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Interannual and seasonal changes in the north polar ice deposits of Mars: Observations from MY 29–31 using MARCI

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ABSTRACT

The MARCI camera on the Mars Reconnaissance Orbiter provides daily synoptic coverage that allows monitoring of seasonal cap retreat and interannual changes that occur between Mars year (MY) and over the northern summer. The northern seasonal cap evolution was observed in MY 29, 30 and 31 (12/2007–04/2012). Observation over multiple Mars years allows us to compare changes between years as well as longer-term evolution of the high albedo deposits at the poles. Significant variability in the early season is noted in all years and the retreating seasonal cap edge is extremely dynamic. Detailed coverage of the entire seasonal and residual ice caps allows a broader view of variations in the high albedo coverage and identifies numerous regions where high albedo areas are changing with time. Large areas of disappearance and reappearance of high albedo features (Gemini Scopuli) are seasonally cyclical, while smaller areas are variable on multi-year time scales (Abalso Mensae and Olympia Planitia). These seasonal and interannual changes directly bear on the surface–atmosphere exchange of dust and volatiles and understanding the current net processes of deposition and erosion of the residual ice deposits. Local and regional variation in high albedo areas reflects an interplay between frost deposition, evolution, and sublimation along with deposition and removal of dust.

1. Introduction

Numerous observations of the polar regions of Mars have shown that the seasonal cycle, as expressed by the location or latitude of the seasonal north cap edge, closely repeats from year to year (e.g. James et al., 1992; James and Cantor, 2001; Benson and James, 2005). It is this process of the CO_2 atmosphere condensing onto the surface during autumn and winter and then subliming back into the atmosphere in the spring that drives the current martian climate. Roughly 25% of the atmosphere, which is 95% CO_2 by volume, is cycled through the seasonal caps annually (Tillman et al., 1993; Forget and Pollack, 1996; Kelly et al., 2006). In additional to this seasonal advance and retreat, earlier workers noted the change in albedo over the northern summer as well. A number of north polar bright outliers and the overall coverage by bright deposits changed between both between Viking summers and between Viking and Mariner 9 (Bass et al., 2000; Kieffer, 1990; Paige and Keegan, 1994). These observations of spring and summer change continued with MGS MOC and TES, Mars Express OMEGA, and MRO CRISM instruments (Calvin and Titus, 2008; Cantor et al., 2002; Langevin et al., 2005; Brown et al., 2012). Variability in high albedo patches between martian summers were noted, and though some events appeared correlated to large planet-encircling dust storms, a great deal of variation is noted that is likely related to local weather, rather than global climate events.

Calvin and Titus (2008) called out several regions of the residual ice cap that undergo varying albedo changes with time. In general, the residual ice cap undergoes a period of decreasing albedo and sublimation of fine-grained water frosts up to Ls ~ 95–100, followed by apparent migration of high albedo areas. That work identified several small locations with persistent high-albedo in the late summer, and areas of Gemini Scopuli and the bright outlier deposits that decrease in albedo, but then brighten again after Ls 105. Most recently, Cantor et al. (2010) report on a synthesis of Mars Reconnaissance Orbiter (MRO) MARCI and CRISM data from the 2008 northern summer season (Mars year 29 or MY 29, after Clancy et al., 2000b). They noted large, high albedo patches in Olympia Planitia over the region associated with gypsum (e.g. Calvin et al., 2009). This relic high albedo deposit had not been previously observed. Cantor et al. (2010) also discussed changes in small anomalous "bright patches" that disappeared in this year

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and changes over Olympia Planitia observed between MY 28 and 29. Large scale darkening and subsequent brightening of the Gemini Scopuli region was observed and could either be attributed to frost removal and redeposition or frost removal followed by dust removal to expose underlying high albedo deposits. In this paper we compare MY 30 and MY 31 with these previous observations.

2. MARCI data and observations

Mars Reconnaissance Orbiter has been in mapping orbit since fall of 2006, Ls ~ 120 of MY 28. Table 1 summarizes the Earth dates and Mars years for seasonal cap retreat and summer observations of the polar region. To date we have observed 3 seasonal recession periods for the north and 4 in the south, and full summer seasons for the residual ice deposits, 3 in both the north and south. This paper focuses on cap recession and summer season interannual variability observed in the north.

The Mars Color Imager (MARCI) is a very wide angle push frame camera with 5 visible color channels (Malin et al., 2001, 2008). The camera acquires pole-to-pole swaths on the sunlit side of the planet. Frames provide limb-to-limb views and subsequent orbits have small overlap at the equator, but significant overlap at the poles. In mapping orbit MARCI acquires 12–13 orbits a day, the vast majority covering the polar regions allowing for high time fidelity synoptic coverage of the varying albedo deposits. The images are stored using an alphabetic nomenclature for mission phase (p = primary, b, g, d extended phases). The phase directory (p01–d14) is provided in Table 1. These images are mosaicked into daily global maps using a summed-2 resolution (averaging of 2 × 2 pixels, or approximately 1.9 km/pixel) with a Minnaert photometric correction, and they are generated from filter bands 3 (604 nm), 2 (546 nm), 1 (437 nm) as RGB (see also Cantor et al., 2010). These are projected into polar stereographic coordinates. Many gaps or "gores" exist in these polar projections due to the spacecraft viewing targeted locations off-nadir. Those images with significant artifacts or that lack full polar coverage are removed from the image list and the full coverage daily images are sequenced into time evolution movies to observe seasonal changes. Still frames allow us to observe the state of the surface deposits at the same Ls value over several martian years. The time sequence movies from MY 29, 30 and 31 are electronic supplements to Fig. 1. The original images are time-stamped in Earth days. As the mosaics include data acquired over the course of an Earth day, Ls varies by about 0.5° from beginning to end. The Ls marker is set for the middle of the day and Earth day is converted to Ls using modified code from Allison and McEwen (2000) with input from Michael Allison.

3. Overview of seasonal cap recession

At Ls ~ 25, the extent of the seasonal cap is similar in all three martian years (Fig. 2, top panel). The underlying albedo patterns of the residual ice dome and surrounding dune fields are evident through the seasonal carbon dioxide. In MY 30, there are large atmospheric dust events, beginning near Ls 25 that obscures the surface and leaves the surface albedo patterns obscured until ~Ls 35. At this time, outlier craters still exhibit frosted, high albedo rims, and the patterns are similar in all years. By Ls 45 (Fig. 2b), infrared data from OMEGA and CRISM has shown that the uppermost surface composition appears to be dominated by the signature of water ice (Appéré et al., 2011; Brown et al., 2012). MARCI data show brighter regions that appear on scarp faces and on topographic plateaus of the residual dome in MY 29 and 31. In MY 30, atmospheric dust is again obscuring subtle surface brightness changes. By Ls 72, there are notable distinctions in each year as the seasonal cap reaches the latitude of the dark sand sea, particularly in the region near Olympia Undae as seen in Fig. 2 (bottom panel) at Ls 83.5. The contribution of atmospheric dust and aerosols will be discussed later, however the transient appearance of atmospheric phenomena is readily distinguished in the movies due to their mobility from day to day. Bright deposits linked to the surface evolve more slowly over many days or several degrees of Ls.

The seasonal and interannual variability of small features near the periphery of the residual north polar cap (RNPC) were discussed in our first paper (Cantor et al. (2010)). In addition, that study focused on Shackleton's Grooves, the part of Gemini Scopuli near 300°W (60°E) and Abalos Mensa, a small outlier of bright frost at 80.8N 72W. These large regional sections show retreat of high albedo deposits followed by brightening after Ls 95. In all years, similar to what was observed by Calvin and Titus (2008), these regions follow a similar seasonal pattern. The Ls of the minimum in high albedo coverage is roughly the same in all years. However, details of the high albedo deposit cover are variable. We note that the extent of high albedo deposits after Ls 100 is greater in MY 29 and the area associated with gypsum deposits on dune crests (e.g. Calvin et al., 2009; Horgan et al., 2009) is also covered longer by high albedo frost early in this particular martian spring.

Cantor et al. (2010) noted that the albedo of Gemini Scopuli at the minimum (~0.25 in Band 3 at 604 nm) was similar to unfrosted surface materials at lower latitudes than the polar dune field. By Ls 114, the albedo (~0.45 in Band 3) was again similar to the values observed on the top of the polar dome on Gemini Lingula. The lack of ice signature followed by increased water ice coverage is also seen in the OMEGA data of Langevin et al. (2005) from Ls 93–98 to Ls 107–110, and CRISM data from Ls 80–86 (Brown et al., 2012) to Ls 132–138 (Brown and Calvin, 2012). Both of these infrared spectral studies note changes in water ice feature strength associated with changes in ice grain size, though the seasonal coverage is different between the two studies.

Additional retreat of high albedo deposits is noted in MY 30. A new high albedo deposit appears off a reentrant in Olympia Planum, that later disappears. In MY 30, portions of Olympia Planitia have larger areas of high albedo. In both years sustained bright patches appear along the cap margins and while some are persistent between years, they are also variable over the northern summer.

Table 1
MRO observations of seasonal and residual ices.

Mars year Earth date of Ls = 0	North recession Ls 25–95	North summer Ls 95–180	South recession Ls 180–325	South summer Ls 325–360
MY 28	Not observed, before Sci Ops	Start ~Ls 120	Planet wide dust event	
1/21/2006		11/06–1/07	4/07–10/07	10/07–12/07
		p01–p03	p06–p11	p12–p14
MY 29	2/08–7/08	7/08–12/08	12/08–8/09	Not observed (spacecraft recovery)
12/9/2007	p16–p21	p21–b04	b04–b12	(b13–b15)
MY 30	12/09–5/10	5/10–11/10	11/10–7/11	7/11–9/11
10/26/2009	b16–b21	b21–g05	g05–g13	g13–15
MY 31	11/11–4/12	4/12–10/12	10/12–5/13	6/13–7/13
9/13/2011	g17–g21	g21–d05	d05–d12	d12–d14