AN OBSERVATIC.. AL SEARCH FOR CO_2 ICE CLOUDS ON MARS; James F. Bell III (NRC/NASA Ames, MS 245-3, Moffett Field CA 94035), Wendy M. Calvin (USGS Branch of Astrogeology, Flagstaff AZ 86001), James B. Pollack (NASA Ames, MS 245-3, Moffett Field CA 94035), and David Crisp (JPL/Caltech MS 169-237, Pasadena CA 91109).

Introduction: CO_2 ice clouds were first directly identified on Mars by the Mariner 6 and 7 infrared spectrometer limb scans [1]. These observations provided support for early theoretical modeling efforts of CO_2 condensation [2]. Mariner 9 IRIS temperature profiles of north polar hood clouds were interpreted as indicating that these clouds were composed of H_2O ice at lower latitudes and CO_2 ice at higher latitudes [3]. The role of CO_2 condensation on Mars has recently received increased attention because (a) Kasting's [4] model results indicated that CO_2 cloud condensation limits the magnitude of the proposed early Mars CO_2/H_2O greenhouse, and (b) Pollack *et al.*'s [5] GCM results indicated that the formation of CO_2 ice clouds is favorable at all polar latitudes during the fall and winter seasons. These latter authors have shown that CO_2 clouds play an important role in the polar energy balance, as the amount of CO_2 contained in the polar caps is constrained by a balance between latent heat release, heat advected from lower latitudes, and thermal emission to space. The polar hood clouds reduce the amount of CO_2 condensation on the polar caps because they reduce the net emission to space [5].

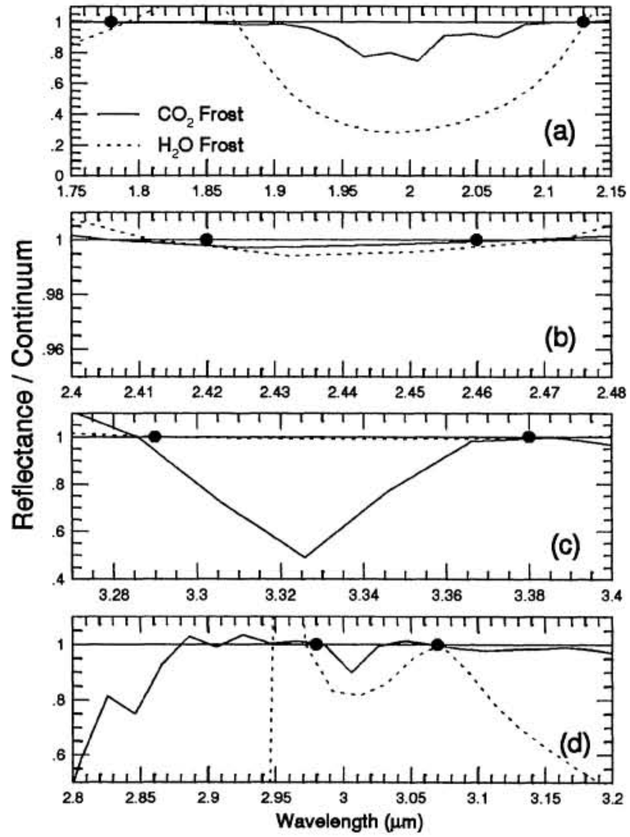
There have been many extensive laboratory spectroscopic studies of H_2O and CO_2 ices and frosts [*e.g.,* 6-9, 13]. In this study, we use results from these and other sources to search for the occurrence of diagnostic CO_2 (and H_2O) ice and/or frost absorption features in groundbased near-infrared imaging spectroscopic data of Mars. Our primary goals are (a) to try to confirm the previous direct observations of CO_2 clouds on Mars; (b) to determine the spatial extent, temporal variability, and composition (H_2O/CO_2 ratio) of any clouds detected; and (c) through radiative transfer modeling, to try to determine the mean particle size and optical depth of polar hood clouds and thus to assess their role in the polar heat budget.

Data Set: The telescopic data examined here were obtained in November 1990 at the NASA IRTF on Mauna Kea using the ProtoCAM near-IR imaging spectrometer [10]. The data set is composed of whole-disk images of Mars at 83 wavelengths between 1.3 and 4.0 μm (R = 100). Data reduction and calibration details are discussed elsewhere [11]. Results are presented here using relative band depth (RBD) maps of the planet. RBD maps are ratios between co-registered images obtained in an absorption band to images that represent the local continuum, where a spectrum of the whole disk has first been divided from all the data in order to remove telluric contamination. Thus, RBD maps show the spatial variations in an absorption band relative to the global "average" depth of that feature [11]. Laboratory frost spectra of CO_2 [7] and H_2O [12] were convolved to the spectral resolution of the telescopic data for comparison and simulation of the RBD maps.

Results and Discussion: Four wavelength regions were examined in detail: 2.04, 2.44, 3.33, and 3.02 μm. These wavelengths exhibit absorptions due to both H_2O and/or CO_2 frost in pure lab spectra [*e.g.,* 6-9]. In Figure 1 we present local-continuum-removed CO_2 and H_2O frost data convolved to the spectral resolution of the telescopic data. The local continuua were chosen at the same wavelengths as the continuua used for the RBD maps, and thus this figure simulates an endmember case (pure frosts) of what could be seen in the image data. The RBD maps corresponding to each of these wavelength regions are shown in Figure 2.

All four RBD maps reveal substantial spatial structure in the north polar region. Specifically, maps at 2.04, 2.44, and 3.33 μm all show a region of enhanced absorption in the north polar region (north of 50°). This polar enhancement is consistent with that observed in a 3.0/2.5 μm ratio map (Figure 3) that has been interpreted as evidence of water ice in the polar hood [11]. Figures 1a,b show that the polar features in Figure 2 at 2.04 and 2.44 μm may in fact be due to water ice; however, the feature at 3.33 μm cannot be caused by water (Figure 1c) and is more likely due to either CO_2 frost or an unidentified surface or atmospheric absorber. Comparison with Figures 2a, 2b, and 3 shows that the 3.33 μm absorber extends farther south than the features ascribed to water frost. It is interesting to note that the 3.33 μm band has also been reported in Mariner 7 spectra of the Mars south polar cap [13]. The 3.02 μm RBD image shows a remarkable

Figure 1: Pure H_2O and CO_2 frosts convolved to our telescopic resolution with a local continuum removed (solid dots). These data provide an endmember simulation of the Band Depth Maps seen in Figure 2.



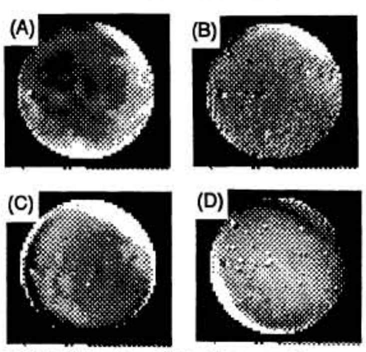


Figure 2: RBD Maps using the continuum values of Fig. 1.: (A) 2.04 μm; (B) 2.44 μm; (C) 3.33 μm; and (D) 3.02 μm. Bright is > disk average band depth; dark is < than average [11]. North is at 2:00.

dark band (weaker than average band depth) that circles the north polar region between latitudes ≈ 50° to 65°. The polar surface north of ≈ 65° does not show enhanced absorption. Figure 1d reveals that water ice should be more absorbing than CO_2 ice for this choice of continuum points, however the sense of the absorption should yield a bright feature (greater than average band depth) rather than a dark band in the RBD map. It is possible that the dark band may be related to the small "emission" peak seen near 3.05 μm in the continuum-removed spectrum of CO_2 frost in Figure 1d. The alternative, that the dark band is due to water ice in the polar hood, is inconsistent with the fact that no absorption is evident north of 65°. The spatially-confined nature of this feature also raises the possibility of a surface, rather than an atmospheric, origin, possibly related to polar cap edge phenomena involving mixtures of H_2O/CO_2 ice and dust.

In summary, these data reveal compelling evidence for solid CO_2 absorption features at 3.33 and 3.02 μm. The feature at 3.33 μm is most diagnostic of CO_2, and the spatial distribution of this feature is consistent with the occurrence of CO_2 clouds in the north polar hood. The spatial distribution of the 3.02 μm feature is more enigmatic because it occurs as an "emission" feature in continuum-removed data and in a spatially-confined north polar annulus. There is as yet no definitive evidence demonstrating a surface or atmospheric origin for either of these two bands; however, this will be the subject of intense future study.

Figure 3: Ratio image of 2.5 to 3.0 μm that shows uniform limb darkening and additional polar absorption attributed to H_2O ice clouds [11] (bright = greater 3 μm band depth).

References: [1] Herr and Pimentel (1970) *Science, 167*, 47. [2] see review in James *et al.* (1992) in Mars, pp. 946-948, Univ. Arizona Press. [3] Briggs and Leovy (1974) *BAMS, 55*, 278. [4] Kasting (1991) *Icarus, 94*, 1. [5] Pollack *et al.* (1990) *JGR, 95*, 1447. [6] Kieffer (1970) *JGR, 75*, 501. [7] Fink and Sill (1982) in Comets, pp. 164-202, Univ. Arizona Press. [8] Warren (1984) *Appl. Optics, 23*, 1206. [9] Warren (1986) *Appl. Optics, 25*, 2650. [10] Bell and Crisp (1991) *LPSC XXII*, 73. [11] Bell and Crisp (1993) *Icarus*, in press. [12] The H_2O frost spectrum used was calculated by one of us (WMC) using Hapke modeling and the optical constants of Warren (1984). [13] Calvin (1990) *JGR, 95*, 14743.