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Building an operational drought framework

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As the frequency of drought events continues to rise, there is an urgent demand for swift adaptive capabilities, coupled with a growing scientific knowledge base to effectively develop and implement them. To address this need, effective Climate Services are crucial for decision-makers to navigate and respond to the challenges posed by drought. In this context, drawing upon the experience gained from the CNR-IBE climate service 'Drought Observatory' and insights gained from direct engagement with decision-makers, we introduce a novel operational drought framework (ODF) providing a synoptic overview of drought at the basin scale. The aim of the ODF is twofold: on one site to increase the understanding of the underlying dynamics of severe droughts, including triggers, and drought onset and propagation to other components of the water cycle; on the flip side to support decision-makers' adaptive capacities by offering concise yet comprehensive and timely insights, ultimately improving their ability to make informed choices in the face of increasing drought occurrences.

The ODF is based on three pillars: *i*) a critical lecture of a set of Standardized Precipitation Index (or whatever SPI-like index) estimated across a continuous range of month-scales; this step allows for a better understanding of drought development and dynamics; *ii*) the computation of the Standardized Integrated Drought Index (□), as a standardized multi-scale ensemble mean of the SPI set, for the identification and effective communication of severe phases of droughts; *iii*) the contextualization of severe droughts into the surrounding water supplies, here accounted by means of the cumulative deviation of SPI_1 from the normal (CDN), where the CDN serves to gain insights into whether the system has received an adequate supply of water resources to cope with upcoming drought events;□

We present a conceptual demonstration of the ODF for monitoring various types of droughts, showcasing its efficacy and versatility over the Po River basin, the hydrographic basin of the longest Italian river. To this end, we introduce the ODF from the Standardized Precipitation Index (SPI), aggregated at the river basin scale, and the Standardized Streamflow Index (SQI), both

estimated across continuous 1–36 month-scales (i.e., SPI_{1-36}, SQI_{1-36}) for the 1964-2023 period.

The resulting ODFs highlight multi-years precipitation patterns that drive the system under alternating periods of relatively wetness and dryness; during prolonged dry periods, single or cumulative occurrence of meteorological drought (drought triggers) could propagate into hydrological severe droughts. Vice versa, the hydrological response is largely absent under wet conditions, indicating a lack of propagation. Based on these outcomes, the ODF could serve as an effective tool to improve the understanding of hydrological responses to meteorological droughts and to develop risk-reducing policies and preparedness planning to face the future severe droughts.