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## Editorial

# Propagation of Drought: From Meteorological Drought to Agricultural and Hydrological Drought

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## 1. Drought in the World and China

Drought is a hazard that occurs everywhere in the world (both in dry and in wet areas). Despite the controversy regarding drought changes in the last decades [1–3], increases in drought intensity are clearly identified in some areas [4] and it is believed that although increased heating from global warming may not directly cause droughts, it is expected that when droughts occur, they are likely to set in quicker and be more intense [5].

Throughout its history, China has frequently suffered from drought disasters due to its monsoon climate and was regularly hit hard by droughts over the last decades. Although little evidence of an expansion of the area affected by droughts was found in China over the last 50 years [6], severe droughts in southwestern China in 2010 and the middle/lower Yangtze Basin and Huaihe River Basin in 2011 have drawn more attention from the research community as well as from the public and governments alike on the impacts and problems brought on by drought. Poor performance by China's emergency response management during recent major drought events highlights the necessity of improving both drought preparedness and emergency response skills.

To improve our skills for drought monitoring and forecasting as a means of reducing society's vulnerability to droughts and the risks they pose, it is important to distinguish between different types of drought, reveal how droughts propagate from one type to another, study the causes of

drought, and know how drought affects various economic sectors (e.g., agriculture, energy production, and navigation) and ecosystems in diverse ways. Furthermore, it is vital that we continue to explore and better understand how aggregated human activities affect the process of drought propagation so as to better prepare for and adapt to future drought changes.

## 2. From Meteorological Drought to Agricultural/Hydrological Drought

Drought originates from a deficiency of precipitation over an extended period of time resulting in a water shortage for some activity, group, or environmental sector. It is the result of a complex interplay between (1) natural precipitation deficiencies, or excessive evapotranspiration over varying time periods and different areal extents, and (2) the demands of human and environmental water use that may be exacerbated by inefficiencies in water distribution, planning, and management [7]. To facilitate communication, management, and response, drought often is categorized into four general types [7]: (1) meteorological or climatological, (2) agricultural, (3) hydrological, and (4) socioeconomic. Drought can develop over short periods (weeks or months) or longer periods (seasons, years, or even decades). Different types of droughts have their own specific spatiotemporal characteristics [8, 9]. Although hydrological drought and agricultural drought start from meteorological droughts, hydrological and agricultural drought indicators cannot be straightforwardly derived from

meteorological drought indicators [10, 11]. Lack of precipitation combined with higher evaporation rates propagates through the hydrological cycle from a meteorological phenomenon/drought into soil moisture depletion to the point where crops or terrestrial ecosystems are impacted, and eventually into a hydrological phenomenon/drought [12, 13].

The development of droughts involves numerous interacting climate processes and various land-atmosphere feedback. In addition, different stores in catchments (providing persistence) lead to potentially complicated propagations of the climate signal into the water system [14]. To fight against drought and mitigate the impacts of major droughts, it is important to distinguish between different types of drought, to understand how drought evolves from one type to another, and to know how human activities influence the cause/linkages of droughts. The study on the topic of drought propagation has been quite a hot issue in the hydrology community over the last decade [8–10, 14–21]. It is found that there is a significant link between meteorological drought and hydrological drought, except for catchments where groundwater storage and snow processes are important [18]. Several common features of drought propagation have been revealed, such as [17]: (a) meteorological droughts evolve collectively into a prolonged hydrological drought (pooling); (b) meteorological droughts are attenuated when storage is high at the start of the event (attenuation); (c) a lag occurs between meteorological, soil moisture, and hydrological drought (lag); and (d) droughts get longer in duration in moving from meteorological to soil moisture to hydrological drought (lengthening).

However, there are still many more mechanisms behind drought propagation that need to be investigated, such as the interaction between surface water and groundwater during the process of drought development, the evapotranspiration of different plant communities in response to droughts, and human (anticipating and response) strategies manipulating these features. On the other hand, while drought mechanism research has certainly moved forward, more progress has been made in the realm of qualitative knowledge rather than quantitatively. Knowing more about the mechanisms quantitatively will provide a stronger basis for monitoring and forecasting hydrological and agricultural droughts.

### 3. The Roles of Human Intervention in Drought Propagation

Human interventions in the water cycle are about manipulating water flows by (groups of) users for different reasons and adapting water availability in time and space and changing the hydrological patterns in their surrounding landscape. Human activities, such as irrigation activities, dam and reservoir operations, and water diversion may significantly alter the propagation process from meteorological to hydrological droughts as well as affecting drought vulnerability [22–25]. Therefore, the impacts of drought could be mitigated by managing water demand through crop management, modifying water allocation rules during times of water scarcity, developing various water resources (such as groundwater

recharge and salt water desalination), managing multiple water use, setting up water-trading mechanisms in advance of times of drought or scarcity, and physically redistributing available supplies during times of scarcity [26].

However, while drought is a climatic phenomenon with relatively predictable biophysical repercussions, social perceptions of and responses to drought from the individual through community and up to the state level are highly varied [27]. At the same time, interactions between natural water availability and societal water demand and management are complex, and drought mitigation strategies in some sectors (e.g., agricultural and energy sectors) may increase the vulnerability of other systems (especially ecosystems) [28]. Multiobjective optimization could be helpful for developing drought plans incorporating traditional short-term tactical measures (e.g., facility operation) and long-term or in-advance strategic mitigation measures for drought preparedness [29] while also balancing the drought risks among different sectors at the same time.

### 4. Drought Monitoring and Prediction

At present, droughts are commonly monitored using indices based on data from three primary sources, that is, ground observations such as the Standardized Precipitation Index (SPI) [30], satellite observations such as the global Drought Severity Index (DSI) [31], and Multivariate Standardized Drought Index (MSDI) [32], as well as model simulations [33–35].

Indicators based on any single source of drought information have their limitations. In order to fully characterize drought magnitude, spatial extent, and potential impacts, drought monitoring methods or indicators should be integrated, coupling multiple climate, water, vegetation, and soil parameters, as well as socioeconomic information retrieved from different sources [36]. Many efforts have been put into developing drought indicators jointly using ground-based, satellite-based, and model simulated data. One of the earliest examples of such a composite, or hybrid, approach is found in the operational US Drought Monitor (USDM) [37], which combines several inputs consisting of modelled data, satellite vegetation health indicators, climate-based indices (such as the SPI), impacts, and local expert input from the field. Other examples include the Aggregated Drought Index (ADI), which comprehensively considers all physical forms of drought through variables like precipitation, streamflow, evapotranspiration, reservoir storage, soil moisture content, and snow water content [38]; the Vegetation Drought Response Index (VegDRI) integrates satellite-based observations of vegetation conditions, climate data, and other biophysical information such as land cover/land use type, soil characteristics, and ecological setting [39]; the Combined Drought Indicator combines the Standardized Precipitation Index (SPI), the anomalies of soil moisture, and the anomalies of the fraction of Absorbed Photosynthetically Active Radiation (fAPAR) [40]. However, there is no significantly preferable or universally accepted multivariate drought index so far (nor is that likely to come) and it is difficult to prove

the superiority of the various multivariate drought indicators because there is no “ground truth” of drought observations for most places that can be used for an exact validation process [41].

Unlike a flood, a drought does not have an obvious start or end. While monitoring has been done for decades, forecasting drought is still in its infancy [42]. As meteorological drought is dominated by precipitation processes, its forecast is fundamentally an issue of medium-to-long range weather forecasting. Hydrological and agricultural droughts are driven by meteorological droughts; therefore their forecasts also heavily depend on weather forecasting. It is common to use atmospheric model outputs to drive hydrological models for making seasonal hydrological drought forecasts [43, 44] or estimating future droughts [45]. In knowing that the drought propagation process is complicated, especially when considering human managed interventions such as reservoir operations, diversions, water consumption, and agricultural activities, many more factors should be involved in hydrological and agricultural drought forecasting. Another major challenge for drought forecasting is due to the fact that forecasts are often unreliable on the seasonal timescale and lack specificity, reducing their usefulness for agriculture and other sectors [36].

## 5. Highlights in the Special Issue

In this special issue, a collection of six papers were chosen that cover topics addressing regional drought changes, drought assessment methods, and impacts of human activities and climate change on drought evolution.

H. Huang et al. investigated the spatial-temporal variation of the aridity index, which is defined as the ratio of potential evapotranspiration and precipitation, in China during 1960–2013, and found that the average annual aridity index showed a decreasing trend. J. Vido et al. found that the frequency of 24 droughts occurring in the Tatra National Park in Slovakia has a cyclical pattern with approximately a 30-year period. Furthermore, the precipitation shadow of the mountains influences the risk of drought occurrence. L. Zhao et al. found strong correlations between the Standardized Runoff Index (SRI) and Standardized Precipitation Evapotranspiration Index (SPEI) in the Xiangjiang River Basin in southern China, with a stronger correlation in the dry season compared to the wet season. M. Yu et al. proposed a multiscale Composites Drought Index (CDI) by integrating the self-calibrating Palmer Drought Severity Index (scPDSI), the 1- and 3-month Standardized Precipitation and Evapotranspiration Index (SPEI), Z index, and standardized Soil Moisture Index (SMI) using a principle component analysis method for improving the skill of drought monitoring. Y. Liu et al. presented a case study in a semiarid catchment in northern China addressing the impacts of human activities, which shows that human activities significantly amplified both drought duration and severity in that catchment. F. Yuan et al. develop a modelling system for projecting the potential climate change impacts on hydrological drought events in

the Weihe River Basin in northern China and show that that basin can expect more severe droughts in the future.

## 6. Future Works on Drought Propagation Mechanisms

Significant progress has been made in the last decade centering around a better understanding of the mechanisms of drought propagation. Future advances are required in order to address the following aspects:

- (1) Develop more long-term and reliable series of drought data, and quantitatively assess data uncertainty whether the data are observed through ground networks or satellites or especially through modelled or simulated approaches, so as to avoid any misinterpretation about changes in drought characteristics.
- (2) Establish more comprehensive drought monitoring frameworks, which use multiple observation techniques and modelling tools conjunctively to reflect drought-related hydrological and biophysical variables at different spatial-temporal scales, in order to meet the specific needs of different sectors.
- (3) Quantitatively describe the water conversion/drought relationship among different existing forms, that is, soil water, snow/ice water, plant water, groundwater, and river water, at multiple spatial and temporal scales in different catchments and geographical settings.
- (4) Reveal the interrelationship between the natural hydrological system and the role of humans played in the process of drought development, considering the effects of different management practices dealing with water allocation, water use, land use/land cover planning, and so on, which are based on multidisciplinary inputs from history, archaeology, anthropology, sciences, and engineering.
- (5) Develop strategies for reducing society's vulnerability to drought by improving the skills of drought response based on the knowledge of drought propagation.

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