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AN ANALYSIS OF MOISTURE TRANSPORT ACROSS SOUTHEASTERN AUSTRALIA - RESULTS FROM THE MELBOURNE UNIVERSITY NETWORK OF ISOTOPES IN PRECIPITATION

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1. INTRODUCTION

The stable isotopes ^{18}O and ^{2}H measured in precipitation are useful as natural tracers of moisture within the hydrological cycle. These isotopes undergo fractionation during atmospheric phase changes and diffusion processes and hence hold information about the condensation history of the parent air mass. Isotopic records constructed from samples of rainfall at a particular site or across small basins can use this as a diagnostic of the atmospheric processes contributing to the variability of the isotopic content of rainwater and inputs to local hydrology. The focus here is primarily upon how particular regional scale processes in the atmosphere are manifest in the isotopic record and how short term variabilty may in turn affect the interpretation of longer term isotopic measurements.

2. METHODOLOGY

2.1 *The Melbourne University Network of Isotopes in Precipitation*

As part of a broader study of moisture transport across southeastern Australia, the Melbourne University Network of Isotopes in Precipitation (MUNIP) was established. MUNIP is an array of observational sites around the metropolitan area of Melbourne (37.8°S 145.0°E), sampling rainfall at half hourly intervals during the passage of rain bearing weather systems. The aim of MUNIP is to record the changing isotopic content of rainfall at short time intervals over a small spatial scale. By collecting a record of isotopes in precipitation in this way, MUNIP can serve as a useful reference against which simulations from general circulation models (GCMs) fitted with isotope hydrology can be verified.

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2.2 *Site location and event criteria*

The city of Melbourne is situated on the northern and eastern shores of Port Phillip Bay, a large body of water covering approximately 1,930km^2. To the northwest across to the east, a low mountain range surrounds the city creating a shallow basin around the bay area. It is an interesting location for a study such as this in that there is a three-fold increase in annual rainfall from west to east across the Port Phillip Bay area.

The MUNIP collection sites vary in altitude, proximity to the bay and in topographical aspect and orientation and cover the key regions of this spatial rainfall variability (Figure 1). At each of the MUNIP sites, manual sampling of rainwater was a highly opportunistic exercise, therefore a number of criteria were devised in order to determine if a particular rain 'event' was suitable for a detailed isotopic analysis. In order for a rain event to be sampled by the network, it

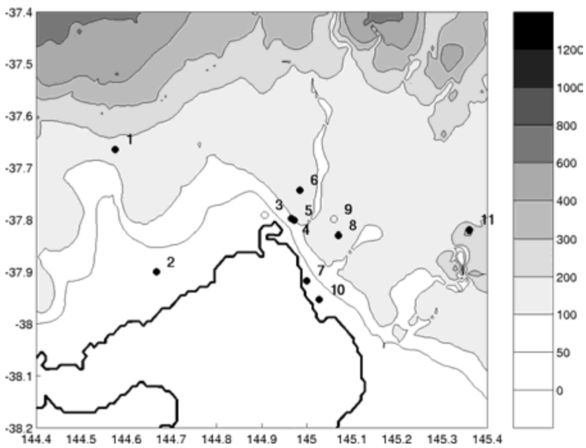

Figure 1: Location of MUNIP sites around Port Phillip Bay: 0. Doncaster (test site), 1.Melton, 2. Werribee, 3.Ascot Vale, 4. Melbourne University (Earth Sciences), 5. Melbourne University (Queens College), 6. Preston, 7. Brighton 8. Camberwell,

9. Canterbury, 10. Hampton East, 11. Kalorama. Topographic elevation contours in metres, open circles indicate sites not used after first event.

should feature continuous rainfall for a period of at least three hours, a time period sufficient to capture both high frequency variability as well as longer term trends in isotopic content. Secondly, the rainfall should be widespread, such that simultaneous measurements could be taken across a number of sites across the network. Finally, the events chosen should feature changes in precipitation dynamics (ie: convection, stratiform) or indicate variation in possible moisture source which may then be reflected by trends in the isotopic record.

3. MUNIP 1 – JUNE 9th, 2004

3.1 *General description and synoptic conditions*

The MUNIP 1 event of June 9, 2004 was characterised by rainfall occurring in two distinct periods. The first period of rain fell continuously from a stratiform rain band for 7 hours between 09:00 and 16:00 (local time). Rainfall ceased until the passage of the main frontal system at 20:00 that featured the development of severe thunderstorms that particularly affected the southeast of the city with local flash flooding and strong wind gusts.

Frontogenesis was occurring ahead of the cold front as it crossed southern Victoria. The cloud band that passed over the city during the day was associated with a pre-frontal trough developing with the mid-latitude cyclone over Bass Strait (Figure 2). Rainfall from this first system was continuous across most MUNIP sites although mostly light in intensity. During the evening, the combination of lifting at the surface in the frontal transition zone together with a

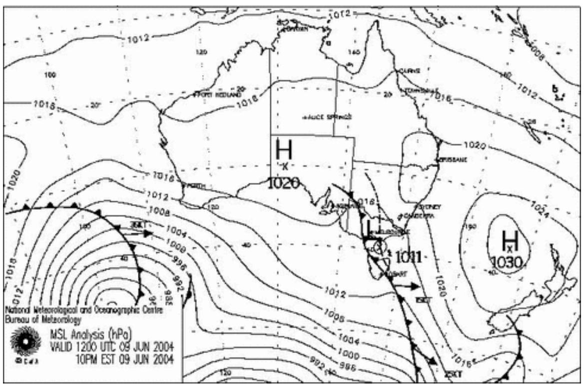

Figure 2: Mean Sea Level Pressure analysis for June 9, 2004 (12UTC). Contour interval is 4hPa. Courtesy Australian Bureau of Meteorology.

diverging upper level wind field acted to initiate the development of severe convection during the evening.

3.2 *Observed $\delta^{18}O$ variability*

Between each half hourly sample, the variability in the rainwater $\delta^{18}O$ content during MUNIP 1 was considerable (Figure 3). The sharp negative 'spikes' in the timeseries were concurrent with local peaks in rainfall intensity (Figure 4), however some trends also indicate that there were other effects that were being captured by the recorded isotopic content.

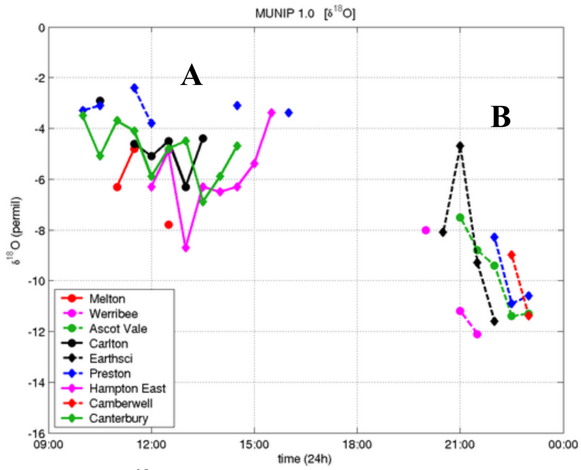

Figure 3: $\delta^{18}O$ time series from MUNIP 1 rainwater samples. Absence of data between 16:30 and 19:30 is a period where no rain fell.

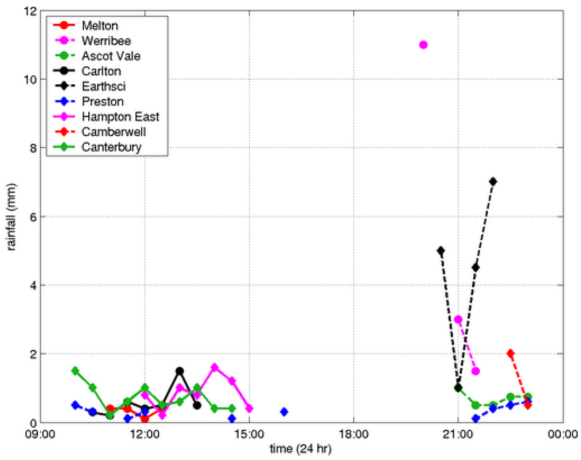

Figure 4: Half hourly rainfall totals for MUNIP 1 rainwater samples. Local times are given (AEST = UTC + 10)

During the first period of stratiform rain (A), the spikes related to rainfall intensity reveal an aspect of the mesoscale structure of the cloud band. Embedded convective cells within the cloud, or mesoscale precipitation areas (MPAs) (Browning and Mason, 1981) are associated with periods of more intense rainfall. During the passage of an MPA, rain intensity is greater and vertical motion is stronger which draws moisture from the colder and more depleted environment higher in the air column (Gedzelman and Lawrence, 1982).

Two other moisture effects are also noticeable in the MUNIP 1 $\delta^{18}O$ observations: droplet evaporation and 'amount effect' depletion. The 'hockey stick' trend observed in the final three early stratiform rain samples from Hampton East show an enrichment of the rain droplets of approximately +2.6‰ during a period of corresponding decline in rainfall intensity. Smaller average droplet size during periods of lighter rainfall (Friedman et al, 1962) results in a greater proportional loss from the drop due to evaporation to the surrounding environment during the fall between cloud and ground (Ehhalt et al., 1963; Dansgaard, 1964). In addition to environmental temperature and humidity, the rate of isotopic modification of rain droplets during descent varies inversely with droplet size (Jouzel, 1986). In a constant environment, evaporative enrichment can become a significant modifying effect once rain droplet sizes fall below a particular threashold.

A gradual trend in time towards more highly depleted rainfall is also apparent in the MUNIP 1 $\delta^{18}O$ observations. Due to the preferential removal of heavy isotopes during condensation, over the duration of a rainfall event the cloud moisture reservoir will gradually become more depleted. The negative trend in the early MUNIP 1 observations is an example of a regional scale 'amount effect' of a $\delta^{18}O$ depletion rate of -0.4‰hr^{-1}.

The pattern of isotopic depletion is markedly different during the severe convection late in the day (B). The sharp negative trend during this period is largely attributable to amount effect depletion which not only reflects a depletion of the moisture within the cloud column, but also the drawing of already depleted low tropospheric water vapour into the convective plume (Lawrence et al, 2002). The rate of $\delta^{18}O$ depletion was -1.0‰hr^{-1} during this phase of the event.

3. NCAR-CAM3 VALIDATION

In support of the MUNIP 1 observational campaign, a version of the NCAR-CAM3 model was run retrospectively for the days leading up to and including the MUNIP 1 event. The model had been modified by Noone (2006) to run with global fields of *u*, *v* and *T* from the NCEP/NCAR reanalysis updated every six hours as a constraint upon the model dynamics. The model hydrology (that has been adapted to include stable isotope fractionation) was left to evolve freely, forced by model parameterizations.

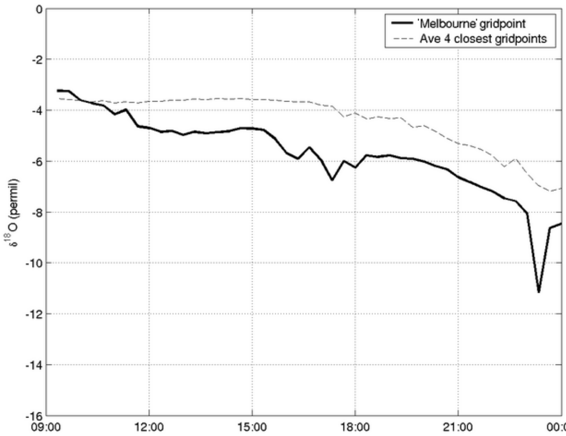

Figure 5: NCAR-CAM3 simulation of MUNIP 1 rain event for 'Melbourne' gridpoint (37^{o}S 145^{o}E).

The NCAR-CAM3 simulation of the MUNIP 1 event showed a good agreement with a stratiform mechanism of precipitation with a simulated rate of $\delta^{18}O$ depletion of -0.3‰hr^{-1} (Figure 5). Synoptic analysis reveals that the model did not capture the cyclone development over Bass Strait or evening convection, maintaining stratiform precipitation throughout the entire period. Despite this, given the relatively coarse 2.5^{o} x 2.5^{o} resolution of NCAR-CAM3, the accuracy of this simulation over such a restricted area is pleasing.

4. SUMMARY AND CONCLUSIONS

In a study of how regional scale atmospheric processes are manifest in isotopic precipitation records the Melbourne University Network of Isotopes in Precipitation was established. Isotopic variability from samples collected during the rain event of June 9, 2004 identified features of the mesoscale cloud structure as well as the effects of droplet evaporation and a temporal depletion of the cloud moisture reservoir. The $\delta^{18}O$ variability recorded during this event was then used as a reference dataset against which a simulation of the event by a version of NCAR-CAM3 with isotope hydrology could be tested. The establishment of MUNIP has proved to be an effective resource in the study of regional scale isotope variability and GCM validation.

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