The Effects of DEM Resolution on Planetary Thermo-rheological Lava Flow Modeling. Ian T.W. Flynn[1], David A. Crown[2], Michael S. Ramsey[1]. [1]Department of Geology and Environmental Science, University of Pittsburgh, Pittsburgh, PA 15260, itf2@pitt.edu. [2]Planetary Science Institute, Tucson, AZ 85719.

Introduction: Modeling Martian lava flow emplacement yields important results about eruption conditions and lava rheology [e.g. 1-3]. Terrestrial validation significantly improves the accuracy and utility of these models. One potential reason for discrepancies between flow observations and model results [e.g., 3, 4] is the incorporation of topographic constraints, including use of digital elevation models (DEMs) with insufficient resolution. Many previous studies modeling Martian lava flow emplacement assumed a constant slope [e.g. 5-7] due to lack of adequate topographic datasets, which can produce erroneous results.

Regardless of the level of complexity included in a lava flow model, topography is an essential parameter [8]. The global DEM from Mars Orbiter Laser Altimeter (MOLA) data has ~463m resolution with a vertical uncertainty of ±3m. The blended MOLA and High Resolution Stereo Camera (HRSC) DEM improves this to 200m (with the same vertical accuracy) in some locations. Higher resolution DEMs created from Context Camera (CTX) (~24m/pixel), HRSC (~50m/pixel), and High Resolution Imaging Science Experiment (HiRISE) (~5m/pixel) stereo pair data, where available, greatly improve topographic constraints for flow modeling.

Here, we investigate the effects of DEM resolution on deriving slopes for lava flow emplacement using the PyFLOWGO thermo-rheological model [9], revisiting prior modeling results [10] and adding DEM resolutions common to Earth and historically used on Mars.

Study Sites: The 2012-2013 eruption of the Tolbachik volcanic complex in Kamchatka Russia [10-12] serves as the terrestrial analog site. Flow dimensions (length 11.3 km), effusion rate (278 m^3/s), composition (basaltic trachyandesite), and rheologic variables are known for this eruption and used to constrain the model. This eruption shares compositional and morphological similarities to the Late Amazonian lava flows observed in the southwest Arsia Mons flow field [10, 13, 14].

Model: PyFLOWGO, a Python-based model, tracks cooling and the corresponding rheological changes for open-channel, cooling-limited flows [9]. Originally developed for terrestrial lava flows, it is easily adaptable to Martian conditions by changing gravity, ambient temperature, and atmospheric conditions [4, 6, 15].

Topographic Datasets and DEM Resolution: The Earth-orbiting Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument acquires stereo image data yielding 30m resolution DEMs. We use 1) the original 30m DEM, 2) the 30m DEM degraded to 200m to approximate MOLA/HRSC blended DEM resolution, and 3) the 30m DEM degraded further to a constant slope of 5° for this study (Figure 1). Slope values were calculated from the 30m DEM in ArcGIS using the “Slope” tool. The 30m DEM slope values were then averaged together in groups to produce the 200m DEM slope profile.

From these elevation data, three hybrid slope profiles, created to simulate partial higher resolution coverage, serve as analogs for CTX topographic data only available for small part(s) of a flow. Three 2 km-long slope profiles from the 30m DEM (corresponding to proximal, medial and distal parts of the flow) are combined with the 200m slope profile (Figure 2).

Results: PyFLOWGO modeling of the Tolbachik flow using the 30m DEM replicates the 11.3 km flow length accurately and serves as the baseline for this study [10]. Changing the DEM resolution and incorporating the hybrid DEMs significantly altered successive runs of the model (Figure 3 and 4).

The 200m DEM resulted in a 23% shorter flow, whereas the constant 5° slope produced a 15% longer flow relative to the baseline. Average flow velocity decreased 22% and 17% using the 200m DEM and constant slope value, respectively. The average viscosity increased 25% and decreased by 47% using the 200m DEM and constant slope value, respectively.

The proximal hybrid DEM model result matched the baseline result to within ~7% (Figure 4). However, the medial and distal runs were ~30% shorter, which is ~10% worse than using the 200m DEM alone. Incorporating a higher resolution DEM proximal to the vent seems to better constrain the initial eruptive conditions, such as velocity and mass flux rate, which then propagate down-flow in the modeling. Errors made in the proximal/starting flow conditions are not corrected (or worse, amplified) down flow upon interaction with a higher-resolution DEM portion of the flow.

Conclusion: Our findings indicate that slope constraints/DEM resolution is an important parameter for lava flow modeling. Use of a lower resolution DEM in thermo-rheological modeling underestimates the flow length and eruptive conditions (e.g., flow velocity, core temperature, emplacement time) necessary to produce that flow. Whereas, a constant slope greatly overestimates the length and corresponding eruptive conditions. If a higher resolution Mars DEM (e.g., HRSC, CTX, HiRISE) is available, it is most useful at the flow's starting position/vent region. Future stereo imaging priority should be given to these flow regions in order to improve modeling efforts. With the ever increasing coverage of high resolution DEMs on Mars, they should be incorporated into new modeling efforts as well as to recalibrate previous studies.

References: [1] Baloga S.M. et al. (2003) JGR, 108. [2] Dundas C.M & Keszthelyi L.P. (2014) JVGR, 282, 92-102. [3] Glaze L.S. et al. (2009) JGR: Planets, 114. [4] Rowland S.K. et al (2002) LPSC XXXIII, Abstract #1441. [5] Baloga S.M. & Glaze L.S. (2008) JGR: Planets, 113. [6] Rowland S.K. et al. (2004) JGR: Planets, 109, 1-16. [7] Garry W.B. et al. (2007) JGR: Planets, 112. [8] Sparks R.S.J. & Aspinall W.P. (2004) Geophys Monogr, 150, 359-373. [9] Chevrel M.O. et al. (2018) Computers & Geosciences, 111, 167-180. [10] Ramsey M.S. et al. (2019) Ann. Geophys, 62, 1-44. [11] Belousov A. et al. (2015) JVGR, 307, 22-37. [12] Plechov P. et al. (2015) JVGR, 307, 182-199. [13] Crown D. A & Ramsey M.S. (2017) JVGR, 342, 13-28. [14] Simurda C.M. et al. (2019) JGR: Planets, 124, 1945-1959. [15] Flynn I.T.W. & Ramsey M.S. (2020) LPSC LI, Abstract #1676.

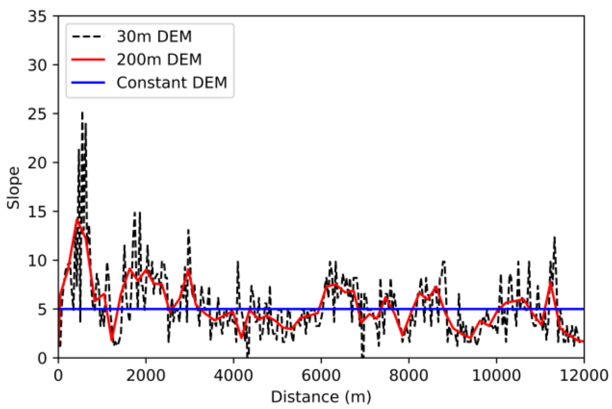

Figure 1: The three slope profiles used in the study showing the loss of topographic variations.

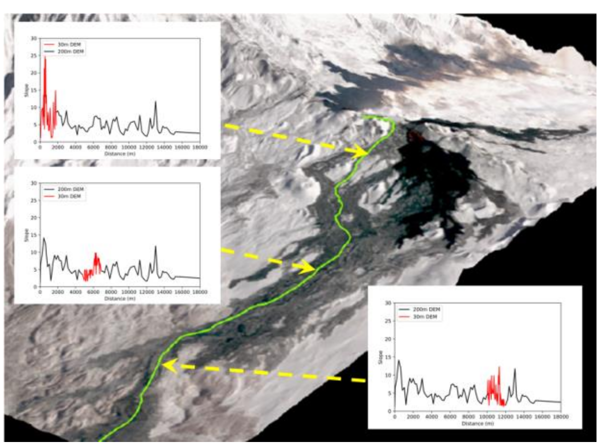

Figure 2: Visual representation of the hybrid slope profiles. The base is an ASTER VNIR image of the 2012-2013 Tolbachik flow field acquired on 28 Feb 2013 draped over the ASTER DEM. The green line marks the central flow channel used for the modeling. The red highlighted sections in each of the inset graphs show where the 30m slope profile is inserted into the 200m slope profile along the original transect.

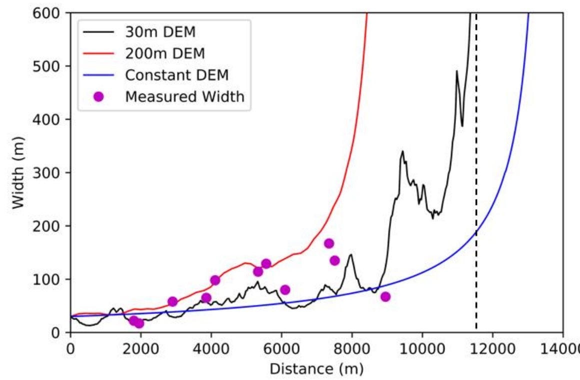

Figure 3: PyFLOWGO modeling results for the Tolbachik lava flow using the three DEM resolutions. The 200m DEM (red) results in a 23% shorter flow than the actual flow length, whereas the constant slope (blue) result is 15% longer. The vertical dashed line represents the actual measured flow length of 11.3 km on 1 Dec 2012.

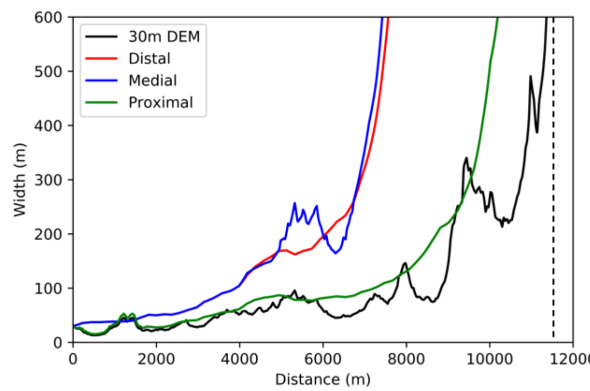

Figure 4: Comparison of PyFLOWGO results using the three hybrid DEMs in relation to the original model. The positioning of the 30m DEM segment proximal to the vent has a substantial positive impact on the modeling. The proximal model run had ~7% difference to the baseline result. Both the medial and distal hybrid DEMs produced much shorter (~30%) flows. The vertical dashed line represents the actual measured flow length of 11.3 km on 1 Dec 2012.