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主 論 文 の 要 旨

論文題目 Modeling Material Stock Using Satellite Observation of Nighttime Lights （夜間光衛星観測を用いたマテリアルストックモデリング）

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論 文 内 容 の 要 旨

Material stock in buildings and civil engineering infrastructure is considered to be closely related to social welfare and urban metabolism. A full accounting of material stock is a pre-requisite for improving the sustainable resource management and cross-boundary material recycling. However, traditional approaches for accounting the material stock are labour-intensive, time-consuming and always hindered by the availability of statistical data. As an alternative of statistical data, satellite observation of nighttime lights (NTL) provides a more efficient way to measure material stock with wide spatial range and real-time observation, and more and more attentions are paid on the model development. To date, three kinds of NTL products are available, including the Defense Meteorological Satellite Program ' s Operational Linescan System (DMSP-OLS) stable NTL, DMSP-OLS radiance calibrated NTL, and Suomi National Polar-orbiting Partnership Visible Infrared Imaging Radiometer Suite (S-NPP VIIRS) NTL. These three NTL products have distinct merits in terms of time scale, spatial resolution, as well as radiometric detection range. In order to better use these NTL products, this dissertation conducted three case studies to investigate their performances for estimating material stock of buildings and civil engineering infrastructure.

DMSP-OLS stable NTL product which provides the time-series observations from 1992 to 2012 is a valuable dataset for deriving long-term material stocks. In chapter 2, the long-term provincial in-use steel stock of buildings (IUSSB) and civil engineering infrastructure (IUSSCE) in China were modelled using the DMSP-OLS stable NTL product. Significant relationships between DMSP-OLS stable NTL versus IUSSB and IUSSCE were observed for provincial variables in a single year, as well as for time series variables of a single province. However, these relationships were found to differ among provinces (referred to as " inter-individual differences ") and with time (referred to as " temporal differences "). Panel regression models were therefore proposed to estimate IUSSB and IUSSCE in consideration of the temporal and inter-individual differences based on a dataset covering 1992-2007. These models were validated using data for 2008, and the results showed good estimation for both IUSSB and IUSSCE. The proposed approach can be used to easily monitor the dynamic of IUSSB and IUSSCE in China. This should be critical in providing valuable information for policy making regarding regional development of buildings and infrastructure, sustainable urban resource management, and cross-boundary material recycling.

S-NPP VIIRS NTL product is a new released NTL composite in 2013, which has enhancements in both spatial and radiometric resolutions compared with the DMSP-OLS NTL products. In chapter 3, in order to evaluate whether these enhancements can improve the estimations of IUSSB and IUSSCE, we compared the performances of S-NPP VIIRS NTL product with those of DMSP-OLS radiance calibrated NTL data for modeling IUSSB and IUSSCE at both sub-national level of Japan and national level of world. Our results indicate that the S-NPP VIIRS NTL data can offer more accurate estimates of IUSSB and IUSSCE (R2 values of 0.952 and 0.909) than those of DMSP-OLS radiance calibrated NTL (R2 of 0.929 and 0.884) at prefectural level of Japan. Similar to DMSP-OLS radiance calibrated NTL product, urban NTL of S-NPP VIIRS data has a stronger relationship with IUSSB, and IUSSCE was more closely related to total NTL. At national level, S-NPP VIIRS NTL also showed better estimations of IUSSB and IUSSCE. We confirmed that dividing the world into different regional groups is also required for estimating IUSSB and IUSSCE from S-NPP VIIRS NTL. For estimation of IUSSCE, two classifications including Asia region and Non-Asia region are appropriate when using S-NPP VIIRS NTL product, which is superior to DMSP-OLS radiance calibrated NTL. For estimation of IUSSB, more classifications may be still required which is similar to DMSP-OLS radiance calibrated NTL. Overall, our study indicated that S-NPP VIIRS data has greater capability in modeling IUSSB and IUSSCE than DMSP-OLS RC data.

In chapter 4, estimation models for stocks of specific construction materials and gross floor area of buildings were established based on DMSP-OLS radiance calibrated NTL. The results demonstrated that the total material stock of buildings followed a clustered distribution pattern, with more material stocks were found in the foundations of buildings than in their superstructures. Moreover, among the four types of regression models conducted between total material stock of buildings and NTL, the power law model exhibited the greatest accuracy ($R2=0.657$, $P < 0.01$). NTL was also found to be a good proxy for the gross floor area and the stocks of four construction materials of buildings. The detailed analysis presented in this chapter provides a fast and efficient means of estimating material accumulation in buildings and a sound basis for the implementation of material recycling in the future.

Three NTL datasets have different superiorities in estimation of material stock. This thesis indicate that time-series DMSP-OLS stable NTL product is a valuable dataset for modeling long-term IUSS (specific to IUSSB and IUSSCE), while both temporal and inter-individual effects should be paid attention when using this product. Our panel approach is the first model to accurately derive long-term IUSS by reducing these temporal and inter-individual effects. The new S-NPP VIIRS NTL product improved estimations of IUSS, and we suggest that its further application in other fields should be investigated in future studies. In addition to IUSS, satellite observation of NTL also has great potential for estimating stocks of other construction materials, as well as the floor area of buildings at the mesh level. NTL based accounting approach proposed in our study is important for monitoring the dynamic change of material stocks and flows, as well as their interrelationships with economy and environment; this will be significant for achieving the sustainable material management and optimization of the urban planning process in both developing and developed countries.