Highlighting image processing techniques used to analyze Martian Water Ice Clouds observed by the NavCam instrument on board Mars2020 Rover, Perseverance.

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Abstract:
Following the landing of Perseverance in February 2021, a variety of instruments have collected substantial data helping us understand the environment and atmosphere of the landing site, Jezero Crater. An important factor in understanding this unique environment is studying the local and regional variations of water over diurnal and seasonal timescales. We specifically study the variations of water ice in the atmosphere by observing cloud activity over Jezero Crater using data collected by the Navigation Cameras, NavCam, on board the Mars2020 Rover, Perseverance.

Introduction:
Martian water ice clouds have been observed for a long time from both the surface and from orbit to understand the role of water in the atmosphere. Between the solar longitude (Ls) of 45 to 150, the Aphelion Cloud Belt (ACB) forms every Mars Year (MY) in the equatorial region (10^{o}S–30^{o}N). (Tamppari et al., 2000) (Smith et al., 2004)

Various lander and rover missions have observed Martian water ice clouds. Using Viking era data, Tamppari (2000, 2003) observed water ice clouds with peak activity seen during the northern spring and summer time. Opportunity Rover acquired images of water ice clouds during the ACB season with peak activity seen from Ls 50^o to 115^o (Lemmon et al., 2015). Similar observations collected with the Surface Stereo Imager (SSI) on-board the Phoenix Lander showed a large variety of cloud types over the course of the 151-sol mission (Moores et al., 2010). In particular, atmospheric movies showed cirrus-like clouds in the early mornings and late nights compared to cumulus-like clouds seen before mid-sol at lower lattitudes. (Moores et al., 2010).

The navigation camera, NavCam aboard the Mars Science Laboratory (MSL, Curiosity) rover has observed cloud activity at Gale crater through cloud movies and surveys. The diurnal and seasonal patterns were comparable with previous observations. The peak cloud activities were observed in the morning/afternoon time and around the ACB period. (Kloos et al., 2018) They have also been reported to leave a thermal signature at night on Gale's surface (Cooper et al. 2021).

NAVCAM data:
Most recently, water ice clouds have been observed through cloud movies and cloud surveys collected using the Perseverance NavCam instrument that collects color stereo images of the surface with a 96^{o}x73^o field of view at 0.33 mrad/pixel. (Maki et al., 2020) Compared to the NavCam on Curiosity, the NavCam on Perseverance hold the capability of imaging in color which may provide advantages in highlighting water ice clouds in the atmosphere.

Cloud surveys are single images taken facing the horizon, generally twice a week, at various times of the day. Similarly, cloud movies are collected by taking 8 frames of images looking towards the horizon with an interval of 15 seconds, producing a movie. A combination of cloud surveys and movies collected by the mission are used to study water ice clouds at Jezero Crater.

Figure 1 shows cloud observations acquired as cloud surveys, in blue triangles and cloud movies, in red circles. The y-axis shows the time of day the data has been collected and x-axis top shows the sol number and x-axis bottom shows the Solar Longitude, Ls. Perseverance has observed water ice clouds during the ACB time period. These data sets are currently being analyzed in detail to determine which ones show water ice clouds.

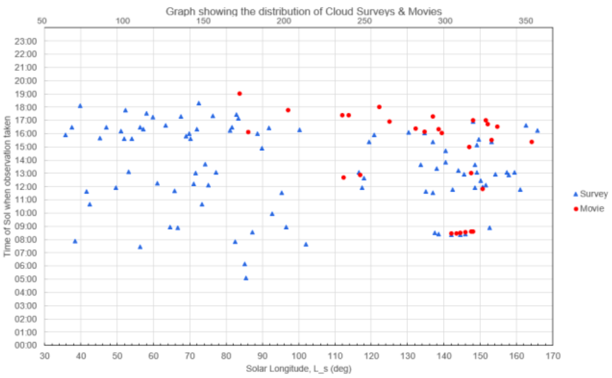

Figure 1: Graph showing the distribution of NavCam cloud observations at various times of sol. Blue triangles show the acquired NavCam cloud surveys and red circles show the acquired NavCam cloud movies

Data Processing: Here, we will highlight image processing techniques used on these data sets that emphasize the presence of water ice clouds in the atmosphere. The NavCam Cloud movies can be processed using an imaging technique known as Mean Frame Subtraction (MFS) to enhance cloud features due to their low optical depths (Campbell et al., 2020) (Moores et al., 2015). This technique takes the average frame of the whole movie and subtracts it from each individual frame (Moores et al., 2015). This isolates the time-variable component, revealing cloud movement within the movie. *Figure 2* shows an example of raw versus MFS processed frames of a NavCam cloud movie.

On top these processed images and movies, we have explored techniques such as two-dimensional fast Fourier transforms to recognize patterns in clouds and classify the various morphologies of water ice clouds on Mars.

We will be presenting the water-ice cloud activity at Jezero Crater with details on various image processing techniques used to determine the variety of characteristics of Martian clouds. The full data set from the start of the Mars2020 mission up to now will be analyzed to determine any seasonal patterns in the cloud activity seen at Jezero.

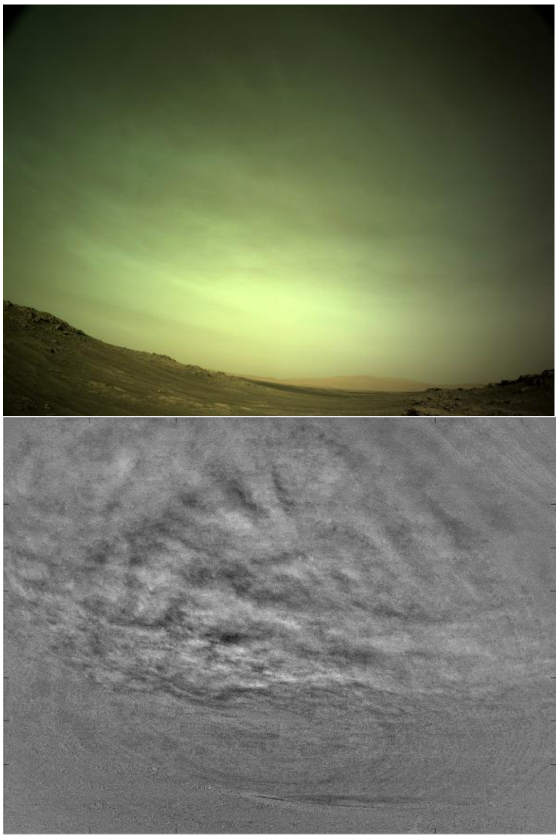

Figure 2: Comparison between raw and Mean Frame Subtraction frames. The raw frame (top) only show faint clouds but when the Mean Frame Subtraction method is applied (bottom), the cloud features become visible.

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