extrusion. However, we find that this is inconsistent with measured mass imbalances. This new idea is that deep ice may squirt in time-pulses. Being faster than the extrusion considered above, episodic extrusion would be mechanically more important. It would cause a drop in ice-surface elevation over the site of origin of the extrusion and surface lifting over the destination. Measurements of relative vertical velocity obtained with precision GPS of an expanded grid on Ice Stream B, Antarctica (Hulbe and Whillans, 1994), do show important topographic changes, but the changes are not at sites that would account for the negative basal drag. Thus, not even episodic, non-steady extrusion can account for the reverse basal drag.

Since conducting the work discussed in Whillans and Van der Veen (1993), we have completed a much more extensive study of the region, using a grid expanded five-fold. The interpretation of these new results is given in Hulbe and Whillans (1994) and Hulbe (1994; which contains data tables). Based on this more extensive survey, our current view is that there are zones of ice of differing viscosity horizontally juxtaposed. Including appropriate horizontal variation in viscosity would lead to more sensible calculated basal drag. We propose that bands of special strength develop in ice after extreme simple shear (at the sides of up-glacier tributaries). The viscosity may vary according to the up-glacier origin of the ice.

Lliboutry's (1995) suggestion is very reasonable to the extent that he carries it. However, the stresses imparted by the envisioned extrusion are too small to explain the calculated backward basal friction. The reason the issue arises for Ice Stream B, Antarctica, could be that the ice stream is unusual or, alternatively, that the survey work was more thorough than on many other glaciers. The ice stream has such a simple geometry that unusual results cannot be attributed to uncertainties in ice thickness or width.

We thank Professor Lliboutry for raising this suggestion. It is good for Science to discuss possible oversights. We remain concerned that we may have overlooked some perfectly good explanation for the results and would welcome more suggestions, including further consideration of extrusion flow.

Byrd Polar Research Center and Department of Geological Sciences, The Ohio State University, Columbus, Ohio 43210, U.S.A. — IAN WHILLANS

Byrd Polar Research Center, The Ohio State University, Columbus, Ohio 43210, U.S.A. — KEES VAN DER VEEN

5 October 1994

REFERENCES

Hooke, R. LeB. 1981. Flow law for polycrystalline ice in glaciers: comparison of theoretical predictions, laboratory data, and field measurements. *Rev. Geophys. Space Phys.*, **19**(4), 664–672.

Hulbe, C. L. 1994. Flow of Ice Stream B, West Antarctica, and a method for determining ice thickness change at remote locations using differential GPS. (M.Sc. thesis, Ohio State University.)

Hulbe, C. L. and I. M. Whillans. 1994. Evaluation of strain rates on Ice Stream B, Antarctica, obtained using GPS phase measurements. *Ann. Glaciol.*, **20**, 254–262.

Hutter, K., F. Legerer and U. Spring. 1981. First-order stresses and deformations in glaciers and ice sheets. *J. Glaciol.*, **27**(96), 227–270.

Lliboutry, L. 1995. Correspondence. Why calculated basal drags of ice streams can be fallacious. *J. Glaciol.*, **41**(137), 204–205

Nye, J. F. 1952. Reply to Mr. Joel E. Fisher's comments. *J. Glaciol.*, **2**(11), 52–53.

Whillans, I. M. and K. C. Jezek. 1987. Folding in the Greenland ice sheet. *J. Geophys. Res.*, **92**(B1), 485–493.

Whillans, I. M. and C. J. van der Veen. 1993. Patterns of calculated basal drag on Ice Streams B and C, Antarctica. *J. Glaciol.*, **39**(133), 437–446.

SIR,

Analysis of satellite-altimeter height measurements above continental ice sheets

In a recent paper in the *Journal of Glaciology* the performance of three radar-altimeter "retracking" algorithms was investigated using simulated waveforms (Femenias and others, 1993). One of the techniques used was described as the Offset Center of Gravity (OCOG) method. There appears to be a misunderstanding about the function of this algorithm which, in itself, is not a retracking procedure but a means of determining the *amplitude* of the waveform. This amplitude is then used to find the position on the leading edge of the waveform which equals some percentage of the amplitude (e.g. 0.3, used by Partington and others (1991)). Furthermore, to reduce the effects of the leading edge on the amplitude estimate, each waveform sample is squared. The centre of gravity and waveform width that can be obtained from using the OCOG procedure were never intended to be used to calculate a retrack position in the way that they have been by Femenias and others (1993). Instead, they were designed to be used as part of a satellite onboard-tracking loop (such as is used for the ice mode of the ERS-1 altimeter). A complete and correct description of a retracking procedure using the OCOG algorithm is given in Bamber (1994). It should be noted that using the waveform width and centre of gravity to find the retrack point on the waveform and using the amplitude to "threshold" retrack it give very different results.

University College London, Department of Space and Climate Physics, Mullard Space Science Laboratory, Holmbury St Mary, Dorking, Surrey RH5 6NT, England — JONATHAN BAMBER

12 July 1994

REFERENCES

Bamber, J. L. 1994. Ice sheet altimeter processing scheme. *Int. J. Remote Sensing*, **15**(4), 925–938.

Femenias, P., F. Remy, R. Raizonville and J. F. Minster. 1993. Analysis of satellite-altimeter height measurements above continental ice sheets. *J. Glaciol.*, **39**(133), 591–600.

Partington, K. C., W. Cudlip and C. G. Rapley. 1991. An assessment of the capability of the satellite radar altimeter for measuring ice sheet topographic change. *Int. J. Remote Sensing*, **12**(3), 585–609.