Probabilistic modeling of the water availability in a large surface reservoir

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We present a probabilistic model (hereafter PM) of water availability in a large surface reservoir, to assess extreme, coinciding events that have not occurred in observed time series. We find that river discharge and regional water intake dominate lake level dynamics and that severe water shortages mainly occur when they coincide.

Background

During dry spells, a large part of the Netherlands depends on water from the IJssel lake, a large surface water reservoir (Figure 1). It is fed by river discharge, mainly from river IJssel, and local precipitation. Drainage occurs by open water evaporation and water intake from the surrounding region, where it is used for e.g. irrigation. We spatially aggregate these fluxes and derive statistical descriptions for them and their correlations.

Inputdata

The Dutch National Water Model (NWM) consists of five sub-models that together simulate the Dutch water system, from groundwater to the main river system (Lange et al., 2014). From an NWM-simulation spanning 101 years (1911-2011), statistical descriptions were derived of: 1) precipitation on the lakes (multiplied by -1 as we are interested in low precipitation); 2) evaporation from the lake; 3) water intake from the surrounding region; and 4) river discharge deficit that formed the input fluxes to the model. We consider summer seasons of individual years as ‘events’, where the summer season spans eight months (March 1st to October 31st), to take into account both spring-droughts and late summer low-flows. Figure 2 shows weekly fluxes for NWM and, to put it in perspective, the ECMWF seasonal reforecast archive of 25 members for 1993-2016.

Marginal distributions

Model input consists of cumulative volumes, that are then distributed over the extend summer season by weekly weight factors. Figure 3 shows frequency lines of the cumulative volumes for NWM and the ECMWF reforecast archive. NWM-volumes were first detrended by Loess-filtering.

Time distribution

The cumulative volume is distributed over the season by weekly weight factors. The most common model is used for one drought of varying length and timing, whereby the volume is uniformly distributed over the remaining period. For evaporation and regional intake we use climatology weight factors, where for intake the volume is distributed over weeks from an average, positive intake. For discharge we derive weight factors from the 25 dryest years and the average of the remaining years.

Correlations

Correlations are modelled by a four-dimensional copula, that is constructed by fitting three bivariate, Gumbel, copulas that relate precipitation, discharge deficit and evaporation to water intake. This is warranted because the former three are independent when conditioned on water intake. The results also fit the other, unfiltered, correlations (e.g. between precipitation and discharge deficit) well.

Results

All combinations of inputs, given the correlations in Figure 4, are fed into a water balance model which produces discharge to the Waddensea and lake level (Figure 5). Important to note is that we assume that water intake is always possible, without hydraulic barriers. This is not realistic, but Figure 6 therefore shows the total potential water shortage (denoted as PM).

Conclusions and outlook

Lake level dynamics are mainly governed by IJssel discharge and, in dry conditions, water intake. Shortages occur when high discharge deficits (i.e. low Rhine discharge) are combined with high local water intake (local meteorological drought) and can be substantial. Precipitation on and evaporation from the lake itself are much less relevant under dry conditions.