THE HYDRAULICS ANALYSIS BASED ON A MULTI-RESOLUTION STEREO DTMS AND LISFLOOD-FP MODEL OVER MARTIAN FLUVIAL GEOMORPHOLOGY Jungrack Kim[1] and Guy Schumann[2], Jeffrey Neal[3], Shih-Yuan Lin[4], [1] Department of Geoinformatics, University of Seoul, Seoul, Korea, kjrr001@gmail.com [2] Jet Propulsion Laboratory, NASA/Caltech, Pasadena, CA, USA [3] School of Geographical Sciences, University of Bristol [4] Department of Land Economics, National Chengchi University, Taipei, Taiwan

Introduction: After liquid water was identified as the agent of ancient martian fluvial activities, the valley and channels on the martian surface were investigated by a number of remote sensing and in-suit measurements. Among all available data sets, the stereo DTM and ortho from various successful orbital sensor, such as High Resolution Stereo Camera (HRSC), Context Camera (CTX), and High Resolution Imaging Science Experiment (HiRISE), are being most widely used to trace the origin and consequences of martian hydrological channels. However, geomorphological analysis, with stereo DTM and ortho images over fluvial areas, has some limitations, and so a quantitative modeling method utilizing various spatial resolution DTMs is required. Thus in this study we tested the application of hydraulics analysis with multi-resolution martian DTMs, constructed in line with Kim and Muller's (2009) [1] approach. To demonstrate the potential hydraulic model for investigating Martian fluvial activities, we chose Athabasaca Valles and its tributaries as the test site, which is one of most controversial area about the cause of formation among all Martian fluvial channels and valles.

Hydrodynamic model: Flood inundation models that simulate river channel and floodplain hydrodynamics are typically discretized in 1D or 2D dimensions, or a combination of the two. 1D hydrodynamic models (e.g. HEC-RAS as used by Burr et al. (2003) [2] to derive water flow estimates for the Athabasca Valles area on Mars) simulate in-channel dynamic wave behavior by solving the 1D Saint-Venant equation derived from the Navier-Stokes shallow water equations that describe fluid motion. Where there are extensive floodplain flows or detailed 2D bathymetry for the river channel, it may be more accurate to simulate flows in two dimensions, especially if the direction of flow is unclear a priori. Thus An advanced LISFLOOD-FP model (Bates et al., 2010) [3], which simulates in-channel dynamic wave behavior by solving 2D shallow water equations without advection, was introduced to conduct a high accuracy simulation together with 150-1.2m DTMs over test sites including. For application to a martian surface, technically the acceleration of gravity in LISFLOOD-FP was reduced to the martian value of 3.71 m s^{-2} and the Manning's *n* value (friction), the only free parameter in the model, was adjusted for Martian gravity by scaling it according to Equation (1) (after Burr, 2003 [2]).

$$n_{Mars} = n_{Earth} * \mathrm{sqrt}\,(g_{Earth}/g_{Mars}) \quad (1),$$

where *n* denotes the friction according to Manning and *g* represents planetary gravity. We used a Martian Manning *n* value of 0.097 as validated by Burr (2003) [2] a 1 million m^3s^{-1}inflow rate that was used.

Inflow modelling: Water flow in the main channel of the Athabasca Valles area on Mars and its main distributary channel has been previously simulated with 1D and 2D hydrodynamic models. Using a 1D HEC-RAS model conditioned by river cross-sections from a digital elevation model of Mars Orbiter Laser Altimeter (MOLA) data, Burr (2003) [3] simulated water flow upstream of any distributary channels and concluded that estimates of maximum instantaneous discharge of around 1-2 million m^3s^{-1} would have been required to reach the palaeoflood height indicator. In the present study, we use a triangular function to define time-varying inflow rates for the main channel with a peak at 1 million m^3s^{-1}as a general consensus reached in previous studies of the Athabasca Valles floods. In order to derive detailed time-varying inflow characteristics of the main tributaries studied, the hydrograph of the main Athabasca Valles channel reaches peak flow following a triangular function which starts with a zero flow rate. The time-varying inflows to the tributaries examined in this paper were derived from the hydrodynamic simulations of the main Athabasca Valles channel, so no inflow assumptions or speculations were made for the tributaries.

Simulation result and implication: LISFLOOD-FP hydraulic simulation with HRSC, CTX HiRISE DTMs were executed respectively based on inflow model and constructed stereo DTMs, i.e. 50m grid resolution HRSC DTM, 12m grid resolution CTX DTM and 1.5m HRSC DTM processed by Kim and Muller's (2009) [1]'s hierarchical approach. The approach employing multi-resolution stereo DTMs and LISFLOOD-FP showed highly important clues about the fluvial evaluation of target area. For instance, the inundation times of outer hydrological channel areas in Figure 1(around character "a") are clearly distinguished (< 1000 hours in total inundation time and > 1500 hours in initial inundation time) from the times in the main channel area. The flooding of these areas might be very temporal, hence the eroded features such as tear drop islands were not observed. The intensive fluvial activities in tributaries1 and 2 are shown in Figure 2, 3 and 4.

The simulation using CTX DTM in Figure 2 also shows an interesting result regarding the origin of the tributary channel. In spite of clear channel morphology, the left branch (around red arrow of Figure 2(a)) was not inundated over the entire simulation period, indicating it might have been created prior to the flood event simulated and the sedimentary materials in that period made higher level of the channel bed. This also meant that the simulated water flows were not able to cross the left branch. Such observations agreed well with the multiple episodic floods scenario outlined by Manga (2004) [4]. The relatively late inundation time of terrace structures of tributary 2 (Figure. 3) might be involved with the model inflow discharge which was slowly increased to the steady state. The simulation result with HiRISE DTMs in Figure 4 which is photogrammetrically re-controlled using the surface-matching shows highly different flow patterns compared with the case in Figure 3 derived from the original HIRISE DTM. Water level was far lower than the simulation result with the original HiRISE DTM (Figure. 3) and confined to a narrower channel. It resulted from the missing flow in the upper right part of the target area, probably due to the few meter vertical adjustments in the DTM.

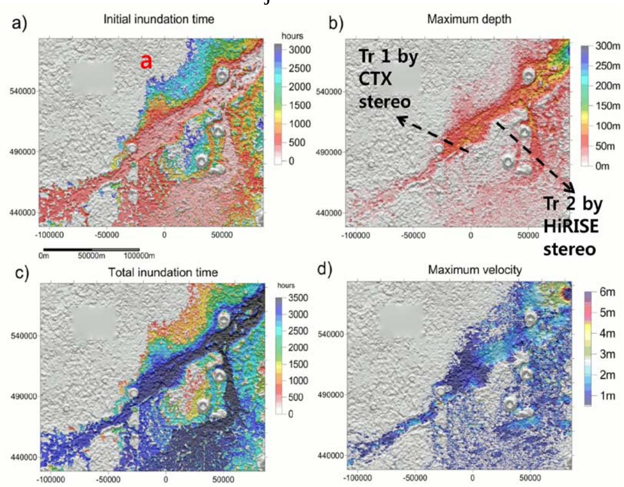

Figure 1. The output quantities from simulation usingthe HRSC DTM (a) initial inundation time (note the area “a” corresponding to the “a” in Figure 11), (b) maximum depth, (c) total inundation time, i.e. the total time a pixel is inundated from the start of the simulation, (d)maximum velocity in each grid cell.

It implys that temporarily the input discharge might have been higher than 1 million m^3s^{-1}, which was originally proposed as the minimum value by previous research studies.

Conclusion and future works: The approach employing multi-resolution stereo DTMs and LISFLOOD-FP was superior compared with the other research cases using a single DTM source for hydraulics analysis. HRSC DTMs was used to trace rough routes of water flows for extensive target areas. After then, refinements through hydraulics simulations with CTX DTMs and HiRISE DTMs were conducted by employing the output of HRSC simulations as the initial conditions.

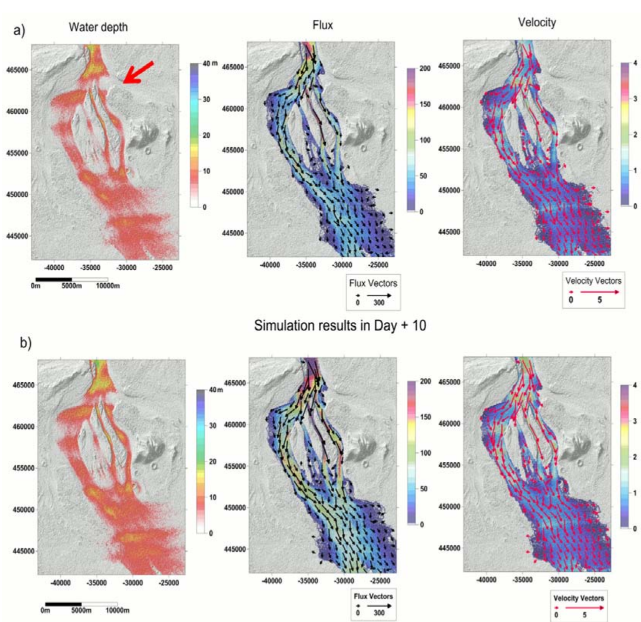

Figure 2.The temporal translation of simulated water flow over CTX at (a) day 10, (b) day 21.

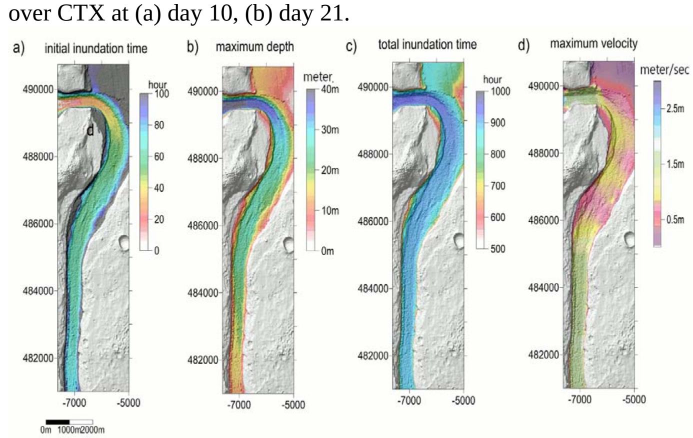

Figure 3. The output quantities from simulation using HiRISE DTM (a) initial inundation time, (b) maximum depth, (c) total inundation time, (d) maximum velocity in each grid cell.

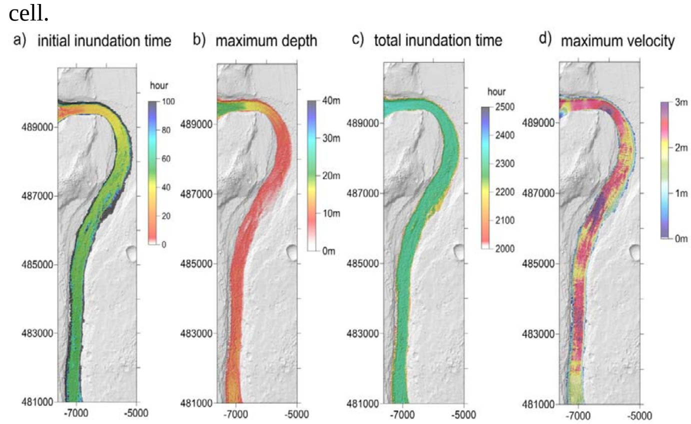

Figure 4.The output from simulation using surface-matched HiRISE DTM (a) initial inundation time, (b) maximum depth, (c) total inundation time, (d) maximum velocity in each grid cell.

Thus even a few high and very high resolution stereo DTMs coverage enabled the performance of a high precision hydraulics analysis for reconstructing a whole fluvial event. In this manner, useful information to identify the characteristics of martian fluvial activities, such as water depth along the time line, flow direction, and travel time, were successfully retrieved with each target tributary. Together with all above useful outputs of hydraulics analysis, the local roughness and photogrammetric control of the stereo DTMs appeared to be crucial elements for accurate fluvial simulation. The potential of this study should be further explored for its application to the other exterritorial bodies where fluvial activity once existed, as well as the major martian channel and valleys.

References:

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