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Technical Report Series on Global Modeling and Data Assimilation, Volume 41

Randal D. Koster, Editor

GDIS Workshop Report

Siegfried Schubert, Will Pozzi, Kingtse Mo, Eric F. Wood, Kerstin Stahl, Mike Hayes, Juergen Vogt, Sonia Seneviratne, Ron Stewart, Roger Pulwarty, and Robert Stefanski

National Aeronautics and
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Greenbelt, Maryland 20771

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GDIS Workshop Report

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I. Overview of the Workshop

The workshop "An International Global Drought Information System Workshop: Next Steps" was held on 10-13 December 2014 in Pasadena, California. The more than 60 participants from 15 countries spanned the drought research community and included select representatives from applications communities as well as providers of regional and global drought information products. The workshop was sponsored and supported by the US National Integrated Drought Information System (NIDIS) program, the World Climate Research Program (WCRP: GEWEX, CLIVAR), the World Meteorological Organization (WMO), the Group on Earth Observations (GEO), the European Commission Joint Research Centre (JRC), the US Climate Variability and Predictability (CLIVAR) program, and the US National Oceanic and Atmospheric Administration (NOAA) programs on Modeling, Analysis, Predictions and Projections (MAPP) and Climate Variability & Predictability (CVP). NASA/JPL hosted the workshop with logistical support provided by the GEWEX program office.

The goal of the workshop was to build on past Global Drought Information System (GDIS) progress toward developing an experimental global drought information system. Specific goals were threefold: (i) to review recent research results focused on understanding drought mechanisms and their predictability on a wide range of time scales and to identify gaps in understanding that could be addressed by coordinated research; (ii) to help ensure that WRCP research priorities mesh with efforts to build capacity to address drought at the regional level; and (iii) to produce an implementation plan for a short duration pilot project to demonstrate current GDIS capabilities. See http://www.wcrp-climate.org/gdis-wkshp-2014-objectives for more information.

The first day (Dec 10) of the workshop was a limited-attendance joint session between GDIS and the GEWEX Hydroclimatology Panel (GHP) devoted to advancing GHP and GDIS collaborations. The second day (Dec 11) focused on GDIS drought science -- papers submitted to the Journal of Climate special collection "Global Drought Information System - Drought Characterization, Occurrence, Driving Mechanisms, and Predictability Worldwide" (http://journals.ametsoc.org/page/GDIS) were reviewed, and various discussions focused on gaps in our understanding of drought mechanisms and predictability, as well as on limitations in our ability to monitor and forecast drought. The third day focused on global and regional drought monitoring and prediction capabilities and needs and included presentations from representatives of key regional drought centers from around the world. Day 4 (Dec 13) addressed the necessary next steps required for moving forward with the development of an experimental real time global drought monitoring and prediction system, consisting of both global providers of drought information and regional pilot studies. The objectives/goals and agenda, along with links to all presentations, may be found at the workshop website:

(http://www.wcrp-climate.org/gdis-wkshp-2014-agenda)

Appendix A of the present report contains a post-workshop press release that briefly summarizes the workshop's main findings. Appendix B summarizes the outcomes of the three breakout sessions. In the following sections, we summarize the workshop and review its outcomes in more depth.

II. Summary of the Joint GHP/GDIS session

Much of joint GHP/GDIS session was devoted to a review of the various GEWEX Regional Hydrological Projects (RHPs), with a focus on drought. GDIS representatives also discussed drought monitoring and prediction activities throughout the world.

Collaboration between GDIS and GHP was discussed in the context of the WCRP Grand Challenges, particularly those on "Changes in Water Availability" and "Climate Extremes". In fact, a key GEWEX science question concerns how a warming world affects climate extremes, and especially droughts, floods and heat waves.

Drought was also mentioned as an important cross-cutting theme that integrates many of the GHP regional hydrological projects and allows a synthesis of the regional drought information at the global scale. As such, GDIS can be an important partner to the various GHP regional projects, with the GDIS pilot projects being a natural point of coordination and collaboration between the GHP and GDIS. In particular, it was noted that the RHPs could help with data issues and improved understanding of the relationships between drought behavior in different regions. Section VI of this report ("Key Outcomes and Action Items") lists some of the RHP projects that could contribute to GDIS as potential pilots for the planned experimental global prediction and monitoring system discussed during day 3 of the GDIS meeting (Section V).

III. Day 1 of the GDIS Workshop: A Scientific Assessment of Drought World-wide

Day 1 started with a review (by S. Schubert) of the three workshop goals (noted above). Each goal was the focus of one day of the workshop: day 1 was devoted to a review of current understanding (focusing on the papers submitted to the JCLIM GDIS special collection on drought) and discussions of research gaps; day 2 was devoted to an appraisal of regional and global needs and capabilities; and day 3 was devoted to moving forward with plans for a limited duration demonstration of a global real time monitoring and prediction capability (with regional pilots playing a central role).

R. Pulwarty presented an overview of current monitoring and prediction capabilities. He highlighted NIDIS and various related efforts throughout the world, including the Global Framework for Climate Services. He emphasized the cross-scale nature of drought, the importance of early warning information, and the corresponding monitoring/prediction, research and response needs. He noted that while there is already extensive engagement on observations and monitoring, the current availability and quality of climate observations and impacts data are, for large parts of the globe, too inadequate to support climate adaptation and support proactive drought management policies for the local population.

The rest of the morning and early afternoon was devoted to a review of the papers submitted to the JCLIM special collection on drought (http://journals.ametsoc.org/page/GDIS). The reader is referred to the website (http://www.wcrp-climate.org/gdiswksp/GDIS_Dec14Wkshp_Agenda.pdf) for the relevant presentations, which describe our understanding of drought in various regions of the world including North America, Australia, Northern Eurasia, the Middle East and Southwest Asia, East Africa, South America, East Asia, Europe, India, and West Africa.

The late afternoon was devoted to special topics and key research gaps. The presentations focused on land coupling (R. Koster), internal versus forced variability (M. Hoerling), and current and future capabilities for monitoring drought (J. Sheffield).

Randy Koster reviewed some of the key aspects of land coupling, noting that it is the memory of soil moisture through which an initial soil moisture anomaly can influence weather variables at subseasonal to seasonal leads. Furthermore, he noted that the connection between soil moisture and the atmosphere seems to be strongest in transition zones between dry and wet areas. In fact, soil moisture has been shown to contribute to (modest) skill in subseasonal precipitation and temperature forecasts in those regions. Land impacts may differ depending on SST or climate regime, and recent work indicates that certain land-atmosphere feedback mechanisms allow remote soil moisture anomalies to affect local precipitation and temperature. Other topics discussed include the impact of vegetation phenology's memory on forecast skill, streamflow forecasting via soil moisture initialization, and new satellite-based sensors (in particular SMAP) that should provide new and valuable data for drought monitoring and prediction.

Marty Hoerling focused on the role of the oceans in recent (1979-2013) trends toward drought and the implications for the predictability of drought regimes. He noted that the observed warming of the Pacific warm pool is likely inconsistent with predictions of coupled model (e.g., CESM1) internal variability, pointing to the need to better understand the causes and predictability of warm pool SSTs, as well as its impacts on global drought. In contrast, observed cold tongue cooling is more consistent (though just barely) with the internal variability of the CESM1 model, but this again highlights the need to assess the decadal predictability of, in this case, the cold tongue SSTs. Taking the entire tropical Pacific basin into account, he underscored the need to better understand the impact on drought of variations in the zonal SST gradients across the tropical Pacific. He particularly noted that drought has been observed to increase in frequency and severity over southwestern North America and the Greater Horn of Africa and that we don't yet have a causal interpretation of such regional drought increases.

Justin Sheffield focused on current and future capabilities for monitoring drought. His overview examined variations in regional monitoring needs and capacities, the availability of tools and data for monitoring, and challenges for the future. He stressed that current global capabilities involve an increasing reliance on remote sensing and hydrological models. He reviewed current and future remote sensing products including remotely sensed precipitation, vegetation stress, surface water storage, evapotranspiration, soil moisture and snow. He also reviewed the various global, regional and national modeling efforts. He noted that a key challenge is to better understand the utility of the various datasets for drought monitoring. Questions to consider include: Are we measuring everything we need? Do we have the necessary resolution and timeliness? Is there data continuity and sufficient record length? How do we merge the various datasets? How do we plan for new and upcoming remote sensing missions that may transform drought monitoring? How do we assess products globally?

IV. Day 2 of GDIS: Regional Needs and Capabilities

Bob Stefanski discussed the wide range of WMO-sponsored drought activities, with a focus on building regional capacity. Regarding the link to GDIS, he noted that global drought research and forecasting is important (linking to WCRP, the Subseasonal to Seasonal Prediction Project (S2S), and the Global Framework on Climate Services Climate Information System (GFCS-CSIS)). He also pointed out that it is important to link to existing projects and capacity development at regional/national scales. Potential users/partners include the Regional Climate Centers/Regional Climate Outlook Forums (RCCs/RCOFs), the UN World Food Program and Food and Agricultural Organization (WFP, FAO), the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), FEWSNET, and the Group on Earth Observations Global Agricultural Monitoring initiative (GLAM). He also pointed to the need to address data issues at several levels (in partnership with GFCS, WMO Integrated Global Observing System *(*WIGOS), and GDIS).

Doug Cripe (GEO Secretariat) discussed the international context for the Global Drought Information System. He noted that the priorities for GEO post-2015 are to address urgent global challenges, support sustainable development, and build on the accomplishments of GEO. In particular, the GEO strategic plan (2016-2025) is intended to implement GEOSS (the Global Earth Observation System of Systems). There are three action areas with strategic objectives: 1) to advocate the value of Earth observations, 2) to engage stakeholder communities, and 3) to deliver data, information and knowledge in order to enable stakeholders to improve decision-making, among other things. He emphasized the need to share water data as part of the water security and global water agenda, and using the GEOSS Portal to connect to the various community portals and other resources. He also suggested that GDIS become allied as a GEO initiative, as part of the effort to address grand challenges.

Will Pozzi discussed expectations and outcomes of an experimental program. He reviewed the basic structure of the proposed real time monitoring and prediction system, which would consist of a global system that interacts/engages with various regional pilots to provide value added products and obtain feedback on the quality and usefulness of the global products. He emphasized the link to the global framework of climate services and the WMO regional climate centers (RCCs). This included reviews of the status of the RCCs in South America, as well as current capabilities in Africa and the Drought Management Centre for Southeastern Europe (DMCSEE). He closed with an overview of the proposed structure of the afternoon breakout sessions (with topic points also developed with Jürgen Vogt and Paulo Barbosa).

The next four talks dealt with regional needs and capabilities and possible pilot programs focused on South America. Lisa Alexander discussed the Expert Team on Climate Risks and sector specific Climate Indices (ET-CRSCI), which also is developing drought climate indices. The advantages of a mutual partnership with GDIS were discussed, with specific attention paid to the ET-CRSCI pilot workshop in Western South America (WSA), held jointly in coordination with Centro Internacional para la Investigacion del Fenomeno de El Nino (CIIFEN, the Western South American designated Regional Climate Center). She reviewed the ET-CRSCI terms of reference, which include developing tools to generate sector-specific climate indices, promoting their use with global consistency, developing training materials, and facilitating the use of climate information in users' decision-support systems. She gave as an example the CLIMDEX project aimed at producing in situ and gridded land-based global datasets of indices representing climate extremes. She noted that the ET-CRSCI pilot workshop was modeled after the Expert Team on Climate Change Detection Indices (ETCCDI) regional workshops (which had carried out more work on precipitation and temperature indices and less on drought per se). These workshops are unique, since actual National Meteorological and Hydrologic Service (NMHS) representatives bring their agency data to the workshops and learn while testing them for homogeneity in setting up climate indices. She noted that there is significant value in producing sector-relevant indices but that data are sparse on daily and sub-daily time scales in many regions. Many countries are, however, willing to exchange indices, so the approach must be consistent, and this must be an on-going activity. The next steps include a reassessment of indices (including new indices for seasonal/decadal forecasts), developing ClimPACT2.0 software for calculating the indices, and continuing to build up a network (data and people) in the Western South American region.

Julián Báez Benítez discussed the Southern South American Regional Climate Centre (RCC). The RCCs will be complementary of and support the various National Meteorological and Hydrological Services (NMHS). The Regional Climate Centres of Region III WMO RA-III consist of RCC-SSA (Southern South America), RCC-WSA (Western South America (CIIFEN), RCC-NSA (Northern South America excluding Colombia and Venezuela, which fall within WSA). The RCC-SSA is comprised of an executive committee (directors of the NMHSs) and 4 working groups encompassing data management, IT infrastructure, training and capacity building, and research activities. The demonstration phase of the RCC-SSA consists of developing a climate atlas, climate prevision (forecasts), monitoring, and applications. Several activities were reviewed including the RCC work to improve data from operational meteorological stations (1961-present), and the Inter-American Institute (IAI-CRN 3035) research program to improve products and processes related to climate services focused on users. He also prefaced Natalia Herrera's succeeding talk about the nature of the drought management activities to be carried out regionally within Southern South America, as part of the RCC.

Natalia Herrera presented maps illustrating station locations for use in drought monitoring within the RCC-SSA. She noted that Argentina and Brazil are the *responsible* countries, whereas Paraguay and Uruguay are *member* countries, and Bolivia and Chile are *partner* countries. The station network consists of 338 stations from these countries with a focus on the period 1961-present. At present, the data includes only daily maximum and minimum temperature and total precipitation, even though some institutions have contributed additional variables, with data updated every 10 days. She described the quality control and homogenization of the data. The key products consist of various drought indices with drought monitoring maps becoming available in early 2015. She also spoke of efforts to improve soil moisture monitoring. She briefly discussed Argentina Servicio Meteorologico Nacional (SMN) efforts to develop modeling and data assimilation capacity based upon use of the NOAA LSM. She concluded by mentioning some of the needs to further improve regional drought monitoring: more surface observations, better description of soil types and land uses, more measurements of soil moisture, increased use of satellite data, improved integration of regional networks, and improved local and regional institutional communication.

Luis Gustavo Goncalves (Centro de Previsao de Tempo e Estudos Climaticos/National Institute of Space Research) spoke about regional drought monitoring and predictive needs and links to early warning communities in Brazil and surrounding regions. The talk provided an overview of CPTEC/INPE, the South American Land Data Assimilation System, and current South American drought monitoring. He described some of the historic droughts in Brazil and also provided a broader view of historical droughts that have occurred throughout South America. In particular, three drought were identified that each covered about 50% of South America, with the years 1963-1964 characterized by the most severe drought in the past 50 years. He noted that CPTEC is one of WMO's Global Producing Centres for long-range forecasts (GPCs) that operationally run a number of models including an Atmosphere General Circulation Model (AGCM), a coupled Atmosphere-Ocean General Circulation Model (AOGCM), and regional and environmental numerical models. Furthermore, a drought prediction system for South America based upon CPTEC's seasonal forecast is under development that is based upon the meteorological drought approach (constructing SPI from merged monitored and forecasted precipitation).

The next two talks dealt with regional needs/capabilities and possible pilot projects focused on Africa. Chris Funk (with Gideon Galu of East Africa) (US Geological Survey and Famine Early Warning System-Net) spoke about an integrated drought prediction system for East Africa (EA) to support food security. Chris reviewed the activities and components of the FEWS NET drought information system. These include the development of centennial trends datasets, gradient based predictions, process understanding using GFSv2 and CESM, and integrated soil moisture (LSM) predictions. They have also recently begun including SPI maps. East Africa has been the focal point and a testbed for work of the Food Security and Nutrition Working Group (FSNWG) involved in classifying and providing justification for drought declarations during the most recent Horn of Africa drought, particularly in areas where nation states are not effectively present (Somalia). Hence, this could serve as the basis for an East African GDIS pilot. He reviewed some of the new cutting-edge research being carried out in the above areas including a comparison of various trend datasets, the use of model simulations to better understand the role of SST forcing, and the development of combined statistical and dynamical climate forecasts. He noted that integrating observations, forecasts, and LSMs offers great potential for drought prediction, but that global information products need to be tested carefully against local conditions on the ground.

Micha Werner (Coordinator of the European Framework project Drought Early Warning System for Africa, or DEWFORA) discussed drought forecasting and warning in Africa, based on experiences from the DEWFORA project. DEWFORA was key in providing funding for the initiation and development of meteorological drought forecasting activities at the European Centre for Medium-range Weather Forecasting (ECMWF), activities that were then tested over Africa. The approach is evidence-based, focusing on the available science, societal capacities, translating the science into policy, and identifying how society can benefit from forecasts. He presented a case study for the Limpopo Basin, addressing the questions of whether we have the science to produce skillful hydrological forecasts, and whether these forecasts are useful to water managers. He described three different forecasting systems using the same hydrological model forced by different meteorological forecasts. The results suggested that hydrological drought indictors can be predicted with skill up to 5 months in advance for the wet season and that the forecasts can be used, for example, by reservoir operators and irrigation districts to plan curtailments and implement demand reduction actions. He also addressed the question of whether seasonal forecasts across southern Africa will gain importance in the future as a result of climate change. The results of a Greater Horn of Africa case study suggested that a drought vulnerability index can be applied but that it is scale and country dependent; several improvements can still be made. He also briefly reviewed DEWFORA-developed tools that have been transitioned to the Joint Research Centre African Drought Observatory (edo.jrc.ec.europa.eu/ado/ado.html).

The next three talks reviewed regional needs/capabilities and possible partners for testing GDIS global products through a testbed or pilot project. Yaohui Li (Institute of Arid Meteorology (IAM), China Meteorological Administration) briefly reviewed the IAM, discussing three main themes: drought research linked to operations, the expected relationship with GDIS, and future efforts underway in China. The research centers on drought monitoring and risk assessment and on extensive field experiments focusing on land surface processes and the atmospheric boundary layer. He described several new approaches to drought monitoring developed by the IAM (including efforts to use hyperspectral remote sensing data), and he presented several examples of their use. Drought monitoring efforts are based on the CABLE land surface model, and comparisons were shown with other models. He also described efforts to quantify drought risk in different parts of China as well as a testbed for techniques for developing an operational drought monitoring system. A number of field experiments were described covering a number of key areas (with varying climatological conditions) throughout central China including the Tibetan Plateau. A preliminary focus in the partnership with GDIS has been comparative testing of the CABLE and NOAA/Center for Climate Prediction Global Land Data Assimilation System (GLDAS) land surface models. There is much interest in developing a close collaboration with GDIS (he also noted that they already have close ties with CPC and EMC). They would like to become formal participants in GDIS, emphasizing that the relationship should be bidirectional, with clearly stated goals.

Albert van Dijk (Australia National University and CSIRO) discussed drought information in Australia. He noted that 4 in 10 Australians see drought and water shortage as the greatest problem facing rural Australia, and that 2 in 3 Australians consider the Federal government responsible for solving it. Drought information can serve as a basis for drought declaration and assistance within the agricultural sector, support media and public debate about drought (e.g., is it fair to assist those affected, role of climate change), and help in planning ahead. Drought information is currently provided by the Bureau of Meteorology, ABARES (Australia Department of Agriculture Bureau of Agricultural and Resource Economics), CSIRO and State agencies. There are multiple information systems used, including gridded climate data (BoM), AVHRR NDVI (BoM), Australian Water Availability Project (AWAP, CSIRO) soil water balance model, and Water Resources Assessment system (AWRA, BoM)-full water system model (soil-river-ground water). Not yet routinely used are remotely sensed soil moisture and GRACE. He summarized the following about drought information:

- Main use of drought information is for rural assistance
- Monitoring focus is on return times and 'record' droughts
- Profoundly politicized
- Seasonal outlooks becoming more useful
- Public service funding cuts causing rationalization of operational systems

He further noted the following R&D priorities:

- Drought impact cascade and drought resilience
- Water□energy□food nexus and policy design
- Decadal variations – natural and man□made
- Compound events (heat waves, bushfires)
- Integrating satellites into monitoring (soil moisture, GRACE, vegetation)
- Seasonal forecasting of drought and agricultural impacts

Possible contributions to the GDIS include:
- Interest on the part of Bureau of Meteorology in partnering with GDIS, providing drought monitoring (gridded rainfall and AWRA model water balance) and seasonal outlooks (ENSO, rainfall, steamflow), among other products.
-Asia-Pacific Water Monitor: drought monitoring (rainfall, modeled water balance)
-GEWEX OzEWEX (Australian Energy and Water Exchange initiative) RHP: GDIS science priorities, pilot evaluation

Gregor Gregorič (Republic of Slovenia Environmental Agency) talked about the activities of the Drought Management Center for SE Europe (DMCSEE, originally coordinated as one of the first regional centres by WMO). He noted that DMCSEE consists of a network of 14 SEE countries. They have had 11 international workshops and training sessions, they publish a drought bulletin, and they promote project frameworks. A main focus of their work is to monitor drought using Numerical Weather Prediction (NWP) models. The idea is to take data from an existing global archive, then to choose an area and resolution, define the grid, and re-simulate weather patterns from the global model to obtain details on a regional scale. An example was presented using the NMM (NCEP) non-hydrostatic meso-scale limited area model and ERA-interim reanalysis. He also gave several examples of drought monitoring using remote sensing products, the EUMETSAT Satellite Application Facility on Land Surface Analysis (LSA-SAF), and the drought Bulletin for SE Europe. He outlined the Global Water partnership Integrated Drought Management Programme – a global initiative supported by WMO with Central and Eastern Europe selected as target regions. He also noted that a small subset of DMCSEE products is already available through the European Drought Observatory (EDO).

Three early afternoon breakout sessions to discuss partnerships over South America, Africa and other regions (see Appendix B) were followed by a plenary session to discuss the breakout session outcomes and to discuss global and regional needs and capabilities. Detailed results of the breakout sessions are provided in Appendix B. Overall there was much interest expressed in participating in the GDIS, including interest from South America (the three regional climate centers), China, Australia, South-Eastern Europe, South and Southeast Asia, and Africa. The NIDIS portal could also play an integral role, housing the data protocols established in each region for sharing global and regional drought information and ancillary supporting information. The NIDIS portal could also host supporting collaborative software. The details about the contacts for potential pilots are provided in the conclusions/summary section. It was also noted that a large number of other efforts are already on-going (e.g., drought watch, EuroCLIMA, EDO, GEOSS, etc.) and that we need to build on them.

Presentations on global capabilities included a talk by Dennis Lettenmaier (University of California, Los Angeles) on the near real-time multi-model GLDAS, a talk by Eric Wood on drought monitoring and forecasting systems for Africa and the globe, a talk from Emanuel Dutra (presented by Will Pozzi) on ECMWF probabilistic monitoring and seasonal forecasting of meteorological drought, a talk by Henny van Lanen (European Framework project Drought: Research and Science Policy Interfacing, or Drought-R&SPI) on drought in the WATCH multi-model ensemble, a talk by Mike Ek (NOAA NCEP) on the operational North American Land Data Assimilation System (NLDAS) and the extension to GLDAS, a talk by Jin Huang (NOAA CPC) on the North American Multi-Model Ensemble, a talk by Jinyoung Rhee (APCC) on the APCC multi-model ensemble seasonal prediction system, a talk by Anna Maidens (UK Met Office Hadley Centre) on GloSea5: the Met Office high resolution global seasonal forecasting system, and a talk by Annarita Mariotti (NOAA, CPO) about the NOAA Drought Task Force (DTF) with a focus on lessons learned, including lessons of possible relevance to GDIS. These talks highlighted the wide array of global capabilities that are potentially available for the real time GDIS monitoring and prediction system. The challenge will be to engage the relevant organizations in partnerships, with an initial focus on their participation in a limited duration experimental system that involves interactions with the regional pilots (see Section VI).

V. Day 3 of GDIS: Regional Pilots: The Way Forward

Day 3 of the GDIS meeting was devoted to defining the path forward to developing a limited duration (1-2 year) experimental GDIS real time monitoring and prediction system. Kingste Mo began the morning session by outlining a proposal for the GDIS pilots. She outlined the goals of the pilots, which include: (i) integrating global and regional drought information, (ii) establishing mechanisms for real time dissemination and user interactions, (iii) the joint development of products for regional applications, and (iv) the establishment of partnerships for long-term drought-related activities including risk management. She outlined the benefits for the information/data providers, for researchers and for the regional pilots. She further discussed the challenges faced in creating a successful GDIS pilot, including the needs for real time drought information, the global drought portal, partnerships, and communication among the pilots and between the pilots and the GDIS community. She then outlined specific steps toward the development of the experimental pilot program. A key aspect is the idea of equal partnerships with regions that have the capacity for drought monitoring and prediction, and building working relationships for those with limited capacity. Finally she outlined specific actions to take, including: (i) producing a survey of data availability and establishing a protocol for data providers (a data survey form is on the web), (ii) establishing protocols for the pilots and hosts and getting institutional commitments, (iii) establishing formats and ways to communicate, and (iv) establishing a list server for participants. She again emphasized the need for full 2-way partnerships that recognize and enhance regional capabilities, and the need to find ways to take advantage of enhanced regional data coverage.

Next there were several talks with a focus on identifying users, as well as assessing the added value in contributing to the GDIS, since the GDIS should meet the differing needs of those experiencing drought within the different regions. Wassila Thiaw (NOAA Climate Prediction Center International Desk) provided an overview of the activities of the CPC International Desk: these include the dissemination of various climate products and services, as well as professional development training. The products include short and medium range weather forecasts, week 1 to week 2 rainfall outlooks, seasonal rainfall outlooks, and ENSO and SST trends. They also provide various products for monitoring including various drought indices and soil moisture and rainfall estimates. He also described the International Desk's website and the professional development training, noting that over 500 meteorologists from developing countries have been trained.

Mark Svoboda (National Drought Mitigation Center, or NDMC) talked about NDMC experience in helping users make informed decisions through drought monitoring and early warning information systems. He emphasized that the scientific information needs to have usability, so one needs to focus on "value-added" products provided in a format that allows for policy applications. He noted that NDMC has extensive stakeholder interactions through workshops, webinars, media contacts, surveys, etc. He discussed the level of trust users place in various information sources about climate change and impacts, with the University extension and scientists being among the most trusted. He cited several examples of decision-making and policy using the U.S. Drought Monitor (USDM) including presidential/congressional briefings. He highlighted the popularity of the USDM which has more than 6M page views and 2M+ visitors/year. He also provided some examples of other drought monitoring and early warning systems in different parts of the world.

Nathan Engle (World Bank Brazil representative) discussed the World Bank E-Learning Platform on weather and climate services. The target audience is project managers of weather and climate services-related investments, government counterparts, and other development practitioners interested in weather and climate services. He noted that weather and climate services are necessary for planning climate resilient development. The platform will be launched in parallel with the World Bank's open learning campus user platform. The e-learning platform consists of 4 modules. He discussed module 2 (the weather and climate services value chain), and noted the need for validation by partners and clients through prototyping. He presented components of lesson 1 on user needs and benefits. Eduardo Martins (Sistema de Monitoramento das Condicoes Meteorologicas Estacoes Meteorologicas automaticas do Instituto Nacional De Meteorologia (FUNCEME) continued the presentation on the second module through its implementation within the drought monitoring and forecasting system that had been set up within East Brazil. Cooperation with GDIS is a two-way street that requires that something, in turn, be made available at the local levels. During the breakout session, Eduardo also mentioned that there was a need to carefully evaluate mapped, displayed drought products at the national level (Brasil), the subnational level, and the continental level (South America) to ensure that when scaling up or down, the drought representation is consistent and accurate. Cooperation with Brazil could be in the areas of data sharing, capacity building and pilots.

Rogier Westerhoff (Coordinator of the European Framework project Global Water Scarcity Information Service, or GLOWASIS): GLOWASIS was a collaborative effort to perform pre-validation of a GMES Global Water Scarcity Information Service (a European Space Agency Global Earth Monitoring Strategy tied to the sentinel satellite series), with objectives to improve seasonal forecasting, to explain the complexity of water scarcity forecasting, and to deliver open data on drought and water scarcity. GLOWASIS, along with DEWFORA, cofounded the meteorological drought forecasting effort at ECMWF. Besides adding value to JRC's European Drought Observatory, GLOWASIS used the PCR-GLOBWB hydrological model in delft-FEWS to hindcast water scarcity and drought related parameters. While GLOWASIS has now ended, the follow-up program EartH2Observe will undertake a global water reanalysis analogous to the meteorological reanalysis projects at ECMWF and NCEP/NCAR, integrating available Earth observations from different missions, different in-situ datasets from various sources, and state-of-art global hydrological/landsurface models, the goal being to construct a consistent Global Water Resources Reanalysis (WRR) dataset of at least 30 years. The project also follows up DEWFORA in carrying out a number of case study validations in Ethiopia, while also carrying out others in Spain, Morocco, Estonia, Colombia, Australia, New Zealand and Bangladesh. Rogier also provided a brief overview of iD-Lab, the goals of which are to develop, use, and demonstrate innovate interactive and collaborative data tools, models and software, at Deltares, in the Netherlands and worldwide, and to develop expertise and knowledge for correct and timely forecasting, warning and response in flood & drought related disaster events.

Global drought monitoring and initialization of global drought forecasting is critically dependent upon the reliability of global precipitation mapping. PingPing Xie (NOAA Climate Prediction Center) noted that existing datasets do not satisfy the requirements for long-term records (> 30 years), reasonable space and time resolution (daily and 0.5° or finer), quantitative accuracy and real time availability. He discussed a new global daily 36-year precipitation dataset for improved hydroclimate monitoring and prediction. The new blended data (gauge and OLR) have daily and 0.25°lat/lon resolution, extend from 1979 to present, and are updated on a quasi real-time basis (with a delay of one day). The data are a combination of information from four individual sources including CPC daily gauge analysis, GPCC monthly gauge analysis, CMORPH high-resolution integrated satellite precipitation estimates, and the HIRS OLR data.

Bailing Li (University of Maryland) talked about a GRACE-based technique for identifying drought signatures in global groundwater, a global extension of the U.S. national program, carried out at NCDC, and made available in NIDIS. She reviewed GRACE, assimilating GRACE data for drought monitoring, and the evaluation of the results. She described how the GRACE data are downscaled and disaggregated via an Ensemble Kalman Smoother and the Catchment Land Surface Model. She provided an evaluation of the groundwater drought indices using in situ data. She also provided information on how to obtain the GRACE-based wetness indices from the NASA GRACE data assimilation system, noting that wetness maps are updated weekly.

Martha Anderson (Department of Agriculture Agricultural Research Service) described how evaporative stress index (ESI) based on thermal remote sensing provides a non-precipitation-based alternative for drought monitoring. She noted that the ESI describes temporal anomalies in evapotranspiration, highlighting areas with anomalously high or low rates of water use across the land surface. ET is retrieved via energy balance using remotely sensed land-surface temperature time-change signals. ESI appears to be especially useful in capturing early signals of "flash drought" brought on by extended periods of hot, dry and windy conditions. She gave several examples of global applications focusing on food and water security.

Amir AghaKouchak (University of California Irvine) described the Global Integrated Drought Monitoring and Prediction System (GIDMaPS), a global drought product based upon analysis of drought indicators within global datasets. He gave several examples, and in summary noted that GIDMaPS provides both monitoring and prediction capabilities. A multivariate Standardized Drought Index (MSDI) leads to a composite product based on the joint distribution of precipitation and soil moisture. It can be used for multi-index drought assessment. Finally, he noted that there are opportunities to integrate the Atmospheric Infrared Sounder (AIRS) relative humidity data into GIDMaPS to improve drought early detection. More information can be found at http://drought.eng.uci.edu.

Finally, Richard Heim (NOAA National Center for Environment Information, formerly NCDC) talked about the NIDIS drought portal as a way of linking GDIS datasets. He discussed what the NIDIS Drought Portal is, the GEO/WMO linkages, how the Portal is being used to support the Global Drought Monitor (GDM), and how the Portal can support the GDIS. He noted that at a 2007 GEO Ministerial Summit, a U.S. proposal was put forward that technical representatives from participating countries could build upon existing programs to work toward establishing a Global Drought Early Warning System (GDEWS) within the coming decade in order to provide a system of systems for data and information sharing, communication, and capacity building to take on the growing worldwide threat of drought, and to provide regular drought warning assessments issued as frequently as possible with increased frequency during a crisis. The idea was put forward to use the NIDIS Drought Portal as the IT Foundation for a clearinghouse for international drought information and services, as an integration of continental / regional drought monitors. He then provided an update of where things stand with the global drought monitor (http://www.drought.gov/gdm/). He proposed that a similar "bottom-up" approach could be used for developing the GDIS including drought monitoring, drought forecasting, research, education, and management components.

VI. Key Outcomes and Action Items

Again, the three goals of the workshop were to: (i) review the current understanding of drought world-wide and identify research gaps, (ii) appraise regional and global drought information needs and capabilities, and (iii) develop plans for a limited duration demonstration of a global real time monitoring and prediction capability (with regional pilots playing a central role). The workshop lead to a number of important conclusions, commitments and actions items that build upon the recommendations of the previous GDIS meeting held in Frascati, Italy, in April 2012[1].

The joint meeting with GHP highlighted areas of collaboration in the context of the WCRP Grand Challenges. The challenges on "Changes in Water Availability" and "Climate Extremes" were considered to be particularly relevant. In the former challenge, a key GEWEX science question concerns how a warming world affects climate extremes (especially droughts, floods and heat waves), while in the latter challenge, heat waves and drought are two of the four core themes. It was further noted that the various GHP regional projects (RHPs) could serve as GDIS pilot projects (see subsection b below).

a. A scientific assessment of drought and research gaps

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[1] These recommendations included: (i) to implement an initial global prediction and monitoring system with pilot studies employing national/regional products focused on comparisons and validation, (ii) to develop a drought catalogue and to organize a special collection on "drought characterization and mechanisms world-wide", and (iii) to develop national and international collaborations to study the mechanisms and predictability of high profile drought and heat wave events, with strong links to the affected users.

The meeting provided a summary of our understanding of drought world-wide based primarily on the contributions to the GDIS Journal of Climate special collection on drought (http://journals.ametsoc.org/page/GDIS). It also summarized some of the key remaining drought research challenges focusing on land coupling, internal versus forced variability, and current and future capabilities for monitoring drought. Areas of active research include new evidence that land impacts may differ depending on SST or climate regime, that certain land-atmosphere feedback mechanisms allow remote soil moisture anomalies to affect local precipitation and temperature, the impact of vegetation phenology's memory on forecast skill, streamflow forecasting via soil moisture initialization, and new satellite-based sensors (in particular SMAP) that should provide new and valuable data for drought monitoring and prediction. Challenges regarding the role of the ocean include the need to better understand the causes and predictability of Pacific warm pool SSTs and its impacts on global drought, the need to assess the decadal predictability of SST, and a causal interpretation of regional drought increases such as those observed over SW North America and the Greater Horn of Africa. Regarding current and future capabilities for drought monitoring, it was stressed that current global capabilities involve an increasing reliance on remote sensing and hydrological models. Key challenges include a better understanding of the utility of the various datasets for drought monitoring, how to plan for new and upcoming remote sensing missions that may transform drought monitoring, and how to assess products globally.

b. Interest in participating in GDIS and regional pilots

Several talks summarized current drought information needs and capabilities in different regions of the world, with a focus on potential contributions to the GDIS. Other talks dealt with identifying users, as well as assessing the added value in contributing to the GDIS, since the GDIS should meet the differing needs of those experiencing drought within the region. Still other talks summarized current capabilities for providing global drought information and the various existing projects/programs upon which the GDIS can build.

Portions of the Global Drought Information System are already being developed through the Group on Earth Observations (GEO) Work Plan, specifically the facilitation of real-time current drought monitoring capabilities over each continent, which are then being displayed through the NIDIS global drought portal (http://www.drought.gov/gdm/content/regional-drought: currently includes information from the North American Drought Monitor, the European Drought Observatory, the Experimental African Drought Monitor, and Australia). Major strides have been made within the U.S. through the Drought Task Force and other efforts by NOAA CPC, NASA, Princeton, and University of Washington (now UCLA) development of multi-model capabilities for drought monitoring. One reason for success is a strong subregional monitoring program, one that includes the US Drought Monitor's provision of a unified regional portrait of drought conditions. Developing real-time drought monitoring and prediction capabilities that are consistent across all regions around the world will provide the capability to test, validate, and calibrate the global-level drought forecasting and monitoring systems. *In fact, a key aspect of the GDIS is to have the various sources of regional drought information fully integrated and consistent across all regions and at the global scale* (see subsection c below).

Those expressing interested in contributing to the GDIS as *global providers* of drought information as part of a limited duration real time monitoring and prediction system include:

- NIDIS global drought portal (POC – R. Heim): Information technology foundation for a clearinghouse for international drought information and services and as an integration of continental / regional drought monitors
- UCLA (POC – D. Lettenmaier), Princeton (POC – E. Wood, J. Sheffield), NOAA/NCEP (POC – M. Ek), UC Irvine (POC - A. AghaKouchak): global drought monitoring and/or prediction
- APCC (POC - J. Rhee), NOAA/NMME (POC - J. Huang), UK Met Office (POC - A. Maidens), ECMWF (POC – E. Dutra): coupled atmosphere/land/ocean model seasonal predictions

The breakout sessions led to several institutions indicating a willingness to participate in GDIS as potential *regional pilots*. These include (see Appendix B1 subsection I, for background information on South America efforts):

Regional Climate Center for Western South America (RCC-WSA), hosted by the International Center for Investigation of El Niño (CIIFEN) in Ecuador. This will support the provision of climate services including seasonal forecasts and tailored information for decision-support in climate-sensitive sectors in the sub-region. GDIS POC – Will Pozzi; Local POC – Rodney Martinez

Regional Climate Center for Southern South America (RCC-SSA): A group of scientists with support of Inter-American Institute (IAI) are already working on the development of monitoring and predictive capabilities. Julian Baez is very supportive of having a pilot project in that region since it can be seen as an extension of what is already being done. Hugo Berbery noted that he will get in touch with other partners to inform and advance the idea of the pilot project in the context of GDIS activities. POC – Hugo Berbery

Brazil: Both Eduardo Martins and Nate Engle confirmed that a pilot linking their work both in Brazil nationally and in northeast Brazil would be welcomed. A pilot there would connect with several ongoing efforts. There would be the natural connections with the WMO Regional Centers in the region (Hugo's message), with the Integrated Drought Management Programme, with the NDMC's collaborations, with the World Bank's strategic plans, and with the planning activities taking place more locally--providing great access to decision makers (and particularly water managers) across northeast Brazil and the nation. It was further noted that CPTEC (and SALDAS) are available for drought-specific data assimilation work and that the CPTEC model is available for drought-specific forecasting (Gustavo Goncalves and colleagues). Besides CPTEC, Argentina

SMN is developing a more simplified LDAS based upon the Noah model, while CIIFEN is experimenting with its own platform, the WRF model for forecasting (CRC-OSA). In addition, the homogenized station record used for producing SPI drought maps will be coming on line, and further, mutual collaborations are envisioned in the near future with ET-CRSCI.

UNESCO-IHP: (Koen Verbist) Collaboration to carry out some comparisons for a set of countries across S. America. Justin Sheffield noted that this was discussed with Koen a few weeks earlier in Santiago, and he was happy to help coordinate as this was being done to some extent under existing IHP activities. The possibility of looking at Chile, Peru and Honduras as three countries with varying levels/needs for drought monitoring was discussed. It was not clear how this would fit under the umbrella of the regional climate centers, and how it may overlap with Hugo's proposed pilot for the RCC-SSA, so that would need to discussed further. POC - Justin Sheffield

Southeast European region - Drought Management Centre for South Eastern Europe (DMCSEE) in Southeastern Europe. The desire was expressed to see it coordinated with JRC EDO (contact Jürgen Vogt): POC - Gregor Gregoric.

China: China Meteorological Administration (CMA) - it was noted that they have the resources, know-how, and willingness to participate. POCs - Yao Hui Li and Kingtse Mo

Southern Asian region: (India and Pakistan) - to be coordinated by WMO. The project is in the process of being established. POC- Bob Stefanski.

It was also noted that the GEWEX RHPs could be a good mechanism for regional engagement, particularly:

> **HYVIC** - Hydrology of Lake Victoria Basin (POC- Frederick Semazzi - semazzi@ncsu.edu)
>
> **Australia-Pacific region:** to be coordinated with Bureau of Meteorology through OzEWEX (GEWEX RHP) -- OzEWEX - Australian Energy and Water Exchanges Initiative. POC - Albert van Dijk, (albert.vandijk@anu.edu.au)
>
> **HyMeX** - HYdrological cycle in the Mediterranean Experiment (Philippe.Drobinski@lmd.polytechnique.fr). POC - Annarita Mariotti
>
> **SASKRB** - Saskatchewan River Basin. Contact – Howard Wheater (howard.wheater@usask.ca)

Earth2Observe: The case study regions might yield suitable candidates as they all have local partner organizations (Mediterranean, Ethiopia, Bangladesh, Colombia, Estonia and Australia/New Zealand), though not all of them are focused on drought. Earth2Observe contact: Jaap.Schellekens@deltares.nl POC

AGRHYMET in Niger and ICPAC in Nairobi, covering West Africa and the Greater Horn of Africa, respectively. Justin Sheffield noted that he still has to confirm this with the relevant people (Abdou Ali at AGRHYMET; Luke Olang at U. Kenyatta/ICPAC) but based on previous discussions he believes that they would be interested. He further noted that there is also the possibility of having UNESCO-IHP-Africa involved. POC – Justin Sheffield

Possible "interest area" that is not yet a pilot area but could serve as a focal point for people and institutions interested in the region (suggested by Matt Barlow): **Middle East and Southwest Asia,** where there seems to be some gathering momentum and a fair amount of interest but not yet the history of collaboration that the pilot areas have. It was suggested that even just a contact list or working group under the GDIS imprimatur would be helpful in building regional coordination and collaboration. As an example, here is a drought resource page for the region:
http://storm.uml.edu/~barlow/drought_me_swa.html

c. *A limited duration demonstration of a global real time monitoring and prediction capability (with regional pilots)*

A key outcome of the workshop was the outline of a proposal for a limited duration experimental real time global monitoring and prediction system with pilots playing a key role. The goals of the pilot program include integrating global and regional drought information, establishing mechanisms for real time dissemination and user interactions, the joint development of products for regional applications, and the establishment of partnerships for long-term drought-related activities including risk management. The specific steps toward the development of the experimental pilot program were outlined based on the idea of equal partnerships with regions that have the capacity for drought monitoring and prediction and on building working relationships for those with limited capacity. Specific actions include 1) producing a survey of data availability and establishing a protocol for data providers (a data survey form is on the web), 2) establishing protocols for the pilots and hosts and getting institutional commitments, 3) establishing formats and ways to communicate, and 4) establishing a list server for participants.

Finally, Robert Stefanski of WMO volunteered to draft a concept note on GDIS outlining the program. This note will be circulated among agencies, regional climate centers, and other potential partners to explain GDIS and secure cooperation. A more detailed implementation plan will follow the concept note.

Acknowledgments. We wish to thank Shannon Macken for providing us with very comprehensive meeting notes that were essential for completing this report.

Appendix A: Press release (prepared by Bob Stefanski/WMO)

Global Drought Information System Workshop

A group of international experts convened in Pasadena, USA, to discuss the next steps in coordinating global and regional information on drought understanding, monitoring, forecasting and management. The International Global Drought Information System (GDIS) Workshop: Next Steps was held from 11-13 December 2014 to review the physical mechanisms and predictability of drought world-wide, review and discuss regional capabilities and needs versus global capabilities, and develop pilot projects as part of a limited duration, real-time demonstration of current GDIS capabilities.

The workshop goals addressed the fact that there is currently no global, authoritative, and consistent information on drought that is easily accessible to all users, including real-time assessments of on-going drought and information on our understanding of the physical mechanisms and predictability of drought.

The workshop participants agreed to add regional and global monitoring products as well as compile a list of peer-reviewed global drought forecasting products to the existing GDIS web portal and to develop a GDIS concept note in the next three months that will establish a framework for participation in the GDIS. The GDIS web portal is supported by US National Integrated Drought Information System (NIDIS) and hosted by the US National Climatic Data Center (NCDC).

Another key outcome of the workshop was that representatives of many existing regional and global drought initiatives tentatively agreed to contribute to the GDIS pilots, including the WMO/GWP Integrated Drought Management Programme. In addition, the review of drought research provided a wide-ranging assessment of current understanding and capabilities, and it highlighted the key gaps that limit our ability to predict and monitor drought world-wide.

There were more than 60 participants from 15 countries spanning the drought research community and selected representatives from applications communities and providers of regional and global drought information products throughout the world.

The workshop was hosted by the NASA Jet Propulsion Laboratory's Climate Center and by the Global Energy and Water Cycle Exchanges Project (GEWEX), which is a core project of the World Climate Research Programme (WCRP). Sponsorship and support for the workshop were provided by the US NIDIS program, the World Climate Research Program (WCRP), GEWEX, CLIVAR, the World Meteorological Organization (WMO), the Group on Earth Observations (GEO), the European Commission Joint Research Centre (JRC), US Climate and Ocean: Variability, Predictability and Change (CLIVAR) program, and the US National Oceanic and Atmospheric Administration (NOAA) programs on Modeling, Analysis, Predictions and Projections (MAPP) and Climate Variability & Predictability (CVP).

Appendix B1: Breakout Session_– South America (Will Pozzi and Hugo Berbery)

Participants: Julian Baez, Rodney Martinez, Hugo Berbery(co-lead), Luis Gustavo Goncalves, Eduardo Martin, Natalia Herrera, Roberto Mercuso, Richard Heim, Michael Hayes, Paulo Barbosa, Ariane Frassoni, Joao Gerd Zell de Mattos, Lisa Alexander, Dennis Lettenmaier, Justin Sheffield, Nate Engel, D. Cripe, Martha Anderson, R. Westerhoff, and W. Pozzi (lead)

Both drought monitoring and drought forecasting are inseparable aspects of the global-level combined monitoring and forecasting system. For example, early iterations of probabilistic ensemble drought forecasting have been attempted by Princeton Land Surface Hydrology Group and NOAA-CPC and IRI deploying the North American Multimodel Ensemble, including CFSv2, as well as ECMWF using S4 seasonal and monthly forecasting systems. Princeton has also studied soil moisture forecasting within the VIC model in West Africa. All of these efforts have looked at aggregate success and failure rates of forecasts over a two to three decade period. In short, this work has developed the methodology to systematically produce forecasts within each region across the globe. However, a strong case can be made that the regional drought forecasting might have stringent results where the ability to provide strong initialization is possible or where strong linkages to teleconnection may exist.

South America may be one of these locations for which drought forecasting may possibly be advantageous. Preexisting work by CPTEC in Brazil, combined with recent strong developments within some of the National Meteorological and Hydrological Services has already developed some capacity that improves the basis for initialization. In keeping with this background, a workshop session was devoted towards discussing what might be the way forward, and what points were in common among needs at local and regional level versus what advantages might accrue from testing the continental-scale implementation of the global-scale GDIS system.

The successful development of the US utilization of the National Land Data Assimilation System for drought monitoring was only made possible by the strong pre-existing networking and developed drought monitoring capability which had been built up through the US Drought Monitor among its partners: US Department of Agriculture, NOAA, and NDMC. By analogy, if the emerging Regional Climate Centers under the Global Framework on Climate Services are developing regional drought monitoring capacity, combined with the respective developments of Regional Climate Outlook Forums, then the sub-regional and regional drought, precipitation, and meteorological pieces are in place both to provide stronger initialization for a drought forecasting effort and have the capability for validation and testing as well. The drought forecasting tests can then provide value to the Regional Climate Outlook Forums, combined with additional capacity added to the NMHS, as with, for example, possible implementation of Global Precipitation Mission precipitation capacity, space-based soil moisture assimilation capacity, or water cycle capacity, such as streamflow forecasts.

I. *A. What are the existing capabilities for drought monitoring and forecasting (data and systems)?*

Pursuant to the WMO Global Framework on Climate Services, two regional climate centers have formed over South America—in the west, the Regional Climate Center for Western South America (RCC-WSA), hosted by the International Center for Investigation of El Niño (CIIFEN) in Ecuador and, in the south, the Regional Climate Center for Southern South America (RCC-SSA). At the same time, Centro de Previsão de Tempo e Estudos Climáticos (CPTEC), in Brazil, the Global Producing Center for long-range forecasts (GPC) has been developing drought management techniques that are incorporated into the South American Land Data Assimilation System (SALDAS), including drought screening of modeled soil moisture percentiles regionally. CIIFEN (RCC-WSA) has followed the lead of the Expert Team on Climate Risks and Sector-specific Climate Indices (ET-CRSCI) in utilizing SPI as a climate indicator for drought, as has RCC-SSA in the south. Argentina Servicio Meteorologico Nacional (SMN) also participated, describing the development of their drought chronological database for Southern South America. These four groups in the South American discussion session were joined by Eduardo Martins (representing the drought management program within Eastern Brazil, and supported by the World Bank). Each outlined their drought programs and discussed commonalities that would be the starting basis for building a continent-wide drought monitoring system that would build upon the products of each of the centers. A continent-wide system of this type would provide ample opportunity to test for variegated spatial conditions in the development of a global monitoring and prediction multimodel system over the overlapping continental area. Improvements in drought forecasting skill, in turn, would feed back to local users.

Both Weisheimer and Palmer (2014) and Dutra et al (2014) have identified South America (and Central America) as being regions having some of the highest potential for carrying out seasonal forecasting, hence being prime areas in which to assess what is likely to be the upper limits for drought seasonal forecasting and early warning. Obviously, this is due, in part, to the role that the South American continental massif plays in generating El Nino Southern Oscillation (ENSO). Weisheimer and Palmer 2014 identified Central and South America as having high (rated “5” or near perfect) for “dry” forecasts during the boreal summer and winter seasons (as affecting Northern South America) and during the reversed seasons for Southern South America, using the European Centre for Medium-range Weather Forecasting (ECMWF) S4 seasonal forecasting system.

As noted above, most probabilistic, ensemble drought forecasting skill tests have been based upon aggregate results over two decades or more. GEO and ECMWF has also conducted a very small handful of case studies *for individual droughts*, and for drought termination, as well as drought onset. While the actual drought record (drought chronology) demonstrates that droughts occur in Australia and India during the El Nino phases of the El Nino Southern Oscillation, such occurrences during El Nino phases is not a simple one-to-one relationship: for example, there is not a direct relationship between ENSO pressure strength (or the magnitude of sea surface temperature anomaly) and drought spatial extent or intensity, but the evidence is clear that more droughts occur during El Nino than otherwise. In the case of the Indian Ocean, the phase of the Indian Ocean Dipole and (for Australia and South Africa) the Southern Annular Mode are equally contributing factors. Drought occurrences during El Nino phases also occur within South America (southern south America, for example), but lack the stronger associations found over the Western Pacific and Indian Ocean. In addition, droughts over Amazonia have also been linked to anomalous sea surface transients over the tropical Atlantic Ocean. Both teleconnection influence and developing infrastructure capacity suggest South America would be a prime location to develop regional drought (forecasting and monitoring) management capacity.

Probabilistic ensemble forecasting utilizes precipitation information both within the meteorological drought forecasts (SPI) and the soil moisture forecasts (involving forecasted precipitation). A regional testbed sited over South America could help further develop precipitation monitoring capacity there as a program for step improvements in the drought forecasting program.

The results derived from the ECMWF seasonal forecasting system also seem borne out in results of forecasting models within the North American Multimodel Ensemble (NMME). A collaboration could be forged in which CPTEC's forecasting products could be added to the global suite, in order to further develop CPTEC forecasting capabilities.

With these views in mind, discussion ranged upon existing (and planned) products that could be the basis for such tests within a testbed.

Station Density

Another objective of the Global Drought Information System (GDIS) is to improve the accuracy with which drought can be documented globally and over each continent. For South America the improvement in station coverage can be seen in the transition from the first South American workshop carried out by the Expert Team on Climate Change Detection and Indices, where only 68 temperature stations and 58 precipitation stations could be obtained for 1960-2000, and the second Expert Team on Climate Risk and Sector-specific Climate Indices, which, in Guayaquil, assembled 261 stations.

As noted above, since SPI is beginning to be somewhat extensively used in meteorological drought forecasts, a large segment of the 2nd Global Drought Information System South American discussion session was devoted towards attaining consensus of possible SPI products at different spatial levels of detail that are compatible with assembly into a continental-scale map of current drought conditions; likewise this would be complemented with the most detailed spatial map possible of precipitation distribution across South America for model forcing (and for SPI construction).

Natalia Herrera, representing Argentina SMN for the Southern South America Regional Climate Center, clarified that drought measurements from 238 stations are and would be made available (for the Southern South America subregion), including 164 from Argentina, 3 from Paraguay, 15 from Uruguay, 35 from Bolivia, 18 from Chile, and 3 from Brazil. Many more station records are available in Brazil from contributions originating from CPTEC and Eduardo. The Western South America Regional Climate Center could then be added to this and cross-compared with Global Precipitation Climatology Centre, Global Precipitation Climatology Project, NOAA NCEI, and NOAA CPC holdings (to investigate whether drought density in spatial maps is improved at different levels of detail). Of course, the station data would be complemented by satellite data (the Global Precipitation Mission, as an example), as an addition to the near-real-time precipitation forcing. At the same time, CPTEC also prepares maps of soil moisture percentiles and soil moisture anomalies. However, most of the additional stations are predominantly provided within the Brazil national borders.

Pozzi mentioned that a more comprehensive, holistic viewpoint of drought was required in order to track and observe "drought propagation" through declining soil moisture, streamflow, groundwater, and water surface elevations within surface reservoirs, as well as monitoring both evapotranspiration via the evaporative stress index (based upon satellite remote sensing data, not just analytically calculated, as in the case of SPEI) and the effect of water stress on vegetation, including crops (as already provided by EuroCLIMA). Some NMHSs in South America already deploy vegetation monitoring.

Julian Baez was very interested in runoff, particularly within the La Plata Basin, and whether the system could be used for streamflow forecasting. Dennis Lettenmaier mentioned that their experience with the University of Washington system was that snow cover and snowmelt runoff was an important source of the forecast signal.

Julian mentioned that some stations are not, as of yet, included in Natalia's database because Automated Weather Stations are not included. Dennis mentioned that one should not be caught up over total number of stations, because when one considers the more reliably reported stations, having the longest continuous duration and record, the number will be smaller (as was the case with the University of Washington "index stations").

Dennis mentioned one has to look at the differences in forcing datasets among the models with an eye to seeing how that might possibly bias model performance.

II. How could the region contribute to GDIS? Are there specific information types (layers) that are considered important to have in GDIS?–Which type of information could be made available?

Since two centers would be involved, the map preparation would have to be standardized (with overlapping time periods) to ensure that the maps could be successfully merged.

Mike (Hayes) said that this would be a good reason for holding a follow-up workshop, in order to work out the actual details for implementation.

Gustavo mentioned that although the soil moisture anomaly (or, alternatively, soil moisture percentile) maps are produced monthly, they could be produced weekly.

Eduardo expressed concern that having multiple maps at different levels of detail would create contradictions in how drought would be displayed among the maps (at what SPI value, for example). Richard (Heim): The way the portal is set up, one starts with a global drought map, then one is directed to more detailed (higher spatial resolution) regional (continental maps). Then one can point and click to a map for a state in Brazil. All three maps are not going to be the same. The spatial detail of the droughts will become higher as you scale down.

III. In what form will drought information be supplied to researchers (within South America and elsewhere), to NMHS agencies, and to the general public? How is the available information transferred to the stakeholders (in one of its forms)?

Pozzi asked Nate Engel to please highlight the World Bank's perspective on South American drought monitoring. He replied that while he couldn't speak for the World Bank, except in the capacity as a World Bank representative for Brazil, the stratagem he has pursued is that of: user first, impact on resilience outcomes, needs, then working backwards on how to develop a system. A cohesive approach has yet to link drought with resilience. Working with agencies dealing with impacts is critical, from the national down to the local agency level. An important factor is vulnerability. Paulo then mentioned that an attempt was being made to assess vulnerability for South America as part of EuroCLIMA.

Regional Drought Catalog

The European Framework 7 project "Drought—Research and Science Policy Interfacing" European Drought Reference (EDR) database plots the areas (percent area) under designated levels of intensity of drought, using SPI. An analogous approach is being implemented by Argentina SMN for the CLARIS LPB (A Europe-South America Network for Climate Change Assessment and Impact Studies in La Plata Basin) database. Spatial maps of drought, which can then be either displayed or imported into a Geographic Information System (GIS), permit subdivision of drought into zones – droughts can easily be identified as (i) pan-continental; (ii) sub-pan-continental; (iii) regional; or (iv) national.

IV. What is the institutional framework? Who could be responsible for the contribution?

Nate: The important thing sometimes is not what the final products are but setting up the procedure and the partners for bringing about something.

A small organizing committee (composed of the Regional Climate Centers, CPTEC, and GDIS, including WMO, NOAA, GEO, and WCRP DIG) will ensure fairness in burdens imposed by manpower requirements for assembling information for testing the global-scale model results (forecasts and monitored products) over South America. The precipitation distribution (and other components of the water cycle, including streamflow and groundwater) can also be cross compared.

After cross-validations are performed, in order to determine the limits of the drought forecasts, they can be made available to the RCC RCOFs for the drought portions of their forecast suite. As noted above, these products will include additional developmental work on those teleconnections (building upon CIIFEN, NOAA CPC, and Australia BoM work) influencing drought formation and dissipation, such as ENSO or tropical Atlantic SST anomaly transients.

Appendix B2: Breakout Session – Africa (Eric Wood and Brad Lyon)

Africa presents some challenges for GDIS. It was noted that no one attended the meeting that directly represented an African institution to develop a pilot with. Pilot development for GDIS would therefore seem to be most feasible via connections with other current or planned activities there, working with intermediaries. One possibility is to try and align our GDIS ideas with those for the GEWEX regional hydroclimate project for Lake Victoria (HyVic) being headed up by Fred Semazzi at NCSU. Another possibility is to work with the famine early warning system (FEWSNET) which is funded by USAID and which Chris Funk, who attended the meeting, is closely engaged with (through USGS and UCSB). Brad Lyon is currently working with Chris on a NASA project in East Africa as well. In West Africa, there is AGRHYMET that could potentially be engaged with. The IRI and Eric Wood have both been working with AGRHYMET for some time. The IRI is closely engaged with the national meteorological agency in Ethiopia, the Tanzanian met service and ICPAC, for example.

There was also some discussion at the meeting about research ideas under the African component of GDIS. Randy Koster, for example, was particularly interested in rainfall variations across the Sahel given the substantial land-atmospheric coupling in climate models for that region.

Overall, it was not clear what the next steps should be for the African effort under GDIS. It was noted that African pilots would likely have to be done by non-Africans, perhaps partnering with some institution like ICPAC.

Appendix B3: Breakout Session – Other Partnerships (Jürgen Vogt and Albert van Dijk)

(1) Candidate GDIS Pilots:

- US & Canada
- Europe (EDO, DMCSEE) – Jürgen Vogt and Gregor Gregoric as contact points
- China – see reply of Kingste
- Australia – Pacific region (BoM) – Albert van Dijk as first contact, to be coordinated with Bureau of Meteorology through OzEWEX (GEWEX RHP)
- South Asia (India & Pakistan) – Bob Stefanski as contact, to be coordinated by WMO. Project in the process of being established.

• It was argued that international activities like FEWS Net, US Aid, US Foreign Agricultural Service, or FAO activities could contribute to this, but it is not clear how.

(2) Potential Users of GDIS Information:

A: Public Organizations, e.g.

- Intergovernmental Organizations (e.g., EU)
- International Agencies/ UN Agencies
- Government Agencies
- World Bank
- Media

→ this group requires targeted information/products

B: Science Community

→ this group requires all kind of information at different scales

C: Other Sectors, e.g.

- Private Sector
- Insurance industries
- Commodity traders
- Media

→ this group requires specific information for their business. There is the question of the use made of the data!

➔ There was agreement that all communities (specifically the public organizations and the science community) can contribute to and profit from GDIS

➔ GDIS should therefore target both groups. However, it is important to clarify the status and the role of each of them. Government and international agencies need authoritative information and continuity. The science community is much more flexible but demands more data. It was not so clear how to handle the private sector.

➔ An important aspect is that GDIS will provide **continuity** and **authoritative information**!

(3) <u>Potential benefits originating from contributing to GDIS (as a pilot):</u>

- Access to global data and information sources. Having relevant information all in one place.
- Possibility to evaluate if the forecasts provided through GDIS are useful for the respective region
- Build capacities, establish international cooperation, learn about best practices
- Gain visibility (publications, web, …)
- Raise awareness about the problem and the activities in the pilot region
- Share tools
- Learn more on
    - How available information is synthesized in other regions/pilots
    - How monitoring and prediction is implemented elsewhere
    - How information is transmitted to and received by decision makers
- Research and innovation aspect
- IMPORTANT: there needs to be a **mutual exchange of information and tools** between the different partners involved!

(4) <u>Discussion on the focus of GDIS:</u>

- Monitoring and forecasting are the focus for the pilots, both cannot be separated!
- Vulnerability and risk assessment are probably not the primary focus for the pilot phase, but they are an integral part of the final GDIS. This is also a question of scale.
- It would be important to improve on impact assessments through the regional pilots as this is currently the area with the biggest deficit.

(5) <u>What will make GDIS a success or a failure?</u>

- It must be clear what GDIS can bring to the pilots, contributors and users in general!
- It must be based on a free and mutual exchange of information (and data).
- Some kind of financing (also long-term) should be available.

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