8.2 AN EXAMINATION OF THE PRECIPITATION DELIVERY MECHANISMS AT DOLLEMAN ISLAND, ANTARCTICA, FROM ECMWF RE-ANALYSIS AND ICE CORE DATA

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1. INTRODUCTION

Dolleman Island (hereafter DI) is located on the eastern side of the Antarctic Peninsula (AP) at approximately S70°35', W60°56'. Like other eastern AP locations it has a cold, continental climate, unlike the warmer, maritime conditions of the western AP. However, Skvarca et al (1998) have shown that during the last 50 years there has been a significant increase in the summer temperature at an eastern AP station (Esperanza) that is double that recorded on the western side (Faraday).

There are several other examples of the apparent dynamic and sensitive nature of the AP to recent climate changes: King (1994) reported a ~2.5°C temperature rise since 1940 on the AP (the largest increase in mean sea level temperature anywhere on the globe); Turner et al (1997) found a statistically significant increase the number of precipitation events occurring in the winter at two AP sites; and there have been two major break ups and continuing retreat of the Larsen Ice shelves (Doake et al, 1998, Rott et al, 2002 and Rignot & Thomas, 2002).

Given these factors and the overall importance of the Antarctic in the global climate system, this work aims to investigate the recent precipitation delivery mechanisms at DI. This will be related to the chemical and isotopic signals that are recorded in two ice cores that have been drilled at DI. The aim of this will be to identify "chemical signatures" that link specific delivery mechanisms with the spatial source of and the path taken by the precipitation and then, from this, to investigate large-scale atmospheric circulation changes.

2. DATA SETS

The source of the precipitation data is the European Centre for Medium Range Weather Forecasting (ECMWF) re-analysis (ERA) project (Gibson et al, 1996). There are two ERA data sets: ERA-15, which contains data for the period 1979-1993 and will be used in this work; and the currently unfinished ERA-40, which will eventually span the years 1957-2001. The daily precipitation variable is found indirectly from the model output, the details of the method can be found in Marshall (2000).

There are 340 years of ice core data available for DI, the cores were drilled and analysed by the British Antarctic Survey (BAS). The two cores were collected in 1993 and 1986 and span the years 1948-1992 and 1652-1986 respectively. The analysis measured or calculated values for $\delta^{18}O$, $[Na^+]$, $[Mg^{2+}]$, $[Cl^-]$, $[NO_3^-]$, $[MSA^-]$, $[SO_4^{2-}]$ and $[nssSO_4^{2-}]$ (where $nssSO_4^{2-}$ is non sea-salt sulphate and $\delta^{18}O$ is a measure of the isotopic ratio ^{18}O:^{16}O incorporating a comparison to a Standard Mean Ocean Water sample). Further details of the cores and the drilling site can be found in Peel et al (1988) and Peel and Mulvaney (2000).

The final significant source of data is the British Atmospheric Data Centre's (BADC) "Back Trajectory" service. This allows air parcels from a given location and date to be traced backwards, temporally and spatially.

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3. METHODOLOGY

In the work presented here the emphasis is placed on the precipitation delivery mechanisms for the period of overlap between the ice core and ERA data. The method employed is described in this section. The ERA data was first used to identify the significant precipitation events that occurred at DI. Secondly, the geographical source and the path taken by the air parcel that delivered this precipitation were found using the Back Trajectory service. The next step was to perform a cluster analysis on the precipitation source and path data that were acquired. Reijmer et al (2002) used a method similar to this to look at the trajectories of air parcels delivering precipitation to 5 sites located on the eastern Antarctic continent.

After this was done, an investigation into the difference in the ice core composition for these precipitation events was carried out. The relationship of the ice core composition to the clusters of precipitation paths and sources was also studied. Peel and Mulvaney (1992) have previously examined the DI ice core composition with respect to the effect of the precipitation delivery mechanisms. Their work concentrated mainly on the influence of the local sea ice. With the inclusion of the back trajectory analysis used here, there is potential for some significant extensions on their findings.

3.1 *Defining the "Ice Core Year"*

One of the aims of this work was to try and identify the signal of specific precipitation events within the ice core. In practice, given the limitations imposed by the nature of ice core analysis, identification of anything on more than a monthly timescale would have proved unjustifiable.

However, it is possible to improve upon an assumption that is often made in ice core analysis; that the trough in the $\delta^{18}O$ concentration represents the 1st July of the yearly accumulation. In this work it was more effective for the accumulation record to be used in conjunction with the ERA precipitation data to find the best date to assign to this trough. The start date used to calculate the annual totals for the ERA precipitation data was varied. Then, by correlating these different annual totals with the annual accumulation of the ice core, it was possible to find the most likely date of the minima of $\delta^{18}O$ in the ice core. The start date used to calculate the total annual ERA precipitation was varied by ±4 months around 1st July. This revealed that the best correlation co-efficient of 0.55 was found using a start date of 30th March.

Even though this correlation co-efficient is rather low, this is to be expected. The date when the trough in $\delta^{18}O$ occurred each year would vary and, therefore, a single date of best fit will only have a low correlation co-efficient.

3.2 *Choosing an ERA Grid Cell*

DI does not cover an entire grid cell of the ECMWF re-analysis model. Further to the method described above to find a date for the $\delta^{18}O$ trough in the ice core data, the annual mean of the ERA precipitation data was calculated for every permutation of 5 model grid cells that are located around DI for each start date. The greatest correlation co-efficient mentioned above was found when a single grid cell, located just to the south of DI, was chosen to represent the precipitation at DI. This chosen cell is, however, classified as being "sea" in the model as a result of the way in which the model orography is smoothed.

As comparisons are being made in this work between precipitation and ice core accumulation, it would be logical to incorporate surface evaporation (i.e. use precipitation minus evaporation rather than merely precipitation). However, evaporation will not be used. This is primarily because the evaporation term for the cell will be biased by the fact that it is defined as sea but also because the ERA model has been reported as having problems with calculating evaporation (Genthon and Krinner, 1998).

3.3 *Defining "Significant Precipitation Events"*

In order to have a manageable number of days which have "significant precipitation", a significant precipitation event is defined here as the arbitrary value of 10mm per day. This occurs on 87 of the 5479 days at the chosen model grid cell.

4. RESULTS

4.1 *Clusters of Precipitation Sources*

Figure 1 shows the source of the air parcels that arrive at DI at 1200hrs on each day that the ERA data shows had significant precipitation. Further, these sources have been grouped into 5 clusters using hierarchical cluster analysis. This was done using Ward's method to cluster the co-ordinates of the source of the air parcel as calculated by the BADC 5-day Back Trajectory.

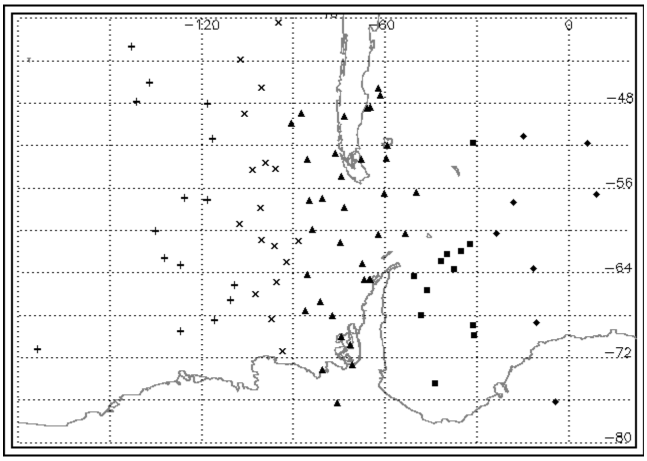

***Figure 1**: Source locations of air parcels for the days of significant precipitation. Source Cluster 1 is represented by ♦, Cluster 2 by ■, Cluster 3 by ▲, Cluster 4 by X and Cluster 5 by +.*

Of the 87 days that were found to have significant precipitation, table 1 shows the number of source co-ordinates that fell into the 5 clusters.

TABLE 1

Source Cluster Number	Number of members
1	8
2	12
3	35
4	17
5	15

4.2 *Clusters of Precipitation Paths*

As well as looking at the source of the air parcel that delivers the precipitation, the paths of the parcels have also been examined. Here, the co-ordinates output by the BADC model at 6-hourly intervals over the 5-day trajectory were analysed using the same technique as the "source" cluster analysis. From the results, the mean of the paths found to be in each cluster where calculated and are shown in figure 2.

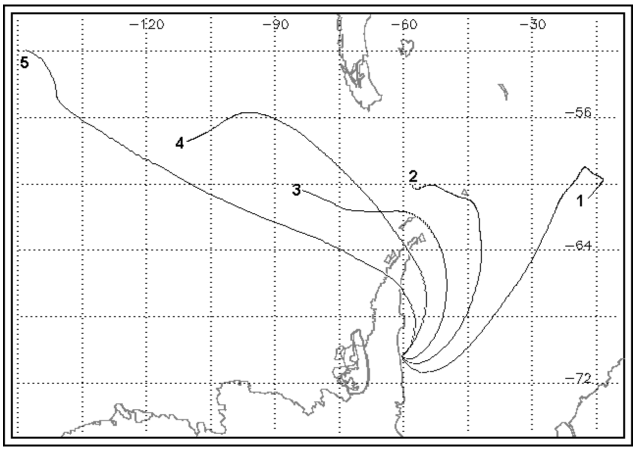

***Figure 2**: Means of the co-ordinates of the paths that fell into the 5 "path" clusters. The number at the start of the path identifies each set.*

As with the analysis of the air parcel sources, 5 clusters were found. However, in this case, 11 of the trajectories were removed from the analysis as they reached ground level (1000mb) before the end of the 5-day trajectory. This data cannot be analysed along side the full 5-day trajectories. Table 2 shows how many of the paths fall into each of the 5 clusters.

TABLE 2

Path Cluster Number	Number of members
1	12
2	15
3	29
4	16
5	4

4.3 *Comparing the "Source" and "Path" Clusters*

It was found that the correlation co-efficient between the dates that were members of a cluster in the source analysis and the corresponding cluster in the path analysis is 0.87. Before this calculation was performed, the 11 dates that were removed from the path analysis were also removed from the source cluster results. Although expected, it is encouraging that there is a high correlation between the two as this implies that significant precipitation events that have come from similar sources are likely to have followed a similar path to reach DI.

4.4 *Ice Core Evidence and the Clusters*

The results that could be found from the analysis of the raw ice core data were rather limited by the number of precipitation events that could be temporally resolved within the data. Table 3 shows the number of events that could be resolved along with this figure as a percentage of the total number in that cluster.

TABLE 3

Path Cluster Number	Members resolved
1	6 (50%)
2	6 (40%)
3	11 (38%)
4	3 (19%)
5	3 (75%)

This problem occurred as a result of many of the precipitation events being used in this work being temporally too close to one another. When this occurs, it is not possible to identify the individual events in the data and the dates were removed from the ice core analysis. This problem is increased by the uncertainty already discussed regarding the definition of the ice core year. Only dates with a ±1 month window around them were used in this analysis.

Given these limitations, there are still some interesting signals in the ice core data: the data relating to Cluster 2 all have relatively high concentrations of MSA^-; for Cluster 3 there are relatively high concentrations of NO_3^- and low concentrations of MSA^- as well as two significant correlations between the concentrations of all the species measured on different days and 6 other high correlations; and Cluster 1 has low concentrations for all species. Clusters 4 and 5 do not have enough data available to comment on.

5. CONCLUSIONS AND DISCUSSION

No clear chemical signatures of the precipitation events from different clusters have been identified in this work. The identification of the clusters themselves, though, can be regarded as a success. This portion of the work would suggest that most (77%) of the significant precipitation events come from the west of the AP (Bellingshausen sea/south Pacific). If the work is repeated using a lower threshold for the significant precipitation event, it would possible to investigate when the precipitation from the Weddell Sea increases in importance. Of course, the fact that it is ERA precipitation data being used and not actual precipitation must be kept in mind. The tendency of ERA to underestimate the number of large precipitation events and the fact that we are using the precipitation from an entire grid cell to represent DI means the use of the ERA precipitation data cannot be pushed too far.

The main reason for the problems encountered in this work is that there are not enough dates being used that can be resolved in the ice core data to study the effects of each precipitation event. However, most of the possible problems regarding the temporal identification of the precipitation events have been encountered. In order to overcome these problems and be able advance this study, there needs to be an increase in the number of precipitation events that are studied. This can be achieved in two ways, either by reducing the threshold of a significant precipitation event or increasing the possible number of events that can be identified by using the ERA-40 data set.

The definition of dates within the core itself needs to be looked at more detail too. Increasing the confidence level of resolution will also increase the number of precipitation events that can be studied. Comparing the $\delta^{18}O$ record to the ERA temperature data from DI or the precipitation sources could do this. As could searching for possible event horizons within the early portions of the core.

The removal of the seasonal cycle from the species analysed in the ice core could also be helpful as this may highlight any chemical signatures present.

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