ANALYSIS OF LIGHT DATA ON THE DMSP/OLS SATELLITE IMAGE USING EXISTING SPATIAL DATA FOR MONITORING HUMAN ACTIVITY IN JAPAN

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ABSTRACT: The main objective of this research is to show how much can be monitored various human activities, e.g. industrial, commercial or transportation activities using night light images by the DMSP/OLS from the National Oceanic and Atmospheric Administration's National Geophysical Data Center (NOAA/NGDC). In Japan, various human activities can be monitored easily without macro scale monitoring data i.e. satellite images because we can use many kinds of detailed spatial dataset and statistics. On the other hand detailed spatial data about human activities are not developed adequately in many countries especially in developing countries. It is expected to develop new data that can alternate such detailed data or new monitoring method of human activities.
Therefore we discuss how to use night light images of the DMSP/OLS for this objective. In this study human activates were explained by 3 factors, i.e. fluid population, accumulation of buildings and road transportation. Each factor can be monitored by the estimated population grid data, digital residential maps and digital road data in Japan. These data and images of DMSP/OLS were resampled into the same aggregate unit (1km square grids) and compared with a light intensity of the DMSP/OLS. In addition it is shown which factor of human activates explains the light intensity more clear than other factors by multiple regression analyses using all factors. It is also shown that results of multiple regression analysis in urban, suburban and rural areas. It is shown that automobile traffic has a major effect on light intensity of DMSP by results of multiple regression analysis. On the other hand, the effect by building distribution becomes large in suburban and rural areas. It is also shown that light intensity of DMSP and accumulation of people do not necessarily accord.

1. INTRODUCTION

Monitoring for location and shape of urban areas are very significant task for planning of urban development, planning of disaster prevention, planning of crime prevention and environmental problems in broad areas. It is often the case that developments of basic spatial data, e.g., distributions of population and society's infrastructures are poor especially in developing countries (Takahashi and Hayashi, 2001). Paucity of these basic data is one of the major obstacles to address above problems.
Therefore there are many previous studies to try to monitor locations and shapes of urban areas without dependence on existing statistics. One of such method is to use night light images by the Defense Meteorological Satellite Program's Operational Linescan System (DMSP/OLS) from the National Oceanic and Atmospheric Administration's National Geophysical Data Center (NOAA/NGDC). For example, Imhoff et al. (1997a) showed distributions of urban areas in United States and Small et al. (2005) showed expansion of urban areas in some major cities around the world using DMSP/OLS images. Some studies also tried to monitor various human activities using DMSP/OLS images. For example, Elvidge et al. (1997b) showed a relationship between spatial distribution of nighttime light intensity of DMSP/OLS with business activity or electricity consumption. Likewise, Dobson et al. (2000a) showed a relationship with population distribution and Ghosh et al. (2009) showed a relationship with GDP. In addition there are some studies to estimate present state of urban areas using DMSP/OLS images. Takahashi and Hayashi (2001) estimated population distribution and the number of buildings and Kohiyama et al (2000b) estimated distributions of damaged areas by earthquakes.
There are many studies to monitor distributions of urban areas and estimate human activities using DMSP/OLS images. On the other hand, there are a few studies to show which kinds of human activities are especially reflected in DMSP/OLS images. Because existing spatial data which can be used for such verifications are not developed adequately especially in developing countries. On the other hand there are many kinds of micro-accurate existing spatial data in Japan. It was expected to be showed that DMPS/OLS images reflect which kinds of human activities to compare existing spatial data in Japan with DMSP/OLS images to aggregate by same spatial units.
Therefore we have developed data of human activities by distributions of people, buildings and roads using some existing spatial data of Japan and showed correlations between light intensities of DMSP/OLS images with these

factors. In addition we have showed which the most affected factor for light intensity of DMSP/OLS is by multiple regression analysis with the light intensity and these 3 factors. It is also shown that results of multiple regression analysis in urban, suburban and rural areas.

2. DATA DEVELOPMENT

Night light images of DMSP/OLS, road data (lines), building data (polygons) and grid data of fluid population were aggregated into same spatial units (grid data).

2.1 Study area and aggregate unit

A Study area is whole area of Miyagi prefecture, Japan (Figure 1). Miyagi prefecture is one of the prefectures in the Tohoku region, Japan. Sendai city, the largest city in the Tohoku region and some small cities are located in this prefecture. In addition there are relatively broad suburban areas adjoined these cities and depopulated rural areas in this prefecture. As a result we decided that here is an appropriate area for our study.
Aggregate units are the 1km-square grids called Japanese standard regional mesh (Hyojun Chiiki Mesh in Japanese; It is described the "Regional Mesh" in following text.). Many statistical grid data of Japan are aggregated into this grid and load data in this study is also aggregated into this grid. There are 7,725 grids in Miyagi prefecture.

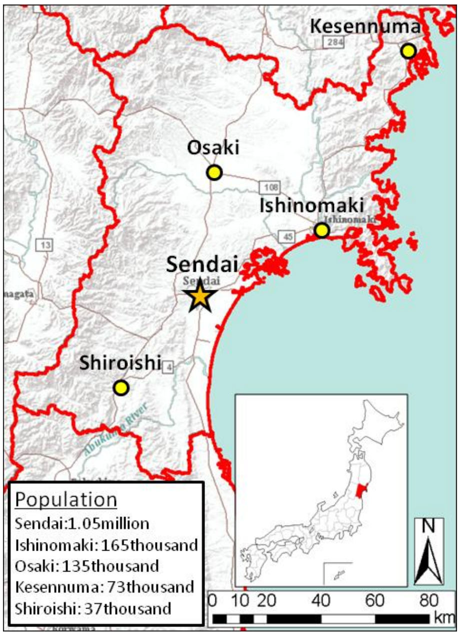

Figure 1: Study area

2.2 Resampling of DMPS/OLS images

We only explain how to resample night light images of DMSP/OLS in 2008 (image opportunities of Japan are approximately 20:00~21:00) into the Regional Mesh. Details about images of DMSP/OLS were showed in previous study (Elvidge et al. 1997b). Pixel size of DMSP night time images is 30 arcseconds. The average length of 1 degree of longitude and latitude around the centroid of Miyagi prefecture (E140.93, N38.45, wgs1984) is approximately 99155.55m, and 30 arcseconds is approximately 826.30m. The pixel size and the pixel shape of DMSP discord the Regional Mesh. Therefore light intensity of DMSP was resampled by the method in Figure 2. Figure 3 shows a grid map of resampled light intensity by DMSP in Miyagi prefecture.

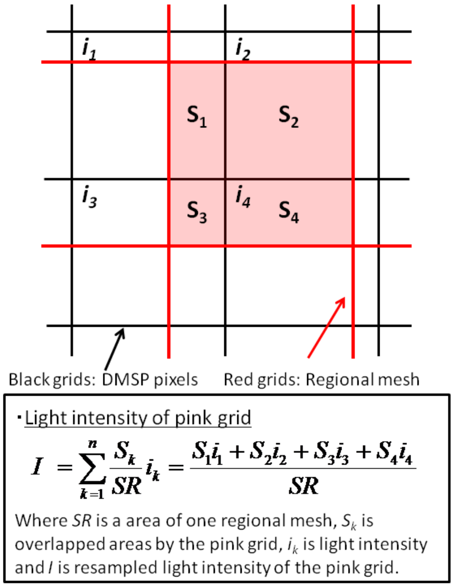

Figure 2: Resampling method of DMSP

2.3 Resampling of road data

The mesh data of road density and road length from the Digital National Land Information of Japan in 2010 (Ministry of Land, Infrastructure, Transport and Tourism) were used as road data. The aggregate unit of this data is the Regional Mesh. Each grid contains total road length of roads under 3.0m width, roads between 3m and 5.5m width and roads over 5.5m width. In this study we defined that roads under 3.0m width are single-lane road, roads between 3.0m and 5.5m width are two-line road and roads over 5.5m width are over-two-line road. As a result road lengths are defined as Equation 1.

$$L_N = L_{1N} + 2L_{2N} + 3L_{3N} \tag{1}$$

where L_{1N} is a total road length under 3.0m width in grid N, L_{2N} is a total road length between 3.0m and 5.5m width in grid N, L_{3N} is a total road length over 5.5m width in grid N, and L_N is a resampled road length in grid N. Figure 4 shows a grid map of resampled road data in Miyagi prefecture.

2.4 Resampling of building data

Digital residential maps in 2008 (ZmapTOWN II, by ZENRIN CO., LTD) were used as building data. Locations, shapes, areas and kinds of building everywhere in Japan can be collected using this data. The kinds of building

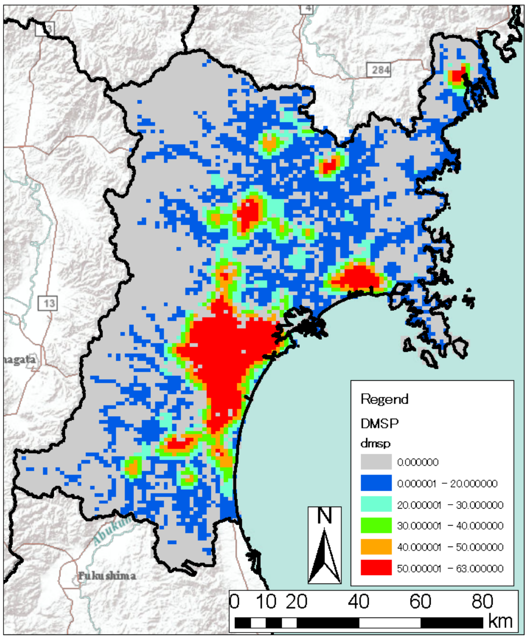

Figure 3: Grid map of resampled night light intensity by DMSP in Miyagi prefecture.

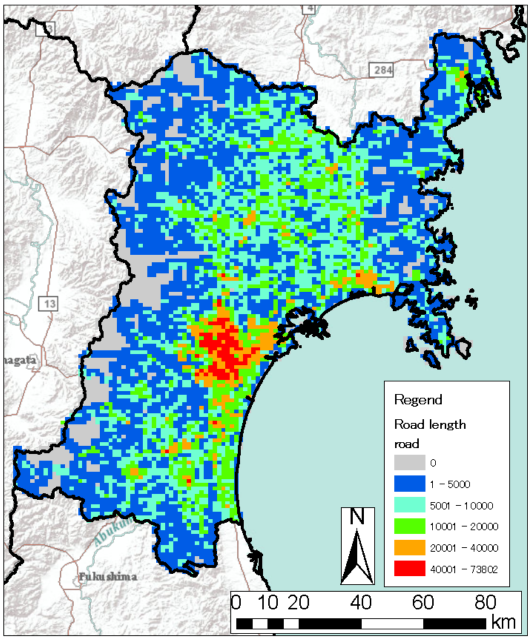

Figure 4: Grid map of resampled road data in Miyagi prefecture.

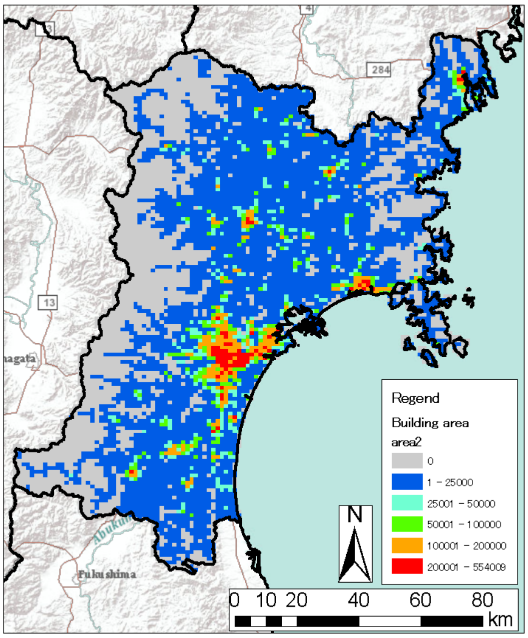

Figure 5: Grid map of resampled building data in Miyagi prefecture.

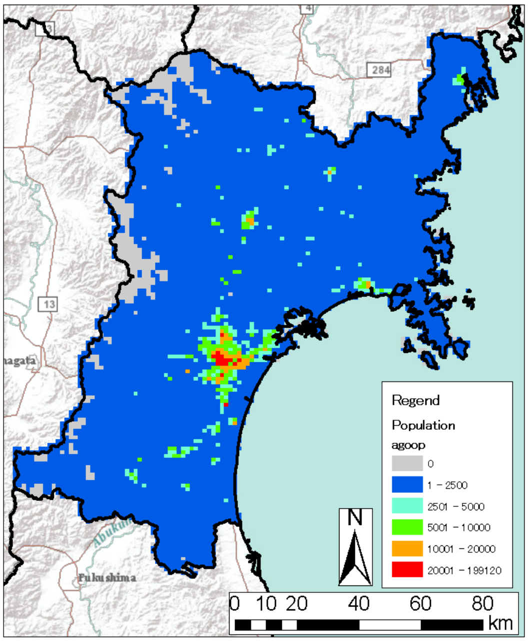

Figure 6: Grid map of resampled fluid population data in Miyagi prefecture.

means an application which contains residential buildings, multi-tenant buildings, shop and office buildings, warehouses and car garages. At first, point data of building centroids in Miyagi prefecture were developed. Secondly, warehouses and car garages were removed because it is considered that these kinds of buildings are not illuminant. Finally area of illuminant building in each grid are defined as Equation 2.

$$S_N = 0.5\sum_{k=1}^{nr} Sr_k + \sum_{k=1}^{nc} Sc_k + 2.0\sum_{k=1}^{nb} Sb_k \tag{2}$$

where Sr_k is an area of residential buildings, nr is the number of residential buildings, Sc_k and nc are multi-tenant buildings, Sb_k and nb is shop and office buildings, and S_N is the total area of illuminant building of grid N.

Sr_k is multiplied by 0.5 because it is considered that light intensity by residential buildings is smaller than other kinds of buildings between 20:00 and 21:00 when DMSP images were taken. On the other hand, Sb_k is multiplied by 2.0 because it is considered that these kinds of buildings are in business and light intensity is larger than other kinds of buildings in this time. Figure 5 shows a grid map of resampled building data in Miyagi prefecture.

2.5 Resampling of fluid population data

The Agoop Data in 2009 (AGOOP Corp.) were used as distribution data of dynamic population. Estimated fluid populations in each month and each hour can be monitored by the unit of the Regional Mesh using this data. The estimated fluid population means the average hourly number of people located in each grid. In this study the Agoop Data between 20:00 and 21:00 were used because image opportunities of DMSP are also between 20:00 and 21:00. In addition, another kind of data which can monitor dynamic population of Japan is the Person Trip Data. Source data of them were acquired between October and November because this season is regarded as best season for explorations of person flow (Hukumoto and Nakamura, 2011). Therefore we also used the Agoop Data in October. Figure 6 shows a grid map of fluid population data in Miyagi prefecture.

2.6 Zonal classification of resampled grids

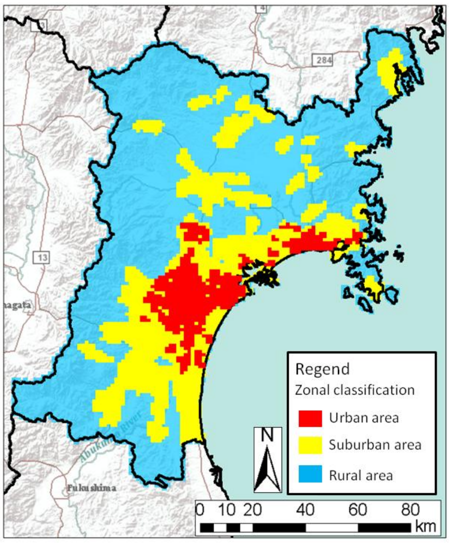

Figure 7: Zonal classification

Finally all resampled grid data were classified into urban areas, suburban areas and rural areas using polygon data of urban areas from the Digital National Land Information of Japan in 2006. Distributions of urban area, suburban area and other area, i.e., rural and mountainous areas defined by the National Land Use Planning Act of Japan can be monitored using these polygon data. Zonal classifications of all resampled grids were realized shown as Figure 7 to integrate these polygon data with the Regional Mesh.

3. RESULTS OF CORRELATION ANALYSIS

Table 1 shows results of correlation analysis that dependent variable and independent variables are light intensities of DMSP and 3 factors, i.e., road, building and fluid population distributions. In addition Table 2 shows a result of correlation analysis in urban areas, Table 3 shows in suburban areas and Table 4 shows in rural areas. On whole area of Miyagi prefecture (Table 1), road and building distributions have relatively strong correlation with light intensity. However a correlation between fluid populations and light intensities is weak.
On the other hand, region-by-region characteristics can be shown by Table 2, Table 3, and Table 4. Urban areas show the same tendency in whole area of Miyagi prefecture. In suburban areas, correlation between fluid population and light intensity is stronger than other areas. In rural areas, an effect of building distribution is strong. In addition, correlations between road or building and light intensity are weaker than the result in whole area of Miyagi prefecture. It is shown that monitoring of distribution conditions of road and building in detail only to use light intensity by DMSP is difficult.

Table 1: Correlation table in whole area of Miyagi prefecture

The number of grids: 7725	Light intensity	Road length	Building area	Fluid population
Light intensity	1.0000	0.7078	0.6329	0.3046
Road length	0.7078	1.0000	0.6455	0.3571
Building area	0.6329	0.6455	1.0000	0.6282
Fluid population	0.3046	0.3571	0.6282	1.0000

Table 2: Correlation table in urban area of Miyagi prefecture

The number of grids: 628	Light intensity	Road length	Building area	Fluid population
Light intensity	1.0000	0.5334	0.4461	0.2029
Road length	0.5334	1.0000	0.4772	0.2661
Building area	0.4461	0.4772	1.0000	0.6060
Fluid population	0.2029	0.2661	0.6060	1.0000

Table 3: Correlation table in suburban area of Miyagi prefecture

The number of grids: 2076	Light intensity	Road length	Building area	Fluid population
Light intensity	1.0000	0.5096	0.4370	0.4006
Road length	0.5096	1.0000	0.4309	0.4250
Building area	0.4370	0.4309	1.0000	0.9198
Fluid population	0.4006	0.4250	0.9198	1.0000

Table 4: Correlation table in rural area of Miyagi prefecture

The number of grids: 5022	Light intensity	Road length	Building area	Fluid population
Light intensity	1.0000	0.4680	0.4892	0.3860
Road length	0.4680	1.0000	0.3793	0.2933
Building area	0.4892	0.3793	1.0000	0.7610
Fluid population	0.3860	0.2933	0.7610	1.0000

4. RESULTS OF MULTIPLE REGRESSION ANALYSIS

We made multiple regression analyses that dependent variable is night light intensities of DMSP and independent variables are 3 factors. There are some previous studies to use the multiple regression analysis for processing and analyses of satellite images. Many of them used the multiple regression analysis to obtain significant objective variables to integrate satellite images with other spatial data (e.g., Nakamura and Kawashima, 1999a and Schneider et al., 2003). On the other hand this study evaluates performance of satellite images using other spatial data. Especially there are a few studies to evaluate performance of DMSP night light images by multiple regression analyses to use detailed spatial data as independent variables.

Table 5 shows results of multiple regression analysis and Figure 8 shows standard partial regression coefficients of 3 factors in each area. Significance levels of all analyses are 95%. There is no multicollinearity in all analyses. Road distributions have the strongest impact on the light intensity and impacts by fluid population are weak in whole area. In addition, urban areas denote the same tendency of whole area. On the other hand, impacts by building distribution increase with translation to suburban areas and they become the strongest factor in rural areas. There is little impact by fluid populations in each area.

As a result, impacts by road distribution are strong without relying on areas. It means that lights from cars and night illuminations on road affect the light intensity of DMSP. Impacts by building distribution become strong in suburban area and rural area. This is because lights from large-scale factories in suburban areas and waterfront areas and large-scale commercial facilities in suburban areas affect the light intensity and impacts by building become relatively large by decreasing of road densities in these areas. There are few affects by fluid populations. It means that there are not necessarily many people in areas with strong light intensity.

Table 5: Results of multiple regression analysis

		Whole area	Urban area	Suburban area	Rural area
Correlation coefficient (R)		0.7495	0.5808	0.5649	0.5770
Coefficient of determination (R2)		0.5618	0.3373	0.3191	0.3329
Adjusted R2		0.5616	0.3342	0.3181	0.3325
Standard deviation		11.3193	14.8238	13.8493	5.4556
The number of grids		7725	628	2076	5022
Coefficient	intercept	2.2768	32.8568	7.0744	0.1868
	Road length (X1)	0.001065	0.000468	0.001064	0.000615
	Building area (X2)	0.000178	0.000064	0.000204	0.000377
	Fluid population (X3)	0.000505	0.000131	0.001192	0.000851
Standard partial regression coefficient	Road length	0.5035	0.4123	0.3977	0.3298
	Building area	0.3791	0.3049	0.3425	0.3422
	Fluid population	0.1134	0.0916	0.0834	0.0288

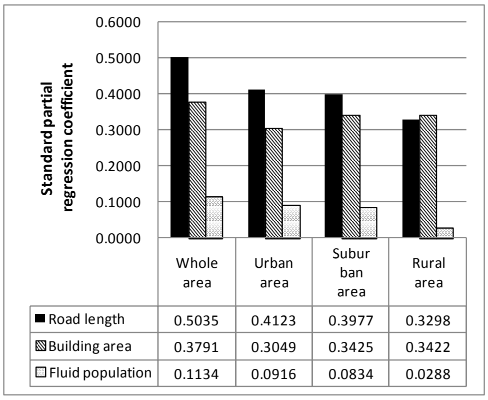

Figure 8: Standard partial regression coefficients in each area

5. COMPARISON BETWEEN DMSP AND ESTIMATED LIGHT INTENSITIES

Estimated light intensities in all Regional Mesh were calculated using results of multiple regression analysis in whole, urban, suburban and rural areas of Miyagi prefecture, and they were compared with the light intensity of DMSP. Estimated light intensities calculated by the result of whole area and urban (or suburban and rural) areas were developed in each mesh and the estimated light intensity which has smaller residual error was employed.

Figure 9 shows the result of estimated light intensity and Figure 10 shows residual errors in each Regional Mesh. Compared to Figure 3, tendency of spatial distribution of the light intensity by the estimated result agrees rather well with tendency by DMSP. However areas with strong light intensity by the estimated result are smaller than areas by DMSP in not only Sendai city but also other cities. It is believed that phenomenon which the light intensity of DMSP was saturated over sensitive ranges in urban areas was happened. Elvidge et al. (1999b) also pointed out this phenomenon. Figure 10 also shows that areas with large residual errors locate around cities like ring shape. This phenomenon is especially prominent around Sendai and Ishinomaki cities. Figure 11 shows the correlation between light intensities of DMSP and estimated intensities in Figure 9. It can be seen that the result in Figure 11 have stronger correlation than results in Table 5 to use estimate values with smaller residual error. It means that light intensity of DMSP is affected by different factors by areas.

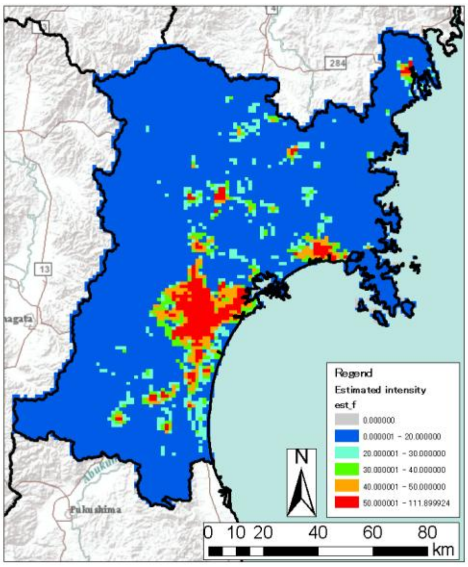

Figure 9: Estimated light intensity

6. CONCLUSIONS

In this study we showed the relationship between night light images of DMSP/OLS and human activities that was explained by distribution conditions of road, building and fluid population. Results of correlation analysis showed that the light intensity of DMSP correlates with distributions of road and building and correlates weakly with fluid population. In addition results of multiple regression analysis showed that automobile traffics have a

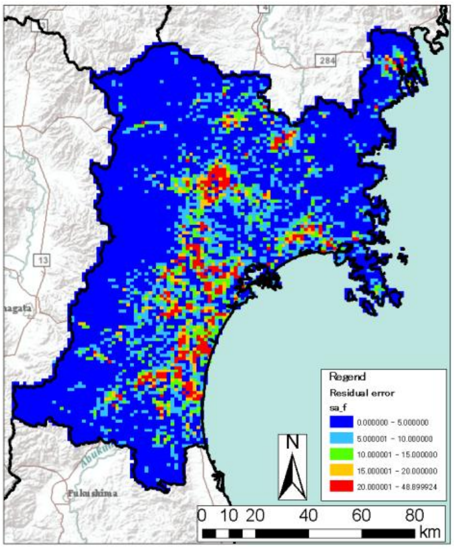

Figure 10: Residual errors

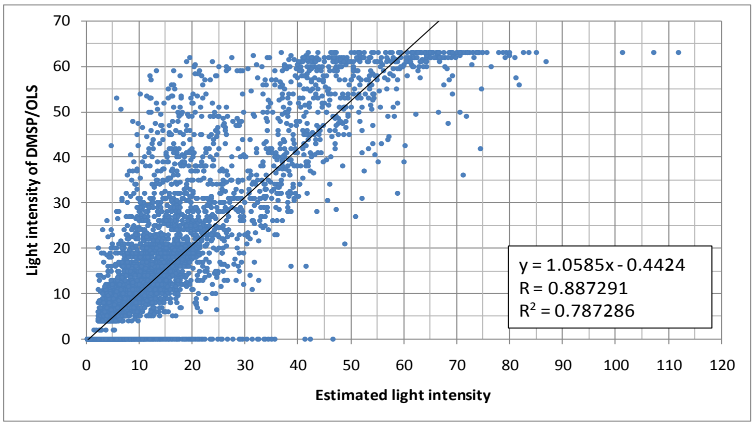

Figure 11: Correlation between light intensity of DMSP and estimated light intensity

major effect on the light intensity of DMSP. On the other hand, the effect by building distribution becomes large in suburban and rural areas. It is also shown that the light intensity of DMSP and accumulation of people do not necessarily accord.

There are some future works. We should expand study areas. It should be evaluated what result we will obtain in prefectures with no large cities like Sendai city and prefectures with megacity, e.g., Tokyo prefecture. In addition, it is needed to improve a reliability of light intensity to calibrate images of DMSP (e.g., Elvidge et al., 1999b). Our study shows that fluid population makes a little contribution to light intensity of DMSP. It is also an important challenge to seek new factors that contribute largely to light intensity with no multicollinearity.

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