Royal Netherlands
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Ministry of Infrastructure
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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.

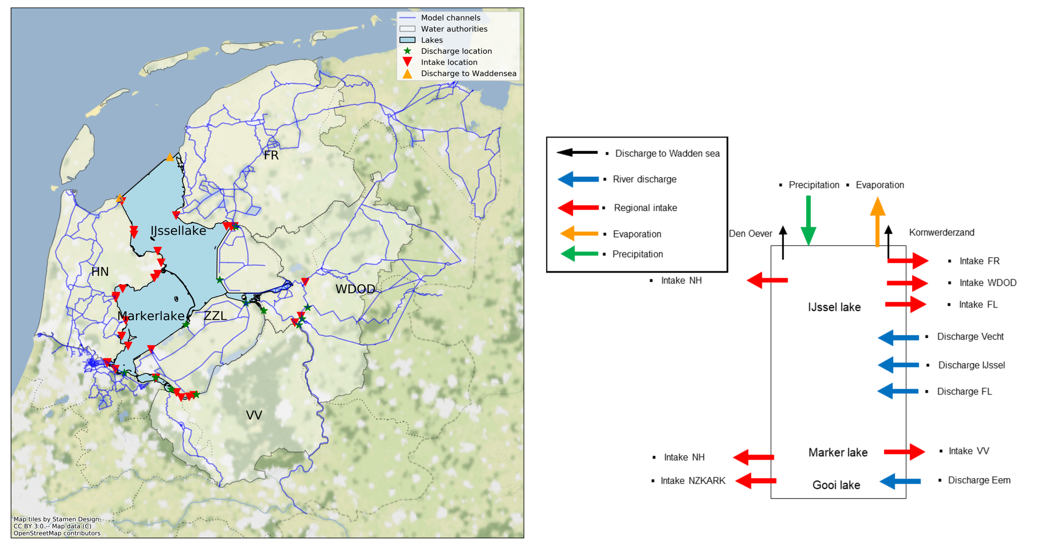

Figure 1: *Geometry of the IJssel lake region and schematisation in the model.*

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 form the four input fluxes to the model. We consider summer seasons of individual years as 'events', where the summer season spans eight months (March 1^{st} to October 31^{st}), 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 reforecasting archive. NWM volumes were first detrended by Loess-filtering.

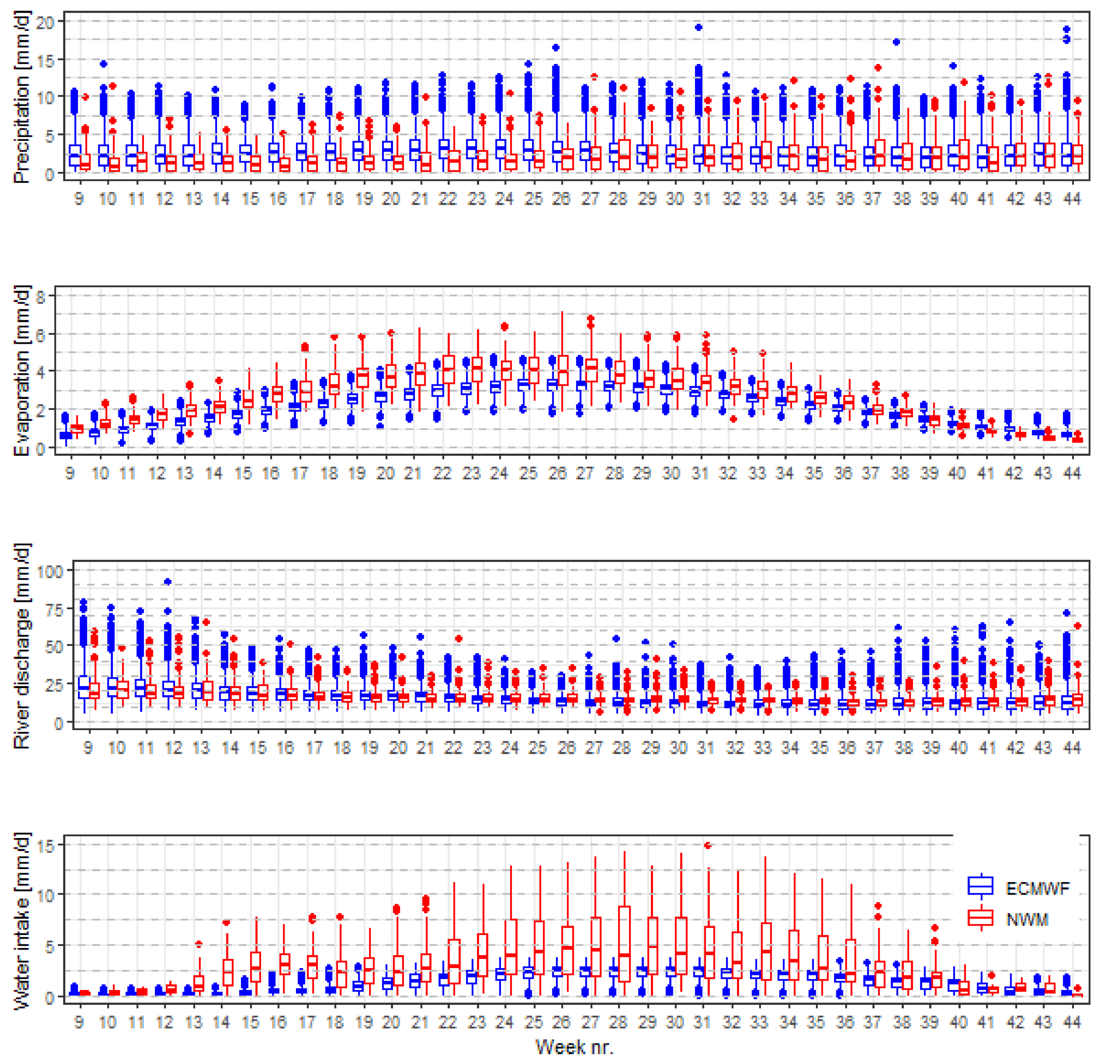

Figure 2: *Box plots, where every box is a week of the extended summer season, of (top to bottom) precipitation, evaporation, river discharge and water intake for NWM (red) and ECMWF (black) data.*

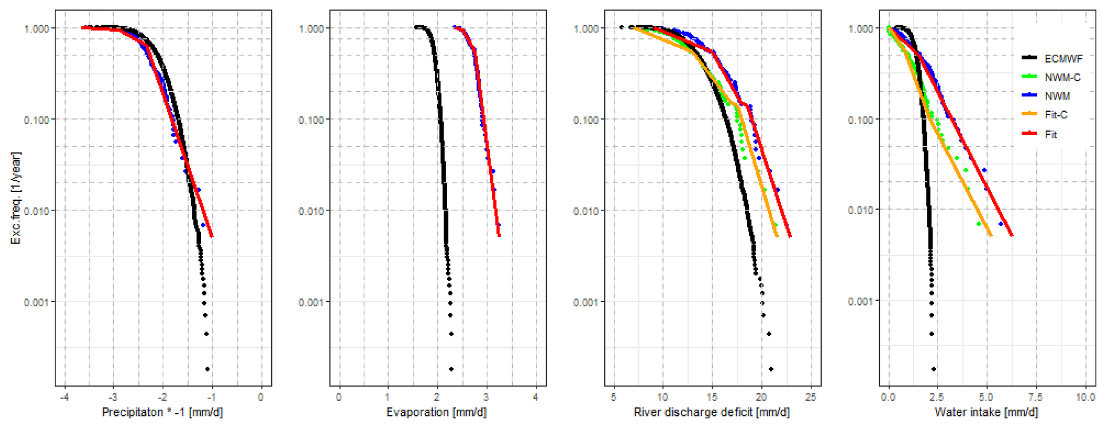

Figure 3: *Frequency curves from NWM (blue/green dots where green includes bias correction), ECMWF (black dots) and fits that form input for PM (red/orange where orange lines includes known bias correction).*

Evaporation differs because ECMWF evaporation is mixed pixels for open water and land, and is, therefore, generally lower. Water intake for ECMWF is calculated from precipitation and reference evaporation using an ANN (Zwet et et., 2018). It is known to underestimate water intake under extreme conditions. The used version of NWM is known to overestimate both the discharge deficit and water intake, therefore also bias-corrected versions are shown in Figure 3.

Time distribution

The cumulative volume is distributed over the season by weekly weight factors. Precipitation is modelled by 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 only distributed over weeks with, on average, positive intake. For discharge we derive weight factors from the 25 dryest years and the average of the remaining years.

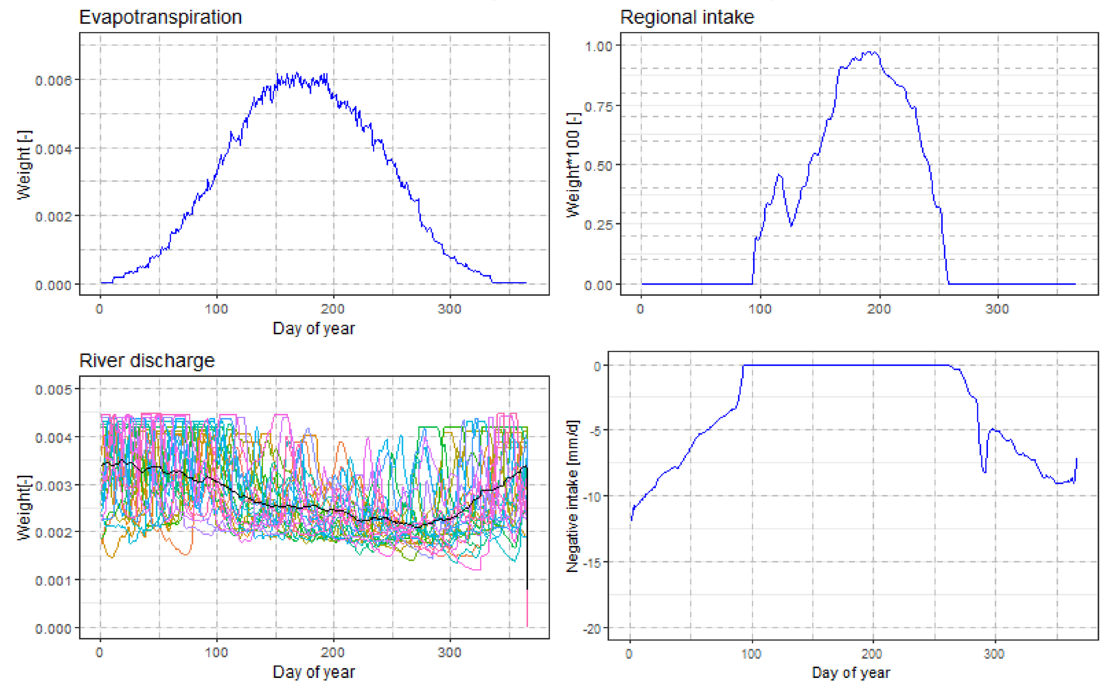

Figure 4: *Time distribution over the season of, clockwise from upper left, evaporation, positive part of intake, negative part of intake and river discharge.*

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 fits the other, unfitted, correlations (e.g. between precipitation and discharge deficit) well.

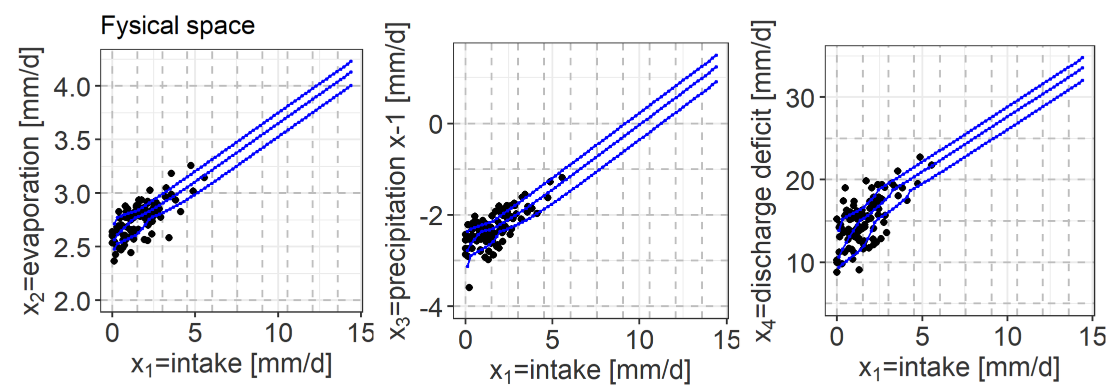

Figure 5: *Copula modeling of correlations*

Results

All combinations of inputs, given the correlations in Figure 5, are fed into a water balance model which produces discharge to the Waddensea and lake level (Figure 6). 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). "PM-Real" shows the results under the assumption that water intake is no longer possible when it drops below -0.40 m+NAP, as is currently the case. "Corrected", refers to the bias correction of NWM (Figure 3).

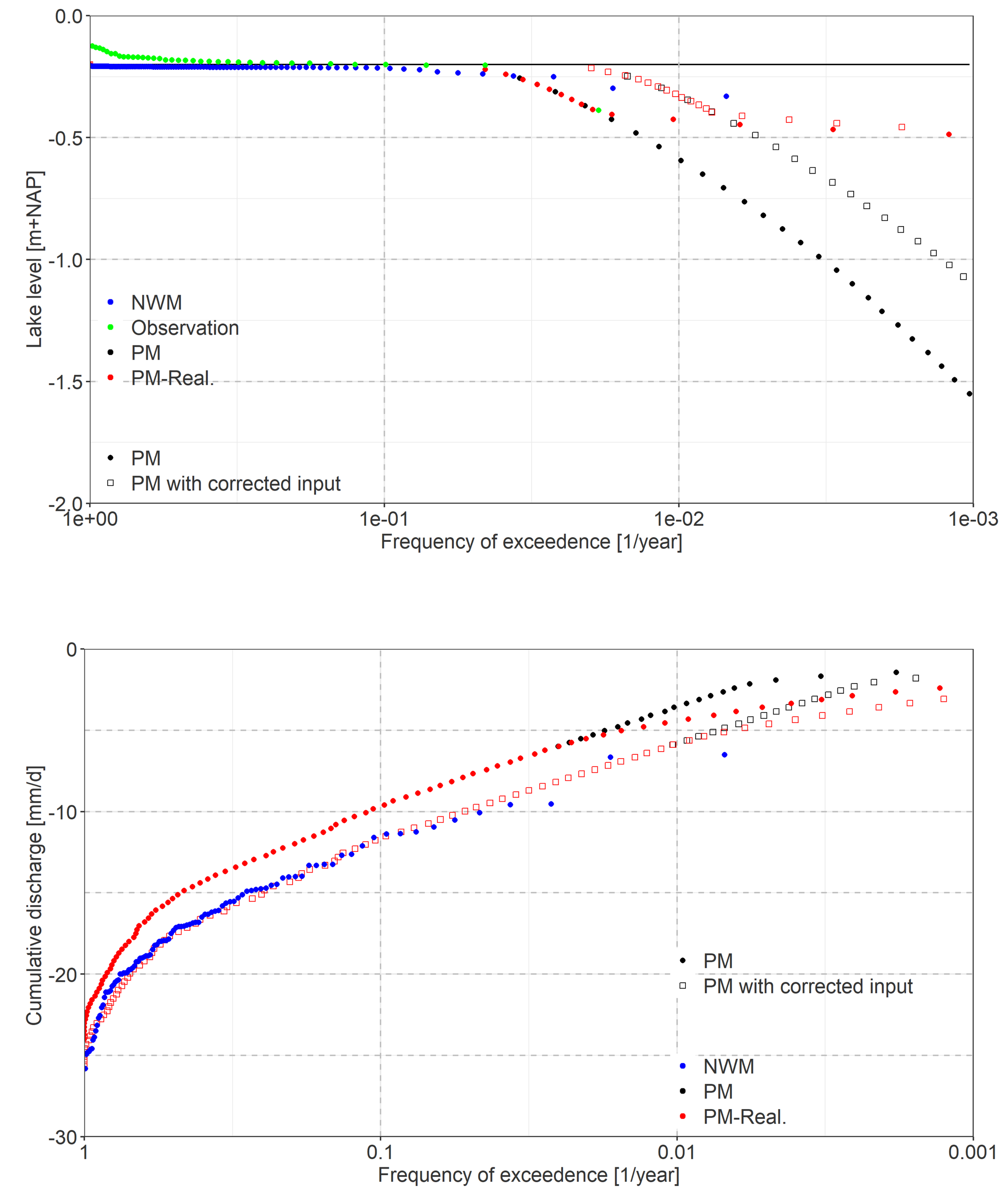

Figure 6: *Resulting frequency lines of lake levels (top) and discharge to the Waddensea (bottom)*

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.

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References:
- *Lange et al., 2014, An operational, multi-scale, multi-model system for consensus-based, integrated water management and policy analysis: The Netherlands Hydrological Instrument, Environmental Modelling & Software, vol. 59, pp. 98–108.*
- *van der Zwet and Horn, 2018, Empirische schatting watervraag en wateraanbod (in Dutch), HKV report $PR3710.10$.*