper quantile (or upper limit of the intensity distribution) are apparent globally. Thus in the satellite era (since 1980) there have been trends in the maximum possible intensity (or maximum of the distribution) observed in the consistent record.

This result is of fundamental importance of the for detection of climate change-related trends in tropical cyclones in the Southern Indian Ocean. We obtained and have been working with the temporally consistent cyclone data. The analysis is technically complicated and so will not be presented in detail here. We have examined the statistical methods used as well as the raw data.

Our paper addresses the global result. The databases relevant to Western Australia have been re-examined by IOCI scientists, drawing on the knowledge of staff from the Perth Forecast Office as well as the National Climate Centre, plus industrial representatives (Woodside) and international agencies (US National Climate Data Centre). Our conclusion for the Indian Ocean region, however, is that in its current form the homogeneous satellite intensity data set cannot be used for trend detection. This is because there was a large shift in the location of the major Indian Ocean observing satellite in 1998, the middle of the period of record. This change in satellite viewing angle introduced a jump-shift inhomogeneity in the satellite infrared brightness data. The authors of the international studies applied a viewing-angle correction to allow for this. However, our analysis reveals the trends change from no trend to a significant trend depending on whether the correction has been applied.

This is shown in Fig.1 below from our paper. The three series are for time series of the number of cyclones with intensity exceeding mean plus two standard deviations over the satellite record. The difference between the red and blue series and the green series is simply whether or not the viewing angle correction has been applied.

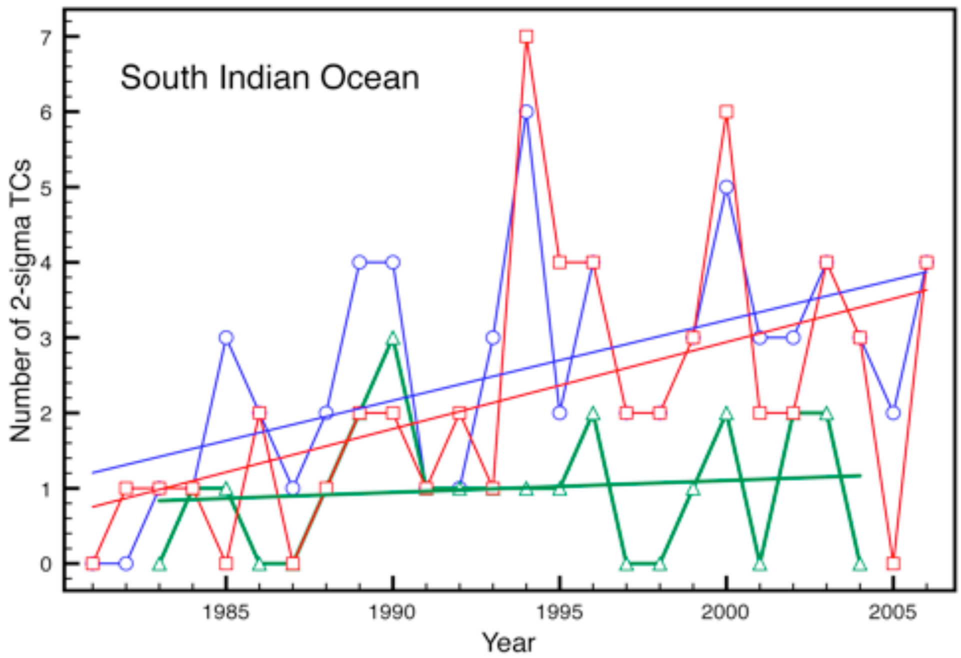

Figure 1: Time series of the number of intense cyclones based on the homogenous satellite intensity data set of the United States National Climate Data Centre. The red and blue curves are for two versions of the intensity data set after the satellite viewing angle correction has been applied. The green curve is for the data set when no viewing angle correction has been applied. Trend lines are added to each curve. Intense cyclones are defined as exceeding mean plus two standard deviations.

Dynamics

There are well recognised necessary conditions for tropical cyclone formation. The dynamic conditions include enhanced low-level relative vorticity and relatively weak vertical wind-shear. The thermodynamic conditions include broad-scale deep convection, enhanced relative humidity and ocean temperatures of at least about 26.5°C.

However, it is known that there are exceptions to these rules. Given that ocean temperatures are likely to warm in the future, the region with sea-surface temperatures greater than 26.5°C might be expected to be greater in extent. For this reason it is worth investigating how robust the 26.5°C threshold is for formation.

Extensive examination of both the local databases and the information held within the international database of tropical cyclone data and tracks for the years 1981 to 2008 of the sea-surface temperature at which tropical cyclones form was undertaken (Dare & McBride, 2011b). Accumulated curves of the percentage of cyclone developments above the sea surface temperature listed on the lower axis are shown in Figure 2. The figure shows that some tropical cyclones form in waters cooler than 26.5°C. It has thus become clearer that the threshold of 26.5°C is not a valid threshold in absolute terms, but in practical terms more than 98% of TCs form above this value of SST

The major finding of our paper is shown in the right hand panel of the figure. This shows three curves; a) accumulated percentages of sea surface temperature for all observations of tropical cyclones, b) for the tropical cyclone at point of development, and c) for the warmest sea surface temperature in the 48 hours prior to development. The shift of the curves towards the right shows that the existence of a threshold temperature is most apparent when the sea temperature over the 48 hours preceding development is used. This is presumably due to the fact that as the cyclone develops it cools the underlying sea surface (Figure 3 below and Dare and McBride, 2011a).

The fact that cyclones move to lower sea surface temperatures after they develop is demonstrated for the Western Australian region in Figure 4 below. The left panel plots all tropical cyclogenesis points for January for the past 30 years. The right panel is for the point of maximum intensity or lowest central pressure, generally a few days later. As can be seen by the poleward shift in the right panel cyclones occur at higher sea temperatures at the early stage of their lifecycle.

Thus, as oceans warm, it cannot be assumed that the region of cyclone formation will correspondingly expand. It has been found that TCs in the WA region are forming over waters warmer than 26.5C in recent years. These results highlight that the SST is just one factor affecting TC formation, so changes in SST alone do not mean that there will be a larger area off the coast that is conducive to TC formation.

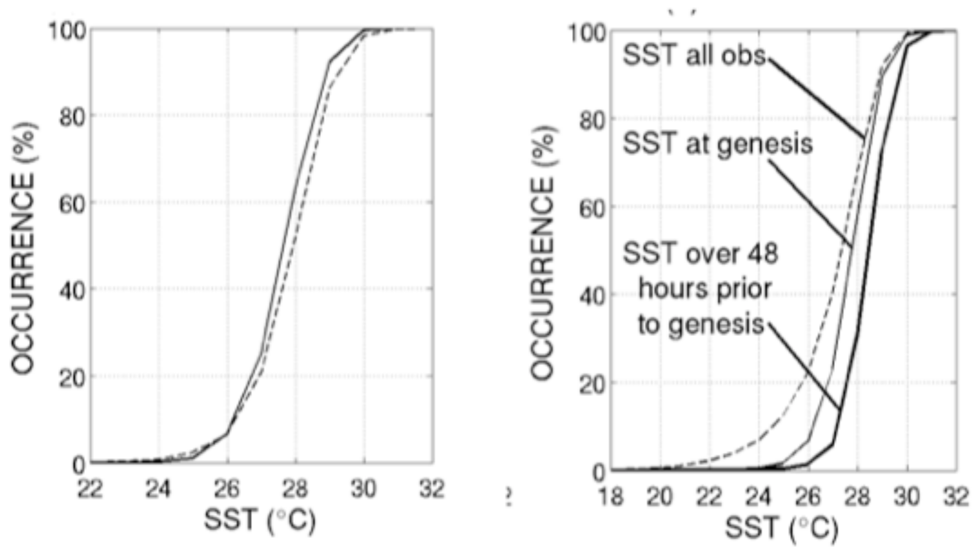

Figure 2: Accumulated percentage occurrences of tropical cyclone genesis events for the globe above each value of sea surface temperature. Left panel compares the first 15 years data (1981-1995 solid line) with the later 15 years (1995-2008 dashed line). The right panel compares all cyclone locations, cyclones at genesis time and cyclone locations over the 48 hours preceding cyclogenesis.

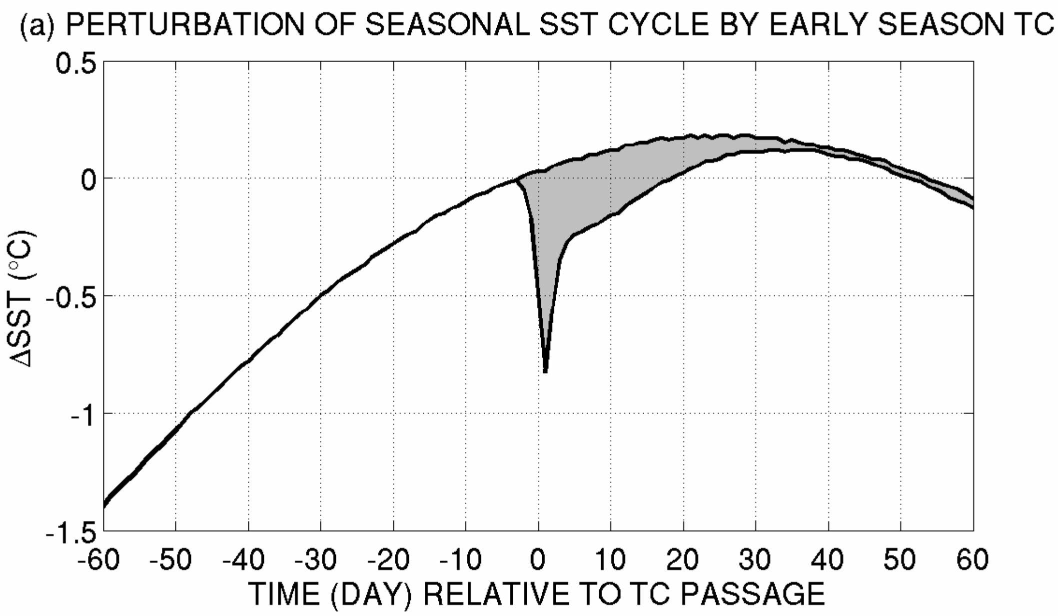

Figure 3. Mean cooling of sea surface caused by tropical cyclones

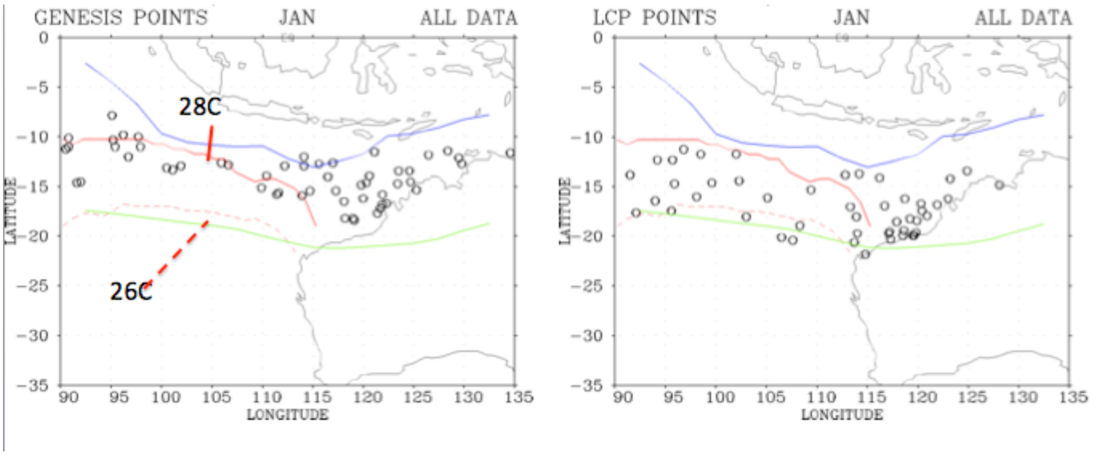

Figure 4: Plot of all tropical cyclone development locations (left figure) and location of maximum intensity of each cyclone (right figure) for all tropical cyclones occurring off Western Australia during the month of January. The blue line is the climatological location of the monsoon trough. The green line is the climatological location of the zone of high vertical wind shear. The red solid line is the location of the January 28 degree sea surface temperature isotherm. The red dashed line is the location of the 26C isotherm.

Milestone 2.2.6: Dependent on the research outcomes of the first two years, a series of expert statements, updates and research papers on the vulnerability of WA to changes in tropical cyclone activity under climate change

Progress Report –due to be completed 31/12/2011

Under this milestone two major pieces of work are going on. The first is a study of the contribution of tropical cyclones to climatological rainfall across Australia. The second is a synthesis of the findings of the papers carried out under this research project (see list below). The papers addressed the issues of trends in observations of tropical cyclone numbers and intensity and the issue of the relationship between tropical cyclone development and intensity change and sea surface temperature. The reason this latter aspect is important is that sea surface temperatures have risen and are projected to continue to rise under global warming. The synthesis paper will draw together the findings of this set of IOCI-funded papers to specifically address the question of climate change impacts on cyclones in the Southern Indian Ocean.

A third study, still being analysed, is the contribution of tropical cyclones to rainfall over Australia. Preliminary results are shown in Figure 4 below. As can be seen, tropical cyclones are a major contributor to wet season total rainfall over North West Western Australia. In current IOCI research (during 2011), these data are being analysed in greater detail to determine the spatial structure of this contribution and the degree of inland penetration.

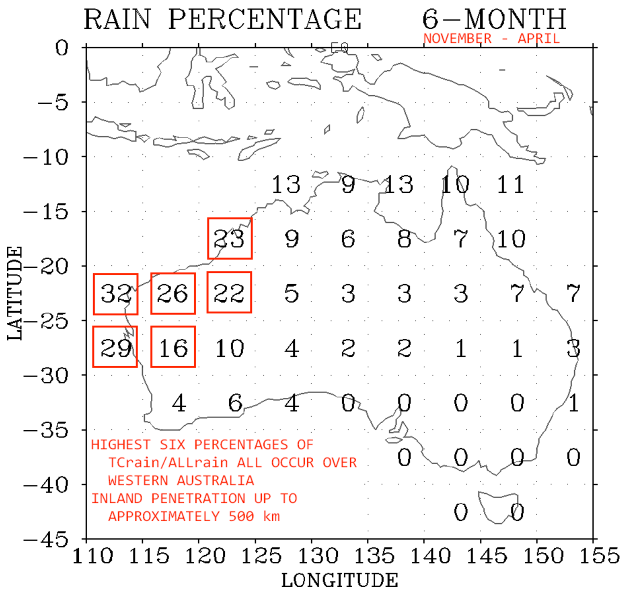

Figure 4: Percentage of rainfall over 5 degree latitude-longitude boxes occurring within 600 km of the centre of a tropical cyclone, over the period of satellite record 1980 to present.

<u>List of publications accepted and submitted</u>

Knutson, Thomas R., J McBride, J Chan, K A Emanuel, G Holland, C Landsea, Isaac Held, J Kossin, A K Srivastava, and M Sugi, March **2010**: Tropical cyclones and climate change. *Nature Geoscience*, **3**, doi:doi:10.1038/ngeo779.(multi-institution paper: McBride and Ramsay contributions funded by IOCI)

Y. Kuleshov, R. Fawcett, L. Qi, B. Trewin, D. Jones, J. McBride and H. Ramsay: **2010a:** Trends in tropical cyclones in the South Indian Ocean and the South Pacific Ocean. *J. Geophys. Res.* **115**, D1, D01101, 0148-0227 (Paper with members of the Bureau of Meteorology National Climate Centre. McBride and Ramsay contributions funded by IOCI)

Y. Kuleshov, L. Qi, D. Jones, R. Fawcett, F. Chane-Ming, J. McBride and H. Ramsay, 2010b: On Developing a Tropical Cyclone Archive and Climatology for the South Indian and South Pacific Oceans. In, *Indian Ocean Tropical Cyclones and Climate Change*, 4, 189-197, DOI: 10.1007/978-90-481-3109-9_23 Springer, Netherlands. Indian Ocean and the South Pacific Ocean. *J. Geophys. Res.* **115**, D1, D01101, 0148-0227 (Paper with members of the Bureau of Meteorology National Climate Centre. McBride and Ramsay contributions funded by IOCI).

Dare, R.A. and J.L. McBride, 2011a Sea Surface Temperature response to tropical cyclones. submitted to Monthly Weather review. Fully funded by IOCI.

Dare, R.A. and J.L. McBride, 2011b. The threshold Sea Surface Temperature Condition for Tropical Cyclogenesis. Submitted to Journal of Climate. Fully funded by IOCI

McBride, J.L, H.A. Ramsay and M. B. Richman. Trend Analyses of Globally Consistent satellite-based estimates of tropical cyclone intensity. Submitted to Geophysical research Letters (Fully funded by IOCI. Submitted during 2011