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Snow Accumulation in the Talos Dome Area: Preliminary Results

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INTRODUCTION

Determining snow accumulation is one of the principal challenges in mass balance studies and in the interpretation of ice core records. Accurate knowledge of the spatial distribution of snow accumulation is fundamental for understanding the present mass balance and its implication on sea level change, for reliable numerical simulation of past and future ice sheet dynamics, and for creating atmospheric climate models. Depth-age models for deep ice cores require knowledge of the temporal variability of snow accumulation. Accumulation of snow principally results from precipitation of snow and its redistribution/ablation by wind at the surface (Frezzotti et al., 2004a). Chemical and isotopic analysis of ice cores reveals seasonal and annual signals. However, these signals may not be representative of annual snow accumulation or of the annual chemical/isotopic composition of snow. Several sources of noise potentially affect snow accumulation time series. Signal noise is produced principally by post-depositional processes such as wind-driven snow deposition/erosion processes (*e.g.* sastrugi). Additional errors are linked to the identification of annual layers in ice cores. Post-depositional noise primarily influences the higher frequencies (Fisher et al., 1985); when annual layers are misidentified, accumulation is overestimated in one year and underestimated in the previous or following year. Both kinds of noise/error reduce the temporal representativeness of ice core time series. Snow accumulation is also an important parameter for establishing chemical/isotopic fluxes.

The detailed reconstruction of past climates based on single records (firn/ice cores, stake farm) must take into account the spatial variability in accumulation in the studied interval of time, especially when single records are compared or used with atmospheric models and meteorological instrumental records.

Moreover, past changes in the distribution of snow accumulation have implications for the flow direction of ice and for morphological relationships between the dome and the ice divide (*e.g.* presence/absence of saddles connecting the domes to the ice divides). The study of the distribution of snow accumulation at ice divides under the present climatic conditions will also help in determining past migrations of the ice divide and dome.

Accurate new field data on local and regional surface mass balances are required in order to characterize spatial and temporal variability and the representativeness of local records. Comparisons also need to be made on local (< 10 km) and annual scales at selected sites.

The variability of snow accumulation must be investigated at several spatial scales:

1. The surface micromorphology (*e.g.* sastrugi, barchans, *etc.*) is highly variable in space (< 1 km) and time (seasonal), and it (>meter scale) significantly influences core and stake records obtained on seasonal to multi-annual scales;
2. Surface morphology and slope (determined on the basis of ice dynamics and bedrock topography) influence wind-driven ablation processes and determine the high variability in snow accumulation at medium scales (1 km< >20 km), thereby influencing medium-depth core records;
3. Ice sheet morphology (based on the accumulation rate history, its spatial pattern and conditions at ice sheet boundaries) influences snow accumulation over very long distances (20 km< >200 km).

Stakes, snow pits, and firn or ice cores provide accumulation data for a single point at the surface. In contrast, Ground Penetrating Radar (GPR) is carried out along profiles with such high resolution that it can be considered a quasi-continuous measurement. Whereas stakes have to be monitored for a long period to obtain a time series, snow pits, firn/ice cores and GPR are able to provide time series from a single deployment. A major problem in establishing accurate annual or seasonal stratigraphy in firn/ice cores is that some annual/seasonal layers may be missing in the stratigraphic record. Stake network measurements and ultrasonic height multi-instruments are the best way to detect zero accumulation or erosion values on an annual or seasonal scale. This information cannot be obtained by ice core analysis.

Talos Dome (TD, 72°48'S; 159°06'E, 2316 m, T -41.0 °C) is an ice dome on the edge of the East Antarctic plateau, about 290 km from the Southern Ocean

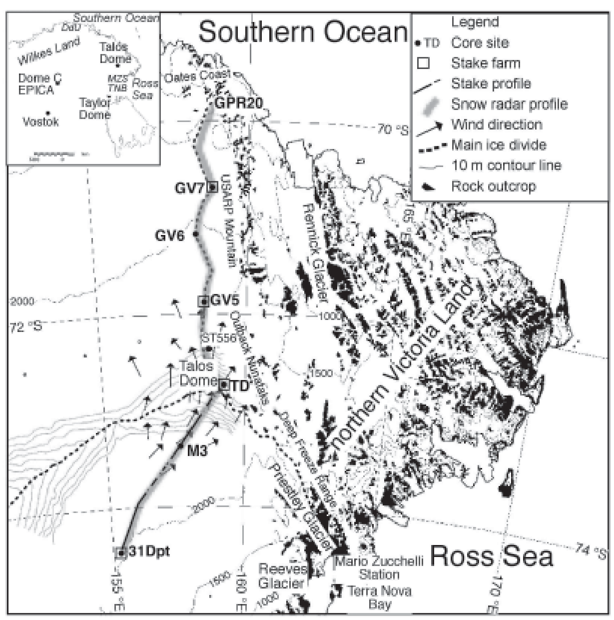

Fig. 1 - Location map of the Talos Dome area and the North-South transect showing core and stake network sites, snow radar and stake profiles, and wind direction derived from satellite images. Contour lines are indicated every 500 m and every 10 m around Talos Dome.

and 250 km from the Ross Sea (Fig. 1). An ice core is currently being drilled at this site (Frezzotti et al., 2004b) within the framework of the Talos Dome Ice Core Project (TALDICE). In order to provide detailed information on the temporal and spatial variability of snow accumulation, research was conducted at Talos Dome and along a North-South transect (GV7-GV5-TD-31DPT) in the framework of the ITASE programme. The 400 km-long transect follows the ice divide from the Southern Ocean to Talos Dome, and then continues in a southward direction towards Taylor Dome. Stake network measurements, ice core analysis and snow radar surveys along the transect have provided detailed information for reconstructing the temporal (annual) and spatial (meter scale) variability of snow accumulation over the last 200 years at the km scale.

MATERIALS AND METHODS

Seventeen stake networks consisting of 60 to 30 stakes each were established at TD, along the ITASE traverse (Frezzotti et al., 2005; Magand et al., 2004) and at AWS between 1998 and 2001. Most stakes were measured 2-4 times a year, and some up to 7 times a year. Density profiles were constructed on the basis of water equivalents in samples taken from the walls of snow pits (up to 2.5 m deep) dug at each stake network site.

Since 1996, an electromechanical drilling system (10 cm diameter) has been used to drill ten snow/firn cores (up to 89 m deep) at 60-80 km intervals along traverses (Stenni et al., 2002; Frezzotti et al., 2005; Magand et al., 2004). The temporal variability of snow accumulation was evaluated on the basis of seasonal variations in $nssSO_4^{-2}$ concentrations, coupled with the identification of atomic bomb markers and $nssSO_4^{-2}$ spikes from the most important volcanic events in the past (Frezzotti et al., 2005; Magand et al., 2004; Stenni et al., 2002; Proposito and Frezzotti, this volume).

It has been shown that the internal layers of strong radar reflectivity observed with GPR are isochronous and that surveys along continuous profiles provide detailed information on the spatial variability of snow accumulation. The integration of GPS and GPR data yields the ellipsoidal height of both the topographic surface and firn stratigraphy. GPS and GPR surveys and subsequent analyses are described elsewhere (Frezzotti et al., 2002). Data acquisition was performed using a GSSI Sir10B unit equipped with a 200 MHz central frequency monostatic antenna.

RESULTS

Accumulation records preserved in firn cores are characterized by large interannual variability associated with year-to-year fluctuations in precipitation and the superimposition of meter-scale morphological noise. Detection of “noise”, which largely reflects snow surface roughness (*i.e.* sastrugi), is important since noise limits the degree to which a single annual snow accumulation value observed in a core may be representative of annual snow accumulation or precipitation. Frequency analysis of accumulation compared to the average annual accumulation reveals that data from a single stake (or from a single core) is not representative on an annual scale, even for the site with the highest accumulation (GV7 about 240 kg m^{-2} yr^{-1}). No accumulation or negative values were observed at sites with accumulation rates lower than 120 kg m^{-2} yr^{-1}. It appears that stake measurements at all sites are strongly linked to the surface morphology. The lowest standard deviation values are present when the slope along the prevalent wind direction is low and accumulation is high. Stake analysis reveals that annual snow accumulation varies by about 50% with respect to the 50 yr average accumulation derived from firn cores. The highest and lowest values occur at GV7, with an up to 146% increase during 2003-04 and a 47% decrease during 2002-03. GV7 and GV5, together with the other stake farms installed in Wilkes Land (D66, GV2, GV3, GV4), show the same trends in accumulation during the same period of observation. These sites show higher accumulation during 2001-02 (from 124% at GV2 to 106% at GV4) and lower accumulation during 2002-03 (from 41% at GV2 to 87% at GV4) under comparable meteorological conditions.

Core analysis revealed that the highest accumulation value was recorded at the site with the lowest elevation closest to the Southern Ocean (GV7), whereas the lowest value was recorded at the Talos Dome site; there is a constant decrease in accumulation from the coastal site (GV7) to the dome (Fig. 2). Using the Tambora and atomic bomb markers (Magand et al., 2004; Stenni et al., 2002; Frezzotti et al., 2004), the GV7, TD and 31Dpt time series reveal a slight increase in accumulation over the last 200 years, in particular since the 60s atomic bomb markers with respect to the Tambora-atomic bomb marker period (1965-1816) or the core bottom accumulation value. Recent stake network measurements show slightly higher snow accumulation values for GV5 and GV7 (2001-2003, 104-105%) and lower values for TD (1996-2005, 94%; 2001-2005, 85%) and 31Dpt (1998-2004, 88%) with respect to the 50 yr average accumulation from firn cores.

The snow radar profile shows a decrease in accumulation from the coast (GV7) up to about 25 km north of Talos Dome, where the lowest values are found. There is a slight increase in accumulation from Talos Dome to 31Dpt. Between 31Dpt and M3, and between 25 km north of Talos Dome and GV7, the snow accumulation profile shows a marked variation in accumulation (up to 50 kg m^{-2} yr^{-1} in 10 km) due to wind erosion driven by the increasing slope towards the Southern Ocean. SSW winds blow uphill to Talos Dome with a gradient of 1-2 m km^{-1} for a distance of 100 km. Higher accumulations in

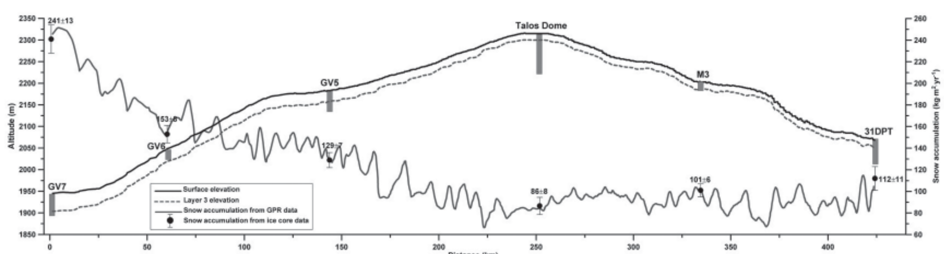

Fig. 2 - Topographic profile along the GPR20-GV7-GV5-TD-31Dpt transect showing cores and stake sites and the spatial distribution of snow accumulation from GPR survey (dated to 1905±9 AD) and the ice core from atomic bomb markers (Stenni et al., 2002; Magand et al., 2004).

the SSW sector of Talos Dome are correlated with reduced wind velocities in this sector due to the positive slope gradient and to the decrease in wind-driven erosion (Frezzotti et al., 2004b). The decrease in accumulation in the downwind sector is due to an increase in wind-driven sublimation controlled by the increasing surface slope towards the Southern Ocean.

Although the transect is not in an area of converging katabatic winds characterized by an extensive wind crust (unlike most of the adjacent areas in East Antarctica), wind-driven processes are a very important component of snow accumulation at scales ranging from one decimeter to tens of kilometers.

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