SEASONAL VARIATION OF THE COLD AND BRIGHT ANOMALIES ON THE NORTH POLAR LAYED DEPOSITS.

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Introduction: The northern polar region of Mars is a very active region, from dust storms on the scale of 5000 km to polar cliff avalanches on the scale of a few meters. In the northern winter and summer, during the formation and the sublimation of the seasonal frost cap, this region is responsible for a significant change in the global atmospheric pressure [1], and the water budget of the planet [2]. Due to this, seasonal variation of the North Pole strongly affects the entire planet. A better understanding of this region will help us predict the future climate for Martian exploration and understand the climate in the past. There are many features and processes that are poorly classified. We focused on the Cold and Bright Anomalies (CABA), first observed by thermal observations [3,4] in order to better understand the water cycle.

The CABA are regions that are colder and brighter than the cap average. They first appear annually during early summer [3] (Fig 1B) and remain brighter and cooler until late summer (Fig 1C). In late summer, these formerly bright regions rapidly darken, within only a few hours, becoming the darkest locations over the polar ice and warmer than the cap average [3,4]. To get a timeline and an explanation of these anomalies, we compared the previously studied CABA Vostok location (Fig 1,3A) [3, 5] to an non-anomalous neighbouring region (Fig 3A) using observations from Mars Color Imager (MARCI) [6], Thermal Emission Imaging System (THEMIS) [7] and Mars Orbiter Laster Altimeter (MOLA) [8].

Observations CABA Timeline: Before L_s 85, there is no albedo and temperature difference between the CABA and the neighbouring region (Fig 2). Around L_s 85, the Vostok region begins to diverge by warming more slowly and increasing reflectivity compared to the neighbouring region. Around this time, we observed low albedo dust streaks appear near spiral troughs in the normal region [9]. These streaks are uncommon at the CABA locations (Fig 1A).

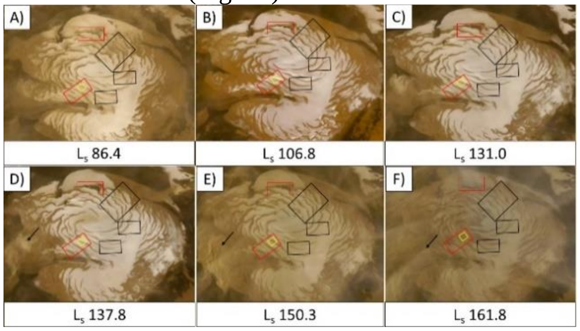

Figure 1: MARCI MY 32 observations. Black boxes outline where dust streaks are most pronounced, red boxes outline CABA study locations, black arrows mark most intense dust storms and yellow boxes show Vostok region (Fig 3A).

Between L_s 90 and L_s 107, the differences continue to increase as the rest of the polar cap darkens due to summertime sublimation and the CABA continue to get brighter (Fig 1B, 2). The temperature and the albedo difference peak around L_s 107, where the Vostok region is ~20 K colder than the neighbouring region (Fig 2D). After which, the difference begins tending towards zero due to widespread refrosting (Fig 1C,2).

For MY 32, and other years more generally, around L_s 138, widespread storms are seen moving over the cap (Fig 1D), and some of the CABA locations darken over a span of a few hours. After a period of about 10 sols, a second darkening event is seen under similar stormy conditions, but the intensity of the storms and the area of the darkened region increases significantly (Fig 1E). Around this time, the Vostok region darkens as its mean pixel value (proxy for albedo) drop by ~31%, and it is now ~3-5 K warmer than the neighbouring region (Fig 2). A final darkening event recurs each year, very close to L_s 161. This is the most intense darkening event, where for MY 32 ~50% of the cap darkens less than a day. Accompanying each darkening event, we observed widespread dust storms seen over and outside of the cap, forming the polar hood. Previously darkened region grow significantly (Fig 1F).

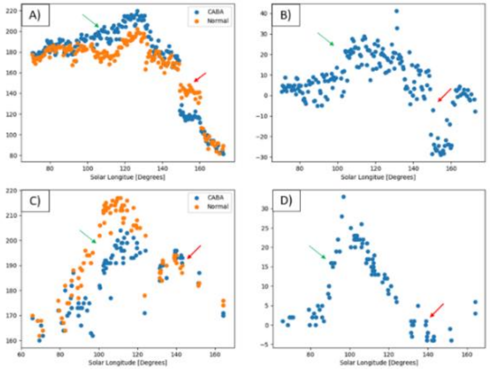

Figure 2: Comparisons of the Vostok CABA and normal region showing a divergence in temperature and albedo around Ls 85. A) Relative albedo measurement of both studied regions using MARCI mean pixel values. B) Difference in the mean pixel values between the two regions peaks at ~Ls 110 and Ls 155. C) THEMIS IR temperature measurement. D) Difference in temperature between the two regions peaks at Ls 107.

Observations MOLA Topography: Examining the local topography of various anomalous locations revealed that the CABA are located on local topographical rises ~30-50 meters tall (e.g Fig 3). The rise is a distinct topographical feature only observed at the CABA locations. In late summer, the darkened regions are located near the center of this raise, and bright halos (CABA remnants) are found on either side of this rise (Fig 3).

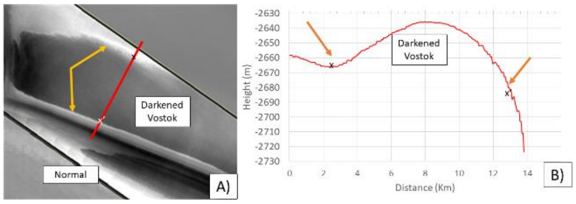

Figure 3: A) THEMIS VIS image (V55595018) showing the bright halos (orange), MOLA track (red), Vostok and the neighboring region. B) MOLA topography showing the topographical raise, halo (arrows) and darkened Vostok location. The topographical rise only exists at the CABA locations

Additional Observations: When the Vostok regions diverges from the cap average, katabatic winds are at their peak, supported by modeling [10,11] and observations of cloud activity [9]. Katabatic winds are known to remove surface ice by two means, mechanical removal of ice and enhancement of sublimation by forced convection [10]. Compared to the regions with the highest katabatic wind activity [11,12], CABA experience slower katabatic wind activity, and fewer to no low-albedo surface streaks (Fig 4), allowing them to retain their higher albedo

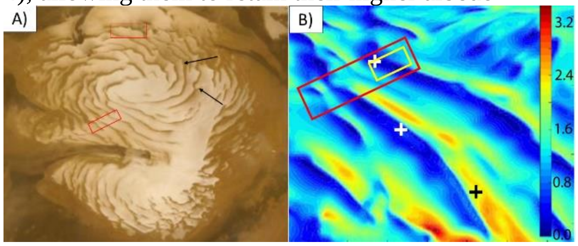

Figure 4: A) MARCI MY 32 at L_s 86.4. Black arrows indication the dust streaks associated with katabatic winds and red boxes show the most common CABA locations. B) Mesoscale simulation of the larger Vostok region (yellow box) [10] showing that winds are weakest on the inter-trough zones (blue). But overall slower near the CABA.

CABA Formation Hypothesis/Interpretation: We interpret these observations to mean that the CABA locations experience slower winds compared locations with similar geologic setting on to the rest of the cap – reducing the removal of bright ice, leaving the CABA brighter than their surroundings. While the non-anomalous regions, which experience lower albedo dust streaks, trap more solar radiation and warm up faster than the CABA regions.

During summertime, when the albedo contrast and temperature differences peak, the CABA experience cold trapping that occurs when a cold spot condenses colder and highly reflective ice from the atmosphere, maintaining smaller grain sizes and high reflectivity [13,14]. This is a self-reinforcing process that enhances the temperature and albedo differences established during katabatic wind season.

During refrosting, when the entire cap begins to brighten and cool [14], the CABA locations would cool down slower due to Newton's Law of Cooling. Eventually, the two regions have the similar albedo and temperature (Fig 2).

CABA Darkening Hypothesis/Interpretation: During late summer, we hypothesize that the surface winds, which are driven by high altitude large scale eddies [12], rapidly strip the surface ice layer and expose a warm dustier ice layer underneath as they move over the CABA raise (Fig 5). The dark layer underneath the surface will be warm due to the heat which was trapped during summertime. The halo features (Fig 3A) are locations where the ice was not stripped during erosion.

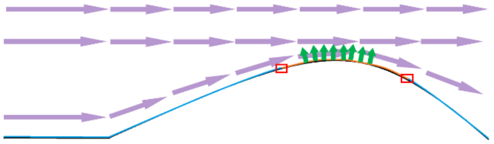

Figure 5: Heuristic model to explain the darkening process. Winds (purple) moving over the refrosted topographic rise (only observed at the CABA locations) speed up to shear off (green) the surface ice. Halos are CABA remnants left behind (red boxes)

The area of the darkened region grows from 136 km^2 at L_s 138 to 156,551 km^2 at L_s 162 in MY 32 -a representative year. Assuming the surface ice layer is ~1-5 mm, the average grain size if 1.6 μm [14] and a density of 0.01 $kg\ m^{-3}$ [15], we find that the amount of surface ice stripped is between 1,565,510 kg and 4,519,710 kg during the largest darkening event for the ice layer which is 1 mm to 5 mm respectively

Future Work: To further test these hypotheses, following previous work [11] we will simulate a large region surrounding the Vostok location between L_s 83 and L_s 170, using the Laboratoire de Météorologie Dynamique (LMD) Mars Mesoscale Model [16]. We plan to use these simulations to determine the wind speed and direction along with shear stress (and frictional velocity) for moving the fine-grained particles. In addition, we plan to request more visual and thermal observations of the CABA locations after L_s 140. We also plan to expand our study of the Vostok region to other less studied CABA locations.

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