J6.8 CREATING A GLOBAL 1-DEGREE DATASET OF CROP TYPE AND CROPPING CALENDAR THROUGH THE TIME SERIES ANALYSIS OF NDVI FOR GSWP2 SIMULATION CONSIDERING IRRIGATION EFFECT

Kazuaki Yorozu*, Kenji Tanaka and Shuichi Ikebuchi
Kyoto University, Kyoto, Japan

1. INTRODUCTION

SiBUC (Simple Biosphere including Urban Canopy) model is one of the participants of the Second Global Soil Wetness Project (GSWP2). It uses mosaic approach to incorporate all kind of land use into LSS.

The baseline simulation of GSWP2 pays no attention to the irrigation effect although not a small part of the world's cropland is irrigated. In order to estimate global soil moisture field as accurately as possible, SiBUC is run with irrigation scheme activated to consider this effect. The main tasks for the implementation of irrigation simulation in global scale are to prepare a global dataset of crop type and cropping calendar with 1-degree resolution.

2. LAND SURFACE MODEL (SiBUC)

2.1 *Mosaic Approach*

The SiBUC model has been developed at DPRI Kyoto University (e.g. Tanaka (1998)). Heat budget characteristics of water body and urban area are much different from those of vegetation and soil surface. Thus, they may have significant effects even when their coverage areas are not so large. LSS should have a framework of treating the urbanized area, inland water. However, these landuses are usually omitted in the existing LSSs without enough investigation about how they act in regional and global climate systems. From such considerations, the SiB (e.g. Sellers et al. (1986)) was expanded to the SiBUC which has three sub-models (green area, urban area, water body) for each grid element. SiBUC is aimed to describe the basin-scale land surface processes more realisticaly than existing models. **Figure. 1** shows a schematic image of surface elements in SiBUC.

* *Corresponding author address:* Kazuaki Yorozu, Water Resources Research Center, DPRI, Kyoto University, Gokasho, Uji, 611-0011, Japan; e-mail: yorozu@wrcs.dpri.kyoto-u.ac.jp

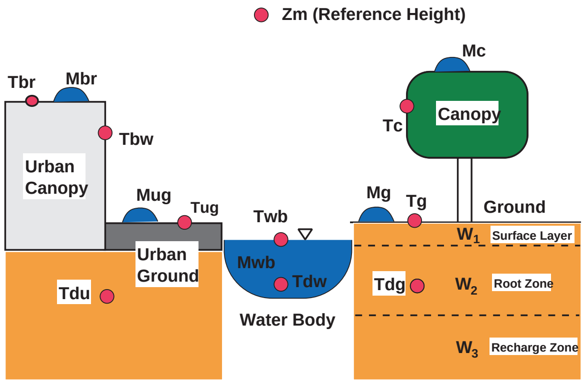


Figure. 1 Schematic image of surface elements in SiBUC

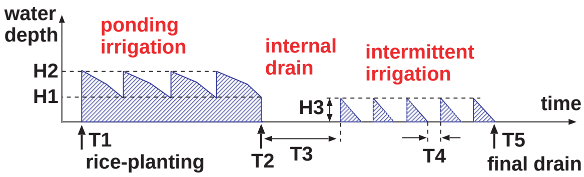


Figure. 2 Water depth control rule in a Japanese paddy field

2.2 *Paddy Field Scheme*

There is a obvious difference between paddy field and other cropland from the aspect of the energy and water budget. Another motivation for the development of the paddy field scheme is to treat the irrigation water. In the irrigated paddy field, as can be seen in India, China and Japan, water is controlled/operated differently according to growing stage of rice. Thus, there is a need for describing the artificial water irrigation/drainage by farmar. Through the detailed analysis of the field data and the numerical simulation with green area model, it was found that the green area model is hard to be used for paddy field if the simulation period becomes longer. Therefore, a water layer which has a temperature and depth is added to the green area model to treat the paddy field more acurately.

Actually, artificial water control is complicated. **Figure. 2** is a schematic image showing the water depth control rule in a Japanese paddy field. This control rule has three stages, ponding irrigation stage, internal

Table. 1 The period of each growing stage (Unit:%) and the low level of water depth (Unit:mm) or soil wetness at the root zone

crop type	growing stage	1	2	3	4	5
spring wheat	period	23	14	14	14	35
	soil moisture	70	60	80	80	55
winter wheat	period	26	20	22	13	19
	soil moisture	70	70	80	80	55
corn	period	8	48	6	14	24
	soil moisture	75	65	70	75	65
rice	period	25	13	33	13	16
	water depth (mm)	20-50	none	20-60	moistening	intermittent
soy bean	period	4	25	16	28	27
	soil moisture	75	65	65	70	65

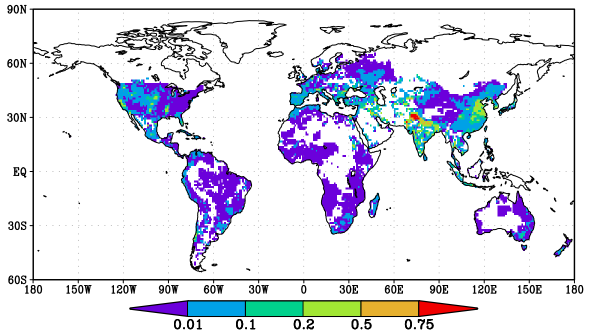


Figure. 3 An irrigation area fraction map by Siebert (2002)

drain stage and intermittent irrigation stage.

2.3 *Irrigation Scheme*

Basic concept of the irrigation scheme is to maintain the soil moisture (water depth) within appropriate ranges that are defined for each growing stage in each crop type. If some parameters which are necessary for the paddy field scheme are defined, it is able to consider the irrigation in farmland by the original green area model as well. The irrigation rules for paddy field and farmland are based on at least four parameters; planting date, harvesting date, the periods of each growing stage, and lower water depth (paddy field) or soil moisture (farmland) in each growing stage.

3. Creating of a global croping map

3.1 *The Global Scale Irrigation*

Table. 1 shows the third and the forth parameters of irrigation rules, the periods of each growing stage and lower soil moisture at the root zone or water depth for each growing stage. This table represents the required water in China for five crops; spring wheat, winter wheat, corn, rice, and soybean. There are five stages in every crop types and the period of each growing stage is represented by percentage of total growing period. So the actual period of each stage depends on total growing period. It is efficient to represent the vegetation state accurately.

There is no global data set of the cultivated crop type and the total growing period. In order to consider irrigation in the global scale, it is necessary to create a global data set of crop type, and determine the planting and harvesting date (total growing period). These could be done through the time series analysis of NDVI data which are included in ISLSCP iniative II. There are two reasons for analyzing NDVI. NDVI obviously corresponds to the vegetation growing state, which can determine the planting and harvesting date. Moreover, the crop types could be defined by using the ”shape” of annual time series.

The other important parameter is a fraction of irrigated area in each grid. There is already an irrigation area fraction map (**Figure. 3**) (e.g. S.Siebert (2002)) and a paddy field fraction map in the Asia from the Olson’s global ecosystem datset.

3.2 *Normalization of NDVI*

In this study, a new index is proposed to determine both a crop type in each grid and a growing period for each type. Since NDVI is given as monthly climatic value, NDVI is normalized for a year. It is called as ’N-NDVI’. This definition is shown as **Eq** (1). The starting month is the month with the minimum value of N-NDVI. That is to say, the starting month is not always January (not constant). There are some advantages in using

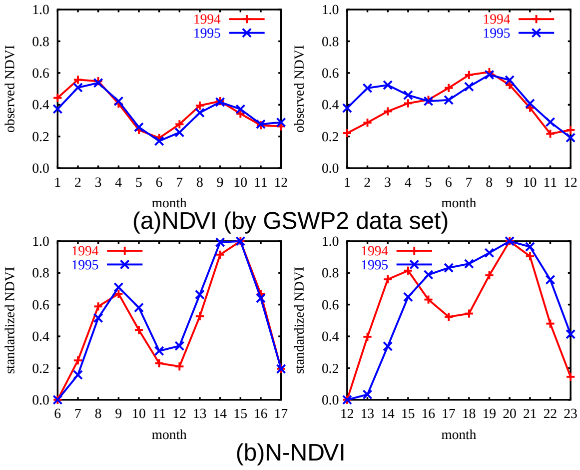


Figure. 4 The frow chart of configuration for N-NDVI in 1994(solid) and in 1995(dots), at point of (73E, 31N:left) and at the point of (116E, 33N:right)

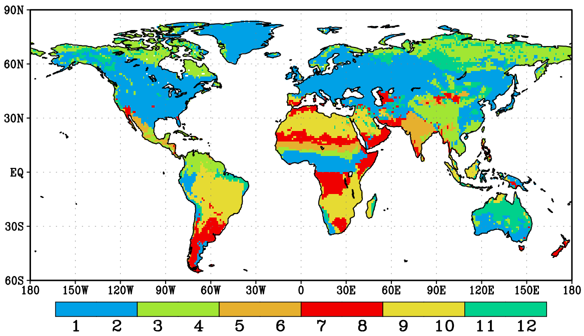


Figure. 5 The month with minimal value of N-NDVI

this index. First, NDVI itself can remarkably represent the vegetation status. Second, there are differences of the range of NDVI in each grid depending on cropland area fraction. Owing to normalization, it is not necessary to consider these mismatched ranges of NDVI.

$$\mathrm{N\_NDVI(i)} = \frac{\mathrm{NDVI(i)} - \mathrm{min}}{\mathrm{max} - \mathrm{min}} \tag{1}$$

n_NDVI(i): N-NDVI on the i time, NDVI(i): the value of the NDVI on the i time, min: the minimum NDVI value through the intended periods, max: the maximum NDVI value through the intended periods.

Another advantage of N-NDVI is the flexibility of the starting month. **Figure. 5** shows the distribution of the month when N-NDVI becomes minimum. From **Figure. 5**, the minimum month is not constant all over the world. Owing to the introduction of starting month concept, it is easy to determine irrigation rules (planting and harvesting date). In this study, the planting date is defined as the date when N-NDVI value beyonds 0.35 first. Also the harvesting date is defined as the date when N-NDVI value becomes lower than 0.6 after the month with the maximum value.

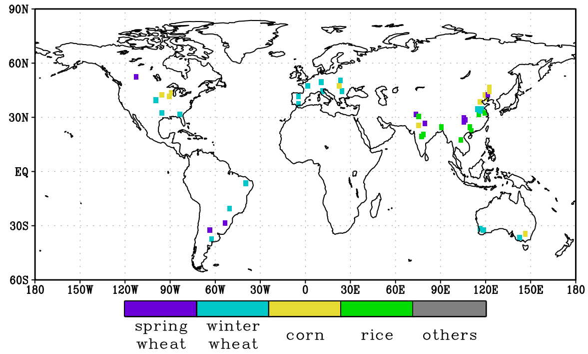


Figure. 6 Representative points

3.3 *Identification of crop type*

Firstly, some representative points with cropland fraction over 0.9 are selected, and crop types on these points are specified according to Major World Crop Areas and Climatic Profiles from U.S. department of agriculture. There are four crop types; spring wheat, winter wheat, corn, and rice. If the shape of time series of N-NDVI in some point is similar to that in a representative point, the crop type in this point is regarded to be same as the representative point. This determination is carried out on 16 times because 16-year period (1982-1997) of the N-NDVI data set is available. Finally, the proper crop type in each grid is identified to be the one with the maximum number of determination. It is necessary to define some criteria for the determination of crop type. In this study, only one regulation are applied all over the world for the determination of crop type. Following four regulations are for the determination of corn.

- N-4<0.36
- N+4<0.19
- N-3>N+3
- Low (0.22) value period<6 months

Here, N-4 means the value of the N-NDVI at 4-month before the month with maximum value of N-NDVI(=1.0). On the other hand, N+4 means the value in the 4-month after the maximum value. And the next three regulations are for the determination of rice.

- N-4>0.36
- High (0.73) value period>6 months
- More than 0.7 on October

As for the grids which did not match the above regulations are basically regarded as wheat. Finally, the

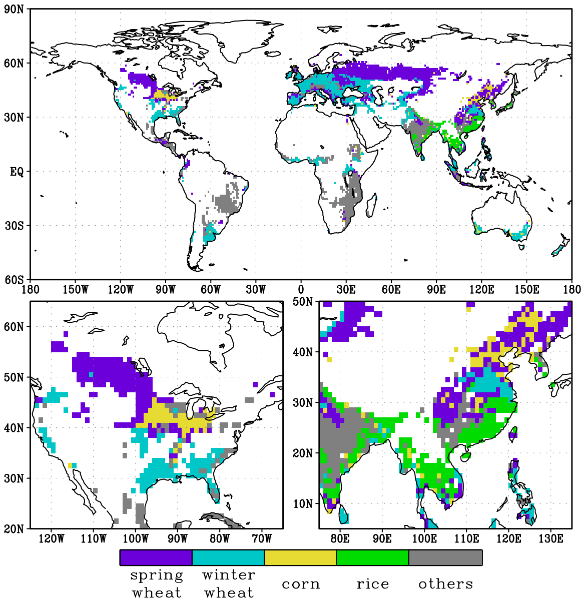


Figure. 7 Spacial distribution of crop type. Shaded for the grid which has more than 10% of cropland fraction (top:global scale, left bottom:The north America, right bottom:The east Asia)

Table. 2 Comparison of the cultivated area of each crop type (Unit:10^6ha)

crop type	this study	FAOSTAT
Wheat	840.1	222.4
Corn	96.0	133.2
Rice	116.0	146.3
Sum of crop	1052.1	702.6
Sum of agriculture	1480.0	1504.4

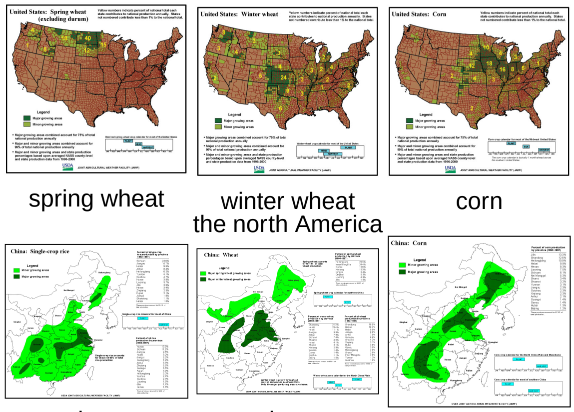
following conditions are applied to classify these grids into spring wheat, winter wheat, and rice.

- Basically spring wheat are cultivated.
- If the N-NDVI value on April is more than 0.5, winter wheat is cultivated.
- If the N-NDVI value on April is less than 0.5 and that on Octobar is more than 0.7, rice is cultivated.

In this way, the global one degree data set of crop type could be created. **Figure. 7** shows the gridded global dataset of crop type map. Only the grids which have more than 10% of cropland fraction are shaded.

3.4 *Validation of Cropping Map*

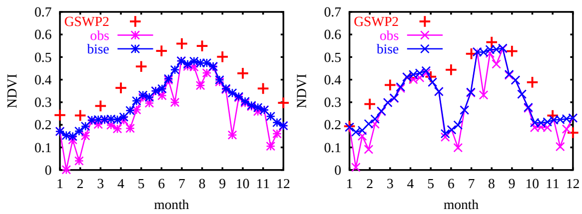
Figure. 8 is a map of crop type by Major World Crop Areas and Climatic Profiles. There is a corn belt in the



spring wheat winter wheat the north America corn

rice wheat the east Asia corn

Figure. 8 Figure by Major World Crop Areas and Climatic Profiles



(a)single cropping point (114E,31N) (d)double cropping point (114E,34N)

Figure. 9 Comparison of the time series of NDVI between GSWP2 data set and NOAA/AVHRR 10-day composite (GSWP2: +, original: solid, smoothed by BISE method)

middle of USA, and spring wheat and winter what areas are located to the north and south of this corn belt, respectively. Compared with **Figure. 7**, our estimation almost corresponds to a given map. It could be said that this is the same in China. According to this gridded crop type dataset, cultivated areas of each crop type are calculated and compared with statistical data (FAOSTAT). From **Table. 2**, it could be said that most part of rice and corn are identified by this method but it is still not enough. Regarding wheat in this study as summary of crops, it is roughly matching. It is possible to adjust some criteria to match with FAOSTAT. But some problems are found int the used datset. **Figure. 9** shows an example of the time series of NDVI at some double cropping area in China. Marks are for GSWP data, and solid lines are for NOAA/AVHRR 10-day composite. Provided monthly data set fail to express the drop-down of NDVI during crop rotation period which is found in 10-day dataset. Thus, there is a limitation of getting accurate results from the provided dataset. So, no calibration (with FAOSTAT data) was done for the crop identification method.

4. IMPACT OF IRRIGATION EFFECT

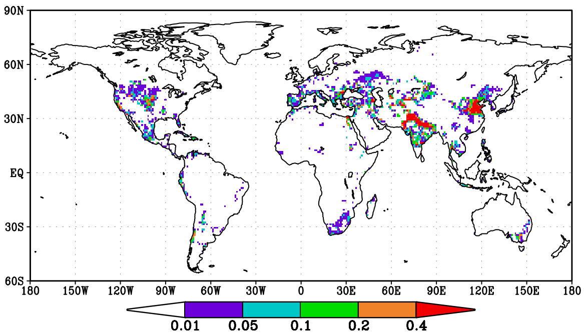
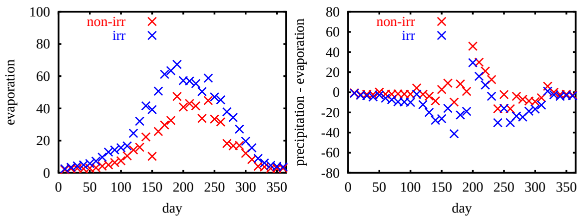


Figure. 10 The increase in soil wetness of root zone



Evaporation Evaporation - Precipitaion

Figure. 11 10 years average of annual variation:unit (mm)

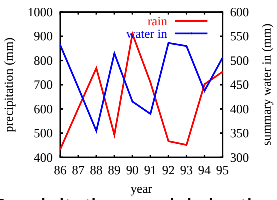


Figure. 12 Precipitation and irrigation water for 10 years:unit (mm)

Figure. 10 shows a difference of soil wetness between baseline and irrigation simulation. There is a significant increase of soil wetness at some irrigated area. **Figure. 11** shows 10-year average of annual cycle of evaporation, precipitation-evaporation at eastern China (115E, 38N). Red line is for baseline simulation (without irrigation) and blue line is for irrigation simulation. When irrigation effect is included, evaporation sometimes exceeds precipitation. This feature is realistic for the area where there is a need for irrigation. **Figure. 12** shows the inter-annual variation of precipitation and irrigated water. The left vertical axis is for precipitation and the right vertical axis is for evaporation. There is a obvious negative correlation between precipitation and irrigation water.

5. SUMMARY

Through the time series analysis of NDVI, a global 1-degree dataset of crop type and cropping calendar are created. There are five crop types (spring wheat, winter wheat, corn, rice, and soy bean) and five growing stages. Owing to this dataset, it is possible to run global simulation of surface energy and water budget considering irrigation effects. From the simulation results, it can be said that irrigation effect is an important factor in order to estimate soil wetness accurately. To conduct a simulation more accurately, it is necessary to re-construct the above dataset from a high temporal and spacial resolution data set.

Acknowledgements

This work is supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology, Grant(B)(1)16360249 (GSWP2).

References

[1] P.Dirmeyer, X.G, T.O: The second global soil wetness project (GSWP-2) science and implementation plan, IGPO Publication Series No.37, 2002.

[2] Tanaka.K, N.E and I.S, 1998: Land-surface Parameterization in the Lake Biwa Project, Annual Journal of Hydraulic Engineering, JSCE, 42, pp.79-84 (in Japanese)

[3] P.J.Sellers, Y.M, Y.C.S, A.D: A simple biosphere model（SiB）for use within general circulation models, *Journal of the Atmospheric Sciences*, Vol.43, No.6, pp.505-531, 1986.

[4] Major World Crop Areas and Climatic Profiles, Joint Agricultural Weather Facility, World Agricultural Outlook Board, U.S. Department of Agriculture Agricultural Handbook, No.664, 1994.

[5] N.Viovy, O.A: The best index slope extraction (BISE): A method for reducing noise in NDVI time series, Int.J.Remote Sensing, Vol.13, No.8, pp.1585-1590, 1992.

[6] Olson.J.S:Global ecosystem framework-definitions: USGS EROS Data Center Internal Report, Sioux Falls, SD, 37p, 1994.

[7] S.Siebert, P.D, J.H: Global map of irrigated areas version 2.1, Center for Environmental Systems Research, Univerity of Kassel, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy, 2002.