Recent Progress in Glaciogenic Cloud Seeding over Southeast Australia and Tasmania

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1. Introduction

From the 1950s through the 1980s, Australia was at the forefront of cloud seeding research, primarily through the Commonwealth Science and Industrial Research Organisation (CSIRO). Over this time, major field campaigns to test glaciogenic seeding methods were undertaken in the states of New South Wales, South Australia, Tasmania and Victoria. The majority of these campaigns ultimately failed to clearly demonstrate a significant positive effect when employing a double ratio analysis. A more complete history of these early efforts can be found in Ryan and King (1997). Ultimately cloud seeding research within Australia was abandoned by the CSIRO in the 1980s.

Of these field campaigns, there were two notable exceptions: the Snowy Mountains in New South Wales and the central plateau of Tasmania. The seeding trials over the Snowy Mountains (1955-1959) reported 19% increase at the 5% significance level (Smith et al., 1963) In Tasmania the first seeding experiment (1964-1971) reported increases of up to 30% at the 3% significance level at times in the Autumn. A second Tasmanian campaign (1979-1983) reported increases of 37% (Ryan and King, 1997). On the basis of these research programs operational cloud seeding has been undertaken over central Tasmania for much of the past 20 years. A field campaign over the alpine region in Victoria was abandoned before completion. While no significant results were recorded for the target region, a statistically significant increase in precipitation was observed within the buffer region (Ryan and King, 1997).

The southeast region of Australia experienced a prolonged drought from 1997-2009, which has led to considerable interest in these historical cloud seeding experiments including a new glaciogenic cloud seeding experiment in the Snowy Mountains (Manton et al., 2011).

A review of the recent progress made in understanding glaciogenic cloud seeding is presented starting with an analysis of historical cloud seeding records over Tasmania. The positive findings for the Snowy Precipitation Enhancement Research Project (SPERP) are summarised. Consistent with the earlier field work, this experiment has found a positive (14%) increase in precipitation during seeded events at the 3% confidence level, when poorly targeted events are removed. Finally the natural environment over this region is explored through in-situ field observations and satellite observations. In comparison to the Western U.S., high concentrations of supercooled liquid water are commonly present, suggesting that the apparent success in this region can be directly linked to superior cloud seeding conditions.

2. Analysis of Historical Record over Tasmania

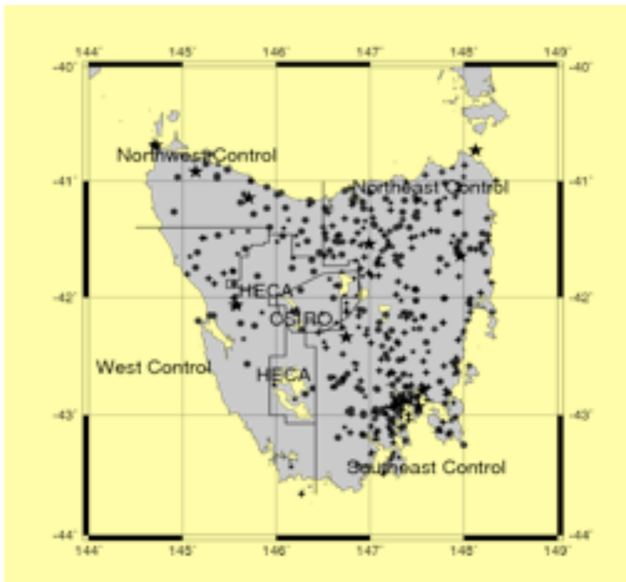

Figure 1. From Morrison et al. (2009) Map of Tasmania highlighting the locations of sites for the period 1960–2005.

In Morrison et al (2009) an analysis of the cloud seeding activity for the period 1960–2005 over a hydroelectric catchment area located in central Tasmania, Australia, is presented (Figure 1.)

The analysis is performed using a double ratio on monthly area-averaged rainfall for the months of May–October. Results indicate that increases in monthly precipitation are observed within the target area relative to nearby controls during periods of cloud seeding activity. Ten independent tests were performed and all double ratios found are above unity with values that range from 5% to 14%. Nine out of 10 confidence intervals are entirely above unity and overlap in the range of 6%–11%. Nine tests obtain levels of significance better than 0.05 level (Figure 2.)

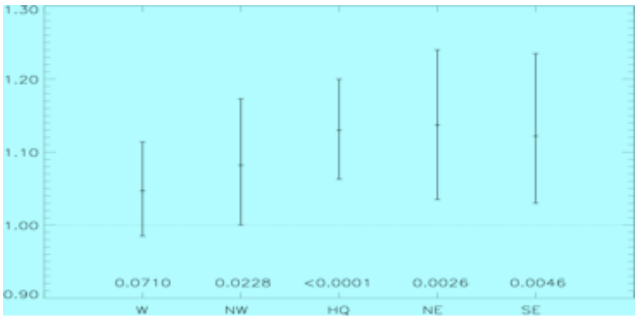

Figure 2. From Morrison et al. (2009.) Double ratios and confidence intervals for the CSIRO targets vs the W, NW, HQ, NE, and SE controls. The bootstrap probabilities for obtaining a double ratio higher than the actual are shown above the horizontal axis.

3. The Snowy Precipitation Cloud Seeding Experiment

In Manton et al. (2011) a description of the Snowy Precipitation Enhancement Research Project (SPERP) is given. SPERP was undertaken from May 2005 to June 2009 in the Snowy Mountains of southeastern Australia with the aim of enhancing snowfall in westerly flows associated with winter cold fronts. Building on earlier field studies in the region, SPERP was developed as a confirmatory experiment of glaciogenic static seeding using a silver chloride material dispersed from ground-based generators. Seeding of five-hour experimental units (EUs) was randomised with a seeding ratio of 2:1. A total of 107 EUs were undertaken at suitable times, based on surface and upper-air observations. Indium (III) oxide was released during all EUs for comparison of indium and silver concentrations in snow in seeded and unseeded EUs to test the targeting of seeding material. A network of gauges was deployed at 44 sites across the region to detect whether precipitation was enhanced in a fixed target area of 832 km2, using observations from a fixed control area to estimate the natural precipitation in the target. Additional measurements included integrated supercooled liquid water at a site in the target area and upper-air data from a site upwind of the target.

In Manton and Warren (2011) a further analysis of the SPERP experiment shows that a substantial source of uncertainty in the estimation of the impact of seeding on precipitation is associated with EUs where the seeding generators operated for relatively few hours. When the analysis is repeated using only EUs with more than 45 generator hours, the increase in precipitation in the primary target area is 14% at the 8% significance level. When applying that analysis to the overall target area, the precipitation increase is 14% at the 3% significance level.

A secondary analysis of the ratio of silver to indium in snow supports the hypothesis that seeding material affected the cloud microphysics. Other secondary analyses reveal that seeding impacted on virtually all the physical variables examined in a manner consistent with the seeding hypothesis.

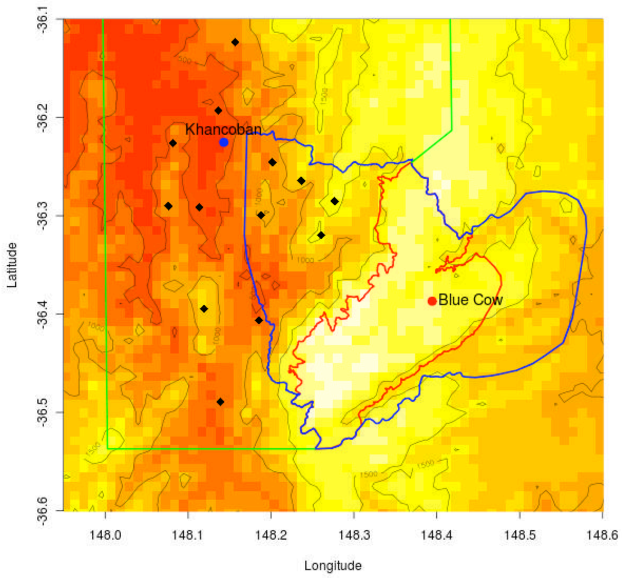

Figure 3. From Manton et al. (2011) Map of Snowy Mountains showing generator sites (black triangles) against the orography, with contours at 500, 1000 and 1500 m; red line shows primary target, blue shows overall target, and green shows control area.

4. In-situ Observations of Supercooled Liquid Water

Tasmania

In Morrison et al. (2010) the cloud structure associated with two frontal passages over the Southern Ocean and Tasmania is investigated. The first event, during August 2006, is characterized by large quantities of supercooled liquid water and little ice. The second case, during October 2007, is more mixed phase.

The evaluated cases are then used to

numerically investigate the prevalence of supercooled and mixed-phase clouds over Tasmania and the ocean to the west with the Weather Research Forecasting (WRF) code. The simulations produce marine stratocumulus-like clouds with maximum heights of between 3 and 5 km. These are capped by weak temperature and strong moisture inversions. When the inversion is at temperatures warmer than 2108C, WRF produces widespread supercooled cloud fields with little glaciation. This is consistent with the limited in situ observations. When the inversion is at higher altitudes, allowing cooler cloud tops, glaciated (and to a lesser extent mixed phase) clouds are more common. The simulations are further explored to evaluate any orographic signature within the cloud structure over Tasmania. No consistent signature is found between the two cases.

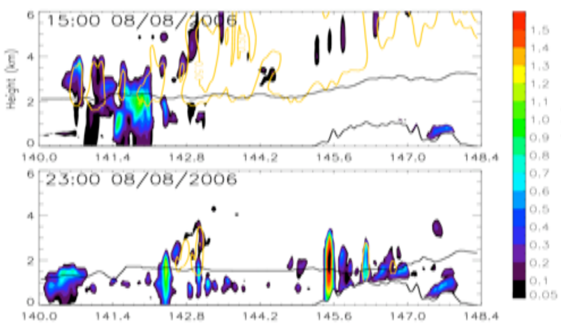

Figure 4. From Morrison et al. (2010). WRF simulations of water and ice to the west of Tasmania (along 42° S). The freezing level is noted to identify regions of supercooled liquid water.

Southeast Australia

Chubb et al. (2011) analysed data from a precipitation gauge network in the Snowy Mountains of South-Eastern Australia to produced a new climatology of wintertime precipitation and airmass history for the region in the period 1990-2009. Precipitation amounts on the western slopes and in the high elevations (> 1000 m) of the Snowy Mountains region experienced a decline in precipitation in excess of the general decline in South-Eastern Australia. The contrast in the decline east and west of the ranges suggests that factors influencing orographic precipitation are of particular importance.

Next a comprehensive discussion of two typical wintertime storms in the Brindabella Ranges of the Australian Capital Territory is considered. Surface observations from automatic weather stations operated by the Australian Bureau of Meteorology, as well as rain gauge data from an independent network, are used to characterise precipitation during these storms. Dual-channel microwave radiometer retrievals provide column-integrated liquid water and water vapour amounts at a mountain-top location, which are compared with MODIS level 2 cloud product data. High resolution numerical simulations are performed with the Weather Research and Forecasting (WRF) model to enhance the interpretation of the observations. The WRF model configuration used is found to be well suited to simulation of wintertime storms in the mountainous Brindabella region. The large-scale dynamics are shown to be well represented, and cloud column-integrated diagnostics compare well with the observed values except during the strongly dynamic frontal passage of the first case. Surface precipitation comparisons are also favourable.

Despite clear dynamical differences between the two storms selected for analysis, the two storms show similarities in the post-frontal conditions. The alpine regions of the Brindabella Ranges experience shallow, supercooled liquid clouds and showery conditions for 12–18 hours following the frontal passage. Numerical simulations suggest that substantial, widespread precipitation is received during this period in elevated

5. Satellite Climatology and Discussion

Morrison et al. (2011) used MODIS satellite imagery to produce a 3-yr climatology of cloud-top phase over a section of the Southern Ocean (south of Australia) and the North Pacific Ocean. The intent is to highlight the extensive presence of supercooled liquid water over the Southern Ocean region, particularly during summer. The phase of such clouds directly affects the absorbed shortwave radiation, which has recently been found to be ‘‘poorly simulated in both state-of-theart reanalysis and coupled global climate models’’ (Trenberth and Fasullo, 2010).

The climatology finds that supercooled liquid water is present year-round in the low-altitude clouds across this section of the Southern Ocean (Figure 5.) Further, the MODIS cloud phase algorithm identifies very few glaciated cloud tops at temperatures above -20°C, rather inferring a large portion of ‘‘uncertain’’ cloud tops. Between 50° and 60°S during the summer, the albedo effect is compounded by a seasonal reduction in high-level cirrus. This is in direct contrast to the Bering Sea and Gulf of Alaska. Here MODIS finds a higher likelihood of observing warm liquid water clouds during summer and a reduction in the relative frequency of cloud tops within the 0° to -20°C temperature range.

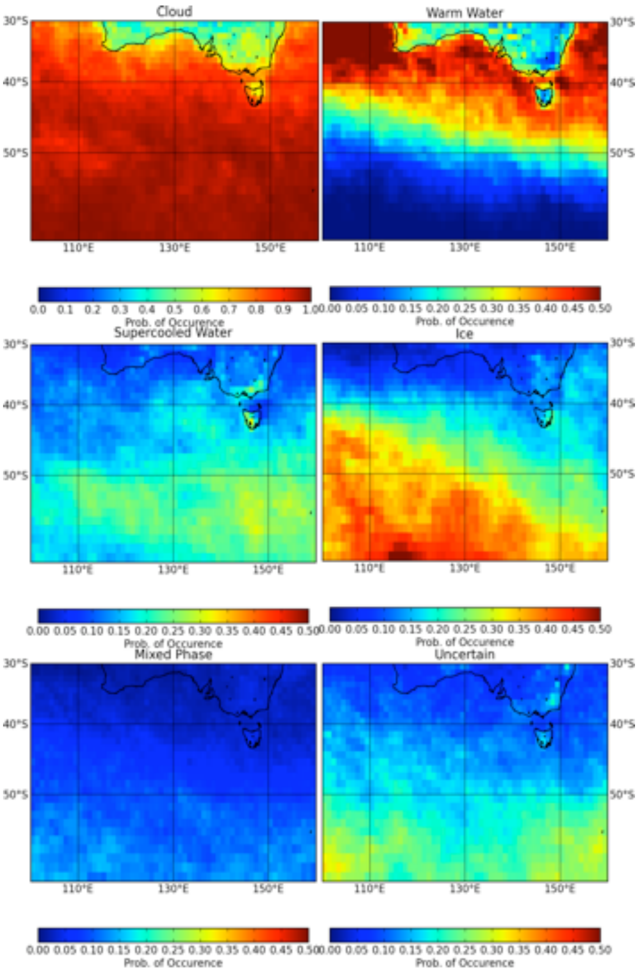

Figure 5. From Morrison et al. (2011). The 3-yr MODIS climatology of thermodynamic phase for the winter months (Jun, July & August.)

This climatology can be further focussed to the cloud seeding regions of Southeast Australia (Figure 6), which reveals peak concentrations in supercooled liquid water along the Australian Great Dividing Range up to the Snowy Mountains. Similar images for cloud seeding regions in the Western U.S. (e.g. the Sierra-Nevada region) find that the conditions for glaciogenic cloud seeding a vastly superior for Tasmania and Southeast Australia.

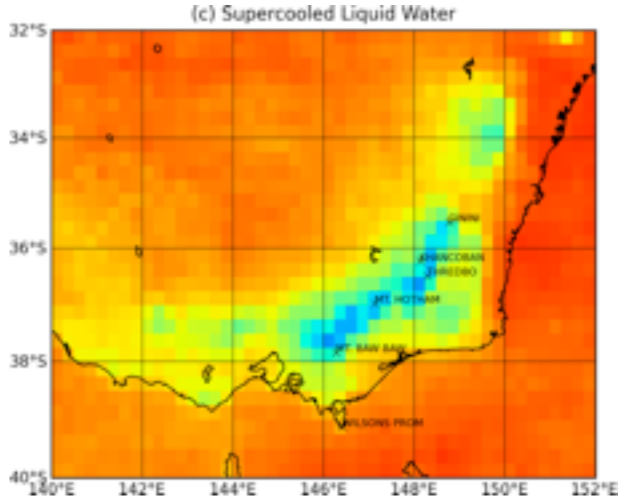

Figure 6. A 5-yr MODIS climatology of supercooled liquid water for the winter months (Jun, July & August.) The scaling is the same as in Figure 5.

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