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CSRD
CLIMATE SERVICES FOR RESILIENT DEVELOPMENT

Climate Services for Resilient Development (CSRD) Partnership's Work in Latin America

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Citation:
International Center for Tropical Agriculture (CIAT). 2020. Climate Services for Resilient Development (CSRD) Partnership's work in Latin America. International Center for Tropical Agriculture (CIAT). Cali, Colombia. 22 p. Available at: https://hdl.handle.net/10568/107883

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CIAT Publication no. 495
March 2020

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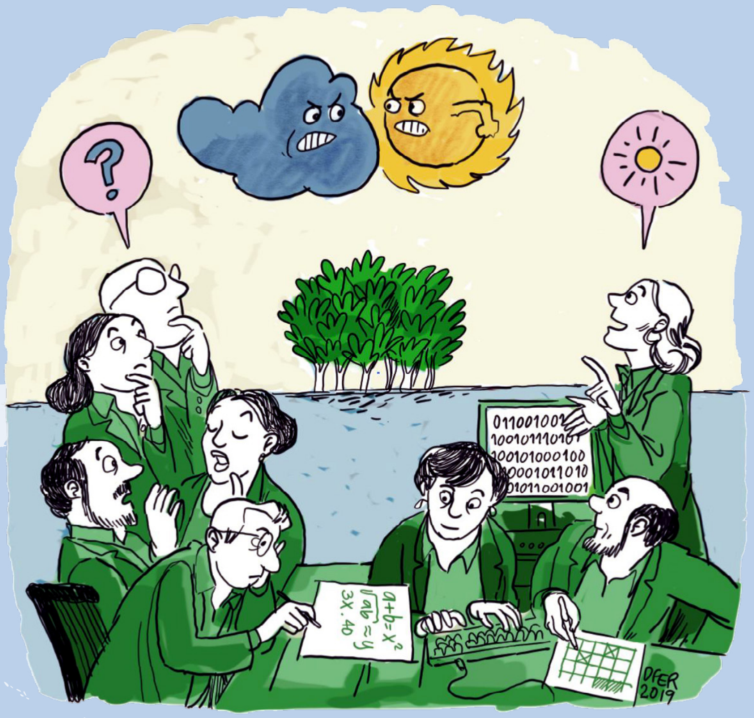
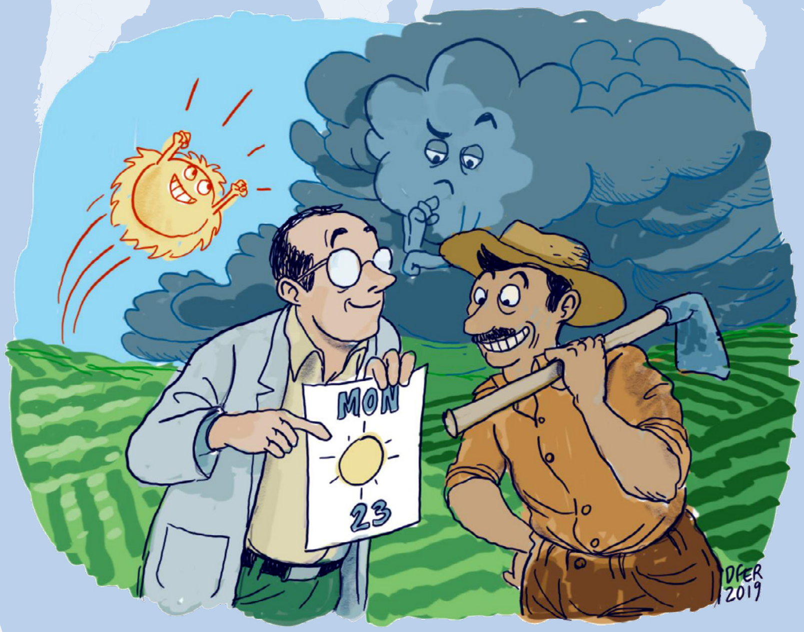
Executive summary

What is the **CSRD partnership?**

The Climate Services for Resilient Development (CSRD) Partnership is a private-public collaboration led by USAID, which aims to increase resilience to climate change in developing countries through the development and dissemination of climate services. The partnership began with initial projects in three countries: Colombia, Ethiopia, and Bangladesh. The International Center for Tropical Agriculture (CIAT) was the lead organization for the Colombian CSRD efforts – which then expanded to encompass work in the whole Latin American region.





What is a **climate service?**

Climate services encompass the production, translation, transfer, and use of climate information to support decision-making and planning. This information can be quite technical (e.g. source code for better seasonal climate modeling) or very simplistic (e.g. SMS flood warning). In agriculture, where interannual climate variability can explain one-third of crop yields, clear, timely agro-climatic information can inform key agricultural practices such as planting or harvest, thus better securing rural livelihoods and national food security.

Our **Approach**

Because the impact of CSRD lies in people integrating the climate information into their planning and decision-making processes, we at CIAT believe that the CSRD process must begin and end with the user in mind. As such, our projects followed an iterative, **four-step process:**

1. **Diagnose user demands and needs,** usually through extension stakeholder consultation.
2. **Identify high-potential new research opportunities.** "High potential" is defined by the research's ability to improve livelihoods or to make key scientific advancements.
3. **Build new knowledge** by engaging in the scientific research, often in collaboration with stakeholders.
4. **Deliver findings back to users as "climate services"** – in a sustainable, scalable way.

Our **Work**

Our work had two stages: the Colombia-focused "lighthouse projects phase, and the expanded Latin American regional phase.

PHASE 1: Colombian lighthouse projects

Assessment and improvement of forecasting methods (statistical and dynamical models)

KEY ADVANCE

We discovered we could downscale dynamical Global Climate Models to localized geographies, and then correct for any regional biases using statistical Canonical Correlation Analysis. This combination of the two modeling techniques – into a "NextGen forecast" – significantly improved forecast skill.

Creation of an online agro-climatic forecasting portal (Pronósticos AClimateColombia)

KEY ADVANCE

We automated the generation of 6-month forecasts, from pulling observed weather station data, gap-filling any missing precipitation data, feeding it into a seasonal forecast model, feeding that input into mechanistic crop models, and finally displaying the resulting agro-climatic forecast via an online interface.

Identification of resilient coffee farms and practices

KEY ADVANCE

We were able to remotely and cost-effectively identify coffee farms (and even classify their type of coffee system, e.g. agroforestry), by searching for coffee's spectral band (reflective color) in satellite images.

PHASE 2: Regional work (ongoing)

Region-wide: We worked to facilitate South-South synergies – organizing trainings in ten countries throughout Latin America – and to communicate the importance of climate services in agriculture, for example, by encouraging agricultural stakeholder representation at key climate events such as the Climate Outlook Forum (COF).

KEY ADVANCE

We organized a Regional Agro-climatic Committee of Central America, to be held alongside the COF. This allowed for representatives from ministries of agriculture to engage with the climate discussions.

In **Mexico,** we are working with the national meteorological office to improve climate forecasts and distribute them to the over 300,000 farmers in their MasAgro network, starting with a trial run in Chiapas.

In **Guatemala,** we supported the creation of four Local Technical Agro-climatic Committees (LTACs), led capacity building efforts with the national meteorological office, and surveyed farmer needs in the country's particularly vulnerable Dry Corridor.

In **Honduras,** we worked with their national meteorological office to improve the seasonal precipitation forecast.

KEY ADVANCE

20% improvement in seasonal precipitation forecast skill in Honduras, by optimizing the Sea Surface Temperature predictor area. This methodology is likely applicable throughout Central America, most of which experiences two rainy seasons per year.

In **Peru,** we trained the national meteorological office on Next-Gen forecasting methods, in preparation for the online agro-climatic forecast platform they plan to build.

Our **Outcomes, Impact** and **Reach**

MORE THAN **200** PEOPLE TRAINED IN **CROP-CLIMATE PREDICTION METHODOLOGIES**

500,000 COLOMBIAN FARMERS RECEIVING AGRO-CLIMATIC INFORMATION FROM THE **CSRD ONLINE PLATFORM**

10 LATIN AMERICAN COUNTRIES HAVE INVITED **CIAT-CSRD** FOR **TRAINING ON FORECASTING** METHODS AND PARTICIPATORY PROCESSES

48 COFFEE FARMS SURVEYED ON **29** AGRICULTURAL PRACTICES, TO IDENTIFY TECHNIQUES **THAT INCREASE CROP RESILIENCE**

3 DYNAMICAL and **2** STATISTICAL MODELS ASSESSED FOR SEASONAL FORECAST PERFORMANCE IN COLOMBIA

2 NATIONAL ONLINE PORTALS: **ETHIOPIA** AND **COLOMBIA** OFFERING AUTOMATED SEASONAL AGRO-CLIMATIC FORECASTS

COLOMBIA'S PLATFORM COVERS **2** MAIN CROPS IN **30** LOCALITIES ACROSS **9** DEPARTMENTS

5 MACHINE LEARNING TECHNIQUES EMPLOYED ACROSS MULTIPLE RESEARCH PROJECTS

33 **LOCAL TECHNICAL AGROCLIMATIC COMMITTEES** SUPPORTED THROUGHOUT THE REGION

Contents

Introduction

In 2015, several private and public sector organizations and agencies joined together to form the Climate Services for Resilient Development (CSRD) Partnership. The partnership aims to increase resilience to climate change impacts in developing countries, through the provision of timely, accessible, and useful climate services. The initial phase of the work focused on three different countries in three distinct global regions: Colombia in South America, Ethiopia in Eastern Africa, and Bangladesh in South Asia. Each country was tasked with selecting target projects within key sectors likely impacted by climate change, namely water, agriculture, and energy. The in-country CSRD work also had to clearly engage local stakeholders to ensure continued future delivery of the climate service past the end of the CSRD Partnership work.

This report provides an overview of the CSRD-for-agriculture work in the Latin American region from 2016 to 2019, beginning with the initial Colombia-specific "lighthouse" projects and then expanding to regional collaborations and still-ongoing research. This CSRD portfolio was led by the International Center for Tropical Agriculture (CIAT) in Cali, Colombia.

What are climate services?

> *Climate services encompass the co-production, translation, transfer, and use of climate information to support decision-making and planning,*

so that users can minimize climate-related risks and take advantage of opportunities. They can provide rather general climate information (e.g. seasonal forecasts for a given district) or very specialized information for a specific sector (e.g. climate monitoring for aeronautical activities). Climate services can be designed for a range of users, from technical data scientists to subsistence farmers, and they can come in different formats, such as raw datasets, interactive tools, reports, smartphone apps, and SMS alerts. Many actors are involved in the creation of climate services, from global organizations such as the World Meteorological Organization to national HydroMet services to local stakeholders. These stakeholders work together in developing infrastructure and capacity in order to deliver timely and relevant climate information.

Why are climate services important for agriculture?

In the face of a changing future climate and increased climate variability, agricultural producers who rely solely on best practices from the past, or on time-honed intuition, are suffering. Indeed, an estimated one-third of the global variability in the production of basic grains is explained by interannual climate variation.[1] Poor yields put food security at risk for millions around the world. Therefore, providing agricultural farmers with clear, timely agro-climatic information will allow them to make informed decisions on what to plant, where to plant – and in some cases – whether to plant at all. Better information will also allow farmers to make more efficient use of water and agrochemicals. In sum, climate services will improve our food systems' resilience to both short-term climate perturbations and long-term climate changes.

However, creating climate services for agriculture, albeit important, is also a challenge. Technically, it often requires melding data from multiple sources, improving climate forecasting methodologies to provide finer-grain information at local and seasonal scales, and ascertaining what climate variables have the strongest impact on crop yields. Yet, none of these technical advances matter if the information is not understandable and usable to the intended audience. Effective climate services must, therefore, also take into account users' real and perceived understanding of climate information, their agricultural priorities, their access to technology (e.g. internet or smartphones), and their preferences for how they receive agro-climatic information.

1 In fact, the 1983 El Niño Southern Oscillation (ENSO) episode led to the largest single synchronous crop failure in recorded history, affecting five major crop-producing regions across the globe.

CIAT's Approach to CSRD

Given the challenges of CSRD for agriculture, our approach to the region's CSRD project was, in essence, quite simple: everything starts and ends with the user. Nearly all our projects followed this four-step process:

1 DIAGNOSE USER DEMANDS AND NEEDS

Since "users" of climate services can be quite diverse, this meant engaging with stakeholders at every level.

2 IDENTIFY HIGH-POTENTIAL OPPORTUNITIES

Based on users' needs, we would assess: What activities would help meet their demands? What work would have the highest potential for impact, both socioeconomically (i.e., improving livelihoods) and scientifically (i.e., creating breakthroughs or closing important gaps)? This process often involved external consultations.

3 BUILD NEW KNOWLEDGE

We would perform the scientific research identified in step #2, in collaboration with key stakeholders (e.g. decision makers, meteorological offices, producers associations, universities).

4 DELIVER FINDINGS AS "CLIMATE SERVICES," BACK TO THE USER(S), IN SUSTAINABLE, SCALABLE WAYS

The climate services we produced were as diverse as the target audiences we had. For example, for a meteorological office, the climate service might be a forecasting tool, delivered as a series of technical capacity-building workshops. For Mexican farmers, it might be a seasonal precipitation forecast, delivered as a 160-character text message (SMS).

In every case, CIAT made sure that a wide variety of stakeholders were heavily involved (if not primarily responsible) for such delivery channels. With this model, even after the CSRD project ends, the climate service will sustainably live on.

It is important to note that these steps are not unidirectional, nor one-time-only. Rather, the steps interact with one another in iterative loop: As knowledge is disseminated (step #4), the demand for certain kinds of climate services might change or increase (step #1). Similarly, the research performed (step #3) may change the state of science, altering what constitutes a "high-potential" opportunity (step #2).

This is not just semantic or theoretical. Indeed, in practice, the first "loop" of these steps (the Colombian lighthouse projects) did in fact generate additional demand, opportunity, and climate service dissemination in other parts of Colombia and elsewhere around the region.

Photo: CIAT/Neil Palmer

Colombian lighthouse projects

Step 1. **Demand**

The CSRD projects in Colombia began with identifying the key sectors and projects to focus on. To do this, CIAT organized several rounds of participatory needs assessments and priority-setting meetings with public- and private-sector experts, across the water, energy, and agricultural sectors (see Timeline in Annexes). What emerged was a set of possible "lighthouse projects" in the country, which would demonstrate how institutions could collaborate around CSRD. After assessing the practicality of the various options, we decided to focus on agro-climatic services.

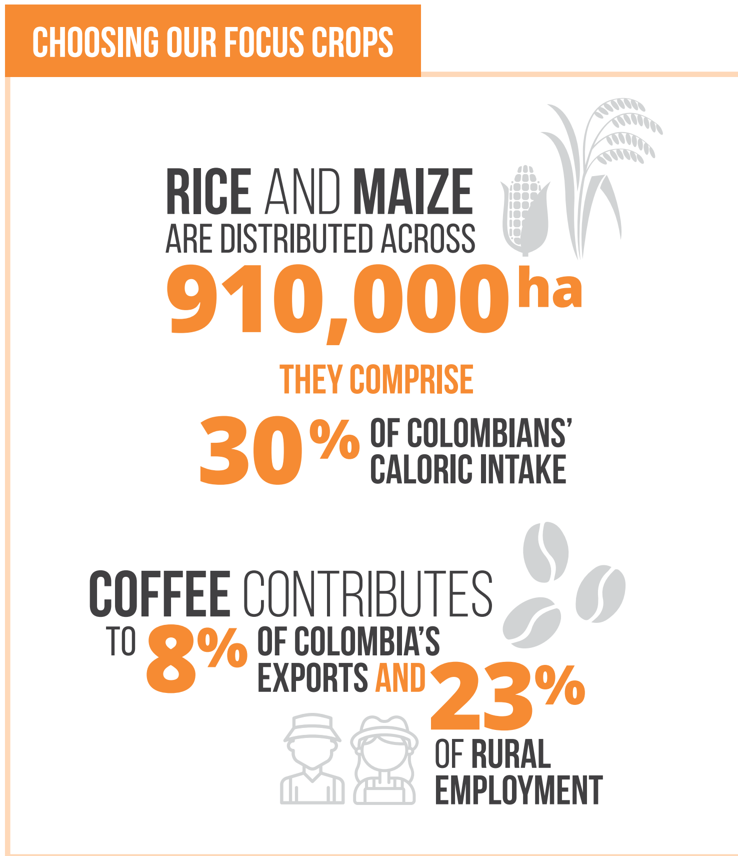
In particular, there seemed to be user demand for two complementary types of climate services:

- *Top-down information:* Seasonal agro-climatic forecasts of the climate itself (e.g. temperature, precipitation) *and* of the expected impact on crops (e.g. yield).
- *Bottom-up information:* Identification of existing resilient farming practices that would minimize the impact of climate shocks.

The former would allow farmers to plan accordingly for a changing climate; the latter would give farmers information on how to best deal with climate variability.

Step 2. **Potential**

Based on potential socio-economic impact, we decided to focus on three key crops: rice, maize, and coffee. Rice and maize are the two most important staple crops in Colombia, contributing 30% of the total calories of the population and distributed across 910 thousand hectares in virtually all of the country's departments. Both of these crops are also substantially affected by climate variability and climate change. Coffee was chosen due to its economic importance in Colombia, where it contributes 8% of the country's total exports and 23% of rural employment, and due to the crop's sensitivity to climate change – particularly problematic since over 80% of coffee-growing areas in Colombia are projected to warm beyond 2 °C, which will likely affect productivity and quality. Finally, all three crops have active producers associations that were interested in collaborating with CIAT on this project and helping to disseminate findings to farmers at the end. These were FEDEARROZ (rice), FENALCE (maize), and FEDECAFE (coffee) (see full list of Acronyms on page 18). Once the focus crops were selected, we turned to identifying high-potential areas for scientific progress that intersected with clearly articulated national demand.



Related to seasonal agro-climatic forecasts, we saw the need for:

- **Better seasonal climate forecasts, at fine enough resolution** (that is, geographically localized). Previously, there were few forecasts for developing countries at the spatial and temporal scales that are relevant for agricultural decision making, and they were rarely assessed for their predictive skill.
- **Better agro-climatic forecasts**, that is, the process of translating climate forecasts into agriculturally relevant information. Previously, climate services offered throughout Latin America focused on providing probabilistic forecasts of precipitation and temperature conditions. We saw potential in translating those forecasts into actionable information. In particular, there were three key research areas: (1) improving the ability of crop models to simulate crop growth and development for rice and maize across different areas of Colombia; (2) connecting these enhanced crop models with the seasonal forecasts to produce information on best-bet planting dates and varieties, and (3) developing strategies for integrating actual users in the interface design process in order to assure relevance and usability of the forecasts.
- **Automation of forecasts.** Before the CSRD projects began, flow of information was somewhat cumbersome. Institutions such as CIAT, FENALCE or FEDEARROZ would get weather station and climate data from Colombia's national meteorological agency

(IDEAM), translate it into crop forecasts, and then work with technicians to provide that information to farmers. We wanted to ensure that the main stakeholders could sustainably and consistently exchange information and improve decision making on their own. A key way to do this would be to automate the creation of forecasts and provide the results through an online portal.

- **Automated identification of areas of low climate resilience.** The first step to identifying resilient farming behaviors would be to identify areas with farming practices. Yet short of manual inspection, this was quite difficult. There was therefore an opportunity to create a new scientific methodology to remotely identify farms using satellite imagery, a much more scalable solution.

This in turn led to the creation of three Work Packages (WPs):

1. Assessment and improvement of forecasting methods and tools
2. Agro-climatic forecasting interface for maize and rice crops (online portal)
3. Creation of farm-level coffee adaptation plans (by studying resilient coffee farms)

Packages 1 and 2 were interlinked, and the two focused on both rice and maize in six initial study sites representing key growing areas, varied meteorological conditions, and production systems[2] (irrigated vs. rainfed), and diverse levels of access to and use of technology. Package 3 focused on the Risaralda coffee region in the Coffee Belt, the most important coffee-producing region by quantity in Colombia.

Step 3. **Science**

We will now briefly highlight some of the main results of these 3 work packages.

WP1 and WP2: Forecast tools assessment and online portal

- Assessment of climate forecasting methods and skills (statistical and dynamical models)
  We focused on comprehensively understanding forecast skill across major crop-growing regions of Colombia. We then developed, implemented, and scaled out methods for enhancing forecast skill in regions where this skill was found to be low.

So to begin, we assessed the forecast skills of both statistical and dynamical models,[3] by testing their retrospective forecasts of Sea Surface Temperature (SST), regional precipitation, zonal wind and vertical velocity, for the years 1982–2013. For statistical models, we examined (1) Columbia University's Climate Predictability Tool (CPT),[4] which is based on Canonical Correlation Analysis (CCA), and (2) Multiple Factor Analysis (MFA), which allows integrating several regions or several predictors simultaneously. We found that CCA models outperformed MFA. The former could be reliably used to produce seasonal forecasts for agriculture in virtually all seasons and departments assessed for both rice and maize.[5]

DISCOVERY

Canonical Correlation Analysis (CCA) more reliably produces seasonal forecasts for agriculture, versus Multiple Factor Analysis (MFA).

For dynamical models, we worked with the University of Leeds Institute for Climate and Atmospheric Science to test the skill of three distinct modeling systems' ability to forecast mean precipitation and mean temperature. We tested the ENSEMBLES project from the EU, the National Center for Environmental Prediction Climate Forecast System v2 (NCEP CFSv2) from the US, and the Met Office Global Seasonal forecasting system v5 (GloSea5) from the UK.

2 Rice study sites: Ibagué in Tolima, Lorica in Córdoba, and Yopal in Casanare. Maize study sites: Espinal in Tolima, Cereté in Córdoba, and La Unión in Valle del Cauca.

3 A note on statistical vs. dynamical models: Statistical models are computationally less expensive and relatively easier to implement operationally, but their forecast capability relies on having and detecting the appropriate teleconnections between local climate conditions and large-scale atmospheric or oceanic drivers (e.g. sea surface temperatures, regional wind fields). Dynamical forecasts, on the other hand, are more computationally expensive and require more technical capacity to implement operationally, but they often capture mesoscale climate dynamics and can, therefore, have greater forecast skill when teleconnections are poor.

4 Here are the technical specifications: The Climate Predictability Tool creates seasonal forecasts by separately pre-filtering predictors and predictands through a principal component analysis (PCA). A conventional PCA is used for the predictand, whereas an Empirical Orthogonal Function (EOF) analysis is used for the predictor. The resulting patterns after pre-filtering are used as inputs into a Canonical Correlation Analysis (CCA). Once the canonical components are determined, a linear regression is performed between the canonical modes of the predictor and the predictand, including a cross-validation and a retrospective validation procedure. CPT is widely used, as it provides a computationally inexpensive, efficient, and user-friendly implementation of CCA-based seasonal forecast models.

5 Results are reported in Esquivel et al. (2018) here: https://www.sciencedirect.com/science/article/pii/S2405880718300177

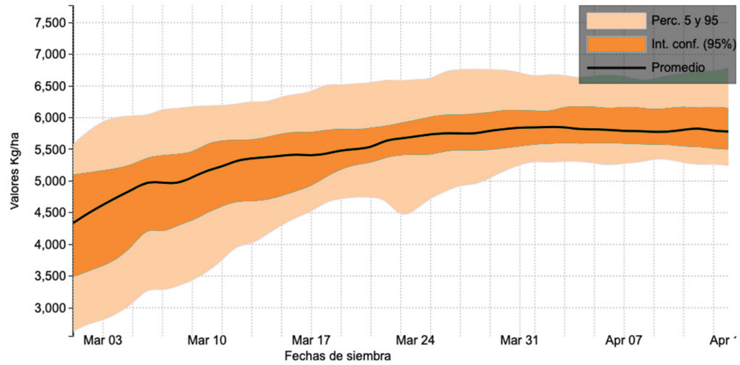
We found that the ENSEMBLE model's seasonal forecasts for the six study sites were very poor, due to the coarse resolution (2.5 degrees, equivalent to ~280 km at the equator). For a region like Colombia with mountainous terrain and highly differentiated altitudes / micro-climates within small geographies, resolution is likely to be particularly important. That said, even the two finer-resolution models (NCEP CFSv2 and GloSea5), which had resolutions of about 90–100km at the equator, performed poorly at the medium time-scale (for inter-annual or inter-seasonal forecasts).

- Improvement of agro-climatic crop yield forecasting
  We developed seasonal agro-climatic models with 6-month lead time, for the six maize and rice study sites. During our research, we first worked on connecting seasonal climate forecasts with crop models, in order to identify best-bet planting dates and cultivars. For areas where seasonal climate forecast skill was low, we identified other variables (e.g. frequency and duration of dry spells) that provided higher-skill predictions than seasonal precipitation (the normal variable used).[6]

DISCOVERY

In some areas, frequency and duration of dry spells was actually a better predictor of crop yield, than seasonal precipitation.

Our final output included tables and graphics showing our recommended cultivars to plant for various sowing dates (see example below).[7]



- Automation of both climate and crop forecasts
  The objective was to automate the generation of 6-month forecasts, to predict either above-normal or below-normal precipitation and then translate that to predict crop yields for varying planting dates and crop varieties. On the climate forecasting side, this required automating a process to gap-fill missing precipitation data in areas with inadequate observed weather station data. This was done using an improved version of RClimTool. We also developed a new tool, R-CPT (an implementation of Columbia's CPT tool, as a series of R scripts) to automate the generation of the statistical forecast. This forecast would then automatically be fed into mechanistic crop models: DSSAT for maize, and ORYZAv3 for rice. This end-to-end processing allowed data to automatically be picked up from online datasets, processed into an agro-climatic forecast, and then displayed on an online portal (see Step 4 below).[8]

WP3: Resilient coffee

- Identification of coffee farms using satellite imagery (remote sensing)
  We wanted to remotely identify coffee farms and categorize them by coffee system (e.g. agroforestry). To do this, we relied on Landsat mission satellite images and machine learning. We first created a sample of data where we knew there was coffee, and then found the corresponding pixel on Landsat mission satellite images. We identified the most appropriate spectral band (reflective color), and then, based on this, trained a model to identify other locations in the Risaralda department where the spectral characteristics indicated likely presence of coffee. (i.e. had similar spectral bands). We then added an elevation filter (had to be 1150–1950 masl) and a size filter (had to be bigger than 1800 sq. meters). The result was a 73,972 ha coffee layer (versus the National Agricultural Survey's designated

6 See Fernandes K; Munoz A; Ramirez-Villegas J; Agudelo D; Llanos-Herrera L; Esquivel A; Rodriguez-Espinoza J; Prager S. 2018. Improving seasonal precipitation forecast for agriculture in the Orinoquía Region of Colombia. Weather and Forecasting. https://doi.org/10.1175/WAF-D-19-0122.1 (In Press).

7 The rough methodology was as follows: First, we modeled out a 6-month seasonal climate forecast. Second, we found historical times with similar weather patterns during cropping seasons. Third, we forecasted the 6-month crop yield based on past performance in similar weather. We also identified the cultivars that performed best in the past times with similar weather patterns.

8 The process is described in full in: Sotelo S; Guevara E; Llanos-Herrera L; Agudelo D; Rodríguez J; Ordóñez L; Mesa J; Muñoz Borja LA; Howland F; Amariles S; Rojas A; Valencia JJ; Segura CC; Grajales F; Hernández F; Cote F; Saavedra E; Ruiz F; Serna J; Jiménez D; Tapasco J; Prager SD; Epanchin P; Ramirez-Villegas J. 2018. Pronósticos AClimateColombia: A system for the sustainable provision of agro-climatic information for climate risk reduction in Colombia. In revision. Computers and Electronics in Agriculture.

area for coffee planting of 53,000 ha). Our model, therefore, overestimates the land with coffee farms (likely due to spectral similarity of coffee and forest). Still, the methodology provides a very cost-efficient map of possible coffee areas. We further classified the kinds of coffee systems also using spectral signatures, since pixels with trees (i.e. agroforestry) had the greatest reflectance.

- Identification of resilient practices
  We first identified historically resilient farms. To do this, we used data interpolation and gap filling methods to create a historical climate dataset at fine enough resolution (250 meters). We then identified climate anomalies (difficult times for coffee); often these were droughts. We then identified coffee farms using remote sensing (see above) and identified the farms that continued running (stayed resilient) through these historical climate anomalies. Finally, we surveyed farms to discover what practices resilient farms employed versus the non-resilient ones. In total, we surveyed 48 farms (21 resilient, 27 non-resilient), asking them 29 questions regarding their agronomic practices. In the end, we found that resilient farms applied more potassium and planted coffee at greater distance intervals.

DISCOVERY

> *Historically resilient coffee farms applied more potassium and planted coffee at greater distance intervals.*

- Identification of future challenges to coffee cultivation
  First, we downscaled short-term (2030) future climate projections to 250-meter resolution. Second, we defined possible data points that could explain the suitability (presence) or unsuitability (absence) of coffee – such as potential evapotranspiration.[9] Based on these, we trained four machine learning models and one classification scheme to retrospectively predict presence/absence of coffee – and identified the best performing model: Random Forest. Once trained, we used the models to project climate suitability in 2030. Generally, the models predicted many losses in the Northeastern part of the Risaralda department and in the central valley. The gains were often in higher altitudes or near snow parks, due to the projected temperature increase.

Step 4. **Delivery**

WP1. Forecast tools assessment and improvement

Since the first work package was very technical, the primary modes of delivering key findings and new methodologies was through the ordinary scientific channels, making the source code publicly available, and engaging in technical exchanges with partner organizations. For example, we published a peer-reviewed article in the journal *Climate Services*, titled "Predictability of seasonal precipitation across major crop growing areas in Colombia", available open access. We have made our source code available in a GitHub repository. We also presented our work at conferences and shared it with other climate science research organizations. Lastly, many technical exchanges were done at CIAT headquarters, as well as at IDEAM, and at the farmers organizations' headquarters in Bogotá. The great strides made in WP1 are a big reason for the demand for CSRD training throughout the region.

WP2. Online platform

The primary intended output of WP2 was an interactive, online agro-climatic platform, now available at pronosticos.aclimatecolombia.org.[10] It was built for multiple types of audiences and, therefore, includes (1) an API for technical institutions to directly access the underlying data and to connect other apps to the data, (2) an Admin layer that allows expert users to manipulate the parameters underlying the crop models (e.g. cultivars, soils), and (3) a simple visual interface for less technical people to see the resulting forecasts.

Since there were multiple intended audiences, we did multiple phases of user testing, involving the full gamut of end users. This included:

- A series of in-person farmer/extension agent workshops, in which we tested their understanding of key climate concepts, identified key information that they would want, and evaluated some prototype data visualization formats (graphs, charts calendars).

9 Results are reported in Esquivel et al. (2018) here: https://www.sciencedirect.com/science/article/pii/S2405880718300177

10 Codebase available at Github at
https://github.com/CIAT-DAPA/usaid_forecast_web
https://github.com/CIAT-DAPA/usaid_forecast_maize
https://github.com/CIAT-DAPA/usaid_forecast_rice
https://github.com/CIAT-DAPA/usaid_forecast

Figure 2. Platform: pronosticos.aclimatecolombia.org

- Prototype tests with a panel of internal experts from the project, including members of CIAT, FEDEARROZ, FENALCE, and IDEAM.
- A beta release of the website, with an accompanying web survey that asked 20 questions to identify whether the platform was both user-friendly and understandable. Some in-person farmer groups were also organized to improve access to the beta platform and the survey. We received 192 responses in total.

Through these different user feedback methods, we made important improvements – including adding new indicators and more written explanations.

Just as importantly, these engagements showed us the limitations of the platform. For example, the web survey found that only half of users (farmers, technical assistants, national agricultural association staff, and meteorological agency staff) were able to identify and interpret information from the interface. Interestingly, more technical individuals did not perform significantly better than farmers. In fact, rice farmers gave more answers rated "good" than rice professionals did. Moreover, there is limited farmer access to such a platform in Colombia. The Observatory for the Information Society in Latin America and the Caribbean (OSILAC) 2008 census indicated that only 2.5 % rural homes in the country had access to a computer and only 0.3% had internet access.

Given these results, we decided to adjust course. Rather than attempting to directly reach farmers through this web portal, we now rely on trained producer association staff and Local Technical Agro-climatic Committee (LTAC) members. The platform was presented to many of the LTACs throughout Colombia. The rice association FEDEARROZ now has 5 people in charge of disseminating agro-climatic forecasts. Their farmers receive a monthly agro-climatic assessment. Meanwhile, the maize association FENALCE now has 2 agro-climatologists on staff, who run the models and produce regular, farmer-friendly agro-climatic bulletins.[11] In total, we estimate that 500,000 farmers in Colombia are currently receiving agro-climatic information that resulted from this CSRD work package with the LTACs and directly with the farmers organizations.

Both FEDEARROZ and FENALCE changed their organizational structure as a function of this activity.

Moreover, we see on Google Analytics that, from the launch date in December 2017, to present day, there continues to be regular and engaged use of the platform, on mobile and desktop.

Lastly, it is important to note that the platform will constantly evolve. Now that it's been built, more crops and regions can be added to it. Indeed, since launch, it has already expanded from covering 6 localities in 5 departments, to 30 localities

11 See for example https://www.fenalce.org/archivos/boletincordoba20.pdf

across 9 departments. More components such as mobile apps can also be added to the platform, allowing for multi-channel dissemination.

WP3. Coffee resilience

Through CSRD, the coffee sector was able to acquire knowledge and technical expertise on methods for identifying coffee farms using satellite imagery, as well as on how to map coffee suitability given climate conditions. These skills have helped make climate adaptation a central topic of discussion for their strategic planning. Moreover, the practices identified through field work and data analysis indicated the need to better understand how farmers are responding to climate variability and long-term change, through better farm practice surveys and agronomic trials. While it is difficult to attribute specific decisions in the coffee sector to CSRD work, it is clear that FEDECAFE is moving towards an integral consideration of digital climate information as part of their decision-making process – for example, through their recent agreement with Microsoft in 2019 to "digitize coffee farmers."[12]

Regional work

Out of the Colombian lighthouse projects emerged a great regional (and indeed global) interest on how to scale CIAT's outputs beyond the borders of Colombia. In particular, other countries were interested in creating their own open-access climate portals, learning how to produce better seasonal climate forecasts and more robust crop yield forecasts that use climate data, and creating their own networks of LTACs.

In the end, we hosted workshops in seven Latin American countries and worked in detail with four: Mexico, Peru, Honduras, and Guatemala. We have also expanded our work to other parts of Colombia beyond the original lighthouse project study sites.

These regional CSRD projects, too, fit the same four-step framework:

Step 1. **Demand**

Normally, a country's national meteorological office or one of its producers associations would contact CIAT for assistance with agro-climatic services. The actual nature of the demand varied by country (see next section, for country-by-country breakdown).

12 https://www.dinero.com/tecnologia/articulo/la-alianza-entre-fnc-y-microsoft-para-digitalizar-a-los-cafeteros-colombianos/276139

Step 2. **Potential**

As in Colombia, we then identified high-potential research opportunities or collaboration opportunities in these countries, given the demands. While, of course, there were differences, there were also some similarities across countries. Most could benefit from better automation of their forecasts, and improved integration of existing climate forecasts with agricultural models. Moreover, all countries, including Colombia, could benefit from the following advances in forecasting:

- Improved selection of predictor areas[13]
- Downscaling of forecast resolutions to be more localized
- Evaluation of alternative prediction methods (e.g. partial least squares, artificial neural networks) and variables (e.g. number of wet days vs. seasonal precipitation amount)
- Implementation of IRI's NextGen seasonal forecast method

Step 3. **Science**

Again, the actual science we conducted depended on each country's needs. In some cases, it was less about CIAT performing new research and more about capacity building to allow each country's meteorological offices and LTACs to conduct their own research.

In other cases, as part of our regional work, we pursued research that was not directly requested but would have strong potential to influence projects in high demand. For example, we began an Artificial Neural Networks project that used machine learning to ascertain the relationship between sea surface temperature and regional precipitation.[14] If successful, the outputs of this work could dramatically improve local precipitation forecasts – something that all countries could benefit from.

13 "Predictor areas" refers to the area of the sea surface temperature (SST), whose information is fed into the model to produce a forecast on land. One of the key advances that came out of CSRD was improved selection of SST areas.

14 The initial work will aim to detect what regions of the sea have more influence on each Colombian department's local precipitation. We are using Convolutional Neural Networks (CNN), a deep learning architecture inspired by the structure of mammals' visual processing systems. CNN is widely implemented in computer vision, speech recognition, and natural language processing. The plan is to feed our CNN two inputs: (1) a video of sea surface temperature historical data changing over time (monthly observed SST for 6 consecutive months), and (2) weather data in different Colombian regions (observed precipitation data from weather stations) for the same 6 months. The model will then find connections, relations, or dynamics between precipitation in the departments and changes to sea surface temperature in parts of the ocean.

Step 4. **Delivery**

Within each country, we leveraged the best local networks for disseminating agro-climatic services, working with our in-country partners to ensure that crucial information reached the end-user.

We also worked to communicate about the importance of climate services in agriculture. One way we have done this is through encouraging agricultural stakeholder representation at climate events. In 2019, we leveraged CSRD outputs to draw a plan, jointly with the Regional Committee for Water Resources (CRRH) and Central American Agricultural Council (CAC), for the implementation of a Regional Agro-climatic Committee for Central America, to be carried out in conjunction with the Climate Outlook Forum (COF). We expect this process to strengthen agricultural stakeholders' understanding of climate prediction and its connection with agricultural modeling. This in turn facilitates more informed demand for climate services relevant for agricultural decision making.

We have also worked to facilitate South-South research synergies. For example, we have also organized in-person trainings on modeling and forecast automation in Panama City, Panama; Antigua, Guatemala; Lima, Peru; San José, Costa Rica; Guayaquil, Ecuador; Asunción, Paraguay; Tuxtla Gutiérrez and Mexico City, Mexico; and in our host campus in Cali, Colombia. We have also hosted online webinars to train meteorological offices.

Lastly, we have disseminated our learnings through existing regional programs and partnerships. For example, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) will be producing an integrated climate services system/portal for the whole region – and will be building on our Colombia platform to do so. As another example, CIAT has collaborated with IRI's ACToday program on their trainings on NextGen seasonal forecasts and sub-seasonal forecasts, which strengthens meteorological services' forecasting capacities. Together, we've hosted several training workshops.

Now, we will turn to examine the CSRD work specific to each of our main partner countries in the region.

Mexico

The main **demand** for agricultural CSRD in Mexico was to reduce climate risk for small-scale maize farmers. This demand came from two main partners:

1. The Sustainable Modernization of Traditional Agriculture (MasAgro) project from the International Maize and Wheat Improvement Center (CIMMYT), which supports more than 300,000 maize producers across the country through a well-established, large network of hubs; and
2. The National Meteorological Service (SMN).

There were three high-**potential** avenues for accomplishing this:

1. Climate models could be downgraded to produce greater-skill and finer-resolution (more localized) seasonal forecasts, and they could be provided in multiple formats – including as downloadable data to facilitate further research. At the time when we began work, the only seasonal forecast was generated by the National Institute for Agriculture and Forestry Research (INIFAP), made available only as flat PDFs.
2. Crop prediction models could be connected to climate models, and these integrated agro-climatic forecasts could be disseminated through MasAgro in multiple formats. In addition to its main communications products (magazine, bulletins, and visiting technicians), MasAgro is currently trying out some new distribution channels, such as the SMS service MasAgro Movil, available to farmers in Chiapas, and the mobile app AgroTutor, currently being tested in Guanajuato.
3. Mexican organizations, both at the national (SMN) and the local organizational (LTAC) level, could benefit from capacity building in some of the key seasonal forecast methodologies developed in the Colombian lighthouse projects.

The **scientific work** is currently in progress but still at the pilot phase.

So far, the primary work has been identifying the pilot area. We began by looking for areas with enough climate data (30+ years of weather station data) to generate seasonal forecasts, as well as enough maize crop data (from the "Bitacora Electrónica MasAgro," or BEM, database) to correlate historic climate with yields.

For example, in the map below, you can see the peach agro-ecological zone spread over the states of Oaxaca, Puebla, Tlaxcala, Mexico, and Michoacán. This cluster had the highest number of crop events (*red dots*) and had multiple weather stations (*blue triangles*) within its boundaries.

In the end, the most feasible three areas were identified as central Mexico (cluster 3 above), Guanajuato, and Chiapas.

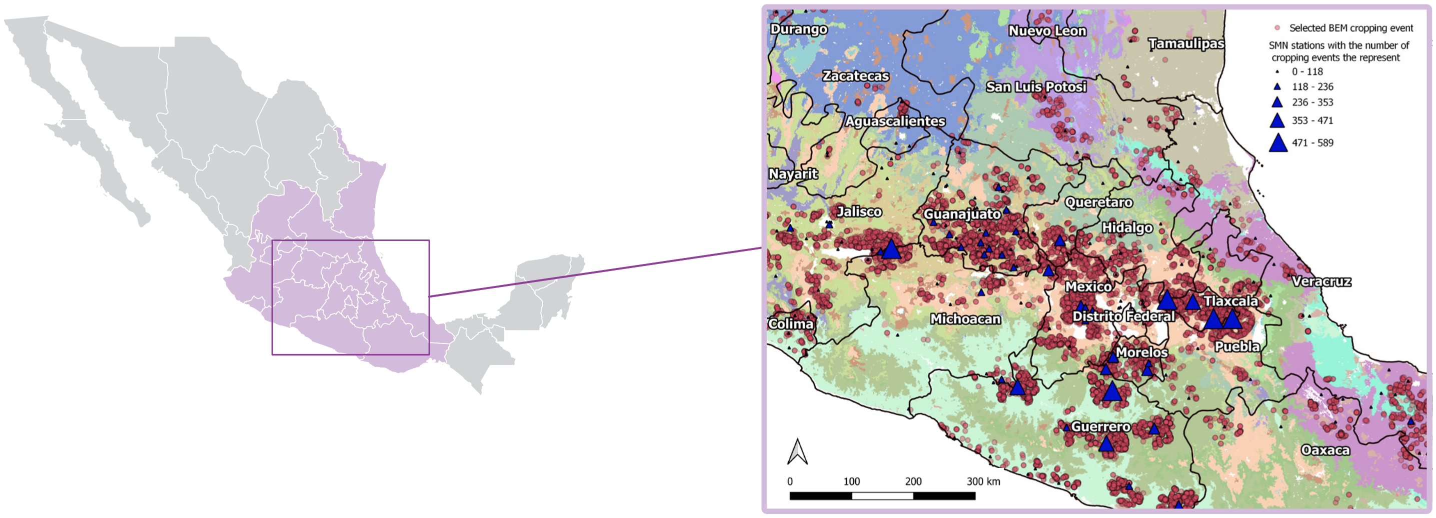


Figure 3. Map of the association between BEM cropping events and SMN weather stations. Detail of the center part of Mexico. The colors in the back of the weather stations and cropping events correspond to agro-climatic clusters.

After various rounds of consultation with MasAgro Hub managers and with CIMMYT's MasAgro project coordination unit, we selected Chiapas as the pilot region for the implementation of climate services. The plan is to improve SMN forecasts, and then work with a LTAC and MasAgro to disseminate the information.

The next steps included:

1. Continued technical exchanges with the SMN for training on the CPT (Climate Predictability Tool), and to design improvements on their operational seasonal forecast system.
2. Meetings and field visits with relevant CIMMYT and MasAgro staff, to liaise with maize farmers and local organizations in Chiapas. We want to ensure their participation from the beginning.
3. Continued engagement with MasAgro Chiapas Hub Manager to implement climate services. As part of this, we will also need to better understand MasAgro Móvil, to identify technical requirements for plugging our forecasts into this SMS channel.
4. Assessment of the most suitable historical management practices in the relevant agro-climatic clusters. This will leverage 2018 and ongoing data-driven agronomy work between CIAT and CIMMYT.

In our Mexico CSRD engagement, we are already approaching the **delivery** step. We have kept users in mind even during the research phase, for example, by selecting Chiapas as a pilot area due to the potential reach via MasAgro Móvil, and the large amounts of data collected by CIMMYT and partners through the BEM (MasAgro Electronic Fieldbook). We will leverage data, already existing SMS services, with the creation of a new LTAC to co-create climate services with users.

Peru

The main **demand** from Peru was from their national meteorological service, SENAMHI, for technical assistance and training on climate prediction tools and techniques. Together with the SENAMHI team, we also identified the **potential** for better alignment with their organizational structure, for example, by ensuring that the climate predictions produced by the Directorate of Meteorology took into consideration the needs of the Directorate of Agrometeorology.

Rather than conducting our own CIAT research, our partnership with Peru has mostly centered around **delivery** of scientific knowledge via a series of capacity building workshops, and helping them implement their own LTAC system. For example, on 13–18 October 2018, we held a workshop on crop modeling tools, reviewing: the fundamentals of crop modeling using different simulation platforms in RStudio; methods and tools for automating simulations and analyses; and best practices for integrating crop and climate models, to develop agro-climatic services. There were also many hands-on activities. Participants were grouped by interest (region, crop, and irrigated/non-irrigated farming system), given a relevant sample data set, and then assigned to apply, calibrate, and evaluate the crop models. Consequently, by the end of the workshop, there were 25 professionals with new skills in simulating crop scenarios for at least two prioritized crops.

Participants to training course on "Agro-climatic Modeling Tools to support agronomic decisions in crop modeling," organized by SENAMHI and the Ministry of Agriculture and Irrigation (MINAGRI), jointly with FAO.

We also provided a web repository of course materials (presentation slides, documents, example data, scripts) for participants to review again later – or to share with their colleagues.

This workshop helped prepare SENAMHI and the Peruvian Ministry of Agriculture and Irrigation participants for the implementation of their own Agro-climatic Management Platform – whose creation has been mandated by Peru's 2019–2030 National Plan for Competitiveness and Productivity.

Honduras

The user **demand** in Honduras was twofold:

1. The Honduran Institute of Coffee (IHCAFE) wanted to automate their agricultural bulletin and coffee rust (pest) early warning systems.
2. The national meteorological office (COPECO–CENAOS) wanted help improving their seasonal precipitation forecast and understanding of mid-summer drought.

In the end, we focused our efforts on the latter project because identifying a new methodology for precipitation forecasts had a high **potential** for impact throughout Central America. The whole region has a similar bimodal climate, with two rainy seasons that coincide with planting seasons (April-June and August-October, generally the wetter of the two). Between these two precipitation peaks is the dry period, known as mid-summer drought, "veranillo" or "canícula." In this context, understanding precipitation patterns (and their timing) is highly important for the region's agriculture. It is the variable with the most interannual variation – versus, for instance, solar radiation or temperature.

> *In Central America, it's super important to time crop planting with the two rainy seasons – and to avoid the dry season in between. But with climate change, those seasons are changing.*

Through our **scientific** engagement with the Honduran SMN, we developed seasonal precipitation forecasts, assessed their predictive skill, and then tested different methods for optimizing the forecasts. In particular, we evaluated the precipitation forecast skill of the NCEP CFSv2 model over various seasons, for all of Honduras, for the years 2006–2016. This model requires an input which it then statistically correlates with precipitation. Subsequently, we used the NOAA's Sea Surface Temperature dataset (ERSST), as the main input, to correlate with observed weather station data (from 33 stations). In other words, we were asking the model to look at how SST and historical precipitation have interacted *historically*, and then determine *future* precipitation based on what we believe *future* SST will be.

We also wanted to test two possible improvements on inputs to the model: First, given the few weather stations, we tested filling in precipitation data with information from the CHIRPS dataset.[15] Second, we tried to optimize the "predictor area" – the part of the ocean from which to pull the sea surface temperature. "Optimizing" meant we retained only areas of the ocean that have most relevance to a given prediction.

More specifically, here's what we found:

- First, both improvements helped. Adding the CHIRPS dataset led to greater forecast skill and allowed covering areas that otherwise would have no forecast (due to the lack of weather stations). Similarly, optimizing the sea surface predictor area led to better forecasts (by up to 20%), with statistically significant improvements, especially in situations with low predictive skill.

15 This is the precipitation dataset produced by the Climate Hazards Group at the University of California, Santa Barbara.

DISCOVERY

We could optimize the sea surface predictor area, to get up to 20% better seasonal forecast performance.

See Goodness Index results below. On this index scale, a 1.0 would indicate a perfect result.

Descriptive stats for the Goodness Index								
Trimester	Mar - Apr - May		Apr - May - Jun		Aug - Sep - Oct		Dec - Jan - Feb	
Predictive Area	Optimized	Complete	Optimized	Complete	Optimized	Complete	Optimized	Complete
Average	0.14	0.09	0.13	0.09	0.30	0.28	0.19	0.15
Median	0.14	0.09	0.12	0.09	0.30	0.28	0.19	0.14
Std Dev	0.06	0.05	0.06	0.05	0.30	0.03	0.05	0.05

- Second, all versions of the model were more skillful in predicting precipitation for the second rainy/planting season (August-October) than for the first (March-May). Future research may need to be conducted to understand the reason for this interannual variability in forecast performance.
- Third, the model performance began worsening in about 2012. This was an unexpected result because, usually, as the training models gain more information (i.e. years of data), they begin to perform better. Therefore, you'd actually expect to see the reverse trend – with forecast skill improving year on year, from 2006 to 2016 (the year range for which we conducted this research). However, climate change may be limiting the predictive power of historical data. This means that we need models that capture climate-change-induced changes in climate variability.
- Lastly, as is normal with seasonal forecast models, the longer the lead time, the lower the forecast skill. We also noted greater forecast skill, when using observed, real-world SST as compared to modelled SST (from NCEP CFSv2).

Our engagement with Honduras will continue through work with the CCAFS Agroclimas Phase 2 Project, the ResCA project (led by The Nature Conservancy and implemented by CIAT in Honduras), and the IFAD-funded "A Common Journey" project. These improved forecast capabilities are being put into practice to provide better information to farmers through the network of 7 LTACs in the country (see below map of region-wide LTAC network).

In Honduras, CSRD leveraged on agro-climate services efforts by the Resilient Central America (ResCA) program, led by The Nature Conservancy and SAG. This contributed to enhancing information co-production capacity beyond what would be possible by each program individually.

Finally, we also expect that Honduras will establish a National Framework for Climate Services, using our progress in agriculture as a beacon for other sectors.


Photo: CIAT/Neil Palmer

Figure 4. Network of 38 LTACs throughout Latin America.

Guatemala

In Guatemala, our work is comprised of two main projects, based again on expressed user **demand**.

First, we have supported the establishment of four new LTACs across Guatemala, in addition to strengthening the already existing Chiquimula LTAC.

> *In Guatemala, CSRD has leveraged work by the CCAFS project Agroclimas and IRI's ACToday program.*

CSRD, CCAFS, and ACToday help LTACs generate user-tailored agro-climatic bulletins. Towards this end, we have led technical exchanges with stakeholders – including both local organizations and the meteorological office (INSIVUMEH) – on crop and climate modeling.

Second, we assisted by performing a diagnostic of user demand in Guatemala's Dry Corridor in the center/south of the country. Irregular precipitation in this region is increasingly affecting the subsistence crop yields, rural employment, and food security of an already vulnerable population. Lack of access to reliable and timely climate-crop information is one of the main reasons why Guatemalans in this region have not been able to effectively manage climate shocks.

We performed a survey among farmers in the Dry Corridor, which revealed clear understanding and demand for the following types of services:

CSRD		
OBSERVATIONAL WEATHER DATA	**CLIMATE FORECASTS**	**CROP-RELATED FORECASTS**
Precipitation Temperature Relative humidity (which affects spread of crop diseases)	Precipitation amount, onset, demise forecast Mid-summer drought (Canícula) onset, demise and intensity forecast Drought forecast Hurricane forecast El Niño Southern Oscillation (ENSO) monitoring and forecast	Crop yield forecast Crop damages and losses forecast Food security seasonal forecast
NON-CSRD		
ACCESS TO	**SOCIAL SERVICES**	**PRICE INFO ON**
Land Seed Irrigation Subsidies Food storage facilities	Health Education	Inputs (supplies) Outputs (local/regional market crop prices)

Finally, we have worked to improve technical proficiency at the national meteorological agency. As part of this, we have actively collaborated with the IRI Columbia ACToday project on the establishment and use of NextGen seasonal climate forecasts in support of agricultural decision-making in the country. We have engaged in constant technical exchange with INSIVUMEH, as well as co-hosted capacity strengthening events with IRI.

Colombia

After the success of the original lighthouse projects in Colombia, there was excitement and **demand** for expanding our CSRD work to other regions in the country and in furthering our research on rice crop modeling. While regional activities were not explicitly designed to include Colombia, the momentum of lighthouse projects led to the expansion of climate services in the country.

We identified the **potential** for additional scientific research to make two key advancements, one geographic and the other thematic. A recent study in Colombia attributed 30–60% percent of rice yield variability to climate, with an important role played by precipitation.[16] However, in some areas of the country, the standard statistical precipitation forecasts perform very poorly. Where there is scant weather station coverage, the problem is exacerbated. One such rice-producing region suffering from both of these problems is the Orinoquia, which also happens to produce 35% of the country's rice. One high-potential piece of *geographically* oriented work would be, therefore, to generate more skilled precipitation forecasts for the Orinoquia.

However, in addition to this, it was unclear if total seasonal precipitation (the total amount of rainfall in the season) was the best variable for predicting rice yield. With this in mind, the second *thematic* high-potential research project would be to test other predictive variables ("predictands") related to rainfall, and seek to identify more highly skilled ones.

The **scientific research** that we conducted and published in the journal *Weather and Forecasting*[17] went as follows. First, we scaled down the coarse-resolution NCEP CFSv2 General Circulation Model and corrected for regional biases, using linear regression models (CCA). To overcome regionally poor weather station coverage, we merged it with the precipitation data from the CHIRPS satellite-based dataset.

Then, we ran nine different experiments involving permutations of three different **predictands**:

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16 See Delerce et al. 2016. Assessing Weather-Yield Relationships in Rice at Local Scale Using Data Mining Approaches (Z. Wang, editor). PLoS One 11(8): e0161620. DOI: 10.1371/journal.pone.0161620.

17 Fernandes K;. Muñoz A; Ramirez-Villegas J; Agudelo D; Llanos-Herrera L., et al. 2019. Improving seasonal precipitation forecast for agriculture in the Orinoquía Region of Colombia. Weather and Forecasting. DOI: 10.1175/WAF-D-19-0122.1.

1. Weather station only June-August precipitation totals
2. Weather station only June-August wet days frequency
3. Satellite-station merged June-August precipitation totals

and three different **predictors**:

1. Tropical Atlantic and Pacific Sea Surface Temperature (SST)
2. Regional precipitation
3. Regional vertically integrated meridional moisture flux (VQ).

We then compared the outputs of these forecast model configurations to the observed climate conditions, to assess climate forecast skill.

We found that seasonal climate-crop forecast skill improved when using the number of wet days ("wet day daily frequency") as the predictand, rather than seasonal precipitation amount. Forecast skill also improved by using the CHIRPS merged satellite-station precipitation for June-August as predictand, especially when the predictor was vertically integrated meridional moisture flux (VQ).

DISCOVERY

For rice in the Orinoquia, climate-crop forecast skill improved when using the variable "# of wet days" vs. "precipitation amount" as the predictand.

This research is now being **delivered** to end users by partnering closely with the ACToday program for their work on #NextGen seasonal climate forecasts with IDEAM. CIAT has donated a Computing Server to IDEAM so that they can create a Public Data Library to make NextGen seasonal forecasts available to users. Concomitantly, we are working with the Ministry of Agriculture and Rural Development (MADR) and the farmer organizations to ensure uptake. We are also developing tools to connect these forecasts with the AClimateColombia platform developed in the lighthouse phase.

A final development in Colombia is the creation of the "*Va a llover o no?*"[18] Platform [Is it going to rain or not? Platform] by FEDEARROZ, which complements the Forecast Platform AClimateColombia.org with site-specific agro-climatic calendars and weather forecasts.

Photo: CIAT/Neil Palmer

18 Available here http://clima.fedearroz.com.co

Photo: CIAT/Georgina Smith

Global reach

Our CSRD work has had global research even outside of Latin America. For example, projects in the two other pilot CSRD regions (Ethiopia/Africa, and Bangladesh/Asia) have used outputs from our Colombian work, as follows:

- The Ethiopian Institute of Agricultural Research (EIAR) has implemented a version of the Pronósticos AClimateColombia climate services platform to deliver climate services for Ethiopian agriculture, primarily focusing on teff, wheat, and maize crops (http://advisory.ethioagroclimate.org).
- In Asia, the DeRISK project led by CIAT is currently enhancing national Meteorological Service Capacities using CSRD's tools and approaches, including forecast automation and RClimTool.
- Following the Ethiopia experience, we are working with the Government of Angola, jointly with The World Bank, through the GFDRR (Global Facility for Disaster Reduction and Recovery), to design a project that implements a version of AClimate in Angola for forecast-based financing and risk reduction for agriculture.

Conclusion

By producing this corpus of scientific research, and working alongside local stakeholders to translate that research into decision-making tools, we hope that we have demonstrated two key principles.

First, we hope that our work has established the importance of user-centricity. Time and again, we have proven that putting user needs and demands first has allowed for the creation of usable, sustainable, and scalable climate service solutions. User centricity was the key to creating an online climate services platform in Colombia (and now in Ethiopia!) that serves both very technical climate modelers and over 500,000 farmers. It was the key for producing more accurate precipitation forecasts to help Central American subsistence farmers in Honduras and Guatemala time their planting seasons with the region's two rainy seasons. And we are sure that it will be the key to ensuring Mexican maize farmers in Chiapas receive helpful and timely SMS agro-climatic forecasts that can help them improve their yields.

Our user-centric, four-step approach can be applied on a very high level (e.g. in deciding which lighthouse projects to pursue in Colombia), or on a very micro level (e.g. in deciding which indicators to include in the AClimateColombia platform). Moreover, as science is disseminated, this can change the demand for and potential of new research. This iterative, looping nature means that scientists will need to continue to consult and collaborate with users/stakeholders to ensure useful end products. In the end, this co-production of climate services is destined to be more sustainable, scalable, and successful.

Second, we hope that our work has validated the importance of Climate Services for Resilient Development. The demonstrated success of CSRD activities within agriculture can hopefully act as a beacon for other sectors to emulate, not only in Colombia and Latin America, but around the world.

Annexes

Acronyms

ANACAFE	National Coffee Association (Guatemala)
ANN	Artificial Neural Network
BEM	dataset of maize and wheat crop yield and farming practices in Mexico
CAC	Central American Agricultural Council
CCA	Canonical Correlation Analysis
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CDRO	Cooperation for Rural Development in Western Guatemala
CENAOS	Center of Atmospheric and Oceanographic Studies (Honduras)
CENICAFE	National Center of Coffee Research (Colombia)
CGIAR	Global research partnership for a food-secure future
CHIRPS	"Climate Hazards Group InfraRed Precipitation with Station," a precipitation dataset based on satellite imagery, produced by the University of California, Santa Barbara
CIAT	International Center for Tropical Agriculture
CIIFEN	International Center for Research on the El Niño Phenomenon (Ecuador)
CIMMYT	International Maize and Wheat Improvement Center
CNN	Convolutional Neural Network, a form of visual deep learning architecture
COF	Climate Outlook Forum
COPECO	Permanent Commission of Contingencies (Honduras)
CPT	Climate Predictability Tool, a CCA forecasting tool developed by Columbia University
CRRH	Regional Committee for Water Resources (Costa Rica)
CSRD	Climate Services for Resilient Development
DMC	The Meteorological Directive of Chile
DSSAT	Decision Support System for Agrotechnology Transfer, a software program with crop simulation models for over 42 crops. With CSRD, we used the maize yield simulation model
EIAR	Ethiopian Institute of Agricultural Research
EOF	Empirical Orthogonal Function
ERSST	NOAA's Extended Reconstructed Sea Surface Temperature Dataset
FAO	Food and Agriculture Organization of the United Nations
FEDEARROZ	National Rice Growers Association (Colombia)
FEDECAFE	National Coffee Growers Association (Colombia)

FENALCE	National Cereal and Legume Growers Association (Colombia)
GCM	General Circulation Model
GFDRR	Global Facility for Disaster Reduction and Recovery
GloSea5	UK Met Office Global Seasonal Forecasting System version 5
IHCAFE	Honduran Institute of Coffee
IDEAM	Institute of Hydrology, Meteorology and Environmental Studies (Colombia)
INIFAP	National Institute for Agriculture and Forestry Research (Mexico)
INSIVUMEH	National Institute of Seismology, Volcanology, Meteorology and Hydrology (Guatemala)
IRI	International Research Institute for Climate and Society at Columbia University
LTAC	Local Technical Agro-climatic Committee
MAG	Ministry of Agriculture and Livestock (El Salvador)
MAGA	Ministry of Agriculture and Livestock (Guatemala)
MARN	Ministry of Environment and Natural Resources (El Salvador)
MasAgro	"Modernización de agricultura sostenible," or Sustainable Modernization of Traditional Agriculture project, led by CIMMYT
MFA	Multi-Factor Analysis
MSD	Mid-summer drought, a seasonal phenomenon in Central America
MTA	"Mesa Técnica Agricultural" or Agro-climatic Roundtable
NCEP CFSv2	US National Center for Environmental Prediction's (NCEP) Climate Forecast System version 2 - which produces 9-month (and beyond) forecast
NOAA	National Oceanic and Atmospheric Administration (United States)
ORYZAv3 or **ORYZA2000**	Rice crop yield simulation models
OSILAC	Observatory for the Information Society in Latin America and the Caribbean
PCA	Principal Component Analysis
RClimTool	Integrated R package that combines the Climdex and Climatol packages
R-CPT	Columbia University's Climate Predictability Tool (CPT), implemented as an R package
SAG	Secretariat of Agriculture and Livestock (Honduras)
SENAMHI	National Meteorology and Hydrology Service of Peru
SICA	Central American Integration System (based in El Salvador)
SMN	National Meteorological Service - known as SMN in both Mexico and Honduras
SST	Sea Surface Temperature
USAID	United States Agency for International Development
WP1, WP2, WP3	Work Packages 1/2/3, within the Colombian CSRD lighthouse projects

Country stakeholders

During the course of the CSRD work, CIAT collaborated with each of these key stakeholders:

COUNTRY	STAKEHOLDERS
Chile	DMC, Ministry of Agriculture
Colombia	CENICAFE, FEDEARROZ, FEDECAFE, FENALCE, IDEAM, Ministry of Agriculture and Rural Development
Costa Rica	CRRH (regional), CAC (regional)
Ecuador	CIIFEN (regional)
El Salvador	MAG, MARN, SICA (regional)
Guatemala	INSIVUMEH, MAGA, ANACAFE, C-DRO
Honduras	IHCAFE, CENAOS-COPECO, SAG
Mexico	CIMMYT / MasAgro, INIFAP, SMN
Peru	SENAMHI, Ministry of Agriculture and Irrigation
Global	CCAFS, IRI

Summary of projects and activities

	PROJECTS
Colombia	Lighthouse projects: • WP1. Assessment and improvement of climate forecasting methods and skills • WP2. Agro-climatic forecasting interface (online portal) • WP3. Identification of resilient coffee farms and coffee adaptation plans Other: • Seasonal precipitation and yield forecasts for rice in the Orinoquia region • Neural networks detection of best sea surface temperature predictor area for forecasting regional precipitation
Guatemala	Technical assistance for LTACs Dry Corridor's needs assessment Assessment of seasonal forecast skill
Honduras	Seasonal precipitation forecasts, with CHIRPS precipitation data and optimized predictor areas. Technical exchange with COPECO-CENAOS to enhance their capacity for co-production of climate services
Mexico	Identification of key improvements for maize climate services Identification of pilot regions for improved agro-climatic services, to be distributed by MasAgro networks, SMS, and mobile App Enhancing the country's capacity on climate services through technical exchange with SMN, and establishment of the Chiapas LTAC
Peru	Technical capacity training with the national meteorological office Central America
Central America	Technical exchange and support to the Climate Outlook Forum towards the establishment of a regional agro-climatic committee

Timeline of events

	2015
Oct	• Preliminary "launch" of CSRD in Colombia, in conjunction with the Inter-American Development Bank (IADB), USAID, and both public and private sector partners of the CSRD working group • Meeting with multi-sector stakeholders to identify and prioritize potential investment opportunities for climate services • Submission of Climate Report (White Paper), identifying eight priority investment options for CSRD, each with estimated costs
Nov	Identified the three Colombian lighthouse "work projects," through additional stakeholder consultations and feasibility analysis
	2016
May	First Progress Report submitted
Jun	Meet with FEDEARROZ and FENALCE to define the study sites for WP1 and WP2
Aug	• WP3: 1st Diagnostic workshop with farmers and local extension agents in Ibargue, Tolima, to identify their climatic and agro-climatic information needs, assess their understanding of the key underlying concepts, and test potential visualization formats • Second Progress Report submitted
Oct	Diagnostic workshops with farmers and local extension agents in the other focus sites: Lorica, Córdoba; Yopal, Casanare; Espinal, Tolima; Cereté, Córdoba; La Unión, Valle de Cauca
	2017
Jan	Third Progress Report submitted
Feb	Famine and Early Warning System (FEWS) Regional Technical Exchange Workshop: "Training Course on Agro-climatological Analysis Using FEWS NET Gridded Climate Data and Software Tools" Attended by ~20 participants from throughout Central America and the Andean region. Hosted by CIAT
Mar	• Training on the automated Climate Prediction Tool, attended by IDEAM meteorologists, agro-climatologists from FEDEARROZ and FENALCE • Reviewed and received feedback on the statistical forecasts generated by CPT. Afterwards, IDEAM implemented CPT-Linux for its operative seasonal forecast, thus reducing the execution time for its processes AND increasing possible model performance (more configurations)
Apr-Oct	Second and third technical knowledge exchange with IDEAM and farmers organizations
Jul	Climate Forecasting Workshop in Paraguay, organized by IRI Columbia University (https://www.youtube.com/watch?v=xyyhkPM8hBA)
Nov	• Two-day workshop during the 17th Forum of Climate Perspectives for Western Southern America (COF-XVII) in Chile. The workshop was attended by participants from Bolivia, Chile, Colombia, Ecuador, Peru, Venezuela. CIAT had 2 time slots (6.5 hours total) over the two days, to present on "CPT versión para lenguaje R" • Training on the use of ORYZA v3.0 for generating agro-climatic forecasts, attended by 4 FEDEARROZ representatives • Training on the use of DSSAT for generating agro-climatic forecasts, attended by 2 agro-climatologists from FENALCE • Technical exchange and meetings with CIIFEN in Guayaquil, Ecuador
Dec	Climate Forum Bogotá
	2018
Mar	Training workshop on climate and agro-climatic modeling. 6-12 March. Peru
May-Jun	Participated in the Climandes meeting, presented a poster on CSRD and carried out a comprehensive diagnostic for collaboration opportunities with SENAMHI in Peru
Jul	Workshop at the Mexican SMN in Mexico City. In collaboration with the IRI Columbia University, we trained the SMN in the generation of seasonal forecasts
Oct	• Workshop in Lima with SENAMHI and FAO-Peru, on modeling tools that would aid in the creation of an MTA in Peru • Third Scientific Forum on Climate Change - in Lima, Peru
Nov	• Regional Climate Forum of Central America in Panama City • CIAT's CSRD team trained regional meteorological offices on the CPT and how to automate it in R
Dec	• First Central American and Caribbean Workshop on Subseasonal-to-Seasonal Predictability of the Mid-Summer Drought (MSD) in Antigua, Guatemala • Introduced new MSD prediction tools and models to the regional meteorological service community. Participants were encouraged to design develop and present a project using the techniques taught during the workshops. Workshop content can be found here: https://msdworkshop.iri.columbia.edu/course/
	2019
Mar	CPT Training with the Mexican SMN
Apr	• Training on how to connect probabilistic climate forecasts to crop models - hosted in collaboration with the Central American Integration System (SICA) • Central American Climate Outlook Forum. We introduced participants to crop modeling and resampling of forecasts
Jun	NextGen forecasts and CPT training with the Mexican SMN
Jul	As part of the COF in San José, Costa Rica: CIAT hosted a workshop - Topics included: Automation and optimization of predictive domain using CPT, Resampling methodology (from monthly to daily), Basic concepts in modeling and fundamentals of CROWPWAT. In attendance were the Honduran COPECO team and some Central American meteorological teams
Oct	• Crop modeling training workshop with 25 experts from SENAMHI, FAO-Peru, and the Peruvian Ministry of Agriculture in Lima, Peru. 14-18 October • 3rd International Forum on Climate Change: Impact on Peruvian Agriculture, hosted by the Peruvian Ministry of Agriculture
Nov	Planning workshop to Strengthen Climate Services in Mesoamerica and creation of the Chiapas LTAC, in Tuxtla Gutiérrez, Chiapas

Other project resources / links

Pronósticos AClimateColombia online platform:
http://pronosticos.aclimatecolombia.org

Previous CSRD project reports:

- Original assessment of potential Colombia CSRD investment areas (October 2015)
- List of potential lighthouse projects (April 2016)
- First Progress Report (August 2016)
- Second Progress Report (January 2017)
- Third Progress Report (July 2017)

Published papers:

- "Predictability of seasonal precipitation across major crop growing areas in Colombia" (2018), *Climate Services*, 36-47, https://doi.org/10.1016/j.cliser.2018.09.001.
- "Improving seasonal precipitation forecast for agriculture in the Orinoquia Region of Colombia" (2019), *Weather and Forecasting*, https://doi.org/10.1175/WAF-D-19-0122.1.
- "Pronósticos AClimateColombia: A system for the sustainable provision of agro-climatic information for climate risk reduction in Colombia" (2019), *Computers and Electronics in Agriculture*, in revision.

Our partners

Colombian lighthouse:

El campo es de todos Minagricultura

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FEDEARROZ FEDERACIÓN NACIONAL DE ARROCEROS

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CIMMYT International Maize and Wheat Improvement Center

IRI International Research Institute for Climate and Society EARTH INSTITUTE | COLUMBIA UNIVERSITY

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Bioversity International is the operating name of the International Plant Genetic Resources Institute (IPGRI)

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