MODELING CO2 GLACIERS ON MARS WITH THE 3D ICE SHEET AND SEA-LEVEL SYSTEM MODEL (ISSM). K. B. Fard[1] (kbfard@yorku.ca) , I. Isola[1], E. Larour[2], N. J. Schlegel[2], and I. B. Smith[1], [1]Lassonde School of Engineering, York University, 4700 Keele St, Toronto, ON, Canada, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

Introduction: Recent evidence demonstrates massive carbon dioxide (CO_2) ice deposits at the south pole of Mars. Such deposits are in layered form. The figure below shows the thickness of the deposits could reach 1000 m, and that the deposits can contain water ice bounding layers (indicated as BL) [1]. The volume of CO_2 deposits is estimated to be about 16,500 km^3 [2]. This is more than the mass of the current Martian atmosphere. This large amount of CO_2 in the south pole of Mars could be an indication of atmospheric collapse through various periods [3]

These deposits behave as glaciers. Geomorphic and modeling evidence demonstrates that the CO_2 deposits flow as glaciers in order to reach their volumetric distribution [7]. This is especially important as deposition models cannot explain thickness, or the volumetric distribution of CO_2 ice in the south pole of Mars [7].

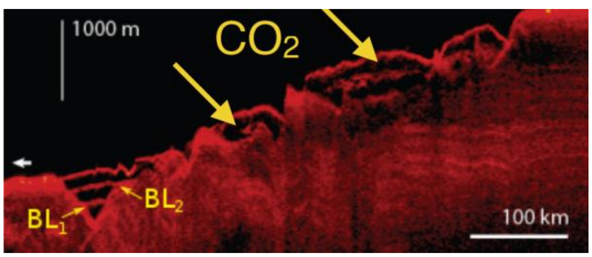

Figure 1: Radar observations showing the presence of massive CO2 ice deposits on the south polar layered deposits. The deposits can reach 1000 m thick and frequently contain water ice bounding layers[1].

Motivation: Studying the workings of the solar system (including its mechanics) requires a detailed understanding of various bodies that exist in the solar system, their histories, and their evolution including their climatic changes. Studying various ice deposits that exist on these bodies can uncover much about the past and help with predicting the future of the body hosting the ice deposits as well as the solar system, e.g., studies of the size of the ice caps on Mars provided evidence of the amount of CO_2 that existed in the Martian atmosphere.

Physical and observational limitations motivate computational and modeling approaches to study exotic ice deposits (e.g., CO_2 ice deposits) on non-terrestrial settings. To this end, development and use of three-dimensional models of ice deposits on the south pole of Mars over different timeframes will provide a view into the history of the ice deposits and the history of the climatic cycles and changes that Mars has experienced in these timeframes.

There is sufficient evidence that ice deposits on solar system bodies (other than Earth) have complex chemical compositions: Recent discoveries using data collected from Mars demonstrate ice deposits on Mars include alternating layers of CO_2, H_2O, and H_2O containing dust. There is evidence of complex ice deposits on other planets (e.g., deposits of N_2 on Pluto). Since different types of ice possess different physical properties and are governed by different rheological laws, the knowledge gained from terrestrial ice deposits, while useful, will be insufficient for estimating dynamics of ice deposits on Mars and other planets. Therefore, we need to update models that work on Earth to work for other planets and other types of ice.

Model Description: The Jet Propulsion Laboratory (JPL) at NASA has developed an open-source software application called *the Ice Sheet and Sea Level System Model* (ISSM) [4]. ISSM estimates the flow of ice sheets, leveraging four different ice-sheet flow models. It builds two- and three-dimensional models of ice deposits. To determine the differential stresses and temperatures across an ice deposit in these models, ISSM sets up thermodynamical differential equations. Solving these differential equations will produce the equations of motions that describe the flow of the modelled ice deposits. ISSM, in order to solve these thermodynamical differential equations, uses Finite Element Method (FEM). Therefore, these models result in more accurate ice flow models in comparison to models that do not leverage FEM (albeit, through a much slower process) [4], [5].

ISSM is capable of leveraging multiple processors (i.e., CPUs) to solve its computationally intensive models (e.g., on a cluster of servers). ISSM main solver engine is developed in C/C++, exposing interfaces through MATLAB, and Python. The ISSM code base contains >2000 files and >290K lines of code.

New Development: Previously, ISSM was designed to simulate setups with ice deposits of only one type of material. As the laboratory work to constrain the rheological properties of CO_2 ice in Martian conditions has been done [6]; this team has already extended the ISSM code to use CO_2 rheological laws on Mars, and developed models for CO_2 deposits, assuming deposits only consists of CO_2 ice on Mars. The developed models are already providing insight into CO_2 deposits flow on the Martian south polar environment [7].

Now, we are upgrading the ISSM modelling capability and its FEM solver engine in order to model ice deposits that consist of various layers with alternating ice compound types (Figure 2, e.g., CO_2, H_2O, H_2O with dust) on planets with different physical properties than those on Earth (i.e., starting with the CO_2 deposits in the south pole of Mars).

Once the multi-layered, multi-ice capability has been added to ISSM, the updated ISSM will be used primarily to develop 3D models of Mars south polar ice deposits. Figure 2 is an example of how the model in 3D will look like. In addition to making substantial changes to the ISSM code base to add the capability of analyzing different chemical components, in alternating layers, the changed code will be integrated into the main code base for the community to access.

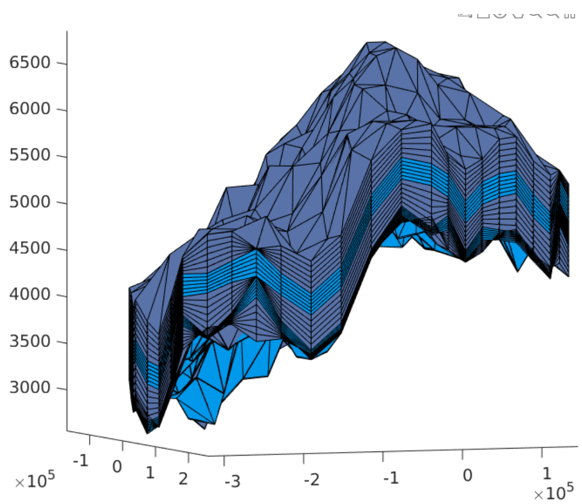

Figure 2: ISSM will be upgraded to provide multi-layered, multi-ice 3D models of ice deposits. As an example, the CO2 ice cap in the south pole of Mars can be modelled with different layers of water ice and CO_2 ice.

The following guiding principles will ensure extensibility of the modelling of ISSM: (1) generalizing the ISSM modelling capability for other planets and ices (i.e., beyond CO_2 based ice caps on Mars); this is to ensure the rheological laws for different ice compounds on various non-terrestrial settings are supported (2) the capability to leverage multiple cores (i.e., CPUs) of computer clusters to solve models, and (3) expanding all tools and techniques offered by ISSM accordingly to leverage various functionality that exists in ISSM for multiple types of ice layers.

Discussion: Detailed 3D simulation of glaciers on other planets (e.g., Mars, Unbiel, Triton, Pluto), while still being a new approach, offers more scientific perspective than 2D models; and with powerful computing powers that are readily available at lower costs now, such simulations will be used more.

In case of Mars the simulations will offer:

1) a scientific way to understand Mars CO_2 glacial flow rates, even when stratified.

2) opportunities to examine the current hypotheses about the timing of the atmospheric collapse events (i.e., collapse into CO_2 ice deposits), through modeling Mars CO_2 glacial flow rates. Understanding Mars recent climate, a high priority to help understand the atmospheric current state on Mars, especially with the rich record of accumulation at the poles, will help us extend our knowledge further back in time, teaching us more about Martian history and refining climate model inputs.

3) supporting efforts to investigate exotic forms of ice, a field that is increasingly critical to understanding the surface evolution of solar system bodies.

Subsequently, as a modeling tool capable of simulating the flow of glaciers that consist of different layers of ice, ISSM will provide 3D models to enable further scientific insight into the climatic variations and the evolution of other ice-rich, non-terrestrial bodies such as Europa and Pluto. It can also be used to more accurately model glacial flows on Earth where glaciers consist of layers of dust and other compounds, in support of better understanding the terrestrial climatic changes.

Acknowledgments: We gratefully acknowledge the generous funding from Canada Research Chair to IBS that is making this work possible.

References:

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