GROUP ON EARTH OBSERVATIONS

Implementation Plan for the Global Drought Information System Global Initiative

1 EXECUTIVE SUMMARY

The purpose of the Global Drought Information System (GDIS) is to develop and deploy drought-tailored early warning maps (which will mesh with the World Meteorological Organization (WMO)'s on-going rollout of the Global Framework on Climate Services, providing opportunities for early warning maps within the Regional Climate Outlook Forums (RCOFs). The second role of GDIS is to identify global atmospheric and oceanic factors that trigger regional and globally synchronized drought, to be picked up for monitoring purposes (many of these are already monitored as with US National Oceanic and Atmospheric Administration (NOAA)'s monitoring of El Nino-Southern Oscillation (ENSO), and ENSO monitoring by the Australia Commonwealth Bureau of Meteorology (BoM). GDIS's third purpose is to synthesize this information in a comprehensible form through the GDIS information portal (housed on the NOAA National Integrated Drought Information System (NIDIS) portal https://www.drought.gov/gdm/current-conditions)

GDIS began to fill a policy mandate within the World Climate Research Programme (WCRP) Grand Challenge on Extremes by documenting and researching the drought extreme. This endeavour was met by the GEWEX/CLIVAR Drought Interest Group (largely synonymous with the NOAA-National Climate Program-sponsored US Drought Task Force, but including international scientists overseas): the refereed Special GDIS Collection, published within *Journal of Climate*, summarized and documented, region-by-region, global atmospheric and oceanic factors responsible for regional droughts.

The ability to monitor and predict the formation and intensity of droughts in near-real-time is limited at the global level (Pozzi et al 2013; Nijssen et al 2014). Current 1st generation global drought monitors, such as the GDIS, and the Copernicus Emergency Services European Commission Joint Research Centre Global Drought Observatory, use DWD (Germany) Global Precipitation Climatology Centre (GPCC) land-based precipitation station records, which introduces a bias towards areas having extensive meteorological and hydrological grids, while neglecting many part of the world; hence, not sufficiently documenting the global distribution of droughts worldwide. Furthermore, if the starting point of the current drought observation is in error (by using month-old information), then subsequent iterations in climate models will be in even further error. GDIS's top priority is to develop a combined space-based, ground-based drought record which will minimize these errors. NIDIS and the NOAA Cooperative Institute for Climate and Satellites (CICS-NC) have taken the standardized Python code of Standardized Precipitation Index (SPI) (for meteorological drought identification) and processed NOAA Climate Prediction Center (CPC), CMORPH space-based global precipitation to produce a space-based drought map for display on the GDIS portal, to display alongside the land-based GPCC-based counterpart. In addition, the US National Aeronautics and Space Administration (NASA)/ Goddard Space Flight Center (GSFC) Global Precipitation Measuring (GPM) mission team is reprocessing the multi-decadal Tropical Rainfall Meteorological Mission (TRMM) space-based precipitation archive with the GPM IMERG algorithm to produce a combined TRMM-GPM archive in summer 2019—which will provide a space-based global precipitation record at higher spatial resolution (10 km) than the 25 km of CMORPH or the half degree (50 km) of GPCC. Tests will be undertaken to determine whether the spatial granularity of mapped drought will improve, providing more useful information to people suffering from drought at local levels.

The 2nd international Global Drought Information System workshop, held in Pasadena (NASA JPL) explored and evaluated how limited was global drought prediction and forecasting: whether more reliable, accurate global drought forecasting was limited to one-month advance forecasting in some areas, and bi-monthly forecasting in others. An outcome of the 2nd GDIS workshop was a NOAA-Modelling Analysis Predictions and Projections (MAPP) financial support for a NOAA Climate Prediction Center (CPC) mapping of SPI-predicted drought, using the North American Multi-Model Ensemble (NMME) of climate and seasonal forecasting models. Unfortunately, this ensemble seasonal forecasting mapping (for precipitation) does not also include European Community Medium Range Weather Forecasting (ECMWF) seasonal forecasts. However, the Copernicus Climate Change Service (C3S) is now making available the ECMWF seasonal forecasts, so that the ECMWF drought forecasting code developed in the European Framework project Drought Early Warning System for Africa (DEWFORA) will be upgraded and updated to use with the Copernicus C3S updated information.

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2 PURPOSE

Outputs:

Actual and Planned Outputs

Datasets: combined climate data records of global satellite precipitation and land-based observations from precipitation stations, as converted to Standardized Precipitation Index for initial drought screening.

Set up of data processing streams for global drought forecasting and early warning mapping, using the North American Multi-Model Ensemble of seasonal forecasting models and set up of a data processing stream for the ECMWF SEAS seasonal forecasting model.

Information service products: GDIS portal, made available through the US NOAA-NIDIS portal.

Under the WMO Global Framework on Climate Services, Regional Climate Outlook Forums (RCOFs) may be linked to Regional Climate Centers or operate as extensions of the national meteorological services. All RCOFs currently display only monthly or seasonal greater incidence or lowered incidence of precipitation; no RCOF prepares drought-tailored forecasts for early warning. The Greater Horn of Africa Regional Climate Outlook Forum (ICPAC) does provide for some “early warning” capability, but this is limited to SPI maps of *current* conditions, not forecasts. The GDIS mission is to make early warning drought outlooks and warnings available. When demonstrated to be viable and accurate, they are likely to be picked up by the RCOFs, given the financial costs of famines and crop failures.

The intended “impact” is to reduce mortality due to famine and to buttress agricultural crop protection against monsoon failure. Drought prediction and monitoring are also linked to wildfire generation.

Policy Mandates:

GDIS began, at its origin, as the coalescence of two activities. One activity was the group activities of the Drought Interest Group within Global Energy and Water Exchanges (GEWEX) and CLIVAR: this group was mandated to deal with the complexities of drought within the World Climate Research Programme (WCRP) Grand Challenge on Extremes. DIG’s governance included: (I) proposing working definitions of drought and related model-predictions of drought; (II) coordinating evaluations of existing model drought depictions; and (III) organize community workshops to present and discuss results. https://usclivar.org/working-groups/drought and http://www.clivar.org/joint-initiatives/dig

An overview of the WCRP Grand Challenge on Extremes (Zhang, et.al., "WCRP Grand Challenge: Understanding and Predicting Weather and Climate extremes," Item 6, "Develop tractable actions on monitoring, quantification, and understanding of the global distribution of droughts and their trends using observational information, model development, land area factors governing drought, and societal interactions. Within WCRP, this involves DIG, WGRC, and the GEWEX and CLIVAR panels. DIG is currently developing its Global Drought Information System activities that identify scientific and technical issues in improving our ability to cope with this particular type of extreme."

Participants within DIG included participants within the NOAA-sponsored US Drought Task Force, including NASA/GSFC Global Modelling and Assimilation Office (GMAO)(Siegfried Schubert); NOAA Climate Prediction Center (CPC)(Kingtse Mo); NASA/GSFC Hydrological Sciences Branch (Christa Peters-Lidard), Princeton University Land Surface Hydrology Group (PU)(Justin Sheffield and Eric Wood), and the University of Washington Civil and Environmental Engineering (Dennis Lettenmaier). The US Drought Task Force was supported by the NOAA Climate Program Office and NOAA Modelling, Analysis, Predictions, and Projections (MAPP) with the aim of improving drought monitoring and forecasting within the USA. The approach used by the Drought Task Force was to use the National Land Data Assimilation System (NLDAS) model and the Variable Infiltration Capacity (VIC) model in tandem with NOAA's dense meteorological grid and US Geological Survey's hydrological grid in predicting the low soil moisture levels found during drought episodes.

The second group responsible for the development of GDIS combined practical drought mapping expertise with the research and model experience of DIG. Participants of the second group included the NOAA representatives of the US Drought Monitor (Richard Heim), the members of the European Commission Joint Research Centre involved in the development and operation of the European Drought Observatory (EDO)(Juergen Vogt), the NASA WaterNet project (Will Pozzi and Rick Lawford, among others), the Princeton University Surface Water Hydrology Group (Justin Sheffield), the University of Technology, Vienna, Austria (Wolfgang Wagner) (soil moisture mapping), Australia CSIRO (Albert van Dijk) and ABARES (Margaret Nicholson), and Brazil CPTEC (Gustavo Goncalves). This second group developed within the Group on Earth Observations (GEO) Architecture Implementation Pilot (AIP-3 in 2010). Combined drought mapping products were combined in real time using web services, linking together the North American Drought Monitor, European drought coverage (European Drought Observatory (EDO). UNESCO had provided a tiny grant to Princeton (Justin Sheffield) to develop an African Drought Monitor (https://www.researchgate.net/publication/309470376_Strengthening_drought_risk_management_and_policy_UNESCO_International_Hydrological_Programme's_case_studies_from_Africa_and_Latin_America_and_the_Caribbean The African Drought Monitor was included to provide African drought coverage for the global Drought Monitor Portal. It was also adopted by the West African Regional Drought Center (AGRHYMET) https://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-12-00124.1 Global Drought Monitor coverage was developed by Benjamin Lloyd-Hughes and housed at University College London.

The activities of the two groups was formally linked during the 1st international Global Drought Information System conference at Frascati, that was held in August 2012 http://www.clivar.org/sites/default/files/documents/GDIS_Report_final.pdf.

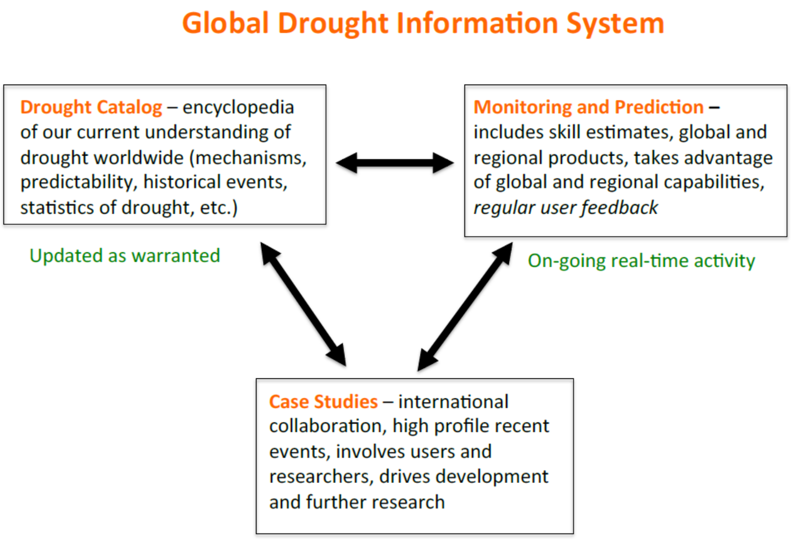

Figure 1 Functions of the Global Drought Information System, outlined in the 1st international GDIS workshop at Frascati.

The prediction and monitoring component (displayed above) for GDIS was slated to be implemented within the NOAA/Climate Prediction Center and the initial global system within the NIDIS Global Drought Portal (GDP) (Workshop Report Section III). A follow-on workshop was to provide initial evaluation of the experimental monitoring and prediction system.

The second Global Drought Information System workshop was held in Pasadena (JPL) in December 2014. https://gmao.gsfc.nasa.gov/pubs/docs/Schubert805.pdf Two European Framework projects, Drought Early Warning System for Africa (DEWFORA)(Micha Werner)(2011-2013) and the Global Water Scarcity Information Service (GLOWASIS)(Rogier Westerhoff)(2011-2013) presented results, including work packages at ECMWF that developed drought prediction capabilities, using the ECMWF seasonal forecast model for Africa, but also applied world-wide https://www.hydrol-earth-syst-sci.net/18/2669/2014/hess-18-2669-2014.pdf

The US Drought Task Force, in turn, had experimented with drought prediction, using the North American Multi-model Ensemble (NMME), an ensemble of models, including the NOAA Climate Forecasting System v2, the National Center for Atmospheric Research (NCAR) model, Canadian climate models, and others. To test GDIS prediction capabilities, Mo (NOAA CPC) and Lyon (IRI) developed a global drought prediction mapping, using exclusively NMME, which is now experimentally operative at NOAA CPC: https://journals.ametsoc.org/doi/pdf/10.1175/JHM-D-14-0192.1.

Outputs of Datasets:

Information Services:

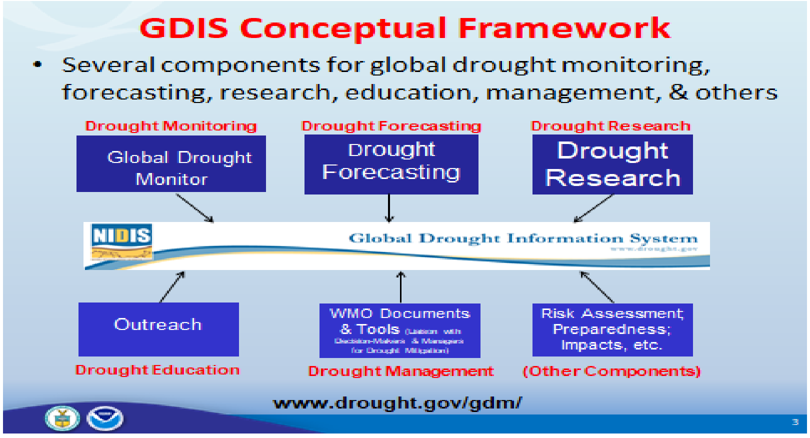

Figure 2 Information Content Categories within the GDIS Portal (Heim, R, "GDIS-Regional Drought Monitoring-North American Drought Monitor, South American Drought Workshop 17 Aug)

Droughts can be produced through the combination of decline of surface water supplies, i.e., low river or low reservoir or lake water levels, declining soil moisture, high rates of evapotranspiration, and declining incoming precipitation. Hence, a drought monitoring program must monitor multiple factors. Monitoring global precipitation only monitors one of these factors.

Global monitoring of evapotranspiration can include factors such as space-based measurement of solar and terrestrial radiation in the outer atmosphere, possible measurement of cloud cover, and other ancillary factors. GDIS as Global ESI user is cited http://catalogue.servirglobal.net/Product?product_id=198
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180000608.pdf

The European Drought Observatory overlays multiple maps of Standardized Precipitation Index (a drought measure of precipitation), modelled soil moisture (a drought measure for soil water), and water stress within vegetation or crops (via anomalies in absorbed photosynthetic active radiation). https://www.nat-hazards-earth-syst-sci.net/12/3519/2012/nhess-12-3519-2012.pdfGDIS currently uses vegetation health index/vegetation condition index from NOAA NESDIS.

Upper surface soil moisture can be mapped from space using ASCAT and Soil Moisture Active and Passive (SMAP).

The Sustainable Development Goal for water uses these global datasets, but they are calculated in an accounting system by each country, rather than be directly based upon the combination of remotely sensed and ground-based hydrological observations. Step-by-step-methodology-6-4-2_Revision-2017-01-19_Final-1.pdf

The precipitation products from global drought monitoring can be directly compared with the precipitation provided by Nation states in compliance with the SDG for water, 6.4.2.

The evapotranspiration products from global drought monitoring can also be compared with evaporation accounting included in SDG 6.4.2 estimation—although the spatial resolution of the evapotranspiration products may differ from the spatial resolution of the precipitation products.

The GDIS portal can provide resources for self-education ("outreach" (see above). Drought indices will be standardized with explanations for use for the benefit of persons living in lesser developed areas.

As has been noted above, the Monitoring and Predicting (early warning) activity of GDIS is considered most crucial and the one offering highest value to potential users. This also provides a baseline to monitor the impact of climate change upon extremes (precipitation monitoring is sub-daily, not only limited to monthly accumulated sums).

3 BACKGROUND AND PREVIOUS ACHIEVEMENTS

Africa

Before the 1st international Global Drought Information System workshop, UNESCO had contacted Princeton University (a GDIS partner) to develop an African Drought Monitor. (https://www.researchgate.net/publication/309470376_Strengthening_drought_risk_management_and_policy_UNESCO_International_Hydrological_Programme's_case_studies_from_Africa_and_Latin_America_and_the_Caribbean

During the 1st international Global Drought Information System workshop, this was more cohesively integrated with the West Africa Regional Drought Center. (AGRHYMET) https://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-12-00124.1

This has now been extended to IGAD Climate Prediction and Applications Centre (ICPAC) in the Greater Horn of Africa region, but both of these products are limited to monitoring *current* drought conditions, through both use of Standardized Precipitation Index and modelled soil moisture. Princeton has the capability to extend this system to mapped predictions, but their system is limited to the North American Multi-Model Ensemble of North American climate models and seasonal forecasting models (i.e., the ECMWF forecasts are not included).

South America

A second Global Drought Information System workshop was held in Pasadena (JPL) in December 2014. GDIS hosted the first, face-to-face meeting of the Southern South America and Western South America Regional Climate Centres that was held in Pasadena to discuss the formation of a unified South American drought monitoring system https://gmao.gsfc.nasa.gov/pubs/docs/Schubert805.pdf. The subsequent Buenos Aires meeting was also attended by the GDIS co-PoC, Richard Heim http://www.crc-sas.org/es/pdf/capacitacion/cursos/0810_08_2017_buenosaires/SADIS_Strategic_Plan.pdf.

The JRC maps, both the Global Drought Observatory and the Latin American and African Drought Observatories, were developed as part of the Copernicus Emergency Management Service https://emergency.copernicus.eu/. (EDO is a GDIS partner)

Princeton also has extended its African Drought Monitor approach to South America.

Both of these products have been made available through the GDIS portal; however, the Regional Climate Centre Regional Drought Management Plan is grounded by the actual meteorological services in South America.

South Asia

During the 1st GDIS international workshop, Robert Stefanski, for WMO, expressed an interest in setting up a South Asia Regional Drought Center. After the 2nd international GDIS workshop, Stefanski contacted the International Water Resources Institute in Sri Lanka to set up this center. The maps from this center are now displayed on the GDIS portal.

GDIS and Global Drought Forecasting

The European Union sponsored two international drought projects (Drought Early Warning System for Africa (DEWFORA) (Micha Werner) (2011-2013) and the Global Water Scarcity Information Service

(GLOWASIS) (Rogier Westerhoff) (2011-2013). GDIS participated with these projects, while the Pozzi was hosted by the University of Technology, Vienna. Both European Framework projects included work packages, located at the European Centre for Medium Range Weather Forecasting (ECMWF), designed to develop drought prediction, both for Africa (in DEWFORA) and world-wide (in GLOWASIS). The global test of regional drought forecasting skill was peer-reviewed published in 2014: https://www.hydrol-earth-syst-sci.net/18/2669/2014/hess-18-2669-2014.pdf

During the second Global Drought Information System workshop, held in Pasadena (JPL) in December 2014, these global forecasting efforts were reviewed. Mo (NOAA CPC) and Lyon (IRI) received funding from NOAA MAPP to develop a global drought forecasting system (using the North American Multi-model Ensemble (NMME) of climate models), which is now experimentally operative at NOAA CPC: https://journals.ametsoc.org/doi/pdf/10.1175/JHM-D-14-0192.1.

Lessons Learned from the 2018-2020 Work Plan Period

The importance of developing a less spatially biased technique for monitoring global precipitation is critical to the success of this mission and for the success of global drought forecasting. Some of the NOAA and NASA activities have been heavily impacted by domestic political events within the USA. The government shutdown has delayed twice, for example, the production of a combined TRMM-GPM archive for use in precipitation monitoring. Furthermore, the cost of ECMWF seasonal forecasts was a significant barrier to drought forecasting, one that has recently been lifted through the Copernicus C3S Climate Change Services program.

4 RELATIONSHIP OF THE GDIS GLOBAL INITIATIVE ACTIVITIES TO GEO ENGAGEMENT PRIORITIES

GDIS plays an important role in the documentation of drought worldwide, a documentary source critical to documenting the links between global warming and incidence and intensity of drought (as succinctly demonstrated below).

Figure 3 Drought as Impacted by Global Warming (P. Lynch, "The emergence of Numerical Weather Prediction: Fulfilment of a dream and Realization of a fantasy," "Mathematics of Planet Earth Jamboree," University of Reading, UK, 22-23 March 2016)

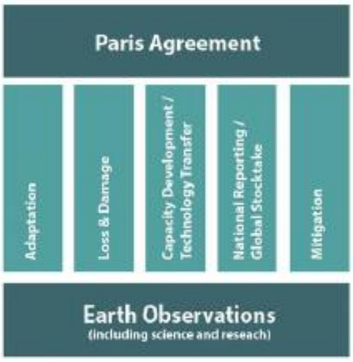

Figure 4 The Role of Earth Observations within the Pillars set up within the Paris Agreement (COP21) (Articles in the Paris Agreement in which Earth Observation are foundational "Report of the Paris Agreement," 10th Programme Board Meeting, 5-6 September 2018 (PB-10.08).

GDIS was acknowledged by the Programme Board for this role in providing documentation under the Loss and Damage category in the Earth Observation requirements for the Paris Agreement. This was further demonstrated in the WCRP references presented above.

While GDIS role was elucidated (by the Programme Board) as "contributing to some extent," much of this qualifier was due to lack of key new resources being available within the past Work Plan period. New Earth Observation resources are available, and more are under consideration for deployment, which will considerably improve the capabilities to monitor drought as an extreme linked to climate change. This is the rationale for the selection of the work packages within the upcoming GEO 2020-2022 Work Plan (please see Section 6 for details).

As far as future engagement is concerned, GDIS is focusing all its efforts in that channel which is likely to have a lasting impact and legacy: setting up reliable, accurate global drought monitoring and prediction. This will provide the documentary evidence required by IPCC (and NOAA and our European, Australian, Chinese, African, and South American partners). This will also improve the State of the Climate reporting (by NOAA).

Secondly, the global precipitation and evapotranspiration Climate Data Records developed by GDIS overlap with reporting requirements of the water accounting system in the Sustainable Development Goal 6.4.2 (Step-by-step-methodology-6-4-2_Revision-2017-01-19_Final-1.pdf). Both issues are linked, but climate is our priority (and weather hazards).

The outputs of the Global Drought Information System of most relevance to other GEO Global Initiatives and Flagships are the GEO Global Agricultural Monitoring (GEOGLAM) flagship and the Global Agriculture Community activity: drought forecasts will advance forward the lead time that countries have to prepare for crop failures. SPI mapping from global precipitation (GPM) is of secondary importance, because it monitors "current" conditions within a 3 hour window (or slightly daily).

5 STAKEHOLDER ENGAGEMENT AND CAPACITY BUILDING

GDIS partners include the Joint Research Centre (European Drought Observatory and its affiliated observatories under Copernicus Emergency Services), Australia Bureau of Meteorology and CSIRO, the Drought Management Centre for Southeast Europe (DMCSEE), the South American Regional Climate Centers, along with CPTEC in Brazil, the China Meteorological Administration (CMA), and others. While this partnership may possibly be construed as being not very active, the products of our partners are updated in near real time using web services. Our collaborations include joint research and joint coordination in undertaking the work passage tasks.

The next generation of GDIS Portal, which will share open code in Python for various models, aligns well with the GEO Knowledge Hub.

6 GOVERNANCE

GDIS's activities and domain were codified during the 1st and 2nd international GDIS workshops. As shown above, this was a natural outgrowth of the mandate from CLIVAR to develop some of the documentary sources required for the Grand Challenge of Extremes. The actual nature of the organization was presented in diagrams above.

As noted above, GDIS was founded by combining two activities: a climate model research effort, linked to WCRP, and a practical drought mapping activity. Many of the leading, most active members of DIG have recently retired, such as Siegfried Schubert of NASA/GSFC Global Modelling and Assimilation Office (GMAO) and Kingtse Mo of NOAA Climate Prediction Center (CPC).

GDIS is divided among these work packages: (I) portal; (II) global precipitation data processing stream; (III) global drought forecasting data processing stream. Other work packages include: (IV) development of new global drought tools for inclusion in the portal (for example Global ESI and global soil moisture mapping) and (V) development of drought-oriented software modules and educational video recordings for distribution

Work Package I

The portal work package is under the guidance of Steve Ansari, with assistance from Richard Heim (NOAA) and Will Pozzi. Additional people will be involved in supplying information to the portal, as, for example, Chris Hain (NASA christopher.hain@nasa.gov) and Martha Anderson (US Department of Agriculture Agricultural Research Service (ARS (martha.anderson@ars.usda.gov) who will provide Global Evaporative Stress Index maps. Additional evapotranspiration mapping is also being investigated. Wolfgang Wagner (University of Technology, Wien ww@ipf.tuwien.ac.at) will be providing soil moisture mapping (soil moisture maps will also be provided via the NASA/JAXA Soil Moisture Active and Passive (SMAP).

Additional GDIS portal partners include the European Commission Joint Research Center (Jürgen Vogt (Juergen.VOGT@ec.europa.eu), for European drought mapping, the Drought Management Centre for Southeast Europe (DMCSEE (gregor.gregoric@gov.si), the South Asian Regional Drought Center (International Water Management Institute, based in Sri Lanka), Albert van Dijk, Australia National University (ANU)(albert.vandijk@anu.edu.au) as coordinator for content provided by Australia Bureau of Meteorology (BoM) and CSIRO. The contact for China drought coverage is Yaohui Li (li-yaohui@163.com) of the China Meteorological Administration Institute of Arid Meteorology.

Additional GDIS portal partners include the Southern South America Regional Climate Center (CRC-SAS) and the Western South America Regional Climate Center (CRC-OSA. South America drought maps are also available from partners European Commission Joint Research Centre (EuroCLIMA) and from Princeton University (partners Eric Wood at Princeton (efwood@princeton.edu) and Justin Sheffield at Southampton University UK (Justin.Sheffield@soton.ac.uk)

Work Package 2

After standardization of the Standardized Precipitation Index code base by the NIDIS data processing manager (Alec Courtright (NOAA alec.courtright@noaa.gov () and his predecessor), the new Python-based code was tested upon different datasets, including the NOAA Climate Prediction Center (CPC) Morphing (CMORPH) global precipitation dataset by Olivier Prat (NOAA Cooperative Institute for Climate and Satellites-North Carolina (CICS-NC (Olivier.Prat@noaa.gov), who used the

SPI code to prepare global SPI maps from the global CMORPH precipitation. Also participating in the project is Brian Nelson, NOAA NCEI Precipitation Lead (brian.nelson@noaa.gov)

The CMORPH SPI product is being validated, by being compared against recorded droughts regionally (and tested against measured SPI values from drought monitoring within these regions). The post validation product will be gridded and mapped on the GDIS portal.

The Global Precipitation Measurement (GPM) Integrated Multi-satellite Retrievals for GPM (IMERG) algorithm is used to synthesize a global precipitation picture from the precipitation satellite constellation. The Tropical Meteorological Rainfall Mission (TRMM) 13 year operational data archive will be reprocessed using the IMERG algorithm, producing as end product a unified TRMM-GPM archive. Contact is George Huffman (NASA/GSFC (george.j.huffman@nasa.gov). This archive will be converted to SPI to compare drought screening from GPM versus drought screening from CMORPH, with respective panels placed on the GDIS portal.

The Work Package 2 team is drafting a proposal for NOAA MAPP to expedite the data processing and lead time with which this will be made available.

Work Package 3

Pozzi will update the ECMWF drought data processing code used in the European Framework projects Drought Early Warning System for Africa (DEWFORA) and Global Water Scarcity Information Service (GLOWASIS) (Florian Pappenberger (Florian.Pappenberger@ecmwf.int) for data processing and subsequent drought mapping of ECMWF seasonal forecasts from Copernicus C3S.

NOAA Climate Prediction Center already has a global drought mapping system by Kingtse Mo (NOAA CPC (Kingtse.Mo@noaa.gov) and Brad Lyon (International Research Institute Columbia University (bradfield.lyon@maine.edu), but this system derives its drought forecasts only from the North American Multi-Model Ensemble (NMME), which includes the NOAA National Center for Environmental Prediction (NCEP) Climate Forecast System v2.

Unfortunately, the existing NOAA-CPC global drought mapping utilizes CPC Gauge - OLR blended daily precipitation analysis, which is a legacy global precipitation dataset, predating both CMORPH and GPM. Data processing of both data streams (NMME and ECMWF) is possible using the upgraded global precipitation monitoring product of Work Package 2. Errors in precipitation (through delays reaching GPCC) will result in errors when compared to mapped drought forecasts (the Global Producing Centres for Long Range Forecasts (GPCs) do not use GPCC for data assimilation.

Work Package 4

Work Package leads are Steve Ansari and Richard Heim.

Existing work has standardized the drought index codes at NIDIS. Additional work will be undertaken preparing educational materials.

7 RESOURCES

The work schedules have been outlined above in section 6. These are supported largely by in-kind contributions, although proposal drafting has also been mentioned.

PoC Pozzi was supported by the NASA WaterNet project at the early stages of GDIS formation; he was subsequently supported by the European Framework project GLOWASIS (while the project was still active).

Richard Heim (NOAA), the NOAA representative of the Inter-agency US Drought Monitor provides in-kind time and effort. The same is true for Steve Ansari, the NIDIS portal manager, as was true of his predecessor, Mike Brewer.

NOAA, at multiple levels, has been supportive of GDIS. As noted above, NOAA direct funded through Modelling Analysis, Predictions, and Projections (MAPP) of the NOAA National Climate Program office has directly funded Kingtse Mo of NOAA CPC and Brad Lyon of International Research Institute, Columbia University) for drought forecasting work, as it funded the US Drought Task Force. In-kind effort has been provided by NOAA Climate Prediction Center (CPC) and NASA/GSFC Global Modelling and Assimilation Office (GMAO) (for Siegfried Schubert).

Additional in kind contributions are expected for the global precipitation work package with the Global Precipitation Mission (GPM) team (George Huffman).

The 1st international GDIS workshop was funded by WCRP; the 2nd GDIS international workshop was funded jointly by WMO and NOAA. Smaller contributions were also made (by, for example, the European Commission).

The in-kind contributions are currently deemed probably adequate for completion of work packages (I) through (IV). Additional funding will be sought for work packages II, and possibly III (the two projects are linked). A small discretionary funds cushion is available, but much depends upon the climate of the USA presidency.

Given the amount of work required to develop work packages 2 and 3, the priorities of GDIS are making available global and regional drought early warning, not travel.

In two cases, NASA has not funded GDIS proposals, so it no longer is considered a serious worth the time of preparing proposals.

8 TECHNICAL SYNOPSIS

The Global Drought Information System is embedded within scientific and space satellite fields that are subject to change over longer time scales than the two year time scale within the GEO Work Plan.

Innovation in supercomputer hardware (and even cloud storage) has increased the spatial resolution of climate models, approaching that of "convection resolving" models. Convective parameterizations are being superseded by data assimilation offering more detail into mesoscale convective complex and typhoon structure, along with greater accuracy in forecast predictions. The other side of the coin is that this Level of Detail is highly chaotic, non-hydrostatic, and may not converge in some situations. Nevertheless, improvements in climate modelling of extremes are anticipated, along with improvements in forecasting. These developments must absolutely be supported by improved ability to monitor precipitation globally at much higher spatial and time resolutions.

What does storm monitoring have to do with drought? The answer is provided by the following graph.

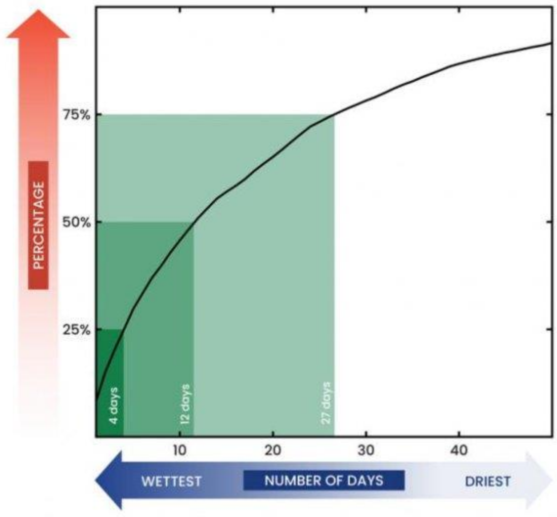

Figure 5 Precipitation is very unevenly distributed by day (A. Pendergrass & R. Knutti (2018) "The uneven nature of daily precipitation and its change," *Geophysical Research Letters)*

The median (half) of all precipitation currently falls on only 12 days; by 2100, climate models predict a decline to 11 days.

Until recently, precipitation was approximated from measured cloud top temperatures taken from geostationary satellites as combined with passive microwave sounders and radiometers which only had the capability of taking measurements twice a day (given their low earth orbit). The Global Precipitation Measurement (GPM) constellation consists of a network of microwave radiometers that are similar but not identical, differing in central frequency, spatial resolution, and viewing geometry (images become distorted close to the limbs). The first step toward unified global precipitation in GPM is inter-calibration using GMI as the reference standard, ensuring observed brightness temperatures are consistent among the sensors, reducing residuals down to below less than one degree Kelvin (Berg et al 2016).

However, in addition to the issue of differences among satellites is the issue of the number of satellites making observations, i.e., their spatial coverage over the globe. Whitcraft, et al (2015) carried out an assessment of number of satellites required to meet Earth Observation requirements for agricultural monitoring remotesensing-07-01482.pdf . A counterpart assessment can, and has, been carried out for precipitation. However, Whitcraft et al (2015) assumed large satellites of the national space agencies. The prospects for monitoring agricultural productivity, particularly in locations such as Africa, improved with the launch of commercial *nanosatellites*. And this is also true for precipitation monitoring. NASA Jet Propulsion Lab (JPL) has launched a nanosatellite carrying a miniaturized version of the GPM precipitation radar in a pilot study test. Similar nanosatellites are being designed to probe typhoons and hurricanes.

Greater resolution within space-time observations will improve global drought monitoring; improvements in climate models will improve global drought forecasting.

A flowchart of the ECMWF Drought Forecasting Python Code:

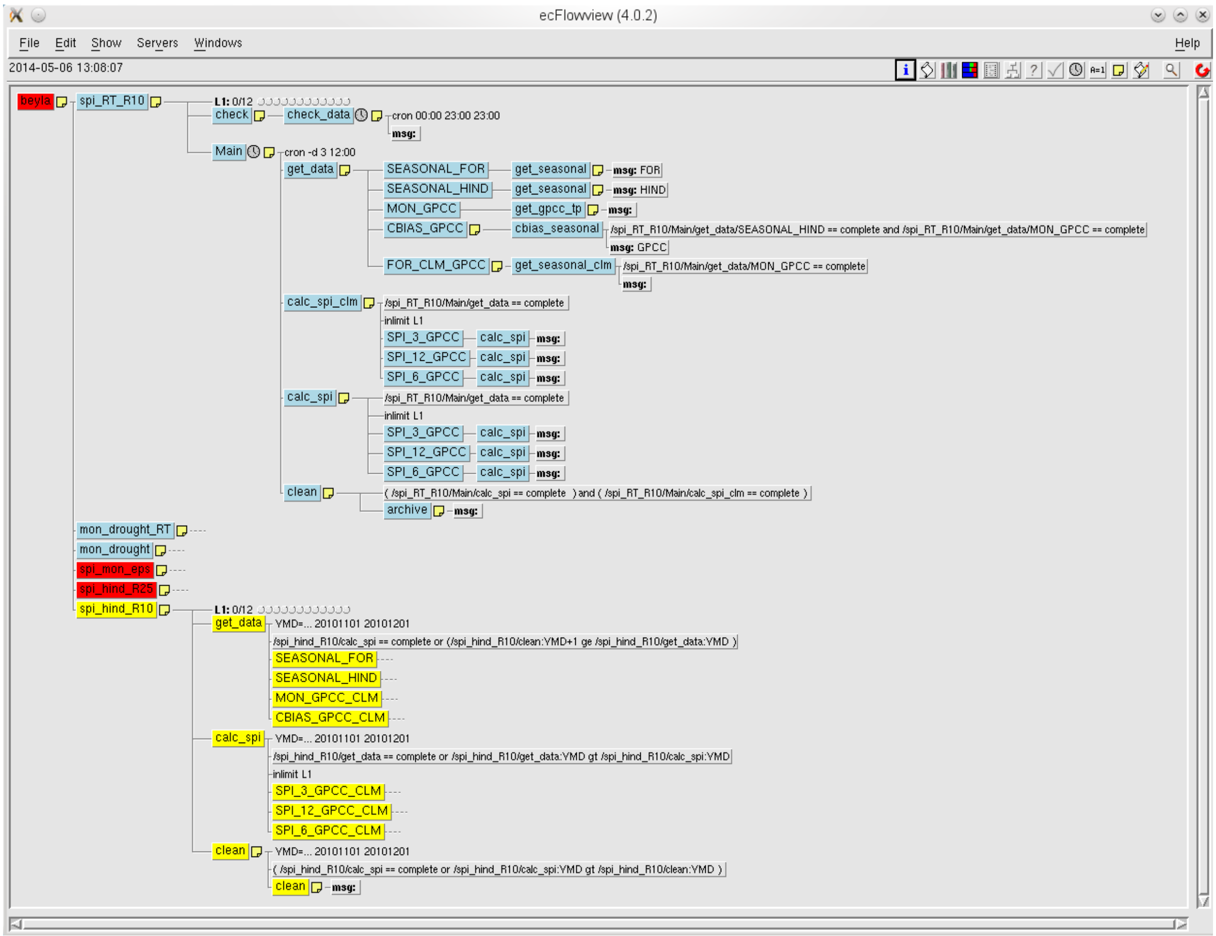

Figure 6 ECMWF Python code used for Africa and Global Drought Monitoring

NIDIS Python SPI code can be accessed https://www.drought.gov/drought/python-climate-indices

An example of mapped SPI over North America is provided below (using the Pearson statistical distribution for SPI). The negative SPI values, located over Texas during this drought episode, are supported by the US Drought Monitor. The global CMORPH satellite-SPI dataset is a confirmed contribution.

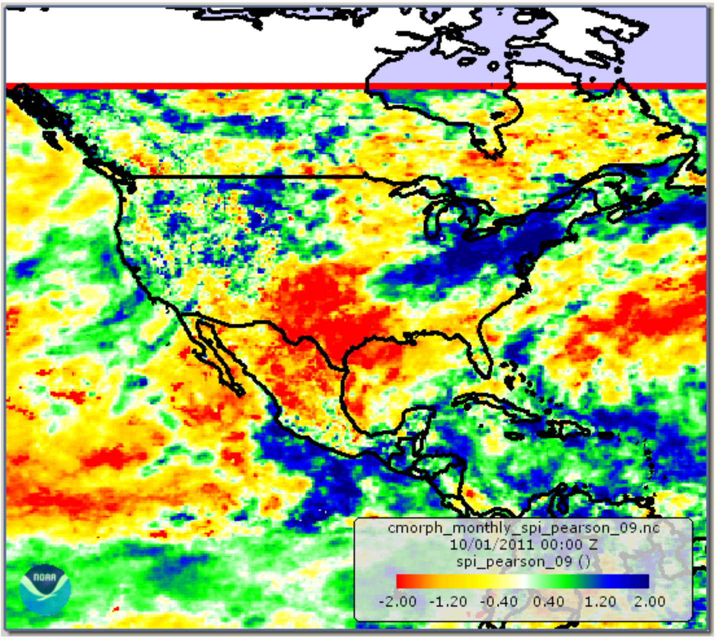

Figure 6 Space-based, as opposed to ground-based, precipitation (CMORPH) from NOAA Climate Prediction Center converted into SPI for drought monitoring (S. Ansari, et. al., (2018) "Overview of drought GIS techniques on www.drought.gov," NOAA CPC CDPW 10.23.2018)

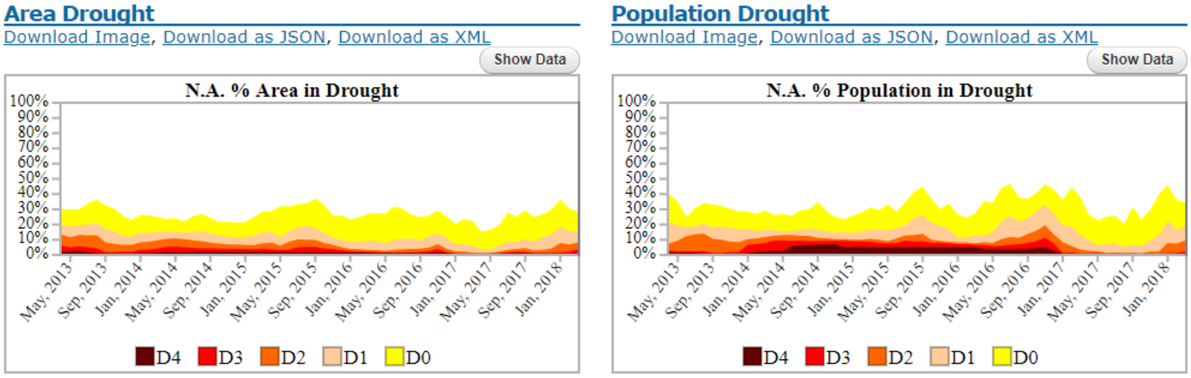

Figure 7 Charting of Continental Areas under Different Drought Categories (The Drought Monitor categories (D0, D1, D2, D3, and D4) can be replaced by SPI ranges (or an overlay of SPI and soil moisture anomaly).

A review of the basic methodology used by the forecasting community is contained within the World Weather Research Program Joint Working group on Forecast Verification Research https://www.wmo.int/pages/prog/arep/wwrp/new/jwgfvr.html . This will be distilled to an understandable explanation for display within the GDIS portal.

Since the Standardized Precipitation Index drought indicator—a measure of incoming precipitation deficiency (SPI)—is used both as predictor and as measured drought condition, they can be assembled into dichotomous yes/no tables. Is a drought forecast or not forecast versus is a drought observed or not observed. SPI determination, in practice, is "fuzzy." Also, in practice, box plots are used to display how closely or dispersed the forecast values are with respect to observed values.

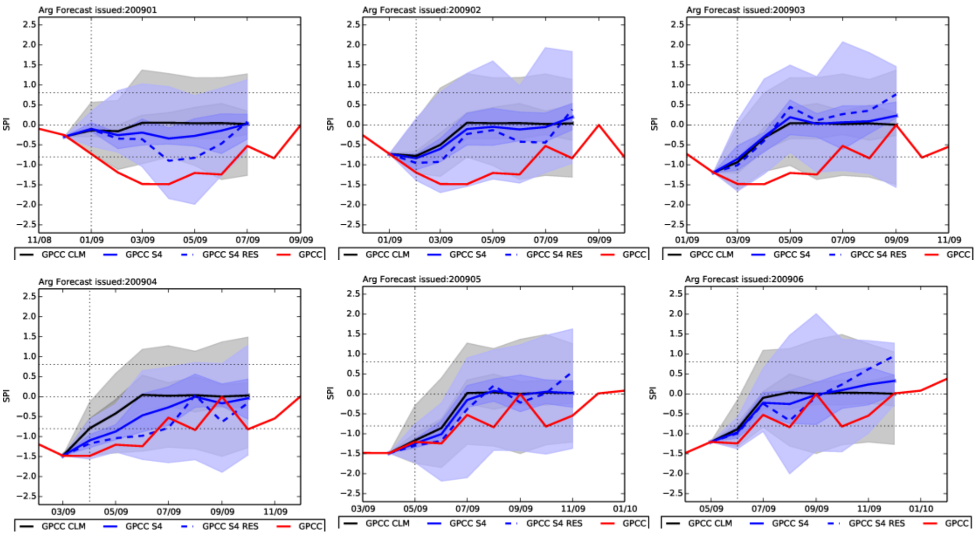

Figure 8 Comparison of ECMWF forecasted drought conditions versus actual drought conditions during the 2009 Argentinian drought.

The selected forecasted variable is SPI-3, a three months accumulated sum of precipitation, relative to its customary occurrence for that time of year. The first seasonal forecast is issued in January (top left as "200901," i.e., 2009-01). The next chart illustrates SPI forecast conditions issued in February ("200902"), March (200903), April (200904), May (200905), and June (200905). The solid red line is the observed SPI-3. The solid blue line is the "ensemble mean" forecast for ECMWF S4. (The solid black line designated "GPCC CLM" is the SPI series in which forecast precipitation is removed and replaced by climatological values).

9 DATA POLICY

GDIS conforms to the GEOSS Data Sharing Principles and GEOSS Data Management Principles.

Most of the information will be accessible via the GDIS portal, http://www.drought.gov/gdm

When the new generation portal data products come online (satellite precipitation-derived drought monitor and combined satellite-land precipitation monitor), specific links will be created to access these through the NIDIS portal. A teleconference will be set up with GEO to ensure that all of these individual products are accessible through the GCI (GEOSS Common Infrastructure).

ANNEX List of key scientific references describing the basis for the work of the initiative

Global Drought Forecasting

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NMME Data Downloads per Continental Region:
https://www.cpc.ncep.noaa.gov/products/international/nmme/nmme_seasonal_body.html

ECMWF seasonal forecasts through Copernicus C3S access

https://confluence.ecmwf.int//display/WEBAPI/Access+ECMWF+Public+Datasets#AccessECMWFPublicDatasets-key

https://cds.climate.copernicus.eu/#!/home

NOAA Climate Prediction Center Global Drought "Outlooks," i.e., drought prediction:

https://www.cpc.ncep.noaa.gov/products/Drought/Monitoring/spi-global_outlooks.shtml

(In this display, the month-1, month-2, and month-3 forecasts are overlain over one another; the mont-3 forecast box needs to be unchecked).

The monitored global drought (SPI) product—which needs to be updated—is here: https://www.cpc.ncep.noaa.gov/products/Drought/Monitoring/spi-global.shtml

South America NMME forecasts:
https://www.cpc.ncep.noaa.gov/products/international/nmme/html_seasonal/precip_anom_samerica_body.html

Africa NMME forecasts:
https://www.cpc.ncep.noaa.gov/products/international/nmme/html_seasonal/precip_anom_africa_body.html

South Asia NMME forecasts:
https://www.cpc.ncep.noaa.gov/products/international/nmme/html_seasonal/precip_anom_sasia_body.html

East Asia NMME forecasts:
https://www.cpc.ncep.noaa.gov/products/international/nmme/html_seasonal/precip_anom_easia_body.html

Central America NMME forecasts:
https://www.cpc.ncep.noaa.gov/products/international/nmme/html_seasonal/precip_anom_camerica_body.html

Monthly rainfall outlook (one month prediction), comparing EMCWF, CFS v2, and UK Met Office climate models (Asean Regional Climate Centre for Southeast Asia and Indonesia): http://asmc.asean.org/asmc-seasonal-outlook/

NOAA MAPP explanation of drought prediction: https://www.cpo.noaa.gov/Meet-the-Divisions/Earth-System-Science-and-Modeling/MAPP/MAPP-Task-Forces/Drought/Drought-Task-Force-I/How-Research-Is-Improving-How-We-Monitor-and-Predict-Drought/Drought-Prediction

European Commission & Copernicus Disaster Risk Management Unit including link to JRC Global Drought Observatory: http://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1011

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1985-1989	**Meteorologist**, Climate Services Division, National Climatic Data Center, Asheville, NC;
1982-1985	**Meteorologist** (Meteorologist Intern), National Weather Service Forecast Office, Great Falls, MT

Current Professional Associations:

Member: American Meteorological Society
Member: American Geophysical Union
Member: American Meteorological Society Committee on Applied Climatology, 1994-97

Recent Publications:

2017 Heim, Jr., R.R., M.J. Brewer, R.S. Pulwarty, D.A. Wilhite, M.J. Hayes, and M.V.K. Sivakumar: Drought Early Warning and Information Systems, Chapter 17 in Vol. 1: Principles of Drought and Water Scarcity, Handbook of Drought and Water Scarcity, Taylor and Francis, USA, 303-319.

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GROUP ON EARTH OBSERVATIONS

GDIS Data Flow Diagram

The purpose of the Global Drought Information System (GDIS) is to rapidly identify "hot spots" of food vulnerability and insecurity (arising out of drought-induced interruptions of water supply. This tracking occurs both in real-time conditions and likely predictions over a month lead time.