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Towards a Drought Information System for South America

A Strategic Plan

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Executive Summary

Drought has important social, economic and environmental impacts throughout South America, a region that relies mostly on rainfall to sustain a large agricultural production, generate hydropower, transport goods along its waterways, and satisfy household, industrial and environmental water needs. Given the importance of this phenomenon, the United States' National Oceanic and Atmospheric Administration, the World Meteorological Organization, and the Regional Climate Center for southern South America have partnered to help identify the actions necessary for the implementation of a Drought Information System (DIS) for South America. An initial step towards that goal was a workshop in Buenos Aires hosted by Argentina's National Meteorological Service in early August of 2017. The workshop brought together about 80 experts from the climate and climate-sensitive sectors of the Americas. This document is one of the outputs of the Buenos Aires workshop.

This document presents a draft Strategic Plan that identifies the operational requirements and necessary functions and activities of a South American DIS. The main DIS functions include (i) drought observation and monitoring through in situ, satellite-based and model data, (ii) predictions, projections and forecasting of drought, (iii) interdisciplinary research on the links between drought characteristics and its likely impacts on different sectors and regions, (iv) compilation, production and synthesis of information to support drought planning, preparedness, mitigation and response, (v) outreach to enhance awareness and knowledge about drought, and (vi) the implementation of a drought portal or repository where relevant useful information will be made available to institutions and individuals from the region. The Strategic Plan also seeks to identify existing and necessary drought information, data, and products, and to elicit regional priorities for the desired capabilities of a DIS. Critical gaps in knowledge, personnel, equipment or training are discussed. Further, the plan explores a possible governance structure for a DIS and the necessary institutional arrangements and partnerships. *Ultimately, the plan seeks to facilitate a shift from the prevalent reactive, crisis mode in which droughts are often managed to a more proactive approach.*

1 Foreword

Drought is among the least understood yet most damaging of all natural hazards (Pulwarty and Sivakumar, 2014), and its occurrence and impacts cross international boundaries. Drought has important social, economic and environmental impacts throughout South America, a region that relies mostly on rainfall to sustain a large agricultural production, generate hydropower, transport goods along its waterways, and satisfy household, industrial and environmental water needs. Accordingly, the United States' National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO), and the Regional Climate Center for southern South America – RCC-SSA, a six-country WMO institution intended to support national meteorological services – have partnered to help identify the actions necessary for the implementation of a Drought Information System (DIS) for South America.

The ultimate goal of a DIS is to allow people, communities, and governments from South America to mitigate or reduce the impacts of drought through preparation, improved monitoring and prediction. Moreover, a DIS will develop information networks that bridge multiple spatial and jurisdictional scales, from supranational to local. Such networks will benefit and empower existing local efforts in the region, and allow the sharing of experiences and mutual learning. The regional DIS seeks to provide state of the art, authoritative and relevant information about drought, its expected impacts, and possible actions to mitigate those impacts. This information will allow institutions from the various South American countries to design preparedness and mitigation actions, issue early drought warnings and initiate responses in specific regions and activities. *That is, the DIS does not in any way replace national, provincial or municipal risk management, civil defense, or disaster preparedness institutions. Instead, it aims to produce and disseminate the information needed by those institutions to plan, prepare, and respond to the negative impacts of drought.*

This document presents a draft Strategic Plan that identifies the operational requirements and necessary functions and activities of a South American DIS. The plan also seeks to identify existing and necessary drought information, data, and products, and to elicit regional priorities for the desired capabilities of a DIS. Critical gaps in knowledge, personnel, equipment or training are discussed. Further, the plan explores a possible governance structure for a DIS and the necessary institutional arrangements and partnerships. Finally, the plan seeks to foster (i) the early and active involvement of those in South America and elsewhere who stand to benefit from use of drought information and knowledge, and (ii) the establishment and coordination of an active interdisciplinary research program on the multiple dimensions of drought and its impacts that will support appropriate national, regional and international institutions.

The Plan provides the basis for a subsequent definition of specific implementation steps once the main DIS governing body (its Executive Board, see Section 5) is assembled. An Executive Board with appropriate regional and sectoral representation will prioritize and organize the functions and components discussed in this Strategic Plan into a specific set of activities with well-defined objectives, deliverables, timelines and an assessment of necessary resources. To facilitate the subsequent implementation process, however, a possible set of early DIS activities is proposed at the end of this document. Because of the multiple drivers, types and scales of droughts, a major challenge for DIS planning is to design a system that can be sufficiently generic and comprehensive, yet flexible enough that it can be adapted to the very different needs and contexts across South America, a large and diverse subcontinent.

2 Characteristics of Drought

Drought is an insidious natural phenomenon characterized by lower than expected or lower than normal precipitation, or limited surface water that, when extended over a season or longer period, is insufficient to meet the demands of people, an activity, and the environment (World Meteorological Organization, 2006). Despite the apparent simplicity of this definition, the typically slow development of drought without a distinct onset and end (the end of a drought is not necessarily tied to the occurrence of rain), the progressive and multifaceted character of its impacts on the hydrological cycle, ecosystems and human activities, and its diffuse spatial extent, make this phenomenon the most complex natural hazard to identify, analyze, monitor and manage (Bachmair et al., 2016; Vicente-Serrano et al., 2012).

In many aspects, drought shares with climate change the distinction of being a creeping phenomenon (Sivakumar et al., 2014). Changes that occur slowly or gradually over a long time are cognitively difficult to detect and track (Weber, 2010; Weber, 2016). The gradual nature of drought hinders recognition of the true extent of impacts as they filter through the economy and the environment, often diminishing the sense of urgency that would otherwise trigger a timely and comprehensive response (Hao et al., 2017). Moreover, drought impacts are nonstructural and thus not as "visual" as the impacts of other natural hazards such as earthquakes or floods, making it difficult for the media to communicate to the public the significance of a drought event and associated effects (Bachmair et al., 2016). Public sentiment to respond is often lacking in comparison to other natural hazards that result in loss of life and property.

As a normal, recurring feature of climate, drought occurs in virtually all climatic regimes, including high as well as low rainfall areas; it is a temporary phenomenon, in contrast to aridity which is a permanent feature of the climate and is restricted to low rainfall areas (Wilhite, 2000). Nevertheless, climate change and associated projected changes in climate variability will likely increase the frequency and severity of drought and other extreme climatic events (Dai, 2011; Dai, 2013). According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), a warmer climate, with its increased climate variability, will increase the risk of droughts (IPCC, 2007). All dimensions of food, water and natural capital security are affected by climate extremes and variability and are likely to be affected by changes in the distribution, nature, and magnitude of extreme events as these affect crops, disease outbreaks, and soil and water quality (Diogo et al., 2017; Pulwarty and Sivakumar, 2014; van den Hurk et al., 2016).

While the most recognized type of drought is the one that slowly sets in, in recent years a different – yet just as damaging – type of drought has been identified: flash droughts (so-called in likeness of flash floods) can develop unexpectedly and very rapidly. Flash droughts are not necessarily the direct consequence of a lack of precipitation – they can also result from the confluence of various factors such as very warm air temperature, low humidity and strong winds – all of which increase evapotranspiration – and anomalously low and decreasing soil moisture (Mo and Lettenmaier, 2016; Otkin et al., 2013; Otkin et al., 2015). If flash droughts coincide with critical growth stages of commercial crops, they can cause significant losses. This type of events has received limited attention in South America, and their occurrence needs to be assessed.

Growing concerns about drought result from an increased global awareness of the economic, social and environmental impacts of climate (including extreme events such as drought) on human activities. This awareness, together with the increased availability and accessibility of climate observations, diagnostics, and enhanced climate prediction capabilities – including the emerging focus on decadal climate prediction – offer the opportunity to plan and implement actions to mitigate damages and manage risks from this phenomenon. *Hence, knowledge about the climate-related aspects of drought is most useful when coupled with a thorough understanding of the likely impacts of this phenomenon on different regions, time horizons, populations and human activities*

2.1 Evolving Approaches to Coping with Drought

In many parts of the world, the usual approach to drought – commonly referred to as "crisis management" – is *reactive*, responding to drought *after* impacts have occurred (Wilhite et al., 2014). Responses to an ongoing drought crisis often involve emergency aid programs to provide tax relief, money or other specific types of assistance (e.g. livestock feed, water, food) to the victims. Admittedly, emergency drought relief remains necessary, as it addresses urgent humanitarian needs. Nevertheless, reactive responses to crises often can be untimely, poorly coordinated, and unnecessarily expensive (Wilhite and Pulwarty, 2005). In the long term, emergency assistance does not contribute to reducing the vulnerability to drought of the affected societies. Instead, emergency assistance may actually *decrease* the coping capacity of individuals and communities by inducing greater reliance on these interventions, rather than increasing self-reliance. In contrast, many preparatory actions aimed at managing drought risks can have substantial co-benefits and positive social returns – even without droughts. Indeed, such actions can be promoted widely as low- or no-regret strategies for sustainable development and building resilience to a variety of environmental, economic and social shocks (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2017). *Therefore, an enhanced approach to drought should move away from the reactive, crisis management mode of the past towards a more proactive approach.*

Moving towards a proactive approach to drought requires a deliberate planning process that establishes a clear set of principles or operating guidelines to govern the management of drought and its diverse impacts on multiple spatial and temporal scales (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2014). Ultimately, national drought policies and regional/sectoral preparedness or contingency plans will be needed. Admittedly, development of a national drought policy can be a challenging undertaking, but the outcome of this process can significantly increase societal resilience to these climatic shocks. *Without a coordinated drought policy, nations will continue to respond to drought in a reactive, crisis management mode. A drought information system (DIS) is the "cornerstone" of effective drought risk management, thus it will represent a key element of national drought policies in South American countries.*

3 A Drought Information System for South America

The goal that motivates this document is the implementation of a South American DIS to provide affected actors with information and tools to (i) monitor and predict drought onset, evolution, and recovery, (ii) assess its diverse region- and sector-specific impacts, and (iii) help prepare for, respond to, and mitigate the risks of this phenomenon. Unfortunately, many countries in the region do not have adequate resources and require outside support to provide the necessary information and knowledge for management of drought risks (Pozzi et al., 2013). In the spirit of regional and global collaboration embodied in the WMO's Global Framework for Climate Services (WMO-GFCS), the countries and organizations involved in the initiative described here seek to join efforts to improve the capacity of South American nations to manage drought-related risks pro-actively.

Taking advantage of past and current efforts, the development of a South American DIS should draw from successful experiences in developing similar systems elsewhere. In an interconnected world, the need for information on a global scale is crucial for understanding the prospect of drought-related declines in agricultural productivity and associated impacts on food prices, food security, and potential for civil conflict. Consequently, a Global Drought Information System has been proposed to improve existing regional and national drought monitoring and forecasting capabilities by adding a global component, facilitating continental monitoring and forecasting (where lacking); a global DIS was discussed in various international workshops (Pozzi et al., 2013; Schubert et al., 2015). These workshops recognized the need for coordination of information delivery for drought-related activities and relief efforts across the world. This goal is especially relevant for regions and nations with relatively limited capacity for drought information and early warning, as happens in many places throughout South America (Pozzi et al., 2013).

An interesting question was raised during the review stage of this Strategic Plan: should a DIS be formed from the collation of existing national efforts (i.e., national DISs) or, instead, should a regional DIS be implemented first and tasked with supporting national drought efforts? As discussed during the Buenos Aires workshop, every effort should be made for a regional DIS to draw on existing efforts and experiences. Furthermore, workshop participants perceived distinct benefits in forming a multi-national institution with minimal infrastructure that would help pool regional talents and coordinate existing efforts to avoid duplication of work in a common context of limited resources. As stressed in several places throughout this document, a DIS will help national institutions to fulfill their drought risk management missions, but will not assume tasks that should remain within member nations.

3.1 Early Steps towards a Drought Information System for South America

Because of the regional importance of agricultural production and water resources in southern South America, the issue of drought has great relevance across all countries in the RCC-SSA. For this reason, since the early stage of the RCC-SSA's activities, its members *identified drought as a common focus* around which initial collaboration activities could be organized. With support from the Inter-American Development Bank (IADB), the RCC-SSA convened a regional meeting in Buenos Aires in December 2012 with participation of all its members and other institutions. Although the meeting had a broader focus on the provision of climate services, drought emerged repeatedly as a crosscutting interest for southern South America. Subsequently, with separate IADB support and through a partnership with the University of Miami in the U.S., the RCC-SSA compiled a quality-controlled database of daily meteorological data and implemented tools for the calculation and visualization of multiple drought indices, thus *laying the groundwork for a regional drought monitoring effort*.

The current thrust for a coordinated South American drought effort originated in a dialog that started in 2014 between the RCC-SSA, NOAA and the WMO. This process culminated in a workshop funded by NOAA and WMO, and hosted by Argentina's National Meteorological Service in Buenos Aires, Argentina, on 8-10 August 2017 (hereafter, "the Buenos Aires workshop"). This workshop sought to help identify the actions necessary for the development and implementation of a trans-national regional drought information system for South America. The workshop convened public and private drought-sensitive stakeholders from the RCC-SSA members (Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay) as well as experts from across South America, Mexico, and the United States. Information on the workshop can be found at http://www.wmo.int/pages/prog/wcp/agm/meetings/sadm17.

One strong recommendation coming out of the Buenos Aires workshop was to *draw from experiences and lessons learned by other institutions and groups* that had successfully undertaken the development of regional or national drought information systems. Several drought systems at regional and national scales exist for Europe (e.g., the European Drought Observatory), Australia, Africa and other parts of the world (Heim and Brewer, 2012; Rossi et al., 2009; Vogt, 2011). In particular, the planning process described here will seek advice and assistance from institutions in the Americas that already have implemented drought systems, such as the United States' National Integrated Drought Information System (NIDIS) and the National Centers for Environmental Information, both involved in the production of the US Drought Monitor. For example, the South American DIS will consider the steps or guidelines originally developed by the US National Drought Mitigation Center (NDMC), now adopted by the Integrated Drought Management Programme (IDMP) to help develop the overarching principles of national or regional drought policies aimed at risk reduction (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2014). The planning also will involve México's Comisión Nacional del Agua (CONAGUA) that – together with Instituto Mexicano de Tecnología del Agua (IMTA) - implemented this country's Drought Monitor (Monitor de Sequía de México) (Brewer and Heim, 2011; Lobato-Sánchez, 2016) and the recent Mexican Drought Persistence Monitor (MPSMx). In Brazil, the Fundação Cearense de Meteorologia e Recursos Hídricos do Ceará (Funceme) and the Agência Nacional das Águas (ANA) jointly coordinate the "Monitor de Secas" in northeastern Brazil (Martins et al., 2016). Representatives from all these institutions were present at the Buenos Aires workshop and have kindly offered to assist the South American DIS planning effort.

4 Main Functions of a South American Drought Information System

The implementation of a DIS for South America should ensure the timely delivery of relevant, useful and integrated information about drought to decision makers, vulnerable communities and sector-based stakeholders to enable preparedness and mitigation measures (Sivakumar et al., 2014). A DIS involves integrated risk assessment, communication and decision support functions that (a) inform the development of strategic responses to anticipate crises and crisis evolution; (b) provide capabilities for generating problem-specific risk assessments and scenarios; and (c) together with critical users and stakeholders, co-develop and communicate plausible proactive actions to support decision making, preparedness, and mitigation (Pulwarty and Sivakumar, 2014). Other important components include effective impact assessment procedures and development of preparedness plans aimed at increasing the capacity to coping with the impacts of drought (Sivakumar et al., 2014). Figure 1 illustrates the main components or functions of a drought information system for South America; subsequent sections discuss briefly each of these functions.

4.1 Observations and Monitoring

A central function and output of a DIS is monitoring the past and current physical states of the environment through various types of observations. The monitoring system should track, assess, and report trends and current conditions of climate and water supply. This information should be communicated in a timely fashion to decision makers at all levels so climate-related risks can be mitigated and reduced. In the absence of a comprehensive, integrated monitoring system that gathers and assesses the status of the water supply on a regular basis, the severity of droughts often goes undetected until the water shortage reaches a crisis level for many sectors (Wilhite, 2016).

As a convention, the ultimate origin of drought is a decrease of precipitation. Nevertheless, it is insufficient to observe only precipitation amounts or compute precipitation-based indices to detect drought onset and evolution, as well as to assess likely impacts and their severity. Instead, modern approaches to drought monitoring should include environmental variables playing a relevant role in the hydrological balance, including precipitation, evapotranspiration, groundwater levels and surface flow, reservoir and lake levels, and soil moisture (Svoboda et al., 2002). Additionally, participants in the Buenos Aires workshop stressed that observations of snowpack depth and extent, although they exist in the region, deserve more attention. Many of these variables can be combined into indices that quantitatively assess the total environmental moisture status or

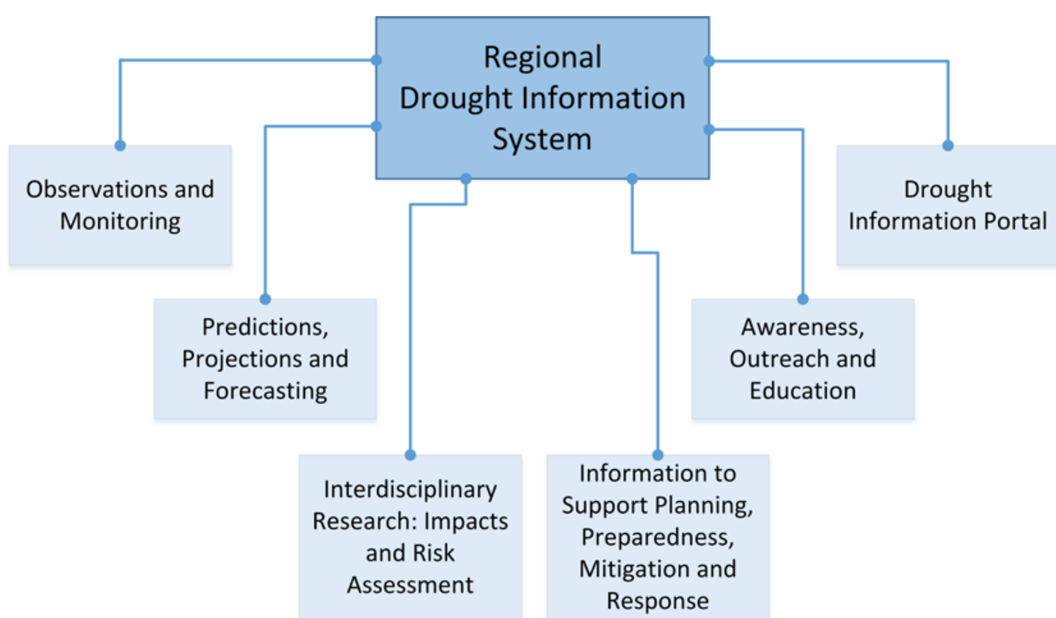

Figure 1. Main components or functions of a regional drought information system.

imbalance between water supply and water demand (Heim, 2002). Direct or indirect estimates of all these variables are available through *in situ,* remotely sensed and model data.

A prerequisite for designing an efficient drought monitoring system is to identify the relevant sectors, actors and decisions to be supported by a DIS. This will allow the formulation of well-defined monitoring objectives and strategies. Once these objectives are defined, it is possible to assess whether the required data (i.e., existing observations and models of relevant variables) are already available and accessible, or whether they can be made available with a reasonable effort. *One of the initial tasks for a South American DIS would be to identify and prioritize the diverse suite of variables that should be monitored to reflect the diverse impacts of drought on drought-sensitive sectors such as agriculture, energy production, waterway transportation, recreation and tourism, household and industry supply, and others. Possibly, a set of variables common to all participating countries can be defined.*

4.1.1 *In Situ* Observational Networks and Platforms

The current collection of *in situ* climatic and hydrologic data (including soil moisture, snow and streamflow) in South America often is fragmented among multiple agencies or ministries. Many networks exist throughout the region, most of them operated by national and/or state/provincial agencies. The number of hydrological and meteorological stations (conventional, automatic, pluviometric, etc.), the length of their records, and the amounts of missing data are highly variable from country to country and region to region within countries. An issue that often receives little attention – perhaps because of the limited detail of metadata about changes in location or instrumentation of meteorological stations – is the consistency or homogeneity of the data (Skansi et al., 2013). Ensuring the quality and homogeneity of data helps enhance the robustness of derived results about droughts. *Consequently, another early action of a South American DIS should be to assess the quantity and quality (including homogeneity) of data available from existing meteorological and hydrological observation networks throughout the region, as well as the accessibility of these data.*

The two existing WMO Regional Climate Centers (the Regional Climate Center for southern South America, RCC-SSA, and the RCC for western South America, RCC-WSA) have expressed their intention to work together towards a South American DIS. Consequently, meteorological and hydrological observations collected by their member National Meteorological and Hydrological Services (NMHSs) will be a major source of observational data in the areas covered by these RCCs. Indeed, both existing South American RCCs have made significant progress in the collation and quality control of daily weather data – although such efforts need to be sustained and enhanced, for instance, to allow faster access to *in situ* data. In contrast, participants in the Buenos Aires workshop pointed out that protocols and common formats to allow for easier sharing and interoperability of hydrological observations are less common. Institutions in the region from the water sector – such as the 5-country Comité Intergubernamental Coordinador de los Países de la Cuenca del Plata (http://cicplata.org) or Brazil's Agência Nacional das Águas – may contribute expertise in the design and compilation of hydrological databases.

Maintaining and, wherever possible, expanding *in situ* observational networks remains a central priority and an ongoing challenge for South America. Nevertheless, a critical gap identified during the Buenos Aires workshop is *the coordination required for the collation of data from various in* *situ networks and their true integration into a comprehensive regional drought monitoring system*. Because relevant data often are not reported in a timely fashion, automating or streamlining the data collation process can substantially improve the timeliness and reliability of drought monitoring and early warning systems. An ambitious target would be to have regular daily updates of *in situ* meteorological and hydrological observations. Towards this goal, a regional DIS should work closely with existing RCCs to develop guidelines on data transmission, formatting and archiving that follow international standards and systems. *Distributed data repositories should be established throughout the region – with RCCs being likely candidates for hosting such repositories, but other institutions may volunteer to host repositories as well. However, a consensus DIS data policy should be defined before repositories are established;* this topic is discussed below (Section 6.1).

In addition to data collected by national and state-level agencies, other *in situ* networks exist throughout South America (e.g., those operated by regional grain traders, farmers' associations and cooperatives, and reservoir or hydropower plant operators) that can provide critical information for a particular region. The performance of these networks is usually unknown, as they do not necessarily follow WMO standards. Consequently, considerable work may be required to compile, digitize (if necessary), and assess the reliability of these data. During the early stages of a regional DIS, a careful tradeoff must be reached between (a) attempting to include every possible source of *in situ* observations to achieve dense spatial coverage and (b) the effort needed to ensure timely access to reliable data from these additional sources.

4.1.2 Satellite-based Instruments

The typically low spatial density of *in situ* observation networks throughout South America should be complemented with the extensive spatial coverage and frequent return periods offered by sensors aboard satellites. Several mature and emerging satellite-derived products are available that show promise in the context of drought monitoring (AghaKouchak et al., 2015; Kogan et al., 2015; Mishra et al., 2017; Pozzi et al., 2013). In particular, substantial progress has been made recently in facilitating access to satellite-based products to monitor drought (Hao et al., 2017). Nevertheless, errors in the various remote-sensing retrievals still need to be well characterized and then reduced, and consistency in time and between products needs to be assured.

Remotely sensed data increasingly provide an ability to monitor drought and provide early warnings through retrievals of several components of the water cycle as well as vegetation health. Improvement in precipitation estimation from satellites follows the development of products like CMORPH and GPM's IMERG – which replaced TRMM and its near real time product TMPA-RT (Kirschbaum et al., 2017; Skofronick-Jackson et al., 2017). Recent advances also have shown that it is possible to define drought indices based on evaporative stress index (EVT) from satellite data (Anderson et al., 2011) that often detect drought onset well in advance of other indices based on precipitation like SPI (McEvoy et al., 2016). The added value of EVT monitoring for yield estimates of major crops grown and for use in the water sector has been demonstrated in Brazil (Anderson et al., 2016). Soil moisture, a key variable not only for drought monitoring but also for drought forecasting (as soil moisture information enhances the skill of seasonal forecasts) can be monitored by satellite-based instruments (Carrão et al., 2016b; Dorigo et al., 2017; Enenkel et al., 2016). Satellite-derived vegetation indices such as the Normalized Difference Vegetation Index NDVI or the Enhanced Vegetation Index EVI are often used to monitor drought (Cunha et al., 2015; Enenkel et al., 2016; Rimkus et al., 2017; Sierra-Soler et al., 2016; Zambrano et al., 2016).

Current use by South American countries of remote sensing products to monitor drought should be assessed in detail by a regional DIS. From national reports made during the Buenos Aires workshop, it would appear that current use of satellite data is relatively limited. Brazil's CEMADEN, for instance, uses the Vegetation Supply Water Index derived from the MODIS radiometer (Cunha et al., 2015). Also in Brazil, CPTEC reported use of satellite-derived precipitation, NDVI, fire monitoring and fire risk to monitor drought. Chile's INIA (Ministry of Agriculture) relies on the Vegetation Condition Index or VCI (Kogan and Sullivan, 1993; Rimkus et al., 2017). Uruguay reported use of NDVI, EVI and NDWI indices to monitor vegetation status. In contrast, no country reported current operational use of satellite-derived precipitation or soil moisture to monitor drought, although a comparison of various satellite-derived precipitation products was reported recently by Zambrano et al. (2017) for Chile. Participants in the Buenos Aires workshop also called attention on potential difficulties or errors introduced in remotely sensed data by the complex topography in parts of South America (e.g., Bolivia, Peru).

As a new and promising source of multiple products, the region should take full advantage of the beneficial orbital position of the GOES-16 satellite (above 75°W) and the ease of access to its products (Schmit et al., 2016). Another upcoming source of useful data is the SAOCOM two-satellite constellation planned by Argentina's Comisión Nacional de Actividades Espaciales (CONAE). The SAOCOM satellites will carry L-band synthetic aperture radars that will provide soil moisture estimates. At the time of writing, the first SAOCOM satellite is scheduled for a mid-2018 launch. Moreover, to support calibration/validation and algorithm development, CONAE also has deployed a network of *in situ* soil moisture measurements in central Argentina that could be accessed by the DIS.

Procedures to retrieve and merge satellite and in situ data routinely and in near-real time must be implemented by a South American DIS. Furthermore, gaps in training and equipment necessary to analyze and interpret existing satellite data products and develop new ones need to be identified. A DIS should establish collaborations with South American and international agencies operating or actively using satellite-based sensors to build capacity on satellite remote sensing. An example of a helpful effort is NASA's Applied Remote Sensing Training (ARSET, https://arset.gsfc.nasa.gov) program, that offers training that builds the skills necessary to integrate remote sensing data into the activities of a DIS. ARSET's free training programs are conducted as webinars or in person, and some programs are even delivered in Spanish. The European Space Agency (ESA) also is undertaking a wide range of education, training and capacity building activities focused on data provided by the instruments they operate (earth.esa.int/web/guest/eo-education-and-training).

4.1.3 Land Surface or Hydrological Model Products

Land surface or hydrological modeling plays a key role in drought monitoring. These models include representations of the land surface water and energy balances, using the latest knowledge in land-atmosphere physical processes and the parameterizations that best represent them. Land surface models taking as input *in situ* and satellite observations can help provide soil moisture, and in some cases groundwater and other drought-relevant products. Land surface initial conditions also provide an important source for skillful drought forecasts for one or two months, thus it remains critical to continue to improve initialization of land surface states in operational systems. Land surface model output also can be compared with retrospective model runs to obtain estimates of the current relative drought severity (McRoberts and Nielsen-Gammon, 2012).

Land Data Assimilation Systems (LDAS) employ several land surface or hydrological models seeking to reduce errors by (a) identifying the best available observations and (b) performing ensembles of the different models (see, e.g., the NLDAS Web site, https://ldas.gsfc.nasa.gov/nldas/NLDASgoals.php). However, there still exist large differences between models, and biases relative to observations exist, especially in regions with low-density precipitation networks. Merging satellite data into land models via assimilation methods holds great promise for removing biases in models and harmonizing data across products and variables (Pozzi et al., 2013).

Prototypes of experimental drought monitoring systems based on LDAS – and their limitations – have been reported (Sheffield et al., 2013). While some of these systems are not operational or not even linked to operational institutions, they may provide useful guidance for producing diagnostics of interest to users and stakeholders. Rodell et al. (2004) and Fang et al. (2009) report that NASA has implemented a Global Land Data Assimilation System (GLDAS) based on four land surface models (CLM, Mosaic, Noah and VIC) to produce global estimates of surface states and fluxes (e.g., soil moisture, surface temperature, evaporation and sensible heat flux). GLDAS products are widely used in South America for monitoring purposes and for studies of the strength of coupling between land and atmosphere. Spennemann et al. (2015) compared simulated soil moisture anomalies over southern South America derived from GLDAS, the SPI, and a multi-satellite surface soil moisture product, concluding that GLDAS products are good indicators of soil moisture states and useful for developing new soil moisture–monitoring indices.

Early efforts towards developing a South American LDAS at Brazil's CPTEC have been reported, although the system was not executed in real time (de Goncalves et al., 2009). Nevertheless, SALDAS has been maintained in research mode and has been updated regularly to match the latest versions of NASA's Land Information System (LIS), the computational backbone for NLDAS and GLDAS in the U.S. Through LIS/SALDAS, CPTEC can deliver high-resolution depictions of the continental South American land surface, resulting from available in situ measurements, model-derived atmospheric forcing, and multivariate land surface data assimilation from local and remotely sensed data. CPTEC is currently planning to release an operational near-real-time instance of SALDAS driven by atmospheric forcing from CPTEC's Global Data Assimilation System analyses and hourly disaggregated precipitation (Vila et al., 2009).

Similar efforts on land surface modeling are being carried out at different institutions in the region with either single or multiple land surface models. Sgroi (2017) implemented the VIC model over the La Plata Basin, to assess the land surface hydrologic cycle and develop a 1980-2010 climatology of drought events. Muller and Berbery (2017) also employed individual models (Noah and Noah-MP, an evolution of the first one that includes groundwater and has dynamical vegetation treatment) forced by observations. While none of these models is being executed routinely in real time, all these efforts could help build a new LDAS for South America under the umbrella of a South American DIS, combining the best information available from each country.

4.1.4 Drought Indices and Indicators

Droughts differ from one another in three essential characteristics: intensity, duration, and spatial extent. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure of some climatic index from normal and is closely linked to duration in the determination of impact (Wilhite et al., 2000). Several methodologies for drought characterization exist; however, using drought indicators or indices is prevalent.

Drought indicators are variables or parameters used to describe drought conditions. Examples include precipitation, temperature, streamflow, groundwater and reservoir levels, soil moisture and snowpack. *Drought indices* are quantitative measures that characterize drought levels by assimilating one or more drought indicators (e.g., climatic variables such as precipitation and evapotranspiration) into a single numerical value. Such an index is more readily usable than raw values of climate variables. Note, however, that indices are technically indicators as well (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016). Several drought indices are available and have been reviewed in the literature (Heim, 2002; Keyantash and Dracup, 2002; Penalba and Rivera, 2015; Quiring, 2009; World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016; Zargar et al., 2011). Nevertheless, guidance on the use of these indices is still insufficient. As pointed out by participants in the Buenos Aires workshop, the need for well-documented drought indices produced by an authoritative source is particularly important when such indices are used as part of an index insurance program; index insurance can be a helpful approach to manage risks from drought.

Defining droughts based on a single variable or drought index (e.g., precipitation, soil moisture, or runoff) may not be sufficient for reliable risk assessment and decision-making. In addition to the use of a single drought indicator or index, there are two alternative approaches for monitoring drought and guiding early warning and assessment: (i) using multiple indicators or indices and (ii) using composite or hybrid indicators such as those in the North America Drought Monitor or the Northeast Brazil Drought Monitor. Due to the complex nature of droughts, a common current approach is to monitor multiple indices simultaneously. The use of multiple drought indices, however, can be confusing for the individual decision maker, who often does not know about the characteristics of each indicator (Mizzell, 2008).

An alternative to multiple drought indices is the use of combined or multivariate indicators consisting of a blend of individual ones (AghaKouchak, 2015; Azmi et al., 2016; Bachmair et al., 2015; Erhardt and Czado, in press; Farahmand et al., 2015; Hao and AghaKouchak, 2013; Hao and Singh, 2015; Reddy and Singh, 2013; Waseem et al., 2015; Zhang et al., 2017). The rationale behind blended indices is that a single index is unable to capture the diversity and complexity of drought conditions across the temporal and spatial dimensions relevant to the different sectors affected by drought (Hao and AghaKouchak, 2013). Moreover, blending several indicators may enhance interpretability for users of the systems, as the diverse information from potentially conflicting indicators is streamlined and simplified into a single answer. On the other hand, any blending approach involves the subjective choice of indicators, weights, and thresholds for delineation of intensity classes that may make the interpretation less intuitive or relevant (Bachmair et al., 2016). If composite indices are used, the levels to define drought must be statistically consistent for all individual indices contributing to the composite. While different indicators would naturally reflect different levels during a drought, the inconsistency is the definition of the level defining drought occurrence (Steinemann, 2014). A useful "common currency" for the comparison and integration of multiple indices involves the quantiles of the distribution of each individual index for a given location and time.

The strengths and weaknesses of each candidate drought index should be carefully assessed, understood and clearly communicated to potential users. Unfortunately, still there is little consensus on which indices are most meaningful for the measurement of drought impacts on society and the environment (Bachmair et al., 2016). *An early activity of the planned South American DIS may be to facilitate a consensus on a minimum set of drought indices and indicators common to all participating countries.* A consensus set of indicators, together with common protocols and even tools for their calculation and reporting would allow products from different countries to be seamlessly merged into a regional map.

4.2 Drought Predictions, Projections, and Forecasting

An important component of any DIS is the preparation and communication of reliable and useful drought forecasts and outlooks, as well as the implementation of the prediction tools and models that inform them. The drought prediction problem essentially boils down to the forecast of crucial meteorological variables such as precipitation and temperature (Hao et al., 2017). During the past few decades, national and international investment in climate observations, research and modelling have resulted in significant progress in experimental and practical climate prediction, as well as significant improvement in scientific understanding of climate variability and change. These advances provide a robust scientific foundation for generating climate prediction products (World Meteorological Organization, 2016). Specifically, substantial advances have been achieved with different drought prediction methods from statistical and dynamical perspectives (Mishra and Singh, 2011; Mishra et al., 2015; Quan et al., 2012; Schubert et al., 2007). Because statistical and dynamical approaches have specific strengths and limitations, integration of both methods (i.e., a hybrid statistical-dynamical approach) may produce enhanced drought forecasts (Hao et al., 2017). Another approach to drought prediction involves the use of machine learning techniques such as artificial neural networks (ANN) and support vector regression (SVR) (Belayneh and Adamowski, 2012; Belayneh et al., 2014; Belayneh et al., 2016; Deo et al., 2017; Deo and Şahin, 2015; Mishra and Desai, 2006; Rhee and Im, 2017).

A DIS aims to detect the emergence or probability of occurrence, and the likely severity of drought. Drought early warning can reduce vulnerability to this natural hazard by providing users such as relief agencies, national authorities, or private interests the maximum possible lead time to put mitigation strategies into place (Pozzi et al., 2013). A necessary component of a DIS is a forecasting component with monthly and seasonal – as well as potentially interannual and decadal – lead times and spatial resolutions of, at minimum, a few tens of kilometers. *Nevertheless, a drought early warning system is more than a forecast: it is also a linked risk information and communication system that informs drought preparedness and response.*

4.2.1 Capabilities for Climate and Drought Prediction in South America

According to reports presented during the Buenos Aires workshop, most countries in South America produce forecasts or outlooks of temperature and precipitation on scales of 1 to 3 months. These predictions often are produced through statistical approaches – the CPT software developed by Columbia University (Mason and Tippett, 2017) seems to be the most commonly used tool. In other cases, output from dynamical models are obtained from international climate modeling centers and used to prepare national or regional outlooks. Apparently, little use is made of the archived model output made available by the WMO and this resource should be explored further. In general, countries in South America do not issue specific predictions of drought indicators, although there are some notable exceptions: Brazil's FUNCEME issues forecasts of SPI and SPEI, as well as standardized runoff and an index based on runs of dry days.

There is a broad range of climate and drought prediction capabilities among countries of South America. These capabilities range from Brazil's CPTEC, that produces climate forecasts operationally and has been designated by WMO as a Global Producing Center (GPC) for Long-Range Forecasts, to minimal capacities in most countries. Argentina's Centro de Investigaciones del Mar y la Atmósfera (CIMA, www.cima.fcen.uba.ar) is among the few institutions in the region producing experimental subseasonal (15-40 days) climate forecasts. To improve the regional capacity to produce, use, and translate climate and drought forecasts, a South American DIS should establish early partnerships with regional and international climate agencies (e.g., WMO GPCs) and sectoral research institutions working on this topic. A goal of the partnership would be to enhance understanding of how global or regional climate variability modes may influence drought conditions throughout South America, and whether these modes can serve as potential sources of drought predictability. *For this reason, during the Buenos Aires workshop enhancing human capacity in climate and drought forecasting was identified as a major gap or need. A particular research need was the enhancement of subseasonal climate and drought predictions.*

4.2.2 Drought Thresholds and "Triggers"

The central purpose of a drought early warning is to allow initiation of different kinds of drought response. The issuance of early warnings, however, is tied to the existence of operational or legal definitions of the occurrence of a drought and its severity. The "legal" definition of drought is an explicit declaration in a regulation that establishes when the event exists for the State and is linked to a public response (Núñez et al., 2014). In most countries, the thresholds for declaring drought – when they exist – are arbitrary (i.e., they are not linked to expected specific impacts in key economic sectors or places). This arbitrariness often results from a misunderstanding of the concept by those formulating definitions. Moreover, little consideration is given to how resource or disaster managers will eventually need to apply the definition in actual drought situations (e.g., assessments of impact in multiple economic sectors, drought declarations or revocations for eligibility to relief programs). Consistency among drought definitions is of the utmost relevance in this work, as the very ambiguity of the concept of drought constitutes one of the main obstacles to the creation of drought policies (Núñez et al., 2014). *Criteria used across South America to declare the occurrence of a drought administratively or legally should be surveyed and documented by a regional DIS.*

A drought "trigger" is a specific threshold value of an index (or multiple indices) that activates levels of drought response (Botterill and Hayes, 2012). Triggers are linked to the timing of management responses in a given sector or activity and can be used to address the question "When do we take action?" (Steinemann, 2014). Identification of drought triggers at appropriate lead times is necessary for devising effective drought mitigation plans (Maity et al., 2013). Without triggers in place, responses to drought are often delayed or do not reach the audience that response plans are intended to serve. If triggers are going to be implemented in drought policy or management decisions, they need to be consistent from event to event and equitable in terms of the people affected (Steinemann et al., 2005). A "good" trigger must have stakeholder buy-in, be comprehensive, and involve a transparent process that engages a range of disciplinary expertise (Botterill and Hayes, 2012). Selected triggers also should (i) be understood by decision makers and the public, (ii) have a scientific and objective basis, and (iii) be able to undergo assessment of their effectiveness in terms of relating drought severity with impacts.

There is an urgent need in South America for improved identification and analysis of indicators and triggers cooperatively designed around specific management priorities and system thresholds. An example mentioned during the Buenos Aires workshop was the draft protocol to deal with meteorological and agricultural droughts in Argentina (www.mincyt.gob.ar/adjuntos/archivos/000/043/0000043540.pdf). This protocol – coordinated by Argentina's Ministry of Science and Technology and involving contributions from multiple institutions from that country – set triggers for "yellow" and "red" warning conditions based on the combined values of multiple indicators. Unfortunately, no rationale was provided in the published protocol for the choice of values separating warning levels.

The increasing use of multiple indices in drought monitoring implies that the values of triggers chosen for different indices should be mutually consistent. For instance, a "severe drought" probability is 6.7% for the Standardized Precipitation Index (SPI), 14% on average for the Surface Water Supply Index (SWSI), and 10% on average for the Palmer Drought Severity Index (PDSI). In addition, if multiple indices are used as part of a trigger, it should be clear when a drought level is invoked or revoked: should declaration of a drought rely on the value of one index, a majority, or all of the indicators?

There are ongoing arguments between "hard triggers" (i.e., definite numerical thresholds for drought levels and associated actions) versus "soft triggers" (more subjective and nuanced assessments of drought). Hard triggers offer a quantitative and justifiable basis for decision-making, but numbers may not reflect the reality of drought. Drought events seldom are similar: some are prolonged but less intense, whereas others are short-lived and extremely severe. Consequently, a trigger that made sense during one event may not be applicable during the next (Finnessey et al., 2016). Soft triggers, on the other hand, offer flexibility without being tied to numbers, but could make it more difficult to explain drought assessments or declarations in a contentious political environment with conflicting interests at stake (Steinemann, 2014). *Drought plans for South America should balance the advantages and disadvantages of both approaches.*

4.3 Interdisciplinary Research: Risk Assessment and Drought Impacts

The assessment of drought risk serves as the basis for drought preparedness and mitigation plans, helping to identify specific *ex ante* and *ex post* actions (Hayes et al., 2004). Drought risk is the probability of harmful consequences or likelihood of losses resulting from interactions between (i) drought hazard (i.e. the possible future occurrence of drought events), (ii) drought exposure (i.e. the total population, its livelihoods and assets in an area where drought events may occur), (iii) and drought vulnerability (i.e. the propensity of exposed elements to suffer adverse effects when impacted by a drought event) (Bernal et al., 2017; Cardona et al., 2012; Hayes et al., 2004). Several authors have warned that more efforts are spent on studying and quantifying drought as a natural hazard than at providing a consistent and equitable drought risk management framework for multiple regions, population groups and economic sectors (Carrão et al., 2016a; Pulwarty and Sivakumar, 2014). Carrão et al. (2016a) provide useful practical advice on approaches and resources for characterizing patterns of drought risk. Bernal et al. (2017) present an end-to-end approach to integrate hazard, exposure and vulnerability into quantitative estimates of drought risks (e.g., the probability of exceeding a certain loss threshold in agricultural systems).

Hazard analysis. This component – the first step of a drought risk assessment – involves an understanding of the frequency, intensity, duration, and spatial extent of drought occurrences, and whether these factors are changing over time (Finnessey et al., 2016; Hayes et al., 2004). Hazard analysis should be undertaken as part of the planned DIS monitoring and observations component. The simplest hazard analysis would involve analyses of time-series of drought indices and indicators over their full available records for locations within the region of interest. The analyses may involve not only *in situ* measurements, but also satellite based observations.

Subsequently, a hazard analysis can include additional components suggested by Finnessey et al. (2016): (i) estimating return periods of droughts of different intensities, durations, and spatial extents; (ii) searching for consistent patterns in the temporal and spatial features of drought (seasonality of emergence, characteristic spatial footprint); (iii) evaluating temporal trends in drought occurrence, important because planners may base their actions on more frequent and less-severe droughts, extreme droughts, or the drought of record for their region; (iv) identifying modes of climate variability (e.g., ENSO phase) associated with greater or lesser drought risk; and (v) identifying a 'drought of record' that represents a worst-case scenario during the period of instrumental record. The presence of temporal trends is especially important for drought planning, as planners may base their actions on more frequent and less-severe droughts, extreme droughts, or the drought of record for their region.

One limitation of hazard analyses based on historical observations is that this record represents a single realization of the weather process. Multiple, equally-likely weather sequences may be generated using stochastic weather generators that simulate data with statistical properties similar to those of the historical record (Wilby et al., 1998). Therefore, probabilistic hazard modelling hazard analysis is not limited to the period of instrumental record and can include extreme conditions that may occur in the region of analysis in the future (Bernal et al., 2017). Moreover, synthetic series can be generated on a dense spatial grid (respecting the inherent space-time structure of real data) required as input by process models (e.g., a hydrological model). The simulated series can also be conditioned on (i.e., reflect) hypothetical climate scenarios such as a plausible multi-annual trend in precipitation, or dry conditions associated with a seasonal forecast (Bernal et al., 2017; Podestá et al., 2009; Verdin et al., 2018).

Exposure analysis. To assess the potential impacts of drought hazard, the first step is to inventory and analyze the *exposure* of a system to occurrence of this phenomenon. Exposure analysis identifies the different types of entities that can be damaged by drought, including built assets, infrastructure, land and people, among others. For example, an agricultural region that is completely covered by rainfed crops is fully exposed to drought, independently of the presence of other elements at risk. In a region such as South America where crop and cattle production has huge economic, social and environmental importance, indicators of drought exposure can be derived from maps of cropped areas, number of cattle heads, production costs by agricultural activity, population densities, etc. (Bernal et al., 2017; Carrão et al., 2016a). Similarly, assets that may suffer damage from exposure to drought must be characterized for other important drought-sensitive sectors (e.g., hydropower generation in Brazil).

Vulnerability analysis. The purpose of a drought vulnerability assessment is to determine who and what is at risk from drought and why (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2014). That is, analyses of vulnerability should capture which people and sectors may be most affected by drought, why these impacts occur, and if these relationships are changing over time.

As with the term "drought", there is no consensus among researchers on the definition of vulnerability (Núñez et al., 2017). In the context of drought, vulnerability refers to the capacity of an individual, group or society to anticipate, cope with, resist, and recover from the impacts of a drought episode (Wilhite, 2016). Another definition of drought vulnerability that has gained growing acceptance is "the characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of this hazard". Despite its importance, quantifying vulnerability to drought can be quite difficult due to the complexity of the system under analysis and the fact that vulnerability is not a directly observable phenomenon (Ren et al., 2012).

A causal analysis of vulnerability to drought directs attention to the underlying causes of vulnerability to drought – such as inadequate structures, management, and technology, or economic, environmental, and social factors – rather than only to its results, i.e., the negative impacts. Naumann et al. (2014) provide an example of this approach in Africa. For example, the direct impact of precipitation deficiencies may be a reduction in crop yields. The underlying or basal cause of this vulnerability, however, may be that some farmers did not use agronomic (e.g., drought-resistant genotypes) or financial (e.g., insurance) risk management practices, because of concerns about their effectiveness or high cost, lack of knowledge about these practices, or because of cultural beliefs (Naumann et al., 2014). The causal analysis allows tracing outward from each impact the multiple environmental, social, and economic underlying factors that contribute to the resulting impacts. In such a process, climatic events are placed among the many factors that accentuate the negative consequences of drought, but human drivers such as surface or groundwater abstraction, urbanization and deforestation also must be considered. That is, drought research should no longer view water availability as a solely natural, climate-imposed phenomenon and water use as a purely socioeconomic phenomenon. Instead, research should carefully consider the multiple interactions between both of these aspects (Van Loon et al., 2016). Finally, analyses must consider the temporal evolution of vulnerability to drought associated with changes in technology, population demographics and behavior, policies, and other drivers. This goal can be achieved by reviewing how drought impacts and causal factors have changed over previous decades, as well as by projecting them into the future (Hayes et al., 2004).

Vulnerability to drought is typically estimated through the aggregation of various relevant, subjectively weighted vulnerability factors. These factors should be the directly observable or measurable conditions of the systems' elements and/or the characteristics of the disturbances to which the system is exposed (Ren et al., 2012). Typically, indicators have been selected that attempt to capture (i) social vulnerability, linked to the level of well-being of individuals, communities and society; (ii) economic vulnerability, highly dependent upon the economic status of individuals, communities, and nations; and (iii) infrastructural vulnerability, i.e., the basic infrastructures needed to support the production of goods and sustainability of livelihoods. Ideally, public data need to be available for candidate indicators so that vulnerability analyses can be validated, reproduced, and improved as new data become available. Bakkensen et al. (2017) present a recent review of the limitations of composite indicators. In particular, efforts to develop drought vulnerability indicators have been met with a lack of agreement on the variables that may characterize this complex concept; another contentious aspect is the subjective choice of weights for the contributing variables.

There have been few attempts to characterize vulnerability to drought in South America. In a recent work, (Núñez et al., 2017) sought to assess the vulnerability of water security to drought among water users in the Elqui River basin, located on the southern border of the Atacama Desert in the arid region of north-central Chile. Mexico defined the concept of drought vulnerability within the framework of its National Program Against Droughts – PRONACOSE for its acronym in Spanish (Meza-González and Ibáñez-Hernández, 2016). This approach was illustrated by Ortega-Gaucin et al. (2018) for the Northwest River Basin System, a very arid region encompassing 71 municipalities in the States of Sonora and Chihuahua. Values of different indicators contributing to vulnerability to droughts were collected, standardized and merged into a single Vulnerability Index for each municipality that could subsequently be mapped.

4.3.1 Assessment of Drought Impacts

The assessment of drought impacts is essential to identify the social, economic, and environmental sectors/activities that are sensitive to drought in a particular region. Despite its importance, an impact-driven perspective is the missing piece of drought monitoring (Lackstrom et al., 2013). A drought impact is "an observable loss or change that occurred at a specific place and time because of drought". An issue that has been relatively neglected not only in South America but throughout the world is the linkage of drought indicators with impacts (Bachmair et al., 2016).

A useful task to be carried out during the early stages of a South American DIS is the compilation of a ranked or prioritized list of relevant drought impacts for each location or activity. Some of the questions that should be addressed include: (a) what economic and social sectors and regions are most vulnerable to drought in a country/region? (b) Historically, what have been the most notable impacts of drought in that country? (c) Historically, how has that country's government responded to drought? (d) What current trends (e.g. climate, land, water and energy demand and use, population growth) may increase the country's vulnerability to drought and conflicts in the future? To be effective and equitable, the ranking of impacts should take into consideration concerns such as the cost of mitigation actions, the area/extent of each kind of impact, trends over time, public opinion and fairness.

Impact assessment examines the consequences of a given drought event. The impacts from drought can be classified as economic, environmental or social, even though many impacts may span more than one category. For example, drought is typically associated with a number of outcomes that result from the shortage of water, either directly or indirectly. Drought impact assessments begin by identifying the *direct consequences* of the drought, such as reduced crop yields, livestock losses, and reduced reservoir levels. These direct outcomes subsequently can be traced to *secondary consequences* (often, social impacts), such as the forced sale of assets, lowered food security, reduced energy production, dislocation or physical and emotional stress.

4.3.2 Linking Drought Indicators to Likely Impacts

Society needs information about when and where drought conditions (expressed by some indicator) translate into impacts. Translation of drought monitoring and early warnings into likely impacts is critical for effective preparedness and mitigation. Presenting the likelihood of specific impacts due to expected drought conditions may be much more relevant and usable to resource managers and policy makers than simply showing the values of drought indices. What is of ultimate interest is the knowledge of when and where drought conditions (expressed by some indicator such as precipitation shortfall, low streamflow, or groundwater level) will translate into impacts on society, the economy, and ecosystems. For example, if the monitoring component of the system warns that in several locations of the Argentine Pampas the 3-month Standardized Precipitation Index (SPI) has shown values < -1 during August, September and October of a given year, what are the likely impacts on the yields of major summer crops in that region? What would happen if SPI forecasts anticipate dry conditions ending after October? Would the expected impacts be reverted? As is apparent from this example, understanding and quantifying the linkages between drought indices and sectoral impacts is a critically necessary step to assess the resilience of affected systems to drought conditions, as well as to develop adequate mitigation measures. This knowledge can help define when various levels of drought warnings are triggered and mitigation actions are started (Steinemann, 2014; Steinemann et al., 2005). *Consequently, there is a vital need for research that links meteorological drought with drought impacts experienced by different sectors of society.*

A major limitation of most existing drought indices is that they just describe general anomalies of meteorological and/or hydrological conditions. Frequently there is little consensus on the indicator that best represents the likelihood of significant drought impacts for a given sector. Nevertheless, thresholds are widely applied to drought indices, but to date little empirical evidence exists about which thresholds are tied to clear impacts on society, the economy, and ecosystems. The main obstacle for evaluating commonly used drought indicators is the paucity of information on drought impacts (Bachmair et al., 2015; Lackstrom et al., 2013). The definition of triggers for early warnings is closely related to the study of linkages between drought indicators and likely impacts by affected sector (Section 4.3.2). Index values at which the likelihood of certain impacts becomes much greater can be used as triggers in drought mitigation plans (Finnessey et al., 2016). *A South American DIS should inform, guide and facilitate discussions with a relevant spectrum of stakeholders to identify critical indicators and triggers for drought planning and operational decisions.*

As an example of this type of research, Blauhut et al. (2015) used a logistic regression model to estimate the regional likelihood of drought impact occurrence (LIO) as a function of a drought index. Their LIO estimates the probability of drought impact occurrence, that is dependent on the drought hazard indicator (in this example, 12-month SPEI). With this probabilistic model, the occurrence of drought impacts is not predicted as 'impact' or 'no impact' but, instead, the likelihood of drought impact occurrence is estimated. This approach was later expanded by Stagge et al. (2015), who used more flexible statistical approaches (generalized additive models, GAMs) to explore how drought impact occurrence could be explained by meteorological drought indices and testing which of these indices were relevant across different impact types and regions. Madadgar et al. (2017) linked drought indices with crop yield data to provide a joint distribution in the form of a two-dimensional probability space. In turn, this joint distribution (obtained using bivariate copula approaches) was used to estimate a distribution of crop yields for any set of environmental conditions (e.g., different percentiles of precipitation or soil moisture). Bachmair et al. (2017) recently tested the potential for developing empirical "drought impact functions" using drought indicators as predictors, and text-based reports on drought impacts as a surrogate variable for drought damage. They found that text-based reports provide useful information for drought risk management, and demonstrated different data-driven methodological approaches to develop drought impact functions. *A critical task for a South American DIS is the identification of linkages or associations between the values of various drought indices and indicators – and their temporal scales when appropriate – and the occurrence of specific impacts in drought-sensitive sectors.*

4.3.3 Building a Regional Archive of Drought Impacts and Costs

Establishing links between drought indices and impacts is likely to help substantially in the communication of drought risks and support decision-making. Nevertheless, an important limitation to these analyses is the difficulty in obtaining reliable drought impact information. Even in data-rich regions such as Europe, the lack of sufficient data often prevent identification of robust models linking drought indicators and impacts (Blauhut et al., 2015).

A desirable function of the planned South American DIS should be to gather information about impacts and costs of drought from all key sectors and groups affected by this phenomenon. The DIS should compile a regional curated archive of quantitative and qualitative information on historical and recent impacts of drought. Advances in communication technology should be fully exploited to facilitate the extraction of information on drought impacts and costs from multiple sources. For instance, electronic newspaper archives, websites, and social network postings must be regularly searched ("scraped") to identify reports of droughts and their impacts.

Examples of the type of drought impacts that should be logged for South America include: (i) reduced productivity of annual or perennial crops; (ii) drought-induced pest infestations or diseases, etc.; (iii) regional shortage of feed/water for livestock; (iv) shortages in municipal water supply and disruptions to water withdrawals; (v) reduced hydropower production; and (vi) impaired navigability of streams and waterways (reduction of loads, increased need for interim storage of goods at ports). The regional archive ideally should also include estimates of the costs associated with drought events throughout the region. Unfortunately, the site- and time-specific nature of droughts often lead to multiple and diverging methods of assessing comprehensively and accurately their impacts and costs. Cost estimates need to include both direct (e.g. reduced crop productivity) and indirect (e.g. increased food insecurity and poverty) impacts of droughts. Ultimately, any approaches proposed should allow comparison of drought costs and impacts between sites and across time (World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2017). As with other natural disasters, however, temporal trends in the frequency or cost of drought impacts should be interpreted carefully, as increasing trends may result from a larger number of reports in recent times – e.g., due to increased population or better communications. In contrast, decreasing trends in reported impacts may be tied to improvements in technology. For instance, when analyzing the performance of the crop Moisture Stress Index, researchers had to account for improvements in green technology (e.g., development of drought-resistant crops, changes in agricultural practices) and their effect on crop yields over the decades (Heim et al., 2003).

A useful template for a standardized and categorized collection of drought impact reports is the European Drought Impact Report Inventory, EDII (www.geo.uio.no/edc/droughtdb/). The EDII aims to compile knowledge on the impacts of historic and recent drought events from a variety of information sources in order to allow interdisciplinary drought research (Stahl et al., 2016). In the United States, the National Drought Mitigation Center operates the Drought Impact Reporter (DIR, droughtreporter.unl.edu), a tool that allows users to input and describe a drought impact they are experiencing. It also supplies summary information gleaned from news sources on U.S. drought (Brewer and Heim, 2011). A valuable example from South America is the DesInventar archive (https://online.desinventar.org) that was started in the 1990s to provide systematically collected inputs for studies on risks from and vulnerability to disasters in Latin America (Aguilar Muñoz et al., 2017). Unfortunately, DesInventar data currently do not cover Brazil.

The proposed regional archive of drought impacts will provide insights into the similarities and differences of drought characteristics and impacts throughout South America. In turn, these insights may help define possible region-wide common actions, as well as the need for tailored solutions to specific situations or contexts. Comparison of drought vulnerabilities among countries and sectors should be facilitated by the collection of common minimum datasets (Sivakumar et al., 2014). The archive will allow identification of sectors, areas, and population groups that are most sensitive to drought – one important component of the assessment of drought risks (see Section 4.3.1). The information gathered also will help researchers and resource managers to identify and model associations between values/thresholds of various drought indices and indicators, and the occurrence of specific impacts (Blauhut et al., 2015; Stagge et al., 2015). Finally, a curated regional archive of information on drought impacts and costs will help policy makers to show how investments in mitigation measures are paying off in the longer term through vulnerability reduction, as measured by reduced impacts and government expenditures on drought assistance.

4.4 Informing Preparedness, Mitigation, and Response

The overriding principle of drought policies is an emphasis on risk management through the application of preparedness and mitigation measures (Wilhite, 2016). In this context, *mitigation* refers to proactive measures that are identified and implemented that increase the resilience of an individual, population group, community, or nation and thus reduce the negative impacts of drought. Nations cannot be completely "drought-proofed," as drought is a naturally occurring phenomenon. Nevertheless, there are actions that societies can undertake to ensure that droughts do not erode hard-won economic growth and development gains.

Once (i) drought impacts have been prioritized and (ii) the corresponding underlying causes of vulnerability have been identified, a next logical step would be to identify the types and sequence of actions that are appropriate for reducing drought risks. That is, the planning process should focus on identifying viable mitigation actions that can be taken in advance or during the early stages of a drought. This stage, however, should be a process, not a one-time action: as results of initial actions are assessed, understanding grows, in turn leading to enhanced or new actions. This cycle of learning and action continues, leading to a progressive increase in drought resilience.

Drought risk reduction plans should be grounded on a thorough understanding of the timing and nature of decisions, as well as who makes those decisions (and how) in specific sectors and locations. This approach sets out the expected timeline of a drought crisis by plotting the sequence and timing of decisions, together with the livelihood and coping strategies people usually undertake, and the alternatives available given present and forecasted climate conditions. Understanding decision needs, contexts and existing protocols should help identify when particular interventions are appropriate and whether they can be delivered in time. The following sequence of questions may be helpful in identifying potential mitigation actions:

- Can the underlying cause for a particular drought impact be mitigated (i.e., can this cause be modified before a drought)? If yes, how?
- Can the basal causes of an impact be modified during or after a drought? If so, how?
- Is there some basal cause, or aspect of the basal cause, that *cannot* be modified and therefore must be accepted as a drought-related risk for this activity or area?

According to reports made during the workshop in Buenos Aires, advance planning and specific measures to mitigate drought risks are relatively uncommon throughout South America. An exception was the reported availability of agricultural insurance instruments in Brazil, Uruguay and Venezuela. In general most existing contingency plans or mitigation actions throughout the region fall in the realm of either general public policies (e.g., the diversification of energy sources to reduce vulnerability of the hydroelectric sector in Uruguay) or, alternatively, short-term emergency response or crisis management, rather than long-term mitigation or risk management. Emergency response is an important component of drought planning, but it should only be one part of a more comprehensive and proactive mitigation strategy. It was also pointed out in Buenos Aires that some countries in the region may have good emergency protocols, but they often apply to natural disasters in general, and not specifically to drought. For example, earthquake-prone Chile has a strong National Emergencies Office, but it has no explicit focus on drought. Finally, multiple participants in the workshop stressed the twin needs for (i) a clear set of regulations and empowerment of key agencies charged with drought response, and (ii) political will and strong leadership to initiate and guide the development and implementation of formal plans for drought risk management.

A session during the Buenos Aires workshop was dedicated to discussing the design of drought preparation and mitigation activities. One of the breakout groups came up with a very detailed list of possible preparatory activities for various drought-sensitive sectors. This list is shown in Table 1 for two important sectors in the region (agriculture and hydroelectricity generation) as an excellent example of the kinds of preparatory actions that this component of the planned DIS should identify. The possible actions intended to increase the resilience of systems to drought (improving soil quality, irrigation efficiency, water policies) and preparing for drought should be discussed as part of any outreach or education materials produced by a DIS.

4.5 Awareness, Outreach and Education

Drought information systems must be people-, location- and sector-centric. This implies that the information produced must be meaningful to people and activities at risk, leading to better informed and timelier decision-making. This component of a DIS, therefore, has two main functions. The first function is to bridge the proverbial gap between scientific evidence and policy- and decision-making (McNie, 2007) and foster a fruitful dialog between producers and users of information and knowledge about drought risks. The second goal is to develop and conduct a broad-based awareness and education program to provide decision-makers from drought-sensitive sectors with the skills and resources that would allow them to prepare and respond better to the occurrence of drought.

Table 1. Examples of planning or preparatory actions that could be undertaken in advance of the occurrence of drought events to mitigate the negative impacts of this phenomenon. Possible actions are listed for two of the main drought-sensitive sectors (agriculture and hydropower) in southern South America.

Agricultural production
Drill new irrigation wells
Enhance harvest of excess water through on-farm reservoirs or other means
Increase efficiency of irrigation systems
Foster policies for efficient water use
Insurance programs
Change land allocation (e.g., use more drought-tolerant crops)
Stock animal feed
Manage animal stocking rates (number of animals per area)
Generation of hydroelectric power
Monitoring reservoirs' status and bathymetry
Increase share of renewable energies (solar, wind)
Review operational procedures in hydropower plants, particularly those with mixed uses
Conduct communication campaigns to encourage reduction of energy consumption
Encourage use of newer, more energy-efficient appliances (e.g., air conditioning units)
Develop smaller, autonomous power plants for small-town or rural energy supply

Regarding the first goal, drought scientists are increasingly being asked to take new roles and responsibilities by co-producing knowledge with users to improve the uptake and practical use of scientific evidence. Unfortunately, most scientists often make a number of assumptions about what they think users need, without fully understanding the needs, limits, contextual factors or pressures faced by decision-makers. Moreover, scientists and users often have very different ideas about what constitutes usable or relevant information (Lemos, 2015; Porter and Dessai, 2017; Stalker Prokopy et al., 2017). Likewise, policy- and decision-makers in drought-sensitive sectors often have a relatively limited understanding of current scientific capabilities and limitations involved in addressing the risks associated with this hazard. Users of drought information may ignore new information because it does not fit with existing working practices, despite its potential usefulness. Ultimately, disappointment can ensue on both sides. Users are left frustrated that scientists have not listened to them, while scientists are left frustrated that their efforts to satisfy user needs go (largely) unappreciated (Porter and Dessai, 2017). *Therefore, a major challenge of the implementation process for a South American DIS is to help integrate the science and policy/decisions aspects of drought management among national institutions. This challenge can be met only through sustained interactions with stakeholders and frequent assessment of needs and capabilities taking advantage of all available communication technologies and media. A South American DIS should inform and facilitate such dialog.*

Improving education and ensuring timely and equitable access to information and encouraging citizen participation are key determinants of building resilience to drought (Aldunce et al., 2016). For this reason, the second goal of this DIS component is to develop and implement a broad-based program to raise awareness of the importance of preparedness and risk reduction for drought management. Recent research shows that while drought severity is the largest predictor of drought awareness, ideological and demographic variables also play a role (Switzer and Vedlitz, 2017). Moreover, an awareness program also should help to ensure that people know how to manage drought when it occurs, and that drought preparedness will not lose ground during non-drought years. Additionally, this task should address crucial requisites for public acceptance and implementation of a proactive drought policy. Drought awareness is actually a stronger predictor of concern for water shortages and support for water policy than drought severity, showing that understanding what determines drought awareness may be crucial for building policy support (Switzer and Vedlitz, 2017).

Participants in the Buenos Aires workshop suggested that outreach or training materials developed by a DIS should be tailored to the needs of specific groups and activities (e.g., small businesses, industry, water managers, agricultural producers, educators, utility operators). Moreover, they stressed that DIS communication efforts should be sustained in time (although they may be intensified before or during a drought event), and take full advantage of multiple media and formats (including social networks). Above all, an outreach effort should convey clear, consistent messages to audiences from drought-sensitive sectors.

5 Assembling a Drought Portal

The last function of a South American DIS discussed here is the development of a portal with state of the art, authoritative and relevant information about drought and its expected impacts. This information will include most of the items described in previous sections, such as drought monitoring and prediction products, likelihood of expected impacts, and underlying drivers of drought risks in different regions and activities. This information will be routinely updated in the DIS portal, from where it may be retrieved and disseminated further by Regional Climate Centers or any other interested governmental, non-governmental and private sector institution. To encourage frequent and sustained feedback about portal materials, all institutions and stakeholders accessing the information will be encouraged to get involved in the DIS as affiliates.

The information provided in the DIS portal is intended to inform the design and implementation of preparedness and mitigation actions to limit negative impacts from drought and to provide objective indicators of the state of water shortages throughout South America. This information may subsequently result in the legal declaration of a drought event, the issuance of early warnings, or the initiation of planned responses in specific regions and activities. These actions, however, will be the sole responsibility of national institutions and authorities. *It is important to note, therefore, that the proposed DIS will support – not replace – the activities of national, provincial, or municipal risk management, civil defense or disaster preparedness and response institutions.*

6 Governance Structure of a South American DIS

A critical step towards implementation of a South American DIS is reaching consensus on a set of overarching governance principles and on possible institutional models. A successful DIS requires a system of institutions, operational procedures, policies and a legal framework to guide, manage, coordinate and oversee implementation. The principles of good governance – inclusiveness, transparency, accountability, efficiency and responsiveness – must guide the DIS implementation process. Major requirements include (i) clarity and agreement on the division of roles and responsibilities among all involved actors; (ii) political/institutional legitimacy or mandate; and (iii) adequate resources. Additionally, to function effectively, the DIS governance structure needs to recognize the legitimate and distinctive roles of a broad range of participating actors.

The institutional model selected for a South American DIS should address the diverse needs and contexts of the many drought-sensitive sectors and groups in this region. Clearly, real progress in the production and dissemination of useful drought information only can occur through the involvement of those who stand to benefit from use of that information to mitigate negative impacts. For this reason, the institutional design chosen for a South American DIS not only should encourage the participation of a wide variety of stakeholders from different sectors and jurisdictional levels, but also provide a structure that promotes collective and shared efforts, allowing multiple groups to participate and cooperate in a decentralized manner. Consequently, one may envision the structure of a regional DIS not as a single, centralized institution performing all necessary functions but, instead, as a broad knowledge network encompassing multiple overlapping sub-networks of institutions or actors targeting different constituencies or sectors sensitive to drought.

An institutional model that was explored during the Buenos Aires workshop was a virtual institution that would rely mainly on existing structures to produce and disseminate most of the information needed. A possible DIS structure is illustrated in Figure 2. A small Executive Board (6-10 members) would provide strategic advice and project oversight. Board members should represent the main institutions or groups involved in the DIS. Strategic guidance from the Executive Board (EB) may be

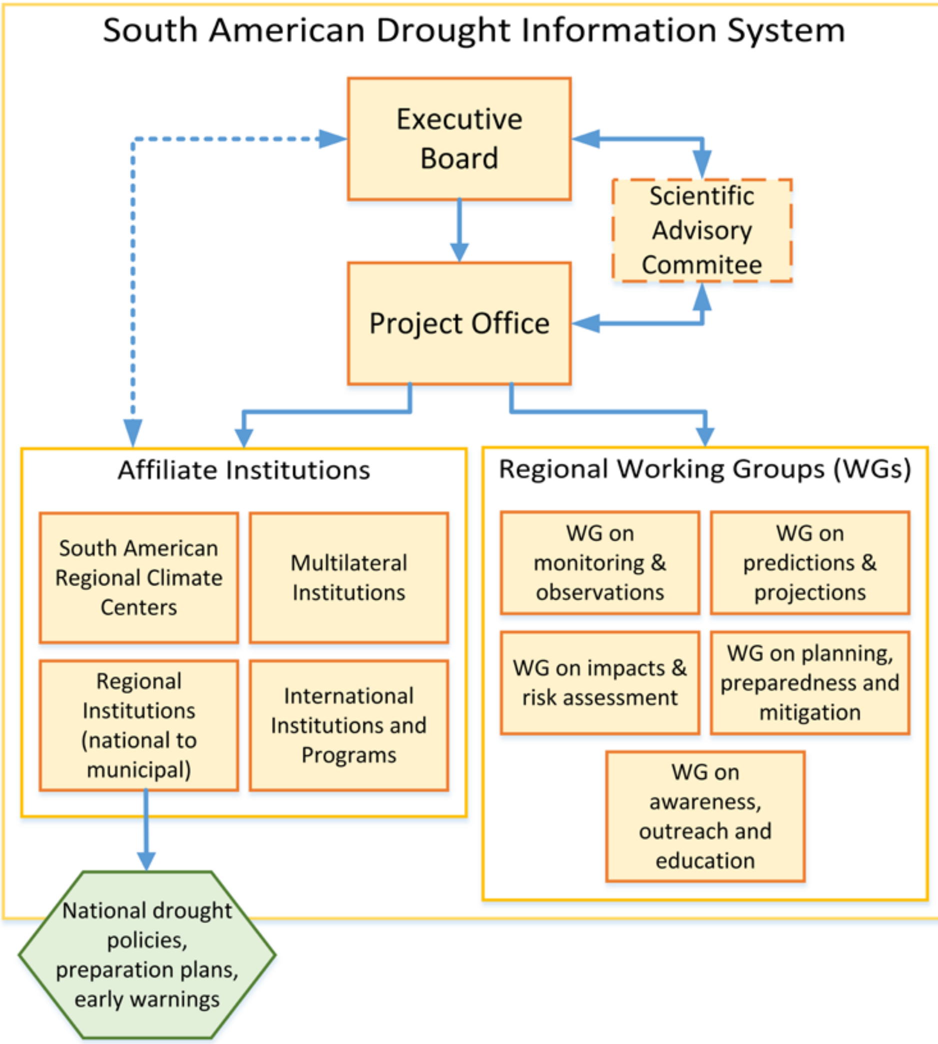

Figure 2. Proposed structure of a regional drought information system.

complemented by a Scientific Advisory Committee (SAC) that would provide specific technical expertise on the functions of the DIS. This component is shown as a dashed box in Figure 2 to indicate that it may be convened later in the implementation. Both the EB and the SAC should work with the DIS Project Office (see below) to conduct periodic assessments of DIS activities. A rigorous assessment process is essential for identifying and documenting lessons learned in order to improve the various stages of DIS implementation and enhance use of produced knowledge.

A Project Office would coordinate all activities and interactions, and provide overall management of the DIS. The Project Office should provide leadership and support functions relevant to the entire DIS, such as managing and disbursing DIS funds, organizing training and outreach efforts, leading the development of the DIS web portal, arranging meetings, preparing reports to members and funders, and representing the DIS at various regional and international fora.

As a virtual organization with little structure beyond a coordinating office, the planned South American DIS must necesarily rely on existing institutions to perform the necessary research and imlementation work. Because affiliate institutions may not be able to undertake the needed tasks with their own budgets, DIS funds (sought from various donors or contributors, see Section 5.3) may be dispersed by the DIS through a process of competitive grants or contracts. The protocols for soliciting, awarding and monitoring progress on work contracted by the DIS should be well-defined through a consensus process involving all member institutions. These protocols should be completely transparent and known by all involved. The Executive Board should monitor and guarantee compliance of protocols for awarding DIS contracts. The Project Office should be responsible for proactive oversight of all work performed through DIS contracts to ensure timely completion of the work.

As suggested during the Buenos Aires workshop, a regional DIS should build on the demonstrated strengths and already-established networks of the two existing and the one planned (in northern South America) Regional Climate Centers in South America. For this reason, Regional Climate Centers (RCCs) may provide the backbone of drought monitoring and prediction information. Nevertheless, effective drought risk management and preparedness requires the disciplinary or sectoral breadth provided by other types of institutions, agencies and programs at international, national or local levels. The "Affiliate Institutions" box in Figure 2 lists multiple types of institutions and groups that should be part of the DIS from the outset. The DIS should establish early on all necessary partnerships and collaborative agreements to ensure multi-level, multi-sector, and cross-scale knowledge exchange and resource sharing among actors and agencies.

The ultimate goal of the planned regional DIS is to provide authoritative and relevant information about drought to help national-to-local institutions responsible for risk management of natural disasters in South America to design preparedness and mitigation actions, issue early drought warnings, and initiate responses in specific regions and activities. In other words, the DIS will produce and disseminate information and tools needed by national institutions to prepare for, and respond to the negative impacts of drought. The implementation of drought preparedness policies, as well as the initiation of specific response actions (from issuance of early warnings to provision of emergency relief) remain within the jurisdiction of national, provincial or municipal risk management, civil defense or disaster preparedness institutions. To emphasize this point, Figure 2 shows that policies, plans and warnings are produced by national and sub-national institutions. Nevertheless, the DIS will produce information and guidance to help risk management institutions in member nations to perform their function.

Clearly, RCCs and national institutions tasked with risk management of natural disasters should be important participants in a DIS, but a broad range of affiliate institutions also should be engaged. Affiliate institutions may include academic and governmental research organizations, non-governmental organizations, international scientific agencies and programs and multilateral institutions that might support initial DIS activities (Figure 2). An important type of DIS affiliates should be intermediary or "boundary" organizations such as agricultural extension agencies or farmers' associations can help connect to the more distant nodes of a DIS knowledge network (Agrawala et al., 2001; Church et al., 2017; Stalker Prokopy et al., 2017). These institutions would provide a useful alternative to a linear, unidirectional model of transfer of scientific information, facilitating instead the multi-directional flow of information among institutions, scientists, and decision-makers (Cash and Buizer, 2005; Kirchhoff et al., 2013). A thorough survey of the institutional landscape in participating nations should allow identification of appropriate candidate DIS affiliates.

As part of the mechanisms to plan and carry out DIS-related tasks, several working groups (WGs) should be convened. Figure 2 shows possible WGs, each one associated with a major function of the DIS. A central mission of the WGs should be to identify knowledge gaps and identify opportunities to draw on research and practice to enhance drought understanding, risk management and preparation throughout South America. The WGs should also assess existing activities, products and resources that are available elsewhere and could be adopted by the South American DIS and subsequently disseminated to its membership. That is, the WGs should continuously strive to facilitate the transition from research results into operational use.

Early on in the DIS implementation, regional institutions will be approached for potential WG members. Existing WMO working groups for Region III (South America) may be a useful initial source of experts, but sustained efforts also should be made to recruit experts and actors from multiple sectors sensitive to drought. To this effect, regional organizations such as the Inter-American Institute for Global Change Research (IAI) – an organization that has supported global change science in the Americas for over 25 years – can play a role by helping the DIS to draw on its established network of experts from multiple disciplines. WG membership should have a manageable number of members (12-18) and balance expertise, geographic distribution, institution type (academic, NGOs, governmental), and jurisdiction level for governmental agencies. Each WG should appoint a group coordinator (or possibly two co-coordinators) for a term sufficiently long (e.g., 24 months) to allow learning and provide continuity of group oversight. Coordination, communication, and transferability of information and actions among the DIS WGs is essential to the overall process of building a collaborative information system. Regular communication and exchange of information among DIS WGs and affiliate institutions should be supported by the Project Office to ensure meaningful engagement and effective collaboration on action items.

A different perspective is shown in Figure 3, where different types of affiliate institutions are organized by spatial scale or jurisdictional level. The figure emphasizes the flow of drought information and knowledge among all these scales/levels. The DIS implementation plan should identify key players at each of these levels and develop procedures or protocols to engage them early on in the process.

The WMO Regional Climate Outlook Fora (WMO RCOF) should be part of a regional DIS institutional design, as they provide useful venues to raise awareness and foster participation in drought preparedness and mitigation efforts. The Fora bring together national, regional and international experts who review conditions and develop climate outlooks (www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html) primarily based on El Niño – Southern Oscillation (ENSO) forecasts and teleconnections. These Fora are now central to implementing the Global Framework for Climate Services (GFCS) and thus can be useful in the context of a DIS. As ENSO conditions develop in a particular year, the WMO coordinates the development of a global scientific consensus, involving a collaborative process to review best available evidences and predictions. Although the Climate Outlook Fora often seek the participation of climate-sensitive interests, many times this participation is minimal and only takes

Figure 3. Flow of drought information and knowledge across DIS member institutions at multiple spatial or jurisdictional scales. The figure lists examples of the types of relevant entities in each scale/level.

place during a forum. In contrast, many of the key functions of a drought DIS described above (e.g., the quantification of associations between drought indices and likely impacts, or the design of viable mitigation responses) will require the sustained involvement of those affected by droughts.

6.1 A Consensus DIS Data Policy

The central purpose of a South American DIS is to produce and disseminate useful information to help prepare for and mitigate the negative impacts of droughts. A fundamental principle of a South American DIS should be the free availability of any derived products or information generated by the system. The DIS will generate specific drought products and information (e.g., various drought indices or indicators) for the region, and will collect, synthesize and interpret information from multiple sources. Nevertheless, the DIS will not operate any observing networks and will rely exclusively on data collected by associated institutions such as national meteorological and hydrological services, hydrological and agricultural agencies, international collaborators, etc. A common data exchange protocol should be established to facilitate collation of data from multiple countries/agencies. A common format also would allow easy sharing of processing and analysis tools (e.g., R or Python scripts to estimate a particular quantity).

One sensitive issue is the fact that some of the institutions that may provide data to a South American DIS have set limitations on the open distribution of data they collect. *To address these* *limitations while, at the same time, ensuring the open and free availability of the products generated by the South American DIS, a consensus data dissemination policy must be clearly defined for the system.* The need for a consistent, transparent and well-communicated data policy for a South American DIS is an issue that surfaced repeatedly during the Buenos Aires workshop. To respect some nation's restrictions on open dissemination of raw *in situ* observations, a viable data policy may follow the protocol currently agreed on by South American RCCs. Derived or computed quantities (e.g., drought indices) and aggregated climate statistics (e.g., the number of rain days per month in a given station) can be openly distributed, but raw daily data must be requested from the institutions collecting the data.

6.2 Financial Sustainability

Ensuring long-term financial sustainability of a DIS should be a major consideration in the planning. Experiences from other regions (e.g., the United States) show that investments in drought-related science, technology, and information systems have been key to enhancing and expanding the quality and range of drought monitoring and forecasting products. The research activities will benefit from the participation of all institutions involved in a DIS, but financial support will be needed to support activities that are currently not included in the operational missions of participating institutions (an important example is the need to sustain communication and interactions among institutions to design, coproduce, and disseminate drought information).

7 Proposed Initial DIS Activities by Component

7.1 Monitoring

- Inventory data quantity and quality from current meteorological and hydrological observation networks throughout the target region. Define common minimum datasets.
- Survey the satellite-derived products currently used throughout the region to monitor drought and/or its impacts.
- Develop a prioritized list of satellite-derived variables or indicators that are not currently used but should be part of a Drought Information System. Define responsibilities for processing and disseminating each of the listed data sets. Determine institutional capabilities and training needs to deal with these data.
- Survey current use of land surface models to monitor drought throughout the region.
- Survey the various drought indices (*in situ*-, model-, and satellite-derived) that are currently used throughout the region to monitor drought or its impacts.
- Develop a prioritized list of drought indices that *are not* currently used but should be part of a Drought Information System.
- Define protocols and responsibilities for producing and disseminating each of the indices.
- Develop a consensus data policy defining guidelines for access to all data compiled and developed by a regional DIS.
- Establish a network of observers to gather impact information from all of the key sectors affected by drought and to create an archive of this information.

7.2 Drought Prediction and Early Warnings: Action Items

- Survey statistical and dynamic methods used in the region for sub-seasonal to seasonal climate prediction.
- Provide a rigorous framework for assessment of the appropriateness and skill of different climate forecasting methods in different regions/times of year.
- Survey existing procedures to forecast drought indices throughout the region.
- Survey existing administrative or legal procedures and criteria used to declare a drought in the target region.
- Recommend procedures to define site- or sector-specific criteria for declaring drought emergencies and triggering various levels of mitigation and response activities.
- Facilitate and inform collaborations and interactions with stakeholders to design appropriate triggers for each region and sector, based on specific management priorities and system thresholds.
- Ensure consistency among trigger values for multiple indices.
- Assess the advantages or disadvantages of "hard" vs. "soft" triggers for the diverse contexts of the target region.

7.3 Drought Impacts and Risk Assessment: Action Items

- Survey all mechanisms currently used to communicate drought to stakeholders in the various countries of the target region.
- Assemble a ranked or prioritized list of relevant drought impacts for different places and activities throughout the target region.
- Survey linkages or associations between the values of available/planned drought indices and indicators, and the occurrence of specific impacts in drought-sensitive sectors. If no such studies are available, undertake research to assess such linkages.
- Establish a network of observers to gather and report information about ongoing impacts of a drought. Create and maintain an archive of this information with standardized and geo-located impacts.
- Define necessary steps for an initial analysis of drought risk in key sectors/regions of South America. Include assessments for data requirements for all risk components: hazard, exposure and vulnerability.
- Assess various drought risk assessment models, their data requirements and scale, and their relevance for decision making and drought planning.

7.4 Preparedness, Mitigation, and Response

- In close collaboration with stakeholders from a region or activity, identify viable mitigation actions, i.e., actions that can be taken in advance or during the early stages of a drought in order to reduce the impacts of the event.

- Develop region- and sector-specific decision calendars – i.e., a list of the timing and nature of decisions.
- Use decision calendars to define when particular interventions are appropriate during an ongoing crisis, and whether these interventions can be delivered in time.
- Develop system- and sector-specific contingency plans - e.g., each water supply system will have its contingency plan, establishing what action should be undertaken according to the triggers defined for that particular system.
- If unavailable, conduct research to identify factors defining the vulnerability of a region or sector to drought (including socio-economic factors).
- Evaluate the effectiveness of index insurance to mitigate drought impacts on small farmers in the region or other highly-vulnerable groups or activities.

7.5 Awareness, Outreach, and Education

- Identify outreach partners, relevant organizations (including appropriate points of contact) and DIS "champions" to establish early collaboration with sectors/actors affected by drought.
- Formalize necessary partnerships; clarify mutual expectations/responsibilities.
- Design an awareness strategy, including active presence in social networks, etc.
- Identify training needs and develop a training strategy (including identification of financial resources).
- Develop objective procedures/protocols to assess the success of awareness and outreach efforts.

7.6 Development of a Drought Portal

- Develop early prototypes of the content and design of a DIS drought portal. Iterate pilot designs with multiple types of stakeholders.
- Develop documentation, examples and tutorials for all data and products included in the DIS portal.

7.7 DIS Governance

- Assemble Executive Board and define initial governance design and procedures.
- Survey and identify institutions in each country of South America that are relevant to the issue of drought.
- Encourage relevant regional institutions to become DIS affiliates. Establish the necessary agreements to formalize their participation.
- Identify potential members of the various Working Groups.

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The agenda, presentations, and a list of participants in the August 2017 Buenos Aires workshop can be found at the following links:

http://www.wmo.int/pages/prog/wcp/agm/meetings/sadm17

http://www.crc-sas.org/es/cursos.php .