Atmospheric Research 87 (2008) 37–51

ATMOSPHERIC RESEARCH

www.elsevier.com/locate/atmos

Estimating future trends in severe hailstorms over the Sydney Basin: A climate modelling study

Lance M. Leslie [a,*], Mark Leplastrier [b], Bruce W. Buckley [c]

[a] *School of Meteorology, University of Oklahoma, Norman, OK, USA*
[b] *Insurance Australia Group, Research and Development, Sydney, Australia*
[c] *Bureau of Meteorology, Perth, Australia*

Received 7 April 2007; accepted 30 June 2007

Abstract

This study estimates future trends in the characteristics of severe hailstorms that affect the most heavily populated region of Australia, the Sydney Basin, using coupled climate model simulations under both fixed (no change) greenhouse gas concentrations and the IPCC SRES A1B future climate scenario. The "future climate", as defined here, is the 50-year period January 1, 2001 to December 31, 2050. First, an assessment is made of the ability of the climate model, in very high-resolution mesoscale model mode, to simulate three of the most severe hailstorms recorded in the Sydney Basin during the "present climate" period, defined here as the years 1990 to 2002. These simulations, nested down to 1 km grid spacing, are compared with the archived hail observations of the storms. The climate model then is used to provide estimates of projected changes in hailstorm frequency, tracks, intensity, duration, and hail size over the Sydney Basin for the "future climate" period.

The model employed in all simulations is the University of Oklahoma Coupled General Circulation Model, known as OU-CGCM, which also can be run as a high-resolution NWP model. The high-resolution version of the OU-CGCM used for the case studies employs a hierarchy of graded mesh and nested model domains, with a sophisticated 10-ice phase cloud microphysics scheme used in the highest resolution domain (1 km horizontal grid spacing) of the model. This work builds upon preliminary hail modelling case studies over eastern New South Wales carried out by the present authors with an earlier version of the model.

The model results under the SRES A1B future climate scenario show significant trends out to 2050 in the key characteristics of severe hailstorms over the Sydney Basin, relative to both the 1990–2002 present climate and the 2001–2050 no-change future climate.

Keywords: Severe hailstorms; Climate models; Sydney Basin; Climate variability

1. Introduction

Severe hailstorms constitute 10 of the 20 largest insurance losses in Australia since 1967, costing an estimated AUS$2.8 billion in "original" dollars (IDRO, 2005). For example, for the Insurance Australia Group (IAG), since 1987 severe hailstorms in New South Wales (NSW) alone make up 15 of their 20 most costly events totaling more than AUS$1.3 billion (Coleman, 2002). To date, little is known of the likely future changes in the frequency, intensity, hail size, duration, and tracks of Australian hailstorms. This work is intended to provide insights into trends in hailstorm

* Corresponding author. School of Meteorology, University of Oklahoma, Norman, Oklahoma, USA. Tel.: +1 405 325 6561; fax: +1 405 325 7689.

E-mail address: lmleslie@ou.edu (L.M. Leslie).

0169-8095/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.atmosres.2007.06.006

activity over one of the areas of Australia most affected by hailstorms, namely the heavily populated Sydney Basin. An Intergovernmental Panel on Climate Change (IPCC) emission scenario, the SRES A1B scenario, is used here. It adds to existing climate modelling work by the University of Melbourne, using the CSIRO Mk3 model, in their investigations of the changes in the climatology of Convective Available Potential Energy (CAPE) across the adjacent southeastern states of Victoria and South Australia (Niall and Walsh, 2005). It also complements the work of McMaster (1999), which focused on winter hail events over rural NSW. The modelling domain and place names referred to in this study are shown in Fig. 1a.

This investigation is confined to a subgroup of the full range of potential hail-producing systems that occur over eastern Australia. Our interest is confined to hailstorms that form during the warm season, defined as October 1 to April 30, which meet the essential criterion of producing hail with a minimum diameter of 2 cm or more; this threshold being required for a hailstorm to be classified as severe in the Australian context.

To our knowledge, the most comprehensive climatology of hailstorms currently available for NSW, with a special focus on the Sydney Basin, has been completed by Schuster et al. (2005). Schuster's work builds on earlier studies by Andrews et al. (1996), Kuhnel (1998) and Leigh and Kurnell (2001), and includes both severe and non-severe events. We note that there are significant problems in identifying the exact climatology of hail in any region, given the localized nature and the high degree of temporal and spatial variability of hailstorms, and the location-specific nature of hail reporting networks. Schuster et al. (2005) assessed all available data sources and their study is the best available benchmark against which the performance of model simulations of hailstorms, in both present and future climates, can be gauged.

Section 2 describes the OU-CGCM climate model, which has been used in a number of applications (e.g. Karoly and Leslie, 2005; Leslie et al., 2007). We outline criteria for identifying hail-producing supercells using climate model generated covariates. Section 3 provides three climate model simulations of hailstorms observed in the Sydney basin prior to the end of 2002. Section 4 discusses future high-resolution model case studies of the hail climate of the Sydney Basin. Section 5 estimates hail size recurrence intervals. Section 6 examines extreme hailstorm events generated under the IPCC SRES A1B future climate conditions. Finally, Section 7 presents our discussion and conclusions and describes plans for future work.

2. Methodology

An extensive series of multiply-nested high-resolution numerical model studies was undertaken, with the finest resolution model domain having a horizontal grid spacing of 1 km, and 40 levels in the vertical. The 1 km high-resolution model runs are computationally extremely expensive, as they utilise a current state-of-the-science, non-hydrostatic, 10-ice phase cloud microphysics model to simulate the growth and decay of hail in intense convective systems. Swathes of large to giant hail can be of the order of tens or hundreds of metres to a few kilometres wide and several kilometres to hundreds of kilometres in length (Dessens, 1986; Changnon, 1977), confirming that the hail swathes cannot be fully resolved even at 1 km grid spacing. However, the model simulations can be used with confidence to infer hail size in the future enhanced greenhouse gas affected climate. Hence, the numerical simulations should provide useful indications of the size of hail generated in future climate regimes, and also indicate areas over which the genesis and initial movement are likely. In particular, trends in hail behaviour possibly will be more accurate than actual hail sizes. Real storm dynamics are exceedingly complex, with secondary and tertiary storm formation possible. This study acknowledges such limitations but also suggests that the results are, at least, a starting point upon which future studies can build.

2.1. The OU-CGCM model description and configuration

The climate model employed here is the University of Oklahoma Coupled Global Climate Model, as described by Karoly and Leslie (2005) and Leslie et al. (2007). It is a non-hydrostatic, coupled atmosphere-ocean GCM based on an atmospheric general circulation model (AGCM) developed originally at The University of New South Wales, Sydney (Leslie and Fraedrich, 1997). The atmospheric model employs high-order finite differencing with a global horizontal grid spacing of $1.5° \times 1.5°$ and has 34 vertical levels. The ocean model is the GFDL Modular Ocean Model (MOM), with $1° \times 1°$ horizontal grid spacing, increasing to 0.5° at the equator, and also has 34 vertical levels. A key feature of the OU-CGCM is the option of a higher resolution region over a selected area, using a graded mesh approach, providing a two-way coupled higher resolution “window”. This window was located over southeastern Australia and potential hail events are detected from covariates derived from the climate model output. Likely major hail-producing situations were run as case studies, multiply nested down to a final resolution of 1 km.