CAN WE ACCURATELY ESTIMATE AEOLIAN DUNEFIELD SEDIMENT BUDGETS ON MARS? J. B. Sankey[1], A. Kasprak[2], M. Chojnacki[3], T. N. Titus[4], Joshua Caster[1], Geoff Debenedetto[5], [1] Southwest Biological Science Center, Grand Canyon Monitoring and Research Center, U.S. Geological Survey, Flagstaff, Arizona, USA [2] Fort Lewis College, Geosciences Department and Four Corners Water Center, Durango, Colorado, USA,[3]Planetary Science Institute, Lakewood, Colorado, USA,[4]Astrogeology Science Center, U.S. Geological Survey, Flagstaff, Arizona, USA, [5]Arizona Water Science Center, U.S. Geological Survey, Flagstaff, Arizona, USA.

Introduction: Sediment budgets are fundamentally important for aeolian planetary science. However, only one primary method, based on remote sensing, is currently available for determining extraterrestrial sediment budgets. For determining sediment budgets on Earth, both in-situ and remote sensing methods are available. Despite the widespread use of the two methods, there has been surprisingly little research on how well the sediment budgets produced by these two approaches agree with one another. This highlights the lack of quantitative understanding of errors for sediment budgets measured with remote sensing in planetary research. Therefore, there is a general need to expand our knowledge of how sediment budgets and their associated uncertainties are determined.

Sediment Budget: A sediment budget is defined as the difference between the volume of sediment entering an area of interest versus that volume of sediment leaving the same area (Equation 1; where ΔS is the change in sediment storage).

ΔS=*Sediment Inputs-Sediment Outputs* [1]

On Earth, sediment budgets are fundamental for understanding geologic impacts to natural resources and infrastructure. Sediment budgets are vital for determining the degree of, and controls on, erosion or deposition processes. Sediment budgets can be influenced in whole or in part by naturally occurring physical processes, such as volcanic eruptions, debris flows, and fluvial, glacial, or aeolian sediment transport. These controls on sediment budgets are applicable in geomorphologically-active regions of planetary bodies, such as Mars, Earth, and Titan.

Two Approaches: Sediment budget are measured: (1) by in situ instrumentation and (2) the use of remote sensing assets.

In-situ measurements of sediment flux ($\Delta S_{In\text{-}Situ}$). On-the-ground sampling equipment, including meteorological and sediment transport sensors, are used to directly measure the amount of sediment entering (influx, I) or leaving (efflux, E) an area of interest. In terrestrial aeolian dunefields, these measurements are typically collected using a vertical array of sediment catchers placed at the upwind and downwind site boundaries. Aeolian sediment horizontal mass flux at a given above-ground height can be determined from a sediment catcher in units of mass per area per time and time-integrated to determine total mass flux. Once in-situ measurements are complete, the difference between the sediment mass flux at I and E over that time period, is computed, where the sediment porosity and density are applied as scaling factors to determine the sediment budget for a given period (ΔS) in units of volume.

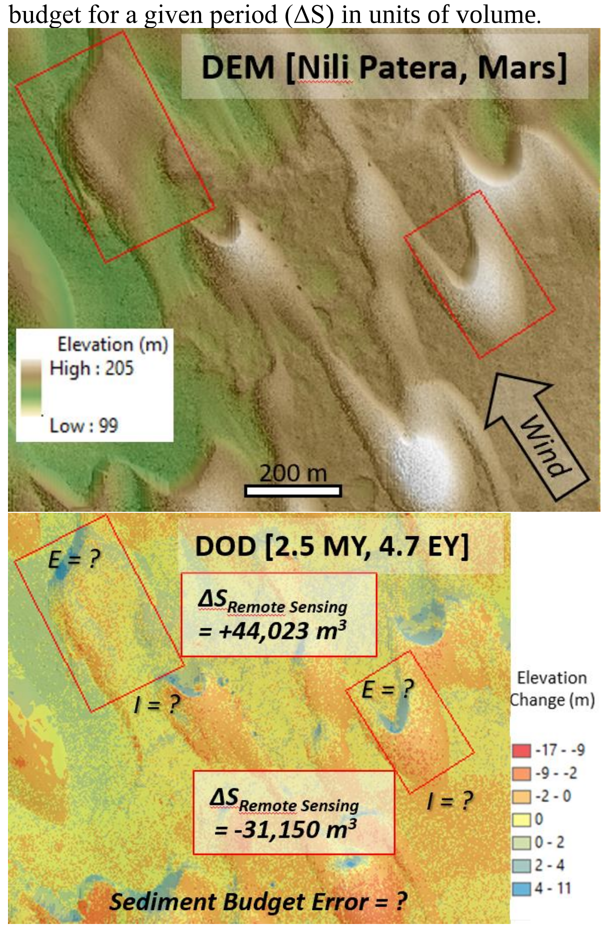

Figure 1: Remote sensing sediment budgets for dunes in Nili Patera, Mars using HiRISE Digital Elevation Models (DEMs) ESP_017762_1890/ESP_018039_1890; ESP_039810_1890/ ESP_ 038887_1890 [6, 7]. DOD is a Digital Elevation Model of Difference, which is the product of differencing two DEMs for topographic change detection. See data availability statement describing the source of HiRISE DEMs. I is sediment influx and E is sediment efflux. $\Delta S_{RemoteSensing}$ is the change in sediment storage (sediment budget) determined from remote sensing.

Remote sensing change detection of repeat topographic datasets ($\Delta S_{RemoteSensing}$). Repeat topographic data collected at multiple timesteps via remote sensing instruments are differenced, producing maps of elevation changes occurring within an area of interest over a given period, from which the amount of sediment entering and leaving the area (termed sediment flux) can be inferred in units of volume.

Mars: Currently, only the remote sensing method is available to investigate sediment budgets on Mars [1-5]; this includes, for example, change detection of data returned from the High Resolution Imaging Science Experiment (HiRISE, [6,7]). Figure 1 illustrates the remote sensing method for Martian dunes using change detection of HiRISE digital elevation models (DEMs)[7, 8] separated by 2.5 Mars years (4.7 Earth years) to produce digital elevation models of difference (DODs) to quantify the $\Delta S_{RemoteSensing}$ sediment budget.

Analog Case Study: An analog case study of an aeolian dunefield in the Grand Canyon, Earth (Fig. 2) was conducted to quantify the shortcomings of remote sensing sediment budgets on Mars. We estimate a 53% error in the sediment budget determined with remote sensing relative to in-situ methods for a simple endmember scenario of a dunefield within an unimodal wind directional regime and no external sediment supply. However, when we incorporated key sources of uncertainty in remote sensing change detection following methods commonly used by geomorphologists on Earth, the estimates of sediment budget errors relative to the in-situ method spanned a much larger range, from 3% to 138%; errors generally decreased with the application of those methods, except for the most conservative error accounting that generated large errors owing to omission of real topographic changes. Our case study also suggests that sediment budget errors could be much larger under more complex wind direction, sediment supply, and physiographic settings, and that variability in those landscape characteristics might be used to better estimate errors for dunefield sediment budgets.

Conclusion: By comparing sediment budgets derived from in-situ measurements of sediment fluxes and from remote sensing measurements at many more analog sites on Earth, the planetary geomorphology research community could gain an understanding of the errors of the remote sensing method, which is used by investigators on other planetary bodies such as Mars. This could improve the ability to quantify sediment budgets on Mars – and, in the future, other planetary environments where high-resolution topographic data are available – as well as directly improve our ability to interpret extraterrestrial landscape evolution related to climate, weather, and geologic history.

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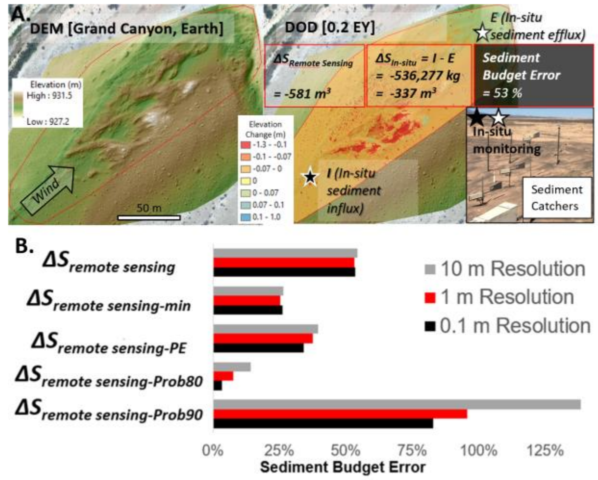

C. I-E in-situ Sediment Flux			
$\Delta S_{in\text{-}situ}$	-337.25		
Remote sensing-based change	0.1 m	1 m	10 m
$\Delta S_{remote\ sensing}$	-583.95	-581.48	-589.14
$\Delta S_{remote\ sensing\text{-}min}$	-438.85	-435.17	-440.44
$\Delta S_{remote\ sensing\text{-}PE}$	-475.42	-493.02	-503.57
$\Delta S_{remote\ sensing\text{-}Prob80}$	-348.9	-363.98	-389.35
$\Delta S_{remote\ sensing\text{-}Prob90}$	-139.91	-119.29	-61.45

Figure 2: Results of the analog case study at the Grand Canyon Lees dunefield. (A.) Illustration of how: $\Delta S_{In\text{-}situ}$ sediment budget was determined from sediment influx & efflux measured with field instrumentation at the upwind & downwind dunefield boundaries; $\Delta S_{RemoteSensing}$ was determined from remote sensing change detection; sediment budget error is quantified as the percent difference of $\Delta S_{RemoteSensing}$ and $\Delta S_{In\text{-}situ}$ budgets. (B.) Sediment budget errors. The error reported for $\Delta S_{RemoteSensing}$ was the difference between remote sensing and in-situ sediment budgets. The errors reported for $\Delta S_{RemoteSensing}$-min, $\Delta S_{RemoteSensing}$-PE, $\Delta S_{RemoteSensing}$-Prob80, and $\Delta S_{RemoteSensing}$-Prob90 are based on remote sensing sediment budgets calculated using significance thresholding methods which account for uncertainty by excluding potential erroneous changes from the change detection results. (C.) Sediment budgets determined by volume (m^3) from the in-situ method and remote sensing methods.

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