SOUTH POLAR Ar ENHANCEMENT AS A TRACER FOR SOUTHERN WINTER HORIZONTAL MERIDIONAL MIXING. A.L. Sprague[1], W.V. Boynton[1], K. Kim[2], R. Reedy[2], K. Kerry[1], and D. Janes[1]. [1]Lunar and Planetary Laboratory, 1629 E. University Blvd., University of Arizona, Tucson, AZ 85721-0092, sprague@lpl.arizona.edu;wboynton@gamma1.lpl.arizona.edu; [2] Institute of Meteoritics, MSC03-2050, University of New Mexico, Albuquerque, NM, 87131-0001 kkim@unm.edu; rreedy@unm.edu

Introduction: Measurements made by the Gamma Ray Spectrometer (GRS) on Mars Odyssey [1] during 2002 and 2003 show an obvious increase in the gamma flux of 1294 keV gamma rays resulting from the decay of ^{41}Ar. ^{41}Ar is made by the capture of thermal neutrons by atmospheric ^{40}Ar. The increase measured above the southern polar region has permitted calculation of the increase in mixing ratio of Ar from L_s 8 to 100 between latitudes 75S and 90S. The peak in Ar enhancement occurs about 200 Earth days after CO_2 freeze-out has begun, indicating that up to this time equatorward meridional mixing is rapid enough to move enhanced Ar from the polar regions northward. Although the CO_2 frost depth continues to increase from L_s 110^o to 190^o, the Ar enhancement steadily decreases to its baseline value reached at about L_s 200^o. Our data permit an estimate of the horizontal eddy mixing coefficient useful for constraining equatorward meridional mixing during southern winter and a characteristic mixing time for the polar southern winter atmosphere. Also, using the drop in excess Ar measured by the GRS from L_s 110^o to 200^o, we estimate an eddy coefficient appropriate for meridional mixing of the entire Ar excess back to the baseline value shown in Fig. 1.

The horizontal eddy mixing coefficients are derived using Ar as a tracer much as the vertical eddy mixing coefficient for the Earth's troposphere is derived using CH_4 as a minor constituent tracer. The estimation of meridional mixing for high latitudes at Mars is important for constraining parameters used in atmospheric modeling and predicting seasonal and daily behavior. The calculations are order of magnitude estimates that should improve as the data set becomes more robust and improves our models.

Data and Analysis: The gamma ray flux at 1294 keV measured at the spacecraft depends upon the abundance and distribution of Ar and thermal neutrons as well as the attenuation of the gamma-ray flux by the atmosphere. Variations in gamma-ray flux caused by changes in the thermal neutron flux produced in the CO_2 frost cap are removed by taking a simple ratio of Ar gamma flux at 1294 keV to that from the 1381 keV gamma-ray made by thermal neutron capture in the Ti structure of the GRS. Because the Ti content in the GRS is constant, the Ar flux can be normalized to that from Ti as a way of eliminating the effects of changing thermal neutron flux above the polar cap as the CO_2 frost thickens. It cannot be assumed *a priori* that the thermal neutron flux determined in orbit changes in direct proportion to the change in the average neutron flux in the atmosphere. To address this question we ran models using the Monte Carlo N Particle eXtended code (MCNPX) [2] to determine the change in thermal neutron flux above surfaces covered with 0, 20, 40, and 80 g/cm^2 of CO_2 frost. The neutron flux increase at all altitudes in the atmosphere, due to the increasing frost thickness, was found to be in direct proportion to the increase in flux at the Odyssey orbital altitude. Thus, no additional correction to thermal neutron flux is required in addition to the correction made by obtaining the Ar/Ti ratio in gamma counts at the detector. The relative increase in Ar abundance is illustrated in Fig. 1 where the ratio of Ar/Ti gamma flux at the detector is plotted as a function of L_s. These measurements are taken over the region from 75S to 90S latitude. Error bars are 1 σ limits.

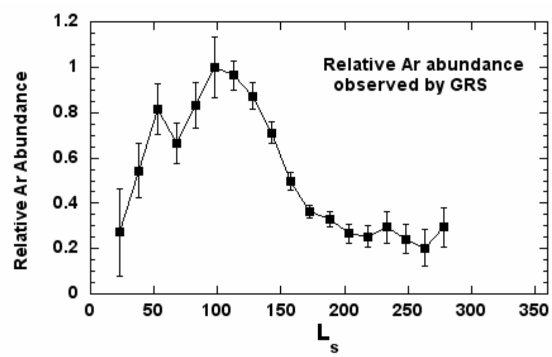

Fig. 1. *Gamma flux ratio from neutron captures in atmospheric Ar to that in Ti in the GRS as a function of season on Mars measured by the GRS on the Mars Odyssey spacecraft.*

Ar is well mixed vertically: To address the question of Ar vertical mixing, we calculated upper and lower limits to the mixing time based on horizontal wind speeds of 0.5 m/s [3] and 10 m/s [4]. In each case the horizontal wind speeds are for southern winter at high latitude. Vertical eddy motions were estimated using mixing length theory where the vertical eddy speed w is estimated from the product of the horizontal wind speed u and the ratio of the scale height H to the radius R of the planet. The product of w and H then gives an estimate for the vertical eddy mixing coefficient K_z (cm^2 s^{-1}) [5]. Vertical eddy speeds of 0.15 and 3 cm/s respectively, were estimated from the horizontal wind speeds above.

An estimate of the vertical mixing time T (an estimate of the time it takes to stir a minor constituent uniformly in the vertical column of atmosphere) can then be obtained by the ratio of H^2 to K_z. We find T of between 80 days and 4 days using the horizontal wind speeds from [3] and [4] respectively. An additional estimate of polar night updraft speeds and duration was made to better understand MOLA observations of CO_2 ice clouds and precipitation [6]. MGCM simulations found updrafts as swift as 10 – 100 cm/s could be present. We conclude Ar is well mixed above the southern winter polar region.

Horizontal eddy mixing coefficient: To compare the mass of Ar detected in the atmosphere to the mass left behind by the freezing out of CO_2 during the same period we used a volume fraction of Ar = 0.016 [7] and estimate the mass of CO_2 frost on the surface from the NASA Ames Research Center Mars Global Climate Model (NASA ARC MGCM) [8] [9].

In Fig. 2 the total mass of Ar over the 75S to 90S latitude region derived from the GRS data (filled squares), and the excess Ar left behind from CO_2 freeze-out derived from the MGCM (open circles) are shown as a function of L_s.

We find that the peak of the excess Ar measured by the GRS has a mass mixing ratio of 0.041 while the theoretical excess for the same season based upon the simple calculation derived from the thickness of the deposited CO_2 frost (as shown in Fig. 2) is 0.08.

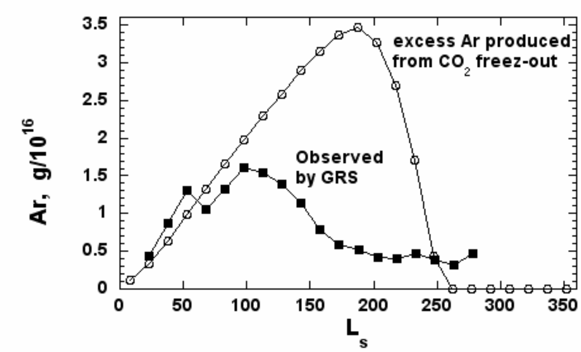

Fig. 2. *Theoretical (from MGCM model) excess Ar, and measured total Ar over latitudes 75S - 90S.*

The discrepancy between the theoretical and measured mass of Ar suggests that Ar is transported away by equatorward meridional mixing slightly faster than it is building up from CO_2 freeze-out.

We now derive the winter eddy diffusion coefficient using the data between L_s 8° and 108°. The mass eddy diffusion flux equation gives: $K_x = \varphi_i / (\rho_{bulk} * d f_i / d x)$ where K_x is the horizontal eddy mixing coefficient ($cm^2 s^{-1}$), φ_i (# $cm^{-2} s^{-1}$) is the flux of Ar atoms out of the polar region (we estimate as a circular cap of 15 degrees latitude radius), ρ_{bulk} ($g\ cm^{-3}$) is the average density of the polar atmosphere for the southern winter season, f_i (unitless) is the enhanced mixing ratio of Ar in the polar atmosphere and x (cm) the horizontal mixing length. For the mixing length we use 1/4 the martian radius or about the arc of 15 degrees of latitude. We obtain and eddy meridional mixing coefficient of $9.8 \times 10^7\ cm^2\ s^{-1}$. We also make an estimate of the time to mix Ar horizontally out of the polar regions and obtain a mixing time of about 800 Earth days. However, based on the GRS data, it appears that meridional mixing has removed excess Ar to the baseline value in abut 100 degrees of L_s (from L_s 110° to 210°, or about 230 Earth days), a factor of about 4 faster than our derived mixing time based on the period of Ar build-up (L_s 7° to 108°). We suggest that the eddy coefficient increased about a factor of 3 in late winter and early spring to about $3.5 \times 10^8\ cm^2\ s^{-1}$ resulting in a faster mixing of excess Ar out of the polar atmosphere (75S to 90S).

We note that Krasnopolsky [10] has made ground-based measurements of CO in Mars atmosphere at Ls 112 (only a few sols after the peak Ar measured by the GRS) and found the mixing ratio to increase from 8.3×10^{-4} at the sub-solar latitude of 23N to 12.5×10^{-4} at 50S. MGCM models generally predict that CO will build up over the southern winter pole but that the measured effect in [10] exceeds amounts predicted from simple photochemical accumulation of CO owing to the freeze-out of water vapor and subsequent reduced odd hydrogen chemistry. Our result using the Ar build up and removal provides additional quantitative information to resolve this and other polar winter meridional mixing issues.

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