Risk of Droughts: Characterization, Challenges and Opportunities

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Abstract

Climate change will have a significant impact in the water resources of the planet. Particularly the intensification of the hydrologic cycle will imply an increase of the climate variability and the frequency and magnitude of extreme events like droughts and floods. Droughts are of particular concern in arid and semi-arid regions where the competition for the water resources due to population pressure and non-sustainable use of both surface and groundwater will need to be addressed soon. The water-energy nexus will also be exacerbated and the competition between agriculture and residential/industrial used of water will be intensified. The US Southwest is a region severely affected by these pressures and current efforts to characterize, forecast and mitigate the impact of droughts will be presented. Droughts are of particular concern due to their large spatial extent and long durations and the lack of a uniform and consistent definition of their intensity and frequency. Recent advances in tele-detection and identification of climatic precursors like ENSO and its relationship to regional climates has facilitated the early warning of drought and its related impact in agriculture and possible famine.

Key words: Drought characterization, global crisis, drought forecasting

1. Introduction

The IPCC postulated that a warmer climate, with its increased climate variability, will increase the risk of both floods and droughts (Wetherald and Manabe, 2002; IPCC AR4, 2007). The challenge with droughts, however, is to characterize and forecast them appropriately, since droughts have many definitions and their risks are influenced by climatic and non-climatic factors.

There are several definitions of droughts but probably the most comprehensive is the one proposed by Huschke (1959) that takes into account the three characteristics of a drought as shown in Figure 1: *"A drought is a period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area."* From this definition, the following statements play an important role:

Abnormal: A hydrologic event that requires long records to characterize
Sufficiently prolonged: duration characteristic
Serious imbalance: severity characteristic

Thus a drought index needs to take into account the multidimensional characteristics of a drought and this has been one of the problems in selecting a single universal indicator of these events, contrary to the case of floods that are characterized by their return period.

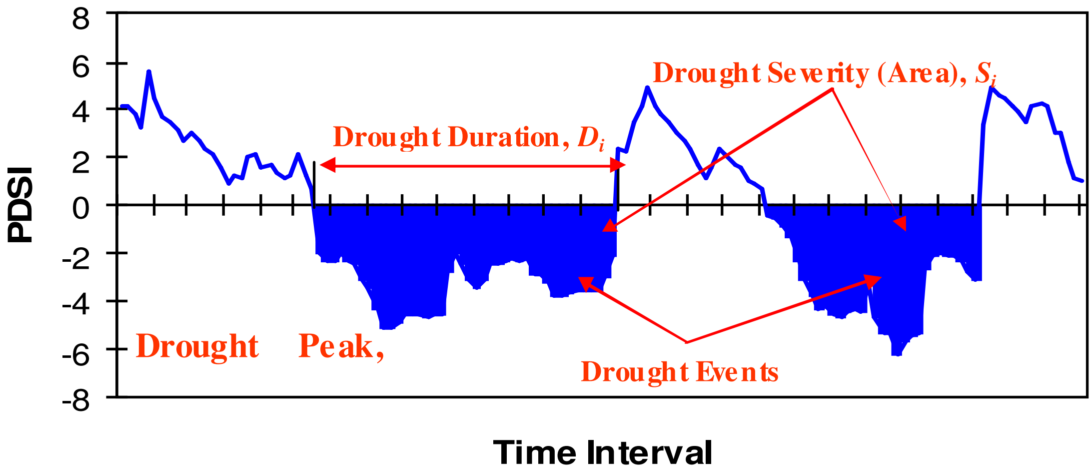

Figure 1. *Drought characteristics.*

The terms aridity, drought and desertification are misleadingly used as synonyms while they indicate very different situations: aridity is a permanent water deficit whereas drought is a temporary condition. Desertification, on the other hand, is the irreversible transformation of land due to nature or anthropogenic factors. Climate change, by exacerbating variability may lead to erroneous conclusions of permanent conditions as the case of the Sahel in which long excursions above and below the mean annual precipitation led to some researchers to indicate that permanent changes have occurred.

2. Drought characteristics

Droughts usually occur over large areas. Figure 2 shows, for instance, the percentage of area of the continental US under drought conditions in the last century. As seen in the figure, during the “dust bowl” drought of the 1930’s, which had significant impacts in the country, the proportion of dry area reached 80%.

Droughts have significant impacts on society and large droughts have been historically associated with social upheaval. A paleoclimatic reconstruction of the Palmer Drought Severity Index (PDSI) over the US Southwest (shown in figure 3) indicates that several social movements were greatly influenced by drought conditions.

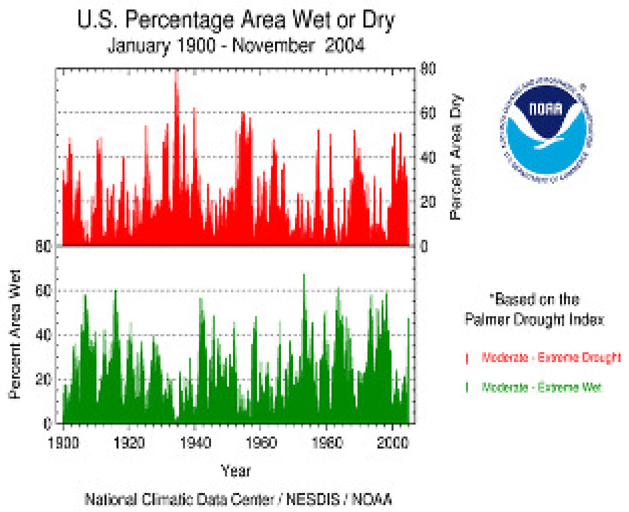

Figure 2. *Proportion of area of continental US under drought using the PDI index.*

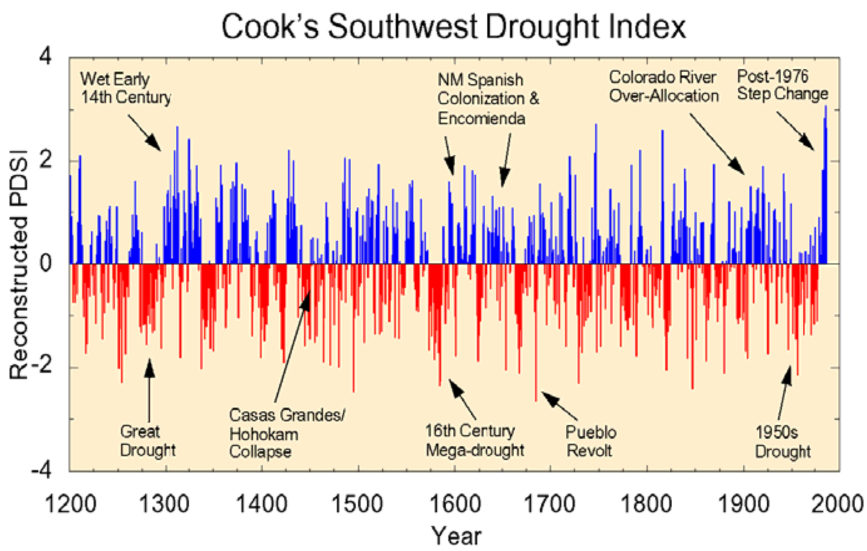

Figure 3. *US Southwest PDSI and related social events (from Aceituno, 1988).*

3. Drought indices

The PDSI and the Standardized Precipitation Index (SPI) (McKee *et al.*, 1993) are two drought indicators commonly used in hydrology, but they have some limitations. González and Valdés (2007) presented an approach for the stochastic characterization of extreme hydrologic droughts according to their random nature. The approach is based on the characterization of random, extreme persistent deviations of a variable (i.e., precipitation) from its normal regime. The characterization is quantified in terms of the mean frequency of recurrence, an equivalent of a drought return period, which constitutes the Drought Frequency Index (DFI).

The DFI index allows analyzing and evaluating droughts over any random hydro-climatic variable affected by droughts. Mapping the DFI, droughts can be stochastically characterized both in time and space. In its computation, the DFI algorithm searches and analyzes, for every time step, the period at this step which is the most extreme from the point of view of persistent lower deviations of the random variable. Each of these periods is characterized in term of its mean frequency of recurrence and this value is associated to the corresponding time step. The scale provided by the DFI is general, universal, and attend to the random nature of the phenomenon. Each application may use the DFI scale to define drought state, setting the threshold frequency according to its vulnerability, which allows homogenizing drought definitions on a single scale.

4. Climate change and droughts

The IPCC has asserted that climate change will intensify the hydrologic cycle as mentioned before. This means that not only changes in the mean but also in the variance will be important. The increase of the variance will be even more significant from the point of view of droughts, since it will affect also the variability of extreme events. Precipitation will be greatly affected, as the IPCC summarizes in their last AR report:

- A robust result, consistent across climate model projections, is that higher precipitation extremes in warmer climates are very likely to occur
- Precipitation intensity increases almost everywhere, but particularly at mid- and high latitudes where mean precipitation also increases

This may be complemented with the IPCC statements on the impact of climate change on droughts:

- An increase of droughts over low latitudes and mid-latitude continental interiors in summer is likely. For example, the proportion of the land surface in extreme drought, globally, is predicted to increase by a factor of 10 to 30; from 1-3 % for the present day to 30% by the 2090s.
- The number of extreme drought events per 100 years and mean drought duration are likely to increase by factors of two and six, respectively, by the 2090s.
- A decrease in summer precipitation in southern Europe, accompanied by rising temperatures, which enhance evaporative demand, would inevitably lead to reduced summer soil moisture (and more frequent and more intense droughts).

Figure 4 shows the impact on droughts in the southern part of Europe, particularly the Iberian Peninsula. GCMs' results have several challenges that need to be addressed before they could be used in water resources management. Among them are the models' low resolution (usually larger than 2º x 2 º), the model's inability to represent in some regions the seasonal characteristics of precipitation and the topographic effects and finally the model's different results for a specific region. Several researchers have addressed these limitations. Dominguez *et al.* (2008), for instance, have evaluated the impact of climatic precursors in the precipitation over the US Southwest and northwestern Mexico and adapted a criterion for selection of the most appropriate GCM for a given region. Cañón *et al.* (2008), in turn, have developed a statistical procedure to take into account the influence of ENSO in precipitation by means of a statistical downscaling technique. This is important since the postulated "end of stationarity" (Milly *et al*, 2008) that maintains that the use of historic records to create statistically undistinguishable time series for water resources management is not longer appropriate, therefore, new approaches are required to deal with time series of hydroclimatic variables like precipitation and evaporation that resemble future climate estimates.

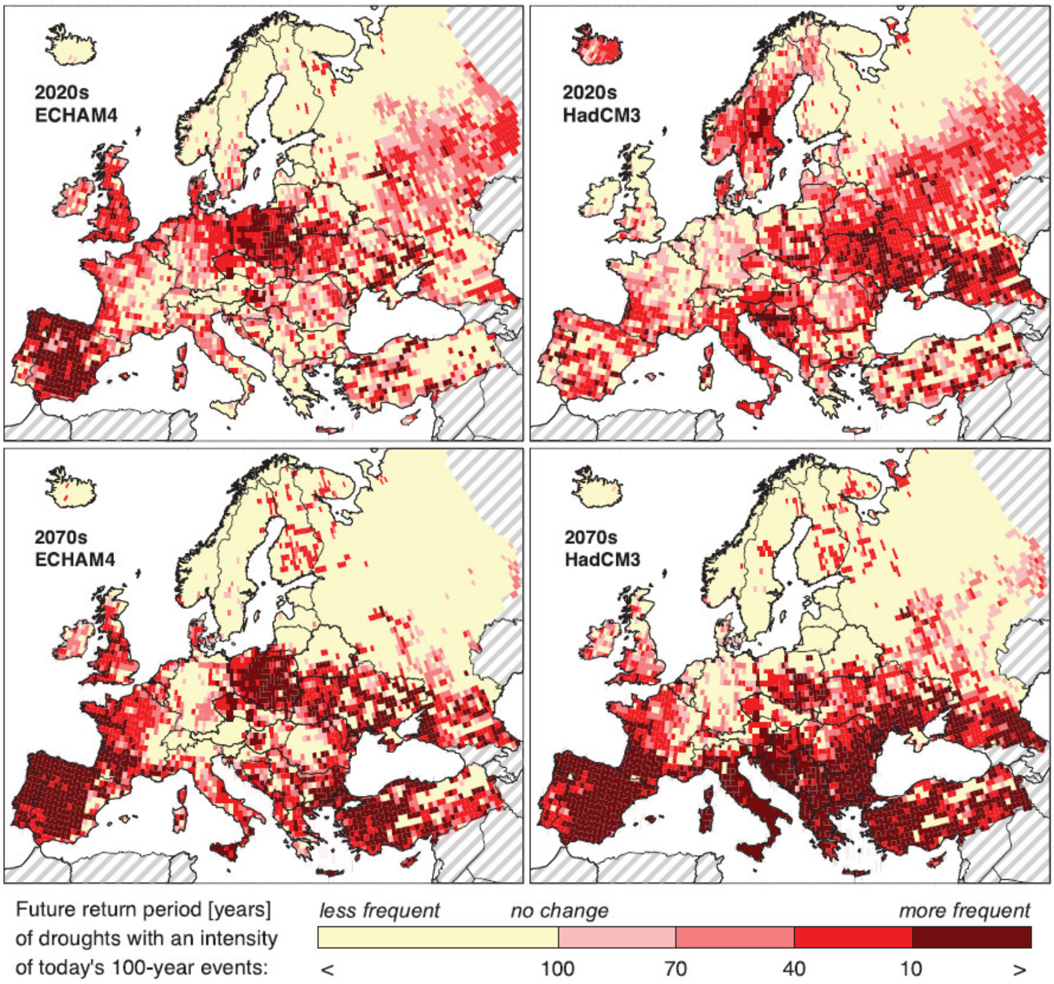

Figure 4: *Drought frequencies in the southern part of Europe, particularly the Iberian Peninsula (from Kundzewicz et al., 2007)*

5. Impacts on water management

Water managers in the Southwestern U.S., like other arid and semi-arid regions, face a number of daunting problems. On the water demand side, population growth in southwestern states is the fastest in the nation. Arizona and Nevada, the two most arid states, have been experiencing annual growth rates of 4% and 5.5%, respectively.

Changing socio-demographics, such as decreasing household size, exurbs, and second homes, are increasing per-capita consumptive demand and exacerbating peak seasonal water demand. This is not a problem of the US Southwest only.

A particular problem has been the over-allocation of water resources. In the Colorado basin, for instance, the projected river discharges were calculated using an unusually wet period at the beginning of the 20th century as a baseline and this is already posing a severe threat to the region. When added to climate trends the challenge magnifies. Urban heat island effects in large Southwestern cities mean warmer nights and longer growing seasons for landscape plants. This extends the irrigation season.

Climate fluctuations, such as the eight-year drought impacting parts of the Southwest, have directly killed large areas of forests, and created ideal conditions for beetle infestations and wild fires, eradicating additional forested areas. These abrupt, large-scale land cover changes fundamentally alter the partitioning of precipitation between infiltration and runoff. While the long-term impacts of climate change are still uncertain, there is a growing consensus that earlier snow melt will effectively reduce the amount of water that can be stored in the spring in reservoirs for use in summer and fall. Figure 5 indicates the changes already observed in the western US both in the onset of the spring snowmelt season (Stewart *et al.*, 2005)

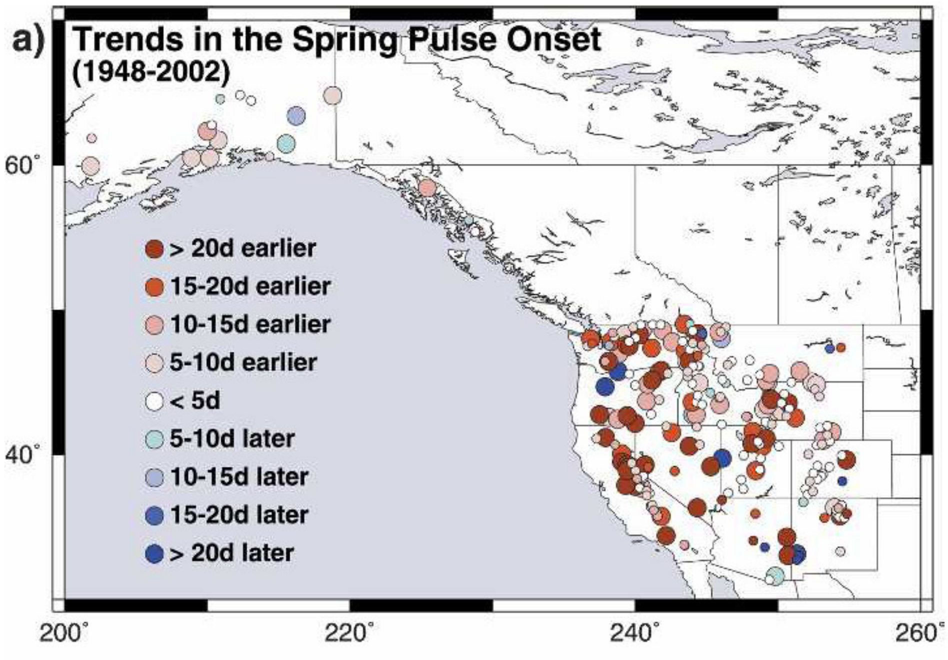

Figure 5. *Trends in the spring pulse onset (Stewart et al., 2005).*

Figure 6 indicates the change of precipitation from snow to rain. This complicates the management of water resources since the flows will be larger and rapid and more difficult to manage with the existing infrastructure.

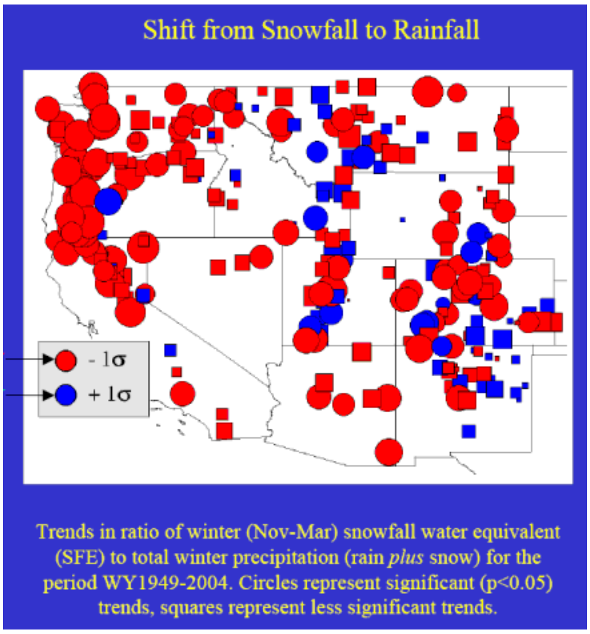

Figure 6. *Observed changes in precipitation mode (Knowles, USGS).*

Other economic, legal, and political realities are creating pressures to shift over-allocated supplies among existing and new water demands. These include greater interest in water-based recreation, endangered species protection, settling American Indian water rights claims, and meeting the needs of a resurgent copper mining industry. The use of the above mentioned DFI as a trigger for the management of a complex system of reservoirs both in the Júcar basin of Spain and the Conchos river in Mexico have been recently evaluated (Gonzalez, 2005, Cañón *et al.*, 2008).

6. A final recall from the IPCC report

The following is a recall list from the IPCC of some urgent issues related to the climate–freshwater interaction in general but totally applicable to the case of droughts that must be addressed in the near future (Kundzewicz, 2007):

- The understanding of sources of uncertainty to improve climate projections and weather forecasting.
- The downscaling from validated regional (large-scale) projections to the catchment scale to serve the needs of water management adapted to local conditions.
- The integrated modeling of impacts due to climate variability.
- The coupling of climate models with land-use change, including changes on vegetation and anthropogenic activities such as irrigation.
- The study of the impacts of climate change on water quality in developed and developing countries, especially the impacts due to extreme events.
- The economic aspects of climate change impacts and adaptation options related to water resources.
- The human-dimension indicators of climate change impacts on freshwater.
- The assessment of the impacts of climate change on aquatic ecosystems (high water temperatures, altered flow regimes, water levels and ice cover).

- The refinement in detection and attribution of observed changes in freshwater resources, particularly related to extremes.
- The formulation of probabilistic climate change scenarios for water resources management.
- The assessment of climate change impacts on groundwater.
- The integrated management of water resources in times of adaptation to a changing climate.
- The worldwide consolidation of sound, reliable data (observation) networks to measure freshwater resources (quantity and quality, sediment transport, uses)

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