AN OBSERVATIONAL SEARCH FOR CO₂ 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: CO₂ 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 CO₂ condensation [2]. Mariner 9 IRIS temperature profiles of north polar hood clouds were interpreted as indicating that these clouds were composed of H₂O ice at lower latitudes and CO₂ ice at higher latitudes [3]. The role of CO₂ condensation on Mars has recently received increased attention because (a) Kasting's [4] model results indicated that CO₂ cloud condensation limits the magnitude of the proposed early Mars CO₂/H₂O greenhouse, and (b) Pollack et al.'s [5] GCM results indicated that the formation of CO₂ ice clouds is favorable at all polar latitudes during the fall and winter seasons. These latter authors have shown that CO₂ clouds play an important role in the polar energy balance, as the amount of CO₂ 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 CO₂ condensation on the polar caps because they reduce the net emission to space [5].

There have been many extensive laboratory spectroscopic studies of H₂O and CO₂ 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 CO₂ (and H₂O) 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 CO₂ clouds on Mars; (b) to determine the spatial extent, temporal variability, and composition (H₂O/CO₂ 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 CO₂ [7] and H₂O [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 H₂O and/or CO₂ frost in pure lab spectra [e.g., 6-9]. In Figure 1 we present local-continuum-removed CO₂ and H₂O 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 CO₂ 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$_2$O 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 $\mu$m; (B) 2.44 $\mu$m; (C) 3.33 $\mu$m; and (D) 3.02 $\mu$m. Bright is $>$ disk average band depth; dark is $<$ than average [11]. North is at 2:00.


Figure 3: Ratio image of 2.5 to 3.0 $\mu$m that shows uniform limb darkening and additional polar absorption attributed to H$_2$O ice clouds [11] (bright = greater than 3 $\mu$m band depth).