PARCA Continuation Proposal

Determining Greenland Ice Sheet Accumulation Rates from Radar Remote Sensing

NAG 5-10276

Final Project Report

Submitted to

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1 Introduction

An important component of NASA's Program for Arctic Regional Climate Assessment (PARCA) is a mass balance investigation of the Greenland Ice Sheet. The mass balance is calculated by taking the difference between the areally integrated snow accumulation and the net ice discharge of the ice sheet. Uncertainties in this calculation include the snow accumulation rate, which has traditionally been determined by interpolating data from ice core samples taken from isolated spots across the ice sheet. The sparse data associated with ice cores juxtaposed against the high spatial and temporal resolution provided by remote sensing, has motivated scientists to investigate relationships between accumulation rate and microwave observations as an option for obtaining spatially contiguous estimates.

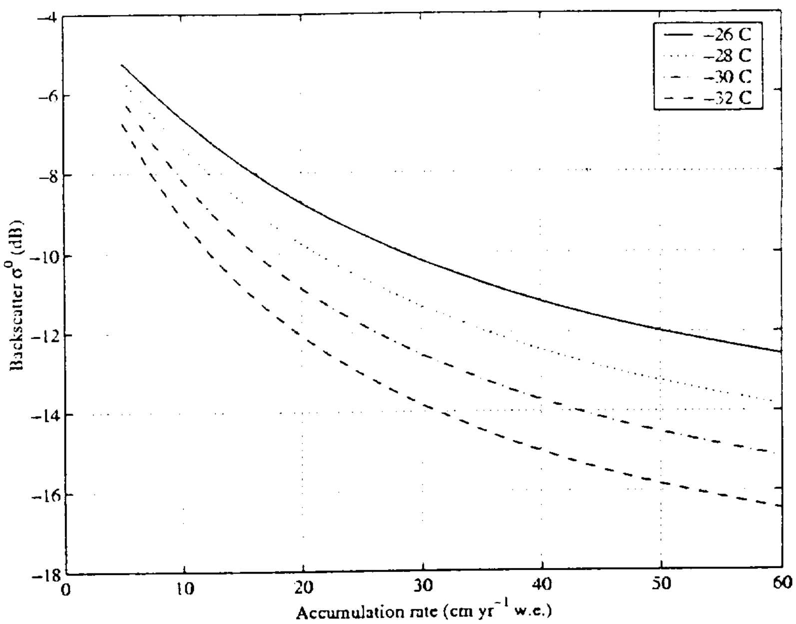
The objective of this PARCA continuation proposal was to complete an estimate of surface accumulation rate on the Greenland Ice Sheet derived from C-band radar backscatter data compiled in the ERS-1 SAR mosaic of data acquired during September-November, 1992. An empirical equation, based on elevation and latitude, is used to determine the mean annual temperature. We examine the influence of accumulation rate, and mean annual temperature on C-band radar backscatter using a forward model, which incorporates snow metamorphosis and radar backscatter components. Our model is run over a range of accumulation and temperature conditions. Based on the model results, we generate a look-up table, which uniquely maps the measured radar backscatter, and mean annual temperature to accumulation rate. Our results compare favorably with in situ accumulation rate measurements falling within our study area.

2 Summary of Results

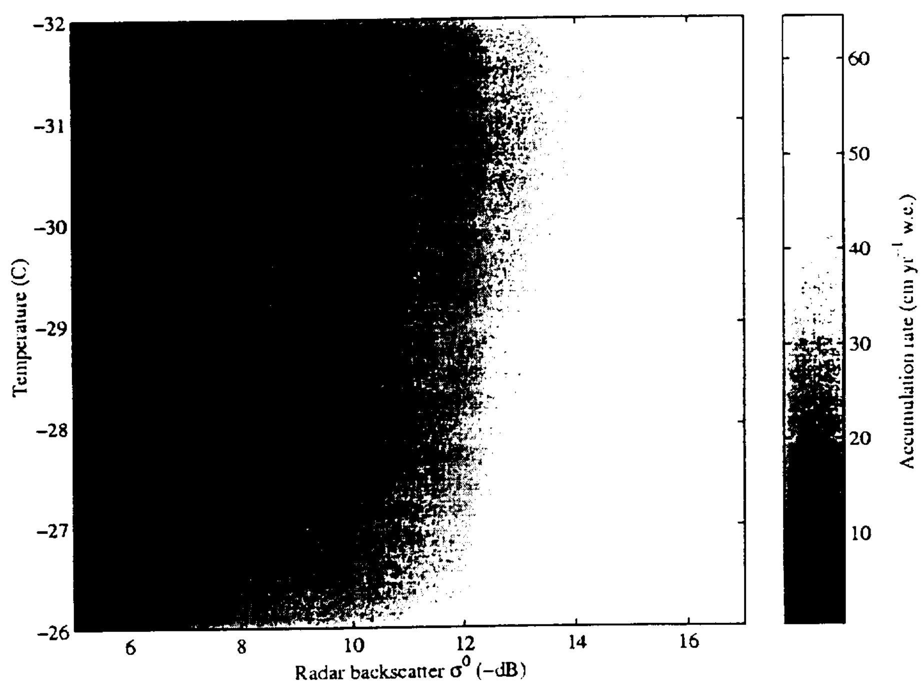
Our forward model is discussed in previous reports and has been published in the literature (Forster and others, 1999). Also as reported in the literature (Baumgartner and others, 1998, 2002), aspects of the model have been validated using in situ and satellitederived data (for example, estimates of the extinction coefficient). The key feature of our model is the look-up table, which relates backscatter, annual temperature and accumulation rate (figure 1) (Munk and others, in review) As evident in figure 1, temperature plays a surprisingly strong role in our analysis by influencing the size of the volume sampled by the microwave sensor. To incorporate temperature, we extract estimates of surface temperature from work by Reeh (1989) who developed a regression formula based on latitude and elevation (figure 2). The temperature data combined with backscatter data from the ERS-1 SAR mosaic (Fahnestock and others, 1993) then yields estimates of accumulation rate in the dry snow zone (figure 3). Our contour map shows a general northeast- southwest trend in accumulation rate across the dry snow facies. Perhaps more importantly, the data also indicate kilometer scale variability in accumulation rate. While not necessarily unexpected, we believe this is the first extensive evidence for spatial variability in accumulation rate at this scale.

Our results compare favorably with surface accumulation rate contours prepared by R. Bales as part of the project (figure 4). We also find excellent agreement between our estimates and individual in situ estimates from core data (figure 5). This is demonstrated by the regression curves shown in figure 5. Point by point comparisons between derived and measured accumulation rates are tabulated in Munk and others, in review.

We expect to continue to investigate relationships between backscatter and accumulation rate as part of a collaboration with the Technical University of Denmark. As part of an exchange program begun during the summer of 2002, OSU provided TUD with a portable, microwave radar. The unit has been used in the field before and it is anticipated that it will be used again in Greenland during the summer of 2003. The unit will be used to further investigate dominant glaciological controls on microwave scattering particularly in the ablation and the wet snow zones.



(a)



(b)

Figure 1. Model estimate of backscatter as a function of accumulation rate (a). Look-up table wherein estimates of surface temperature and backscatter can be used to estimate accumulation rate.

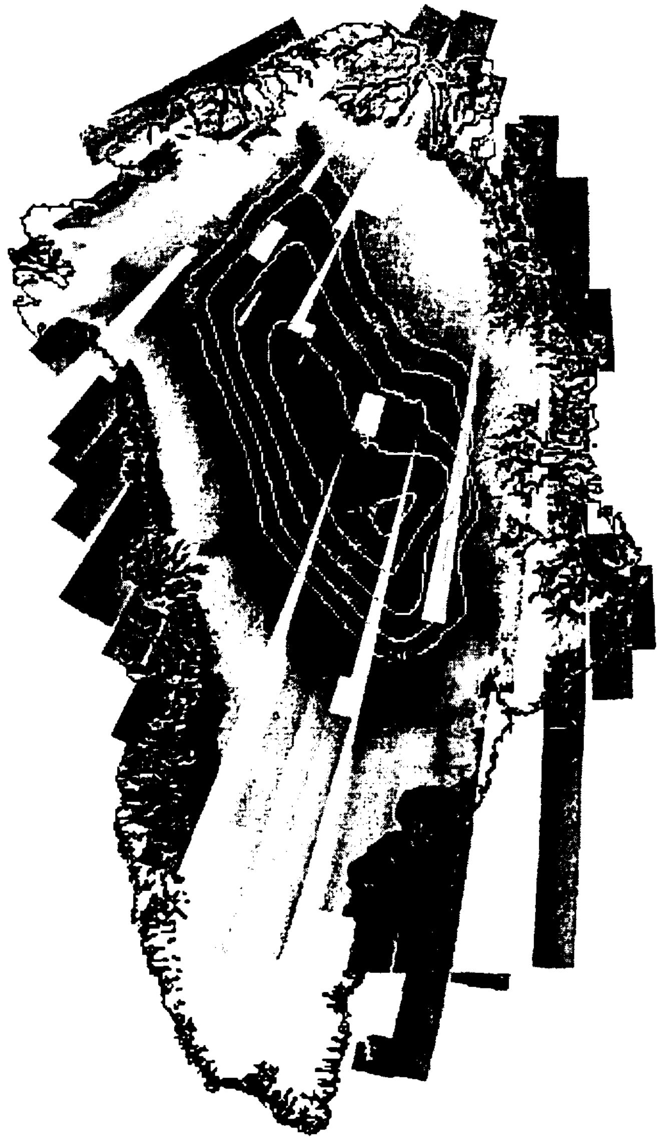


Figure 2: ERS-1 SAR mosaic compiled from data obtained during September-November, 1991 [*Fahnestock et. al.*, 1993]. Contours with the ice sheet correspond to mean annual isotherms calculated from Reeh (1989). Contours are shown in 1° C intervals.

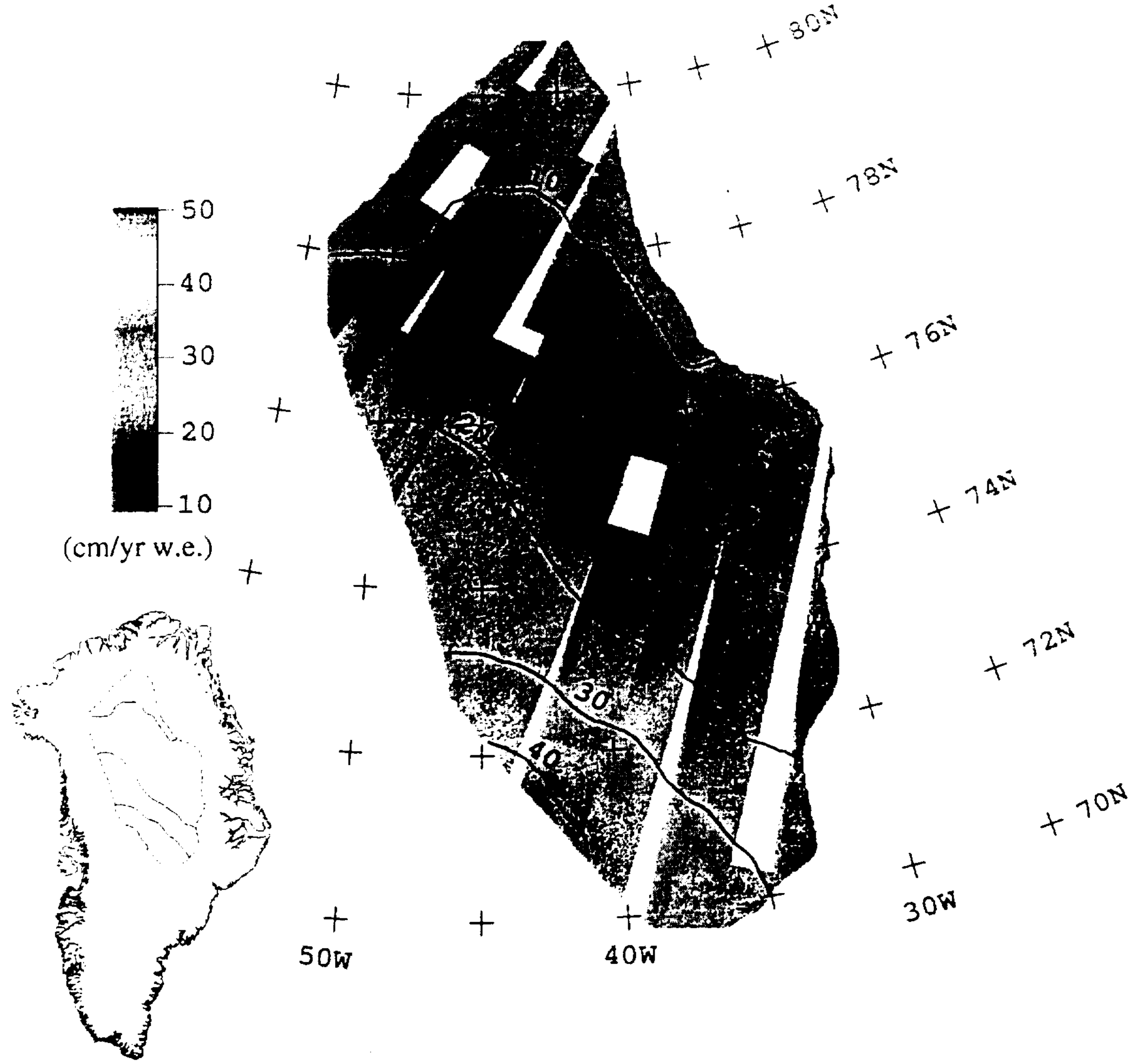


Figure 3: Derived accumulation rate map, with purple and red corresponding areas of low and high accumulation, respectively. Contours are given in cm/yr w.e., and were obtained using a smoothed version of the 100m resolution mosaic shown. The inset in the lower left-hand corner shows the location of the map on the Greenland ice sheet.

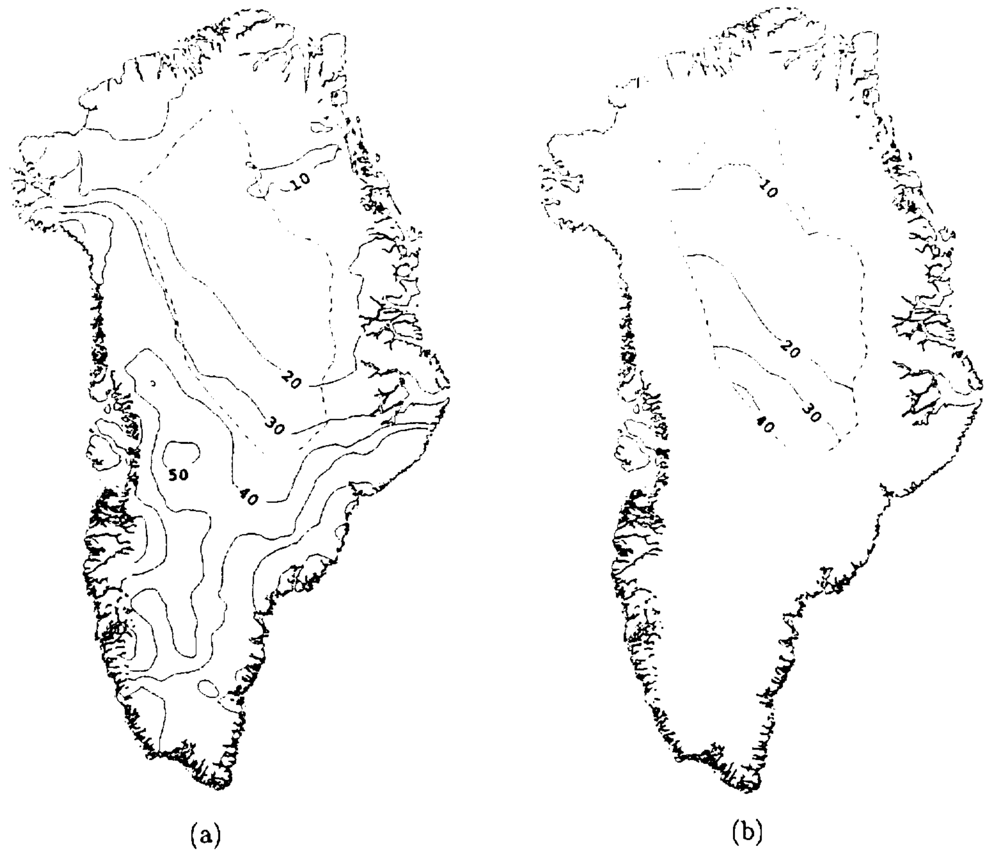
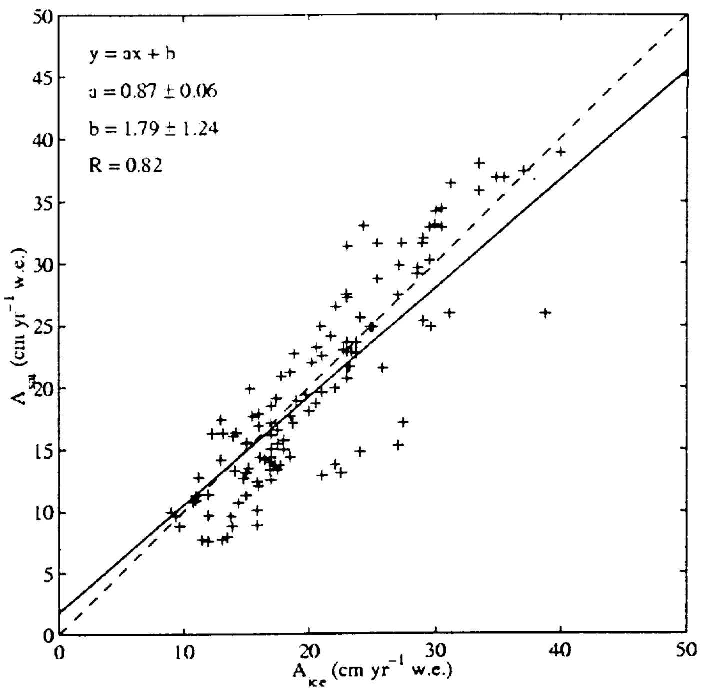
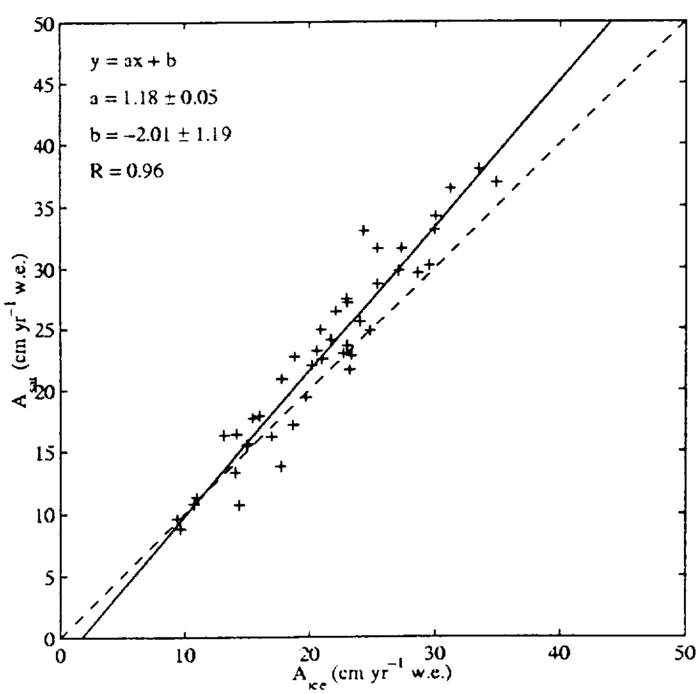


Figure 4: Comparison between; (a) Bales accumulation map; (b) present work. Contours are given in cm/yr w.e., with the dashed line corresponding approximately to the dry-snow zone.



(a)



(b)

Figure 5. Regression between in situ and microwave derived accumulation rates for all available in situ core data (a) and the most recent core data (b).

3 Contributions to PARCA

3.1 Cumulative Presentations and Publications

Baumgartner, F., K. Jezek, R. R. Forster, and S. P. Gogineni, 1998, ``Ultra wide-band ground-truth radar data, Greenland, May 1995", Wallops Island, October, 1998.

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Baumgartner, F. J. Munk, K. Jezek, and S. Gogineni. 2002 On reconciling ground-based with space-borne normalized radar cross-section measurements. Trans. Geosci. and Rem Sens, vol 40, no 2 p. 494-496.

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Zabel, I. I. H., K. C. Jezek, P. A. Baggeroer and S. P. Gogineni, 1995, ``Ground-based radar observations of snow stratigraphy and melt processes in the percolation facies of the Greenland ice sheet'', *Annals of Glaciology*, **21**, 40-44.

3.2 Thesis and Dissertations

Baggeroer, P. A., 1994, *Geoscience Data Management System: Design, Implementation and Analysis*, Master's Thesis, The Ohio State University, 110 p.

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4.0 AdditionalReferences

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