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Early Warning Systems: The "Last Mile" of Adaptation

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Recent scientific assessment studies of climate change impacts, including those from the Intergovernmental Panel on Climate Change, provide evidence of the negative effects of climate variability and change on natural and human systems. For instance, recent climate trends have caused loss in wheat and maize production, negatively affected coral reefs, and changed characteristics of some hazards in high-mountain regions. Assessment studies furthermore suggest that related risks to ecosystems, commerce, and daily life may increase over the coming decades as temperatures warm.

Adaptation to climate change is required to reduce the effects of unavoidable changes, especially for the most vulnerable regions and populations. Substantial international funding for adaptation, of the order of tens of billions of U.S. dollars annually by 2020, is foreseen under the Green Climate Fund of the United Nations Framework Convention on Climate Change, established at the Conference of the Parties in Cancún, Mexico, and Durban, South Africa, in 2010 and 2011, respectively. However, scientists and policy makers often have limited experience in channeling scientific information into adaptation policies and measures. Most adaptation efforts are still on the planning level, and others are decoupled from the scientific background. For many adaptation efforts the difficulty in ensuring connectivity between providers and users is reminiscent of what is known in telecommunications as the "last mile" issue—the final leg in the infrastructure network that channels communications from a provider to individual customers.

Societies may need to adapt as a response to gradual climate change or increased climatic variability, or both, but extreme events have been recognized as the more important driver of the need for adaptation in the short term [*Berrang-Ford et al.,* 2011]. Early warning systems (EWSs) provide an important tool for risk management and can serve as the "last mile" in alerting communities to impending extreme events. EWSs, which are primarily short-term adaptation measures that operate at the local to regional scale, integrate inputs from multiple geophysical data sources. With the support of computer programs, scientists and risk managers analyze real-time data, define warning levels, and communicate with local residents, who can then take steps to protect themselves and their livelihoods from hazards such as floods, landslides, or droughts.

The tropical Andes are considered to be particularly vulnerable to climate change and related risks. Two case studies from this region demonstrate the use of in situ climate observations and remotely sensed data in support of EWSs within the specific socio-environmental context of the Central Cordillera in Colombia and the Altiplano region in southern Peru (Figure 1).

Landslide and Flood Early Warning

Like many other parts of Colombia, the Central Cordillera is characterized by steep mountains, dense tropical vegetation, and a significant number of population centers, with a total of about 7 million people. Both long-lasting and intense rainfall events are recurrent climate hazards in this region, occasionally resulting in severe landslides and floods. The Combeima Valley in the Tolima province is notorious for such disasters, which have resulted in hundreds of human lives lost over the past several decades. To reduce related risks and local casualties, a task force was established to promote the design and implementation of an EWS. The task force is composed of about 10 national and international governmental, nongovernmental, and science organizations.

Hydroclimatic baseline information and past landslide records are critical to understanding the nature, frequency and magnitude, and triggering of landslides and floods and to defining warning thresholds accordingly [*Huggel et al.,* 2010]. Because of gaps in the rainfall record in space and time, a team of scientists investigated the use of complementary information, specifically Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) data. TMPA provides rainfall data at 0.25° grid spatial and 3-hourly resolution [*Huffman et al.,* 2007]. Recent studies in the Andes of Peru and Bolivia have shown that the correlation of TMPA and data from gauging stations on the ground increases with the length of the record, suggesting possibilities of blending TMPA with in situ measurements and obtaining more accurate precipitation estimates [*Scheel*

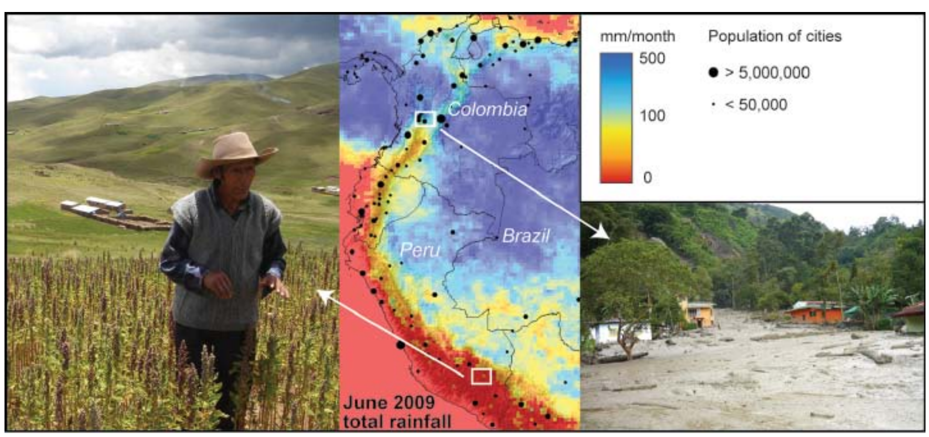

Fig. 1. (left) A farmer in his quinoa field at about 4000 meters above sea level in the Peruvian Altiplano (photo by C. Huggel). (middle) Rainfall map for the Andes for June 2009 based on Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) 3B43 data. High-rainfall areas in Colombia contrast with the dry conditions of southern Peru. (bottom right) Damage caused by the landslides of 1 July 2009 in the Combeima valley, central Colombia (photo by Regional Tolima Disaster Prevention Committee).

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et al., 2011]. However, local, short-lived, high-intensity rainfall events are still inadequately captured (Figure 2), so new real-time monitoring stations for rainfall, river discharge, and other hydroclimatic parameters were installed between 2008 and 2010 in the Combeima region. These monitoring stations and additional devices have the ability to communicate data and alerts to the provincial emergency center and local communities.

To create redundancy in monitoring and reduce the risk from sensor and communications failures, geophones registering ground motion by floods and landslides were also deployed. In addition, local residents were equipped with radios. Operators and local people were trained, and eventually a series of emergency protocols, institutional coordination, and preparedness activities were developed by the task force.

Drought Early Warning

The Altiplano region in southern Peru has population centers that exceed a total of about 1.5 million people and extend from about 3500 up to 5000 meters above sea level. This region features distinct wet and dry seasons during the austral summer and winter, respectively, and is exposed to extreme temperature and drought events. Agriculture is practiced largely at a subsistence level, and local production systems are often based on rain-fed cropping. Among the climate hazards that threaten food security, drought has long been of primary concern. Shortfalls in precipitation during the wet season have especially serious effects on agriculture, food security, and local livelihoods.

Not many drought EWSs are operational worldwide, and no such system is in place for the Andes region. Existing systems elsewhere, such as the Famine Early Warning Systems Network (FEWS NET) of the United States Agency for International Development, combine satellite-based climate monitoring and forecasting with in-country analyses of agricultural production, grain stores, prices, and political conditions to identify problems in the food supply system for some regions in Africa [*Funk and Verdin,* 2009]. Because the typical time scale of drought ranges from weeks to months, benefits are expected from a combination of ground- and satellite-based multiparameter monitoring of the vegetation state and soil water availability in conjunction with seasonal climate forecasts.

For the Altiplano region in Peru, monthly precipitation amounts and low-intensity rainfall events estimated by TMPA were found to be highly correlated with observations [*Scheel et al.,* 2011], indicating that TRMM-TMPA could provide a useful complement to the existing agrometeorological network. Yet much remains to be done to implement a fully operational drought EWS, and communicating with end users (the last mile of adaptation) continues to be a significant challenge. Because of the isolated locations of farmers and villages, some in extreme environments at up to 5000 meters above sea level, radio broadcasting and radio communications are potentially feasible mediums to transmit alerts and recommendations to end users, but this will require an adapted method of processing of information that fits the needs, understanding, and sociocultural background of local farmers.

Challenges Ahead

Scientists and government and funding institutions alike can contribute to carrying out the last mile of adaptation to enhance society's resilience to current and future climate risks. This was seen in Colombia, where the last mile was successfully implemented in the context of a landslide EWS. While monitoring, modeling, and forecasting of climate and other geophysical processes were necessary elements to the landslide EWS, in-depth communication as well as engagement and negotiation among scientists, governmental organizations, and local people was critical to securing this last mile.

EWSs will need to be adapted to cope with future climate risks. For Colombia, climate projections indicate an increase in heavy precipitation events during the 21st century [*McSweeney et al.,* 2010], while for the Altiplano a decrease in soil moisture and summer precipitation is likely to occur within the coming decades [*Thibeault et al.,* 2012]. First steps toward investigating how to best adapt the landslide EWSs in Colombia to future changes in rainfall have been undertaken [*Khabarov et al.,* 2011] but have not yet been incorporated into the operational system.

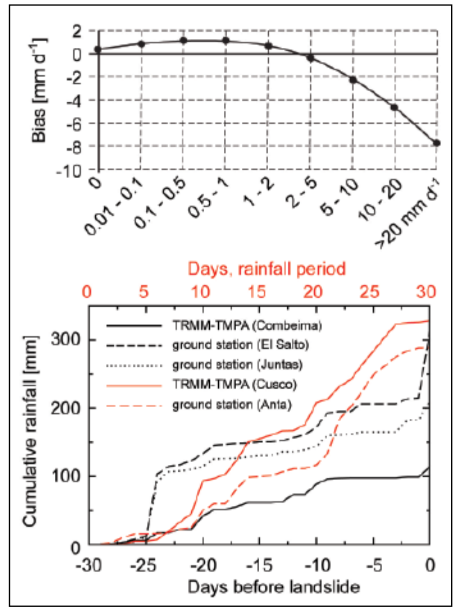

Fig. 2. (top) Bias of TRMM-TMPA 3B42 data as compared to observed daily rainfall in Cusco (modified from Scheel et al. *[2011]), demonstrating a decreasing performance of TMPA with increasing precipitation intensity. (bottom) Comparison between TRMM-TMPA 2B42 data and local rainfall gauges (black curves) for cumulative rainfall over the 30 days prior to the 2009 landslide event at Combeima, Colombia. Because of locally highly variable rainfall conditions, high-intensity events are inadequately represented by TMPA data. Larger-scale rainfall events responsible for floods and landslides in Cusco during January 2010 (red curves), on the other hand, show better correspondence between TRMM-TMPA and local observations.*

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