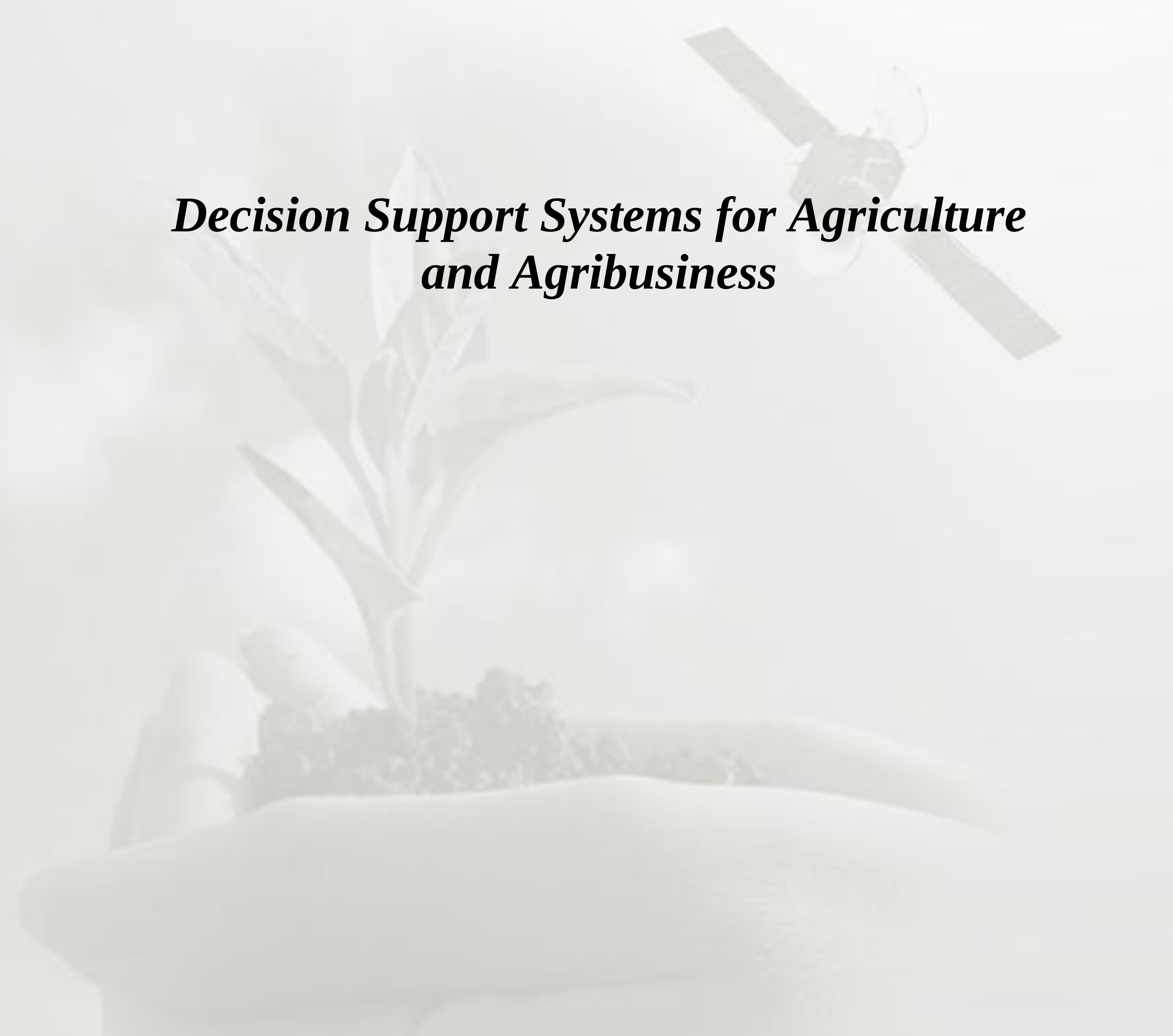

Decision Support Systems for Agriculture and Agribusiness

Tool for Predicting the Possibility of Rice Cultivation using SIMRIW

Kei Tanaka
NARC, NARO and
University of Tsukuba
Tsukuba, Ibaraki, Japan
tanaka.kei@affrc.go.jp

Takuji Kiura
Grid Computing Team
NARC, NARO
Tsukuba, Ibaraki, Japan
kiura@affrc.go.jp

Masahiko Sugimura
Language and Media Lab.
Fujitsu Laboratories
Kawasaki, Kanagawa, Japan
suginy@jp.fujitsu.com

Seishi Ninomiya
Masaru Mizoguchi
Grad. Sch. of Agr. and Life Sci.
University of Tokyo, Japan
snino@isas.a.u-tokyo.ac.jp
amizo@mail.ecc.u-tokyo.ac.jp

***Abstract*—A tool for predicting the possibility of rice cultivation using the rice growth simulation model known as the Simulation Model for Rice-Weather Relations (SIMRIW) has been developed. This is a Web application that can display the potential for cultivation, the optimal transplanting date, and the maximum yield on a map by executing SIMRIW throughout the world. This application was developed as a decision support system (DSS) tool for policy decision makers and farmers rather than researchers, although the original SIMRIW model was developed for researchers.**

SIMRIW had already been implemented as a Web application by using the crop model development framework. The model execution engine was improved to allow a large amount of repetitive model execution in order to simulate the entire earth with a large parameter set. Moreover, MetBroker, which is a supplier of meteorological data, was improved to allow handling the one degree grid meteorological data.

The model was executed 365 times while the transplanting date was moved by one day each time, and the cultivation possibility was determined by whether or not the yield is zero. At the same time, it was executed for eight cultivars (five Japonica and three Indica), three air temperature addition values, and two CO_2 concentrations. The results of the model are stored in an XML format, and a user can see them using the Flash version or Google Earth version of the data viewer application.

Keywords*—*rice cultivation possibility, SIMRIW, Web application, Google Earth

I. INTRODUCTION

Our role is "Development of a safe farm products management technology and the traceability system", which is one of the missions of Data Integration and Analysis System (DIAS) [5]. It is our purpose to develop a system that uses the data provided by the core system, makes farm production management support information widely accessible, and makes the influence on food production of global warming in the long term and the short term more widely known. In this presentation, a tool for predicting the possibility of rice cultivation, which is one of the applications of the system, is described. This tool displays the areas of possible rice cultivation all over the world with a sophisticated user interface.

We have developed several Web applications for crop modeling [22] using the crop model development framework [23]. The Simulation Model for Rice-Weather Relations (SIMRIW), which is a rice growth model, is included among these models. SIMRIW is suitable as a rice growth model to predict the possibility of rice cultivation in areas throughout the world, because it uses only air temperature and solar radiation as meteorological data, and these can be easily acquired, and does not use regional parameters. The model engine improvement, which shortens the processing time, was necessary in order to execute the crop model using many parameter sets of a huge station all over the world.

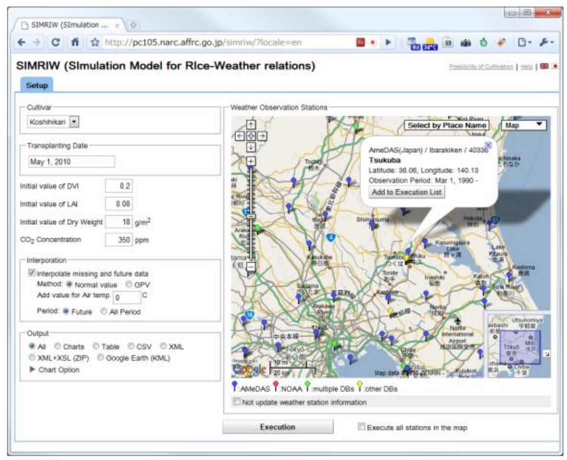

Figure 1. Setup window of SIMRIW (Servlet version)

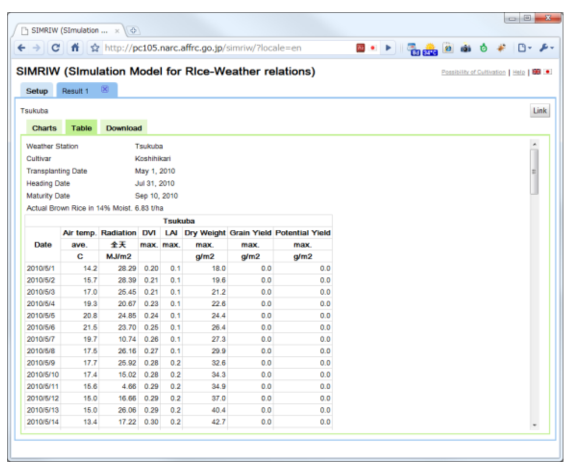

Figure 2. Results window of SIMRIW (Servlet version)

The original SIMRIW was not easy to use for everyone, because it has many setup items in the input interface (Fig. 1), and the sequential meteorological data and results were mainly displayed in charts and tables in the output interface (Fig. 2). Therefore, a new user interface that would be easy for anyone to use was developed.

The National Agricultural Research Center (NARC) of the National Agriculture and Food Research Organization (NARO) were responsible for the development of the execution program and for providing the meteorological data, and Fujitsu Laboratories was in charge of the user interface development.

II. METHOD

A. Rice Growth Model

The rice growth models known well are the following [3]: (1) Crop Environment Resource Synthesis (CERES)-Rice [17] included in the Decision Support System for Agrotechnology Transfer (DSSAT) [11] developed by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) group [24]; (2) ORYZA [2][10] developed by the International Rice Research Institute (IRRI) and Wageningen University; and (3) CropSyst [21] developed by Washington State University. It is necessary to prepare many parameters in the cultivation experiment, although these rice models can reflect detailed terms in the simulation.

It is necessary to adopt a rice model that does not require regional parameters, because it is impossible to perform the cultivation experiment all over the world to predict the possibility of rice cultivation. SIMRIW [8] satisfies this condition, because it achieved good results in a large area simulation without regional parameters.

SIMRIW is a rice growth model developed by Kyoto University that is simpler than the other models mentioned. This model determines the crop growth stage such as heading or maturity by means of a developmental index (DVI) that integrates the developmental rate (DVR) [4]. It was attempted to improve the prediction accuracy by using different DVR formulas in SIMRIW whether the sensitivity period is photoperiodic or not, and whether the development phase is a vegetative stage or reproductive state or maturation period [9][16]. SIMRIW cannot simulate the influence of water stress and nitrogen stress, because it simulates only potential growth in fertilized and irrigated paddy fields. However, cultivation in regions with very little precipitation was assumed to be unrealistic, and an annual rainfall threshold of 300 mm/year was introduced.

B. Meteorological Data

To execute SIMRIW, daily air temperature and solar radiation are required as meteorological data. It is advantageous that so little meteorological data is necessary to execute the model throughout the world. However, solar radiation data are somewhat difficult to acquire compared with air temperature and precipitation. A sunshine hours - solar radiation conversion model [14] is available in SIMRIW to help meet the requirement for solar radiation data. SIMRIW became executable in AMeDAS (Automated Meteorological Data Acquisition System) [1] stations in Japan where sunshine hours are measured by using this conversion model.

MetBroker [12][13][15] is used to acquire meteorological data from meteorological databases according to the framework [23] used to develop SIMRIW. MetBroker is mediation software that enables data to be acquired from a meteorological database throughout the world (about 20 at present) without the need for a complex database access program. AMeDAS (for Japan) and NOAA (for the rest of the world) [17] can be used as the main meteorological databases. However, because solar radiation could not be acquired from NOAA, SIMRIW was able to be executed only in several countries that provided solar radiation data. The Global Dataset of DR and TR (GD-DR&TR) database was successfully treated with MetBroker to simulate areas all over the world, and it came to be able to acquire air temperature, precipitation, and solar radiation in one degree grid (only for land).

C. Model Program

1) SIMRIW program

The FORTRAN source code of the original SIMRIW program was published in the report of Grants-in-Aid for Scientific Research (KAKENHI) as an appendix [9]. The web application version of SIMRIW [20] was developed in Java based on the source code by using the crops model development framework [23]. Because the model calculation and the state variables are appropriately designed using the features of object oriented programming (OOP), the developed source code is easy to maintain and reuse.

2) Model execution engine

As for the existing Web application version, a version of SIMRIW that assumed that the model would be executed in the interactive mode with a user was developed. Therefore, meteorological data were acquired every time the model was executed, specifically in the execution cycle "data acquisition - execution - result display". A method that could repeatedly reuse the acquired meteorological data while the cultivar and the parameter sets "transplanting date from Jan. 1 to Dec. 31, air temperature addition value, and CO_2 concentration" were changed was added to the model execution engine, and it improved the efficiency of the meteorological data acquisition that had consumed a great deal of execution time. Moreover, the model calculation was sped up by using multithreading. The execution cycle of the rice cultivation possibility data generation is shown in Fig. 3. The parts of the figure highlighted in gray are the improved parts of the model execution engine.

D. Output Format

The result regarding the possibility of rice cultivation is output to one XML file per station, cultivar, and parameter set (Fig. 4). Its file name is "data base ID" + "station ID" + ".xml". All the transplanting dates, harvesting dates, and yields are recorded in the XML file, and sequential data of air temperature, solar radiation, and DVI value at maximum yield are recorded. The size of the XML file is 100 Kbytes (about 3200 lines) when it is possible to cultivate on all transplanting dates, and 500 Bytes (14 lines) when it is not possible to cultivate on all transplanting dates. The total file size of all of the XML files becomes about 600 MBytes (or 46 Mbytes for a ZIP compressed file) for about 15,000 stations all over the world.

Furthermore, an XML file “max-yield.xml” that collects only the maximum yield data is generated from the files from 15,000 stations all over the world (Fig. 5). The max-yield.xml file is about 230,000 lines, and the file size is 10 MBytes (the ZIP compressed file is 600 KBytes).

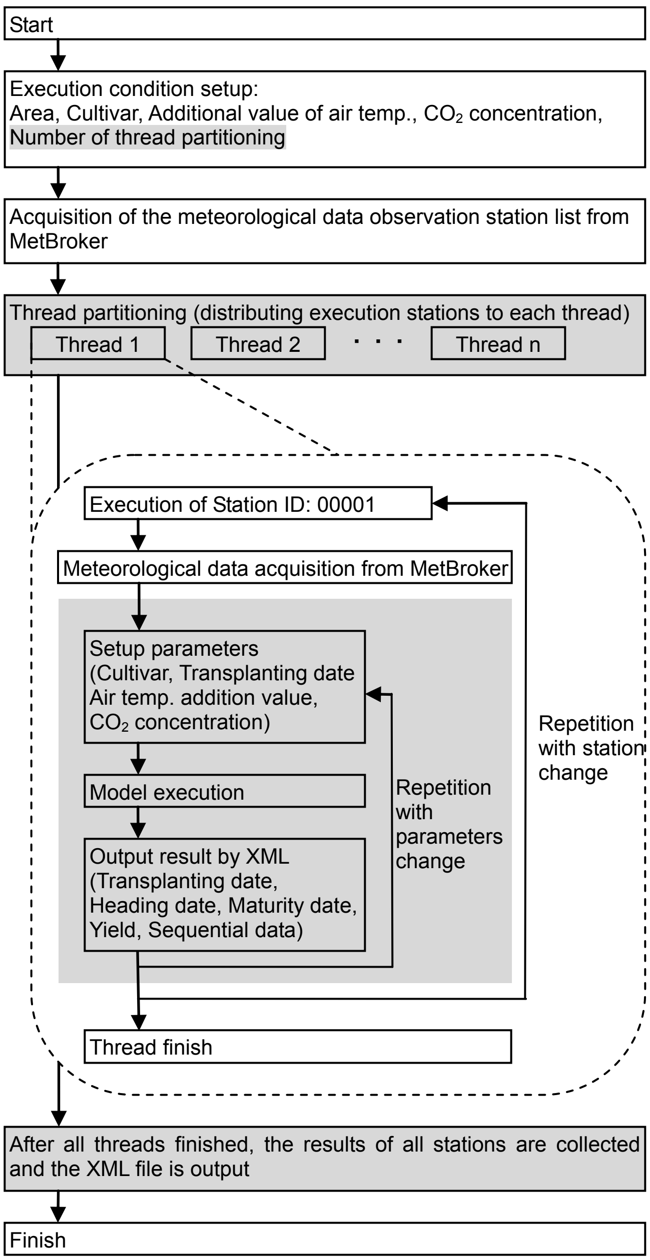

Figure 3. Execution cycle of rice cultivation possibility data generation (The parts of the figure highlighted in gray are the improved parts of the model execution engine)


```xml
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<cultivation_possibility>
<cultivar>Koshihikari</cultivar>                                          } (1)
<year>1990</year>
<air_temp_add_value>0</air_temp_add_value>
<co2>350</co2>
<station region_id="12032" source_id="GD-DR&amp;                           } (2)
                                   TR" station_id="19401">
   <place_name>latitude=36.5_longitude=140.5</place_name>
   <place latitude="36.5" longitude="140.5"/>
   <area ne_latitude="37.0" ne_longitude="141.0"
         sw_latitude="36.0" sw_longitude="140.0"/>
</station>
<yields>                                                                  } (3)
   <yield>
      <transplanting_date>1990/3/22</transplanting_date>
      <heading_date>1990/8/1</heading_date>
      <maturity_date>1990/9/12</maturity_date>
      <weight state="14%moist">
         <actual_brown_rice unit="t/ha">5.61</actual_brown_rice>
      </weight>
   </yield>

   . . .

</yields>
<possibility>true</possibility>                                           } (4)
<max_yield>                                                               } (5)
   <transplanting_date>1990/3/30</transplanting_date>
   <heading_date>1990/8/2</heading_date>
   <maturity_date>1990/9/12</maturity_date>
   <weight state="dry">
      <crop_including_roots unit="t/ha">18.14</crop_including_roots>
      <panicle unit="t/ha">9.48</panicle>
      <potential_brown_rice unit="t/ha">6.48</potential_brown_rice>
      <actual_brown_rice unit="t/ha">7.54</actual_brown_rice>
   </weight>
   <weight state="14%moist">
      <potential_brown_rice unit="t/ha">9.92</potential_brown_rice>
      <potential_rough_rice unit="t/ha">4.86</potential_rough_rice>
      <actual_brown_rice unit="t/ha">5.65</actual_brown_rice>
      <actual_rough_rice unit="t/ha">7.44</actual_rough_rice>
   </weight>
   <sequential_data>                                                      } (6)
      <element id="airtemperature" name="Air temp.">
         <subelement name="ave." unit="C">
            <value date="1990/3/30">11.1</value>
            . . .
         </subelement>
      </element>
      <element id="radiation" name="Radiation">
         <subelement name="Global" unit="MJ/m2">
            <value date="1990/3/30">14.61</value>
            . . .
         </subelement>
      </element>
      <element id="DVI" name="DVI">
         <subelement name="max." unit="">
            <value date="1990/3/30">0.2</value>
            . . .
            <value date="1990/9/11">2.0</value>
         </subelement>
      </element>
   </sequential_data>
</max_yield>
</cultivation_possibility>
```


(1) Cultivar, air temperature addition value, CO_2 concentration
(2) Information of station
(3) Heading date, maturity date, and yield when transplanting date is executed from Jan. 1 to Dec. 31
(4) Cultivation possibility
(5) Conditions at maximum yield
(6) Sequential data of air temperature, solar radiation, and DVI value at maximum yield

Figure 4. XML file of cultivation possibility data of each station GD-DR&TR19401.xml

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<cultivation_possibility>
<cultivar>Koshihikari</cultivar>                         (1)
<year>1990</year>
<air_temp_add_value>0</air_temp_add_value>
<co2>350</co2>
<stations>
  <station region_id="03010" source_id="GD-DR&amp;
                                   TR" station_id="50506">
    <place_name>latitude=-50.5_longitude=-74.5</place_name>
    <place latitude="-50.5" longitude="-74.5"/>          (2)
    <area ne_latitude="-50.0" ne_longitude="-74.0"
          sw_latitude="-51.0" sw_longitude="-75.0"/>
    <possibility>false</possibility>
  </station>

  . . .

  <station region_id="12032" source_id="GD-DR&amp;TR"
          station_id="19401">
    <place_name>latitude=36.5_longitude=140.5</place_name>
    <place latitude="36.5" longitude="140.5"/>
    <area ne_latitude="37.0" ne_longitude="141.0"
          sw_latitude="36.0" sw_longitude="140.0"/>
    <possibility>true</possibility>
    <max_yield>
      <transplanting_date>1990/3/30</transplanting_date>
      <heading_date>1990/8/2</heading_date>
      <maturity_date>1990/9/12</maturity_date>
      <weight state="dry">
        <crop_including_roots unit="t/ha">18.14</crop_including_roots>   (3)
        <panicle unit="t/ha">9.48</panicle>
        <potential_brown_rice unit="t/ha">6.48</potential_brown_rice>
        <actual_brown_rice unit="t/ha">7.54</actual_brown_rice>
      </weight>
      <weight state="14%moist">
        <potential_brown_rice unit="t/ha">9.92</potential_brown_rice>
        <potential_rough_rice unit="t/ha">4.86</potential_rough_rice>
        <actual_brown_rice unit="t/ha">5.65</actual_brown_rice>
        <actual_rough_rice unit="t/ha">7.44</actual_rough_rice>
      </weight>
    </max_yield>
  </station>

  . . .

</stations>
</cultivation_possibility>
```


(1) Cultivar, air temperature addition value, CO_2 concentration
(2) Information of station and cultivation possibility (in case of false)
(3) Information of station, cultivation possibility (in case of true), transplanting date, heading date, maturity date, and yield

Figure 5. XML file of cultivation possibility data of all stations max-yield.xml

E. *Viewer Application*

1) *Flash*

This is an application that displays the rice cultivation possibility data in Google Maps using Adobe Flash. Because the size of the XML file “max-yield.xml” is large at about 10 MBytes, it is difficult to parse it in real time. Therefore, the image converted from the XML data beforehand is displayed on Google Maps.

Following the top page of the tool (Fig. 6), the result is displayed by the user interface program as the window of cultivation possibility of a specified cultivar (Fig. 7) and the window of the cultivar that obtains maximum yield (Fig. 8). When a station on the map in Fig. 7 is clicked, information regarding the station, the growth curve, and the yield according to transplanting date, etc., are displayed under the map.

Figure 6. Top page window of rice cultivation possibility prediction tool

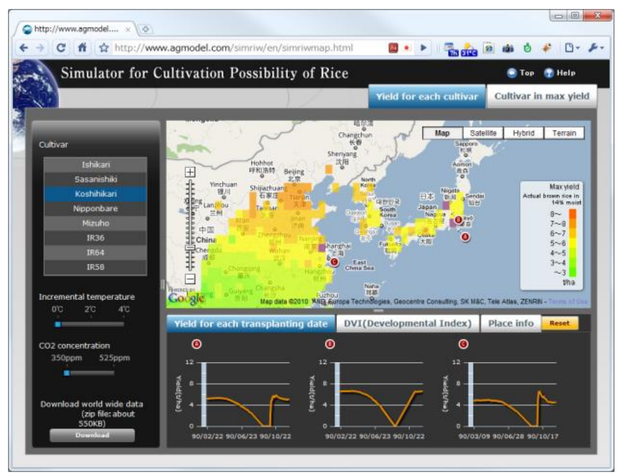

Figure 7. Window of cultivation possibility of specified cultivar (Flash version)

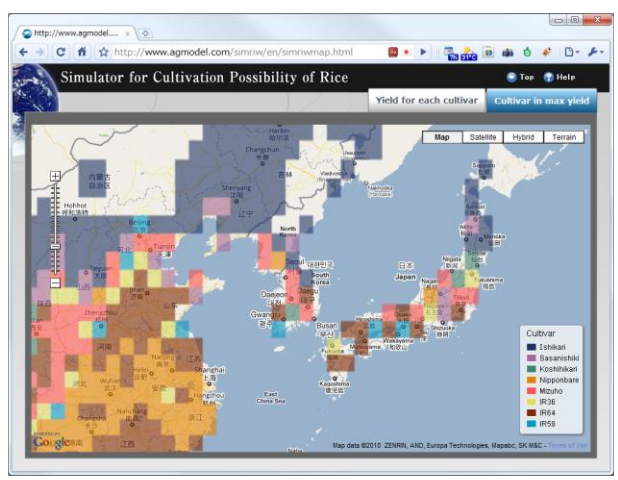

Figure 8. Window of the cultivar that obtains maximum yield (Flash version)

2) Google Earth

It is possible to display the rice cultivation possibility data on Google Earth through the conversion of the XML file “max-yield.xml” to a KML file (Fig. 9). The KMZ file “max-yield.kmz” (about 300 KBytes) converted from “max-yield.xml” is an archive ZIP file that includes the KML file and the icon image files. Because it is a conversion of the same XML format, conversion from max-yield.xml to max-yield.kmz is easy.

At first, the KML file for Google Earth was created as a way to confirm the Flash version. The ability to overlap and compare the data of two or more cultivars or parameters and the ability to display the data as an animation of sequential data make the Google Earth version an actual application like the Flash version.

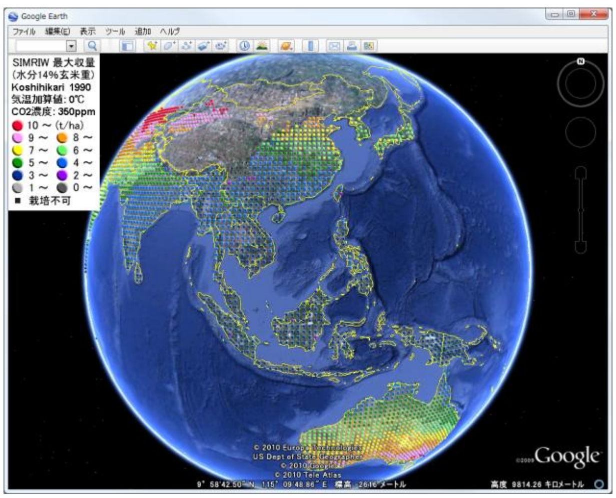

Figure 9. Window of cultivation possibility of a specified cultivar (Google Earth version)

Figure 10. Display of cultivation possibility of a specified cultivar (Tangible Earth version)

3) Tangible Earth

The tangible earth [6] is a digital world globe that can recreate the dynamism of the earth. The earth and overlay data are projected from the inside of the globe, and there is an interface on which the displayed data is rotated, and it can be expanded by touching it with the hand. The unique data image for the tangible earth is made from the KML file for Google Earth by the production company (Fig. 10). The tangible earth version of the cultivation possibility prediction tool was exhibited at various events.

III. RESULTS

The model was executed under conditions including eight kinds of cultivars, three air temperature addition values, two CO_2 concentrations, and transplanting dates that included all 365 days of the year. To satisfy these conditions, the model was executed 17,520 times per station. The time required to execute this calculation for 15,000 stations was seven days using the Core i7-860 PC. The data calculated beforehand were used in the display, because it takes a long time to generate the cultivation possibility data for locations all over the world.

When the model is executed with several parameter sets for all years for which meteorological data exist (GD-DR&TR has data for forty years from 1961 to 2000), considerable time is required, even if the data are calculated before being displayed. We calculated for only five years within forty years, because it will take three months to calculate for forty years in this condition. Moreover, when the calculating formula of the model is corrected, it is necessary to do all the calculations over again. However, when the target area is narrowed at tens of stations, the user can execute the model on demand.

The cultivation possibility data are displayed as shown in Fig. 7, Fig. 8, Fig. 9, and Fig. 10. The user interface is excellent and sophisticated in operability, and the visibility is comparable with the existing user interface shown in Fig. 1 and Fig. 2.

This tool can be applied to other crop models by replacing the calculation part of the model. The rice cultivation possibility prediction tool using SIMRIW can be accessed at http://dias.tkl.iis.u-tokyo.ac.jp/simriw/en/.

IV. FUTURE WORKS

We will increase the number of parameter set for rice cultivars in SIMRIW and apply this tool to other crop models in the future. Moreover, we are examining whether 0.1-degree grid data can be used by MetBroker, because a 1-degree grid is too rough for judging the cultivation possibility when using this tool in Japan.

ACKNOWLEDGMENTS

This study was financially supported by the special coordination funds for promoting science and technology, specifically under the category “Development of the earth observation data integration and the information uniting base technology,” from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.

REFERENCES

[1] AMeDAS (2002) http://www.jma.go.jp/en/amedas/

[2] Bouman, B.A.M., M.J. Kropff, T.P. Tuong, M.C.S. Wopereis, H.F.M. ten Berge, and H.H. van Laar (2001) ORYZA2000: modeling lowland rice. International Rice Research Institute, Wageningen University and Research Centre, Los Baños, Wageningen, 235pp., ISBN971-22-0171-6, with CD-ROM.

[3] Confalonieri, R. and S. Bocchi (2005) Evaluation of CropSyst for simulating the yield of flooded rice in northern Italy. European Journal of Agronomy 23(4):315-326, doi:10.1016/j.eja.2004.12.002.

[4] de Wit, C.T., R. Brouwer, and F.W.T. Penning de Vries (1970) The simulation of photosynthetic systems. Proceedings of the International Biological Program / Plant Production Technical Meeting, Trebon, 47-70.

[5] DIAS (2006) http://www.editoria.u-tokyo.ac.jp/dias/english/

[6] GK TECH (2001) Tangible Earth, http://www.tangible-earth.com/

[7] Horie, T., H. Nakagawa (1990) Modelling and Prediction of Developmental Process in Rice : I. Structure and method of parameter estimation of a model for simulating developmental process toward heading, Japanese Journal of Crop Science 59(4):687-695 (in Japanese).

[8] Horie, T., H. Nakagawa, H.G.S. Centeno, and M.J. Kropff (1995) The Rice Crop Simulation Model SIMRIW and Its Testing in Modeling the Impact of Climate Change on Rice Production in Asia, R.B. Matthews, M.J. Kropff, D. Bachelet, and H.H. van Laar, Eds. CAB International, Wallingford, UK, ch.5, 51-66, ISBN0-85198-959-4.

[9] Horie, T., N. Inoue, M. Ohnishi, H. Nakagawa, T. Matsui (1995) Development of Dynamic Model for Predicting Growth and Yield of Rice. Report of Grants-in-Aid for Scientific Research, Research Project Number:03404007, with FORTRAN source code of SIMRIW.

[10] IRRI (2004) ORYZA2000, http://www.knowledgebank.irri.org/oryza2000/

[11] Jones, J.W., G. Hoogenboom, C.H. Porter, K.J. Boote, W.D. Batchelor, L.A. Hunt, P.W. Wilkens, U. Singh, A.J. Gijsman, and J.T. Ritchie (2003) The DSSAT cropping system model. European Journal of Agronomy 18(3-4):235-265, doi:10.1016/S1161-0301(02)00107-7.

[12] Laurenson, M.R. (2001) MetBroker Programmers Guide. http://www.agmodel.net/ProgrammersGuide.pdf

[13] Laurenson, M.R., A. Otsuka, and S. Ninomiya (2002) Developing Agricultural Models Using MetBroker Mediation Software. Journal of Agricultural Meteorology 58(1):1-9.

[14] Masaki, Y., T. Kuwagata, and Y. Ishigooka (2009) Precise estimation of hourly global solar radiation for micrometeorological analysis by using data classification and hourly sunshine. Theoretical and Applied Climatology 100(3-4):283-297, doi:10.1007/s00704-009-0191-0.

[15] MetBroker (2000) http://www.agmodel.org/projects/metbroker.html

[16] Nakagawa, H., T. Horie (1995) Modelling and Prediction of Developmental Process in Rice : II. A model for simulating panicle development based on daily photoperiod and temperature, Japanese Journal of Crop Science 94(1):33-42 (in Japanese).

[17] NOAA (2004) http://www.weather.gov/

[18] Ritchie, J.T., E.C. Alocilja, U. Singh, and G. Uehara (1987) IBSNAT and the CERES-Rice model in Weather and Rice. IRRI, Los Baños, Philippines, 271-281, ISBN971-104-178-2.

[19] SIMRIW for Cultivation Possibility of Rice (2009) http://dias.tkl.iis.u-tokyo.ac.jp/simriw/en/

[20] SIMRIW (Java Servlet) (2008) http://pc105.narc.affrc.go.jp/simriw/

[21] Stöckle, C.O., M. Donatelli, and R. Nelson (2003) CropSyst, a cropping systems simulation model. European Journal of Agronomy 18(3-4):289-307, doi:10.1016/S1161-0301(02)00109-0.

[22] Tanaka, K. (1997) http://cse.naro.affrc.go.jp/ketanaka/model/

[23] Tanaka, K. (2006) A Java Framework for Developing a Plant Growth and Disease Prediction Model, Agricultural Information Research 15(2):183-194, doi:10.3173/air.15.183 (in Japanese).

[24] Uehara, G. and G.Y. Tsuji (1993) The IBSNAT Project in Systems Approaches for Agricultural Development, F.W.T. Penning de Vries, P. Teng, and K. Metselaar, Eds. Kluwer Academic Publishers, Dordrecht, the Netherlands, 505-513, ISBN0-7923-1880-3.