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Extensive computation of albedo contrast between martian dust devil tracks and their neighboring regions

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ABSTRACT

We have developed a method to compute the albedo contrast between dust devil tracks and their surrounding regions on Mars. It is mainly based on Mathematical Morphology operators and uses all the points of the edges of the tracks to compute the values of the albedo contrast. It permits the extraction of more accurate and complete information, when compared to traditional point sampling, not only providing better statistics but also permitting the analysis of local variations along the entirety of the tracks. This measure of contrast, based on relative quantities, is much more adequate to establish comparisons at regional scales and in multi-temporal basis using imagery acquired in rather different environmental and operational conditions. Also, the substantial increase in the details extracted may permit quantifying differential depositions of dust by computing local temporal fading of the tracks with consequences on a better estimation of the thickness of the top most layer of dust and the minimum value needed to create dust devils tracks. The developed tool is tested on 110 HiRISE images depicting regions in the Aeolis, Argyre, Eridania, Noachis and Hellas quadrangles. As a complementary evaluation, we also performed a temporal analysis of the albedo in a region of Russell crater, where high seasonal dust devil activity was already observed before, comprising the years 2007–2012. The mean albedo of the Russell crater is in this case indicative of dust devil tracks presence and, therefore, can be used to quantify dust devil activity.

1. Introduction

Dust devils are thermally generated cyclostrophic vortices that are driven by insolation. Rising warm air from solar-heated surfaces is replaced by colder, dense air surrounding the vortex. They become visible when particles are lifted by the turbulence produced by wind shear and perhaps by a suction effect produced by the vertical instability inside the low-pressure convection core (Sinclair, 1969; Renno et al., 1998; Greeley et al., 2003; Balme and Hangerman, 2006). They have been studied on Earth for more than a century (Baddeley, 1860; Brooks, 1960) and were first observed on Mars in the 1980s in orbital images taken by the Viking orbiters (Thomas and Gierasch, 1985).

Dust devil tracks are albedo patterns on the surface that result from the removal of particles by the activity of a dust devil exposing an underlying surface with a different albedo. As dust devils remove bright air fall dust from the surface, the tracks left behind may reveal a darker substrate Reiss et al. (2010). In some rare cases tracks are brighter than the surrounding areas. Reiss et al. (2011a,b) argue that these bright tracks occur when dust devils disintegrate superficial dust aggregates, which are coarser and have lower albedo, into fine grained material with a higher albedo. Those albedo features tend to fade with time, which is attributed to the deposition of dust (Malin and Edgett, 2001; Balme et al., 2003).

Martian dust devil tracks display linear, curved, and irregular morphologies that generally range from 10 m to greater than 200 m in width and can be up to a few kilometers in length (Edgett et al., 2000; Balme and Greeley (2006); Fisher et al., 2005).

Martian albedo changes from region to region and over time as described in Geissler (2005), who reported albedo ranges from 10% to 19% in dark regions and up to 25% in bright areas for a few of these albedo features located in the equatorial region. In general, the bond albedo (that is, the fraction of the total electromagnetic radiation incident on a body at all wavelengths that is scattered back out into space) of Mars is around 25% (Read and Lewis, 2010; Fanale et al., 1982). In particular, the observed albedo of

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dusty plains ranges between 20% and 30% while dust devil tracks albedo has been reported to be about 20% (Bell et al., 2006; Rice et al., 2007). Consequently, multi-temporal monitoring of albedo variations in Mars is of great interest as it allows us to study resurfacing phenomena and the redistribution of dust on the planet surface. Moreover, albedo measurements can shed light on the nature of the surface materials and can be also used to derive the thermal inertia and to evaluate the heat balance of Mars (Esposito et al., 2007).

In Verba et al. (2010) the authors have performed a seasonal study on Russel and Gusev craters using HiRISE images focusing on the tracks left by the activity of dust devils. According to their reasoning, tracks observed in Gusev are primarily formed by rare, large dust devils while smaller vortices fail to leave tracks that are visible from orbit, perhaps due to the limited surface excavation depths. On the other hand, they report that the Russell crater displays more frequent and smaller sinuous tracks than the Gusev, which may be due to the thin dust cover in Russell, allowing these smaller dust devils to penetrate the bright dust layer and consequently leave marks of their presence. Verba et al. (2010) also observed larger dust devils (track widths in the range 40–60 m) on the Gusev region, whereas more numerous but smaller dust devils (widths of 30–40 m) in Russell crater. In comparison, dust devil tracks in Russell crater are more numerous but are shorter, more sinuous, and narrower than those found in Gusev crater.

Whelley and Greeley (2006, 2008) state that if a layer of dust is thicker than the depth of excavation of a dust devil, which Balme et al. (2003) estimates to be around tens of microns, then a passing dust devil would not produce a noticeable track. These authors observed dust devil tracks in Gusev and in Argyre Planitia and, as they mention, Gusev crater taken alone appears to be an active area for dust devils. However, compared to the Hellas basin and Argyre Planitia, dust devil tracks are far less common in Gusev crater.

Based on the discussion above, it should be noted that the mechanism by which dust devils leave tracks is still controversial. Some researchers explain tracks as differences in excavation depths whilst others explain it as a photometric effect caused by grain size distribution. We believe that the extraction of intensity of information at the scale of each individual track and, hypothetically, for every track detected on an image could provide helpful insights into that procedure. Thus, whatever the formation mechanism is, calculating the albedo contrast between tracks and their surroundings could be used to investigate, at once, differences at local scale (the one of each track or scene under analysis) but also at a larger scale, to know if such contrast is significantly different from region to region, with a better statistics and possibly envisage objective relationships between tracks and topography or tracks and dust coat depth. In addition, together with a correct delineation of the dust devil tracks at large scale, the relative quantities of albedo contrast can provide more robust information on the variation of the surficial features than a direct measure, like the albedo, can give.

Thus, our main objective in this paper is to present a tool we have developed to measure in an fully automated manner the albedo contrast between dust devil tracks and their neighborhood regions and how its application to a large variety of image datasets belonging to distinct martian regions can envisage the development of regional and global studies that can improve our knowledge on the formation of these vortices and on the characteristics of the surface. For testing the approach, we have extensively calculated separately, with the novel algorithm, the albedo of dust devil tracks and the albedo of their surroundings to obtain an albedo contrast measure in 110 regions of interest (ROIs) cropped from 47 HiRISE images depicting regions in the Aeolis, Argyre, Eridania, Noachis and Hellas quadrangles. In addition, as a complementary evaluation, we also performed a multi-temporal analysis of the albedo in a particular region of Russell crater where we verified that the mean albedo of the region decreases significantly when dust devil tracks are present.

2. Method

2.1. Image dataset

The dataset comprised 110 regions of interest (ROIs) cropped from 47 HiRISE scenes (Table 1). The images were cropped (some images contained two or more ROIs) so that irrelevant information for our purposes (such as large areas with no tracks) was discarded and the time of processing was significantly reduced (some HiRISE images were up to 2 Gb size).

The search for images containing dust devil tracks was driven by the knowledge that dust devils are more likely to occur in the southern hemisphere and on the fact that they are formed during the spring and summer seasons (Balme et al., 2003; Fenton et al., 2005; Örmo and Komatsu, 2003; Whelley and Greeley, 2008). Therefore, we only searched for images with solar longitude (Ls)

Table 1
Names and center coordinates of the initial set of images.

Name	Region	Latitude (°)	Longitude (°)	Extent (pixels)
PSP_003834_1650	Aeolis	−14.6	175.5	29,895 × 47,677
ESP_012927_1245	Argyre	−55.2	318.6	25,022 × 42,726
ESP_013204_1260	Argyre	−53.8	316.7	13,820 × 21,375
ESP_013310_1200	Argyre	−59.6	303.4	14,874 × 26,117
ESP_013626_1245	Argyre	−55.2	318.6	35,333 × 59,130
ESP_013520_1180	Argyre	−62.0	330.8	28,474 × 52,845
ESP_013996_1155	Argyre	−64.1	295.7	27,001 × 31,959
ESP_014049_1200	Argyre	−59.9	287.6	26,839 × 31,985
ESP_014259_1230	Argyre	−56.9	313.7	27,697 × 52,753
PSP_005596_1245	Argyre	−55.0	318.5	25,640 × 126,617
PSP_005397_1270	Argyre	−52.7	351.5	27,004 × 43,005
PSP_005820_1320	Argyre	−47.4	321.7	28,829 × 63,084
PSP_005846_1235	Argyre	−56.0	333.5	29,318 × 72,063
PSP_006163_1345	Argyre	−45.3	316.3	31,665 × 94,909
PSP_006176_1225	Argyre	−57.1	323.6	30,379 × 72,210
PSP_005780_1215	Argyre	−58.1	335.8	17,667 × 50,793
ESP_021874_1175	Eridania	−62.2	136.4	25,586 × 32,460
ESP_021939_1170	Eridania	−62.9	162.0	26,047 × 32,265
ESP_021940_1205	Eridania	−59.1	133.8	26,533 × 32,315
PSP_004086_1180	Eridania	−61.9	145.1	30,686 × 71,421
PSP_005510_1290	Eridania	−50.6	145.5	26,974 × 140,471
ESP_023021_1160	Eridania	−63.9	142.2	27,031 × 32,297
ESP_014121_1180	Eridania	−61.7	122.4	23,466 × 22,223
PSP_006248_1235	Eridania	−56.0	157.5	25,556 × 42,298
PSP_002548_1255	Noachis	−54.3	12.9	31,137 × 63,003
PSP_003326_1255	Noachis	−54.3	12.9	28,011 × 40,964
PSP_004038_1255	Noachis	−54.3	12.9	28,528 × 52,499
PSP_004249_1255	Noachis	−54.3	12.9	28,602 × 52,315
ESP_013321_1175	Noachis	−62.3	3.9	17,008 × 45,764
ESP_013557_1245	Noachis	−55.0	39.0	27,895 × 42,357
PSP_005238_1255	Noachis	−54.3	12.9	31,617 × 67,818
PSP_005383_1255	Noachis	−54.3	12.9	31,848 × 77,994
PSP_005528_1255	Noachis	−54.3	12.9	31,646 × 74,756
ESP_013992_1170	Noachis	−62.5	44.5	26,905 × 41,739
ESP_014020_1150	Noachis	−64.8	0.7	29,764 × 42,248
ESP_014322_1215	Noachis	−58.3	35.4	31,472 × 63,325
PSP_005659_1335	Noachis	−46.4	36.9	13,842 × 30,977
ESP_014399_1220	Hellas	−57.8	92.5	14,413 × 26,257
ESP_014176_1155	Hellas	−64.3	60.3	30,139 × 52,395
ESP_014108_1200	Hellas	−59.5	116.8	26,604 × 32,036
ESP_014070_1170	Hellas	−62.6	75.9	27,955 × 42,356
ESP_014069_1180	Hellas	−61.6	102.1	26,132 × 41,841
ESP_014056_1180	Hellas	−61.8	97.1	23,514 × 22,206
ESP_014004_1180	Hellas	−61.6	76.7	26,303 × 41,926
ESP_013991_1160	Hellas	−63.8	72.3	28,366 × 41,867
ESP_013965_1165	Hellas	−63.2	62.0	27,686 × 41,765
PSP_006264_1420	Hellas	−37.6	77.5	28,374 × 74,795