ALPINE DROUGHT OBSERVATORY

Report on the drought impact probability mapping for the Alpine region (D.T3.2.2)

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ADO - Alpine Drought Observatory (ASP940)

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Aim and method

Impact modelling background

Drought impact information and specifically the link of impact knowledge to certain drought indices can be useful in a number of ways: the search for historical analogues, the identification of a 'best-suited' drought index for monitoring or early warning of a particular drought impact, or impact-based forecasting. Once a best-index is identified, a particular threshold is needed that will indicate directly whether an impact is likely. The development of statistical 'impact models' can help this task. They use drought hazard indices (as predictors) for a particular drought effect or impact (predictand) to derive empirical relations (model functions) (Figure 1a). The statistical model (Fig.1b) can then be used to estimate an impact occurrence probability for given index values. If such models are derived and applied to many regions for which index and impact data is available, an impact probability map can be assembled for given index levels (Fig. 1c).

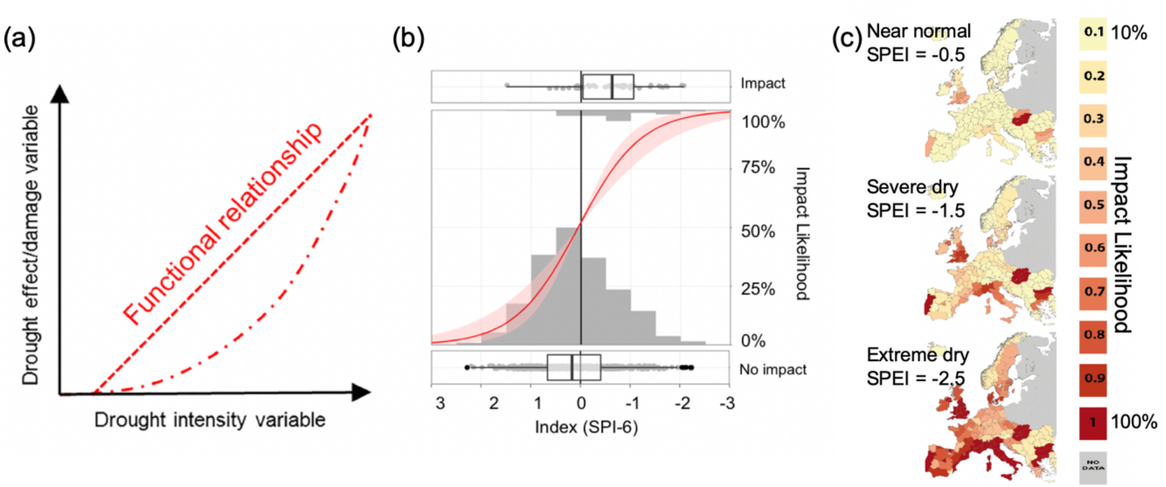

Figure 1*. Three steps of impact likelihood modelling: (a) the general concept of damage functions (plotting hazard intensity against damage) from Bachmair et al. (2017), (b) applied by fitting a logistic regression model predicting the likelihood of impact occurrence by the drought index SPI-6 (Stagge et al., 2015), and (c) maps for Europe showing the predicted impact likelihood in the category 'Public water supply' for three hazard levels of the SPEI index (Blauhut et al., 2016). Figure modified from Van Loon et al. (2016).*

The aim was to add value to specific drought indices in that manner. The indices provided and monitored by the ADO (Task 1) were to be tested for modelling and mapping the probability of impact occurrence associated with certain drought (index) conditions. The **Deliverable itself are the resulting maps which are displayed on the ADO platform at https://ado.eurac.edu**. This report describes how they were derived and how they can be used.

Selection of hazard indices, impact response and model application

Current research efforts are underway to find suitable multivariate impact models (e.g. Blauhut et al., 2016; Stephan et al., in prep). For demonstration purposes on a platform such as ADO, however, the decision was to develop simple models to present a risk map that is easily interpretable. Therefore, the impact probability mapping demonstration for ADO is based on single drought indices, similar to the application by Blauhut et al. (2015). This methodological choice avoids having to understand and account for complex statistical interactions between various drought drivers and it enables users to identify changes in impact probabilities along with an index value's increase or decrease. In order to use single index values to determine the risk of impact occurrence, there is the need to identify the most suitable index from the set of indices developed by the work packages Task 1 and Task 2. Therefore, we conducted a prior analysis in order make a reasonable index selection.

This prior analysis was based on recursive partitioning with decision trees. The indices splitting a sample into true or false impact occurrence at the top of the tree were then selected for the impact probability modelling. The prior analysis considered the following indices: the Standardized Precipitation Index (SPI), and the Standardized Precipitation and Evapotranspiration Index (SPEI), both with the accumulation period of 3 months (SPI-3, SPEI-3) and 6 months (SPI-6, SPEI-6). The Soil moisture anomalies of the top soil layer (SMA-1) and second soil layer (SMA-2), the Vegetation Health Index (VHI) and the Vegetation Condition Index (VCI), all from the ADO monitoring datasets (EURAC, 2022).

Reported drought impact data stems from the $EDII_{ALPS}$ (Stephan et al., 2022). For all months from the year 2001 to the year 2020 drought impact reports were transformed into binary time series of impact occurrence - no occurrence. This quantitative impact response data was created for the grouped impact types D_{SM} (soil moisture drought impacts) and D_H (hydrological drought impacts) introduced by Stephan et al. (2021). Only impact data with information about the impact location of at least NUTS 3 region was used. For each NUTS 3 region, a set of corresponding NUTS-region-average drought index values and regional impact occurrences was then subject to the recursive partitioning. In several subregions the SPEI-3 was determined as the first splitter for the D_H impacts and the SMA-1 or SMA-2 for the D_{SM} impacts. Based on these results, **the SPEI-3 was chosen to serve as predictor for the probability models for D_H impacts, and the SMA-1 was chosen to model the D_{SM} impact probabilities**.

The already established monthly time-series of D_{SM} and D_H impact occurrence along with the selected indices then provided the data for the actual impact models. The distribution of D_H impacts vs D_{SM} impacts across the Alpine Space shows that most of the D_H impacts are located in France and fewest in Italy and Slovenia. D_{SM} impacts show higher numbers in Slovenia, Switzerland, Germany and Austria, fewer in Italy, and almost no records in France (Fig. 2). NUTS 3 regions without impact data were excluded from the modelling exercise. For each NUTS 3 region a generalized linear model was fit with a logit link to regress the likelihood of a drought impact against the selected drought index. The fitted model can then be used to predict impact occurrence probabilities for different SPEI-3 and SMA-1 values (scenarios of particular drought severity assumptions) for each NUTS 3 region as a basis for the maps. The presented probability maps are a first demonstration and should be interpreted with care (see Section: *Uncertainty of the approach and note of caution*).

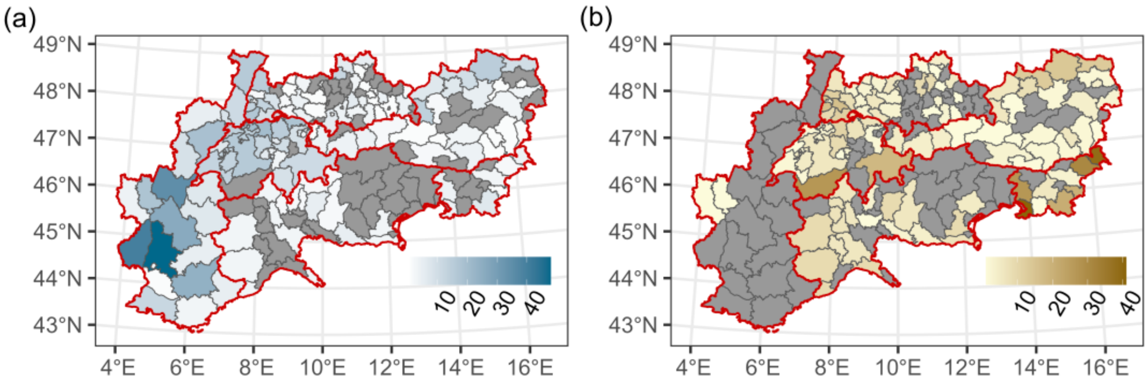

***Figure 2**. Distribution of the total monthly true impact occurrences between 2001-2020 for all NUTS 3 regions across the Alpine Space for (a) D_H impacts and (b) D_{SM} impacts. NUTS 3 regions without impacts are gray.*

Impact probability maps for ADO: index scenarios

Model-predicted impact probability maps for hydrological drought impacts D_H

The impact probability maps of the D_H impact group (Fig. 3) generally suggest that the risks are higher, the more negative the SPEI-3 is in the scenario. However, for a given SPEI scenario, they also show substantial regional variation of the model-predicted impact probabilities among neighboring NUTS 3 regions. For SPEI-3 > -1 the modelled impact probabilities are rather low throughout the region. For SPEI-3 ≤-2.0 the risk of D_H impacts increases for selected regions and for SPEI-3 ≤ -2.5 the modelled probability increases more substantially. A general pattern of selected regions with higher probabilities emerges with similar relative differences for all more severe SPEI scenarios. For the most severe scenario of an assumed SPEI-3 ≤-3 a probability of >50% is predicted for many regions.

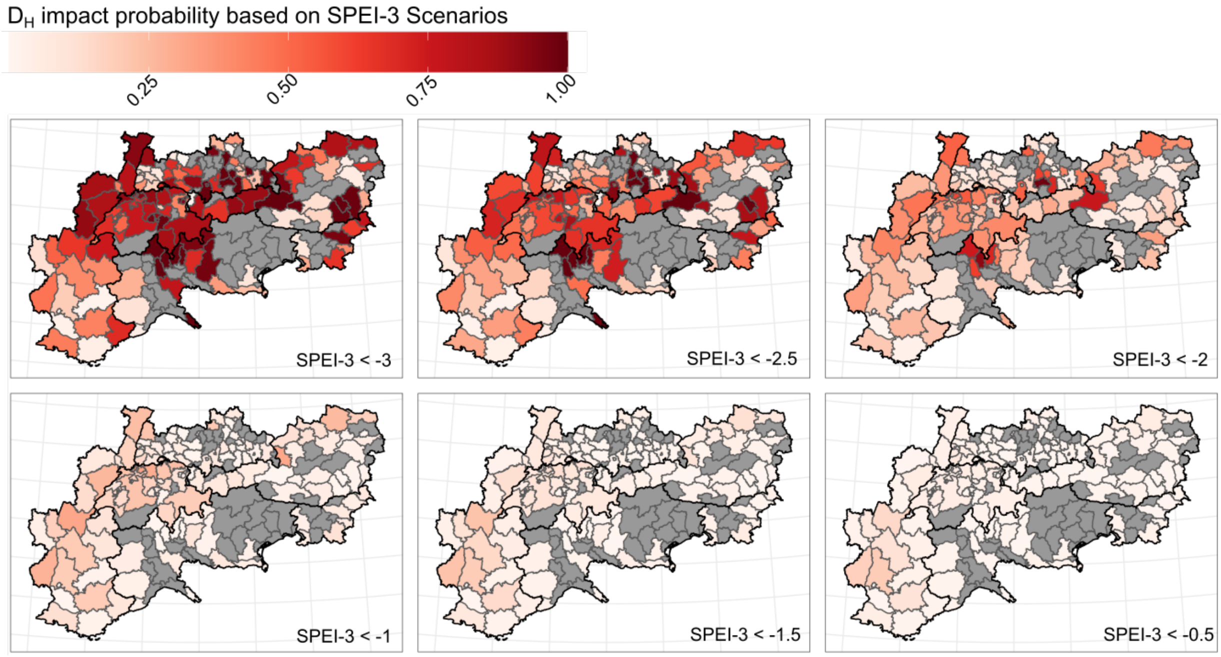

Figure 3. *Modelled impact probability map of D_H impacts based on SPEI 3 scenarios. The darker the red, the more likely D_H impacts might occur. NUTS 3 regions without any D_H impacts are colored in gray. National borders across the Alpine Space are shown in black.*

Modelled impact probability maps for soil moisture drought impacts D_{SM}

The impact probability maps of the D_{SM} impact group (Fig. 4) also suggest that the risks are generally higher, the more negative the SMA index is in the scenario. For a given SMA scenario, the NUTS regions also show substantial variation of the model-predicted impact probabilities. Compared to the rather low probabilities for the least severe scenario for D_H impacts, the model predictions for the least severe scenario of the D_{SM} impacts already suggest a higher probability for a few selected regions, for example in Slovenia and northern Austria. With increasing severity of the SMA scenario, also for the D_{SM} predictions, the pattern remains relatively similar with increasing probabilities predicted. Especially, for the scenario of SMA-1 ≤ -3 the risk of D_{SM} impacts increases substantially according to the modelled probabilities, especially in Slovenia, Northern Austria, Central Switzerland and in Southern and Eastern parts of Italy.

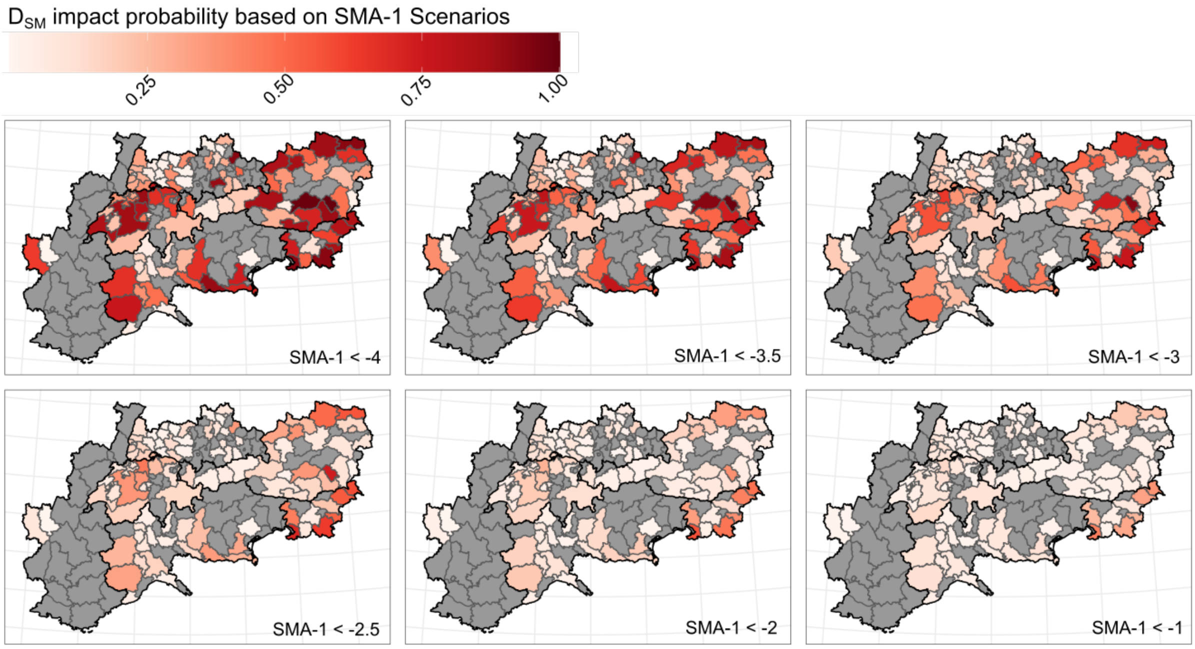

Figure 4*. Modelled impact probability map of D_{SM} impacts based on SMA 1. The darker the red, the more likely D_{SM} impacts occur. NUTS 3 regions without any D_{SM} impacts are colored in gray. National borders across the Alpine Space are shown in black.*

Uncertainty of the approach and note of caution

The presented maps are the result of statistical models. Therefore, they depend on the underlying data. While more data points (Fig.2) do not necessarily lead to better model fit, the model fit varies substantially from NUTS region to NUTS region. Therefore, Fig. 5 presents the NUTS regions for which the predictor (D_H models: SPEI-3, D_{SM} models: SMA-1) was identified to be significant during the fitting process. Predictions derived from regions with significant predictors can be considered more reliable. Interestingly, these regions are not necessarily those with more date points (Fig. 2). The maps should be seen as a demonstration and proof of concept at this stage. Further quantification of uncertainties and filling gaps of poor model performances by enhancing the data base will be needed should these models be used operationally (next section).

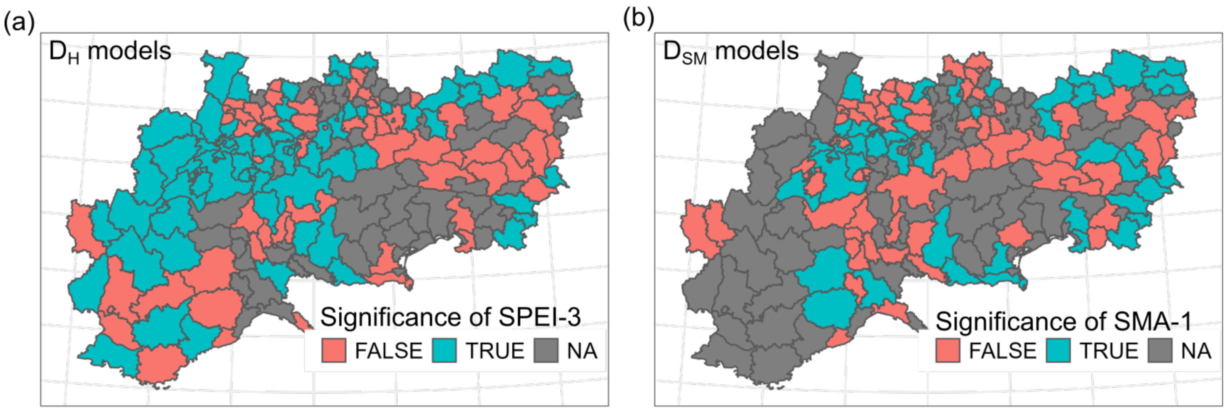

Figure 5*. NUTS regions with significant predictors in the fitted models (p-value ≤ 0.05).*

Impact probability map: 1st August 2018 as a test case

The fitted models can also be used to predict and create impact probability maps for the condition on historic dates or in real time as maps for 'rapid-risk assessment', i.e. displaying the risk at a certain time - rather than for a certain assumed scenario index-situation. In the year 2018, a drought affected the northern Alpine Space region. As a further model application test, this case was selected to illustrate how such a future real-time impact probability monitoring might be implemented. For this application the models were applied to the SPEI-3 and SMA-1 for the 1st of August, 2018 for all NUTS 3 regions across the Alpine Space and Fig. 6 shows the corresponding probability of occurrence of D_{SM} and D_H impacts for that situation. Overall, the severe drought conditions in the Northern regions result in higher impact probabilities, more pronounced for DH impacts. While broadly covering the same areas, the comparison of the hazard values in Fig. 6 (upper) and the impact probabilities (lower) show somewhat different patterns in their relative severities.

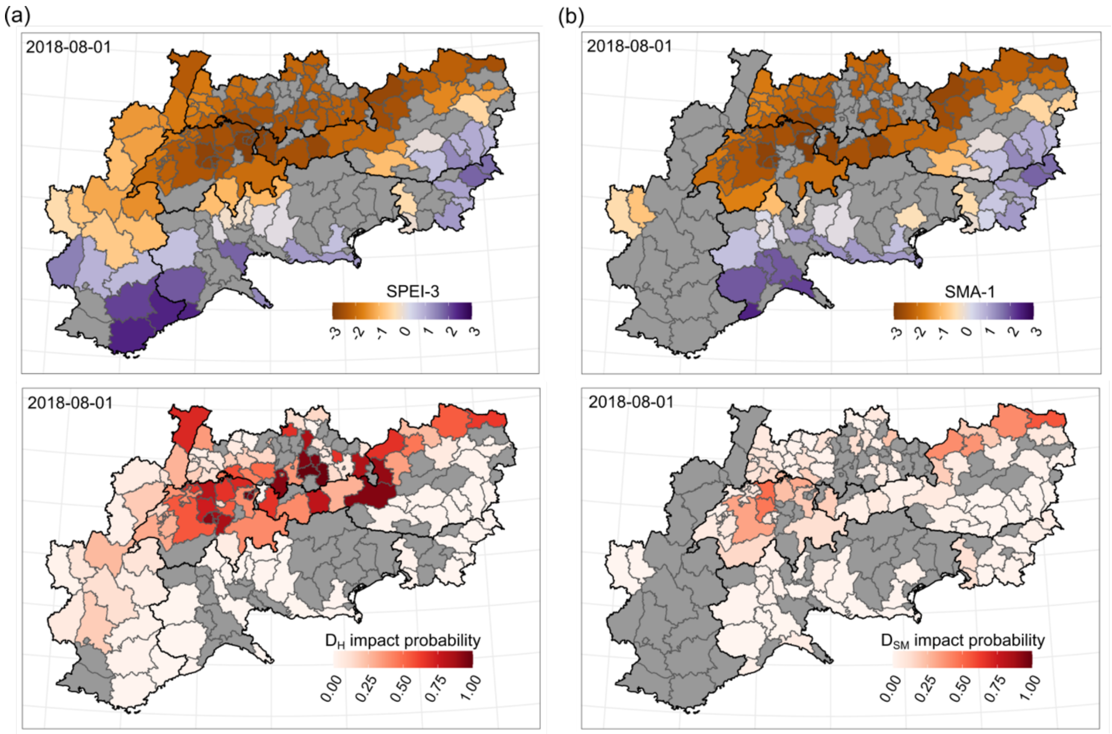

***Figure 6**. Situation of 1st of August, 2018. (a) SPEI-3 values and predicted D_H impact probabilities. (b) SMA-1 values and predicted D_{SM} impact probabilities. NUTS 3 regions without data to fit the models are colored in gray.*

Concluding remarks

The presented maps of modelled impact probabilities for the two impact groups are a demonstration what could be implemented operationally into a monitoring system in the future. For any interpretation, the uncertainty within the $EDII_{ALPS}$ data base and the simplification in the risk model based on single indicators have to be taken into account. The risk models for this demonstration were fit with past drought impact data meaning that the model parameters are not updated with recent impact data and potential adaptations that will change the relation between indices and impact probability. Therefore, the maps are an illustration of the potential of this approach, but a long-term implementation for monitoring needs to update the models with more data and might consider perhaps using multi-variable models to obtain better predictive ability. Also, models should be validated and the uncertainty quantified visibly for users of the information. Nevertheless, the scenarios and time-prediction test illustrate how such maps might allow to find regional to local warning thresholds that could be used to trigger mitigation measures and therefore this example serves as an outlook how impact models could serve as scenario maps or as real-time risk maps.

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