Chapter 5

Qualitative Modeling of Ice Sheet Accumulation for Identification of Mass Balance Variation

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ABSTRACT

Formation and evolution of ice sheets is one of the “hot” problems of modern geosciences, as it has direct implication on the issues of climate change and sea level rise. Different methods of measurement or computing the mass balance of modern ice sheets based on various physical models sometimes give conflicting results. To understand them, one should first reconcile the models they are based on. This, in turn, requires one to decipher the vision different researchers have on the generation and evolution of ice sheets. This vision is initially qualitative. Hence, a qualitative model is desired that would reconcile various, and sometimes conflicting, physical models. This chapter proposes this model.

INTRODUCTION

In the studies of present climate changes the mass balance of the Greenland ice sheets (GrIS) is of particular interest because its potential melting is critical for sea-level change and freshwater impact on ocean circulation. Wide range of satellite measurements during the last two and a half decades allowed significant improving of our knowledge about such extreme polar environments as ice sheets. Various

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estimates show that the GrIS mass balance over this period is negative and mass loss is accelerating in time (AMAP, 2011).

Previously it was considered that mass changes of the ice sheets on the decadal time scale are primarily caused by surface mass balance, i.e. difference between snow accumulation and water runoff due to summer surface melting. Area extent of the surface melting varies significantly from year to year, but water runoff occurs only in the narrow zone over GrIS margins, while above the equilibrium line most water from surface melting refreezes in the firn (Figure 1). In this case variability of snow accumulation is the main parameter of the mass balance over most area of the ice sheet. At the same time water runoff from melting accounts for about half of the mass loss from the ice sheet. Another source of mass loss is the ice discharge through iceberg calving (Figure 2a, b). Rate of the ice discharge depends on the ice flow velocity, which was considered to vary very slowly as a response to mass balance changes hundreds and thousands years ago and therefore may be assumed as constant (Figure 4).

However recent studies have shown that ice flow velocity may vary considerably on inter-decadal and even inter-annual time scales (e.g., Rignot et al., 2011; Moon et al., 2012). Significant ice loss over the GrIS low-elevation areas occurred during the last one and a half decades is explained partly by the intense surface melting due to increased temperature and partly by the acceleration of the ice flow. This acceleration is observed not only over the ice streams and outlet glaciers, characterized by the high flow velocities of up to several kilometers per year, but also propagates inland of the ice sheet. These rapid changes in ice flow velocities were not predicted by the ice flow models, which were not able to resolve short time scale variations of the ice dynamics and did not account for the effect of all external forcing components.

Currently two mechanisms responsible for the increased ice flow velocities are considered. One of them is related to changes in basal lubrication and sliding of the ice following increased melting on the surface and drainage through moulins (Zwally et al., 2002; Joughin et al., 2008; Van de Wal et al., 2008; Bartholomew et al., 2010). The other mechanism is connected with changes in buttressing of outlet glaciers caused by removal of their floating ice tongues due to warmer waters and allowing ice-flow speed-up (e.g. Thomas et al., 2004; Nick et al., 2009). However although these processes may explain recent ice flow acceleration it is not obvious that they will remain dominant over longer-term scale. For example, it was shown (van de Wal et al., 2008) that rapid drainage of melt water significantly speeds-up ice flow over the period of only several days implying that the englacial hydraulic system adjusts constantly to the meltwater input. As for another mechanism, high sensitivity of tidewater outlet glaciers to changes