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Inter-Annual and Intra-Annual Variabilities of NDVI, LAI and Ts Estimated by AVHRR in Korea

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Abstract : This study analyzes time variability of the normalized difference vegetation index (NDVI), the leaf area index (LAI) and surface temperature (Ts) estimated from AVHRR data collected from across the Korean peninsula from 1981 to 1994. In the present study, LAI defined as vegetation density, as a function of NDVI applied for the vegetation types and Ts defined by the split-window formulation of Becker and Li (1990) with emissivity of a function of NDVI, are used.

Results of the inter-annual, intra-annual and intra-seasonal variabilities in Korea show:

(1) Inter-annual variability of NDVI is generally larger in the southern and eastern parts of the peninsula than in the western part. This large variability results from the significant mean variation.

(2) Inter-annual variability of Ts is larger in the areas of smaller NDVI. This result shows that the NDVI play a small role in emissivity.

(3) Inter-annual variability of LAI is larger in the regions of higher elevation and urban areas. Changes in LAI are unlikely to be associated with NDVI changes.

(4) Changes in NDVI and Ts are likely dominant in July and are relatively small in spring and fall.

(5) Urban effect would be obvious on the time-varying properties of NDVI and Ts in Seoul and the northern part of Taejon, where NDVI decreases and Ts increases with a significant magnitude.

Key Words : NDVI, LAI, surface temperature, AVHRR, intra-annual variability, inter-annual variability.

1. Introduction

Land surfaces are important determinants of absorption for solar energy. The regional implementation of land-surface models has accounted heterogeneity in land surface by recognizing several vegetation types that differ in structural and hydro-physiological properties. In Korea, the significant changes on the surface temperatures and the relative humidity in urban areas have been reported (Um *et. al.*, 1997), which may result from the changing land surface.

This study aims to figure out the changes in land surfaces including canopies with the use of satellite data. To present the changes in land condition, NDVI, LAI and surface temperatures are estimated by AVHRR (Advanced Very High Resolution Radiance) long-term data. The raw

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channel data were averaged to get unbiased estimates of monthly mean data. The AVHRR data are able to show some aspects of temporal-spatial variations in regional area. Over Korea, the AVHRR data was applied to estimate the surface parameters from Suh *et al.* (1997).

Particularly, the regional model needs LAI and roughness length as a measure of interaction between land surface and atmosphere, and eventually shows the effect of considerable biomass in fluxes at the surface. There are still considerable debates over how to parameterize the nonlinear effects of land-surface heterogeneity at the spatial scale smaller than those explicitly resolved by regional models. The LAI, however, is defined as vegetation density, and the most important parameter to present the surface energy fluxes of the regional models. The Ts is a good-representative variable to separate the urban and rural effects due to the change in NDVI.

In the present study, the inter-annual variability and the intra-annuals variability of LAI and surface temperature as well as NDVI are estimated with use of satellite datasets.

2. Data

This study reviews satellite datasets of 8km × 8km resolution from the NOAA AVHRR. The NDVI was derived from the visible and near-infrared channel reflectances (0.58 to 0.68 and 0.73 to 1.10, respectively). This data set, which is produced as part of the NOAA/NASA Pathfinder AVHRR Land (PAL) program contains global and continental monthly composites over 8km resolution. The data are covered the period from 1981 to 1994.

3. Analysis

1) NDVI-LAI Relation

The LAI is defined as the whole leaf density accumulated by all leaf layer over an unit area. Globally, the LAI is estimated per unit of ground area, 0 to 6 in the coarse atmospheric model grid. However on a small scale, climatological ecosystems are classified by detailed species as an annual function of LAI. For example, an area classified as needle-leaf evergreen forest may consist of needle leaf evergreen trees, broad leaf deciduous trees, and bare ground as a function of LAI. Actually, the LAI distribution is needed to formulate the evapotranspiration from canopy root and the extinction of solar radiation, which regulates the surface temperature and turbulent mixings of water vapor and momentum.

Here, the LAI is formulated as a function of the NDVI by 8km × 8km, which is calculated using the Ch-1and Ch-2 AVHRR. Using 90m × 90m orography and NDVI data, a sub-sectioning of an

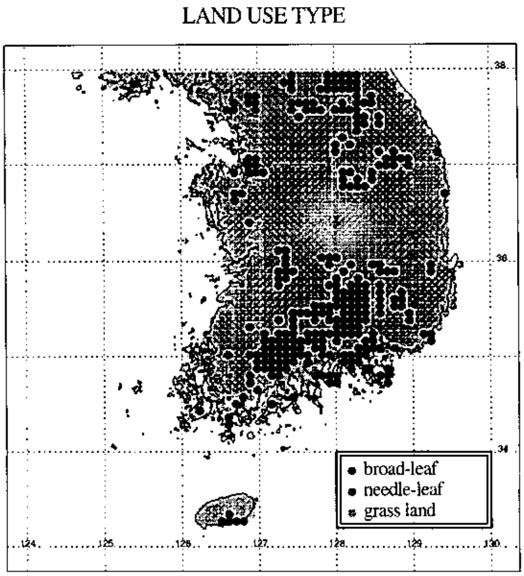

LAND USE TYPE

Fig. 1. Three vegetation types for LAI calculation in this study.

outline/mask was performed by three vegetation types (Fig. 1) of broadleaf type for deciduous, evergreen broadleafs, and mixed forest, needle-leaf type for deciduous and evergreen needle-leafs, and grassland type for remnants shown in Table1. A monthly LAI estimation according to three types of NDVI was applied to simple empirical formulations such as linear and quadratic relationships (Fig. 2). In arrangement to the three vegetation types, the grass-land (Asrar *et al.*, 1985), needle-leaf (Spanner *et al.*, 1990) and the broad-leaf (Pierce *et al.*, 1993), the LAI are formulated respectively as follows,

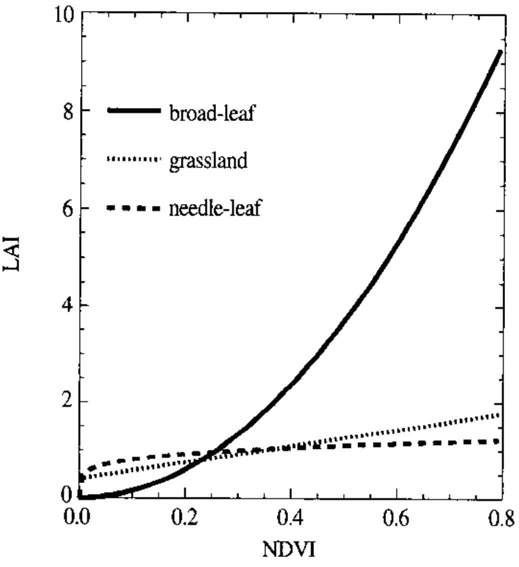


Fig. 2. LAI as a function of JJA(June-July-August) mean NDVI for each vegetation type.

$$\mathrm{LAI} = \mathrm{NDVI} \times 1.71 + 0.4 \tag{1}$$

$$\mathrm{LAI} = \left(\frac{\mathrm{NDVI}}{0.31}\right)^{0.2} \tag{2}$$

$$\mathrm{LAI} = \left(\frac{\mathrm{NDVI}}{0.26}\right)^{2} \tag{3}$$

2) NDVI-Ts Relation

The surface temperature (Ts) is formulated by the split-window method (Becker and Li, 1990) as a function of temperature from Ch. 4, water vapor effect (δ_w), and emissivity effect (δ_e). The effects of water vapor and surface emissivity are formulated by the Gutman (1994) method as follows:

$$Ts = T_4 + \delta_w + \delta_e \tag{4}$$

$$\delta_w = 2.63(T_4 - T_5) + 1.274 \tag{5}$$

$$\delta_e = [0.078(T_4 + T_5) + 1.69(T_4 - T_5)](1 - e)/e \tag{6}$$

T4 and T5 are the temperatures retrieved by Ch. 4 and Ch. 5, respectively and *e* is the surface emissivity coefficient as a function of the vegetation index from Van de Griend and Owe (1993) as follows:

Table 1. Sub-sectioning criteria of outline/mask for three vegetation type by using 30sec/30sec vegetations in MM5 USGS.

Classification \ Criteria	Land use type
Grass-land	Urban Drylnd Crop. Past. Irrg. Crop. Past. Mix.Dry/Irrg.C.P. Crop./Grs. Mosaic Crop./Wood Mosc Grassland Shrubland Mix shrb./Grs. Savanna Decide. Broadlf. Decide. Needlf. Evergrn. Braodlf. Evergrn. Needlf. Mixed Forest Water Bodies Herb. Wetlan Wooden Tundra Bar. Sparse Veg. Herb. Tundra Wooden Tundra Mixed Tundra Bare Grnd. Tundra Snow or Ice
Needle-leaf	Decids. Needlf. Evergrn. Needlf.
Broad-leaf	Decids. Broadlf. Evergrn. Broadlf. Mixed Forest

$$e=1.009+0.047\ln(V_s) \quad (7)$$

Here the vegetation index is used by NDVI. The above algorithm is the only possible approach that should be further developed and tested. In fact, unresolved thin clouds can lead to an increased (T4−T5) and a decreased NDVI. In such case, the corrections for water vapor and emissivity compensate for the underestimated brightness temperature.

3) Time Variability

The time variability was distinguished by intra-annual [*IntraAV*] and inter-annual [*IntraAV*] variabilities as:

$$\text{Intra\_annual variance} = \frac{1}{J}\sum_{j=1}^{J}\left[\frac{1}{K}\sum_{k=1}^{K}(x_{ijk}-\overline{x}_{ij})^2\right],$$

$$[IntraAV]_i \equiv (\text{Intra\_annual variance})^{1/2} \quad (8)$$

$$\text{Inter\_annual variance} = \frac{1}{J}\sum_{j=1}^{J}(\overline{x}_{ij}-\overline{\overline{x}}_i)^2,$$

$$[InterAV]_i \equiv (\text{Inter\_annual variance})^{1/2} \quad (9)$$

Here, *i* means spatial distribution, and *J* is total years of collected data. Here, *K* is the number of months, and [*IntraAV*] indicates month to month variation for the yearly mean. $\overline{x}_{ij}$ is the yearly mean and $\overline{\overline{x}}_i$, for the period of 1981-1994, is assumed as a climatological mean. For a specific month, we can present the inter-annual variability by considering the *J*-year averaged variances.

4. Inter-annual Variability

Fig. 3 shows the annual mean and the inter-annual variability [*InterAV*] of NDVI for 1981-1994. The NDVI area mean for domain analyzed over Korea is 0.357, with a variation within 20% of the inter-annual variability for the climatological mean. The annual mean NDVI shows that there is a larger NDVI in the southern and eastern parts than in the western. In overall, the inter-annual changes of NDVI are more localized than their mean distribution. The largest inter-annual changes exist in the north-eastern coastal area. Locally Seoul and the Seosan/Asan coastal areas, which have a small mean NDVI, show large differences inter-annually.

The annual mean and inter-annual variabilities for satellite derived surface temperatures (Fig. 4)

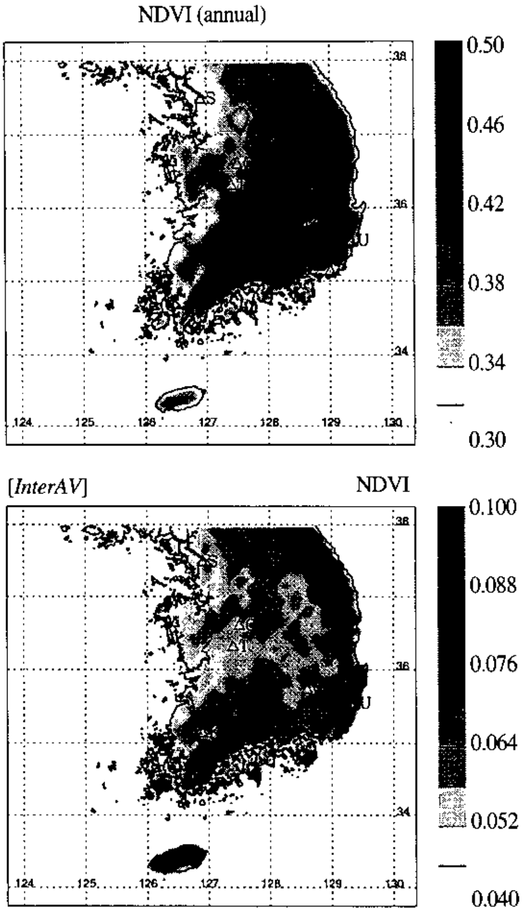


Fig. 3. Annual mean and [*InterAV*] for NDVI. [*InterAV*] is the inter-annual variability in NDVI estimated by Eq.(9). The symbols of ΔS, ΔC, ΔT, ΔG, ΔK, ΔU, and ΔP indicate the position of big city of Seoul, Chongju, Taejon, Taegu, Kwangju, Ulsan, and Pusan, respectively.

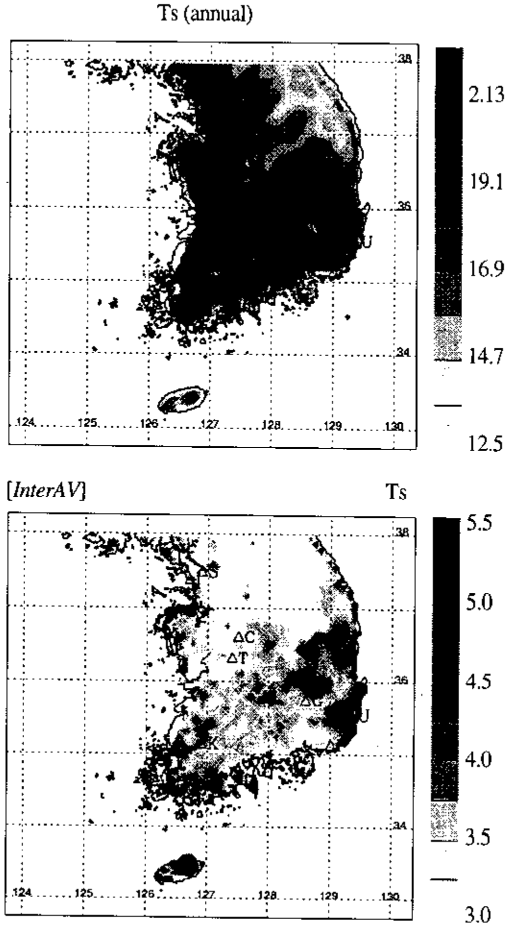


Fig. 4. Same as Fig. 2 except for surface temperature.

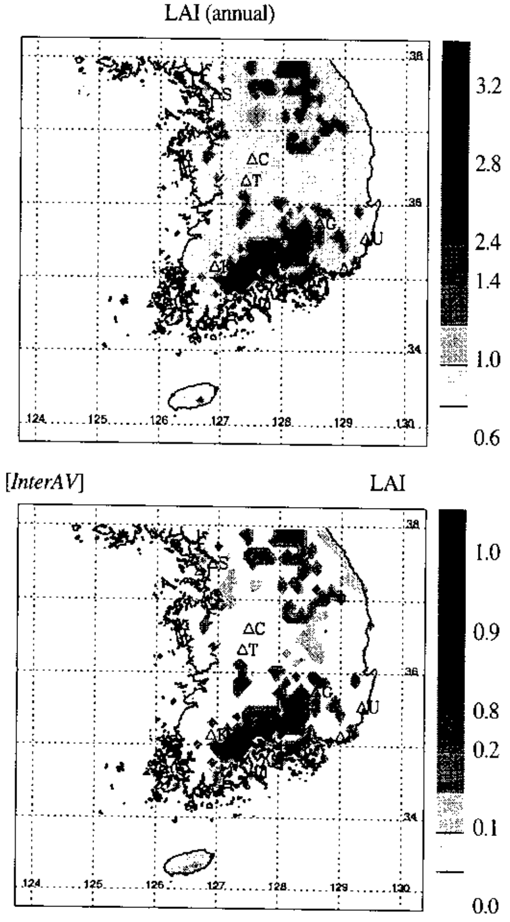


Fig. 5. Same as Fig. 2 except for LAI.

tends to have a localized aspect. The climatological annual mean for surface temperature over Korea is 18.37°C with an averaged inter-annual variability of 5% for the climatological mean. In the smaller NDVI areas, there exists significant high mean and inter-annual variability. Especially, inter-annual variances in big cities, such as Seoul and Ulsan are significant as inter-annual variability.

In Fig. 5, the [*IntraAV*] of LAI is highly dependent on the vegetation type. With an annual mean LAI of 1.40 and an inter-annual variability of 20%, two large LAI regions split the Korean peninsula into north and south.

5. Intra-annual Variances

Fig. 6 shows the intra-annual variability for NDVI (a), Ts (b), and LAI (c). The intra-annual variability is significant in the north. This is mainly due to the differences between the warm and cold seasons. The intra-annual variability of surface temperature is of a significant magnitude on the urban areas, and the lower NDVI areas. There is small [*IntraAV*] over the southern and eastern coastal areas. Large [*IntraAV*] can be seen over the continental areas located far from coastal regions and areas of low altitude with the rare vegetation. These indicate that both the vegetation

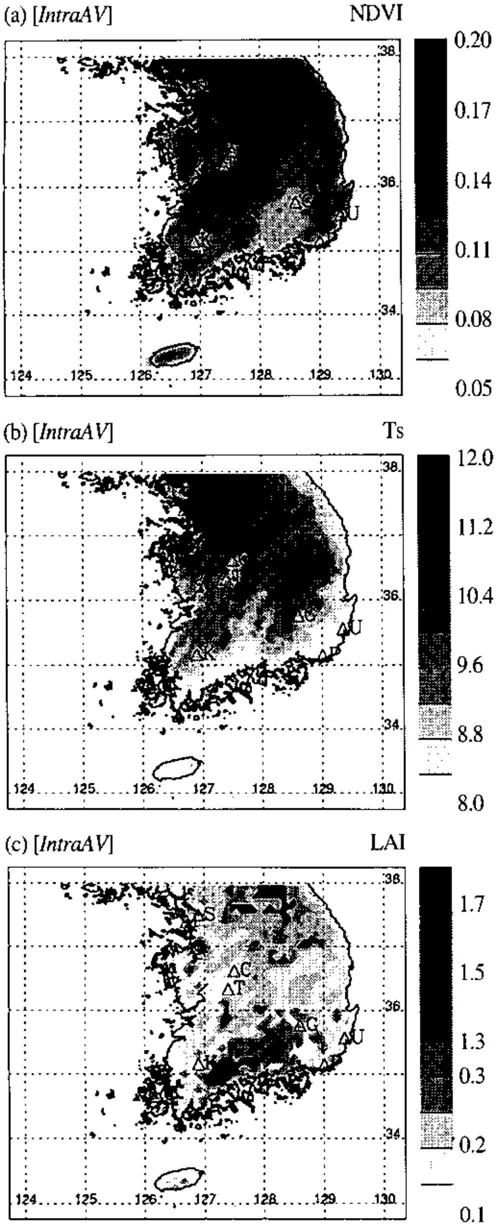


Fig. 6. [*IntraAV*] for (a) NDVI, (b) surface temperature, and (c) LAI. [*IntraAV*] is the intra-annual variances estimated by Eq.(8) in the text.

layer and coastal areas can play an important role in reducing the intra-annual variability by the effects of evapotranspiration of the canopy layer and ocean currents. On the other hand, the intra-annual variances for the lower NDVI areas might be over-estimated due to an excessive emmissivity correlation.

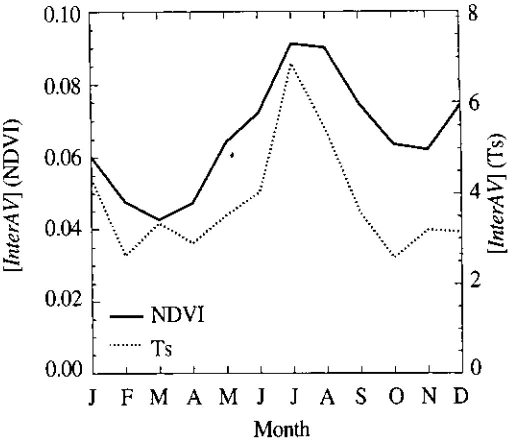


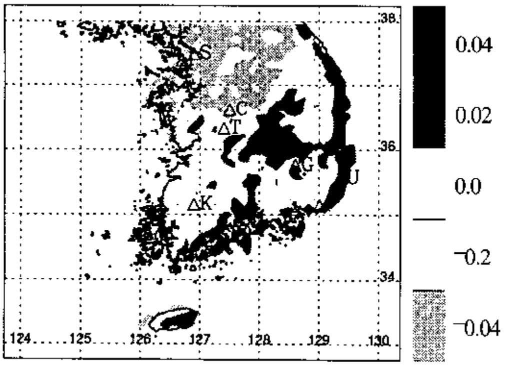
Fig. 7. Seasonal March of [*InterAV*] for NDVI and surface temperature (Ts).

From monthly march of [*InterAV*] for both NDVI and Ts (Fig. 7), it is clear that they are changing because of each other and the change is of a significant magnitude in summer. In July, the biggest [*InterAV*] for NDVI and Ts occurs. This is mainly due to a high NDVI and Ts mean value. The NDVI minimum for inter-annual variability is in March, when it is early spring, while the Ts inter-annual variability is reduced in spring and fall seasons. This shows that the variability mainly results from the warm and cold seasons.

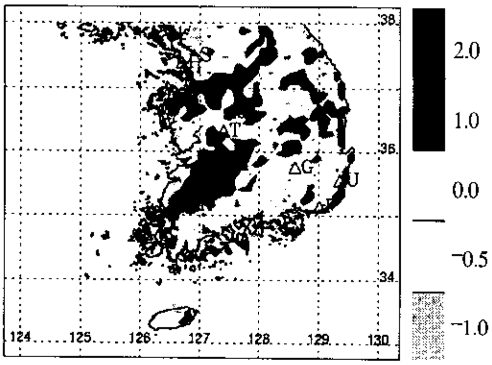
6. Urban Effect

In Korea, the changes in the land use and surface type have been observed when the surface temperature changes have been considered. For example, Fig. 8 shows the difference between the first three-year mean and the last three-year mean of the analyzed period.

(a) NDVI2−NDVI1



(b) Ts2−Ts1



(c) LAI2−LAI1

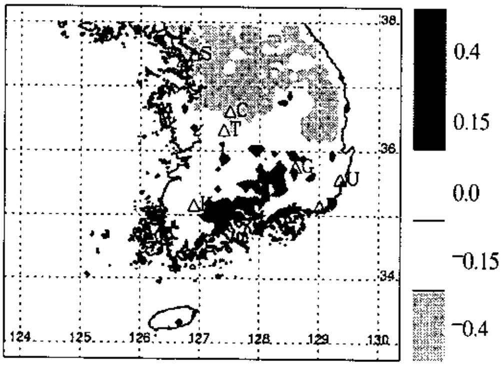


Fig. 8. Differences between the late three years mean and the early three years for NDVI, surface temperature, and LAI.

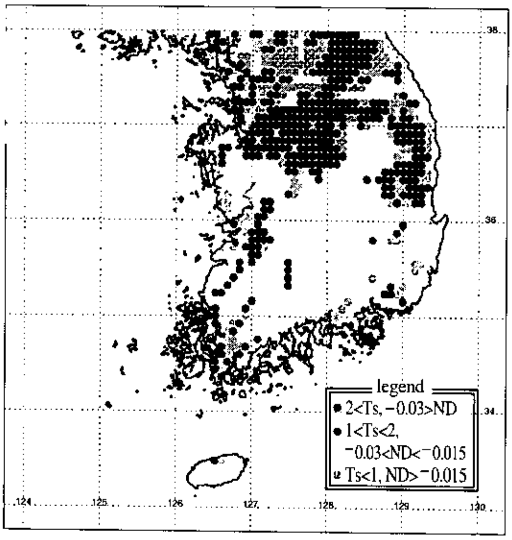


Fig. 9. Distribution of the changing rate for Ts and NDVI. The symbols of ●, ● and ● indicate the above 0.015 for ΔNDVI and below 1 ΔTs, −0.015 ~ −0.03 for ΔNDVI and 1~2 for ΔTs, below −0.03 for ΔNDVI and above 2 for ΔTs, respectively.

The Ts and NDVI have opposite trends in the first three-year and last three-year period as shown in Fig. 8. Distribution analysis shows that the trend decreases in the northwest while increases in the southeast regions. The changes in the LAI distributions are unlikely to follow the NDVI distribution. In the regions of the Kyungsang basin and east coast line, their differences are dominant. When the surface temperature is considered, however, the increasing trend dominates the whole peninsula. Particularly, this indicates that the NDVI and surface temperature correlate each other. The decreasing NDVI might relate to the increasing surface temperature in the urban areas. In the seasonal NDVI distribution (not shown) there is a decreasing trend overall in the warm season, an increasing trend in the southern and eastern areas during growing and fall seasons. When surface temperatures are distributed to the NDVI, during the cold season some regions display the opposite trend.

To evaluate the urban effect on the NDVI and Ts changes, the time-varying properties for NDVI are compared to surface temperature to separate land cover. The Urban effect area are assumed by region, to have increasing Ts and decreasing NDVI in this study. Fig. 9 shows that the areas influenced by the urban effect with significantly varying NDVI and Ts are distributed in the region north Taejon and in those with high populations. The darkness in Fig. 9 indicates the changes in magnitude as legend.

7. Conclusions

The inter-annual variability and intra-annual variability have been described using the available AVHRR datasets that have proven useful for land-surface analysis. Unfortunately, so far, it seems that at present there is no long-term dataset for climate changes in land surface parameters.

The results of the [*InterAV*] and [*IntraAV*] for NDVI, LAI and surface temperatures are summarized as follows. There are significant inter-annual variability over the area of large mean and cities. It is obvious that high surface temperatures exist in the smaller NDVI areas. The inter-annual variability is significantly high in the southern and eastern parts of the main mountain range in the peninsula for the NDVI and Ts. The urban effect is assumed as both the decreased NDVI and the increased Ts and NDVI show that the significant surface changes might be induced by a decreased canopy layer. The [*IntraAV*] has a maximum magnitude in July, which shows the possibility of the interaction of surface parameters.

The LAI distribution in the Korean peninsula can be used to simulate the surface fluxes over the heterogeneous landmasses in regional models.

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