

## Validating a Dynamic Global Vegetation Model with Remotely Sensed Vegetation Index

<sup>1</sup>Jiaxin Jin, <sup>1</sup>Xiuying Zhang, <sup>2</sup>Bin Zhou and <sup>2</sup>Xiaodong Ding

<sup>1</sup>International Department for Earth System Science, Nanjing University,  
Hankou Road 22, Nanjing, 210093, China

<sup>2</sup>Department of Remote Sensing and Earth Sciences, College of Science,  
Hangzhou Normal University, Hangzhou, 310029, China

**Abstract:** The present study aims to evaluate the ability of IBIS model to capture the difference in vegetation characteristics among six major biomes in the Northeast China Transect and to calibrate the simulated LAI by IBIS, using the product of MODIS LAI (Leaf Area Index). The results showed that IBIS simulated a little lower growing season LAI over temperate evergreen conifer forest and boreal evergreen forest, while it overestimated LAI relative to MODIS in non-growing season. IBIS performed poorly on LAI over savanna, grassland and shrub land, compared with MODIS and it nearly simulated higher LAI throughout the year. Based on regression analysis, the simulating LAI by IBIS (Integrated Biosphere Simulator) presented a significant linear correlation with that from MODIS over temperate evergreen conifer forest in spring and winter, boreal evergreen forest throughout the year and grassland from summer to early autumn. Therefore, it was help to adjust the model parameters over these plant functional types to calibrate the estimated LAI in a large spatial scale.

**Keywords:** IBIS, Leaf area index, MODIS LAI

### INTRODUCTION

Long-term data at global scale suggest that recent rapid climate change and anomalous climate are substantially influencing the phenology, physiology and a wide variety of organisms of some plant species during the past half-century (Edwards and Richardson, 2004). It is essential to use terrestrial ecosystem models to predict future resource availability and ecosystem functioning. Many dynamic global vegetation models have been developed, including IBIS, CLASS, GLAM, LPJlm (Kucharik *et al.*, 2006; Kothavala *et al.*, 2005; Osborne *et al.*, 2007; Bondeau *et al.*, 2007). These models support the simulation of the growth and functioning of both natural and managed ecosystems (Twine and Kucharik, 2008; Osborne *et al.*, 2007).

Evaluation and calibration of model parameters and processes have been limited to ground-based data sets constituted of point data or gridded data sets from site measurements, which could not meet the needs of the global validation overall. These models are obliged to be assessed for their ability to capture large-scale carbon-water budget and this is where satellite remote sensing can provide an advantage (Twine and Kucharik, 2008).

At the beginning of 1990s, the project of the International Geosphere-Biosphere Programmed (IGBP) developed the method of terrestrial transects to study global changes (Koch *et al.*, 1995). To cover most

environmental conditions and biomes or ecotones, the IGBP terrestrial transects were located in critical regions of the world along specific environmental gradients such as temperature or precipitation and along more conceptual gradients of land use intensity. Terrestrial transects are powerful to test the mechanistic knowledge critical for model development and validation, because they could untangle the often confounding factors along single environmental gradients (Canadell *et al.*, 2002).

In this study, we use remotely sensed Leaf Area Index (LAI) to evaluate the ability of IBIS model to capture the difference in vegetation characteristics, as the seasonal variations and the magnitude of peak values of LAI, among six major biomes within The Northeast China Transect (NETC), then to calibrate IBIS to simulate LAI and at last to improve the estimation of carbon budgets responding to climate and land cover changing.

### MATERIALS AND METHODS

**Study area:** In this study, The NETC (Northeast China Transect) is selected as the study area. NETC is proposed as an initial IGBP Terrestrial Transect in mid-latitude semi-arid region, covering 42~46°N and 106~134°E (Fig. 1). The major global change gradient is precipitation, ranging from 1000 mm in the east, 600 mm in the middle and 300 mm in the west.

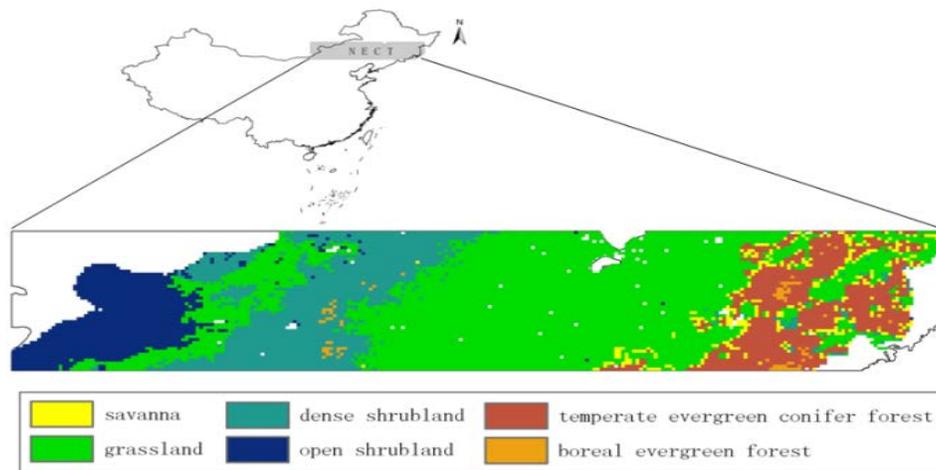


Fig. 1: The Northeast China transects and land cover in NECT

The biomes varies gradually from temperate evergreen conifer-deciduous broad leaf mixed forests, deciduous broad leaf forests, woodlands and shrub lands in the east to agricultural fields, temperate savannas and meadow steppes in the middle, then to typical steppes and desert steppes in the west (Ni and Zhang, 2000).

The year of 2005 is selected as the simulation time and the spatial resolution is  $0.085^{\circ} \times 0.085^{\circ}$ .

**Integrated biosphere simulator:** The Integrated Biosphere Simulator (IBIS) model includes land surface processes, canopy physiology, vegetation phenology, vegetation dynamics and terrestrial carbon balance (Foley *et al.*, 1996). It allows for explicit coupling among ecological, biophysical and physiological processes operating at different timescales. The existence of one or more plant functional types in a given location is determined primarily by a simple set of climatic constraints that determine cold tolerance limits, growing degree-day requirement and minimum chilling requirements (Kucharik *et al.*, 2006).

Input data sets include meteorological data from 1950 to 2006, vegetation type, soil type and DEM. IBIS simulated the upper and lower canopy, LAI and LAIU. For total ecosystem LAI (totLAI),  $\text{tot LAI} = \text{LAI} + \text{LAIU}$ . The gridded simulation results of vegetation type and monthly LAI in 2005 are selected. Then, overlapped with the bound of NECT, six vegetation types are identified.

**Remote sensing data:** The MOD15A2, MODIS product obtained from NASA (<http://wist.echo.nasa.gov>), provides the most recent remote sensing simulation of LAI at the resolution of  $1 \times 1$  km. This data set has made great progress in calibration, cloud screening, atmospheric correction and removing noise (Friedl *et al.*, 2002). The Collection 4 LAI monthly data sets composited by the 8-day composite ones for the year 2005 are selected, then re-

projected and aggregated to a  $0.085^{\circ} \times 0.085^{\circ}$  by averaging the LAI value within each  $0.085^{\circ}$  grid cell.

## RESULTS AND DISCUSSION

**Inner-annual differences of vegetation types:** For IBIS, leaf optical properties vary between the upper and lower canopy. The upper canopy properties are time invariant, the lower level properties such as grass vary by season depending on whether the leaves are green and growing or brown and senescent (Bonan, 1995). Therefore, IBIS estimated the upper canopy LAI consistently for each vegetation type respectively, while the simulated lower LAI appeared an obviously seasonal variation (Fig. 2). At the beginning of growing season in May, the lower LAI suddenly increased to high value, then maintained stable until the end of growing season in October when the LAI value declined rapidly.

Figure 2 shows for temperate evergreen conifer forest and boreal evergreen forest, IBIS overestimated LAI relative to MODIS in non-growing season. From June to September in growing season, IBIS underestimated LAI value than MODIS, which may make up for the overestimation of non-growing season to some extent for the whole year. This result was consistent with studies on evaluating IBIS with ground measurements or satellite information of greenness in other countries (Cohen *et al.*, 2006). Twine and Kucharik (2008) pointed that Agro-IBIS could get a reasonable LAI at simulating peak LAI in deciduous and conifer forest. Compared with MODIS data, Agro-IBIS simulates sensible but somewhat lower growing season LAI over deciduous forest as a whole. Peak conifer forest LAI was also slightly underestimated. For savanna, except the peak LAI in August, IBIS overestimated LAI compared with MODIS product, especially in October and November. Similarly, IBIS

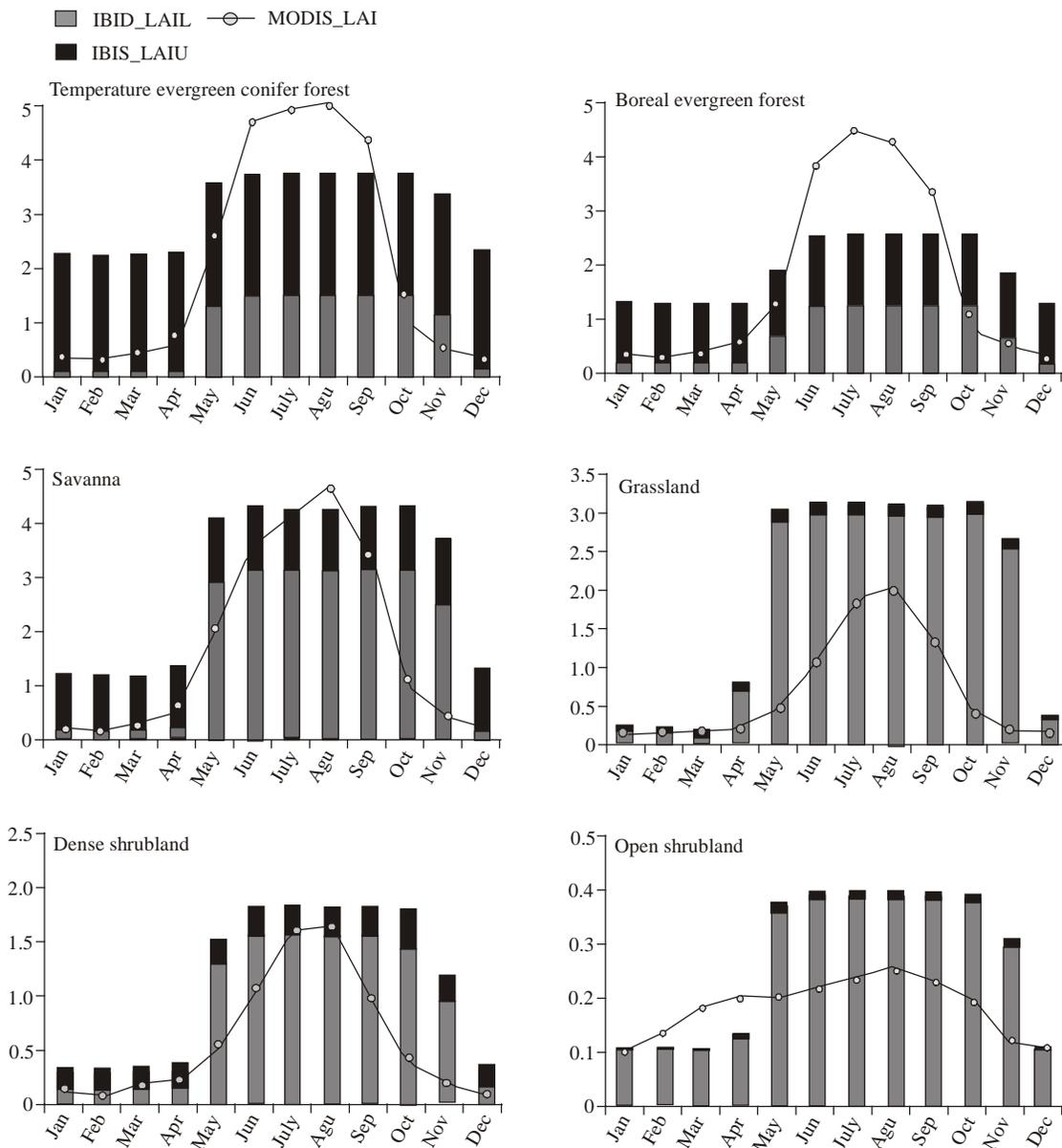


Fig. 2: Monthly LAI for each of six vegetation types in 2005 for MODIS-IBIS comparison in the NECT

notably simulated higher LAI over grassland and dense shrub-land throughout the year. This overestimation was consistent with ground measurements at a FLUXNET site too (Cohen *et al.*, 2006). Moreover, Twine and Kucharik (2008) also suggested that Agro-IBIS performs poorly over grasses compared with MODIS. The model significantly overestimated the magnitude of LAI across the grassland region. In open shrub land, MODIS estimated lower growing season LAI, while it relatively close to IBIS LAI in winter.

**Linear regression analysis between IBIS and MODIS LAI:** Through the linear regression analysis by the function  $LAI_{IBIS} = a * LAI_{MODIS} + b$ , IBIS LAI was linearly correlated to the MODIS LAI well for

boreal evergreen forest. Shown as Table 1, the strongest linear relationship appeared in winter and the R ranged from 0.79 to 0.80, followed by autumn and spring, the averaged R were 0.69 and 0.69, respectively. For temperate evergreen conifer forest, the linear relationship in winter and early spring was much stronger than other seasons, with R ranging from 0.44 to 0.51. As for the grassland, the significant linear correlation appeared during summer and early autumn, the R ranged from 0.56 to 0.72. While considered to other vegetation types, the simulated LAI showed weak linear correlation between IBIS and MODIS throughout the year. Twine and Kucharik (2008) concluded that the high correlation coefficients of 0.68 in April, 0.78 in May, 0.63 in October and 0.53 in November suggest

Table 1: Regression statistics (LAIBIS = k \* LAIMODIS + b) for the IBIS-MODIS LAI for each month

Vegetation type	Coefficient	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Temperate evergreen conifer forest	k	1.218	1.413	1.473	1.260	0.067	-0.090	-0.071	-0.051	-0.123	-0.168	-0.684	1.354
	b	1.900	1.900	1.658	1.573	3.511	4.323	4.245	4.146	4.440	4.070	3.806	1.843
	R	0.512	0.507	0.454	0.444	0.105	0.170	0.100	0.055	0.167	0.110	0.167	0.465
Boreal evergreen forest	k	2.645	2.866	2.919	2.524	0.400	0.162	0.157	0.174	0.179	0.727	2.093	2.618
	b	0.425	0.473	0.142	-0.058	1.444	1.914	1.837	1.796	1.940	1.929	0.776	0.482
	R	0.801	0.799	0.759	0.767	0.539	0.623	0.520	0.559	0.666	0.637	0.771	0.790
Savanna	k	0.273	0.247	0.233	0.061	0.064	-0.052	0.008	-0.108	-0.125	-0.059	-1.165	0.063
	b	1.150	1.159	1.118	1.378	3.939	4.456	4.235	4.764	4.721	4.330	4.083	1.274
	R	0.192	0.155	0.170	0.032	0.071	0.077	0.032	0.105	0.134	0.032	0.130	0.032
Grassland	k	-0.234	-0.310	0.668	0.891	0.712	0.695	0.678	0.617	0.810	1.916	1.005	0.106
	b	0.218	0.227	0.052	0.054	2.663	2.344	1.790	1.813	2.027	2.234	2.463	0.337
	R	0.110	0.152	0.237	0.130	0.365	0.564	0.718	0.679	0.653	0.455	0.063	0.032
Dense shrubland	k	0.112	0.030	0.583	1.096	0.290	0.174	0.099	0.131	0.211	0.591	1.462	0.418
	b	0.335	0.345	0.224	0.087	1.355	1.621	1.649	1.590	1.601	1.580	0.879	0.314
	R	0.045	0.032	0.152	0.362	0.255	0.349	0.243	0.302	0.335	0.277	0.179	0.158
Open shrubland	k	0.036	0.001	0.058	0.078	0.272	0.160	0.234	0.351	0.336	0.964	0.813	0.012
	b	0.102	0.106	0.096	0.116	0.312	0.353	0.333	0.298	0.312	0.201	0.213	0.108
	R	0.187	0.032	0.253	0.071	0.114	0.145	0.255	0.373	0.281	0.263	0.212	0.045

that Agro-IBIS captured the onset and offset of the growing season well in forests. Moreover, they indicated a strong correlation of simulated LAI appeared in July and August over grasses, which was consistent with this result.

The simulated LAI presented a significant linear correlation between IBIS and MODIS over temperate evergreen conifer forest in spring and winter, boreal evergreen forest throughout the year and grassland from summer to early autumn. Take advantage of the linear relationship, we could adjust the model parameters over these plant functional types to calibrate the estimated LAI at a large spatial scale based on remote sensing. Drawbacks of this study are both based on model and remote sensing. For IBIS, estimating accuracy is limited by model parameters and algorithms and input data sets such as climate, soil or land cover classification, as well as their uncertainties. Uncertainty in remotely sensed products rises from the quality of satellite-derived spectral information and the inversion algorithms for simulated LAI.

### CONCLUSION

The remotely sensed vegetation Index of Satellite (MODIS) observations was used to evaluate the ability of IBIS model to capture the difference in vegetation characteristics, such as the seasonal variations and the magnitude of peak values of LAI, among six major biomes within NETC in 2005. IBIS simulates somewhat lower growing season LAI over some forested biomes. For temperate evergreen conifer forest and boreal evergreen forest, IBIS overestimated LAI relative to MODIS in non-growing season. While in growing season, IBIS underestimated the LAI value than MODIS. For savanna, except the peak LAI in August, IBIS overestimated LAI than MODIS product. IBIS performs poorly over grassland and shrub land compared with MODIS and it notably simulated higher LAI throughout the year. Based on regression analysis, the simulated LAI presented a significant linear

correlation between IBIS and MODIS over temperate evergreen conifer forest in spring and winter, boreal evergreen forest throughout the year and grassland from summer to early autumn, that is useful to adjust the model parameters of these plant functional types to calibrate the estimating LAI in a large spatial scale based on remote sensing.

### ACKNOWLEDGMENT

Funding support from open foundation of Hangzhou Normal University (PDKF2012YG03) and National Natural Science Foundation of China (41101315 & 41171324).

### REFERENCES

- Bonan, G., 1995. Land-atmosphere CO<sub>2</sub> exchange simulated by a land surface process model coupled to an atmospheric general circulation model. *J. Geophys. Res.*, 100: 2817-2831.
- Bondeau, A., P.C. Smith, S. Zaehle, S. Schaphoff, W. Lucht, W. Cramer and D. Gerten, 2007. Modelling the role of agriculture for the 20th century global terrestrial carbon balance. *Global Chang. Biol.*, 13: 679-706.
- Canadell, J.G., W.L. Steffen and P.S. White, 2002. IGBP/GCTE terrestrial transects: Dynamics of terrestrial ecosystems under environmental change. *J. Veget. Sci.*, 13: 297-450.
- Cohen, W.B., T.K. Maier-Sperger, D.P. Turner, W.D. Ritts, D. Pflugmacher, R.E. Kennedy, A. Kirschbaum, S.W. Running, M. Costa and S.T. Gower, 2006. MODIS land cover and LAI collection 4 product quality across nine sites in the western hemisphere. *IEEE Trans. Geosci. Remote Sensing*, 44: 1843-1857.
- Edwards, M. and A.J. Richardson, 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature*, 430: 881-884.

- Foley, J.A., I.C. Prentice, N. Ramankutty, S. Levis, D. pollard, S. Sitch and A. Haxelne, 1996. An integrated biosphere model of land surface processes, terrestrial carbon balance and vegetation dynamics. *Global Biogeochem Cycl.*, 10: 603-628.
- Friedl, M., D. Mciver, J. Hodges, X. Zhang, D. Muchoney, A. Strahler, C. Woodcock, S. Gopal A. Schneider, A. Cooper, A. Baccini, F. Gao and C. Schaaf, 2002. Global land cover mapping from MODIS: Algorithms and early results. *Rem. Sens. Envir.*, 83: 287-302.
- Koch, G.W., P.M. Vitousek, W.L. Steffen and B. Walker, 1995. Terrestrial transects for global change research. *Vegetation*, 121: 53-65.
- Kothavala, Z., M. Arain, T. Black and D. Versegny, 2005. The simulation of energy, water vapor and carbon dioxide fluxes over common crops by the Canadian Land Surface Scheme (CLASS). *Agri. Forest. Meteorol.*, 133: 89-108.
- Kucharik, C., C. Barford, M. Maayar, S. Wofsy, R. Monson and D. Baldocchi, 2006. A multiyear evaluation of a Dynamic Global Vegetation Model at three AmeriFlux forest sites: Vegetation structure, phenology, soil temperature and CO<sub>2</sub> and H<sub>2</sub>O vapor exchange. *Ecolog. Model.*, 196: 1-31.
- Ni, J. and X. Zhang, 2000. Climate variability, ecological gradient and the Northeast China Transect (NECT), *J. Arid. Envir.*, 46: 313-325.
- Osborne, T.M., D.M. Lawrence, A.J. Challinor, J.M. Slingo and T.R. Wheeler, 2007. Development and assessment of a coupled crop-climate model. *Global. Change. Biol.*, 13: 169-183.
- Twine, T. and C. Kucharik, 2008. Evaluating a terrestrial ecosystem model with satellite information of greenness. *J. Geophys. Res.*, 113: G03027.