# Applications of geostatistics to glaciology from centimeter to continental scale

*Ute Christina Herzfeld*

*Geomathematik, Universitaet Trier, 54286 Trier*
*email: uch@denali.uni-trier.de*

Geostatistical methods have been adapted or especially designed for glaciological research problems. In the sequel we present applications of geostatistics to glaciology at a range of scales, these applications have proven useful for iceshelf research (geostatistical interpolation of satellite data) or may provide useful data on Antarctic iceshelves in the future (geostatistical characterization of ice surface morphologies from high-resolution field data) (Herzfeld 1999).

## Geostatistical interpolation of Antarctic satellite radar altimeter data

Although the importance of Antarctica in the global system has long been recognized and discussed in the literature, data as basic as topographic maps of a resolution amenable to geophysical analysis are still lacking for large parts of the continent. Mapping, surveying, and monitoring of the large expanses in remote areas are facilitated by remote-sensing technology. The best source for topographic mapping is satellite altimetry. It is often argued that satellite radar altimeter data over ice cannot be used to map ice surfaces with a slope exceeding 0.5 degrees. We have extended the limits of altimeter data evaluation using (a) geostatistical methods and (b) an atlas approach to mapping all of Antarctica north of 72.1 deg S (GEOSAT) and 82.1 deg S (ERS-1) at 3-km resolution. Ordinary Kriging has been applied to altimeter data from the GEOSAT Geodetic Mission (1986), selected for its denser coverage as compared to the Exact Repeat Mission, and to ERS-1 altimeter data from 1995. Half a year of data is sufficient to construct an atlas covering Antarctica (Herzfeld and Matassa 1999).

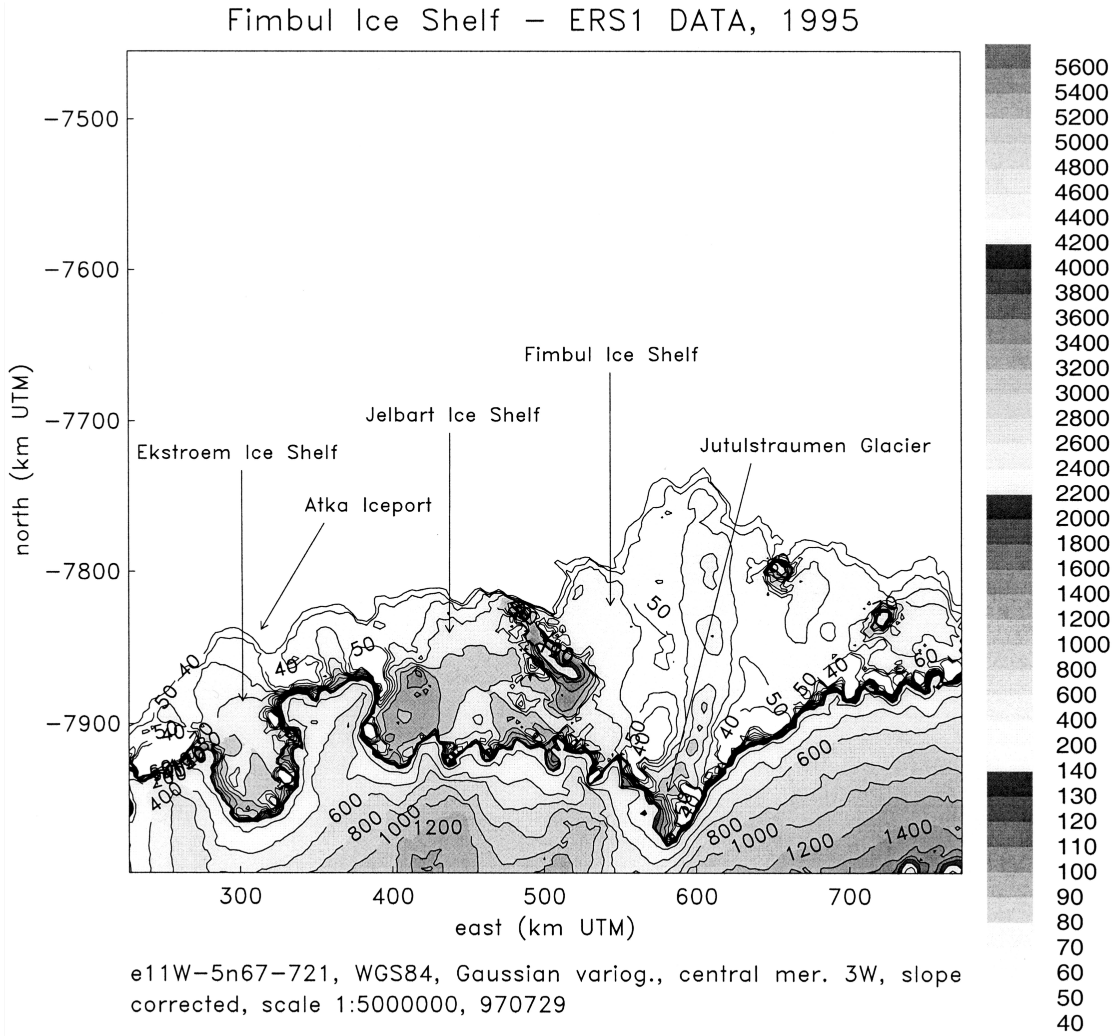


*Figure 1. An atlas sheet of Fimbul Ice Shelf from ERS-1 data.*

The resultant maps yield a wealth of new information, in particular along the margin of the Antarctic Ice Sheet including location and topography of drainage systems of small glaciers and location of some of the ice shelves. An example of an atlas sheet (Fimbul Ice Shelf from ERS-1 data) is presented in Figure 1.The 3-km grids contain more information than is visible in the atlas sheets, an example is a map showing Mertz Glacier with its receding tongue and details of the drainage basin that permit calculation of slopes (Figure 2). Mertz Glacier was only visited in the late 1950's in association with the geophysical year and recently (1998/99).

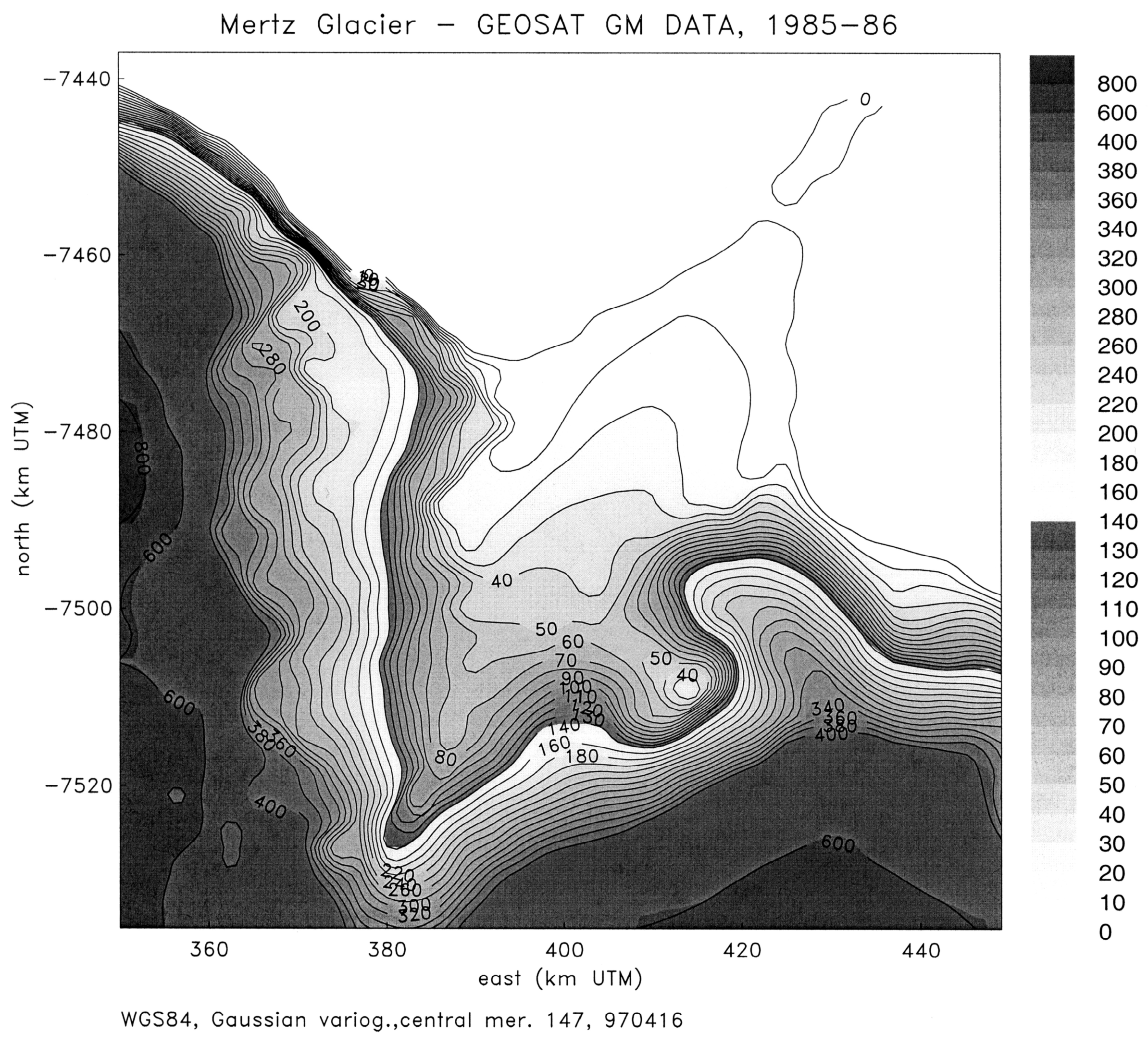


*Figure 2. Map of Mertz Glacier*

Repeated mapping facilitates the monitoring of changes in surface elevation indicative of dynamically and climatically induced mass changes in the East Antarctic Ice Sheet (Herzfeld et al. 1997). A combination of satellite data from various sources, such as elevation and image data, yields maximum information (Herzfeld and Matassa 1997, Herzfeld et al. 2000).

**Geostatistical characteristics of ice surface morphologies from high-resolution field data**

The surface of the Greenland Inland Ice may be segmented into provinces of characteristically different morphologies (Mayer and Herzfeld 2000). The fast-moving Jakobshavns Isbrae has a heavily crevassed surface with flow-line parallel units that are homogeneous in crevasse type.

In the Jakobshavns Isbrae drainage basin's slower moving ice, typical morphologies are those generated by wind and surficial-melting-and-refreezing processes. The objective of geostatistical surface characterization is to devise a set of parameters that describe each morphologic type uniquely.

*Figure 3. The multi-channel instrument, called "Glacier Roughness Sensor" (GRS)*

Large features are visible in satellite data (SAR data), and intermediate scales are best observed in video data (Herzfeld et al. 2000; Herzfeld and Zahner, in press). To observe small-scale features, we designed and built a multi-channel instrument, called "Glacier Roughness Sensor" (GRS) (Figure 3). The GRS measures ice surface roughness at a resolution of 0.2 meters across track and with a 10 Hertz sampling rate along track. During expeditions MICROTOP 97 and MICROTOP 99 to the Greenland Inland Ice, the GRS was utilized to collect surface roughness data in the drainage basin of Jakobshavns Isbrae (Herzfeld et al. 1999). Kinematic processing of GPS data which are recorded simultaneously to the GRS data aids in accurately referencing GRS data to position. ERS-2 SAR data acquired contemporaneously to the field surveys and aerial video data collected during the flights into the field provide the basis for lower scale analyses. Geostatistical surface characterization was applied to SAR data, video data, and GRS data. As one result of the GRS data analysis, surficial melting processes dominate over wind structures in the study area, as derived from a seasonal comparison based on 1997 data, collected in May, and 1999 data, collected in late July.

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