On the Use of NASA Earth Observations to characterize the 2012 US Drought

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Introduction:

As the harvest season approached in August 2012, much of the United States remained in the grip of a major drought. According to the United States Drought Monitor (USDM), 52% of the United States and Puerto Rico was in moderate drought conditions or worse by August 7, 2012 (see Figure 1a). Drought areas were concentrated in the agricultural states in the central U.S.A. The drought threatened global food prices and US biofuel feedstocks. Although areas east of the Mississippi River experienced some relief due to Hurricane Isaac, the drought persisted west of the Mississippi River Basin. The USDA Economic Research Service reports about 80 percent of the US agriculture experienced drought in 2012 making it the most extensive drought since the 1950's. The Financial Times reported 2012 losses at roughly $30 billion dollars. NASA maintains satellite and modelling capabilities that enable the assessment of drought severity and extent on a national and global basis.

Drought Monitoring:

Drought monitoring is required to identify the occurrence of droughts, to classify their intensity and extent, and to anticipate their impacts. NASA products such as soil moisture, GRACE groundwater, and vegetation maps are used in conjunction with data from other U.S. agencies to provide drought information through the US Drought Monitor (USDM) (see Sovoboda et al., 2002). NASA products increased the accuracy of USDM drought contours and improved drought detection with NLDAS soil moisture and snow cover maps that supplemented *in-situ* data especially in data-sparse regions. (See www.emc.ncep.noaa.gov/mmb/nldas and http://ldas.gsfc.nasa.gov/nldas/)

Agricultural and Pastureland Drought Monitoring

According to the National Agricultural Statistics Service (NASS/USDA), as of July 29, 2012 the drought had left 48% of the corn and 37% of the soybean harvests rated as poor or worse and 33% of the nation’s cattle were trying to survive in extreme to exceptional drought. In 2012 the Internal Revenue Service used USDM products for tax deferrals in many states, and the USDA applied USDM products in their Livestock Forage Disaster and Conservation Reserve Programs. The USDA’s Global Economic Intelligence System provides a global overview of crop production (Reynolds, 2011). In 2012, this system utilized weather from geostationary satellites, Normalized Difference Vegetation Index (NDVI) from polar-orbiting satellites, soil moisture from passive microwave, and lake level estimates from radar satellite altimeters (Birkett, 1998), to develop monthly US and global updates. Increasingly agricultural agencies rely on high resolution VegDRI products (see Figure 1b) to map the drought effects down to 1-km resolution (Wardlow et al., 2012). VegDRI integrates MODIS data from the TERRA observations of vegetation conditions with a modified Palmer Drought Severity Index classification scheme and the biophysical characteristics of vegetation to produce an estimate of drought stress on vegetation. The eMODIS VegDRI product proved even more valuable because it provided frequent updates during the 2012 drought.

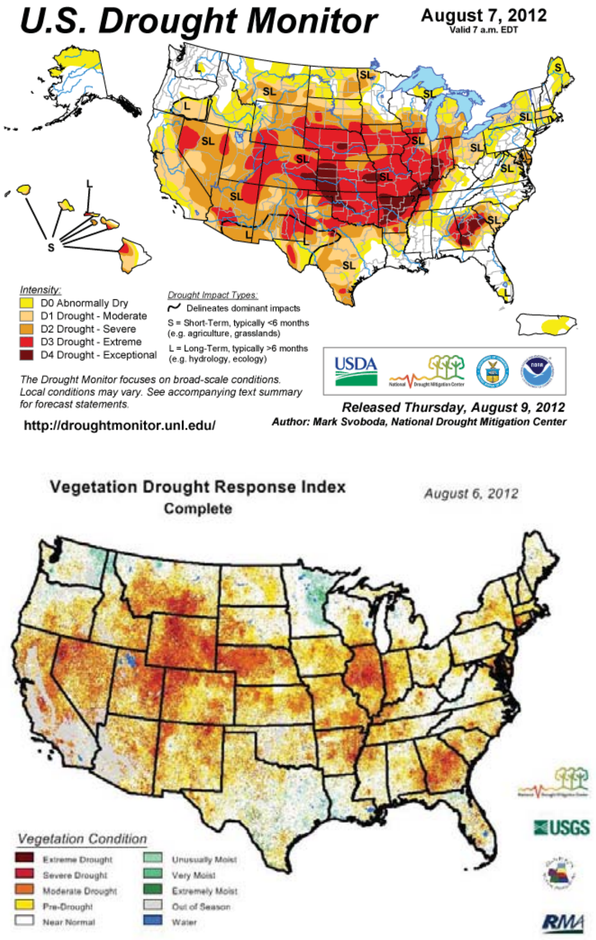

Figure 1. a) The US Drought monitor map for August 7,2012 and b) the VegDRI map for August 6, 2012. The drought severity has migrated eastward (1a) but the impacts are still largest in the western grain producing states (1b).

Soil moisture can be used to indicate the availability of water for plant growth and irrigation requirements as well as an indicator of the potential for reductions in streamflow and water infiltration. During 2012, soil moisture and surface water storage were estimated from Active/Passive Microwave Sensors including AMSR-E/TMI/SSMI Radiometers and the QuikSCAT Scatterometer. In 2014, the launch of the Soil Moisture Active Passive (SMAP) mission will map soil moisture globally and support a range of drought-related applications including the USDM.

Hydrologic Drought Monitoring

Streamflow and surface water storage were affected by the 2012 drought. In July almost 80% of the contiguous United States experienced low streamflows with Iowa and other central states experiencing flows of less than 25% than of normal leading to stress on fish and aquatic bird habitats. USDM products provided guidance on the timing of the implementation of federal agricultural drought assistance programs in many states. Due to satellite limitations in measuring flows on smaller rivers and streams, streamflow droughts were assessed using *in-situ* streamflow data operated by the United States Geological Survey (USGS) and individual states and from the NLDAS output.

The drought resulted in falling groundwater levels in many central states until August. A large number of farmers in Indiana and nearby states reported that their wells had failed and spent up to $10,000 each on deepening their wells or drilling new ones. NASA's Gravity Recovery and Climate Experiment (GRACE) mission combined with other data and a data assimilating land surface model produced useful maps (see Figure 2b) for assessing drought impacts on groundwater (Rodell, 2012). Weekly national GRACE-based drought maps are available through the National Drought Mitigation Center's website (http://www.drought.unl.edu/MonitoringTools/NASAGRACEDataAssimilation.aspx).

A comparison of the center of drought in Figures 1 and 2 shows that atmospheric, agricultural and hydrologic drought experience both time and space lags and displacements due to the processes responsible for their manifestations.

Meteorological Drought Monitoring:

Prolonged periods without precipitation are the main drivers for natural drought. NASA Earth Observations that contribute to meteorological drought monitoring include the Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA), measurements of temperature (AIRS), radiation (CERES), clouds and humidity (AIRS), and MODIS vegetation. NASA has led the development of Global Precipitation Climatology Project (GPCP) products available at http://precip.gsfc.nasa.gov/ that provide a 30-year climatology of precipitation and provide a benchmark for drought monitoring. Integrated precipitation products include PERSIANN, which is derived from TRMM, DMIP and NOAA geostationary satellite data and is widely used for monitoring precipitation at higher resolutions. Experimental high resolution short-term Standardized Precipitation Indices (SPI) maps produced from PERSIANN data (Arasteh, 2011) are providing guidance for water resource planning.

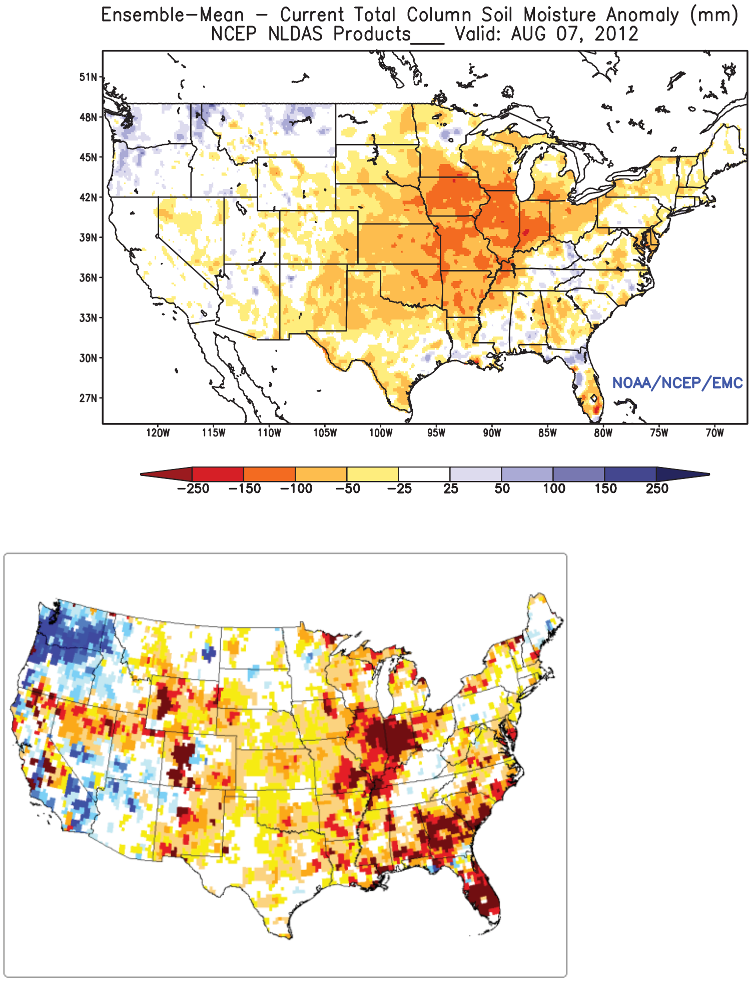

Figure 2: Soil moisture outputs including a) the total column soil moisture anomaly on August 7, 2012 from NLDAS four-LSM ensemble-mean (See Xia et al., 2012) and b) GRACE data for August 12, 2012.

The water stress produced by drought affects Evapotranspiration (ET) and its role in the local water budget. The 2012 drought was monitored by using Atmosphere-Land Exchange Inverse (ALEXI), a thermal approach (Anderson et al, 2011) to drought monitoring supported by USDA and NASA. This inverse modeling technique combines clear-sky fluxes from Landsat TIR with coarse (5-20 km) satellite data (AIRS, GOES, MSG); moderate (1 km) resolution (MODIS, AVHRR, ATSR) and high resolution (90-120 m (ASTER, LANDSAT)) to produce multi-scale ET, drought monitoring, and soil moisture maps. Peters-Lidard et al. (2011) showed that improved estimates of ET arose from the assimilation of AMSR-E soil moisture, leading to optimism that SMAP soil moisture data will produce significant improvements when they become available in 2014.

Drought Prediction:

To mitigate drought impacts, society must have access to reliable forecasts of a drought's onset, persistence, and termination. In May 2012, the USDA issued a forecast indicating that the U.S. corn crop would be the largest on record. By July the forecasts of yield were reduced to below average due to the emergence of the 2012 drought. Drought predictions rely on comprehensive observations of surface conditions on oceans and land. Forecasts can be improved with higher resolution LSMs that could use the NASA high resolution data products (Cai et al., 2011) and improved soil moisture information which has a significant impact on streamflow prediction and drought monitoring (Koster et al., 2011).

Ensemble forecasts can increase confidence in drought predictions (Schubert and Koster, 2012). They show that ensembles for GMAO forecasts for precipitation and soil moisture deficits July 30 initialized in early May, early June and early July have some skill (See http://gmao.gsfc.nasa.gov/research/climate/US_drought) At local scales, the Climate extension of Weather Research and Forecasting (CWRF) model has been used to show that model downscaling reduces forecast errors of seasonal mean precipitation and produces greater skill for heavy rainfall predictions (Yuan and Liang, 2011). Ensembles of physics configurations can also provide important skill enhancements because they incorporate the full range of regional physics to be captured (Liang et al., 2012).

Communicating information on drought to end users remains a challenge. Options for doing this more effectively include:

1) Using organizations and groups as intermediaries between scientists and users,
2) Holding user workshops to train users on ways to apply drought information,
3) Developing capacity and applications for users and data providers,
4) Improving strategies for coping with and adapting to drought based on access to better monitoring and prediction information.

Summary:

NASA made many important contributions to the US government's response to the 2012 drought through its unique Earth science program. The strength of NASA's satellite measurements comes from their ability to provide meaningful information at high resolution continuously over the USA and the globe and the availability of data assimilation systems to integrate these data with *in-situ* data and model outputs. NASA will continue to support global drought monitoring activities by providing maps for the evaluation of current conditions, tools for customized and interactive visualization, analysis and data downloading, multi-sensor, multi-source data integration, and the integration of drought-related data products.
NASA could strengthen its support to drought preparedness by:
1) reducing the time required for data acquisition, download, processing and distribution thereby substantially increasing the potential benefit of its products for its users.
2) continuing to make the strongest possible case for Earth Observations, Earth missions, science and applications to support all aspects of drought preparedness so they remain a clear well-articulated priority in NASA's budget and function within a framework for extreme events that

accounts for the effects of land and water management, population growth and climate change, and provides a strengthened focus on Earth Observations for monitoring and providing warnings.

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