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PRACTICE PAPER

Design and Implementation of a Training Course on Big Data Use in Water Management

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Big Data has great potential to be applied to research in the field of geosciences. Motivated by the opportunity provided by the Data Integration and Analysis System (DIAS) of Japan, we organized an intensive two-week course that aims to educate participants on Big Data and its exploitation to solve water management problems. When developing and implementing the Program, we identified two main challenges: (1) assuring that the training has a lasting effect and (2) developing an interdisciplinary curriculum suitable for participants of diverse professional backgrounds. To address these challenges, we introduced several distinctive features. The Program was based on experiential learning – the participants were required to solve real problems and worked in international and multidisciplinary teams. The lectures were strictly relevant to the case-study problems. Significant time was devoted to hands-on exercises, and participants received immediate feedback on individual assignments to ensure skills development. Our evaluation of the two occasions of the Program in 2015 and 2016 indicates significant positive outcomes. The successful completion of the individual assignments confirmed that the participants gained key skills related to the usage of DIAS and other tools. The final solutions to the case-study problems showed that the participants were able to integrate and apply the obtained knowledge, indicating that the Program's format and curriculum were effective. We found that participants used DIAS in subsequent studies and work, thus suggesting that the Program had long-lasting effects. Our experience indicates that despite time constraints, short courses can effectively encourage researchers and practitioners to explore opportunities provided by Big Data.

Keywords: Big data and e-infrastructure; DIAS; water management; interdisciplinary education; mixed method; international summer program

1. Introduction

Advances in computational technologies have enabled the unprecedented exploitation of Big Data in multiple domains, including geosciences and global environmental change. The characteristics of Big Data along with specific demands for its acquisition, management, processing, and analysis require innovative e-infrastructure and new methodologies (Fan and Bifet, 2012; Chen et al., 2014; Sharma et al., 2014; Belmont Forum, 2015). Recently developed web-based tools for processing Big Data related to Earth and the environment (Vitolo et al., 2015) are able to address the most significant interdisciplinary and transdisciplinary challenges in contemporary research. While these existing tools are critical for successful work with Big Data, it is also essential to expand human capacity to effectively use these tools (Fergusson, 2013; Belmont Forum, 2015; Aitsi-Selmi et al., 2016). From the viewpoint of data science, Fergusson (2013) made recommendations for academic institutions to develop curricula focused on distributed computational skills and the practical use of e-infrastructure for students in different disciplines. At the same time, from the viewpoint of geosciences, Merwade and Ruddell (2012) discussed challenges to the wider adoption of data and modeling resources in geoscience education and proposed a set of recommendations for including data science and e-infrastructure components into a hydrology education curriculum.

Academic institutions have begun to offer courses that combine computing, information technology, Big Data, and domain research. However, training programs on Big Data exploitation are also demanded by non-students (e.g., researchers, lecturers, practitioners, and decision-makers) along with students who do not have the opportunity to enroll in a regular course that features Big Data. Therefore, it is important to provide different training options. One possible option is shorter but intensive programs organized during vacation periods that are affordable in terms of time and expense and available to a broader community. The advantages of such short-term courses have been documented (Donnelly-Smith, 2009). Several short programs dedicated to the use of Big Data in science were initiated by the Committee on Data for Science and Technology (CODATA) of the International Council for Science in cooperation with academic and non-academic institutions (CODATA, 2016). These programs focused on modern research data skills essential to all disciplines (e.g., research data management, use of multiple data platforms, and techniques for large-scale analysis, statistics, visualization, and modeling). At the same time, each discipline has its own standards for handling data; thus, more specialized training programs on using Big Data to solve problems in particular arenas are of great importance.

In this paper, we describe our experiences with the development and implementation of a two-week international summer program focused on the use of Big Data and e-infrastructure for addressing water management issues. The program entitled *International Summer Program on Sustainable Water Management in an Era of Big Data* was organized jointly by the University of Tokyo (UTokyo) and the International Center for Water Hazard and Risk Management (ICHARM) under the auspices of UNESCO, Public Works Research Institute, Tsukuba, Japan. The limited duration of such short interdisciplinary programs poses certain challenges when preparing the course structure and curriculum. The main challenges that we identified include: (1) ensuring that the training has a long-lasting effect (i.e., the participants will be able to utilize the gained skills and knowledge in their future study and work) and (2) developing a proper curriculum that covers all key subjects, supports interdisciplinary synthesis, and at the same time is comprehensible to participants with diverse backgrounds. To address these challenges, we have adopted certain measures and designed the Program with specific features that are explained in following sections. One of the aims of this paper is to discuss the effects of our approaches to addressing the said challenges. In addition, although a great number of summer programs are offered by universities (e.g., "Shortcoursesportal", 2017), many in the field of water resources and a few including Big Data, evaluations of their efficacy and guidance for their organization remain rare. Through this paper we also aim to share our experience in organizing a short summer program to provide useful guidance for planning similar endeavors. The paper is based on two occurrences of the Program in 2015 and 2016, which were attended by 50 participants from 21 countries. In Section 2, we introduce the motivation and aims of the Program. Section 3 explains the Program's format and academic design with regards to the aforementioned challenges. Section 4 describes the Program's outcomes based on participant evaluations and Section 5 outlines benefits and lessons learned.

2. Outline of DIAS and motivation and aims of the program

2.1 Outline of DIAS

The Data Integration and Analysis System (DIAS) was launched in Japan in 2006 with the goals of collecting and storing Earth observation data; analyzing these data in combination with socio-economic data; and applying the results to guide decision- and policy-making (DIAS, 2017; Kawasaki et al., 2017). Since its planning phase, the DIAS was intended to be an advanced e-infrastructure system capable of efficiently handling Big Data. Its prototyping phase, completed in 2010, established a unique platform to provide scientific information based on integrated Earth observation data and model outputs. Starting in 2011, the second phase of the DIAS further applied the DIAS as a tool for social and public infrastructure, significantly expanded its research and development community, and promoted interdisciplinary and transdisciplinary approaches. Currently, the third phase aims to exploit Big Data in various domains with the intention of serving a wider range of users, including researchers, practitioners, decision-makers, and policy-makers. Furthermore, DIAS usage is expected to expand into the industrial sector.

The CMIP5 Data Analysis System (Kawasaki et al., 2017) is a publicly available tool that comprises a set of dedicated functions that allow users to access, browse, visualize, analyze, subset, and download data from the fifth phase of the Coupled Model Intercomparison Project (CMIP5), which is a standard experimental protocol for studying the output of coupled atmosphere–ocean general circulation models (coupled GCMs) (Meehl et al., 2000). The third and fifth phases of CMIP (CMIP3 and CMIP5, respectively) (Meehl et al., 2007;

Taylor et al., 2012) delivered comprehensive and coordinated data sets including future climate projections, which were used to prepare the fourth and fifth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC, 2007; IPCC, 2013). Koike et al. (2015) described the methodology for using CMIP3 and CMIP5 data to assess the impact of climate change on hydrological regimes and water budgets in river basins; this is an important step in developing sustainable water-management solutions. Pilot studies (Koike et al., 2015) and broader national studies on planning future water resources (Jaranilla-Sanchez et al., 2013; JICA Final Report, 2013) were carried out using the proposed methodology, thus demonstrating the efficiency of the DIAS CMIP tools in exploiting large CMIP data sets.

2.2 Motivation

After the completion of the aforementioned pilot studies, we considered activities for promoting the use of the DIAS and other relevant tools for addressing water-related issues under the impact of changing climate. This resulted in multiple demonstrations of DIAS functions during lecture-type sessions. These demonstrations helped increase awareness of the DIAS and its potential but did not enhance its actual usage to a greater extent. We also organized several two- and three-day training courses on the use of the CMIP3 data to assess the effects of climate change on water resources. These training modules consisted primarily of hands-on sessions in which participants worked with the CMIP3 tool and obtained relevant data from the GCM output for past and future climate. However, due to time constraints, the exercises were limited to the use of the tool; participants did not apply the obtained data in further analyses or integrate the obtained data with other data and information.

2.3 Aims of the program

Based on the aforementioned experience, we proposed an international summer program in the format of an intensive two-week course. The primary aims of the short course were to (1) train participants in the effective use of Big Data (particularly CMIP5 data) and relevant e-infrastructure (the DIAS) to solve problems in water-resource management and (2) ensure that participants gain knowledge and practical skills to successfully use the introduced tools in their future research and/or work. The desired outcomes for the participants are described as follows. The participants should know what Big Data is and be aware that working with Big Data is inevitable for sustainable water management. They should be able to acquire and analyze data from various sources and synthesize them into factual evidence relevant for solving problems. They should understand the interdisciplinary nature of water resources and be able to approach problems from various viewpoints. In addition, they should be aware of the transdisciplinary dimension of water-resource management and be able to incorporate societal and policy aspects when solving problems. During the short course, participants should learn to work in international, multidisciplinary teams and confront, explain, and discuss their views with collaborators. The participants should enjoy their training, feel that it was worthy of their investments of time and money, and have good memories of Japan and the organizing institutions.

3. Challenges, academic design, and content of the program

3.1 Challenges and academic design

In consideration of the aims mentioned above, we identified two main challenges associated with the short duration of the course: (1) ensuring that the training has a long-lasting effect (i.e., the participants will be able to utilize the gained skills and knowledge in their future study and work) and (2) developing a proper curriculum that covers all key subjects, supports interdisciplinary synthesis, and is comprehensible to participants with diverse backgrounds. Our approaches to addressing these challenges are described as follows.

Regarding the first challenge, it is important that the participants are able to put the knowledge gained in context, connect it to their focus area, and feel confident in applying it. Abundant evidence in the literature suggests that experiential learning (learning that supports students in applying their knowledge and conceptual understanding to real-world problems or situations in which the instructor directs and facilitates the learning) is beneficial in this regard (Wurdinger and Carlson, 2010; Thiry et al., 2011). Therefore, we built the Program around real problems that the participants were charged with solving using knowledge and skills acquired through the program. The participants were required to obtain necessary data, propose a solution, and defend that solution. To solve the given problems the mixed method approach was adopted that combines a quantitative analysis and a synthesis of qualitative data with the quantitative analysis results.

Thus, participants processed, analyzed, and integrated data to support problem solutions during individual hands-on sessions. Each participant was required to submit a report that summarized his or her results and interpretation of the data in the context of the given problem; the participant was then provided with written feedback within a few hours. These individual reports ensured that the participants were able to apply the introduced tools and process the required data. After obtaining the data, and analyzing and interpreting it into relevant evidence, the participants worked in teams to synthesize the evidence with information from lectures and propose a solution. The teams were assembled to include participants of different nationalities, backgrounds, and career levels. Thus, the participants had to communicate and work with people from different disciplines, sectors, and positions along with different ages, life experiences, and views. Such teamwork imitated the real-world problem-solving process and hence enhanced the benefits of experiential learning. In addition, peer interactions and teamwork is instrumental in developing interpersonal competence and cognitive complexity (Kuh, 1995). The diverse team compositions also helped the participants to address the interdisciplinary nature of the problems.

It was important to maintain balance between the individual and the team work in order to provide adequate opportunities for the participants to attain the targeted skills and knowledge. From the personal experiences, we were aware that it is important that students work individually when learning to use a new tool or methodology to assure they personally proceed with all the steps and fully understand them. When working in groups or even in pairs, there is a high probability that some students will – more or less – only observe rather than to carry out each task by themselves and therefore their acquired skills may not be fully sufficient for independent usage of the tool/method in future. Since the participants' ability to meaningfully use the DIAS tools in their future work was one of the primary aims of the Program, the relevant hands-on exercises and ensuing assignment were designed as individual work. On the other hand, the synthesis part of the problem solving benefits from multiple views and in the real world – as mentioned above – involves multiple experts from various disciplines. Therefore the synthesis of the obtained data and information and the solution presentations were carried out in teams. The breakdown between the individual and team work also corresponds to the respective scopes of the quantitative analysis (individual work) and the qualitative synthesis (team work).

To address the challenge of a suitable curriculum, we tried to optimize the combination of expert lectures and hands-on exercises by identifying the topic areas essential for solving the given problems and limiting the expert lectures to these essential subjects. The lectures were designed to provide required knowledge on the subject and to also put this knowledge in the context of the given problems. We invited leading experts in their fields who had experience in interdisciplinary teaching to deliver the lectures. We also allocated sufficient time for debate at the end of each lecture; thus, the participants had the opportunity to obtain additional clarification if necessary. In 2015, when we organized the Program for the first time, we allocated more time to the expert lectures than to the hands-on exercises (37% vs. 21% of the total time, **Table 1**) with the intention to provide the participants with a sufficient scope of knowledge for addressing the interdisciplinarity of the given problems. However, we learned from the participants that the scope of lectures felt too extensive and parts of the provided information were not much relevant to the solving of the given problems. At the same time, the participants voiced that more time dedicated to hands-on exercises would be welcome to ensure adequate practice of the trained skills. Considering these suggestions, we revised the curriculum and reduced the number of the expert lectures, while allocating more time to the hands-on exercises. In 2016, the expert lectures accounted for 25% of the total time (**Table 1**) and approximately one-third of the total time was devoted to hands-on sessions, which allowed for sufficient explanation of the methodologies and training on the usage of DIAS and other tools. The analysis of the participant surveys from 2015 and 2016, which is provided in Section 4, confirmed that this curriculum revision was appropriate.

Table 1: Breakdown of the Program's time by session type in 2016 and 2015 (in parentheses).

Session type	Proportion of allocated time (%)
Experts' lectures	25 (37)
Hands-on exercises (individual work)	33 (21)
Excursions	15 (15)
Teamwork: discussion and problem solving	12 (12)
Teamwork: presentation of proposed solutions	5 (5)
Social events	10 (10)

Table 2: The Program's schedule in 2016.

Day	Location	Activity
Day 1 Mon	UTokyo, Tokyo	Program Introduction Lecture: Integrated Water Resources Management Lecture: Case Problem Setting Group work: First Group Discussion and Presentation
Day 2 Tue	UTokyo, Tokyo	Lecture: Global Water Circulation Lecture: Current Issues on Water Lecture: Big Data and New World Lecture: DIAS Introduction and Demonstration
Day 3 Wed	UTokyo, Tokyo	Lecture and Exercise: DIAS CMIP5 Tool and its Use (Climate Model Output Selection), Individual Assignment Lecture and Exercise: DIAS CMIP5 Tool and its Use (Climate Model Output Bias Correction), Individual Assignment
Day 4 Thu	Shimokubo Dam, Gunma	Excursion to the site of the dam: lecture and structure visit BBQ and a short walk along the river
Day 5 Fri	UTokyo, Tokyo	Lecture: Introduction to GIS: ArcGIS software Exercise: ArcGIS software
Day 6 Sat	UTokyo, Tokyo	Optional program: Additional hands-on: GIS and the DIAS CMIP5, consulting with lecturers
Day 7 Sun	Tsukuba	Optional program: Climbing Mt. Tsukuba, Ibaraki Prefecture
Day 8 Mon	Tsukuba Kasukabe Saitama	Lecture: JAXA's GSMaP precipitation product Excursion: JAXA Space Center Exhibition Hall Excursion: Metropolitan Area Outer Underground Discharge Channel
Day 9 Tue	ICHARM, Tsukuba	Lecture: Introduction to ICHARM Lecture: Social Science Approach to Water-related Disasters Lecture: Hydrological Modeling and Integrated Flood Analysis System (IFAS)
Day 10 Wed	ICHARM, Tsukuba	Lecture: Water Disaster Management Lecture: Economic Evaluation of Natural Disaster and Mitigation Policy Exercise: IFAS
Day 11 Thu	ICHARM, Tsukuba	Exercise and Teamwork: IFAS Teamwork: Work on the Case Problems, Presentation Preparation
Day 12 Fri	ICHARM, Tsukuba	Teamwork: Work on the Case Problems, Presentation Preparation Final Presentation; Certificate Ceremony and Closing; Reception

The Program was also enriched by two excursions to successful realization of water-management structures in Japan, namely a multipurpose reservoir and an underground flood protection tunnel. During the excursions, facility managers gave presentations, and plenty of time was allotted for questions and answers. The presentations introduced the technical and operational details along with information on historic economic aspects and the planning process, including negotiations with local communities (or lack thereof). These experiences helped the participants without hydrology and water-resource backgrounds to connect the information from lectures to reality, thus improving their understanding of water management issues.

The teamwork sessions occupied approximately 17% of the Program. Successful team collaboration depends on trust and connectivity among individuals (Renzl, 2008); however, building such connectivity within a multidisciplinary team is challenging because of communication difficulties and differences in world views and priorities among people from different disciplines (Mills, 2011). Blöschl et al. (2012) recognized the benefits of informal social gatherings for developing relationships, connectivity, and trust. Our Program dedicated approximately 10% of the time to social events, including a welcome party, a barbecue event during one of the excursions, and an optional one-day hiking trip. The approximate breakdown of the Program's time according to session type is shown in **Table 1**. For illustration, the Program's schedule in 2016 is provided in **Table 2**.

3.2 The Program's content

As mentioned earlier, the central component of the Program was case-study problems that focused on issues in water resources and water-related disasters under the changing climate, particularly (i) water and food security, (ii) poverty alleviation through flood-disaster risk reduction, and (iii) integrated water resources management considering community life and the environment. Real problems in two Asian river basins (the Pampanga River basin in the Philippines and the Bago River basin in Myanmar) that are components of recent or current larger-scale projects were selected. The Pampanga River basin problem in the Program was inspired by the "The Study of Water Security Master Plan for Metro Manila and its Adjoining Areas," particularly the part that focused on climate change impact assessment and hydrological simulations, which were undertaken as part of a project of the Japan International Cooperation Agency (JICA, 2013). In our Program, the Pampanga problem focused on developing water resources to assure a stable water supply for Metro Manila in the future in consideration of climate change impacts. The Bago River basin problem was based on the current science and technology project of the Official Development Assistance (ODA) in Japan (SATREPS, 2017), which aims to reduce poverty and flood risk in the basin in consideration of climate change (Htut et al., 2014; Win et al., 2015).

On the first day of the Program, the participants were provided with a brief introduction of the case-study basins, and the target problems were stated. The first teamwork session was then scheduled, and the participants were asked to propose an initial solution for a problem based on their existing knowledge and limited information provided during the introduction to the problem. This allowed the final proposed solutions based on the knowledge and skills acquired through the Program to be compared with the initial solutions. **Figure 1** shows the framework used to guide participants' work on the given problems. The major tasks included (i) acquiring evidence, (ii) synthesizing the evidence with

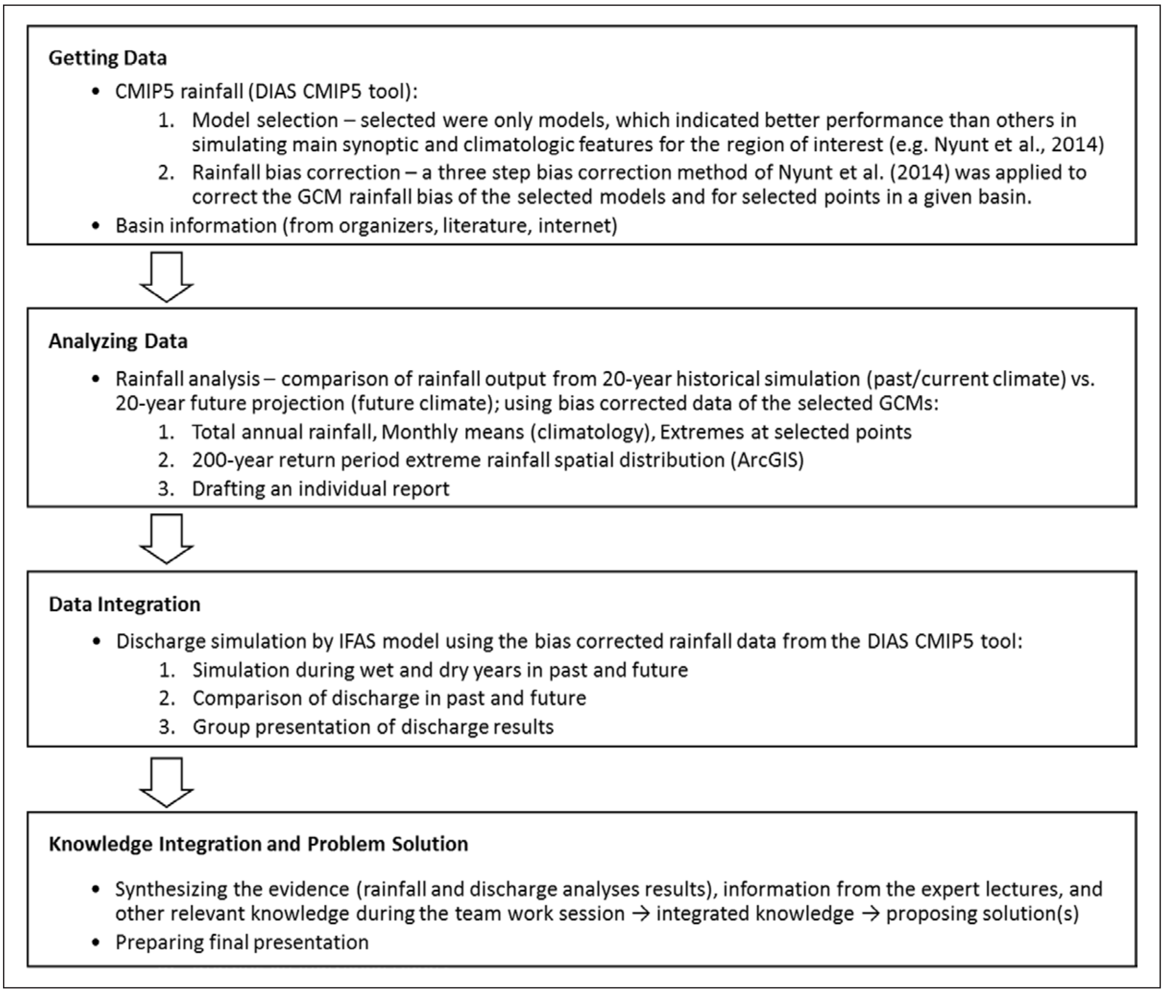

Figure 1: Framework of the workflow used to solve case-study problems.

information provided through the experts' lectures and background knowledge, (iii) proposing a solution to the given problem based on the gathered and synthesized evidence, and (iv) presenting and defending the proposed solution.

The experts' lectures covered hydrology and climatology, data and information technology science, the DIAS, water resources management, disaster management, and the economic evaluation of disasters. The Big Data and DIAS lectures took place at the Institute of Industrial Science of UTokyo, where the core hardware system of the DIAS is located. The participants were given a demonstration of the DIAS and visited the server room to assuring that they went away with an accurate understanding of the system and its complexity. The participants were able to see the large server room in person and meet members of the DIAS team; this experience imparted a better understanding of the DIAS compared to experiencing it only through the online use of its services.

The evidence for the problem's solution was acquired through individual work during the hands-on sessions. These sessions focused on the appropriate use of various observational data, model outputs, and data integration functions available on the DIAS along with geospatial technologies such as GIS. The exercises introduced:

i. The DIAS CMIP5 tool, with a focus on model output selection, bias correction, and the downloading of precipitation data from past simulations and future projections for assessing the impact of climate change on water resources in the given river basins.
ii. The ArcGIS software, particularly the functions for spatial interpolation and map preparation that targets the spatial analysis of precipitation in the given basins.
iii. The Integrated Flood Analysis System (IFAS) developed at ICHARM to simulate river flows using precipitation data obtained from the CMIP5 tool. The IFAS streamflow outputs and the corrected precipitation were then used as a basis to propose solutions to the given problems.

Special attention was paid to developing a proper understanding and interpretation of the data along with the ability to draw proper conclusions from the results. To ensure that participants truly mastered the use of the tools and understood the data they were working with, each participant was asked to draft a report summarizing their work and results and submit it no later than one day before the end of the Program. Each report contained the following components (the key skills demonstrated by the different components are provided in parentheses):

i. A brief introduction to a basin and its climatology (finding relevant information through Internet search);
ii. A description of using the CMIP5 tool to obtain suitable GCM outputs for further analysis (understanding of GCM output and the appropriate use of the CMIP5 tool);
iii. An analysis of rainfall data to identify future changes in total annual rainfall, climatology, and extremes (understanding the rainfall data and its analysis and interpreting changes in rainfall patterns for water resources and water-related disasters);
iv. A spatial distribution analysis of extreme rainfall (ability to practically use GIS software, particularly functions for spatial interpolation and map creation, and understand the possibilities and limitations of spatial interpolation related to rainfall); and
v. A brief conclusion that summarizes the findings into implications for future water resources management in the given basin (ability to interpret the results and synthesize the obtained information, including material from the lectures).

These individual reports were reviewed, and feedback in the form of corrections and comments was returned to participants prior to their final presentation preparation session. In case of IFAS training, the participants worked in teams and were asked to run the model for several wet and dry years in the past and future using at least two model outputs; they then analyzed the resulting hydrographs at the basin outlets. The teams presented the results and their interpretations of the results at the end of the IFAS training session (before preparing the final presentations) and received feedback from the lecturer.

The excursions provided a welcome diversion from the intensive study program while also giving participants additional information on water resources management solutions. The operations staff of the visited facilities introduced the technical and operational details along with information on historic economic aspects and the planning process, including negotiations with local communities (or lack thereof).

The participants were able to utilize the knowledge gathered during the excursions in their proposed solutions.

After the complete set of lectures and exercises, the participants completed three sessions of teamwork to synthesize the gathered evidence with information from the lectures and excursions along with their own preexisting knowledge. We provided the participants with some instructions on how to conceive their proposals and prepare presentations. These instructions were rather general and left ample space for the participants to incorporate their own ideas. We requested that the final proposals contained the following components:

- Statement of the main problem to be solved;
- Hydrological assessment that considers climate change impacts (to the extent of the content of the course);
- Possible water resources management solutions;
- Economic aspects (investment vs. reducing loss, improving economy); and
- Consensus building among stakeholders, including local citizens.

Obviously, the two-week course was not long enough to produce in-depth and fully comprehensive analyses and solutions. Rather, we asked the participants to elaborate their proposals within the extent of the Program's contents and to incorporate their own views and knowledge based on their backgrounds. The formats of the final presentations were not limited to the usual oral presentation of slides; instead, the participants were encouraged to be creative and consider different performance types (e.g., one team performed a skit). The final presentations were evaluated by a committee that consisted of the Program lecturers based on five criteria: focus on the main goal, innovation, feasibility, presentation, and capability to answer questions. To make the session more attractive and imitate the real process of evaluating water management plans from multiple perspectives, the committee members were asked to play the roles of high-level representatives of various ministries, United Nations organizations, and ODA agencies and consider the presented proposals from the viewpoint of their organization. Thus, the participants faced a wide spectrum of questions and gained an understanding of the complexity of decisions related to water management. At the end of the Program, the participants received a Certificate of Completion, and awards were given for the two best team presentations and the best individual assignment.

Snapshots from different sessions of the Program are shown in **Figure 2** and **Figure 3** presents group photos from excursions. A short video was produced from both events in 2015 and 2016 (see ref.: Summer Program, 2015 and 2016, respectively). More information on the Summer Program, including a summary of reports, is available from the UTokyo Water Cycle Integrator Unit's website: http://wci.t.u-tokyo.ac.jp/summer/.

4. Program Evaluation and Outcomes

To date, the Program has been held twice, in 2015 and 2016, and was attended by 33 and 17 participants, respectively. The larger number of participants in 2015 was attributed to the lack of a participation fee and furnishing of accommodation by the organizers. By contrast, in 2016, the participants had to fully support themselves during their stays in Tokyo and Tsukuba and also had to pay a participation fee that covered the expenses associated with excursions and social events (no tuition fee applies to this Program). Moreover, because it was logistically challenging to manage the group of 33 people in 2015, we decided to limit the number of participants to 25 in 2016 and in the future. In both years, we received slightly over 100 applications. The participants were selected primarily based on their motivations and interests detailed in their applications. In 2015, all the selected applicants attended the Program. In 2016, of the accepted 25 applicants, eight could not come because of scheduling conflicts or financial limitations. The participants included undergraduate and graduate students, postdoctoral scientists, researchers, practitioners, and government officials.

Based on our observations, the participants worked enthusiastically, showed great interest in learning about the application of Big Data to water management, were active during the discussion parts of the lectures, and keenly collaborated during the teamwork sessions. The participants' answers to the Program's questionnaire, which is discussed below, suggest that they truly enjoyed the Program. The outputs produced by the participants (i.e., the individual assignments, IFAS presentations, and initial and final presentations) indicate that the Program's aims delineated in Section 2.2 were achieved. The participants demonstrated a true understanding of the role of Big Data and the need for interdisciplinary approaches in water resources problems. They demonstrated their capability to use the introduced tools (i.e., DIAS CMIP5, ArcGIS, and IFAS) to process, analyze, and integrate relevant data and produce the required evidence. Some of the individual assignments on climate change impacts assessment were very high in quality; these assignments

Figure 2: Photos from the Program: **(a)** 2015: a lecture session; **(b)** 2016: the initial teamwork session; **(c)** 2016: the excursion to the Shimokubo dam; **(d)** 2015: the IFAS training session; **(e)** 2016: the final presentation; **(f)** 2016: the final presentation preparation; **(g)** 2016: the hiking trip to Mt. Tsukuba; **(h)** 2016: the final group photo with Certificates.

were drafted with the intention to do an excellent job (not simply to meet the minimum requirements). The final presentations demonstrated that the participants properly interpreted the evidence for possible changes in hydrological regimes based on the CMIP5 data.

Figure 3: Group photos of the Program participants in 2015 – the Metropolitan Area Underground Channel excursion (above) and in 2016 – the Shimokubo dam (below).

The participants were also able to synthesize the information from lectures and their own study/work to come up with sound solutions to the given problems. The teams approached the given problems in an interdisciplinary fashion with clear input from various participants' fields. In 2015, one participant was a medical student, and their team addressed the issue of water quality in considerable detail. In 2016, one team proposed an advanced technology for flood debris combustion to generate energy and thus profit, which would contribute to poverty reduction. This idea came from a Master's student who studied waste management. All the proposals also contained ideas for raising awareness among local communities and plans for building a consensus around the implementation of the proposed solution; this indicates that the participants understood the transdisciplinary nature of water management problems.

We also surveyed the participants for their opinions regarding the Program. We prepared a questionnaire with 20 questions focused on the Program's content and structure, the logistical support, and the lecturers' performance. The combined results of the surveys from 2015 and 2016 are presented in **Table 3** and discussed as follows. In total, 48 participants submitted responses, 31 in 2015 and 17 in 2016. Here, we present only the results of the questions relevant to the content and structure of the Program, which is the focus of this paper; responses to questions related to logistics and lecturer performance are not included. The questions focused on the primary Program's content: Big Data and the tools to work with Big Data,

Table 3: Responses to the Summer Program's evaluation surveys given by the participants of the two events in 2015 and 2016. The first row of numbers shows totals for both events; the second-row and third-row numbers are the results from 2016 and 2015, respectively. *Question 11 was included only in 2016, when a participation fee was charged.

Question	Strongly agree (%) Total 2016 2015	Agree (%) Total 2016 2015	Neutral (%) Total 2016 2015	Disagree (%) Total 2016 2015	Strongly disagree (%) Total 2016 2015	No. (%) responding (Total only)
1. The Program content was academically challenging.	38	56	4	2	0	48 (100%)
	47	47	6	0	0	
	32	62	3	3	0	
2. The Program provided a valuable addition to my university education or research/professional focus.	47	49	4	0	0	47 (98%)
	53	47	0	0	0	
	43	50	7	0	0	
3. I have gained useful knowledge for my future study/work.	61	35	4	0	0	48 (100%)
	65	29	6	0	0	
	58	39	3	0	0	
4. The set of provided lectures was appropriately combined and provided good basis for acquiring the targeted skills and completing the given assignments.	31	63	6	0	0	48 (100%)
	35	65	0	0	0	
	29	61	10	0	0	
5. I have improved my understanding of water-resource management problematics and their relevance and linkages to other disciplines.	54	44	2	0	0	48 (100%)
	65	35	0	0	0	
	48	49	3	0	0	
6. The interdisciplinary approach was clearly visible and well incorporated into the case problems.	23	64	13	0	0	47 (98%)
	19	75	6	0	0	
	26	58	16	0	0	
7. I have gained a better notion of Big Data and their value and usage for water-resource management.	55	41	4	0	0	47 (98%)
	63	31	6	0	0	
	52	45	3	0	0	
8. The case problems were designed well to exercise problem-solving skills – I feel I improved this capability.	23	66	11	0	0	47 (98%)
	31	63	6	0	0	
	19	68	13	0	0	
9. The international format provided an opportunity to gain a cross-cultural experience.	50	48	0	2	0	46 (96%)
	56	44	0	0	0	
	47	50	0	3	0	
10. Diversity of participants in terms of profession provided a unique experience of working in interdisciplinary and multi-profession teams. I feel I improved my ability to incorporate new values and ideas into my own thought and decision-making process.	45	49	4	2	0	47 (98%)
	38	50	12	0	0	
	48	49	0	3	0	
11.* I feel my expectations from the course were met, and the course was worthy of my invested funds and time. I would recommend the course to my friends.	63	37	0	0	0	16 (33%)

General evaluation	Excellent (%)	Very Good (%)	Good (%)	Satisfactory (%)	Unsatisfactory (%)	No. (%) responding
12. Please evaluate the Program as a whole by a single grade.	53	41	6	0	0	47 (98%)
	82	18	0	0	0	
	37	53	10	0	0	

water resources management, problem-solving skills, and interdisciplinary approaches. The respondents chose from five possible answers (strongly agree, agree, neutral, disagree, and strongly disagree) and spaces were provided for optional comments after each question and for general comments. **Table 3** indicates that the feedback from participants was positive for all questionnaire items.

The first three questions related to the academic challenge, value, and usefulness of the gained knowledge; these questions were intended to determine if the course was meaningful and provided an appropriate level of academic challenge. Not surprisingly, the perception of the academic challenge of the course was related to the level of education and field of the participant. Even so, most participants considered the Program to be rather challenging and to be a valuable addition to their knowledge. In addition, 61% of the participants *strongly agreed* and 35% *agreed* that the knowledge and skills gained would be useful in their future endeavors. Moreover, in 2016, when participants had to pay a participation fee and fully support their stay at the course venue, a majority of participants (63%) *strongly agreed* that the Program met their expectations, was worth their investment of time and money, and was worth recommending to others (Question 11). These responses indicate that we succeeded in our goal of making the Program beneficial for the participants' careers and worthy of their investments. Some selected participant comments confirm this assessment:

> *"Attending this summer program doesn't only mean you get to learn something from the four-lecture-a-day class but also how to make the best use of every single knowledge in the final task. That's how I have enhanced myself throughout the entire process. I am utterly impressed with program overall: the various useful programs, in-class exercises, the individual assignment, field trips and group work and, most importantly, all admins/organizers from The University of Tokyo and ICHARM. Thanks to this program for giving me the worthwhile experience and wonderful friends ever."*
>
> *"This only-two-weeks program has been one of the most important learning programs in my education curriculum. As a GIS Analyst, I got tremendous new knowledge on climate change, GCMs, Big Data, Micro Geodata and skills like using the DIAS System, GIS, IFAS, and so on. The knowledge I acquired will be helpful to me for my Master's research, which is about flood-disaster management in Abidjan."*
>
> *"I would like to recommend this to my team members at work as their senior engineer in order for them to gain similar or more experience from this summer program."*
>
> *"Exceeded my expectations. Technically, though, very intense."*
>
> *"I spent all the money from my savings and I could say: 'It is so much worth it'."*

Questions 4–8 focused on the Program structure and curriculum. Approximately one-third of participants *strongly agreed*, and two thirds *agreed* that the set of experts' lectures was well devised to provide the knowledge needed to solve the case-study problems. Meanwhile, more than half of participants *strongly agreed* and most others *agreed* that they improved their understanding of water resources management problems and their relevance to other disciplines. Surprisingly, even graduate students and professionals in the fields of hydrology and water management felt that their knowledge in these areas further improved as a result of the Program. The aspect of Big Data seems to have been very well covered by the Program, and most participants acknowledged an improvement in their understanding of the role of Big Data in water management. The participants acknowledged the fact that the information conveyed in the lectures and exercises was immediately useful for solving the case-study problems and that the entire Program was convergent:

> *"We are encouraged to make a presentation that is really based on our data acquisition, and the Program is convergent at the end."*

The participants felt that the Program's arrangement of activities helped them build confidence in their capabilities to use the DIAS CMIP5 tool in future:

> *"I found DIAS CMIP5 to be a very sophisticated tool for climate change data sets; it provides an easy way to select the GCM, perform bias correction and handle data sets. I have done the same procedure during my Master's thesis without this kind of tool, and it took me so much time in every process from the selection of GCMs, bias correction and downscaling. I hope to carry out my research again using this tool and dynamical downscaling."*

"The DIAS-CMIP5 is an appropriate software for researchers who want to study climate change impacts on water resources, disaster management, and health. It is convenient and easy to use even for beginners like me who only know the basics of hydrology and climate change."

At the same time, the interdisciplinary nature of the Program and the incorporation of interdisciplinary approaches during the case-study problems were less visible to participants; the responses were *strongly agree* (23%), *agree* (64%), and *neutral* (13%). This may be attributed to the fact that the hands-on exercises, which accounted for one-third of the total Program's time, focused on the use of hydrological data, while the linkages to other disciplines (e.g., disasters, economy, and consensus building) was introduced mainly in the lectures (i.e., passively). Thus, we should consider improving the curriculum to enhance its interdisciplinary nature. Regarding the design of the case-study problems, 23% of the participants *strongly agreed,* 66% *agreed*, and 11% were *neutral* about the Program fulfilling the aim of improving problem-solving skills and strengthening the new knowledge and skills gained through the experts' lectures and practical sessions. This indicates that not all participants found the process of solving the case-study problems to be beneficial for improving their problem-solving skills. This may be attributed to the already high level of problem-solving skills of some participants, weak points in the Program design, or both. Including an introduction to problem-solving methodologies in water resources and the provision of specific instructions on this aspect at the beginning of the Program might reduce this deficiency.

Questions 9 and 10 focused on participant diversity. The responses indicated that the participants considered the diversity of the working teams to be beneficial, and some thought that the level of diversity should be increased:

"I enjoyed working with people from all over the world. Each participant had a different field of study, and it helped us to develop our understanding toward global water issues by sharing our knowledge."

"Very grateful for the experience with professionals and older students!"

Some participants indicated that the scope of the individual assignment was too demanding. However, we believe that ambitious individual assignments are necessary to help participants absorb the new knowledge and become familiar with the new tools. Some participants agreed with us in this regard, for example:

"It is good that we got this exercise which forced us to work on this during the workshop's time period so that we will solve our difficulties and apply the knowledge without any doubt to solve our problems in the future."

Most participants rated the overall Program as *excellent* (53%) and *very good* (41%), with the remaining 6% evaluating the Program as *good*.

Table 3 also shows that the evaluations were notably better (overall and for some specific questions) in 2016 than in 2015. This indicates that the revisions made to the Program's content and structure based on participants' feedback in 2015 were appropriate and helped to improve the Program. One of the most significant changes made in 2016 was the allocation of more time to hands-on sessions at the expense of lectures. This meant that we had to narrow the variety of the subjects taught to only those essential for solving the case-study problems. Simultaneously, we asked the lecturers to depict more clearly the connection of the subject topic to the case-study problems in their lectures and explain the role of Big Data in that particular topic area. Similarly, more emphasis was put on linking the contents of the hands-on exercises to the problem-solving task of the Program, i.e., all the outputs from the performed exercises on the usage of DIAS and other tools were necessary for proposing solutions to the case-study problems. In this manner, we ensured that all the components of the curriculum were highly relevant to the final goal – the case-study problem solution and thus improved the consistency of the whole Program. This overall consistency and convergence to the final goal helped the participants to stay focused and fully engaged in the work. Evaluation for Question 4 confirmed that the combination of lectures in the revised curriculum felt more appropriate. Question 5 and Question 7 inquired whether the participants improved their knowledge on water resources and Big Data, respectively. Better evaluation scores for these questions in 2016 than in 2015 indicate that the less extensive but more focused curriculum was more effective in terms of providing new knowledge and improving understanding to the subject topics. Question 8 regarded the improvement of the problem solving skills. The evaluation scores suggest that the 2016 curriculum was more suitable in this regard. One of the most instrumental features was ensuring high relevancy of the contents of the lectures and exercises to the case-study problems. In Question 9 we asked if the Program contributed to the participants' cross-cultural experiences and also for this question the evaluation was notably better in 2016 than 2015. We speculate that it may be due to the fact that the Program provided more opportunities for informal gatherings such as the optional hiking trip.

Regarding our aim for the Program to have long-lasting effects, some participants informed us in subsequent communication that they used the DIAS CMIP5 tool after the Program in their studies and research. One participant (a professional in the hydrology field) has conducted three studies on the impacts of climate change on rainfall in several areas in his country for planning purposes; these studies have been presented at conferences and published in conference proceedings. That same participant has delivered several seminars and lectures on DIAS and the use of the DIAS CMIP5 tool in climate change research. Motivated by the Program, one undergraduate student has decided to select hydrology and water resources management as her major for graduate studies. Another graduate student has expressed interest in studying for a semester at UTokyo under the supervision of Dr. Kawasaki as a part of the Student Exchange Program of his university. Several graduate students who had been dealing with climate change impacts before attending the Program found the DIAS CMIP5 tool to be useful in their work, and one participant, a lecturer, considered developing a similar program at his university. Although the participants may not follow up on all of these plans, the mostly positive feedback leads us to believe that the course is beneficial, and its structure and content are effective in helping participants apply DIAS and Big Data to water management issues.

5. Benefits and lessons learned

5.1 Benefits

The participants gained the skills to use the introduced Big Data tools at a level sufficient to use them individually in the future. They also learned how to practically apply the tools in specific problems related to water resources management. Some of the benefits of the Program are related to its interdisciplinary nature; the participants expanded their knowledge beyond their area of study/research/work and interacted with students and professionals from different disciplines and at different career stages. When working on the case-study problems, the participants exercised various skills to synthesize information, including aggregating data, analyzing patterns and trends, combining knowledge from various disciplines, and combining different measures to address water-management problems. The team sessions trained the participants in collaborative work skills, including communicating with colleagues, resolving conflicts to reach a consensus, and sharing the workload. They also practiced skills related to presenting and defending their work. Finally, the participants gained some cross-cultural experience by working in international teams.

The Program also had benefits for the DIAS team and organizing institutions, including an expansion of the DIAS system and the IFAS user community. The course also fostered interest in the application of Big Data to sustainable water management. Some participants also showed an interest in further collaboration with UTokyo and ICHARM.

5.2 Lessons learned

Based on the two occasions of the Program, we have learned some lessons that may be useful for others planning a similar short course. Some of the difficulties we identified in 2015 were addressed in the design of the 2016 Program, and the improved participant evaluations indicated that the changes were effective. The lessons learned from the 2015 and 2016 Programs are summarized as follows.

- An experiential learning approach based on solving case-study problems was effective at motivating participants and keeping them actively engaged in the work throughout the course. Having the participants use the new tools and data to solve real case-study problems was effective at demonstrating the potential of these tools/data.
- It is important to provide a balanced mixture of lectures and hands-on exercises; it is especially important to refrain from too many lectures. Considering the time constraints, the spectrum of subjects taught should be narrowed down to those that are essential for solving the case-study problems. The lectures should be prepared for a multidisciplinary audience and with consideration of the participants' different career stages.
- Although perceived as demanding, the individual assignments were instrumental in getting participants to combine and apply their new skills related to using tools, analyzing data, and interpreting data since everyone had to complete the assignments individually.

- Teamwork proved effective for synthesis part of problem solving (i.e., integrating hydrological data with other data, information from the lectures and participants' preexisting knowledge) and was appreciated and enjoyed by the participants. Participants felt that the diversity of the participants within teams was beneficial and contributed to interdisciplinary solutions to the problems.
- Asking the participants to propose initial solutions to the given problems at the beginning of the course provided a basis from which to evaluate improvement in the participants' skills. Requiring the participants to prepare presentations helped them to consolidate the acquired knowledge.
- Although it is critical to provide some instruction on how to solve case-study problems, it is also important to encourage participants to think creativity when developing solutions.
- Excursions to the DIAS and water management facilities helped the participants connect the contents of lectures and case problems to reality. The excursions were also a welcome break from the typical classroom setting and provided an excellent opportunity to foster the development of relationships and trust among participants. Informal gatherings, including the welcome reception and the hiking trip were also instrumental for the development of relationships.
- Obtaining feedback and assessing the Program are essential, and surveys of participant opinion have been instrumental in improving the Program.

6. Conclusion

The *International Summer Program on Sustainable Water Management in an Era of Big Data* is an example of how a short, intensive course on the exploitation of Big Data in a water-related domain can be designed and implemented. The development of this Program was motivated by a call to enhance the human capacity to exploit Big Data for global environmental change research combined with the existing opportunity provided by the DIAS. Based on the two programs conducted in 2015 and 2016, certain challenges resulted from the short duration of the Program. Specifically, we faced challenges related to ensuring long-lasting effects of the training and preparing an interdisciplinary curriculum for diverse groups of participants. This paper describes how these challenges were addressed in the Program design by incorporating the following:

- Experiential learning based on solving case-study problems;
- A curriculum of experts' lectures strictly linked to the case-study problems;
- Excursions to relevant facilities [i.e., the e-infrastructure (DIAS) core system and water resources management structures];
- Sufficient time for hands-on exercises;
- Individual assignments that require participants to work with Big Data tools as well as analyze and interpret data;
- Teamwork on the synthesis part of problem solving; and
- Opportunities for informal gatherings and communication.

The Program discussed herein is an intensive two-week course that is open to participants from Japan and abroad with a variety of backgrounds, including students, researchers, and professionals at different career stages. The Program is affordable for a wide range of people and provides effective training on the application of specific Big Data tools to real problems in water management. Our experience indicates that even during the limited timeframe of two weeks, participants acquired sound skills related to Big Data tools and their practical application. The participants used the new Big Data tools to solve specific problems, thereby ensuring their ability to utilize the tools independently in future work. The diversity of the participants created challenges for the course's design but facilitated the interdisciplinary nature of the Program and added value for the participants by allowing them to work in multidisciplinary teams. The highly participatory and interactive format of the Program contributed to an unstrained atmosphere and fostered the development of trust and relationships among participants as well as between participants and lecturers.

The development and implementation of the Program have been rewarding experiences for the organizers. It has been enjoyable to work with diverse groups of people with different backgrounds, who are interested in learning more about Big Data in the context of water management. We have also been pleased to find that the training provided during the course was perceived as meaningful and useful for the future careers of participants. The Program also helped to expand the user communities of the introduced tools and promoted interest in water resources problems. Our experience indicates that short courses are an effective device of encouraging domain researchers and practitioners to explore opportunities related to Big Data, and the rewards of organizing short courses are well worth the efforts involved in course preparation and implementation.

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Competing Interests
The authors have no competing interests to declare.

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