USE OF MARS ODYSSEY GRS RESULTS TO CONSTRAIN THE EXCHANGEABLE MASS OF MARTIAN CO_2.

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Introduction:

It is known that the atmospheric pressure on Mars varies significantly over a martian year due to the formation of seasonal CO_2 frosts at each pole during their winter season. Knowing the total mass of exchangeable CO_2 is an important constraint on general circulation models (GCM) of the martian atmosphere. This quantity is not precisely known and is generally a free parameter in GCMs [Hourdin et al. 1993, 1995; Pollack et al. 1990 and Haberle et al. 1993]. For example, Hourdin et al. (1993) found a total exchangeable mass, expressed as the equivalent globally averaged pressure, of 7.2 mbar, while Hourdin et al. (1995) found 6.854 mbar.

The mass of the atmosphere is constrained by the variations in pressure at the two Viking lander sites, but a significant amount of the exchangeable reservoir of CO_2 is present in the seasonal frost. The Viking data can constrain the amount of CO_2 in the atmosphere, but it provides only a weak constraint on the total amount of exchangeable CO_2 because there is no time when both poles are free of the seasonal frost.

Estimates of the thickness of the CO_2 frost have been determined by instruments of the GRS suite [Boynton et al., 2005] on the 2001 Mars Odyssey Mission. The High-Energy Neutron Detector (HEND) and the Neutron Spectrometer (NS) were used to estimate the thickness based on the effect of CO_2 frost on the orbital flux of epithermal and fast neutrons [Feldman et al. 2003; Prettyman et al. 2004; Litvak et al. 2005]. The Gamma Sensor System was used to estimate the thickness based on the attenuation of the hydrogen gamma-ray flux caused by the frost [Kelly et al. 2003]. These observations provide a further constraint on the total exchangeable mass of CO_2, but they all have, to a greater or lesser extent, some significant model dependence in their results.

This work is an effort to understand the error sources and to minimize the model dependency of the GRS results. The aim is to provide a hard quantitative constraint on the mass of CO_2 present in the seasonal frost.

Nature of the GRS data:

The neutron instruments rely on model-dependent calculations using a Monte Carlo program, MCNPX, which calculates the expected neutron flux generated from cosmic ray interaction with a variety of models of frost thicknesses over different layers of soil and ice. It is not clear exactly how good a job this program does in exactly predicting the neutron fluxes, but something on the order of 10% is probably reasonable. It can be seen from figure 1 that the epithermal flux increases linearly with frost thickness over the range from 20 to 60 g/cm^2 but then begins to saturate. In the linear range, a 10% error in the model calculations yields an error of 5.2 g/cm^2. It is clear from the figure that the fast neutron flux, which has a much weaker dependence on frost thickness, yields a much larger error for a given uncertainty in the model calculation.

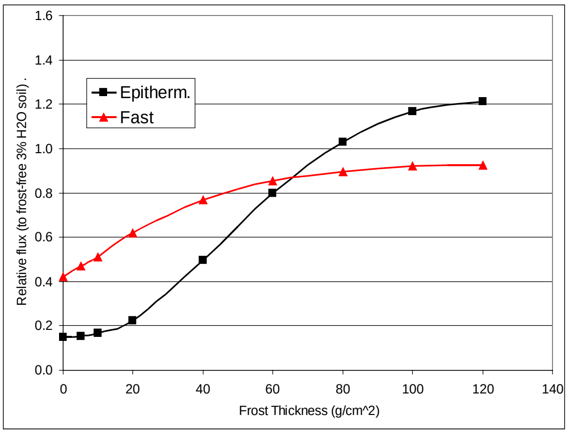

Fig. 1. Relative epithermal and fast neutron flux vs frost thickness. A 10% uncertainty in the epithermal flux or the MCNPX model calculation yields a 5.2 g/cm^2 error in the frost thickness.

In the work of Feldman et al. (2003) the thickness of the frost was taken as a known quantity (ground truth) and actually used as the basis for calibration of the Neutron Spectrometer. The thickness of the frost calculated by a GCM was adjusted slightly based on an early gamma-ray determination of the frost thickness. In this case the data from the Neutron Spectrometer cannot be used to independently determine the frost thickness in an absolute sense since the model frost was the basis for the instrument calibration. These data can, however, be used to estimate the relative thickness of frost at other times of the martian year.

The gamma data is also somewhat model dependent, but in different ways. To first order, the model dependency of the gamma results is small. The calculation of the frost thickness relies simply on a comparison of the H gamma-ray flux determined during the summer frost-free period with the flux at various times during the year when the frost is present. The frost attenuates the gamma-ray signal based on very well known mass attenuation coefficients.

If this attenuation were the only effect on the gamma signal strength, there would be no model dependencies at all. There are second-order effects, however, that need to be taken into account. Because the presence of the CO_2 frost has a significant effect on the moderation of neutrons as pointed out above, we have to make an adjustment to the un-attenuated H gamma flux. The flux of H gamma rays depends directly on the flux of thermal neutrons, which is the excitation source for the gamma rays.

We examined this effect by using the same Monte Carlo program mentioned above, MCNPX. We found that the presence of the CO_2 frost raised the thermal-neutron flux in the soil, where the H gamma rays are generated, by about 20% in the range of frost thicknesses applicable for this work. Here we also have a dependence on the ability of MCNPX to accurately predict the neutron flux, but since it is only a small change on the frost-free neutron distribution, we found that a 10% error in the MCNPX results gives only a 2% error in the calculated flux. This uncertainty translates to a 2% uncertainty in the implied thickness of the frost.

An additional uncertainty on the determination of the frost thickness via gamma rays derives from an uncertainty in the H background signal that comes from the GRS instrument itself. We estimate this background signal from the observed flux determined over the winter poles when the CO_2 frost is thickest. This frost is nearly thick enough to fully attenuate the H signal coming from Mars, but a few percent of the Mars flux still comes through the thickest frost. If we knew the frost thickness, we could account for the amount that is transmitted through the frost, but then we would find ourselves in the same circular reasoning that we had with the Neutron Spectrometer. We could use the data for the determination of the relative thickness of frost at other times in the year, but we would not have an independent verification on the absolute thickness.

For this work we took a wide range of estimates of the amount of CO_2 in the southern polar cap at its maximum extent, and we calculated a range of background signals for this range in frost mass. The range of CO_2 frost values used (again, in equivalent globally averaged pressure) was 1.46 to 1.72 mbar. The uncertainty in the background is not so important in determining the thickness of the frost when the frost is thinner than about 40 g/cm^2 because the background is a small fraction of the total flux.

For this work we concentrate on the determination of the total mass of CO_2 on the ground during the two minima in the total mass of CO_2 frost vs. L_s (figure 2). During these times there is a small amount of frost at each pole. These frost thicknesses are all less than 40 g/cm^2, and thus the uncertainty in the background signal is not so significant.

Results:

The GRS gamma data were averaged over 15 degrees of L_s and were binned in 5-deg latitude bands. The thickness of the CO_2 frost was determined in each band, and this thickness (units of g/cm^2) was multiplied by the surface area within that latitude band to give the mass in that band. The total mass of CO_2 present as frost was determined simply as the sum of each of these latitude bands.

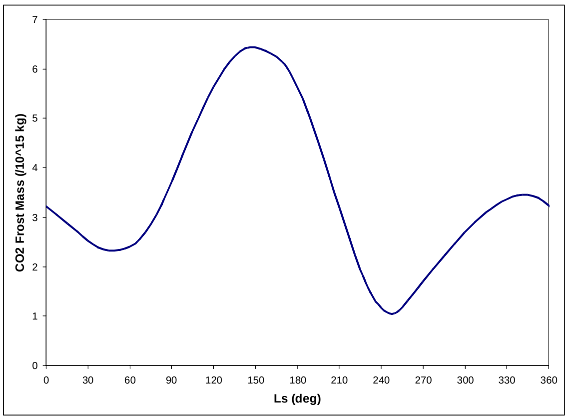

Figure 2. GCM estimate of the mass of frost on the ground vs. L_s. These results are from model 2002.17 and are shown only to point out the two minima that occur near L_s=60° and L_s=240°.

The results are shown in Table 1. The atmospheric pressure is the average from two of our models that do a good job of matching the pressures at the Viking landing sites (runs 2002.17 and 2005.26). The sum of the equivalent pressures in the frost and in the atmosphere is taken as our best estimate of the total inventory of exchangeable martian CO_2.

In Table 2 we show our estimates of all known error sources in the mass of frost dervived from GRS data. Based on the RMS deviations in the fit of the GCM, we tentatively estimate the uncertainty on the GCM-derived atmospheric pressure to be about 0.1 mbar (figure 3).

Table 1. Partitioning of exchangeable CO_2 between frost and atmosphere at the two minima in frost thickness vs. L_s.

	L_s 45° to 60°	L_s 240° to 255°
Mass in frost (kg/10^{15})	1.91	1.33
Equiv. pressure (mbar)	0.496	0.343
Pressure in atmos. (mbar)	6.45	6.71
Total CO_2 (mbar)	6.95	7.05

Table 2. Estimates of uncertainties from all known sources in GRS determination of frost thickness (global equivalent pressure).

Gamma counting statistics	0.015 mbar
Background uncertainty	0.011 mbar
MCNPX model	0.01 mbar
Overall uncertainty in frost (RSS)	0.02 mbar

Discussion:

Our current best estimate of the total mass of CO_2 in the atmosphere-frost reservoirs is 7.00 ± 0.10 mbar. The uncertainty of 0.1 mbar on the amount of CO_2 is lower than the typical range found in different GCM solutions, e.g. the two values cited in the introduction differ by 0.35 mbar. It is hoped that using this estimate of the total CO_2 inventory as a constraint will provide more insight into the seasonal factors that affect the exchange of CO_2 between the atmosphere and frost.

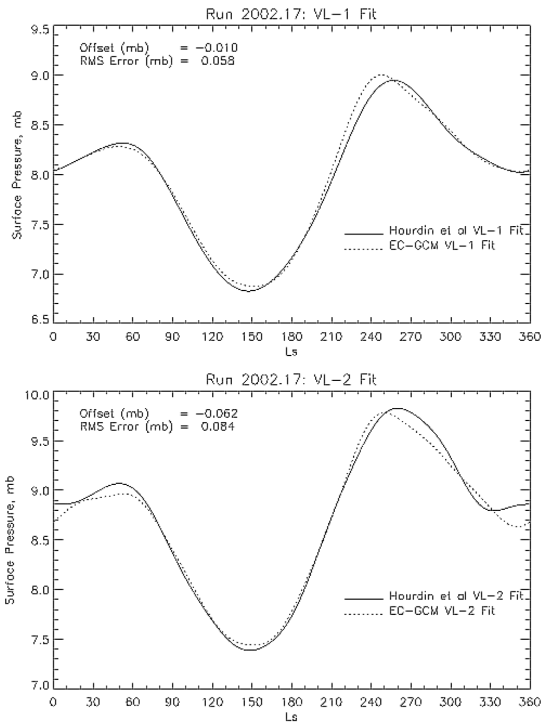

Figure 3. Comparison of pressures between GCM run 2002.17 and the Viking observations.

We are also hopeful that this constraint on the total inventory of CO_2 will provide a much more tightly constrained mass of frost during the peak winter seasons. If, as expected, this cuts down the possible range of winter-time frost masses, then we can determine a more reliable background signal for the H gamma rays by making the constraint that the total mass of frost must equal the GCM predicted masses during each winter. With a more tightly constrained H background determination, we can have more confidence in the absolute frost thickness distribution as a function of latitude and time of year.

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