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Improving ice core interpretation using in situ and reanalysis data

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[1] Back trajectory analysis, provided by the British Atmospheric Data Centre using meteorological parameters from the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis ERA-40 (1980–2001) and operational analysis (2002–2006), is used to investigate transport pathways and source regions of climate proxies preserved in a new ice core (Gomez) from the southwestern Antarctic Peninsula. The ECMWF data are compared with automatic weather station data and ice core annual accumulation records to demonstrate that the ECMWF data capture a large proportion of the annual and subseasonal precipitation variability at the site. The back trajectories reveal that precipitation preserved in the ice core accumulation record, and hence climate proxies contained therein, originate from the low-pressure systems from the Bellingshausen Sea transported via circumpolar westerly winds. Hence, precipitation-dependent ice core proxies, such as isotopic composition, will be influenced by both localized sea ice extent and large-scale circulation changes, such as the Southern Annular Mode. Sea ice proxies from the ice core are expected to be dominated by sea ice extent in the Bellingshausen Sea but also influenced by sea ice in the Weddell Sea, with a small proportion of air mass trajectories originating from this region during the summer. Comparison with other ice core sites reveals a stronger influence of easterly transport at more northerly locations, thus explaining the observed differences in snow accumulation records between ice cores and the poor correlation with instrumental records at these sites.

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1. Introduction

[2] Ice cores provide a wealth of information about past climate and atmospheric circulation. They are especially valuable in remote areas such as Antarctica where long-term observations or historical records are sparse and short. The snow accumulation records preserved in Antarctic ice cores have been used to investigate changes in surface mass balance, of particular importance in relation to sea level rise, and have been used in recent studies on the Antarctic Peninsula to relate to changes in atmospheric circulation, notably the Southern Hemisphere Annular Mode (SAM) [*Miles et al.*, 2008; *Thomas et al.*, 2008]. Further proxy records, such as the relationship between stable isotopes and temperature [*Dansgaard*, 1964; *Jouzel et al.*, 1997] have been used to reconstruct Antarctic temperatures over a range of timescales [*EPICA Community Members*, 2004; *Schneider et al.*, 2006; *Schneider and Steig*, 2008]. In addition, the interpretation of aerosols and chemical species contained within the ice have been used as tracers for long-range atmospheric transport and loading, such as the analysis of continental dust [*Legrand et al.*, 1988; *Basile et al.*, 1997], and local source changes, including the estimation of sea ice extent from marine biogenic species [*Curran et al.*, 2003; *Abram et al.*, 2007] and sea salts [*Wolff et al.*, 2006]. The ability to reconstruct climate in isolated areas on timescales that exceed the observational period make ice cores a valuable tool in understanding climate change. A region of particular interest is the Antarctic Peninsula, which has experienced dramatic warming in recent decades, larger than anywhere else in the Southern Hemisphere [*Vaughan et al.*, 2003]. The meteorological observations from Faraday station (renamed Vernadsky station) on the western Peninsula indicate a warming of more than 2.9°C between 1951 and 2005 [*King and Comiso*, 2003] while increasing temperatures on the eastern side have led to the collapse of floating ice shelves and the retreat of marine glacier fronts [*Cook et al.*, 2005].

[3] Although warming on both sides of the Peninsula is attributed to changes in atmospheric circulation, the very large (mostly winter) warming at Faraday is thought to be driven by an increase in northerlies since the late 1950s combined with a strong coupling between temperature and regional sea ice extent [*King*, 1994; *King and Harangozo*, 1998]. By comparison, the large summer warming over the northeast of the Peninsula, which is responsible for the collapse of the northern sections of the Larsen ice shelf, is due to the intensification of westerlies [*Marshall et al.*, 2006]. These changes in the westerlies project strongly onto the SAM, which is the principal mode of atmospheric variability in the Southern Hemisphere, defined as negative

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(positive) pressure anomalies over Antarctica and positive (negative) pressure anomalies in the midlatitudes.

[4] If we are going to understand the mechanisms behind the recent changes on the Antarctic Peninsula, or indeed the significance on longer timescales, we must incorporate the proxy records. However, interpretation of all ice core–derived climate proxies is dependent on the local and regional climate affecting the ice core site and the influence of small-scale weather patterns. In this paper we evaluate the precipitation and the air mass trajectory pathways affecting an ice core site, Gomez, on the southwestern Antarctic Peninsula, to assess its value as a proxy for past climate and atmospheric circulation. Of particular interest is determining if we can obtain a record of past atmospheric circulation and sea ice extent, changes in both of which have been suggested as mechanisms for the recent warming. We utilize the available data from the Gomez ice core, together with the European Centre for Medium-Range Weather Forecasts (ECMWF) operational analysis and reanalyses data and in situ data from an automatic weather station to characterize the atmospheric conditions influencing the Gomez site in order to better interpret the ice core data.

2. Method and Data

[5] The Gomez ice core (GZ07) is a medium-depth (136 m) ice core drilled in a high-accumulation site (73.59°S, 70.36°W, mean annual accumulation 0.87 m water equivalent yr^{-1}, 1400 m above sea level (asl)) on the southwestern Antarctic Peninsula during 2007 [*Thomas et al.*, 2008]. The ice core was cut into 550 mm sections and packed in the field into polythene layflat tubing (to avoid contamination) and insulated boxes for transport to the United Kingdom. Subsequently, continuous longitudinal samples with a cross section of 34 mm × 34 mm were cut and transported to the Desert Research Institute, for trace element analysis. The samples were analyzed at very high resolution ($\sim$10 mm, average 90 samples per year) using the Continuous Flow Analysis with Trace Elements-Dual (CFA-TED) method adapted from *McConnell et al.* [2002] for a broad range of elements and chemical species. The accumulation record was derived from the winter minima of hydrogen peroxide (H_2O_2) and the summer maxima in non–sea salt sulphate. An earlier 20 m shallow core (GZ05) was drilled at the site in January 2005 (R. J. Arthern et al., Direct in situ measurements of Antarctic snow compaction, submitted to *Journal of Geophysical Research*, 2009). The GZ05 core was dated using the summer-summer maxima in sulphate and melthysolfonic acid (MSA), analyzed using a Dionex ion chromatograph. The accumulation records from both cores were converted into water equivalents based on density and corrected for ice thinning using a simple Nye model [*Nye*, 1963], which assumes a linear vertical strain rate. The GZ07 record encompasses the period 1854–2006, while GZ05 captures 1994–2004.

[6] In situ weather observations were recorded using an automatic weather station (AWS) deployed to the Gomez site in January 2005 (R. J. Arthern et al., submitted manuscript, 2009). The Gomez ice core (GZ07) was drilled 500 m from the site of the AWS, to minimize the risk of contamination or snow surface disturbance induced during its deployment. Studies of accumulation variability and topographic effects were carried out using ground-penetrating radar (GPR), from a total of seven GPR transects run from the central drill site using 100 and 200 MHz antenna to recover both high- and low-resolution reflections. The impact of thinning as a result of flow was estimated using the GPR horizons and Global Positioning System (GPS) measurements. Hourly measurements of wind speed, wind direction, surface temperature, and snow accumulation are available until December 2006, when the AWS was buried by accumulating snow.

[7] The data from ECMWF operational analysis (2002–2006) and the 40-year reanalysis (ERA-40) [*Uppala et al.*, 2005] have been used to estimate precipitation between 1980 and 2006, using a Gaussian N80 grid with a resolution of $\sim$125 km, interpolated to the Gomez site to the nearest 0.1° latitude and longitude. The ERA-40 reanalysis is thought to be reliable at the high southern latitudes after 1979, when satellite observations were assimilated into the model, and is generally considered more accurate than National Center for Atmospheric Research–National Centers for Environmental Prediction output for Antarctica [*Marshall*, 2003; *Bromwich and Fogt*, 2004; *Bromwich et al.*, 2007]. ERA-40 correlates with ice core accumulation records from West Antarctica [*Genthon et al.*, 2005] and is believed to represent precipitation variability across the majority of the Antarctic Peninsula [*Miles et al.*, 2008]. Three-dimensional air mass back trajectories, employed to assess the source of precipitation and climate proxies reaching the Gomez site, were provided by the British Atmospheric Data Centre (BADC) (for more information contact badc@rl.ac.uk) trajectory service (available at http://badc.nerc.ac.uk) using ECMWF archived 2.5° × 2.5° data.

3. Results and Discussion

[8] The air mass bringing precipitation to the Gomez site is of vital importance in understanding the source of climate proxies preserved in the ice core. In order to estimate changes in sea ice extent, from the sea salts and biogenic species contained in the ice core, we must first understand which sea ice region has the greatest influence on the data. The same is true of the stable isotopic composition of precipitation (the ratio of $^{18}O/^{16}O$, expressed as $\delta^{18}O$), that exhibits a linear relationship with temperature in high latitudes [*Dansgaard*, 1964] and is dependent upon the temperature and humidity of the evaporative source, the air parcel trajectory, and the final condensation temperature of the air parcel. Back trajectories from ECMWF can provide a powerful tool for understanding source regions, transport pathways, and the proximity of trajectory pathways to reliable in situ observations, such as research stations or other ice core sites. However, we must first evaluate the ability of ECMWF to capture accumulation variability at the ice core site.

3.1. Accumulation Variability

3.1.1. Subannual Accumulation Variability From in Situ Measurements and Operational Analysis

[9] The AWS located at the ice core site during 2005–2006 provides an hourly record of accumulation variability. The close proximity of the AWS to the ice core site ensures that

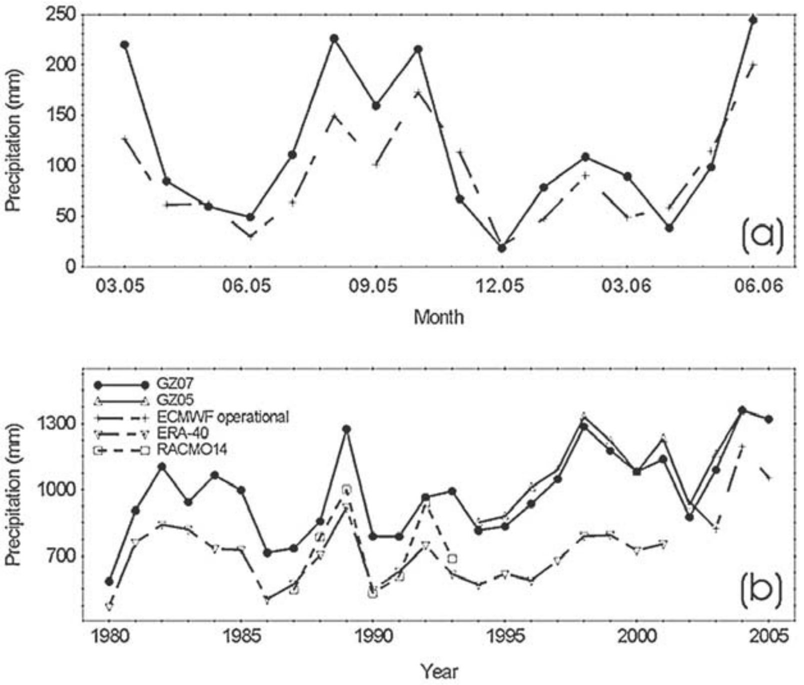

Figure 1. (a) Monthly precipitation from the AWS (solid circle) and $P - E$ from ECMWF operational analysis (dashed cross) between March 2005 and June 2006. (b) Annual $P - E$ from the ECMWF operational (dashed cross), ERA-40 reanalysis (dashed triangle), RACMO14 (dashed square), and the GZ07 (solid circle) GZ05 (solid triangle) ice core accumulation in millimeter water equivalents, between 1980 and 2005.

localized synoptic-scale precipitation events, periods of ablation, and wind-blown snow deposition that affect the ice core will be recorded. If the operational analyses are able to capture this subseasonal variability, then we can have confidence that the operational and reanalysis data will be representative of subseasonal changes occurring in the ice core.

[10] The AWS record of snow surface height is influenced by changes in precipitation, ablation, densification, and wind-blown deposition and erosion of snow. In order to extract precipitation changes at the site, negative accumulation values (resulting from ablation and densification) can be removed. However, it is not possible to distinguish between precipitation and accumulation from snow drift. Studies of wind transport in the Antarctic Peninsula estimate that as much as 5% of surface snow is removed by wind transport across the whole peninsula region [*van Lipzig et al.*, 2004]. The amount of snow ablation is strongly controlled by wind, which is in turn influenced by orography. The winds are stronger on the eastern side of the Peninsula than the western side, and the gentle sloping gradient in the southwestern peninsula probably indicates that a much smaller effect of wind-blown transport of snow will be observed at the Gomez site, where the average wind speed from the AWS and the operational analysis (March 2005 to June 2006) is 6 m s^{-1}. Indeed, analysis of the GPR horizons, which are generally accepted to result from density changes caused by layers of isochronous deposition of snow [*Vaughan et al.*, 1999], reveal only a small amount of accumulation variability at the site, typically less than a 1% change in annual layer thickness across a 20 km radius from the GZ07 ice core site.

[11] The monthly accumulation recorded by the AWS and the monthly precipitation minus evaporation ($P - E$) from ECMWF operational data for the period March 2005 to June 2006 are shown in Figure 1a. The accumulation from the ice core is calculated using hydrogen peroxide (H_2O_2), a photochemical species with a strong seasonal cycle which reaches a minimum during the winter solstice [*McConnell et al.*, 1997]. Therefore, annual accumulation in the ice core is assumed to start on 20 June and subsequently in the analysis of the monthly data from the AWS and the ECMWF data the month starts on the twentieth day. The correlation between monthly AWS snow accumulation and monthly ECMWF precipitation for the period between March 2005 and June 2006 is 0.88 (significant at the 99% level) with comparable monthly wind speeds (r = 0.62, >95% significance) indicating that the ECMWF fields capture a large amount of the precipitation variability at the site.

3.1.2. Annual Accumulation Variability From in Situ Measurements and Operational Analysis

[12] In order to assess how well the accumulation record from the AWS captures the accumulation in the ice core, the annual accumulation for the period June 2005 to June 2006 is compared. On the basis of the snow depth from the AWS, which does not account for densification or snow compaction, the total snowfall (264 m) is just 76 mm higher than that of the accumulation derived from the ice core, implying that the AWS is able to reliably estimate most of the snow accumulation at this site. Thus, we can utilize the AWS

monthly accumulation record to test the capability of the operational analysis.

3.1.3. Annual Accumulation Variability From the ERA-40 Reanalysis Data

[13] Comparison between the annual $P - E$ from the reanalysis (ERA-40) data and the accumulation from the Gomez ice cores GZ07 and GZ05 (converted to millimeter water equivalents using density) is shown in Figure 1b. Both ice cores show a strong positive correlation ($r = 0.84$, >98% significance for GZ07 and $r = 0.92$, >98% significance for GZ05) between the annual accumulation preserved in the ice core records and the $P - E$ estimated from the reanalysis data. The interannual variability recorded in the ice core records is captured by the ERA-40 data; however, the amount of precipitation is consistently lower (average 260 mm yr^{-1}) in the reanalysis data than is preserved in the ice cores. Small-scale postdepositional changes, either as a result of wind-driven ablation or accumulation, will account for some of the variability; however, as discussed in section 3.1.1, these effects are expected to be small. The different spatial resolution of the two approaches is probably responsible for the systematic lower values observed in ERA-40. The resolution of the ice core is essentially only equal to the diameter of the drill, in this case 104 mm, while the ERA-40 data operate on a grid spacing of ~125 km. The modeled orography of the Antarctic Peninsula is smoothed, severely underestimating the actual height; thus, orographic-induced changes in accumulation will be lower than in reality. This is consistent with the findings of *Orr and Bechtold* [2009] who compared warm season precipitation over the Alps with ECMWF short-range forecasts, which showed that the ECMWF model underestimated light precipitation, i.e., <10 mm d^{-1}. This is known to be a long-standing bias in the ECMWF model. Note that although the paper considers analysis data (i.e., any available precipitation observations or satellite observations should correct for this bias), the lack of observations around Antarctica would suggest that the analysis data would strongly follow the forecast data and underestimate light precipitation. For further comparison the ice core annual accumulation is compared with a regional atmospheric model (RACMO14) with a horizontal grid spacing of 14 km during the period 1987–1993 [*van Lipzig et al.*, 2004] (Figure 1b). As with the ERA-40 annual $P - E$, the RACMO14 $P - E$ is highly correlated to the ice core data ($r = 0.84$, >95% significance), but the underestimation in total $P - E$ is less than ERA-40 (20% lower than the ice core accumulation compared to 26% in ERA-40 for the same 7 year period).

3.2. Trajectory Pathways of Precipitation Preserved in the Ice Core Record

[14] The three-dimensional back trajectories from BADC, using ECMWF 40-year reanalysis (ERA-40) and the operational analysis, track the location of air parcels reaching a particular region and can provide valuable information about source locations and transport mechanisms of climate proxies captured in ice cores. Trajectories were run backward in time to track air parcels reaching the Gomez site over a period of up to 5 days. Climate parameters such as precipitation, surface temperature (inferred from stable isotopes), and chemical deposition via wet deposition are only recorded in the ice core record at a time when there was actual precipitation at the site. Therefore, we only need to investigate the air parcel trajectories that resulted in precipitation at Gomez.

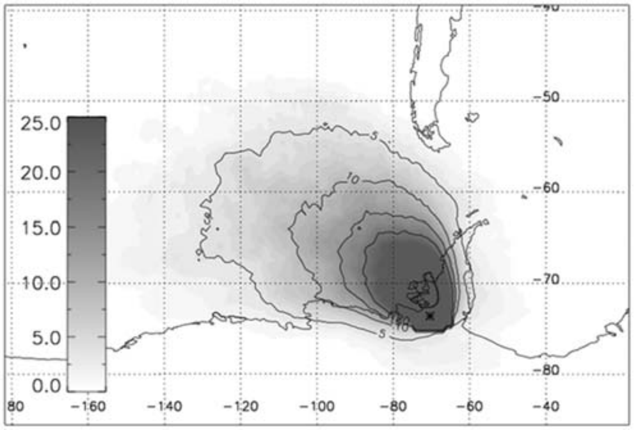

Figure 2. Track densities from ERA-40 (1980–2001) shown as a percentage. On the basis of a total of 1380 precipitation events. The star indicates the location of the Gomez ice core.

3.2.1. Operational Analysis

[15] For 2005 (February–December) the AWS data reveal a total of 195 precipitation days compared to 260 days from the operational analysis data. Much of this constituted precipitation of less than 0.01 mm d^{-1} which will have a negligible effect on the interpretation of the ice core record, which is analyzed at a minimum of 100 times this resolution. Therefore, a minimum threshold for precipitation events was applied such that only events where the amount of snowfall during a 24 h period exceeded the minimum ice core sampling resolution, in this case 10 mm, were included. During 2005 the AWS data have a total of 51 days above this threshold compared to 63 days in the operational analysis.

3.2.2. ERA-40 Reanalysis

[16] The spatial track density of 5 day back trajectories of air parcels reaching the Gomez site for all major precipitation events (>10 mm) during the period 1980–2001, is shown in Figure 2. Figure 2 represents 1380 individual trajectories, including all moderate and heavy precipitation events, and together account for 68% of the ice core snow accumulation during this period.

[17] The majority of the air masses reaching the Gomez site originate from the low-pressure systems from the Bellingshausen Sea with the greatest density coming from the northwest of Alexander Island, approximately 69°S, 72°W. Most (83%) are from low-level air masses (below 850 hPa) with only 2% originating from higher altitudes (above 750 hPa). This pattern also reflects the blocking effect of the Antarctic Peninsula, which with an average height of ~1000 m acts as an obstacle for the circumpolar westerlies that dominate the atmospheric circulation around Antarctica [*Orr et al.*, 2004]. The resulting air mass is unable to flow over the Antarctic Peninsula and is instead directed south toward the Gomez site.

[18] The spread of trajectory locations for the period 1980–2001 is quite large, extending as far north as 50°S

and as far south as 75°S. This broad source region could confirm findings by *Turner et al.* [1997], in a study of precipitation events at Faraday station, that the variability of precipitation over the western Antarctic Peninsula is dependent on synoptic weather system activity. The trajectory paths from the northwest (Figure 2) will be largely a result of depression activity in the Amundsen-Bellingshausen Sea related to the climatological low-pressure system known as the Amundsen-Bellingshausen low, a semipermanent low-pressure system centered in the Ross and Amundsen seas that governs the direction and magnitude of the meridional moisture flux in this region.

[19] The west to east spread extends from ~140°W to ~60°W. There are a small number of trajectory paths that reach Gomez from an easterly location, indicating that some precipitation is transported via less frequent easterly wind events, either from a strong low-pressure region over the Weddell Sea, or from occasional strong synoptic easterlies [*Schwerdtfeger*, 1975]. It is also possible that these western trajectory locations are an artifact of the ECMWF model, which underestimates the height of the Peninsula by as much as 50% while substantially overestimating its width. To overcome this, the model incorporates a simulated atmospheric flow that is heavily reliant on the subgrid parameterization of low-level blocking and gravity wave breaking [*Lott and Miller*, 1997; *Orr and Bechtold*, 2009]. The smoothed orography of the ECMWF reanalysis system might be spreading trajectories too far to the east due to the "spread" of the land sea mask, effectively adding land out into the sea, which would act on the wind by blocking it.

[20] The western spread of trajectories is probably the result of the different wind speeds which allow a large spread of trajectory locations over the 5 day period prior to reaching the Gomez site. This may also be influenced by the seasonally dependent location of the Amundsen Sea low, which during summer weakens and moves east toward the peninsula [*King and Turner*, 1997].

3.2.3. Seasonality of Precipitation Events

[21] The average annual cycle of precipitation from ERA-40 reveals a summer minimum in total precipitation at the Gomez site, which as one would expect corresponds to a minimum in the number of significant precipitation events (>10 mm). Just 204 of the 1380 precipitation events between 1980 and 2001 fell in the months of December, January, and February. The largest number of precipitation events occurred during the autumn (429 days) followed by winter (386 days) and spring (361 days).

[22] Despite these seasonal variations, the effect on the ice core proxies during the low-precipitation months may still be significant. For example, the annual average isotopic composition from the ice core is precipitation biased, in that it is the sum of precipitation-only days; however, the monthly or seasonal contribution to the isotopic contribution is not uniform. Large changes in the source or trend of precipitation during the winter and summer, the two extremes of site surface temperatures, will have a larger contribution to the annual average isotope value than changes during the autumn and spring months.

[23] The trajectory track density is separated into seasons in Figure 3. There is a seasonal shift in the trajectory paths which is most apparent during the warmest months. The northern extent of the track densities during the summer (December, January, and February) is considerably less than the other seasons (by approximately 5°) and also reveals a greater number of trajectory paths originating from east of the Gomez site. The individual trajectories for all summer precipitation events (1980–2001) are shown in Figure 4, with pressure level indicated by the color of the lines. Two explanations for this distinct summer pattern were identified. First, a less stable vertical temperature gradient in the summer months lessens the barrier effect of the peninsula on the atmosphere thus allowing more frequent incursions of air from the Weddell Sea region. Second, the climatological weakening and eastward shift of the Amundsen Sea low in summer corresponds to a weakening of the westerly wind regime and a larger frequency of easterly wind events across the peninsula.

3.3. Comparison With Other Peninsula Ice Cores

[24] In Figure 5 the annual track densities from the Gomez site are compared with track densities from other ice core locations on the Antarctic Peninsula: Dyer Plateau, on the spine of the peninsula (70.80°S, 64.52°W, 2002 m asl) obtained in 1988 [*Thompson et al.*, 1994] and James Ross Island, in the northeast of the Antarctic Peninsula (64.2°S, 57°W, 1600 m asl) drilled in 1998 [*Aristarain et al.*, 2004]. The Gomez track densities reveal a dominant westerly transport from the Bellingshausen Sea (with the exception of a small number of easterly trajectories during the summer); however, the two more northern ice core locations have a much larger number of trajectories from the east. Therefore, the climate signal contained within these cores will be influenced by two very different climate regimes. This might explain why the snow accumulation records from Dyer Plateau and James Ross Island are poorly correlated with Gomez and do not mirror the dramatic increase in accumulation observed in the southwestern Peninsula [*Thomas et al.*, 2008].

3.4. Effect of the Transport Pathways on the Ice Core Proxies

[25] The back trajectories from this study confirm previous findings that precipitation reaching the southwestern Peninsula, and hence the Gomez site, are dominated by the meridional wind component and synoptic-scale weather systems moving in the Bellingshausen Sea [*Turner et al.*, 1995].

[26] It has been shown that the strength of the circumpolar westerlies has been increasing since the 1970s, especially during the summer, associated with the more positive phase of the SAM [*Marshall et al.*, 2006]. The resulting increase in northerlies, as the air masses are blocked by the Antarctic Peninsula and deflected south, brings warmer and more humid maritime air to Gomez. This has been demonstrated in the accumulation record from Gomez which revealed a large increase in snowfall since the 1970s and a positive relationship between annual accumulation and the SAM [*Thomas et al.*, 2008].

[27] The positive relationship between changing atmospheric circulation and precipitation will also dominate the stable isotope record from this site, which is essentially precipitation dependent. Therefore, we can expect that the isotopic composition in the Gomez core will reflect warmer

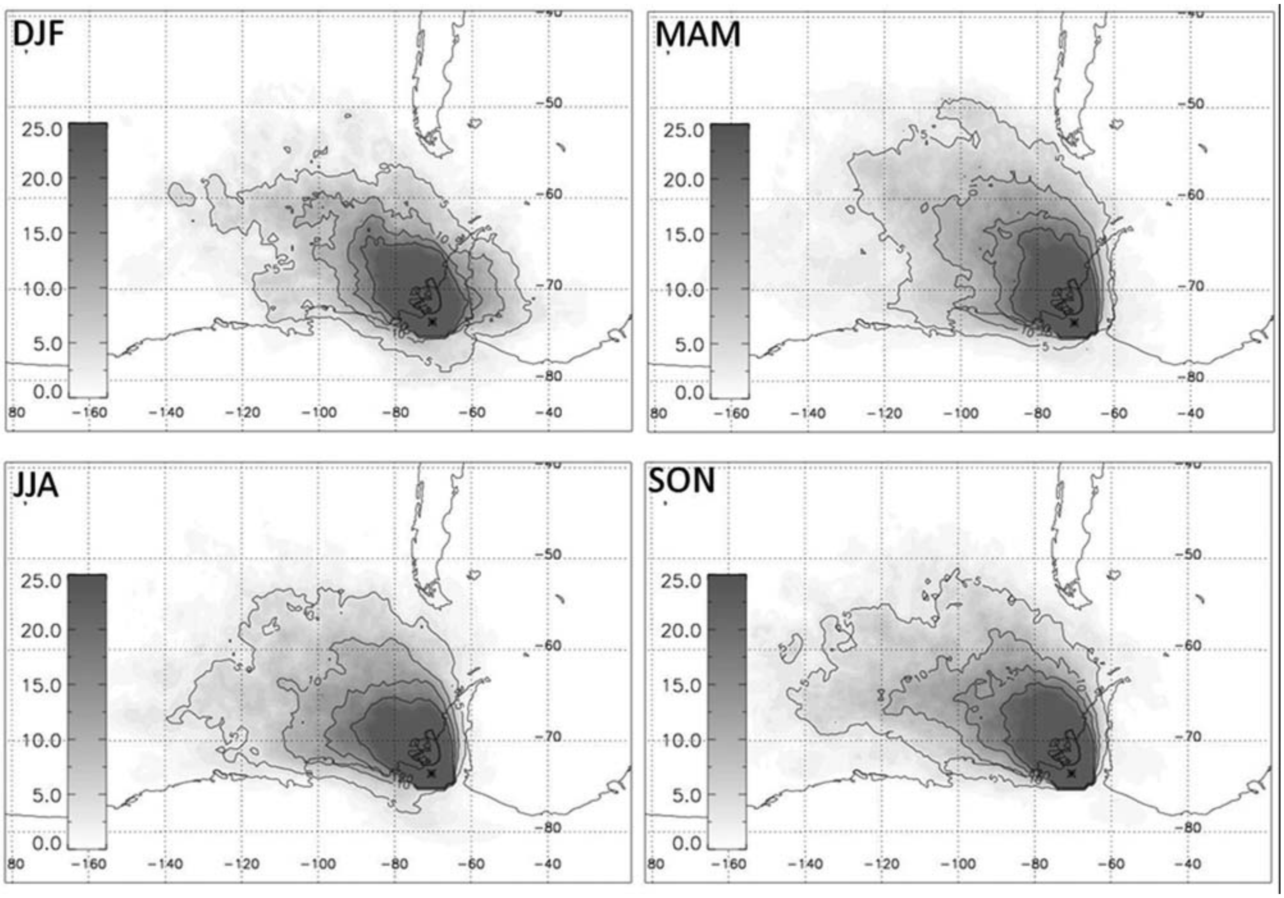

Figure 3. Seasonal track densities from ERA-40 (1980–2001) shown as a percentage. (top left) austral summer; (top right) autumn; (bottom left) winter; (bottom right) spring.

temperatures during the positive phase of the SAM as a result of increased northerlies.

[28] The density of trajectory locations (Figure 2) is of particular interest with respect to the recent warming captured in instrumental records from the west coast of the peninsula. The majority of the trajectory paths to reach Gomez pass over a region of strong spatial coherence in interannual winter season temperature variability that was identified by *King and Comiso* [2003]. This region extends along the coast and adjacent ocean of the western Antarctic

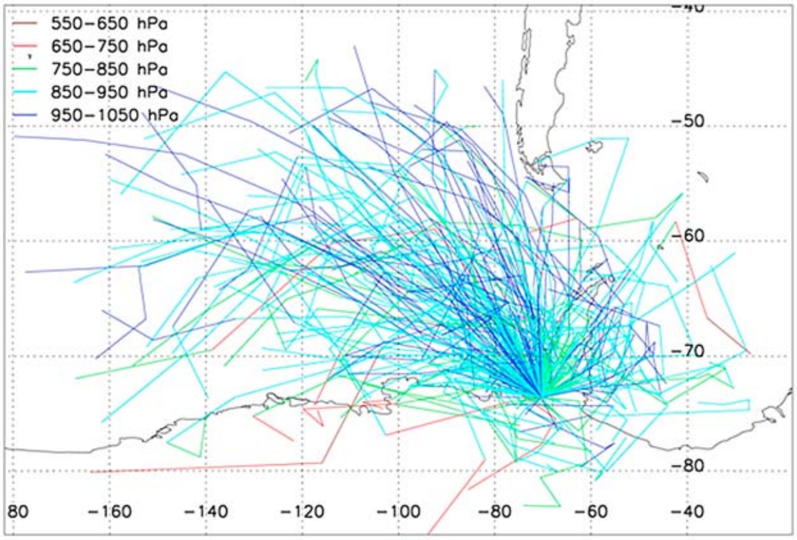

Figure 4. Five day summer trajectory paths from ERA-40 (1980–2001) separated by height (pressure). Near-surface (blue), midlevel (green), and high-level (red) air masses.

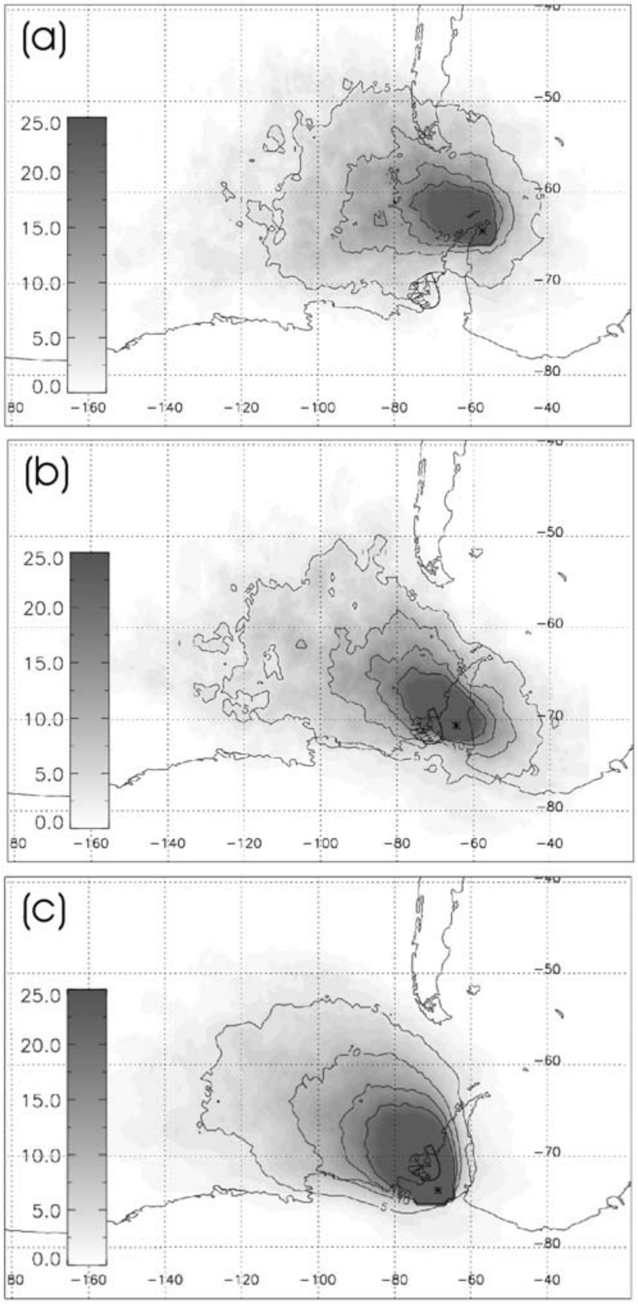

Figure 5. Annual track densities from ERA-40 (1980–2001) for three ice core sites on the Antarctic Peninsula. (a) James Ross Island, (b) Dyer Plateau, and (c) Gomez, stars indicate ice core locations.

Peninsula and includes Faraday and Rothera stations. Thus, we might deduce that temperature changes occurring at these stations will be reflected in the Gomez isotope record.

[29] The track densities for the Dyer Plateau also pass over part of this region of strong spatial coherence; however, this site is influenced by both western and eastern climate regimes suggesting that the stable isotope record from cores drilled here will be a reflection of both. In addition fewer trajectories originate from low-level air masses (below 850 hPa) at this site, 75% compared to 83% at Gomez, suggesting that air parcels may have had a smaller influence from the sea surface over a 5 day timescale. Thus, the west coast signal will be diluted, possibly explaining the poor correlation between the stable isotope record from the Dyer Plateau ice core and Faraday temperatures [*Vaughan et al.*, 2003].

[30] Sea ice has been shown to play a major role in modulating climate variability in the west coast of the Antarctic Peninsula. Observations of sea ice extent from satellite data are short, and thus, ice core proxies such as methanesulphonic acid (MSA), a derivative of dimethyl sulphide emitted by algae during sea ice break up, are utilized to reconstruct sea ice extent beyond the satellite era [*Curran et al.*, 2003; *Abram et al.*, 2007]. The trajectory paths determined from ERA-40 reveal that the preferred transport route during the spring and summer, the period of sea ice breakup, is from the north to west Bellingshausen Sea, suggesting that sea ice proxies from the Gomez core will be representative of changes here. However, during the summer months there is an increase in trajectories from the east of the Gomez site (Figure 4), which will result in transport of MSA originating from the Weddell Sea region. Thus, the interpretation of the MSA and other sea ice proxies from the Gomez core must be considered sensitive to changes in both the Bellingshausen and Weddell Sea. If the easterly transport during the summer months is sensitive to changes in the SAM, then the source of sea salt proxies in the Gomez ice core may not be consistent in time. Further investigation of the marine aerosols and sea ice proxies from this core is needed to understand the influence of the easterly transport; however, circulation changes of this nature should be a consideration when interpreting any coastal ice core.

4. Conclusions

[31] The investigation into the subseasonal precipitation confirms that the reanalysis data adequately reproduce the precipitation variability at the Gomez ice core site. Despite differences in the resolution of the ECMWF model during the operational analysis (2002 to the present) and the ERA-40 reanalysis (used in this paper from 1980 to 2001) the annual variability captured by the ERA-40 series is close to that of the ice core accumulation record indicating that the lower-resolution model is still able to adequately capture subseasonal precipitation variability at the site. Therefore, the air mass trajectories produced by the model for precipitation events (defined as greater than 10 mm) were run backward in time to investigate the dominant climate regime affecting the Gomez site and hence the source and transport mechanisms affecting the ice core climate proxies.

[32] The analyses of the trajectory paths reaching the Gomez site confirm that precipitation is dominated by the circumpolar winds and subsequently the orographic barrier produced by the Antarctic Peninsula which transports air south toward the Gomez site. The greatest track densities occur over the Bellingshausen Sea, with a small proportion crossing the peninsula from the Weddell Sea during the summer months. These findings indicate that the Gomez ice core has the potential to provide a valuable record of past climate in the Antarctic Peninsula that is dominated by the circumpolar westerlies, making it a valuable proxy for

changes in the SAM, and weather patterns over the Bellingshausen Sea. This is of particular importance when interpreting sea salts or proxies for sea ice, which can be assumed to be dominated by changes in the west of the Antarctic Peninsula, but may also have a contribution from the Weddell Sea.

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