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IMPACT-BASED FORECASTING FOR THE COASTAL ZONE

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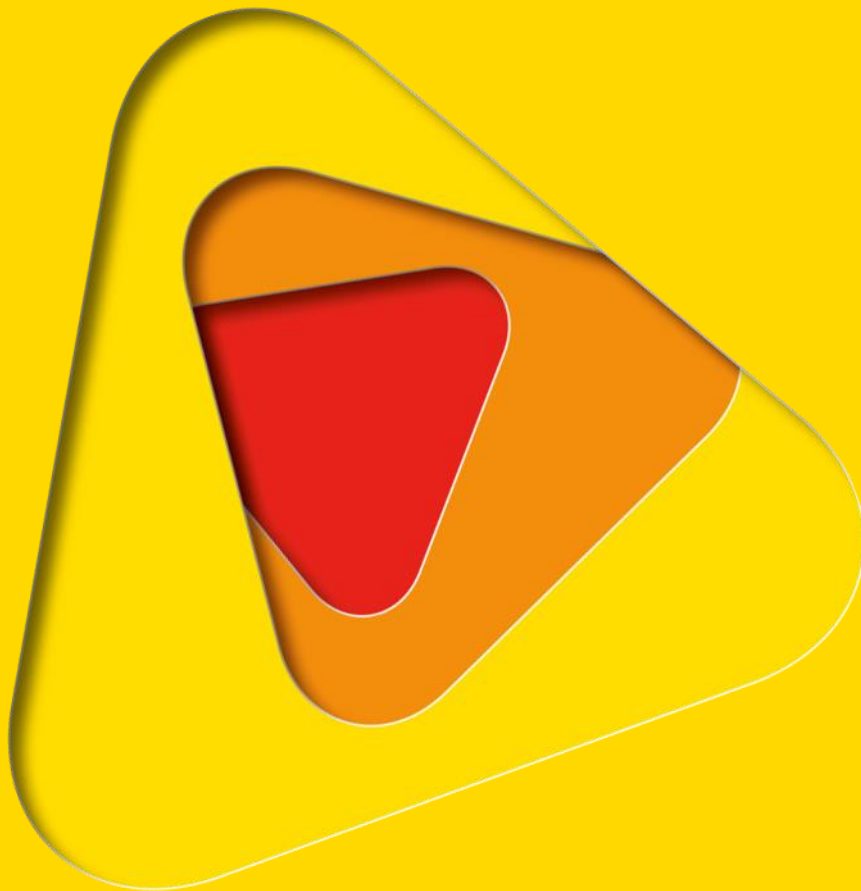**Perth, 5 – 8 September 2018**

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ABSTRACT

IMPACT-BASED FORECASTING FOR THE COASTAL ZONE

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Strong surface wind gusts and heavy rain are meteorological hazards that are predominantly produced by storms such as east coast lows, tropical cyclones or thunderstorms. Interest in these hazards from a response agency point of view lies in their impact on the natural and built environment. At present, weather forecast models still predict mostly 'raw' meteorological output such as surface wind speeds at certain times, or rain accumulations over a specified period. This model output needs to be combined with exposure and vulnerability information to translate the forecast hazard into predicted impact.

The Bushfire and Natural Hazards CRC project Impact-based forecasting for the coastal zone: East-Coast Lows attempts to demonstrate a pilot capability to deliver impact forecasts for residential housing from an ensemble of weather prediction models runs. The project is a collaborative effort between the Australian Bureau of Meteorology and Geoscience Australia.

The project is initially focusing on the wind and rainfall impact from the 20-22 April 2015 east coast low event in NSW. The wind and rainfall hazard data are provided by a 24-member ensemble of the ACCESS model on a 1.3 km grid, with damage data acquired from NSW State Emergency Services (SES) and the Emergency Information Coordination Unit (EICU) for the 2015 event.

We will show that the multi-hazard nature of an east coast low event makes attributing the observed building damage to a single hazard difficult. Wind damage to residential housing in this case is largely due to tree fall. This 'damage-by-intermediary' mechanism requires not just the knowledge of building properties in an exposed area, but also additional knowledge of the surrounding vegetation and its response to strong winds. We will discuss enhancements to the SES/EICU damage survey templates that would lead to improvements in the development of the hazard-damage relationships.

EXTENDED ABSTRACT

INTRODUCTION

Weather Services around the world have gradually been shifting their focus from the delivery of weather and hazard information to value-added information that better characterises the impacts that such hazards can have. Weather impact forecasts have matured or are maturing to the point of operational delivery. One such example is the impact and likelihood matrix employed by the Met Office Severe Weather Warning Service in the UK (Neal et al. 2014).

The prediction of weather impacts can be accomplished on many levels. A simple approach to estimate impacts is to recast weather variables produced by a numerical weather prediction model in terms of how unusual a specific forecast is relative to a reference climatology (Perry 2017). The implication is that the more unusual an event the more likely it is that the event has an appreciable impact. The other end of the spectrum is marked by impact prediction models where the effect of a hazard (or interacting hazards) is quantified. Examples of impact models are the Vehicle Overturning Model (Hemingway and Gunawan 2018) or the Surface Water Flooding Model (Aldridge et al. 2016). Both impact models are at a pre-operational stage of development at the UK Met Office as of April 2018. In-between these two types of impact estimation approaches are various levels of hazard, exposure and vulnerability specifications that, to a varying extent, invites the user to subjectively integrate the various impact drivers (hazards, exposure, vulnerability) in an attempt to estimate the resulting impact.

As part of the three-year Bushfire and Natural Hazards CRC Project "Impact forecasting in the coastal zone: East coast lows", we integrate the wind and heavy rain hazards with information on vulnerability and exposure to estimate the impact on residential properties. The study aims to produce a proof-of-concept system to demonstrate that high-resolution weather forecast models, exposure data and vulnerability relationship estimates have reached a stage of maturity that allows for the production of meaningful spatial impact estimates for residential buildings. The project is developing these impact forecasts in the first instance for Bureau weather forecasters as they work alongside and provide advice to emergency response agencies.

The study will draw on available data from recent extratropical and tropical cyclone events, notably, the Dungog east coast low event in 2015. Observations and insights into the quality, scale and extent of available damage and exposure data to drive impact models will be made and contrasted with the detailed impact models in development at the UK Met Office. This paper describes aspects of the data, methods and findings during the first year of this three-year project.

DATA AND METHODOLOGY

At the most general level, the project will adopt the standard workflow of estimating impact, i.e. combine hazard with exposure data and vulnerability models. This workflow, from the raw high-resolution model output to the final spatial impact estimate on residential buildings, is shown in Fig. 1. High-resolution weather forecast model output for wind and rainfall is first produced on a spatial grid with 1.5 km grid spacing by the Australian Community Climate and Earth System Simulator – City Model (ACCESS-C; Bureau of Meteorology 2018). Basic model wind output, such as

the 10 m mean wind U_{10m}, is not the most suitable estimator for wind damage, given wind damage is more closely related to wind gusts rather than mean winds. It is therefore useful to distinguish between "raw" model output and a related wind hazard specification. A promising model output variable for estimating wind damage is the wind gust diagnostic U_g, derived from the 10 m above ground wind speed. U_g is calibrated to represent a 3 second gust wind speed (P. Clarke, pers. comm.), and corresponds closely to the observed gust wind speed recorded at automatic weather stations.
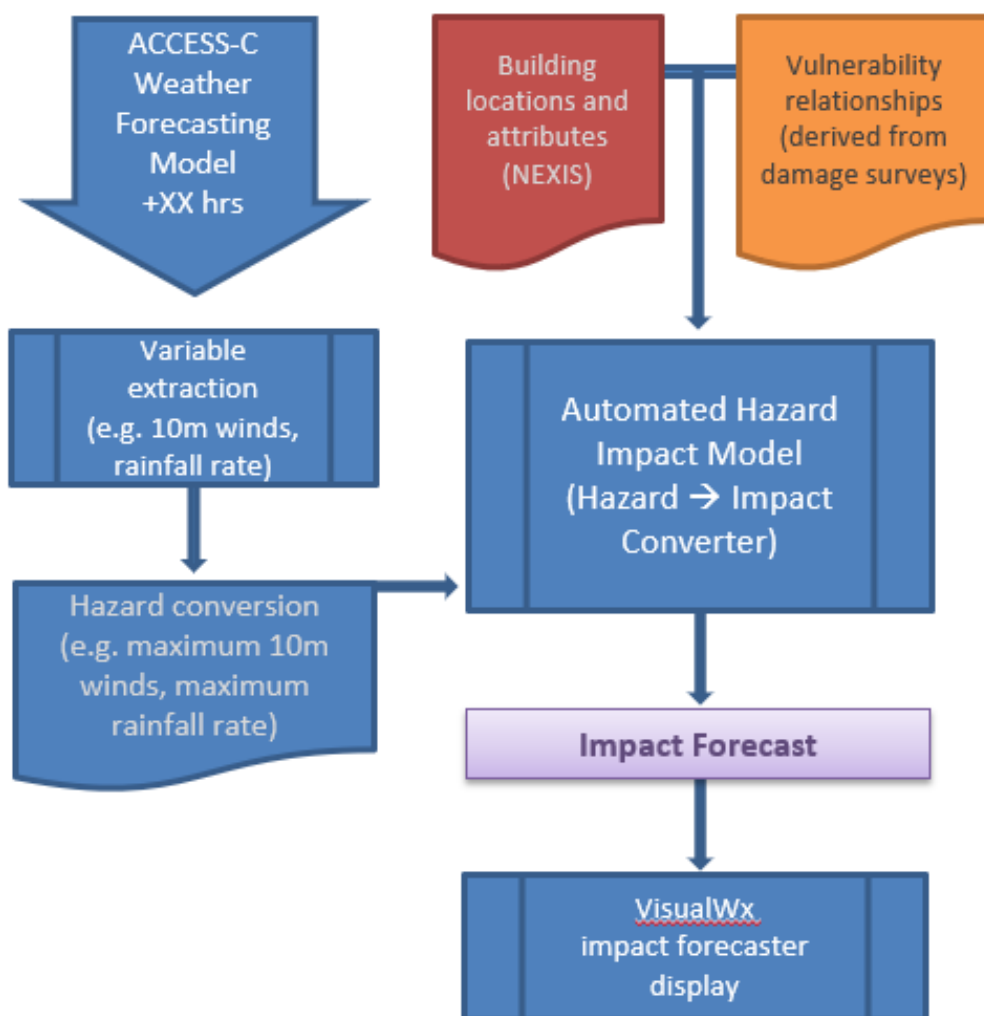

Figure 1: Idealised project workflow from high resolution model output to a spatial display of impacts in the Bureau of Meteorology's operational data display system (Visual Weather).

Apart from the gust diagnostic, other options exist to sensibly define a wind-based damage proxy or hazard. These options include spatiotemporal maxima of the horizontal winds from the native model grid. One such maximum is the hourly maximum field (or HMF) which is an attempt to capture the grid point maximum wind speed across all dynamical model time steps within a given hour (Kain et al. 2010).

Exposure information is sourced from the National EXposure Information System (NEXIS) developed by Geoscience Australia (Nadimpalli 2007). NEXIS contains information on building locations, including structural, economic and demographic attributes at the building level. The quality of the NEXIS data is spatially variable; it is reliant on the quality and availability of building specific input data. Where local building survey data is available, the quality of the NEXIS data, at the building level, is better compared to areas where attributes need to be derived statistically. The statistically derived data areas are representative at an aggregated level but less likely to represent the exact building specific attributes, on the ground.

Vulnerability relationships were originally intended to be derived from two damage assessment datasets, one provided by the State Emergency Services in NSW (the BEACON data), and the other by the Fire and Rescue NSW Emergency Information Coordination Unit (the EICU data). Both damage datasets cover the 20-22 April 2015 East Coast Low impact around the Dungog NSW area. Vulnerability relationships are derived by plotting the degree of damage reported for residential buildings against the wind and rain hazard specification based on the ACCESS-C model output.

The automated generation of a spatial impact estimates through Geoscience Australia's open source HazImp software requires input information on exposure and vulnerability relationships in addition to the ACCESS-C-based hazard inputs.

Finally, the spatial impact estimates are primarily (but not exclusively) intended to be made available to Bureau of Meteorology forecasters through Visual Weather, their primary operational data display system. This way, severe weather forecasts and warnings can be augmented with impact information to enhance their utility to a variety of end users, including the emergency response agencies.

EARLY PROJECT FINDINGS

One year into the three-year project our findings focus on the complexity and usability of the available exposure and vulnerability data in relation to the resolution of the weather forecasts. The properties and limitations of the available datasets largely shape our ability to produce meaningful impact forecasts. However, this knowledge importantly provides the project with the opportunity to showcase how improvements in data collection can improve the quality of impact forecasts and critically, provide the evidence to emergency services to amend damage recording practices for their long-term benefit.

The key impediments to the derivation of vulnerability relationships for the Dungog event were twofold. First, only the EICU data contained a categorical degree of damage (none, minor, major, severe and destroyed). Such a categorisation is needed to relate the damage severity to the magnitude of the associated hazard. Second, the wind speeds produced by the Dungog event mostly stayed well below the design wind speeds for newer housing in the Hunter area (34-40 m s^{-1}) and therefore cannot be expected to define the full wind vulnerability relationship. In addition, whilst damage was reported in the BEACON and EICU data it was not possible to determine which hazard(s) caused the damage, i.e. wind or rain or other hazards. The wind-related damage that did occur was mostly due to tree fall, rather than direct wind impact on buildings. This 'damage by intermediary' causality chain greatly complicates the derivation of vulnerability relations given tree response to strong winds depends on a multitude of other factors.

An outcome from these findings has been a recommendation to amend the damage reporting detail in BEACON to include damage categories and to relate all reported damage to the underlying hazard(s).
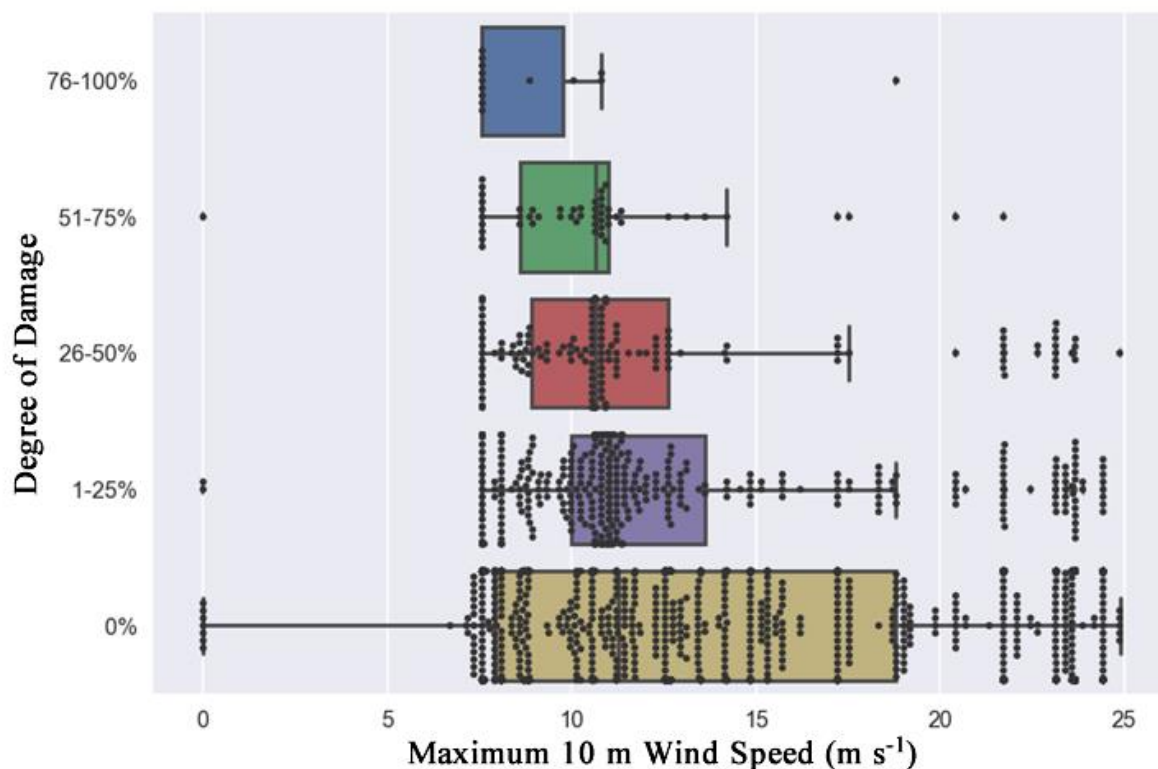

Figure 2: 20-22 April 2015 EICU damage data for the town of Dungog (NSW). The recorded building damage, categorised into five classes (none, minor, major, severe, destroyed), is shown in relation to the matching 48-hour maximum 10 m mean wind speed from one individual ensemble member (member 12) of a 24-member high resolution model run on a 1.3 km grid. The coloured boxes show the inner two quartiles of the model wind distribution for each damage category.

The detailed examination of the damage data for the Dungog event also confirmed a well-established view that most impacts are multi-hazard in nature. Fig. 2 demonstrates that the reported total damage in the EICU dataset is not sensibly related to the model-derived wind speed alone, but is the aggregated product of interacting hazards including wind, heavy rain and overland flooding. Particularly the damage reports in the 76-100% (destroyed) category are related to flooding as a nearby creek rose beyond its banks (Wehner et al. 2015).

The derivation of vulnerability relationships from damage assessment data either requires an unambiguous link between the reported damage and a single underlying hazard that caused the damage, or it will be necessary to explore the use of multi-hazard predictors to estimate the spatial event-integrated damage pattern in a more statistical sense.

Akin to the vulnerability relationships, the available exposure information has also been tested for its level of uncertainty. For the township of Dungog, the NEXIS information is statistically derived from known point source data in equivalent nearby

towns. The building attributes "wall material" and "roof material" in NEXIS for houses in Dungog are derived from exposure survey results in Newcastle (Dhu and Jones 2002) and Alexandria (Maqsood et al. 2013). The "age" attribute for houses built pre-1982 are sourced from NSW cadastral parcel registration date. The "age" attribute for houses built 1982 and onwards is sourced 75% from NSW median suburb year and 25% from cadastral parcel registration date.

We examined all 856 dwellings in Dungog in a desktop exposure survey (using Google Streetview, aerial and other imagery) and compared the surveyed (actual) wall and roof types to the statistically derived attributes within NEXIS. Fig. 3 shows the degree of agreement between the surveyed and statistically derived house types (a house type is defined as a specific combination of one of ten possible roof types and one of six possible wall types).
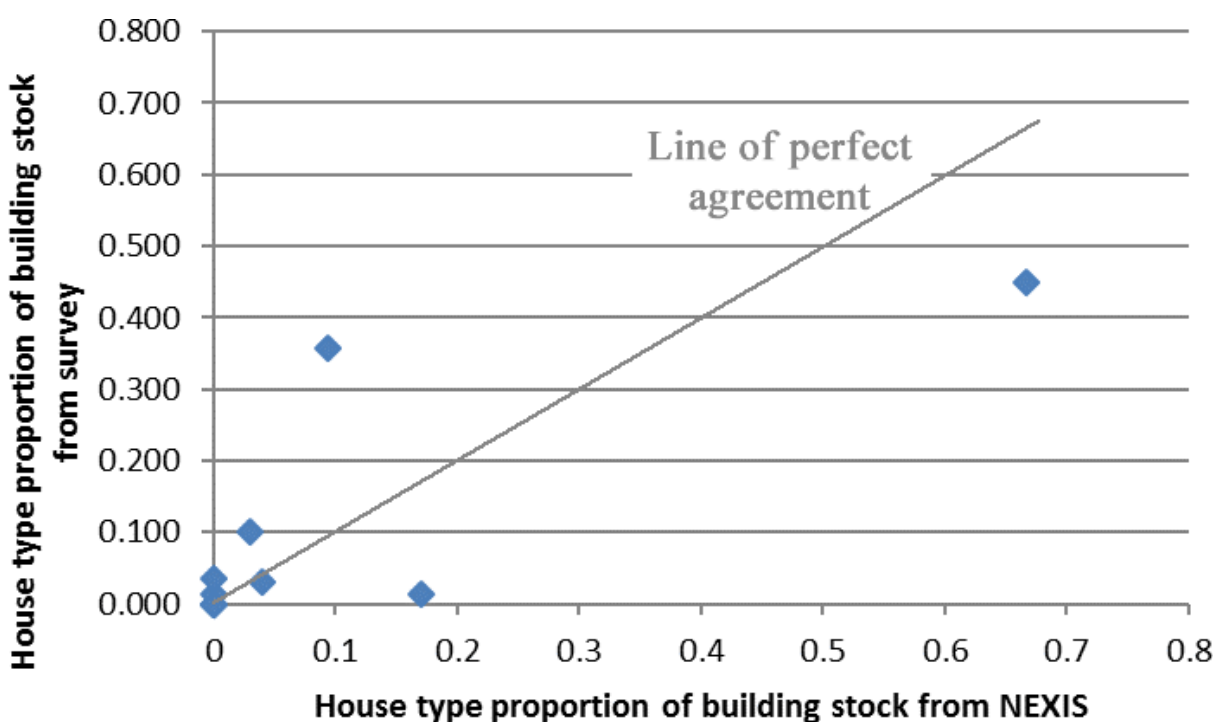

Figure 3: Relationship of statistically derived NEXIS and surveyed house types for all post-1982 houses in the town of Dungog NSW. A "house type" is defined as a combination of wall material (10 categories) and roof material (6 categories). Note that only a small number out of all 60 possible house types is actually present in Dungog.

Fig. 3 implies that the statistically derived residential building attributes for Dungog do not agree well with the actual attributes on the town scale. This suggests that in areas where residential building attributes need to be derived statistically due to lack of in-situ survey data, wind and rain impacts on such housing can only be meaningfully considered on scales larger than the town scale. This observation is well understood by the NEXIS data custodians. Implementation of an impact forecasting system nationally will require a nationally consistent exposure system which in turn relies on what data each jurisdiction collects and the quality of that data. This decision will become a cost-benefit analysis for each government.

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SUMMARY

This study ultimately aims at deriving useful multi-day spatial impact forecasts for residential buildings based on wind and rain forecasts from high-resolution numerical models. Damage assessment data for the 20-22 April 2015 Dungog NSW east coast low event was sourced and its relationship to the wind strength and rainfall rate explored.

We found that the damage data available were lacking critical information needed to establish vulnerability relationships of residential houses with respect to wind and rain. The reported damage needs to be categorised and linked to the hazard or hazards that caused it. The observed damage was often due to more than one hazard, raising the prospects that vulnerability relations might have to be crafted based on multiple interacting hazards. In regard to the available exposure data, areas where local building attributes need to be derived from surveyed housing attributes elsewhere (e.g., Dungog NSW) have significant errors in their exposure data. Currently this does not allow meaningful impact estimates at town scales or smaller.

The project plans to extend our severe weather data collection to multiple tropical and extra-tropical cyclone cases for which high-resolution model data and high quality damage assessment data are jointly available. These datasets will be used to derive statistically more robust vulnerability relationships that will employ multi-hazard predictors for the impact on residential buildings. However, starting this project using the Dungog example as a case-study is highly instructive as it allows many of the data issues to be identified and highlights the reality in the varied quality and extent of damage and exposure data. Without this example, the impact forecast user community may see this as a trivial problem, when it simply is not.

In the meantime, we will employ interim vulnerability relations that have been used by Geoscience Australia for scenario impact assessments for emergency management planning purposes to demonstrate the full end-to-end workflow in a pseudo-operational environment – from high-resolution weather model output to spatial impact data.

REFERENCES

Bureau of Meteorology, 2018: APS2 Upgrade to the ACCESS-C Numerical Weather Prediction System (22 February 2018). Operations Bulletin 114. http://www.bom.gov.au/australia/charts/bulletins/BNOC_Operations_Bulletin_114.pdf.

Dhu, T., and T. Jones, 2002: Earthquake Risk in Newcastle and Lake Macquarie. Geoscience Australia Record 2002/15.

Hemingway, R., and O. Gunawan, 2018: The Natural Hazards Partnership: A public-sector collaboration across the UK for natural hazard disaster risk reduction. Int. J. Disaster Risk Reduct., 27, 499–511, doi:10.1016/j.ijdrr.2017.11.014. https://doi.org/10.1016/j.ijdrr.2017.11.014.

Kain, J. S., S. R. Dembek, S. J. Weiss, J. L. Case, J. J. Levit, and R. A. Sobash, 2010: Extracting unique information from high-resolution forecast models: Monitoring selected fields and phenomena every time step. Wea. Forecast., 25, 1536-1542.

Maqsood, T., M. Wehner, N. Corby, and M. Edwards, 2013: Urban Stormwater Climate Change Impact Study: Alexandra Canal. Geoscience Australia.

Nadimpalli, K., M. Edwards, and D. Mullaly, 2007: National Exposure Information System (NEXIS) for Australia: Risk Assessment Opportunities, Proceedings of MODSIM07 Conference, Christchurch, New Zealand.

Neal, R. A., P. Boyle, N. Grahame, K. Mylne, and M. Sharpe, 2014: Ensemble based first guess support towards a risk-based severe weather warning service. Meteorol. Appl., 21, 563-577.

Perry, M., 2017: Understanding Weather and Climate Risk. What is risk in a weather and climate context? https://www.geolsoc.org.uk/~/media/shared/documents/Events/Past%20Meeting%20Resources/Sharing%20an%20Uncertain%20World/Perry%20Matthew.pdf

Wehner, M. and T. Maqsood, 2015: Dungog Flood, 20-21 April, 2015 Post-Flood Damage Survey. Geoscience Australia Record 2015/21.