APPLICATIONS OF ICE-FLOW MODELS TO MARS. M.R. Koutnik[1], A.V. Pathare[2], E.D. Waddington[1], C.E. Todd[3], and J.E. Christian[1]. [1]University of Washington, Earth and Space Sciences, Seattle, WA 98195 (mkoutnik@uw.edu), [2]Planetary Science Institute (pathare@psi.edu), [3]Pacific Lutheran University, Tacoma, WA.

Introduction: Over the past few decades there have been many studies that have applied knowledge of ice-sheet and glacier flow to improve understanding of the evolution of martian ice masses. As in terrestrial glaciology, flow models of martian ice have been constructed with different assumptions about ice-flow physics, different numerical schemes, and for different objectives. These decisions depend on the size and setting of the ice mass. In each application there must be data to constrain or evaluate the choice of necessary model initial conditions and boundary conditions. For this discussion we focus primarily on ice-flow models applied to "viscous-flow features" (VFF; [1, 2]), which include features categorized as "glacier-like forms" (GLFs; [3]) and as "lobate debris aprons" (LDAs) found in the midlatitudes of Mars. We separately consider flow models applied to the polar layered deposits [e.g., 4 - 8] and to support reconstructions of past ice sheets [e.g., 9]. This means that we separately consider models developed for terrestrial glaciers, especially in alpine settings, compared to terrestrial ice sheets.

Glacier flow models: On earth, models of glacier flow are used to investigate how glacier length, volume, surface topography, and velocity are influenced by climate, ice properties, catchment geometry, and basal conditions [10]. The equilibrium sensitivity of glacier length to a change in climate can be constrained using the glacier's geometry. However, glacier evolution in response to a change in climate must include an appropriate representation of ice dynamics as well as realistic geometric and climatic boundary conditions. The representation of ice dynamics in the model must be considered carefully.

The simplest and most efficient models applied to glaciers are analytical [e.g., 11, 12]. More sophisticated, numerical models with a shear-deformation rheology (known as the Shallow Ice Approximation; SIA) are the models that have been most commonly applied to valley glaciers [e.g., 13, 14]. These models are also simple to implement and efficient enough to run for long timescales. However, these models are strictly valid only where horizontal gradients in thickness and velocity are small and where bedrock slopes are low, which we know does not apply on many glaciers. For this reason the ability of shear-deformation models to realistically represent glacier dynamics has been investigated for general cases [e.g., 15, 16] and for specific glaciers [e.g., 17, 18]. This work has shown that the SIA is less accurate for higher bedrock slopes, where ice-flow speeds increase, and also where changes in the spatial gradient of surface mass balance is more important than ice dynamics in determining the glacier geometry [18]. While we expect that full-stress (Stokes) models can give the most accurate solutions for glacier evolution, these models are relatively expensive computationally and are complex to develop. Recent development of open-source Stokes models has made new analyses more tractable but there can remain challenges with computation time, and a critical consideration is that the lack of necessary bed topography and the poorly known surface mass balance often does not warrant using a more sophisticated dynamic model. Therefore, low-order models may be just as effective and just as "accurate", but the uncertainties in the calculated glacier evolution associated with the choice of model physics may need to be evaluated. Any application of a glacier flow model must assess its assumptions, and the choice of model must fit the objectives of the application.

With lessons from terrestrial studies in mind, we have three objectives in reviewing select published applications of ice-flow models to Mars: 1) summarize the different goals of these studies, 2) group different modeling strategies, and 3) evaluate results in context with this range of goals and assumptions. Then, we will present initial results from our new application of a glacier flow model to LDAs with the aim to better constrain the evolution of LDAs based on current surface topography.

Applications to Mars: Initial modeling of martian ice was based on qualitative constraints from imagery. More recently, the primary data used in flow models of martian ice are surface topography from laser altimetry and bed topography and internal structure from radar. Models are constructed to match these data in order to constrain ice-mass formation [e.g., 19, 20], ice rheology [e.g., 21], ice temperature [e.g., 22], ice volume [e.g., 23, 24], flow history [e.g., 6, 25, 26], and climate response [e.g., 27]. Key questions include: How did the combination of accumulation, ablation, and flow over time shape ice masses on Mars? What is the rheology of ice masses in the mid-latitudes and in the polar regions? When was the last episode where ice flowed at a rate significant enough to affect its shape, and what was the climate forcing at that time? In general, how can we robustly interpret past climate on Mars from glaciological and glacial geomorphological features?

These key questions have analogues in terrestrial glaciology, and the challenge is that all problems may be ill posed. This means that the available data cannot be used to uniquely determine the parameter values that we wish to reconstruct. For example, the climate history and the ice-flow history may leave similar imprints on ice-mass shape and internal structure. When both climate and ice-flow histories are unknown, this nonuniqueness can be broken only by making assumptions about one or the other. We consider previously published work and evaluate how to best apply ice-flow models in order to constrain histories that would have produced the present state observed in available data. This review informs our new application of a glacier flow model to lobate debris aprons that we will present.

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