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ESTIMATION OF GROSS PRIMARY PRODUCTION USING SATELLITE DATA AND GIS IN URBAN AREA, DENPASAR

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Abstract. Remote sensing data with high spatial resolution is very useful to provide information about Gross Primary Production (GPP) especially over spatial coverage in the urban area. Most models of ecosystem carbon exchange based on remote sensing data used light use efficiency (LUE) model. The aim of this research was to analyze the distribution of annual GPP urban area of Denpasar. Two main satellite data used in this study were ALOS/AVNIR-2 and Aster satellite data. Result showed that annual value of GPP using ALOS/AVNIR-2 varied from 0.130 gC m^{-2} yr^{-1} to 2586.181 gC m^{-2} yr^{-1}. Meanwhile, using Aster the value varied from 0.144 gC m^{-2} yr^{-1} to 2595.264 gC m^{-2} yr^{-1}. The annual value of GPP ALOS was lower than the value of Aster, because ALOS have high spatial resolution and smaller interval of spectral resolution compared to Aster. Different land use could effect the value of GPP, because the different land use has different vegetation type, distribution, and different photosynthetic pathway type. The high spatial resolution of the remote sensing data is crucial to discriminate different land cover types in urban region. With heterogeneous land cover surface, maximum value of GPP using ALOS/AVNIR-2 was smaller than that of Aster, however, the annual mean of GPP value using ALOS/AVNIR-2 was higher than that of Aster.

Keywords: *ALOS/AVNIR-2, Aster, gross primary p roduction, Denpasar, Bali*

1. Introduction

Considered globally, the most important interaction between the biosphere and atmosphere are the transfer of energy, water, and carbon. Carbon is assimilated by the biosphere through photosynthesis and released through autotrophic and heterotrophic respiration (Malhi *et al*., 1998). Emissions and re-absorption of these gases from natural ecosystem have been in equilibrium for million of years. However, this balance has been disturbed by human activities. Consequently, the atmospheric concentrations of CO_2 have been increasing rapidly and it is widely believed that higher concentration of these gases is responsible for global warming (Hazarika and Yasuoka, 2002).

Understanding the control on spatial and temporal pattern of surface–atmosphere CO_2 exchange is therefore needed so that improved prediction of future level of atmospheric CO_2 could be made (Jenkins *et al*., 2007). This highlights the need to monitor plant cover and corresponding surface CO_2 uptake on a large scale. Such data will aid in more accurate estimates of regional and global carbon budget and, ultimately, more accurate prediction of carbon source-sink relationships and atmospheric CO_2 concentration (Hunt *et al*., 2002).

Remote sensing could be used to estimate surface–atmosphere CO_2 exchange. Remotely sensed optical signatures have proved useful for

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estimating ecological variables such as leaf area index (LAI) and the absorbtivity of photosynthetically active radiation (fAPAR) (Asrar *et al*., 1984 *in* Inoue, 2008; Turner *et al*., 2002). Fraction of absorbed photosynthetically active radiation (fAPAR) by the vegeta tion cover is related to the normalized difference vegetation index (NDVI). The strong relationship between NDVI and fAPAR has been examined in detail with theoretical and experimental analyses (Myneni and Williams, 1994; Kumar and Monteith, 1981 *in* Hooda and Dye, 1996; Inoue *et al*., 2008). The NDVI has become a popular tool for assessing different aspects of plant processes, while simultaneously determining spatial variation in vegetation cover (La Puma *et al*., 2007).

Most models of ecosystem carbon exchange based on remote sensing use by using the light use efficiency (LUE) model. The LUE model states that carbon exchange is a function of the amount of light energy absorbed by vegetation and the efficiency with which that light energy is used to fix carbon (Monteith, 1972 *in* Sims *et al*., 2006). Monteith (1972) in Bradford (2005) developed method for estimating plant productivity from observation of absorbed photosynthetically active radiation (APAR) and estimates of LUE.

Denpasar represent one of urban city in Bali Island. Remote sensing is a tool for mapping and monitoring urban area. For application remote sensing to urban area, we need imagery with moderate until high spatial resolution. The satellite imagery with a high spatial resolution has been effectively used to classify homogeneous landscapes. A higher spatial resolution is greatly desirable for land application (e.g., ecosystem and hydrology) (Liang *et al*., 2007) and very useful to acquire vegetative information (Yüksel *et al*., 2008) in urban areas.

Remote sensing often requires other kinds of ancillary data to achieve both its greatest value and the highest level of accuracy as a data and information production technology. Geographic Information Systems (GIS) can provide this capability (Star and Estes, 1990). GIS can make order to develop the required capability of natural resources mapping and periodical monitoring (Muzein, 2006).

Several previous research such as in Kalimantan tropical forest shown the value result of GPP was from 2859 until 3227 gC m^{-2} yr^{-1} (Hirano *et al*., 2005) and the research in Amazon tropical forest the value of GPP was 3040 gC m^{-2} yr^{-1} (Malhi *et al*., 1998). According to Xiao *et al*. (2004), the seasonal dynamics of GPP prediction from satellite data were similar to those of GPP from observation. Seasonally integrated GPP observation over eight month period accounted for 98% of annual GPP prediction. In tropical evergreen forest, Amazon-Brazil, prediction of GPP from MODIS satellite data was consistent with GPP estimation from the eddy flux tower (Xiao *et al*., 2005; Seleska *et al*., 2003), GPP value prediction from MODIS satellite data was about 2977 gC m^{-2} $year^{-1}$ (Xiao *et al*., 2005).

The aims in this research were 1) To evaluate how GIS application can estimate GPP using satellite data, 2) To evaluate how much value of GPP in urban area, Denpasar by using satellite data, 3) To evaluate the different spatial resolution of satellite to influence GPP values, and 4) To evaluate land use difference affected GPP value.

2. Research Methods

2.1. Research Location

The research location is in Denpasar city with the specific location at 08°36'56"S – 08°42'01"S and 115°10'23"E – 115°16'27"E (Figure 1).

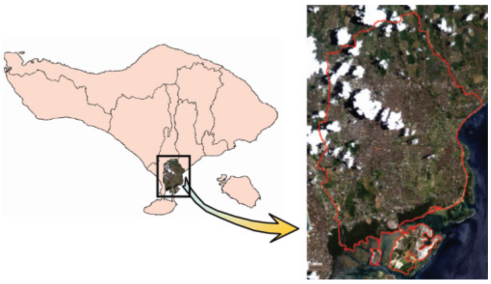

Figure 1. Research location

Materials that used in this research were as follows: 1) digital image of Denpasar area in 13 October 2006 from ALOS/AVNIR-2, 2) digital image of Denpasar area in 5 September 2006 from ASTER, 3) land use map image of Denpasar area in 2006 from Quick Bird, 4) topography map 1 : 25.000 region of Denpasar from Bakosurtanal (2000), 5) solar radiation data from Indonesian Meteorology and Geophysics Agency (BMG), and 6) Quick Bird image of Denpasar area in 2006.

Digital numbers (DN) in each band of the ALOS/AVNIR-2 and Aster image used in this research were converted to physical measurements at sensor radiance (L_{sat}) using a formula that accounts for the transformation function used to convert the analogue signal received at the sensor to DN stored in the resulting image pixels (eq. 1)

$$L_{sat} = (DN + a) * UCC \quad (1)$$

Where L_{sat} is at sensor radiance, a is an absolute calibration coefficients contained in the ancillary record of the leader file: 0 for ALOS/AVNIR-2 and -1 for Aster satellite data, and UCC is Unit Conversion Coefficient, this was different for each image band, and also depends on the gain setting that was used to acquire the image. UCC for ALOS/AVNIR-2 and Aster image are presented in Table 1.

Table 1. Shows the unit conversion coefficient for each band

Band No.		ALOS/AVNIR-2 *ALAV2A038223770*	Aster
ALOS/AVNIR-2	Aster		
1	1	0.588	0.676
2	2	0.573	0.708
3	3N	0.502	0.862
4	-	0.835	-

Source: LED-ALAV2 A038223770-O1B2R_U (2006), Abrams and Hook (2002)

2.2. Data Analysis

The carbon budget consists of several major processes that describe the exchange of carbon dioxide between terrestrial ecosystems and the atmosphere. Gross primary productivity (GPP) is the total carbon assimilated by vegetation (Ibrahim, 2006). Satellite remote sensing provides consistent and systematic observations of vegetation and has played an increasing role in the characterization of vegetation structure and estimated GPP of vegetation (Xiao *et al.*, 2004). GPP estimation was calculated using eq. 2.

$$GPP = \varepsilon + fAPAR + PAR = \varepsilon + APAR \quad (2)$$

PAR is actually restricted to just a portion of sunlight's spectrum from 400 to 700 nanometers (nm) which is comparable to the visible range of light that could be seen by human eye (Horning, 2004). The value of PAR is assumed to be approximately 0.5 of the incoming solar radiation (Waring and Running, 1998; Slamet and Haryanto, 2006), solar radiation data was taken from Indonesian Meteorology and Geophysics Agency (BMG). Fraction of absorbed photosynthetically active radiation (fAPAR) by the vegetation cover is related to the NDVI, NDVI has been widely used for the remote estimation of fAPAR because of its positive linear relationship with fAPAR (Myneni and Williams, 1994). Ochi and Shibasaki (1999) tabulated various relationships between fAPAR and NDVI in some Asian countries, they recommended the relationships as follows:

$$fAPAR = -0.08 + 1.075\ NDVI \qquad (3)$$

NDVI computed from image data using the following formula (eq. 4):

$$NDVI = \frac{\text{Near Infra Red Band - Red Band}}{\text{Near Infra Red Band + Red Band}} \qquad (4)$$

Light use efficiency (ε) is a biomespecific value representing optimal potential of the vegetation for converting PAR to GPP, Light use efficiency values are similar for all plant types and biomes (Horning, 2004). Estimation of LUE has, however, proven more problematic. Light use efficiency can be estimated from mechanistic models based on leaf biochemistry and micrometeorological parameters but these models are complex and generally require many parameters that cannot directly be estimated from remote sensing (Running *et al.*, 1999 *in* Sims *et al.*, 2006). Light use efficiency may be assumed to be constant under non stressed conditions, but it is affected by stresses, phonological stages, and the physical environment (Inoue *et al.*, 2008). Ochi and Shibasaki (1999) recommended the value of ε is 1.5 gC MJ^{-1} in some Asian countries. The result of this model is compared with GPP which derive from MODIS GPP product (MOD17) in Denpasar area derived from http://daac.ornl.gov/MODIS/modis.html.

Analyses were carried out using ENVI 4.4 and ArcView GIS (version 3.2) software with Spatial Analyst Extensions, including in ArcView GIS (version 3.2) software.

3. Result

The GPP annual value showed different result with different satellite data. Annual value of GPP in ALOS/AVNIR-2 varied from 0.13 gC m^{-2} yr^{-1} to 2586.18 gC m^{-2} yr^{-1}, mean value of annual GPP was 836.23 gC m^{-2} yr^{-1}. In Aster satellite, minimum value of GPP was 0.14 gC m^{-2} yr^{-1} and maximum value was 2595.26 gC m^{-2} yr^{-1} with mean value of GPP of 776.83 gC m^{-2} yr^{-1}. Totally GPP per year in Denpasar from ALOS/AVNIR-2 was 52421.46 tC yr^{-1} with the area of 6267.56 ha. With Aster satellite data, total GPP in Denpasar per year was 59355.49 tC yr^{-1} with the area of 7647.84 ha (Table 2 and Table 3). The GPP pixel value distribution from ALOS/AVNIR-2 satellite data was dominated by low pixel value (< 250 gC m^{-2} yr^{-1}) with the area of 1236.62 ha, which decreased until the GPP pixel value in high range (2250 – 2587 gC m^{-2} yr^{-1}) with the area of 17.17 ha. In the other case, the GPP pixel value distribution from Aster satellite data was dominated by low pixel value (< 250 gC m^{-2} yr^{-1}) with the area of 1694.56 ha, which decreased until the GPP pixel value in high range (2250 – 2595 gC m^{-2} yr^{-1}) with the area of 6.59 ha (Table 3). The map distribution of annual GPP from ALOS/AVNIR-2 and Aster is shown in Figure 2.

Table 2. Annual and total value of GPP with different satellite data

Satellite Data	GPP ($gC\ m^{-2}\ yr^{-1}$)				Total GPP
	Max	Mean	Min	Std. Dev.	$tC\ yr^{-1}$
ALOS/AVNIR-2	2586.18	836.23	0.13	583.51	52421.46
Aster	2595.26	776.83	0.14	565.03	59355.49

Table 3. Total pixels and area of annual GPP value with different satellite data

GPP value	ALOS/AVNIR-2		ASTER	
($gC\ m^{-2}\ yr^{-1}$)	Total pixels	Area (ha)	Total pixels	Area (ha)
< 250	123662	1236.62	75314	1694.56
250 – 500	101694	1016.94	59523	1339.27
500 – 750	88378	883.78	49242	1107.94
750 – 1000	76929	769.29	42346	952.78
1000 - 1250	70423	704.23	36175	813.94
1250 - 1500	61249	612.49	30336	682.56
1500 - 1750	52544	525.44	24785	557.66
1750 - 2000	34440	344.40	14900	335.25
2000 - 2250	15720	157.20	6990	157.27
> 2250	1717	17.17	293	6.59
Total		6267.56		7647.84

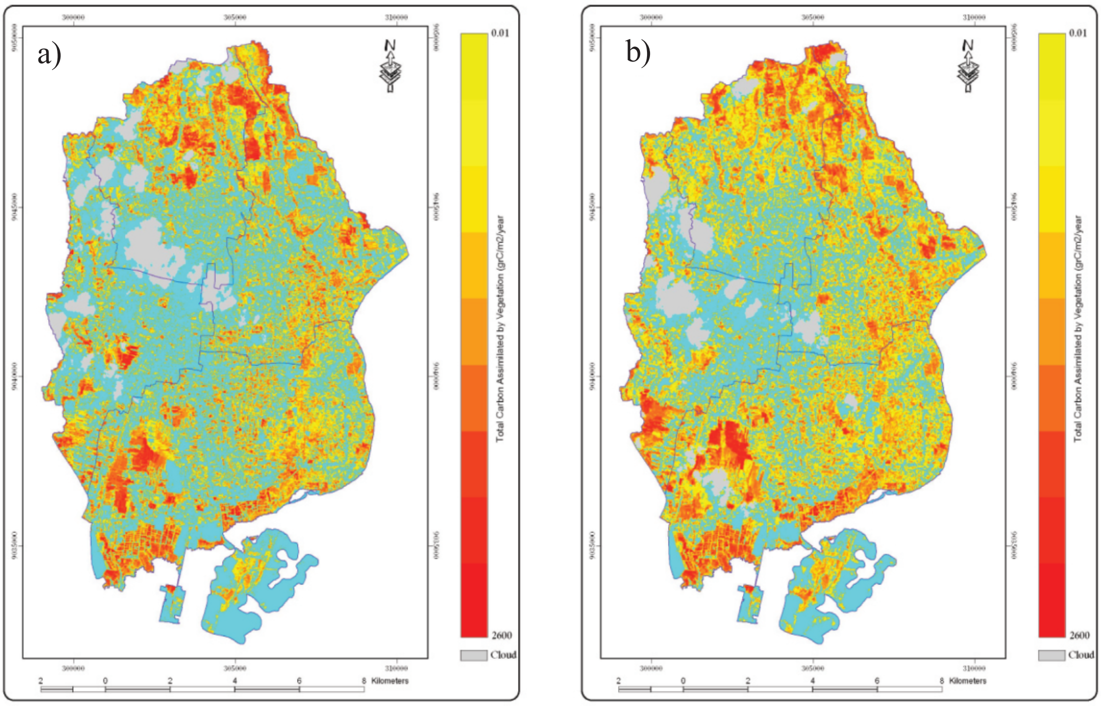

Figure 2. Annual distribution of GPP from a) ALOS/AVNIR-2 and b) Aster satellite data

The maximum value of GPP from the two satellite data was smaller than the maximum GPP value derived from MODIS GPP product (MOD17; 2707.8 gC m^{-2} yr^{-1}) in Denpasar area (Figure 3), smaller than the 2859 gC m^{-2} yr^{-1} measured over a tropical peat swamp forest in central Kalimantan-Indonesia (Hirano *et al.*, 2005), and smaller than the 3040 gC m^{-2} yr^{-1} measured over a tropical forest in central Amazonia, Brazil (Malhi *et al.*, 1998).

The different land use will effect to annual GPP value. In ALOS/AVNIR-2 satellite data, the maximum value of annual GPP was come from rice field land use withthe value of 2586.18 gC m^{-2} yr^{-1} and the minimum value of annual GPP was 0.13 gC m^{-2} yr^{-1} from all land use (Figure 4a. and Table 4). In Aster satellite data, the maximum value of annual GPP was come from forest (mangrove) land use with the value of 2595.26 gC m^{-2} yr^{-1} and the minimum value of annual GPP was from all land use, which value is 0.14 gC m^{-2} yr^{-1} (Figure 4b and Table 4).

The totally of annual value of GPP with difference land use in ALOS and Aster satellite imagery is shown in Table 5 and Fig. 4.

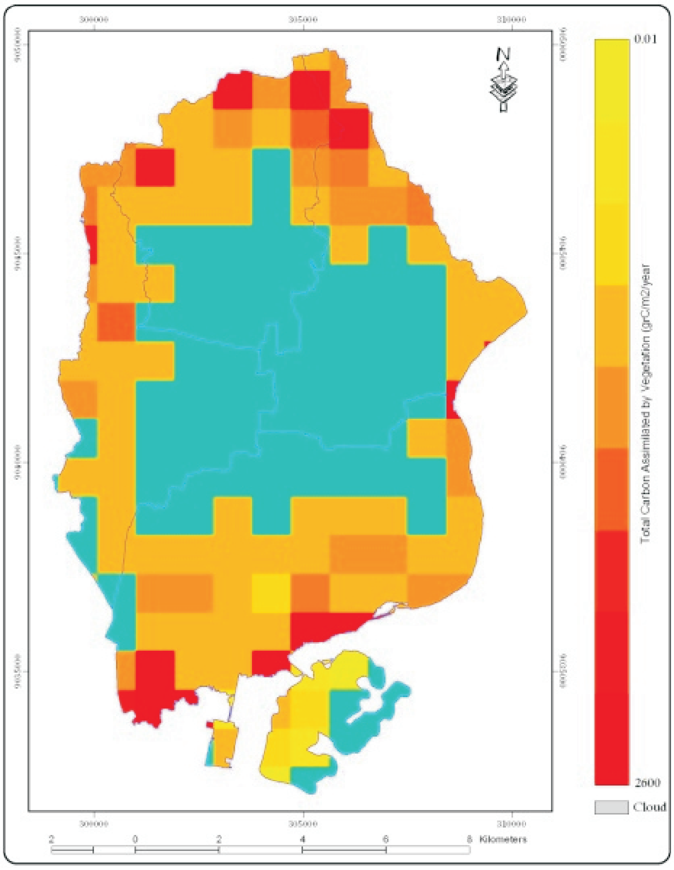

Figure 3. Annual distribution of GPP from MODIS product (MOD17)

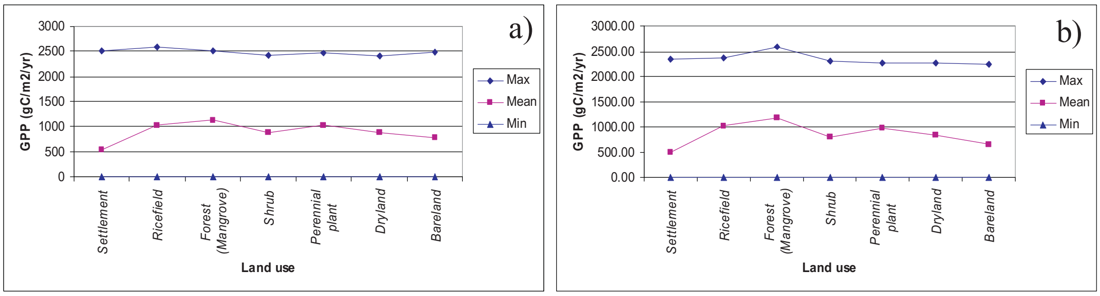

Figure 4. Graphic of annual GPP value with different land use in (a) ALOS/AVNIR-2 and (b) Aster satellite data

Table 4. Annual value of GPP with differences land use in ALOS/AVNIR-2 ans Aster satellite data

Land use	GPP (gC m^{-2} yr^{-1})					
	ALOS/AVNIR-2			ASTER		
	Max	Mean	Min	Max	Mean	Min
Settlement	2511.43	540.49	0.13	2353.91	492.44	0.14
Ricefield	2586.18	1030.08	0.13	2371.86	1020.65	0.14
Forest (Mangrove)	2501.92	1123.58	0.13	2595.26	1177.40	0.14
Shrub	2427.54	882.11	0.13	2305.14	794.37	0.14
Perennial plant	2456.39	1034.77	0.13	2257.76	989.24	0.14
Dryland	2414.05	893.46	0.13	2261.80	830.61	0.14
Bareland	2489.12	771.56	0.13	2244.33	648.17	0.14

Table 5. The totally of annual value of GPP with differences land use in ALOS and Aster satellite data

Land Use	Hectarage	GPP (tC yr^{-1})	
		ALOS	Aster
Settlement	7179.17	12675.23	15992.84
Ricefield	2616.34	20254.15	22571.65
Forest (Mangrove)	700.69	6255.51	7081.16
Shrub	81.10	469.55	460.96
Perennial plant	961.75	8300.74	8567.52
Dryland	263.26	1888.87	1930.72
Bareland	827.39	2577.41	2750.65
Total	12629.70	52421.46	59355.49

In ALOS/AVNIR-2 satellite data, the maximum value of annual GPP in South Denpasar district with the value of2586.18 gC m^{-2} yr^{-1}, in West Denpasar district the maximum value of GPP was 2511.43 gC m^{-2} yr^{-1}, in North Denpasar district the maximum value of GPP was 2462.30 gC m^{-2} yr^{-1}, and in East Denpasar district the maximum value of GPP was 2449.19 gC m^{-2} yr^{-1} (Figure 6a. and Table 6). In Aster satellite data, the maximum value of annual GPP in South Denpasar district was 2595.26 gC m^{-2} yr^{-1}, in West Denpasar district the maximum value of GPP was 2289.77 gC m^{-2} yr^{-1}, in North Denpasar district the maximum value of GPP was 2304.26 gC m^{-2} yr^{-1}, and in East Denpasar district the maximum value of GPP was 2322.60 gC m^{-2} yr^{-1} (Figure 6b. and Table 6).

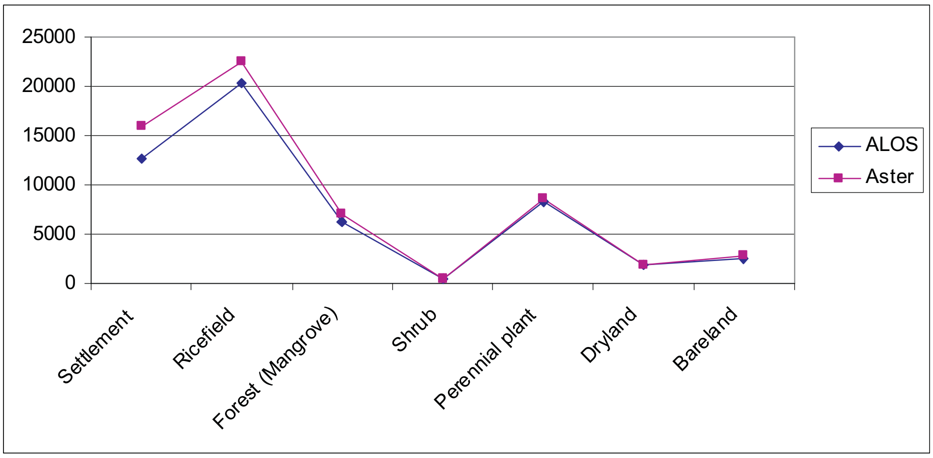

Figure 5. Totally of annual value of GPP with differences land use in ALOS and Aster Satellite Data

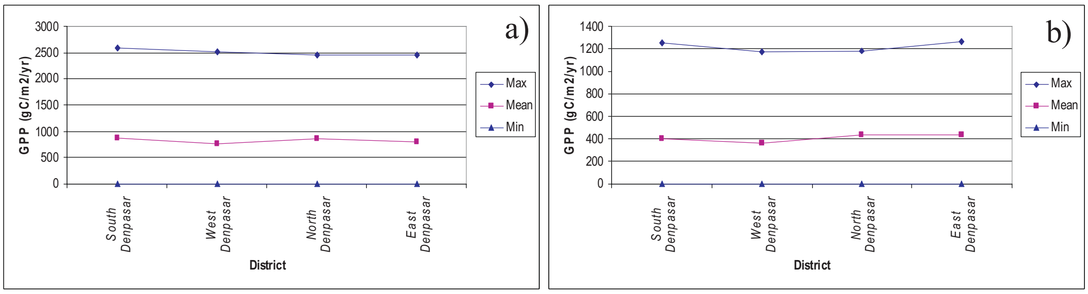

Figure 6. Totally of annual value of GPP by district in (a) ALOS/AVNIR-2 and (b) Aster satellite data.

Table 6. The totally of annual value of GPP by district in ALOS/AVNIR-2 and Aster satellite data

District	ALOS/AVNIR-2				ASTER			
	Max gC m^{-2} yr^{-1}	Mean gC m^{-2} yr^{-1}	Min gC m^{-2} yr^{-1}	Total tC yr^{-1}	Max gC m^{-2} yr^{-1}	Mean gC m^{-2} yr^{-1}	Min gC m^{-2} yr^{-1}	Total tC yr^{-1}
South Denpasar	2586.18	870.36	0.13	22965.17	2595.26	831.15	0.14	25773.41
West Denpasar	2511.43	767.55	0.13	6301.49	2289.77	703.77	0.14	6873.89
North Denpasar	2462.30	854.38	0.13	10137.18	2304.26	731.22	0.14	11944.11
East Denpasar	2449.19	802.05	0.13	12982.13	2322.60	764.10	0.14	14747.20

4. Discussions

In Denpasar area, the GPP value from ALOS/AVNIR-2 and Aster satellite data was smaller than the GPP value from MODIS product (MOD17) because ALOS/AVNIR-2 and Aster satellite data have a smaller interval of spectral resolution than MODIS satellite. Smaller interval of spectral resolution will give higher capability of sensor in detecting object in surface.

The decreasing of spectral resolution will loss the ability of map fine spectral to distinguish in detail. Coarser spectral resolution can prohibit discrimination and identification of specific object (Kruce, 2000). According to De Jong and Van Der Meer (2005), the spectral resolution is a direct function of the material that is trying to identify, and the contrast between that material and the background materials.

The different land use which has a different vegetation type, percentage vegetation cover and dissemination could be affected the different value of GPP. This is the reason why ricefield and forest (mangrove) give higher annual mean value of GPP than settlement land use. According to Soegaard and Møller-Jensen (2003), in the center of town, the canopy shows great height fluctuations. This creates a problem if aiming at a satellite-based subdivision of urban areas into generalized classes of urban land use and activity based on the spectral values of each individual pixel.

Differences of temporal resolution between ALOS/AVNIR-2 and Aster satellite affected the different of the total annual of GPP in ricefield land use. Higher spatial resolution from ALOS/AVNIR-2 is better than Aster in detecting specific object such as settlement land use which has a high heterogeneous landscape. This matter caused the annual mean GPP from ALOS/AVNIR-2 in settlement land use higher than in Aster. As states by Soegaard and Møller-Jensen (2003), the urban landscape of the flux measurements get more complicated due to the surface heterogeneity and the NDVI loses its importance for scaling the CO2 exchange.

Lower spatial resolution from Aster gave a higher total annual of GPP in settlement land use. This was becaused Aster satellite detected vegetation around settlement region as pixel with low value vegetation index and not as building area. As states by Kerr and Ostrovsky (2003) *in* Rocchini (2007), satellite data with better spatial resolution seems to narrow the scale gap between field and remotely sensed data perceived with coarse resolution satellites. According to Kruce (2000), spatial resolution was the key to mapping of detailed scale-dependent variation. Increasing the pixel size (decreasing the spatial resolution) results in the loss of image detail.

A wider ricefield and forest land uses in South Denpasar provided high total annual of GPP. However, in West and North of Denpasar showed a low total annual of GPP because those area are covered by a wide area of settlement and bareland.

The GIS capability of displaying graphics, while linking features to attribute tables, has become a valuable tool for maintaining and updating value of GPP in surface. Displaying the road network on monitor computer is a very effective and efficient tool in observing the relationship between the spatial and physical attributes of human activity. Modern advances in GIS-based cartography make it easier than ever to create large numbers of maps quickly, using automated techniques.

5. Conclusions and Suggestions

5.1 Conclusion

Collaboration between high resolution remote sensing data with GIS application can be used for estimation GPP value in urban area like Denpasar, where more communicative layout result could be given by GIS application. Value of GPP from ALOS was smaller than the value from Aster, where totally GPP per year in Denpasar from ALOS/AVNIR-2 was 52421.46 tC yr^{-1} and from Aster was 59355.49 tC yr^{-1}.

The high spatial resolution of the remote sensing data is crucial discriminating different land cover types in urban land cover. With the surface heterogeneous of land cover, maximum value of GPP from ALOS is smaller than the value GPP from Aster. Meanwhile, the annual mean of GPP value by ALOS/AVNIR-2 is higher than the annual mean of GPP by Aster.

Different land use affected the value of GPP where higher mean value of GPP was found in forest (mangrove) and ricefiled with value of 1123.58 gC m^{-2} yr^{-1} and

1030.08 gC m^{-2} yr^{-1} from ALOS/AVNIR-2 satellite data and 1177.40 gC m^{-2} yr^{-1} and 1020.65 gC m^{-2} yr^{-1} from Aster satellite data. The lowest mean value of GPP was found in settlement land use with value of 540.49 gC m^{-2} yr^{-1} from ALOS/AVNIR-2 and 492.44 gC m^{-2} yr^{-1} from Aster satellite data.

The maximum value of GPP by those two satellite data, ALOS/AVNIR-2 and Aster, was smaller than the maximum GPP value by MODIS GPP product (MOD17) in Denpasar area. It was also smaller than the measurement over a tropical peat swamp forest in central Kalimantan-Indonesia and tropical forest in central Amazonia, Brazil.

5.2. Suggestion

The differences of spatial and spectral resolutions affected the accuracy of object detection. The object detection for heterogeneous area such as settlement land use is recommended to use satellite with high spatial resolution, meanwhile for homogeneous area such as forest (mangrove) and ricefield is recommended to use satellite with high spectral resolution.

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