Modelling the Flow Regime of Filchner-Schelfeis

K. Saheicha, H. Sandhäger, M.A. Lange

Institut für Geophysik der Westfälischen Wilhelms-Universität Münster
Corrensstraße 24, 48149 Münster, Germany

INTRODUCTION

The Filchner-Schelfeis (FIS) (Figure 1), is the part of the Filchner-Ronne Ice Shelf situated to the east of Berkner Island, which represents the world largest Ice Rise (Grosfeld et al., 1998). It has been investigated less extensively than its western counterpart (Ronne-Ice Shelf) due to its heavily crevassed surface, so the access is logistically more difficult.

In particular, an elongated shear zone along the eastern grounding line of Berkner Island is visible on satellite images. In this shear zone the ice is fragmentarily destroyed in the upper part of the ice shelf. A second significant morphological feature is the crevasse train which extends from the central east coast of Berkner Island to the region west of the grounding zone of Recovery Glacier (Figure 1) and consists of open surface crevasses (Radarsat Antarctic Mapping Project). Both features determine the flow regime of the ice shelf and consequently have great impact on the velocity of the ice flow (Grosfeld et al., 1998). In this study this effect will be investigated by means of numerical flow modelling.

Firstly the ice dynamics are simulated with an ice-shelf model which yields a velocity distribution differing substantially from ice velocities derived from SAR-interferometry. Therefore, a parameterisation describing the effect of fractures on the large-scale ice flow has been implemented into this model. The corresponding results largely agree with the interferometric observations.

STANDARD MODELLING STUDY

To simulate the ice dynamics of central and western parts of FIS and the eastern slope of Berkner Island, a numerical three-dimensional time-independent model including a coupling between ice shelf and ice sheet is used (Sandhäger, 2000). Hence, the especially interesting morphological structures, i.e. the shear zone along Berkner Island and the crevasse train in the central southern part of FIS, lie within the modelling area and therefore are not necessarily given by boundary conditions.

The model is based on the fundamental balance equations of thermodynamics, an empirical equation of state for large natural ice bodies and material equations for polycrystalline ice. For the numerical treatment of the resulting model equations, the method of finite differences in combination with special solving algorithms was chosen. The input parameters include the geometry of the ice body, the mean annual surface temperature, the snow accumulation rate and the geothermal heat flow.

At the ice divide on Berkner Island, fixed boundary values (0 m/a) are chosen. The boundary conditions for the eastern and southern border of our modelling area are also determined by boundary values varying from 10 m/a to 400 m/a at the influx area of Recovery Glacier into the ice shelf.

Numerical integration yields the speed and direction of the ice flow, the distributions of stress and the temperature at each model grid point. The horizontal resolution of the model grid is 2.5 km and in the vertical it consists of 10 non-equidistant levels.

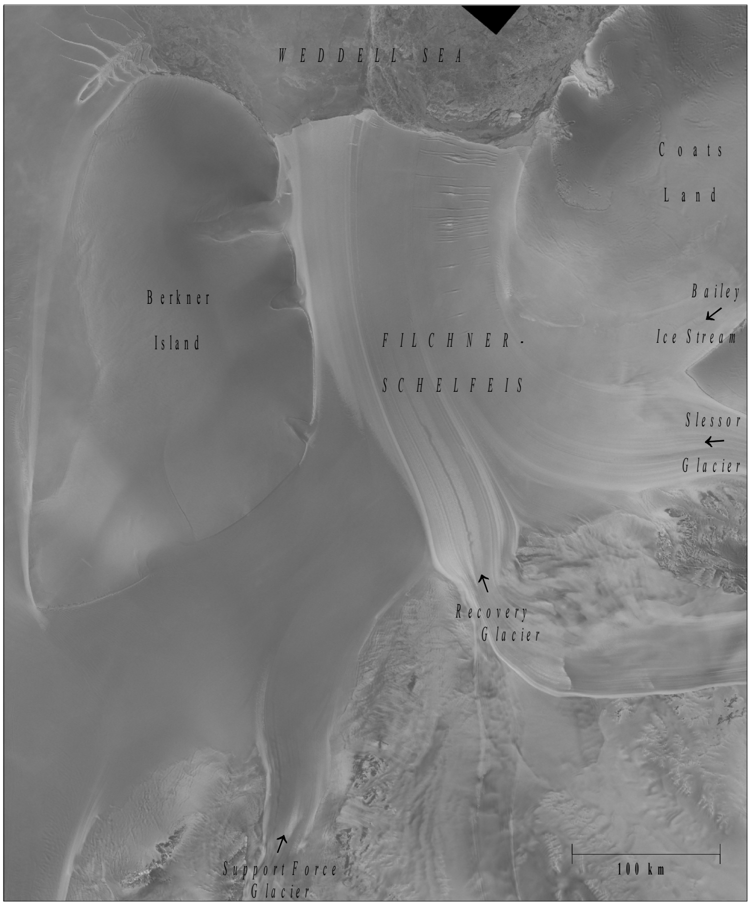

Fig 1 Radarsat intensity mosaic images (Radarsat Antarctic Mapping Project) from 1998

In Figure 2 the simulated distribution of the vertical mean speed of the horizontal flow is shown. The maximum speed amounts to 800 m/a and is located in the central of FIS. The velocity gradient along Berkner is continuous. Another noticeable feature is that the speed retards in the area of the Recovery Glacier. Low velocities (mostly below 10 m/a) are detected in the southwest of FIS and on Berkner Island.

For an evaluation, a velocity field is used which is obtained from satellite data (Schmidt et al., 1999) for the northern part of FIS (Figure 3). Although the velocity field still includes the effect of vertical tidal displacements, it is the only independent data set available for this area. In particular the speed is higher with a maximum value of 1400m/a, furthermore the area of maximum flow speed is moved to the west.

Obviously, the comparison between the ice velocities obtained from interferometric data and the numerically modelled reveals significant differences in the shapes of the contour lines of ice speed.

One probable reason for the discrepancy between both ice speed patterns seems to be the effect of fracture structures (Grosfeld et al., 1998). Thus it is necessary to take them into consideration.

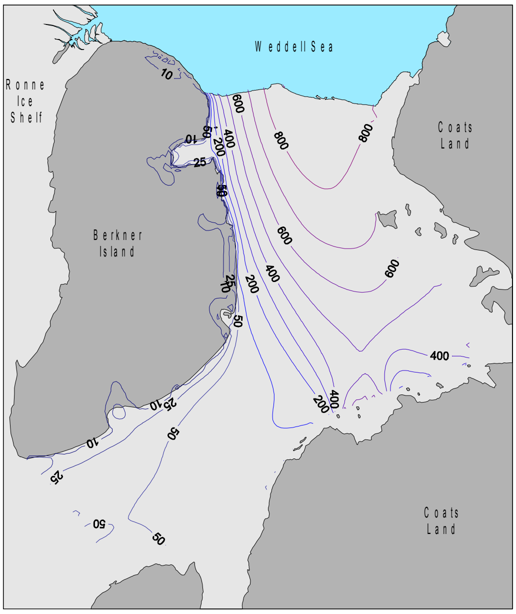

Fig 2 Numerical simulation of the velocity field with fracture structures not included. Base map here and on fig 4 from IfAG/AWI 1994.

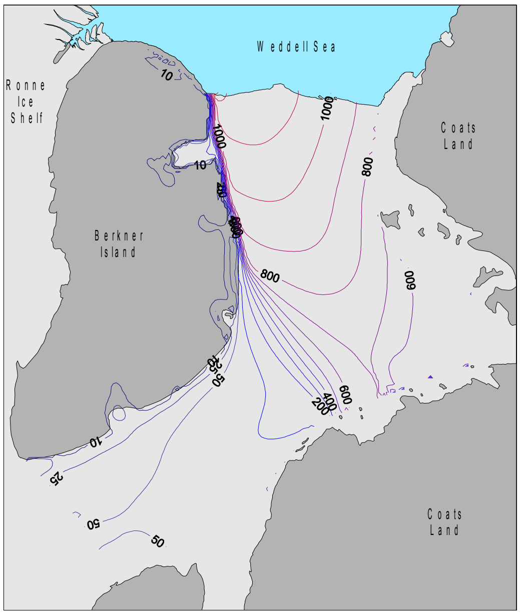

Fig 4 Numerical simulation of the velocity field with fracture structures included.

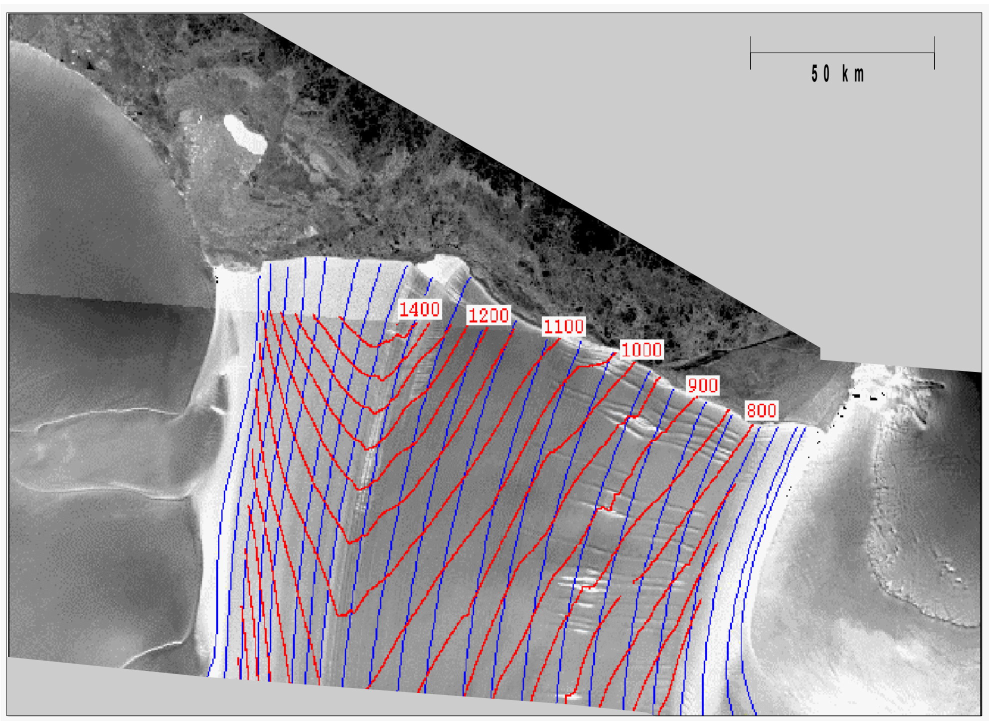

Fig 3 Interferometric ice velocities derived from the ERS-1 SAR intensity mosaic by J. Schmidt (Feb. 1994)

PARAMETRISATION OF THE EFFECT OF FRACTURE ZONES

It is not possible to simulate the process of fracturing in detail with the model because it is not sufficiently known and a high resolution is necessary. Therefore only the macroscopic effect of fracture structures on the ice body has to be parameterised. For this purpose two different steps have to be achieved: I) identification of areas where fracture structures are formed and II) characterization of the effects of fracture structures on the flow regime.

Ad I) One very simple criterion is the "von Mises" criterion (Vaughan, 1994), which expresses a relationship between the tensile strength and the effective stress. This failure criterion assumes that the ice body can support only a limited stress before failure. These areas of higher stress are identified with the crevasse area and the shear zone obtain from satellite data. So the occurrence of a crevasse area or a shear zone depends on a critical value of the effective stress, i.e. 145kPa respectively 245kPa. These values belong to the range of values Vaughan (1993) used likewise for determinating crevasses.

Ad II) Two different effects are regarded as characterising the influence of these areas of higher stress. On the one hand, the ice is softened and on the other hand the ice flow inside and outside the fracture zone is decoupled. These two effects occur in shear zones as well as in crevasse areas, however both effects have a greater impact in shear zones. Thus, if a stress field is detected that exceeds the critical value for shear zones or crevasses, the calculation of the temperature and the velocity differs from the calculation in the remaining model area. Taking into account that our model is three-dimensional, shear zones as well as the crevasses occur not only on the surface, they also penetrate in depth. So in the areas of fracture structures, a temperature or velocity is used in the fracture area which is more influenced by a deeper layer.

To calculate the temperature in fracture areas, the model first distinguishes between crevasses and shear zones. In the next step the depth is taken into consideration, i.e. down to which layer the critical stress extends. The new temperature is a combination of the temperature calculated as usual and the temperature in the deeper level. Using a different temperature calculation than in the remaining area, the ice is softened and that it is what seems to happen in fracture areas from the macroscopic point of view.

To implement the decoupling of the ice flow inside and outside the fracture area into the model, the numerical scheme of the discretized model equations (the method of finite differences) is taken into account. Thus a place-dependent emphasis in the numerical treatment is required for the calculation of the velocity field. In the crevasse train the decoupling is small but shear zones are mostly determined by a decoupling.

Therefore, new tuning-parameters, which simulate the influence of the different fracture structures on the flow regime, have been implemented. The disadvantage of this parameterisation is the dependence on the grid-space.

APPLICATION OF THE IMPROVED FLOW MODEL

The first result is that the improved model is able to identify the different fracture zones, i.e. the shear zone and the crevasse train, on the basis of the modelled stress. If a critical value on the effective stress of 145 kPa for the crevasses and for the shear zone of 245 kPa is chosen, areas are identified which correlate with the noticed zones of fracture structures seen on Figure 1. So the "von Mises" criterion is one very useful criterion to mark the shear zone as well as the crevasse train.

In Figure 4 the simulated distribution of the vertical mean speed of the horizontal flow is shown. The maximum speed amounts to 1100 m/a and shifts from the central of FIS to the west. Thus the velocity gradient along Berkner has narrow spacing contour lines.

Comparing the velocity field simulated with the improved model (Figure 4) against the already obtained modelled velocity field (Figure 2), the difference becomes rapidly apparent. The contour line pattern differs. The area of maximum flow speed is moved to the west and the speed has a higher value. The velocity field simulated with the improved model closely matches the velocity field obtained from the satellite image.
Thus the aim to simulate a "realistic" flow regime of Filchner-Schelfeis has been reached.

CONCLUSIONS

A coupled three-dimensional ice shelf inland-ice model is applied to Filchner-Schelfeis to calculate the velocity field.

By parameterising the influence of fracture structures, a significant improved modelled velocity field is obtained. Thus the flow model is modified by taking the effect of fracture structures into consideration and highly is applicable for further investigations.

Thus for a time-dependent simulation taking into consideration the evolution of an ice rumple to an ice rise, the effect of fracture structures are of great importance in the transition zone between ice rumple/rises and the shelf ice.

Another fracture structure beside shear zones and crevasses is the calving mechanism. Because most calving is believed to have been initiated by the formation of crevasses by tension this could be regarded as a basic approach which has to be developed.

This work is only a first step to find a better correlation between numerical simulation and observation. For verification of the improved model we have to consider another area, i.e. the Filchner –Ronne Ice Shelf (FRIS).

REFERENCES

Grosfeld, K., H.H. Hellmer, M. Jonas, H. Sandhäger, M. Schulte and D.G. Vaughan (1998). Marine ice beneath Filchner Ice Shelf: evidence from a multi-disciplinary approach. *Antarct. Res. Ser.*, **75**, AGU, Washington, D.C., USA, 319-339.

IfAG/AWI 1994. Digital topographic Antarctic database. Version 1.94(G), Institut für Angewandte Geodäsie, Frankfurt am Main, and Alfred Wegener Institute for Polar and Marine Research Bremerhaven, Germany.

Radarsat Antarctic Mapping Project (1998).

Sandhäger, H. 2000. Quantifizierung eisdynamischer massenhaushaltsrelevanter Basisgrößen eines antarktischen Inlandeis-Schelfeis-Systems unter Einsatz eines numerischen Fließmodells. *Dissertation*, Westfälische Wilhelms-Universität Münster (Germany).

Schmidt, J., K.-H. Thiel and H. Sandhäger (1999). Large scale Interferometry over Filchner-Ronne Ice Shelf. Workshop; ESA Fringe; Liege, Belgium; 10-12 Nov. 1999.

Vaughan, D.G. (1993). Relating the occurrence of crevasses to surface strain rates. J. *Glaciol.*, **39 (132)**, 255-266.