Remarks concerning the Antarctic mass balance

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Abstract: Mass budget studies are reviewed, and a new estimate of snow accumulation is made by extrapolating data on the basis of a correlation between accumulation and surface temperature. Ice velocities are tabulated and discussed, and iceberg discharge is estimated. Indirect evidence on the state of the mass balance is considered, and some notes on ice temperatures are included.

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Recent studies have given a good outline of the Antarctic mass economy but the final state of the balance remains uncertain.

Published budgets indicate a large positive mass balance, with surpluses in the range 4.0 — 12.2 x 10^{17} g yr $^{-1}$. Confidence limits for these estimates are low, and the surpluses may arise from systematic errors, but the results cannot be summarily dismissed. Weak reasoning has been advanced to support assumptions of neutral or negative balance.

Snow accumulation, estimated in the range 1.34 — 2.55 x 10^{18} g yr $^{-1}$, is the largest single budget item. A major source of error in estimates is the poor areal distribution of data, and therefore the possibility of correlating accumulation with a more widely measured parameter is examined. In the belief that a correlation exists between precipitation and temperature, a correlation of net accumulation with mean annual surface temperature for areas of positive accumulation was attempted, using 256 pairs of data from the literature. An exponential form of relation yielded the best correlation, giving the regression line log A = 1.949 — 0.0235T, where A is accumulation rate (g cm $^{-2}$yr^{-1}) and T is temperature (^{0}C below 0 ^{0} C). Regarding isotherms as isopleths, a plot of mean annual surface isotherms was planimetered to give an accumulation estimate for the whole ice sheet of 1.96 x 10^{18} g yr $^{-1}$, after adjustment for areas of zero and negative accumulation.

The accumulation data are used to predict the discharge of the Lambert Glacier after defining its drainage basin from surface form lines. At lat. 73 ^{0} S the glacier carries 9.3 x 10^{16} cm^3 yr^{-1}, calling for a velocity

$$\text{of } \frac{2.3 \times 10^{10}}{D} \text{ cm yr}^{-1},$$

where D is the effective flow depth in cm.

Ice velocities for various parts of Antarctica are tabulated; included are 20 values for ice shelves, 9 for unchanneled continental ice, 30 measured values for ice streams, and 22 ice strem values estimated morphologically. The data for ice streams show little correlation between stream with and velocity. Velocity estimates made morphologically have a mean value 1.8 times as high as the mean for a comparable group of measured values. There seem to be theoretical and statistical grounds for undertaking further studies of periodic morphological features on Antarctic glaciers.

Existing data sugget that ice shelves discharge icebergs at the rate of 7.8 x 10^{17} g yr^{-1}, while unchanneled continental ice produces bergs at only 0.37 x 10^{17} g yr^{-1} The berg contribution from ice streams cannot be assessed with stream dephts unknown; theoretical consideration of stress conditions and temperature distribution in the ice suggests that ice streams are much deeper than the 250 m commonly assumed. If an average depth of 1 km is assumed, the total mass discharge from ice streams is 8.3 x 10^{17} g yr^{-1}.

Indirect evidence on the state of the mass budget is inconclusive. The Antarctic ice margins have shown no appreciable advance or retreat in recent decades; volume changes are likely to be out of phase with climatic perturbations, but it is suspected that a margin response should be detectable if a major imbalance of the budget has persisted for more than a century. The obser-

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ved eustatic rise of sea level apparently conflicts with estimates of a large budget surplus in Antarctica. Calculations of thermal expansion based on warming of the whole ocean seem unrealistic in view of sea bed geothermal data, but the observed rise can still be accounted for by warming of the uppermost 1 km at a rate of 10^{-2} C yr^{-1}. Even so, a large mass surplus in Antarctica would more than nullify the effects of such a thermal expansion.

Transient temperature distributions in the ice reflect surface warming. To help define relative magnitudes of warming by ice flow and by climatic change, measurements on high ice divides are proposed. Thermal calculations indicate that melting occurs at the base of very thick ice; the water mass involved has little direct effect on the budget, but melting at the beds of ice streams (where heat generation is significant) is of some rheological significance.

Elektronische Distanzmessung hoher Genauigkeit im Polargebiet

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Zusammenfassung. Der Bericht bringt Einzelheiten über den Einsatz von Tellurometern in Grönland und in der Antarktis und über die notwendigen Modifikationen der Geräte zur Erzielung genügender Reichweite und Betriebssicherheit.

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Summary. The report gives details about the use of Tellurometers in Greenland and Antarctica and the modifications on the instruments which are necessary for reasons of reliability and range.

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Bei der Internationalen Glaziologischen Grönland-Expedition 1959 (EGIG 59) und der Ross ice shelf survey-expedition 1962 bis 1963 (RISS 62/63) wurde das Tellurometer [1]) erfolgreich zur genauen Einmessung von Schneepegeln (Balisen) verwendet. Diese Pegel sollen nach einigen Jahren wieder eingemessen werden; aus ihrer Verschiebung ergeben sich Fließrichtung und Fließgeschwindigkeit der Eismassen und damit Unterlagen für die Berechnung des Massenhaushaltes.

Das Profil der EGIG 59 über das Grönländische Inlandeis von Manitsoq im Westen bis Cecilia Nunatak im Osten wurde vorwiegend als Diagonalen-Viereckskette, d. h als Streckenkette ohne Winkelmessung mit einem Punktabstand von ca. 10 km gemessen; der mittlere Fehler der Einzelstrecke betrug ± 7,5 cm [2]).

Das RISS-Profil von McMurdo-Station nach Camp Michigan (Bay of wales) wurde den anderen topographischen Verhältnissen entsprechend als gestreckter Polygonzug mit ca. 8 km Punktabstand eingemessen; der mittlere Fehler der Einzelstrecke betrug ± 5,5 cm [3]).

Die Genauigkeit und Reichweite der Tellurometer wird durch den dicht über der Schneeoberfläche meist sehr großen Temperaturgradienten, die Schneedrift und die dielektrische Grenzfläche Schnee — Luft beeinflußt [4]).

In den bodennahen Luftschichten genügt die Bestimmung des Refraktionskoeffizienten der Luft an den Endpunkten der Strecke allein nicht, andererseits ist es praktisch unmöglich, simultan an weiteren Punkten entlang der Strecke meteorologische Messungen anzustellen. Die Abhilfe besteht in den meisten Fällen darin, die Antenne möglichst hoch zu setzen, so daß die Verbindungslinie zwischen den beiden Tellurometerstationen unter Berücksichtigung der Erdkrümmung und der örtlichen Topographie in einem homogeneren Luftkörper möglichst hoch über der Schneeoberfläche verläuft und diese keinesfalls tangiert [5]).

Um die innere Genauigkeit der Tellurometer zu erhalten, ist es erforderlich, die Thermo-

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