DOCTORAL THESIS

Propagation from Meteorological to Terrestrial Water Storage-derived Hydrological Droughts and their Possible Drivers

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Abstract

Drought is a multiscale phenomenon that may synchronously spread over multiple temporal scales and various hydrological systems. Several drought indices based on the Gravity Recovery and Climate Experiment (GRACE) have been developed in previous studies, however, these indices seldom consider the accumulative changes in terrestrial water storage (TWS) and thus hardly quantify the TWS deficit across different time scales. The response of hydrological drought to changes in meteorological variables vary considerably owing to the differences in the frequencies of variations. Few studies have investigated how different meteorological components affect TWS-based droughts. Furthermore, the mechanisms underlying the effects of climate teleconnections on the propagation from meteorological drought to hydrological drought remain uncertain.

Therefore, this study develops a multiscale standardized TWS index (STI) that covers different time scales through the probability density function method. The index is compared with multi-scalar drought indices and uni-scalar drought metrics in terms of temporal and spatial distributions and the performance in representing vegetation changes. The results show that the STI is comparable to other drought indices in spatiotemporal scales and more robust in describing droughts with less noise. Short-time-scale STIs share some similarities with multiscale meteorological indicators. The multiscale STI agrees better with the normalized difference vegetation index (NDVI) than other indicators on a stationary time scale.

The patterns of propagation from meteorological drought to TWS-derived hydrological drought across the world under different climate zones are analyzed by using the multiscale Standardized Precipitation Index (SPI) and the proposed STI. The results show that meteorological and hydrological droughts are comparable in the tropical climate areas (e.g.., Amazon, Caribbean) but highly different in the Pacific Ocean coastal regions (i.e., Southeast Asia and Southern Tropical Pacific), indicating that the propagation systems may be affected by the topography and atmospheric teleconnections. Moreover, the SPI and STI have more similarities in the temperate climate regions but fewer in polar climate regions where glacier melting under climate change contributes to hydrological drought, while the little change in precipitation affects meteorological drought.

Teleconnections, which reflect climate variability over non-contiguous geographic regions are the primary factors driving the change in hydrological variables and drought conditions in many regions. However, the mechanisms underlying the effects of the interactions on drought propagation are still not fully clear. To address this question, we evaluate the contribution of teleconnections to drought propagation. The results indicate that the atmospheric teleconnections affecting drought propagation are similar to those affecting drought characteristics in numerous regions; however, the dominant factor affecting droughts may not influence drought propagation, such as in the Tibetan Plateau and Central Asia.

The results of this study can serve as an important scientific reference to improve drought monitoring and evaluation under the effects of climate change and further clarify the hydrological processes of drought propagation. Moreover, the results provide a scientific basis for decision-making on drought prevention and water resources management to achieve long-term sustainability in the changing environment.

Keywords: GRACE, TWS-based hydrological drought, drought assessment, drought propagation, teleconnections