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Surface melting observations in Antarctica by microwave radiometers: Correcting 26-year time series from changes in acquisition hours

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Abstract

Surface melting duration and extent of the Antarctic coasts and ice-shelves is a climatic indicator related to the summer temperature and radiative budget. Surface melting is easily detectable by remote sensing using passive microwave observations. The preliminary goal of this study is to extend to 26 years an existing data set of surface melting [Torinesi, O., Fily, M., Genthon, C. (2003), Interannual variability and trend of the Antarctic summer melting period from 20 years of spaceborne microwave data, J. Climate, 16(7), pp. 1047–1060] by including the most recent years of observation. These data come from 4 microwave sensors (the Scanning Multichannel Microwave Radiometer (SMMR) and three Special Sensor Microwave Imager (SSM/I)) observing the surface at different hours of the day. Since surface melting varies throughout the day as the air temperature or the radiation, the interannual melting extent and duration time series are biased by sensor changes. Using all the sensors simultaneously available since 2002, we were able to model the diurnal variations of melting and use this hourly model to correct the long-term time series. This results in an unbiased 26-year long time series better suited for climate analysis. The cooling trend found by Torinesi et al. using uncorrected time series for the 1980–1999 period is confirmed but the decreasing rate is weaker after correction. Furthermore, extending the series up to summer 2004–2005 reveals recent changes: the last 2 summers have been particularly warmer over all the East Antarctica compared to the 10 previous years, thus ending the cold period of the 1990s. The trend over 1980–2005 is no longer toward cooling but complex climatic variations appear. The time series are available at http://www.lgge.obs.ujf-grenoble.fr/~picard/melting/.

Keywords: Surface melting; Antarctica; Climate; Passive microwave; Brightness temperature

1. Introduction

Surface melting occurs every summer on Antarctic coasts and ice-shelves. In contrast with Greenland, melting concerns a marginal surface of the continent and its contribution to the mass balance is negligible. The presence of liquid water tends to reduce the albedo and water percolation results in downward heat transport within the firn. In the Antarctic Peninsula, these processes participate in embrittling the shelves, which lead to their break-up (Vaughan & Doake, 1996), but are likely negligible elsewhere on the continent. Although surface melting has a minor overall contribution to the mass balance (Ohmura et al., 1996), it is of interest for climatology: surface melting extent and duration are climatic indicators related to the surface temperature and the radiative budget. Melting events can be detected by remote sensing with a daily accuracy for the entire Antarctic continent. Such observations complement the sparse network of meteorological stations for climate analysis (Turner et al., 2005).

Remote sensing by passive and active microwaves is sensitive to surface melting, i.e. the presence of liquid water in the first meter of the firn. Detection is based on the large difference between the dielectric constants of ice and water in the microwave domain. This difference causes large changes of brightness temperature or backscattering coefficient when snow melts. Efficient algorithms to detect dielectric changes were developed for radiometer data in Greenland (Abdalati & Steffen, 1997) and in Antarctica (Ridley, 1993; Torinesi et al., 2003; Zwally &

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Fiegles, 1994) or for scatterometer data in Greenland (Wismann, 2000). All these algorithms provide melted/not-melted information but do not provide any quantification of the amount of liquid water. Recently, a more sophisticated algorithm was developed (Ashcraft & Long, 2005) to differentiate stages of the melt cycle. In Torinesi et al. (2003), 20-year long time series (1980–1999) of surface melting extent and duration are derived from 4 radiometers: the Scanning Multichannel Microwave Radiometer (SMMR) and three Special Sensor Microwave Imager (SSM/I). The authors find a clear decrease in the melting extent and duration in East Antarctica (Dronning Maud Land, Amery, Wilkes) and in the Ross ice-shelf. This agrees with cooling observed in temperature measurements (Comiso, 2000; Doran et al., 2002; Turner et al., 2005).

The primary goal of our study is to extend the surface melting series derived by Torinesi et al. (2003) with the 6 last years of data and produce the series on a yearly basis in the future.

However, the period 1979–2005 includes observations from 4 different sensors whose characteristics vary. As a consequence, sensor replacement may induce artifacts in the derived melting information which may, in turn, bias the climatic analysis of the series. These characteristics include:

- *Frequency*. The frequency of the channel used by Zwally and Fiegles (1994) and Torinesi et al. (2003) changed slightly between SMMR (18 GHz) and SSM/I (19.3 GHz). Nevertheless, this difference of 7% is unlikely to affect significantly the detection, as the dielectric constant of snow varies smoothly near 19 GHz and no sharp resonance caused by layering of the firn has been reported yet.
- *Incidence angle*. The difference of incidence angle between the SMMR (50.3°) and SSM/I (53.1°) is small. Additionally, firn thermal emission comes from a volume rather than a surface as it is the case for wet soils, and processes of emission or scattering by volumes are known to be less angular-dependent than for surfaces.
- *Resolution*. As the melting detection algorithms are highly non-linear, the sensor resolution may affect the detection: small and isolated melted regions are not detected by coarse resolution sensors. On the opposite, unmelted areas on the border of large melted regions tend to be detected as melted. Coarse resolution can therefore lead to under- or over-estimations of melting extent, depending on the granularity of the melting regions. The difference of resolution between SSM/I and SMMR is small and has a likely negligible effect on the detection. The case is different for the Advanced Microwave Scanning Radiometer for EOS (AMSR-E), which resolution is twice finer than SSM/I and SMMR ones. To deal with this problem, AMSR-E images are degraded in our study: we use a 2×2 pixels running average over the image to reduce the resolution from 25 km to 50 km which correspond approximately to the resolution of SMMR and SSM/I.
- *Observation hour*. Melting varies throughout the day as the air temperature and the incoming radiation. Areas melted during the day may refreeze during the night. It is therefore less probable to detect melting during the night than in the afternoon. Since the 4 radiometers used to detect melting during the period 1979–2005 are aboard satellites on sun-synchronous orbits, they observe each point of Antarctica at quasi-constant local hours everyday during their entire lifetime, excepted SSM/I F11 which slightly drifted. This ensures a constant probability to detect melting during the lifetime of each sensor. However, the observation hours changed by about 7 h between SMMR and SSM/I and about 1 or 2 h between each one of the SSM/I sensors (F8, F11, F13). These changes are significant.

Among those characteristics, observation hour has the most significant effect on the melting extent and duration time series. We propose in this paper to quantify and correct the effect of observation hour changes. For this purpose, we use observations from a constellation of similar sensors observing the surface at various hours of the day since 2002. The constellation includes three SSM/I sensors (namely SSM/I-F13, SSM/I-F14, and SSM/I-F15) observing each point of Antarctica within a 2 or 3 h interval twice a day (morning and evening) and AMSR-E observing in the afternoon and around midnight. All together, at least 8 observations a day are acquired at a yet limited but useful set of hours. In this paper, we combine all these data, first to model the diurnal variations of surface melting and second to correct the time series of melting duration and extent.

The paper is organized as follows: Section 2 recalls the algorithm developed by Torinesi et al. (2003) and presents the microwave data used in this study. The effect of the observation hour is addressed in details in Section 3. The algorithm for correcting the time series is developed and the corrected time series are shown in Section 4. The last section proposes general comments about the method, the results and future work.

2. Materials

2.1. Melting detection algorithm

Microwave radiometers measure a brightness temperature T_b, linked to the surface thermodynamic temperature T_s. In a first approximation, this relation can be expressed as follows:

$$T_b = \epsilon T_s \quad (1)$$

where ϵ is the apparent emissivity. In dry snow, the grains scatter the microwaves emitted by the lower layers, thus reducing the energy given off by the surface. ϵ ranges between 0.65 and 0.8 depending on the grain size and layering. The presence of liquid water on the snow crystals, even in small amount, dramatically reduces scattering and increases ϵ up to 0.9 (Cagnati et al., 2004; Zwally & Fiegles, 1994).

Assuming temperature in the firn is almost 273 K (near freezing conditions), the brightness temperature is about 218 K–220 K for dry snow and 245 K for wet snow. Such a 40 K difference is easily visible on brightness temperature time series (e.g., Fig. 2 in Zwally and Fiegles and Fig. 2 in this paper). Since a 40 K change in thermodynamic temperature is unrealistic, large raises of temperature brightness are surely due to changes