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The International Research Institute for Climate & Society: why, what and how

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Abstract

A climate-informed and climate-ready world is possible. Large investments are being made toward adaptation and resilience to climate change, but many of those investments are separated from the more immediate climate-related vulnerabilities and opportunities that society faces. Information is increasingly available that could be used to guide action; however, information alone is not sufficient. Research at the International Research Institute for Climate and Society (IRI) since 1996 has led to the identification of the several guiding principles to scope and address climate-related challenges to decision- and policy-makers at local-to-regional scale. These include climate-related information, such as assessment of the main vulnerabilities to climate variability and change in countries or regions, and the provision of climate information, products and tools to support decisions, including financial tools that are appropriate to the climate-related risk and that can mediate residual risk. The guiding principles also include identifying the technologies and practices that optimize results in coming years, demonstration of the usefulness of climate information to support climate-related decisions, training and capacity building, and partnerships for research and implementation. This essay introduces the evolution of the IRI and its work that is then elaborated through a series of articles that constitute a special issue of Earth Perspectives: Transdisciplinarity Enabled. The collection of articles provides insight into the science and process that lead to better climate-informed choices. Part of the collection of articles in the special issue covers specific stories of local-to-regional engagement with partners to address climate-related problems. Other articles represent how we do what we do, in particular highlighting the research, the climate forecast effort, and the IRI Data Library. Finally, there are two papers offered from partners that have long-time engagement with the IRI.

Keywords: Climate adaptation; Climate risk management; Climate variability and change; Resilience; Sustainable development; International decision support

Problem: real-time adaptation

Society is impacted by climate on all timescales. However, efforts to mediate those impacts are mostly devoted to climate change adaptation. International funding for climate-related programs and assistance has focused on climate change adaptation with over $4 billion dedicated to date. The total sum of adaptation spending is orders of magnitude greater, and harder to calculate, when factoring in national expenditures for developing and developed countries, as well as private sector investments. A 2010 study (Egan 2005) of 125 developing countries documented over $10 billion programmed in current adaptation projects, admitting that there are many projects for which financial data are not available. The future will be much costlier: the United Nations Framework Convention on Climate Change (UNFCCC 2008) estimates that by 2030, between $60 and $182 billion will be needed a year for adaptation globally – large numbers with a very large range of uncertainty that rival the number for global development assistance which totals about $130 billion a year (OECD 2012).

These are just the dollars invested in 'discrete adaptation,' or climate change- focused adaptation (McGray 2007). The costs of year-to-year climate variability are generally unaccounted for in these exercises, including loss and damages from hydro-meteorological disasters, the costs of humanitarian response to extreme events, or investments in the resiliency and productivity of climate-sensitive sectors such as transportation, public

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health, and food security. For example, it has been estimated that sizeable El Niño events cost about $10-50B dollars in losses (Sponberg 1999). The drought experienced in Texas in 2010–2012 resulted in about $8B dollars in agricultural and livestock losses alone (Combs 2012). Additionally, extreme weather events, which are often related to large-scale interannual climate variability, such as land-falling tropical cyclones, flooding events and heat waves, lead to substantial human and economic impacts that can exceed a hundred billion U.S. dollars (U.S.-falling Hurricanes Katrina and Sandy) or cause the untimely deaths of tens of thousands of people (2003 European heat wave). These examples of devastating hydro-meteorological impacts on economies, infrastructure, and human life from year-to-year variability involve the same types of climate events that are the focus of those who work on and invest in climate change adaptation. The Special Report on Extremes (IPCC 2012) concludes with high confidence that the dominant factor behind trends in many of these impacts is related to increased exposure of people and economic assets, which means that the impacts are likely to increase in coming years even in the absence of climate change.

It is clear that what is needed is better climate adaptation – at all timescales, from weather, to interannual variability, to decadal variability, to trends associated with manmade climate change. For example, the numbers cited above for economic losses during El Niño events are consistent with losses incurred in all years, El Niño or not; however, there is greater ability to predict and prepare for the regional climate impacts during El Niño events (Goddard & Dilley 2005). That society has been negatively impacted by climate variability is clear from historical records (e.g. (Davis 2001; Egan 2005)). As human population numbers increase, in some cases reducing options for geographic mobility in the face of adverse climate events, and in others just demanding more of the environmental resources, societies will be increasingly vulnerable to climate variability. Additionally, as climate change trends continue their slow monotonic progression, they can exacerbate the adverse impacts of climate and weather variability such as heat waves and drought severity, but also precipitation intensity and thus risk of flooding.

International policy structures and historical legacy may best explain why climate change adaptation, humanitarian relief, and sustainable development programs often take very different approaches to climate science. Much of the adaptation effort to date has focused on climate scenarios expected 50 to 100 years into the future. However, this information was created to help understand the long-term consequences of greenhouse gas emissions, not to provide the temporally- and spatially-specific information that is needed for planning and management. Long-term climate trends have a foreseeable direct impact on glacial melt and sea level rise, and for these a general sense of how much temperatures are likely to rise is helpful. The problem is that for a large percentage of vulnerable populations this information is not very useful. They are impacted by real climate events now and need to better adapt and manage the entirety of climate now. As we have seen from the last couple years of extreme weather and climate in the United States, population vulnerability is not synonymous with poverty, though that can certainly make things worse. What developing and developed countries both need is the information and the intellectual and financial capacity of society to implement adaptation measures to today's climate variability, not just the change of the mean climate 50–100 years from now. Most adaptation measures that aim to make individuals, communities, or natural resources more resilient to climate change and variability cannot provide a complete safeguard because this becomes prohibitively expensive. However, it may be possible to better anticipate imminent climate risks and develop risk management options, including financial tools that can at least buffer against remaining risk.

The International Research Institute for Climate and Society (IRI) has been working on this challenge since the late 1990s. The IRI strives to develop the best possible climate information for use in real-world decision-making settings based on past observations, current monitoring, and future outlooks. It has been our experience that most decision makers, resource managers, and societies in general are not sufficiently well adapted to the current year-to-year climate. Considerable economic benefit could be realized, lives saved, and sustainable development supported by explicit consideration and management of the risks and opportunities of climate variability. Of course, climate change is a reality and it is impacting regional climate, but climate change is being realized one year at a time. Therefore the IRI's research, services, and training target better adaptation to sub-seasonal to inter-decadal climate, of which manmade climate change is some contribution. Such an approach can incrementally build adaptation to future climate change for many, though admittedly not all, climate-impacted sectors of society.

History: our start as an institutionally-funded cooperative agreement with NOAA

The concept of an IRI grew out of the TOGA (Tropical Ocean Global Atmosphere) program of the 1980s (NRC 1996), which had greatly increased the understanding of the El Niño-Southern Oscillation (ENSO) phenomenon. Research conducted under TOGA led to the first successful attempts to predict this ocean–atmosphere phenomenon that results in large-scale warming of the equatorial Pacific Ocean sea surface temperatures about every 2–7 years

(Cane et al. 1986). It was recognized that many climate anomalies around the world, many in developing countries of the tropics, were associated with El Niño events. The idea was that if we could predict El Niño, we could predict its climate impacts on many of these developing countries and provide information that could help societies better cope with the adverse conditions.

Beginning in 1994, a NOAA pilot project for the IRI was started (back then named International Research Institute for Climate Prediction) with climate prediction efforts at Scripps Institution of Oceanography at the University of California San Diego, and an educational training program on climate variability and societal/sectorial impacts, primarily focused on ENSO, at the Lamont-Doherty Earth Observatory (LDEO) of Columbia University. In 1996, the IRI was funded as a cooperative agreement with NOAA (Vaughan et al. 2014) to form a research institute that would house climate scientists plus sectorial and social scientists to develop and disseminate climate information, as well as conduct research on the range of contextual issues that would better define the climate-related problems faced in specific regions and how the current state of the science could address them within specific social and institutional settings. When the IRI was formally established in 1996, the forecast effort was still located at Scripps, and the rest of the IRI was at LDEO. A decision was made in 1999 to consolidate campuses. Now in 2014, the IRI staff numbers about 55 including research, technical, and administrative staff. About half of the scientists focus on climate issues, and the other half work in areas impacted by climate such as agriculture, water, health, disasters, ecosystems, and economics.

The NOAA Cooperative Agreement, which was in place from 1996–2011, and then ramped down through 2013, funded approximately 90% of IRI's expenses. This large institutional grant that covered over 15 years was essential to building what the IRI has become (Vaughan et al. 2014). It enabled considerable flexibility in exploring projects with regional partners, and building long-term relationships. Such long-term engagement is critical to building the trust necessary to affect change, whether it is change in technology or change of perspective.

The IRI has recently transitioned into a new financial phase. Rather than receiving 'institutional' support from a single national agency, the IRI now works with funding partners from a range of national agencies, as well as development and humanitarian agencies, NGOs, national ministries, and foundations. However, the importance of the foundation laid during the period of the NOAA Cooperative Agreement cannot be overstated in the benefits to the IRI's scientific progress, as well as in building strong partnerships and collaborative projects. Long-term stable funding, and the accomplishments it yielded, also helped enable the IRI to connect its work to a range of new funding partners. The value in moving to this new funding model is that the IRI is now better connected to a range of perspectives, leading to increased opportunities to be relevant to the climate-related challenges at the local-to-regional, and even international, level.

This is particularly critical to the IRI's goal of supporting climate adaptation across timescales. The mission of the IRI has been, and remains, squarely to enhance society's capability to understand, anticipate, and manage climate impacts in order to improve human welfare and the environment, especially in developing countries. The IRI conducts this mission through strategic and applied research, education, capacity building, and by providing forecasts and information products with an emphasis on practical and verifiable utility and partnership. The IRI has been true to this mission for over 10 years.

Establishment of the IRI was motivated by the advent of real-time seasonal forecasts and by the growing public awareness of climate via climate change. However, the IRI has also played a considerable role in shaping the landscape that has developed in the last 10–15 years. One example is the Climate Services Partnership network, which is a platform for knowledge sharing and collaboration to advance climate service capabilities worldwide. Another prominent example is the Climate Change, Agriculture and Food Security (CCAFS) project of the Consultative Group on International Agricultural Research (CGIAR), which includes a theme on 'Adaptation Through Managing Climate Risk' (Hansen et al. 2014).

Approach: science-based climate services

Science is at the core of all of the IRI's work. Climate science is central, but its relevance is tied to the interdisciplinary research, which both motivates and incorporates the climate research. The scientists at the IRI come from a range of backgrounds. Just over half the researchers are climate scientists; the others specialize in the connection of climate to areas such as health, water, agriculture, financial tools, disasters, ecosystems, anthropology and decision-making. IRI scientists work within and across disciplines.

The vast majority our climate and sectorial research priorities are often defined through a problem-driven, real-world context. Rather than ask, 'what is needed' and answer back with 'what is provided', experience has shown that a more effective and lasting approach is to is to analyse the target system context to determine the problem faced and the relative role of the climate (Hansen et al. 2006; Meinke et al. 2006; Thomson et al. 2006; Greene et al. 2012; Hammer 2000a). Often solutions within these types of demonstration projects start with existing, but under-utilized, information that can bring better awareness of opportunities and risk mitigation – whether it is an analysis of past risks, monitoring present conditions, or forecasting future seasons or years. In many cases, this process identifies gaps in existing information or in the scientific understanding that is needed to address the issue at hand. Research may be able to build on initial successes through possible improvements in the climate information and the decision support system. This route towards iterative development of science-based, action-oriented information is grounded in real world settings. It involves partners at the local, national, regional, and international level to address their climate issues.

Strategic research of climate and climate-related impacts and decisions, described above, provides the foundation but is not the entirety of the IRI's work. The other two main areas are service and training. All three areas are inter-related. Service includes applied research and development of technical products that are used broadly by our partners, such as the IRI Data Library (Blumenthal et al. 2014) and the IRI Net Assessment seasonal climate forecasts (Barnston and Tippett 2014). Service also includes technology transfer to partners, such as National Meteorological Services or Regional Climate Centers, to tailor and deliver their own climate information. Service includes implementation of the relevant science and technology through partner collaboration on integrated decision support systems (IDSSs). The demand to continually improve these products and decision support systems drives a considerable amount of the IRI's disciplinary and inter-disciplinary research.

Training and capacity building are important both to enable scientific collaboration with partners—through understanding the available science or tools that could address the problem(s) at hand—as well as to build the technical capacity of institutions in developing countries to take over and lead in the future. Simply providing products and tools or publishing papers is not enough to affect real operational change. Every year, the IRI holds numerous training workshops around the world and at the IRI, on the Lamont Campus of Columbia University, to train scientists and decision makers, for example, on how to generate seasonal forecasts for their countries based on state-of-the-art techniques and how to convert those forecasts into usable information such as rainfall characteristics, crop yields, public health risks, and river flow estimates (Mantilla et al. 2014). The participants come from national meteorological agencies, regional climate centers, national ministries, and universities. For example, the IRI has led several two-week Summer Institute programs on Climate Information for Public Health, in partnership with other Columbia University Earth Institute units. The Summer Institutes train public-health professionals from the World Health Organization and national health ministries on how to understand and utilize climate information to make planning decisions for malaria, dengue, malaria, and other climate-sensitive diseases (Cibrelus & Mantilla 2010). At the same time, involvement of IRI scientists in training and capacity building helps identify important elements of the problem like the correct entry points for influencing policy or decisions, or how to build effectively on existing approaches, or where the current scientific understanding and predictive modeling is lacking. All of our scientists are involved in these three areas of strategic research, service, and training, though the balance naturally varies among individuals, and often over time for a particular individual.

Climate services involve all three elements described above: research, service, and training. Climate risk management is one critical area of climate services, especially in developing countries. It is a term the IRI began using around 2000 to refer to these three elements when implemented with partners in specific regional and/or sectorial settings. Climate risk management is a process that informs real-world decision-making through the application of climate knowledge and information. The IRI's approach consists of several guiding principles:

- *Identify main vulnerabilities to climate variability and change in countries or regions.*

Every country is susceptible to droughts, floods, heat waves, etc., but the ability to mitigate adverse effects will depend on the livelihoods of local communities and the local-to-national technical capacity to anticipate and manage climate impacts.

- *Ensure institutional arrangements and policies exist to support action.*

Where such policies or institutions do not exist, that foundation will need to be developed before a wide-scale change in the approach to risk management or sustainable development will be possible. Localized pilot projects to develop decision support systems that integrate target system analysis, climate, environment, and socio-economic factors are still possible (Hammer 2000b). Such projects can do a lot to motivate policies or national to regional planning efforts. However, pilot projects will have little enduring impact if they are not consistent with, or do not help develop, the policies that can support the pathway from knowledge to action. Over the years, the IRI has contributed to the evolution of adaptation policy and practice at organizations such as the International Federation of Red Cross/Red Crescent World Health Organization, Oxfam America, the US Agency for International Development, the UK

Department for International Development, the World Bank, and Regional Development Banks, and is frequently in collaboration with national meteorological services and other public agencies. At national scales in countries such as Uruguay, Ethiopia, and Indonesia, IRI scientists have worked with policy makers, public officials, donors, and civil society organizations to help create a policy environment that enables action.

- *Provide climate information, products and tools to support decisions.*

This includes the availability of observational data about past climate, monitoring capability of current climate and environmental conditions, and demonstrated skill in predicting future climate particularly through seasonal climate forecasts, though potentially longer time-scale climate outlooks also. (See also (Barnston and Tippett 2014; Ceccato et al. 2014; Dinku et al. 2014; Robertson et al. 2014)) Where possible, the ability of national and regional agencies to deliver these services should be developed and supported. In an ongoing collaboration with Ethiopia, for example, IRI scientists worked with the National Meteorological Agency (NMA) to help them quality control and merge their station data with satellite products to deliver a 30-year history of monthly rainfall, gridded at 10 km across the entire country. Additionally, they are now able to deliver real-time monitoring of 10-day rainfall and analyze that in the context of recent years, as well as merge this information with other environmental data to build sector-specific map rooms (Figure 1, (Dinku et al. 2014)).

- *Identify technologies and practices that optimize results in coming years, based on past performance.*

In many cases, seasonal forecasts tailored for specific sectors can provide guidance within the context of the current conditions. In the agricultural sector, forecasts can help food-security agencies determine if, when, and where to pre-position food aid in anticipation of a crisis. Some crop failures may not be avoidable, but every famine is. In the water sector, engineers using good quality climate information can optimize the design of new dams; for existing ones, they can use the information to

Figure 1 NMA Website. Screen shot of the web page of Ethiopia's National Meteorological Agency (NMA). The base of the arrows indicate links to map rooms provided by NMA using the IRI's Data Library and Map Room technology to display historical rainfall and real-time monitoring of precipitation, and also sector-specific map rooms. (see (Dinku et al. 2014; Robertson et al. 2014)).

make better decisions on how to allocate the water, or better quantify the chances of getting extremely low or high reservoir levels (e.g. (Robertson et al. 2014; Block & Goddard 2012)). A recent study of economic benefit from hydropower conditioned on differing levels of confidence in precipitation, and thus inflow, forecasts indicated that requiring very high confidence (95%) was too conservative, and that a slightly lower confidence (80%) yielded greater benefits on average, while maintaining reliability of power generation (Table 1; (Block & Goddard 2012)).

- *Demonstrate the potential usefulness of climate information to support climate-related decisions.*

Decision support systems will almost always include more factors than just climate. Demonstrations of their effectiveness, and in particular of the value of the climate information to the effectiveness, must be conducted collaboratively with the decision makers, as well as scientists, practitioners, and information providers. These are the 'real world' individuals and arrangements that enable implementation of climate-related risk management. To date, most of the IRI's evaluation work has been post-facto and largely qualitative, based on the perceived usefulness to the user or decision maker, but certainly based on examples where climate information has served as the basis for action. One example is the documented case of International Federation of Red Cross and Red Crescent (IFRC) appeal for emergency aid in 2008 ahead of the rainy season in West Africa (Braman et al. 2013). This was the first time ever that the IFRC sought financial assistance ahead of a disaster, in this case based on a probabilistic seasonal climate forecast from the regional climate outlook forum to which the IRI contributed. In particular, the IRI contributed an outlook indicating an enhanced risk of extreme seasonal rainfall. Another example is the Uruguayan Ministry of Agriculture asking parliament for emergency funds based on current monitoring of the vegetation and on soil water balances, and also based on a seasonal forecast showing a high likelihood for another deficient rainy season (Baethgen, personal communication). Going forward, the IRI will consider systematic evaluation of regional climate services as part of the initial project design.

- *Develop, if necessary, financial tools that are appropriate to the climate-related risk and that can mediate residual risk.*

Even the best quality climate information will still show a range of possible outcomes and thus risk. Financial tools such as climate or weather index insurance can address that residual risk. Well-designed financial tools can cover catastrophic losses, and perhaps more importantly allow individuals and businesses to take productive risks in normal and good years. For example, index insurance can enable rain-fed farmers to take loans for improved seeds and fertilizers without worrying about going into debt in the event of a drought, and

Table 1 Hydropower benefits by forecast technique using various probabilities of exceedance and threshold of 200 GWh/mo

Forecast Technique	Mean benefits [$M/dec]	Mean losses [$M/dec (*f*)]	Dependability [%]	Superior decadal [%]	Benefit cases annual [%]
Perfect Forecast	3,350	—	100%		
prob = 80%					
Statistical	2,740	25 (10%)	100%	18	23
Dynamical	2,610	100 (66%)	100%	0	15
Multi-model	2,780	5 (2%)	100%	82	35
No-Forecast	2,610	—	> 99%	0	27
prob = 95%					
Statistical	2,500	35 (23%)	100%	8	20
Dynamical	2,500	237 (23%)	100%	0	0
Multi-model	2,500	48 (5%)	100%	88	44
No-Forecast	2,440	—	100%	4	36

Table shows economic benefit over 10-year time periods of reservoir management for a planned reservoir in the Blue Nile Basin of Ethiopia, based on assumptions of the upcoming seasonal climate predicted by a statistical model, a dynamical model, a combination of statistical and dynamical models, and No-Forecast, which assumes that every year behaves the same. The probability is the confidence level from the prediction in formation in a given year that the precipitation, and thus inflow, will exceed a certain value. That value then triggers the release decisions and determines how much energy can be generated.
Notation: "Prob" = precipitation probability of exceedance; "**$**M/dec" = million US dollars per decadal simulation; "f " frequency of occurrence in%; "Dependability" = percent of months above threshold. "Mean losses" represents average of simulations for which loss occurred, defined as years when no-forecast benefits are greater than given forecast technique benefits. For "superior benefit" cases, quantities reflect percent of simulations for which that technique produced benefits greater than other techniques. "Perfect forecast" uses observed precipitation; "no-forecast" uses climatological precipitation. See (Block & Goddard 2012) for details on hydrological models and climate forecasts used to generate the table.

at the same time can protect lenders who issue those loans (Dinku et al. 2014; Osgood et al. 2011).

- *Look for training and capacity building opportunities.*

Teaching and learning opportunities are important throughout the process and across the groups involved. As described above, two-way capacity building plays an important role in managing climate-related risks. It is important that all involved understand the factors involved in climate and its prediction, that those responsible for delivery of climate information have the access to, and working knowledge of, technical tools that can be used to create or apply information, and that participants share best practices through successes and lessons learned (Mantilla et al. 2014).

- *Partnerships for research and implementation*

Given the richness of the international climate community and the complexity of the decision networks in any particular setting, IRI has benefited greatly from collaborations with dozens of institutions and agencies on collaborative research and implementation of the science for society. Within the United States, the IRI has benefited greatly from NOAA products and collaboration. This includes collaboration on prediction methodology, climate diagnostics studies, and use of state-of-the-art models with the Climate Prediction Center of the National Weather Service, the Geophysical Fluid Dynamics Laboratory, and the Earth Systems Research Laboratory. The IRI works with many international national-level climate services and ministries, such as those in Brazil (Sun et al. 2006) (Hastenrath et al. 2009), Chile (Verbist et al. 2008), Ethiopia (Dinku et al. 2013) (Dinku et al. 2011) (Korecha & Barnston 2007), India (Mohanty et al. 2013), Indonesia (Robertson et al. 2009), Kenya (Omumbo et al. 2011) (Chidzambwa & Mason 2008), Madagascar (Cibrelus et al. 2010), Philippines (Lyon et al. 2006) (Moron et al. 2009), Senegal (Martínez et al. 2012) (Ndiaye et al. 2013) (ANACIM, WFP, IRI 2013), South Africa (Landman 2014), Tanzania (TMA 2013), Uruguay (Gimenez & Baethgen 2006) (Baethgen & Gimenez 2009), and others. The IRI also works with regional climate centers that can be important hubs for information development and dissemination on the regional scale, and which also organize trainings for countries within the region. Examples of regional centers with which IRI is involved are ACMAD[a], Agrhymet[b], CIIFEN[c], CCROM[d], CRRH[e], APCN[f], ICPAC[g], and CIMH[h]. In addition, the IRI works internationally with the World Meteorological Organization on subseasonal-to-interannual climate, with the World Health Organization on climate and health, with the International Federation of Red Cross and Red Crescent on disasters, and with several programs of the Consultative Group on International Agricultural Research on climate information and agricultural and ecological systems.

The guiding principles elaborated above factor into nearly all of the IRI's work with regional or national partners. Within these projects, and with these principles in mind, several recurring themes arise consistently. These themes, or information areas, have proved themselves particularly important aspects of either initiating and/or implementing meaningful climate risk management efforts and climate services, more broadly. These are briefly discussed below.

Climate change and variability across timescales

One of the most important areas of evolution for IRI's work has been to broaden the timescales over which we research and develop climate information. The foundation of our climate information is the seasonal-to-interannual variability and predictions. The IRI Net Assessment forecasts (Barnston and Tippett 2014; Mason et al. 1998) were the first to use a combination of climate model predictions based on their past performance to provide probabilistic seasonal forecasts. Considerable effort has been invested over the years to create seasonal forecasts that are reliable as well as sharp. However, the problems confronted by our research and decision-making partners have urged us to also address near-term climate change and weather within climate.

The climate varies across a range of temporal and spatial scales from local daily weather to global climate change in a manner that appears seamless; even specific climate phenomena or certain processes may act on specific time and space scales. Climate change, or more specifically manmade climate change, refers to the slow changes in the mean climate and the statistical characteristics of the mean climate that are due to increasing greenhouse gases and other pollutants, as well as changes in land use and land cover. Climate variability is due to natural interactions between the non-human components of the Earth's climate system, such as ocean–atmosphere-land. Most of the focus of adaptation efforts, and of the general public, is on manmade climate change. In some circles, 'climate' has become synonymous with 'climate change.' However, for many parts of the world, and especially in the case of precipitation, climate change is a relatively small part of the climate we have experienced to date (Figure 2).

Our experience of climate change is necessarily a combination of variability and change. Because there are slow natural processes in the climate system, even 30–40 years may not be long enough to distinguish variability from trends. Even in places with relative large trends, the decadal-scale variability can be as large or larger over a span of 10 years compared to changes over 50–100 years (Figure 3). Nonetheless, when those signals combine in the

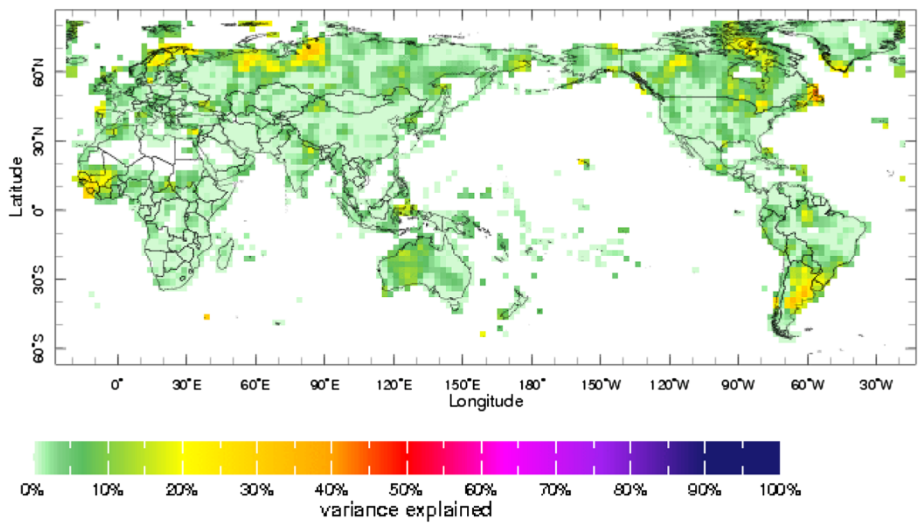

Figure 2 Variance of rainfall trends. Estimated percent of 'variance' of 20th century observed precipitation, taken from University of East Anglia's Climate Research Unit version 2p1 (UEA-CRU2p1: (Mitchell & Jones 2005)), annual mean, ascribed to non-linear trend. Data and maps available at IRI Time Scales map room available at: http://iridl.ldeo.columbia.edu/maproom/Global/Time_Scales/. The non-linear trend for each grid box is estimated by regressing the rainfall timeseries on a 'climate change index' that is estimated as the decadally-smoothed multi-model average of global mean temperature from the IPCC models used in the 4th Assessment Report (i.e. CMIP-3 models). Note that the observational dataset used on the Time Scales map room, may be updated over time.

same sense, it can be particularly devastating, particularly in the case of drought. Climate variability is evident at the global scale, and as a result society has been faced with statements such as, 'Climate change is accelerating,' during the 1980s when decadal-scale variability was in a warming phase consistent with global warming. Similarly, there have been statements since the late 1990s such as, 'Climate change has leveled off' as decadal variability has entered a cooling phase. As spatial scales become more localized variability becomes increasingly larger and constitutes a larger proportion of the climate one experiences relative to anthropogenic trends. Given that nearly all management decisions and even many planning decisions and adaptation investments, and associated evaluation, typically consider timescales much shorter than 30–40 years, and that these decisions and investments typically consider local-to-regional spatial scales, variability must be explicitly addressed in adaptation efforts as much as in climate risk management efforts.

Tools such as IRI's Time Scales Map Room (Figures 2, 3), have been extremely valuable to building understanding on the distinction between trends and variability, and also to help users or decision-makers consider what type of information should be considered for the timescales over which they are making decisions, investments, or evaluations.

Early warning/early action: the 'ready-set-go!' approach

Actors or agencies often have responsibilities at multiple space and/or time scales. In that case, it can be helpful to provide not only long-term outlooks of potential risk, but also to refine that information as time draws closer to the potential hazard and to put the risk in context of the current state. For example (Figure 4), a regional agency may be able to use a seasonal forecast to update contingency plans or alert associated local agencies ('Ready'). As time of a potential impact comes closer they can mobilize resources to the region, and at the same time, local actors may begin initial preparations ('Set'). Near to the time of the climate impact, actions can then be taken directly and appropriately ('Go!'), and greatly reduce the socio-economic impact on the local community and the cost of recovery. Early warning, response, and recovery from climate related hazards are studied as an integral management theme. One example where this has been put into action - in fact, the example that led to this framing – is the 2008 floods in West Africa and the actions of the regional hydro-meteorological services and the IFRC (Braman et al. 2013). A similar example is drawn from the health community where malaria outlook forums in southern Africa considered the current environmental conditions and susceptibility of the human populations, in combination with the seasonal precipitation forecasts (tailored to their threshold of interest), as the malaria early warning (Thomson et al. 2006). If a risk of epidemic appeared on the horizon it would trigger local action by health ministries and closer monitoring by the meteorological services. Similar efforts for locust early warning systems in West Africa (Ceccato et al. 2007) have also triggered action by the environmental ministries.

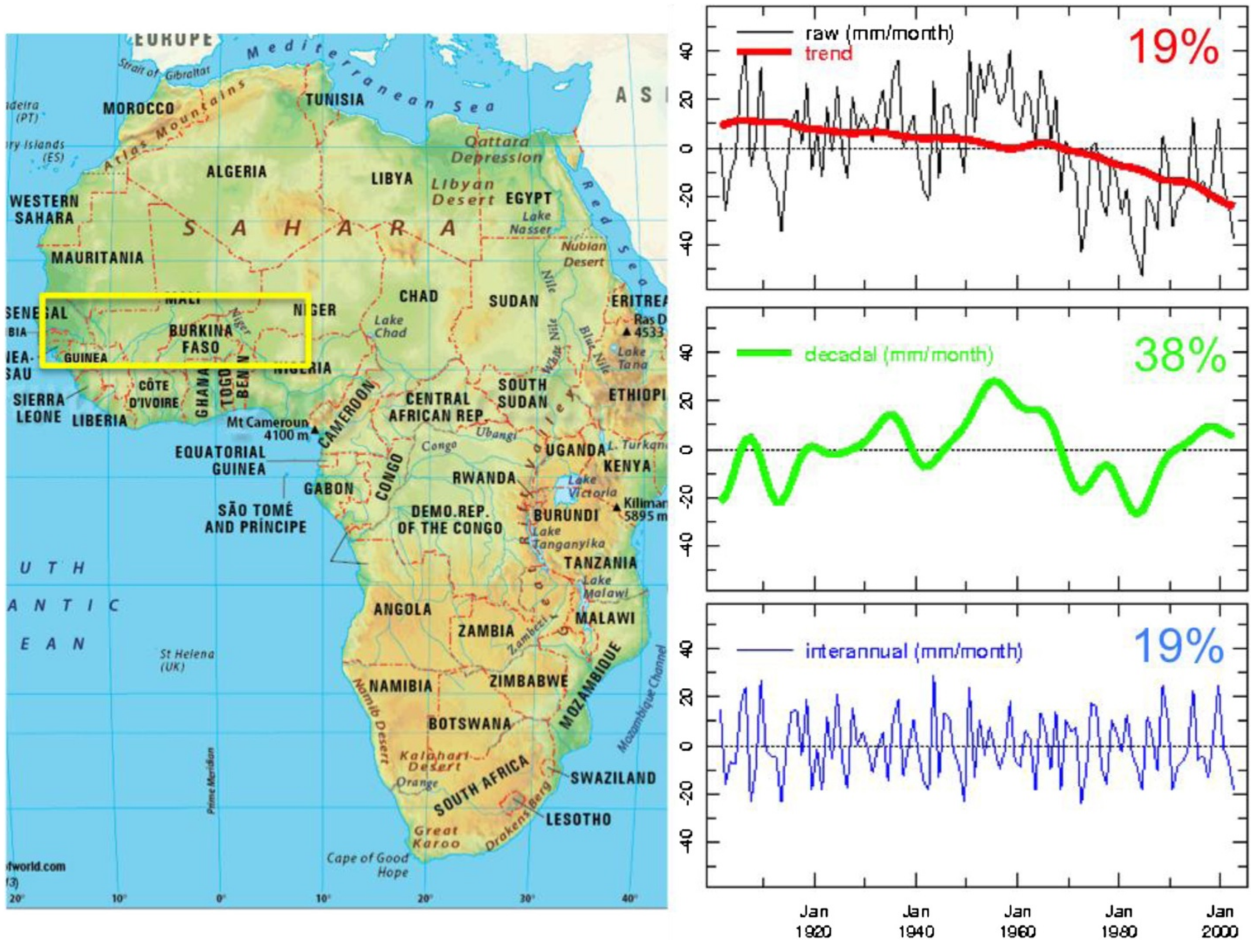

Figure 3 West Africa rainfall decomposition. Illustration of 'time scales decomposition' for west African box shown on the map, for the July-August-September season. The numbers on each graph are the percent of variance of the full observational timeseries explained by each of the timescales. The determination of the trend component is as dscribed in Figure 2. The "natural variability" remaining after subtracting the trend component, is filtered into a low-frequency, or decadal component, and a high frequency, or interannual component. The difference between the sum of these numbers and 100% is the covariance between the interannual and decadal components. As in Figure 2, the precipitation data is taken from University of East Anglia's Climate Research Unit version 2p1 (UEA-CRU2p1: (Mitchell & Jones 2005)). Data and maps available at IRI Time Scales map room available at: http://iridl.ldeo.columbia.edu/maproom/Global/Time_Scales/. Note that the observational dataset used on the Time Scales map room, may be updated over time.

Decisions at longer timescales also benefit from an integral management perspective. A simplified structure of this is the overlap between operation (intraseasonal-to-interannual, or ISI) and planning (decadal variability, or DV) timescales. They appear to be separate timescales and decisions, but planners must consider that the characteristics of the ISI variability, and the ISI climate impacts affecting management may be modulated in strength due to DV, which affects vulnerability and risk. A more realistic structure considers the interaction across scales as well, i.e., how policy and planning processes on DV timescales shape management processes on ISI timescales. Further, how do the frequency and severity of events in a changing climate impact the local or regional exposure and the ability to respond to subsequent climate events? Here, we propose to assess the resilience of water/hazard risk mitigation systems relative to potential sequences of 'events' over time at the two major timescales of interest. One of the grand challenges here is to identify and merge the information on climate, vulnerabilities, and potential mitigation actions that may be reasonably well defined at a given spatial and/or temporal scale (i.e. ISI) with information that may be much more qualitative or uncertain (i.e. decadal).

Flexible and/or tailored climate information

The IRI's Net Assessment forecast of seasonal average precipitation and near-surface temperature, based on critical consideration of multiple climate models, pioneered

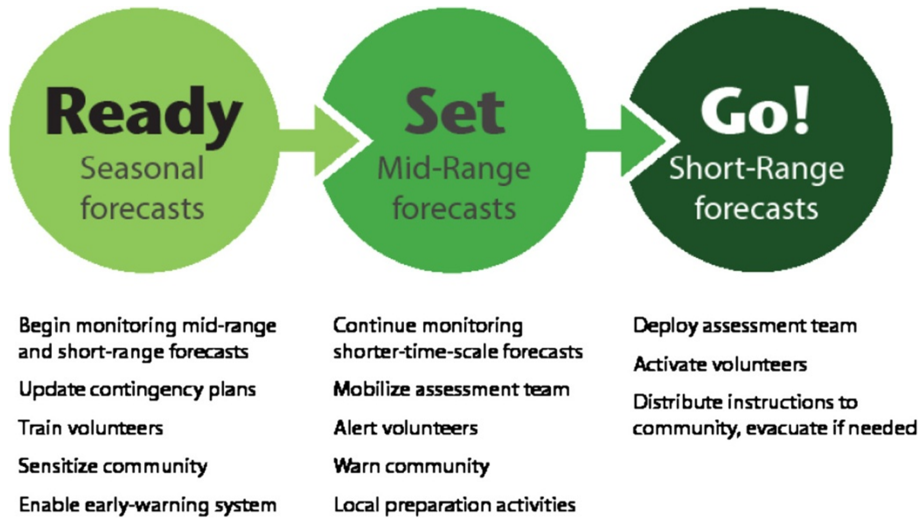

Figure 4 Ready-set-go!. Example schematic for ready-set-go! framing. (Source: M.Daly).

the probabilistic seasonal forecasts now made at many global producing centers. These forecasts are issued in terms of the likelihood of three categories, expressing anomalies in terms of below-normal, near-normal, and above-normal seasonal average conditions. This format was motivated by its simplicity and to broadly match the level of information content of seasonal forecasts. However, IRI's participatory and transdisciplinary approach with stakeholders over the years has highlighted the importance for the climate information to match needs of varied sectorial decision makers (Barnston and Tippett 2014). These demands led to research into designing tools to express seasonal forecasts in a more flexible way, and where possible to 'tailor' the forecasts to stakeholders. However, the evolution in the forecast format goes beyond a new product responding to user's needs. It transcends disciplines by working with many sectoral researchers and practitioners to understand the complexity of how their systems of study respond to climate variability and change and to respect the unique psychologies of the many audiences who could potentially use the information. Clearly, static information on a map or in a table will be of limited use within even a single decision network. Therefore, the IRI enables those who use the information directly, or who use our information and tools to add further value, to ask the questions of the climate information that are relevant to their decisions, such as relative outcomes, self-chosen categorical outcomes, or thresholds of exceedance.

One of these tools is the IRI's CPT 'Climate Predictability Tool,' which is a toolbox of robust regression techniques that allows the practitioner to relate a field of climate predictors from seasonal forecast models, to chosen 'predictands' that could be streamflows or rainy season onset dates. Another of these tools is a new online map room developed to present the IRI Net Assessment forecasts in a flexible format that allows the user to choose the percentile of interest, so that s/he is not limited to the traditional tercile categories. The work on climate information tailoring also spawned research on the seasonal predictability of 'weather within climate,' for example, the statistics of the daily rainfall variability within the season in terms of number of wet days or dry spells that are of more relevance to agriculture than the seasonal rainfall total. Research found that in the tropics rainfall frequency is generally more predictable at the local scale than seasonal rainfall total because of the higher spatial coherence of the former (Moron et al. 2006; Moron et al. 2007), which is a win-win situation where a variable with higher relevance for agriculture turns out to be more predictable (Robertson et al. 2014).

Uniqueness: climate & society, together

The uniqueness of IRI's approach is that Climate & Society are interlinked in almost all work. Similarly, the research and the context-specific problems faced by IRI's research and implementation partners are tightly linked. IRI's research addresses both the science and the process of developing climate information – of addressing climate risk management and ultimately of delivering climate services and informing adaptation efforts. This research is critical to the quality of, and trust in, the products and services that IRI develops and delivers. The value of science-based climate information and climate services is increasingly recognized not only by our regional collaborators but also by funding partners such as development agencies and NGOs. In equal measure, science agency funding partners see the importance to the research of the problem-specific context, whether region- or sector-specific, and the likelihood that positive outcomes will be taken up. Furthermore, there is an important leveraging that can be gained in working with both science agencies and development organizations. Both may be interested in the ultimate goal of climate-literate societies working towards adaptation across timescales, but their mandates cover different parts of the process. Working through an organization like the IRI allows these agencies to effectively 'hold hands' and accomplish something greater. This support can then benefit IRI's regional partners and collaborators by providing a stronger foundation to address the problem and to strengthen the network of individuals and institutions responsible for delivering the solutions.

Thus, the IRI's prominent uniqueness lies in its process. IRI works with an entire network; for example, Figure 5 a simple network involved in agricultural decision-making. It has been drawn with the meteorological service at the hub, because the focus here is on the use of climate information. Agricultural decision-making may involve cropping decisions such as what to plant and when, fertilizer strategies, crop sequences, or rotation with pastures. For different, but connected, actors in the network, it may be necessary to involve policy decisions such as promoting certain crops, pastures, or agricultural production systems, or preparing infrastructure for irrigation, for example. By working with the entire network and considering the broader context of the problems faced by decision-makers, additional factors come forward that must be accounted for in the climate-related decision support. For example, in addition to climate variability and change, the variability and change in crop prices on the international market is a driving force behind agricultural production. Here, the management decisions may stay the same, but additional policy considerations may include maximizing exports, ensuring food security in poorer countries, and maximizing farmers income, all while ensuring natural resource conservation, such as avoiding soil erosion, soil degradation, and water contamination.

Within the schematic shown in Figure 5, the IRI would be located on the left in 'International Research Climate.' We see direct connections to our research and implementation partners in the 'International Research Agriculture' box through collaborations with local universities, and with the national meteorological agency. Often the national meteorological service is the appropriate entry point, but it is important to be aware of the existing network and information sources and to work within that structure. Working within the network, it is then possible to ascertain what is the IRI's role in helping to develop understanding, build technical capacity, and transfer and co-develop products and methodologies that allow local-to-regional entities to serve their own audiences.

Note that the important expertise and local responsibility lies between the providers of the climate information (meteorological service) and the decision maker (e.g. farmer or ministry); however, there are often intermediaries that put the contribution of climate information in context with other factors that may affect decisions. The "International" boxes are not necessarily referring to IRI; often IRI has multiple entry points through the network

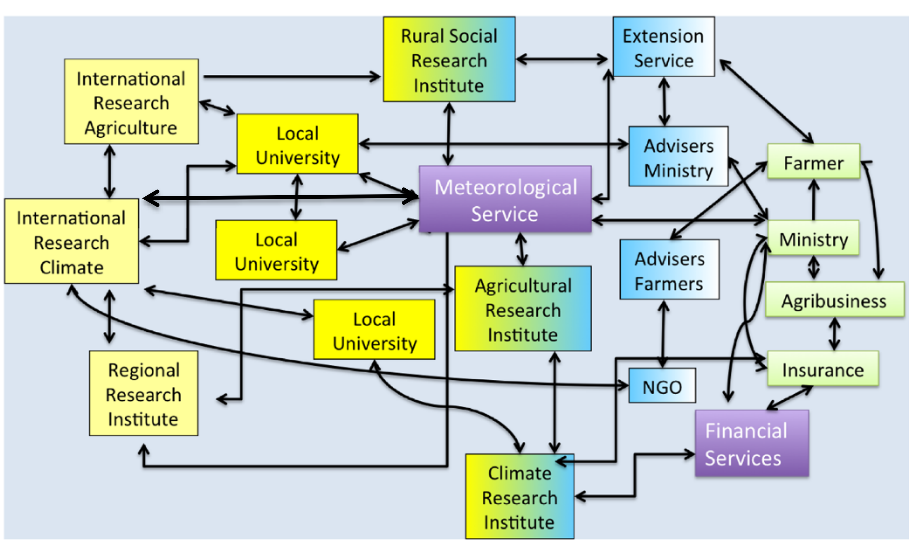

Figure 5 Decision network. A VERY simplified decision network for agriculture. The illustration indicates the types of institutions and expertise involved in connecting relevant climate information to agricultural decision-making, recognizing that agricultural decisions are occurring in many places, not just on the farm. The arrows between boxes indicate connections and flow of information that could be accomplished in many ways including the media, trainings, and direct interaction and collaboration. (Source: Walter Baethgen).

that could involve research, training, and/or information development and delivery. The IRI has discovered the value of ensuring the strength of the linkages between the elements responsible for information delivery and flow, and assisting in building that strength when necessary, rather than circumventing weak links. In this way, IRI has managed to build many lasting partnerships with local-to-regional climate services that can use, and improve upon, products produced by IRI and others, to deliver their own climate services and to take more responsibility in addressing the decision context of their stakeholders as well as voicing their research priorities to their academic community and the international research community.

The IRI has worked hard and earnestly to develop an international network of collaborators, clients and partners, which we consider an integral part of our success now and in the future. We have no lack of research questions, often spawned by the answers to previous questions, which we could pursue to increase further our understanding and improve our methodologies. Because of their real world context, these research questions typically resonate with many audiences. Because of their real world context there is also rarely a set of single clean answers to the questions. A tangible benefit to bringing climate and society together in our research and in our engagement, is that it leads very naturally to an iterative process of engagement, where existing approaches can be continuously evaluated and thus potentially improved, and unique elements identified (thus leading to new sets of questions).

Report and conclusions

The IRI has been working since 1996 to develop credible climate information and to make that information useful to those who could benefit from it. A strong foundation in science underlies a three-pronged approach to climate services: conduct strategic research, develop relevant products and tools, and provide training and capacity building that enable more informed use of the information and to help motivate research to improve information and decision support. The guiding principles of the IRI in project engagement include project scoping, informing/enabling policy and practice, and improving information including access, quality, and collaboration. Within the IRI's projects and collaborations, the themes that drive much of the research include:

- consideration of climate information across timescales,
- understanding of the target system and the decision domain relevant to climate information
- development of decision support that considers Early Warning/Early Action, which again motivates the need for climate information across timescales,
- tailored and flexible information of the climate and the natural and human environment with which it interacts, and
- consideration of climate and society together, particularly in the context of human and institutional networks.

The IRI is committed to research and implementation on these themes with sound and documented science and process. The IRI's work to date, rooted in this philosophy, has influenced many changes in the landscape of climate information development and service delivery. The world is experiencing climate change one year at a time, and that is how the IRI will address the greatest challenge facing the world today – by anticipating, managing, and adapting to climate in its entirety – one month at a time, one year at a time, one decade at a time.

Endnotes

[a]ACMAD: African Centre of Meteorological Applications for Development (Niger).

[b]Agrhymet: AGRiculture, Hydrology, METeorology (Niger).

[c]CIIFEN: Centro Internacional para la Investigación del Fenómeno de El Niño (Ecuador).

[d]CCROM: Centre for Climate Risk and Opportunity Management (Indonesia).

[e]CRRH: Comité Regional de Recursos Hídricos (Costa Rica).

[f]APCN: Asia-Pacific Climate Network (Korea).

[g]ICPAC: IGAD Climate Prediction and Application Centre (Kenya).

[h]CIMH: Caribbean Institute for Meteorology and Hydrology (Barbados).

[i]See regional profiles of 'Current and Planned Adaptation Action' based on country-level assessments: http://www.iisd.org/adaptation/ap_review/.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

LG conceived of and proposed the special issue concept that this essay introduces, and drafted the manuscript. HB contributed information and references on adaptation investments and helped to draft the manuscript. WB contributed conceptual description and graphics on decision support networks and helped to draft the manuscript. AR contributed information on climate research and helped to draft the manuscript. All authors read and approved the final manuscript.

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