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SUMMARY OF DOCTORAL THESIS

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Title: Developing an Index based on surface temperature for assessment of moisture availability over vegetated land

地表面温度を用いた植生地の水分効率評価指標の開発

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In arid regions of the world, agricultural production is limited by the availability of water and severely affected during times of drought. Drought occurs when there is insufficient soil moisture available for plants. The available soil moisture in the root zone is the central issue in food security. This background highlighted the need of a reliable indicator for the surface wetness status. Thermal inertia represents a measure of the material's resistance to temperature change, and it is a function of the material's conductivity and heat capacity. Water has a large heat capacity and heat conductivity, so the thermal inertia of wet soil is larger than that of dry one. This fact makes thermal inertia a useful physical parameter that indicates the surface wetness; however, it cannot be measured remotely, instead it is inferred from the diurnal surface temperature range, especially from the difference between daytime and nighttime surface temperature. It is commonly used in surface soil moisture estimation for bare land. When there is vegetation cover, since the surface wetness is a function of soil surface water content plus leaf water content, this complication limits the use of thermal inertia on vegetated cases. Therefore, the effects of physiological activities, that is the change of vegetative surface temperature due to the transpiration, have to be taken into account to develop an effective index based on diurnal surface range for assessing and monitoring the surface wetness. This research is the first attempt to apply the diurnal surface temperature difference to model vegetated surface wetness metric (referred to as moisture availability (m_a); defined as the ratio of actual to reference evapotranspiration ET) through combining meteorological data and surface energy balance models. This research conducted on the Loess Plateau of China, which is a water scarce region under threat of drought.

A new index was proposed, Normalized Day-Night Surface Temperature Index (NTDI), which normalizes the maximum daytime surface temperature and the minimum nighttime surface temperature, by the difference between the simulated maximum and minimum surface temperature, estimated from meteorological data by applying energy balance equation. The simulated surface temperatures represent the hypothetical maximum diurnal range of surface temperature (when ET = 0), which is determined only by the meteorological condition.

Firstly, the potential use of a diurnal surface temperature range to estimate the surface wetness metric (i.e. moisture availability (m_a)) was investigated. The

diurnal surface temperature range $T_{s(day)} - T_{s(night)}$ (the maximum daytime surface temperature minus the minimum nighttime surface temperature), was weakly correlated with m_a . This could be attributed to that, since moisture availability is a ratio between the actual ET determined by physiological and meteorological parameters, and reference ET represents the atmospheric demand, determined by only meteorological parameters, the divide process left the moisture availability just a representative of biophysical varieties. However, the diurnal surface temperature range is determined by both biophysical and meteorological conditions. Accordingly to improve the moisture availability estimate, the effects of varieties of physiological activities on $T_{s(day)} - T_{s(night)}$ has to be separated from the effects of meteorological variables. The NTDI showed a significant inverse-exponential correlation with m_a ($R^2 = 0.97$, $p<0.001$). This result indicates that the normalization relative to the index denominator (represent the hypothetical maximum range of surface temperature, determined only by meteorological condition) dramatically improved the accuracy of estimation. The relationships between the NTDI and soil moisture (θ) for each soil layer from the surface to the root zone and the averaged θ of all layers were examined. The NTDI was found to be most highly related to the total soil moisture, but less so to that in the near surface layer. This result implies that the moisture availability is a combination of transpiration and evaporation. The transpiration through the root system is representing water uptake in the entire soil layers down to the root zone, as well as evaporation at ground surface.

The NTDI was used as a metric of moisture availability (m_a), based on point observed meteorological data, and then its application was extended to wide area by combining MODIS (Moderate Resolution Imaging Spectroradiometer) land surface temperature (LST) and ground-based meteorological data. MODIS remotely sensed day/night LSTs offer considerable advantages and should be an integral part of monitoring drought, especially for the temporal and spatial evolution of drought. This is still a challenge to remote sensing, especially in vegetated case. The combination of both meteorological data and remotely sensed land surface temperature on daily basis from MODIS provides potential to derive m_a assessment over a region scale. The accuracy of MODIS to retrieve the land surface temperature was assessed. The effect of the sensor passing time on stability of NTDI calculation was also assessed. Finally, NTDI estimate was expanded over 100-km^2 area in the Loess Plateau. The NTDI map showed similar spatial pattern to that of NDVI image and land use classification map. However, comparison between NTDI and NDVI for each land use, indicated that the spatial distribution of NTDI reflects surface wetness variation more precisely than that derived from NDVI, as the ranking of wetness of the different land uses (obtained from unsupervised classification) based on NTDI coincides with the former studies, estimated the ET for these land uses in the Loess Plateau. Land use with large ET corresponds to that with the high moisture availability and low NTDI. Based on NDVI, the land use ranking did not agree well with ET ranking.

This research indicates that the NTDI is a robust indication to quantify the moisture availability (ma). Moreover, NTDI based on combining remotely sensed and meteorological data effectively represents the spatial distribution of moisture availability, which can provide a potential drought assessment tool over local to large-scale. Such assessments can be used as regional measures of drought stress, as tools for planning water allocation, or as indicators of the efficiency with which water is being used.