ATMOSPHERIC CORRECTIONS FOR NEUTRONS REVEAL VARIATIONS IN SURFACE COMPOSITION IN THE THARSIS REGION.

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Introduction: The output of neutrons from Mars is sensitive to atmospheric mass (areal density in units of g/cm^2), which changes seasonally and with elevation. A portion of the neutron population observed at orbital altitudes is generated within the atmosphere directly by cosmic ray interactions. In addition, neutrons emitted from the surface are slowed down by interactions with atmospheric nuclei. We have calculated the dependence of the neutron output on atmospheric mass using a radiation transport model and have developed a correction algorithm to remove artifacts of topography from neutron counting data. Here, we remove the effect of the atmosphere from neutron count rate maps measured by the neutron spectrometer subsystem of the gamma ray spectrometer on 2001 Mars Odyssey to reveal spatial variations in surface composition and stratigraphy in the Tharsis region.

Elevation changes considerably within and around Tharsis, from the highest point on Mars to the troughs that comprise Valles Marineris to the surrounding northern lowlands. Volcanic, tectonic, and possibly fluvial processes have shaped the terrain and surface composition within this region. Major geological features, including the volcanic shields and associated lava flows, nearby volcanic plains, and portions of Valles Marineris, including regions containing outflow channels are on the scale of the spatial footprint of the neutron spectrometer, which is roughly 600 km full-width-at-half-maximum (roughly 10° arc length).

Data Reduction: Neutron count rates have been mapped from late winter (L_S=346°) to early summer (L_S=100°). Time-dependent count rate maps (on 7.5° L_S intervals) have been made to study the evolution of the seasonal frost at the poles. In addition, time-averaged maps binned on 2° equal-area pixels have been constructed, which have ample coverage and precision for mid-latitude regional composition studies.

Time-dependent maps are determined by normalizing time-series counting data to the average count rate observed between latitudes ±40° every 12 orbits (about one Martian day). The normalization eliminates variations in count rate due to instrumental drift, variations in the galactic cosmic ray flux, and diurnal and seasonal changes in globally averaged atmospheric mass. The normalization enables precise determination of seasonal variations in count rates at polar latitudes. Mid-latitude count rate maps used in this study were determined by averaging the normalized time-dependent maps over the duration of the mapping phase of the mission.

Effect of Atmospheric Mass on Neutron Output: A radiation transport code (MCNPX) was used to calculate the energy- and angular-dependence of the flux of neutrons from Mars at the top of the atmosphere for different surface compositions and atmospheric masses. The code was modified to model gravitationally bound neutrons that return to the atmosphere and surface without decaying. The neutron flux calculated by MCNPX was converted into count rates using a transport model that accounts for the ballistic trajectories of the neutrons, the velocity and orbit of the spacecraft, and the response function of the neutron spectrometer.

The variation of thermal, epithermal, and fast neutron count rates with atmospheric mass was calculated for surface water concentrations ranging from 0.5% to 10%, which could be present at mid-latitudes in the form of hydrated mineral deposits. The stratigraphy of water was also varied to determine the effect of dry soil or rocks covering water-rich material. For each surface composition, count rates were normalized to the count rate calculated for an atmospheric mass of 16 g/cm^2. For example, for 3% water, the variation of normalized fast neutron count rate (C_f) with atmospheric mass (M) can be fitted to a polynomial:
$C_f(M) = -2.47\times10^{-5}M^3+2.26\times10^{-3}M^2-7.54\times10^{-2}M+1.73$.
The normalized epithermal neutron count rate (C_e) is given by $C_e(M) = 3.58\times10^{-4}M^2-2.68\times10^{-2}M+1.34$ and the normalized thermal neutron count rate (C_t) is given by $C_t(M) = 1.97\times10^{-3}M+0.97$. Fast neutron count rates are the most sensitive to atmospheric mass, monotonically decreasing by 40% between 8 g/cm^2 and 24 g/cm^2. Over the same range, the epithermal neutron count rate decreases by 30% and the thermal neutron count rate increases negligibly, by 3%.

Correction Method: We found that the relative dependence of epithermal and fast neutron count rates on atmospheric mass was insensitive to water equivalent hydrogen abundance and stratigraphy over the range of compositions considered. Consequently, atmospheric mass and surface composition are, to first order, separable at near-equatorial latitudes. If the atmospheric mass is known, measured count rates can be divided by C_e or C_f to determine the equivalent count rate for a 16 g/cm^2 atmosphere. In this way, spatial variations in atmospheric mass can be removed. The error introduced by assuming that atmospheric thickness and surface composition are separable is expected to be less than 5% (1σ) for epithermal neutrons and less than 10% for fast neutrons.

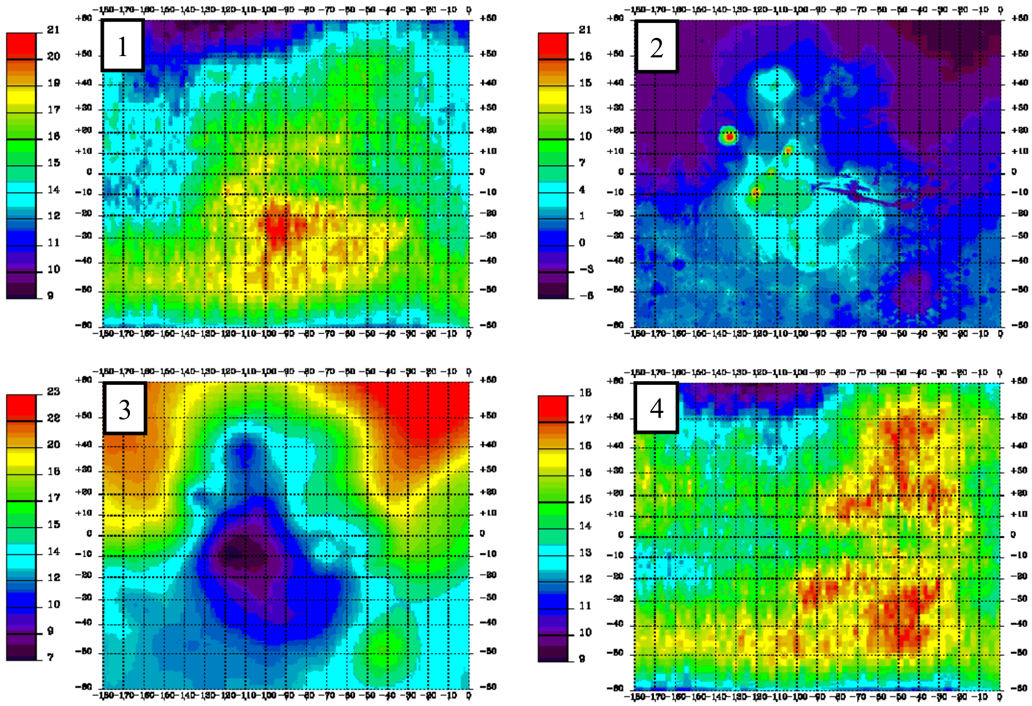

Figure 1. Atmospheric correction for fast neutrons: 1) Uncorrected fast neutron count rate map (counts per 19.8s); 2) MOLA topography; 3) atmospheric mass convolved with the fast neutron spatial response function; 4) corrected fast neutron count rate map.

A medium-resolution map (<120 km per pixel) of atmospheric mass was determined from MOLA elevation data assuming an atmospheric scale height of 11 km and a seasonally-averaged fiducial mass of 15 g/cm^2 at an elevation of 0 km. This map was convolved (smoothed) with epithermal- and fast-neutron spatial response functions to determine maps of atmospheric mass seen by the spectrometer. The smoothed maps were used to determine the mass used to correct fast and epithermal count rates to 16 g/cm^2. Information used in the correction process and the corrected fast neutron map is shown in Fig. 1. The corrected epithermal map is shown in Fig. 2. The maps are valid between ±45° latitude.

Surface Composition of the Tharsis Region: The map of atmospheric mass in Fig. 1 provides an indication of the scale of features that can be resolved by the neutron spectrometer. A portion of Valles Marineris, centered on Candor Chasma, and Olympus Mons span roughly 10° and are visible on this map. Arsia Mons is resolved in the uncorrected fast neutron map; however, the volcanic shields and plains appear as relatively uniform regions with intermediate count rates in the corrected epithermal and fast maps. A notable exception is Solis Planum, which has relatively high count rates, comparable to those found in Argyre Planitia, which is thought to contain between 2% and 3% water-equivalent hydrogen. Thermal neutron count rates take on relatively high values in a region that is delineated by young geological units associated with the volcanic shields. The composition of this region is different than the surrounding volcanic plains and will be investigated in more detail when adequate precision is achieved for gamma ray maps of major elements.

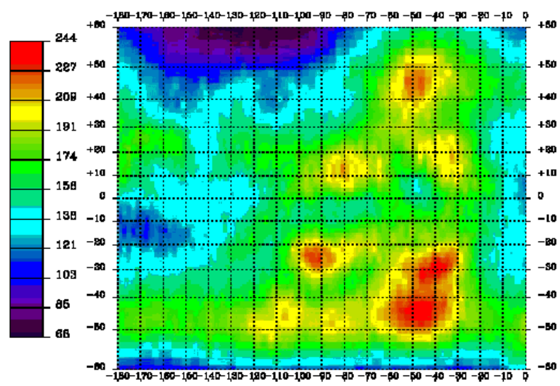

Figure 2. Corrected epithermal neutron map.

Fast and epithermal neutron count rates vary inversely with water abundance. However, some regions in which fast count rates are near maximum have relatively low epithermal count rates. Because fast neutrons are more sensitive to near surface water abundance, the surface in these regions may have a dry covering, possibly in the form of rocks. Fast neutrons are correlated with thermal inertia, which is related to rock abundance and other physical properties of the surface. Future studies will combine neutron maps and thermal inertia data to develop improved models of surface structure, water abundance and stratigraphy.