CSRD
CLIMATE SERVICES FOR RESILIENT DEVELOPMENT

CLIMATE SERVICES FOR RESILIENT DEVELOPMENT IN SOUTH ASIA

Annual Report 2016-17

Strategic alignment

CGIAR RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security CCAFS

Grant Summary Information

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Has this project been granted a no-cost extension?
The potential for a no-cost extension is under discussion with USAID. Please refer to the 'Implementation Challenges' section of this document.

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Acronyms and Abbreviations

ACToday	Adapting Agriculture to Climate Today for Tomorrow
ADB	Asian Development Bank
APHRODITE	Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation
AGU	American Geophysical Union
NAST	NASA Applied Science Team
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agriculture Research Institute
BAU	Bihar Agricultural University
BMD	Bangladesh Meteorological Department
BRRI	Bangladesh Rice Research Institute
BT	Brightness Temperature
BWDB	Bangladesh Water Development Board
CCAFS	Climate Change Agriculture and Food Security
CFSv	Climate Forecast System version
CHIRP	Climate Hazards Group Infrared Precipitation
CHIRPS	Climate Hazards Group Infrared Precipitation with Station data
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CSISA	Cereal Systems Initiative for South Asia
CRAFT	CCAFS Regional Agricultural Yield Forecasting Toolkit
CPT	Climate Predictability Tool
CSRD	Climate Services for Resilient Development
CRP	CGIAR Research Program
DST	Decision Support Tool
DAE	Department of Agricultural Extension
DG	Director General
ERD	External Resources Division
ESI	Evaporative Stress Index
ET	Evapotranspiration
FEWS NET	Famine and Early Warning System Network
FFS	Farmer Field School
FTE	Full Time Equivalent
GDAS	Global Data Assimilation System
GeoCLIM	Geo-Climate

GFS	Global Forecast System
GIS	Geographic Information Systems
GoB	Government of Bangladesh
GRACE	Gravity Recovery and Climate Experiment (Satellites)
GTS	Global Telecommunication System
HDP	High Disease Pressure
HKH	Hindu Kush Himalaya
ICCCAD	International Center for Climate Change and Development
ICIMOD	International Center for Integrated Mountain Development
ICT	Information and Communication Technology
ICAR	Indian Council for Agricultural Research
IOP	Investment Options Paper
IPCC	Intergovernmental Panel on Climate Change
IPNI	International Plant Nutrition Institute
IRI	International Research Institute for Climate and Society
IRRI	International Rice Research Institute
IUB	Independent University of Bangladesh
JHU	Johns Hopkins University
LoA	Letter of Agreement
LCAT	Local Climate Analysis Tool
LDAS	Land Data Assimilation System
LST	Land Surface Temperature
MoD	Ministry of Defense
MODIS	*Moderate Resolution Imaging Spectroradiometer*
MoT	*Magnaporthe Oryzae Triticum*
NARC	Nepal Agricultural Research Council
NARES	National Agriculture Research and Extension System
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NCDC	National Climatic Data Center
NDVI	Normalized Difference Vegetation Index
ODK	Open Data Kit
PANI	Program for Advanced Numerical Irrigation
PBIAS	Percentage Bias
PET	Potential Evapotranspiration
PICSA	Participatory Integrated Climate Services for Agriculture
QA	Quality Assessment
R^2	Coefficient of determination for a linear statistical regression model
RNO	Request for No Objection

RMSESD	Root Mean Square Error normalized by Standard Deviation
S2S	Seasonal to Sub-Seasonal
SAAO	Sub-Assistant Agricultural Officer
SALDAS	South Asia Land Data Assimilation System
SASCOF	South Asian Seasonal Climate Outlook Forum
SB	*Stemphylium* blight
SOW	Scope of Work
SM	Soil moisture
SPAM	Spatial Production Allocation Model
SSAOs	Sub Assistant Agricultural Officers
SB	*Stemphylium* blight
SMCI	Soil Moisture Condition Index
SPI	Standardized Precipitation Index
TCI	Temperature Condition Index
ToC	Theory of Change
VCI	Vegetation Condition Index
USAID	United States Agency for International Development
USGS	U.S. Geological Survey
UPF	*Universidade de Passo Fundo*
UoR	University of Reading
URI	University of Rhode Island
WRC	Wheat Research Center
WRF	Weather Research and Forecasting Model

Executive Summary

Efforts to meet the Sustainable Development Goals are challenged by climate change and climate variability. This is especially the case in the tropics, and in smallholder dominated farming systems in developing nations. The Climate Services for Resilient Development (CSRD) partnership is led by the United States Government, and has developed a consortium of global leaders in science, technology and development finance to assist at-risk nations to adapt to these problems. Aligned with the the Global Framework for Climate Services, CSRD works in Bangladesh, Ethiopia, and Colombia, as well as more broadly in South Asia, East Africa, and South America. The consortium creates and provides timely and useful climate data, information, tools, and services to assist decision makers – including farmers and agricultural development planners – to cope with climatic variability and extremes.

Khaled Hossain, CSRD Research Associate prepares an automatic weather station for field deployment in wheat blast and lentil stemphylium blight hotspots across India, Nepal, and Bangladesh. Photo: T. Krupnik (CIMMYT)

CSRD facilitated a first-of its kind technical exchange on participatory and institutional approaches to agricultural climate services from October 17-19, in Dhaka, Bangladesh. Photo: U. Barman (CIMMYT)

CSRD's partnership with the Bangladesh Meteorological Department (BMD) is now fully formalized. Here BMD staff check weather stations in Rajshahi, Bangladesh. Photo: T. Krupnik (CIMMYT)

Within South Asia, efforts to develop agricultural climate services under CSRD are led by the International Maize and Wheat Improvement Center (CIMMYT). CSRD supports the agricultural climate services track described in the Investment Options Paper (IOP) for CSRD in Bangladesh, compiled by the Asian Development Bank (ADB) in 2016. CSRD's core objectives are to prepare farmers, extension services, and agricultural policy makers with actionable climate information and crop management advisories to reduce agricultural production risks, thereby increasing the resilience of smallholder farming communities. These broad objectives are underpinned by three aligned project objectives that include (1) the development of impact-based national-scale decision tool platforms to support the Bangladesh Meteorological Department's (BMD) agro-meteorology track, (2) collaborative development and refinement of South Asian regional-scale agro-climate decision support tools, services, and products, and (3) coordination with the Asian Development Bank and other CSRD partners to boost awareness and use of climate information and services in the agricultural sector. This report summarizes CSRD activities, achievements, and challenges during the first year (from November 2016 through December 2017). Key highlights include the following:

- CSRD has established formal partnerships with a suite of strategic and qualified organizations to support Objectives 1-3 as described above. These partnerships include the Bangladesh Meteorological Department (BMD), the Bangladesh Department of Agricultural Extension (DAE), the Bangladesh Agricultural Research Council (BARC), the Bangladesh

Agricultural Research Institute (BARI), the International Center for Integrated Mountain Development (ICIMOD), the International Institute for Climate and Society (IRI), the University de Passo Fundo (UPF), and the University of Rhode Island (URI).

- CSRD's success in establishing formal partnership with BMD is particularly notable. As Bangladesh's lead meteorological services institute, BMD is the apex organization of the CSRD project in South Asia. After gaining approval from the Prime Minister's office in Bangladesh, CSRD now has the full endorsement of the Ministry of Defense, under which BMD is housed, to collaborate in support of CSRD Objectives 1 and 3.
- In cooperation with IRI, CSRD completed a forecasting skills and climate services communication skills assessment of BMD and DAE in the third quarter of 2017. The results of this assessment are now being used to adaptively manage and guide Objective 1 CSRD activities to develop more viable and useful climate services, as described below.
- Based on the skills assessment and a series of focus groups held with farmers and extension agents across Bangladesh, several new work streams have been identified that partly replace BMD's 2016 request to USAID to focus on extended-range and accumulative rainfall outlooks. These new focus areas have been agreed on by BMD and DAE as part of CSRD, and were chosen because they are far more agriculturally relevant and actionable from the standpoint of smallholder farmers and rural extension advisory services. CSRD is now working to develop these climate information service products, which will appear on the BMD website, in BMD's regular agro-meteorological bulletin, and which will be scaled-out by DAE through associated climate services initiatives in Bangladesh (see details below). New climate information and services topics include analysis of historical climatological data to assist in agricultural planning, with emphasis on mapping areas with sudden heavy rainfall events that can damage crops, and monitoring the progression of the monsoon season as a function of deviation from the long-term climatological norm. The skills assessment also identified opportunities to increase forecast skill and generate more agriculturally relevant forecast products that can be used by DAE to advise farmers in real-time. CSRD activities now focus on developing using multi-model ensembles to calibrate, improve, and downscale the forecasts currently produced by BMD, in addition to depicting extended-range forecasts as map of crop species-specific probabilities of encountering thermal stresses. These maps will be coupled with risk-mitigating crop management advisories that can be used by DAE to better advise farmers.
- In collaboration with BARI, field experiments to validate the PANI irrigation scheduling app (Program for Advanced Numerical Irrigation) that makes use of precipitation and temperature forecasts is now underway in three locations in Northern, Central, and Southern Bangladesh. Experiments will continue over two years, after which the PANI app will be released to BMD and DAE for use in assisting farmers to more efficiently manage irrigation of wheat and maize.
- Wheat blast is one of the most fearsome and intractable wheat diseases in recent decades. It is caused by the fungus *Magnaporthe oryzae* Triticum, and threatens 300 million undernourished people in Sotuh Asia whose inhabitants consume over 100 million tons of wheat each year. Working with UPF, a preliminary wheat blast disease early warning system was developed for Bangladesh in 2017 through CSRD. The system relies on a model driven by forecasted temperature, relative humidity, and precipitation, and identifies specific locations with high-, medium-, or low-risk of wheat blast outbreak. This early warning system is available online in beta-for, and is one year ahead of planned schedule. CSRD's efforts now focus on model validation and re-calibration, which requires additional field observation and data collection. To this end, hundreds of farmer's fields will be observed for disease incidence and severity across Bangladesh, in an effort carried out in collaboration with the CIMMYT-led and USAID/Bangladesh Mission funded 'Training, surveillance, and monitoring to mitigate the threat of wheat blast disease in Bangladesh and

beyond' project. BMD and DAE are also participating in model development and are positioned to support the longer-term use of the model as an early warning system for wheat farmers in Bangladesh.

- A preliminary graphical user interface for a South Asia Land Data Assimilation System has been developed in cooperation with ICIMOD's USAID supported SERVIR-Hindu Kush Himalaya program. The system can be used to monitor and forecast agricultural drought, and is being applied in Bangladesh in addition to Nepal, Pakistan, and Afghanistan. CSRD has established a network of 51 and 102 rain and soil moisture gauges in drought prone regions of Bangladesh to assist in SALDAS model validation and re-calibration. CSRD is also working with the Bangladesh Agricultural Research Council (BARC) to establish national SALDAS monitoring and forecasting capabilities, and to deliver seasonal drought risk advisories to the DAE to better inform and advise farmers on crop choice.

CSRD solidified its strong partnership with the Bangladesh Meteorological Department (BMD) in August of 2017, by signing a sub-grant agreement to facilitate formal project collaboration and data sharing between CIMMYT and BMD. In this photo, Mr. Md. Bazlur Rashid and BMD's meteorologists participate in training and discussions to improve extended-range forecast skill. Photo by E. Gawthrop (IRI)

- With support from IRI, CSRD's climate scientists are working to improve BMD's forecasting skills by identifying relevant global circulation patterns and other factors that affect seasonal-scale meteorological phenomena. Emphasis is being placed on improving BMD's ability to predict monsoon season onset timing, to better inform farmers as to when to prepare land for rice transplanting, with coupled analysis on the effects of late monsoon season onset on rice and subsequent winter crop productivity.

- Working with the USAID and Bill and Melinda Gates Funded Cereal Systems Initiative for South Asia (CSISA), the Bihar Agricultural University in India, and Nepal Agricultural Research Council, CSRD has initiated field work to validate a weather-based lentil *Stemphylium* blight disease model in Bangladesh, India, and Nepal. The 'Stempedia' model will provide early warnings of the risks of *Stemphylium* blight disease infection for lentil farmers, while advising when and where fungicides can be safely and profitably used to control the disease. In Bangladesh. CSRD has heavily engaged DAE in data collection and model development. DAE is enthusiastic about the usefulness of this climate service and is positioned to scale-out its use after CSRD is completed.

- 415 people have participated in CSRD activities in the last year in Bangladesh, India, and in Nepal. Key achievements include the CSRD Technical Exchange on Participatory Approaches to Agricultural Climate Services Development and Extension in South and South East Asia (September 17-19, in Dhaka, Bangladesh), attended by delegates from 11 countries. CSRD's new partnerships with the Columbia University's World Project 'Adapting Agriculture to Climate Today for Tomorrow (ACToday)' initiative and the International Center for Climate Change and Development (ICCCAD) are also relevant, as work is under way to initiate a Climate Services Academy in Bangladesh. CSRD also broached several new partnerships and facilitated awareness raising and workshop activities in 2017.

Looking forward into 2018, CSRD has also strategically positioned itself in partnership with the large- scale World Bank supported Bangladesh Weather and Climate Services Regional Project implemented by the Ministry of Defense, Ministry of Agriculture, and Ministry of Water Resources. This project aims to increase the Government of Bangladesh's capacity to deliver reliable weather, water, and climate information services and improve access to such services by priority sectors and communities. CSRD has met with the World Bank team administering this project, in addition to representatives from the DAE involved in project coordination. Agreement has been reached to see the agricultural climate information and service products developed in CSRD scaled-up and -out through the Agro-Meteorological Information Services project throughout Bangladesh. This development offers significant opportunities to sustain CSRD's impact at a scale much larger than initially feasible with CSRD consortium funds alone, and highlights the importance of partnerships and synergies in developing relevant and useful climate information services.

Introduction

Farmers in South Asia supply food to over 1.6 billion people – approximately 23% of the global population – from just less than 10% of the world's agricultural land. While remarkable progress in poverty alleviation and food security have been made in the past decades, nearly half of South Asia's population continues to subsist near the poverty line. Combined with continued population growth and shrinking farm sizes, the impact of climate change presents formidable challenges to meeting food security goals. South Asian farmers experience considerable variability in precipitation. Where irrigation is not used to overcome water deficits, drought is common on much of the regions' rain fed agricultural land. Heat stress is a crucial concern of increasing importance due to shortening winters and impact of high spring temperatures on crops such as wheat and maize. The vulnerability of South Asian's staple cereal farming systems to climate is also likely to increase in the future, if adaptation measures are not undertaken at scale.

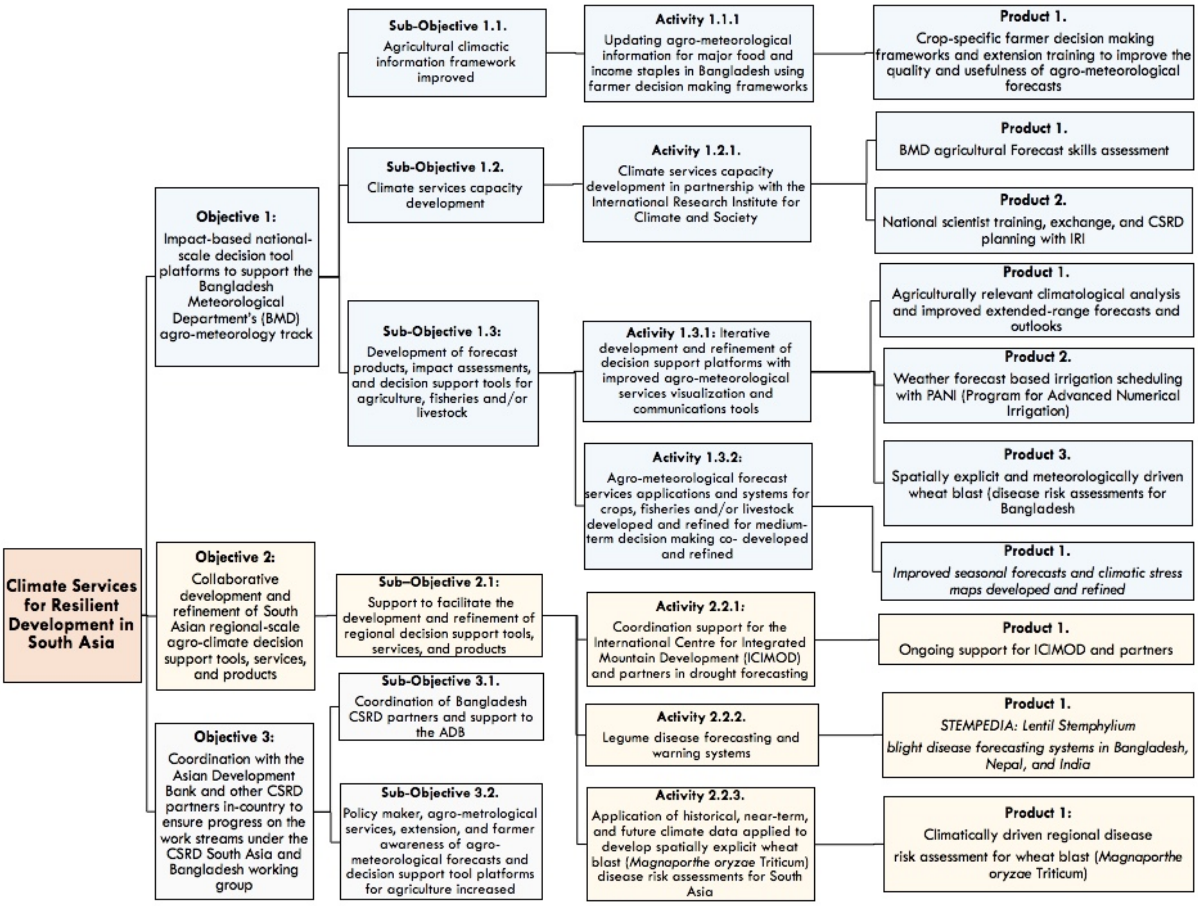
Climate Services for Resilient Development (CSRD) is a global partnership that connects climate science, data streams, decision support tools, and training to decision-makers in developing countries. The CSRD partnership is led by the United States Government and is supported by the UK Government Department for International Development (DFID), UK Meteorological Office, ESRI, Google, the Inter-American Development Bank, the Asian Development Bank, the Skoll Global Threats Fund, and the American Red Cross. In South Asia, CSRD is led by the International Maize and Wheat Improvement Center (CIMMYT), with funding from USAID. The partnership aims to increase resilience to climate change in South Asia by creating and providing timely and useful climate data, information, tools, and services. These activities are strategically aligned with the Global Framework for Climate Services and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

CSRD's main activities in South Asia include applied research and the facilitation of partnerships and capacity development to assure the supply of actionable climate information and crop management advisories for weather and climate variability that affecting key farm management decisions. Over the last 12 months, a group of qualified regional and international partners has the CSRD as a consortium in South Asia. This partnership is now actively working to develop and supply climate information and services to benefit decision makers in the agricultural sector, with emphasis on smallholders in cereal based farming systems that occupy most the region's arable land.

A smallholder maize farmer in Barisal, Bangladesh observes the sky and wonders if it will rain. Climate change, climatic variability and weather related risks are key sources of uncertainty that affect the productivity of smallholder farmers across South Asia. Challenges include drought, unreliable rainfall, extreme temperatures, and the spread of pests and diseases triggered by specific climatic conditions, among others. The CSRD consortium in South Asia works to develop actionable climate services to aid farmers, extension agents, and agricultural decision makers to better manage farm productivity and increase resilience to climatic variability and extremes. Photo: Saikat Mojumder

CSRD aims to achieve three clear Objectives. The first of these is the development of 'Impact-based and national-scale decision tools to support the agro-meteorology track of the Bangladesh Meteorological Department's (BMD)'. The second Objective focusses on work that spans the South Asian region, primarily emphasizing Bangladesh, India, and Nepal, but also supporting the work of CSRD partners in Afghanistan and Pakistan. Objective 2 is titled 'collaborative development and refinement of South Asian regional-scale agro-climate decision support tools, services, and product. The third and final CSRD Objective establishes CSRD's service role in support of climate information services in agriculture, and is titled 'coordination with the Asian Development Bank and other CSRD partners in-country to ensure progress on the work streams under the CSRD South Asia and Bangladesh working group'. There are several aligned Sub-Objectives, Activities, and resulting climate information services products that fall under each Objective, as depicted in the figure below.

This report details activities under each of these Objectives during the CSRD project's first twelve months. Major research and capacity development activities are described, as are the established CSRD partnerships with the BMD, the Department of Agricultural Extension (DAE), the International Center for Integrated Mountain Development (ICIMOD), and the Bangladesh Agricultural Research Council (BARC). The International Research Institute for Climate and Society (IRI), the University of Rhode Island, and the Brazilian *Universidade de Passo Fundo* (UPF) are also partners, in addition to new partnerships currently emerging with the University of Reading (UK), the Nepal Agricultural Research Council, and the Bihar Agricultural University in India. Through these partnerships, CSRD works to collaboratively develop, test, refine, and extend climate information and actionable services to farmers in South Asia.



The structure of the Climate Services for Resilient Development project in South Asia, depicting the three major Objectives, aligned Sub-Objectives, and Activities to support resulting climate information and service products.

The CSRD consortium in South Asia

CSRD across South Asia

Under the leadership of the International Maize and Wheat Improvement Center, the CSRD project in South Asia receives guidance from the United States Agency for International Development's (USAID's) Global Climate Change Office (Bureau for Economic Growth, Education and Environment) in addition to the broader CSRD Steering Committee. CIMMYT serves as the facilitating organization for agriculturally oriented climate services in the region, and works to facilitate research, training, and coordination linkages between the CSRD partners across South Asia. The consortium aims to improve the skill and quality of agriculturally relevant meteorological forecasting and climate information in South Asia through research, technical support, and capacity development.

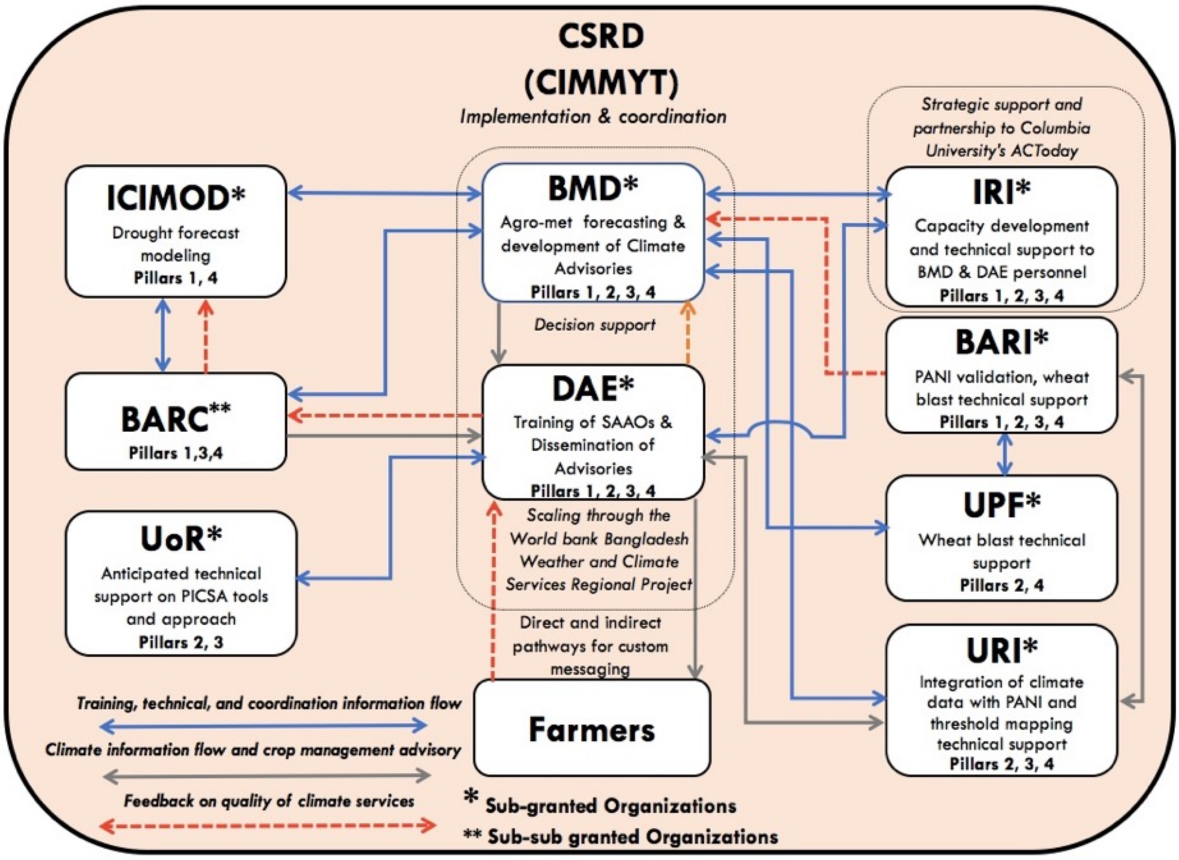
CSRD Partnerships in Bangladesh

Although CSRD is a regional effort in South Asia, much of the focus of the consortium's efforts focus on Bangladesh (See Objective 1). To this end, CSRD works closely with the Bangladesh Meteorological Department (BMD) and Bangladesh's Department of Agricultural Extension (DAE). BMD's objective is to inform the public on climate and meteorological information and forecasts in Bangladesh, and to maintain the country's network of surface and air observatories, radar and satellite stations, agro-meteorological observatories, and geomagnetic and seismological observatories. DAE is Bangladesh's primary agricultural extension organization and maintains more than14,000 sub-assistant agricultural officers (SSAOs) as extension agents. These SAAOs provide regular technical assistance to farmers across Bangladesh.

CSRD is a platform to actively facilitate high-level cross-institutional discussion, learning and linkages research, decision support tools, and products to support agricultural climate services across in South Asia. This meeting on improving the delivery of relevant climate services to Bangladeshi farmers, which was held in July of 2017 in Dhaka, Bangladesh, was attended by the Director General and scientific staff of the Bangladesh Meteorological Department (BMD), as well as the Director General and leadership staff of the Bangladesh Department of Agricultural Extension (DAE). Scientists from the International Center for Integrated Mountain Development (ICIMOD), International Research Institute for Climate and Society (IRI, Columbia University), were also present, in addition to CSRD staff from the International Maize and Wheat Improvement Center (CIMMYT). Photo by M. Kamal (CIMMYT)

CSRD succeeded in formalizing partnerships with both BMD and DAE in 2017 (Annex 1 and 2), and is now working with both agencies to collaboratively develop decision support tools (DSTs) and farmer advisories for improved crop management based on climate and meteorological information. The DSTs and associated CSRD products are designed to provide relevant and actionable agricultural advice to farmers during periods of the year when climate information is most crucial key farm management decisions. CSRD uses both direct and indirect (ICT based) dissemination to reach farmers with improved climate services, information, and advisories, and ultimately aims to embed these products with BMD and DAE as lead national partners.

CSRD's overarching goal is to establish collaborative partnerships supporting climate services research and development that will outlast the timeframe of the project. This is achieved by developing capacity and communication between BMD and DAE to collaborate and extend the use of climate information to farmers and agricultural decision makers in Bangladesh. To this end, CSRD is also harnessing BMD and DAE's partnership in the larger World Bank funded Bangladesh Weather and Climate Services Regional Project (the DAE-led component of this effort is termed the *Agro-Meteorological Information Services project*) in Bangladesh. This sister project aims to strengthen Bangladesh's capacity to deliver reliable weather, water, and climate information services and improve access to such services by priority sectors and communities. The Agro-Meteorological Information Services project aims to run until 2022, and was approved by the Government of Bangladesh June of 2017. As such the project, which focusses mainly on the procurement of equipment and infrastructure, has only just begun. CSRD responded to the approval of the project with quick action in 2017 to harness opportunities for synergistic collaboration and out-scaling of research and capacity development products through this aligned project.



Updated CSRD project coordination and relationship among partners and associated CSRD pillar support. Organizations marked with asterisks are current or anticipated sub-grant or consultancy partners of CSRD. Those with double asterisks are sub-sub grantees of the CSRD partnership. Information feedback on the usefulness and quality of climate services is a key aspect of the CSRD project, which emphasizes feedback from farmers to DAE, DAE feedback to BARC and to ICIMOD, BMD and DAE feedback to and from IRI (including Columbia University's ACToday project), and DAE feedback to BMD. Research on meteorologically informed irrigation scheduling and crop disease forecasting is supported by BARI, with back-stopping from UPF. URI provides programming services to BMD, BARI and DAE on irrigation scheduling and information on crop stress threshold mapping through CSRD. The CSRD project's products and climate information services will also be embedded in the World Bank funded Bangladesh Weather and Climate Services Regional Project. This will assure sustained scaling-up of the results of CSRD's work and is a major achievement of CSRD activities in 2017. Note that anticipated in-kind collaborations with Bihar Agricultural University (BAU) and the Nepal Agricultural Research Council (Grain Legumes Research Program) are also under discussion to support regional work on climate-based lentil disease forecasting and early warning systems.

Agreement with BMD and DAE has since been reached for CSRD to support the Agro-Meteorological Information Services partners in Bangladesh on a technical advisory basis. This has also been verbally approved during consultation with the World Bank's project advisory team in October of 2017 in Dhaka. CSRD scientists will therefore attend the Agro-Meteorological Information Services partners meetings on a regular basis to offer technical support and advice. DAE has also agreed to incorporate the climate information services, tools, and products developed through CSRD into the Agro-Meteorological Information Services project. This is now formally stipulated in the CSRD sub-grant for DAE. CSRD's collaboration to technically advise on aspects of this project at the invitation of BMD and DAE therefore offers significant opportunities to scale-up the products of CSRD's work in Bangladesh over a longer-term period than the CSRD project is anticipated to run.

The Bangladesh Agricultural Research Institute's (BARI's) involvement with CSRD is also crucial. Working with CSRD, BARI focusses on validating irrigation scheduling decision support tools developed by CIMMYT. Through CSRD's links to BMD, these tools are being improved by incorporating more precise precipitation forecasts based on WRF model outputs. CSRD is also working with BARI in a technical support capacity to develop and implement wheat blast disease risk forecasts, both nationally and regionally (Objective 2). These forecasts are important for an early warning system for wheat blast disease, so that DAE and other stakeholders in South Asia can prepare farmers to take mitigating action if outbreaks are predicted.

CSRD South Asian Regional Partnerships

At a regional level, CSRD also works to support the International Center for Integrated Mountain Development (ICIMOD) for South Asian drought monitoring and forecasting using earth observation data. This work is aligned with ongoing efforts in the USAID supported SERVIR-Hindu Kush Himalaya (HKH) program (see Objective 2), and spans Afghanistan, Pakistan, Nepal, and Bangladesh. Through this partnership, the Bangladesh Agricultural Research Council (BARC) is another CSRD affiliated organization. BARC has been sub-contracted by ICIOMOD to house computer facilities supplied through CSRD and to build national scientists' capacities to implement a nationally-based drought monitoring and forecasting center using the results of CSRD's work.

Two additional partnerships are currently under development. These pertain to CSRD's work to validate and improve a model and forecasting system for lentil *Stemphylium* disease in Nepal, India, and Bangladesh. Field work is currently under way in each of these countries to generate data that will provide the basis for an integrated early warning system for *Stemphylium*. To this end, CSRD has initiated discussions with Bihar Agricultural University (BAU) and the Nepal Agricultural Research Council (NARC), both of which are anticipated to provide in-kind technical support for disease identification and laboratory isolation confirmation.

CSRD International Partnerships to support work in South Asia

Internationally, CSRD also associates with the *Universidade de Passo Fundo* (UPF) in Brazil. UPF scientists have been working on disease forecasting for wheat blast disease for several years, and have made considerable progress in the development of a wheat blast forecasting system for South America. CSRD has been successful in 2017 in adapting this model to Bangladesh and developing a preliminary web-based predictive climate-based index for wheat blast outbreak risks. This has been accomplished well ahead of planned schedule. Field observations were conducted in 2017 and are planned for early 2018 to improve the model and climate-based index. In the long-run, these tools are anticipated to be managed by BMD and/or DAE.

The University of Rhode Island (URI) is also collaborating with CSRD to integrate WRF model outputs into PANI. URI is also assisting in developing R code packages and maps that will be used on the BMD website to depict crop-specific thermal stress thresholds. The results of this work will ultimately be used to improve BMD's Agricultural Meteorology Bulletin, thereby providing better information to DAE to transmit to farmers.

The International Research Institute for Climate and Society (IRI) at Columbia University is another international CSRD partner. Scientists at IRI have been collaborating with BMD for over four years. CSRD is leveraging this partnership to provide consistent technical support and backstopping to BMD for improved forecasting skill. IRI also aids in climate services communications and extension strategies with DAE through contributions to the Climate Change, Agriculture and Food Security (CCAFS) Research Theme on Adaptation through Managing

Climate Risk. CSRD is also working with IRI's *ACToday* (Adapting Agriculture to Climate Today for Tomorrow) initiative, initiated in late 2017. CSRD and CIMMYT are supporting *ACToday* and the International Center for Climate Change and Development (ICCCAD) at the Independent University of Bangladesh (IUB) to cooperate with BMD and implement a *Climate Services Academy* in Bangladesh. The Academy will be established in association with the Bangladesh Gobeshona initiative and will develop curricula and teaching in cross-sectoral climate services in Bangladesh, in addition to other services (See Objective 3).

CSRD is also pursuing strategic links with the University of Reading (UoR) in in the United Kingdom to adapt the PICSA (Participatory Integrated Climate Services for Agriculture) approach to agricultural climate services and pilot PICSA in three pilot locations across Bangladesh. These activities are anticipated to pave the way for a sustainable roll out in Bangladesh through DAE and through the Agro-Meteorological Information Services partners in Bangladesh. PICSA seeks to build resilience at the farm level by supporting decision-making through the integration of information on location-specific climate, crops, livestock, and livelihoods. It emphasises practical hands-on and experiential learning methods that can easily be used and understood by farmers.

Details of the primary scientists involved in implementing CSRD in South Asia and Bangladesh can be found in Annex 1 of this document. CSRD's key project subcontractors and partner organizations can be found in Annex 2, which also details each partnership objective and the status of completed and anticipated sub-grants.

CSRD's theory of change and strategic pillars in South Asia

A custom Theory of Change (ToC) has been developed for CSRD activities in South Asia. The ToC guides project activities and improves their impact by anticipating and providing pathways to overcome obstacles to project implementation. This is indicated by the figure below that depicts increased use of climate services and climate information assist farmers in improved decision making and farm management. CSRD in South Asia also contributes to the broader CSRD Action and Learning Framework Pillars 1-4, as detailed below. The ToC depicts major project outcomes that flow from the communication of research results and relevant climate information to stakeholders. These outputs are generated by an iterative process of research uptake and capacity building, which are in turn supported and driven by USAID.

CSRD Action Learning Pillars and Strategic Framework

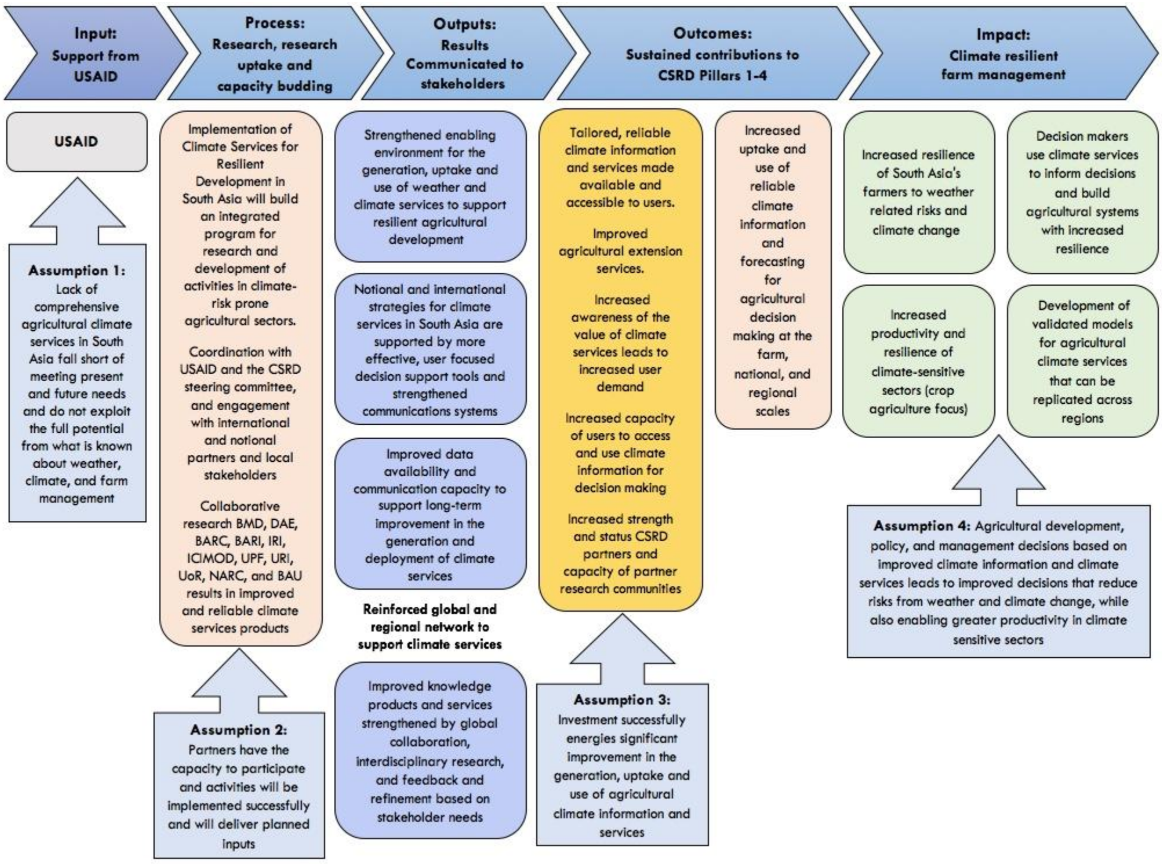
Each of the CSRD activities detailed within this report support an action and learning framework that is exemplified by four interrelated pillars of climate services. These are as follows:

Pillar 1: Create the solution space	Pillar 2: Utilize quality data, products, and tools	Pillar 3: Build capacities and platforms	Pillar 4: Build knowledge
The principles of this pillar are to establish a problem-focus, to engage key stakeholders, to create a platform for sustained communication and collaboration, and to build synergies among relevant programs.	The principles of this pillar are to provide access to useful and available information and technology, and to develop tailored products and services responsive to problem-specific needs.	The principles of this pillar are to support the use of targeted products and services, and to promote sustainability, scalability, and replicability.	The principles of this pillar are to identify and promote good practices among the global climate services community, and to support research efforts and innovation that increase the effectiveness of climate services.

CSRD Objectives in South Asia

Within these pillars, CSRD maintains four objectives with aligned sub-objectives and activities. The 2017 Annual details progress made in achieving the sub-objectives, activities, and resulting climate services products under each of these objectives. The report narrative describes how each product and activity contributes to the climate services pillars, with milestones and indicators of success described in the monitoring and evaluation framework (Annex 3).

Objective 1	Objective 2	Objective 3:
Development and refinement of impact-based national-scale decision tool platforms to support the Bangladesh Meteorological Department's Sector 3 agro-meteorology track.	Collaborative development and refinement of South Asian regional-scale decision support tools, services, and products.	Boosting the capacity of partners in Bangladesh to ensure the progress of the CSRD South Asia and Bangladesh working group.



CSRD in South Asia and Bangladesh's customized theory of change used to guide and provide reference for project activities

Objective 1: Impact-based national-scale decision tool platforms to support the Bangladesh Meteorological Department's (BMD) Sector 3 agro-meteorology track

Sub-Objective 1.1. Agricultural climactic information framework improved

Activity 1.1.1 Updating agro-meteorological information for major food and income staples in Bangladesh using farmer decision making frameworks

Product 1. Crop-specific farmer decision making frameworks and extension training to improve the quality and usefulness of agro-meteorological forecasts

Background

Applied research lies at the heart of Activity 1.1.1. Efforts under this activity aim to elucidate how farmers in South Asia understand climate and weather patterns, and how this information does or does not influence their crop and farm management decisions. This approach builds on ethnographic science and is important in identifying specific farm management activities and decisions, for example the choice of crops, when to sow, fertilize, irrigate, manage pests, and harvest and store crops, that farmers perceive can benefit from climate and weather information. This approach avoids some of the pitfalls of research whereby scientists alone decide on what information is relevant (cf. Stiller-Reeve et al. 2014), and can be useful in efforts to tailor climate information and services so they can be more useful to – and rapidly applied by – their intended users.

Left: CSRD Research Associate Khaled Hossain works with farmers to design a crop calendar depicting major farm management decisions and their linkages to climate and weather phenomena for Rajshahi, Bangladesh. This methodological approach is described in the PICSA manual, and will be deployed in six case study areas across Bangladesh in 2018 in collaboration with the University of Reading. Right: Dr Dr. Maharul Aziz, Agro-Meteorological Information Systems Development Project Component-C of Bangladesh Weather and Climate Services Regional Project at DAE, and Dr. Ghulam Hussain, CSRD Senior Partner coordinator, discuss major farm management decisions and their linkages to climate and weather phenomena. Both photos: T. Krupnik (CIMMYT).

Climate however is not an isolated influence on farmers' decision making processes. Other factors that can impact farm management decisions include biophysical variables such as soil type and drainage class, and socioeconomic considerations like labor availability and cost, input and output market prices, ability to store and sell farm produce, and household food security and income generation needs, among others. Research conducted under Activity 1.1.1 therefore evaluates the relative importance of these factors, while exploring farmers' understanding to better design climate information and services that are sensitive to the multiple influences that condition farm management. By doing so, the data generated through Activity 1.1.1 will be used to be used to better communicate relevant weather and climate information in support of farming communities.

Activity in 2016-17

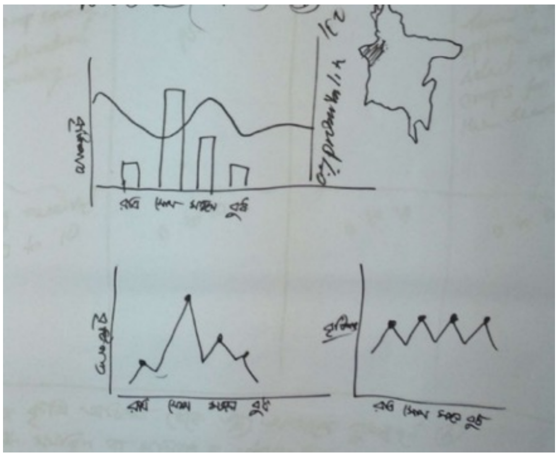
A series of focus group discussions were conducted with 68 farmers and 59 DAE sub-assistant agricultural officers (SAAOs) in Barisal Division (inclusive of Barisal, Bhola, and Patuakhali Districts), and Rajshahi, and Dinajpur Districts in Bangladesh in 2017. Both CSRD staff and partners in the Department of Agricultural Extension's Agro-Meteorological Information Systems Development Project Component-C of Bangladesh Weather and Climate Services Regional Project, funded by the Word Bank, participated in these meetings. Each of the areas chosen for the focus groups lie in the southcentral coast, central western, and north western areas of Bangladesh, respectfully. The coastal areas can be described as climate-risk prone as they tend to experience more cyclonic activity in the pre- and post-monsoon seasons, whereas Rajshahi and Dinajpur are comparatively more drought-prone, higher elevation regions.

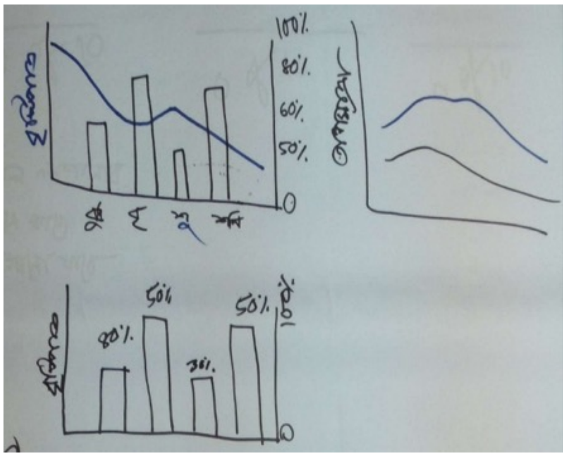
The focus group discussions examined farmers' understanding of predominant climate and weather patterns, and their related impact on agricultural decision making and crop productivity. Farmers' current use of weather forecasts and degree of trust in extended and seasonal forecasting were also explored, alongside preferences for how climate information can be graphically communicated to farming communities. SAAO focus groups also examined the perceived utility of extended range and seasonal forecasts for extension agents, while also exploring various media and methods for rapidly communicating climate information and advisories to farmers.

Right: CSRD Research Associate Khaled Hossain works with farmers to design a crop calendar depicting major farm management decisions and their linkages to climate and weather phenomena for Rajshahi, Bangladesh. This methodological approach is described in the PICSA manual, and will be deployed in six case study areas across Bangladesh in 2018 in collaboration with the University of Reading. Right: Farmers in Rajshahi, Bangladesh display their crop calendar depicting major farm management decisions and their linkages to climate and weather phenomena Both photos: T. Krupnik (CIMMYT).

Focus group results indicated that neither farmers nor SAAOs make regular use of, or have strong confidence in, weather forecasts. Both groups highlighted the lack of location-specific information as a barrier to more reliable use; where either group had received forecast information in the past, it was widely perceived as too geographically broad to be of use in agricultural information. The high degree of agronomic complexity and microclimates in Bangladesh were a common subject in focus groups. Farmers and extension agents did conversely state an interest in forecasts of high-intensity weather events, for example storms, heavy rainfall or hail that can damage crops. There was however a generally poor understanding of both groups on the day-to-day effect of weather and less 'dramatic' climatic events (such as high temperatures or cold) on crop productivity.

Considering forecast accuracy, farmers stated a preference for 1-7 day forecasts and indicated that they had never heard of, or were unlikely to trust longer-range forecasts. SAAOs also preferred 1-7 day forecasts, but also saw the value in seasonal forecasting so they could better assist farmers with pre-seasonal planning and crop selection. That said, both farmers and SAAOs may have unrealistically high expectations for forecast accuracy; both groups indicated a that unless forecasts were at least 80% accurate on a regular basis, that forecast information might be difficult to utilize in agricultural planning. Options for graphical depictions of climate forecast information were also explored with farmers in a participatory manner, with graphical results shown below.





Options for displaying climate information in graphs as drawn collaboratively with farmers, as explored during focus group discussions in Barisal Division, and in Rajshahi and Dinajpur Districts. Left: Line graph options drawn with farmers during focus groups. Farmers had difficulty in understanding these graphs, and greatly preferred either column charts and/or column charts with line graphs with forecast probabilities clearly depicted (right). Both photos: K. Hossain (CIMMYT).

Planned activity in Quarters 1 and 2 of 2018

The results of the focus groups conducted in 2017 are being used in the design of more comprehensive surveys to understand farmers' decision making processes and frameworks with respect to climate and weather implications for farm management planning and decision making. Surveys are to be deployed across Bangladesh, India, and Nepal in CSRD working locations in the first half of 2018. Although surveys had been planned to be completed by the end of 2017, they have been slightly delayed due to the time and effort requirements to align the CSRD partners in Bangladesh (see 'Implementation Challenges') and because of additional efforts to conduct focus groups as described above to fine-tune ideas for survey design and administration. As such, the initial report on farmer decision making framework for key food and income staples identifying best-bet ways to incorporate meteorological information will be completed in the first two quarters of 2018, with the formal decision making framework refined with participation of BMD and DAE (in Bangladesh) by the third quarter of 2018, which is still in time to include insights from this work in the design and refinement of the other CSRD technical products designed in this report.

In addition to survey work, efforts in Objective 3, Sub-Objective 3.1 during the 'Participatory and Institutional Approaches to Agricultural Climate Services Development: A South and Southeast Asia Regional Technical and Learning Exchange' from September 17-19th generated considerable interest among CSRD's DAE partners in the PICSA (Participatory Integrated Climate Services for Agriculture) approach to agricultural climate services. PICSA aims to facilitate farmers to make informed decisions based on accurate, location specific, climate and weather information, locally relevant crop, livestock and livelihood options, and with the use of participatory tools to aid their decision making. The PICSA approach provides a step-by-step guideline and approach for NGO staff for extension agents and farmer groups. PICSA has been widely applied in sub-Saharan Africa, but has not yet been trialed in South Asia. DAE has expressed interest in embedding the approach in their ongoing farmer field schools and farmer club programs. Finally, CSRD will facilitate the adaptation of the PICSA approach to Bangladesh, with trials of the approach undertaken in six communities in Barisal, Rajshahi, and Dinajpur in Bangladesh (two per location). More detail on these activities are described in Objective 3, Sub-Objective 3.1.

Contribution of Activity 1.1.1 to CSRD's Action and Learning Framework

Pillar 1, Indicators 1.1 and 1.2, Pillar 2, Indicators 2.1 and 2.2, Pillar 3, Indicators 3.1, and 3.2, and Pillar 4, Indicator 4.1 (see Annex 3).

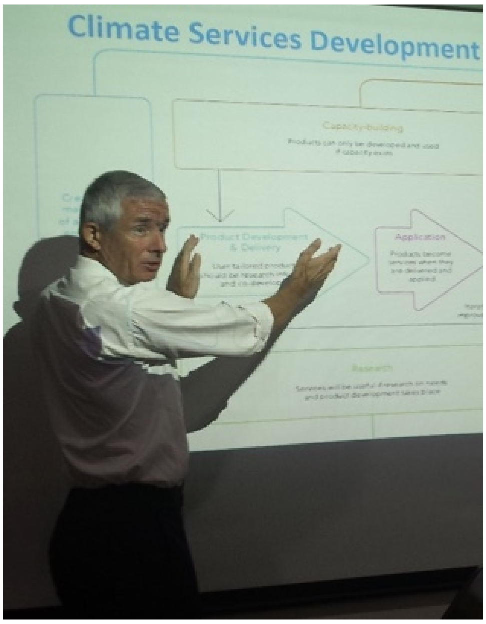
Sub-Objective 1.2. Climate services capacity development

Activity 1.2.1. Climate services capacity development in partnership with the International Research Institute for Climate and Society

Product 1. BMD agricultural Forecast skills assessment

Background

The International Research Institute for Climate and Society (IRI), based at Columbia University in the United States, is the globe's leading climate research institute with significant experience in seasonal forecasting and climate services applications in developing nations. CSRD has therefore chosen to partner with IRI to assist in improving the skill and relevance of short, extended-range, and seasonal forecasts produced by the Bangladesh Metrological Department. To this end, CSRD cooperated with Senior IRI scientists familiar with the BMD to implement a participatory assessment to identify and prioritize (1) BMD's capacity development needs and (2) technical opportunities for improving forecast skill. In addition to meeting with the BMD, Senior IRI scientists also engaged in discussion with Bangladesh's Department of Agricultural Extension to assess their capacity to understand, communicate, and extend weather and climate information to farmers on a timely basis. The text below details activities undertaken in 2017, which were all completed on time in accordance with the



Dr. Simon Mason, Senior Research Scientist at IRI, conducts an agro-meteorological forecast skill assessment with Bangladesh Meteorological Department staff in Dhaka, Bangladesh. Photo by M. Khan (CIMMYT)

CSRD Scope of Work presented to USAID in January of 2017.

Activity in 2016-17:

Under this activity, CSRD cooperated with Dr. Simon J. Mason, Senior Research Scientist, who initiated the BMD and DAE skills assessment during July 9 – 17, 2017. Dr. James Hansen, Research Scientist and CCAFS Theme Leader, and Mrs. Mélody Braun, Staff Associate, also from the IRI also assisted by participating in a full-day meeting with senior DAE officials on September 15, 2017. Based on the findings of the initial draft report produced with the assistance of CSRD's lead science team, the results of the skills assessment were presented to BMD and DAE between November 4 and 12, 2017. This permitted BMD and DAE to provide feedback and necessary corrections to the skills assessment, which was completed and formalized on time in accordance with the CSRD in South Asia Scope of Work. The skills assessment is available in Annex 4 of this document. The following capacity strengthening needs in (1) data and processing, (2) engagement with stakeholders, (3) research, (4) climate information production, (5) application and evaluation of climate information, (6) historical analyses and monitoring, (7) and forecasting were identified:

Data and processing capacity strengthening needs

- Data quality control, missing value estimation, homogenization and statistics tools to summarize data
- Database training (Clisys data management tool)
- Fortran, Matlab and R programming, together with Linux Shell scripting skills for data processing and automation of routine tasks, such as data reformatting and database updates
- Coordination efforts between CSRD and MET Norway initiatives to assist in realizing these objectives.

Engagement with climate information users and stakeholders

- Increased sectoral awareness of agriculture and what climate information is relevant for agricultural decision making (on the part of BMD)
- Increased understanding and awareness of climate and forecast science (on the part of DAE)
- Renewed focus on communication of weather and climate information generated by BMD to non-specialists in ways that improve saliency of and confidence in the service provided. This is best achieved through coordinated efforts to obtain climate information user feedback on a regular and systematic basis.
- Strengthened technical communication should assist stakeholders in understanding key concepts, in recognising the limitations of the potential to provide the information desired, and in identifying possibilities for new and tailored information.

Research topics to build climate services capacity

- Understanding of the impacts of global and regional drivers of climate variability over Bangladesh
- Identification of the most useful climate models for seasonal prediction
- Predictability of seasonal weather statistics of relevance to agricultural decision making
- Interdisciplinary research on sectoral impacts of climate variability and trends
- Recalibration procedures and uncertainty estimation for weather forecasts

Production of climate information

- Product design and content improvement – e.g., clearer and more relevant graphics, clearer text, more relevant variables incorporated into current agricultural meteorological bulletins regarding forecasts and observed conditions

Application and evaluation of climate information

- Increased and improved flow of information from BMD to DAE, and vice versa
- Regular elucidation of user feedback
- Regular forecast skill evaluations
- High-priority opportunities for new products that could be targeted to specific farm management decisions or crop stresses (see below)

Historical climate analyses and monitoring

- Crop specific risk-mapping of (1) heat stress, (2) cold stress (3) monsoon season dry-spells and potential for irrigation as a mediating management strategy in rice, (4) heavy and potentially crop damaging rainfall events, (5) monsoon season progression in terms of cumulative rainfall as a percent of long-term historical average, (6) potential risk mapping of hail and extreme storm events (that can cause waterlogging or defoliation and lodging of crops).

Forecasting

- Forecasts of early pre-monsoon season (and hence late winter '*rabi*' season) extreme heat (i.e., in March and April) that can cause heat stress for crops. Forecasts could be used to plan for irrigation and other mitigating actions.
- Probabilities of 7 to 14-day dry spells within the monsoon season. Forecasts could be used for planning of irrigation, rice seed bed establishment, land preparation (puddling) and transplanting dates, and potentially for fertilizer application.
- Cold spell forecasting (from mid-November to mid-March). Forecasts could be used to advise farmers for actions to mitigate cold stress in winter '*boro*' rice production (e.g., plastic sheet blanketing to protect seedlings from cold damage and/or delayed transplanting to avoid cold transplant shock). Other possible applications would likely require unrealistically accurate forecasts at long lead-times.
- Verification of forecast information, and possibly verification comparisons between meteorological services, particularly for temperatures, relative humidity, and precipitation.

Other opportunities for new forecast products that could be explored are discussed in detail in the Skills Assessment in Annex 4.

Planned activity in Quarters 1 and 2 of 2018:

In agreement with the CSRD partners, two major activity themes emerged from the skills assessment. These activities are being carried into Quarters 1 and 2 of 2018. The first activity theme addresses issues of data and processing capacity strengthening needs, research to build climate services. More details on this topic can be found in Objective 1, Sub-Objective 1.3, Activity 1.3 under which the relevant priority areas identified during the skills assessment are being addressed. The second activity theme focusses on to the need for increased engagement on the part of BMD with stakeholders, and with the production, application and evaluation of climate information themes identified in the skills assessment. Activities undertaken following the skills assessment involve collaborative redesign of the weekly agro-meteorological bulletin produced by BMD to present clearer and more agriculturally relevant information, in consultation with DAE. Several meetings have already been held to achieve this aim.

Left: Following on the skills assessment, Bangladesh Department of Agricultural Extension staff participate in a review facilitated by CSRD of the Bangladesh Meteorological Department's Agro-Meteorological Bulletin on November 9, 2017. Based on this work, the weekly Bulletin will be revised in the first quarter of 2018 to provide information more relevant and easily understandable by agricultural decision makers. Right: Dr. Timothy J. Krupnik, CSRD Project Leader, interacts with Department of Agricultural Extension staff to redesign the BMD agro-meteorological bulletin. Both photos by E. Gawthrop (IRI)

Prototype designs for the new bulletin, which is available through BMD's website and email circulation lists, are currently under discussion. The improved agro-meteorological bulletin is expected to be made publically available by the completion of Q1 of 2018, with ongoing updates as forecast skill and climate information products become increasingly available.

Product 2. National scientist training, exchange, and CSRD planning with IRI

Through the CSRD collaboration, IRI was to host 5-6 scientists from CIMMYT, DAE, and BMD at IRI for a period of approximately 2-3 weeks at Columbia University in July, 2017. The purpose of the visit was to provide on-the-job training in agriculturally relevant climate forecasting, communication of climate services information, and the development of CSRD strategies for Bangladesh. A custom curriculum for the visit was developed (see Annex 5) involving a combination of lecture, discussion, and hands-on training on topics pertaining to agricultural climate services, improved seasonal and sub-seasonal forecasting, methods for effectively communicating meteorological information to farmers and influencing farm management decisions, and other topics collaboratively agreed on by CSRD partners to be of relevance.

Activity in 2016-17:

Because of challenges faced in reaching agreement with the Ministry of Defense (MoD), under which BMD is managed, CSRD was unable to secure permission for BMD's climate scientists and meteorologists to travel to the United States to work at IRI in July of 2017. As a result, a contingency plan was enacted to initiate portions of the Annex 5 training curricula within Bangladesh, with both BMD and DAE staff, during the second and third quarters of 2017. At the same time, CSRD staff worked to secure high-level agreement with the MoD for BMD to formally enter the CSRD consortium in South Asia (see Implementation Challenges for details of this process). Agreement was finally reached on August 29 of 2017, paving the way for renewed efforts to gain approval for the extended residential scientific exchange at IRI. Current plans are for BMD staff to travel to IRI between the end of March and early April of 2018 (the earliest free period in their schedule due to BMD staff requirements to remain within Bangladesh during periods of the year when cyclone activity is expected), and all required paperwork to gain permission for BMD staff to travel is currently with the MoD. The text below therefore provides details of the contingency training visits made by IRI staff to work with BMD and DAE in Bangladesh during 2017.

On September 15, 2017 both Dr. Jim Hansen, Senior Research Scientist/CCAFS Theme Leader and Melody Braun, Staff Associate of IRI traveled to Bangladesh and conducted a day-long meeting and training with CIMMYT and DAE focal persons assigned to work with CSRD. The agenda focused on reviewing DAE's structures and processes for communication of extension information – including relevant climate advisories – to farmers. Working with CIMMYT, Hansen and Braun provided advice on how DAE could improve the speed of information delivery and interactions with farmers on climate services-related topics. A significant portion of the discussion focused on identifying ways that DAE could regularize the provision of feedback from farmers regarding the usefulness of information delivery, in addition to discussions on gender-equitable agricultural climate services options.

DAE's ongoing projects that utilize Farmer Field Schools (FFS) as a means of increasing farmers' capacity emerged as a promising mechanism for introducing climate information, and training and facilitating famers to incorporate the information into their farm management planning. Both FFFs and farmers' clubs are used by DAE across Bangladesh and significant interest emerged from DAE staff in using these structures to increase the availability of climate information and use of climate services in DAE's broader portfolio of projects. Including climate and weather information into those curriculums would build the capacity of those farmer groups to understand and use climate information.

The high penetration of mobile phones in Bangladesh were also identified as a promising and low-cost means of disseminating climate information and advisories to a large number of people in a short time. Further discussions explored the potential of using mobile phones to collecting feedback from farmers through toll-free SMS question responses. An intentional, accountable, iterative (e.g., annual) process was recommended for incorporating farmers' feedback into the design and continuous refinement of climate services. Smartphones offer additional opportunities for more detailed information delivery and feedback through climate service oriented apps.

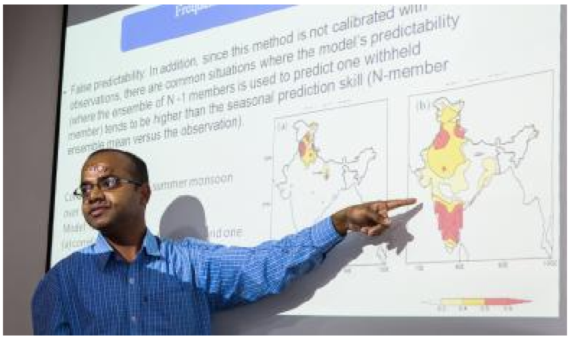
DAE is one of the lead institutes in the large-scale World Bank funded Bangladesh Weather and Climate Services Regional Project (also known as the *Agro-Meteorological Information Services project*). This effort focusses on strengthening the Government of Bangladesh's (GoB's) capacity to deliver reliable weather, water, and climate information services and improve access to such services by priority sectors and communities. Approved by the GoB in June of 2017, the project focusses primarily on infrastructure and procurement of forecasting and ICT equipment and will run to 2022. CSRD has positioned itself to assist by increasing forecast skill and developing relevant climate services and tools that can be scaled-up in the *Agro-Meteorological Information Services project*. Meetings have also been held with the World Bank team administering the project, who have endorsed CSRD's partnership.

Through the *Agro-Meteorological Information Services project*, DAE expects to equip approximately 30,000 lead farmers and farmers' clubs across Bangladesh with smartphones or internet equipped tablets. Farmer club presidents or lead farmers are then expected to inform their communities when relevant agricultural information is shared. The proliferation of these ICTs therefore offer new opportunities to reach farmers at scale with climate information and service advisories developed through CSRD. CSRD is therefore now actively pursuing incorporation of the products of its work into the apps that will be included on the smartphones and tablets, and DAE has agreed to prioritize use CSRD's climate service products in the *Agro-Meteorological Information Services project* as part of their sub-grant agreement. More details on the scaling opportunities offered through the *Agro-Meteorological Information Services project* can be found in Objective 3. Insights from these discussions were also written up and added to the BMD and DAE skills assessment (Annex 4).

From November 5-9, 2017 Dr. Simon Mason, Senior Research Scientist, Dr. Nachiketa Acharya, Associate Research Scientist and Elisabeth Gawthrop, Communications Specialist from IRI also visited Bangladesh to implement portions of the curricula clarified in Annex 5. The main agenda of this meeting included lectures and training on the science and probability of forecasting (for BMD), science and forecast communication skills (for DAE and BMD), and recalibration of forecasts (for BMD). Further emphasis was placed on hands-on software training (Rstudio, Matlab, etc.) for climatic data analysis

Sessions on probability and forecasting included exercises with BMD participants to measure the confidence level of their forecasting and indicate if they are over- or under-confident. Varying definitions of probability, uncertainty quantification methods, and seasonal forecasting reliability were also discussed. Ms. Gawthrop also led discussions on the need for improving science communication skills to increase farmers' and other stakeholder's use of climate information and advisories.

Dr. Nachiketa's training sessions focused on recalibration of forecast to quantify uncertainty and present it to climate information users in robust and easy to understand formats. Frequentist and subjective methods were discussed, as well as parametric statistical procedures to calculate forecast probability methods of measuring uncertainly by model correlation, ensemble model spread, and residual error were also presented and discussed. Dr. Nachiketa also conducted a training on how to most appropriately plot climate data graphically and calculate correlations using open-access Rstudio software.



Dr. Nachiketa Acharya, Associate Research Scientist at IRI, conducts an educational session on multi-model ensemble forecasting at the Bangladesh Meteorological Department facilitated by CSRD. Photo by E. Gawthrop (IRI)

Planned activity in Quarters 1 and 2 of 2018:

As indicated above, ongoing training for BMD staff is expected to take place between March and early April of 2018 at IRI in Columbia University at Palisades, New York. Topics to be covered in the training will build on the progress made in 2017 as described above, and cover missing subject matter not yet addressed from the curriculum shown in Annex 5.

Contribution of Activity 1.2.1 to CSRD's Action and Learning Framework:

Pillar 1, Indicator 1.1and Pillar 4, Indicator 4.1 (see Annex 3).

Sub-Objective 1.3: Development of forecast products, impact assessments, and decision support tools for agriculture, fisheries and/or livestock

Activity 1.3.1: Iterative development and refinement of decision support platforms with improved agro-meteorological services visualization and communications tools

Background

Activity 1.3.1 priorities set forth by BMD for CSRD following consultation with USAID for the Sector 3 Agro-meteorology track on 12 July of 2016. Three topics were prioritized, including (1) provision of GIS maps displaying climatic stresses, (2) forecasts for integrated irrigation management services, and (3) development of "impact based agro forecast" systems incorporating improved forecast and vulnerability to identify impacts, with emphasis on the development of crop specific pest and disease models.

The activities below detailed support BMD's prioritization of these topics, and include steps taken to develop (a) agriculturally short- and extended-range forecasts graphically depicted as climactic stress risk maps for major cereals, (b) an ITC platform for meteorologically integrated irrigation management services, and (c) spatially explicit and meteorologically driven wheat blast *(Magnaporthe oryzae Triticum*, MoT) disease risk assessments for Bangladesh.

Product 1. *Agriculturally relevant climatological analysis and improved extended-range forecasts and outlooks*[1]

Activity in 2016-17:

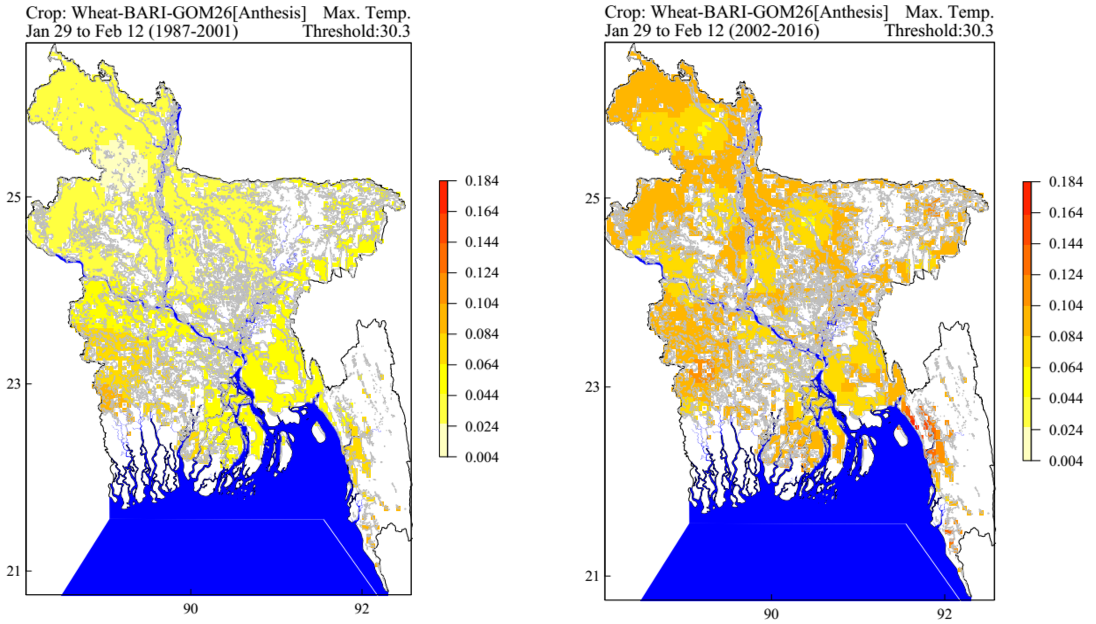
Following on the completion of the skills assessment (Objective 1, Sub-Objective 1.2, Activity 1.2.1, Product 1) that was completed ahead of schedule in the third quarter of 2017, a series of activities have been held involving the CSRD team and partners from BMD, DAE and IRI to address Activity 1.3.1 Product 1 '*Agriculturally relevant climatological analysis and improved extended-range forecasts and outlooks*'. These activities have resulted in a more appropriate and comprehensive work packages aimed at improved and more relevant climate information generated by BMD for stakeholders in the agricultural sector. Product 1 activities therefore now integrate both historical climatological analysis with efforts to improve forecasting focus on the following:

Deriving climate information for services from historical data in Bangladesh

- Analysis of historical data to map crop species-specific potential of encountering thermal stress In cooperation with URI, CSRD is making progress in using historical climatological data provided by BMD to crop species-specific potential of encountering thermal stresses that can reduce yield and productivity. An example map showing the probabilistic risk of exceeding temperature thresholds for terminal heat stress in wheat during flowering is provided below for areas of Bangladesh deemed suitable by BARC to wheat cultivation. Preliminary maps for winter season '*boro*' rice, wheat, and maize have been produced alongside maps for monsoon season '*aman*' rice thermal stress risks.

  The thermal thresholds for each crop are being verified and refined based on the results of a systematic literature review to be completed in the first quarter of 2018. Once complete, maps are anticipated to be provided on BMD's website. Research co-operators at URI are also producing R code packages that will be made available online as a CSRD product for analysists wishing to apply similar methodologies to crops and climatologies in other countries and regions.

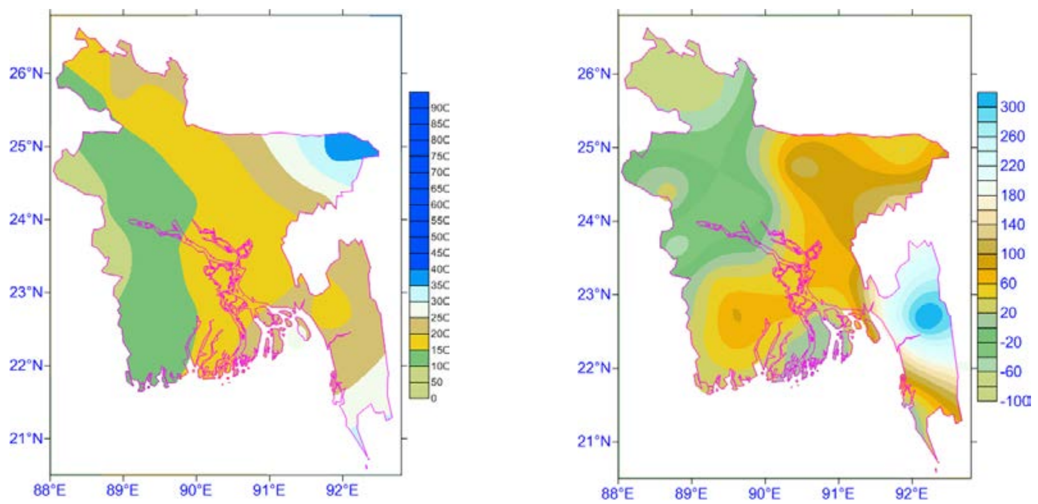
[1] The initial SOW developed by USAID based on the 12 July of 2016 consultation with BMD suggested focusing on the development of 'Seven-day rainfall forecasts with 15-day accumulative rainfall outlooks' (Task i. ii.). Upon commencement of the project, CSRD staff found that BMD is already generating seven-day rainfall forecasts using WRF model outputs. 15 cumulative rainfall outlooks are however relevant in the context of several other forecasting parameters that were identified during the BMD skills assessment. Importantly, these topics are more agriculturally relevant for farmers than generic seven-day or 15-day accumulative rainfall outlooks. With the endorsement of BMD, CSRD has therefore begun focusing on these forecasting needs under this activity product now renamed 'Agriculturally relevant climatological analysis and improved extended-range forecasts and outlooks'.



Preliminary climatological assessment of the risk probability of exceeding high-temperature stress thresholds during crop anthesis that can lower wheat yield across Bangladesh. Left: probabilities from calculated using daily temperature observation data from 1987 to 2001. Right: data from 2002 to 2016. The methods used to develop these figures, which will be incorporated into the Bangladesh Meteorological Department's weekly Agro-Meteorology Bulletin are currently under refinement and improvement.

- Mapping of the seasonal progression of the monsoon and deviation from climatological normal

  The skills assessment highlighted a strong interest by both BMD and DAE in showing the progression of monsoon season rainfall accumulation and deviation from the long-term climatological norm. Preliminary R code and maps have been accordingly generated, as shown below. Code and maps are now under refinement and will be automated in the first quarter of 2018 for regular inclusion in BMD's weekly agro-meteorological bulletin.



Examples of preliminary mapping of the seasonal progression of the monsoon and deviation from climatological norm. Maps will be automatically generated for inclusion in the BMD agro-meteorological bulletin.

- Mapping of monsoon dry spells (consecutive 5 days with < 1 mm, monsoon seasonal scale)

  Dry spells during the monsoon season can cause problems for rainfed '*aman*' rice, which is the predominant crop throughout Bangladesh. Working with CSRD staff, BMD's meteorologists are now mining the historical record to develop maps of where and when dry spells tend to be most common during the monsoon. Combined with forecasting efforts (see below), locations can later be targeted for campaigns encouraging 'life-saving' irrigation by DAE and other agricultural development projects in Bangladesh, for example the USAID and Bill and Melinda Gates Foundation funded Cereal Systems Initiative for South Asia (CSISA).

- Mapping of heavy rain events (moderately heavy and greater in February to March)

  Although one of coastal Bangladesh's most highly profitable crops, mungbean is climate-risk prone in that unexpected heavy rainfall events and storms can cause both waterlogging or destruction of seedpods, both of which significantly reduce yield. Where farmers can access weather forecast advisories of heavy rainfall or storms, they can be empowered to more rapidly harvest their crop to avoid significant losses. By integrating and disseminating weather-forecast information, climate-smart advisories for when and how to harvest can help farmers to escape from some of the climate risks associated with mungbean production. To this end, CSRD is collaborating with BMD to mine the historical data and map where and when heavy rainfall events are most frequent. This study will assist in forecast probability mapping of heavy rain events (detailed below).

Dr. Timothy J. Krupnik, CSRD Project Leader, leads a session with Department of Agricultural Extension in Dhaka in October of 2017. Discussions focussed on how to depict maps of crop stress thresholds that can be understood by field extension agents across Bangladesh Photo by E. Gawthrop (IRI)

Forecasting to improve climate information and services in Bangladesh

- Quantitative assessment and improvement of BMD forecasting skill

  The meteorological forecasting provided by BMD is currently under additional quantitative evaluation of its accuracy. BMD's current forecasting work is deterministic, and implemented using the Weather Research and Forecasting Model (WRF) at a maximum of18 km^2 spatial resolution. Forecasts are forced by outputs from the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS). To achieve these aims, CSRD has installed a server at BMD to store data obtained from the short-term forecasting by WRF model for subsequent analysis of uncertainty and to identify areas for potential improvement.

  Depending on results of this activity, the evaluation of the relevance of using a single ensemble member to force the WRF model is considered, for which the option of a higher number of global forcing models or the selection of the one that generates better forecasting results will be analyzed. In addition, the application of regression-based methods, ensemble/single model output statistics or contingency tables is envisaged to calibrate the meteorological forecasts. This procedure will be performed for different seasons and locations and will allow obtaining the information required to understand the forecast uncertainty and to improve its quality.

- Extended range forecast mapping of crop species-specific probabilities of encountering thermal stress

  The improved weather forecasting and observations from BMD weather stations will be used to generate a series of numerical products through the BMD website and the agrometeorological bulletin that is published weekly. These products will be presented as maps, tables and text, considering information of agricultural interest such as weekly-scale forecasted precipitation complemented by the progression of the rainfall season presented as accumulated rainfall of the previous weeks starting from the onset of the monsoon. Emphasis will also be placed on climate-related agricultural hazards such as heat/cold stress, dry spells, and heavy rainfall events, which must be previously defined in terms of thresholds and complementary climate or land surface variables (see example preliminary maps above). This new information will be provided by regions, using refined interactive maps, and support text to enable the easy understanding by users. The latest include the necessary training to BMD and DAE people for a correct interpretation of the new products.

Mr. S.M Quamrul Hassan, Meterologist, with the server installed by CIMMYT at the Bangladesh Meteorological Department that permits CSRD to access historical and numerical weather forecast information, and to work to improve the predictability of forecasts. Photo: F. Khan (CIMMYT)

Planned activity in Quarters 1 and 2 of 2018:

Research conducted under the *Deriving climate information for services from historical data in Bangladesh* and the *Forecasting to improve climate information and services in Bangladesh* work packages will be completed by the end of Q2, 2018. Whatever the product developed in this activity, there will be an effort to incorporate this information the BMD website and into the *Agro-Meteorological Information Services project* managed by DAE. Preliminary outputs in the form of maps and crop advisories, inclusive of both online desktop and mobile Android formats are planned for completion in the last quarter of 2018.

Product 2. *Weather forecast based irrigation scheduling with PANI (Program for Advanced Numerical Irrigation)*

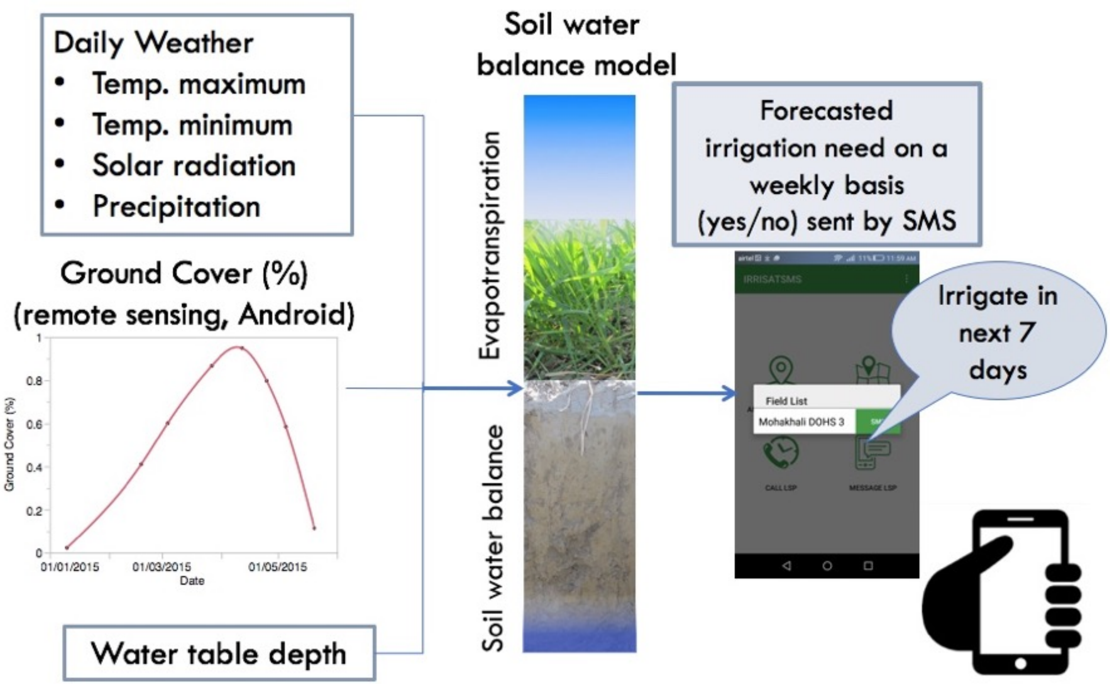
Activity in 2016-17:

A considerable portion of South Asia's farmland is irrigated. This presents a challenge to the implementation of climate services in agriculture, as climate services programs for rainfed agriculture are in generally high demand in more arid and water-resource scarce regions. Optimal irrigation management is nonetheless key to successful *rabi* (winter) season crop production in South Asia, and can also benefit greatly from climate and weather information. About 2/3 of Bangladesh's cropland are under irrigation (Qureshi et al., 2015; Ghani, 2016). The main source of water utilized is ground water (79 %). A few canal-based irrigation schemes have also been developed in different areas. In some parts of the country where irrigated winter season rice predominates, ground water levels are declining (Qureshi et al., 2015). This is predominantly the case for the farmers in the North-western regions of Bangladesh, i.e., the Dinajpur and the Barind Tract, where farmers are reporting that water needs to be pumped from increasingly lower depths to assure water availability (Rahman et al., 2013). Many shallow tube wells in these areas fail to lift sufficient water for the entire dry winter season irrigation period (Dey and Ali, 2010), as water tables tend to fall below critical levels between mid-February and April (Ghani, 2016). In a survey conducted in the Jessore region, 95% of the respondents replied that have not received sufficient extension advice on irrigation and that they lack structured knowledge on irrigation efficiency and crop water use (Rahman et al., 2016).

PANI for field-specific irrigation scheduling

Smart phones are conversely increasingly being used as an inexpensive tool to provide customized crop management recommendations to farmers. This work package focusses on 'weather forecast based irrigation scheduling in Bangladesh with 'PANI', the Program for Advanced Numerical Irrigation. PANI responds to these constraints and opportunities by developing an ICT-based irrigation scheduling decision support tool for irrigation scheduling. A prototype for PANI, which means water in Bangla, was developed by CIMMYT as smart phone application in 2016. The app provides irrigation recommendations for wheat and maize farmers on a weekly basis by integrating several relevant factors – including weather forecasts obtained from the CSRD server installed at BMD – in an integrated model to determine irrigation needs.

PANI captures relevant data from the user (see figure below), transmits them to a server, which then generates irrigation recommendations for specific fields (Annex 10). PANI was initially designed to address the needs of farmers in the south of Bangladesh, where irrigation remains lacking (Krupnik et al., 2017), and farmers have little or no experience with irrigation scheduling. Work in CSRD therefore focusses on validating and adapting PANI to other regions through cooperative efforts with the Bangladesh Agricultural Research Institute (BARI), while integrating weather forecast and historical climate information to fine-tune irrigation recommendations.



The main components of PANI, an irrigation scheduling mobile phone app developed for Bangladesh that is being validated and improved as part of the CSRD project. PANI provides recommendations for farmers on when to irrigate maize and wheat crops based on photographic or remote sensing assessment of crop ground cover, a simple soil-water balance model, and seven-day precipitation forecasts supplied through the Bangladesh Meteorological Department's WRF model outputs.

At the heart of PANI is a soil moisture module that was initially developed for the widely-used CERES crop simulation models. PANI requires region-specific soil information that can be supplied from available databases or measured *in-situ*. Soil texture and organic matter strongly determine water holding capacity, down-flow and capillary up-flow. In addition, PANI requires the following information from the farmer or irrigation pump owner: (1) name and phone number, (2) location of field(s) to be irrigated (coordinates supplied automatically through smartphone location finder), (3) crop type, (4) date of sowing, (5) anticipated Irrigation dates and amounts. A CERES model derived algorithm then integrates these data with information on water table depth, percent ground cover, and daily weather observations and short-term forecasts. In return, PANI provides the user with a weekly recommendation as to whether a field needs to be irrigated or not. Preliminary results from these trials Weather conditions (daily maximum and minimum temperatures, solar radiation and precipitation) as well as percent ground cover (percent of ground covered by leaves) also key drivers of crop water use, and thus are important for developing irrigation scheduling advisories.

Sub-optimal irrigation, either by under or over applying water can cause significant yield losses and/or extra cost for fuel and irrigation services. Through the CSRD project, PANI is therefore being properly calibrated and validated for different parts of Bangladesh before it is released to the public. BARI is leading this effort as a core CSRD partner, and has initiated a series of experiments to examine and refine PANI app performance for wheat and maize irrigation scheduling in the winters of 2017/18 and 2018/19 in Barisal, Rajshahi and Dinajpur (Annex 11).

Bangladesh Agricultural Research Institute (BARI) staff setting up controlled field trials to validate PANI at the Regional Agricultural Research Station in Barisal, Bangladesh in November of 2017. Photo: G.M. Rokon (CIMMYT)

Research station experiments have the advantage that it will be possible to install instruments for continuously monitoring the soil water balance with moisture sensors connected to data loggers. BARI will also monitor percent ground cover with red-blue-green (RDB) photos taken with a smart phone and record all crop management activities, including irrigations, and phenology. The ultimate purpose of this activity is to get the official endorsement for PANI from BARI, so that the Department of Agricultural Extension, which is also part of the Ministry of Agriculture, can include it in its suite of crop management advisory systems. Preliminary results from these validation trials will be presented in the 2018 semi-annual CSRD report.

∂-PANI for regional weather-based irrigation scheduling advice

In addition to the above field-specific PANI irrigation scheduling app, CSRD is also working to develop regional irrigation advisory system, called ∂-PANI. While irrigation is best scheduled for specific farmers, Bangladesh's dense population and limited extension services present logistical challenges to scaling-out the use of field-specific recommendation advisories. ∂-PANI will address these issues by providing more generalized irrigation recommendations. This is accomplished through an algorithm that integrates observed and forecasted weather information, while also examining the recent climatological patterns to provide users with a relative irrigation recommendation. Current observed weather and forecasts are compared to a base-line established with data from the prior three years. The algorithm, which will also be house in a mobile phone app, will generate weekly recommendations as to whether crops are likely to require irrigation more or less frequently (∂ days) than usual.

Based on the location of the smart phone of the user, both PANI apps will provide irrigation recommendation for the region or field where the phone is located. Information can be sent to user via SMS, voice message, or through the App itself. Example of recommendations (in English) include the following: "*It has been more sunny and warmer than usual the past 2 weeks. We recommend that you carefully examine your field and consider to irrigate 3 days earlier than usual.*" Another recommendation might be "*It has been cold and overcast in recent days and we expect a shower or two in the next few days. For these reasons, we recommend that you might want to consider delaying the irrigation of your crops by a few days.*"

Planned activity in Quarters 1 and 2 of 2018:

BARI has completed sowing of field-specific PANI app experiments in Dinajpur, Rajshahi, and Barisal in Bangladesh in December of 2017. Wheat and maize crops will be grown until March and June, respectively, with data collected to provide preliminary validation of the app. At the same time, CSRD is currently conducting preliminary business model investigations in each of these regions to better target both PANI applications to increase user potential. This is because there are different types irrigation payment structures used in Bangladesh. For example, irrigation pump owners may charge farmers a fixed rate for different crop types per season. They may also through sharecropping arrangements under which a portion of the crop harvested is given to irrigation pump owners. Other examples may include charging farmers by land area cultivated, the amount of time an irrigation pump is run for, or through direct pump rental arrangements. Irrigation is conversely rarely priced on a volumetric basis, although emerging initiatives by the GoB in Rajshahi are working to popularize this approach as a natural resource conservation strategy. For these reasons, a business model study is currently under way to determine which pricing structure the field-specific PANI app might be appropriate for. This information can be used to better target out-scaling efforts following BARI's validation of the app. While the business model study was to have been completed by the end of 2017, it was delayed so that preliminary data on water use and scheduling in Dinajpur, Rajshahi, and Barisal from the BARI PANI trials could be included in focus group discussions with farmers. Initial results of both the experimental and business model efforts to validate the field-specific PANI app will be presented in the 2018 semi-annual CSRD report.

In the first two quarters of 2018, CSRD will also develop a pilot version of ∂-PANI. This preliminary version of the app will be shared with BARI scientists, extension agents and other agronomists so that we can capture their opinions and suggestions for improvement. The Department of Agricultural Extension (DAE), one of CSRD's core partners, will also support these efforts by organizing and conducting focus groups to determine the appropriateness of the irrigation scheduling platform. DAE will engage in collecting preference data from farmers, providing expert knowledge, and sharing knowledge of water pricing structures. Further details of the research, validation, and adaptation procedure for the PANI apps can be found in Annex 10.

Farmers in Barisal, southern Bangladesh, apply irrigation to maize fields as part of research efforts to develop the PANI irrigation scheduling advisory app. Photo: U. Schulthess (CIMMYT)

Product 3. *Spatially explicit and meteorologically driven wheat blast (Magnaporthe oryzae Triticum, MoT) disease risk assessments for Bangladesh*

Prior to 2016, the fungal disease wheat blast (*Magnaporthe oryzae* pathotype *Triticum*) was found only in South America. When temperature, precipitation, and relative humidity conditions are right, and the disease inoculum is present, blast can attack wheat causing grain sterility and significant lowering yield. The appearance of blast in Bangladesh in 2016 caused alarm and concern for governments across the South Asian region. Blast again re-emerged in 2017 in Bangladesh, but with comparatively lower infection rates. Wheat area in southern Bangladesh nonetheless dropped from 62,763 hectares in 2016 to just 14,238 hectares over one year, a result of Government of Bangladesh policies recommending reduced production of wheat as a precautionary measure. Analysis of climatic conditions in South Asia however indicate that while there may be year-to-year variability in the disease's severity, blast will continue to be a problem in the future. 300 million people in South Asia consume over 100 million tons of wheat annually. The uncertainty in productivity caused by the establishment of therefore presents a significant threat to food security.

Activity in 2016-17:

CSRD has initiated a partnership with the University of Passo Fundo (UPF, Brazil) to develop an early warning forecasting system for wheat blast in Bangladesh. Because wheat blast has its origins in South America, and teams in Brazil have been working to mitigate its negative effect for many years, partnership with UPF was logical. The disease pathology and epidemiology team that CSRD has partnered with at UPF has developed a weather-based model for predicting early season inoculum build-up and wheat spike infection by wheat blast (Fernandes et al., 2017). The model calculates wheat blast inoculum potential and a spore cloud potential derived from models adapted from blast pathology literature to predict inoculum build-up and disease risk. Days favoring infection are calculated by relating temperature and relative humidity for the day derived the epidemic analysis in Brazil. Using data from 2001-2012, the UPF team could employ the model to successfully visualize and identify patterns in weather variables during two major outbreaks (2004 and 2009) in Paraná state in Brazil. The UPF team also developed an interactive risk-mapping tool that collects hourly real-time weather data to warn potential outbreaks. Building on this work, agreement was made with UPF to partner with CIMMYT under CSRD to adapt this model and graphical user interface to Bangladesh in 2017.

The preliminary model is available online in beta-form, and uses a similar inoculum build-up routine to determine when and where wheat blast outbreaks may occur. The model is currently being used to examine data collected in Bangladesh in February of 2017 on locations where wheat blast infections occurred (see the previous CSRD semi-annual report), and to calibrate the model to better fit conditions in Bangladesh. This work is ongoing at the time of writing. Additional field data will be collected in Bangladesh in February-March of 2018 to further validate the model.

The web-based graphical user interface for the prototype wheat blast risk assessment and early warning system in Bangladesh developed by the University of Passo Fundo and CIMMYT for Bangladesh through the CSRD project. Using forecasts of relative humidity (middle graph), temperatures (bottom graph), and precipitation (second from bottom graph), the model estimates wheat blast disease inoculum build-up potential (top graph) and spore cloud development (second from top graph) to the risk of wheat blast outbreak (red shading) on user-chosen dates and locations over a chosen time period (x-axis). The model also integrates the Decision Support System for Agrotechnology Transfer (DSSAT) model to predict wheat crop phenological stages most susceptible to wheat blast infection. This example shows the estimated risk of outbreak in Bhola District in south central Bangladesh. Field data will be collected throughout Bangladesh through the CSRD project in February and March of 2017 to improve model performance.

In addition, the CSRD server now installed at BMD permits the integration of numerical weather forecasts in the wheat blast model, thereby rendering it a tool for agricultural decision support and a key consideration in integrated pest management programs for farmers in Bangladesh. Once completed, this model should offer a tool whereby the Department of Agricultural Extension (DAE) can predict blast outbreak risks several days in advance of actual occurrence, so farmers can be alerted when and where it is necessary (or not necessary) to use fungicides for control. Where farmers do not need to apply fungicides, farmers' financial burden and risks to the environment are considerably lower.

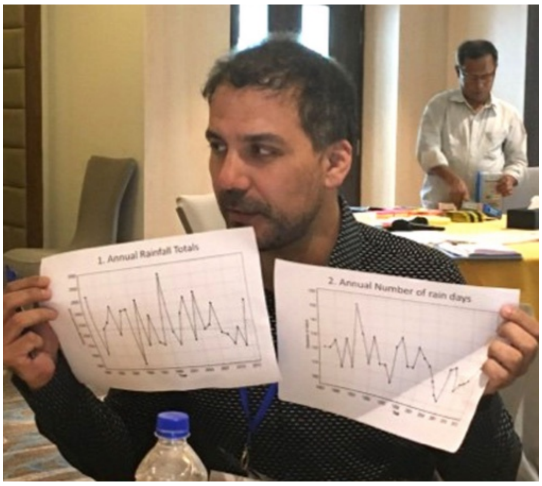
Planned activity in Quarters 1 and 2 of 2018:

Because of CSRD's strategic partnership with UPF, work on wheat blast model development is nearly 12 months ahead of schedule. A large-scale wheat blast field surveillance program is still necessary and is now being planned in collaboration with BARI, DAE, and two other USAID funded programs supporting work on wheat blast (CSISA Phase III in Bangladesh and a small 1-year investment by USAID/Bangladesh titled 'Training, surveillance, and monitoring to mitigate the threat of wheat blast disease in Bangladesh and beyond', both synergistically led by the CSRD Project Leader) for February-March of 2018. Following a series of consultations with CIMMYT's lead pathologists and UPF scientists, it was decided that field surveillance was a more expedient way to generate relevant data to calibrate the model to Bangladeshi conditions than the previously planned leaf wetting experiments described in the 2017 CSRD semi-annual report. Combined CSRD's work to improve forecast skill, the results the 2018 field monitoring and calibration efforts will be described in the semi-annual 2018 CSRD report.

Mr. Md. Abdul Mannan, climatologist at the Bangladesh Meteorological Department's Storm Warning Centre, discussing South Asian regional circulation observations with Dr. Clare Stirling, CIMMYT Senior Scientist and CCAFS coordinator working with CSRD, in Dhaka Bangladesh. Photo: T. Krupnik (CIMMYT)

Contribution of Activity 1.3.1 to CSRD's Action and Learning Framework:

Pillar 2, Indicators 2.2 and 2.3, Pillar 3, Indicator 3.1 and Pillar 4, Indicator 4.1 (see Annex 3).



Dr. Carlo Montes, CIMMYT Agricultural Climatologist working with CSRD, discusses the interpretation of long-term historical temperature and precipitation data in Dhaka, Bangladesh. Photo: T. Krupnik (CIMMYT)

Activity 1.3.2: *Agro-meteorological forecast services applications and systems for crops, fisheries and/or livestock developed and refined for medium-term decision making co-developed and refined*

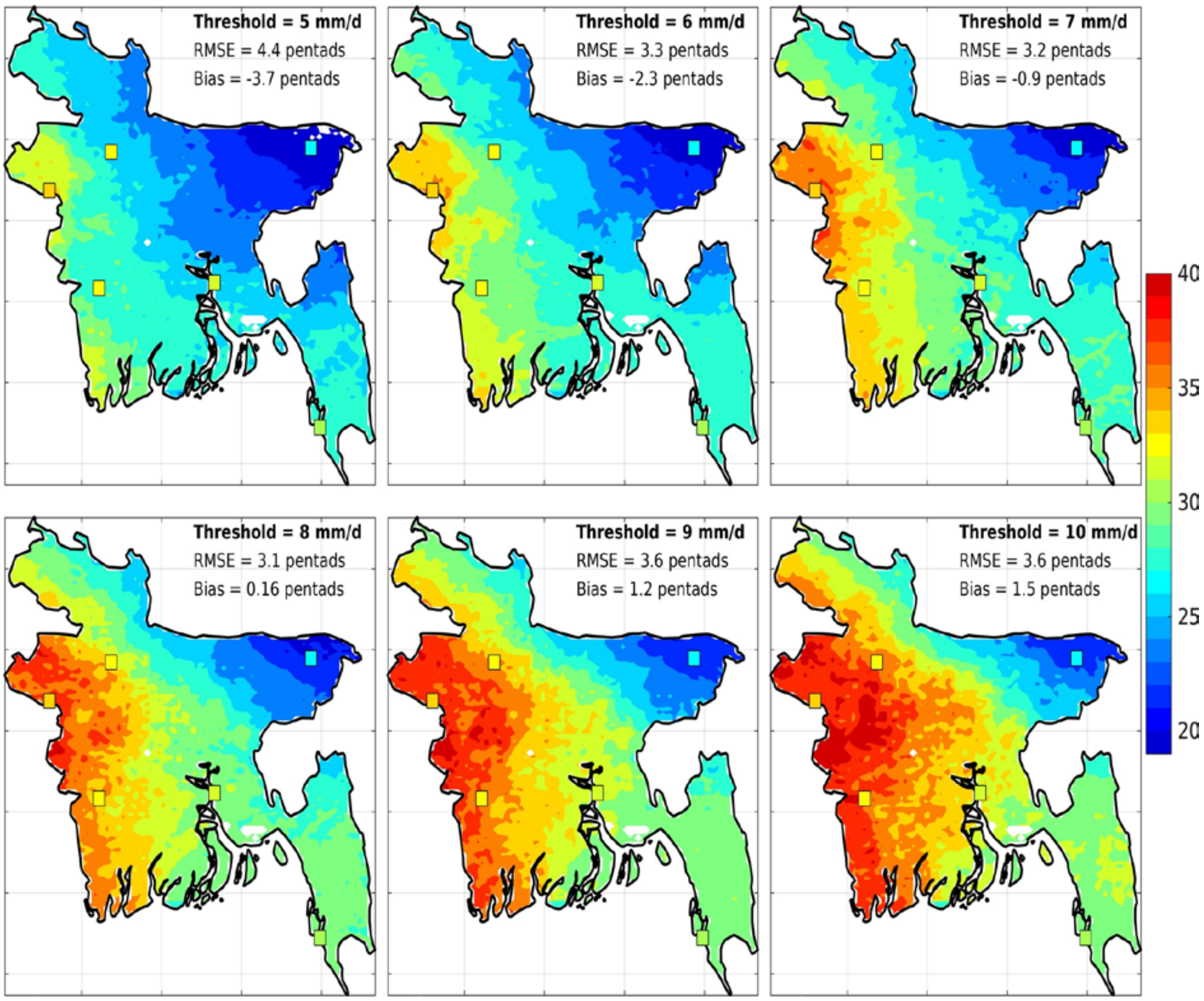
Background

Activity 1.3.2 of CSRD also responds to the request by BMD for CSRD following USAID's consultation for the Sector 3 Agro-meteorology track in 2016. Activity 1.3.2 develops improved seasonal forecasts and climatic stress maps using insights and techniques identified during the BMD skills assessment completed in 2017 (see Activity 1.2.1). These outputs will ultimately be made available on BMD's website, can be used by DAE and other development projects, including the World Bank funded Agro-Meteorological Systems Development project, to assist farmers and other relevant decision makers pre-season crop planning.

Product 1. *Improved seasonal forecasts and climatic stress maps developed and refined*

Activity in 2016-17:

A series of technical exchanges between CSRD partners have taken place to support Activity 1.3.2 Product 1. The first took place in Dhaka in July of 2017; the second one was held in November 2017. During each visit, Simon Mason, IRI Senior Research Scientist spent considerable time discussing technical needs for improving seasonal forecasting and communication of climate information to general audiences. Further exchanges are scheduled for March – April of 2018, to be held at IRI in Palisades in New York, with BMD senior staff attending an intensive two-week training session to boost technical knowledge of forecast methodology and skill. During this visit, which had to be rescheduled due to delays in reaching formal agreement with the Ministry of Defense to permit BMD's active participation in CSRD, the Climate Predictability Tool (CPT) developed by IRI, which can be used to make seasonal forecasts, will be fine-tuned increase forecast skill. This is crucial to improve seasonal forecasting for Bangladesh, which tends to be less straight-forward to predict than other temperate and sub-tropical regions. The CSRD team is therefore currently exploring alternative drivers of seasonal climate (e.g. sea surface temperature, El Niño Southern Oscillation phases) to be further examined during the visit to IRI.



Preliminary outputs of multi-year monsoon onset pentads for different threshold precipitation amounts identified by farmers in Bangladesh. Square-symbols represent locations were locally-relevant monsoon onset dates were provided by farmers.

In addition, the collection and quality-control of long-term climatic data produced by BMD is under way, together with the identification of suites of seasonal climate predictors variables to be explored as inputs to CPT. At present, work focusses on the study of the monsoon onset definition for Bangladesh and South Asia along with its potential seasonal predictability. This topic was identified as a core research need during the BMD skills assessment, and was highlighted by farmers in focus groups conducted under Activity 1.1.1 due to its importance for planning land preparation and transplanting of monsoon season *aman* rice in Bangladesh. As a preliminary result, the figure below shows the monsoon onset Julian pentad (5-day periods) using different threshold precipitation amounts together with field onset dates provided by farmers through surveys and ethnographic study provided by Stiller-Reeve et al. (2015). These maps indicate that monsoon onset can be highly sensitive to the rainfall amount used as a threshold, and that a high spatial variability exists, with a clear pattern represented by an East-West gradient.

Planned activity in Quarters 1 and 2 of 2018

In addition to predicting monsoon onset, Activity 1.3.2 Product 1 item also considers the mapping of risk occurrence of extreme climatic events at the county scale for specific crops important for food security such as rice and wheat, which will serve as a basis for the subsequent activities related to the seasonal climate forecasting of crop stress conditions over the region. The seasonal (months) and weather (days) scale forecasts will include variables such as early pre-monsoon season heat conditions that can damage crops during flowering, probabilities of dry spells within the monsoon season (consecutive 5 d < 1 mm seasonal forecasts), and cold spells during the period from November and March during which winter *boro* season rice can suffer from yield-reducing cold injury. These products can be used by farmers to make decisions in terms of irrigation to mitigate thermal stresses or water deficits, for example. Progress on these topics will be further reported on in the 2018 semi-annual CSRD report.

Contribution of Activity 1.3.2 to CSRD's Action and Learning Framework:

Pillar 2, Indicators 2.2 and 2.3, Pillar 3, Indicator 3.1 and Pillar 4, Indicator 4.1 (see Annex 3).

Objective 2: Collaborative development and refinement of South Asian regional-scale agro-climate decision support tools, services, and products

Sub–Objective 2.1: Support to facilitate the development and refinement of regional decision support tools, services, and products

Activity 2.2.1: *Coordination support for the International Centre for Integrated Mountain Development (ICIMOD) and partners in drought forecasting*

Product 1. *Ongoing support for ICIMOD and partners*

Background

Agriculture plays a central role in South Asian economies, lives, and livelihoods. While recent changes in the intensity of rainfall events combined with increased risk of critical temperatures being exceeded more frequently, increased climate related losses are expected in the agricultural sector. Climate information and services therefore hold potential to contribute to more resilient rural livelihoods by increasing farmers' ability to plan for and cope with climate related uncertainties. Around this region, capacities in area of agro-climatic services are highly differentiated.

Defining drought

The concept of drought originates from a deficiency of precipitation over an extended period that results in a water shortage for an activity, group, or environmental sector Drought however is not solely a physical occurrence. Both conceptual and operational definitions of drought are therefore useful Take for example "drought is a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield". This is a conceptual definition useful for policy development, whereas an operational definition may be more useful in acting to mitigate the effect of drought, as it may define the onset, severity, and end of droughts. Operational definitions nonetheless are complicated in that they vary by region and situation, and as such may be described as 'slippery'.

More appropriate definitions of drought should be location and impact specific. Four types of drought are commonly categorized: (i) meteorological drought: deficiency of precipitation compared to an average value over an extended period; (ii) agricultural drought: reduction in soil moisture below the levels required by crops at different phenological stages, with implications for slowed growth and/or reduced yield, and (iii) hydrological drought: when the lack of precipitation reduces surface and subsurface water resources and recharge compared to normal levels, and finally (iv) socio-economic drought: changes in human activity patterns that result from precipitation or moisture deficits, which are usually associated with the thee definitions provided above.

References: NDMC, 2017 and Wilhite 2000.

Recent advances in forecasting science and understanding of ENSO impacts on South Asia regional climate patterns may hold promise to provide insights that can be used to develop pre-season advisories to support farmers in climate related decision making. In past limited infrastructure constrain the potential of ICTs for agro-meteorological advisories to farmers. Where drought risks are an issue for farmers reliant on predominantly rain fed production, provision of locally calibrated, easily accessible, decision-relevant and user oriented information in the form of drought advisory service can help communities to cope with drought related vulnerabilities.

To expand the use of earth observation tools and technologies while facilitating farmer advisory services in South Asia, a collaborative effort is now underway to strengthen existing or establish new drought monitoring and early warnings in four South Asian countries including Afghanistan, Bangladesh, Nepal and Pakistan. This is accomplished by incorporating standard ground-based observations of drought with earth observation (satellite derived) datasets, combined with the integration of numerical forecasting models. ICT based agricultural drought monitoring platforms, hosted at national agriculture and meteorological institutions, are also being developed to enable the national translation of scientific data into understandable agricultural advisories of relevance to smallholder farmers. This emerging operational drought monitoring and forecast system is supported by the NASA SERVIR Hindu-Kush Himalaya hub and CSRD in South Asia. The overall goal of this drought monitoring and forecasting service is to produce and deliver climate information for drought monitoring and early warning to contribute to preparedness and planning well ahead of specific drought events. Specific goals include:

- Development of regional agricultural drought monitoring and forecasting data products
- Enhancing national drought monitoring systems by incorporating high spatial and temporal resolution satellite data products and contextualizing drought indices with local cropping patterns and crop calendars
- Strengthening of technical capacities and information/data communication platforms among national partners

This NASA SERVIR Hindu-Kush Himalaya and CSRD supported service aims to provide drought monitoring and seasonal forecast conditions on 10-days interval with a spatial resolution of 5 km^2. In Bangladesh, 1 km^2 spatial scale monitoring methods will also be evaluated. Associated databases on spatial and temporal cropping pattern distribution are also expected to increase the understanding, interpretation, and effective use of the service by decision makers and policy planners in the agriculture sector.

The sub-seasonal to seasonal (S2S) South Asia Land Data Assimilation System (SALDAS) is a data assimilation and forecasting platform that is intended to capture hydrological extremes on short to seasonal timescales. The potential to use SALDAS to develop decision-relevant S2S forecasts for drought across south Asia is being assessed as part of the CSRD project[2]. The system leverages the South Asia Land Data Assimilation System while also making use of North American Multi-Model Ensemble forecast efforts. Keeping with the S2S framework of the system, preparation options and forecast probabilities are being tested in Afghanistan, Pakistan, Nepal, and Bangladesh for a range of lead-times. Forecasts will be initialized from South Asia LDAS simulations that have been optimized to provide realistic estimates of soil moisture anomaly and snow storage. Preliminary evidence from other countries indicates that quality initialization of these surface fields can contribute to increases in skill for seasonal hydrological forecasts. The SALDAS platform will support multiple land surface models and meteorological forcing datasets to characterize uncertainty. Sub-seasonal to seasonal hydrological forecasts will also be produced by driving SALDAS with downscaled meteorological fields drawn from an ensemble of global dynamically-based forecast systems.

Activity in 2016-17:

The SALDAS is being implemented in the Hindu Kush Himalayan (HKH) region through ongoing partnership between CSRD and ICIMOD, the latter with NASA and Johns Hopkins University.

CSRD's contribution is facilitate the examination of SALDAS and drought forecasting in Bangladesh compared to the other countries where is being tested and validated. The beta version of SALDAS has been successfully deployed on Linux platform and is now running at ICIMOD headquarters in Kathmandu. The baseline LSAS system includes a Land Surface Data

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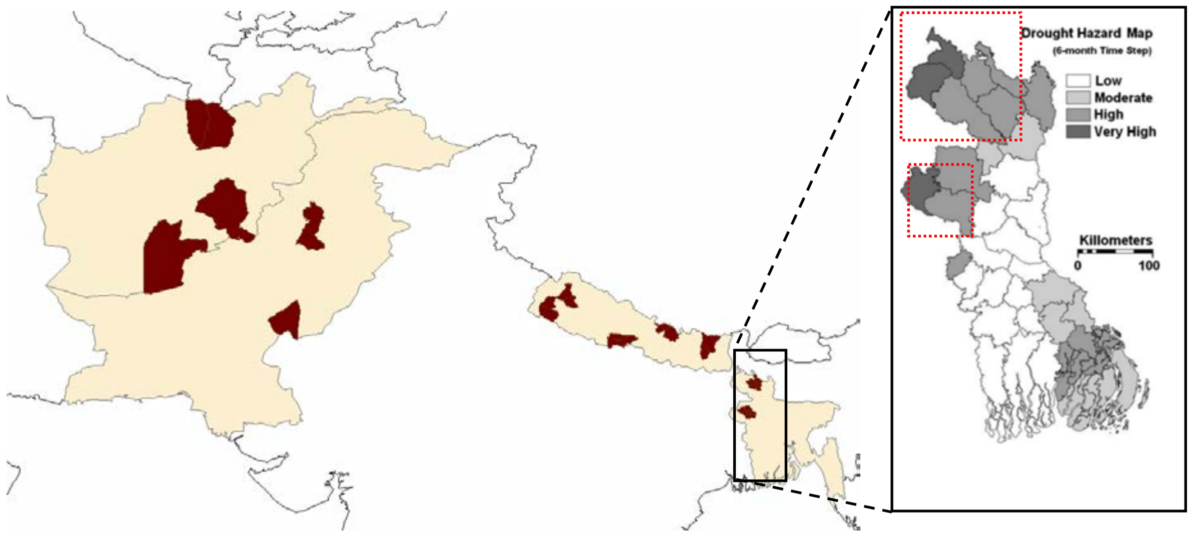
[2] To provide an open and spatially integrated information decision support system for South Asia, the South Asia Land Data Assimilation System (SALDAS) has been designed to provide best-bet estimates of hydrologic states and fluxes. SALDAS is based on the LDAS platform and can be used to analyze historical or near-real time data. The system integrates land-surface models with ground and earth observation datasets. These include both meteorological and climate information, as well as landscape and geophysical observational data. The system applies these data frameworks to run ensemble land-surface model simulations that are regularly updated with modeled variables (for example soil moisture) to improve simulations. The NASA Global Modeling and Assimilation Office and the NOAA Climate Prediction Center are also now sufficiently robust that they can be applied to water and agricultural management. By integrating seasonal forecast estimates derived from this source with the LDAS, the potential for additional value in hydrological prediction is being assessed.

Some examples of LDAS's use include the following:

- The World Resources Institute (WRI) Aqueduct water information platform (http://www.wri.org/our-work/project/aqueduct)
- The North American LDAS (NLDAS), utilized by the U.S. National Climate Assessment (http://nca2014.globalchange.gov/)
- The U.S. Drought Monitor (http://droughtmonitor.unl.edu/ , https://lis.gsfc.nasa.gov/blog/nldas-one-inputs-new-quickdri-drought-index) and the
- The Famine Early Warning System LDAS (http://ldas.gsfc.nasa.gov/FLDAS/FLDASgoals.php), that supports U.S. food aid and food security planning in East Africa.

Adding to these efforts, LDAS is now being implemented as part of CSRD for South Asian regional drought monitoring support as the South Asia Land Data Assimilation System (SALDAS). The guiding principle for this approach is that models and observations – including satellite observations and standard ground-based observations are integrated in a single platform – to provide information that is valuable for water resource analysis and decision making processes.

Toolkit (LDT) and Land Surface Model (LSM), while current SALDAS version includes data from Noah, CHIRPS and GDAS. Emphasis is being placed on local calibration and validation of data products through retrospective analysis of time series data as well as setting up additional field based measurement networks (see Annex 12).



Countries (yellow) and locations (red) involved in the NASA SERVIR Hindu-Kush Himalaya drought monitoring and forecasting efforts. The addition of Bangladesh in 2017 was made possible through CSRD. Inset: Drought hazard map indicating risks in locations where CSRD is working. Areas outlined in red dotted boxes were chosen for further study in Activity 2.2.1.

To contextualize monitoring products with local cropping systems information, district level farming practices calendars are being compiled and cross checked with expert knowledge. Satellite remote sensing based high resolution crop distribution maps are also being developed as part of the inputs for the drought monitoring and forecasting platforms. Key national partners working in meteorology and agriculture in Afghanistan, Pakistan, Bangladesh and Nepal have been closely involved in product design, and are now assisting with validation and operationalization processes. Based on the drought concepts and definitions described above, progress made through 2017 in regional and national drought monitoring products are explained below.

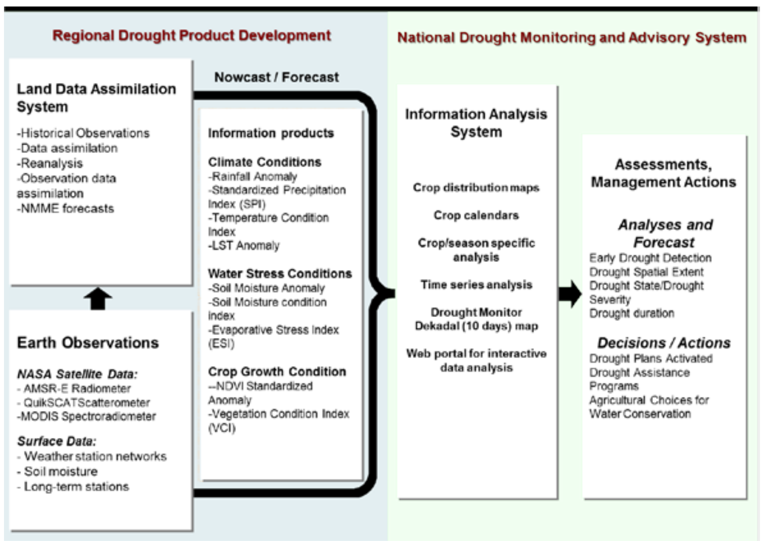
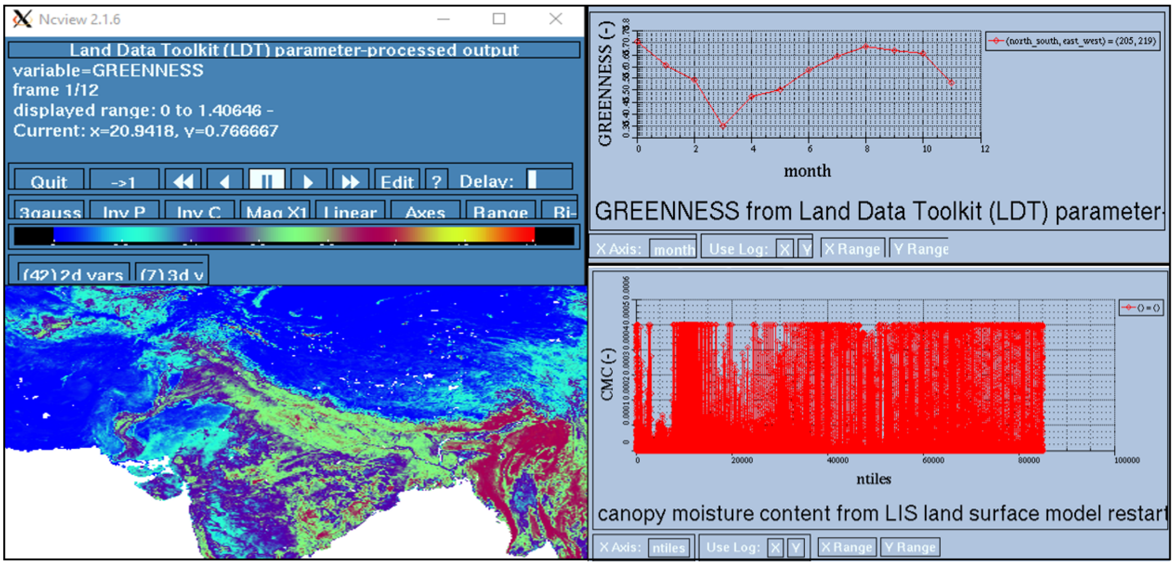


Illustration of key components of the regional drought monitoring and advisory system under development by the NASA SERVIR Hindu-Kush Himalaya and CSRD program, which are divided into (i) regional drought product development and (ii) utilization of drought monitoring products in national/local context for decision making process.

Meteorological Drought

Scientists at the Famine and Early Warning System (FEWS NET) used 30 years (1982-present) of multiple satellite data sources and ground observations to produce a 5 km^2 spatial resolution and 5-day temporal resolution operational rainfall data product called Climate Hazards Group (CHG) Infra-Red Precipitation (RP), or CHIRP dataset Along with data products, the CHG also produced tools to incorporate local meteorological stations data to improving accuracy. This product is termed the gridded Climate Hazards Group Infra-Red Precipitation *with Station* (CHIRPS) data, also available at 5 km spatial resolution.

Work undertaken in 2017 and continuing in 2018 aims to improve CHG data products by comparing CHIRP with CHIRPS for Afghanistan, Pakistan, Nepal and Bangladesh through local level data integration. Results from these initial analyses can be found in Annex 12. Resulting climate-based drought Indices will include rainfall distributions and anomalies and standardized precipitation index (SPI).



A screen shot of the graphical user interface for the South Asian Land Data Assimilation System (SALDAS) deployed at ICIMOD in collaboration with CSRD. Preliminary Land Information System (LIS)-derived drought indices for temperature condition index (TCI), soil moisture condition index (SMCI) and a simple precipitation deviation index can now be produced, all calculated at 10-day, 5km resolution using LIS model Noah3.6. Retrospective analysis is being performed for major drought events in the past 20 years that would be particularly important to see the ability of the system to capture anomalies.

Land surface heat stress

Land Surface Temperature (LST) quantifies surface temperature (also known as 'skin temperature'), as opposed to air temperature. The latter is which is more commonly applied in crop physiological studies such as those described in Objective 1, Sub-Objective 1.3, Activity 1.2.1, Product 1. Because some physiological activities (for example evapotranspiration) of crop canopies however are likely to be closely related to their actual (canopy) rather than air temperature, researchers have argued that LST could potentially be used as a secondary and indirect indicator of canopy physiological activity. Studies have provisionally indicated that yield depression caused by heat stress could potentially be measured using satellite derived LST on an area-wide basis. As such, timely monitoring of LST occurrence that deviates from average conditions could be of use in crop management decision support.

The MODIS Land Surface Temperature and Emissivity products (LST/E; MOD11A1 from the Terra satellite and the MYD11A1 from Aqua satellite) map land surface temperatures and emissivity under clear-sky conditions, and could therefore be suited to the drier winter season in South Asia. Satellite derived heat stress indices include: LST distributions and LST standardized anomalies, in addition to a Temperature Condition Index (TCI) calculable using the following formula, where BT indicates Brightness Temperature measured from satellite image reflectance values:

$$TCI = \frac{BT_{max} - BT}{BT_{max} - BT} \quad (1)$$

Agricultural Drought

Agricultural drought links meteorological (or hydrological) drought to agricultural impacts. Key phenomena include precipitation shortages, exceedance of actual to potential evapotranspiration, and crop heat stress linked to soil water deficits. In agriculture, spatial variability in soil moisture (SM) can be responsible for low and/or variable crop productivity. Physical measurements or modeling of SM is however logistically challenging and has tended to be costly. In the last two decades, however, the increasing numbers of satellite mounted sensors with complete, periodic and synoptic coverage have boosted the ability to estimate earth surface parameters including soil moisture from remotely sensed data.

The current implementation of SALDAS in the LIS provides simulations of distributed water balances 5 to 10 km^2 gridded spatial resolution. The system supports a suite of advanced land surface models and has been validated using numerous meteorological forcing datasets (MERRA-Land, GDAS, Princeton, CHIRPS, etc.), and can ingest GRACE satellite-derived terrestrial water storage estimates. SALDAS simulations were tested in 2017 to provide realistic estimates of soil moisture distributions and anomalies including a SM Condition Index (SMCI) calculated as follows:

$$SMCI = \frac{SM_i - SM_{min}}{SM_{max} - SM_{min}} \quad (2)$$

Temporal variation in evapotranspiration (ET) to potential ET can be described using the evaporative stress index (ESI), using remotely sensed information from the thermal infrared (TIR) atmospheric window channel (10–12µm). This approach can highlight areas with anomalously high or low rates of SM water use at a landscape scale, as indicator of potential drought. In combination with shortwave data of vegetation cover fractions, evaporative fluxes at the 5–10 km^2 spatial resolution can be estimated using the Atmosphere-Land Exchange Inverse Model at 7-day interval periods, each of which can be compared with normal ET and PET conditions over the past 15 years.

The Normalized Difference Vegetation Index (NDVI) – the normalized difference between the near infrared (NIR) and visible red reflectance of a vegetation surface – is a good indicator of crop leaf area and ground cover. Low NDVI indicates low crop productivity, and when combined with measures of SM and other water stresses, drought can be inferred. Time series NDVI can therefore be useful in measuring in trends in crop productivity and water stress over or across growing seasons.

The Moderate Resolution Imaging Spectroradiometer (MODIS) acquires NDVI at 16-day time intervals at 250 m^2 resolution. A total of 253 NDVI 16-day composite images are being employed in the SALDAS analyses to derive NDVI distributions and standard anomalies (i.e. NDVI z-score of the compared to the historical records, in addition to an integrated vegetation Condition Index (VCI) calculated as follows:

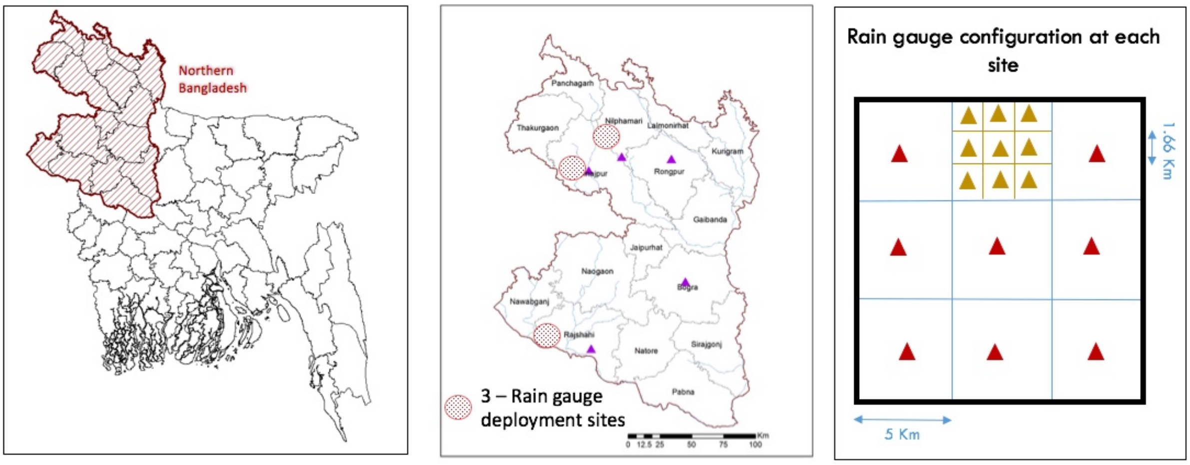
$$VCI = \frac{NDVI - NDVI_{min}}{NDVI - NDVI_{min}} \quad (3)$$

A collection of indicators and indices were processed in 2017 that are under consideration for drought condition monitoring in South Asia. Each index however needs to be evaluated and discussed in each country context to determine their suitability for national agro-climatic zoning differences and cropping practices in 2018.

Validation and calibration of monitoring data products

The Climate Hazard Group's CHIRPS rainfall datasets is one of the most crucial for the functioning of the SALDAS. Like many other derived data products, CHIRPS data also come with some level of uncertainty that could affect the accuracy of predictions when used for drought assessment. Work in CSRD is therefore focusing on national calibration and validation of data products. This is being accomplished through retrospective analysis of time series precipitation gauge data, as well by setting up additional field based measurement networks at varying spatial scales. At the regional level, the CHIRP dataset (1981 – 2015) will be evaluated for its accuracy in comparison to station data collected from national meteorological agencies from Afghanistan, Bangladesh, Nepal and Pakistan.

Bangladesh's northern region has higher drought frequency but fewer ground weather stations. To compensate this spatial gap, additional 51 additional manual rain gauges and102 soil moisture (1m depth) PR access tubes have been installed in three key locations of Dinajpur, Nilphamari and Rajshahi districts (Annex 13). Data will be collected daily for a full year to facilitate the validation and calibration of CHIRP data products in this region.



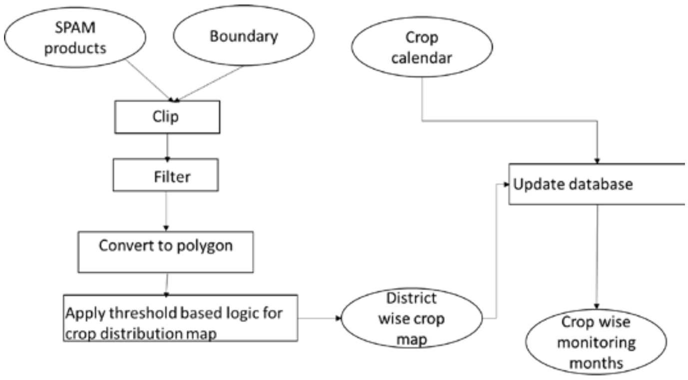
Rain gauge deployment locations in Bangladesh (left) and schematic in Rajshahi and Dinajpur Districts (middle) for 12+ month monitoring and dataset development per the gridded precipitation sampling plan to enable 1 km² downscaling assessment made possible through CSRD (right). Rain gauges and soil moisture monitoring equipment have been installed in all locations.

Establishment of computing facilities at ICIMOD and BARC

Based on the high computational requirements needed to deploy the SALDAS system with S2S forecast capabilities, specifications for a high-performance server was designed in consultation with the NASA Applied Science Team (NAST) from Johns Hopkins University. Through support from CSRD acquisition of hardware has completed and deployed at ICIMOD in Kathmandu. In addition to facilities installed at ICIMOD headquarters, 1 Work Station, 3 Desktop computers and 1 Laptop computer along with 56 TB server storage and other accessories were acquired and handed over the Bangladesh Agricultural Research Council (BARC) to upgrading support SALDAS in Bangladesh. Full details of these computer systems are summarized in Annex 14.

Planned activity in Quarters 1 and 2 of 2018:

In addition to daily precipitation and soil moisture measurements in 51 additional locations across north western Bangladesh used for the 1 km^2 downscaling assessment, work in Activity 2.2.1 will focus on further visualization and statistical analysis of drought monitoring variables. To track the timing of monitoring and seasonally aggregated statistics, crop masks and crop calendrers for major cereals will be produced. Combined with expert knowledge, the Spatial Production and Allocation Model (SPAM, 2005 v3 r1), which permits customized data fusion and disaggregation of crop statistics to administrative units, will be used to create district-wise crop masks.



Preliminary decision tree for deriving district level crop area masks for drought monitoring and forecasting across the Hindu-Kush Himalaya region including Afghanistan, Pakistan, Nepal and Bangladesh.

A description of the anticipated process of SPAM product development for Bangladesh is as followed. Firstly, crops of interest (in this case maize, rice, and wheat) are clipped with country boundaries. The pixels having "No Data" are filtered and replaced by zeros, with the result converted to polygon shapefiles. District-wise crop maps will then be generated by applying thresholds and expert knowledge. Finally, months during which rice, maize, or wheat are grown, and values (0-3) are inserted as attributes using crop calendars, with values (0, 1, 2, and 3 corresponding to fallows, planting, mid-season and harvest, respectively) will be applied to the expected phenology for each month of interest in the analysis. Preliminary rice and wheat crop suitability area masks are available for Afghanistan, Pakistan, and Nepal. Insights from this work will be used to complete SPAM based crop masks for Bangladesh to be reported on in the 2018 CSRD semi-annual report.

Contribution of Activity 2.2.1 to CSRD's Action and Learning Framework:

Pillar 1, Indicator 1.1, Pillar 2, Indicator 2.2, and Pillar 4, Indicator 4.1 (see Annex 3).

Activity 2.2.2. Legume disease forecasting and warning systems

Product 1. *STEMPEDIA: Lentil Stemphylium blight disease forecasting systems in Bangladesh, Nepal, and India*[3]

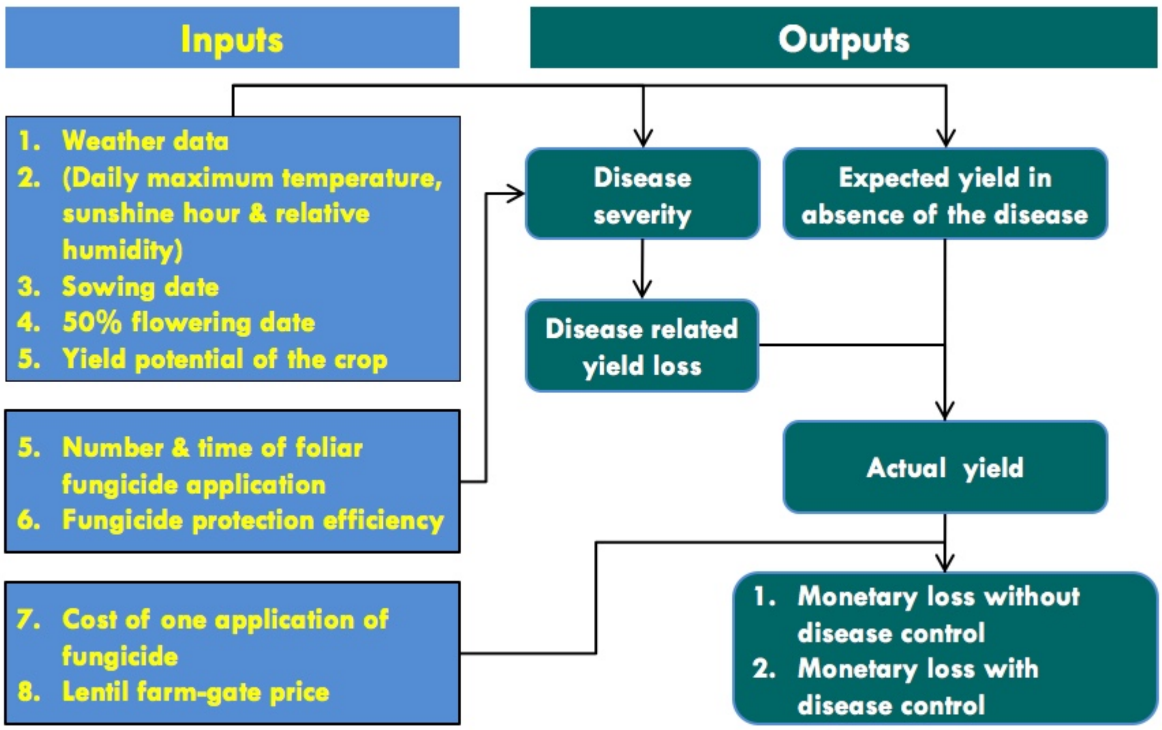
Background:

Lentil (*Lens culinaris*), an economically profitable legume crop, is an integral part of many nutrition-sensitive cropping systems in South Asia. *Stemphylium* blight (SB) disease, caused by *Stemphylium botryosum*, however presents considerable threat to sustainability of lentil production in the region. The disease develops as small lesions on leaves. These can be found on the lower canopy then spread to the upper canopy of the crop. These small lesions eventually

[3] Note that this work stream replaces 'Precision Nutrient Management' as described in the original CSRD SOW for South Asia. The change to the current work stream was agreed with USAID in Q3 of 2017, and was chosen because of the potential for rapid model validation and impact in the context of integrated disease management across Nepal, India, and Bangladesh.

become larger, irregularly shaped lesions that can kill whole leaves, branches, and plants. Once spreads, it can cause up to 60% yield loss (Mwakutuya 2010). *Stemphylium* is also commonly reported in Bangladesh, India and Nepal.

Foliar application of fungicides for disease control is recommended from mid- to the end-January; this recommendation, which was based on research station studies, however does not always work in farmers' fields (Salam et al. 2016). This appears to be because the severity of the disease varies not only between locations within a year, but also between years within a location. Such variability is caused by differences in temperature, relative humidity, and sunshine hours within location-specific microclimates, making it difficult for farmers to properly formulate financially-viable fungicide-based disease control measures. To address these issues, the 'Stempedia' model was developed by Salam et al. (2016) to assess the regional and seasonal risks of SB in lentil, and to formulate principles for need-driven (rather than blanket preventative application) foliar fungicide application to achieve financial gains. Stempedia is a weather-based model. It has eight inputs (see figure below).



Structure and operational pathways of 'Stempedia' on predicting Stempedia blight disease in lentil (modified from Salam et al. 2016).

The Stempedia model is driven by three climatic variables (Inputs 1-3), including daily maximum temperature, sunshine hour and relative humidity. These data are used to simulate the severity of the disease in a relative scale of 0 (no disease) to 5 (the highest disease). Days from sowing to 50% flowering from sowing of the crop (Input 4) also influences the disease severity. The time and number of foliar fungicide application (Input 5) and its efficacy (Input 6) moderate the disease severity in a simulated environment. The yield loss is then estimated from the predicted disease severity. The sowing date of lentil and its yield potential calculate the expected yield in a hypothetically disease-free crop, which is moderated by expected disease-inflicted yield loss to estimate the actual yield. The costs of fungicide and application (Input 7) and farm-gate price of lentil (Input 8) covert actual yield into economics of the disease and/or its fungicide control.

Activity in 2016-17:

Dr. Abhijeet Ghatak, Associate Professor of Plant Pathology at Bihar Agricultural University (BAU) and CSISA staff cooperate with CSRRD to count Stemphylium blight infected lentil plants in the taal region of Bihar in India as part of CSRD. Photo: T. Krupnik

A farmer in Jessore, Bangladesh displays two Stemphylium infected lentil plants. Photo: MK Hasan (CIMMYT)

NARC, CSRD, and CSISA staff meeting in Nepalganj to initiate efforts for Stemphylium lentil disease monitoring and weather-based forecasting modelling. Photo by NARC support staff.

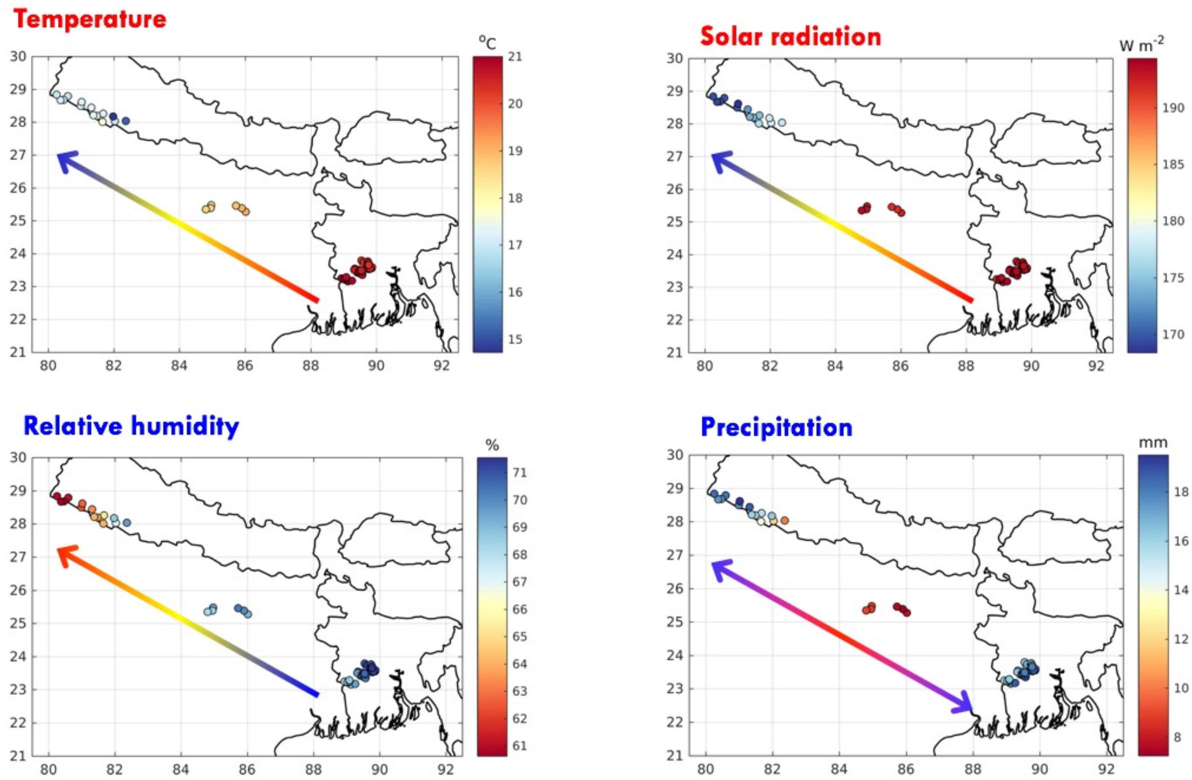
As a preliminary step, the Stempedia model's simulation was quantitatively tested with long-term research station data from Bangladesh and Nepal (kindly supplied by BARI and NARC, respectively), both without and with fungicide application scenarios. Applied to the central regional district of Bangladesh, the model identified that gradual reductions in sunshine hours (increased cloudiness) have increased disease severity over the last 30 years. The model identified the north-western regional districts of Bangladesh as more disease prone than the central or south-eastern regional districts. Datasets in Nepal were too small to investigate geographic variability, but in both countries, Stempedia predicted seasonal variability of the disease and showed reduced severity with delayed sowing. The best financial return on disease control was found with an early fungicide application, as soon as the disease appeared during initiation of flowering, followed by further application(s) if a disease-producing environment was expected.

These results indicated that 'Stempedia' has potential to be used as a tool for forecasting SB disease in lentil. However, the model has been validated only with limited datasets, and in Bangladesh and Nepal only. Work in CSRD therefore focusses on intensive efforts to collect field data to validate and re-calibrate the model to assure that it properly functions across a variety of microclimatic environments and at full scale field application. To this end, Objective 2, Activity 2.2.2, Product 2 aims to:

- Gather data, relevant to testing 'Stempedia' model, from multi-location sites of lentil growing regions in Bangladesh, India and Nepal in the in 2017 and 2018's lentil growing seasons
- Validate and re-calibrate the model with these field data.
- Convert the model into an open-access format in an R code driven environment

- Provide a framework that integrates improved weather forecasts upon to predict Stemphylium blight disease in Bangladesh, and potentially in India and Nepal.

In collaboration with the USAID and Bill and Melinda Gates Funded CSISA project, CSRD has established *Stemphylium* field monitoring locations for over 300 lentil farmers' fields in Bangladesh, Nepal, and India (see Annex 13 for sampling protocol details). Sites have been chosen so that they represent a gradient of climatic variables used to drive the Stempedia model, thereby providing more stringent evaluation of the model's performance in differing environments, and generating a high-quality dataset for model re-calibration, as shown below. In addition, the key developer of the 'Stempedia' model has been engaged in by CSRD in late 2017 as a consultant. The structure and operational principles of the model have been briefed to CSRD in Bangladesh, Nepal and India CSISA staff (who will be collaborating with CSRD on an in-kind basis) through formal presentation and field visits.



Gradients in historical temperature, solar radiation, relative humidity, and precipitation derived from the WoldClim climatology dataset at 1 km² resolution across field observation and sampling locations for lentil Stemphylium disease in the western terrain region of Nepal, the state of Bihar in India, and across Jessore, Faridpur, Rajbari, and Jheneidah Districts in Bangladesh. Sites have been chosen based on the land area and cultivation importance of lentil, reports of Stemphylium disease severity, and differences in climatology. The latter is crucial for validating the performance of the STEMPEDIA model in different agro-climatological zones in South Asia where Stemphylium presents an increasing problem for lentil production.

Planned activity in Quarters 1 and 2 of 2018:

The following activities will be completed in the first two quarters of 2018, and reported on in the CSRD semi-annual 2018 report.

- Final selection specific monitoring fields in Bangladesh, India and Nepal as clarified in Annex 13 (Before January 12, 2018)

- Formal training of temporary scientific staff who will be engaged in monitoring and data collection (Before January 12, 2018)
- Field data collection (January 12-March 15, 2018)
- Coding of the model into R to later develop and Rshiny based graphical user interface (before mid 2018; preliminary coding is already completed)
- Data analysis, model validation and calibration, as required (March 15-May 2018)
- By mid 2018, completion of a preliminary report on 2018 model performance

Based on the above, further field data collection, validation, and recalibration will take place in the 2018/19 lentil season in the same countries and fields.

Contribution of Activity 2.2.2 to CSRD's Action and Learning Framework:

These efforts contribute to Pillar 2, Indicator 2.1, and Pillar 4, Indicator 4.1(see Annex 3).

Activity 2.2.3. Application of historical, near-term, and future climate data applied to develop spatially explicit wheat blast (*Magnaporthe oryzae* Triticum) disease risk assessments for South Asia

Product 1: Climatically driven regional disease risk assessment for wheat blast (*Magnaporthe oryzae* Triticum)

Background

Activity 2.2.3 is builds on wheat blast forecasting efforts undertaken in Activity 1.2.1 by exploring the potential climatic suitability for wheat blast in the broader South and South East Asian region, including China. Yet although political delegates from Bangladesh, India, and Nepal all initially endorsed the need for wheat blast early warning systems during 'Regional Consultation Meeting in Response to the Wheat Blast Epidemic in Bangladesh and Beyond', held in Kathmandu in 2016, the subject remains very politically sensitive outside Bangladesh. This is most likely due to the threat to food security and hence political stability in other South Asian nations. Media reports of the spread of wheat blast from Bangladesh into West Bengal in India came to light in 2017. Governmental officials in West Bengal reacted by enforcing the burning of potentially disease infected fields. The Government of India however has not yet officially announced that wheat blast may be present within its borders. No incidence of wheat blast has conversely been reported in Nepal, and considerable uncertainty remains regarding the habitat suitability of the disease over the broader region. Activity 2.2.3 responds by providing exploratory data analyses of the risk of wheat blast spread and establishment in the broader South and South East Asian region, including China. This analysis is driven by coarser climatcic data than used in Activity 1.2.1, which

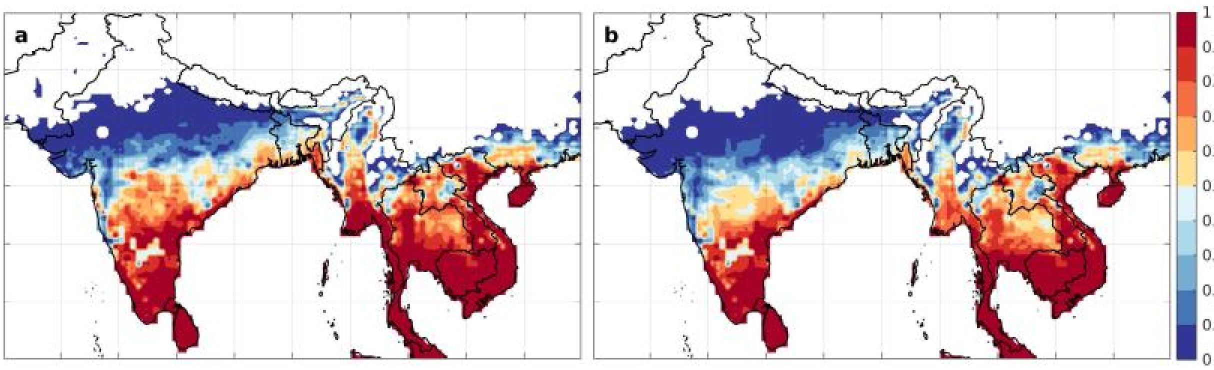
A wheat crop with severe wheat blast disease infection. In a healthy wheat crop, the heads (tops) of the wheat plants would still be green. In this photo, all grains are infected and show characteristic wheat blast bleaching, resulting in significantly lower yields. Photo: JCM Fernandes.

relies on hourly weather information. Activity 2.2.3 now makes use of daily data, which permits the wider applicability of analysis using generic weather generating models and resulting datasets.

Activity in 2016-17:

As alluded to above, CSRD's ability to implement a regional tool to forecast the risk of wheat blast outbreak is conditioned by the availability of appropriate and high quality meteorological data in the region, which is contingent on achieving official cooperation in each country to pursue early warning systems. While Bangladesh has openly acknowledged the establishment of the disease, India has not yet done so on an official basis, and officials in Nepal have been relatively silent on the topic since 2016. As such, CSRD is waiting for clearer guidance from our governmental partners these countries on how they choose to proceed in this area. In the interim period, CSRD's efforts focus on preliminary studies related to the assessment of wheat blast risk across South and South East Asia using climate information derived from different sources. Based on the existing knowledge regarding the relationship between wheat blast incidence and severity and climate variables such as air temperature and relative humidity, this Activity 2.2.3 provides exploratory knowledge about the variability in the climate-associated wheat blast risk in the countries of South and South East Asia where wheat is a crop of importance.

This has been accomplished using data fusion approaches whereby historical climate data from national station observations and gridded products, together with climate model-based future projections, are applied used to understand the variability in conditions favorable for wheat blast outbreaks, their trends and dynamics, and the relationship with large-scale climate drivers such as El Niño and La Niña, Pacific Decadal Oscillation, or circulation patterns. As such, this regionally focused analysis is broader and more comprehensive than that described in Activity 1.2.1 that provides a more rapid solution for country-specific disease forecasting. The broader regional analysis undertaken in Activity 2.2.3 conversely is useful to identify areas with higher wheat blast risk, their variability in time, and association with other factors that can be later incorporated into predictive tools developed in Activity 1.2.1.



Preliminary climate suitability map outputs showing the probabilities of wheat blast establishment (a) and outbreak (b) in South Asia based on 30 years (1980-2010) climatology and methods developed by Cruz et al. (2016).

As a preliminary result, the figure above shows the generated maps of probabilities of wheat blast establishment and outbreak in South Asia after applying a risk infection model presented by Cruz et al. (2016) for the United States. Applying this model to the South and South East Asian region, these very preliminary maps show a high degree variability in the establishment and outbreak probabilities, which follows a clear latitudinal pattern. According to Cruz et al. (2016) areas with probabilities ≥ 0.1 correspond to suitable climate conditions for wheat blast. This analysis – which must be stressed as preliminary – a large area of Bangladesh can be categorized as potentially under risk of wheat blast infection (confirming model results from

Activity 1.2.1), with a northern decreasing pattern for both establishment and outbreak ranging from 0.1 to 0.6. Large portions of the central belt of India also appear to be at risk, but the northern 'bread basket' regions in India and Nepal's western Indo-Gangetic plains may be at less risk. Portions of southern China are also at risk, but these areas, as well as those in Southern India, and portions of the South East Asian countries are relatively small wheat producers.

Planned activity in Quarters 1 and 2 of 2018:

It is important to stress that these results are preliminary are currently being corroborated in terms of infection score thresholds necessary for wheat blast establishment and outbreak. During Q1 and Q2 of 2018, these preliminary results will be refined by evaluating the use of different thresholds for infection score based on results provided by the wheat blast forecasting model described in Activity 1.2.1 and field observations of disease incidence, together with comparison with different regions where this model has been applied. In addition, use of a generic potential infection model developed by Magarey et al. (2005) is planned, which represents a more detailed/sub-daily time-scale scale version of model developed by Cruz et al (2016) one. Although both models provide similar information in terms of the potential establishment and outbreak of wheat blast, the approach advanced of Magarey et al. (2005) appears more appropriate to be applied during the dry season, where rainfall events can last only for a few hours, taking also into account the impact of both air temperature and leaf wetness duration. The probabilistic risk of establishment and outbreak in each country's primary wheat producing areas are therefore likely to be quantifiable based on this approach. This activity is well ahead of schedule, and further insights will be reported in the 2018 semi-annual CSRD report.

Contribution of Activity 2.2.3 to CSRD's Action and Learning Framework:

Pillar 2, Indicator 2.2, Pillar 4, Indicator 4.1 (see Annex 3).

Objective 3: Coordination with the Asian Development Bank and other CSRD partners in-country to ensure progress on the work streams under the CSRD South Asia and Bangladesh working group

Sub-Objective 3.1. Coordination of Bangladesh CSRD partners and support to the ADB

Background:

The Asian Development Bank (ADB) was also initially assigned as the main coordinating body for CSRD activities in the South Asian region. The CSRD project therefore remains available for coordination assistance as requested from the ADB. In addition, CIMMYT assists in organizing CSRD partnership activities in Bangladesh. The goal of this work is to boost institutional development and use of climate information and services in the agricultural sector. Key partners include Bangladesh's Ministry of Defense (under which BMD operates), the Ministry of Agriculture (under which BARI and DAE operate). Activities detailed below summarize CSRD's efforts in 2016 and 2017 to coordinate these institutions and support to the ADB. This section also details additional high-level partnerships that offer significant opportunities to scale-out and –up the results of CSRD's work on climate information services and products.

Activities in 2016-2017:

Formalization of partnership with the Bangladesh Meteorological Department

In August of 2017, the Bangladesh Meteorological Department (BMD) formally joined the CSRD partnership in South Asia with the signing of a sub-grant agreement under the project (see Annex 2 and 3 for details). This accomplishment was achieved after eight months of coordination and negotiation with Bangladesh's Ministry of Defense, under which BMD is governed and operates. CSRD is the first-ever non-governmental partnership agreement for research and development that the BMD had participated in.

While the Director of the BMD was extremely supportive of the CSRD partnership since CIMMYT coordination formal discussions in December of 2017, the goals and working modalities of CSRD should be explained and negotiated at several higher administrative and political different levels in Bangladesh. This was necessary to assure conformity with the rules and regulations of the Ministry of Defense, which prior to CSRD has no significant experience with similar research for development initiatives at the BMD level, nor had they experienced partnering with a USAID supported and ADB backed initiative. Clarification of these issues required included four in-person meetings with Mr. Akhter Hussain Bhuyia, Bangladesh's Secretary of Defense, in addition to three meetings with the Brigadier General (BG) in charge of BMD, as well as extended working meetings with the BG's Personal Secretary to assure that the CSRD sub-grant agreement met the stringent standards of the Ministry of Defense. With the leadership and diplomatic efforts of the CIMMYT team, and the agreement was ultimately cleared by the Bangladesh's Office of the Prime Minister (Annex 7) on 29 August, 2017.

The official signing of the CSRD agreement with CIMMYT and BMD held at the Ministry of Defence in Dhaka, Bangladesh on September 28, 2017. Right to left of the front row: Mr. Akhter Hussain Bhuyia, Secretary, Ministry of Defense, Dr. TP Tiwari, CIMMYT Country Representative, Mr. Shamsuddin Ahmed, Director, BMD, and Mr. David Westerling, the Acting Economic Growth Office Director and Feed the Future Team Leader, USAID.

Approximately one month later (28th September), CSRD Partnership in South Asia lead and the Ministry of Defense (MoD) held a formal signing ceremony for the agreement at the Ministry of Defense in Dhaka, Bangladesh. The signing ceremony was attended by Mr. Akhter Hussain Bhuyia, Secretary, Ministry of Defense attended as the chief guest. Mr. David Westerling, the Acting Economic Growth Office Director and Feed the Future Team Leader, USAID as also present as special guest. Mr. Shamsuddin Ahmed, Director, BMD, Dr. Timothy J. Krupnik, CIMMYT and CSRD in South Asia Project Leader and Dr. Thakur Prasad Tiwari also attended, in addition to a delegation of scientists from BMD and CSRD. Further implications of the efforts to secure agreement with BMD are detailed in 'Implementation Challenges' below.

Achieving synergies with the World Bank funded Weather and Climate Services Regional Project in Bangladesh

In mid 2017, the large-scale ($133 million) Bangladesh Weather and Climate Services Regional Project (also known as the *Agro-Meteorological Information Services project*) was formally agreed to after more than 1.5 years of negotiation between the World Bank and the Ministry of Defense, Ministry of Agriculture, and Ministry of Water Resources. The project aims to increase the Government of Bangladesh's capacity to deliver reliable weather, water, and climate information services and improve access to such services by priority sectors and communities. Much of the Bangladesh Weather and Climate Services Regional Project focusses on improving infrastructure and procurement of forecasting and ICT equipment. More than 200 additional automatic weather stations will be installed by BMD throughout Bangladesh, and DAE will supply smart phones and internet enabled tablets to increase the speed of delivery of climate information to tens of thousands of extension agents and lead farmers throughout the country. The project however has less focus on increasing forecast skill, or on the translation of forecast information into easy to implement advisories for farmers. Specific model and product development are also unrepresented in the project.

Turning these constraints into opportunities, CSRD has been working with the same teams of people in the BMD and DAE that are assigned to administer the World Bank Project. CSRD has therefore positioned itself to assist by increasing forecast skill and developing relevant climate services and tools that can be scaled-up in the context of the World Bank funded project. This was verbally agreed to in a meeting held in mid-November of 2017 with the Dr. Maharul Aziz, Agro-Meteorological Information Systems Development Project Component-C of Bangladesh Weather and Climate Services Regional Project at DAE, and Dr. Poonam Pillai and Ms. Arati Belle, part of the World Bank Task Leadership Team for Bangladesh Weather and Climate Services Regional Project. Mr. Shamsuddin Ahmed, the Director of BMD, has been equally supportive of this initiative, and has also invited CSRD team scientists to participate in the monthly technical coordination committee of the World Bank project as observers and advisors upon request in support of agricultural climate services.

Planned activity in Quarters 1 and 2 of 2018:

CSRD will continue to coordinate partners in Bangladesh and assist the ADB upon request with climate services popularization and awareness raising efforts in 2018. In addition, the World Bank supported Bangladesh Weather and Climate Services Regional Project will benefit from CSRD's efforts to increase agro-meteorological forecast skill at BMD and through capacity development efforts at DAE. DAE for example has agreed to several areas in which which synergies and scaling of CSRD's can be extended through the Agro-Meteorological Information Systems Development Project Component-C of Bangladesh Weather and Climate Services Regional Project:

- Trials of Bangladesh adapted PICSA training modules that can be incorporated in to farmer field school programs in projects led by DAE to more effectively raise awareness and understanding and use of climate information for productive agricultural decision making. More details on PICSA can be found in Activity 1.1.1. Through CSRD, DAE will also develop systems to assure that these modules and the adapted PICSA approaches are incorporated into the Bangladesh Weather and Climate Services Regional Project
- Use of CSRD generated and agriculturally relevant short-term forecasts and outlook advisories, as well as crop-specific climactic stress risk maps
- Design and implementation of a CSRD 'exit strategy' whereby the DAE will incorporate other relevant tools and products, including weather-based crop disease forecasting models, into the Agro-Meteorological Information Systems Development Project Component-C of Bangladesh Weather and Climate Services Regional Project (to be completed in 2019).

Contribution of Sub-Objective 3.1 to CSRD's Action and Learning Framework:

Pilar 2, Indicator 2.2 (see Annex 3).

Sub-Objective 3.2. Policy maker, agro-metrological services, extension, and farmer awareness of agro-meteorological forecasts and decision support tool platforms for agriculture increased

Background:

CSRD contributes much more than the development, testing, refinement, and implementation of climate services. It also creates create awareness of the importance of climate services among the public. This is accomplished through a variety of mechanisms, including educational events and trainings, internships, media events, and round-table discussions. This section highlights key activities undertaken to support these aims in 2016-2017.

Activities in 2016-2017:

CSRD Technical Exchange on Participatory Approaches to Agricultural Climate Services Development and Extension in South and South East Asia

Over 50 leaders in climate science, agricultural development, and climate services from 11 countries participated in September 2017 CSRD Technical Exchange on Participatory Approaches to Agricultural Climate Services Development and Extension in South and South East Asia, held in Dhaka, Bangladesh. Photo: U. Barman (CIMMYT)

In partnership with the USAID SERVIR and Climate Services Support Activity, CSRD organized a three-day workshop titled 'Participatory and Institutional Approaches to Agricultural Climate Services Development: A South and South East Asia Regional Technical and Learning exchange" between September 17-19, 2017, in Dhaka, Bangladesh, with more than 50 leaders in agricultural climate services from 11 countries attending. More details on the Technical Exchange can be found in Annex 9.

Collaboration with the Columbia University's World Project and Adapting Agriculture to Climate Today for Tomorrow (ACToday)

CSRD is assisting the Columbia University's World Project's Adapting Agriculture to Climate Today for Tomorrow (ACToday) initiative, which is led by IRI, to establish activities and formalize partnerships in support of cross-sectoral climate services in Bangladesh. CSRD for example assisted ACToday in arranging meetings on November 28 and 29th, 2017, with a wide variety of potential partner organizations in Bangladesh working in agriculture, aquaculture, livestock development, climate change adaptation and disaster preparedness and response. CSRD's Project Leader in South Asia, Dr. Timothy J. Krupnik, attended these meetings alongside IRI's Deputy Director John Furlow and Mélody Braun, Staff Associate, and Dr. Saleemul Huq, Director of the International Center for Climate Change and Development (ICCCAD). Outcomes from the meetings – which included a highly positive meeting with Mr. Shahmsuddin Ahmed, Director of the Bangladesh Meteorological Department that was facilitated by CSRD – include the establishment of a cross-sectoral Climate Services Academy in Bangladesh, detailed below. CSRD will continue to support the Columbia World Project and ACToday as core partners to assist in growing these projects in Bangladesh.

Founding the first-ever Climate Services Academy for Bangladesh

Several efforts are already underway to address climate services challenges in Bangladesh. Examples include CSRD, The World Bank supported Agro-Meteorological Services project, and the efforts of myriad NGOs in developing information communication technologies (ICTs) and advisories for farmers and rural communities that integrate climate and weather information.

The experience gained during the implementation of the above projects, and consultations in the context of the Columbia university Adapting Agriculture to Climate Today for Tomorrow (ACToday) project, have resulted in the identification of key climate services themes that require deeper technical and cross-project coordination, in addition to educational and training efforts. These themes include the need to support farmers with better climate information and advisories in terms of local contexts, a better understanding of new information and models being generated to allow the design of new climate services, and the expansion of climate services to support currently less emphasized sectors such as aquaculture and livestock. Additional opportunities exist to use climate information to improve nutrition programming and weather-based index insurance, and forecast-based disaster preparedness and response to climate-related hazards.

To bridge these gaps and help address the coordination challenges, BMD together with the International Center for Climate Change and Development (ICCCAD), the Independent University of Bangladesh (IUB), CIMMYT, and the International Research Institute for Climate and Society (IRI) at Columbia University, which leads the Adapting Agriculture to Climate Today for Tomorrow (ACToday) project focusing on climate challenges to food systems in six developing countries, are jointly establishing a *Climate Services Academy* in Bangladesh. The proposed activities for the Academy respond to the information and capacity gaps identified above, and are likely to include the following:

- Provide a forum to support decision makers in climate-sensitive sectors and those responsible for supporting adaptation in the Bangladesh government to elucidate and analyze how climate variability and change can shape and undermine the performance of sectors important to Bangladesh's economy and society. Decision makers will learn to identify which decisions could be improved by considering climate information, and will be empowered to work with the climate science community to develop new climate services initiatives in response to identified needs.

- Develop and implement need-based educational curricula and professional degree and certification programs for cross-sectoral training in climate science, relevant scientific products including decision support tools, early warning systems, and seasonal forecasts, and climate services communication and extension accessible to relevant Bangladeshi institutions.
- Provide technical support to and cross-institutional learning opportunities for existing climate services projects and initiatives across sectors in Bangladesh
- Provide long-term opportunities for increased use of climate information and services in sectors currently lacking consistent support in Bangladesh, including aquaculture and livestock, nutrition initiatives, and forecast-based disaster preparedness and response, weather-based index insurance, among others
- Respond to the priorities and interests of its members and students wishing to increase their climate services skills and knowledge, thereby facilitating the exchange of knowledge and learning opportunities
- Improve access to climate data (forecasts, ground data, satellite data).

The *Climate Services Academy* will be established in association with the Bangladesh Gobeshona umbrella, and as such it will be hosted at the Independent University of Bangladesh with curricula and teaching provided by the partners listed above and other qualified institutions. Monthly meetings of participating stakeholders are envisioned to improve direction and governance of the *Climate Services Academy*. Further detail on CSRD's support of this initiative will appear in the 2018 semi-annual CSRD report.

Supporting the Gobeshona Initiative

Gobeshona, which means *research* in Bangladesh, is a knowledge sharing platform for climate change research on Bangladesh. It aims to bring together the national and international research community to encourage sharing, enhance quality and, in doing so, make climate change research on Bangladesh more effective. Gobeshona addresses the quality of research being produced in Bangladesh by encouraging constructive discussion and feedback among researchers. Gobeshona also provides mentoring services for young researchers. Gobeshona supports a web portal to support this aim, as well as organizing monthly seminars, which are hosted in Bangladesh by the institutions on the Gobeshona Steering Committee. Through the CSRD in South Asia partnership, CIMMYT became a member of the Gobeshona Steering Committee in December of 2017. Support of Gobeshona also brings CIMMYT and CSRD into contact with over 40 national and international organizations working on climate change adaptation research and development in Bangladesh. This membership therefore affords CSRD another avenue for highlighting the development of climate services products, research, and decision support tools developed in Bangladesh. Discussions are underway with the Gobeshona Steering Committee to host a seminar on agricultural climate services in Bangladesh and South Asia sometime in the first three quarters of 2018, which if realized will be highlighted in the next CSRD annual report.

Exploring partnerships with Wageningen University's Waterapps project

The Waterapps project is led by the Wageningen University and Research Centre in the Netherlands, and works to develop water information services for sustainable food production in peri-urban delta areas in Ghana and Bangladesh. In the latter, Waterapps is working in areas outside of Khulna, in the South West of Bangladesh. Dr. Saskia Elisabeth Werners, who coordinates Waterapps, participated in the September 2017 CSRD Technical Exchange in Dhaka. Links made during the technical exchange have resulted in exploration of collaborative opportunities between CSRD and the Waterapps team to bring researchers from the University of Reading (UoR) involved with the development of PICSA (Participatory Integrated Climate Services for Agriculture) to Bangladesh. CSRD and the Waterapps team are exploring options for cost-sharing arrangements to facilitate the sustained involvement of the PICSA team in

Bangladesh during 2018 and beyond. Further information on this engagement will be provided in the 2018 CSRD semi-annual report.

Partner engagement in agricultural drought monitoring and

A CSRD and SERVIR HKH initiative orientation workshop was organized at Bangladesh Agriculture Research Council (BARC on 03 January 2017). The focus was on use of remote sensing/GIS applications fir drought monitoring. The workshop brought together key partners including BARC, BMD, DAE, BARI and BRRI, to discuss on proposed methods, work plan and the user engagement process for effective development and long-term sustainability of the agricultural drought monitoring service for Bangladesh. Along with relevant scientists, Dr. Muhammad Jalal Uddin, Executive Chairman of BARC and Mr. Shamsuddin Ahmed, Director of BMD also attended the meeting.

Glimpses from the consultation workshop held in Dhaka, Bangladesh on 17 August, 2017. Photo: Santosh Raj Pathak (ICIMOD)

As part of the field work on product calibration, a plan for deploying a network of rainfall gauges and soil moisture profile probes was prepared in Dinajpur, Nilphamari and Rajshahi districts (see Annex 14). This increased the number of precipitation measurement points will facilitate the validation and calibration of CHIRP data product in the drought-prone regions of Bangladesh. Through these efforts, CSRD and SERVIR HKH partners can look forward to establishing a regional agricultural drought monitoring and warning information system for drought events. To complicate this effort, CSRD and the SERVER HKH initiative are preparing a comprehensive training manual on drought monitoring methods. The content of the manual is targeted early to mid-carrier professionals working in agriculture and meteorological institutions who have some background in GIS and remote sensing. The manual will include hands-on exercises based on locally relevant GIS and remote sensing datasets and open source software like QGIS, GeoCLIM, and potentially Google Earth Engine. The first trainings are anticipated in the first half of 2018.

Establishing facilities at the Department of Agricultural Extension for improved access to geospatial and climate information

To facilitate increased use of geospatial and climate information by the Department of Agricultural Extension, CSRD established a small GIS laboratory at DAE's headquarters at Khamarbari, Farmgate, Dhaka. Equipment supplied included for desktop computers with: i7 processors (6th generation – 6 cores), 32 GB of memory, and 500 GB booting drives, in addition to a 2 TB storage drive. DAE staff involved with CSRD were trained in the use of this equipment during a week-long hands-on intensive educational session on '*Basic GIS for Climate Services Using QGIS, R, SAGA & GRASS GIS*' (see below).

CSRD Training of DAE staff on Basic GIS for Climate Services Using QGIS, R, SAGA & GRASS GIS

CSRD partner staff in the Department of Agricultural Extension (DAE) participated in a training to build capacity in the use of GIS to process geospatial climate information using open source software platforms such as QGIS, R, SAGA & GRASS GIS. Fourteen participants (9 from DAE and 5 from CIMMYT-CSRD) took part in the five-day training facilitated by Mr. Mustafa Kamal, GIS and Remote Sensing Analyst with CIMMYT. On the opening day of the training (September 24, 2017), a ribbon-cutting event took place to hand over the computer lab to DAE from CSRD project. Also an inaugural ceremony was also held with the opening speech from the then Director General of DAE, Mr. Md. Golam Maruf. By the conclusion of the end of the training, participants were acquainted in the basics of GIS, and use of QGIS, R, SAGA & GRASS GIS to analyse spatial data in Bangladesh. A detailed set of training modules, which can be used for self-learning, was developed to support the training will be released as an open-source publication together by the CSRD and CSISA projects in Bangladesh (see Annex 8 for cover page).

Mr. Md. Golam Maruf, former Director General of the Department of Agricultural Extension (DAE), senior DAE staff, and CSRD scientists inaugurate the CSRD supported training on basic GIS in Dhaka, Bangladesh on 24 September, 2017. Photo: Uttam Barman (CIMMYT)

Mustafa Kamal, GIS and Remote Sensing Analyst, and CSRD staff member, led the training. Photo: Uttam Barman (CIMMYT)

Boosting awareness of agricultural climate information services and CSRD at the Digital World conference in Dhaka, Bangladesh

The 2017 Digital World Conference in Dhaka, Bangladesh serves as a platform to connect investors, innovators, entrepreneurs, industry leaders and the IT workforce of Bangladesh. IT companies, startups and public sector organizations showcased their products, services with over 400 exhibitors from Bangladesh and abroad including policy makers, senior government officials & ministers, industry leaders, civil society spokespersons, investors and multinational software vendors. Speaking on behalf of CSRD, Dr. Timothy J. Krupnik was invited to present on a symposium on Digital Agriculture entitled 'Smart Agriculture, Smart Future' held at Digital World on 7 December 2017.

Dr. Krupnik's presentation focused on CIMMYT research conducted in the context of CSRD, including the use of weather forecasting and remote sensing technologies to develop irrigation scheduling and pest management advisories appropriate for Bangladeshi smallholder farmers. Joining him on the Symposium panel were Mr. Md. Fazle Wahid Khondaker, Additional Secretary, Ministry of Agriculture, Mr. Anis Ud Dowla, President, Bangladesh Seed Association, Dr. Sekender Ali, Pro-Vice Chancellor, Sher-e-Bangla Agricultural University, Dr. Nurul Islam, Director, IT & Planning, DAE, Mr. Burra Dharani Dhar, Data Scientist, International Center for Tropical Agriculture (CIAT), and Mr. Md. Shahid Uddin Akbar, CEO, Bangladesh Institute for ICT in Development. The event was attended by over 200 people. In addition to the Symposium presentation, CSRD staff displayed a media and technology table showing some of the research tools and equipment used field research, including automatic weather stations, thermal infrared cameras, unmanned aerial vehicles, apparent electrical conductivity (salinity meters), among others. Leaflets and information on CSRD's work were also handed out to all Symposium attendees.

Dr. Timothy J. Krupnik, CSRD in South Asia Project Leader, presenting on the use of digital tools for agricultural climate services during the 'Smart Agriculture, Smart Future' Symposium at the Digital World conference on 7 December 2017. Photo: BIID

CSRD and CIMMYT staff presenting climate and agronomy research equipment and CSRD leaflets the Digital World media table on 7 December, 2017. Left to right: Khaled Hossain, Fahmida Khanam, Khairul Islam, Mustafa Kamal, Mehedi Hasan and Taposh Mollick. Photo: BIID.

Planned activity in Quarters 1 and 2 of 2018:

In 2018, CSRD will continue to support policy maker, agro-metrological services, extension, and farmer awareness of agro-meteorological forecasts and decision support tool platforms for agricultural climate services in South Asia. Of interest is the *Climate Services Academy*, which is being co-founded by CIMMYT through CSRD, will be presented and discussed in a Symposium on Climate Services in Bangladesh at the Gobeshona conference 2018, on January 10th from 2:10 to 3:30 pm. The symposium, which is jointly organized by CSRD and which will feature a presentation by Dr. Timothy J. Krupnik, CSRD in South Asia Project Leader, and discussant comments from Dr. Maharul Aziz, Agro-Meteorological Information Systems Development Project Component-C of Bangladesh Weather and Climate Services Regional Project, in addition to CSRD associated staff from IRI. Along with IRI, the Columbia World Project's ACToday, and ICCCAD, the symposium will welcome participation from all sectors and institutions interested to learn more about climate services and help define the role, roadmap and priorities of the Academy.

Contribution of Sub-Objective 3.2 to CSRD's Action and Learning Framework:

Pillar 3, Indicator 3.1(see Annex 3).

Implementation challenges

Most the activities under Objectives 1-3 discussed in this report remain on schedule for completion. However, as indicated in the 2018 semi-annual report, several set-backs encountered this year nonetheless delayed complement implementation. Key among these was gaining Government of Bangladesh (GoB) endorsement for the Bangladesh Meteorological Departments' participation in CSRD. Without the BMD's participation, achievement of Objective

1, which relies on access to Bangladesh specific climate data streams, forecasting models managed by BMD, and meteorological staff at BMD, would not be possible.

The way for CSRD's partnership with the Bangladesh Meteorological Department was to have been paved by the ADB's work to clear a formal Request for No Objection (RNO) to the CSRD Investment Options Paper (IOP) with Bangladesh's Ministry of Finance. As the regional coordinator for South Asian CSRD activities, the ADB submitted the IOP to the GoB in late November of 2016. While this coincided with the start of CIMMYT organizational activities under CSRD, the IOP was under review by the GoB for several additional months following submission. Following a lengthy review period, the ADB submitted the RNO to the GoB on 16 March, 2017, 4.5 months after project activities began. Conversely, CIMMYT encountered no difficulty in engaging DAE, BARI, or other partners that operate under the Ministry of Agriculture. This was due to CIMMYT's established MoUs with several Ministry of Agriculture organizations, whereas partnership with the Ministry of Defense was an entirely new challenge for both CIMMYT and other environmentally-oriented USAID supported projects in Bangladesh.

To speed the process of gaining Ministry of Defense approval, USAID supported CIMMYT in attempting to facilitate a sub-grant agreement with BMD by making use of an alternative Letter of Agreement (LoA) option. A document proposing this alternative written by USAID was given to the Secretary in Charge of the Ministry of Defense on March 22, 2017. It was hoped that use of this option in place of the RNO approval might kick-start formalization of CSRD activities. CIMMYT and BMD jointly followed up on this option, by having discussions with the Brigadier General responsible for BMD activities, and with the Secretary of Defense. Both pledged provisional support for CSRD, although the Ministry of Defense clarified that the RNO to the IOP remained prerequisite for BMD's full involvement.

Despite submission to the Government of Bangladesh in mid-April, it however took until late April for BMD to receive the RNO and IOP from ADB. Consent for partnership from BMD given on May 4, 2017, although it took another month (until July 6, 2017) for the Ministry of Finance to agree to the RNO for the IOP. BMD again remained supportive of CSRD throughout this period, and regularly met with CIMMYT to plan and participate in a limited number of CSRD activities. It however became clear that full implementation however was not possible without additional formal consent by the Ministry of Defense, in addition to the work done by ADB with the Ministry of Finance.

CIMMYT consequently worked diligently in addressing these issues and to assure the Ministry of Defense of the importance of the CSRD partnership. Despite the RNO and IOP, the goals and working modalities of CSRD were still unclear to the Ministry of Defense in mid 2017 and had to be negotiated at several higher administrative and political different levels in Bangladesh. Changes in staffing and other priority tasks within the Ministry of Defense played a strong contributing role to the difficulties encountered.

To assuage any concerns held by the Ministry of Defense regarding BMD's participation in CSRD, CIMMYT undertook four additional in-person meetings with Mr. Akhter Hussain Bhuyia, Bangladesh's Secretary of Defense, in addition to three meetings with the Brigadier General (BG) in charge of BMD, as well as extended working meetings with the BG's Personal Secretary. These meetings helped to assure that the CSRD sub-grant agreement planned with BMD met the stringent standards of the Ministry of Defense. With the leadership and diplomatic efforts of the CIMMYT team, the agreement was ultimately cleared by the Bangladesh's Office of the Prime Minister (Annex 7) on 29 August, 2017, allowing formalization of a sub-grant agreement from CIMMYT to BMD on behalf of CSRD on 28 September of 2017.

The CSRD partners are now unrestrained in their ability to work with BMD, including access to Bangladesh's climatological datasets and WRF model forecasts through the server installed within BMD's offices. The project is now moving at full speed, but as noted above, the time required to reach agreement with the Ministry of Finance and Ministry of Defense did result in significant set-backs that may delay the ability to achieve all relevant activities and products in Objective 1 by the end of Q1 in 2019. Key activities that have been delayed include:

- Objective 1, Sub-Objective 1.1, Activity 1.1.1, Product 1: Crop-specific farmer decision making frameworks and extension training to improve the quality and usefulness of agro-meteorological forecasts
- Objective 1, Sub-Objective 1.2, Activity 1.2.1, Product 2: National scientist training, exchange, and CSRD planning with IRI
- Objective 1, Sub-Objective 1.3.1, Activity 1.3.1, Product 1. Agriculturally relevant climatological analysis and improved extended-range forecasts and outlooks, Product 2: Weather forecast based irrigation scheduling with PANI (Program for Advanced Numerical Irrigation), and Product 3: Spatially explicit and meteorologically driven wheat blast (Magnaporthe oryzae Triticum, MoT) disease risk assessments for Bangladesh
- Objective 1, Sub-Objective 1.3.2, Activity 1.1.2, Product 1. Improved seasonal forecasts and climatic stress maps developed and refined

Although CSRD is now largely over these hurdles, six of the climate information service products planned under Objective 1 were set back in to varying degrees by nearly 10 months. Focused efforts are now underway to make up for this lost time, although were significant progress is not possible before mid-2108, it may be necessary to consider a project extension due to these unavoidable and unforeseen circumstances. These topics are now under discussion with USAID and will be further reported on in the 2018 semi-annual CSRD report.

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Annexes

Annex 1. Key Staff and Core Partner Designations

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Mr. Ansar A Siddiquee Iqbal	Project Manager	CIMMYT	Dhaka, Bangladesh	+880-171-3044764	a.siddiquee@cgiar.org	25% FTE
Dr. Shafiq Islam	Jessore Hub Coordinator	CIMMYT	Jessore, Bangladesh	+880 17 1145 1064	Shafiqul.Islam@cgiar.org	In-kind contributions to lentil disease model validation in Bangladesh through CSISA
Dr. Dinabandhu Pandit	Senior Technical Coordinator (CSISA)	CIMMYT	Faridpur, Bangladesh	+880 17 1213 0599	d.pandit@cgiar.org	In-kind contributions to lentil disease model validation in Bangladesh through CSISA
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CIMMYT - India						
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Dr. Poonia SP	CSISA India Research Platform Coordinator		Patna, India	+91 8292525557	S.Poonia@cgiar.org	In-kind contributions to lentil disease model validation in India through CSISA
Dr. Tek Sapkota	Agricultural Systems and Climate Change	CIMMYT	New Delhi, India	--	T.Sapkota@cgiar.org	15% FTE, 10% in-kind CCAFS contribution
CIMMYT - GLOBAL						
Dr. Clare Maeve Stirling	CIMMYT CCAFS Representative	CIMMYT	El Batan, Mexico	+44(0) 756340907	C.Stirling@cgiar.org	15% FTE
Dr. Bruno Gérard	Sustainable Intensification Program Director	CIMMYT	El Batan, Mexico	+52 (55) 5804 2004 ext. 2123	b.gerard@cgiar.org	3% FTE strategy and guidance

Name	Role	Institution	Address	Phone	Email	Comments
REGIONAL AND INTERNATIONAL PARTNERS						
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International Research Institute for Climate and Society (IRI, Columbia University)						
Dr. Simon J. Mason	Chief climate scientist	IRI	Palisades, NY, USA	+1-845-680-4514	simon@iri.columbia.edu	IRI focal point for CSRD in South Asia. 10.5% FTE
Dr. James Hansen	Senior Research Scientist CCAFS Theme Leader	IRI	Palisades, NY, USA	+1 (845) 680-4410	jhansen@iri.columbia.edu	5% FTE
Mr. John Furlow	Deputy Director for Humanitarian and International Development	IRI	Palisades, NY, USA	+1 (845) 680-4466	jfurlow@iri.columbia.edu	In-kind contribution through the Columbia World program and ACToday
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Department of Agricultural Extension (DAE)						
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Bangladesh Agricultural Research Institute						
Dr. M.A. Razzak	Chief Scientific Officer, Irrigation and Water Management Division	BARI	Joydebpur, Gazipur, Dhaka, Bangladesh	+880 17 1157 0461	razzaquebari@gmail.com	Time in-kind; sub-grant costs for experiments only
Md. Shariful Bin Akram	Scientific Officer	BARI	Wheat Research Centre, Dinajpur, Bangladesh	+88 01717-545797	sariful.santo@gmail.com	Time in-kind; sub-grant costs for experiments only
Md. Jakir Hossain	Scientific Officer	BARI	Regional Wheat Research Station, Shampur, Rajshahi, Bangladesh	+88 01710-375943	zakzubari@gmail.com	Time in-kind; sub-grant costs for experiments only

Name	Role	Institution	Address	Phone	Email	Comments
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***Universidade de Passo Fundo* (UPF)[1]**						
Dr. José Maurício Cunha Fernandes	Senior Scientist – Plant Epidemiology	UPF	Passo Fundo, RS, Brazil	--	mauricio.fernandes@embrapa.br	Time in-kind for scientific coordination
Mr. Felipe de Vargas	Computer scientist	UPF	Passo Fundo, RS, Brazil	--	119685@upf.br	100% FTE (wheat blast computer model coding)
University of Reading						
Dr. Peter Dorward	Professor, School of Agriculture, Policy and Development	UR	Reading, UK.	+44 (0) 118 378 8492	p.t.dorward@reading.ac.uk	Currently being determined
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Bihar Agricultural University (BAU)						
Dr. Abhijeet Ghatak	Assistant Professor of Plant Pathology	BAU	Sabour, Bihar, India	--	ghatak11@gmail.com	In-kind contribution to lentil disease monitoring activities
Nepal Agricultural Research Council (NARC)						
Dr. Rajendra Darai	Senior Scientist and Coordinator, Grain Legumes Research Program	BAU	Khajura, Banke, Nepal	--	Nglrp_khajura@narc.cov.np	In-kind contribution to lentil disease monitoring activities

[1]. Partnership with UPF is achieved through in-kind scientific coordination by Dr. José Maurício Cunha Fernandes and a consultancy for Mr. Felipe de Vargas

Annex 2. Project subcontractors and key partners

Partner	Partnership Objective	Strategic Alignment	Leveraging Opportunity	Anticipated or committed funding (USD)	Objective and activity contributions (Core activity contributions)	Status of Partnership
Bangladesh Meteorological Department (BMD)	Integrative CSRD partner to produce and control the quality of climate information and forecasts. Iterative development of climate services frameworks and decision support tools.	Pillars 1, 2, 3, and 4	BMD is Bangladesh's lead agency for meteorological forecasting in Bangladesh and is interested to improve the quality of their ag-meteorological forecasts. Improvement of short-term and seasonal forecasts and integration of the resulting information as crop specific climate service advisories will be deployed through CSRD partners.	$195,598	Sub-Objective 1.1., Activity 1.11., Sub-Objective 1.2, Activity 1.2.1., Sub-Objective 1.3: Activity 1.3.1 (all three sub-activities), Activity 1.3.2, Sub–Objective 2.1, Activity 2.2.1, Objective 3, Sub-Objective 3.1.	The sub-grant agreement between CIMMYT and BMD has been signed on 29 August 2017 (Dated June 15, 2017) with full approval of the Ministry of Defense. Sub-grant copies are available for review upon request.
Department of Agricultural Extension (DAE)	Iterative development of climate services frameworks and communication strategies. Extension and dissemination of agriculturally relevant meteorological information and advisories to farmers.	Pillars 1, 2, 3, and 4	DAE has over 14,000 field extension agents operating throughout Bangladesh. DAE also has capabilities in ICT tools for extension purposes.	$100,000	Sub-Objective 1.1., Activity 1.11., Sub-Objective 1.2, Activity 1.2.1., Sub-Objective 1.3: Activity 1.3.1 (all three sub-activities), Activity 1.3.2, Sub–Objective 2.1, Activity 2.2.1, Objective 3, Sub-Objective 3.1.	The Sub-grant agreement between CIMMYT and DAE has been signed on 16 October 2017. CIMMYT maintains a formal partnership MoU with the DAE, collaboration in CSRD has been initiated and is ongoing, although a formal sub-grant for DAE has not yet been signed as it is contingent on integration of activities with the sub-grant to be allocated to BMD (see above details). Sub-grant copies are available for review upon request.
Bangladesh Agricultural Research Institute (BARI)	Validation and improvement of irrigation scheduling decision support tools (PANI). Collaborative research to develop and improve wheat blast forecasts and decision support systems.	Pillars 1, 2, 3, and 4	BARI is Bangladesh's lead institute for research in non-rice crops, with significant technical capacity in irrigation and wheat related research.	$30,000	Sub-Objective 1.3: Activity 1.3.1 (PANI and wheat blast activities)	The sub-grant agreement between CIMMYT and BMD has been signed on 8 August 2017 and is now under way. Sub-grant copies are available for review upon request. Please see report sections on PANI for more details. Sub-grant copies are available for review upon request.

Partner	Partnership Objective	Strategic Alignment	Leveraging Opportunity	Anticipated or committed funding (USD)	Objective and activity contributions (Core activity contributions)	Status of Partnership
International Research Institute for Climate and Society (IRI)	Skills assessments and advanced forecasting and agriculturally relevant climate services training for BMD and DAE, consistent technical backstopping and support.	Pillars 1, 2, 3, 4	Scientists at IRI have been collaborating with BMD for over four years. CSRD is leveraging this partnership provide consistent technical support and backstopping to BMD, and to develop improved climate services communications and extension strategies with DAE through IRI's contributions to *CCAFS's Research Theme on Adaptation through Managing Climate Risk*.	$300,000	Sub-Objective 1.1., Activity 1.11., Sub-Objective 1.2, Activity 1.2.1., Sub-Objective 1.3: Activity 1.3.1 (all three sub-activities), Activity 1.3.2, Objective 3, Sub-Objective 3.1.	The sub-grant agreement has been signed between IRI and CIMMYT on 31 August 2017. Sub-grant in near final stages of development, signatures and formalization expected by approximately the third week of May, 2017. Sub-grant copies are available for review upon request.
International Centre for Integrated Mountain Development (ICIMOD)	Collaborative development and refinement of South Asian regional-scale decision support tools, services, and products with emphasis on seasonal to sub-seasonal drought forecasts and integration with BARC[1].	Pillars 1 and 4	Drought modeling downscaling at different resolutions and development of seasonal to sub-seasonal forecast of drought aligned with ongoing work in the SERVIR-Hindu Kush Himalaya (HKH) program	$195,000	Sub-Objective 1.1., Activity 1.11., Sub-Objective 1.2, Activity 1.2.1., Sub-Objective 1.3: Activity 1.3.1 (all three sub-activities), Activity 1.3.2, Objective 3, Sub-Objective 3.1.	The sub-contract agreement between CIMMYT and ICIMOD has been signed and completed on 1 May 2017. Sub-grant copies are available for review upon request.
Universidade de Passo Fundo (UPF)	Collaborative development and refinement of disease forecasting model and decision support system for wheat blast early warnings, supporting BARI	Pillars 2, 4	• Establish a web-based application and decision support tool (DST) for in-season 5 and 10-day lead time forecasts to present the probabilistic risk of wheat blast infection • Adapt a surveillance smartphone application to Bangladesh. • Engage with CIMMYT's partners in Bangladesh to incorporate input and	$15,000	Objective 1, Sub-Objective 1.3, Activity 1.3.1: (MoT forecasting) Objective 2, Sub–Objective 2., Activity 2.2.3.	A consultancy has been awarded to Mr. Felipe de Vargas of UPF for 11 months (total value of the consultancy is $15,000). Total duration of the consultancy will be June 2017-May 2018, with potential for renewal based on performance. de Vargas is supervised by Dr. José Maurício Cunha Fernandes, Senior Scientist – Plant Epidemiology at UPF, and developer of the preliminary wheat blast forecasting model. The terms of reference for de Vargas are available upon request

Partner	Partnership Objective	Strategic Alignment	Leveraging Opportunity	Anticipated or committed funding (USD)	Objective and activity contributions (Core activity contributions)	Status of Partnership
			feedback on performance of the application DST detailed in Objective 1, and to assist in training and advising partners on use of the application DST			
University of Reading	Embed PICSA into DAE programming	Pillars 2, 3	• Identify the key opportunities for a locally adapted form of PICSA to enable farmers to make effective plans and decisions in the context of (a) existing farming and livelihood systems and (b) climate and related challenges • Provide technical support and training for the piloting of PICSA with DAE and other stakeholders • Develop recommendations for the wider roll out of PICSA in Bangladesh by DAE	Under negotiation (likely $47,419)	Objective 1, Sub-Objective 1.3, Activity 1.3.2, Objective 3, Sub-Objective 3.2	Under negotiation, with sub-grant award expected in Q1 of 2018.

Annex 3. Monitoring, Evaluation and Learning Plan

Action and Learning Framework Report for November 2016 – December 2017

Climate Services for Resilient Development (CSRD) in South Asia and Bangladesh

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
Pillar 1: Create the solution space	**1.1.** Number of collaborative climate services development processes (e.g., working groups) established with identified problem focus and participation of key stakeholders.	• Collaboration among the CIMMYT-CSRD partners in an integrated way, including Bangladesh Meteorological Department (BMD), International Centre for Integrated Mountain Development (ICIMOD), Department of Agricultural Extension (DAE), International Research Institute for Climate and Society (IRI), the Bangladesh Agricultural Research Institute (BARI), Universidade de Passo Fundo (UPF), University of Rhode Island (URI), and University of Reading (UoR)	• Number of formal climate services working groups that have a clearly defined problem focus and participation of approved and designated stakeholders	**Achieved:** • *CSRD working group in Bangladesh established*: The Director General (DG) DAE has nominated three focal persons and Director BMD nominated three focal persons to work with CSRD on a consistent basis. Fortnightly coordination meetings are underway since August of 2017 • *Climate Services Academy established*: BMD together with the International Center for Climate Change and Development (ICCCAD), the Independent University of Bangladesh (IUB), CIMMYT, and the International Research Institute for Climate and Society (IRI) at Columbia University, which leads the Adapting Agriculture to Climate Today for Tomorrow (ACToday) project focusing on climate challenges to food systems in six developing countries are jointly establishing a *Climate Services Academy* in Bangladesh. The *Climate Services Academy* will be established in association with the Bangladesh Gobeshona umbrella, and as such it will be hosted at the Independent University of Bangladesh with curricula and teaching provided by the partners listed above and other qualified institutions. Monthly meetings of participating stakeholders are envisioned to improve direction and governance of the *Climate Services Academy*. • Five climate services thematic meetings were held with Dr. Hamidur Rahman, Former DG-DAE; Mr. Manzurul Hannan, Current DG-DAE; Mr. Golam Maruf, Former DAE-DG (DAE has changed DGs several times in the last year, necessitating repeat meetings). • One meeting with Mr. Golam Maruf, Former DAE-DG and Mr. Shahmsuddin (Director, BMD) was held in July of 2017 to shore-up collaboration on CSRD. • IRI scientists have visited Bangladesh on three occasions to collaborate with CSRD partners (BMD and DAE). • Seven one-on-one meetings were held with BMD's Director to steer and discuss progress on CSRD. • Focal points for CSRD have been assigned by the ICIMOD-DG. Six consultations have been held, including a large-scale partner workshop on

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
				drought monitoring hosted by ICIMOD at BARC (for details, click here). CIMMYT is assisting ICIMOD in coordination with BARC. After signing of ICIMOD sub-grant, ICIMOD has joined the formal CSRD working group with national research and extension partners (NARES) in Bangladesh. As per contract with BARC, CSRD has supplied the requisite hardware and software to BARC to permit national drought monitoring. • With support of USAID, CSRD and the USAID SERVIR and Climate Services Support Activity hosted an international 'Participatory and Institutional Approaches to Agricultural Climate Services Development: A South and Southeast Asia Regional Technical & Learning Exchange' between September 17-19, 2017 in Dhaka, Bangladesh. Participants were from eleven countries, mainly in South and South East Asia. This created unprecedented opportunities for South-South linkages in agricultural climate services. • Four consultation meetings have been held with focal points from BARI's Irrigation Management Division, for a sub-contracting mechanism. The sub-grant has been signed and BARI is now conducting field experiments for validation of PANI for wheat and maize in three locations across Bangladesh. Regular discussions are being held with BARI to assure proper implementation of PANI experiment. • CSRD and UPF scientists hold skype calls on at least a weekly basis to coordinate modeling and forecasting efforts on wheat blast. • A webinar took place on 11 October at 8:30 AM in the CIMMYT office. Dr. Jose Mauricio Fernandes from UPF made a presentation on wheat blast model that they have developed. The meeting was attended by focal points from DAE and BMD, the Director, WRC and other relevant scientists • UoR was invited to the CSRD Technical Exchange in September of 2017 to present on PICSA. This led to considerable interest by DAE in PICSA. Ongoing discussions between CSRD and UoR have focused on their inclusion in the CSRD project to achieve the aims detailed in Annex 2.
		• Sub-grants awarded to CSRD partners awarded	• Signed documentation of sub-grant agreements or consultancies with eight CSRD partners (BMD, DAE, ICIMOD, IRI	**Achieved:** • After significant effort to clarify CSRD's purpose to the Ministry of Defense, which houses BMD in Bangladesh, CSRD was successful in securing approval for collaboration with the BMD by the Prime Minister's office of Bangladesh. The BMD sub-grant of USD 195,598 was signed on August 29, 2017. See Annex 2 for more details. • The DG of DAE approved sub-granting from CIMMYT to DAE using an existing Memorandum of Understanding (MoU) between the organizations.

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
			and BARI, UPF, URI). Sub-granting to UoR is expected in early 2018	Due to the delay in sub-granting to BMD, the DAE sub-granting was also delayed. After assuring that both organizations agree on their key points of collaboration the sub-grant to DAE of $100,000 was finally signed on October 16, 2017. See Annex 2 for more details • The BARI sub-grant of USD 30,000 to the Irrigation Management Division was signed on June 15, 2017. See Annex 2 for more details. • The IRI sub-grant of USD 300,000 was signed on August 18, 2017. See Annex 2 for more details. • The ICIMOD sub-grant (USD 195,000) was signed on May 1, 2017. • The URI sub-grant of USD 20,000 was signed on June 14, 2017. See Annex 2 for more details. • UPF entered into partnership with CSRD on July 19, 2017 through a consultancy agreement to F. de Vargas (see Annex 2 for details) **In Progress:** • UoR sub-grant to contextualize the potential of PICSA and pilot the approach in three pilot locations for a sustainable roll out in Bangladesh is under negotiation and expected to be completed in Q1 of 2018
		• National scientist training, exchange, between CSRD partners and IRI	• Completion of at least 10 days of exchange training with DAE and BMD focal points at IRI at Columbia University.	**Achieved** • Curricula for training has been development with IRI and formalized as part of the IRI sub-grant (available upon request). • Problems with gaining clearance of the Ministry of Defense and endorsement of the BMD sub-grant under CSRD, which were resolved on August 29, 2017 with approval of the Prime Minister's office, prevented the planned summer 2017 visit of BMD and DAE officials to IRI. • In response, CSRD organized two training visits by IRI scientists to Bangladesh to complete BMD skill assessment and forecast skill and science communication training on July 9-18 and 4-12 November, 2017. **In Progress** • These events however have not dashed plans for CSRD's in-depth training visit to IRI: BMD scientists are expected now to visit IRI in March-April, 2018, pending Ministry of Defense travel approval, which has already been requested and is now in process. See Objective 1, Sub-Objective 1.2, Activity 1.2.1 for details.

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
		• BMD and DAE knowledge and technical skill gaps identified	• Completion of BMD forecast and communication skill, and DAE communication skills completed	**Achieved** • The skills assessment of BMD and DAE by IRI and CIMMYT has been formalized as part of the IRI sub-grant. Dr. Simon J. Mason from IRI, The Earth Institute of Columbia University conducted an agriculturally-relevant weather and climate services skills assessment during July 9 – 17, 2017. • Dr. Jim Hansen and Melody Braun IRI visited Bangladesh and conducted a day-long assessment with CIMMYT and DAE focal persons on September 15, 2017. • The results of these efforts can be reviewed in Annex 4.
		• BMD, DAE, BARC, BARI, ICIMOD, IRI and other secondary partners' involvement in CSRD (supply of in-kind human resources, facilities, logistics)	• Letters of support from CSRD collaborating organizations clarifying in-kind partnerships and support	**Achieved:** • CSRD has achieved in-kind staff time contributions to support agricultural climate services work from the following organizations: CIMMYT-Bangladesh, CIMMYT-India, CIMMYT-Nepal (all through the CSISA program), IRI through Columbia University's ACToday project, the Department of Agricultural Extension in Bangladesh, the Bangladesh Agricultural Research Institute, and the *Universidade de Passo Fundo*, Bihar Agricultural University, the Nepal Agricultural Research Council (See Annex 1 for further details) **In Progress:** • BMD has approved office-space to CSRD staff in their headquarters in Dhaka, Bangladesh. The office is in the process of being furnished and will be opened officially in January of 2018 as a facility to support CSRD researchers and the above-mentioned *Climate Services Academy*. Details will follow in the next quarterly report. • CSRD is currently seeking formal letters of support from the above partners clarifying in-kind support. These will be shared in the next Annual Report.
Pillar 2: Utilize quality data, products, and tools	**2.1.** Number of and type of information and technology resources identified and offered, or brokered, by CSRD to meet problem needs and support targeted climate services.	• Crop specific forecasting maps + management advisories refined and made publically available with ongoing refinement following user feedback	• Support to CSRD partners in developing regional drought monitoring and forecasting products and interfaces • Report on planning sessions to develop crop specific forecasting maps +	**Achieved** • Through CSRD's partnership, work on the South Asia Land Data Assimilation System (SALDAS) has been expanded to Bangladesh to include drought monitoring and forecasting (see Objective 2, Sub-Objective 2.1, Activity 2.2.1, Product 1). **In Progress:** • R code (which is being developed into an R code package for public download and use, in collaboration with URI) and a preliminary method for determining cereal crop thermal stresses in Bangladesh has been developed and is currently under refinement (see Sub-Objective 1.3, Activity 1.31.1,

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
			management advisories • Prototype crop specific forecasting maps + management advisories • Public launch of crop specific forecasting maps + management advisories • Refinements made in crop specific forecasting maps + management advisories	Product 1. Improved seasonal forecasts and climatic stress maps developed and refined. Completion is anticipated on schedule by Q2 of 2018. • Three planning sessions on the development of crop-specific forecasting maps + management advisories have been held with BMD and DAE. Further progress in actual dissemination of crop specific forecasting maps + management advisories area has been delayed because of the delay gaining formal agreement with BMD through the Ministry of Defense. • Planning sessions have been initially fruitful in generating many ideas for improvement in crop specific forecasting maps + management advisories. Refinement of these ideas is expected to take place in Q2 of 2018 as part of the training exchange with IRI at Columbia University. • Refinements in the crop specific forecasting maps + management advisories will continue throughout the project period.
	2.2. Number of tailored products developed to support specific decisions	• Establishment of Program for Advanced Numerical Irrigation (PANI) prototype, subsequent field calibration experiments incorporating precipitation forecasts implemented with BARI	• Availability of PANI prototype application • Protocols for field experiments, and upload of resulting datasets to publically available databases • Revised PANI prototype following CSRD partner and farmer evaluation.	**Achieved:** • A PANI prototype irrigation DST app has been completed and is under refinement based on experimental trials initiated in November of 2017. Validation trails are being conducted by BARI Irrigation Management Division at three locations (Rajshahi, Barisal and Dinajpur). • Protocols for field experiments have been completed in partnership with BARI (see Annexes 9 and 10. **In Progress:** • Discussions are underway with BARI, BMD, and DAE regarding the feasibility of different public platform (portal and/or application DSTs) for the longer-term housing of PANI. • Refinement of PANI will take place in 2018/19.
		• Agriculturally relevant climatology, extended-range and outlooks articulated as climactic stress risk maps generated	• Prototype availability of agriculturally relevant climatology, extended-range forecasts and outlooks articulated as climactic stress risk maps	**Modifications:** • Initial USAID consultation with BMD in 2016 revealed an interest in developing seven-day precipitation forecasts with 15-day accumulative rainfall outlooks. Subsequent consultations with CSRD during the skills assessment and IRI trainings however resulted in new priorities being set that better reflect and respond to management decisions made by farmers and agricultural decision makers in the DAE and other relevant organizations. As such, the Product from these activities has been renamed 'agriculturally relevant climatology, extended-range forecasts and outlooks'. These changes are detailed below and are under research and therefore in progress, with completion anticipated before Q2 of 2018.

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)

			• Refinement of agriculturally relevant climatology, extended-range forecasts and outlooks articulated as climactic stress risk maps based on CSRD partner and farmer feedback
			• Formal establishment of agriculturally relevant climatology, extended-range forecasts and outlooks articulated as climactic stress risk maps on BMD website, with links from other CSRD partner websites
				In Progress:
				• Five meetings have been held between CIMMYT, DAE, IRI and BMD on the development agriculturally relevant climatology, extended-range forecasts and outlooks.
				• Key sub-products resulting from this work will include the following, which have been agreed on by CSRD partners:
				  • **Historical Monitoring**
				    • Crop-specific thermal stress risk mapping
				    • Monsoon progression: Seasonal accumulation
				    • Monsoon progression: Deviation from the norm
				    • Pseudo-monsoon onset
				    • Monsoon dry spells (consecutive 5 d < 1 mm, monsoon seasonal scale)
				    • Heavy rain events (moderately heavy and above, February-March)
				    • Improved language, text, format for agricultural meteorological bulletin produced by BMD
				    • *Historical and projected variability in monsoon onset and withdrawal over South Asia using NASA-NEX Ensemble* Forecasts
				  • **Forecasts**
				    • Crop-specific thermal stress risk mapping (extended range, < 14 day periods)
				    • Heavy rain events (moderately heavy and above, 0-15 day forecasts in Feb-March)
				• Further details on progress are provided in Objective 1, Sub-Objective 1.3, Activity 1.3., Product 1.

		• Spatially explicit and meteorologically driven *Stemphylium* disease risk assessments model for South Asia (Replacement for previous Precision Nutrient Management work stream as agreed on with USAID)	• Preliminary model availability • Field protocols for model calibration in India, Bangladesh, and Nepal • Model converted to R code for	**Achieved** • A preliminary model for lentil crop *Stemphylium* disease risk assessments has been developed based on Salam et al. (2016), see Objective 2, Sub-Objective 2.2, Activity 2.2.2, Product 2 'STEMPEDIA: Lentil *Stemphylium* blight disease forecasting systems in Bangladesh, Nepal, and India' for details • The protocol for data collection for validating and calibrating the prediction of onset and severity of Stemphylium disease of lentil using 'Stempedia' model in India, Bangladesh, Nepal (Rabi season 2017/18) has been developed and is currently being implemented (see Annex 15)

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
			integration into a formal DST • Refinement and improvement of model to improve suitability in India, Bangladesh, and Nepal	• Site selection (India (Bihar), Nepal (Terrai), Bangladesh (Jessore, Faridpur) has been completed. • Model converted to R code for integration into a formal DST has been completed **In Progress:** • Data are being collected following the protocol in Annex 15 from over 400 farmers' fields in Bangladesh, India and Nepal to validate the model. • Combined with weather data from each country, the model will be refined and improved to increase suitability in India, Bangladesh, and Nepal • Where adequate model fit is achieved, CSRD will explore opportunities for developing a Lentil *Stemphylium* blight disease forecasting and early warning system in South Asia
		Spatially explicit and meteorologically driven wheat blast (MoT) disease risk assessments model for Bangladesh and South Asia	• Coding for preliminary back-casting and forecasting models for MoT disease risk competed • Prototype of MoT forecasting DST completed Refinement and public availability of MoT forecasting DST	**Achieved:** • In partnership with UPF, initial modelling and preliminary back-casting and forecasting models for MoT disease risk completed for Bangladesh and the South and South-East Asian region. Coding (available on GitHub) and a prototype of MoT forecasting DST (web-based portal) for Bangladesh has been completed, more than six months ahead of schedule. • CIMMYT has established regular communications with the Wheat Research Centre of BARI's pathologists to leverage intellectual support on this work stream. • A webinar took place on 11 October at 8:30 AM in the CIMMYT office. Dr. Jose Mauricio Fernandes from UPF made a presentation on wheat blast model that they have developed. The meeting was attended by focal points from DAE and BMD, the Director, WRC and other relevant scientists. • MoT forecasting in Bangladesh DST is reliant upon regular access to BMD WRF model outputs. CSRD has achieved installation of a server to access BMD WRF model outputs as inputs to the MoT forecasting model (for details on the server, please see Objective 1, Sub-Objective 1.3, Activity 1.3., Product 1) **In Progress:** • Based on models developed by Cruz et al. (2016), preliminary code and maps have been generated using ECMWF climatologies for the South and South-East Asian region to determine land area that may be at risk of wheat blast infection. This work is in progress and can potentially be incorporated into a forecasting model, although further effort is needed to refine the current

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
				climatological model. For further details, see Objective 2, Activity 2.2.3, Product 1. • Efforts to implement regional forecasting efforts in South Asia remain heavily dependent on the Government of India and Nepal's directives in mitigating risks of wheat blast. Through CIMMYT, CSRD is well positioned to interact with the relevant Indian and Nepali research and meteorological agencies. Next step decisions will be taken depending on how each Government chooses to respond to the risk of wheat blast.
		• Contributions to climate services products developed by other CSRD partners to support specific decisions	• Number of climate services products developed by other CSRD partners that the CSRD South Asia and Bangladesh group contributed to	**Achieved:** • CSRD is actively supporting ESRI that has developed a preliminary portal and repository of shapefiles and datasets that can be publically accessed to support climate services decision making. Eight spatial datasets have been shared so far. • CSRD in South Asia's Project Leader has met with the World Bank delegation responsible for administering the large-scale Agro-Meteorological Information Services project in Bangladesh in which BMD, DAE, and the BWDB collaborate. The Agro-Meteorological Information Services project was approved by the Government of Bangladesh only in late 2016 and as such the project – which focusses mainly on the procurement of equipment and infrastructure – has only just begun activities. Verbal agreement was achieve to continue communications and support Agro-Meteorological Information Services project partners in Bangladesh and the region on a technical advisory basis. • DAE has agreed to incorporate the tools and products developed through CSRD into the Agro-Meteorological Information Services project, as stipulated in the CSRD sub-grant for CSRD. • Both BMD and DAE have invited CSRD and CIMMYT to participate as an external partner and technical advisory participant for the Agro-Meteorological Information Services project leadership committee (whose monthly coordination meetings are expected to begin in the first quarter of 2018). • CSRD has reached agreement with Columbia University's ACToday project, led by IRI, and the International Center for Climate Change and Development's (ICCCAD, housed at the Independent University of Bangladesh (IUB)) Gobeshona platform to implement a *Climate Services Academy* in Bangladesh (see Objective 3, Sub-Objective 3.2 for details). **Progress:** • CSRD and CIMMYT remain available to support ADB on CSRD related efforts in South Asia. ADB however has not been overly pro-active in reaching out for

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
				support. CSRD is in contact with the ADB office in Bangladesh and regionally in the Philippines, and remains at ADB's disposal for assistance. • The *Climate Services Academy* will be presented and discussed in a Symposium on Climate Services in Bangladesh at the Gobeshona 4 conference 2018, on January 10th from 2:10 to 3:30 pm. Through the Academy, CSRD and CIMMYT will be involved in the following activities: • Provision of a forum to support decision makers in climate-sensitive sectors and those responsible for supporting adaptation in the Bangladesh government to elucidate and analyze how climate variability and change can shape and undermine the performance of sectors important to Bangladesh's economy and society. Decision makers will learn to identify which decisions could be improved by considering climate information, and will be empowered to work with the climate science community to develop new climate services initiatives in response to identified needs. • Development and implementation of need-based educational curricula and professional degree and certification programs for cross-sectoral training in climate science, relevant scientific products including decision support tools, early warning systems, and seasonal forecasts, and climate services communication and extension accessible to relevant Bangladeshi institutions. • Provision of technical support to and cross-institutional learning opportunities for existing climate services projects and initiatives across sectors in Bangladesh • Provision of long-term opportunities for increased use of climate information and services in sectors currently lacking consistent support in Bangladesh, including aquaculture and livestock, nutrition initiatives, and forecast-based disaster preparedness and response, weather-based index insurance, among others • Response to the priorities and interests of its members and students wishing to increase their climate services skills and knowledge, thereby facilitating the exchange of knowledge and learning opportunities • Improved access to climate data (forecasts, ground data, satellite data)
	2.3. Number of people benefitting from CSRD activities.	• Quantification of people and agricultural land area benefitting from CSRD activities	• Number of people (disaggregated by gender) participating in research activities and/or	**Achieved:** • *Number of people (disaggregated by gender) participating in research activities and/or applying technologies or management practices resulting from CSRD research products:* 415 people, 386 male and 29 female. Division by organization and gender (male/female) is as follows: CSRD staff and partners (47/8), additional DAE staff participating in CSRD activities (8/4), additional BMD staff

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
			applying technologies or management practices resulting from CSRD research products • Number of people (disaggregated by gender) trained resulting from the CSRD partnership • Number of hectares upon which farmers participating in research activities and/or applied technologies or management practices because of CSRD's research products	participating in CSRD activities (5/2), farmers participating in CSRD focus group meetings (69/2), SAAOs participating in CSRD focus group meetings (59/10), farmers participating in preliminary PANI business model surveys (8/0), farmers participating in PANI field experiments (16/0), participants in drought monitoring and forecasting workshops (35/3), farmers' who permitted monitoring and sampling for wheat blast data collection (140/0). • *Number of people (disaggregated by gender) trained resulting from the CSRD partnership:* 119 people, 96 male and 26 female. Division by training event and gender (male/female) is as follows: CSRD Technical Exchange participants, Sept 17-19, 2017, (42/11), CSRD QGIS training, Sept 24-28, 2017, (11/3), CSRD PICSA Webinar, November 27, 2017 (19/5), IRI training participants to improve forecast skill (21/7) • *Number of hectares upon which farmers participating in research activities and/or applied technologies or management practices because of CSRD's research products:* Farmers on 35 hectares (140 farmers) participated in wheat blast model development activities by permitting disease monitoring and sampling in their fields in February of 2017 **In Progress:** • Since formal collaboration with BMD stated in late August 2017, most progress towards these indicators (specifically farmer numbers and land coverage) will be reported on in mid-2018 onwards. A substantial number of SAAOs of DAE and farmers in the study locations are expected to benefit from with the improved weather related advisories.
Pillar 3: Build capacities and platforms	**3.1.** Number of new capabilities to operate, deliver, or utilize climate services that are demonstrated.	• At least 150 DAE agents trained as trainers to extend use of PICSA and CSRD DSTs to DAE sub assistant agricultural officers (SAAOs).	• Training inventories and pre- and post-training test scores	**In Progress:** • Planning with DAE are ongoing with respect to implementation of these work plans. Most training will take place in 2018/19 and will be reported on in the 2018 Annual Report
		• At least 350 SAAOs subsequently trained in interpreting and communicating meteorological	• Training inventories and pre- and post-training test scores	**In Progress:** • Planning with DAE are ongoing with respect to implementation of these work plans. Most training will take place in 2018/19 and will be reported on in the 2018 Annual Report

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
		information effectively to farmers.		
	3.2. Number of efforts aimed at better understanding existing activities, new opportunities, and any limitations of climate services to achieve scale, replication or sustainability.	• Farmer decision making surveys	• Decision tree and/or choice experiment surveys deployed with farmers in CSRD field sites • Decision tree and/or choice experiment surveys data made publically available on DATAVERSE	**In Progress:** • Surveys were delayed and not completed in 2018. The reason for this set-back was the delay in achieving formal agreements with the BMD and hence DAE to participate in CSRD activities. Until agreements were reached BMD and DAE staff were prevented by organizational rules from commenting on and assistance with administering surveys. • Surveys are now under development and will be deployed and completed before the next reporting period (before Q3 of 2018).
		• PANI business model study	• Geographically explicit business model study (quantitative and qualitative) articulating the conditions under which irrigation scheduling services are most feasible deployed in CSRD field sites	**Achieved:** • An initial Literature review has been completed to determine components for business model studies in Bangladesh and India (see Annex 9) • A preliminary focus group discussion survey instrument has been developed for more detailed PANI assessment and is currently under pre-testing and refinement. **In Progress:** • Due to technical implementation and coordination difficulties in India, CSRD has chosen to focus PANI work in Bangladesh alone. Complete business model study will be deployed with a summary document provided by Q2 of 2018.
		• Number of people (disaggregated by gender) in CSRD partner organizations contributing towards, operating, or using climate services to improve agricultural decision making	• Participant observation, listing, and validation of collaborators at BMD, DAE, ICIMOD, IRI and UPF, and BARI contributing towards, operating, or using climate services to	**Achieved:** • *Number of people (disaggregated by gender) in CSRD partner organizations contributing towards, operating, or using climate services to improve agricultural decision making:* 74, 60 male and 14 female. Disaggregation by organization and gender (M/F): CSRD project and partner organization staff (47/8), additional DAE staff who have participated in CSRD activities (8/4), additional BMD staff who have participated in CSRD activities (5/2). **In Progress:** • Further progress will be made in 2018 and reported on in the 2018 Annual Report.

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
			improve agricultural decision making	
Pillar 4: Build knowledge	**4.1.** Number of captured and shared lessons learned (e.g., case studies) pertaining to the policy, practice, and research of climate services development, adoption, and maintenance.	1. **Report:** Initial report on crop specific climate thresholds and farmer decision making framework for key food and income staples identifying ways to incorporate meteorological information.	• Availability of short report/case study/success story	**Achieved:** • In initial progress a narrative report on crop-specific weather constraints and farmers' decision making processes with respect to crop management and weather in in Bangladesh has been made (See Objective 1, Sub-Objective 1.3, Activity 1.3.1, Product 1) **In progress:** • Crop specific climate thresholds for farmer decision making are being refined following CSRD partner feedback. A systematic literature review is under way. Results will be completed before Q2 of 2018.
		2. **Report:** Farmer decision making survey analysis. Information used to further refine packaging of climactic information presented by BMD and DAE.	• Availability of short report/case study/success story	**In progress:** • As detailed above, this activity has been delayed. Surveys will be completed by Short report completed Q2 of 2018. • A preliminary short report completed Q2 of 2018
		3. **Report:** Potential for incorporation of maps and decision tools into existing decision support platforms (CARFT, LCAT, CPT, etc.).	• Availability of short report/case study/success story	**In progress:** • Report to be developed as part of IRI sub-grant completed in Q1 of 2019. Report results will be incorporated into scientific papers (see below).
		4. **Report:** Business model appropriateness and results of PANI calibration experiments.	• Availability of short report/case study/success story	**In progress:** • As indicated above, this activity has been slightly delayed. Business case study completed by the end of Q1, 2018. • Remaining Report to be developed based on field experiments conducted in Q4 2017–Q2 of 2018. Final report completed Q3 of 2018.
		5. **Graphical report (Maps):** Use of historical gridded climatic data to evaluate the past frequency of occurrence of the	• Availability of short report/case study/success story	**Achieved:** • Initial modelling and preliminary back-casting and forecasting models for MoT disease risk completed for South and South-East Asia (see Objective 2, Sub-Objective 2.1, 2.2.3, Product 1. **In progress:**

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
		climactic conditions conducive to wheat blast outbreak		• This item is ahead of schedule and a short-report will be compiled for inclusion in the 2018 Q2 semi-annual CSRD report.
		6. Report: STEMPEDIA: Lentil *Stemphylium* blight disease forecasting systems in Bangladesh, Nepal, and India	• Availability of short report/case study/success story	**In progress:** • This item is on schedule. An initial report on 2017/18 lentil disease monitoring and model validation activities will be completed after by Q2 of 2019. • An initial report on model performance in Nepal, Bangladesh, India will be supplied after the CSRD project.
		7. Report: BMD and DAE forecast and climate services assessment report	• Availability of short report/case study/success story	**Achieved:** • Completed as per schedule. See Annex 4 for the report.
		8. Success story or Case study: At least 10 CSRD case studies and success stories completed	• Availability of short report/case study/success story	**Achieved:** • Two success stories were included in the semi-annual report completed in April of 2017. • Three more success stories communicating CSRD's work considering the CSRD pillars completed and are included in this report. **In progress:** • At least five more success stories communicating CSRD's work considering the CSRD pillars to be completed (2 success stories or case studies) each to be completed by June end, 2018, December end, 2018, and as part of the final project report, anticipated in 2019.
		9. Scientific paper: Farmer decision making structures: What role is there for climate information in Bangladesh?	• Paper drafted and submitted to open-access, per review journal	**In progress:** • As indicated above, surveys to build the data needed for this activity have been delayed. Anticipated initial report submission before the end of 2018. • A scientific paper will be submitted to a peer-reviewed journal before the completion of the CSRD project
		10. Scientific paper: Opportunities and constraints for agricultural climate services in Bangladesh	• Paper drafted and submitted to open-access, per review journal	**In progress:** • Anticipated submission before the end of 2018
		11. Scientific paper: Incorporating forecast information into	• Paper drafted and submitted to open-	**In progress:** • Anticipated submission before the completion of the CSRD project

Pillar	Indicator(s)	Milestones	Measurement method	Progress report (November 2016 – December 2017)
		irrigation scheduling services in Bangladesh	access, per review journal	
		12. Scientific paper: Towards early warning systems for MoT in South Asia	• Paper drafted and submitted to open-access, per review journal (BARI, BMD, DAE, UPF)	**In progress:** • Anticipated submission before the completion of the CSRD project
		13. Scientific paper: Feasibility assessment of drought forecasting for agricultural climate services: A comparison of resolution scales (led by ICIMOD with BARC)	• Paper drafted and submitted to open-access, per review journal	**In progress:** • Anticipated submission the completion of the CSRD project

Annex 4. Bangladesh Meteorological Department and Department of Agricultural Extension Climate Services Skills Assessment

Skills Assessment
Of the Bangladesh Meteorological Department for Climate Services Development and the Department of Agricultural Extension

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Executive Summary

Bangladesh Meteorological Department (BMD) staff have the expertise to address many of the technical challenges involved in developing new products, but are likely to benefit from further assistance in identification of priorities and in interdisciplinary work as they pertain to the supply of agriculturally focused climate services. Much of the interdisciplinary work under the Climate Services for Resilient Development (CSRD) project will be conducted in collaboration with the Department of Agricultural Extension (DAE), for whom and with whom climate services for the agricultural sector within Bangladesh will be developed. On-the-job capacity development needs for both organizations were identified following a climate services development framework. This framework distinguishes between engagement, research, production, application and evaluation. In addition, a review was performed of climate data collection and processing capabilities at BMD. since these are essential inputs to any climate service output.
The following capacity development needs were identified:

Data and processing

- Data quality control, missing value estimation, homogenization and statistics tools to summarize data
- Database training (Clisys data management tool)
- Fortran, Matlab and R programming, together with Linux Shell scripting skills for data processing and automation of routine tasks, such as data reformatting and database updates
- Although addressing some of the above listed needs may be beyond the scope of the CSRD project, coordination efforts between CSRD and MET Norway initiatives, in the context of the existing collaboration program, could be beneficial in realizing these objectives.

Engagement

- Sectoral awareness of agriculture and what climate information is relevant for agricultural decision making (and climate and forecast science awareness on the part of DAE)
- Communication of weather and climate information generated by BMD to non-specialists in ways that improve saliency of and confidence in the service provided. Strengthened technical communication should assist in understanding of key concepts, in recognising the limitations of the potential to provide the information desired, and in identifying possibilities for new and tailored information.

Research

- Collaboration to increase research output on:
- The understanding of the impacts of global and regional drivers of climate variability over Bangladesh
- Identification of the most useful climate models for seasonal prediction
- Predictability of seasonal weather statistics of relevance to agricultural decision making
- Interdisciplinary research on sectoral impacts of climate variability and trends
- Recalibration procedures and uncertainty estimation for weather forecasts

Production

- Product design and content – e.g., improved graphics, clearer text, more relevant variables incorporated into current agricultural meteorological bulletins regarding forecasts and observed conditions

Application and Evaluation

- Increased and improved flow of information from BMD to DAE, and vice versa
- Eliciting user feedback
- Forecast skill evaluations
- High-priority opportunities for new products that could be targeted to specific farm management decisions were identified from both the demand and supply perspective. The highest priority opportunities include:

Historical Analyses and Monitoring

- Crop specific risk-mapping of:
- Heat stress
- Cold stress
- Dry-spells and potential for irrigation as a mediating management strategy;
- Heavy rainfall events.
- Monsoon season progression in terms of cumulative rainfall as a percent of long-term historical average.
- Risk mapping of hail and extreme storm events (that can cause waterlogging or defoliation and lodging of crops).
- *Forecasting*
- Forecasts of early pre-monsoon season (and hence late *rabi* season) extreme heat (i.e., in March and April) that can cause heat stress for crops. Forecasts could be used to plan for irrigation and other mitigating actions.
- Probabilities of 7- to 14-day dry spells within the monsoon season. Forecasts could be used for planning of irrigation, rice seed bed establishment, land preparation (puddling) and transplanting dates, and potentially for fertilizer application.
- Cold spell forecasting (from mid-November to mid-March). Forecasts could be used to advise farmers for actions to mitigate cold stress in *boro* rice production (e.g., plastic sheet blanketing and/or delayed transplanting to avoid cold transplant shock). Other possible applications would likely require unrealistically accurate forecasts at long lead-times.
- Verification of forecast information, and possibly verification comparisons between meteorological services, particularly for temperatures, relative humidity, and precipitation.

Other opportunities for new forecast products that could be explored include:

- Monsoon season onset date climatologies and forecasting at all timescales. An onset definition does need to be set as agreed on by the parties involved in CSRD, and regarding available literature. Forecasts could be used for planning for land preparation and sowing of *aman* rice, in addition to transplanting. For this reason, discussions on the agricultural relevance of onset criteria will be necessary.
- Identification of false onset of the monsoon. Information could be used to advise farmers to postpone *aman* rice sowing, or to establish multiple aged seedbeds to hedge risk. This product is a special case of the dry-spell forecasts.
- Extended-range weather and seasonal forecasts of heavy rainfall risk. Heavy rainfall warnings are already issued a few days in advance, but extended-range forecasting could be implemented using probabilistic forecasting methods Forecasts could be used for planning sowing, fertilizer application, and harvests, particularly for sensitive crops such as mungbean.
- An additional opportunity is contingent upon the results of the disease modelling research being conducted by Climate Services for Resilient Development (CSRD) partners:
- Joint extended forecasts of rainfall, temperature, and relative humidity to be used as input for a preliminary model that is already completed but that needs to be implemented to ingest BMD's improved forecast data. Forecasts could be used to plan fungicide application for wheat blast disease.

Skills Assessment of the Bangladesh Meteorological Department

Introduction

This skills assessment identifies capacity development needs of Bangladesh Meteorological Department (BMD) staff to facilitate the short-term development of agriculturally relevant climate services in partnership with the Department of Agricultural Extension (DAE). The intention is to develop new information products and/or develop and tailor existing products to better suit DAE and farmers' needs, thus recognizing that any climate information generated by BMD should be:

Useful –

- issued at appropriate timescales for agriculture (i.e., predominantly for the next few weeks to months maximum)
- issued at relevant spatial scales for agriculture
- targeted for specific application purposes (e.g., to inform crop-specific management decisions and to mitigate climate risks in agriculture)

Reliable –

- with sufficiently sharp probabilities to justify action and changes in crop management
- issued on a regular schedule to assure consistency and opportunity of use
- *Credible* –
- backed by sufficient meta-data (e.g., using only data that can be properly sourced and referenced)
- *Relevant* –
- Information should be produced that can be interpreted and utilized to inform agricultural decision making with emphasis on the field-scale, so that users are positioned to employ climate information where they deem most useful.
- First, however, an assessment is provided of the available observational and modelling data with which to generate information products

Data

Bangladesh has 10 meteorological stations with data starting from 1949, but with many missing values during the first 30 years. Since 1980 there have been 35 stations providing good quality (i.e., with few missing values) daily data, although the data require homogeneity testing. The 35 stations are distributed across the entire country. Since 2001, three-hourly data are available for about 15 stations, and the number of climate stations has increased to 47 (although the extra 12 stations do not yet have sufficiently long histories for climate analysis). Under the parallel Bangladesh Weather and Climate Services Regional project an additional ~200 automatic weather stations will be deployed within the next two years.

There are no in-country or domestically produced gridded climate datasets for Bangladesh. By preference, interpolation is performed using kriging algorithms, although external parameters such as elevation are not considered in the current algorithms. Since most of the country is flat and close to sea-level, the failure to consider geographical features is not a serious issue, but doing so may be a useful development if the intention is to make maps applicable to the whole country, which can be relevant for mountain regions to the north, where geographic gradients exist.

The three-hourly data from the automatic stations are received via internet and so are available for weather analysis in real-time, but the climate data nevertheless are digitized manually from paper (CL-17) forms as a quality control step (the data entered into the forms are double-checked at the recording office). Variables available include: rainfall, sunshine hours, temperatures, dew-point temperatures, and pan evaporation. Unfortunately, a few variables of interest, such as hail and thunder are not as easily available. The digitization process involves a delay of at least a month, but could be streamlined by effective use of the Clisys database software. The Clisys software could be used to make the real-time data available for climate analyses, but the software is not running operationally because of lack of expertise. It would be worth investigating with MET Norway have any plans to hold training in the software. If they do not, then the World Meteorological Organization (WMO) should be able to advise on training opportunities. Ideally, in-country training should be provided to avoid dependence on the skills of a single, or a limited number of, individual(s). In the meantime, if necessary, some simple quality control procedures could be implemented based on buddy-checks (i.e., comparisons with neighbouring stations), tests for multivariate consistency, and comparisons with climatological data and with persistence of observations. See *Supplementary Information* for further details.

Once the data are entered from the CL-17 forms, they are quality controlled using a set of Fortran programmes. This process seems to be fairly thorough, involving multivariate quality tests to check for consistency of different meteorological parameters, as well as so-called "buddy" checks, which test for spatial consistency. Where there may be some scope for development is for long-term homogeneity checking and correction in the event of updated instrumentation, or re-location of the measuring sites, for example. These procedures are best implemented by building on the existing Fortran programmes or by using Clisys if BMD policy is to use this software as its database management tool, in order to avoid unnecessarily adding to the complexity of a critical quality control procedure that needs to be managed in a coordinated manner. Data quality control is a critical procedure that should be developed carefully without disrupting existing procedures. It is critical to build on existing capabilities rather than overhaul the entire process.

The data are stored in text format (CSV files), and there is a suite of Fortran programmes that can be used to extract selected data, calculate monthly totals or averages, apply various filters etc. These programmes are run by staff from the Climate Division to service internal and external requests for data. A few of the staff have the expertise to modify the programmes to calculate new variables of interest. Output is in a set format that is not necessarily one that can be used easily by other software packages, and so some programming skills are required to reformat the data. The programmers' ability to output data in different formats is limited. Some simple training of the Climate Division staff in Fortran would provide an immediate enhancement of their efficiency and ability to process data requests. However, a longer-term plan should consider the implementation of a data portal that could be used by BMD research and operational staff to view and access the required data directly. The portal could potentially be opened to people beyond BMD, perhaps with password protection and/or restrictions, as data policies dictate. The IRI Data Library is an example of such a portal. It has been previously implemented at the Indian Meteorological Department.

All the Climate Division programmes are written in Fortran 77; knowledge of more modern forms of Fortran is very limited. An introduction to some of the basic new Fortran features would assist in writing programmes more quickly and easily. Some of the programmes could be automated. The programmers do not currently have these skills, so could be taught very quickly to schedule jobs. Other tasks may be more effectively written using shell scripts rather than Fortran programmes. The staff also currently have only limited skills in shell scripting, although this presents an opportunity for improved training. There are some online courses[4] that could be used rather than investing in any training programmes.

Matlab has been licensed recently, and there are plans to train about 10 people in its use. Similarly, Easyfit has been acquired. Some of the scientists are learning R (which has been installed at BMD for about 5 years under a Norwegian project). A few of the scientists have developed strong R programming skills, and who could work towards setting up routines for the generation of new information products, and in performing some climate research analyses. Examples include: the generation of new maps and graphs for the agro-meteorological bulletin and the webpage; the implementation of a forecast verification procedure; and some of the work on analysis of global drivers of climate variability over Bangladesh. Some training could be provided through the collaboration with IRI, but collaboration on the development of code is likely to be required.

In addition to the station observations, the BMD have recently extended their WRF model runs to predict out to day-10 and are considering extending to day-15. In isolation, the skill of a single ensemble member extended-range weather prediction is likely to be of very limited skill, even after the application of a sophisticated recalibration procedure. The single ensemble member could potentially be used in a multi-model context, by accessing other forecasts from global centres, but it would still be difficult to demonstrate added value. It may make more sense to run the WRF model at BMD to generate an ensemble of shorter lead forecasts only. In other words, given limited computing resources, greater value could be achieved by creating a larger ensemble than by extending the lead-time. Some initial testing on ensemble generation has been performed at BMD, but further is work is required to implement an ensemble system operationally. The plan is to run 21 ensemble members out to 72 hours, which would be an excellent resource for generating probabilistic forecasts.

In the meantime, to provide extended-range weather forecasts for DAE (or for anyone else), BMD would have to rely on other models, which they would only post-process. However, that reliance is completely consistent with their current reliance on global models to provide the boundary conditions for the WRF model anyway (see the section on Production), as well as consistent with the way the seasonal forecasts are made. This reliance could be a temporary

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[4] For example: http://ryanstutorials.net/bash-scripting-tutorial/

arrangement until BMD can acquire the infrastructural capacity to generate an adequate ensemble for their own extended-range forecasts.

In conclusion, there are at least 35 stations with almost 30 years or more of daily data for multiple variables, as well as single-member 5- and, more recently, 10-day forecasts. An inventory needs to be developed of archived model forecasts. The programming staff have sufficient expertise and tools to extract data of interest, and to service many demands for additional derived variables, but could benefit from short training to automate some processes and to modernize and accelerate the system. Further ongoing training in programming for the support programmers and the scientists is to be encouraged.

Engagement

The BMD district office staff have semi-regular interactions with agricultural extension officers, and so are likely to be aware of the needs of the agricultural community. There is, however, no clarity on how DAE incorporates information given from BMD district staff into their activities, planning, or interactions with farmers. The situation is a little different in Dhaka: BMD HQ staff do not have similar opportunities to attend DAE meetings (at least as regularly) and so the staff feel unaware of the information needs of DAE as well as of DAE's level of understanding of existing products. Unfortunately, BMD is not at this time permitted to spend resources on assessing the use of its products, and so it could benefit from project activities in this area of evaluation.

DAE staff do attend monthly forecast meetings at BMD. The discussions at these meetings are targeted at BMD staff, and involve comprehensive discussions of current weather conditions, some historical analyses, and various model projections for the next few months. It is believed that these meetings have provided DAE with some reasonable exposure to climate information, although much of the information may be too complex for non-meteorologists to understand clearly. However, different representatives from DAE may come to each monthly meeting. There is no regularized system or clear accountability however for communication of the information supplied by BMD to DAE offices for agricultural action. This situation presents significant opportunities for improvement, and will be requisite for climate services development.

BMD has three or four broadcast meteorologists and is planning to double this number. These meteorologists receive training in elocution, but not in science communication (e.g., the use of simple language, or how to explain complex scientific concepts to the public by avoiding jargon, using analogies, and making comparisons to recent events), nor do they have a broad awareness of the agricultural relevance of forecasts. Training of the broadcast meteorologists, and of the scientists more generally, in science communication would assist with engagement, and in text content of information products. The communication training could be targeted to address the following immediate needs:

Improved visual and textual communication of information in the agricultural meteorological bulletin, and on the weather forecast page more generally;
Improved verbal communication of weather and climate information to the public by public broadcasts, and to DAE and other communities in meetings and discussions;
Exploration of the potential to develop existing and new communication strategies using social media.

Research

BMD have a cadre of competent researchers. It produces a biannual refereed research journal, *Dew-Drop*. There is no specific need for training in climate research, but opportunities to collaborate on research projects would be beneficial. Some areas of core climate research for which collaboration would be useful include: improved understanding of global drivers of climate variability over Bangladesh such as El Niño – Southern Oscillation (ENSO), and identification of the most useful climate models for prediction. A review of the current scientific literature, plus some simple composite analyses using reanalysis data would be a useful start towards improving understanding of the atmospheric circulation anomalies associated with climate variability over the country. The composite analyses can be used to explore how ENSO and other factors affect climate in the region, but can also be used to identify the circulation anomalies associated with climate extremes over Bangladesh.

Where BMD staff are less experienced is in interdisciplinary research, and in identifying research priorities for the development of tailored forecast products for users. These topics are developed further in the section on Production, and are particularly relevant for agricultural climate services. In addition, for the extended-range weather forecasts, BMD requires guidance on how to recalibrate forecasts and estimate forecast uncertainty when only one ensemble member is available. An introduction to some basic recalibration procedures using contingency tables or logistic regression, for example, can be incorporated in the CSRD training programmes for BMD.

Production

The BMD webpage[5] provides access to meteogram products based on the Weather Research and Forecasting (WRF) Model 18-km runs (generated at BMD) forced by National Centres for Environmental Prediction (NCEP) Global Forecast System (GFS) outputs. The page presents graphical 7-day forecasts at 6-hourly intervals of geopotential height for different levels, sea-level pressure, air temperature, relative humidity, and rainfall at 64 locations (See Table 1). The forecasts are also available in map form, for day-1 to day-3. The forecasts are deterministic, and based on a single ensemble member, and there is no recalibration or uncertainty information. Preliminary analyses and training in probability forecasting and suitable recalibration methods would be useful as a first step towards addressing these shortcomings. To extend these forecasts out to 15 days, the BMD has the in-house expertise and capacity to run the WRF model for the additional lead-times. As discussed above, extending a single ensemble member beyond about 5 days is likely to be of limited value, and establishing an ensemble system for shorter range forecasts would be a more useful initial activity. This ensemble could be developed to produce extended-range predictions once computing resources permit. In the meantime, some training on forecast recalibration and probability forecasting would be valuable, and could lead to implementation of procedures to improve the skill of the forecasts and to the provision of uncertainty information.

Procedures such as contingency tables, linear regression estimation of prediction intervals, and logistic and extended logistic regression could be considered. Other options include combination with various global high-resolution model outputs, such as those that are available as part of the North-American Multi-Model Ensemble (NMME). The advantages of working with the NMME models is that hindcasts and real-time forecasts are freely available, and the data are easily accessible from the IRI Data Library in a wide range of formats[6], including for the Climate Predictability Tool. All the NMME hindcasts and forecasts are now available for direct download within CPT (version 15.7). The BMD does have access to some forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF), but there are some issues with licence fees that would have to be considered before deciding how much to use these products.

[5] http://bmd.gov.bd/?/nwp-products/&/meteogram/
[6] https://iridl.ldeo.columbia.edu/SOURCES/.Models/.NMME/

Other web products include maps of 4- to 7-day rainfall accumulations, and deterministic 1- and 3-month rainfall and temperature forecasts. Anomalies are shown for some of the products and one- and three-month standardized precipitation index (SPI) maps are shown in real-time using interpolated climatic data. However, there is further scope for comparing the products to climatologies, using percent of average or differences from last year, or comparison to extremes, for example.

These various products provide most of the inputs for the BMD's Agrometerology page[7]. This page includes a weekly one-page bulletin showing observed rainfall for the last week, expected rainfall for the coming week, and for week-2. The week-2 map is output from the Japanese Meteorological Agency (JMA) model and is not developed in-house. BMD is interested to develop a replacement product. There is also text highlighting recent observed events, and explaining the outlook for the next two weeks. The text often focuses on synoptic descriptions rather than the experienced weather or relevant variables for agriculture, and contains no information or interpretation of forecasts or observed data to advise on agricultural management decisions. BMD forwards the bulletins to the Agricultural Information Service, which in turn forwards them to DAE, which in turn again forwards to extension officers etc. (The CSRD project focal points at DAE, however, do not currently receive these bulletins, despite belonging to DAE's ICT and climate services wings. It is not clear if or how DAE makes use of the bulletins.) The bulletins are now being forwarded directly to DAE, which should help with lead-time loss, and may facilitate the provision of feedback, as BMD has not previously been receiving any.

Ideas for improving the Agrometerology and meteogram products include:

- Providing temporal information by region, for observations and forecasts;
- Interactive maps, and interfacing to Google maps;
- Including digital elevation and other fixed aspects of the geography of the country in the spatial interpolation of data;
- Providing monitoring maps that indicate the progression of the monsoon rather than just the last week;
- Information on historical extremes and distributions, and more detailed comparisons with climatologies and past data;
- Improvements to text, such as simplified and more precise language, clearer highlights;
- Interpretation in terms of agricultural impacts, and suggested actions for specific crops and areas;
- Including some of the static products from the *Climate of Bangladesh*[8] atlas;
- Providing maps of climate-related variables such as satellite vegetation indices (e.g. NDVI, EVI) for vegetation status monitoring, which can be complementary to SPI;
- Providing information about the status and projections of global climate drivers such as ENSO;
- Including information about sea-surface temperature that can be of interest for fisheries;
- Providing information that is specific for agriculture in terms of temperature accumulation or crossing of thresholds, or reference evapotranspiration calculated by classical approaches (e.g. FAO Penman-Monteith method) instead of providing just pan evaporation;
- Providing a glossary of technical/scientific terms used in the text at the end of the document.

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[7] http://bmd.gov.bd/?/p/=Agromet-Forecast
[8] http://bmd.gov.bd/?/p/=Climate-Report

- The BMD have the capacity to implement most changes (with the exception of the interpretations) without assistance, but would benefit from further discussions with the CSRD team on what changes to make. Modification and improvement of these products is, however, highly recommended as a next step following this report. The scientific staff have been developing valuable skills in R for more sophisticated analyses and product development, including an interactive mapping facility that offers good promise for developing products for the DAE.

If any changes were made to the Agrometerology bulletin, the production staff would need to be trained in the new procedures, and the district offices staff would also require training in interpretation since they act as the primary contact points for the agricultural community users. Given these needs, it may be useful to assess what information district level DAE and BMD staff deem as most relevant for agricultural decision making, as part of the process of redesigning these products.

Standard operating procedures (SOPs) are in place only for aviation. BMD is encouraged to develop them for their other products so that specific guidance is documented and can be followed for weather and climate information products. The SOPs are most urgently required for daily operational products, such as weather products, although it may be simpler and more in-line with the CSRD objectives, to start with the Agrometerology bulletin.

Application and Evaluation

In general, there is a sense that many potential users do not refer to BMD products and that they (including in DAE) look elsewhere for weather and climate information. The reasons for over-looking BMD are not entirely clear, but likely include accessibility and ease of interpretation. BMD do not actually issue quantitative daily weather forecasts, and instead provide only subjective qualitative statements. The subjectivity is not a problem per se, but the lack of quantitative information means that the forecasts appear to lack precision and may appear vague. It also renders agricultural decision making highly difficult to implement, which represents an area of priority for improvement under CSRD activities.

However, BMD have developed a new smart-phone weather App that appears to be well-designed, although it too could benefit from forecast information (it currently shows only current conditions) and with supplemental agricultural management advisories. Any new information that would be included in the app would most likely be based on numerical weather product (NWP) outputs, and it is quite likely that the quality of the forecasts provided by BMD is superior to those from competitors, notwithstanding the fact that BMD's current NWP outputs are not calibrated. This skills assessment identified the need to perform evaluations and to publicize the results as an important requisite for improving BMD's capabilities and public trust in climate services. BMD staff have been involved in the Joint Working Group on Forecast Verification Research (JWGFVR) training programmes, and so further training is not required, although collaboration would be useful, especially for comparative verifications.

Calibrating forecasts should be considered a high priority activity for BMD and CSRD. BMD scientists are understandably concerned about the difficulty of providing meaningful forecasts with only a single ensemble member from a single NWP model, but there are some simple statistical procedures, such as contingency tables or various regression options, that could be implemented and developed into more sophisticated procedures at a later date. The implementation of these model output statistics (MOS) procedures is a widespread practice. Even with only two or three years of forecasts, a reasonable calibration procedure could be implemented. The calibration would need to be location- and season-specific. It would likely be advisable to have separate calibration schemes for each month, or at least for each of the four meteorological seasons: monsoon (June – September), post-monsoon (October – November), winter (December – February), and pre-monsoon (March – May). Archiving the NWP outputs is a major challenge because of disk-space requirements, but a subset of the outputs could be archived as a compromise. Saving the full model output is an inefficient use of storage capacity; instead archiving only the surface variables for verification purposes could be considered.

New Product Development to Meet the Information Needs of the Department for Agricultural Extension

The largest impacts of hydro-meteorological hazards that of are concern to the DAE are for flooding and inundation, and for hail damage. These, however, are either not the purview of BMD (in the case of flooding and inundation), or are hazards for which realistically accurate forecasts would provide few if any opportunities for agricultural mitigation (in the case of hail and flooding). For the flooding and inundation problems, higher resolution land-use mapping may prove valuable, although integration with the Bangladesh Water Development Board is advised. For the hail damage, BMD may be able to provide risk maps because hail occurrence is reported on the CL-17 forms. It is unclear whether a sufficient history of the hail-occurrence data have been digitized, or whether they are available in an easily usable digital format.

High-priority opportunities for new products that could be targeted to specific farm management decisions were identified from both the demand and supply perspective. The identification of specific decisions that could be informed by weather and climate information was a prerequisite for inclusion in the list. The highest priority opportunities include:

Monitoring products

- Crop specific risk-mapping of
- Heat stress;
- Cold stress;
- Dry-spells and potential for irrigation as a mediating management strategy;
- Heavy rainfall events.
- Many of these products are already available in the *Climate of Bangladesh* atlas, but could be usefully packaged as part of an agro-meteorological resource webpage, for example.

Mapping and monitoring

- Risk mapping of hail and extreme storm events (that can cause waterlogging or defoliation and lodging of crops).
- Monitoring of the monsoon progression. The Agrometerology page of the BMD website includes information on the weather of the previous week, but this short-term retrospective could be usefully supplemented during the monsoon season by weekly updates on the cumulative rainfall since the beginning of the monsoon season. These updates are probably most easily understood if expressed as %s of average. India produces similar information in its *Monsoon On Line*[9] page. The information would be largely of public interest rather than targeting specific decisions within the DAE or by farmers, but would help raise broad awareness of areas of possible drought development, for example. More targeted drought monitoring and forecasting products could be developed for DAE if required, perhaps using appropriately defined SPI mapping.

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[9] http://www.tropmet.res.in/~kolli/MOL/Monsoon/frameindex.html

Forecast products

Forecasts of early pre-monsoon season (or alternatively late *rabi* season) heat (i.e., in March and April) that can cause heat stress for crops, particularly near flowering. Forecasts could be used to plan for irrigation to mitigate heat stress (assuming that farmers are already aware of the need to sow early to escape stresses, and/or are using heat tolerant cultivars). Predictability could be explored from seasonal (which could enable sowing time and variety selection options) to weather (which could enable heat mitigating irrigation) forecasting scales. The format of the forecast would have to depend on the lead-time. For the shorter-range, forecasts could be presented as probabilities of hot days occurring on each of the next few days (maximum one week) above crop species-specific threshold temperatures, and then as probabilities of any day being hot within the following week. Seasonal forecasts would likely be presented as probabilities of at least *n* hot days above the same thresholds, where *n* could be defined appropriately based on the climatological frequencies, and with prediction targeted at the phenological stage of the crops in which heat stress is the largest concern. The BMD have definitions of heatwaves already based on the maximum temperature:

- mild 36° – 38°C
- moderate 38° – 40°C
- severe > 40°C

They are considering using a comfort index as part of a MET Norway project. For agrometeorological purposes, crop-species specific thresholds and time-frames need to be determined based on the literature review in process by CIMMYT.

Probabilities of 7- to 14-day dry spells within the monsoon season (or possibly first and second half of season, and possibly in the pre- and post-monsoon seasons). Forecasts could be used for planning of supplementary irrigation, rice seed bed preparation, and preparation, seedling transplanting, and potentially for fertilizer application. Predictability could be explored from seasonal to weather forecasting scales. The format of the forecast would have to depend on the lead-time. For the shorter-range, forecasts could be presented as probabilities of a 7-day or longer dry-spell commencing within the next approximately two weeks. Seasonal forecasts would likely be presented as probabilities of at least *n* days within 7-dry spells, where *n* could be defined appropriately based on the climatological frequencies and/or based on literature-derived assumptions of how much water might be required to keep rice paddies sufficiently moist without drought stress. (Predicting the number of dry spells does not make sense at seasonal timescales because of problems with handling duration.) The BMD define a dry-day as one receiving less than 1 mm of rain. This definition is likely to be suitable for agricultural purposes, with the caveat suggested above.

If successful, the seasonal forecasts of dry spells could be introduced to the pre-monsoon South Asian Seasonal Climate Outlook Forum (SASCOF).

Cold spell forecasting (from mid-November to mid-March Forecasts could be used to advise farmers for actions to mitigate cold stress in *boro* rice production (e.g., plastic sheet blanketing and/or delayed transplanting to avoid cold transplant shock). Other possible applications such as informing crop variety selection, planting dates and site selection, would likely require unrealistically accurate forecasts at long lead-times. Predictability could be explored from seasonal to weather forecasting scales. The format of the forecast would have to depend on the lead-time. For the shorter-range, forecasts could be presented as probabilities of cold days occurring on each of the next few days (maximum one week), and then as probabilities of any day being cold within the following week. Seasonal forecasts would likely be presented as probabilities of at least *n* cold days, where *n* could be defined appropriately based on the climatological frequencies. (Predicting the number of distinct cold spells, as opposed to the total number of cold days, does not make sense at seasonal timescales because of problems with handling duration.) The BMD does have definitions of cold days already, using the minimum temperature:

- mild 8° – 10°C
- moderate 6° – 8°C
- severe < 6°C

For agrometeorological purposes, the mild threshold of 10°C might be useful during November and December because of its impact on germination. Additional thresholds of 13°C (seedlings), 15°C (tillering), and 18°C (anthesis) would be of interest, although CIMMYT is working to verify these temperatures based on literature reviews.

Verification information, and possibly verification comparisons.

Other opportunities for new forecast products that could be explored include:

- Monsoon season onset forecasting at all timescales. Forecasts could be used for planning for land preparation and sowing for *aman* rice, in addition to transplanting. There is no formal definition of monsoon onset in Bangladesh and a definition would have to be set. The definition could be set in terms of sufficient rain for *aman*, and not worry about whether this definition is a suitable onset from a meteorological perspective.
- Identification of false onset of the monsoon. Information could be used to advise farmers to postpone *aman* sowing, perhaps by an alert system, or to sow multiple seedbeds to mitigate risk and assure correct transplant age. Although there is no formal definition of monsoon onset in Bangladesh, useful information could still be provided without agreement on the precise definition by re-casting the problem as one of predicting the probability of a dry-spell commencing shortly after early-season rains.
- Probabilities of heavy rainfall during the late dry *rabi* season or early pre-monsoon seasons. Forecasts could be used for planning of sowing, fertilizer application, and harvests, particularly for sensitive crops such as mungbean. These forecasts could be formulated in a similar way to the dry-spell forecasts.
- An additional opportunity is contingent upon the results of the disease modelling research being conducted by Climate Services for Resilient Development (CSRD) partners:
- Joint extended forecasts of rainfall, temperature, and relative humidity. Forecasts could be used to plan fungicide application for wheat blast disease. A preliminary model is already completed, although it needs to be coded to ingest BMD's improved forecast data.
- Depending on the lag between weather events and disease development, there may be value in providing monitoring information.

Table 1

Product	Type	Details	Suggestions for development
Home page weather information http://www.bmd.gov.bd/	Monitoring and 24-hour forecasts	Maximum and minimum temperature; weather symbols; significant weather; astronomical information; rainfall; wind; humidity; atmospheric pressure	• Clarify the meaning of the shading on the map (if shading is simply to distinguish districts, provide shading for a weather parameter) • Clarify whether the textual weather information is a forecast or the latest observations • Add comparisons on the graphs, e.g., to climatology or last year
Weather forecast http://www.bmd.gov.bd/?/p/=Weather-Forecastand accompanying downloadable PDF Additional model outputs are available from the NWP Outputs page: http://www.bmd.gov.bd/?/nwp-products/&/wrf-model/	24-hour forecasts and 2- and 5-day outlooks, plus 3-day NWP outputs	Synoptic situation; forecast statement; qualitative temperature and precipitation forecasts for the entire country and for individual divisions Forecasts are based on single-ensemble member WRF model output; other pages are available for HRM and GSM (JMA)	• Place the forecast statement first • Provide quantitative calibrated temperature and precipitation (or probability of precipitation) forecasts, using MOS corrected WRF model output • Introduce ensemble system when available • Provide locally specific forecasts • Make distinction between forecasts and observations clearer • Table of observations should be distinct from the forecasts, and ideally made available through a portal so that archived data can be accessed (possibly password protected) • Temperature and surface RH maps do not display • Package the various pages as a clear weather forecast rather than as model outputs
Meteogram products http://www.bmd.gov.bd/?/nwp-products/&/meteogram/	10-day forecasts	Graphs of predicted atmospheric pressure, temperature, humidity, rainfall, and winds at various altitudes.	• In general, the web-page is presented more as a resource for meteorologists than the general public – the forecast should be clearly identifiable, and information that is model output should be removed, or made less immediately accessible • Skill from a single ensemble member is likely to be very weak beyond about 3 days • Recalibrate • Most of the information is too technical

Accumulated rainfall http://www.bmd.gov.bd/?/nwp-products/&/meteogram/	4-. 5-, 6-, 7-, and 10-day forecasts	Maps	• Potentially useful, but skill from a single ensemble member is likely to be very weak beyond about 3 days • Recalibrate and use an ensemble
One-month outlook http://www.bmd.gov.bd/?/nwp-products/&/meteogram/ and accompanying PDF One-month JMA model prediction: http://www.bmd.gov.bd/?/nwp-products/&/meteogram/	1-month outlook and review of previous month JMA ensemble-mean outputs	Observations of last month. Forecast of coming month presented as prediction intervals for rainfall, rain-days, and soil moisture How are prediction intervals generated? One-month ensemble mean maps of rainfall and temperature (plus anomalies)	• Rainfall % departure do not seem to match with observations and climatology • Outlook should probably come before observations • Format as a newsletter rather than as a technical report • Prediction intervals are appropriate, but some probabilities of exceedance / non-exceedance might be useful for agriculture • Verify previous forecasts • Define and implement SOPs – requires research on appropriate models and predictors • Combine the two pages into a distinct outlook page • JMA forecast maps need some uncertainty information
Three-month outlook http://www.bmd.gov.bd/?/nwp-products/&/meteogram/Three-month JMA model prediction: http://www.bmd.gov.bd/?/nwp-products/&/meteogram/	3-month outlook	Expert assessment of various GPC and other forecasting centre products Three-month ensemble mean maps of rainfall and temperature (plus anomalies)	• Define and implement SOPs – requires research on appropriate models and predictors • See previous comments on JMA maps
Climate outlook http://www.bmd.gov.bd/?/nwp-products/&/meteogram/	Seasonal forecast	Latest SASCOF product	• Clarify its purpose with respect to the 3-month outlook (e.g., highlight the regional perspective). • Provide access to archives

Agrometerology Forecast http://www.bmd.gov.bd/?/nwp-products/&/meteogram/	Weekly monitoring, one- and two-week outlooks	Updated weekly	• See main text of this skills assessment for reformatting content, and calibration suggestions

Climate Services Communication and Extension Skills Assessment

Objective: Identify potential areas within Bangladesh's Department of Agricultural Extension (DAE) where climate services capacity development might be beneficial

DAE is currently using a large range of communication tools to communicate agricultural information to farmers. These include national and community radio in several areas, trainings, field days, farmer field schools (FFS) and group meetings, making, voice messages to sub-assistant agriculture officers (SAAOs; who are front-line extension agents), videos and short movies, cinema vans, TV agricultural programs, among others. However, the existing communication does not yet include any climate-related information, and there is an interest from DAE to incorporate climate services into their activities.

The upcoming World Bank Weather and Climate Services Regional Project (which is expected to run through 2020) aims at creating agrometeorological information through a collaboration between the Water Development Board and the Bangladesh Meteorological Department, and by using different agricultural extension methods to synthetize, translate and disseminate this information to farmers. New information will be generated through the installation of new automated weather stations, radars, ocean buoys and river gauges. CSRD is uniquely placed to develop training guidelines and decision support systems that can be incorporated into the World Bank project to scale up science-informed climate services in Bangladesh.

While a lot of information is already available (and more will be generated), and a large range of dissemination tools are already used, support is mostly needed in the effort of translating the information into something digestible, useful and directly useable for farmers. To do that, the first priority is to understand farmers' needs for information, and the best format to deliver that information. This can be done through participatory processes in selected villages, or through farmers workshops. In parallel, in order to match farmers' needs with realistic options, DAE extension agents could use some basic training on the type of information available.

Opportunities for CSRD

Communication and dissemination tools are the vehicle to bring a specific information from point A to point B. If the intended end users (point B) are farmers, then two questions should be explored: (i) what is the type of information that farmers need, and in which format (this can be done through participatory processes in selected villages); and (ii) Who generates / has access to this information, and can disseminate it (or who is point A). The number of people, or elements, or steps between point A and point B are likely to play a role in the efficiency of the process. A long chain involving several levels of decision makers, and requiring approvals or specific actions at each levels, is likely to be too slow, and costing a lot of time and resources. Answering those two questions should help identify the best dissemination channels. Efforts are under way already in CSRD to address these questions, which will help to guide further project implementation.

Another element to be considered is the gender-differentiated access to information. The diversity of existing tools seems to reach a broad range of end users, although the access of information to women should be explored as it is not explicitly accounted for at this time. While farmer field schools often require a minimum percentage of women participants, and radios are largely used by women in households, other tools such as TVs at tea stalls, cinema vans or activities taking place outside of the household may reach predominantly men. CSRD should take note of these issues in planning dissemination strategies, as should the above described World Bank project.

Farmer Field Schools and Common Interest Clubs/Groups are used by DAE in a number of locations. Including climate and weather information into those curriculums would build capacity and knowledge of those farmer groups on climate services and their possible uses. Including such information into curriculums would involve efforts to train the DAE staff in charge of conducting the farmers field schools, which could be conducted in the context the planned training of SAAOs by CSRD using approaches similar to those used in the Participatory Integrated Climate Services for Agriculture (PICSA) programs in Africa and South America. There are over 3000 identified lead farmers in Bangladesh, who could be trained as trainers and included in the preparation of the curriculums together with SAAOS. All skilled women among SAAOs and lead farmers should be included in the training to reach a ratio as close to parity as possible. CSRD should explore opportunities for initial SAAO and lead farmer training on a provisional basis, and develop case study lessons from which learning can be drawn for potential incorporation into DAE's general FFS and farmer club curriculums, in addition to the World Bank project.

Using mobile phones appears to be a valuable option to disseminate information to a large number of people in a very quick, cheap and effective way, if it can be relatively direct, without a large number of intermediaries. Work will however be needed to assess the degree to which farmers trust and act on messages deployed through mobile phone networks. Initial participatory processes can help decide whether messages should be written or audio, and who would have access to those. They could also be used to collect feedback from farmers, or other potential useful information. Further ideas include the validation of forecast accuracy using text message responses from farmers (e.g., reporting back if it is raining in a particular location or not, as an aid for forecast down scaling). Voice messages are already used to disseminate flash flood warnings, but these only go to the SAAOs level and don't necessarily reach farmers. End users should thus include both SAAOs and lead farmers from FFS and Common Interest Groups.

The initial discussion about the use of mobile phones should be pursued in CSRD, with the goal of limiting the number of intermediaries in the information chain and automating the process as much as possible. The potential development of an app for irrigation scheduling under CSRD could include some climate information, and be accessible to 11,000 SAAOs through the distribution of tablets by the World Bank project, however it should be considered in addition to mobile communication to non-smartphones to reach as many people as possible. Last but not least, further dissemination through the ICT/media platform of the Agricultural Information Communication Center from the Agricultural Information Service (AIS), which is tasked with generating information and media that can be used by DAE, should be explored through CSRD.

Suggestions for how DAE might be able improve feedback from farmers on the quality of extension and climate services

One possible feedback loop that seems to be already implemented at least occasionally for agriculture advisories is the organization of farmers' workshops to collect information and communicate to Upazila (sub-district) DAE committees, then to district committees. This mechanism then relays the information at national level to (BARI, BRI, BRC, NGOs etc.). It is not clear to us at which frequency or scale these are organized, however. Such workshops could be regularized also be used to assess the use of and need for climate information and services, the type of information that farmers already have access to (through other channels – which ones?), and the type of information they think they would need, or would like to have access to. This could constitute the first step in the wider participatory design of a climate services information sharing mechanisms, and could further be turned into a continuous or regular feedback loop, once climate information start being provided to farmers. Mobile apps/sms could also be used to ask basic questions to / collect basic feedback from partners to assess whether they had access to / used / understood climate information.

Supplementary Information: A simple quality control test

Most data quality control procedures involve calculations of how likely the value of a meteorological parameter is, and then deciding whether the value is sufficiently unlikely to warrant rejection. The simplest approach is to compare the value with the climatological values for that location and time of year, but there is a danger of then rejecting data whenever a severe weather event occurs. The procedure can be made more sophisticated, without becoming overly complicated, by comparing the value with other observations that are taken either at the same time or immediately prior to the value in question. These procedures are can be implemented as follows:

For comparisons with climatological observations, select data for the same location and month of the year (it may be possible to use additional months in the same season if sample size is a problem). Fit an appropriate distribution to the data. For daily data, and quick solutions, a normal distribution should be adequate for temperature, while a negative exponential distribution should be adequate for precipitation. For precipitation it may be worth fitting a distribution only to the days with rain so that the distribution parameters are not dominated by the dry days (presumably for comparisons with climatological data, the interest will be only with the validity of heavy rain days – once of the other tests described below would be more appropriate if there is question over an observation of no-rain). Next calculate the probability of exceedance (or non-exceedance for questionably low values) from the cumulative distribution function. Set an appropriate probability threshold for rejecting the value. Comparisons with climatology are likely to be the simplest procedure to implement, but are recommended only for isolated stations with many missing vales. The procedure can almost always be improved by considering the current context, which can be done in one of the following ways.

If other observations for the location are available then tests for consistency with other weather parameters can be made. For example, temperature and rainfall are generally negatively correlated in the tropics (more rain implies lower temperatures). Using data for the same location and time of year (month or season, as discussed above) fit a regression model between the variables, with the parameter containing the questionable value as the dependent variable. Depending on the distribution of the data, it may be preferable to use generalized linear models rather than simple or multiple linear regression, but for a quick implementation, a standard regression model should work reasonably well. Next calculate the estimated value of the dependent variable and compare this value with the disputed observation, to identify whether the disputed values is an outlier. For a standard regression model the difference between the disputed and estimated value can be compared to the scatter about the regression line to decide whether the observation is an outlier. Set an appropriate threshold for defining an outlier. This multivariate procedure aims to identify whether the disputed observation is consistent with other recorded weather conditions at the same time and location.

Alternatively, this regression procedure can be applied using observations from neighbouring stations as the independent variable(s). The procedure is otherwise identical, but the aim is to identify whether the disputed observation is consistent with other recorded weather conditions in the region.

Similarly, the same procedure can be applied using observations immediately prior to the disputed observation. The objective is to identify whether the magnitude in the implied change in weather is reasonable.

Annex 5. Anticipated curricula for CSRD visiting scientist exchange to IRI

Objectives: Provide scientists from Bangladesh Meteorological Department (BMD), Department of Agriculture Extension (DAE) and CIMMYT (International Maize and Wheat Improvement Center) at IRI with the skills to provide agriculturally relevant climate forecasting, communication of climate services information. Assist in the development of CSRD strategies for Bangladesh.

Course Overview: The first part of the course will introduce all participants to the key concepts and challenges from both climate and agriculture perspectives. In the second part of the course, the BMD and DAE participants will separate into two groups for more in depth training in their respective specialties. The third part of the course brings all participants back together for shared learning and to agree on next steps.

Course Structure: Mornings will primarily involve lectures and interactive discussions. Afternoons will focus on hands on work, including exercises and training assignments.

Week 1	Topics and Activities	Notes
Monday (Day 1)	**Morning: Introduction to the course, IRI, and climate services** • Introduction, objectives, course content, participant introductions, logistics • Overview of agricultural climate services and lessons from different global regions (Jim) • Introduction to Climate Risk Management in the smallholder agriculture in developing nations: vulnerabilities, uncertainties, technologies and policies (Walter) **Afternoon: Data Library (DL) and Maprooms** • Introduction to the IRI Data Library and Map rooms (DL Team) • Data Library Exercises with emphasis on the South Asian region. (DL Team) • Accessing, visualizing and analyzing data in the DL (DL Team) **Homework:** • Data analysis and visualization from the DL	All participants together
Tuesday (Day 2)	**Morning: Climate fundamentals** • Review of homework exercises • Climate fundamentals: Typologies of different types of forecasts and their precision (Simon/Nachi/Colin) • Climate fundamentals: Seasonal climate processes, different types of forecasting models and predictability (Simon/Nachi/Colin) **Afternoon:** • Climate exercises using the DL - Group 1: Identifying ocean influences using the DL; Group 2 - Global and Regional Scale Processes, Models, and Predictability,	All participants together

	and Methods for Seasonal Prediction, Downscaling and Tailoring (IRI team) • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain) **Homework:** • Complete DL exercises and prepare group presentations	
Wednesday (Day 3)	**Morning: Climate services and communication strategies** • Group homework presentations • Introduction to communication methods for extending climate information and meteorological advisories to farmers and extension services (Jim) • Weather Index insurance advantages and constraints (Jim, Braun) • Presentation of Bangladesh farmer and extension agent focus group results (Tim, Hussain, Aziz) **Afternoon: Climate services and communication strategies continued** • Examples of what works (and does not work) in ICT and media platforms for increasing farmers' awareness of climate information and crop advisories (Jim/Alison) • Social media technology overview (Francesco/Elisabeth) • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain) **Homework:** • Readings on communicating climate services	All participants together
Thursday (Day 4)	**Morning: Climate Predictability Tool** • Review of homework readings • Introduction to the Climate Predictability Tool (Simon/Nachi/Colin) • Practical exercises using the CPT – sub-divide participants into two groups with unique exercises (Simon/Nachi/Colin) **Afternoon: Tailoring climate forecasts and CPT exercises** • Tailoring seasonal forecasts for agriculture using CPT (Simon/Nachi/Colin) • Practical exercises in interpretation and communicating CPT results for agricultural climate services (Simon/Nachi/Colin) • Work on CPT group exercises and homework • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain)	All participants together

	Homework: • CPT exercises and preparation of group presentations for tomorrow	
Friday (Day 5)	**Morning: Introduction to agricultural modeling** • CPT homework presentations by group • Introduction to integrating climate information with agricultural modeling (Jim) • Status of wheat blast in Bangladesh and South Asia (Tim – CIMMYT) • Wheat blast disease forecasting systems and integration with agricultural modeling + Discussion (Guest presentation over Skype by UPF, U. Florida, EMBRAPA) **Afternoon: General sessions** • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain) • Co-defining individual work project for all participants and refining training needs (all) • Individual tutoring/discussions on week 1 topics (as needed) **Homework:** • Climate services readings and introductions to crop modeling	All participants together
Saturday (Day 6)	**Morning** • Free time **Afternoon:** • Trip to Manhattan + Dinner	Voluntary
Sunday (Day 7)	**All day:** Free time	Voluntary

Week 2	**Topics**	**Notes**
Monday (Day 8)	**Morning: Recap and hands-on introduction to crop modeling**	All participants together

	• Recap of prior week, taking stock (all) • Review of homework readings • Introduction to the uses of APSIM (Hussain – CIMMYT) • Introduction to the uses of DSSAT (Eujin) **Afternoon: DSSAT modeling** • Instillation and basic use of DSSAT (Eujin) • Practical DSSAT exercises (Eujin) • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain) **Homework:** • Continued DSSAT Exercises	
Tuesday (Day 8)	**Morning: Recap and hands-on introduction to crop modeling** Review of DSSAT exercises • (Eujin) • Advanced DSSAT exercises (Eujin) **Afternoon: DSSAT modeling** • Advanced DSSAT exercises (Eujin) • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain) **Homework:** • Complete advanced DSSAT exercises	All participants together
Wednesday (Day 9)	**Morning: Advanced climate fundamentals** • Review DSSAT homeworks (Eujin) • Weather within climate: monsoon onset/cessation dates/ rainfall frequency and intensity (Facilitator TBD) • Dry/wet spell characteristics (Facilitator TBD) **Afternoon: Advanced climate fundamentals continued** • Forecast verification and digitization (Facilitator TBD) • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain) **Homework:** • No homework	All participants together
Thursday (Day 10)	**Morning: Crop abiotic stresses and historical stress analysis for Bangladesh** • Crop abiotic stresses in South Asia (Tim, Simon, Hussain) • Guest presentation on historical thermal stress analysis for Bangladesh (Alfi Md. Hasan, U. Of	Together and parallel sessions for BMD and DAE participants

	Rhode Island) • Discussion on refinement of BMD's agro-meteorology forecast structure (all) **Afternoon: Individual learning tutoring sessions + group work** • *For BMD* – incorporating lessons learned so far and work to improve forecast skill and resolution • *For DAE* – Development of climate services communication structures for Bangladesh and work on extension agent training modules • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain) **Homework:** • No homework	
Friday (Day 11)	**Morning: Individual learning tutoring sessions** • *For BMD* – incorporating lessons learned so far and work to improve forecast skill and resolution • For DAE – Development of climate services communication structures for Bangladesh and work on extension agent training modules **Afternoon: Group work** • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain) • End of week: Recap of day, taking stock (all) **Homework:** • Work over the weekend on CSRD project structure and integration of activities	Together and parallel sessions for BMD and DAE participants
Saturday (Day 12)	**Morning** • Free time (additional activities to be announced) **Afternoon:** • Free time (additional activities to be announced)	Voluntary
Sunday (Day 13)	**Mid-morning onwards:** • Group CSRD discussion, planning, and coordination (Tim, Simon, Hussain)	All participants together
Monday (Day 14)	**Morning: Individual learning tutoring sessions** • *For BMD* – incorporating lessons learned so far and work to improve forecast skill and resolution • For DAE – Development of climate services communication structures for Bangladesh and work on extension agent training modules **Morning: Group work**	Together and parallel sessions for BMD and DAE participants

<table>
<tr><td></td><td>Group CSRD discussion, planning, and coordination + preparation of integrated participant presentations on project work (Tim, Simon, Hussain)
Homework:
Integrated presentation preparation</td><td></td></tr>
<tr><td>Tuesday (Day 15)</td><td>Morning: Individual learning tutoring sessions
For BMD – incorporating lessons learned so far and work to improve forecast skill and resolution
For DAE – Development of climate services communication structures for Bangladesh and work on extension agent training modules
Morning: Group work
Group CSRD discussion, planning, and coordination + preparation of integrated participant presentations on project work (Tim, Simon, Hussain)
Homework:
Integrated presentation preparation</td><td>Together and parallel sessions for BMD and DAE participants</td></tr>
<tr><td>Wednesday (Day 16)</td><td>Morning: CSRD project presentation
Final integrated participant presentations on project work to all IRI staff
Overview of training outcomes, assessment of next steps
Afternoon:
TBD, as needed</td><td>All participants</td></tr>
</table>

Bangladesh Met. Department joins climate services partnership

With approval from the Office of the Prime Minister, the Bangladesh Meteorological Department (BMD) formally joined the Climate Services for Resilient Development (CSRD) partnership in South Asia in September of 2017.

The Bangladesh Meteorological Department (BMD) formally joined the CSRD partnership during a signing ceremony on 28th September, 2017, held in the conference room of the Ministry of Defense in Dhaka. Representatives from BMD and International maize and Wheat Improvement Center (CIMMYT), which leads CSRD activities in South Asia, signed as the collaborative parties of the project. CSRD is a global partnership whose core mission is delivering climate services — including the production, translation, transfer, and use of climate information — purposefully designed to enable decision-makers to address climate problems and create solutions. CSRD's efforts in South Asia focus on assisting smallholder farmers and stakeholders in agriculture to make better use of climate information to increase farm resilience.

Mr. Akhter Hussain Bhuyia, Secretary, Ministry of Defense, Mr. David Westerling, the Acting Economic Growth Office Director and the Feed the Future Team Leader, USAID, Mr. Shamsuddin Ahmed, Director, BMD, Dr. Timothy J. Krupnik, CIMMYT and CSRD in South Asia Project Leader, Dr. Ghulam Hussain, CSRD Senior Coordinator, and Dr. Thakur Prasad Tiwari, CIMMYT-Bangladesh Country Representative, were present in the ceremony.

"By working CIMMYT and the and other national and international CSRD partners, BMD will greatly benefit from this unique partnership that aims to integrate agriculturally relevant meteorological information into easy-to-use and demand-driven decision support platforms to improve climate advisory services for crop management" said Mr. Shamsuddin Ahmed, Director, BMD.

Part of the Government of Bangladesh, BMD issues meteorological forecasts and warnings in Bangladesh and is responsible for providing climate information to public and private sector agencies in Bangladesh.

"We are excited by this new opportunity to develop new tools, services, and approaches and to increase forecasting capacity in BMD through CSRD." Mr. Shamsuddin Ahmed added that "This work will strengthen our ability to generate agriculturally relevant information and increase climate resilience in Bangladesh."

Dr. Thakur Prasad Tiwari, Country Representative, CIMMYT-Bangladesh and Mr. Shamsuddin Ahmed, Director, BMD signed the partnership agreement in Dhaka, Bangladesh on 28th September 2017. Photo: MSH Khan (CIMMYT)

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. In South Asia, CSRD supported by USAID and led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI).

Strategic alignment

Scientists set new regional climate services agenda

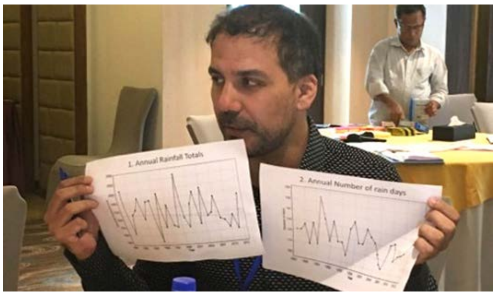
Scientists from across South and Southeast Asia launched a new agenda to boost farmer involvement in developing climate information and services

Over 45 climate researchers gathered in Dhaka, Bangladesh for a three-day workshop from September 17-19, 2017. They evaluated how climate and agricultural extension advisories are currently produced and conveyed, and identified opportunities on how to improve these services for farming communities in Bangladesh, India, Indonesia, Myanmar, Nepal, Philippines, Sri Lanka and Vietnam.

"Key to climate services is emphasis on the *service*," said Dr. Timothy J. Krupnik, Systems Agronomist at the International Maize and Wheat Improvement Center (CIMMYT) and Project Leader for Climate Services for Resilient Development (CSRD) activities in South Asia. "We must be able to rapidly extend information to farmers and others who require climate data and tools to inform their decision making, and to assure that research outputs are translated in an easy to understand way that communicates to farmers, extension workers and policy makers," said Krupnik. "Equally important is feedback from farmers on the quality of climate services, so they can be adapted and improved over time."

During the workshop, which was supported by USAID and implemented with the assistance of the USAID funded SERVIR and Climate Services Support Activity, delegates assessed different ways to incorporate seasonal climate forecasts into farmer decision making, using several African countries as examples. Participants learned how to simply but effectively depict probabilistic forecasts in graphs understandable by farmers. Participants also identified strengths, weaknesses, opportunities and threats for climate services in each country. Subsequent discussions examined how participants can collaborate in south-south exchanges to support ongoing work in agricultural climate services. Weather index based agricultural insurance was also discussed, after which participants proposed new institutional arrangements to improve climate information generation and flow to farmers in each of their countries.

"CSRD's activities are relevant to the U.S. government's commitment to building resilience of smallholder farmers and to ensure increased production, as well bolster country resilience," said David Westering, the Acting Economic Growth Office Director and Feed the Future Team Leader for the United States Agency for International Development's mission in Bangladesh. "That is why we are behind this effort."



(Top) Participants' gathering in front of the workshop venue. (Below) Dr. Carlo Montes, CIMMYT Ag. Climatologist, discusses the interpretation of historical climate data. Photos: CIMMYT

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. In South Asia, CSRD supported by USAID and led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI).

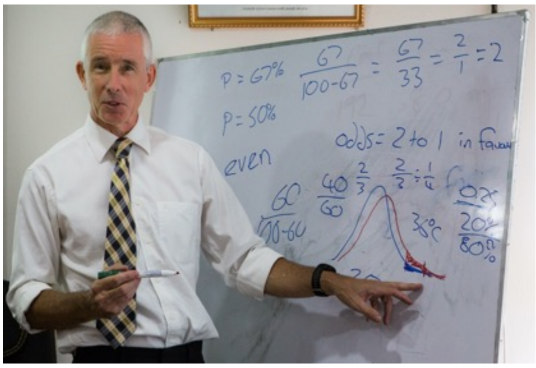
Strategic alignment

Boosting forecasting skills in service of agriculture

By partnering with United States based advanced research institutes, the CSRD partnership supports agricultural climate services for resilient development in South Asia

Half of Bangladesh's population in some way works in agriculture. A new effort from the International Research Institute for Climate and Society (IRI) and International Maize and Wheat Improvement Center (CIMMYT) under the Climate Services for Resilient Development (CSRD) partnership in South Asia aims to give the Bangladesh's agricultural sector better access to climate information to farm production risks including drought and extreme temperatures that can lower farm productivity.

Providing technical support to the Bangladesh Meteorological Department (BMD) in developing new climate information products tailored to agricultural needs is the core to CSRD. Recently, IRI's Senior Research Scientist, Dr. Simon Mason, visited BMD to help increase forecasting skills and capacity to develop new climate information products.



International Research Institute for Climate and Society's Senior Research Scientist for International Outreach, Simon Mason, spent several weeks in 2017 assisting BMD through the CSRD project Photo: E. Gawthrop (IRI)

"The BMD has a core of very competent and highly qualified meteorologists, but these scientists have not had sufficient opportunity to engage in sustained interaction with BMD's clients," said Mason. BMD could therefore benefit from collaborations aimed at making climate information more relevant and understandable. "This can be done without compromising on the technical standards," commented Mason.

Mason and the CSRD team therefore worked with BMD throughout 2017 to identify actions required to improve climate data collection, processing and analysis, all of which underpin the development of quality climate services products. The team also identified specific crop management decisions and activities implemented by farmers that could be improved with climate information and services. Weather events that affect farm productivity, such as heat waves, cold and dry spells were also prioritized for improved forecasting, in addition to efforts to the supply of extended-range forecasts to farmers and extension agents.

"CSRD's engagement with IRI is highly strategic. As a US-based and global leader in climate services, linking IRI with BMD will strengthen forecasting skills and capacities to deliver relevant climate information. We are mobilizing the best minds in climate science in service of smallholder farmers through CSRD", commented Timothy J. Krupnik, CSRD Project Leader and CIMMYT scientist.

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Strategic alignment

Annex 7. Prime Minister's office approval of CIMMYT and CSRD partnership with BMD

অতি জরুরি

গণপ্রজাতন্ত্রী বাংলাদেশ সরকার
প্রতিরক্ষা মন্ত্রণালয়
গণভবন কমপ্লেক্স
শেরেবাংলা নগর, ঢাকা
www.mod.gov.bd

নম্বর ২৩.০০.০০০০.২২০.১৪.০৩৫.১৬.৪৮৬

তারিখ: ৫ ভাদ্র ১৪২৪ / ২০ আগস্ট ২০১৭

বিষয়: 'Climate Services for Resilient Development (CSRD) in South Asia and Bangladesh' শীর্ষক প্রকল্পের আওতায় ১,৯৫,৫৯৮ ইউএস ডলার এর অনুদান চুক্তি স্বাক্ষরের অনুমতি।

সূত্র: (ক) বিএমডি'র পত্র নম্বর ২৩.০৯.০০০০.০৯০.২৫.০২৮.১৭.৫০২০, তারিখ: ২১ জুন ২০১৭
(খ) ইআরডি'র পত্র নম্বর ০৯.০০.০০০০.০৪১.২৫.০০১.১৬-৭৮, তারিখ: ১০ জুলাই ২০১৭

উপর্যুক্ত বিষয় ও সূত্রোক্ত পত্রদ্বয়ের আলোকে বাংলাদেশ আবহাওয়া অধিদপ্তর কর্তৃক প্রস্তাবিত 'Climate Services for Resilient Development (CSRD) in South Asia and Bangladesh' শীর্ষক গবেষণা প্রকল্পের আওতায় বাংলাদেশ আবহাওয়া অধিদপ্তর এবং International Maize and Wheat Improvement Center (CIMMYT) এর মধ্যে ১,৯৫,৫৯৮ ইউএস ডলার এর Sub-Grant Letter of Agreement স্বাক্ষরের অনুমতি প্রদান করা হলো। এতে অর্থনৈতিক সম্পর্ক বিভাগের সম্মতির প্রেক্ষিতে এ মন্ত্রণালয়ের দায়িত্বে নিয়োজিত মাননীয় প্রধানমন্ত্রীর অনুমোদন রয়েছে।

২. এমতাবস্থায়, বাংলাদেশ আবহাওয়া অধিদপ্তর কর্তৃক প্রস্তাবিত Sub-grant Letter of Agreement স্বাক্ষরপূর্বক স্বাক্ষরিত চুক্তির এক কপি এ মন্ত্রণালয়ে প্রেরণ করার জন্য নির্দেশক্রমে অনুরোধ জানানো হলো।

20/8/2017

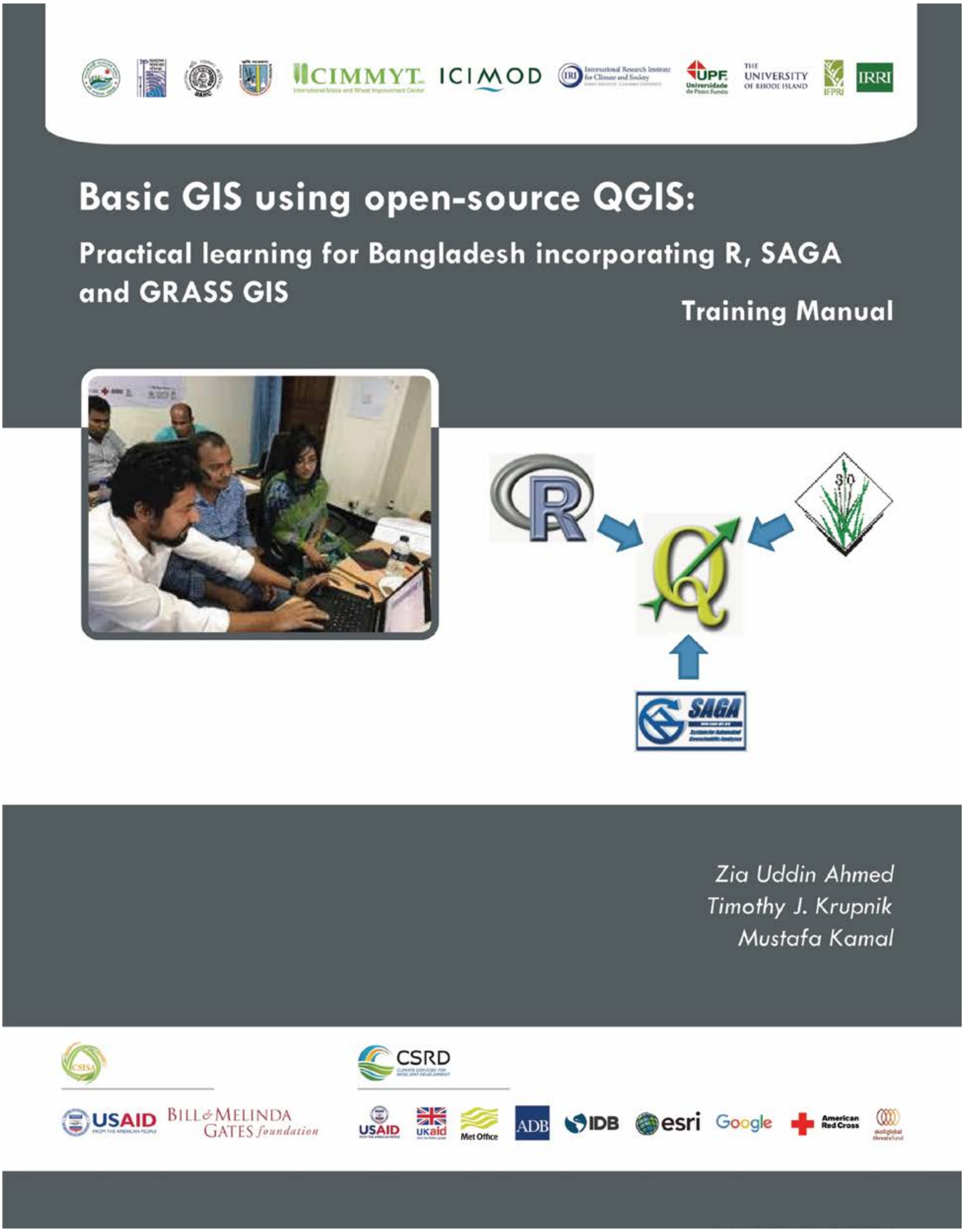
(শেখ মোহাম্মদ জোবায়েদ হোসেন)
সিনিয়র সহকারী প্রধান
ফোন: ৯১১৩১৮৭
ই-মেইল jobayeed@yahoo.com

পরিচালক
বাংলাদেশ আবহাওয়া অধিদপ্তর
আগারগাঁও, ঢাকা।

অনুলিপি:

১. সচিবের একান্ত সচিব, প্রতিরক্ষা মন্ত্রণালয়।
২. যুগ্মসচিব (পূঃউঃ)-এর ব্যক্তিগত কর্মকর্তা, প্রতিরক্ষা মন্ত্রণালয়।

Annex 8. Cover page for QGIS learning manual



Basic GIS using open-source QGIS:

Practical learning for Bangladesh incorporating R, SAGA and GRASS GIS

Training Manual

Zia Uddin Ahmed
Timothy J. Krupnik
Mustafa Kamal

Annex 9. Participatory and Institutional Approaches to Agricultural Climate Services Development: A South and Southeast Asia Regional Technical & Learning Exchange. Report cover and executive summary.

CSRD
CLIMATE SERVICES FOR RESILIENT DEVELOPMENT

CIMMYT International Maize and Wheat Improvement Center · ICIMOD · International Research Institute for Climate and Society · UPF Universidade de Passo Fundo · THE UNIVERSITY OF RHODE ISLAND

WORKSHOP REPORT

Regional Technical and Learning Exchange on Participatary and Institutional Approaches to Agricultural Climate Services Development

17-19 September, 2017
Golden, Tulip, Dhaka, Bangladesh

USAID · UKaid · Met Office · ADB · IDB · esri · Google · American Red Cross · skoll global threats fund

Strategic alignment

CGIAR · RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security · CCAFS

Participatory and Institutional Approaches to Agricultural Climate Services Development: A South and Southeast Asia Regional Technical & Learning Exchange

Executive Summary[10]

The World Meteorological Organization (WMO) and the Global Framework for Climate Services (GFCS) define climate services as providing "… *climate information in a way that assists decision making by individuals and organizations. Such services require appropriate engagement along with an effective access mechanism and must respond to user needs. Such services involve high-quality data from national and international databases on temperature, rainfall, wind, soil moisture and ocean conditions, as well as maps, risk and vulnerability analyses, assessments, and long-term projections and scenarios. Depending on the user's needs, these data and information products may be combined with non-meteorological data, such as agricultural production, health trends, population distributions in high-risk areas, road and infrastructure maps for the delivery of goods, and other socio-economic variables.*[11]"

Agricultural climate services collect, analyze and share climate information to ensure that farmers and other stakeholders have access to relevant information to make better-informed decisions. Some of these decisions might include how to manage livestock, and when and where to sow particular crops or varieties, as well as how to manage these crops (both in the field and after post-harvest) so that climate risks are mitigated. Weather-based crop insurance programs, and pest and disease early warning systems, in addition to seasonal yield predictions, are among the fastest growing agricultural climate services sectors. What, however is most important, is that climate information must be conveyed in ways that are decision-relevant.

This requires a radical re-thinking of how many agricultural extension and ag-meteorological bulletins and advisories are produced and conveyed, with emphasis on involving farmers themselves in the development of appropriate climate information and participatory extension messaging. The ultimate goal is to empower farmers, extension agents, agricultural development organizations, and policy makers with knowledge and new insights. This will give them the capability to innovate and make informed decisions, so they are better equipped to respond to climatic variability to overcome climate-related production and livelihood risks. Achieving this aim requires an ability to communicate across scientific disciplines, to establish the institutional arrangements to facilitate the exchange of climate information to and from farming communities.

In order to share experience and boost capacity in agricultural climate services, a three-day workshop titled 'Participatory and Institutional Approaches to Agricultural Climate Services Development: A South and South East Asia Regional Technical and Learning exchange" was held between September 17-19, 2017, in Dhaka, Bangladesh, with more than 50 leaders in agricultural climate services from 11 countries attending. The workshop was sponsored by the U.S. Agency for International Development (USAID) behalf of the Climate Services for Resilient Development (CSRD). The workshop was organized by the International Maize and Wheat Improvement Center (CIMMYT) alongside the SERVIR and Climate Services Support Activity and CSRD South Asian partners.

CSRD is an international public-private partnership dedicated to promoting and enabling climate services to improve resilience to the impacts of climate variability and climate change, and to positively change behavior and affect policy in developing countries. CSRD is committed to delivering climate services - including the production, translation, transfer, and use of climate

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[10] The full technical exchange report will be made available on the CCAFS and CIMMYT websites in January of 2018.
[11] WMO. 2017 What are Weather/Climate Services? Global Framework for Climate Services. World Meteorological Organization (WMO). Available online: http://www.wmo.int/gfcs/what_are_climate_weather_services. Accessed 12 December 2017.

information - purposefully designed to enable policymakers and decision-makers to address significant problems and create solutions. Toward this end, CSRD promotes services that are user-centric and collaborative and effectively harness the power of information, technology, and innovation from around the world. CSRD's founding partners are the government of the United States through USAID, the White House Office of Science and Technology Policy (OSTP), and the National Oceanic and Atmospheric Administration (NOAA), the government of the United Kingdom (through DFID and the UK Met Office), the American Red Cross, the Skoll Global Threats Fund, Esri, Google, the Inter-American Development Bank, and the Asian Development Bank. Focusing on South Asia, CSRD implementing partners include the Bangladesh Meteorological Department (BMD), the Bangladesh Department of Agricultural Extension (DAE), the Bangladesh Agricultural Research Council (BARC), CIMMYT, ICIMOD, the International Research Institute for Climate and Society (IRI), The University of Passo Fundo, and the University of Rhode Island. CSRD is also aligned with the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). CCAFS seeks to ensure a food-secure world in the face of a variable and changing climate, through a strategic research-for-development collaboration. It brings together agricultural, climate, environmental and social sciences to identify and address the most important interactions, synergies and trade-offs between climate change and agriculture.

The three-day workshop was interactive and offered new opportunities to bring leaders working on participatory approaches and instructional arrangements for the development of relevant agricultural climate services from across South and South East Asia together in one location. The workshop goals were to:

- Develop a broad overview of South and South East regional agricultural climate services programs;
- Assure that participants become familiar with participatory approaches and methods in agricultural climate services, and able to enact or improve them in their own country contexts;
- Develop an increased understanding among workshop participants of how to identify and leverage 'decision points' in the agricultural calendar during which climate information and advisories can most benefit farmers;
- Assure that participants are able to understand and verbalize the need for appropriate intuitional arrangements to facilitate the flow of relevant climate information and advisories to farmers, and to supply feedback to meteorological, extension, development, and policy oriented organizations;
- Improve participants sense of information communication and visualization skills required to develop relevant climate services.

The key outcomes and discussions held during the workshop are summarized in the pages of this report. Some of the key themes that surfaced that require further efforts to increase farmer participation and the effective delivery of climate services include the following:

- Each country that participated in the technical exchange is at a different stage in the use of climate services to advise and assist farmers. Some are highly advanced, while others are only just starting. Continued 'south-south' communication and further efforts to facilitate linkages among leaders in each country and region are needed. Exchange visits, visiting scientist sabbaticals, and professional internships for somewhat extended periods could benefit in rounding-out knowledge sharing among the region.

- Large data gaps – especially for historical information – are prevalent in several countries. Where data do exist, they are often available at scales that are too large to adequately assist farmers with climate information. Further efforts are therefore needed to increase both data access and data sharing – ideally on an open-access basis – and to boost technical skills for forecast downscaling.

- Programs focusing on participatory climate services may need to emphasize multi-meeting trainings and educational efforts with farmers. Farmers are often aware of the concept of climate change, but may not fully understand the mechanisms behind global-scale change processes, nor how they may affect them in the future.

- Considerable interest was raised among participants in the Participatory Integrated Climate Services for Agriculture (PICSA) approach to popularizing climate information and services. PICSA has been widely used Africa, and involves agricultural extension staff working with groups of farmers ahead of the season to analyze historical climate data and use participatory tools to develop and choose crop, livestock and livelihood options best suited to farmers' circumstances. Immediately prior to and during the season, extension staff and farmers consider the practical implications of seasonal and short-term forecasts on the plans farmers have made. PICSA is intended for National Meteorology Agencies, government extension agents and non-governmental organizations. Several participants expressed interest in making use in portions of the PICSA approach in South and Southeast Asia, although each participant noted that the approach would require significant adaptation to best fit their countries and farming systems.

- Season to season climate variability is also often more important than 'climate change' in terms of facilitating livelihood resilience options for farmers. Projects and programs that work to increase farmers' understanding of climate information, and involve communities in climate data collection and reflective analysis, tend to be well positioned for increasing climate adaptive capacities. This however often entails a trade-off in terms of project costs versus the degree of participatory interactions with farmers. These issues require further evaluation on a country-by-country basis, and are likely to differ in needs and outcomes depending on farming systems. Toolkits and approaches to assess how to address these issues and choose the most appropriate and cost-effective approach to participatory climate services development with farmers are lacking but are urgently needed.

- All countries and participants highlighted the need for skill-building in the 'translation' of climate information into simple to understand formats that are relevant to farmers. These skills however are rarely taught in meteorological or climate sciences training programs, nor are they common in agricultural sciences degree programs. As such, further educational efforts may be needed to boost scientists' communication skills and ability to package information in ways that are of use and benefit to farmers. Including farmers' feedback in programs disseminating climate information can be highly beneficial in meeting this goal.

- Information communication technologies (ICTs) are increasingly used for the *delivery* of climate information to farmers. Only a few programs however are using ICTs to *collect* information or *feedback* on the usefulness of such information or climate advisories. Fewer programs use ICTs to engage farmers in surveys or to collect ideas for the design of climate services programs. This represents a large area of opportunity to get large-scale feedback from farming communities, and to adapt climate and agronomic advisory messaging, for example through programs that request farmers to send back feedback via SMS or simple ICT based surveys.

- There is considerable interest among countries in developing weather-index and flood-index based crop insurance. Although there are several technical and social limitations on uptake of these options in different countries, participatory process can be used in the design of insurance programs. Experiences from several of the participating countries' representatives indicate that these approaches are more likely to have a strong rate of success and sustainability. Although index-insurance is widely studied in the academic literature, there remain large opportunities for participatory insurance development approaches in several countries in South and South East Asia. Many workshop participants stated their interest in in-depth training and technical assistance to establish index insurances in their home countries. This area in particular should be further explored, ideally with assistance from the International Research Institute on Climate and Society (IRI) that has developed a number of participatory tools and games to advance research and development in weather-indexed insurance programs in multiple countries.

- Cross-sector coordination between agriculture and meteorological departments are a large opportunity. There are many opportunities for co-operation between the agriculture and meteorological departments in Bangladesh, Philippines, India and Myanmar, but they remain inadequately exploited. This is a necessary area of coordination and collaboration to develop and deliver quality climate service products, and to share working expertise in participatory approaches that place farmers at the heart of the climate information service innovation process.

- Institutional relations are crucial for the development of viable climate services. Farmers should be placed in the center of programs aiming to develop, extend, and refine and adapt climate services. Strong multi-directional communication links between meteorological services, extension services, and farmers are required, but only a few participating countries appear to be deliberately designing their programs in this way. Differences may be due to the degree of funding available to implementing organizations, as well as cultural and institutional differences in each country. Nonetheless, all participants agreed that increased focus and effort to facilitate links and communication between these three core stakeholder groups, and to strategically link additional partners – especially those working with ICTs, participatory project design, and weather index insurance – in the future.

The above list is far from conclusive, and the following pages of this report provide much more detail and further insights from the 'Participatory and Institutional Approaches to Agricultural Climate Services Development: A South and South-East Asia Regional Technical and Learning Exchange'. It is hoped that this event will not be a single occurrence, as all participants recognized the value of the workshop and the need for continued cross-country and cross-regional communication, knowledge, and skill sharing. overall, however, the workshop can be considered a success in meeting the goals outlined above, with participants all benefiting from increased knowledge, ideas, inspiration, and professional links to others working in the growing and crucially important field of agricultural climate services.

Annex 10. Product development plan for PANI within the context of CSRD

Within the context of the CSRD project, the Bangladesh Meteorological Department (BMD), in collaboration with the International Centre for Integrated Mountain Development (ICIMOD) and the International Research Institute for Climate and Society (IRI), will produce updated short-range precipitation forecasts with extended range rainfall accumulative precipitation data articulated as climatic stress risk maps for major cereals. The objective of CSRD *Activity 1.3.1 Product 2* is to develop an information and communication technology (ICT) platform for meteorologically integrated irrigation management services for maize and wheat farmers. This activity will be done in collaboration with the above-mentioned partners, in addition to the Irrigation Division of the Bangladesh Agricultural Research Institute (BARI), the Department for Agricultural Extension (DAE) and CIMMYT. The aim of this Annex is to describe the required research and development efforts in more detail.

CIMMYT previously developed a prototype smart phone app, called PANI (Program for Advanced Numerical Irrigation), that forecasts an irrigation recommendation on a weekly basis for specific fields. It addresses and connects farmers and irrigation service providers (irrigation pump owners who charge farmers for water access). PANI captures all the relevant data from the user (detailed below), transmits them to a server, which then generates field-specific irrigation recommendations.

PANI was designed to address the needs of farmers in the south-central area of the Feed the Future Zone of Bangladesh, where they have little or no experience with irrigation and the contribution of the water table (which tends to be very shallow) to the soil water balance can be substantial. Thus, standard irrigation recommendations generated for other parts of the country – which is a goal of the CSRD project – cannot be transferred automatically.

PANI's current main modules are:

- Soil water balance from the CERES models that calculates plant available soil moisture and up flow from the water table on a daily basis
- Estimation of crop water use based on weather data and ground cover measurements, which can be derived from satellite data or photos taken with a smartphone
- Recommendations for irrigation scheduling are currently generated on a weekly basis, using forecasted temperature data to estimate evapotranspiration, using the Blaney-Criddle equation (Liyanage et al., 2008).

Data requirements for PANI

PANI has the following data requirements:

- Location of field (coordinates)
- Soil (for each layer, up to 1 m depth)
- Texture
- Organic matter
- Depth of water table (if closer than 7 m to the surface)
- Temperature maximum (daily)
- Temperature minimum (daily)
- Solar radiation (daily)
- Precipitation (daily)
- Crop management
- Crop type
- Date of sowing
- Irrigation dates and amounts
- % ground cover. Can be derived from Satellite imagery or RGB photos taken with smart phones

About 2/3 of Bangladesh's cropland are under irrigation (Qureshi et al., 2015, Ghani, 2016). The main source of water is ground water (79 %). Some canal based irrigation schemes are in place as well. In the South, mainly in Barisal Division, farmers usually do not irrigate their winter dry season crops, except for '*boro*' rice in some pockets. In that region, ground water tends to be saline. There more than sufficient surface water available, but the infrastructure to bring surface water to all cropland is not up-to-date (Krupnik et al. 2017).

In some parts of the country, ground water levels are declining (Qureshi et al., 2015). Farmers are reporting that water needs to be pumped from lower depths, at considerable economic and energy costs (Rahman et al., 2013). For home consumption in these areas, most tube wells fail to lift sufficient water for the entire winter period (Dey and Ali, 2010), as water tables tend to fall below critical levels between mid-February and April (Ghani, 2016). In a survey conducted in the Jessore region, 95% of the respondents replied that they didn't get training for irrigation and do not have enough knowledge on irrigation efficiency and crop water use (Rahman, et al., 2016).

Cost of irrigation

Cost estimates for irrigation vary widely, according to the source of energy (electricity vs fuel), ground water level, labor cost, public vs private ownership of the pumping facility, etc. IRRI, recently quoted by Rahman et al. (2016) found that the average cost of irrigation for rice was $117.60 per hectare compared to $25.58 in India, $17.94 in Thailand and $17.98 in Vietnam. For the north-west of Bangladesh, Dey et al. (2013) reported that the cost for irrigation of rice varies between BDT $91 to $402 per ha. Wheat and maize require fewer irrigations, and thus the cost presumably is less. To complicate these matters, rice is not irrigated using the same water pricing structure throughout Bangladesh. Rather, different business models including crop-share schemes, irrigation cost by time, and fixed costs are used. Volumetric pricing is either rare or non-existent.

Payment systems for irrigation services

Irrigation with ground water is done by a service provider or by the farmer. In regions where deep and shallow tube wells (DTW and STW) are installed, the owners irrigate their own and partners' land and sell excess water to irrigate plots of their neighboring farmers. Farmers often are buyers and sellers, since their parcels can be disbursed in the land scape. In 2013, Rahman et al. conducted a survey using group discussions in 96 villages spread over Bangladesh. They found that almost 50% of the contracts were fixed charge, 1/3 two-part tariff and the reminder crop share. Different payment schemes are in place and they are usually established for an entire growing season, but primarily for rice:

1. Flat rate for the season
2. Users pay service charge for actual use of the STW
3. Two-part tariff system: fixed cost plus payment for the actual amount of water used
4. Crop share (usually 1/3 to 1/4 of the yield)
5. Rental arrangement (for pumps)
6. Payment by credit card according to water consumption (metered) in parts of Rajshahi (as part of a water conservation project recently implemented)

For non-rice crops like wheat or maize, fixed price per irrigation event or seasonal payments are comparatively more common, although in parts of Rajshahi, credit card schemes may be used.

Incentives for farmers to use an irrigation service advisory system like PANI

PANI, by considering forecasted weather data, will presumably allow farmers to reduce the number of irrigations required to grow a crop, and/or to increase irrigation efficiency. It is however yet to be established as to how much water can be saved over current farmers' practices. This analysis can be done once PANI has been calibrated and validated for other regions of Bangladesh. Other studies have reported that 20% of irrigation water can be saved with optimal management (Dey et al., 2013).

Assuming that PANI indeed helps reduce over- or badly timed irrigations, farmers may decide to use the PANI app for the following reasons:

- Cost savings: In some regions, e.g., pockets of Jessore (Rahman, et al., 2013) and Rajshahi (Dey, et al., 2017), ground water tables are declining (although there remains some disagreement on this matter, e.g., Qureshi et al. 2015), which increases the cost for pumping, making irrigation more expensive.
- More efficient use of resources (ground water), also related to cost-savings: In many parts of the country, tube wells tend to run dry in the spring. While a single farmer is unlikely to benefit from judicious water use, a community based approach would benefit all farmers. This would allow them to maintain their fields an optimal (or close to optimal) soil moisture content during the entire growing season or to increase the area of irrigated land. Salem, et al. (2017) for example calculated that the cost for irrigation can be reduced considerably if adaptive measures are taken.
- Better use of inputs, particularly nitrogen (N) fertilizer: Excessive irrigation causes leaching of nitrates out of the rooting zone. Thus, judicious irrigation could help reduce input cost (potentially fewer irrigation events and reduction in N rates)
- Due to climate change, weather patterns are expected to become less stable and extreme weather events are likely tend to occur more frequently. Using accurate weather forecasts, the irrigation practices can be adjusted to increasingly unfavorable conditions.
- Use of PANI and smart phones could potentially become a status symbol, especially among the young farmers and rural irrigation entrepreneurs. PANI services might become even more attractive when bundled with other services, such as commodity price information transfer by app and SMS, etc. These options are being explored in the long-run.

Focus groups and key informant interviews indicate that the interests of the irrigation service providers are different, but not necessarily diametrical to those of the farmers:

- PANI could give them access to more potential customers in areas where surface water is being used and pumps can be moved from one place to another
- A service provider could potentially cover larger areas (more fields) with more efficient irrigation
- If PANI recommends fewer irrigations, the service provider is positioned to save time and energy (fuel or electricity), thereby lowering costs
- PANI could help avoid conflict between the irrigation service provider and the farmer, if it is perceived as an objective and accurate advisory system

The original version of PANI requires some smart phone savviness on the part of the user. Although minimal, some information needs to be provided to the system and this might be too high of an entry barrier for some users, although it should be noted that mobile and smart phone use now exceed 80 and 20%, respectively, in Bangladesh. For this reason, different versions of PANI are proposed.

PANI Field App:

This version of the PANI app will provides field-specific irrigation recommendations (corresponding to the original version of PANI). Functionalities include the following:

- The farmer needs to sign up for use of PANI, providing information on the location of the field(s), crop type, and sowing date. Farmer can pick the irrigation service provider and register them to a centralized database.
- The PANI app will send irrigation scheduling recommendations to farmer and irrigation service providers on a weekly basis.

Example of PANI field app recommendations (in English):

- "It has been hot and no rain is expected. An irrigation for your wheat field is highly recommended within the next 7 days"
- Soil moisture is still high and we expect some rainfall in the coming days. No irrigation is recommended for the next 7 days"

∂ PANI Regional App

The ∂ PANI Regional App provides users with a relative irrigation recommendation. It compares the current weather year to a baseline established with data from the prior 3 years as recorded from the nearest weather station operated by the BMD. It also takes into account BMD weather forecasts and generates weekly recommendations as to whether crops need to be irrigated more or less frequently (∂ days) than usual.

Input information:

- From the user's side, no input is required (assuming telephone location service is enabled). Based on the location of the phone, the app provides the user with a recommendation for the region where the phone is. Information can be sent to user via
    - SMS
    - Voice message
    - App

Example of preliminary recommendations in English:

- "It has been more sunny and warmer than usual the past 2 weeks. We recommend that you carefully examine your field and consider irrigating 3 days earlier than usual"
- "It has been cold and overcast in recent days and we expect a light rain shower or two in the next few days. For these reasons, we recommend that you might want to consider delaying the irrigation of your crops by a few days"

Note: CSRD will evaluate whether this minimalized approach is accurate enough for farmers' understanding and action. Knowledge of sowing date will greatly increase the accuracy and specificity of the forecast. We will also attempt to integrate daily weather forecasts for the next 7-14 days into the ∂ PANI app.

The focus of activities through early 2019 in CSRD is on the development of the PANI apps. A decision on the best ways to promote PANI, raise public awareness and how to distribute it (platforms) will be made towards the end of the project.

Work packages

Integration of PANI with BMD forecasts and spatial soil information

PANI is currently set up to take information from the geographically nearest weather station and a default soil type. Through CSRD, the PANI apps are being integrated into a spatial framework, so that they can generate field or region specific recommendations for the farmers. To achieve these aims, CSRD is working to link PANI to the BMD weather data base by forming forecast code and data through a secondary server system. We are also working to create a database for representative and region specific soil profiles, with emphasis on soil texture and organic matter content in the rooting zone. Furthermore, the PANI interface will have to be changed so that it meets the needs for the different types of uses, based on feedback from farmers. CSRD anticipates this will be an iterative development process, with close collaboration with the farmers and software developers.

Product testing
The following quote has been attributed to Henry Ford: "If I had asked people what they wanted, they would have said faster horses." Dynamic, weather based, field or region specific irrigation recommendations delivered via a smart phone are new to farmers. The best and most accurate feedback from them can be obtained only after they have seen and used PANI.

The following regions have been selected for PANI development, testing, and refinement:

- **Dinajpur District**: Driest region, with deep and declining water tables. Important maize and wheat production region. High irrigation costs.
    - Field trial locations: (1) the Bangladesh Agricultural Institute (BARI) Wheat Research Center (WRC) station headquarters in Dinajpur, and (2) Surrounding villages in 2018/19

- **Barisal District:** Coastal region with heavy clay soils, spatially variable soil salinity, shallow water tables. Farmers have little experience with irrigation. Region with most significant rainfall in the winter months.
    - BARI Regional Agricultural Research Station (RARS), Rahmatpur, Barisal
    - Field trial locations: Shaistabad: New irrigation scheme installed by the Bangladesh Agricultural Development Corporation (BADC) in the winter of 2017, covering 20 ha. It is community managed and can serve as a testbed for PANI. Farmers have no or very little experience with irrigation.

- **Rajshahi District:** Rajshahi is a drought-prone area, linked to the 'High Barind Tract" of Bangladesh (a higher-elevation area with distinctly coarser soil textures) where ground water levels are being depleted at a rate of 40 cm per year (1981-2014), according to Dey et al., 2017. Wheat, maize, and boro rice are dominant crops, as are orchard crops like mangoes.
    - Field trial locations: (1) the Regional WRC research station under BARI, and (2) surrounding farmers' fields in 2018/19

Components of PANI to be tested in the 2017/18 season:

- Algorithm of PANI Field App (soil moisture estimation and forecast, calibration and validation)
- Various components need to be considered:
    - Soil profiles characterized
    - Accuracy of soil moisture predictions. This work will be done in close collaboration with the Irrigation Division of BARI.
    - Calibrate Theta and TDR Probes with gravimetric soil moisture measurements
    - Measure soil moisture up to 100 cm depth with a TDR probe every 2 weeks
    - Crop cuts for yield at the end of season
    - Crops: region specific, priorities will be maize, wheat, sunflower, and mungbean. Wheat and maize are to be prioritized, and other crops will be considered.
    - Record key growth stages (phenology)

- Minimum number of ground cover photos needed per field to characterize leaf area index and percent ground cover.
- Quantify within field variability of ground cover with unmanned aerial vehicles and smart phone cameras
- Interface/usability
- Mode of interaction with the farmers
    - App
    - SMS
    - Voice messages

Recommendations:
Translating uncertainty of forecasts in to actionable products, that are easy to understand and don't disappoint the farmers will be a challenge.

- What is the best way to phrase recommendations?
- What kind of recommendations are farmers looking for?

Schedule for testing of PANI Field, ∂ PANI Regional App

- Winter 2017/18
    - Establish on-station experiments and in farmers' fields in collaboration with BARI and WRC
    - Conduct business model study (via focus groups and key informants) to identify where and how farmers and irrigation service providers are most likely to consider using both PANI apps, and to improve the user interface
- Winter 2018/19
    - Continue validation with BARI
    - Create PANI user's groups in 2 villages in each District noted above
    - Improve interface and messages based on farmers feed-back – rapid prototyping.
    - Collect feed-back on accuracy and usefulness of PANI recommendations

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Annex 11. Calibration and Validation of PANI apps for Wheat and Maize Crops in Contrasting Environments of Bangladesh: Experimental Protocol (2017-18 winter season in Bangladesh)

Objectives of the study

- Collect soil moisture data to calibrate and validate soil moisture module of PANI
- Determine at what soil moisture content plants show symptoms of drought stress
- Collect data set to enable BARI to assess suitability of PANI for providing advice on irrigation scheduling

Locations for randomized complete block trials:

- Wheat Research Centre (WRC), Nasipur, Dinajpur.
- Regional Wheat Research Station (RWRS), Shyampur, Rajshahi.
- Regional Agricultural Research Station (RARS), Rahmatpur, Barisal

Crop management practices and treatments

Irrigation treatments

Irrigation: All experiments receive a starter irrigation, immediately after sowing (within 1 day)

Wheat irrigation treatments (T)

- T_1 = **Dry**: First irrigation 2 weeks after sowing, stop irrigation until severe stress is detected[12], one more irrigation thereafter
- T_2 = **BARI**: Three irrigations at CRI (17-21 DAS), booting (45-50 DAS) and grain filling (70-75 DAS) stages (BARI recommendation)
- T_3 = **PANI**: First irrigation at CRI (17-21 DAS, subsequent irrigations according to PANI recommendations

Maize irrigation treatments (T)

- T_1 = **Dry**: First irrigation 3 weeks after sowing, then stop irrigation until severe stress is detected[1]. Then apply one more irrigation.
- T_2 = **BARI**: Three irrigations at seedling (25-30 DAS) vegetative (40-45DAS),
- Silking (65-70 DAS), and grain filling(95-100 DAS), stage (BARI
- recommendation)
- T_3 = **PANI**: First irrigation 25-30 DAS subsequent irrigations according to PANI recommendations

Crop varieties: Wheat (BARI Gom-30) and maize (NK 40)

Land preparation and sowing:

Identical BARI standard methods for land preparation and sowing will be used for all three sites. Sowing will be done by hand. Standard BARI recommendations for seeding depth, row distance and plant density will be followed.

[12] Separate protocol to measure the effect of water stress on leaf growth will follow by December 15

Tentative sowing dates:

Middle of November at Rajshahi and Dinajpur and 1st week of December RARS, Barisal.

Fertilizer rates:

- N_{120} P_{30} K_{50} S_{20} $ZN_4B_{1.5}$ (Wheat)
- N_{255} P_{75} K_{120} S_{52} $ZN_4B_{1.4}$ (Maize)

Fertilizer application for Wheat

One-third of the nitrogen and all of phosphorus, potassium, Sulphur, zinc, boron and organic manure (Cow dung @ 5 t/ha) should be applied as basal during final land preparation. Another third of nitrogen should be applied at first irrigation after crop emergence and application of last third will be right before the 2nd irrigation.

Fertilizer application for Maize

One-third of nitrogen and all of phosphorus, potassium, Sulphur, zinc and boron should be applied during sowing in 7-10 cm deep furrows (5-8 cm apart from the maize rows) and covered with the soil. Remaining nitrogen should be applied in two equal splits as side dressing in maize rows at the first irrigation and at the irrigation around silking (2nd irrigation for dry treatment)

Data Collection Activities

Ground cover photos will be taken on a weekly basis, starting one week after sowing until flowering. After flowering, they will be taken every 2 weeks until maturity. From each plot, BARI technicians will take 4 photos, resulting in 16 photos for each treatment. Photos will have to be taken in exactly the same sequence every time:

- T1, Rep 1 (photos 1-4)
- T1, Rep 2 (photos 5-8)
- T1, Rep 3 (photos 9-12)
- T1, Rep 4 (photos 13-16)
- T2, Rep 1 (photos 17-20)
- T2, Rep 2 (photos 21-24)
- ....
- 48. T3, Rep 4 (photos 45-48)

The layout of the photo sampling procedure is shown in Fig 1. The sampling spots need to be entered through the furrows, once the crops are knee high or taller.

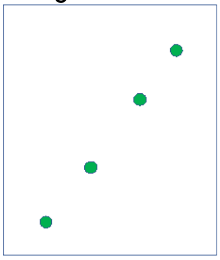

Figure 1. Sampling locations for the 4 ground cover photos to be taken from each plot

For maize, the photos are to be taken with a selfie stick once the plants are taller than 1 m.

Smart phones will be provided by CIMMYT for the duration of the experiments.

Irrigation amounts need to be recorded for each plot, using a calibrated flow meter.

TDR probe measurements: They are to be taken on a weekly basis and before each irrigation. The access tubes will be installed 1.2 m from the edges of each plot (Fig 2). They are to be installed in the seeded rows (not in the space between the rows).

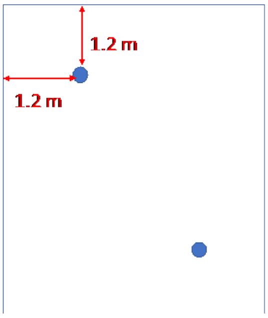

Figure 2. Location of installation of access tubes for TDR probes in each plot.

Theta probes: A total of 6 Theta probes will be installed at each site in the dry treatments of maize and wheat (3 in maize and 3 in wheat). Depths:

- 0.05 m
- 0.15 m
- 0.5 m

They are to be installed at an angle of 20 degrees using the probe extension tubes (Fig 3). The theta probes are to be connected to a data logger, In addition, a "permanent" TDR probe also needs to be installed and connected to the data logger. If possible, they should be installed in the center of the plot. Measurement interval: 15 minutes.

Note: Two dry wheat and maize plots are to be selected that are close to each other. The layout of the treatments of Rep 2 may have to be adjusted accordingly. The TDR and Theta probes need to be connected to the same data logger. The horizontal distance between the TDR access tubes and the Theta probes should be around 0.3 m. Same depths will be recorded from the TDR probes: 0-0.1 m, 0.1-0.2 m, 0.4-0.6 m.

Figure 3. Installation of Theta probes at an angle of 20 degrees.

Soil moisture from sampling probes lent to BARI's IWM Division for use (http://www.delta-t.co.uk/product/pr2/ sampling depths:

- 0 – 0.1 m
- 0.1 – 0.2 m
- 0.2 – 0.3 m
- 0.3 – 0.4 m
- 0.4 – 0.6 m
- 0.6 – 1.0 m

Piezometers:

3 piezometer will be installed on each site. BARI is supposed to provide the material and installation. Depth: **7m. Bottom 3m are need to be porous.** Piezometer above ground should be 25cm and diameter should be 2.5 inch. Water table depth is to be measured on a weekly basis. Corner 2 piezometer should be at least 2.5m away from the boundary of the plot and 5 meter will be better if space allow.

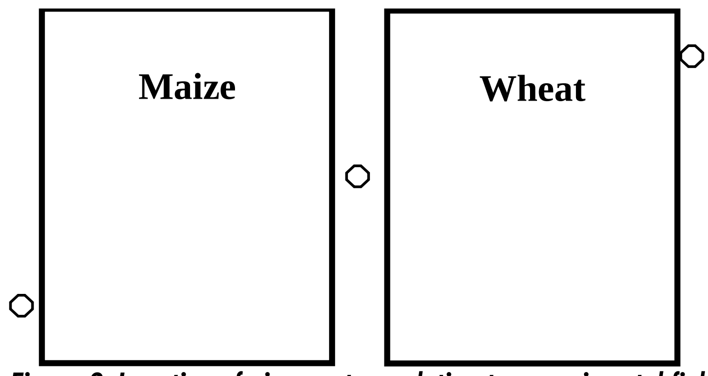

Figure 3: Location of piezometers relative to experimental fields

Crop growth stage: weekly data will be collected by BARI

- Date of emergence
- Flowering/tasseling
- Maturity (corresponding to black layer in maize)

Ground control points (GCPs) (minimum 5) installation and UAV Flight: Minimum 5 GCPs will be required for each site, displayed as in Figure 4. This activity will start from the beginning of the month of January, 2018.

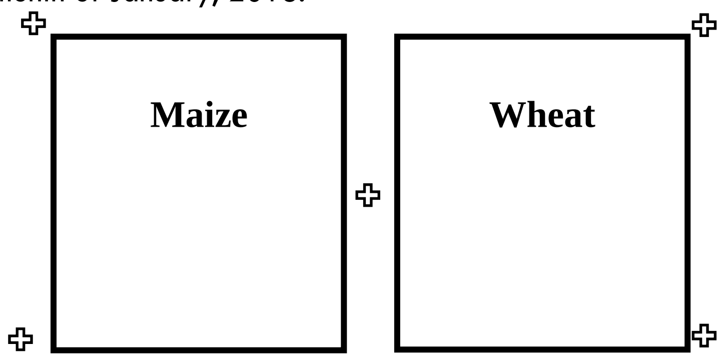

Figure 4: Location of Ground Control Points (GCPs)

Annex 12. Evaluation of Climate Hazards Group rainfall data products for drought monitoring in South Asia

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7 International Maize and Wheat Improvement Center (CIMMYT). Dhaka, Bangladesh

Background

Considerable amounts of climate data have been made available by researchers over the past few decades. However, use of this information – especially in the context of drought monitoring – by policy makers, development planners, and farmers remains low. Provisioning of locally calibrated, easily accessible, decision-relevant and user-oriented information, in the form of drought advisory services, may hold potential to help communities to cope with drought-related vulnerabilities. A collaborative effort is now underway to strengthen existing or establish new drought monitoring and early warning systems (EWSs) in Afghanistan, Bangladesh, Nepal and Pakistan. This will be accomplished by incorporating standard ground-based observations, earth observation datasets along with the integration of numerical weather forecasting models. ICT-based agricultural drought monitoring platforms, hosted by national agriculture and meteorological institutions, are being developed to enable the translation of this fata into agricultural advisories that are at once understandable and actionable by farmers and livestock producers.

Study objective

Reliable information on precipitation at sufficiently detailed spatial and temporal scales is essential for drought early warning systems. South Asia is characterized by considerable spatial and temporal variability in rainfall patterns. Drought advisories therefore require a dense rain gauge observation network to capture precise precipitation information. The distribution of ground monitoring stations in South Asia are however currently very limited and unevenly distributed. This makes water resources assessment and drought prediction difficult. This is particularly the case in mountainous areas with a limited, or no, rain gauge network, as in the Himalayan region. In this environment, satellite-based rainfall estimation (CHIRP/S) can provide information on rainfall occurrence, amount, and distribution. Similarly, in lowland and deltaic areas, CHIRP/S data can help fill gaps in existing precipitation data sets. Several high-resolution global and regional satellite-based rainfall products are available from different operational agencies and research and academic institutions. Among those products, CHIRP/S, is available at a high spatial and temporal resolution, and can provide an opportunity to develop drought monitoring and early warning applications in data sparse regions using rainfall estimates. However, CHIRP/S data also have some level of uncertainty, and this could therefore affect the accuracy of predictions when they are used in drought outlook scenario.

Along with a review of the scientific basis and coarser global evaluation of these products, it is important to assess their quality regarding precision and uncertainty at the local level. Their advantages and drawbacks should be carefully understood before they can be integrated into operational applications for decision-making, such as for EWS for severe weather, drought, and flood monitoring. This study therefore aims to assess the accuracy of two CHG products – the satellite-only product (CHIRP) and station-blended product (CHIRPS) – in representing the rainfall field over representative climate zones of South Asia across Bangladesh, Nepal and Pakistan (Figure 1), with the goal of using them for drought monitoring, assessment, and forecasting in this region.

Datasets

- CHIRP/S: The CHIRP/S dataset, developed by the U.S. Geological Survey (USGS) and the Climate Hazards Group at the University of California, Santa Barbara, is a blended product combining a pentadal precipitation climatology, quasi-global geostationary TIR satellite observations from the CPC and the National Climatic Data Center (NCDC) atmospheric model rainfall fields from the NOAA Climate Forecast System version 2 (CFSv2), and *in situ* precipitation observations.
- APHRODITE: APHRODITE gridded precipitation data is a long-term, continental-scale, high-resolution daily product. The product is based on data collected from 5,000–12,000 stations, which represent 2.3–4.5 times the data made available through the Global Telecommunication System network. These data are used for most daily gridded precipitation products.
- Rain Gauge Data: Daily rain gauge observations from three countries from 1981 to present will be used obtained from the national meteorological institutes of the countries listed above. The daily rainfall data will be accumulated to dekadal totals and compared with dekadal CHIRP and APHRODITE product.

Evaluations Methods

Visual verification, continuous statistics, and categorical statistics will be used to compare satellite rainfall estimates with local rain gauge measurements. The gauged rainfall data will be checked for consistency and accuracy. Incomplete, Global Telecommunication System (GTS), duplicate, and dubious datasets will be discarded. The datasets will be then formatted to GIS format and transformed to the same projection as the CHIRP/S datasets. For analysis, gauged data will be interpolated using the spatial interpolation techniques.

Validation Statistics

Two groups of statistics will be used to evaluate the satellite products: pairwise comparison statistics that evaluate the performance of the satellite products in estimating the amount of rainfall, and categorical validation statistics that assess rain-detection capabilities.

Goodness of fit statistics

To evaluate the accuracy of the satellite-based products when compared against the ground-based rainfall depths, two goodness of fit statistics are proposed, namely the percentage bias – PBIAS and the ratio of the root mean squared error to the standard deviation of the observations – RSR.

$$PBIAS = \frac{\sum(R_{gauge} - R_{satellite})}{\sum(R_{gauge})} x100 \quad (1)$$

$$RSR = \frac{\sqrt{\sum(R_{gauge} - R_{satellite})^2}}{\sqrt{\sum(R_{gauge} - \overline{R_{gauge}})^2}} \quad (2)$$

Where, $R_{satellite}$ is the rainfall estimates from the CHG product; R_{gauge} is the rainfall recorded from a particular rain gauge and $\overline{R_{gauge}}$ is the average gauge reading over the considered time span.

- CHIRP/S will be compared with point station measurement from Bangladesh, Nepal and Pakistan, representing all key climatic zone of South Asia (1981-2016).
- CHIRP/S will also be compared with APHRODITE gridded data products (1981-2007)

In cased of gridded data product (CHIRP, CHIRPS and APHRODITE) comparisons, trends and averages will be calculated and compared using Sen's trend estimator for dry, wet and moderate seasons.

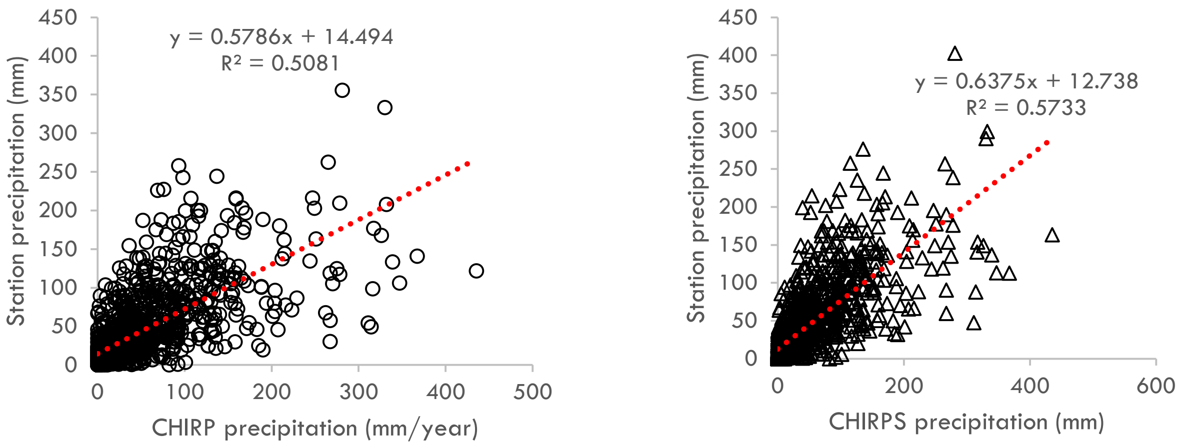
The accuracy of drought monitoring relies primarily on good rainfall data in terms of temporal and spatial resolution and accuracy. The main purpose of this analysis is to validate CHIRP and CHIRPS provided by the CHG, determine their operational viability, and to obtain a sense of their accuracy and expected error characteristics. This will be done by the grid to grid and point to point comparison method.

Preliminary results: Data processing and analysis for Bangladesh

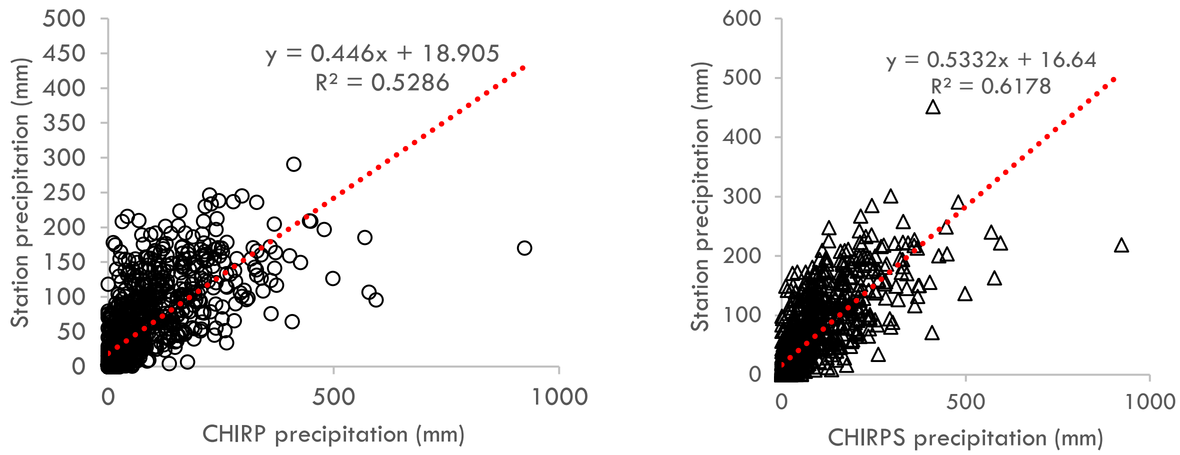
In Bangladesh, rainfall data was collected for the period of 1981-2014 from the Bangladesh Meteorological Department (BMD). 31 active stations with quality data have been selected for study. Other data sources do not have continuous observed data for the study period, so, those stations were not considered. The data quality of 31 stations has been checked using double mass curve analysis and no significant inconsistency was found. CHIRP and CHIRP-2.0 which is also being utilized in South Asian LDAS work.

Three types of comparison completed, including:
- Regression analysis
- Percentage Bias (PBIAS)
- Root Mean Square Error normalized by Standard Deviation (RMSED)

The last two comparisons show how two similar data fit well with each other, in other words, they describe the *goodness of fit* statistics. Here, examples of Rajshahi and Dinajpur districts have been given. These two districts fall within the north-western part of Bangladesh, which is the most drought prone area in Bangladesh per the previous studies and historical drought records. This analysis is in progress and current results are only indicative of work approach and progress.



Left: Rainfall station data versus CHIRP data – Rajshahi. Right: Rainfall station data versus CHIRPS data – Rajshahi. It can be inferred that CHIRPS data is more correlated with station data at a R^2 value of 0.57 than the CHIRP, which is related with station data at the R^2 value of 0.50



Left: Rainfall station data versus CHIRP data – Dinajpur. Right: Rainfall station data versus CHIRPS data – Dinajpur. Similar results for Dinajpur district were found. CHIRPS data (R^2= 0.61) is better correlated with station data compared to CHIRP (R^2= 0.52).

Goodness of fit statistics

A detail about the evaluation of goodness of fit statistics (i.e. PBIAS and RSR) can be found in a previous study conducted in Nepal[13]. That study adopted different qualitative performance ratings based on several ranges of PBIAS and RSR as shown below.

Range of adopted values of the Percentage of Bias (PBIAS) and Root Mean Squared Error normalized by Standard Deviation (RMSESD) for a particular qualitative rating:

Performance rating	PBIAS (%)	RMSESD (–)
Very good	$< \pm 15$	0 to 0.50
Good	± 15 to ± 30	0.51 to 0.60
Satisfactory	± 30 to ± 55	0.61 to 0.70
Not Satisfactory	± 55	> 0.71

Based on the above, the result of goodness of fit statistics are as follows:

District	PBIAS of CHIRP	PBIAS of CHIRPS	RMSESD of CHIRP	RMSESD of CHIRPS
Rajshahi	6.027	4.508	0.709	0.659
Dinajpur	21.06	16.459	0.707	0.635

The PBIAS values of Rajshahi (6.02 and 4.5) is very good in term of performance ratings and RMSESD of CHIRPS data (0.65) is satisfactory, while, RMSESD of CHIRP (0.70) is at the threshold of satisfactory and unsatisfactory. Consequently, CHIRPS appears to perform better than CHIRP. This is also true for Dinajpur district, where, both the PBIAS value and RMSESD value of CHIRPS are lower than the corresponding values of CHIRP and the RMSESD value of CHIRPS is satisfactory as well.

Future analysis

[13] Shrestha, N.K., Qamer, F.M., Pedreros, D., Murthy, M.S.R., Wahid, S.M., Shrestha, M., 2017. Evaluzating the accuracy of Climate Hazard Group (CHG) satellite rainfall estimates for precipitation based drought monitoring in Koshi basin, Nepal. Journal of Hydrology: Regional Studies 13, 138-151.

In future analyses to be conducted in 2018, valid pairs (that have rainfall values at least 1 mm for both station data and CHG data) will be taken for comparison and the filed bias will be corrected from satellite data. It is expected that the fitness of regression lines and fitness of good statics will improve after those two considerations. To way forward this work a small exercise has been done for Barisal district and the result improved a lot in terms of R^2 value.

Annex 13. Protocol for placement and installation of rain gauges and access tubes for collecting rainfall and soil moisture data for SALDAS and drought monitoring validation

Introduction:

Bangladesh has a limited network of manual and automated weather stations that supply measurements of temperature, precipitation, wind speed, sunshine hours, solar radiation and additional climate information. At present, the Bangladesh Meteorological Department (BMD) provides weather forecasting at 18 km spatial resolution, which is certainly coarse to influence and support most farmers' decision-making on climate-related and risk mitigation activities in Bangladesh effectively.

The Climate Services for Resilient Development in South Asia and Bangladesh (CSRD) project lead by CIMMYT in partnership with ICIMOD will work on implementing a drought forecasting system based on meteorological and satellite remote sensing observations. The system focusses on 5 km^2 grids and seasonal forecasts time ranges. Since most of farmers' fields in Bangladesh are very small, the CSRD project also considers the evaluation and validation of drought forecasting on 1 km^2 grid resolution using SERVIR data at three test locations in north-western Bangladesh. This drought monitoring and forecasting activity will be based on the use of satellite data whose spatial and time resolution is not detailed enough to capture the rainfall and soil moisture content pattern necessary for an accurate drought monitoring considering the agricultural plot as a basic unit. Therefore, collecting real time data of rainfall and soil moisture to validate satellite data products to be used is necessary. For this activity, a series of rain gauge and access tube for soil moisture should be installed appropriately in three regions of Bangladesh.

Objectives:

- Increase the number of precipitation measurement points for validation and calibration of CHIRP data products.
- Improve the understanding of spatial variations in rainfall and drought at small scale to accuracy the use of satellite data products in context of Bangladesh.

Methodology:
Location and measurements period:

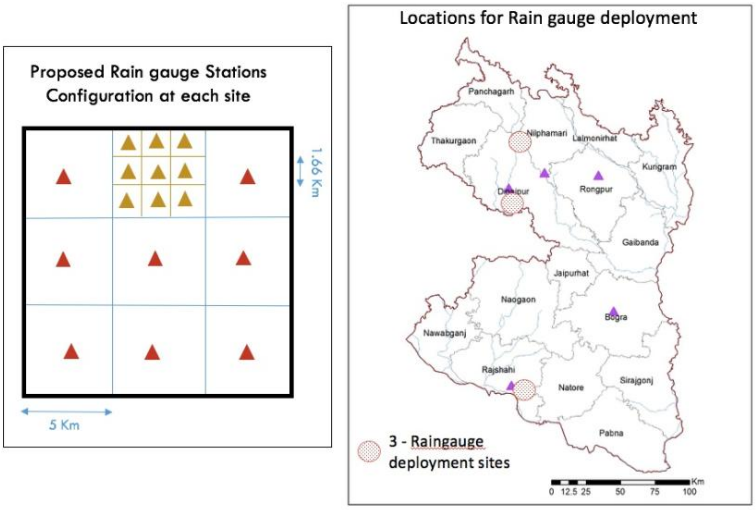
A total of 51 rain gauges and 102 access tubes (see figures below) will be installed in three different locations of Dinajpur, Nilphamari and Rajshahi districts and close to three BMD meteorological stations for the period October 2017 to February 2019. For each site, 17 rain gauges will be deployed covering a 225 km^2 area. Considering the proximity to BMD weather stations, 9 points will be selected maintaining approximately 5 km from each other, as shown in Fig. 1. Among the 9 points, one of them will be the BMD station, where rain gauges will be deployed at 1.66 km, 8 rain gauges will be deployed in the remaining 8 places.

Placement of Rain Gauges:

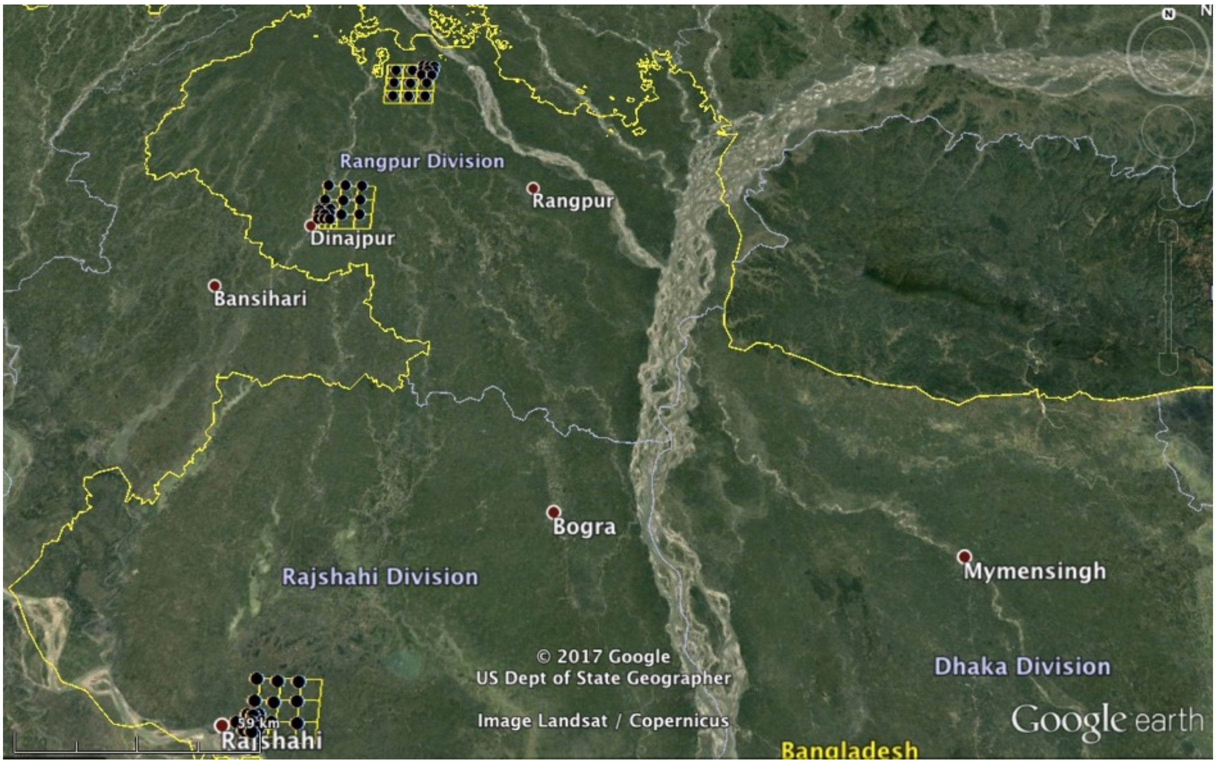
The placement of a rain gauge is very important for obtaining quality data. It should be placed in an area that is protected from strong winds and not bothered by obstacles that could either block precipitation reaching to the gauge or cause precipitation to splash towards it. A small open field surrounded by forest, or an open back yard not too close to buildings or trees is an ideal location.

The gauges should be installed 70-150 cm above the ground mounted on the side of a single post. The top of the rain gauge should extend several inches above the top of the mounting post. The mounting post should have a rounded, pointed, or slanted top to avoid upward splash towards the rain gauge.

The rain gauge should be installed at a reasonable distance from obstacles like as buildings or trees. As for example, if a tree is 10 m tall the gauge should be placed at least 20 m downwind from it. This will help avoid potential blockage of the rain gauge. It is not always possible to find a perfect location.



Left: Pain gauge and access tubes points configuration for each site. Right: regional locations for rain gauge sites deployment.



Google earth depiction of rain gauge and soil moisture monitoring grids in Bangladesh.

Note: It is advisable to place gauges with a direct participation of farmers under the existing active IPM/ICM/IFMC club or farmers field school.

Frequency of rain gauge monitoring:

The measurement should be taken from the gauges daily between 5:00 AM and 9:00 AM. But 7:00 AM is the best. Always read from the bottom of the meniscus.

Precautions:

(i) Avoid large obstacles that could block precipitation.
(ii) Avoid mounting the rain gauge where other sources of artificial precipitation can affect the data.
(iii) Assure that the top of the rain gauge is levelled.
(iv) The rain gauge should be mounted so that heavy rain could not splash into it from any nearby surfaces.

Installation of Soil Moisture Measurement Access tubes:

For accurate measurement of soil moisture using Delta T Profile Probes, the correct installation of access tube is crucial. The goal of installation is to produce optimal contact between the soil and the wall of the access tube. The hole where the tube will be installed should be straight, smooth sided, and the correct diameter. To achieve the best possible access tube installation, Delta-T auguring kits should be used. Avoid stony soils.

Site selection:

The sites should be truly representative of irrigation management areas. It should be in agricultural land but it should be selected in that site where land will not disturbed by ploughing, weeding, irrigation or any other agricultural operations. As such, it is likely better to select in a corner of a farmer's field.

Number of tubes and frequency of monitoring:

Two (2) access tubes should be installed centering each rain gauge with 15 Meters distance from both sides of the rain gauge (see below). So, the total 102 access tubes will be installed in three test sites in mid-October of 2017. The data will be collected only for dry season (mid-October to May) at 7 (seven) days interval.

Precautions:

(i) The access tubes must be installed in a way that fit tightly in the soil along their entire length because poor or hasty installations can result in the permanent errors in the readings. Any air gaps between the length of the access tube and the soil will cause the data deviations.
(ii) Remember to take time taken in careful installation to assure accurate and meaningful data.
(iii) Safety precautions should be taken while working with installation equipment and carrying them into the field.
(iv) It is important to keep all items clean and to put them away in their protective cases when not in use.

Annex 14. Specifications of agricultural drought monitoring and forecasting computing facilities installed at ICIMOD through the CSRD project

Dell(TM) PowerEdge(TM) R730XD Rack Mount Server - [ASPER730XD] Quantity: 1	1
PowerEdge R730xd MLK Server	1
Trusted Platform Module 1.2v2	1
Chassis with up to 24, 2.5" Hard Drives	1
Intel® Xeon® E5-2699A v4 2.4GHz,55M Cache,9.60GT/s QPI,Turbo,HT,22C/44T (145W) Max Mem 2400MHz	1
Upgrade to Two Intel® Xeon® E5-2699A v4 2.4GHz,55M Cache,9.60GT/s QPI,Turbo,HT,22C/44T (145W)	1
2 CPU Standard	1
2400MT/s RDIMMs	1
Performance Optimized	1
32GB RDIMM, 2400MT/s, Dual Rank, x4 Data Width	8
C1: No RAID for H330/H730/H730P (1-24 HDDs or SSDs)	1
PERC H730 RAID Controller, 1GB NV Cache	1
2TB 7.2K RPM NLSAS 12Gbps 512n 2.5in Hot-plug Hard Drive	24
iDRAC8, Enterprise with Open Manage Essentials, Server Config Mgmt	1
Intel Ethernet X540 DP 10Gb + I350 1Gb DP Network Daughter Card	1
Risers with up to 4, x8 PCIe Slots + 2, x16 PCIe Slots	1
Performance BIOS Setting	1
No Energy Star	1
UEFI BIOS Setting	1
Dual, Hot-plug, Redundant Power Supply (1+1), 750W	1
Long Jumper Cord, C13-C14,4m,12a (APCC except ANZ)	2
No Operating System	1
3 Years SADMG Rapid Parts Exchange Service	1
For SADMG Countries only - No Installation Service Required	1
No Remote Advisory Services Purchased - Indo, Vn, Ph, Bru & SADMG	1
Dell/EMC QSYNC Bezel for PowerEdge R730/XD - APJ excluding China, Hong Kong, Taiwan	1
ReadyRails™ Sliding Rails With Cable Management Arm	1
Ship Mod for PowerEdge™ R730xd (APCC/Taiwan)	1
No System Documentation, No OpenManage DVD Kit	1
Mod Specs Info (SADMG)	1
PowerEdge-SE02 Handling & Insurance Charges(DDD|PkNpBgAfSr)	1
For SADMG Countries - Future Technical Support	1
System Information Label	1

Annex 15. Planned curricula for a standardized manual on agricultural drought monitoring

1. **Introduction to drought monitoring systems**
    a. Global to Regional drought Monitoring Systems
    b. Drought monitoring in context of Hindu Kush Himalayan and associated deltaic regions

2. **Conventional drought monitoring**
    a. Drought type and characteristics
    b. Weather station and soil moisture monitoring
    c. Implications in agricultural systems

3. **Remote sensing and drought monitoring**
    a. Introduction to remote sensing
        i. History of remote sensing
        ii. How remote sensing works?
        iii. Major Components of Remote Sensing Technology
        iv. Remote sensing types
        v. Understanding resolution of satellite data
        vi. Limitations to remote sensing and the need for ground truth validation

    b. Remote sensing in context of drought monitoring
        i. Drought indicators and indices
        ii. Spectral and temporal characteristics from remote sensing

    c. Data requirements for drought monitoring
        i. Satellite Observations
        ii. In–Situ observations
        iii. Satellite data products-MODIS Data-NDVI, LST
        iv. Time series NDVI/EVI data cleaning and processing
        v. Satellite data acquisition

4. **Drought Monitoring**
    a. Drought Classification
    b. Drought Indices
        i. Drought indices based on different climate variables
            1. Standardized Precipitation Index (SPI)
            2. Soil Moisture Condition Index (SMCI)
            3. Evaporative Stress Index (ESI)
    c. Vegetation related indicators
    d. Physically-based vegetation state indicators
    e. Pure vegetation empirical indices
    f. Water content Indices
    g. Combined vegetation and temperature based indices
    h. Comprehensive drought indicators
    i. Phenological indicators

5. **Drought communication and dissemination systems**
    a. Examples of systems used to communicate and disseminate drought to stakeholders
        i. Speed of data availability and planning
    b. Communication of drought information to farmers

    i. Timing of communication
    ii. Method of communication

6. **Hands-on exercises**
    a. Hands-on exercise I: Exploring optical satellite images and calculating image indices
        i. Environment settings
        ii. Create composite band image
        iii. Visualization using different band combinations
        iv. Getting Image value
        v. Calculate Normalized Difference Vegetation Index (NDVI)
        vi. Making use of swipe tool for comparisons

    b. Hand on Exercise II: Visualizing and interpreting time series data; detecting anomalies
        i. Installation of SPIRITS and getting started
        ii. Map templates and visualizing one image
        iii. Generate map series
        iv. Time series analysis across seasons
    c. Hand on Exercise III: Monitoring drought using climate variables- Average, Trend, SPI
        i. Introduction to the GeoCLIM software
        ii. Exploring the GeoCLIM
        iii. Climate analysis using CHIRP: calculating trends, percentiles, cv, SPI
        iv. Blending station data with rasters, CHIRPS
        v. Climate analysis using CHIRPS: calculating trends, percentiles, cv, SPI
7. Hand on Exercise IV: Drought Monitoring using indices
    a. Calculating VCI
    b. Calculating TCI
    c. Calculating VHI
    d. Visualization and index analysis

Annex 16. Example preliminary protocol for data collection for validating and calibrating the prediction of onset and severity of Stemphylium disease of lentil using 'Stempedia' model in India, Bangladesh, Nepal (Rabi season 2017/18, example from Nepal)

Country: Nepal [Code: N]

Data collection sites
Site 1: {Kanchanpur – Far West} [Code: 1] [#14 C]
Site 2: {Kailali – Far West} [Code: 2] [#10 C]
Site 3: {Bardiya – Mid-West} [Code: 3] [#7 C]
Site 4: {Banke – Mid-West} [Code: 4] [#4 C]

Field selection in EACH site
Total number of FIELDS (per site): 40
Select 40 FIELDS in each SITE.
In selecting the FIELDS, use the main road along the length of the SITE.
Divide the length of the main road, i.e. the transect, into equally lengthen ten (10) segments.
Each segment is 1.0 km in length). Follow Fig. 1. The minimum length covered the main road, i.e. the transect, is 10 km.
Drive 1 km from the first point on the transect and stop.
Select two (2) FIELDS on the left side of the road that are at least 20 m from the edge of the road for the first transect segment.
Next select two (2) fields on the right side of the road that are at least 20 m from the edge of the road. *These four (4) samples complete the first segment of the transect.*

Note:
No FIELDS will be selected that are in contract with seed companies.
In the case, you don't find FIELDS on the LEFT, pick four (4) FIELDS on the RIGHT.
In the case, you don't find FIELDS on the RIGHT, pick four (4) FIELDS on the LEFT.
In the case, you don't find any FIELDS in 1 km drive on the transect, move forward, and pick up the FIELDS what you immediately find.

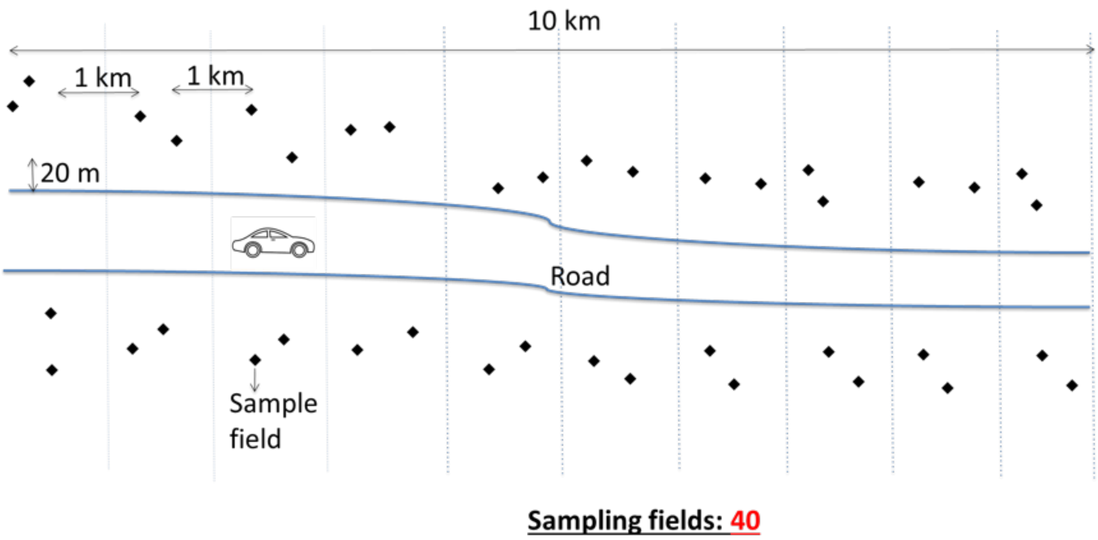


Fig. 1. Layout for segmented sampling units (FIELD) selection in each SITE selected in Nepal.

Drive the next 1km from the current transect segment point and stop.

Repeat the above until you have sampled forty (40) FIELDS and travelled at least 10 km in length along the transect (Fig. 1).
Nepal will have four (4) sites. Total sampling FIELDS in Nepal will be 4 × 40 = 160.

Data collection frequency and time and procedure

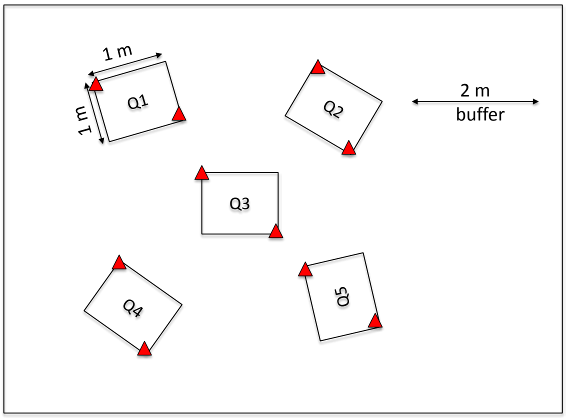


Fig. 2 Hypothetical location of five quadrats in each sampling plot. ▲s denote for sticks or pegs to be permanently placed to identify the quadrats for repeated sampling.

Data will be collected in three (3) times; so there will be three (3) visits in each FIELD.
Visit 1: 10 January (or early as convenient) [Code: 1]
Visit 2: Around 50% flowering time [Code: 2]
Visit 3: Maturity stage [Code: 3]

Visit 1

Select five 1 m^2 locations in each FIELD semi-randomly by throwing a 1 m^2 quadrat behind your back.

Each 1 m^2 quadrat should fall four around four corners (four of them) and the other in the middle. Through a 1 m^2 quadrant from at least two corners (at diagonals) of the field and demark it with a wooden stick or peg as sampling location (sticks or pegs are indicated by the ▲ shape in Fig. 2).

Mark each quadrat as Q1, Q2, Q3, Q4 and Q5. Facing the FIELD from transect, Q1 is the far-left corner, Q2 the far-right corner, Q3 the middle, Q4 the near left corner and Q5 is the near right corner.

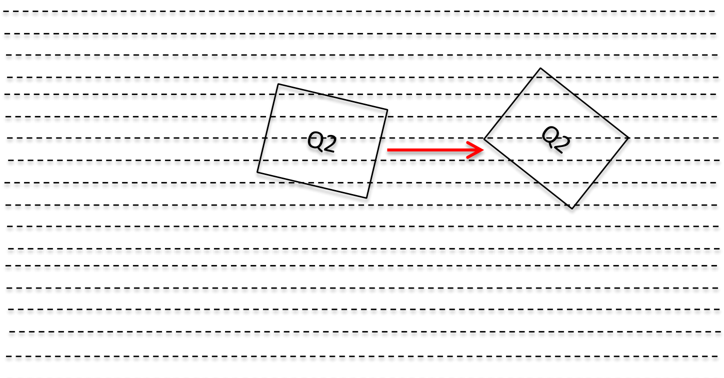


Fig. 3 Adjusted position of the quadrat when FIELDS were line-sown.

In case of line-sown FIELDS, quadrats to be adjusted such a way that the middle row lines up diagonally with the quadrat to avoid spatial sampling error caused by random quadrat placement (Fig. 3).

Fig. 4 Nine (9) sub-quadrants within a 1 m^2 quadrant for ease of plant counting and disease rating.

The quadrants will placed in be permanent locations and will be mark so that each time you return to observe the field you are examining the same area. For ease of plant counting and disease rating, divide each 1 m^2 quadrant into 9 sub-quadrat as shown in Fig. 4.

Record the following information for each field (assessment and conversation with the farmer) into ODK on tablets:

Name of the variety (ask the farmer)
Sowing date (ask the farmer)
Expected date of 50% flowering (ask the farmer)
Expected yield (ask the farmer)
Farmer's name
Farmers' mobile number
GPS location (Around the center of the field)
Record the phenological / development stage of the crop (Seedling, early vegetative, late vegetative, flowering and maturity, √ as appropriate).
Visually estimate (0-100%) of the crop ground cover in each 1 m^2 quadrat (five per field).
Record NVDI for each nine (9) sub-quadrats; use data recording format as shown in Table 2.
Take three (3) photographs relating each 1 m^2 quadrat as described below (one above the quadrat, one oblique photo of an infected plant, and one infected leaf).
Visually score the disease (Photo 1 & 2) using the scale in Table 1; use data recording format as shown in Table 2.
Take two diagonal NDVI readings for each field as described below.

<u>Visit 2</u>
Record the phenological / development stage of the crop (Seedling, early vegetative, late vegetative, flowering and maturity, √ as appropriate).
Visually estimate (0-100%) of the crop ground cover in each 1 m^2 quadrat (five per field).
Record NVDI for each nine (9) sub-quadrats. ; use data recording format provided
Visually score the disease (Photo 1 & 2) using the scale shown below; use data recording format as shown below.
Take three (3) photographs relating each 1 m^2 quadrat as described below.
Take two diagonal NDVI readings for each field as described below.
Additionally, collect diseased (only Stemphylium) plant samples for laboratory isolation – see Fig. 4. Wrap each sample (5 plants in a group) with paper towel, after dryings put that in envelope writing appropriate ID. When pulling the plants, make sure infected leaves don't shade on ground.

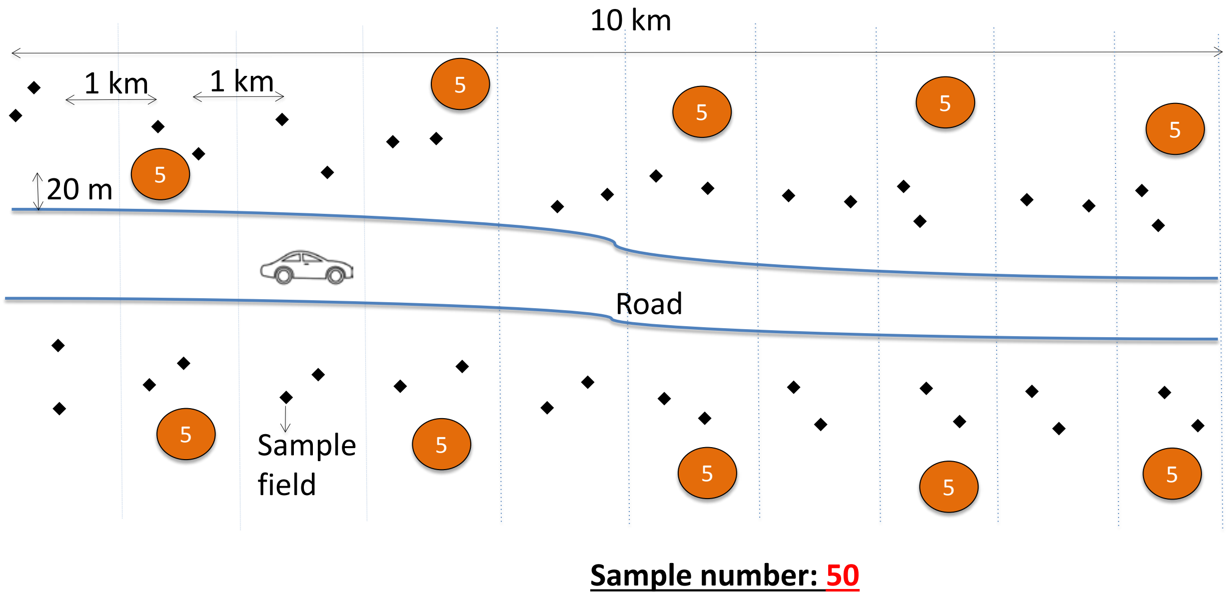


Fig. 4. Destructive sampling for pathogen isolation. Five diseased plants, outside the sampling quadrats in alternate sampling clusters in each location.

Visit 3

- Visually score the disease using the scale in Table 1 in the pre-designated sampling locations in each field.
- Visually estimate (0-100%) the crop ground cover in each 1 m^2 quadrat (five per field).
- Record NVDI for each nine (9) sub-quadrats. Use the data recording format as shown below.
- Visually score the disease using the scale in Table 1; use data recording format as shown below.
- Take three (3) photographs relating each 1 m^2 quadrat as described above.
- Take two diagonal NDVI readings for each field as described in below.
- Harvest the crop in each sampling location.
- Thresh and measure the lentil grain yield in each 1 m^2 sampling location in each field using a precise digital balance with at least three units after each digit.
- Record the moisture content (MC) of the lentil grain. The grain weight will be corrected at 14% MC. To achieve this, bulk the seed of five (%) sampling locations of each field. Record the MC from two randomly drawn samples from the bulk.
- Consult with the farmers if any fungicide was sprayed. If 'yes', note the product, dose and time of application. Also record the active ingredient from product level locally.
- Complete the crop management survey supplied in ODK to characterize the production practices of each farmer in detail (supplied in January)

Scale / rating for assessing Stemphylium blight and/or other symptoms

Scale / Rating	Symptom
1	All healthy plants (free of the disease)
2	Up to 25% of the plant is infected (leaves and/or the stems)
3	Up to 50% of the plant is infected (leaves and/or the stems)
4	Up to 75% of the plant is infected (leaves and/or the stems)
5	Over 75% of the plant is infected (leaves and/or the stems)

Photography

Take three (3) photos (This applies when you surely identify the disease as Stemphylium):
Whole quadrat from the above
Oblique photo of a stemphylium infected plant
Leaf symptom of an stemphylium infected plant (from nearby but outside the quadrat)
Sending photos

Three USB sticks will be provided to the CIMMYT coordinator in each location. The USB stick will have empty folders for each crop type into which you can place the photos you have taken with the GPS camera. The folders will have sub-folders marked so images can be placed in their correct locations. They will then be uploaded to a cloud location for storage. Please also keep a back-up copy of the folders from the USB stick, with photos in them, on at least two separate other computers in your hub office.

NDVI measurement procedure/sampling procedure:

NDVI will be measured in each field (in addition to done on each sub-quadrat within each quadrat) in two diagonal sections:

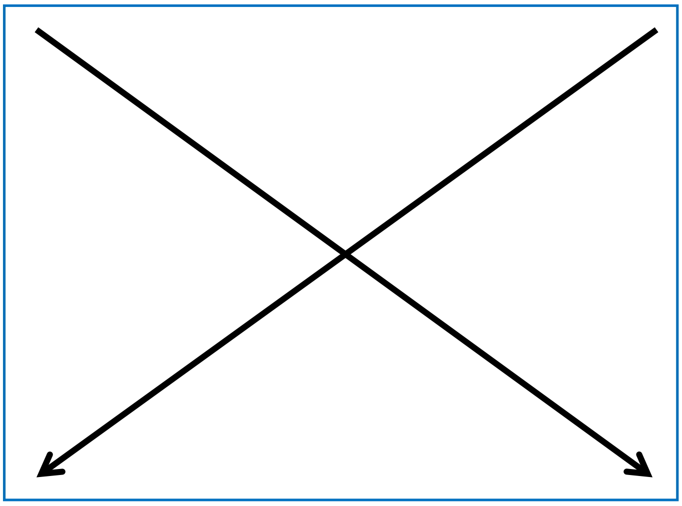


Fig. 7 Diagonal transects in each plot for measuring NDVI

Hold the Green Seeker over the crop canopy and then pull the trigger and walk across the corner of the field. The trigger must be held in place. The sensor should be held ~60 cm above the crop.

Walk across the field in an X pattern as shown above. Each of the four transects across the field will result in an NDVI measurement. Record individual each of the four NDVI measurements for each field in your ODK tablet.

The following diagram illustrates the NDVI measurement process:

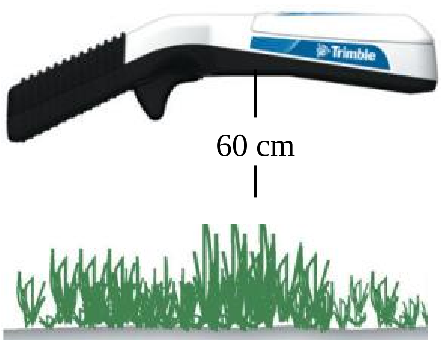


Fig 8. Proper use of the Greenseeker for NDVI measurement.

Observe the reading on the display.

The sensor's field of view is an oval; its size increases with the height of the sensor (approximately 10" wide at 24"above the ground, 20" wide at 48" above the ground). To obtain a reading representing a larger area, walk with the sensor while keeping the trigger engaged and maintain a consistent height above the target. The display updates continuously, but accumulates multiple readings and provides an average when the trigger is released. The maximum measurement interval is 60 seconds.

Note the NDVI value in ODK (Reading 1). Then pull the trigger to start a new measurement. The unit automatically turns off after completing the measurement. Pull the trigger to clear the screen and begin a new measurement at any time. Repeat the above instructions until you have made two (2) measurements of the field.

Annex 17. News generated or posted online by CSRD in South Asia in the last reporting period[14]

Success stories and leaflets

1. Shout it out!: Bangladesh to boost farmer-friendly climate advisories
   http://repository.cimmyt.org/xmlui/handle/10883/18983

2. From weather forecasts to the field: New partnerships reduce drought risks in South Asia
   http://repository.cimmyt.org/xmlui/handle/10883/18984

CSRD in South Asia Project brochure

https://drive.google.com/file/d/0B6xNZevqYGHHZmRVYWVLTTV5ZWs/view?usp=sharing

Project news stories and blogs

1. CSRD Technical Exchange on Participatory Approaches to Agricultural Climate Services Development and Extension in South and South East Asia
   https://ccafs.cgiar.org/csrd-technical-exchange-participatory-approaches-agricultural-climate-services-development-and#.WeQdsROCxE8

2. New initiative strengthens agricultural drought monitoring in Bangladesh
   http://www.cimmyt.org/new-initiative-strengthens-agricultural-drought-monitoring-in-bangladesh/

3. Bangladesh Agricultural Research Council and Partners to Collaborate on Strengthening Climate Services for Drought Monitoring
   https://reliefweb.int/report/bangladesh/bangladesh-agricultural-research-council-and-partners-collaborate-strengthening

4. High-level meeting to set climate services agenda for South and Southeast Asia
   http://www.cimmyt.org/high-level-meeting-to-set-climate-services-agenda-for-south-and-south-east-asia/

5. Scientists, policymakers meet in Bangladesh to produce climate services agenda for Asia
   http://www.cimmyt.org/press_release/scientists-policymakers-meet-in-bangladesh-to-produce-climate-services-agenda-for-asia/

6. Researchers set new climate services strategy in Bangladesh
   http://www.cimmyt.org/climate-services-asia/

Press Release

Scientists, policymakers meet in Bangladesh to produce climate services agenda for Asia
http://www.cimmyt.org/press_release/scientists-policymakers-meet-in-bangladesh-to-produce-climate-services-agenda-for-asia/

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[14] **Note:** These and other materials will soon be posted on a CCAFS landing page for CSRD in South Asia, which is under development and will be online by November 1, 2017 here: https://ccafs.cgiar.org/flagships/climate-services-and-safety-nets/projects. In addition, a CSRD brochure was also developed in 2017 (see Annex 18).

Annex 18. CSRD brochure detailing activities in South Asia

Climate Services for Resilient Development (CSRD) in South Asia

Climate Services for Resilient Development (CSRD) is a global partnership that connects climate and environmental science with data streams to generate decision support tools and training for decision-makers in developing countries. Translating complex climate information into easy to understand actionable formats to spread awareness in the form of climate services is core to CSRD's mission. CSRD works across South Asia (with emphasis on Bangladesh), the Horn of Africa (Ethiopia), and in South America (Colombia) to generate and provide timely and useful climate information, decision tools and services. In South Asia, CSRD focusses the development, supply and adaptation of agricultural climate services to reduce vulnerability by increasing resiliency in smallholder farming systems, which is strategically aligned with the Global Framework for Climate Services.

Strategic alignment

The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI). This partnership provides strength and technical expertise to develop relevant climate products to assure the access of farmers and other stakeholders to relevant information for a better-informed decision making to increase resilience to climate-related risks. The partnership also works to assure that climate information can be conveyed in ways that are decision-relevant to farmers and stakeholders in agricultural value chains.

The CSRD Approach in Bangladesh and South Asia

CSRD's core objectives are to prepare farmers, extension services, and agricultural policy makers by providing actionable climate information and crop management advisories to increase the resilience of smallholder farming communities to risks to agricultural production.

Some of our activities focus on:

Updating agro-meteorological information for major food and income staples in Bangladesh using farmer decision making frameworks

This activity focusses on identifying critical farm management decisions that could result in increasingly resilient agricultural productivity outcomes through the incorporation of climate services. Examples of climatic factors that influence farm management and crop performance include the risk of encountering drought or flooding, the timing and intensity of predicted rainfall, and the probability of extreme heat, among others. These factors influence the decisions farmers make with respect to crop and livestock management, including but not limited to choice of crop species and variety, when to sow, fertilize, irrigate or harvest, in addition to key pest and disease management decisions. This activity therefore investigates the relative importance of climatic information compared to other biophysical and socioeconomic factors, to identify ways to communicate relevant meteorological information in support of farming communities.

Presenting meteorological forecasts that are relevant to the decisions farmers make on a daily basis can help to reduce climate related risks and increase resilience in South Asia's farming systems. Photo: Timothy J. Krupnik

Climate services capacity development for a more resilient future

The usefulness of climate services in agriculture is dependent on the accuracy of weather forecasting. This activity focusses on scientific exchanges between BMD, DAE, URI, and IRI, and seeks to increase the skill of meteorological forecasts, and to render them in easy to understand formats for farmers and agricultural decision makers. Key focus areas include the improvement of crop specific risk-mapping heat stress, cold stress, dry-spells, and heavy rainfall and storm events that can damage crops. This activity also seeks to develop appropriate training and technical materials on climate services for extension services and farmers.

Development of an ITC platform for meteorologically integrated irrigation management services

The Program for Advanced Numerical Irrigation (PANI) is a mobile smart phone based application developed by CIMMYT that provides farmers and irrigation pump owners with irrigation recommendations for specific fields one week ahead of time. Under CSRD, we are working to upgrade PANI so that it can make use of forecasted and downscaled precipitation data that will be generated to provide field-specific and regional irrigation scheduling recommendations in Bangladesh and South Asia.

CSRD partners are forecasting drought risk and producing easy to understand messages in the form of crop choice and management advisories for farmers. Photo: Faisal Mueen Qamer

Spatially explicit and meteorologically driven wheat blast (*Magnaporthe oryzae Triticum*) disease risk assessments

For the first time ever outside South America, wheat blast disease (*Magnaporthe oryzae Triticum* (MoT)) was detected on over 15,000 hectares in Bangladesh in 2016. The fungal disease caused rapid and in some cases complete yield loss. Blast's initial outbreak had a significant and negative impact on wheat production in southern Bangladesh in 2017. Media have also reported that blast has spread beyond Bangladesh's borders. This work stream responds requests made by Bangladesh's Ministry of Agriculture to develop an early warning system for wheat blast outbreaks. CSRD is working with Brazil's Universidad de Passo Fundo (UPF) to adapt previously validated wheat blast forecasting model to South Asian climatic conditions, and to train extension services in its use. This activity will result in both decision support tools and advisories to assist in rational and integrated disease management in South Asia.

Regional drought forecasting and early warning systems utilizing earth observation data

The USAID supported SERVIR-Hindu Kush Himalaya (HKH) program of ICIMOD aims to increase use of earth observation information and geospatial technologies for environmental management, and to improve resilience to climate change. Through this program, which is aligned with CSRD, a regional effort is ongoing to establish new drought monitoring and early warning systems by incorporating suitable earth observation datasets and linking them with local cropping systems and meteorological data. The decision support products developed through ICIMOD-HKH-CSRD collaboration will be utilized by both national meteorological agencies and institutions involved in Bangladesh, Nepal, and Afghanistan to provide farmers and agricultural planners advanced information and advisories to overcome drought.

STEMPEDIA: *Stemphylium* blight disease forecasting and early warning system to reduce risk for lentil farmers

Stemphylium blight disease forecasting and early warning systems can reduce risk for lentil farmers. Photo: Ranak Martin

Lentil *Stemphylium* blight is a fungal disease threatening the sustainable production of lentil in South Asia. This activity builds on efforts conducted in Bangladesh to develop a preliminary weather-based model to predict *Stemphylium*, called 'Stempedia'. Through CSRD, the model is being validated, adapted, and refined in Bangladesh, India, and in Nepal, where lentil is a key income generating and nutritional crop for smallholder farmers. Work is also underway to incorporate extended range forecasts into the model, to develop a robust early warning system that can be used to more effectively advise farmers when and where *Stemphylium* outbreaks may occur, and how to control the disease.

Increasing policy maker, agro-metrological services, extension, and farmer awareness of agro-meteorological forecasts and decision support tools, with the support of all partners

CSRD focusses not just on the development, testing, refinement, and implementation of climate services. The project also endeavors to create awareness of the importance of climate services among the public. Trainings, media events, and round-table discussions for relevant stakeholder organizations, including government, civil society groups, and NGOs, are a key part of our work in South Asia.

CSRD is supported by the United States Agency for International Development (USAID), UK AID, the UK Met Office, the Asian Development Bank (ADB), the Inter-American Development Bank (IDB), ESRI, Google, the American Red Cross, and the Skoll Global Threats Fund. CSRD is also aligned with the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

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Annex 19. Scientific presentations made describing CSRD and showing the results of CSRD's work

Papers presented at the American Geophysical Union (AGU) 2017 fall meeting (11-15 December), New Orleans, USA.

Two papers on Regional Drought Monitoring System were presented in 2017 AGU Fall Meeting. First on South Asia Land Data Assimilation System (SALDAS), a modelling platform that supports multiple land surface models and meteorological forcing datasets to characterize uncertainty, and sub-seasonal to seasonal hydrological forecasts. The second on localizing drought monitoring data products through local level validation and contextualizing monitoring system with local farming practices. The abstracts for these presentations are shown below:

Localizing drought monitoring products to support agriculture advisories in South Asia

Faisal M. Qamer[1], Mir A Matin[2], Nabin Kumar Yadav[3], Birendra Bajracharya[4], Benjamin F Zaitchik[5], Walter Lee Ellenburg[6], Timothy J Krupnik[7] and Ghulam Hussain[7], (1)International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal, (2)ICIMOD, Kathmandu, Nepal, (3)International Center for Integrated Mountain Development, Kathmandu, Nepal, (4)International Center for Integrated Mountain Development, MENRIS, Kathmandu, Nepal, (5)Johns Hopkins University, Baltimore, MD, United States, (6)NASA Marshall Space Flight Center, Huntsville, AL, United States, (7)International Maize and Wheat Improvement Center, Dhaka, Bangladesh

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change identifies drought as one of the major climate risks in South Asia. During past two decades, a large amount of climate information has been made available by scientific communities, but the use of these information remained low for local level decision making. Provisioning of locally calibrated, easily accessible, decision-relevant and user oriented information, in the form of drought advisory service can help communities to cope with drought related vulnerabilities. A collaborative effort is being made to strengthen the existing or establish new drought monitoring and early warning systems in Afghanistan, Bangladesh, Nepal and Pakistan by incorporating standard ground-based observations, earth observation datasets along with integration of numerical models. ICT based agriculture drought monitoring platforms, hosted at national agriculture and meteorological institutions, are being developed to enable agriculture experts to translate scientific data into commonly understandable agriculture advisories. Particular emphasis is given on calibration and validation of data products through retrospective analysis of time series data as well as setting up additional wireless sensor networks. In order to contextualize monitoring products with local cropping system, district level farming practices calendars are compiled to identify critical timings and satellite remote sensing based high resolution crop distribution maps are developed to add the spatial context in the drought indices development process. The programme will initially target to enhance capacity of agriculture extension staff in understanding climate information and related technologies. The extension staff equipped with new technologies will be in better position to translate drought monitoring products to the local farmers for helping them in their climate related decision making.

Informing Drought Preparedness and Response with the South Asia Land Data Assimilation System

Benjamin F Zaitchik[1], Debjani Ghatak[2], Mir A Matin[3], Faisal M. Qamer[4], Bhupesh Adhikary[5], Birendra Bajracharya[6], Jim Nelson[7], Sarva Pulla[8] and Walter Lee Ellenburg[8], (1)Johns Hopkins University, Baltimore, MD, United States, (2)IMCS, Rutgers University, New Brunswick, NJ, United States, (3)ICIMOD, Kathmandu, Nepal, (4)International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal, (5)International Centre for Integrated Mountain Development, Kathmandu, Nepal, (6)International Center for Integrated Mountain Development, MENRIS, Kathmandu, Nepal, (7)Brigham Young University, Civil and Environmental Engineering, Provo, UT, United States, (8)NASA Marshall Space Flight Center, Huntsville, AL, United States

Decision-relevant drought monitoring in South Asia is a challenge from both a scientific and an institutional perspective. Scientifically, climatic diversity, inconsistent in situ monitoring, complex hydrology, and incomplete knowledge of atmospheric processes mean that monitoring and prediction are fraught with uncertainty. Institutionally, drought monitoring efforts need to align with the information needs and decision-making processes of relevant agencies at national and subnational level. Here we present first results from an emerging operational drought monitoring and forecast system developed and supported by the NASA SERVIR Hindu-Kush Himalaya hub. The system has been designed in consultation with end users from multiple sectors in South Asian countries to maximize decision-relevant information content in the monitoring and forecast products. Monitoring of meteorological, agricultural, and hydrological drought is accomplished using the South Asia Land Data Assimilation System, a platform that supports multiple land surface models and meteorological forcing datasets to characterize uncertainty, and sub-seasonal to seasonal hydrological forecasts are produced by driving South Asia LDAS with downscaled meteorological fields drawn from an ensemble of global dynamically-based forecast systems. Results are disseminated to end users through a Tethys online visualization platform and custom communications that provide user oriented, easily accessible, timely, and decision-relevant scientific information.

Paper to be presented at the 2018 Gobeshona4 conference on climate change (8 - 11 January 2018). Dhaka, Bangladesh

Seasonal prediction of the monsoon onset in Bangladesh: Implications for cropping systems management

Carlo Montes[1], Timothy J. Krupnik[1], Ghulam Hussain[1], Mathew A. Stiller-Reeve[2,3] and Simon Mason[4]

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[2] *Uni Research Climate, Uni Research, Bergen, Norway*
[3] *Bjerknes Centre for Climate Research, Bergen, Norway*
[4] *International Research Institute for Climate and Society, The Earth Institute of Columbia University, New York, USA*

The onset timing of the monsoon is a major climate feature impacting agriculture in Bangladesh. Farmers' decision as to when to begin land preparation, the date of sowing and transplanting, are highly dependent on monsoon onset date, with consequences for rice crop productivity. A late onset can also delay the date of rice transplanting and therefore harvest date, causing further sowing delays for subsequent dry season crops that can experience heat stress due to late sowing. Variability in the timing of monsoon onset consequently crucial in mitigating agricultural risk and increasing the resilience of Bangladesh's rice-based cropping systems. In this research, we assess the potential for one to two-month advance monsoon onset predictability in terms of probabilities of "early", "normal" or "late" occurrence. To achieve this, we use a monsoon onset definition that has been previously applied and validated using multiple data sources and indigenous knowledge of farming communities Bangladesh. This analysis is combined with long-term last generation high-

resolution gridded precipitation data to assess the inter-annual variability of the monsoon onset and its relationship with large-scale climate drivers. We examine monsoon onset for different regions obtained by statistical classifications of precipitation time series (e.g. cluster analysis), for which the monsoon onset predictability is evaluated by using multivariate statistical tools. The subsequent implementation of this information as a climate service for meteorological and agricultural institutions are discussed.

Abstract submitted to the 2nd International Conference on Climate Change 2018 (15th-16th February), Colombo, Sri Lanka

Historical and projected variability in monsoon onset and withdrawal over South Asia using NASA-NEX Ensemble: Implications for Agriculture

Carlo Montes[1], Mathew A. Stiller-Reeve[2,3], Ghulam Hussain[1] , Simon Mason[4], Timothy J. Krupnik[1]

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The timing of the monsoon onset and withdrawal is a major climate feature impacting agriculture across South Asia, where over 1.5 billion people rely on monsoon 'kharif' season rice followed by dry 'rabi' season wheat for sustenance and income generation. This crop rotation covers over 13 million hectares, and the timing of land preparation and sowing/transplanting of kharif rice are highly dependent on monsoon timing. A late onset can delay rice transplanting and therefore harvesting, causing further sowing delays for subsequent dry 'rabi' season crops sown in the same fields. These delays can result in heat stress for rabi season wheat. Overcoming these problems is crucial to mitigate agricultural risk and increasing the resilience of cropping systems to climate variability. In response, we assess the variability in long-term historical and climate change projections of monsoon onset and withdrawal and their implications for agriculture in South Asia. We use daily precipitation issued from the NASA-NEX GDDP downscaled (0.25° × 0.25°) ensemble from 21 general circulation models for recent climate (1950-2005) and climate change projections (2006-2099) for two representative concentration pathways (RCP4.5 and RCP8.5). The historical APHRODITE data product, which provides precipitation data at the same spatial resolution (0.25° × 0.25°) for the period 1951-2007, is used as an observational reference. Monsoon onset and withdrawal are determined employing a definition that has been previously applied using multiple data sources and that is adaptable to farmers' information needs and requirements. We examine the multiscale variability in monsoon timing and future projections using relative differences in spatial and inter-annual/inter-decadal variability, amplitude, statistical distribution and long-term trends, both to quantify differences among models, and with respect to APHRODITE. Implications for the productivity of kharif and rabi season agriculture are discussed in terms of observed and projected variability, and in relation to model uncertainty.