Tropical cyclones in a changing climate: research priorities for Australia

Abstracts and recommendations from a workshop held on 8 December 2006 at the Bureau of Meteorology in Melbourne

Scott Power and Karen Pearce (Editors)
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FOREWORD

In the wake of a number of recent high impact, high profile tropical cyclones, such as Hurricane Katrina in the United States and Tropical Cyclone Larry in Australia, there has been a great deal of interest in the impact of climate change on tropical cyclones. Recent studies suggest that the frequency of the most intense tropical cyclones has increased in many regions, while other studies highlight observational errors that makes quantification of trends difficult (Kepert 2007). While the apparent increase can not be unambiguously linked to the global warming that has already taken place, a general increase in tropical cyclone intensity is expected in response to future global warming (IPCC 2007).

These issues have highlighted the need for greater understanding of tropical cyclones in our region, how they have changed in the past, how they might change in the future and what implications the changes have for Australia.

In December 2006 a national workshop was held at the Bureau of Meteorology, at the request of the Australian Greenhouse Office, to discuss research priorities for tropical cyclones in the context of a changing climate. The workshop was attended by 24 experts from the Australian Greenhouse Office, CSIRO, Geoscience Australia, Systems Engineering Australia, Macquarie University, JDH Consulting, Risk Frontiers, Monash University, James Cook University, the University of Melbourne, and the Bureau of Meteorology.

Workshop participants were asked to identify the key issues for Australia related to tropical cyclones in a changing climate, and the research that is needed to address the issues. Issues and priorities in both climate science and in “impacts and adaptation” research were considered.

This document is a record of that workshop. It provides recommendations for research priorities for Australia and a brief description of suggested activities to address these priorities. This report also includes abstracts of the seminars given during the workshop.

Should you have any feedback on the priorities, recommendations or activities suggested in this report, please don’t hesitate to contact me.

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References

Tropical cyclones in a changing climate: Key issues for Australia

Climate science

1.1 How will tropical cyclones (e.g. intensity, tracks, frequency, size and fetch) in our region change in the future under global warming?

1.2 How have tropical cyclones in our region changed in past, during and before the historical period?

1.3 What caused these changes? To what extent has human interference in the climate system played a role?

1.4 A substantial increase in our understanding of the physics of tropical cyclones, from genesis, through maturation and decay, is required in order to improve our ability to address 1.1-1.3.

Impacts and adaptation

2.1 What is our current exposure and vulnerability to tropical cyclones, and what are the associated risks?

2.2 How will the impact of tropical cyclones on extreme winds, storm surge, wave action, coastal inundation, coastal erosion, flood, landslides, groundwater recharge, etc. change in the future under global warming?

2.3 How will vulnerability and risks associated with tropical cyclones (to e.g. health, life, natural and agricultural systems, infrastructure and economic growth) change in the future because of global warming*?

2.4 How can these risks be reduced by government, business, community or individual action?

*Vulnerability and risks will also change because of other factors e.g. rapid population growth and more infrastructure in regions where tropical cyclones make landfall. The changes due to global warming will be a function of these other factors.
Tropical cyclones in a changing climate: Research priorities

Climate science

CS1. Increase understanding of the physics of tropical cyclones, and use this to improve techniques underpinning projections of tropical cyclones

Most important

CS1.1 Improve understanding of the physics associated with tropical cyclone genesis and the intensity, tracks, and size of tropical cyclones in our region, using observations and models specifically designed to examine tropical cyclones. Improve representation of tropical cyclone winds in idealised models used to drive e.g. storm surge models.

CS1.2 Understand (i) upper bounds of tropical cyclone intensity by improving “potential intensity theory” and (ii) critical relationships between tropical cyclones and the coupled atmospheric and oceanic boundary layers.

Important

CS1.3 Increase understanding of the properties and behaviour of land-falling tropical cyclones, and associated rainfall, winds (especially at low levels, e.g. using portable towers), wind gusts (and their relationship with winds averaged over 10 minutes and longer), turbulence and interactions with boundary layers and steep topography.

CS1.4 Improve the categorisation of relationships between tropical cyclone genesis types, tropical cyclone intensity and broad-scale fields (e.g. SST, vertical shear, large-scale atmospheric vorticity/circulation). Understand tropical cyclone genesis precursors such as monsoon onset, the El Niño-Southern Oscillation, and the Madden-Julian Oscillation.

CS2. Detection and attribution

Most important

CS2.1 Document trends and decadal changes in tropical cyclones in our region during the historical period and examine causes.

CS2.2 Infer multi-decadal and longer-term variability in tropical cyclones in the pre-instrumental period using palaeo-climate records (e.g. beach ridges, lagoon sediments, speleothems, corals) and analysis. Clarify chance of extremely high (“super tropical cyclone”) winds over Australia.

Important

CS2.3 Make the most recent high resolution dynamical atmospheric reanalyses available for analysis and use.
CS3. Data rehabilitation and reanalysis

Most important

CS3.1 Rehabilitate and re-analyse tropical cyclone best track, intensity and size data, to produce homogeneous tropical cyclone track, intensity, size, frequency data from the beginning of the geostationary satellite era.

Important

CS3.2 Rehabilitate and re-analyse tropical cyclone data during the pre-geostationary satellite era using available polar-orbiting data.

CS3.3 Re-analyse land-falling tropical cyclone data to produce a more homogeneous multi-decadal data set.

CS4. Improve the ability of climate models to simulate tropical cyclones and tropical cyclone variability

Most important

CS4.1 Improve ability of climate models to simulate ENSO and other natural modes of variability that influence tropical cyclones.

CS4.2 Increase the resolution of climate models (e.g. ACCESS) and improve the treatment of subgrid-scale processes in climate models (e.g. ACCESS, regional models) crucial to tropical cyclones (e.g. convection, air-sea fluxes).

CS5. Projections

Most important

CS5.1 Use existing techniques to estimate what will happen to tropical cyclones (intensity, frequency, tracks, peak winds, rainfall, cyclogenesis, structure, size, relationships with large-scale “forcing” fields, transition to extratropics) under global warming using (i) regional climate models (ii) ACCESS, (iii) high resolution limited domain models specifically designed to simulate tropical cyclones. Production of projection data and uncertainty estimates in the form of probability density functions (e.g. frequency, intensity) needed to force impacts models is a priority.

CS5.2 Use CS1.1 and CS1.2 to improve our ability to diagnose tropical cyclones from regional models and global climate models (ACCESS), and use this information to improve projections.

CS5.3 Understand how global warming influences things that modulate tropical cyclone genesis, like ENSO, the monsoon, and the Madden-Julian Oscillation.

Important

CS5.4 Examine the impact of global warming on the zone of “extra-tropical transition”.
CS6. Strongly endorsed research climate change science research priorities

CS6.1 Ensure that research conducted in Australia is coordinated at national level (e.g. through collaboration with the Australian Tropical Cyclone Coastal Impacts Program) and that strong collaborative links are maintained with key researchers at the international level.

Initiatives in the wider community to conduct the following research are strongly endorsed:

CS6.2 Examine the feasibility of obtaining a more accurate description of tropical cyclone structures and properties to increase understanding and to improve the calibration of satellite tropical cyclone intensity estimates by conducting reconnaissance flights into future Tropical cyclones that occur in the Australian region.

CS6.3 Improve our ability to forecast ENSO events using systems based on dynamical models.

Impacts and adaptation

IA1. Increase understanding of the potential future impacts from tropical cyclones

Most important

IA1.1 Increase understanding of the potential future impacts from tropical cyclones in the following regions, systems and sectors thought vulnerable to tropical cyclones and climate change:

- tropical and sub-tropical population and resort centres;
- remote indigenous communities, particularly in far north of Australia, including Torres Strait Islands;
- developing countries in our region;
- key, iconic or World Heritage listed systems thought vulnerable to global warming (e.g. the Great Barrier Reef, wetlands including Kakadu, Ningaloo Reef, tropical rainforests, coastal mangroves; agricultural, industrial and resource sectors;
- key infrastructure.

IA1.2 Undertake 1.1 by estimating the future impact of tropical cyclones on: sea-level, winds, wave action, storm surge, and flooding in vulnerable regions. Quantification of uncertainty is essential. [Associated project: Apply improved idealised tropical cyclone forcing functions, statistics on tropical cyclone frequency, projections of sea-level rise, and dynamical models of storm surge and waves, to provide improved estimates of the impact of tropical cyclones on storm surge and waves in current and future climate.]

IA2. Increase understanding of the current impacts from tropical cyclones in regions and systems thought vulnerable to tropical cyclones

Most important

IA2.1 Quantify the impact of tropical cyclones on coastal communities under “current” conditions by e.g. conducting case studies of past events to build a better catalogue of tropical cyclones. (What happened? What damage occurred? What costs were incurred?)
IA2.2 Increase understanding of current tropical cyclone exposure, vulnerability and associated risks.

IA3. Develop and improve data sets needed for impacts research

Most important

IA3.1 Reanalysis of tropical cyclone tracks, intensity, size, frequency data during the geostationary satellite era to produce best estimate of each event with less emphasis on homogeneity issues.

IA3.2 As in 3.1 but reanalyse pre-geostationary satellite era using available polar-orbiting data.

IA3.3 Reanalyse related properties – central pressure, eye size (radius of max winds), radius of gales (i.e. size), intensity, forward speed, rainfall, (non-homogeneous).

IA3.4 Develop high resolution coastal terrain height information (bathymetry and topography).

IA3.5 Digitise and obtain more tide gauge data for model assessment.

IA3.6 Develop a flood extent database for further development and assessment of inundation models.

Endorsed

IA3.7 Develop a high quality wind data set.

IA4. Improve impact models

Important

IA4.1 Assess and improve inundation models

IA4.2 Improve ability to model coastal erosion

Endorsed

IA4.3 Support development of models that provide better estimates of wave set up and run-up changes

IA5. Behavioural science

Endorsed

IA5.1 Understand reactions to climate change projections, preparation conducted (e.g. take out insurance), and perceptions of risk in the community.

IA6. Assist risk management

Endorsed

IA6.1 Determine options and recommendations for mitigation strategies for tropical cyclone disaster risk management in face of global warming.
Tropical cyclones in a changing climate: Addressing the research priorities

After the workshop participants and others with expertise in the area who were unable to attend were asked to suggest projects and activities that address some of the recommendations. The suggestions are given below.

Understanding the relationship between tropical cyclones and large-scale atmospheric parameters.
Research priorities: CS1.1, CS1.2/Contacts: John McBride, Kevin Walsh and Neil Holbrook

This project will look at which aspects of the large-scale structure of the tropical atmosphere lead to tropical cyclone development, and what controls tropical cyclone frequency, and provide information that is crucial if scientifically sound projections of tropical cyclones from climate models are to be made. The project aims to:

- Document trends in tropical cyclone frequency in the Australian over the satellite era, including associations with sea surface temperature.
- Document the dynamical atmospheric structures leading to tropical cyclone development for all cases over the past five years, thus giving a synoptic climatology of tropical cyclone development.
- Document large-scale atmospheric structure accompanying all cases of extreme or unusual tropical cyclone behaviour in the historic record. Besides the most intense cyclones, such extreme events would include those making landfall furthest south and those leading to large scale flooding.
- Exploit the improved understanding to infer tropical cyclone changes under global warming using climate models.

Document and understand decadal and longer-term changes in the frequency of land-falling tropical cyclones over north-eastern Australia.
Research priority: CS2.1/Contacts: Jeff Callaghan and Scott Power

The frequency with which tropical cyclones have made landfall in north-eastern Australia has varied considerably over the past century. The purpose of this study is to document decadal and longer-term changes and to examine possible reasons for the variability.

Improving our understanding of tropical cyclone behaviour from palaeo-records.
Research priority: CS2.2/Contact: Jon Nott

It has been suggested that humans may be responsible for an increase in the destructiveness and intensity of tropical cyclones over the past 30 years. Others suggest that the apparent changes in tropical cyclones during recent decades are due to natural variability. We have records of tropical cyclone incidence for Australia that only date back to the late 19th century. This is not very long if one wishes to examine trends and multi-decadal variability. There is a clear need to significantly improve our knowledge of the size and character of naturally occurring changes in Australian tropical cyclones over the past 1,000-2,000 years. This project will address this need by assembling and analysing palaeo-data in northern Australia.

Long-term, high-resolution isotope records of tropical cyclones in calcite stalagmites will be used. These records provide superior proxies to tropical cyclones than do sedimentary records (ridges of sand, coral and shell) because they register a broad intensity spectrum of events and at
much higher resolution (annual and sub-annual). Preliminary work on these records in north Queensland shows that they record decadal to centennial tropical cyclone/climatic variability over the past 1,000 years. This variability can be used as a benchmark for comparisons with recent changes in tropical cyclone behaviour. Our technique - examining isotopic records of tropical cyclone rainwater in calcite stalagmites - is the only approach developed thus far that will provide us with this information.

We will collect and analyse stalagmite samples from across tropical northern Australia (Queensland, Northern Territory and Western Australia) to obtain a high resolution record of these events for the past 1,000-2,000 years. We expect to collect at least 10-15 individual samples which will provide a broad geographical coverage of the tropical cyclone affected northern Australian coast. Analysing these samples is time consuming and we expect to be able to run 4-5 samples per year. Hence we envisage this project taking approximately three years. As a consequence we will obtain the most detailed insight into long-term tropical cyclone behaviour for any region globally.

A new high quality tropical cyclone data base for the Australian region.
Research priority: CS3.1/Contact: David Jones

Considerable debate exists over whether significant changes in tropical cyclone frequency and/or intensity can be detected in the observational record. A key uncertainty in all observation based studies of tropical cyclones is the reliability of historical cyclone observations. The Bureau of Meteorology, in partnership with the Australian Greenhouse Office, has recently developed the first consolidated and quality controlled database for Australian tropical cyclones. These data are now freely and openly available at http://www.bom.gov.au/climate/change/. This dataset is based on operational best track data from the Bureau’s weather forecasting offices and elsewhere.

While this new data set represents a considerable improvement, there remains uncertainty about past tropical cyclone track and intensity estimates, and the influence of changing data availability and analysis techniques on trends in the data, particularly the effect of increased use of satellite data. These mean that all subsequent analyses are subject to some uncertainty which increases backwards in time.

There is a need to engage a full and comprehensive reanalysis of past tropical cyclones using modern day analysis techniques and associated systems applied to past data.

This project has an important scientific component centred on two key questions. The first is defining the most suitable method for reanalysing historical data such that these become most consistent with current practice. The second relates to the impact that observation changes (e.g., in networks, satellites) have on track and intensity estimates of tropical cyclones. This second issue sets the confidence bounds that can be placed on tropical cyclone datasets and subsequent analyses.

The project will deliver a new high-quality reanalysed tropical cyclone database for the Australian sector together with uncertainty estimates for tracks and intensities.

Improve the landfalling tropical cyclone database in north-east Australia.
Research priority: CS3.1/Contact: Jeff Callaghan

The tropical cyclone landfalling database provides an invaluable record of the tropical cyclones that have actually made landfall, including all of the tropical cyclones in the region that have caused the greatest damage and the greatest loss of life. The database used information from a
variety of sources including newspaper reports. Some old newspaper reports have not yet been exploited. This will be addressed in this project in order to improve the database.

**Improving tropical cyclone projections**  
Research priorities: CS4.1, CS4.2, CS5.1, 5.2, 5.3/Contacts: Kevin Walsh and Debbie Abbs

One of the main issues limiting confidence in climate model projections of changes in tropical cyclone characteristics is that climate models generally tend to produce too few tropical cyclones (i.e. tropical cyclone genesis problem), and those that are produced tend to be of insufficient intensity compared with observed tropical cyclones. In addition, tropical cyclone numbers in the Australian region are related to “large scale” circulations such as ENSO, the Interdecadal Pacific Oscillation and the Madden-Julian Oscillation. The ability of GCMs to simulate these circulations is still another cause for uncertainty in the development of projections for changes in tropical cyclone characteristics.

There are a number of possible ways that the intensity and genesis issues could be addressed. Increased resolution is obviously one, through the use of regional climate models or variable-resolution models. It has been suggested that resolutions of at least 5 km, and possible as fine as 1 km, are needed for accurate simulation of tropical cyclone intensity. These resolutions have not yet been achieved for climate simulation of tropical cyclones, and yet are feasible provided that a regional or variable-resolution model is used. Considerable savings in computer time could be accomplished if the storms were only simulated at this resolution when precursor vortices are generated at lower resolution, since tropical cyclones are rare events. Higher resolution and complex cloud microphysics schemes provide an improved representation of the convective processes that are at the foundation of tropical cyclone genesis. Sensitivity tests with these more complex modelling systems will improve our understanding of tropical cyclone genesis and provide a framework that allows us to define the physical processes important for tropical cyclone genesis and the resolution necessary to capture this process. Similar experiments are important for the real-time prediction of tropical cyclone genesis, although in that case the initiation of convective scale processes is aided through the assimilation of satellite-based convective heating.

Performance of the ACCESS modelling system at generating tropical cyclones needs to be assessed. It is likely that its current capability, whatever that is, will need to be improved, involving experimentation with resolution of its limited-area climate modelling capability, with convective and microphysical parameterizations and perhaps even elements of the dynamics in the model. The ACCESS modelling system and existing simulations should be assessed to determine their performance in capturing the relationship between the large-scale circulations described above and tropical cyclone numbers in the Australian region.

**Improve understanding of landfalling tropical cyclones**  
Research priority: CS1.3/Contact: Jeff Kepert

Landfall is typically the moment in a tropical cyclone’s life where it is most hazardous, since the cyclone has not yet begun its inevitable decay as it moves inland, but first encounters a large amount of people and infrastructure. In addition, storm surge is a major cause of death and damage that occurs only at landfall, while freshwater flooding from rain can extend inland from the landfall zone and remain an issue for days after the cyclone passage. Forecasting the latter can be particularly difficult, and it is not unusual for relatively weak storms to be major flood producers. In cases where the landfall region is mountainous, such as during the landfall of Tropical Cyclone Larry near Innisfail, channelling and acceleration of the winds by topography can lead to locally severe damage, while orographic uplift can cause extremely heavy rainfall.
A complete characterisation of the hazard posed by tropical cyclone winds requires knowledge of their turbulent structure, since it is the gusts which are responsible for much of the damage. The recent discovery of coherent roll vortices in the tropical cyclone boundary layer complicates the issue, and further observational and theoretical work is needed to adequately characterise the risk posed by these features. Proximity to land imposes a frictional asymmetry on the near-surface winds in a tropical cyclone, which early work indicates may have a major impact on the location and strength of the strongest winds. Further research is needed to fully elucidate the consequences of this process, and extend the work into a consideration of the interaction of the tropical cyclone boundary layer with orography.

**Improve the tropical cyclone coastal impacts data base**
Research priorities: IA1.1, IA1.2, IA2.1, IA2.2/Contact: Bob Cechet

The public perception of their exposure to tropical cyclones (winds, inundation and estuarine flooding) is extremely poor, mainly due to the generational or greater return period (20-50 years) between significant damaging events. An increased understanding of current tropical cyclone exposure, vulnerability and associated risks has emerged as a high priority among the delegates at this workshop, and is extremely relevant to the future risk of these occurrences.

To demonstrate how cyclone impact information can be prepared/displayed for "public consumption", we need to analyse some of the high-impacting past tropical cyclone landfall events (historical case studies linked to actual impact such as damage and environmental destruction) and explore using scenarios with such factors as the effect of level of the tide and extent of estuary flooding (interactively) embracing GIS mapping techniques. This allows the public and interested parties the ability to overlay the local roads, infrastructure and critical facilities (hospital, police, SES) onto high resolution satellite maps to visualise their vulnerability. Extending this case study so that the tool can be used with a preliminary understanding of "return period" for the magnitude of the tropical cyclone would allow us to introduce the consideration of climate change and demonstrate its impact in a spatial sense.

The goals of this project would be public/community education and engagement, with tools being available on the Internet. In this way the wider community could also gain some insight (i.e. If the damaging 1918 cyclone that hit Mackay was studied - 2-3 metre waves in the main street - the concepts would be relevant to nearby towns such as Rockhampton, Townsville, etc as structures types and planning regimes are common). These case studies could initiate similar work in other communities when the utility of these case studies is understood and embraced by local planning authorities and emergency services.

Indicative timelines: Considering three sites are selected, one in each of the three cyclone prone states (i.e. Mackay, Darwin, Broome for example), and evaluating outcomes for wind damage, storm surge and estuarine flooding, this project could be undertaken by two people in one year. It may be prudent to spread the project over two years so that initially one site is considered and the web-enabling tool is developed and discussed with some stakeholders. In the second year, the initial site could be refined and the other two locations could be undertaken to the same level.

**Improve the tropical cyclone coastal impacts data base**
Research priorities: IA1.1, IA1.2, IA2.1, IA2.2/Contact: Jim Davidson

The Australian Tropical Cyclone Coastal Impacts Program (ATCCIP) was launched in 1994 to help focus research attention and resources on the problem of increased hazard levels and vulnerability of our coastal communities from tropical cyclone impacts. The increased pressure on tropical cyclone risk management results from the large demographic growth in coastal
areas. Seed funding for specific research projects was provided by the National Greenhouse Advisory Committee and has since been augmented by funding from Queensland Emergency Services, The Australian International Decade for Natural Disaster Reduction Committee, Australian Research Council, US Office of Naval Research, and the insurance industry as well as substantial commitments by Macquarie University, Bureau of Meteorology, James Cook University and Australian National University. ATCCIP provides an excellent coordinating framework in which Australia can advance our understanding and management of tropical cyclone impacts on coastal communities and environments. This project will help enable ATCCIP to update the Australian coastal impacts data base. (ATCCIP could also act as a coordinator of research through the development of a web-site and through annual, national conferences, if funding was made available).

**Develop a data base on storm surge risk assessments made across northern Australia.**
Research priorities: IA1.1, IA1.2, IA2.1, IA2.2/Contacts: Jim Davidson and Kathy McInnes

Tropical cyclones represent a major driver of storm surge in northern Australia and this can have major impacts on coastal communities and environments. Storm surge risk assessments have been made in many parts of Australia by numerous agencies. There is currently no single data base that summarises the assessments that have been made. The methodologies used are not always easily identified by other groups making assessments. Nor is it clear which assessments have factored in risks associated with climate change. A coherent single data base would be useful to people who have to make assessments in the future.

ATCCIP will convene a national conference to develop a coherent description of storm surge risk assessments that have been made across northern Australia. This will include a description of contact information, conclusions, methodologies, and the extent to which climate change was considered in making the assessment.

**Contribute towards international data base on tropical cyclone impacts**
Research priorities: IA1.1, IA1.2, IA2.1, IA2.2/Contact: Jim Davidson

The International Workshops on Tropical Cyclones (IWTC) are a quadrennial series of workshops organized by the World Meteorological Organization. The goals are to bring researchers and forecasters from around the world together in a workshop format to discuss pressing tropical cyclone issues and to plan for future collaborative activities. A major recommendation of the most recent workshop (IWTC-VI, Costa Rica, November 21-30, 2006) was that:

“… an international database should be developed to track the loss of human life and socio-economic impacts of tropical cyclones as well as the costs associated with tropical cyclone forecasting and disaster mitigation initiatives. A small multi-disciplinary taskforce should be formed to monitor the development of the database and to liaise with other groups having a similar goal.”

**Quantifying storm surge risk**
Research priority: IA2.2/Contact: Kathy McInnes

Due to the sparsity of tropical cyclone and tide gauge data in tropical locations, different methodologies have been devised and applied to establish current storm surge risk that rely on a combination of statistical modelling to generate a sufficient sample of tropical cyclones over a location of interest and deterministic modelling to determine the coastal ocean response using
mainly storm surge models, although some studies have also included the wave effects. However, differences between these methodologies have led to markedly different return level estimates for storm tide. The assessment of the impact of climate change on tropical cyclone introduces another potential point of divergence with broad estimates of the change in tropical cyclone intensity or frequency being interpreted and applied differently to the statistical modelling of tropical cyclones. Finally, little attempt has been undertaken to assess the affect of climate variability on storm surge risk. A priority research activity involves obtaining some consensus between practitioners in this field as to the most appropriate methodology to follow. This may be best undertaken through an intercomparison project that leads finally to recommendations that are published in the peer reviewed literature. This could be achieved running a series of workshops between people having undertaken studies to quantify storm surge hazard to establish a best practice methodology for use in such studies. It is envisaged that this could be carried out as an ATCCIP activity with funds supporting the involvement of key practitioners in this area.

**Improve estimates of overland flooding driven by storm surge**

Research priority: IA4.1/Contact: Kathy McInnes

While a number of studies have evaluated current and future likelihood of extreme sea level as a result of climate change, few studies have addressed the overland flooding of the storm surges and the risk that this poses to coastal communities. There are several reasons for this, including:

1. the high resolution of models required to undertake this work
2. the lack of high resolution digital terrain information
3. the lack of established data bases of flood extent from historical storm surges that would facilitate the benchmarking and improvement of the inundation capability of coastal ocean models.

The development of high resolution digital elevation data for use in coastal modelling is a broader issue for coastal modelling and should sit outside the scope of this proposed program of work. However, the other two issues need to be addressed by supporting activities that improve coastal inundation modelling in tropical regions. The first is support for detailed case studies that attempt to reconstruct and document the characteristics of significant historical storm surge and flood events and compile the associated data that accompanies them. Such data could then be used in subsequent inundation model development and application which would form the second class of research activity that should be supported to improve the inundation modelling capability. Further development in these two areas will help to underpin subsequent studies into studies of storm surge impact under current and future conditions.
Impact of tropical cyclones on Australia

Bob Cechet and Craig Arthur

Risk Research Group, Geoscience Australia

Introduction

As humans continue to develop coastal regions around the world, the monetary impacts of tropical cyclones will continue to increase. Worldwide, an average of 84 tropical cyclones form each year. Those that make landfall kill over 20,000 people and cause about $10 billion in damage. In the past few decades, the primary cause of increased damage by the landfall of tropical cyclones (particularly in the United States) has been increased coastal development. Of particular concern is the damage potential of intense tropical cyclones, which is likely to increase with sea surface temperature increases caused by global warming. Equally of concern is the significant economic impact that is very much influenced by “one-off” events due to the continuing urbanisation of the Australian continent. Detrimental changes in cyclone extent, peak rainfall, flood and storm surge return periods appear likely in a warmer world producing a greater risk of damage to coastal infrastructure and environment. A better understanding of cyclone hazard, exposure, vulnerability and associated risks is needed to promote appropriate, cost-effective mitigation measures.

Key issues

- Issues are not limited to changes in tropical cyclone characteristics such as intensity, frequency, path and rainfall.
- Effects of sea level rise with respect to storm surge and wave action, inundation, coastal erosion, wave action on infrastructure and the urban envelope (urban fringe adjacent to estuaries or coastlines).
- Impact of urbanisation of coastal areas. This leads to increased exposure of not only population, but critical infrastructure such as health and emergency services and utilities.
- The perceived northward migration of the Australian population (according to the Australian Bureau of Statistics, Queensland, Western Australia and the Northern Territory have highest population growth rate). Associated with this is the population age profile – Australia’s ageing population.
- Impacts on agriculture and local economies (tourism), e.g. Tropical Cyclone Larry and the direct impact on Innisfail. Secondary impacts such as sediment and nutrient runoff associated with increased rainfall; inland rainfall climatology and groundwater recharge. Effects on spawning areas and nutrient runoff on fisheries.
- Rainfall – sediment and nutrient runoff (effects on agriculture, aquaculture, Great Barrier Reef). Inland rainfall climatology and groundwater recharge from ex-tropical cyclones and tropical depressions. Rainfall and associated effects (flooding, landslip, mudslides) have been the major cause of loss of life in recent decades (e.g. Typhoon Durian in the Philippines recently killed 1,000 people in mudslides (Holland 2002); Hurricane Katrina, Hurricane Mitch).
- Required changes in building codes and engineering design in the built environment – wind loading, flooding/inundation & stormwater.
- Death, damage, time rate of change of death rate.
- These are all related to landfall impacts of tropical cyclones, yet there is no national centre for tropical cyclone landfall research to coordinate this research.
• For tropical cyclone characteristics such as intensity, frequency and paths, and improved forecasts of these, there are no regular reconnaissance flights into tropical cyclones in the Australian region. Although there has been research into the changes of tropical cyclone characteristics in other regions, the applicability of these findings to Australian region tropical cyclones is not well known due to the lack of data.

Impacts

• Civil and municipal infrastructure: vulnerability of shelter and community infrastructure; role of building regulations (retrofitting older structures)
• Social dimension: vulnerability of different social groups; role of social networks (coping)
• Economic dimension: vulnerability of different economic sectors, such as tourism or agriculture
• Environmental dimension: environmental fragility (groundwater, land); dependency on environmental services
• Institutional dimension: effectiveness and failure of structures and institutions; critical infrastructure (communication, water, sewer, power, roads, bridges, airports)

Review of current activities in tropical cyclone impact research

Impact/landfall

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<thead>
<tr>
<th>Organisation</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bureau of Meteorology</td>
<td>• Development of cyclone track forecasting and verification techniques</td>
</tr>
<tr>
<td></td>
<td>• Forecast of rainfall at landfall</td>
</tr>
<tr>
<td></td>
<td>• Tropical Cyclone Coastal Impacts Program (ATCCIP) (managed by the Bureau)</td>
</tr>
<tr>
<td>Geoscience Australia</td>
<td>• Specification of wind field at landfall which is applicable to studies of the nature of induced damage and also storm surge.</td>
</tr>
<tr>
<td></td>
<td>• Event-based forecast of likely damage (via vulnerability relationships) and also long-term risk.</td>
</tr>
<tr>
<td>James Cook University</td>
<td>• (Centre for Disaster Studies) Assessing and evaluating community vulnerability to tropical cyclone impact and then devising strategies to minimise and reduce the vulnerability.</td>
</tr>
<tr>
<td>Australian Maritime College</td>
<td>• (Marine Modelling Unit) modelling waves and current and determining storm tide and storm surge water level frequencies</td>
</tr>
</tbody>
</table>

Understanding exposure

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geoscience Australia</td>
<td>• National Exposure Database (NBED) provides an inventory of commercial/ industrial/residential structures for major cities and towns (&gt;50,000 inhabitants)</td>
</tr>
</tbody>
</table>
Vulnerability

Bureau of Meteorology
- (Linda Anderson-Berry) investigating societal impacts of tropical cyclones and climate change

Geoscience Australia
- Developing both empirical and engineering-based vulnerability models relating wind-hazard to damage.

James Cook University
- (Centre for Disaster Studies) Population preparedness in tropical cyclone-prone regions
- (Cyclone Testing Station) Wind loading and engineering aspects of tropical cyclone impacts
- (Marine Modelling Unit) Wave exposure and storm surge along the Queensland coast

Scientific research that Australia needs to do in this area

Response
- Forecasting the impact (spatial features): damage, economic and social (displacement of population, medical needs, recovery, rebuilding)
- Critical infrastructure (maintaining or reinstating power, gas, sewerage, water supplies)
- Isolating/identifying worst affected areas for assigning resources (emergency services, rebuilding, clean-up)
- Research:
  - Establish a national centre for tropical cyclone landfall research to determine return rates, exposure and vulnerability, and undertake impact forecasting as well as to conduct research into recent historical and palaeo events, decay rates. There is little skill in forecasting intensity and structure of tropical cyclones at or near landfall. Tropical cyclone rainfall and resultant flooding requires significant research.
  - Undertake regular planned aircraft (or Aerosonde) flights to assist track and intensity forecasts and impact prediction.
  - Impacts of ENSO (or other inter-seasonal oscillations) on tropical cyclone variability in the east Indian Ocean and the South Pacific basins
  - Maximum intensity of tropical cyclones: Bister and Emanuel’s (1997) analysis shows the Timor/Arafura Sea region has the highest Maximum Potential Intensity (MPI), but this is not necessarily the site of the most intense storms. This could influence the hazard posed to Darwin and surrounds.

Mitigation
- Prioritise vulnerability (cities, towns, regions)
- Climate adaptation: changes to building standards; appropriate siting; retrofitting older buildings to current or new standards (Pielke 2006)
- Community capacity as part of a total warning system (Anderson-Berry 2006)
- What can historical data tell us about tropical cyclone risk and impacts (viz palaeotempestology)?
- What trends are there and what do they mean for impacts?
Foreign aid (AusAid)

- Response (assisting neighbours) – particularly developing countries
- Leadership – Australia is the first world nation in the region. We need to develop a region-wide understanding (not just local) and provide our nearby neighbours assistance, particularly with regard to infrastructure vulnerability and risk.

References


Observed global trends in tropical cyclones

Jeff Kepert

Bureau of Meteorology Research Centre

Introduction

Observed trends depend on the historical database. Best-track analyses are prepared as a by-product of operational forecasts and warnings, and are inhomogeneous with respect to both observations and analysis technique. A recent homogeneous database removes these problems, albeit over a relatively short period.

There are multiple measures of tropical cyclone activity, relating to various combinations of intensity, duration, track, landfall, area affected, and so forth. Assessed trends may be different for different measures.

Key issues

The key question is the quality of the database from which trends are being assessed. The introduction of, and subsequent improvements to, satellite imagery has lead to profound changes in our ability to detect and diagnose storms. It is difficult to impossible to separate the expected small climate signal from these observational changes, except perhaps in the North Atlantic where there is a long aircraft observational record. However, even this record is far from homogeneous in measurement technology, sampling strategy, or interpretation.

Once the data-quality issue is resolved, the trend in a variety of metrics can be explored. Metrics which emphasise intense storms are useful for assessing likely changes in wind impact. The historical databases’ record of storm size is less reliable than that of intensity, so assessing changes of surge hazard are more difficult. Rainfall is poorly correlated with intensity and not included in the database, so assessment of historical trends in this important parameter requires the integration of additional information.

Studies to date suggest the existence of multi-decadal cycles, possibly with a recent trend superimposed, in the North Atlantic record of the most intense storms. Similar trends apparently exist in other basins, but the data problems are sufficiently extreme as to engender low confidence in these findings.

Economic loss statistics show a marked upwards trend, but this can be attributed almost entirely to societal changes, which are substantially larger than changes in tropical cyclone activity.

Review of current research activities

Kossin et al. (2007) have prepared a satellite imagery record, dating back to the 1980s, centred on storm position, calibrated, and homogeneous in resolution (spatial, temporal and spectral). Objective analysis of storm intensity from this record reveals similar trends to other databases in regions with aircraft observations, but different elsewhere. There is a tendency for better agreement in more recent years.

Harper and Callaghan (2006) presented the results of a “re-Dvoraking” of some tropical cyclones in the Western Australian region. The trends in their reanalysis were smaller than in other studies.
Kamahori et al. (2006) compared the occurrence of intense tropical cyclones between the Japanese Meteorological Agency and U.S. Joint Typhoon Warning Center in the western North Pacific. The two best-track databases exhibited opposite trends for the most severe storms.

Shriver and Huber (2006) examined trends in the ERA-40 reanalysis’ depiction of tropical cyclones, but later analysis (reported on the tropical storms email list) casts substantial doubt on their methodology.

**Scientific research that Australia needs to do in this area**

Reanalysis of the historical record, and ensuring homogeneity in the future, are critical issues. We cannot reliably determine long-term trends in the Australian region at present; there is a risk that this statement could still be true in 20 years.

Interpretation of a reliable historical record requires an understanding of the processes that modulate tropical cyclone activity on intra-seasonal, inter-annual and multi-decadal time scales. This statement applies to multiple aspects of tropical cyclone activity: genesis, intensity, track, size and rainfall. Better understanding of the natural cycles will be of considerable value in its own right. Moreover, knowledge of such aspects is a necessary precondition to detecting anthropogenic changes, and to understanding the dynamics which connect oceanic and atmospheric temperature increases to tropical cyclone climate.

**References**


Tropical cyclone reanalysis
Blair Trewin
National Climate Centre, Bureau of Meteorology

Introduction

Determining the extent to which the occurrence of tropical cyclones, particularly intense tropical cyclones, has changed during the observational record is a very active field of research at present, especially in the North Atlantic basin. Similar analyses for the Southern Hemisphere have been limited by a lack of good-quality historical data. A number of projects are currently under way, or planned, at the Bureau of Meteorology to address this limitation.

Key issues

The ability to effectively analyse changes in tropical cyclone occurrence in the Australian region is inhibited by limitations in data availability and quality, particularly prior to the introduction of current satellite-based analysis techniques in the mid-1980s. Records of tropical cyclone occurrence are reasonably complete from about 1970 onwards, but the occurrence of intense tropical cyclones was greatly underestimated prior to about 1985, due to a reliance on surface data which rarely captured the full intensity of cyclones. The current database structure also does not contain information on the category rating of cyclones, or wind speeds prior to 1985, requiring imperfect records of central pressure to be used as a proxy for the purpose of defining intense tropical cyclones.

Prior to the introduction of the first satellite observations around 1970, there were also issues in the detection of tropical cyclones. Many systems over the open ocean were undetected, particularly prior to 1950, whilst conversely numerous systems were classified as tropical cyclones which would now be considered extra-tropical, or too weak to be fully-fledged cyclones.

The net effect of these issues is that the total number of cyclones is probably under-estimated prior to 1950 and then over-estimated between 1950 and 1970, while the number of intense cyclones is under-estimated before 1985, and especially before 1970.

Review of current research activities

A major project is currently under way at the Bureau of Meteorology to correct historical tropical cyclone data. This involves two separate sub-projects: one covering the Australian region and the other the broader Southern Hemisphere region. The main objectives of this project are to construct an agreed list of tropical cyclones according to a consistent set of criteria, and to correct gross errors in track and intensity. It does not involve any reanalysis of source data.

For the Australian region, the construction of a list of tropical cyclones is essentially complete, whilst work to remove gross errors is in progress. The major effects of this work have been to reduce the number of cyclones in the database between 1950 and 1970, thereby greatly reducing the observed downward trend in the number of tropical cyclones from 1950 to the present.
An interface web page has also been developed, allowing ready access to the tropical cyclone data, and allowing filtering according to a number of criteria, such as passage within a specified distance of a given location.

**Scientific research that Australia needs to do in this area**

There are plans for a full reanalysis of Australian region tropical cyclone data, based primarily on available satellite observations. At the time of writing, funding or a timetable for this is yet to be confirmed but a number of avenues are being explored. The major potential of such a project will be to develop reasonably consistent records of tropical cyclone intensity back to about 1970. It is unlikely that it will be possible to substantially improve intensity analyses prior to 1970, due to the absence of remotely-sensed data and a reliance on sparse surface data, supplemented by radar for some near-coastal systems.

Whilst a full Australian region reanalysis prior to 1970 is unlikely to be possible, it may be feasible to perform a limited reanalysis for earlier periods for systems which crossed or approached populated coastlines. This is particularly true for the Queensland coast from Cairns southwards, most of which has been relatively densely settled since before 1900.
Detection and attribution of climate change effects on tropical cyclones

Kevin Walsh

School of Earth Sciences, University of Melbourne

In climate change science, detection is the “process of demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change” (IPCC 2001). This could involve anything from a simple statistical analysis of a trend of a chosen observed variable to a complex fingerprint analysis of a combination of variables. Additionally, attribution implies not only that a signal has been detected but that it is of the correct magnitude expected from projections of climate change due to anthropogenic forcing. These projections are typically made by an ensemble of climate models, and for successful attribution to be claimed, the detected change must fit within the envelope of the ensemble predictions. Moreover, it must also be shown that the detected change is not consistent with alternative, physically-based explanations.

For these reasons, recent claimed trends in tropical cyclone characteristics are not successful examples of attribution studies. Recent results (Emanuel 2005; Webster et al. 2005; Sriver and Huber 2006; Curry et al. 2006) suggest that large trends are evident in parts of the observed tropical cyclone record. For this to constitute successful detection of a trend there must be confidence in the magnitude of both the signal and the noise. In the case of a climatological analysis of tropical cyclone trends, we therefore must be confident that there are no artefacts in the tropical cyclone data that would give either a spurious trend or a record that was incomplete. Unfortunately, it can be easily argued that the current tropical cyclone records are not free from data inhomogeneities. The most telling examples of this so far are the analyses of Kamahori et al. (2006) and Wu et al. (2006). They examine trends in severe tropical cyclone numbers in different competing “best-track” data sets in the north-west Pacific region, finding very large differences in trends even for the same tropical cyclones and even in very recent times, when the data should be best. They ascribe this result to the different analysis techniques used in the rival data sets. At present, it is not clear which data set best represents reality.

Recent partial reanalyses of the tropical cyclone record have shown substantial corrections in trends compared with studies that have analysed existing best-track data. Kossin et al. (2007) have employed a reanalysis of global geostationary satellite data from 1983 to 2005 to remove time-dependent biases, finding that detected changes in tropical cyclone formation basins other than the Atlantic are less than in previous analyses. This is particularly relevant to Webster et al.’s (2005) near-global analysis, as their largest claimed increase in severe category 4 and 5 tropical cyclone numbers occurs in the early to mid 1980s. A recent reanalysis of the record in the western Australian region (Harper 2006) has also found that increases in severe tropical cyclone numbers are less than previously estimated using best track data. Landsea et al. (2006) uses modern intensity estimation methods applied to satellite images of non-Atlantic tropical cyclones from the late 1970s and early 1980s to show that the intensities of the storms are likely significantly underestimated in the best track data that were compiled at that time.

The region where tropical cyclone data is best is undoubtedly the Atlantic basin, where regular aircraft reconnaissance is combined with the latest intensity estimation techniques. Here, detected trends in tropical cyclone intensities are harder to dismiss. Emanuel (2005) and Mann and Emanuel (2006) argue that trends since the 1950s in a measure of tropical cyclone strength, the power-dissipation index (PDI), are highly significant and well correlated with observed
increases in sea surface temperatures since that time, a phenomenon which is well known to be associated with anthropogenic warming.

Even so, it is by no means clear that even the Atlantic data is free from inhomogeneities that would cause intensity data from the 1950s and 1960s to have biases compared with recent data. But even if the tropical cyclone trends in the Atlantic constitute a detection of a climate change signal, is it clear that they do not at present represent formal attribution of a climate change effect. This is because the projected size of the intensity change in the Atlantic to date due to the observed increase in sea surface temperature (SST) is considerably smaller than the claimed observed change in intensity. For the observed increase in Atlantic SST since 1960 of about 0.4°C, theories of tropical cyclone maximum intensity (Emanuel 1988; Holland 1997) predict an increase in maximum intensity of about 2%, corresponding roughly to a PDI increase of about 10% (Emanuel 2006), not about 60% as observed. Thus since the magnitude of the response is not as expected, attribution is not possible at this time.

The projections of expected climate change used in attribution studies are usually obtained from climate models. For tropical cyclone studies, the utility of climate models is currently limited by their relatively poor performance at simulating important aspects of tropical cyclones and by the wide range in their projections of climate change effects on tropical cyclones. This should not be a cause for pessimism, however; attribution studies for other climate variables have become widely accepted (e.g. Barnett et al. 2005), and as climate model simulations of tropical cyclone characteristics improve, it may one day be possible to ascribe any detected trends in the observational record of tropical cyclones to the effects of anthropogenic global warming. Other approaches, though, might also prove productive. The development of a quantitative theory of tropical cyclone formation, particularly severe tropical cyclone development, would enable attribution studies to be performed without the need for full fine-resolution general circulation model experiments. Refinements to the existing theory of maximum potential intensity may enable more confidence to be placed in the magnitude of its predictions. Thus a serious modelling effort needs to be combined with observationally-based theoretical studies and further efforts to homogenize the existing tropical cyclone data.

References


Curry, J.A., Webster, P.J. and Holland, G.J. 2006. Mixing politics and science in testing the hypothesis that greenhouse warming is causing a global increase in hurricane intensity. Bulletin of the American Meteorological Society, 87, 1025-1037.


Global climate change and the tropical cyclone palaeo-record in Australia

Jonathan Nott

School of Earth and Environmental Science, James Cook University, Cairns

Introduction

A critical question being asked at present is, ‘Are humans, through global climate change, responsible for an observed increase in tropical cyclone activity (intensity and duration) over the past 30 years?’ Preliminary evidence suggests that the answer may be yes.

Global air temperatures have now risen beyond that experienced over the past millennium (Mann 1999). Sea surface temperatures (SSTs) have also increased in recent decades and this is possibly due to the rise in air temperature. Theoretical and statistical evidence shows that the destructiveness and duration of tropical cyclones in the Atlantic and North Pacific Ocean basins has mirrored the increases in SSTs over the past 30 years (Emanuel 2005a, 2005b) as has the frequency of intense events (Webster et al. 2005). Determining the extent of human involvement, however, requires decoupling these recent trends from the long-term natural variability. To date this has not been possible.

If the trend in tropical cyclone activity reverses over forthcoming decades in concert with natural climatic oscillations then the present increase could be argued to be at least in part, if not substantially, due to natural variability even though global air temperatures continue to increase. Unfortunately, determining whether this is the case will take at least several decades. We can, however, gain a more immediate understanding by examining records encapsulating the long-term natural variability of tropical cyclones. Such records need to be of sufficient length to display multiple successive climatic oscillations. The extent to which cyclone behaviour varies during these oscillations can be used as a benchmark for comparisons with recent changes in cyclone behaviour. Long-term, high resolution (annual to sub-annual) records of tropical cyclone behaviour (such as isotope records) are able to provide us with this information.

Key issues

The acid test for establishing the role of humans in causing the increase in global air temperature was a comparison of recent trends against records of air temperature variations spanning the last 1,000 years (Mann 1999). This long-term record was crucial in decoupling the recent increases from natural variations in air temperature. We have not had an equivalent long-term record of tropical cyclones and hence have minimal knowledge of their natural variability.

Attempts to model the longer-term natural variability of tropical cyclones are commonly based on extrapolations from the either the historical record (past ~ 100 years) or the instrumental record (past 30-40 years). Inherent in this approach is an untested assumption that the longer-term synthetic records should display the same statistical properties as the shorter record upon which they are based. These properties are stationarity and randomness of successive events. Statistical tests of these assumptions for numerous real or actual (non-synthetic) long-term records of natural hazards from around the globe (floods, droughts, thunderstorms, earthquakes, volcanic eruptions) along with a number of the causative mechanisms of some atmospheric hazards such as sea surface temperature (SST), ENSO and IPO show that both serial correlation and non-stationarity are common properties of natural records when they exceed 100-150 years in length (Nott 2006). This suggests that in the vast majority of cases the shorter historical and
instrumental records display an apparent white noise signal which is in reality part of a longer term cyclic trend whose mean and variance can change at centennial scale periodicities. This work implies that we cannot use the short-term records of tropical cyclones as the basis for modelling the long-term variability without first testing the inherent assumptions of stationarity and randomness; the only way to do this is against long-term records of actual or non-synthetic events.

In order to assess whether global climate change therefore is really having an impact upon the behaviour of tropical cyclones in a region it is critical that any changes in behaviour are examined against the natural variability and the only way to do this at present is to use long-term records of actual events.

**Review of current research activities**

Long-term sedimentary records of tropical cyclones in the form of coral shingle, shell and sand ridges and sheets register only the most extreme events at multi-century to millennial scales (Chappell et al. 1983; Chivas et al. 1986; Liu and Fearn 1999; Nott and Hayne 2001; Nott 2003, 2004). The resolution of these records is too coarse to determine the natural variability of these events. High resolution (annual) records are needed for this purpose. To this end an 800-year long, high resolution (annual) record of tropical cyclones (AD 2004-1200) has been derived for the Cairns region of North Queensland. This record registers the isotopic signature of tropical cyclone rainwater within an annually layered limestone cave stalagmite. Comparisons of the first 100 years of the record against the Bureau of Meteorology’s best track cyclone database showed that every major cyclone and greater than 75% of all cyclones to track within 300 km of the site (130 km inland of Cairns) were registered within the stalagmite.

This annual record suggests that there have been centennial scale variations in tropical cyclone landfall frequency over the past 800 years. The centuries from AD 1800 to 1600 and AD 1500 to 1400 were very active, the period from AD 1200-1400 was exceptionally quiet and since AD1800 activity has been moderately quiet and especially so since European settlement of the region in the late 19th Century. These variations in tropical cyclone landfall frequencies appear to be best related to the behaviour of steering winds in the region, at least for the past 400 years rather than variations in sea surface temperatures. The heightened phase of cyclone landfalls (AD 1800-1600) also correlates closely with a 400-year long coral luminescence record of river discharge which shows heightened flood activity here during the period AD 1800-1600.

Both the isotope and sedimentary records from this region suggest a different long-term climatology of tropical cyclones for northern Australia than that assumed from the short (30-40 year) instrumented record.

**Scientific research that Australia needs to do in this area**

A high priority needs to be to gain a realistic picture of the natural variability of tropical cyclones in our broader region. This will involve increasing the number of palaeo-records around Australia. Towards this end the Australian Research Council has awarded a 5 year Discovery grant to derive high resolution isotope records for the broad Australian region.

We also need to develop or apply alternative statistical techniques to incorporate serial correlation and stationarity when modelling long-term variability from short term records. There is also a need to develop statistical approaches to incorporate the palaeo-record with the shorter-term records.
References


Impacts of tropical cyclones

Kathy McInnes

CSIRO

Introduction

Tropical cyclone impacts cover a broad range of topics, from a hierarchy of geophysical impacts to social impacts. Climate change adds a new dimension to the complexity of issues that need to be addressed to obtain a better understanding of the risk tropical cyclones present to society now and into the future.

Rising sea levels and changing characteristics of tropical cyclones such as intensity, frequency and location of occurrence are the two key ways in which climate change will influence future tropical cyclone impacts. Of these, sea level rise carries a high certainty of occurrence even though the precise magnitude of the rise is much less certain.

However, the changes in the behaviour of tropical cyclones themselves carry high uncertainty due to a range of underlying factors. These factors include our incomplete understanding of the fundamental physics of cyclones such as cyclone genesis and the inability of climate models at their current resolutions to represent tropical cyclones realistically. Tropical cyclones produce extreme winds, which themselves are a hazard to coastal communities. They also cause oceanic responses such as storm surge and high waves which are a hazard to the coastal zone due to coastal flooding and coastal erosion. The uncertainties in models and techniques used to quantify the impacts of climate change at the scale required for impacts research needs to capture and quantify the inherent uncertainty to deliver meaningful and relevant advice to inform sound planning of adaptation responses into the future.

Key issues

The impact research relating to tropical cyclones can be highly multidisciplinary, drawing upon tools and models from other scientific disciplines to evaluate the impacts. Examples include the use of coastal ocean and wave models to determine the oceanic contribution to inundation; hydrological and hydraulic models to determine freshwater flood extend and tools such as GIS for the spatial evaluation of impacts. It is also reliant on the scientific advances of tropical cyclone and climate change research in order to formulate plausible climate change scenarios for impacts research. Therefore, many issues facing the impacts area are similar to those facing other aspects of tropical cyclone research. Within the impacts research area, there are also issues regarding the assessment of climate impacts from tropical cyclones in the future. For example, different methodological approaches for assessing the impact of climate change on storm tides from tropical cyclones have yielded different results both for the current and future climate. There needs to be an agreed methodological framework within the impacts community for assessing the impacts of climate change since different approaches can yield vastly different results.

Review of current research activities

Owing to the complexity of carrying out climate change assessments, relatively few studies have been carried out. The largest recent study to address the impact of climate change on storm surges was the Queensland Climate Change Community Vulnerability to Tropical Cyclones study in which the return periods of storm tide due to tropical cyclones were evaluated for
locations along the east coast of Queensland (Hardy et al. 2004). The impact of climate change on storm surges at Cairns was also studied by McInnes et al. (2003) and current climate risk of storm surges in Cairns has been evaluated by Harper (see Harper 1999). The results of the studies at Cairns yield considerably. The return periods for storm surge estimated for current climate in the McInnes et al. study yield similar results to those of Harper (1999) and may be attributable to a similar approach used for estimating tropical cyclone occurrence. However the James Cook University study yields results that are lower than the previous two studies and the key difference appears to be the specification of tropical cyclones. To date, the impact of climate change has not been assessed in a systematic way across northern Australia (including the Gulf of Carpentaria) or the north-west coast of Australia. Some studies, which have been undertaken by consultants, exist for selected locations in the north and west, but these have mainly been for current climate situations with at most an allowance for future sea level rise.

**Scientific research that Australia needs to do in this area**

There are three key topics relating to the impact of climate change on tropical cyclone storm surges that need ongoing research.

The first is the establishment of an agreed methodology for assessing tropical cyclone risk under current and future climate conditions. This is a challenging task due to the limitation of data to validate the devised methodologies. The methodology also needs to adequately address the uncertainty in future climate projections.

The second is an ongoing program of work to address tropical cyclone storm surge risk across the northern and western coastlines of Australia taking account of the latest available research into the effect of climate change on tropical cyclones and sea level rise.

The third is ongoing research into the numerical modelling of extreme sea levels that consider contributions due to waves as well as storm surge and the modelling of the overland inundation caused by such extremes.

**References**


Priorities for climate change research linked to tropical cyclones: Regional perspectives

Andrew Burton, Jeff Callaghan and Ian Shepherd

Senior Meteorologists, Regional Severe Weather Sections, WA, QLD and NT, Bureau of Meteorology

Introduction

In recent years there has been a marked increase in interest in the potential impact of climate change on the climatology of tropical cyclones. A number of high impact events (e.g. Hurricane Katrina, Tropical Cyclone Larry) have contributed to this along with recent scientific articles that reported a large increase in tropical cyclone energy and wind speeds over recent decades. Here we examine the issue of priorities for climate change research linked to tropical cyclones from a regional perspective.

Key issues

Pjelke et al. (2006) demonstrate that in a USA context economic damage is more strongly dependent on socio-economic changes such as inflation, demographic changes, and income per capita changes than on changes in tropical cyclone numbers or intensity. They conclude that such factors will lead to an approximate doubling of tropical cyclone related normalised economic losses in the USA every ten years.

We expect that similar statements can be made in the Australian context especially along the east coast of Queensland and in other areas of rapid population and infrastructure growth.

![Figure 1. Tropical Cyclone Dinah passing over Fraser Island](image)

Since the impact of major severe tropical cyclones on the Gold Coast and northern New South Wales such as the 1954 Great Cyclone (25 to 30 deaths) and Tropical Cyclone Dinah (Figure 1), there has been a huge increase in population and infrastructure in these areas. The Gold Coast in 1954 consisted mainly of three small towns - Southport, Burleigh and Coolangatta. Today
Brisbane effectively sprawls southwards as mixed suburban and rural residential allotments to at least Lismore. Clearly, impacts in south-east Queensland or New South Wales today from systems worse than or even similar to past events would result in unprecedented damage and loss of life as much of the area has a population and coverage growing faster than anywhere else in Australia.

In the Western Australia context the rapidly growing population in the south-west of the state will have a predominant effect on the magnitude of tropical cyclone related disasters arising from extra-tropical transition. In the north-west of Western Australia and in the Timor Sea, increasing infrastructure is already heightening demand for improved understanding of the effects of climate change on tropical cyclones.

All existing theory and modelling studies indicate that the effect of climate change on tropical cyclone numbers and intensity will have less consequent impact on the magnitude of tropical cyclone related disasters than these socio-economic changes. However the impact of climate change on the scale of tropical cyclone disasters remains a concern because it will exacerbate the increased vulnerability caused by socio-economic changes.

There has been limited research to date on the potential for significant track changes under climate change scenarios and this could have a significant influence on changes in regional vulnerability.

For all regions, but particularly noted as significant in the Northern Territory region, a key issue is the influence of climate change on tropical cyclone genesis, and the genesis precursors such as monsoon onset, ENSO, Madden-Julian Oscillation (MJO) active phases and other tropical wave types.

The quality of the existing tropical cyclone “best track” database is of obvious concern in relation to determining trends in cyclone numbers, tracks and intensity. Whilst improving the reliability of the database must be a high priority it should also be recognised that it will not be possible to establish a homogeneous database of sufficient length and quality for separating as yet poorly understood inter-decadal signals from longer-term climate trends.

In some areas sea level rise will have a significant effect on storm surge impacts, in others (with high tidal ranges, like much of northern Australia) this will have a lesser effect though it will shift the distribution function of storm tides toward more severe inundation.

The competing potential intensity theories of Holland (1997) and Emmanuel (1988) are recognised as having limitations, and can clearly not both be correct. We need to have a better understanding of potential intensity if we are to understand the influence of climate change on tropical cyclone intensity.

If we are to forecast possible changes in cyclogenesis under a changed climate we need to better understand the processes of cyclogenesis. The existing theories are in some cases contradictory and further work is required to understand the significance and interrelation of processes on the large scale and those on the smaller scale stochastic processes.

**Review of current research activities**

The interested reader is directed to the excellent review of current research activities in this area provided by Knutson *et al.* (2006), which we will not attempt to reproduce here. The following two paragraphs briefly summarise key findings from recent research.

Simulations of warmer global climates generally find that hurricanes are more intense for warmer climate. (~4% increase in wind speeds for every 1°C warming. This is one of the more
robust results from simulations. This could increase destructiveness by as much as 30% per degree warming – based on cubing wind speeds and more intense storms lasting longer.)

Simulations also tend to show fewer tropical storms globally in the future, but sign of regional changes varies between basins and models. Confidence in these projections is currently low.

Kossin et al. (2006) is not discussed in Knutson et al. (2006) as it is still under review, however some results from this work were presented at the recent International Workshop on Tropical Cyclones (IWTC-VI), 21-30 November 2006, San Jose, Costa Rica. Kossin et al. (2006) is significant because it directly addresses the issue of the reliability of the existing tropical cyclone climate records for detecting climate trends. Kossin et al. use an objective methodology for intensity estimation on a homogeneous dataset of satellite imagery. The paper thus addresses the concerns of other authors (Landsea et al. 2006) regarding the use of inhomogeneous datasets such as the existing tropical cyclone climate records.

The technique shows good agreement with the Atlantic (where there is reconnaissance data), which provides some confidence in the technique. The results also show good agreement in other basins post-1992 but poor agreement with earlier years, which is encouraging in that it suggests we are doing better with the datasets now. Most importantly, this study did not show any trend toward increasing intensity of tropical cyclones globally within the last 25 years, with the exception of the Atlantic and North-East Pacific basins.

Figure 2 shows the accumulated Southern Oscillation Index (SOI) since 1900, and indicates that post-1950 there have been two distinct phases separated by the so-called Pacific Climate Shift in 1977. The rising graph 1950-1976 indicates a dominance of positive SOI and La Niña events. The falling graph since 1977 indicates a dominance of negative SOI and El Niño events.

ENS0 is the biggest modulator of tropical cyclone activity on a regional scale. The 1949 to 1976 period was characterised by extreme tropical events impacting on eastern Australia. Severe tropical cyclones made landfall in 1949 (one in Cooktown and another in Rockhampton.), 1950 (Carmila), 1954 (Gold Coast/NSW), 1955 (Sarina), 1956 (Townsville), 1958 (Bowen), 1959 (Bowen), 1967 (Fraser Island), 1970 (Airlie Beach), 1971 (Townsville), 1972 (one in Gladstone and another on Fraser Island and 1976 (St Lawrence). There were also severe impact tropical hybrid systems: 1950 (Sydney, 10 deaths), 1955 (Maitland, 25 deaths), 1958 (Mackay, 3 deaths), 1963 (Sunshine Coast), 1964 (inland Queensland), and 1974
(Brisbane, 18 deaths). Additionally there were several of the most destructive east coast lows (ECLs) experienced in eastern Australia, 1950 (Queensland/New South Wales, 30 deaths), 1974 (Newcastle Sygna storm) and 1967 (series of Gold Coast ECLs).

Over the period since 1977 there have been much less severe tropical cyclone and tropical hybrid events. The only severe tropical cyclones to make landfall between 1977 and 1998 were 1980 (Yeppoon), 1986 (Innisfail), 1989 (Ayr) and 1990 (Bathurst Bay). Since 1999 there has been an increase in activity perhaps heralding a new phase.

Scientific research that Australia needs to do in this area

- **Improvement of Australian tropical cyclone database to redefine current risk.**

- **Work on identification of historical tropical cyclone impacts from proxy data such as tree rings, beach ridges and lagoon sediments**, to provide a baseline context for climate modelling and assessment of current and future risk trends.

- **Work on the possible influence of climate change on tropical cyclone track distribution.** This is a very important area for research. Discussion at IWTC-VI concluded that track forecasting was still the most important element of tropical cyclone forecasting, and it can be shown from considerations of variance in the different forecast elements that at lead times greater than around 24 hours the track forecast adds the greatest uncertainty to the warning process (de Maria et al. as presented by Russ Elsberry in Topic 3.0 at IWTC-VI). While it is possible to run coupled ocean-atmosphere models and identify and track tropical cyclone-like vortices it is also recommended that this approach be supplemented by a more indirect approach involving looking at changes in mean steering flows.

- **Further work to remove the current uncertainty as to whether there is actually a reliable trend in tropical cyclone intensity over recent decades.** The emphasis here should be on trying to replicate the type of work done by Kossin, i.e. using an objective technique on a homogeneous dataset. The only thing approaching a homogeneous dataset at present is satellite imagery.

- **There is a desperate need to improve ENSO forecasting.** ENSO is the biggest modulator of inter-seasonal variation, and a possible mode through which climate change may take effect. We still suffer from an inability to accurately forecast ENSO at significant lead times. It is recognized that the need for ENSO forecasting extends well beyond the tropical cyclone requirements but we need to support that research and ensure that the importance for Tropical cyclones and climate change is highlighted.

- **There is a need to understand the potential impact of climate change on other modulators of tropical cyclogenesis such as the north Australian monsoon and the Madden-Julian Oscillation.**

- **Further work on the theory of environmental controls on the potential intensity of tropical cyclones.**

- **Improved understanding of cyclogenesis.**
References


Priorities for tropical cyclone research: 
An insurance risk management perspective

John McAneney

Risk Frontiers – Macquarie University

Introduction

Risk Frontiers is an independent research centre devoted to helping the insurance industry better understand and price natural hazard risks in Australasia and Asia-Pacific. In Australia, our research shows that over the last 100 years meteorological hazards have been responsible for some 95% of building damage with tropical cyclones responsible for about one third (McAneney 2005). Half of Australia’s population live within 7 km of the coast (Chen and McAneney 2006). Clearly insurers have a strong need to better understand tropical cyclone risks and the likely role of climate change.

Key issues

1. A more complete and reanalysed database of landfalling cyclones and their physical attributes: central pressure, radius of maximum winds, forward speed, rainfall, etc. This is the industry’s single most important meteorological data requirement if we are to improve industry loss modelling with or without global climate change. This is what the industry looks toward the Bureau of Meteorology to provide.

2. Rainfall – a high proportion of insured losses is associated with flooding rather than wind e.g. Cyclone Wanda (1974). NOAA claims that a heavy rainfall prediction for a hurricane landfalling in Florida might mean anywhere between 250 mm and 500 mm. Outcomes for the insurance industry are clearly very different for the two ends of this range. How well can we do this for Australia?

3. How is rainfall affected by topography close to the coast? This would seem to be very important in parts of Queensland.

4. Currently, we do not see any climate change signal on tropical cyclones in terms of their potential destructiveness or frequency. Actual losses are well explained by changes in inflation, wealth, population and building codes (Crompton and McAneney, in preparation). So how will we be able to detect when global climate change kicks in? One answer to this question is to extend the catalogue of landfalling events as far back as possible, hence point 1 above.

5. What tropical cyclone attributes are most likely to be affected by global climate change and to what extent? Are current climate models or our understanding of the physics of tropical cyclones capable of answering these questions?

6. Outcomes from natural catastrophes often depend heavily upon how people behave – react to warnings, take mitigation seriously, have insurance, etc. Katrina was a case in point. Behavioural science issues need to be taken seriously by the research community or they risk being ignored.
Review of Risk Frontiers’ current research activities in this area

- Reviewing past events
- Indexing the Insurance Council of Australia’s Disaster Database to determine likely costs to insurers if damaging historical tropical cyclone events were to be repeated today
- Exploring impacts of tropical cyclones both here and overseas
- Understanding Australian exposure
- Risk perception

References

Priorities for tropical cyclone research: An insurance industry perspective

Mark Leplastrier

Insurance Australia Group

Introduction

Insurance Australia Group (IAG) is Australia and New Zealand’s largest general insurer and has growing presence in Asia and UK. As understanding weather and climate risk is core business to us, a significant portion of our research budget is directed at better understanding the risk.

Over the past five years we have directed much attention at understanding both current and future climate tropical cyclone risk in the Australian and New Zealand domain with more attention to Queensland and particularly the highly populated and growing south-east. The results from our current and future (IS92a) coupled climate model runs over Queensland waters will appear in an international journal very early next year but the general findings are:

1. Increasing frequency of major tropical cyclones (Category 3+)
2. Longer tropical cyclone seasons
3. Poleward shift in genesis.

Research priorities

Apart from the issues/priorities raised by McAneney (this volume) I feel that there are two extras that need attention. IAG intends to address these issues in the near future:

1. For landfalling tropical cyclones, we need better understanding of where extra-tropical transitioning of tropical cyclones takes place and whether this changes with climate change. Most major tropical cyclones that affect the south-east Queensland region will be travelling in a general southerly direction. If a tropical cyclone has largely undergone extra-tropical transition as it reaches south-east Queensland latitudes, the strongest winds will remain offshore rather than over the populated coastal areas. Will climate change mean a poleward shift in the extra-tropical transition (ET) of tropical cyclones? Our modelling shows that the difference in losses between a tropical cyclone and an ET tropical cyclone on south-east Queensland could be an order of magnitude. There is also little research addressing the current climate risk with Sinclair (2001) the only known paper and possibly not entirely appropriate for the south-east Queensland coast.

2. The overland surface wind profile of landfalling tropical cyclones that impact significant topography. Most insurance loss models use an open water/flat land profile such as the Holland (1980) profile, but for Queensland the impact of the Great Dividing Range must feedback on the internal processes of a tropical cyclone and therefore affects the surface wind profile. This is a current climate issue.

References

Priorities for tropical cyclone research: Engineering and risk analysis needs

John D. Holmes

JDH Consulting

Introduction

This presentation discusses engineering issues regarding the performance of buildings and infrastructure in coastal communities and industrial complexes under wind loads during coast crossings by tropical cyclones

Key issues

- Design of new buildings and structures for wind loads
- Prediction of windstorm damage to existing buildings and structures
- Zoning planning issues with respect to storm surge

Review of current research activities

- Negligible publicly funded basic research on wind loads in Australia since 1980s
- Federal government support for risk studies by Geoscience Australia
- Damage surveys from major events (e.g. Cyclone Larry by Geoscience Australia and by James Cook University Cyclone Testing Station for the Australian Building Codes Board)

Scientific research that Australia needs to do in this area

- Tropical cyclone database should be corrected and updated
- Better information on intensity of approaching and coast-crossing storms (portable anemometer arrays)
- Wind speed and turbulence profiles from tower measurements essential for design of taller structures (North West Cape tower study should be revived – compare with dropwindsonde profiles)
- Simulation studies urgently required for improved values of design wind speeds for coastal regions affected by tropical cyclones – especially Queensland and Northern Territory coasts (Region C in AS/NZS1170.2)
- Effect of steep topography on tropical cyclone boundary layers should be studied further
- More understanding of the dynamic effects on internal pressures in buildings is required

References

Florida Coastal Monitoring Program. Website: http://users.ce.ufl.edu/~fcjmp/


Summary of key issues and priorities from a workshop on the reanalysis of the Australian tropical cyclone record

Kevin Walsh

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Introduction

A workshop sponsored by the Bureau of Meteorology and the ARC Network for Earth System Science was held at the Bureau head office on 16 August 2006 to identify the main deficiencies in the Australian tropical cyclone record, and to make recommendations how this might be reanalysed. This abstract briefly summarizes the conclusions, but more details can be found in the workshop proceedings (http://www.arcness.mq.edu.au, under “News and Announcements”).

Key issues regarding tropical cyclones and climate change

These are largely summarized in the proceedings of this workshop. Briefly, the main issue is data inhomogeneity. The current best track tropical cyclone data are clearly not homogeneous in time, which of course is a crucial requirement for any realistic analysis of climate trends.

Review of current research activities

The main efforts in tropical cyclone data reanalysis are taking place overseas (e.g. Landsea et al. 2004; Kossin et al. 2007). In Australia, the Bureau of Meteorology has begun a process of making the existing best track data more consistent, but no full-scale reanalysis of these data has yet been attempted. A partial reanalysis of Western Australian storms, funded by Woodside Petroleum, has many useful lessons for future Australian reanalysis projects.

Scientific research that Australia needs to do in this area

The reanalysis workshop made several recommendations for future work. The first was that a scoping study was needed to formulate the work plan for such a reanalysis, as it was not clear at the end of the workshop exactly what form it should take. Certainly the climate community’s need is for a homogeneous data set that does not necessarily have to be of fine detail, whereas data for engineering purposes needs to have as much information as possible, but does not necessarily need to be climatologically homogeneous. More information is given in the workshop proceedings.

References


Summary of issues from the 6th International Workshop on Tropical Cyclones (IWTC-VI)

Jeff Kepert
Bureau of Meteorology Research Centre

Introduction

The recent WMO International Workshop on Tropical Cyclones held in Costa Rica reviewed and discussed many issues relevant to understanding tropical cyclone climate and climate change. Of the five main topic areas at the workshop, one was devoted to climate, while most of the others also contained material relevant to the problem. The workshop was organised around invited review talks and lengthy discussion sessions. The written review reports and presentations are available from http://severe.worldweather.org/iwtc/.

One major outcome of the workshop is a detailed list of recommendations for future research, including into climate change issues. A second major output is a consensus statement on the state of knowledge on climate change effects on tropical cyclones, together with a one-page summary. This statement represents a consensus, as distinct from a majority view, of the workshop. The summary is included in this volume as an appendix. Both the statement and summary are available from the WMO website at http://www.wmo.ch/web/arep/arep-home.html.

Key issues regarding tropical cyclones and climate change

There is hardly any aspect of tropical cyclone behaviour for which climate variability, either natural or anthropogenic, is unimportant. Compare for instance the record-breaking 2005 season in the North Atlantic, to the near-normal 2006. Differences between the seasons include: (i) many more storms formed in 2005, (ii) a higher proportion of 2005 storms became very intense, (iii) an unusually high proportion of 2005 storms moved into the Gulf of Mexico and/or made landfall, and (iv) a 2005 storm, Katrina, severely impacted the extraordinarily vulnerable city of New Orleans.

Thus to understand the differences between these two seasons requires knowledge of at least tropical cyclone genesis, intensification, motion, and mitigation. Similarly, projection of future tropical cyclone risk for the Australian region demands a careful consideration of each of these aspects of tropical cyclone dynamics, coupled with climate-scale processes. This is challenging, since the current level of understanding of intraseasonal and interannual influences on these aspects is limited.

It is also important to consider storm surge and rainfall in evaluating risk. Increases in sea level will exacerbate the surge threat, even in the absence of other changes. Fresh-water flooding is a major cause of cyclone-related death and property loss, but rainfall is largely independent of cyclone wind intensity.

Review of current research activities

Tropical cyclogenesis can be regarded as a combination of generating a large-scale favourable environment, often as a result of modulation by various zonally-propagating tropical waves, together with mesoscale organisation processes which build the incipient vortex. Agreement is slowly being reached on what mesoscale processes are important, and recent work (Tory et al.
2006a, 2006b) has explored the relationship between these processes in models of grid resolution 2-15 km. The location and frequency of genesis is known or suspected to vary on time-scales ranging from a month (e.g. the MJO) to decades (e.g. the Atlantic Multidecadal Oscillation).

Intensification similarly depends upon both a favourable environment, and the operation of mesoscale internal processes. A key measure of the environmental favourability is the potential intensity (PI), a thermodynamic measure, although dynamical factors are also known to be important. There are two major PI theories, which have markedly different sensitivities to some input parameters. Until these differences are resolved, they cannot be regarded as mature theories. However, several researchers, including those whose work is based upon these theories, predict an increase in peak intensity of a 3 to 5% per degree of sea surface temperature increase.

Cyclone motion depends upon an inherent propagation, combined with environmental steering. Little is known about the climatological factors that affect the steering, but see the work on the north-west Pacific by Wu et al. (2006) and the brief discussion of the Australian region by Kepert (2006). How track climate might vary under climate change scenarios seems to be almost entirely unexplored.

Scientific research that Australia needs to do in this area

- Reanalysis of past data – we cannot understand the future if we don’t properly know the past.
- Calibrating remote-sensing intensity estimation techniques against in situ data in the Australian region.
- Understanding of the relationship between genesis in the real atmosphere, and as depicted by coarse-resolution climate models.
- Understanding of the upper bounds of intensity, and the processes which limit less intense storms.
- Understanding of the physical mechanisms behind intraseasonal, interannual and multidecadal associations involving tropical cyclones, including formation, intensification and motion. Knowledge of the present climate dynamics will inform predictions of changes.
- Understanding of the feedback (if any) from tropical cyclones to the oceanic and atmospheric general circulations.

References

Appendix 1:

Summary Statement on Tropical Cyclones and Climate Change
6th International Workshop on Tropical Cyclones

The surfaces of most tropical oceans have warmed by 0.25 – 0.5 degree Celsius during the past several decades. The Intergovernmental Panel on Climate Change (IPCC) considers that the likely primary cause of the rise in global mean surface temperature in the past 50 years is the increase in greenhouse gas concentrations.

The global community of tropical cyclone researchers and forecasters as represented at the 6th International Workshop on Tropical Cyclones of the World Meteorological Organization has released a statement on the links between anthropogenic (human-induced) climate change and tropical cyclones, including hurricanes and typhoons. This statement is in response to increased attention on tropical cyclones due to the following events:

a) There have been a number of recent high-impact tropical cyclone events around the globe. These include 10 landfalling tropical cyclones in Japan in 2004, five tropical cyclones affecting the Cook Islands in a five-week period in 2005, Cyclone Gafilo in Madagascar in 2004, Cyclone Larry in Australia in 2006, Typhoon Saomai in China in 2006, and the extremely active 2004 and 2005 Atlantic tropical cyclone seasons - including the catastrophic socio-economic impact of Hurricane Katrina.

b) Some recent scientific articles have reported a large increase in tropical cyclone energy, numbers, and wind-speeds in some regions during the last few decades in association with warmer sea surface temperatures. Other studies report that changes in observational techniques and instrumentation are responsible for these increases.

Consensus Statements by International Workshop on Tropical Cyclones-VI (IWTC-VI) Participants

1. Though there is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record to date, no firm conclusion can be made on this point.
2. No individual tropical cyclone can be directly attributed to climate change.
3. The recent increase in societal impact from tropical cyclones has largely been caused by rising concentrations of population and infrastructure in coastal regions.
4. Tropical cyclone wind-speed monitoring has changed dramatically over the last few decades, leading to difficulties in determining accurate trends.
5. There is an observed multi-decadal variability of tropical cyclones in some regions whose causes, whether natural, anthropogenic or a combination, are currently being debated. This variability makes detecting any long-term trends in tropical cyclone activity difficult.
6. It is likely that some increase in tropical cyclone peak wind-speed and rainfall will occur if the climate continues to warm. Model studies and theory project a 3-5% increase in wind-speed per degree Celsius increase of tropical sea surface temperatures.
7. There is an inconsistency between the small changes in wind-speed projected by theory and modelling versus large changes reported by some observational studies.
8. Although recent climate model simulations project a decrease or no change in global tropical cyclone numbers in a warmer climate, there is low confidence in this projection. In addition, it is unknown how tropical cyclone tracks or areas of impact will change in the future.
9. Large regional variations exist in methods used to monitor tropical cyclones. Also, most regions have no measurements by instrumented aircraft. These significant limitations will continue to make detection of trends difficult.
10. If the projected rise in sea level due to global warming occurs, then the vulnerability to tropical cyclone storm surge flooding would increase.

The comprehensive scientific statement is available at: http://www.wmo.ch/web/arep/arep-home.html
Appendix 2:

Workshop participants

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