SEASONAL CYCLE OF CARBON DIOXIDE AND ATMOSPHERIC CIRCULATION IN MARS' SOUTHERN HEMISPHERE AS OBSERVED BY NEUTRON SPECTROSCOPY.

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Introduction: The south polar seasonal cap consists of CO_2 ice that condenses and sublimes in response to seasonal changes in insolation, advancing equatorward during the fall and winter and receding poleward during spring [1]. Cycling of CO_2 between the surface and atmosphere at high latitudes plays a significant role in global atmospheric circulation. During winter, the south polar seasonal cap may contain up to 30% of the total atmospheric mass [2]. The rate of cap growth and recession depends on factors such as atmospheric dust optical depth, surface thermal inertia, and the albedo of the CO_2 ice, all of which affect the polar energy balance [3].

While the martian atmosphere consists primarily of CO_2, it also contains lesser amounts of noncondensable gases, including N_2 and Ar [4]. As the cap grows, mass is advected poleward from lower latitudes. Because the net flow of mass is towards the pole and CO_2 is being removed from the atmosphere, an increase in the column abundance of noncondensable gases at high latitudes is expected to occur. As the CO_2 ice sublimes during spring, the situation is reversed, and noncondensable gases may be depleted relative to the global average. For example, enrichment of noncondensable gases near the surface in the polar regions has been considered in interpreting observations of anomalously low surface brightness temperatures (cold spots) by Viking and Mars Global Surveyor [5,6,7]; however, other possibilities such as granular ice or snowfall may also explain these observations [8]. Dynamical weather patterns, such as the formation of a polar vortex and latitudinal mixing produced by atmospheric waves, affect the enrichment and depletion of noncondensables. Thus, noncondensable gases could serve as an atmospheric tracer, providing information needed to understand these processes.

The purpose of this study is to analyze data from the Mars Odyssey Neutron Spectrometer to determine the column abundance of noncondensable gases and CO_2 ground ice as a function of position and time in the southern hemisphere. Data acquired by the neutron spectrometer span the advance and recession of the south polar cap during a single martian year. The spectrometer can resolve spatial features on the surface that are 10° of arc length in scale (600 km) and temporal variations on the order of 5° of L_S can be monitored.

Theory: Neutrons are produced in the surface and atmosphere by galactic cosmic rays (GCR). Neutrons produced by these interactions lose energy by successive collisions with atmospheric and surface nuclei, ultimately achieving thermal equilibrium with their surroundings. A portion of the neutron population escapes the atmosphere and reaches orbital altitude (400 km). The neutron spectrometer sorts these neutrons into three energy ranges: fast (>0.7 MeV), epithermal (between 0.1 eV and 0.7 MeV), and thermal (<0.1 eV). Count rates measured in these energy ranges depend on the composition and structure of the surface and atmosphere [9]. Fast neutrons are sensitive to the column density of CO_2 surface ice. Epithermal neutrons are sensitive to CO_2 surface ice and also depend weakly on the abundance of noncondensable gases. Thermal neutrons have the highest sensitivity and range for determining CO_2 surface ice abundance and are also very sensitive to the column abundance of noncondensable gases, whose main constituents (N_2 and Ar) strongly absorb thermal neutrons. Based on simulations of the response of the spectrometer to neutrons produced by GCR interactions, we constructed a system of equations that can be solved to uniquely determine the column abundance of CO_2 surface ice and noncondensable gases from measured neutron count rates. Note that all three neutron energy ranges are weakly sensitive to surface pressure. In the analysis presented here, a constant surface pressure of 4 mbar was assumed.

Sensitivity to N_2 and Ar: To demonstrate the sensitivity of thermal neutrons to the enrichment and depletion of noncondensable gases, we made a scatter plot of zonally-averaged count rates (between latitudes -70° and -60°) for thermal vs. epithermal neutrons (**Fig. 1**). The count rates correspond to roughly 5° L_S intervals. Arrows on the plot show the progression of time as the frost advances and recedes. Epithermal neutrons are weakly sensitive to noncondensable gases and are thus used in the figure as a proxy for the column abundance of CO_2 ice. If there was no variation in atmospheric composition, the count rates would scatter about a single regression line since both epithermal and thermal neutrons would only depend on CO_2 ice column abundance. However, the observed count rates trace a well-defined loop. Thermal neutron count rates are lower during the advance than during the recession, which suggests that the column abundance of N_2 and Ar is elevated during cap growth [10].

Results and Conclusions: The time variation of the column density of CO_2 ice and the weight fraction of noncondensable gases was determined from the neutron counting data. Results of the analysis are shown for the 65° to 75° south latitude zone (**Fig. 2**). The weight fraction was calculated assuming composition of the atmosphere was constant throughout the column. The abundance of noncondensable gas rises rapidly achieving a broad maximum during the winter when the condensation rate is high. As the condensation rate diminishes and the column density of CO_2 ice achieves its maximum value, the weight fraction of noncondensable gases begins to drop rapidly due to the advection of noncondensable gases to lower latitudes, which is driven by the sublimation of the seasonal cap. The fact that a broad maximum is sustained during cap growth and that high enrichment is achieved (nearly a factor of 5 times the summertime value) suggests that latitudinal mixing by eddies across the equatorward boundary of the south winter polar vortex is weak. If the entire column is uniform in composition, the observed enrichment of noncondensable gases should have little effect on the CO_2 condensation temperature.

The mass of CO_2 surface ice was determined by integrating the column density over the surface. The total mass of CO_2 in the seasonal cap along with the mass for selected zonal regions is shown as a function of time in **Fig 3**. The total atmospheric column density (atmospheric mass) predicted by the Ames Research Center General Circulation model for equatorial latitudes (blue curve) and near the south pole (red curve) is shown for comparison. The peak inventory of CO_2 (7×10^{18} g) in the seasonal cap determined by neutron spectroscopy is similar to that predicted by the ARC-GCM (6.5×10^{18} g) and also corresponds to the predicted minimum in atmospheric mass. The neutron measurements confirm that the southern seasonal cap can contain almost 30% of the total atmospheric mass of approximately 2.5×10^{19} g. Further work is underway to determine longitudinal variations in the seasonal cap and atmosphere, and to include temporal and spatial variations in surface pressure in the analysis. The results will be used to constrain parameters for the polar energy balance and atmospheric circulation in the southern hemisphere.

References: [1] Neugebauer, G. et al., *Astron. J.* 76, 719-749, 1971. [2] Prettyman, T.H. et al., 3rd International Conference on Mars Polar Science and Exploration, #8099, 2003. [3] Paige, D.A. and A.P. Ingersoll, *Science* 228, 1160-1168, 1985. [4] Owen, T. et al., *JGR* 82, 4635-4639, 1977. [5] Kieffer, H.H. et al., *Science* 193, 780-786, 1976. [6] Hess, S.L., *JGR* 84(B6), 2969-2973, 1979. [7] Weiss, B.B., and A.P. Ingersoll, *Icarus* 144, 432–435, 2000. [8] Titus, T.N., *JGR* 106(E10), 23,181-23,196, 2001. [9] Prettyman, T.H. et al., submitted manuscript *JGR*, 2003. [10] Prettyman, T.H. et al., Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract P21A-06, 2003.

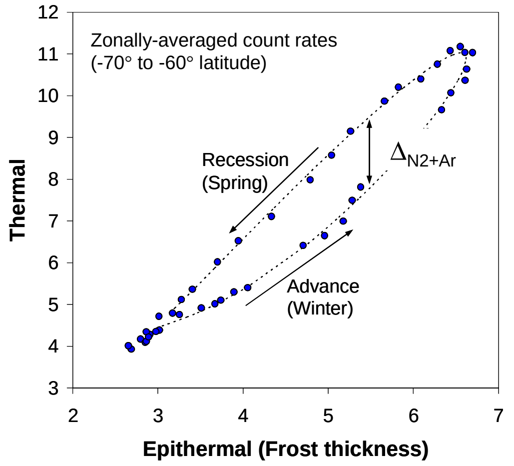

Figure 1. (see text)

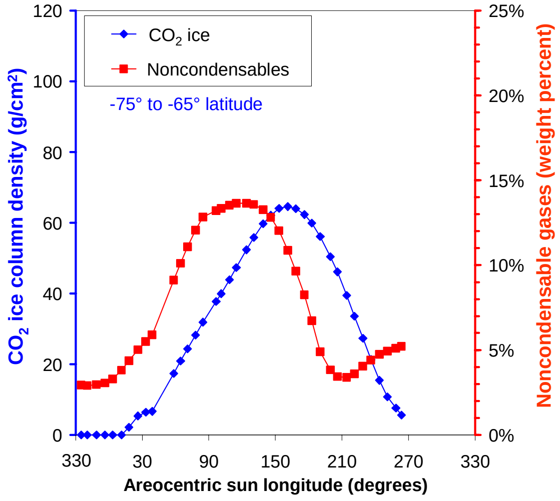

Figure 2. (see text)

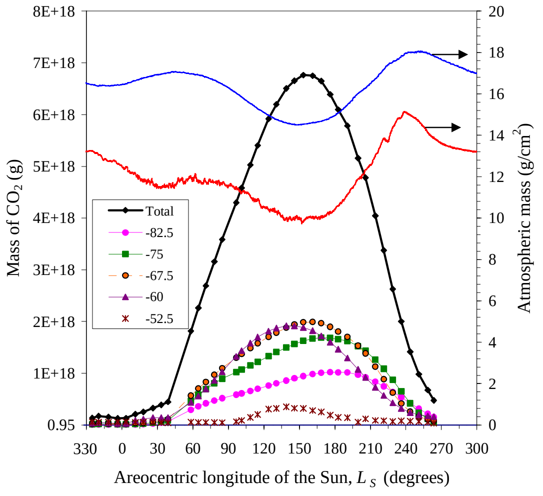

Figure 3 (see text)