Sensitivity Analysis with Visualizations of the ACE Index to Understand the Driving Parameters of Tropical Cyclone Impact Models

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Background

▪ Climate variability modulates tropical cyclone (TC) activity on multiple temporal scales, from intra-seasonal (e.g. Madden Julian Oscillation) to multi-decadal (e.g. Atlantic Multidecadal Oscillation).
▪ Observed TC records have temporal limitations and known inhomogeneities. Is it sufficient to rely on the observed TC records to evaluate the variability of tropical cyclone hazard?
▪ Recent advances in high-resolution General Circulation Modelling (GCM) provide an opportunity to complement limited observations.

➢ We present a GCM-based tool to explore the impact of variability on risk evaluation.
➢ We highlight various challenges, some of which we start to address.

Purpose of the Tropical Cyclone Model Laboratory

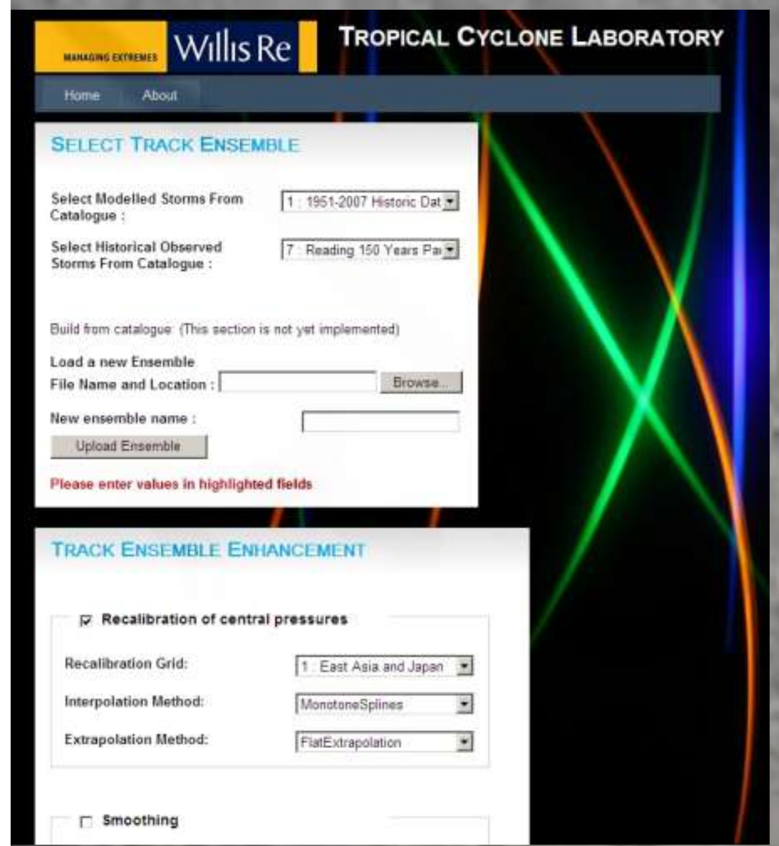


Figure 1: Tropical Cyclone Model Laboratory

Purpose:
to investigate how changes in resolution & control parameters affect the results of TC hazard models.

Web-based platform:
to test various aspects of the modelling:
▪ Model data selection
▪ Recalibration
▪ Sampling
▪ Creation of wind fields
▪ Testing control parameters

Scope
NW Pacific basin: Japan, East/South China Seas, Philippine Sea, Sea of Okhotsk.
Parameterized approach for easy extension to other basins.

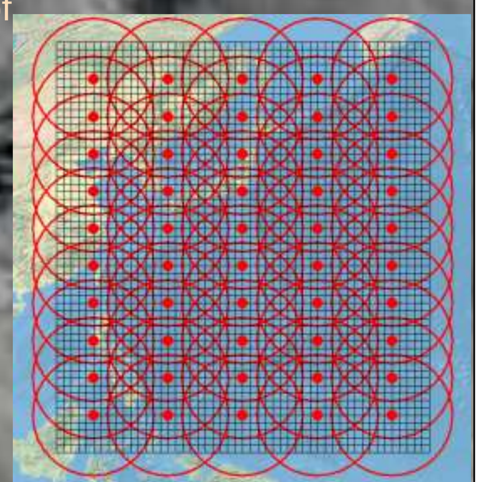


Figure 2: Analysis grid for NW Pacific (red dots & circles show the calibration grid)

How does this benefit research and the insurance industry?

▪ **Research** – our testing platform allows researchers to explore the impact
- and limitations of simulated versus observed storms in terms of hazard
- of variability on weather-related risk - of interest to both academia & industry

▪ **Insurance** – better estimation of risk (intensity, severity, spatial distribution, understanding of global correlations and temporal regimes)

Methodology

▪ We use ensembles of storm tracks extracted from a hierarchy of high-resolution GCMs based on the Hadley Centre Unified Model of increasing resolution (HiGAM/NUGAM - developed through the High Resolution Global Environmental Modelling Project/UK Japan Climate Collaboration), and ensembles of observed historical storms.
▪ Simulated storms are calibrated using historical storms, then resampled.
▪ Wind fields are created around the storm pressure centres along each track.
▪ Each step has a set of control parameters for investigation and tuning.

Who is involved?

▪ **Reading University, National Centre for Atmospheric Science-Climate (NCAS-Climate)** – a feature-tracking algorithm is applied to multi-century high-resolution General Circulation Model (GCM) simulations in order to extract tropical cyclone-like features. These storms are then used to build a simulated database of storms
▪ **Exeter University** – statistical modelling: calibrate, smooth & resample the GCM-simulated storms, assess the results
▪ **Willis Analytics, Product Development team** – implementing the Tropical Cyclone Model Laboratory, as a collaborative platform, which can be used to test the importance of data and parameters

Model validation

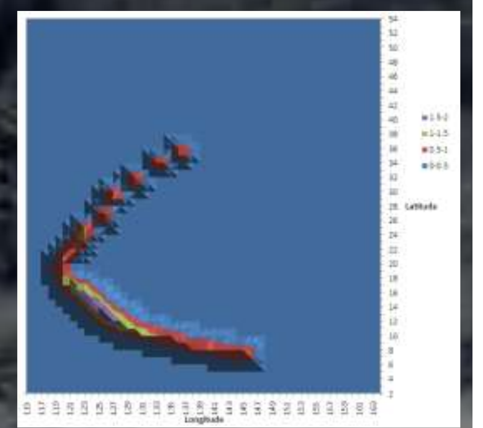
This is a key stage in building a hazard model. We compare outputs from the model (on intensity, severity and spatial distribution) for the following
1. historical records (IBTrACS)
2. high-resolution GCM
3. high-resolution GCM, calibrated

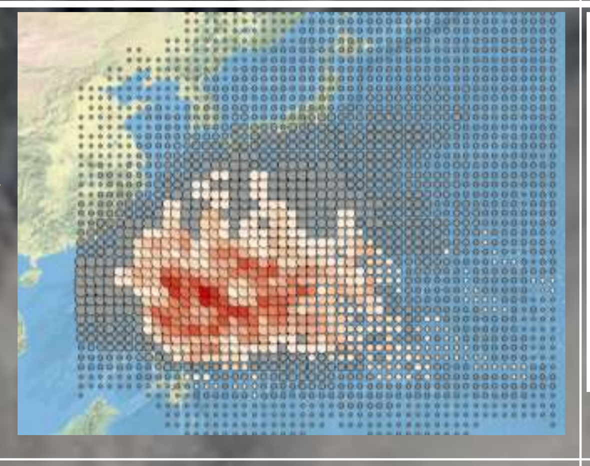
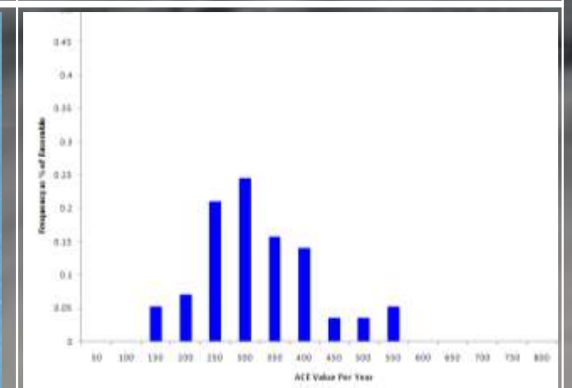
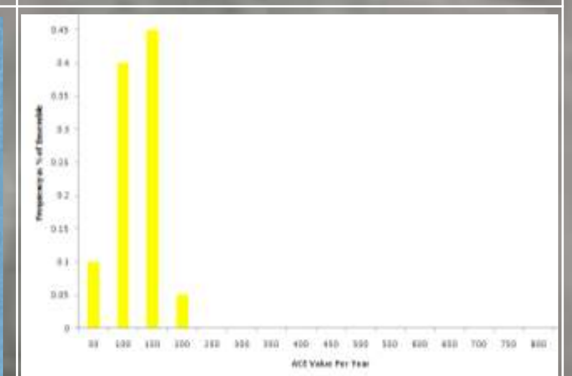
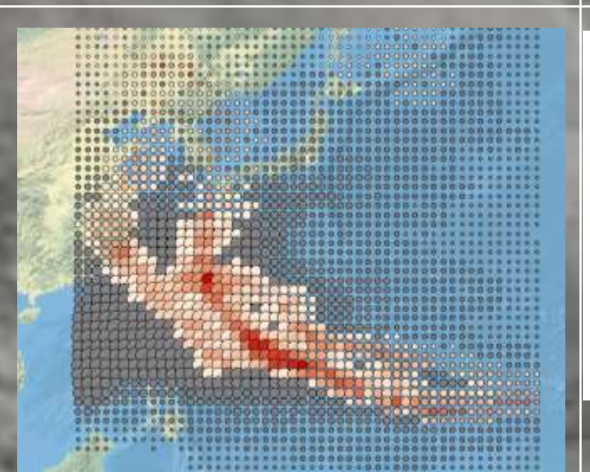
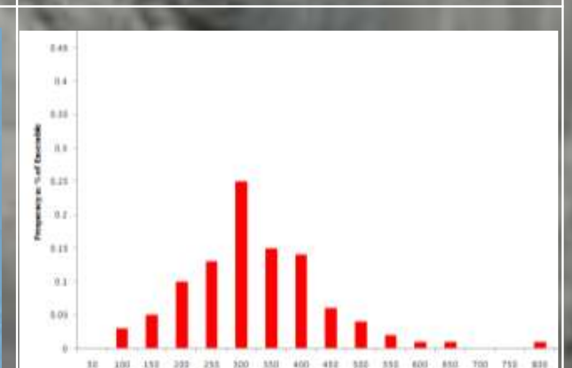
Using the ACE index

▪ Results are explored by using a variety of statistics, mapped or charted. The Accumulated Cyclone Energy (ACE) index

$$ACE = 10^{-4}\,\Sigma\, v^2_{max}$$ (where v^2_{max} is the max wind speed)

was used as a proxy for storm activity over a certain period (time scale or ensemble). This index provides a good summary of frequency and intensity of TC activity (See [1] for details)
▪ Comparing visual representations of the ACE index for different model runs allows a better understanding of the overall impact of certain parameters.

Figure 3: Local ACE index for one storm


Ensemble	Cat 4 proportion (size of dots = nb of storms, colour = % cat4 – grey = 0%)		ACE index spread (histogram of annual ACE index)
(1) Historical data IBTrACS 1951 – 2007 1,515 storms 55,592 storm points* *6-hourly pressure readings	Figure 4a: Spatial distribution bi-variate Storm freq / Cat 4 freq		 Figure 5a: ACE index for IBTrACS
(2) Reading Original NUGAM High res N216 (~ 60km) 20-year simulation 512 storms 26,005 storm points	Figure 4b: note the absence of cat 4 storms		 Figure 5b: ACE index for raw NUGAM
(3) Reading NUGAM Calibrated 50 pnt Monotone Spline interpolation, Flat extrapolation, Gaussian smoothed Separate Freq & Severity 100 year resampled (2,553 storms / 94,043 storm points)	Figure 4c: Calibration & resampling captures cat 4 frequency while increasing intensities in less observed areas		 Figure 5c: ACE index for calibrated NUGAM

Discussion

▪ The comparison between (1) and (2) shows clearly that NUGAM correctly represents the observed spatial distribution of storms. However, it underestimates the intensities (no cat 4 or 5 in NUGAM).
▪ The comparison between (1), (2) and (3) shows that calibration and smoothing restore these high intensities, with a smoother distribution of yearly ACE indices. Spatial distribution, largely preserved, may even be enhanced. This should be investigated further.

References & Thanks

[1] Bell et al. Climate assessment for 1999. Bulletin of the American Meteorological Society, (81): S1-S50, 2000.
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[3] Hodges, K. I. Feature Tracking on the Unit Sphere. Mon. Weather Rev., 123, 3458-3465, 1995.
[4] Holland, G.J. An analytical model of the wind and pressure profiles in hurricanes. Monthly Weather review, 108(8):1212-1218, 1980.
[5] Vitolo, R., J. Strachan, P.L. Vidale, D.B. Stephenson, I. Cook, S. Flay. A Global Climate Model based event set for tropical cyclone risk assessment in the West Pacific. EGU2010, Vienna.
Our thanks to Dr Gero Michel for discussions and suggesting the use of the ACE index
Background image: 2004 Typhoon Tokage: NASA image courtesy Jacques Descloitres, MODIS Land Rapid Response Team at NASA GSFC

Sensitivity analysis

Importance of "Smoothing" the pressure points

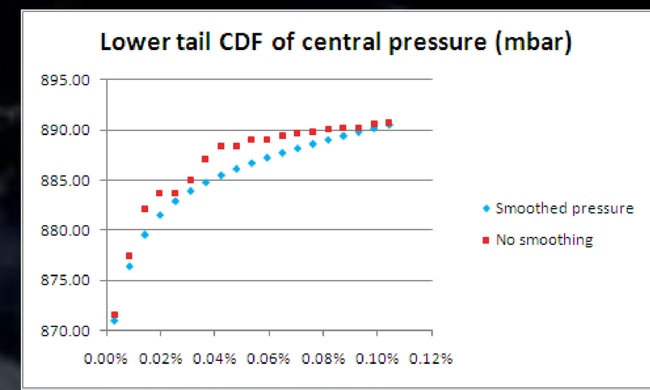

Figure 6a: Smoothed pressure curve

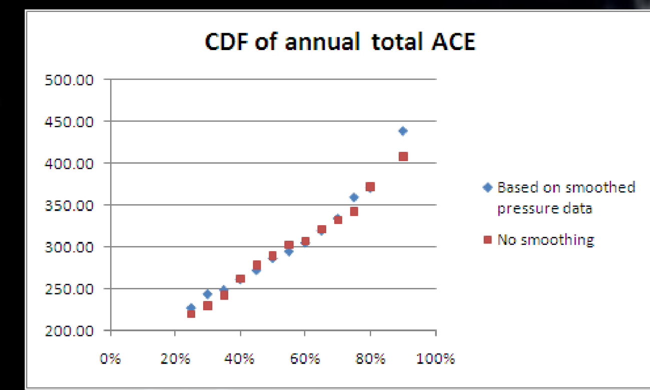

Figure 6b: Comparison of ACE index percentiles

▪ Smoothing seems to have a large impact, in particular on the upper tail of the annual ACE values
▪ Concern that Kernel Smoothing extends data beyond the smallest observed pressure was unfounded
▪ However, smoothing reduces the pressure points at the lower tail (see Fig. 6a) which seems to be an artefact of the dataset.

Importance of the granularity of the "calibration grid"

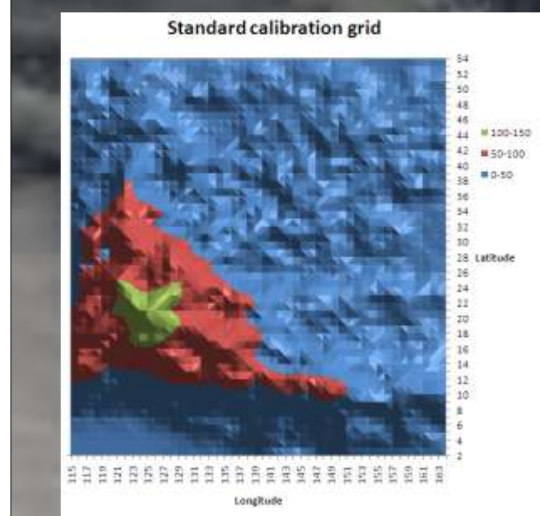

Figure 7a: Local ACE index – 2.5º x 5º cells

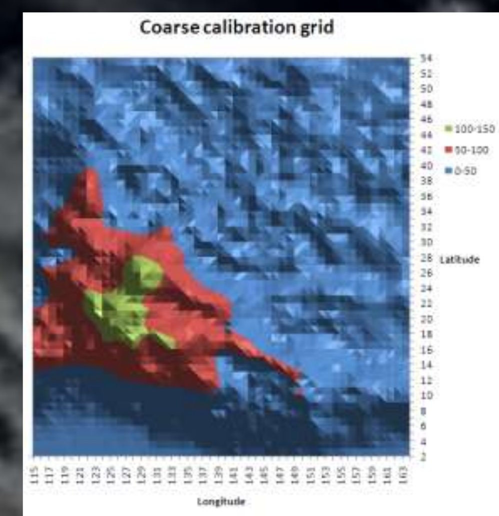

Figure 7b: Local ACE index – 5º x 10º cells

▪ Granularity of calibration grid has an impact on total ACE values and spatial resolution. High granularity offers better spatial detail, but fewer data points in each grid cell reduces quality of calibration.

Conclusions and future steps

▪ GCM simulations offer an invaluable alternative to limited historical records. Although they are unable to attain intensities as high as those observed, a **combination of statistical techniques (calibration, smoothing and sampling)** can help. Determining the **best parameters** for those steps requires **careful sensitivity analysis.**

▪ Here we resampled only **100 years (from 20 years of NUGAM data)**, i.e. not long enough to produce a rich dataset from which firm conclusions can be reached. The intention is to now increase the **sample size**.

▪ **Smoothing**: results show that Gaussian smoothing has a limited but positive effect. Extending the sample size to 1,000s of years is expected to show a marked difference between different smoothing methods.

▪ **Calibration grids**: Choosing an effective grid size and area has large effects on resulting cyclone intensities. Experimenting with finer and coarser grids with varying sizes of calibration circles should lead to more realistic cyclones within the sample set.

▪ **Future work:**

• Comparing **different resolution GCM sets** to understand the impact of model resolution:
HadGAM= N96 (~ 135km) - HiGAM= N144 (~ 90km) - NUGAM= N216 (~ 60km)

• The '**Never observed cyclone**' : current calibration techniques do not yet extrapolate central pressures lower than those in the historic data set. Creating super cyclones over long sample runs is an essential goal to allow better preparations for potentially devastating storms.

• **Multi-year correlations**: Study the effects of climate variability, such as the El Niño/La Niña-Southern Oscillation, will be necessary to more fully evaluate inter-seasonal and multi-year climate variability.