SCAR Fellowship Report 2006/07

Olaf Eisen

Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich, Switzerland (2006)
Alfred Wegener Institute for Polar and Marine Research (AWI), Bremerhaven, Germany (2007/8)

Institution visited

British Antarctic Survey (BAS), Cambridge, UK
Host: Dr. Richard Hindmarsh Scientists involved: C. Martin, D. G. Vaughan, R. Arthern, J. B. T. Scott

Dates

August 2006 – October 2008 (several visits of one to two-week duration)

Work towards scientific objectives of the fellowship: Reconstructing Antarctic ice-sheet history from internal layering

The purpose of the fellowship was to analyse the internal structure of the ice sheet at Berkner Island, as mapped by radio-echo sounding (RES) surveys, to obtain insights into past and present accumulation rates and ice dynamics. The research objectives, as laid out in the proposal, included the following main questions:

- Which information can be retrieved from internal structures, and under which conditions?
- Can we separate accumulation rates for different time periods from ice-dynamic effects?
- Can inversion schemes be generalized towards time dependence?

During the beginning of the fellowship the opportunity appeared to extend the underlying BAS-RES data base by data recorded in 1995 during a joint Berkner Island pre-site survey of the University of Münster (UM), BAS, and AWI. The ground-based UM-RES data comprises an extensive RES grid around the BAS deep drilling site, several common-midpoint (CMP) measurements, polarimetric RES measurements along a circle profile, and a long-distance profile along the Berkner Island ice divide from the southern (Thyssenhöhe) to the northern dome (Reinwarthhöhe), crossing a saddle caused by the trough of McCarthy Inlet. Incorporation of the UM-RES data set into the analysis brought along some surprises, as illustrated by the overall findings of the project:

• DEP-conductance data of the BAS deep ice core over the full ice thickness and the radar wave speed-depth profile from the UM-CMP near the drill site were input to numerical forward model of radar wave propagation. Ideally, the synthetic data provide a link between ice-core properties, and thus age–depth scale, and dominant continuous radar reflectors as observed in BAS- and UM-RES data. Some ambiguities for deeper data could not be resolved at the present point. Measured RES data show considerable lateral differences in reflection characteristics, likely related to variations in the physical structure in the upper few meters, as caused by sastrugis, windcrusts, or recrystallization features. The variations imply the mandatory usage of RES profiles instead of only single traces for inter-system and synthetic data comparison. Dominant reflections originate from strong conductivity peaks, but also from interference of smaller reflections at a number of smaller peaks.

• Variations of the RES backscatter with polarization azimuth for the upper hundreds of meters from different sites indicate that either the shape of air bubbles, or the bubble density distribution can be anisotropic. This anisotropy is caused by ice-dynamic strain and provides a promising new way to determine strain distributions.

• Accumulation rates show only smooth gradients, making the application of the kinematic inversion model only feasible near the dome locations, where significant variations in the internal layer architecture are present (e.g. Raymond bump at Thyssenhöhe). The simultaneous determination of ice dynamics and accumulation by the kinematic inverse approach was not possible. Either some assumptions about horizontal velocities have to be considered to determine the accumulation pattern, or vice versa.

• A generalized inversion scheme that includes time dependence is not within reach. The most successful way to pin down time dependence is probably the application of FE-forward modeling for different scenarios, and subsequent application of an inverse method.

• The UM-RES profile along the ice divide shows a Raymond bump at the saddle of McCarthy Inlet. Having been unrecognized in the data since their recording, this is the first evidence for a Raymond bump to occur at saddle points of ice flow. The novelty of this discovery, together with the insights into special dynamics and particular features of Raymond bumps and isochrone arches obtained by the glaciological community only over

the last few years, shifted this feature in the focus of the fellowship. It was found that the isochrone arch actually consists of two bumps at larger depth. With the current knowledge of ice dynamics, this indicates that the crystal orientation fabric is strongly anisotropic at larger depth, influencing the rheological properties and thus ice flow at Berkner Island.
• For the first time, a three-dimensional time-dependent anisotropic Full Stokes model that considers strain-induced fabric evolution was employed to analyse the ice flow and fabric characteristics of internal layer architecture at the saddle. Together with the observed layer pattern, this observation has several implications. Apart form low deviatoric stresses, the model indeed indicates a strongly evolved anisotropic crystal fabric at larger depth. As the transition from a single bump to a double bump appears at rather shallow depths (35

Milestones and deliverables

Further development of inversion schemes will concentrate on models describing the full dynamics of the system, as the kinematic inversion scheme cannot simultaneously provide results for ice dynamics and accumulation. Other results were and will be presented at conference talks and are incorporated in papers in progress (see publications below). Main emphasis is the reconstruction of the ice dynamics of the saddle. The fellowship successfully provided the base to start and continue this collaborative work.

Additional work conducted

As described above, older RES data from the University of Münster, not included in the initial proposal, was incorporated in the analysis. The publication of a review paper on the measurements of surface mass balance in East Antarctica made considerable progress during the visits through discussions with co-authors and other scientific staff at BAS, which did not participate in the proposal (see publications below). Shallow radar data recorded with different radar systems in the percolation zone of the Greenland ice sheet during several ESA's CryoSat Cal/Val-campaigns were jointly compared to investigate the retrieval of internal layering for accumulation estimates, including comparison to the ASIRAS airborne system. Based on the findings from the Berkner saddle, a joint AWI–BAS airborne reconnaissance field survey was planned for the upcoming season 2008/9.

What SCAR funds were allocated?

€3800 / US $5000 were awarded to the fellow.

How were the SCAR funds spent?

The original budget request was for US $5000 to cover a 10 week visit. The full amount is spent to date for the meetings with the project partners in the period 2006-2008. Greatest category of expenses by far was accommodation, followed by transportation and food. Several one- to two-week visits were found to be more efficient for the progress of the project because of time constraints imposed by the host and my home institutions. This actually decreased spending of funds because of the high ratio of per-night accommodation to per-roundtrip travel expenses.

Future work plans

Continued work aims at modeling the kinematics and dynamics of the Raymond (double) bump/isochrone arch underneath the saddle of Berkner Island with the dynamic model available at BAS to retrieve information about anisotropic distributions of the crystal orientation fabric. The upcoming airborne radar survey with AWI's Polar 5 and logistic support from BAS's Halley Research Station originated from the results found in this project. The aim is to use a more powerful radar system to image the internal layers over the full depth of the Berkner Island saddle to identify the characteristics of the double bumps at deeper depths. This will be done along two perpendicular profiles to indicate the three-dimensional shape of an isochrone arch and double bump, of which there is no data available to date. If this survey proves to be successful, a full survey forming a grid centered on the saddle, and ideally if logistically feasible, also incorporating a complete coverage of Berkner Island is envisaged.

Publications

Eisen, O., Martin, C., Hindmarsh, R., Blindow, N., Steinhage, D., The somewhat different ice divide: internal structure and ice dynamic implications of the Berkner Island saddle point, in preparation.

Eisen, O., Frezzotti, M., Genthon, C., Isaksson, E., Magand, O., van den Broeke, M.R., Dixon, D.A., Ekaykin, A., Holmlund, P., Kameda, T., Karlf, L., Kaspari, S., Lipenkov, V., Oerter, H., Takahashi, S., Vaughan, D.(2008).

Ground-based measurements of spatial and temporal variability of snow accumulation in East Antarctica, Reviews of Geophysics, 46, RG2001, doi:10.1029/2006RG000218.

Talks

Eisen., C. Martin, N. Blindow, D. Steinhage and R. Hindmarsh, Manifestation of ice properties and dynamics in radar stratigraphy: Berkner Island ice saddle as a case study, IGS Radioglaciolgy, Madrid, 2008.

Martin, C., G. H. Gudmundsson, H. Pritchard and O. Gagliardini, Ice flow and crystal fabric near ice divides, IGS Radioglaciolgy, Madrid, 2008.
(Includes findings from Berkner Island saddle modelling study.)