Investigating the Morphologies of Local-Scale Dust Storms in the Northern Hemisphere of Mars

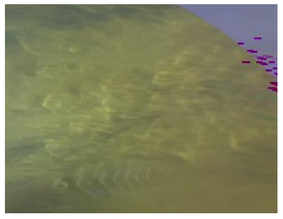
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Introduction

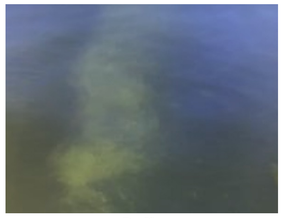
- Solar arrays, the lowest cost method of power generation on Mars, have greatly reduced efficiency during dust storms. This has caused the termination of numerous missions, including *Opportunity* and *InSight.*
- Recent studies have suggested a connection between the morphologies of local-scale dust storms (storms < 1.6 x 10^6 km^2) and westerly jets [1].
- We investigate whether this claim is accurate through an analysis of 28 storms near the polar ice cap.
- We also investigate the convective environment of storms of different formation mechanisms.
- We obtained satellite data from the Mars Color Imager (MARCI) Mars Daily Global Map (MDGM) database [4] and meteorological data from the Ensemble Mars Reanalysis System (EMARS) [5].

Methods

- We extracted storm images from MDGM database. We identified storms by observing albedo anomalies surrounding the north polar ice cap.
- Storms were classified based on the system proposed by Kulowski et. al. [2] and Heavens [3]. The four categories are shown in Fig 1. We also assign each storm a subjective confidence level (CL) between 1 and 4 depending on how clearly its structure is defined.
- We fit a parabola to the storm to obtain curvature and orientation values as demonstrated in Figs 2 & 3.
- We extracted the time from the image metadata and found the corresponding time at the prime meridian in EMARS. We added/subtracted hours based on the distance of the storm to the prime meridian.
- EMARS was used to find winds at the 0.29 mb level. Winds at least 85% of the maximum value are considered part of a jet streak.
- We compared the position of the storm and jet streak.
- Finally, we found the temperature profile at the storm's location and modeled the updraft by numerically approximating the momentum equation for a dusty dry heated atmospheric parcel using Euler's Method.



Pebbled



Puffy



Ruffled



Plume-like

Fig 1 Well-defined examples (CL = 4) of each storm type cropped from images obtained from [4].

Results

Image Analysis



Fig 2 Storm P13-04a split into its eight grids for a parabola to be fit to each. Each grid of points is shown in a different color. Adapted from [4]

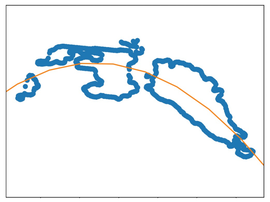


Fig 3 The final parabola fit to Storm P13-04a. Note the image has been rotated to ensure the best possible fit. Adapted from [4]

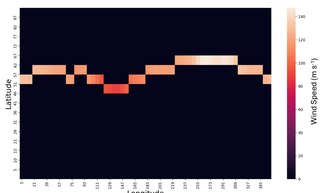


Fig 4 The jet stream axis for the time associated with Storm P13-04a. Only the latitude with the highest windspeed is shown for each longitude. Adapted from [5]

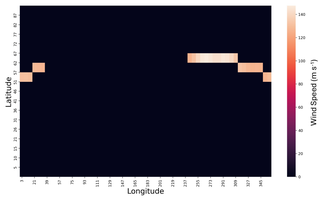
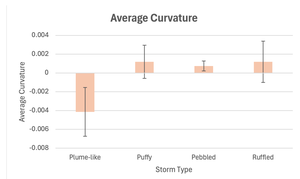
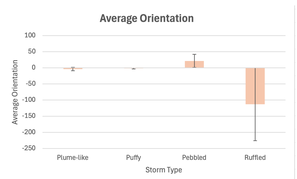


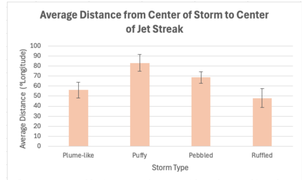
Fig 5 The jet streak associated with Storm P13-04a. We eliminated all wind measurements but those at least 85% of the maximum. Adapted from [5].



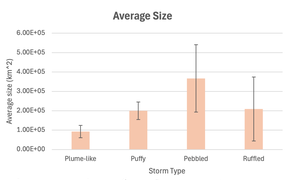
Average curvature of each storm type measured in a unitless derived parameter.



Average orientation of each storm type measured in a unitless derived parameter.



Average distance from the longitude of the center of a storm to the center of a jet streak, measured in degrees longitude.



Average size of each storm type measured in km^2.

Fig 6 Analysis of storm data from MY 28 L_s~160°–195° and MY 28 L_s~330°–340°. All storms were recorded to be west of the center of a jet streak. Error bars show standard error of the mean. Note that one ruffled storm had an anomalously low orientation parameter, skewing the results

Updraft Modeling

$$\frac{dw^2}{dP} = -\frac{R^*}{P}[(T_p - T) - T\ell_C] - \left[\frac{1}{2P}\left(1 + \frac{R^*}{g}\frac{\partial T}{\partial z}\right) + X - \frac{R^* T C_D}{Pg\, r_0}\right]w^2$$

Eq 1 Momentum equation for a dusty dry heated atmospheric parcel. Adapted from [1].

Var	Description	Value	Unit
w	Updraft velocity	Var.	m s^{-1}
T	Temperature of the environment with respect to height	[5]	K
T_p	Temperature of the air parcel with respect to height	[5]	K
P	Barometric pressure with respect to height	[5]	mb
z	Height above the surface	Var.	m
R*	Gas constant for Mars's atmosphere	188 [6]	J kg^{-1} K^{-1}
ℓ_C	Ratio of dust mass to total air parcel mass	1 x 10^{-6} [1]	
g	Acceleration due to gravity	3.7 [6]	m s^{-2}
X	Entrainment parameter $X = \frac{-gP}{R^*T}\frac{0.2}{r_0}$	[1]	mb kg J^{-1} s^{-1}
C_D	Drag coefficient	0.1 [1]	
r_0	Initial radius of the air parcel	2500 [1]	m

Tbl 1 Variables and constants used in the numerical approximation of updrafts

Var	Description	Value	Unit
w_0	Updraft velocity at z = 0	0.0001	m s^{-1}
ΔT_0	Difference in temperature between air parcel and environment at z =0	0.5	K
Γ	Dry adiabatic lapse rate	-4.5 x 10^{-3} [6]	K m^{-1}

Tbl 2 Initial conditions and assumptions used in the numerical model of updrafts. We assume that as an air parcel rises, it follows a dry adiabatic temperature profile

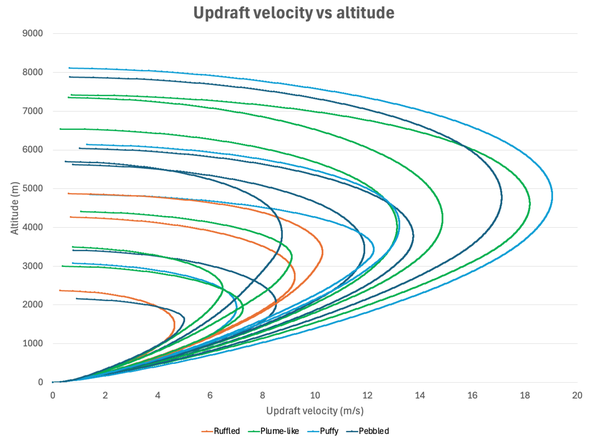


Fig 7 Modeled updraft velocities of storms with CL = 3-4 using Eq. 1 and the parameters listed in Tbl 1 & 2.

Storm Type	Average w_{max}	Storm Type	Average w_{max}
Plume-like	11.987 m s^{-1}	Pebbled	10.840 m s^{-1}
Puffy	12.880 m s^{-1}	Ruffled	8.060 m s^{-1}

Tbl 3 Average w_{max} for each storm type using the graphs in Fig 7

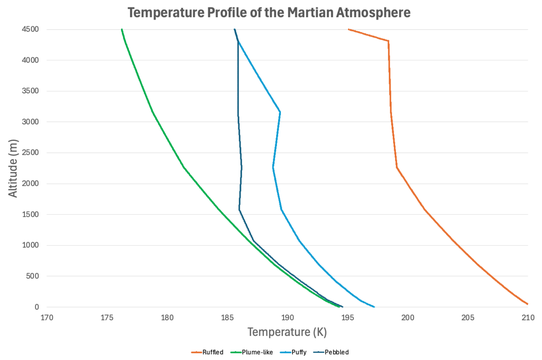


Fig 8 Temperature profiles to 4500 m for select storms shown in Fig 7. Adapted from [5]. Note that the ruffled storm was located significantly closer to the equator, shifting the profile to the right.

Conclusions

- All 28 observed storms were recorded to have formed in entrance regions of jet streaks, indicating that these regions are conducive to dust storm formation.
- Our findings conflict with Sánchez-Lavega et. al.'s [1] claim that storms were likely to have different orientations and curvatures based on where they formed in relation to jet streaks.
- Plume-like and ruffled dust storms formed similar distances away from jet streaks and were of roughly similar sizes, with ruffled averaging slightly larger.
- Our findings align with the claim presented by Heavens [3] that ruffled storms may be misclassified plume-like storms.
- We find no evidence that the orientation and curvature of storms are dependent on the presence of jet streaks.

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