（Format　No. 13）

SUMMARY OF DOCTORAL THESIS

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Title: Factors affecting sand transport flux in the Gobi Desert, Mongolia
（モンゴル・ゴビ砂漠における飛砂フラックスに影響する要因）

The sand transport is the most important process of emission of dust, which is globally transported and affects the Earth system, the marine ecosystem, etc. It also drives dune evolution, desertification, and shaping arid landscapes in arid and semi-arid regions. However, quantification of sand transport is challenge. This suggests that sand transport models have not account for some factors. The sand transport flux depends on a number of environmental factors, namely, (1) weather (wind, rainfall, etc.); (2) soil type (soil texture, particle size, etc.); (3) soil state (wetness, aggregation, sand availability, etc.); (4) roughness elements (vegetation, stone, and crust, etc.). The sand transport flux (Q) is quantified by the friction velocity, u_*, a measure of wind shear at the surface, and by the threshold friction velocity, u_{*t}, which defines the minimum friction velocity required for sand transport; u_{*t} is determined by soil particle size, the surface roughness such as stone and vegetation, soil moisture, and soil crust. However, the simulated Q is fitted to observed Q, ratio has high variation in previous studies. It suggests that sand transport models have not accounted for some factors. The model simulation studies assumes that saltation takes place under the full sand availability condition. In reality, the sand availability is often limited.

As mentioned above, the factors employed in the current sand transport models were wind speed, soil particle size, surface roughness, soil moisture, and soil crust. Sand availability was listed as a factor that was not employed in the current model but was considered essential. In this thesis, since the field observations were made under low soil moisture condition, we focus on the factors of wind speed, roughness, soil crust and sand availability. Regarding the roughness, there are studies, which show that it can be quantified by Synthetic Aperture Radar (SAR) data. To improve the current sand transport models, the main objective of this thesis is to understand the factors affecting the sand transport flux on dry surface in the Gobi Desert, Mongolia. The specific objectives are (I) to evaluate the effects of stones on the u_{*t} at observation sites, (II) to estimate spatial and temporal distribution of the u_{*t} from high resolution the Sentinel-1 SAR data over study area, and (III) to identify the effect of sand availability on the Q and its relation with SAR data over study area during dry periods.

In Chapter 2, the effects of roughness density of stone on the u_{*t} were evaluated. The field observations were made for different roughness densities at three year-round sites and eight temporary sites during sand and dust storms in springs 2018 and 2019. The observed sand saltation threshold (u_{*t}-observed) was low (0.23 m s^{-1}) at the smooth sand sheet surface. The u_{*t} noticeably increased (from 0.41 to 0.71 m s^{-1}) with the roughness density of stones (from 0.05 to 0.32). This result implies that stone is one of important factors to determine the threshold of sand transport. Numerical simulations of the threshold were also conducted by inputting our measured roughness density of stone into a 0-dimensional theoretical model. The comparison between simulated threshold (u_{*t}-simulated) and u_{*t}-observed showed that the model reproduced the threshold very well if neither dead vegetation nor soil surface crust were present. The result also means that the roughness density of stone is important parameter to determine the sand

saltation threshold. The failure of the simulation when dead vegetation or soil surface crust existed means the effects them are non-negligible factors to determine the threshold.

In Chapter 3, a relation between the u_{*t}-observed and Sentinel-1 SAR gamma naught VV (GVV) intensity was investigated for three year-round sites and eight temporary sites in dry periods of spring 2018–2020. We found a linear relationship between the SAR intensity and the u_{*t}-observed at stony and vegetated sites, except when the surface was crusted. We attribute this exception to the physical properties of crust, which are difficult to quantify; as a result, the roughness factor value of crust is variable. The SAR intensities and u_{*t}-observed were low (–22.2 dB and 0.23 m s^{-1}, respectively) at a sandy site in a topographic depression. However, they were high (from –20.1 to –16.5 dB and from 0.41 to 0.71 m s^{-1}, respectively) at stony and vegetated sites on slopes and mountains. Even though in the same topographic depression, if the surface was crusted, they were moderate (from –20.2 to –19.2 dB and from 0.24 to 0.55 m s^{-1}, respectively). From these results, we obtained a function to estimate the threshold friction velocity from the SAR data (u_{*t}=0.0828(SAR intensity) +2.0831, r=0.91, p<0.0001). The high correlation indicates that the SAR data has a potential to estimate spatiotemporal distribution of the threshold if the land surface is dry. The estimated threshold friction velocity from SAR (u_{*t}-estimated) showed that the sand saltation threshold varied greatly both spatially and temporally over the study area during the dry periods of spring from 2017 to 2021.

In Chapters 2 and 3, we explored the effect of the factors such as stone, vegetation and soil crust on the u_{*t}, which is a variable of sand transport model. In Chapter 4, adding sand availability as a factor, we explored the effects of the factors on horizontal sand transport flux (Q), which is the main target in this thesis. The highest observed Q was at a site of low threshold where the sand availability was high. The lowest Q was at a site of high threshold where sand availability was limited at stony and vegetated surface. When we set the sand availability fraction is full (δ=1) in the model, the simulated Q were similar to the observed ones at the sandy surface (i.e., high sand availability), but the simulation 2-4 orders overestimated at stony and vegetated surface (i.e., low sand availability). These results suggest that the sand availability is also an important factor affecting sand transport flux. The δ was high (0.080-1.000) at sites of the high sand available surface, and it was low (0.003-0.042) at sites of the low sand available surface. We found that an exponential relation between the SAR intensity and the δ. Finally, employing this relation, a spatial distribution of Q was quantified under spatially constant wind speeds at 1.7 m such as 6 m s^{-1}, 10 m s^{-1}, 14 m s^{-1} and 18 m s^{-1} over the study area. The simulated horizontal sand flux by the SAR based method varied spatially and temporary. The Q is always zero or very small at Mountains during spring 2017-2021, but it was 5 order different at topographic depression.

The findings in Chapters 2 and 3 indicate stone, dead vegetation and soil surface crust are important factors affecting the u_{*t}, which determines starting and ending of sand transport through their roughness and coverage effects and, thus affects its flux. However, we also clarified that the Q cannot be reproduced by the u_{*t} alone, and sand availability is the key factor to reproduce it. The SAR data has a potential to represent the spatial distribution of u_{*t}, δ, and z_0 over natural complex surface when it is dry. Therefore, the spatial distribution of Q can be quantified by our developed SAR based method when wind speed data is available at any heights. Further research is required on measurement of the sand transport flux at during not only dry but also humid periods because SAR data also sensitive to soil moisture which is another important factor affecting the sand transport flux.