PROJECT 2.2 TROPICAL CYCLONES IN THE NORTH-WEST

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Objectives

To advance the science of tropical cyclones in the Western Australian region by making contributions to:

- Their climatology and Interannual variability
    - Improved forecasting methods
    - Expert assessments of the impact of climate change on tropical cyclone activity
- To review the literature, data-bases and current knowledge related to tropical cyclone activity and impacts in Western Australia.

- To develop a theoretical framework for understanding the problem of changes in tropical cyclone activity as a function of changing large-scale atmospheric structure.
- To conduct detailed observational studies of severe tropical cyclone behaviour in Western Australia.
- To provide expert advice on the vulnerability of Western Australia to changes in tropical cyclone activity under climate change

Key Research Findings

- The IOCI research activities marked the first time the researchers had focussed their attention on Tropical Cyclones in the Southern Indian Ocean. Research during this first year has concentrated on gaining familiarity with the tropical cyclone data set in the region and on investigating whether there are trends. It is well documented that the sea surface temperatures during the cyclone season have increased over the past 25 years by approximately half a degree C. It is important to determine whether there has been an increase in tropical cyclone activity in response to this climate signal.
- A collaborative study with the Bureau of Meteorology National Climate Centre was conducted looking at trends in the official tropical cyclone data set since the beginning of the satellite era. For the Southern Indian Ocean it was found that the trends in the frequency of cyclones are small and not significant. Looking at the trends in the more intense cyclones, for most cyclone categories there is no significant trend. However, for the proportion of cyclones exceeding 940 hPa there has been an increase of the order of 20% increase in this proportion over a 25 year period. This trend is significant.
- The relationship between tropical cyclone and sea surface temperature has been studied for both the Southern Indian Ocean and for the entire Southern Hemisphere. The major finding is that in-situ statistical relationships (such as liner correlations) between indices of cyclone activity and sea surface temperature are dominated by large scale patterns, reflecting the large scale structure of the El Nino-Southern Oscillation or ENSO phenomenon.

- The implications of this for tropical cyclone response to global warming are that the relationship between cyclone activity and sea surface temperature is not simply a local one. The sea surface temperature responds to the circulation on a planetary scale. Possibly the cyclones respond to local sea surface temperatures; but they also respond to the same planetary scale influences that govern ENSO behaviour. This makes the scientific issue of determining the response of tropical cyclones to changing sea surface temperatures more complicated. To determine such a response the sea surface temperature changes must be interpreted in terms of their effect on the larger scale dynamical circulations systems which give rise to cyclones.
- The IOCI project contributes to Dr John McBride's participation (as co-chair) of a WMO (World Meteorological Organizations) Expert Team on Climate Change Impacts on Tropical Cyclones. During year-one of IOCI-3, this group has prepared an expert assessment statement on tropical cyclones and climate change, submitted to Nature Geosciences.
- A statistical forecast model the 1 week to 3 week time frame has been developed for the western Australian region. The model is based on an earlier model developed by Leroy and Wheeler (Monthly Weather Review 2008). To carry out the development of the new model the first author of the earlier model (Anne Leroy) was employed on IOCI funds on a 2-week consultancy in late 2009.
- Work has started on developing a theoretical framework for understanding the inter-annual variability of tropical cyclone behaviour in the southern Indian Ocean.

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

Background

Summary

The IOCI research activities marked the first time the researchers had focussed their attention on Tropical Cyclones in the Southern Indian Ocean. Research during this first year has concentrated on gaining familiarity with the tropical cyclone data set in the region and on investigating whether there are trends. It is well documented that the sea surface temperatures during the cyclone season have increased over the past 25 years by approximately half a degree C. It is this important to determine whether there has been an increase in tropical cyclone activity in response to this climate signal.

This broad approach has resulted in IOCI contributions to a number of studies, described in the following paragraphs as studies 1 to 4. The IOCI authors contributed to a multi-author paper accepted for an international journal and to another that has been submitted to Nature Geosciences. We have a third at an advanced stage of preparation and have presented IOCI research papers at several international symposia.

Technical Details

Study 1. Documentation of the quality of the tropical cyclone data set and of trends in cyclone numbers and intensity.

There have been a number of earlier studies demonstrating the existence of trends in either tropical cyclone numbers or in cyclone intensity in the Australian region. The studies have varied greatly in methodology and approach and the results are not consistent from study to study. An issue with such studies is that the primary methodology for determining both occurrence and intensity of tropical cyclones is based on imagery (visual and infrared) from meteorological satellites. The quality and availability of satellite imagery has changed continuously over recent decades; and algorithms to determine cyclone intensity have changed with them. This lack of "homogeneity" in the data set makes detection of trends difficult.

To help resolve these issues, the IOCI researchers combined with researchers from the Bureau of Meteorology National Climate Centre to carry out a careful documentation of the trends that occur in the official tropical cyclone data set since the beginning of the satellite era. Much attention was paid to documentation of changes in procedure. The second major focus was on the methodology of determining statistical significance. The purpose of the significance testing is to determine whether there are trends in the SH TC occurrence and intensity time series beyond what can be attributed to inter-annual variability and changes in observing procedure.

Through the collaboration with the National Climate Centre the study was carried out for tropical cyclones in the entire Southern Hemisphere. Reporting here the results for the Southern Indian Ocean only it was found that during the satellite era (since 1981) the trends in the frequency of cyclones are small and are not significant. Looking at the trends in the more intense cyclones, for most cyclone categories there is no significant trend. However, for the proportion of cyclones exceeding 940 hPa there has been an increase of the order of 20% increase in this proportion over a 25 year period. This trend is significant.

Some results of the study are shown in Figure1which is from the paper in press in the Journal of Geophysical Research. The ordinate of the figure is statistical significance (or p-value) expressed as a logarithm. The significance levels of 5% and 10% are marked by dashed lines. Any significances above these lines denote positive trends (increasing cyclones) significant at that level. Equivalent dashed lines at the lower section of the graph express the same significance levels for negative trends (decreasing cyclone numbers). The abscissa denotes various pressure intensity levels. Thus the plot at an x-value of 950R is the trend in the proportion of tropical cyclones with an intensity of 950 hPa central pressure or less. Similarly for 945R, 960R etc. The lines are for cyclone tracks across the Southern Indian Ocean (SIO), the entire

Southern Hemisphere (SH), the Australian Region (AR) and the South Pacific (SPO). The plot for the Southern Indian Ocean shows statistically significant trends in the proportion of higher intensity cyclones (945 and 950 hPa) but not for the proportions of medium intensity and not for the total number of cyclones (plotted as 995 TC's).

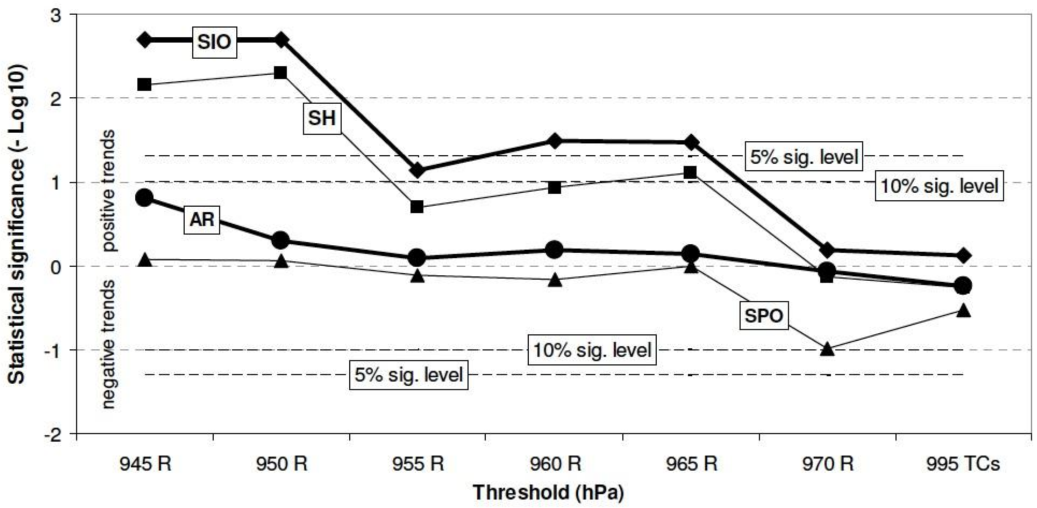

Figure 2.2.1 Significances of the linear trends in tropical cyclone indices over the 26-year period 1981/82 to 2006/07 for four regions (Southern Hemisphere SH, South Indian Ocean SIO, South Pacific Ocean SPO and Australian Region AR). Significances are shown for the trends in the 995 hPa TC numbers (effectively the total number of cyclones) , and trends in the proportions of 995 hPa 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. Also plotted are the 5% and 10% (two-tailed) significance levels.

A break-point analysis and qualitative assessment of changes in data availability and in operational procedures would suggest that these trends are influenced to some extent by changes in data quality. However, given the theoretical expectation that the response to the warming oceans will be in the number of most intense cyclones, it is also possible that the trends are indicative of this physical effect.

This study was completed during the first year of the IOCI project. It has been submitted to the Journal of Geophysical Research and is in Press: Reference:

Kuleshov, Y., R. Fawcett, L. Qi, B. Trewin, D. Jones, J. McBride, and H. Ramsay (2009), Trends in tropical cyclones in the South Indian Ocean and the South Pacific Ocean, J. Geophys. Res., doi:10.1029/2009JD012372, in press.

Study Two: Investigation of the ability to determine cyclone intensity trends from a homogeneous satellite data set.

During our investigations of the tropical cyclone data set for the Southern Indian Ocean we obtained a copy of a homogeneous satellite-derived cyclone intensity data set developed by researchers from NOAA. This data set is known as the University of Wisconsin/ National Climate Data Center UW-NCDC intensity data set. The data set was constructed from a reanalysis of global satellite imagery specifically for the purpose of constructing a set of uniform quality. Once completed, such a set could be used to develop a consistent satellite technique for determination of trends in cyclone intensity. Results of such a procedure have been published by the NOAA authors in two papers in Science in 2007 and in Nature in 2008. The IOCI authors have obtained these data sets from the authors and have attempted to reproduce the results for the Southern Indian Ocean. As a result of these investigations we have learned the original authors have applied a satellite viewing angle correction to the Indian Ocean data which has the effect of changing the trends in intense Indian Ocean cyclones from non significant trends (pre-correction) to positive trends (post correction). We have also carried out investigations into the appropriate statistical significance tests to be applied in this work. A paper on this research is currently under preparation to be submitted to an international journal. The implications of this research for cyclone projections is that the noise in the system (the interannual variability) is so large that it will take many more years of data before a trend can be distinguished from the background “noise”.

Study three: Investigation of the relationships between Indian Ocean cyclone activity and the underlying sea surface temperature.

The relationship between tropical cyclone and sea surface temperature has been studied for both the Southern Indian Ocean and for the entire Southern Hemisphere. The major finding is that in-situ statistical relationships (such as liner correlations) between indices of cyclone activity and sea surface temperature are dominated by large scale patterns, reflecting the large scale structure of the El Nino-Southern Oscillation or ENSO phenomenon. This is illustrated in the Figure 2. The figure shows the linear correlation coefficient between the number of tropical cyclones in the West Australian region with gridded sea surface temperature analyses. The value at each point is the correlation between sea surface temperature at that point with the total number of tropical cyclones over a season.

The box off Northwestern Australia denotes the region over which the tropical cyclones were counted. The upper panel shows the correlations against sea surface temperatures at the beginning of the cyclone season: October through December. There is a red coloured area of positive correlations in the box, denoting the correlations are positive, meaning warmer seas correspond to more tropical cyclones. However, the in-situ correlations in the box are no greater than correlations across wider oceanic domain; and in fact the correlation pattern closely resembles the patterns of sea surface temperature associated with the ENSO phenomenon. This is confirmed in the lower panel which shows tropical cyclone numbers in the same box off Western Australia correlated against mid-season (January to March) sea surface temperatures. Now the in-situ correlations (in the box) are blue or negative. This corresponds to warmer sea surface temperatures being associated with fewer cyclones. The proposed explanation for this is that the in-situ association is dominated by the large scale structure of the sea surface temperature anomalies. The variability of both tropical cyclones off western Australia and sea surface temperatures across the domain is dominated by their separate associations with ENSO. A common index of ENSO is the sea surface temperature over the Nino 3.5 region, which is marked by the black-boxed outline on the figure in the central Pacific.

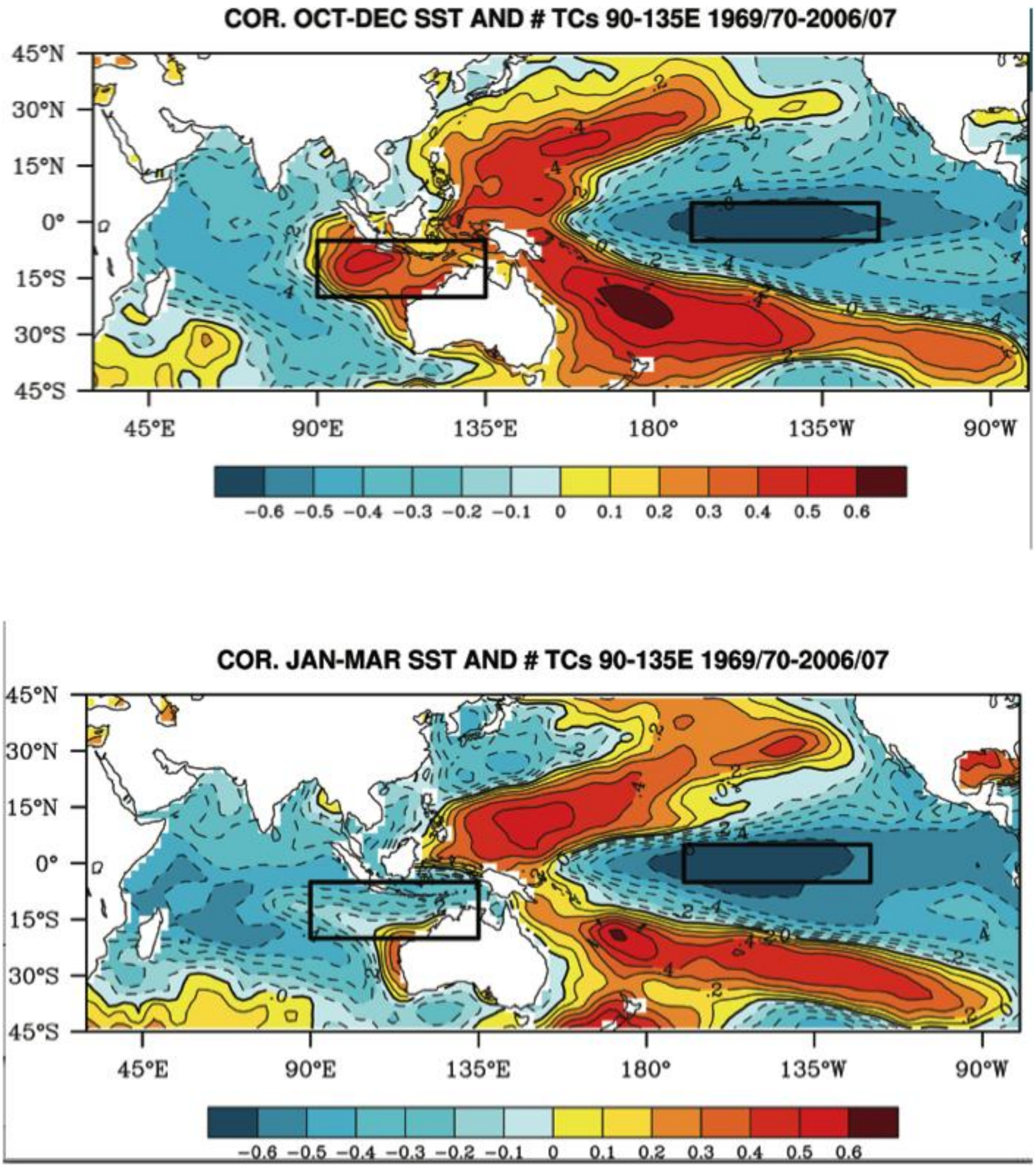

Figure 2.2.2 Patterns of linear correlation coefficient between the number of tropical cyclones in the boxed area northwest of Australia versus sea surface temperature at each point in the Indian and Pacific Oceans. The upper panel shows correlations with sea surface temperatures during October-December. The lower panel is for sea surface temperatures from January to March. The boxed area in the Central Pacific denotes the region of the Nino-3.5 Enso index.

The implications of this for tropical cyclone response to global warming are that the relationship between cyclone activity and sea surface temperature is not simply a local one. The sea surface temperature responds to the circulation on a planetary scale. Possibly the cyclones respond to local sea surface temperatures; but they also respond to the same planetary scale influences that govern ENSO behaviour. This makes the scientific issue of determining the response of tropical cyclones to changing sea surface temperatures more complicated. To determine such a response the sea surface temperature changes must be interpreted in terms of their effect on the larger scale dynamical circulations systems which give rise to cyclones.

This work has been presented at two major conferences.

Study 4: An international assessment statement on progress in the science of climate change impacts on tropical cyclones.

The IOCI project contributes to Dr John McBride's participation (as co-chair) of a WMO (World Meteorological Organizations) Expert Team on Climate Change Impacts on Tropical Cyclones. During year-one of IOCI-3, this group has prepared an expert assessment statement on tropical cyclones and climate change, submitted to Nature Geosciences. Since the paper is still under review, we will include a full report in the next Milestones Report.

Publications

Thomas Knutson, John McBride, Johnny Chan, Kerry Emanuel, Greg Holland, Chris Landsea, Isaac Held, James Kossin, A. K. Srivastava, and Masato Sugi, Tropical Cyclones and Climate Change: An Assessment. Submitted to Nature Geosciences.

IOC-Related Presentations

John L McBride and Hamish Ramsay: Southern Hemisphere Sea Surface Temperatures and Tropical Cyclone Activity. Greenhouse 2009. Perth Australia, 23 – 26 March 2009.

John McBride and Hamish Ramsay: Relationships between tropical cyclone activity and
sea surface temperature in the Southern Hemisphere. Second International Summit on Hurricanes and Climate Change, Aegean Conference, Corfu Greece, 31 May – 4 June 2009.

MILESTONE 2.2.2: A STATISTICAL FORECAST MODEL FOR TROPICAL CYCLONE ACTIVITY ALONG THE WESTERN AUSTRALIAN COASTLINE (2-WEEK LEAD TIME)

Summary

A statistical forecast model the 1 week to 3 week time frame has been developed for the western Australian region. The model is based on an earlier model developed by Leroy and Wheeler (Monthly Weather Review 2008). To carry out the development of the new model the first author of the earlier model (Anne Leroy) was employed on IOCI funds on a 2-week consultancy in late 2009.

One change from the earlier model are new predictors representing the influence of ENSO, the Indian Ocean dipole and the Modoki structure of ENSO events. The second change is the representation of the forecasts in terms of spatial maps. The forecasts are based on a logistical regression model. The primary predictors are a smoothed daily climatology at each forecast The project is essentially completed; and the forecasts from this new model are operational on the web-page of Meteo France at web address http://www.meteo.nc/espro/previcycl/cyclA.php

An example forecast from that web-page is shown in Figure3. Despite the fact the research has been completed, the paper for an international journal has not yet been written. In addition, development of the model has produced a set of data and algorithms that will be useful for investigation of large-scale forcing on Southern Hemisphere and Southern Indian Ocean cyclones. It is anticipated there will be further development in the coming year under the IOCI project.

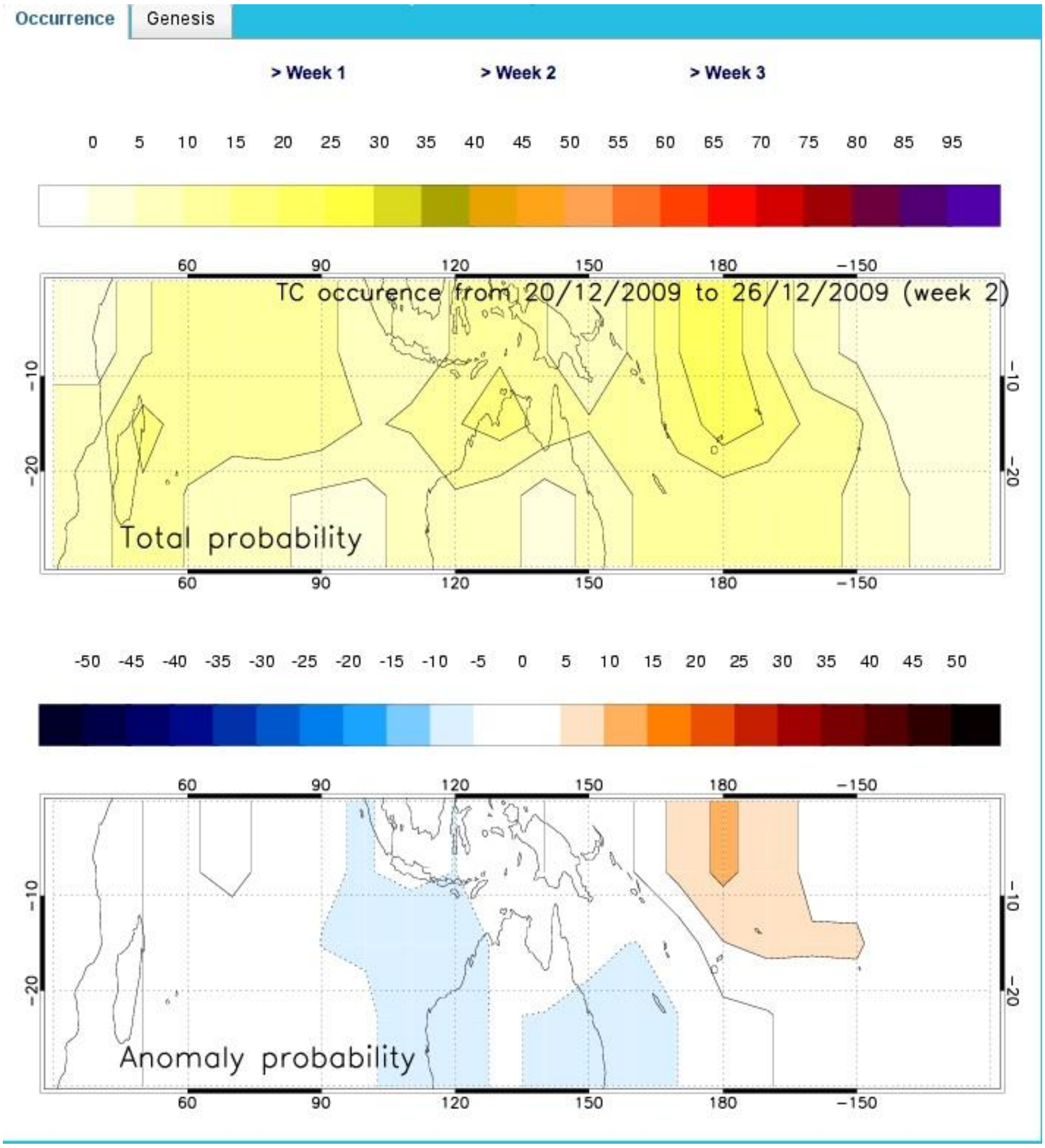

Figure 2.2.3 A sample forecast for tropical cyclone activity screen captured from the Meteo France website http://www.meteo.nc/espro/previcycl/cyclA.php. This forecast model was developed by the IOCI project in collaboration with researchers from CAWCR and from MeteoFrance. The upper panel is the forecast probability of occurrence for a period from 8 to 14 days future from the time the forecast was issued. The lower panel shows the deviation of the forecast from one obtained simply by use of the primary predictor: daily climatology. The coloured shading represents different probability levels as denoted on the keys.

MILESTONE 2.2.3: RESEARCH PAPER ON THEORETICAL FRAMEWORK FOR UNDERSTANDING INTERANNUAL VARIABILITY OF TROPICAL CYCLONE BEHAVIOUR IN THE SOUTHERN INDIAN OCEAN.

Summary

This research is scheduled to occur over the period 1 January 2009 to 31 December 2010. There are several approaches being undertaken. Known large scale influences on tropical cyclone behaviour are the a) monsoon trough and b) Sea Surface temperature. A data set has been constructed of daily values of relative vorticity and vertical shear in the monsoon trough across the Southern Hemisphere. A data set has been constructed for daily sea surface temperature for each tropical cyclone in the Australian region, including those in the Southern Indian Ocean. The first analysis exercise has been on the relationships between daily sea surface temperature and tropical cyclone life-cycle. The influence goes both ways: the value of sea surface temperature should have some influence on whether cyclone development occurs and on the final intensity of the cyclone. A statistical phase-space analysis is being carried out to determine the nature and strength of these relationships. The influence in the second direction is that the tropical cyclone extracts energy from the underlying sea surface. In addition it causes dynamical upwelling of the sea bringer deep,colder water to the surface. Both influences can cause a cooling of the sea surface through the presence of the tropical cyclone. A statistical analysis is under way to determine the magnitude of this effect. It is expected a paper will be submitted on this research during 2010.

MILESTONE 2.2.4: REPORT ON EXTREME TROPICAL CYCLONE BEHAVIOUR IN WESTERN AUSTRALIA AND THEIR ECONOMIC IMPACTS

Summary

So far only preliminary discussions and investigative research have been carried out in support of these milestones. The IOCI contract schedules this work to occur during 2010-2011.

MILESTONE 2.2.5: STATE OF KNOWLEDGE REPORT ON TROPICAL CYCLONE DYNAMICS, DATABASES AND CURRENT PRACTICES RELEVANT TO WESTERN AUSTRALIA

Summary

So far only preliminary discussions and investigative research have been carried out in support of these milestones. The IOCI contract schedules this work to occur during 2010-2011.

LIST OF FIGURES