PROSPECTS FOR MEASURING VERTICAL CHANGE ON THE MARTIAN RESIDUAL SOUTH POLAR CAP USING HIRISE DIGITAL ELEVATION MODELS. P. B. Buhler1, J. Dickson1, B.L. Ehlmann1,2, A.P. Ingersoll3, S. Byrne1, Y. Tao1, and J-P. Muller4. 1Div. Geological & Planetary Sciences, California Institute of Technology (bpeter@caltech.edu), 2NASA Jet Propulsion Laboratory, 3Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ. 4Imaging Group, Mullard Space Science Laboratory, University College London.

Fig 1. Top: Difference between MY 30 Ls 272 and MY 33 Ls 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 CO₂ ice perched on top of the much larger H₂O ice cap. The RSPC is the only permanent CO₂ deposit definitively known to be exchanging with the primarily (96%) CO₂ 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 km² regions and co-registered by hand using tie-points to static fiducial points, such as annually reappearing polygonal fractures in the CO₂ and H₂O 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 Ls 272 and MY 33 Ls 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 CO₂ mesas where H₂O 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).

<table>
<thead>
<tr>
<th>Image Pairs</th>
<th>MY</th>
<th>Ls</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP_022210_0930/ESP_022064_0930</td>
<td>30</td>
<td>272/279</td>
</tr>
<tr>
<td>ESP_047237_0930/ESP_047304_0930</td>
<td>33</td>
<td>209/213</td>
</tr>
<tr>
<td>ESP_047488_0930/ESP_047503_0930</td>
<td>33</td>
<td>221/222</td>
</tr>
<tr>
<td>ESP_048477_0930/ESP_048702_0930</td>
<td>33</td>
<td>270/281</td>
</tr>
<tr>
<td>ESP_049768_0930/ESP_049782_0930</td>
<td>33</td>
<td>330/330</td>
</tr>
</tbody>
</table>

Table 1. HiRISE image pairs for polar DEMs. MY = Mars Year, Ls = 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 Ls 272 and MY 33 Ls 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).

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. nonuni-
form, terrain-dependent change) appears better than the
prospect for measuring absolute change (e.g. uniform
change across an entire scene) within the same sub-
region. 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 reso-
lation, and shadow measurements [8], which do not re-
quire stereo coverage but give less information about
the horizontal scale of vertical change.

et al. (2016) ISPRS Congress XLI-B3 [5] BAE Sys-
Aharonson et al. (2004) JGR 109, E05004 1-10 [8] Tho-

![Image](image1.png)

**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).

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

![Image](image2.png)

**Fig 4.** Profiles on the raster of the difference between the
DEMs from MY 30 Ls 272 and MY 33 Ls 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.