Transit time distributions to assess contamination risk of karst aquifers over Europe and the Mediterranean

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MOTIVATION

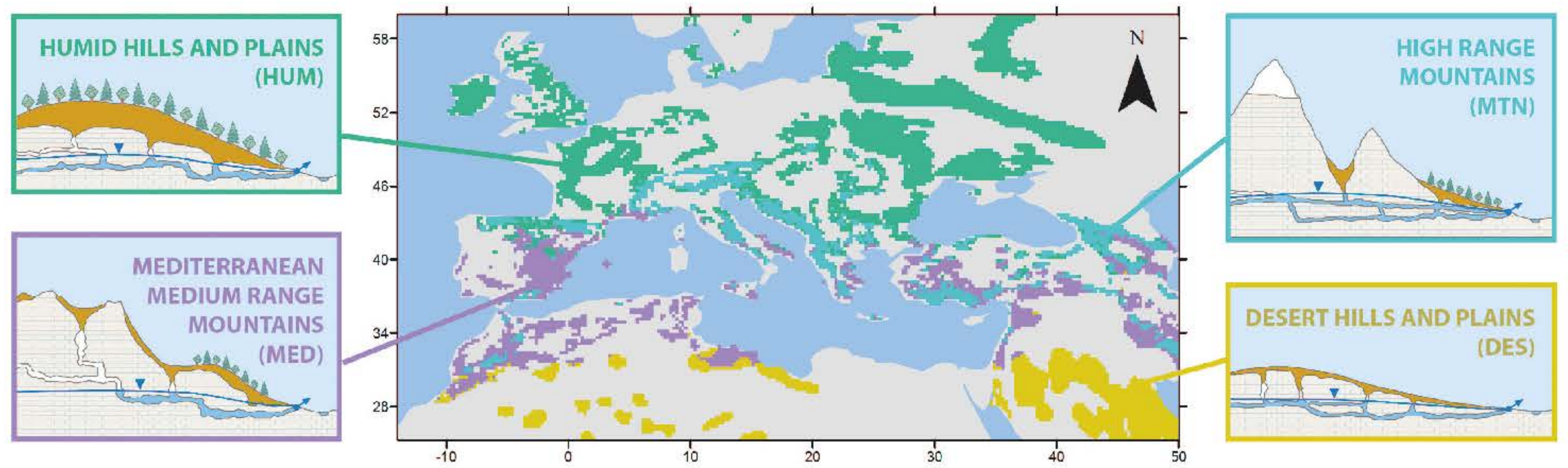
Karst develops through the dissolution of carbonate rock. Karst groundwater in Europe is a major source of fresh water contributing up to half of the total drinking water supply in some countries. Climate model projections suggest that in the next 100 years, karst regions will experience a strong increase in temperature and a serious decrease of precipitation - especially in the Mediterranean region. Previous work showed that the karstic preferential recharge processes result in enhanced recharge rates. But as there is fast water flow form the surface to the aquifer, there is also an enhanced risk of groundwater contamination.

STUDY DOMAIN

Since calibration data is not available at the modeling scale, we used cluster analysis (k-means methods) and three climate and relief descriptors (aridity index AI, days of snow DS, range of altitudes within the grid cell RA) to define typical karst landscapes.

Descriptor	Unit	Number of cluster/karst landscape			
		1. HUM	2. MTN	3. MED	4. DES
AI	[–]	0.80	0.98	3.18	20.00
DS	$[a^{-1}]$	85	76	16	1
RA	[m]	228	1785	691	232

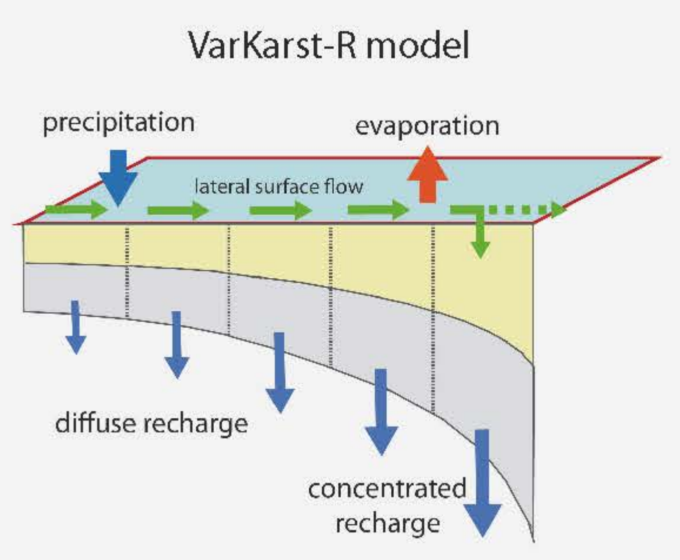
By trial and error (ellbow method) we found 4 landscapes with distinct climatic and topgraphic characteristics.
The data for cluster analysis and model frocings (2002-2012) are obtained from SRTM3 and GLDAS.



APPROACH

RECHARGE ESTIMATION

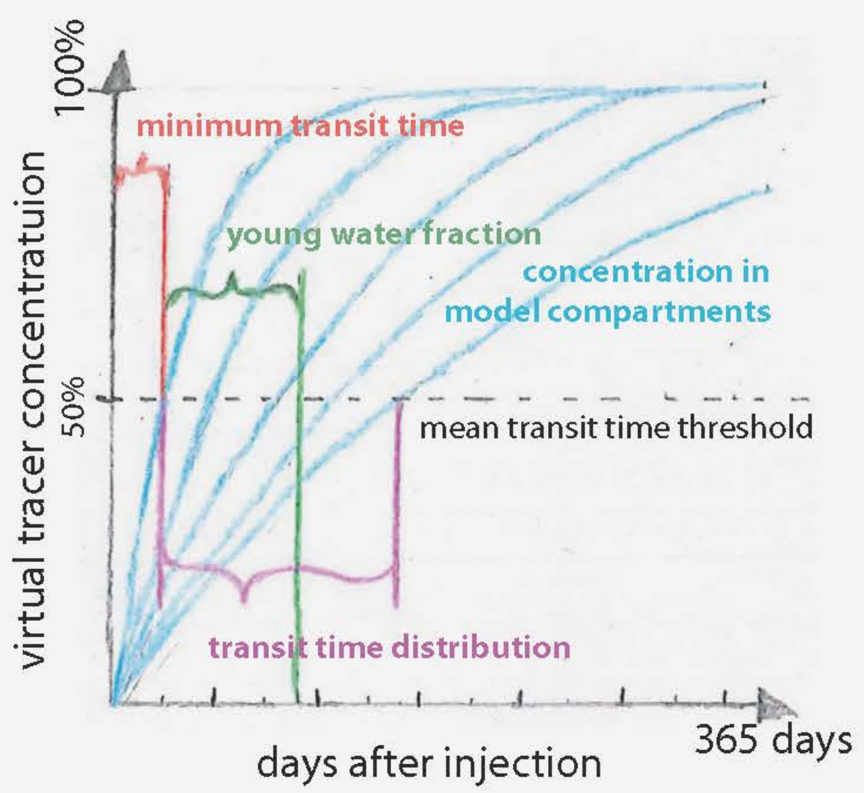
We simulate groundwater recharge with a new type of semi-distributed model that considers the spatial heterogeneity of the karst system by distribution functions.
A newly developed parameter estimation scheme is applied to derive parameter sets and remaining parameter uncertainty for each of the karst landscapes using AET (Fluxnet) and soil moisture (ISMN) observations for 2002-2012.



More details in Hartmann, A., Gleeson, T., Rosolem, R., Pianosi, F., Wada, Y. and Wagener, T.; Geosci. Model Dev., 8(6), 1729–1746, doi:10.5194/gmd-8-1729-2015 (2015).

TRANSIT TIME ESTIMATION

Transit time distributions os simulated recharge derived by applying a virtual tracer each grid cell's precipitation at each hydrological year. The time when the recharge concentration of a model compartment reaches 50% of the input concentration is considered as mean transit time. All mean transit times form the transit time distribution.

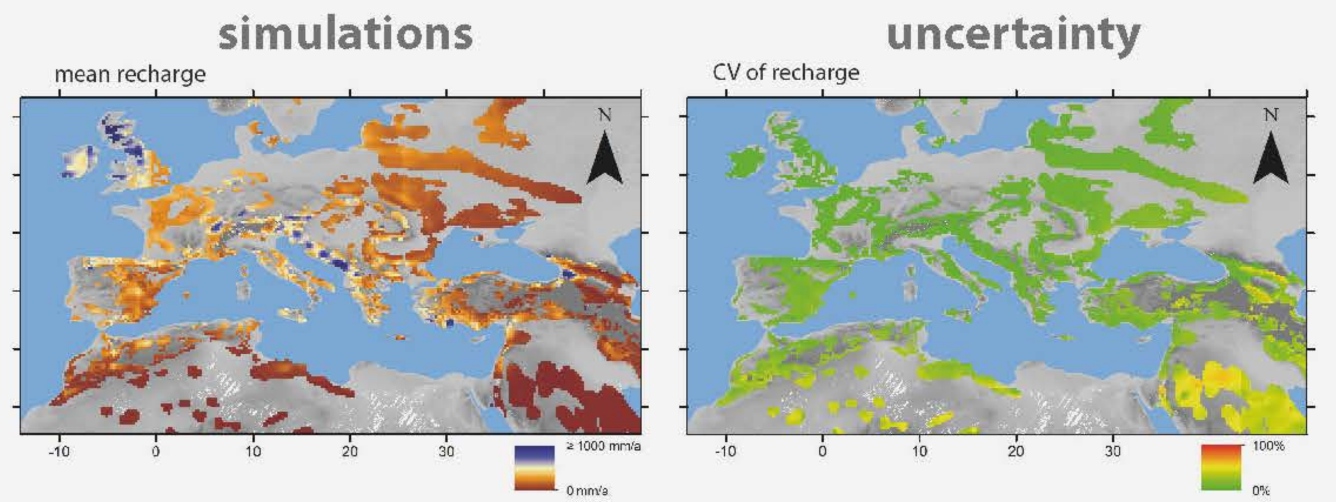


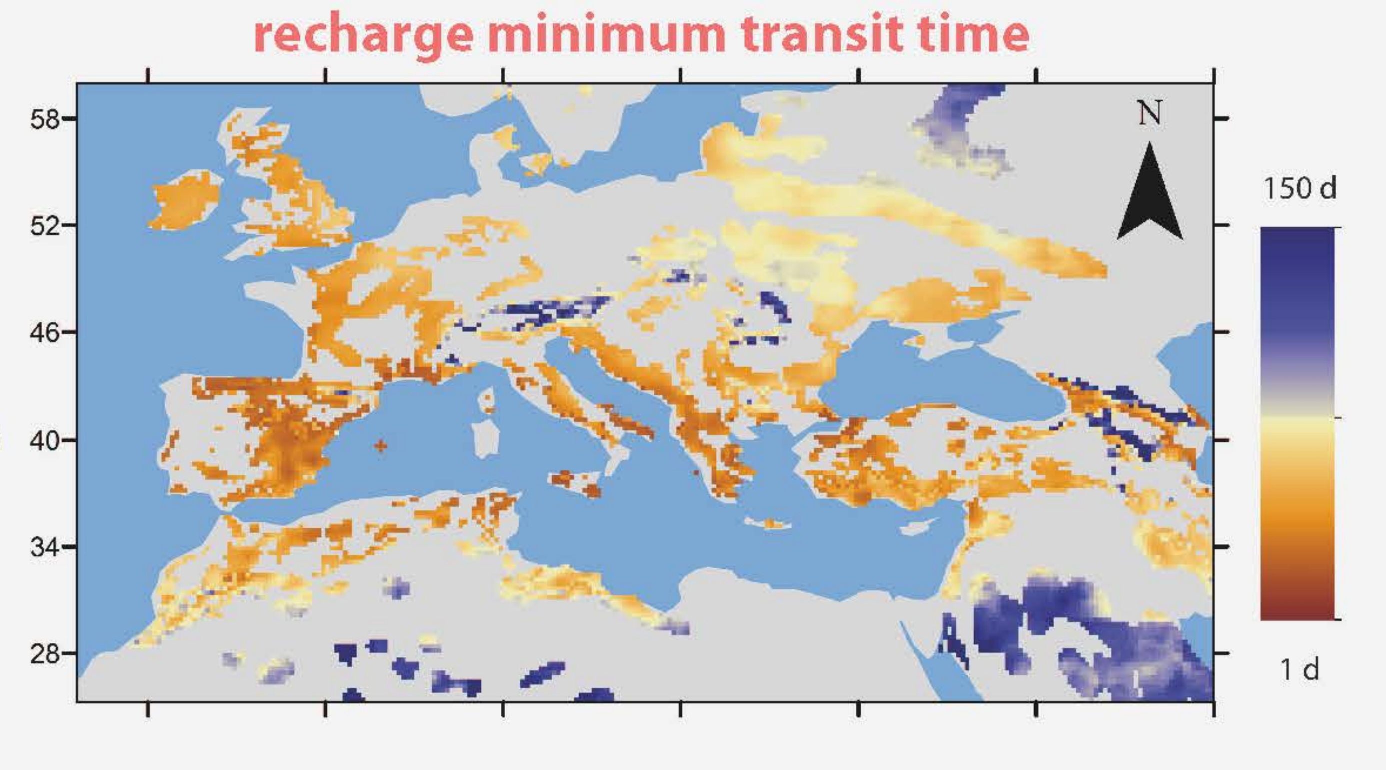
For our analysis of vulnerability we use the minimum transit time. Using a threshof of 1.8 months (Kirchner, 2016) we can also alculate the young water

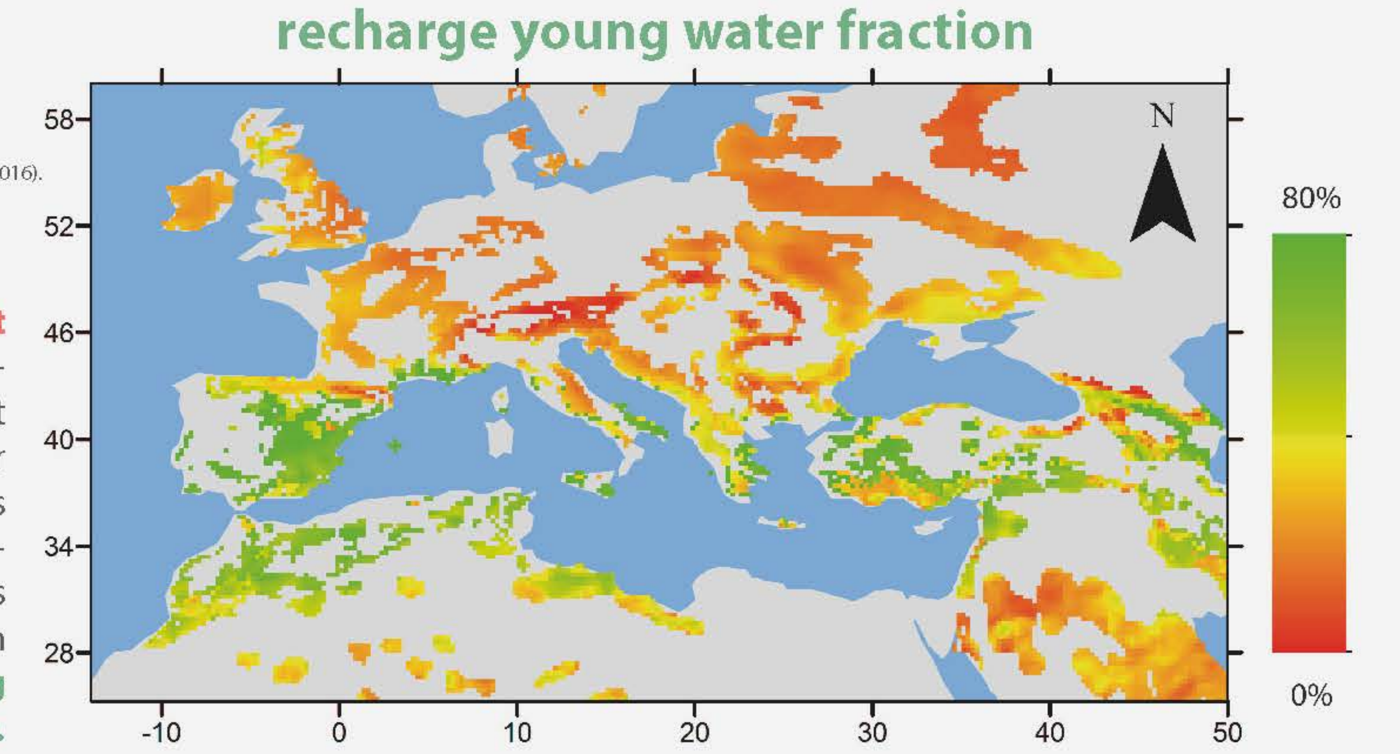
More details in Hartmann, A., Kobler, J., Kralik, M., Dirnböck, T., Humer, F. and Weiler, M.; Biogeosciences, 13, 159-174, doi:10.5194/bg-13-159-2016 (2016).
Weiler, M. and McDonnell, J. J.; J. Hydrol., 285, 3–8 (2004).

RESULTS

The simulations show high annual recharge rates in Northern Europe and in the high mountain areas, very low values occur for Southern Europe and Northern Africa. The paramter uncertainty due to the limited data avilability remains low in most of the study domain.



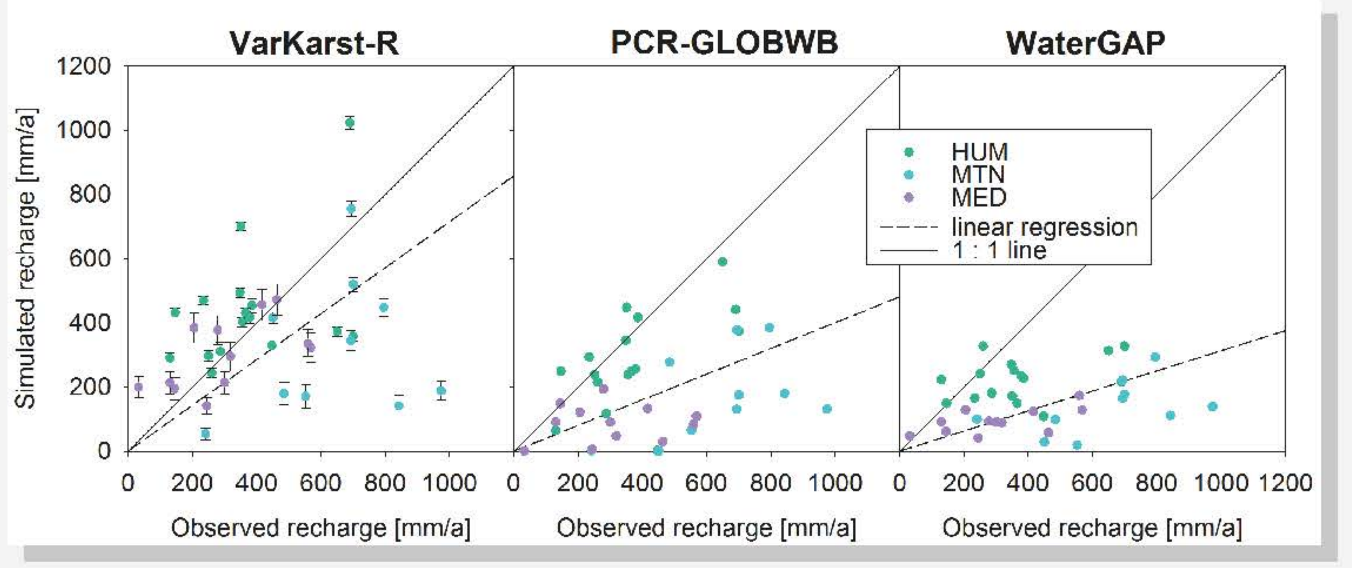




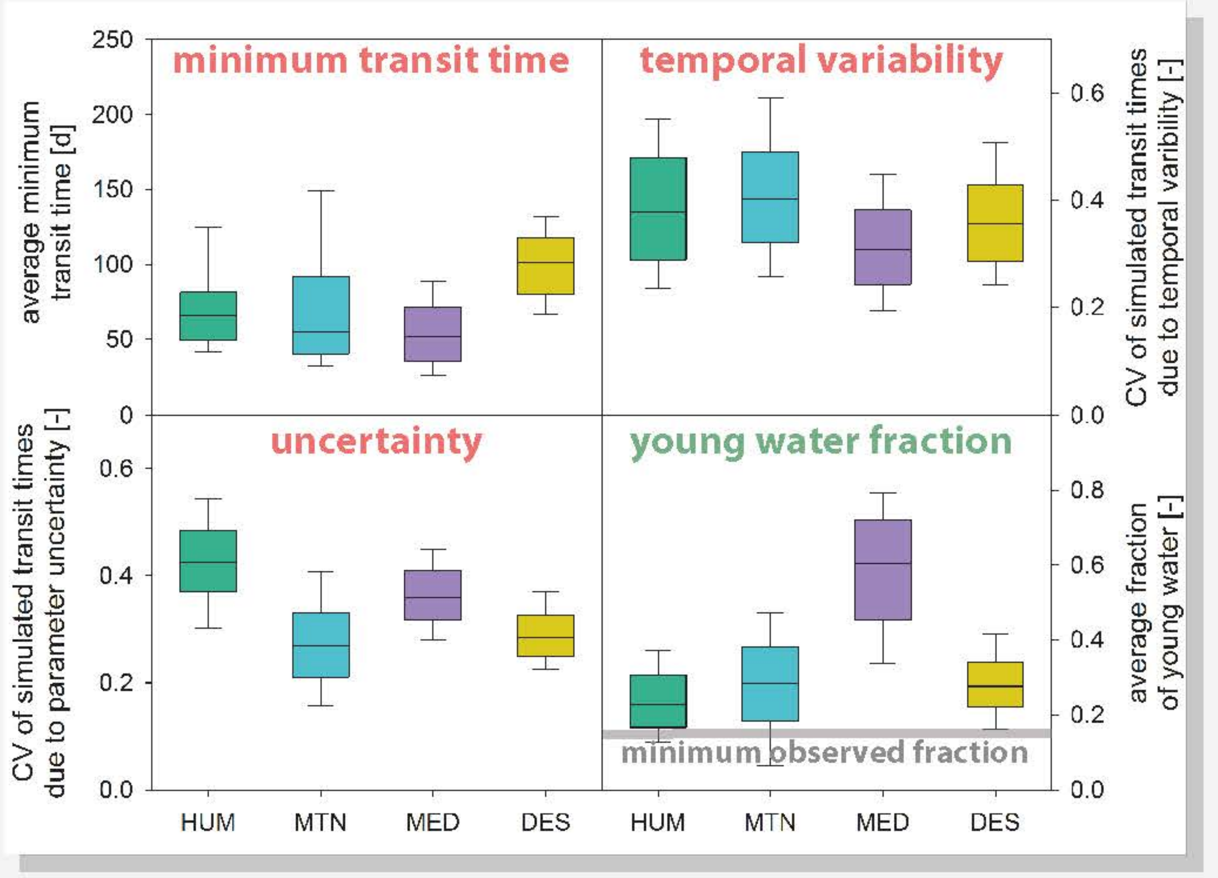
Shortest **minimum transit times** are found in the Mediterranean while longest transit times occur in the higher mountains and dry regions with low recharge rates. Regions with short transit times correspond to regions with **high fractions of young water.**

EVALUATION

Comparizon with recharge volumes assessed from from the literature shows that although there is a considerable spread across the simulations, their bulk plots well around the 1 : 1 line.



Another comparizon with simulated recharge volumes of 2 other large-scale models we find a strong tendency of under-estimation, in particular at the MTN and HUM regions.



Shortest **minimum transit times** are found in the MED regions, while they are longest in DES where lowest recharge amonts occur. All regions show significant temporal variability. Uncertainty is mostly below 40%, but it simlar ranges as temporal varibility.

Observed fractions of young stream water of karst dominated catchments (>50% carb rock, n=11) are available from Jasechko and Kirchner (2016).

Their range, 13%-15%, can be seen as a slight indications for the consistency of our results as **young water fractions** of groundwater recharge will further decrease when mixing within the aquifers takes place. Our results indicate that for HUM, MTN and DES young water fractions of recharge decrease by ~10% before reaching the streams. The MED regions indicate a much stronger decrease propbaly due to the abundance of the importance of focussed recharge in those regions.

SYNTHESIS

Transit time distributions have proven to be a valuable tool for contamination risk assessment. We show that they can also be applied on a larger scale where simulation approaches have been focussing on water quantity estimations. To increase reliability stricter evaluation with water isotope data of karst springs is necessary.

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Jasechko, S., Kirchner, J.W., Welker, J. M. and Mcdonnell, J. J.: Substantial proportion of global streamflow less than three months old; Nat. Geosci., doi:10.1038/NGEO2636 (2016).
Kirchner, J.W.: Aggregation in environmental systems – Part 1: Seasonal tracer cycles quantify young water fractions, but not mean transit times, in spatially heterogeneous catchments, Hydrol. Earth Syst. Sci. Discuss., 20, 279–297, doi:10.5194/hess-20-279-2016 (2016).