1.8 ARE TEMPERATURE VARIATIONS AT ANTARCTIC ICE CORE SITES REPRESENTATIVE OF BROAD-SCALE CLIMATE VARIATIONS?

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1. INTRODUCTION

Stable isotope variations in ice cores are related to temperature variations at the core site through complex transfer functions. Even if the core record could be inverted to give a perfect local temperature history, it is important to know how representative temperature variations at the core site are of regional climate fluctuations when using the core to reconstruct regional palaeoclimates. The locations of core sites have generally been chosen for glaciological reasons (e.g. well-defined ice flow) and the climatological representativity of these sites cannot be guaranteed.

The sparsity of the observing network in the Antarctic has made it difficult to assess whether temperature variations at ice core sites are representative of a broader region. Indeed, long-term instrumental temperature records are not available for most core sites. In this paper we use newly-available remotely sensed data, together with output from regional and global climate models, to assess the spatial representativity of temperature records from a number of ice core sites.

2. SOURCES OF DATA

We make use of a dataset of monthly mean surface temperatures for the Antarctic region derived from satellite infrared radiometer data (Comiso, 2000). In this study we use data for the period 1982-2000 when temperatures were obtained from the Advanced Very High Resolution Radiometer (AVHRR) carried on National Oceanographic and Atmospheric Administration (NOAA) polar-orbiting meteorological satellites. Monthly average surface brightness temperatures on a 6.25 km x 6.25 km polar stereographic grid were calculated from the 5 km x 3 km resolution Global Area Coverage (GAC) data from this instrument after application of the cloud-clearing techniques described in Comiso (2000).

Monthly mean surface temperatures derived from satellite observations may differ from near-surface air temperatures measured at a climatological observatory for a number of reasons. Most importantly, the satellite-derived temperature is conditionally sampled for clear-sky conditions. During the Antarctic winter, near-surface temperatures are generally lower during clear sky conditions than during cloudy conditions so the satellite-derived monthly mean temperatures may be biased cold and may not properly reflect temperature variations associated with varying cloud cover.

Comiso (2000) compared temperatures from this dataset with monthly mean surface air temperatures from a number of Antarctic stations. He concluded that the satellite-derived surface temperatures represent seasonal and interannual fluctuations well and that biases in monthly mean temperatures due to conditionally sampling clear-sky conditions are on average less than 0.5 ^{o}C. King and Comiso (2003) found correlation coefficients in the range 0.7 to 0.9 between winter season temperatures at selected stations and the corresponding temperatures extracted from the satellite data. The satellite data thus appear to provide a realistic measure of interannual variability.

In addition to these satellite observations we use data from a 14-year (1980-93) run of the RACMO regional climate model at 55 km resolution on a domain covering Antarctica and the surrounding ocean (van Lipzig et al., 2002). Prognostic variables at the boundaries of the domain were relaxed towards values from 6-hourly fields from the ERA-15 reanalysis (Gibson et al., 1997). Sea ice extent and sea surface temperatures within the domain are prescribed from observations. The model provides a good representation of the spatial and temporal variation of surface temperature over Antarctica (van Lipzig et al., 2002).

Finally we use results from a 150 year segment of a control integration of the Hadley Centre global coupled atmosphere-ocean model, HadCM3 (Gordon et al., 2000). The atmospheric component of this model has a horizontal resolution of 2.5^{o} latitude by 3.75^{o} longitude with

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19 vertical levels. The ocean model has a resolution of 1.25^o latitude by 1.25^o longitude with 20 vertical levels and includes a dynamic-thermodynamic sea ice model.

3. METHODS

3.1 *Locations Studied*

We have studied the spatial coherence of interannual temperature variation at three sites. Dome C (75.1^{o}S, 123.4^{o}E, 3250 m) is the location of a deep ice core drilled by the European Project for Ice Coring in Antarctica (EPICA). This site is typical of the high interior plateau of East Antarctica. Our second location, DML05, is at 75.0^{o}S, 0.0^{o}E in Dronning Maud Land, and is the site of a second EPICA ice core. This site, at an elevation of 2900 m, is transitional between the high plateau and the coastal slopes of the Atlantic sector of Antarctica. Our third site is on Berkner Island (79.6^{o}S, 45.7^{o}W), an ice rise within the Ronne-Filchner Ice Shelf. A British Antarctic Survey team are currently drilling an ice core at this relatively low elevation (886 m) site, which is likely to be more strongly influenced by maritime airmasses than are Dome C or DML05.

3.2 *Assessment of Representativity*

Following King and Comiso (2003), we identify regions for which a base point may be considered representative by constructing maps of the correlation coefficient between annual mean temperature variations at the base point with those elsewhere. For the satellite temperature dataset (19 years) and the RACMO model dataset (14 years) correlation coefficients greater than about $r=0.7$ are significant at the 1% level after allowing for serial autocorrelation in the data. We choose to highlight areas where $r > 0.75$, i.e. where temperature variations at the base point can explain 56% of the variance at the remote point.

We have produced temperature correlation maps for base points located at all three sites using the satellite temperature dataset and data from the RACMO and HadCM3 models. The RACMO model data allow us to investigate whether the conditional sampling inherent in the satellite data are biasing our results and also enable us to study the spatial coherence of temperature variations at levels other than the surface. The long time series of data available from the HadCM3 run enable us to determine whether the correlation patterns obtained from the relatively short satellite and RACMO data series are representative of those associated with longer-period climate fluctuations. In addition, consistency between satellite data and model output can give us confidence that the variations in atmospheric circulation that drive variations in surface temperature are realistically represented in the models.

4. RESULTS

4.1 Satellite Data

Figure 1 shows correlation maps for annual mean temperature derived from the satellite temperature dataset with base points located at Dome C, DML05 and Berkner Island. Temperatures at Dome C and DML05 correlate well with temperatures across most of the East Antarctic plateau but correlations decrease towards the coast and become rather small over the surrounding ocean. Consistent with the findings of King and Comiso (2003), temperature variations over East Antarctica are not well correlated with those over West Antarctica or the Antarctic Peninsula. Temperature variations at Berkner Island appear to be representative of a smaller area, with the highest correlations confined to the Ronne-Filchner Ice Shelf and Coats Land together with a limited region on the East Antarctic plateau.

4.2 RACMO Data

In order to check that the correlation patterns seen in Figure 1 were not being strongly influenced by the conditional sampling of the satellite data, the analysis was repeated using annual mean surface temperatures from the RACMO model. The results for all three base points are reassuringly similar to those obtained from the satellite data. The correlation map for Dome C is shown in Figure 2. At all three sites, the region of highest correlation ($r > 0.75$) is rather more compact than that seen in the satellite data. In addition, areas of anticorrelation over the surrounding ocean and sea ice are both stronger and more extensive in the RACMO data than in maps produced from the satellite data. At Berkner Island (not shown), RACMO data indicate high correlations extending northwards over the Weddell Sea. This latter effect may be an artefact of the rather crude representation of sea ice in the model.

The atmosphere over Antarctica is characterised by the presence of a strong and persistent surface inversion, particularly during winter. Isotopic temperatures recorded in ice cores reflect condensation temperatures and are thus more strongly linked to the temperature above the inversion layer than to surface temperature. Using RACMO data, we have produced correlation maps for the inversion temperature, T_i, at all three base points. T_i is defined as the warmest temperature found in the model troposphere.

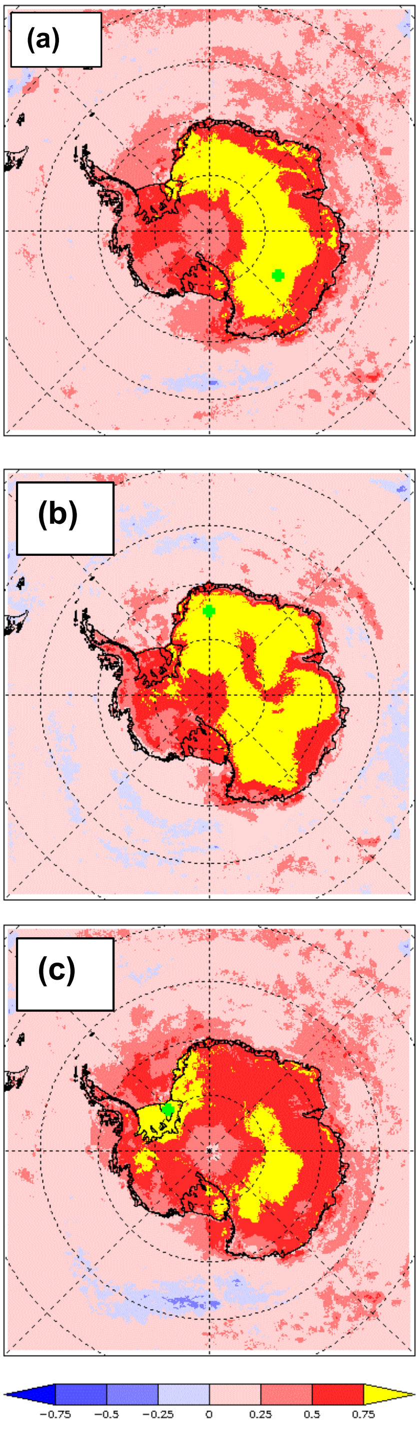

Figure 1. Correlation maps for annual mean surface temperature from the satellite dataset for base points (green crosses) at (a) Dome C, (b) DML05 and (c) Berkner Island.

Figure 3. shows the correlation map for T_i at Dome C. The pattern is very similar to that seen in Figure 2, which is not surprising since analysis of RACMO data shows that interannual variations in T_i are highly correlated with those in surface temperature, T_s, over most of Antarctica. Good spatial correlations between T_s and T_i have been noted previously (Jouzel and Merlivat, 1984; Connolley, 1996). Our results demonstrate that there is also a good temporal correlation. At DML05, the region of highest correlation (r > 0.75) is significantly larger for T_i than for T_s but is still largely restricted to the East Antarctic Plateau.

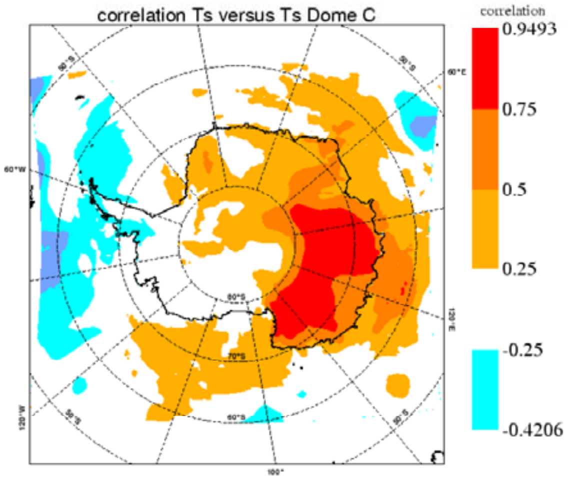

Figure 2. Correlation map for annual mean surface temperature from the RACMO model for a base point at Dome C (c.f. Figure 1(a))

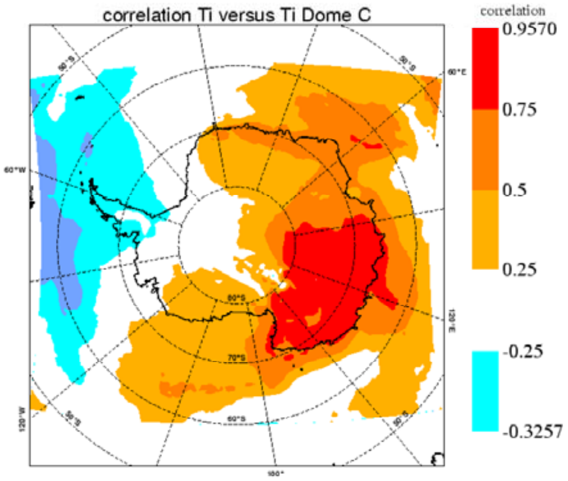

Figure 3. Correlation map for annual mean inversion temperature, T_i, from the RACMO model for a base point at Dome C

4.3 Seasonal Variability of the Patterns

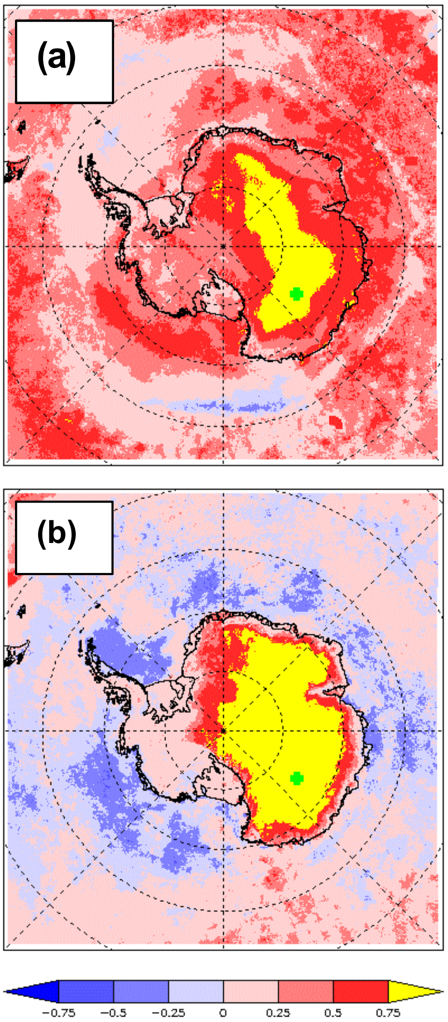

Figure 4. Correlation maps for a base point at Dome C from the satellite dataset. (a) Winter season (JJA), (b) Summer season (DJF)

Correlation maps for individual 3-month seasons show significant differences from those shown above for annual mean data. Figure 4 shows correlation maps for a base point at Dome C for the winter (JJA, figure 4a) and summer (DJF, figure 4b) seasons, calculated from the satellite dataset. While the region of r > 0.75 over the East Antarctic Plateau is not as extensive in winter as in the annual mean, correlations over the surrounding oceans are higher. In summer, the reverse is seen: temperatures are well-correlated over most of East Antarctica but correlations over the ocean are small or even negative. RACMO data (not shown) show little change over the continent between the seasons but echo the change from positive to negative correlations over the ocean. This suggests that the seasonality seen in the satellite data is a genuine feature and is not related to the conditional sampling inherent in that data.

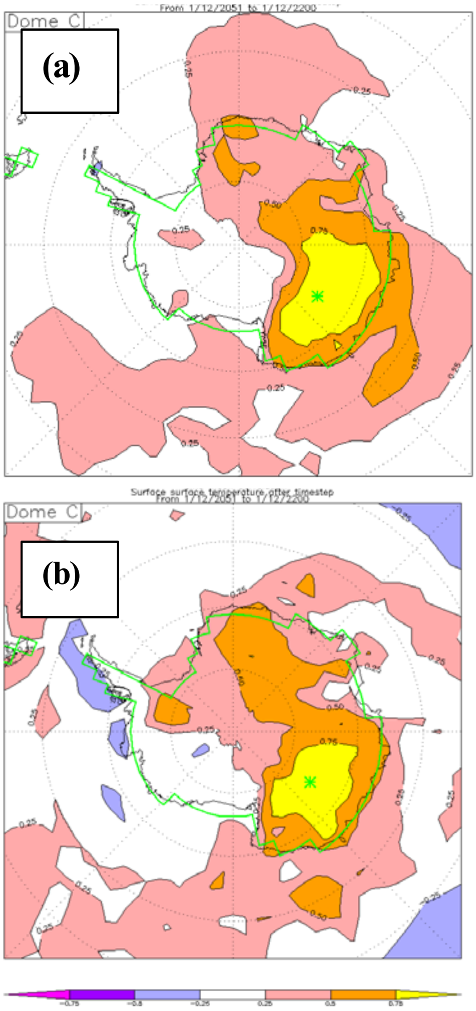

Figure 5. Correlation maps of surface temperature from a 150 year control run of HadCM3 for a base point at Dome C. (a) Correlation map for annual means, (b) correlation map for annual means filtered with a 13-year running mean.

4.4 Spatial Coherence of Interdecadal Variations

The satellite and RACMO datasets are relatively short and it is not clear that the correlation maps obtained using them will be representative of the lower-frequency signals that can be extracted from long ice core records. Indeed, the highly episodic nature of precipitation on the East Antarctic plateau means that ice core records from this region are unlikely to contain useful information on interannual temperature variations (van Lipzig et al., 2003). In order to investigate the spatial coherence of longer timescale variations we have produced correlation maps for surface temperature from a 150-year control run of the HadCM3 global model.

Figure 5(a) is the correlation map for surface temperature with a base point at Dome C constructed using 150 years of annual average data from HadCM3. The correlation pattern strongly resembles that obtained from the shorter RACMO run (Figure 2), suggesting that the pattern of spatial coherence associated with decadal to century scale variability is not greatly different to that associated with interannual variability. We then recreated the correlation map after first filtering the data with a 13-year running mean in order to retain only interdecadal and longer timescale variability. The resulting correlation map, shown in Figure 5(b), shows little difference from that created using unfiltered data.

5. DISCUSSION

We have examined the spatial representativity of interannual fluctuations in surface and lower atmosphere temperatures at three Antarctic ice core sites. Temperature fluctuations are well-correlated across most of the East Antarctic plateau but temperatures on the plateau do not correlate well with those in the coastal regions or over the surrounding oceans. The lack of correlation between temperatures over West Antarctica and the Antarctic Peninsula with those over East Antarctica noted by King and Comiso (2003) is confirmed in the present study. Correlation patterns calculated using data from the RACMO model are in reasonable agreement with those calculated using satellite-derived surface temperatures. This gives us confidence that the results obtained using the satellite data are not unduly influenced by the conditional sampling of clear sky conditions in that dataset.

Using data from the RACMO model, we have shown that the spatial coherence of fluctuations in temperature at the top of the surface inversion, T_i, does not differ greatly from that for surface temperature, T_s. Over much of Antarctica, T_i and T_s show strong temporal correlation, suggesting that surface temperature variations are driven by variations in advection rather than by processes that vary the strength of the inversion. This result lends support to the practice of using the more readily available T_s instead of the more relevant variable, T_i when interpreting isotopic data from ice cores.

Correlation patterns constructed from both satellite and RACMO data exhibit some seasonal variation. Winter season temperature variations over the East Antarctic plateau show weak positive correlations with those over much of the surrounding ocean. In summer these are replaced by weak to moderate negative correlations. Interestingly, some of the areas of strongest negative correlation are in regions where sea ice persists through the summer season (e.g. the western Weddell Sea and the coast of West Antarctica between the Antarctic Peninsula and the Ross Sea) so the seasonality cannot be simply related to seasonal changes in sea ice extent. We do not yet have an explanation for this seasonality but note that it may have implications for the interpretation of ice core records from the East Antarctic plateau.

Correlation maps produced from the long control run of HadCM3 show very similar patterns to those produced using the shorter satellite and RACMO datasets. This is an important result as it suggests that the spatial structure of temperature variations is similar on a range of timescales from interannual to interdecadal. Antarctic temperature variations on large spatial scales are associated with large-scale modes of atmospheric circulation variability, such as the Southern Hemisphere Annular Mode and ENSO-related teleconnections (Kwok and Comiso, 2002; Schneider and Steig, 2002). These modes control circulation variability on a wide range of timescales. We can thus have some confidence that results derived from the relatively short satellite and RACMO datasets are relevant to determining the spatial representativity of decadal scale variability recorded in ice cores. However, we should not assume that the correlation patterns associated with variability on timescales of a century or more will be similar to those we have produced from shorter records. On these longer timescales, temperature variability may be dominated by other processes, such as changes in oceanic circulation, which may have different characteristic spatial patterns. Until we are able to extend our analysis using even longer model runs, our results are probably most relevant to the interpretation of decadal-to-century scale variability seen in ice core records covering the latter part of the Holocene. Despite this limitation, we believe that our results provide a useful framework for putting climate records derived from ice cores into a proper regional context.

6. REFERENCES

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