The estimation and validation of CO_2/H_2O fluxes in Mongolia using Sim-CYCLE HR

LEE Pilzae[1], LEE Gilzae[1], CHEN Yuxiang[1], MARIKO Shigeru[2] and OIKAWA Takehisa[2]

[1] Institute of Life and Environmental Science, University of Tsukuba, Tsukuba, Japan
[2] Institute of Biological Sciences, University of Tsukuba, Tsukuba, Japan

Key words: carbon cycle, water cycle, Mongolia, ecosystem model, net primary production

I Introduction

Mongolia is located at northeastern Asia and its area is around 1.56 × 10^6 km^2, where a forest-grassland-desert ecotone is formed along a steep gradient in the geographical and climatic condition. The ecotone is a sensitive transitional area between two adjacent ecological communities and generally sensitive for climate and vegetation change (Di Castri, 1988). Thus, it is important to understand the responses of carbon/water cycle in Mongolia to climatic change and human disturbance for their sustainable management. With the results through RAISE project, we became able to understand Mongolia ecosystems better than before. This enabled us to estimate carbon/water dynamics in whole Mongolia using Sim-CYCLE.

II Methods

A mechanistic model, termed Simulation model of Carbon cYCLe in Land Ecosystems (Sim-CYCLE) has been developed and used for analyzing atmosphere-biosphere CO_2 exchange (Ito and Oikawa, 2000, 2002). Sim-CYCLE has five compartments for carbon storage: photosynthetic organs (leaves), aboveground non-photosynthetic organs (branches and stems), belowground non-photosynthetic organs (roots), dead biomass (litter), and mineral soil (humus) (Fig. 1). The temporal resolution and spatial resolution of Sim-CYCLE are month and 0.5° × 0.5° in longitude and latitude respectively. These resolutions are suitable for global scale estimation. In order to estimate carbon/water fluxes in Mongolia, we used Sim-CYCLE high resolution (Sim-CYCLE HR). It has 5′ × 5′ spatial resolution in longitude and latitude without any other change of Sim-CYCLE structure.

A simulation of whole Mongolia is performed with Sim-CYCLE HR. The biome distribution is derived from an actual vegetation map of GOGE2 form U.S. Geological Survey (USGS); vegetation is classified into 94 types. Among them, 33 vegetation types are in Mongolia (Table 1). The carbon cycle model is applied to each of the grid points with vegetation cover (57,107 points, 1,484,507 km^2). Altitude and soil conditions (water holding capacity and rooting depth) are derived from ETOPO5 and a global soil dataset (Webb *et al.*, 1993), respectively. Climatic data is gained from a global dataset of the U.S. National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR; Kistler *et al.*, 2001). Since the original NCEP/NCAR data were produced for a T62 Gaussian grid (about 1.9° × 1.875°), each climatic point data is interpolated into a 5′ × 5′ grid, taking the altitudinal temperature lapse rate into account. Using these climatic input variables, a sub-module of the water and energy budget estimates evaporation and transpiration, runoff, and soil water content.

1. Intensive validation site

To examine the model validity, we selected Kherlenbayan-

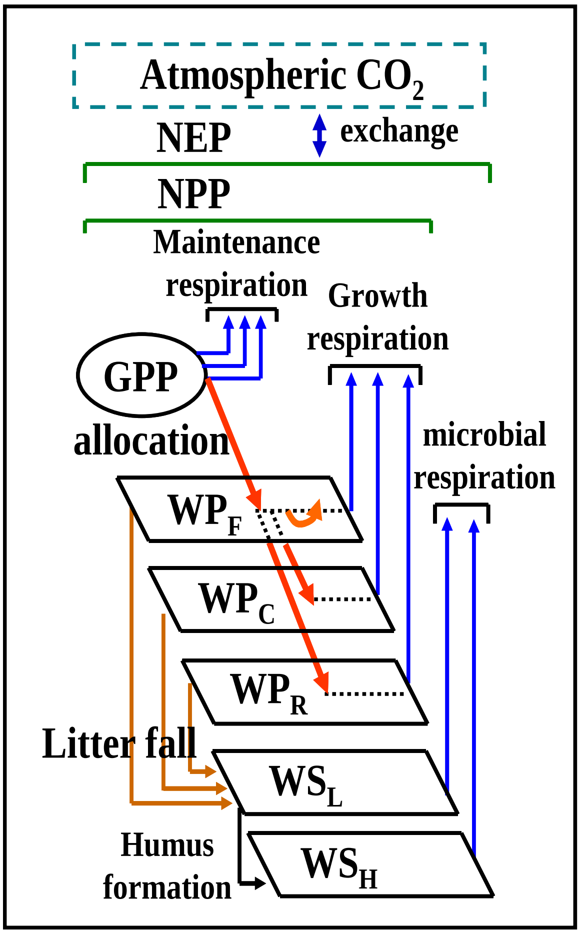

Fig. 1 Schematic diagram of the compartment model of carbon cycle used by Sim-CYCLE. WP_F, WP_C, WP_R, WS_L, and WS_H are foliage, branch and stem, root, litter, and humus respectively.

Table 1 Category and area of 33 vegetation types in Mongolia among 94 vegetation types in GOGE2 from USGS.

Num	Vegetation Name	# of cell point	Area km^2
2	Low Sparse Grassland	16,581	622,132
51	Semi Desert Shrubs	13,514	419,099
42	Cold Grassland	7,391	164,642
8	Bare Desert	5,544	153,656
91	Woody Savanna	2,902	36,480
94	Crops,Grass,Shrubs	2,853	27,701
4	Deciduous Conifer Forest	953	9,314
63	Wooded Tundra	1,048	9,045
93	Grass Crops	1,152	8,635
60	Small Leaf Mixed Woods	1,130	8,398
9	Upland Tundra	525	5,053
61	Deciduous and Mixed Boreal Forest	817	5,027
23	Cool Mixed Forest	453	3,932
5	Deciduous Broadleaf Forest	301	2,378
57	Cool Forest and Field	412	1,408
11	Semi Desert	234	1,359
38	Cool Irrigated Cropland	139	1,299
21	Conifer Boreal Forest	318	1,095
31	Crops and Town	190	913
53	Barren Tundra	196	757
58	Fields and Woody Savanna	135	716
50	Sand Desert	49	501
44	Mire,Bog,Fen	135	470
43	Savanna (Woods)	72	385
62	Narrow Conifers	22	43
10	Irrigated Grassland	9	20
24	Mixed Forest	13	19
45	Marsh Wetland	7	11
22	Cool Conifer Forest	3	6
40	Cool Grasses and Shurbs	3	5
37	Hot Irrigated Cropland	4	4
19	Evergreen Forest and Fields	1	3
36	Rice Paddy and Field	1	1
	Total	57,107	1,484,507

Ulaan (KBU) where carbon dynamics was measured by ecological methods. KBU site is located at Mongolia (47° 28′ N, 108° 78′ E). Altitude is 1,245 m a.m.s.l. The mean annual precipitation is 187 mm averaged during the last ten years (1993-2002). The mean annual temperature is 1.6 °C averaged during same period of precipitation. Vegetation is a typical steppe and dominant species is *stipa krylovii* (C3 plant).

2. Extensive validation sites

To validate the model applicability at the whole Mongolia scale, we performed an extensive comparison (LAI, aboveground biomass) for 9 sites in the wide range of Mongolia. Among these 9 sites' data, 8 sites data are the results of RAISE project, and remained 1 site's data is the result of Tumentsogt site (Chuluun *et al.*, 1995).

III Results

1. Point scale validation

Sim-CYCLE HR appropriately retrieved the carbon flux transitions and the carbon storage in KBU site (Table 2). However, respiration showed a large difference between model output and field data because of assumption of stable stage in Sim-CYCLE HR. Especially,

Table 2 Comparison of model outputs with field data in KBU site.

KBU	LAI	AGB	BGB	GPP	NPP	Respiration
		$g C m^{-2}$	$g C m^{-2}$	$g C m^{-2} yr^{-1}$	$g C m^{-2} yr^{-1}$	$g C m^{-2} yr^{-1}$
Field data	0.6	50	480	177	n.a.	140
Sim-CYCLE	0.61	50	484	174	110	174

in the seasonal change of LAI, model and measured value showed similar pattern with similar values (Fig. 2). This area is arid, thus most of precipitation went to the atmosphere through evapotranspiration annually. In particular, evaporation was over 10 times higher than transpiration because of low LAI (Fig. 3.).

As a consequence of parameter calibration (values not shown), Sim-CYCLE retrieved adequately carbon dynamics in the 9 sites of Mongolia. Fig. 4 shows correlation between field measurement and Sim-CYCLE estimation for LAI, aboveground biomass.

2. Estimation of carbon/water fluxes in Mongolia

Sim-CYCLE HR estimated the annual GPP, NPP, and plant biomass as 167.9 Tg C yr^{-1}, 101.1 Tg C yr^{-1}, and 1,181 Tg C, respectively, as well as estimated the amount of evaporation and transpiration as 277.1 Pg H_2O yr^{-1}, and

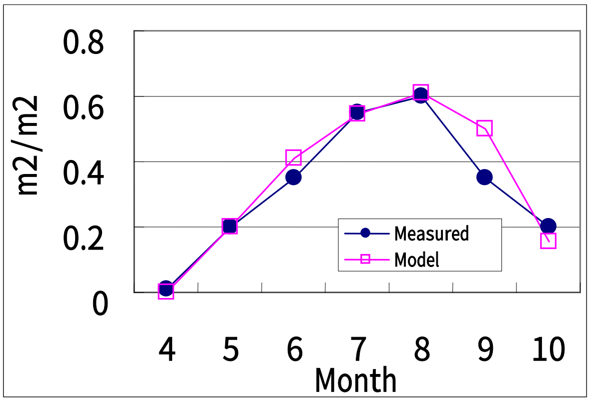

Fig. 2 Seasonal change of model and measured LAI.

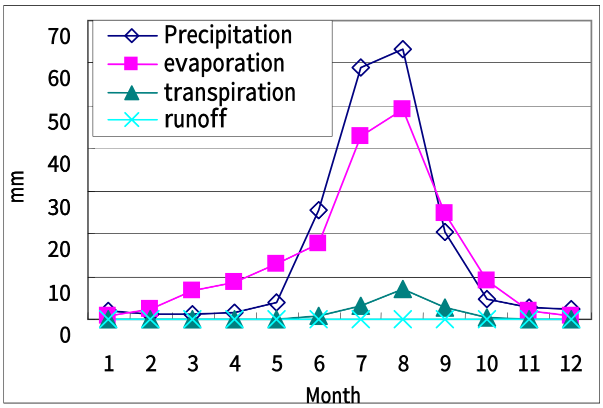

Fig. 3 Estimation of water flux in KBU site.

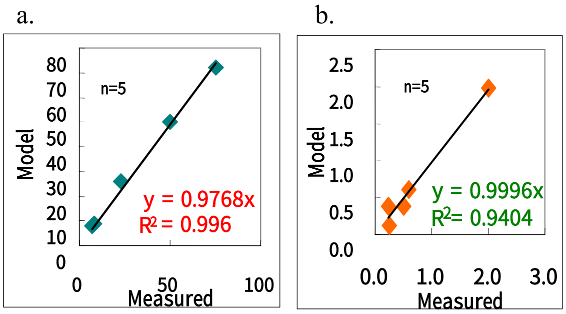

Fig. 4 Correlation between estimations and observations with respect to carbon dynamics in the 9 sites ((a) aboveground biomass and (b) leaf area index).

29.0 Pg H_2O yr^{-1}, respectively. These results suggested that plant productivity and water cycling in Mongolia are closely related with each other, and dependent on limited precipitation and relatively low temperature.

References

Chuluun, T., Ojima, D. S., Jargalsaihan L., Dodd, J. and Williams, S. (1995): Simulation studies of grazing on the Mongolian steppe. N.E. West, ed. : *Proceedings of the 5th International Rangeland Congress, Salt Lake City, Utah, U.S.A., July*. Society of Range Management, Denver, Colorado, U.S.A., 561-562.

Di castri, F. (1998): A new look at ecotones: emerging international projects on landscape boundaries. *Biol. Inst. Sqec. Iss*, **17**.

Ito, A. and Oikawa, T. (2000): A model analysis of the relationship between climate perturbations and carbon budget anomalies in global terrestrial ecosystems: 1970-1997. *Clim. Res.*, **12**, 161-183.

Ito, A. and Oikawa, T. (2002): A simulation model of the carbon cycle in land ecosystems (Sim-CYCLE): A description based on dry-matter production theory and plot-scale validation. *Ecol. Model.*, **151**, 147-179.

Kistler, R., Kalnay, E., Collins, W., Saha, S., White, G., Woollen, J., Chelliah, M., Ebisuzaki, W., Kanamitsu, M., Kousky, V., Van den Dool, H., Jenne, R. and Fiorino, M. (2001): The NCEP-NCAR 50-year reanalysis: monthly means CD-ROM and documentation. *Bull. Am. Meteorol. Soc.*, **82**, 247-267.

Webb, R. S., Rosenzweig, C. E. and Levine, E. R. (1993): Specifying land surface characteristics in general circulation models: soil profile data set and derived water-holding capacities. *Global Biogeochem. Cycles*, **7**, 97-108.