PROSPECTS FOR MEASURING VERTICAL CHANGE ON THE MARTIAN RESIDUAL SOUTH POLAR CAP USING HIRISE DIGITAL ELEVATION MODELS. P. B. Buhler[1], J. Dickson[1], B.L. Ehlmann[1,2], A.P. Ingersoll[1], S. Byrne[3], Y. Tao[4], and J-P. Muller[4]. [1]Div. Geological & Planetary Sciences, California Institute of Technology (bpeter@caltech.edu). [2]NASA Jet Propulsion Laboratory. [3]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ. [4]Imaging Group, Mullard Space Science Laboratory, University College London.

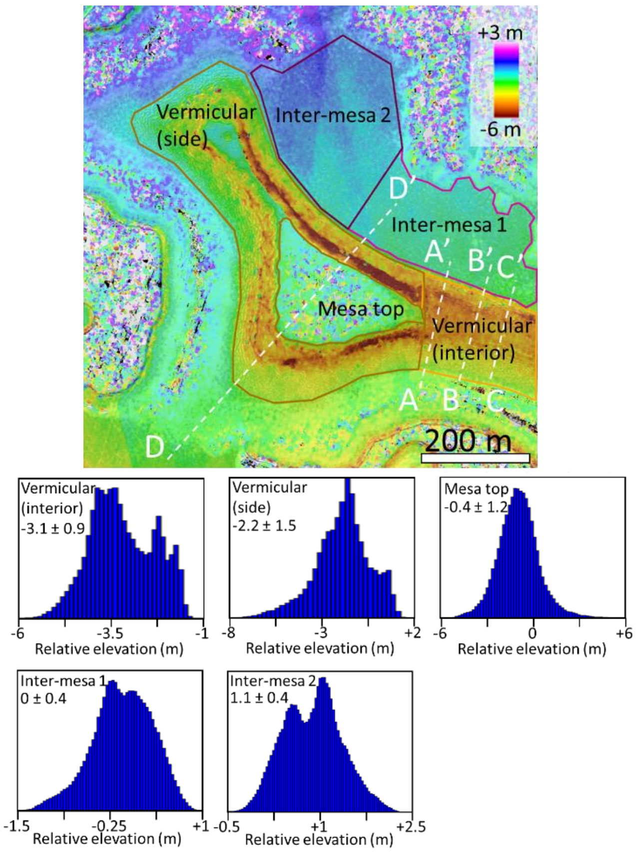

Fig 1. Top: Difference between MY 30 L_S 272 and MY 33 L_S 330 DEMs over the region of interest with terrains mapped and transects shown for Fig. 4. Bottom: Normalized histograms of pixel values within each terrain. Elevations are shown relative to mean value in Inter-mesa 1. Estimated errors are shown by approximating the distributions as Gaussian; some of the spread may also be due to real variation in change across a particular terrain.

Introduction: The martian Residual South Polar Cap (RSPC) is a 1-10 m thick deposit of permanent CO_2 ice perched on top of the much larger H_2O ice cap. The RSPC is the only permanent CO_2 deposit definitively known to be exchanging with the primarily (96%) CO_2 martian atmosphere [e.g. 1,2]. Thus, determining the seasonal and net-annual mass exchange between the RSPC and the atmosphere is important for understanding the martian climate. RSPC morphology annually evolves horizontally at meter scales due to sublimation and deposition. However, to determine volumetric evolution (e.g. as a step in determining mass balance), vertical change must also be measured. Here we explore the prospect of using Digital Elevation Models (DEMs) derived from High Resolution Stereo Imaging Experiment (HiRISE) stereo pairs to detect vertical changes (Fig. 1).

Methods: We obtain five stereo pairs over one region of the RSPC (Tbl. 1) and produce 25 cm/px DEMs and orthorectified images from them using Ames Stereo Pipeline [3] and CASP-GO [4]. The orthorectified images are cropped into ~1 km^2 regions and co-registered by hand using tie-points to static fiducial points, such as annually reappearing polygonal fractures in the CO_2 and H_2O ice (see methods in [6]) in ArcMap 10. The DEMs are then imported and transformed by this grid of tie-points. The co-registered DEM rasters are then subtracted from each other to find differences between scenes. Sub-regions of morphologic interest identified in the orthorectified images are then masked and quantitatively analyzed for change. We also perform this analysis on two mid-latitude DEMs (Fig. 2) as a control.

This abstract looks at the change between the first and last DEMs (from MY 30 L_S 272 and MY 33 L_S 330) because the temporal baseline is longest, which should maximize change and provide the most favorable conditions for detecting change. When comparing these two DEMs, we subtract an offset of ~100 m across the entire scene based on the offset in the mean value within the Inter-mesa 1 region (Fig. 1) between the two DEMs. We look for vertical changes relative to the mean value of the Inter-mesa 1 region that are correlated with specific terrains. We explore four types of terrain: i. the region between permanent CO_2 mesas where H_2O ice basement is exposed in the summer, ii. the vermicular texture on the sides of mesas, iii. the generally smooth mesa tops, and iv. regions where the smooth top has been eroded to expose a vermicular texture (Fig. 1,3).

Image Pairs	MY	L_S
ESP_022210_0930/ESP_022064_0930	30	272/279
ESP_047237_0930/ESP_047304_0930	33	209/213
ESP_047488_0930/ESP_047503_0930	33	221/222
ESP_048477_0930/ESP_048702_0930	33	270/281
ESP_049768_0930/ESP_049782_0930	33	330/330

Table 1. HiRISE image pairs for polar DEMs. MY = Mars Year, L_S = solar longitude, with 0 at northern winter solstice.

Results: There is a vertical difference between the mean values of the two mid-latitude control DEMs of ~11 m and relative vertical differences up to ~6 m, even though the topography is not expected to change (Fig. 2). Although the offset between the DEMs has a generally linear gradient of ~8 m/km from the southeast to the northwest corner, offsets are spatially complex and not amenable to a simple polynomial removal.

The mean of the difference between the DEMs in Inter-mesa region 1 and Inter-mesa region 2 are offset by ~1 m (Fig. 1). Because these two regions are the same type of terrain, we expect them to behave similarly, suggesting that the ~4 m/km gradient from the southeast of Inter-mesa 1 to the northwest of Inter-mesa 2 may be representative of a gradient in the difference between the two DEMs with a similar magnitude as the gradient in the control DEMs. Additionally, relatively featureless regions (e.g. the Mesa Top, Figs. 1,3,4) in the RSPC exhibit speckling in the DEMs.

Some vertical differences between the DEMs from MY 30 L_S 272 and MY 33 L_S 330 show correlation with terrain type (Fig. 1,4). The largest vertical changes relative to the Inter-mesa 1 region in both vermicular terrains and are typically ~ -2 to -3 m, (Fig. 1,4). Vertical change in the smooth mesa tops relative to the Inter-mesa 1 region is zero within 1σ error and this terrain also displays the largest scatter (Fig. 1,4).

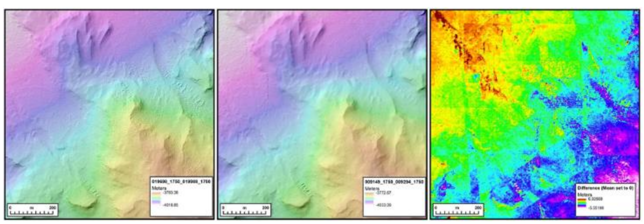

Fig 2. Mid-latitude DEMs from Gale crater made by the USGS with SOCET SET [5] (left: ESP_019698_1750 & ESP_019988_1750; mid: PSP_009149_1750 & PSP_009249_1750) and their difference (right). Scale bar: 200 m. Color scale (m): -3763 to -4019 (left), -3773 to -4033 (center), -5 to 6, with mean set to zero (right).

Discussion: The meter-scale vertical change (relative to the Inter-mesa 1) of the vermicular terrain indicates promise that the vermicular terrain is deflating rapidly enough to quantify its vertical change. However, local vertical scatter on the order of 10s of cm (Fig. 4), systematic vertical offsets between the mean values of DEMs, relative vertical offset artifacts between DEMs (Fig. 2), and speckling over featureless mesa tops (Figs. 1, 4) will make a robust determination of the uncertainty on the change difficult. If the apparent deflation over the vermicular terrain (Fig. 1,4) continues into the future, a longer baseline of DEMs will make change detection easier as the total change increases.

Despite the challenges, we are cautiously optimistic that HiRISE DEM subtraction can be used to detect vertical changes above the level of the uncertainty of the technique. The prospect of determining the relative change between subregions within a scene (e.g. nonuniform, terrain-dependent change) appears better than the prospect for measuring absolute change (e.g. uniform change across an entire scene) within the same subregion. If successful, the use of DEM differencing to measure vertical change will be useful for correlating vertical change with terrains at fine horizontal spatial scales. This is complementary to laser altimetry [7], which covers a larger spatial scale at lower spatial resolution, and shadow measurements [8], which do not require stereo coverage but give less information about the horizontal scale of vertical change.

References: [1] Thomas, P. et al. (2016) *Icarus 268*, 118-130. [2] Malin, M. (2001) *Science 294*, 2146-2148. [3] Moratto, Z. et al. (2010) LPSC 41 #2364 [4] Tao, Y. et al. (2016) ISPRS Congress XLI-B3 [5] ® BAE Systems [6] Buhler, P. et al. (2017) *Icarus 286*, 69-93. [7] Aharonson et al. (2004) *JGR 109*, E05004 1-10 [8] Thomas, P. et al. (2013) *Icarus 225*, 923-932.

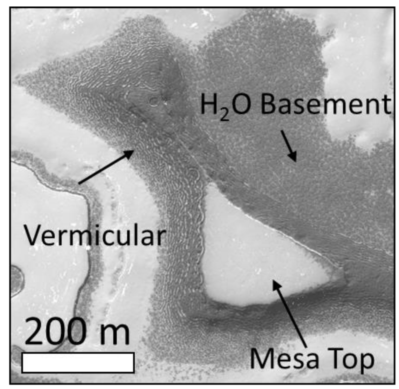

Fig 3. Orthorectified HiRISE image (ESP_04976_0930 and ESP_04978_0930) showing region mapped in Fig. 1.

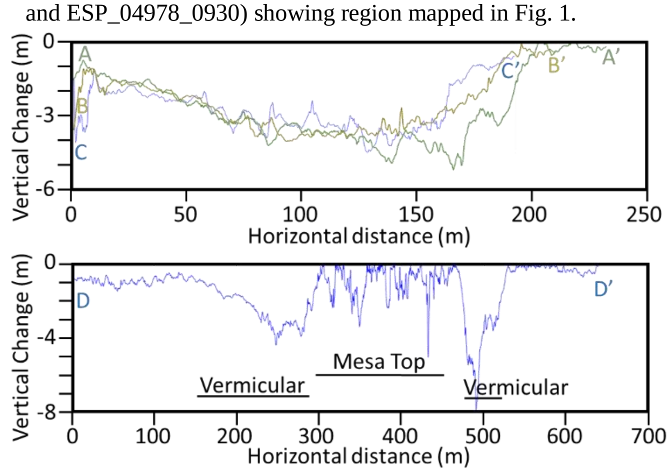

Fig 4. Profiles on the raster of the difference between the DEMs from MY 30 L_S 272 and MY 33 L_S 330 along transects shown in Fig. 1. Local scatter on profiles is typically ~10s of cm. Note the large scatter from speckling on the mesa top and the large vertical difference in the vermicular terrain.