Recharge heterogeneity and high frequency rainfall events increase contamination risk for Mediterranean groundwater resources

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MOTIVATION
Kart 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 various countries. Previous work showed that the karstic recharge process results in enhanced recharge rates and potentially to more available groundwater for development. But as there is fast water flow from the surface to the aquifer, there is also an enhanced risk of groundwater contamination. In this study, we quantify the contamination risk of karstic groundwater recharge with virtual tracer experiments.

STUDY AREA & DATA
Since calibration data is not available at the regional scale, we used cluster analysis (k-means method) and three climate and relief descriptors (aridity index AI, days of snow DS, range of altitude within the grid cell (HA)) to define typical karst landscapes.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Land</th>
<th>Ratio of karst landscapes</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>90%</td>
<td>2.50</td>
</tr>
<tr>
<td>2</td>
<td>90%</td>
<td>3.00</td>
</tr>
<tr>
<td>3</td>
<td>80%</td>
<td>4.00</td>
</tr>
<tr>
<td>4</td>
<td>80%</td>
<td>6.00</td>
</tr>
</tbody>
</table>

By trial and error (k-means method) we found 4 landscapes with distinct climatic and topographic characteristics: HUMid, DIESert, DIESert and MEDITerranean. The data for cluster analysis and model inputs (2002-2012) are obtained from SRTM and GLODAS.

SIMULATION APPROACH
VarKarst-R model
We simulate groundwater recharge with a semi-distributed model that considers the spatial heterogeneity of the karst system by distribution functions. A newly developed parameter estimation scheme is devised to allow parameter sets and remaining parameter uncertainty for each of the karst landscapes using MIKE (Modeling) and soil moisture (SMOS) observations for 2002-2012.

Derivation of young water fractions
Transit time distributions of simulated recharge are derived by applying a virtual tracer at each grid cell's precipitation 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 from the transit time distribution. For our analysis of vulnerability we calculate the fractions of young water (transit-time < 1.8 months).

TOTAL VOLUMES OF GROUNDWATER RECHARGE
The simulations show high annual recharge rates in Northern Europe and in the high mountain areas, where low values occur for Southern Europe and Northern Africa. The parameter uncertainty due to the limited data availability remains low in most of the study domain.

YOUNG WATER FRACTIONS OF GROUNDWATER RECHARGE

Comparison with independently obtained recharge volumes (measured experimental and modeling studies) shows that the simulations of the VarKarst-R model plot around the 1:1 line. Other established models tend to under-estimation, in particular at the MTF and HUM regions.

CLIMATIC CONTROLS

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.