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Seasonal Variations in SEB Components over Gale crater

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Abstract

The surface energy budget (SEB) is a comprehensive strategy to understand the thermal behaviour of a planetary surface. Knowledge of the surface radiative transfer helps us understand near surface thermal environments. There are various methods and numerical models to partially compute energy budgets. The best methods for efficient calculation of each SEB component are assimilated and an attempt is made to enhance computational accuracy using in situ rover observational data from MSL Curiosity. The variations of each of these components are analyzed on a seasonal timescale and ground heat storage is indirectly calculated, whose computation, otherwise, is difficult.

1. Introduction

The study of energy interactions at the Martian surface and sub-surface determines the near-surface thermal environment and therefore presents a significant role in understanding its habitability and major physical processes [1]. The SEB is based on the law of conservation of energy and is given by Eqn.1

$$(1-A)S\downarrow + L\downarrow = L\uparrow + H + \lambda E + G \quad (1)$$

where, A is the albedo of the surface, S↓ is the downwelling short-wave radiation, L↓ is the downwelling longwave radiation, L↑ is the upwelling longwave radiation, H is the sensible heat flux, λE is the latent heat flux and G is the heat exchange by conduction into ground. The terms on the LHS correspond to the forcing terms and those on the RHS correspond to the response terms of the radiative transfer. It is to be noted that many models have been developed to calculate components of the surface energy budget [2,3,4]. However, the variation of these components on a seasonal timescale is yet to be determined. Seasonal studies of SEB components can give us an idea of the microclimates and the nature of each season on Mars. In the present research, an attempt is made to study this variation and understand the factors influencing the same. It is to be noted that seasons in the southern hemisphere are studied here. Similar analogies can be derived for corresponding northern hemisphere seasons.

2. Datasets

Ground Temperature Sensor (GTS), Air Temperature Sensor (ATS) and Pressure Sensor (PS) data from Rover Environment Monitoring Station (REMS) onboard MSL Curiosity were used in this study. The time of study was chosen based on two factors – solar longitude and the movement of the rover. In order for the study to provide an efficient representation of each season, the sols are so chosen so that they lie in the mid (second month) of each three-month season period wherein peak characteristics of each season are experienced. As a result, sols 108, 110, 112, 234, 251, 270, 440, 441, 443, 610, 620 and 631 were chosen. The rover was in Point Lake, Yellowknife Bay, Cooperstown and Mt. Remarkable respectively during the chosen dates [5].

3. Methodology

Downwelling shortwave radiation was computed using the radiative transfer model developed by [6] wherein the albedo was varied from 0.20 to 0.25 in the model, a satisfactory approximation of the range of albedo values for dry land. The diurnal values of atmospheric dust opacity for the twelve sols under study were obtained from the Mars Climate Database v5.2 (MCD) [7]. The downwelling longwave radiation components were also obtained from MCD. The upwelling longwave radiations were calculated by applying Stefan-Boltzmann law on surface temperature measurements made by the GTS. The emissivity was varied from 0.9 to 1.0 to calculate minimum and maximum values of L↑ [4]. The sensible heat flux was calculated using Eqn. 2.

$$H = K^2 C_p\, u\, \rho_a\, f(R_b) \frac{(T_g - T_a)}{\ln^2\left(\frac{z_a}{z_0}\right)} \quad (2)$$

where H is the sensible heat flux, ρ_a is the atmospheric density computed from the surface pressure, C_p is the specific heat of CO_2 at constant pressure (≈736 J kg^{-1} K^{-1}), T_g is the GTS recorded surface temperature, T_a is the ATS measured atmospheric temperature, K is the von Karman constant, Z_a is the height at which atmospheric temperature and wind speed 'u' are recorded (= 1.6m), Z_0 is the surface roughness and $f(R_b)$ is a function of Bulk Richardson number R_b which is used to incorporate effect of wind turbulence [8]. The surface roughness length was assumed to vary from 0.5cm to 1.5cm based on TES measurements at Gale crater [9]. Maximum and minimum values of sensible heat flux were obtained when the absolute difference of (Tg – Ta), surface roughness Z_0 and wind speed u were maximum and minimum respectively. A simple rearrangement of the surface energy budget equation would result in ground heat flux calculation if all other components are computed.

4. Results and Discussions

The Martian surface energy budget follows a pattern similar to that of Earth, being significantly dominated by the downwelling shortwave and upwelling longwave radiations (Fig 1). Sensible heat and downwelling longwave radiations contribute very less to the budget unlike that of Earth where their contribution is at least an order higher. This could be essentially due to the absence of a relatively denser atmosphere on Mars that decreases the degree of atmospheric absorption and thereby magnitude of atmospheric emitted longwave radiation. Global planetary temperatures too do not experience drastic changes as much of the upwelling longwave radiations emitted from the surface go back to space without much atmospheric intervention. Table 1 shows the maximum and minimum values obtained for the SEB components during the 12 sols chosen for study.

Spring is the shortest but hottest season of the Martian year. It experiences the highest magnitude of surface energy fluxes. Average maximum surface and atmospheric temperatures range around 285 K and 260 K respectively. Spring also experiences the highest diurnal variation in temperatures, roughly around 90 K. Mars is closer to the Sun for most parts of spring when compared to that of summer, thereby causing the atmosphere to emit the highest magnitude of longwave radiation. Spring also marks the onset of global wide dust storms and is the most affected season due to dust absorption, with almost 34% of solar insolation getting trapped in the atmosphere.

Southern summers are at least 10 sols longer than spring. Surface temperatures rise up to around 275 K, almost 5 to 10 K lesser than spring. The diurnal variation of temperature is comparatively lesser in summer i.e. of the order of 75 K. the effect of global wide dust storms gradually recede through the summer and the winds thereby become less turbulent. The percent dust absorption is roughly around 32%, a tad lower than that of spring. With decrease in concentration of dust particles as represented by the lower dust optical depth, the longwave radiation emitted by the atmosphere also reduces and hence, summer has a lower downwelling longwave radiation than that of spring. But, lower surface temperatures create an imbalance between solar insolation and emitted surface longwave radiation, thereby allowing greater flux to be stored as ground heat.

Table 1 Maximum and minimum values of SEB components for the 12 sols

Season	Sol	L↑ (W/m^2)		L↓ (W/m^2)	(1-A) S↓ (W/m^2)		H (W/m^2)	
		Max	Min		Max	Min	Max	Min
Spring	108	388	64	65	450	0	45	-23
	110	387	65	66	444	0	44	-24
	112	389	63	66	447	0	44	-23
Summer	234	328	73	47	436	0	42	-16
	251	330	72	48	434	0	37	-15
	270	310	75	48	438	0	34	-16
Autumn	440	247	63	33	349	0	34	-12
	441	254	62	33	347	0	36	-13
	443	249	63	33	346	0	38	-15
Winter	610	276	41	30	340	0	31	-25
	620	284	39	31	347	0	34	-26
	631	291	49	32	356	0	33	-20

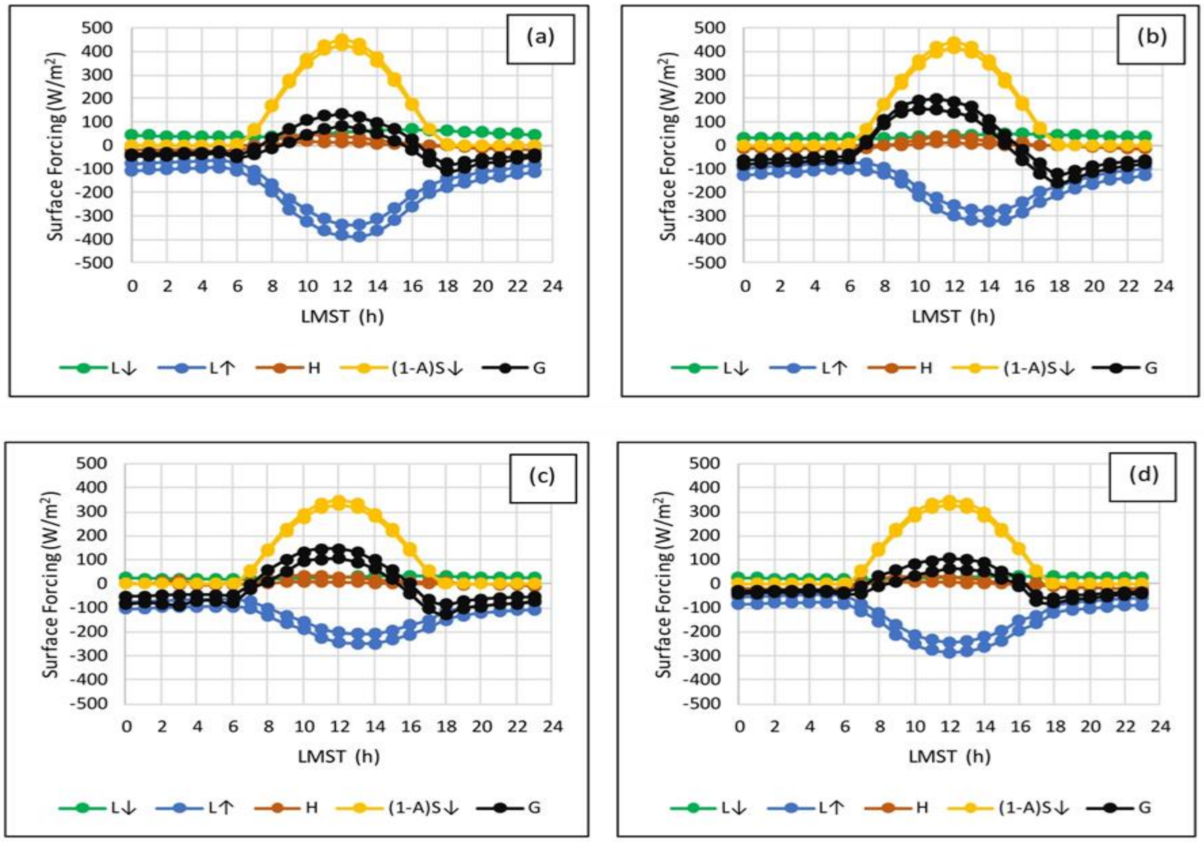

Fig 1 Surface forcing in (a) Spring (b) Summer (c) Autumn (d) Winter

Autumn forms the longest season of the Martian year, and the surface temperatures reach a maximum of around 255 K at noon. Autumn also experiences the least diurnal variation in ground temperature roughly around 60 K. The aphelion tends to occur in late autumn and it is seen that the Mars – Sun distance tends to be larger for most part of autumn than winter. This results in autumn experiencing the least upwelling longwave radiation. However, an irregularity in sensible heat flux variation is seen at night time.

Winter experiences the least diurnal insolation period and is least affected by dust. Temperatures can go as low as 177 K and as high as 265 K., thereby showing an increased diurnal variation of temperature. It is to be noted that Martian atmospheric conditions do not vary much and are somewhat stable in the autumn and winter months, as determined by similar magnitudes of surface energy budget components. Since the magnitudes of all fluxes are low, the resulting ground heat storage is also low.

From this study, it can be inferred that rover missions, landing in the southern hemisphere must be scheduled in such a way that the rover lands towards the end of winter and begins its science activity from the onset of spring as this would enable optimum solar power utilization and uninterrupted science activity by the rover as spring and summer are found to experience greatest solar insolation in a Martian year. Studies of geothermal heat and ground conduction could be undertaken during summer as it reports the highest magnitudes of ground heat storage. It is to be noted that spring and summer however are the maximum dust affected seasons in the Martian southern hemisphere. Hence, additional arrangements for dust cleaning the solar panels in the rovers need to be made in order to achieve maximum power utilization. The mission scheduling of MSL Curiosity is well-planned and can be followed for future Mars missions. Provisions may also be made for an alternative source of power during the autumn and winter seasons like utilization of nuclear power in the form of radio-isotope thermoelectric generators (RTGs) which have implemented by NASA to power

25 different US space crafts including the Viking landers [10]. This is essential because the latter seasons constitute to more than 65% of the Martian year in the southern hemisphere. So, if complete utilization of these two seasons can be made, the mission would become highly efficient and would result in greater science study of the Martian surface.

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