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Observed diurnal variations in Mars Science Laboratory Dynamic Albedo of Neutrons passive mode data

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ABSTRACT

The Mars Science Laboratory Dynamic Albedo of Neutrons (DAN) experiment measures the martian neutron leakage flux in order to estimate the amount of water equivalent hydrogen present in the shallow regolith. When DAN is operating in passive mode, it is sensitive to neutrons produced through the interactions of galactic cosmic rays (GCR) with the regolith and atmosphere and neutrons produced by the rover's Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). During the mission, DAN passive mode data were collected over the full diurnal cycle at the locations known as Rocknest (sols 60–100) and John Klein (sols 166–272). A weak, but unexpected, diurnal variation was observed in the neutron count rates reported at these locations. We investigate different hypotheses that could be causing these observed variations. These hypotheses are variations in subsurface temperature, atmospheric pressure, the exchange of water vapor between the atmosphere and regolith, and instrumental effects on the neutron count rates. Our investigation suggests the most likely factors contributing to the observed diurnal variations in DAN passive data are instrumental effects and time-variable preferential shielding of alpha particles, with other environmental effects only having small contributions.

1. Introduction

The Dynamic Albedo of Neutrons instrument (DAN) onboard the Mars Science Laboratory (MSL) rover *Curiosity* has been acquiring data from the surface of Mars since August, 2012. The mission has been successful in finding a habitable environment for life [1] and expanding our understanding of Mars history and the role water has played in that history [2]. The DAN instrument has contributed to this understanding by making measurements that are sensitive to local variations of hydrogen and chlorine content within the shallow regolith [3–5].

DAN measures the martian neutron leakage flux. It utilizes two ^{3}He proportional counters, one of which is unshielded and detects neutrons of energies up to ~100 keV, however, detection efficiency above 1 keV is very low [6]. This counter is known as the counter of total neutrons (CTN). The second counter, known as the counter of epithermal neutrons (CETN), is shielded with a cadmium jacket, which absorbs thermal neutrons below ~0.4 eV, the cadmium cutoff [6]. This allows for detection of only neutrons at epithermal energies above the cadmium cutoff. By differencing the count rates produced by the two counters, DAN is made sensitive to the thermal neutron population. DAN can operate in two modes, an active mode and a passive mode. Active mode involves the use of a pulsed neutron generator (PNG) to produce high intensity pulses of high energy neutrons [6]. Results from DAN active mode operations are presented in [3,4,7,8]. In passive mode, DAN is sensitive to two sources

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of neutrons: those produced through the interactions of Galactic Cosmic Rays (GCR) with the regolith and atmosphere and those produced by the rover's Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). For further discussion of DAN's passive mode of operation, specifically in relation to the radiation environment, see [9]. For DAN passive results and water equivalent hydrogen estimates, see [5] and [10]. This work will focus on the DAN passive data acquired from two specific locations early in the mission.

An unexpected observation from DAN passive data is the presence of a weak diurnal variation in the martian neutron leakage fluxes measured at the locations Rocknest and John Klein during multi-week, stationary observations. The purpose of this work is to test proposed hypotheses for the cause of the observed variations. We will show the diurnal variations as detected in the data, present multiple working hypotheses for the cause of the variations, and describe the methods used to test each hypothesis. This will be followed by an evaluation of the results that leads to the conclusion that the most reasonable explanation for the variations is a combination of instrumental effects and effects due to variations in the local environment of which an increase in neutron production in the regolith due to time-variable preferential shielding of primary GCR alpha particles by the martian atmosphere is the largest.

2. Data

2.1. DAN passive data

Though *Curiosity* is nearly always on the move and investigating new locales, there were two sites early in the mission where the rover stayed for an extended duration, enabling an examination of time-variability in neutron count rates while isolating the effects of varying non-volatile regolith compositions throughout the traverse. These locations are known as Rocknest (sols 59–100) and John Klein (sols 166–272). Rocknest was a small (size), weakly-cemented aeolian bedform [11]. John Klein was a specific location within the larger Yellowknife Bay area which was presumed to be an ancient lakebed composed of clay-rich mudstones with prevalent post-diagenetic alteration fractures, veins and concretions [2]. Staying at the same locations for multiple weeks allowed the DAN instrument to acquire data over many diurnal cycles with nearly complete time-of-sol coverage. Fig. 1 shows the DAN passive acquired thermal neutron count rates from sol 0 to sol 500 with the Rocknest and John Klein data highlighted for comparison.

When these data are examined, however, an increase is observed in the CTN and thermal neutron count rates and a decrease is observed in the CETN neutron count rates that coincides roughly with the middle of the sol and peaking in early to mid afternoon hours. Figs. 2 and 3 show the data from the two locations versus time of sol acquired. There is no reason to suppose that there is anything unique about these locations that would produce the observed diurnal variations in neutron count rates. The amplitudes of the variations are simply too weak to be noticeable against the statistical noise in the count rates from locations where the rover had shorter stays, and they are far smaller than the changes in count rates associated with compositional variations encountered by the rover along its traverse [5]. The amplitudes and phases of the variations in measured neutron count rates can be seen in Figs. 2 and 3. CTN and thermal neutron count rates at each location increase in the afternoon, while CETN count rates decrease. Rocknest average CTN count rates show a minimum to maximum 3.3% increase. Average thermal neutron count rates increase by 9.5% and average CETN neutron count rates decrease by 6.7%. At John Klein, average CTN neutron count rates increase by 2.7%. Average thermal neutron count rates increase by 5.7%. Average CETN neutron count rates decrease by 4.1%. Furthermore, CETN neutron count rates typically do not vary with compositional changes [5,9] and thus it is interesting that the epithermal population in these cases is responding to some other factor, which is possibly instrumental.

In order to verify that the observed variations are occurring on a diurnal time scale with a one sol periodicity, we have performed Fourier analyses on the thermal neutron count rates from each location. Figs. 4 and 5 show the power spectra from the Fourier analysis at each location. These results show a large increase in the power at a frequency of 1/sol confirming the diurnal nature of the variations observed in the DAN passive measurements.

2.2. Data from other MSL instruments

The MSL Rover Environmental Monitoring Station (REMS) experiment measured surface temperature and atmospheric pressure, which also vary with diurnal periodicity [12]. REMS measures surface temperature within a patch of ground 100 m^2 adjacent to the rover [12]. We have used REMS surface temperature and atmospheric pressure data to model the response of neutron leakage fluxes to variations in those quantities. The average atmospheric pressures and surface temperatures measured by REMS at Rocknest and John Klein are shown in Figs. 6 and 7.

We have also used data and results from the MSL Radiation Assessment Detector (RAD) [13]. We use RAD penetrating counter data in our analysis to constrain the variations in the energetic particle environment at the surface per Tate et al. [5]. We have also used results of investigations into diurnal particle fluxes as measured by RAD during the first 350 sols of the mission [13].

2.3. Engineering data

Engineering data sets have also been used in the work presented here. MSL telemetry data, specifically DAN detector temperatures, have been used to investigate the relationship between detector temperature and DAN passive measurements.

3. Hypotheses tested

We have investigated the following hypotheses to attempt to explain these diurnal variations in count rates: (1) variations in subsurface temperature, (2) variations in atmospheric pressure which leads to variations in secondary neutron production in the atmosphere and variations in neutron production in the regolith due to preferential shielding of alpha particles by the martian atmosphere, (3) variations in detector temperature, and (4) diurnal water vapor exchange between the regolith and the atmosphere. In order to investigate the diurnal variations in the measured neutron count rates, it is necessary to develop multiple hypotheses which might be contributing to the variations and investigate each individually. This is done by modeling each of the hypotheses' effects on the neutron leakage flux with either real data or constraints placed by real data. Modeling is performed with the Monte Carlo Neutral Particle eXtended radiation transport code (MCNPX) [14] and then the modeled amplitude and phase of the induced variations on the neutron leakage flux are compared to what is observed in the DAN passive data. This allows for elimination of most of the proposed hypotheses as the dominant sources of the observed variations.

3.1. Subsurface temperature

3.1.1. Methods

The first environmental property that we have explored as a possible cause of the diurnal neutron variations is subsurface temperature. As neutrons propagate through a moderating medium, the neutron population loses energy through interactions with the nuclei of the moderator. These neutrons will come into an equilibrium in which the neutron energies are equal to the thermal energy of the moderating nuclei and have a Maxwellian–Boltzmann distribution of velocities. Thus neutrons within the medium can only lose energy until their energies are equal to the thermal energies of the moderating nuclei. In this way, the temperature of the medium can affect the final neutron energy distribution.