BIOMASS MAPPING BY ALOS/PALSAR OVER BOREAL FOREST IN ALASKA ACCOMPANIED WITH GROUND-BASED FOREST SURVEY

PI No. 316

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1. INTRODUCTION

For the better understanding of the carbon cycle in the global ecosystem, investigations of the spatio-temporal variation of the carbon stock which is stored as vegetation biomass is important. An international framework, Global Earth Observation System of Systems (GEOSS), also mentions the observation requirement of the biomass in its 10-year implementation plan [1].

The observation by the sensor "Phased Array type L-band Synthetic Aperture Radar (PALSAR)" of the satellite "Advanced Land Observing Satellite (ALOS)" which was launched in January 2006, has an inestimable potential to provide us the forest above-ground biomass (FAGB) information of the vegetation that widely covers the land surface. This study made an attempt to develop the estimation algorithm of FAGB by PALSAR, targeting the ecotone region from the boreal forest to tundra in Alaska by establishing a south-north transect along a trans-Alaska pipeline (Fig. 1).

To develop the estimation algorithm, it is inevitable to acquire the *in-situ* biomass value by ground-based survey. Moreover, such ground-based information has to be acquired at as possible many sites, so a quick measurement method is required. First, this paper introduces the applicability of a combined way of Bitterlich Angle Count Sampling method and Sampled-tree Measuring (BACS-STM) method as a quick method for FAGB measurement for the boreal forests in Alaska.

The backscatter intensity of the PALSAR measurement is strongly influenced by the slope of the terrain, and the intensity from the slope with large incident angle in the slant range is generally larger than that with small incident angle. This study develops a simple approach to reduce this so-called "slope-effect" that possibly contaminates the FAGB estimation.

Moreover, although the PALSAR Level 1.5 image is ortho-corrected, the distortion of the image due to layover and foreshortening effects caused by the topography

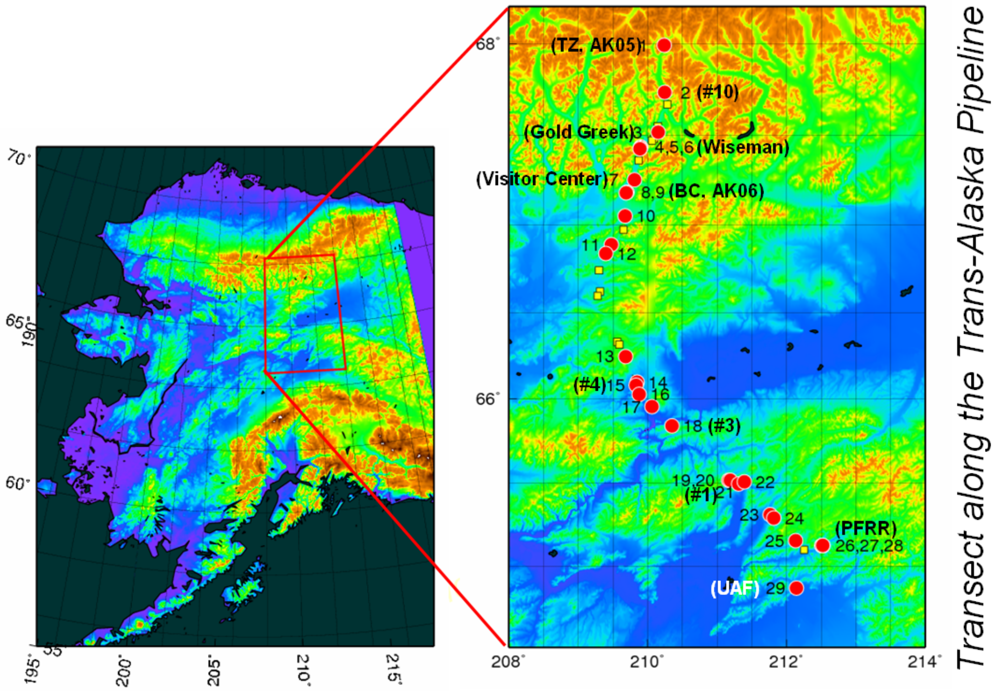

Fig. 1 Distribution of 29 forest sites (red circle) and no-forest sites (small yellow square) in interior Alaska.

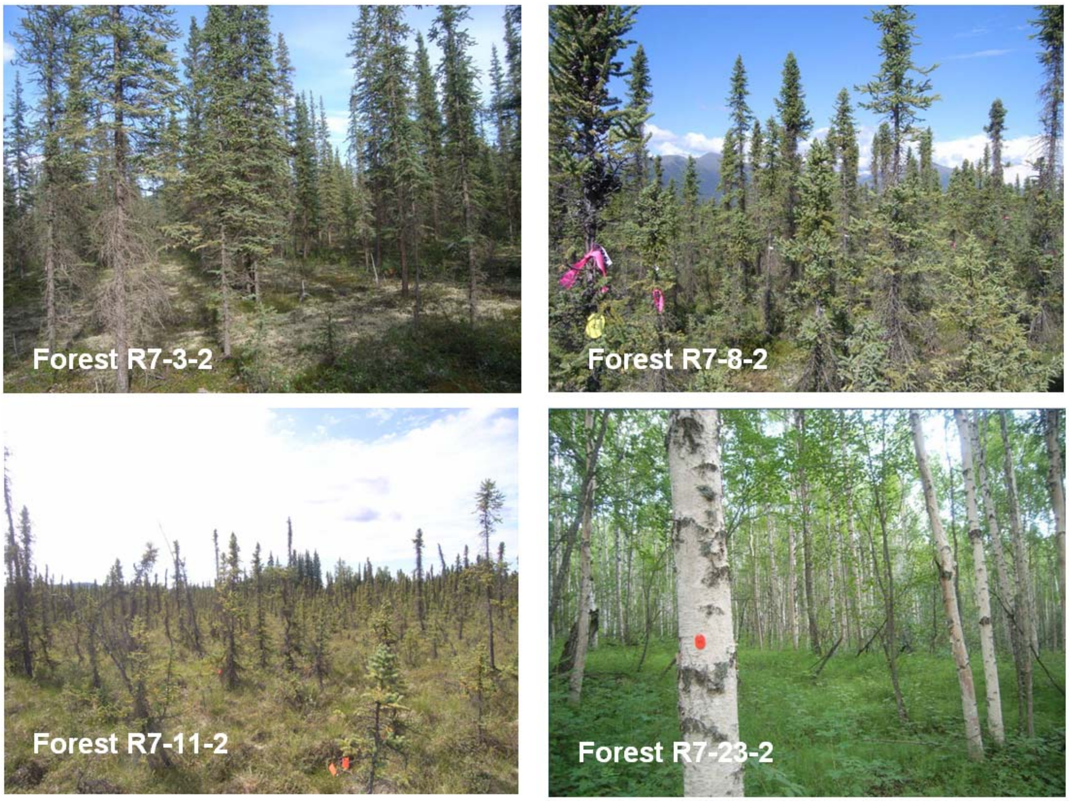

Fig. 2 Pictures of typical forests in Alaska. Sparse white spruce forest (top-left), sparse and low black spruce forest, (bottom-left), dense and low black spruce forest (top-right), high birch forest (bottom-right).

remains in the data. This study tried to correct this terrain effect.

The goal of this study is to estimate the FAGB accurately over the forest-tundra ecotone transect along a trans-Alaska pipeline by PALSAR data accompanied with ground-based measurements, and to make a map of the FAGB geographical distribution that is applicable to a carbon cycle modeling.

2. FIELD SURVEY OF FOREST ABOVE-GROUND BIOMASS IN ALASKA

2.1. BACS-STM

The procedure of BACS-STM, a quick method to measure the FAGB at field site, is: first, a tree which has wider trunk than a threshold horizontal viewing angle (called "basal area factor") is identified (15 – 20 tree stands) by the relascope (Criterion RD1000, Laser Technology, Inc., USA) from a representative point in the target forest; next, the FAGB (dry matter) of the identified tree is estimate by the allometric equation with the tree height and diameter at the breast height (DBH). Through these processes, the FAGB per unit area in the

Table 1 Forest above ground biomass (FAGB; dried matter) of forests derived by Bitterich Angle Count Sampling method and Sampled-Tree Measuring method (BACS-STM method). The unit is Mg/ha. Forest number corresponds to the map of Fig. 1. No-forest sites are not indicated because their biomass is zero.

Forest #	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Biomass (Mg/ha)	4.7	31.9	27.5	25.5	2.2	20.9	5.9	22.4	35.0	12.4
Forest #	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
Biomass (Mg/ha)	4.4	69.8	24.9	7.3	12.6	115.8	81.9	30.9	67.0	36.1
Forest #	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	
Biomass (Mg/ha)	40.1	16.3	100.2	92.4	15.3	50.7	6.6	12.7	12.8	

target forest is estimated.

2.2. *Field survey of boreal forest in Alaska*

In July 2007, a forest survey was carried out in the south-north transect (about 500 km) along a trans-Alaska pipeline which profiles the ecotone from boreal forest to tundra in Alaska. Since several papers reported that the recent secular change is apparent in the ecotone vegetation in Alaska [2, 3, 4], this transect will be appropriate for the biomass monitoring.

29 forests in the transect, indicated in Fig. 1, were targeted for the field measurement. These forests were satisfied following conditions; accessible from the road, almost no slope, and wider than 100 m × 100 m. As indicated in Fig. 2, the major species of the tree is black spruce (*Picea mariana*), white spruce (*Picea glauca*). Birch (*Betula neoalaskana*) occurs in some forests, but relatively rare. We used the allometric equations for those trees in Alaska derived by Dr. Yarie [5]. Following surveys were carried out in July, 2007 in Alaska.

- FAGB at 29 forests (FAGB 2 or 3 points were measured and averaged for each forest) by BACS-STM method. Tree height and DBH were simultaneously measured.
- The geo-position of 16 non-forest areas for zero FAGB reference.
- Hemispheric pictures of forest canopy for plant area index (PAI) at 2 or 3 points in 29 forests. PAI will be used for supplemental information of the forest property.

2.3. *In-situ forest above-ground biomass*

Table 1 shows the biomass of 29 forests estimated by BACS-STM method. Only about 30 minutes was required for measuring the FAGB at one point. This quickness enabled us to acquire the FAGB at 29 forests (total were 60 points) by about one month field survey. The smallest FAGB among the 29 forests were 2.2 Mg/ha. Such forest was generally very sparse black spruce forest and most of the tree height was below 10 m. On the other hand, the largest FAGB was 115.8 Mg/ha. That forest was dense white spruce forest and the most of the tree height was around 20 m. Generally, forests with small biomass tend to be young forest which appears to

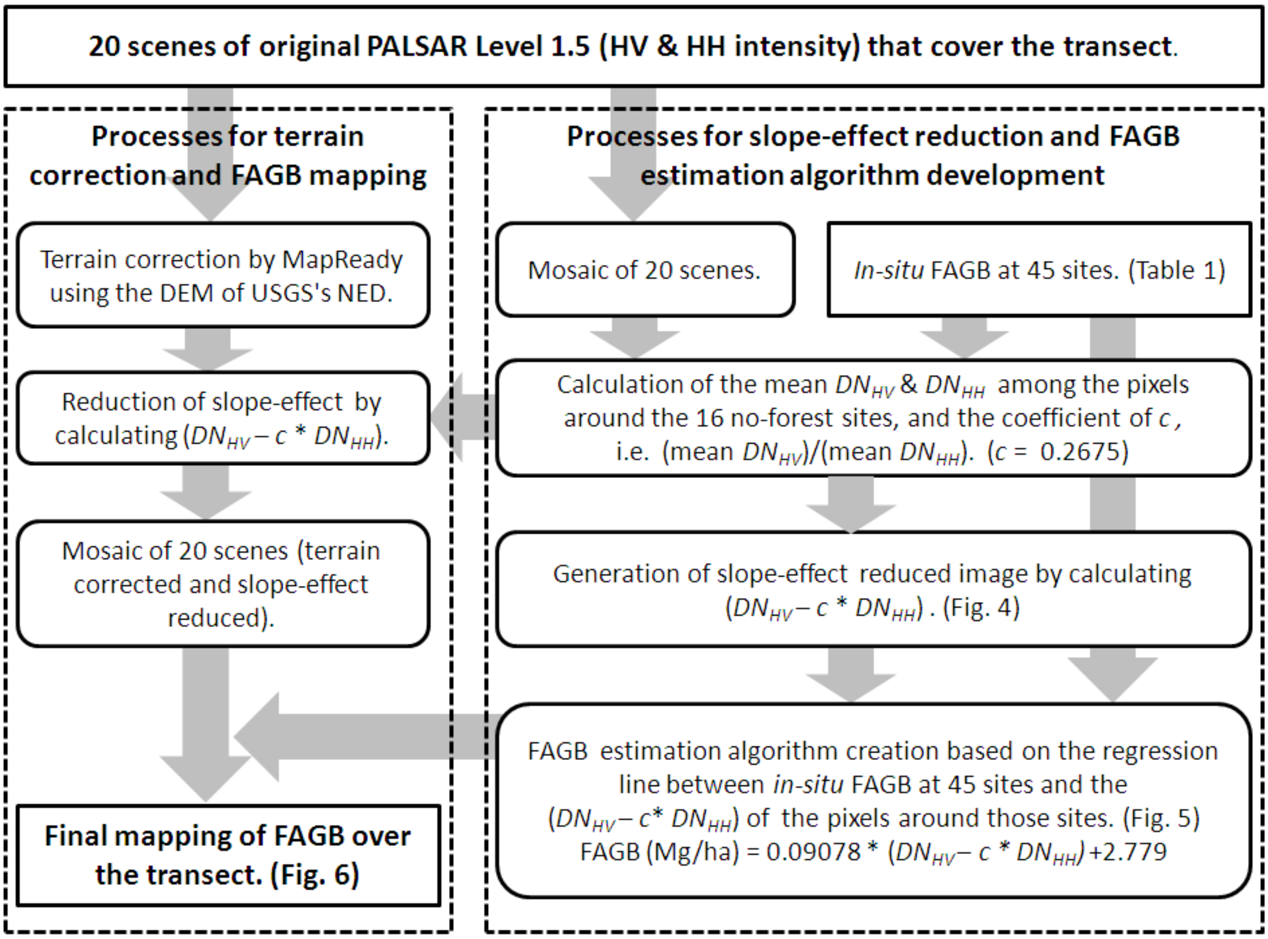

Fig. 3 Flow chart of data processes.

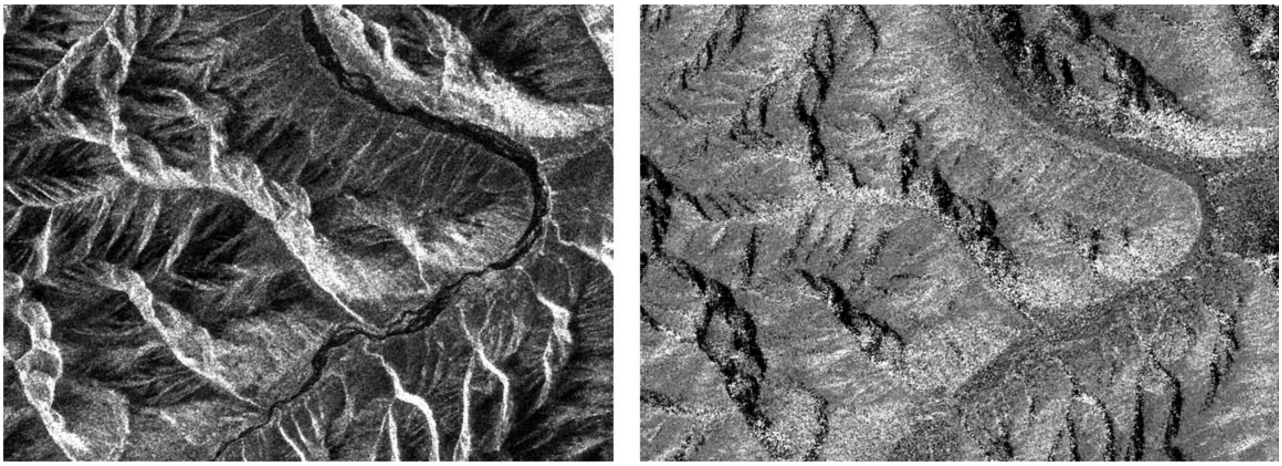

Fig. 4 Close-up of original Level 1.5 PALSAR image (HV intensity; digital number) (left) and slope-effect reduced image (right) around 67˚ 40’ 18.27” N, 149˚ 57’ 8.94” W.

experience a forest fire recently.

3. PROCESS OF PALSAR IMAGE

The processes of the PALSAR image in this study are summarized in Fig. 3. The processes of the original 20 scenes of PALSAR Level 1.5 (spatial resolution is about 15 m) that cover the transect were composed of (1) slope-effect reduction and development of the FAGB estimation algorithm (the right column in Fig. 3) and (2) the terrain collection and the final FAGB mapping (the left column in Fig. 3).

3.1. Reduction of slope-effect and development of the FAGB estimation algorithm

Firstly, the 20 scenes of HH and HV intensity images were mosaicked. Generally, the backscatter intensity of the microwave is stronger from the slope that has high incident angle than from the slope that has low incident angle in the slant range of the microwave radar. For this reason, we tried to reduce the slope-effect. Since it can be assumed that the slope-effect is equivalently involved both in HV and HH intensities [6], it is considered that the slope-effect can be reduced by subtracting HH intensity from HV intensity. However, the overall absolute intensity of HH is much larger than that of HV. Therefore, a coefficient “*c*” (basic ratio of HV to HH), is required to make two intensities comparable. To derive *c*, this study calculated the ratio of mean DN_{HV} (digital number of HV intensity) and mean DN_{HH} (digital number of HH intensity) at 16 zero-FAGB sites. Consequently, we got 0.2675 for *c*.

Fig. 4 compares the original image of HV intensity (digital number; DN) with the slope-effect reduced image derived by the calculation of $DN_{HV} - c * DN_{HH}$, demonstrating that the relief of the topography that is apparent in the original image (left) is considerably reduced in slope-effect reduced image (right).

Next, based on the slope-effect reduced mosaic, the FAGB estimation algorithm was constructed according the regression line between the *in-situ* FAGBs at 45 sites and the mean value of $DN_{HV} - c * DN_{HH}$ among the pixels around those sites. As indicated in Fig. 5, there is almost linear relationship between them and the correlation is strong ($r = 0.75$). The regression formula is,

$$\text{FAGB (Mg/ha)} = 0.09078 * (DN_{HV} - c * DN_{HH}) + 2.779.$$

3.2. Terrain correction

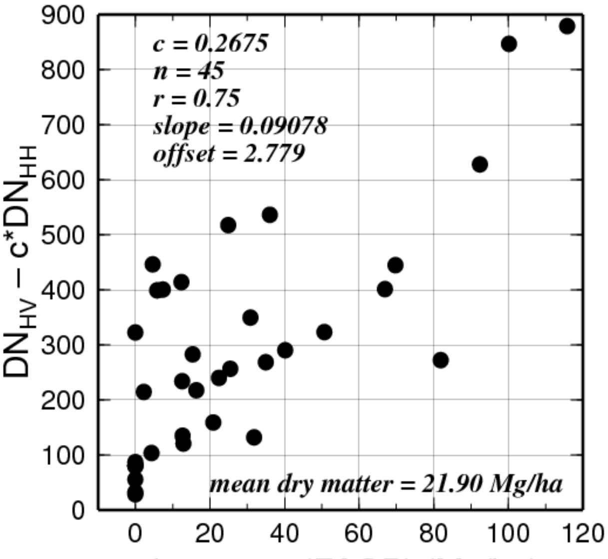

Fig. 5 The relationship between the forest above-ground biomass (FAGB) (dry matter; Mg/ha) and $DN_{HV} - c * DN_{HH}$ of PALSAR.

Although the PALSAR Level 1.5 image was ortho-corrected, the distortion of the image due to layover and foreshortening effects of the microwave radar due to the terrain remains. This distortion due to the terrain effect was corrected by the software “MapReady” that was developed by Alaska Satellite Facility (ASF) (http://www.asf.alaska.edu/downloads/software_tools). As for the digital elevation model (DEM), the National Elevation Dataset (NED), distributed by the United States Geological Survey (USGS) was used (http://ned.usgs.gov/). Since the spatial resolution of NED over Alaska is 2-arc-second (about 60 meters), the original PALSAR images were coarsened, while the layover and foreshortening effects were corrected.

4. FINAL MAPPING OF ESTIMATED FOREST ABOVE-GROUND BIOMASS

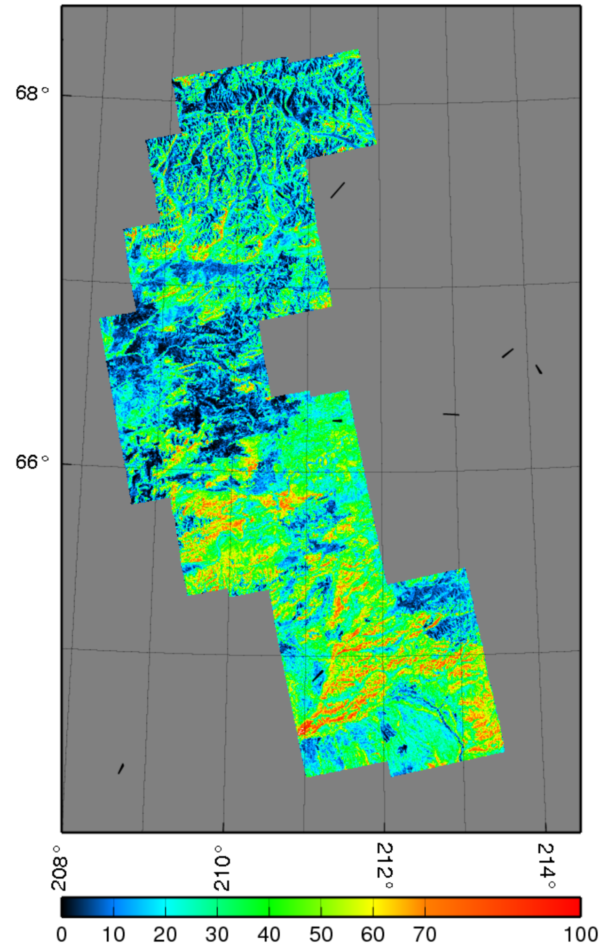

Fig. 6 Distribution of the estimated forest above-ground biomass (FAGB) (Mg/ha) based on the terrain corrected and slope-effect reduced mosaic. The region with negative FAGB estimation is set at zero.

Finally, the FAGB mapping was done by applying the aforementioned FAGB algorithm (regression formula) to the terrain collected mosaic (Fig. 6). Negative FAGB estimations were set at zero.

Generally, there is a south to north gradient in FAGB that reflects the vegetation biomass gradient from southern forest-rich region to northern forest-sparse region in the ecotone. The FAGB in some regions in southern part reaches 100 Mg/ha. Whereas there is small FAGB zone around 66.5˚N. This is because no-forest lands prevail over this zone due to mountainous topography. In the southern region, high FAGB regions are observed along large valleys.

The FAGB in northern mountainous region indicates a complicated pattern corresponding to the topography. Although we tried to reduce the slope-effect, those effects still remain especially in the complicated topography region with steep slopes. Next step will be the further reduction of this effect from the FAGB estimation.

Although it is not apparent in Fig. 6, there are gaps at the boundary line between neighboring two scenes in the mosaic. It is considered there are two major reasons: (1) geo-registration error during the terrain correction process by MapReady and NED, and (2) a contamination due to the backscatter difference between near range and far range of PALSAR. These effects shall be also reduced in the future.

5. SUMMARY

The FAGB at 29 forests in the ecotone in the south-north transect along a trans-Alaska pipeline was measured in July 2007 by using the BACS-STM method. PALSAR Level 1.5 image was process for the slope-reduction and the terrain correction. We calculated $DN_{HV} - \mathrm{c} * DN_{HH}$ ($c = 0.2675$) for the slope-effect reduction, while original image was processed by MapReady with NED, a digital elevation model, for the terrain correction

We compared the *in-situ* FAGB with $DN_{HV} - c * DN_{HH}$, and found strong linear relationship of them ($r = 0.75$). Based on the regression line, the FAGB along a trans-Alaska pipeline was mapped.

To improve the estimation algorithm, further reduction of slope-effect will be one of challenging tasks for more accurate biomass mapping in Alaska. Also, similar studies will be planned at boreal forests in Mongolia. It is hoped that global forest biomass data base that is useful for carbon cycle modeling will be constructed in the future.

6. AKNOWLEDGEMENT

The author of this report is grateful to Prof. Yongwon Kim (International Arctic Research Center (IARC), University of Alaska Fairbanks (UAF)), Dr. Reiichiro Ishii (RIGC, JAMSTEC), Mr. Jeremy Nicoll (UAF), and Prof. Shusun Li (UAF) for their contribution to the study.

7. REFERENCES

[1] Group on Earth Observations, "*Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan Reference Document*," ESA Publications Division, The Netherlands, 2005.

[2] L.D. Hinzman, N.D. Bettez, W.R. Bolton, F.S. Chapin, M.B. Dyurgerov, C.L. Fastie, B. Griffith, R.D. Hollister, A. Hope, H.P. Huntington, A.M. Jensen, G.J. Jia, T. Jorgenson, D.L. Kane, D.R. Klein, G. Kofinas, A.H. Lynch, A.H. Lloyd, A.D. McGuire, F.E. Nelson, W.C. Oechel, T.E. Osterkamp, C.H. Racine, V.E. Romanovsky, R.S. Stone, S.A. Stow, M. Sturm, C.E. Tweedie, G.L. Vourlitis, M.D. Walker, D.A. Walker, P.J. Webber, J.M. Welker, K.S. Winker, and K. Yoshikawa, "Evidence and implications of recent climate change in northern Alaska and other arctic regions," *Climatic Change*, 72, pp 251-298, 2005.

[3] D.A. Stow, A. Hope, D. McGuire, D. Verbyla, J. Gamon, F. Huemmrich, S. Houston, C. Racine, M. Sturm, K. Tape, L. Hinzman, K. Yoshikawa, C. Tweedie, B. Noyle, C. Silapaswan, D. Douglas, B. Griffith, G. Jia, H. Epstein, D. Walker, S. Daeschner, A. Petersen, L. Zhou, and R. Myneni, "Remote sensing of vegetation and land-cover change in arctic tundra ecosystems," *Remote Sensing of Environment*, 89, pp 281-308, 2004.

[4] K. Tape, M. Sturm, and C. Racine, "The evidence for shrub expansion in northern Alaska and the pan-arctic," Global Change Biology, 12, p.p. 686-702, 2006.

[5] J. Yarie, E. Kane, and M. Mack, "*Aboveground biomass equations for tree species present in interior Alaska*," 2007.

[6] S. Li, T. Wurtz, and R. Gens, "A Preliminary Study of Biomass Estimation of Boreal Forest in Alaska Using ALOS PALSAR Polarimetric Images," *Eos Trans. AGU*, 88(52), Fall Meet. Suppl., Abstract B42B-01, 2007.