2.4.7 Water- Drought Scenario

The objective of the Drought Scenario is to support the development of a Global Drought Early Warning System capability, permitting users to visualize the impacts of drought and drought forecasts, including the role of water on famine and the cross-cutting societal benefit area of sustainable agriculture.

2.4.7.1 Targeted or Supported Community

The targeted and supported community includes water planners, drought management agencies, and members of the public who wish to find out information on their water supplies, with such information being provided through the portal and through targeted cell phone alerts during emergencies

2.4.7.2 Context and pre-conditions

2.4.7.2.1 Actors

1. End use decision maker at the local and state level, having the jurisdictional authority to authorize the rationing of water;
2. A utility who has the authority to set ceilings on water use;
3. Emergency support personnel who have the financial resources to authorize emergency delivery of food packages to a community suffering from catastrophic famine due to drought.

2.4.7.2.2 Information Assumed to be Available

Below is a list of information assumed to be available in order to support the scenario. This information has to be spatially of sufficiently high enough density to be useful at application scales and permit reliable estimation of water supply (and reduce uncertainties in estimating the water budget).

Princeton currently has an experimental global drought monitor (http://hydrology.princeton.edu/~justin/research/project_global_monitor/index_global.html) as does Benfield Hazard Research Centre, Department of Space and Climate Physics, University College London.

The US National Integrated Drought Information System (NIDIS) (http://www.drought.gov/portal/server.pt/community/forecasting/209/soil_moisture/338) also lists multiple drought monitors for the USA. The European Union drought monitors include (http://www.geo.uio.no/edc/) and the Drought Management Center for Southeast Europe (http://www.dmcsee.org/en/drought_monitor/). The USA drought monitors include the NASA/GSFC National Land Data Assimilation System (http://www.emc.ncep.noaa.gov/mmb/nldas/drought/) modeled soil moisture and several global regional implementations currently under development. The USA NOAA Climate Prediction Center includes a 1 week to 2 week soil moisture forecast, based upon the Global Forecasting System, as outlined below (http://www.cpc.noaa.gov/soilmst/forecasts.shtml).

Some of this information is acquired, processed and accumulated by national governments, such as the National Integrated Drought Information System (NIDIS), in the case of the USA, the Drought Management Center for Southeast Europe, the USA NASA/Goddard Global Land Data Assimilation System, NCEP drought monitor, the Australia Ministry of Water Resources, and multiple other organizations. Some academic institutions also carry out regional (and some experimental global) drought forecasting, such as Princeton and the University of Washington in the USA.

Note that most of the information resources are not yet accessible via the GCI.

1. Distributed information on available water supply must include measures of the accumulation of snowpack during the winter season (where mountainous terrain or high latitude locations are found), since during the winter season, lower surface temperatures and lower surface evaporation rates, allow accumulation of water to take place; this water supply melts in spring recharging the unsaturated vadose zone and groundwater table—providing water for the remainder of the year.
2. Distributed, high-resolution information on precipitation, as determined by multiple observables, including radar (such as Doppler radar), rain gage network, and satellite-monitored precipitation
3. Synoptic station measurements of wind speed within the planetary boundary layer (at anemometer level), air temperature, atmospheric humidity, incoming solar radiation, and measured terrestrial (infra-red) radiation are required to estimate: 1) evapotranspiration from Land Surface Models; or 2) sensible heat flux (and soil storage flux), so that evapotranspiration may be derived as a residual from the surface net energy equation, using satellite observations of radiation budget components. Much of the synoptic meteorological station and short-range forecast information is provided by the US National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Prediction (NCEP) models or the European Union European Community Medium Range Forecasting modeling suite.
4. Groundwater observations are also required, to ascertain whether groundwater supplies may compensate for surface water scarcity and drought (on agricultural crop production and other water uses).
5. Additional required information: water surface elevation of reservoirs and lakes and rivers (including discharge of rivers)
6. Reliable estimation of water usage and consumption is required so that the consumption of water can be compared against available water supply using tools.
7. Reliable monitoring of water usage and consumption through evapotranspiration by crops is required, at different rates for different types of crops and over different types of natural land cover (wetland, urban surfaces, desert, etc). This requires high-resolution spatial data on agricultural acreage and crop type.
8. Reliable knowledge of the population of farm animals, to account for water consumption by animals, including both direct consumption and water consumption growing crops fed to animals as foodstuffs or forage. This also allows the "water footprint" to be estimated for beef production and processed foods.
9. Accurate, high-resolution topography is required in order to model streamflow within a drainage basin, as provided by, for example HydroSHEDS or the Aster digital elevation model.
10. Most commonly used routing algorithms (such as the Muskingum method or the 1D St. Venant equation) are too crude to directly use HydroSHEDS and Aster

topography, so that such very high-resolution topography must be resampled to reduce it to a coarser resolution to use the routing algorithms (and, by doing so, dropping out fine river network details such as river meander bends).

11. A streamflow gauging network is required, such as the national Ministry of Water Resources or hydrometeorology authority, and the Global Runoff Data Center.
12. Seasonal forecasts are available from the NCEP Climate Forecasting System (CFS) or the European Union, from which estimates are made on the prolongation or abatement of a drought, providing some additional lead time for mitigation measures to protect the population and water users.

2.4.7.2.3 Processing and Collaboration Functionality Needed

The following are the processing and collaboration functionality needed to best leverage and grow the GCI within the context of the Drought scenario:

- Community Catalog for registering data and services
- Community Portal for finding and accessing data and services needed for the execution of the scenario.
- Additional functionality and facilities include tools for processing, analyzing, and visualizing observational and modeled data for near-real time (NRT), historical analysis (to derive soil moisture anomalies, for example), and for seasonal forecasting.
- Real-time assimilation of observational data into numerical models (direct insertion or ensemble Kalman Filter) is carried out to improve forecasts in Land Surface models, including the US National Center for Atmospheric Research (NCAR) Community Land Model (CLM), the Noah land model, the Variable Infiltration Capacity (VIC) model, WBM/WTM, Matsiro-TRIP, JULES, etc.
- Effective mechanisms for distributing in NRT maps/images and alerts to emergency response and water management authorities, to mass media, and the general public.

2.4.7.3 Scenario Description

Drought indices are based upon *meteorological drought, agricultural drought* (soil moisture anomalies), and *hydrologic drought* (areas where snowmelt-runoff are important, as in the Western USA, parts of South America, Himalaya and Tibet meltwater production regions, and Central Asia).

Drought is determined as water scarcity from the amount of water (for example, snowfall or incoming precipitation) customarily received. This must include "latency," i.e., winter water storage as snowpack which melts and recharges soil in spring, affecting late spring and summer available water supplies. Soil Moisture anomalies provide one index of drought; soil moisture anomalies require long-term statistical distributions of Soil Moisture (SM). These products are modeled data, created using multi-model ensembles run using 60 year to 100-year driving data (precipitation, temperature, etc) and stored as gridded statistical distribution data. The modeled data are based upon observations of temperature and precipitation which are used as forcing variables with land surface models in order to estimate soil moisture within the limits of model error and observational errors. Models are used, because *in situ* observational data over a 50 year period or longer are temporally-coarse and spatially-coarse. The produced modeled fields are spatially high-resolution and temporally high-resolution, but model errors introduce uncertainties.

There are four types of time scales on which different global drought forecasting systems may be based:

(1) "Nowcasting" system;
(2) Short-term forecasting
(3) Seasonal forecasting; and
(4) Climate change forecasting.

Forecasts work by applying precipitation and meteorological forecast fields (such as temperature) to land surface models and hydrological models.

The seasonal forecast models may include forecast models, such as the USA NOAA NCEP CFS seasonal model or EU or Japanese seasonal forecast systems.

The short-range forecasting systems may include as forecast components the USA NCEP Global Forecasting System or European Community Medium Range Forecasting model forecasts.

Forecast soil moisture conditions are produced from Land Surface Models or Hydrological Models (or a multi-model ensemble MME*), and the forecast soil moisture can be compared with historical soil moisture for the same time of year* to prepare a drought forecast.

A *climate change* forecast is made using Global Climate Models (General Circulation Models or GCMs), but the precipitation must be derived from cyclonic and convective precipitation estimated within the GCM, which is subject to considerable uncertainty. There is also uncertainty regarding the accuracy of the ranges of IPCC scenarios. Considerable progress is being made in Japan (and elsewhere) developing a new generation of 10 km (or finer) GCMs, which may alleviate the need for downscaling precipitation fields to application scales (i.e., agricultural scale) (although the convection parameterization problem remains).

A GEO global drought forecasting system might be based upon combining multiple regional drought forecasts.

Beyond two weeks, hydrological forecasts degrade rapidly. This suggests segregating nowcasts and short-term forecasts from the longer range seasonal and climate change forecasts. Obviously, the longer the lead time, the more time to prepare remedial efforts to mitigate drought or catastrophic crop failure.

2.4.7.3.1 Scenario Events

1. A policy officer is trying to locate where water is geographically scarce, so that remedial efforts may be launched and initiated in a timely fashion, if warranted. He combines various sources of data within the decision support system (possessing user-friendly visualization). The data combined include the forecasts described above in addition to
    a. House household data (organization such as Oxfam, Red Cross and Red Crescent, US-AID, etc) on the ability of households in the region to survive drought (*along with the resources of the household in providing ability to substitute foods*, given local crop failures due to drought). This is important because S*usceptibility* is a critical factor determining *drought vulnerability*.
    b. Information retrieved and processed from satellite systems, such as the Soil Moisture and Ocean Salinity (SMO(S) and Soil Moisture Active and Passive (SMAP) provide global spatial coverage. In addition to radar and microwave estimation of the upper soil column soil moisture, SEBAL (Surface Energy Balance Algorithm), Simplified Surface Energy Budget (SSEB), ALEXI, and dis-ALEXI data also estimate evapotranspiration from the entire root zone using satellite measured radiances from pixels derived from Landsat and MODIS imagery (but with errors using the surface energy balance equation and estimated sensible heat flux and soil heat fluxes). The combination of evaporation of water by vegetation and measurement of water held in the upper soil column—when combined with land surface models—may reduce the errors accumulating in using the land surface models and meteorological data, by themselves. *Such satellite-based information can be effectively applied in nowcasts or to provide data assimilation within short-term forecasts.*
2. Research staff who assist the policy officer are tasked to map the *intensity* and *spatial extent* of the incipient drought—as displayed in the high-resolution distribution of soil moisture, indicating severity, area, and duration.
3. These preceding steps produce a data product that can be displayed using a geographic information system—a visualized product—such as high-resolution maps of soil moisture anomalies.
4. Drought is determined by contrasting water availability against water usage. The dominant usage of water is agriculture. Hence, such a comparison must compare agricultural water demand against water availability. The gridded soil moisture data—in nowcasts and short-term forecasts—is compared with high-resolution distributed crop distribution and crop type data, from which water demand can be estimated. Such "crop dominance" and "crop type" is being assembled by the

GEO Global Agricultural Monitoring System and GEO Water Cycle Community of Practice pilot projects. This crop acreage and crop type information can be updated using crop vitality data from satellite systems, such as fused Landsat-MODIS data, derived by *comparing the current condition of the crop with the previous states of the crop at the same time of growing season* (as in the "continuity index" in Global Agricultural Monitoring (GLAM).

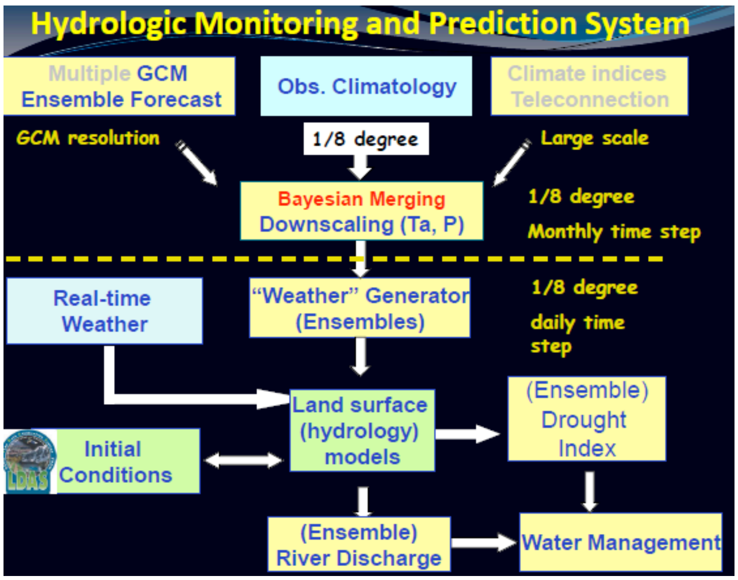
a. An *agricultural production* estimate per pixel (as partly determined by Landsat-MODIS fused data) (kg per square meter) may be *divided by crop water use* (cubic meters of water per square meter) to *derive water productivity* (kg of crop per cubic meter of water). Such an Agricultural Water Productivity Mapping system will display where water use is wasteful or where particular crops (such as biofuels) are wasteful for purposes of conserving water and substituting crops that would mitigate impacts of drought.

5. Assessment of drought requires a surface water appraisal and a groundwater appraisal. Agricultural areas of declining soil moisture may be sustained by surface irrigation canals drawn from tanks or rivers or reservoirs or sustained by wells appropriating groundwater. Models employed by the national meteorological services, such as NOAA National Weather Service Community Hydrologic Prediction Service Flooding Early Warning System (FEWS) and MIKE provide, along with models such as VIC and WBM/WTM and Matsiro-TRIP, some estimates of *surface* water availability. Areas where snowmelt-runoff is important may also use the Surface Water Supply Index as a drought indicator. Post-processing routing of land surface models is also possible and provides estimates of surface water imports. In addition to these *surface water* models, *ground water* models, combined with groundwater table measurements, have to be consulted, such as MODFLOW.

a. Gridded site information (for example, station data) is cross-listed with the water cycle ontology and the agricultural ontology and the geographical ontologies, reducing the semantic heterogeneity found among multiple countries and sites, following the practices of the Asian Water Cycle Initiative and the East Asia water cycle community of practice.

b. Web services, such as an upgraded version of WaterML, can update catalog data and station data, such as the time series of point streamflow property data, including the data contained within the Global Terrestrial Network on Hydrology global data sets, such as Global Runoff Data Center and International Ground Water Resources Assessment Center, supplemented by additional data to close the inputs required by models. The virtual observatory reduces semantic heterogeneity which complicates data integration. The surface water models (used for surface water assessment) include modules within their code ("frameworks") that automate the process of calling web services to update model user variables, including the use of ontologies. These ontologies will be registered with the GEO geophysical variable ontologies and geographical ontologies.

6. The officer preparing a drought forecast or a drought alert may integrate different drought forecasts or may choose different systems to produce multiple lines of evidence for synopsis and prediction
7. Based on this assessment, the policy officer will provide stakeholders with advice on possible mitigation strategies, which are *based upon* the combination of *severity, area, duration, and susceptibility*, for which the extreme case is water rationing or famine relief. Triggers are based on thresholds that are used to send automated email alerts (or cell phone alerts) to listed decision making bodies, such as NIDIS and the Drought Center for Southeast Europe, etc.,



An Example of a Global Drought Prediction System (Wood, Luo, Sheffield, and Li 2010)

2.4.7.4 Enterprise Model

An Enterprise Model will be developed later depending on the responses to the CFP.

2.4.7.5 References

GEO Task WA-06-02: Droughts, Floods and Water Resource Management includes *a) Forecasting and Early Warning Systems for Droughts and Floods* and *b) Impacts from Drought*

Imam, B. 2009 A survey of drought indices: Input, output, and available datasets, presentation made at the Water Resources in Developing Countries: Planning and Management in a Climate Change Scenario, Trieste, Italy

Pozzi, W., P. Thenkabail, N. L. Miller, J. Sheffield, P. R. Houser, B. Fekete, H. Su, R. Shrestha, K. Sharma, R. Kaur, 2009 Methods of Agricultural Water Productivity Mapping using Remote Sensing, American Geophysical Union, Fall Meeting U43B

Wood, E., L. Luo, J. Sheffield, H. Li, 2010: Towards a Global Drought Monitoring, Forecasting, and Projection Capability, presentation