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Seasonal variability in winds in the north polar region of Mars

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ABSTRACT

Surface features near Mars' polar regions are very active, suggesting that they are among the most dynamic places on the planet. Much of that activity is driven by seasonal winds that strongly influence the distribution of water ice and other particulates. Morphologic features such as the spiral troughs, Chasma Boreale, and prominent circumpolar dune fields have experienced persistent winds for several Myr. Therefore, detailing the pattern of winds throughout the year is an important step to understanding what processes affect the martian surface in contemporary and past epochs. In this study, we provide polar-focused mesoscale simulations from northern spring to summer to understand variability from the diurnal to the seasonal scales. We find that there is a strong seasonality to the diurnal surface wind speeds driven primarily by the retreat of the seasonal CO_2 until about summer solstice, when the CO_2 is gone. The fastest winds are found when the CO_2 cap boundary is on the slopes of the north polar layered deposits, providing a strong thermal gradient that enhances the season-long katabatic effect. Mid-summer winds, while not as fast as spring winds, may play a role in dune migration for some dune fields. Late summer wind speeds pick up as the seasonal cap returns.

1. Introduction

Studies of the polar regions of Mars provide evidence of significant wind activity as wind streaks (Howard, 2000), volatile transport (Warner and Farmer, 2008), dune movement (Hansen et al., 2011), and spiral trough evolution (Howard et al., 1982; Smith and Holt, 2010; Smith et al., 2013,2014). The polar layered deposits (PLD) strongly interact with the atmosphere on diurnal, seasonal, and annual bases and are therefore considered to be among the most active places on the surface of Mars (Byrne, 2009; Hvidberg et al., 2012). Because of this activity, significant work has gone into understanding polar processes and evolution. Furthermore, recent observations have captured dune and ripple migration, allowing for measurements of mass flux and estimations on timing and magnitude of events (Ewing et al., 2010; Middlebrook, 2015), so comparisons with modeled wind directions and speeds are becoming a reliable test for thresholds of geomorphic activity.

Some of the greatest questions about the origin, onset, and development of the PLD, especially the north PLD (NPLD), have been answered by modeling (Levrard et al., 2007) and later supported with radar investigations (Putzig et al., 2009; Smith et al., 2016a). Levrard et al. (2007) focused on long-term evolution but left other interesting questions regarding the PLD morphology and current activity unanswered. To get a better understanding of the current processes, especially the volatile transport that shapes the NPLD and surrounding dune fields, seasonal studies using regional-scale (mesoscale) atmospheric modeling are required.

High-resolution atmospheric modeling offers the benefit of providing context for many processes, both above and at the surface, in our current situation of a relative paucity of polar observations on Mars. Based on more and more sophisticated physics and increasing computing power, modern models represent a breakthrough in our ability to describe the martian environment. The models, both Global Climate Models (GCMs) and mesoscale models, provide predictions for weather hazards and entry descent and landing, or study of the global water, dust, and CO_2 cycles. During the last several decades modeling skills have improved sufficiently along with increasing resolution and number of observations that they are now being used in complementary ways to study individual features or annual weather patterns.

With the increase in frequency and potency of models, many studies found success in answering limited questions by employing GCMs and mesoscale atmospheric models using boundary conditions from GCMs. Regarding polar weather and surface features, these investigations used techniques that fell into one of three categories: studies of small features at high temporal and spatial resolution (Fenton et al., 2014,2005); studies covering large areas

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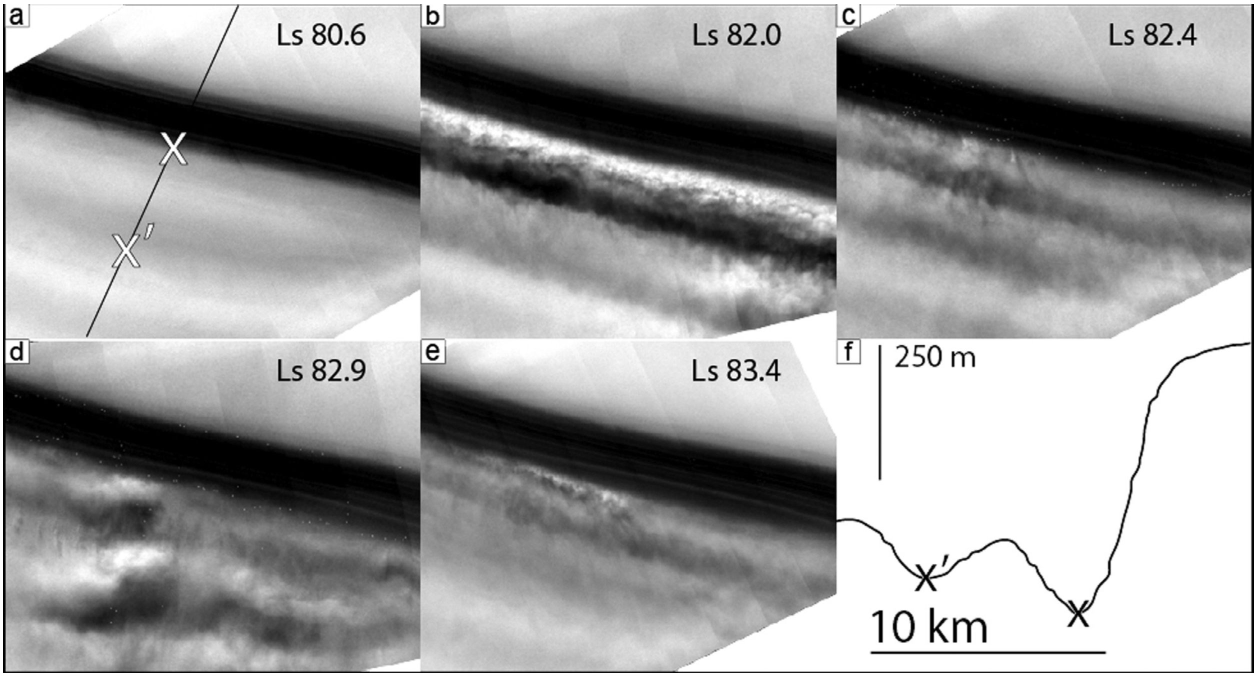

Fig. 1. Trough clouds seen at about 85° N, 90° E in a single martian year. (a) to (e) Thermal Emission Imaging System (THEMIS) images with same footprint: V28706003, V28744006, V28756004, V28769004, V28781003. Dates and scales listed. (f) Topographic profile of vertical line in (a). Xs mark the local minimum elevations in the imaged trough. Clouds are especially prominent in this region between L_s 80° and 83°.

over many dates but with low resolution (Hayward et al., 2007, 2009); and studies at high spatial resolution covering a large area but with limited date ranges (Tyler and Barnes, 2005, 2014). The benefit of these targeted studies is clear; each resulted in an answer that addressed a specific question regarding surface features or atmospheric observations. However, the narrow focus of each study fundamentally limited them to targeted investigations, and one cannot be applied to another.

Here we present a new approach that combines simulations over extensive date ranges with intermediate resolution, providing more context for atmosphere-surface interactions than previous targeted studies. Our product is a database of simulations useful for extracting wind speeds during a nominal day with diurnal circulation over large regions. In this study, we are able to readily extract seasonal wind speeds at specific locations in the northern polar region of Mars to determine which date ranges experience the greatest wind velocity. In the following sections we use this technique to compare the wind's influence on surface and atmospheric activity with our simulations.

2. Background

2.1. Polar processes

Many processes are proposed to explain the formation of the polar landscape, but, excluding impact related features, three stand out as the most likely: wind transport, atmospheric deposition of volatiles and dust, and sublimation. These processes are sufficient to explain the creation of large chasmae (Warner and Farmer, 2008; Holt et al., 2010), spiral troughs (Howard et al., 1982; Smith et al., 2013, 2014; Smith and Holt, 2010), large scours called "wirebrush terrain" (Koutnik et al., 2005), dune fields (Ewing et al., 2010), outlier deposits (Conway et al., 2012; Brothers et al., 2013), and surface streaks and various other surface features (Howard, 2000).

These three processes have the benefit of being observable directly from orbit and indirectly by monitoring surface changes. Wind transport leaves streaks on the surface and is responsible for moving ice from one side of a trough to the other (Howard, 2000; Smith et al., 2013). Direct detection of CO_2 and H_2O snowfall (Whiteway et al., 2009; Hayne et al., 2014), changes in elevation and mass (Smith et al., 2001), seasonal albedo variations of both PLD (Calvin and Titus, 2008), and atmospheric column abundances (Farmer and Doms, 1979) demonstrate the occurrence of seasonal deposition and sublimation. Of these processes, wind likely plays the most prominent role in creating the variability in landforms, as described from mapping based on observations of the Shallow Radar instrument (SHARAD) on Mars Reconnaissance Orbiter (Brothers et al., 2013, 2015; Holt et al., 2010; Smith and Holt, 2010, 2015). This is also true for dune fields, which respond much more quickly to winds (Bridges et al., 2012) than the larger, ice dominated PLD.

2.2. Katabatic jumps and trough clouds

Besides surface changes, the detection of atmospheric phenomena, such as clouds, attests to the potency of winds, sublimation, and deposition. In a pair of papers describing observations on both poles Smith et al. (2013, 2014) cataloged nearly 1000 clouds within the spiral troughs on both poles. The material that made up these clouds was interpreted to be water ice based on arguments of pressure and temperature, and the location of these clouds (parallel to and directly above the spiral depressions) indicated that wind, upslope sublimation, and downslope condensation into ice crystals control their formation (Fig. 1). The clouds were interpreted as Martian analogs to clouds that form on Earth at the site of katabatic jumps (Lied, 1964; Pettré and André, 1991). A katabatic jump is most concisely described as "a narrow zone with large horizontal changes in wind speed, pressure, and temperature," (Pettré and André, 1991). They are analogous to hydraulic jumps found at the bottom of waterfalls, in kitchen sinks, or in rivers (Fig. 15 from Smith et al., 2013).

The clouds that result from katabatic jumps are found just above the lowest portion of the spiral troughs (Fig. 1) because a