Precipitation over the Interior East Antarctic Ice Sheet Related to Midlatitude Blocking-High Activity

ROBERT A. MASSOM,* MICHAEL J. POOK,+ JOSEFINO C. COMISO,# NEIL ADAMS,@
JOHN TURNER,& TOM LACHLAN-COPE,& AND TIMOTHY T. GIBSON**

*Antarctic Climate and Ecosystems Cooperative Research Centre, University of Tasmania, Hobart, Tasmania, Australia
+CSIRO Marine Research, Hobart, Tasmania, Australia
#Oceans and Ice Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland
@Antarctic Climate and Ecosystems Cooperative Research Centre, University of Tasmania, and Australian Bureau of Meteorology, Hobart, Tasmania, Australia
&British Antarctic Survey, Cambridge, United Kingdom
**Antarctic Cooperative Research Centre, University of Tasmania, Hobart, Tasmania, Australia

(Manuscript received 4 February 2003, in final form 17 September 2003)

ABSTRACT

Intermittent atmospheric blocking-high activity in the South Tasman Sea is shown to play a key role in delivering substantial snowfall as far south as at least 75°S on the central East Antarctic Ice Sheet plateau. Typically, cyclones fail to penetrate this far (>1000 km) inland, and accumulation was thought to be dominated by clear-sky precipitation. In East Antarctica, the meridional cloud bands delivering the moisture originate from as far north as 35°–40°S, and appear to preferentially pass over the East Antarctic coast in a corridor from ~120° to 160°E. Comparison of surface observations, model, and satellite data suggests that a few such episodes contribute a significant proportion of the (low) mean annual accumulation of the central East Antarctic Ice Sheet (e.g., an estimated 44% at Dome C over 18 days in December 2001–January 2002). Blocking-high-related incursions also cause abrupt increases in the surface wind speed (snow redistribution) and air temperature; this has implications for the interpretation of ice core data. Blocking-high-related precipitation episodes can generally be detected over the ice sheet interior, via abrupt changes (of ~0.02–0.04) in polarization in 37- and 85-GHz SSM/I data, due to the relative stability of the surface and its ''background'' microwave signature and the relative lack of cloud cover overall. This is not the case in high-accumulation near-coastal regions such as Law Dome, where additional information is required. Ambiguities remain due to blowing snow and hoarfrost formation. Further research is necessary to examine the frequency of occurrence and variability of midlatitude blocking-high systems, their effect on precipitation in the Antarctic Ice Sheet interior, and the potential effect of global change.

1. Introduction

In this paper, we use case studies to demonstrate the episodic occurrence of significant precipitation events deep inland on the East Antarctic Ice Sheet, and the link between these events and intermittent blocking anticyclone activity at the midsouthern latitudes. Due to the sparsity of direct contemporary surface observations, this study relies on output from numerical weather prediction model analyses and satellite passive microwave data, with the latter providing an independent means of inferring snowfall events via their impact on ice sheet surface and therefore microwave properties. The importance of such events lies in the fact that the high plateau of Antarctica is the world's largest and driest desert (Schwerdtfeger 1984; Bromwich 1988). In the central East Antarctic Ice Sheet, the snow that falls each year is equivalent to only about 50 mm of rainfall (Bromwich 1988). Significant contrasts exist, however, between interior and coastal zones in terms of the mean annual accumulation of snow (Vaughan et al. 1999; Giovinetto and Bentley 1985), as shown in Fig. 1. Over central Antarctica, the 50-mm water-equivalent isopleth accords well with the estimate of mean annual precipitation there of around 50 mm of water equivalence, given that climatological wind speeds, and thus sublimation, are relatively low. In contrast, the accumulation rate on the eastern slopes of the near-coastal Law Dome, eastern Wilkes Land (~110 km east of Casey Base) exceeds 600-mm water equivalent per year. This meridional contrast results from orographic uplift of moisture-laden air masses prevailing from the east by the ice sheet as the air mass moves inland, and resultant moisture loss in the near-coastal zone in the form of snowfall (Bromwich 1988; Xie et al. 1989). Due to the higher ice sheet elevation in East Antarctica, cyclones penetrate this region much less frequently than they do interior West Antarctica (Bromwich 1988). For the continent as a whole, the estimated mean annual snow accumulation is equivalent to about 150 mm of water (Turner et al. 1999; van Lipzig et al. 2002).

Climatological studies (e.g., Carleton and Carpenter 1990; Murray and Simmonds 1991; Sinclair 1994) have suggested that cyclones and polar lows seldom if ever penetrate far inland onto the Antarctic Ice Sheet, with their impact being largely confined to the coastal margin. However, Pook and Cowled (1999) and Pook and Gibson (1999) have recently shown that major weather systems occasionally penetrate deep into the Antarctic continental interior. They further establish an association between the inland migration of lows and the in-

Corresponding author address: Dr. Robert Massom, Antarctic Climate and Ecosystems Cooperative Research Centre, c/o University of Tasmania, Private Bag 80, Hobart, Tasmania 7001, Australia.
E-mail: r.massom@utas.edu.au

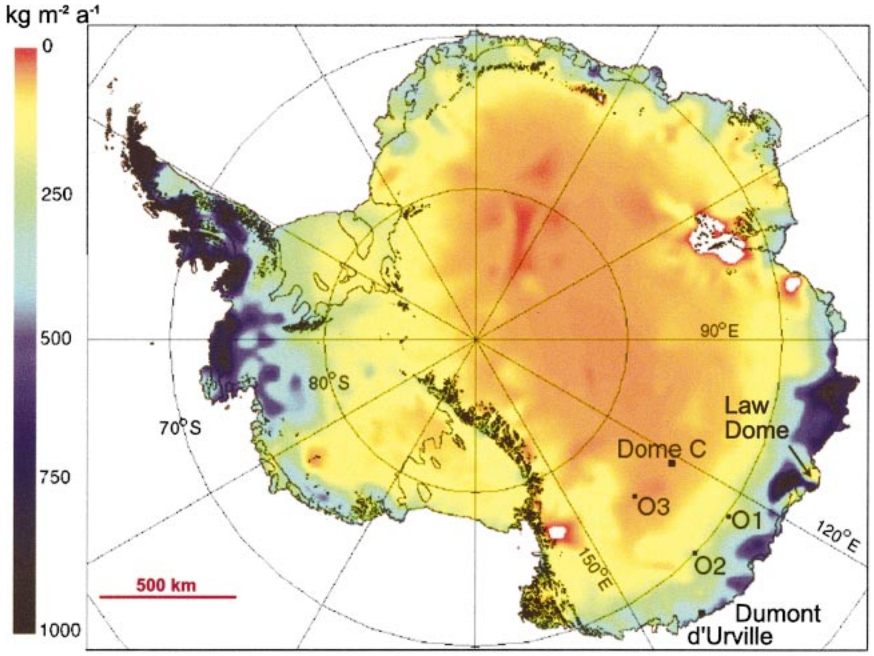

FIG. 1. A map of net surface mass balance precipitation minus evaporation per annum across Antarctica, computed by Vaughan et al. (1999) from an updated data compilation including analysis of atmospheric moisture transport into the region (e.g., Connolley and King 1993), combined with the earlier compilation of Giovinetto and Bentley (1985), which used glaciological data. Areas of interest are marked. Adapted from Vaughan et al. (1999).

cidence of intense anticyclonic blocking activity in the Tasman Sea (SW of New Zealand), which is a preferred region for blocking in the Southern Hemisphere (Pook 1995; Pook and Gibson 1999; Trenberth and Mo 1985; Wright 1974). Other regions of frequent blocking are the South Atlantic (Sinclair 1996) and SE Pacific Oceans (Marques and Rao 1999). A blocking anticyclone is defined as a tropospheric high pressure system that remains approximately stationary for ≥6 days in an area where zonal flow usually prevails, and the frequent passage of cyclones is the norm (Wright 1974). Autumn is the period of maximum blocking activity in the Tasman Sea/SW Pacific, with somewhat less activity in winter and spring and a definite summer minimum (Gibson 1995).

Pook and Cowled (1999) attribute the fact that deep inland incursions of heat and moisture have gone largely undetected to limitations in the observational network, the difficulty of resolving these features in numerical models and manual analyses, and the difficulty in distinguishing associated cloud signatures from the underlying ice surface due to similarities in their optical and thermal signatures (Turner and Row 1995). Furthermore, the elevation of the Antarctic Plateau, which rises from approximately 2 km close to the coast to over 4 km at its highest point, requires that synoptic and mesoscale systems moving inland have well-defined vertical structures in order to survive.

Pook and Cowled (1999) and Pook and Gibson (1999) cite an example of blocking from late July, 1994, in which a positive 500-hPa geopotential anomaly of at least 20 m (at 55°S) persisted in the southwest Pacific Ocean for approximately 1 week. We initially analyze satellite passive microwave data from this period to infer the occurrence of snow accumulation events related to blocking-high episodes, which are detected in meteorological data and satellite cloud pattern time series. The analysis is then extended to include similar cases from 1995 and 2001–02. Due to the large scales involved and the difficulty in accurately measuring accumulation on polar ice sheets in situ, research has evaluated satellite microwave remote sensing as a means of gaining information on large-scale accumulation patterns (e.g., Fily and Benoist 1991; Zwally 1977; Zwally and Giovinetto 1995). Such studies rely on accurate and detailed knowledge of firn (upper ice sheet) properties through time and independent knowledge of the upper-snow-temperature profile with depth (Alley 1987; Comiso et al. 1982). This information is lacking here. As such, the estimation of absolute snow accumulation, which also needs to account for the net gains from snowfall, frost deposition, and drifting (Budd 1966), minus losses from sublimation and drifting (Warren 1996), is beyond the scope of this paper. We therefore use modeled operational analysis data to determine precipitation rates, and independently infer changes in ice sheet surface characteristics due to precipitation events associated with blocking highs from changes in satellite microwave emissions.