Applicability of the Global Scale NPP Estimation Model for Regional Uses

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Abstract

Net Primary Production (NPP) has been an important environmental variable to understand productivity of several ecosystems. In recent years, global scale NPP models are developed by combining satellite remote sensor images and meteorological data for the estimation of global carbon budget. MODIS NPP algorithm is one of such model that incorporates satellite remote sensor data for deriving several input parameters for the model. Although MODIS NPP product has a great potential for global scale carbon cycle processing, the global-scale estimate of NPP may not fully represent the regional and local attribute of various ecosystems. Some of input parameters applied to the MODIS NPP algorithm may be too crude to use for the regional-scale NPP estimate.

As a preliminary study to evaluate the relevance of MODIS NPP products in region-scale, we generated a reference NPP map using rather fine-resolution input datasets. The sensitivity of MODIS NPP algorithm was analyzed by applying fine-resolution leaf area index (LAI) map, land cover map, and local meteorology data over the study area in Kyongan watershed near the Seoul metropolitan area. Input parameters used for the model were derived from various sources data including ground measured LAI, Landsat ETM+ image, meteorology data of local weather station. A reference NPP map of the study area was produced with 30m spatial resolution and then compared with 1km resolution MODIS NPP data. Initial results show that the accuracy of NPP estimate is largely dependent on the fidelity of input parameters rather than the model itself.

1. Introduction

The consequence of global environment change has been known to have direct relationship with human society. In particular, the increasing atmospheric CO_2 concentration is mainly due to the human-induced land use change and the combustion of fossil fuel. As one of major greenhouse gases, the high concentration of CO_2 has something to do with global climate. Global mean air temperature has increased along with the increasing greenhouse gases concentration. Many developed and industrial counties adapted a new plan, called Kyoto Protocol, for reducing CO_2 emissions during the conference in 1997. As early as in 2008, each country joined the Kyoto Protocol has obligation to report the exact amount of carbon emission to reduce. Therefore, monitoring the regional carbon budget can be a critical component for not only for the global carbon cycle but also for the regional and national ecosystem managements.

Primary production by terrestrial ecosystems plays important role as a source of carbon sink budget. NPP, defined as the net amount carbon stock, is a key environmental parameter to understand the terrestrial carbon cycle. There has been increasing number of approaches to estimate global scale NPP over land using satellite remote sensor data. Moderate resolution imaging spectroradiometer (MODIS) sensor was designed for deriving several global-scale environmental and ecological variables including NPP. Currently, global-scale NPP data are being produced at the 1km spatial resolution (Running et al., 2000). Although MODIS NPP product has a great potential for analyzing the global-scale carbon cycle, this global estimate of NPP may not fully represent the regional characteristics. The objective of this study is to analyze the applicability of MODIS NPP algorithm to regional-scale by applying input parameters at high spatial resolution.

2. MODIS NPP Algorithm

MODIS NPP algorithm is based upon the biome-specific light use efficiency factors that are derived from the process-based Biome-BioGeochemical Cycles (BGC) model (Running et al., 2003). The Biome-BGC model requires daily climate data and several key variables of vegetation conditions, such as leaf area index (LAI). MODIS NPP algorithm uses several input parameters derived from climate data as well as from multispectral satellite image data (Figure 1). The model initially calculates daily gross production (GPP) and daily maintenance respiration of roots and leaf mass to estimate daily net photosynthesis. Then the annual NPP is estimated by subtracting the growth respiration from the sum total of daily GPP.

To obtain the annual NPP, several input parameters are required. Since the NPP estimate algorithm is applied separately for each of different biome, land cover map is an essential part to spatially separate each biome. MODIS land cover (MOD12) and LAI/fPAR (MOD15) products are other datasets derived from MODIS satellite data and used as input parameters for the NPP algorithm. Other important input parameters are meteorological data, including average and minimum air temperature, incident photosynthetically active radiation (PAR) and specific humidity and they are derived a global weather model based on extensive sets of ground and satellite-based climate data. MODIS land cover and LAI maps are produced at 1km spatial resolution while the daily meteorological data are distributed at a spatial resolution of 1° by 1°. Because of the coarse resolution meteorological data, the 1-km resolution NPP map often shows unusual rectangular pattern corresponding to the 1 degree grid pattern.

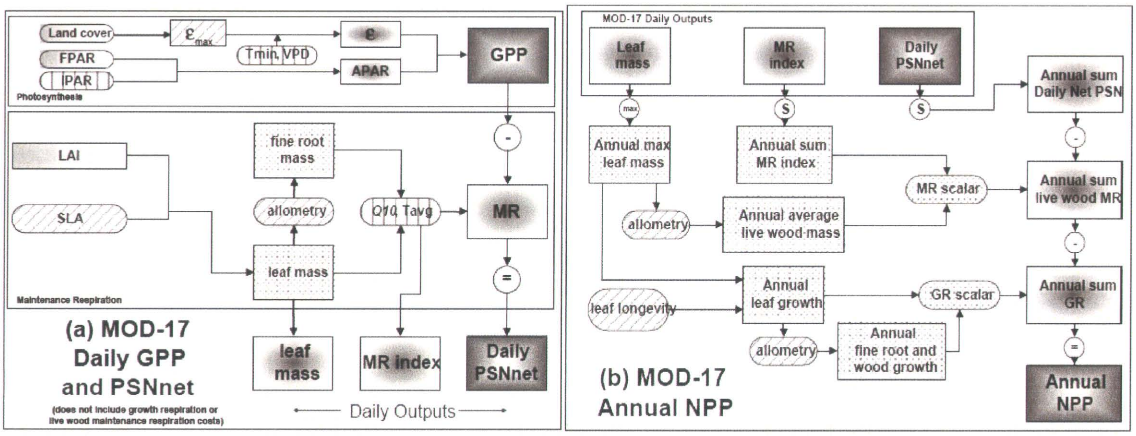

Figure 1. Flowcharts showing the logic behind the MODIS NPP algorithm in calculating both (a) Daily net photosynthesis and (b) annual NPP (Running, 2003).

3. Methods

3.1 Study area

To test the MODIS NPP algorithm for regional uses, we decide to apply the model over a relatively small watershed area. Approximately 600km^2 of the Kyongan watershed was chosen for this study. The two third of the study area, located near the Seoul, is covered largely by mixed coniferous and deciduous forests and the remaining one third of the area is agricultural croplands and built-up area (Figure 2). The temperate mixed forest has diverse group of species composition and forest stand age of between 20 to 50 years and the crown closure is over 80%.

Landsat ETM+ data, obtained on September 10, 2003, were used to generate fine resolution vegetation-related input parameter (LAI) required for the MODIS NPP algorithm. Initially, ETM+ data were georeferenced to the local plane rectangular coordinates by using a set of ground control points obtained from the 1:5,000 scale topographic maps. Further, ETM+ data were atmospherically corrected and converted to percent reflectance value.

Daily meteorological data were also prepared for the same spatial resolution as ETM+ data by interpolating the local climate data collected from nearby weather stations. Local-scale meteorological data used for the model include minimum and maximum air temperatures, solar radiation, and vapor pressure deficit

3.2 Ground measurements of LAI

During the growing season of 2003, 30 ground sample plots were selected and leaf area index, species composition, and stand density were measured using Li-Cor LAI 2000 (Gower et al., 1999). To minimize any discrepancies due to the phenological variation of leaf growth, the field measurement were conducted as close to the date of Landsat ETM+ acquisition. Each plot has an area of 20x20m^2 and includes five subplots for LAI measurement within it. All subplot measurements were averaged to provide a single value for the LAI at each plot. Plot location were determined using a differential global positioning system (DGPS).

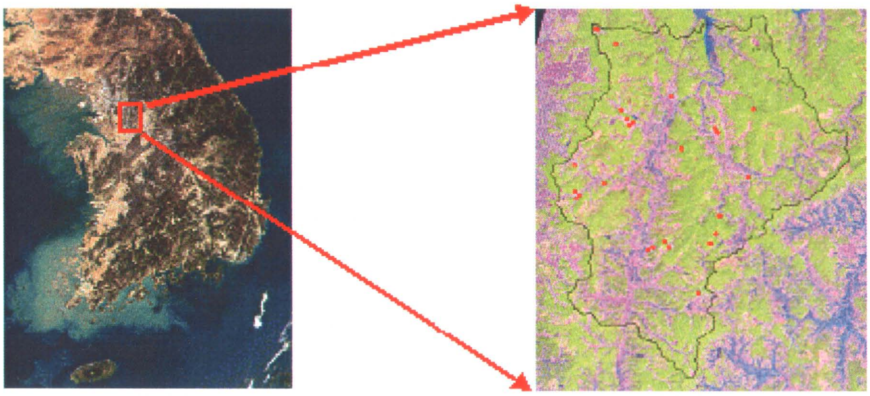

Figure 2. Distribution of 30 ground plots of LAI measurements within the study area of the Kyongan Watershed.

In addition to the 30 plots measurements, additional LAI were measured continuously over the same forest stands. In temperate forest, LAI value continuously changes from the early spring of leaf onset to the late fall. One way of generating annual LAI maps is to generate a temporal function developed by monthly LAI values over the same plot and link them to a time-specific LAI map. To find the temporal pattern of annual LAI change, LAI were measured throughout the year at two forest stands of deciduous and coniferous forests. Figure 3 shows the annual changes of LAI values over the sample forest stands.

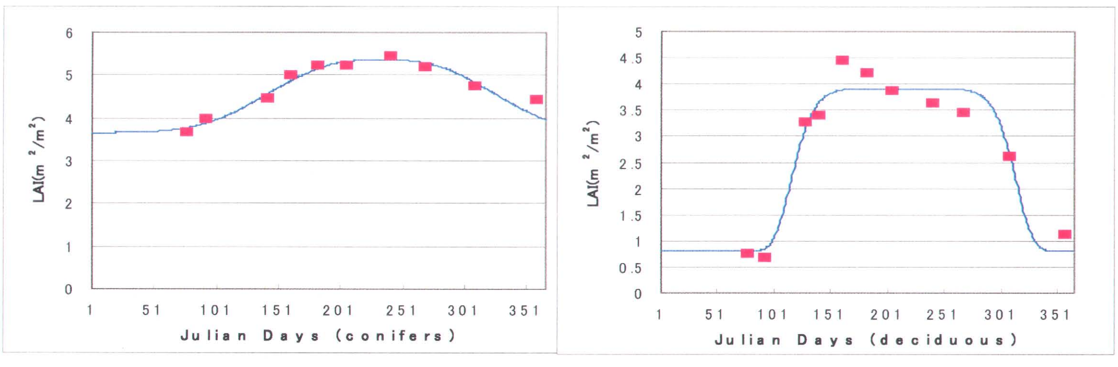

Figure 3. Annual pattern of LAI change obtained from monthly LAI measurements.

3.3 Generation of fine resolution input datasets for the NPP model

1) LAI map

The LAI map of the study area was generated by an empirical model to relate field measured LAI with ETM+ reflectance values (Lee et al., 2003). However, this LAI map only represents the canopy leaf mass at the time of the field LAI measurement. As seen in Figure 1, daily LAI map is necessary to estimate daily maintenance respiration. The multiple LAI maps were produced by applying the temporal functions seen in Figure 4 to the LAI map obtained by the ETM+ reflectance. The temporal LAI functions of other than forests (crop and grassland) are adopted from previous studies (Jin, 1986; Hong, 1998).

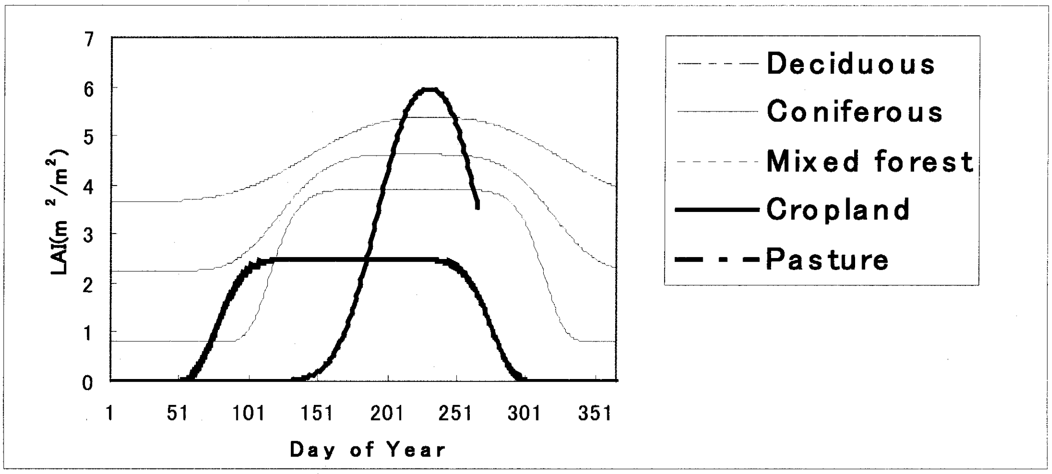

Figure 4. The temporal functions of LAI change used to generate daily LAI maps .

2) fPAR from the seasonal LAI map

The fPAR is fraction of incident photosynthetically active radiation absorbed by the surface, which can be calculated as a function of LAI. A research ground working on the validation of MODIS products has developed one of such functions (BigFoot, 2004; Cohen et al., 2003).

$$fPAR = 1\text{-}\exp(-0.6194*LAI) \qquad (1)$$

The canopy light extinction coefficient 0.6194 was computed using ground-measured LAI and fPAR from several validation sites, which include several different biomes. Time series fPAR maps are generated by applying the equation (1) to the daily LAI map.

3) Land cover map

Land cover map used for the model was originally produced by the Ministry of Environment. Using several multispectral data including IRC-1C and Landsat TM data, the land cover map includes 23 cover types. The land cover map was reclassified into the MODIS land cover classes of evergreen needle-leaf forest (ENF), deciduous broadleaf forest (DBF), mixed forest (MF), and cropland (C), which are among those biomes defined by the Biome-BGC model. The 30m-resolution land cover map was then converted to 1km spatial resolution to compare with the MODIS land cover product. As can be seen in Figure 5-b, the 1km resolution converted land cover map show increased portion of mixed forest while the original 30m resolution map (Figure 5-a) shows the largest portion of deciduous forest. The increase of mixed forest is due to the merging of coniferous and deciduous forests within 1km spatial resolution.

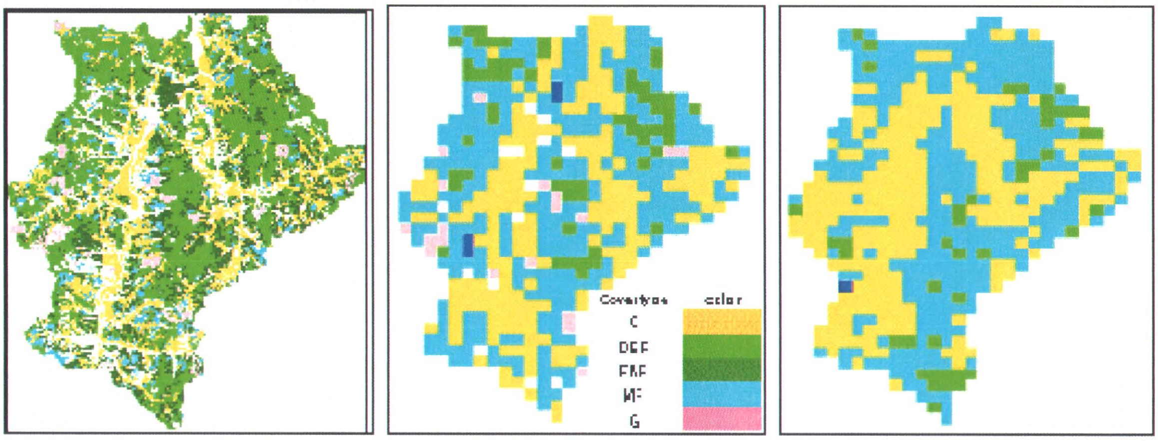

Figure 5. Reference land cover map with 30m spatial resolution (a), resampled 1km reference land cover map (b), and 1km MODIS land cover map (c).

4) Meteorological data from local weather stations

MODIS NPP algorithm requires daily meteorological data including minimum and maximum temperature, solar radiation, and vapor pressure deficit. MODIS NPP product is based on the meteorological data of a spatial resolution of 1° by 1°, which do not quite represent the site-specific variation of weather pattern in local-regional scale over the mountainous area. Daily meteorological maps at 30m spatial resolution were produced by interpolating weather data collected nearby local weather stations data.

4. Results and Discussions

Combining all these input parameters into the MODIS NPP algorithm in Figure 1, the 30m resolution reference NPP map was obtained and compared with the MODIS NPP product over the study area. Figure 6 shows the reference NPP map that was resampled to 1km spatial resolution and the MODIS NPP product of the year 2002. The average NPP values between the reference NPP map and the MODIS NPP products are 379.9 g_C/m^2 and 578 g_C/m^2, respectively. Although the

MODIS NPP estimate is much higher than the reference NPP, it is hard to tell which NPP estimate is more accurate than the others without reliable ground truth data. These two maps are obtained basically from the same algorithm. Only difference is that the reference NPP was derived by using input parameters, which incorporated the site-specific variation at 30m spatial resolution.

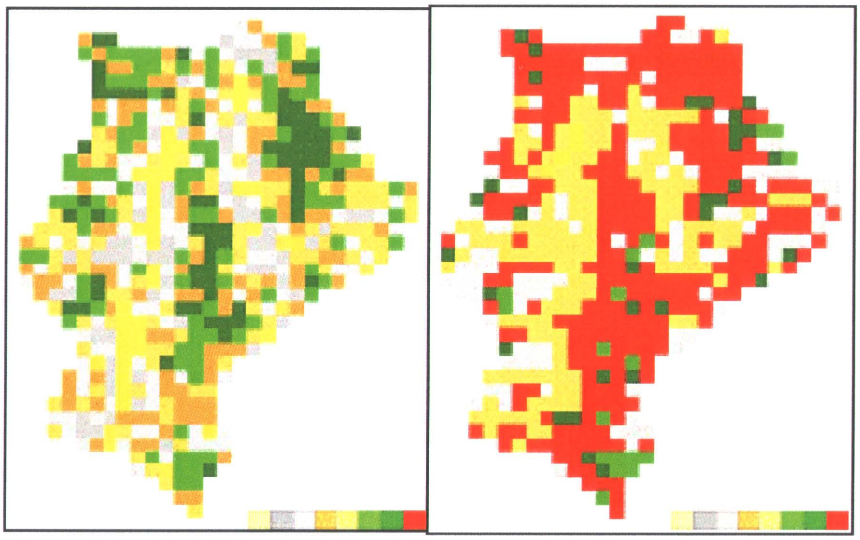

Figure 6. The reference NPP map (left) estimated by using local input parameters as compared to the MODIS NPP product (right).

Even though there was no direct ground survey on the forest NPP in the study area, we were able to find a few field ecology studies related to the primary production of forests that have similar stand structure to the study area. The ground survey of forest NPP was carried out by traditional forest inventory method, in which the annual increment of biomass growth was measured for every tree within the sample plot. Although forest NPP varies by the species, stand age, and site conditions, the ground survey results were very similar to the reference NPP estimate. Figure 7 shows the forest NPP of several stands of different species and compared them with the MODIS and the reference NPP estimates. In overall, the mean NPP value of the reference NPP map appears to be more comparable to the ground measured NPP than the MODIS NPP product. It is interesting to see that the MODIS NPP map shows lower NPP estimate in coniferous stands while it has higher NPP estimate in deciduous stands.

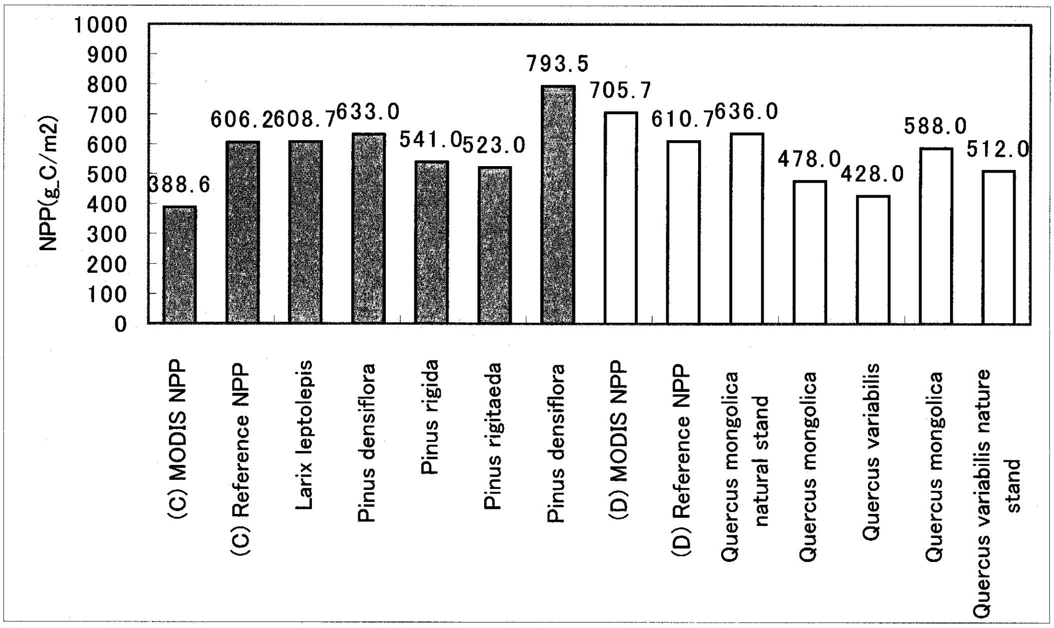

Figure 7. NPP estimates of the reference NPP map and the MODIS NPP product as compared by the ground surveyed NPP results over various forest stands in coniferous (C) and deciduous forest (D).

Figure 8 shows the one-to-one relationship between the reference NPP and the MODIS NPP maps of 1km resolution. No significant trend is found between two NPP estimates, except that the MODIS NPP product shows higher estimates than the reference one. Probably, the two groups in Figure 8 may correspond to different biome. The variance of the reference NPP value is larger than the MODIS NPP value, which may indicate that the reference NPP estimates is more sensitive to different biomes.

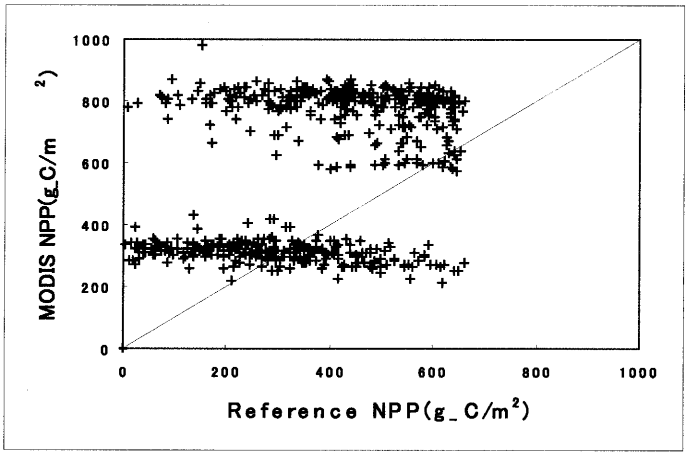

Figure 8. The relationship between the reference NPP and the MODIS NPP over the study area.

5. Conclusions

This study attempts to evaluate the applicability of the global-scale MODIS NPP product and the estimation algorithm for regional and local scale uses. Although the MODIS NPP product may be useful to analyze global-scale carbon cycle as well as other terrestrial ecological studies, they are not likely to represent the regional variability of diverse biomes. The discrepancy between the MODIS NPP product and the reference NPP estimates can be explained by the fidelity of input data required by the estimation model. There are several input parameters that influence the NPP estimate. First of all, since the NPP estimation algorithm is separately applied within each biome, we need accurate land cover map. Leaf area index (LAI) is another key input parameter that should incorporate the local variability of vegetation canopy. The MODIS LAI estimate is based on the inversion of radiative transfer model and empirical relationship with spectral vegetation index, there are not quite appropriate for the forest where the canopy closure and LAI in relatively high. In addition, it is also very important to generate time series LAI maps that should reflect the temporal variation of canopy leaf mass in particular at the temperate forest.

In overall, the MODIS NPP is overestimated than the reference NPP. This discrepancy between MODIS NPP and reference NPP may be caused by the overestimation of MODIS LAI product and by the misclassification in the MODIS land cover map. Although the MODIS NPP product does not represent the local variation, the NPP estimation algorithm itself seems to work fine and can be used for estimating NPP over regional scale ecosystems. Further study is planned to develop suitable methodology to generate the fine resolution input datasets required for the MODIS NPP algorithm.

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