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Linking spatial heterogeneity of geomorphic properties, flow persistence and hydrological connectivity

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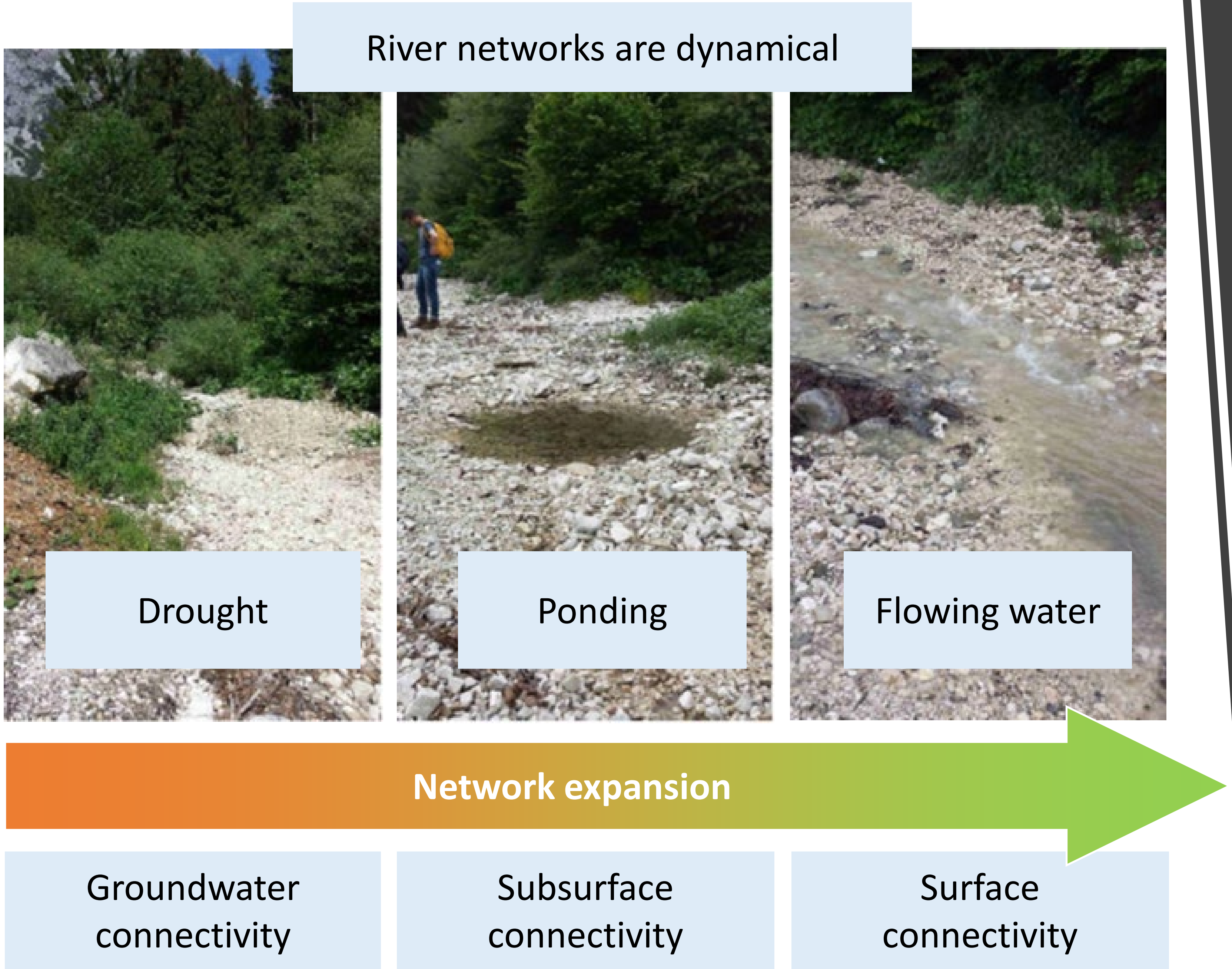
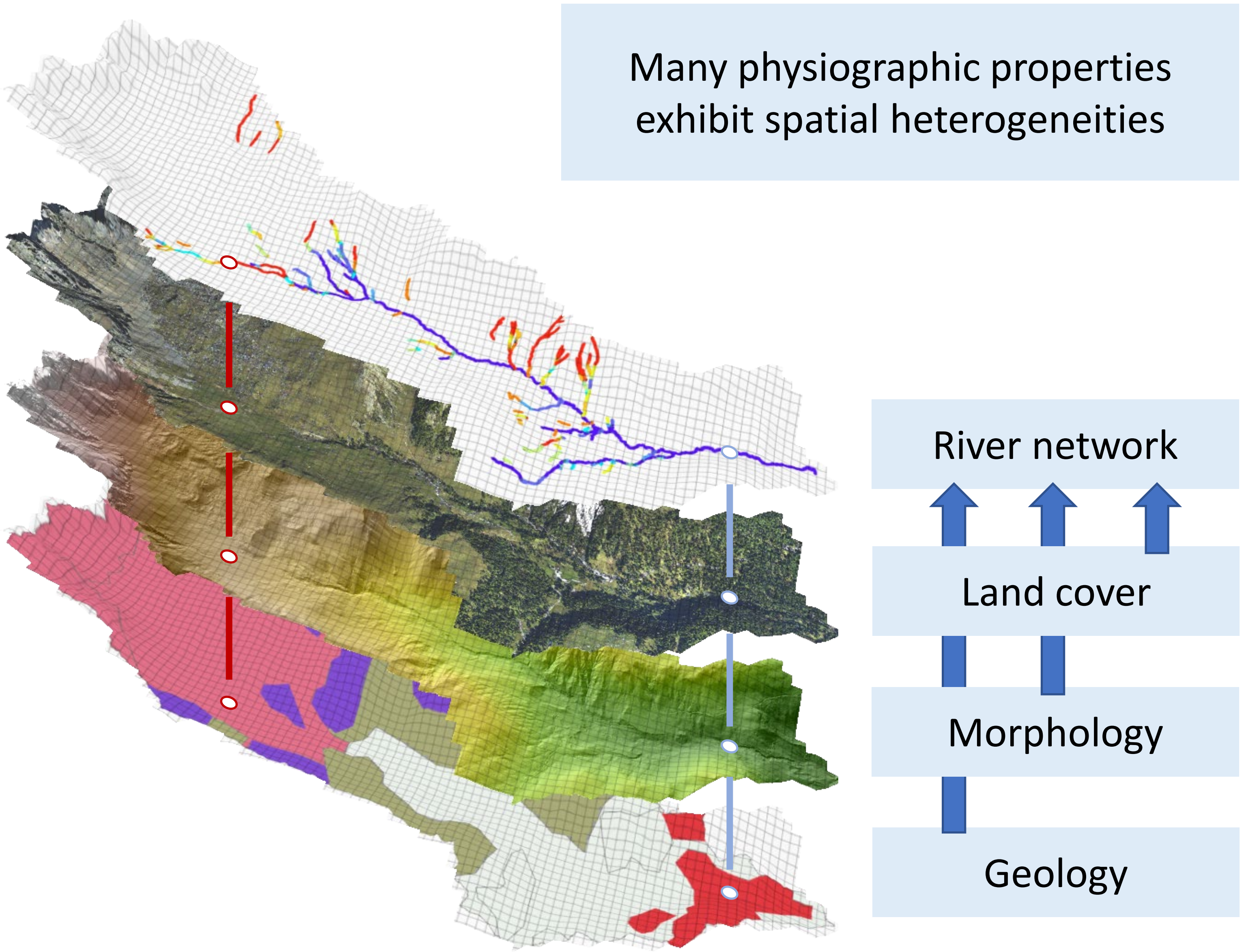


River networks are dynamical

Trough time, the same location can experience flowing water, ponding and drought.

For this reason, the nature of the connectivity that is provided by each stretch changes trough time [Garbin 2019]. This dynamicity impacts the transport processes of water and nutrients, dictating the quantity and quality of water at the outlet.



River networks are heterogeneous

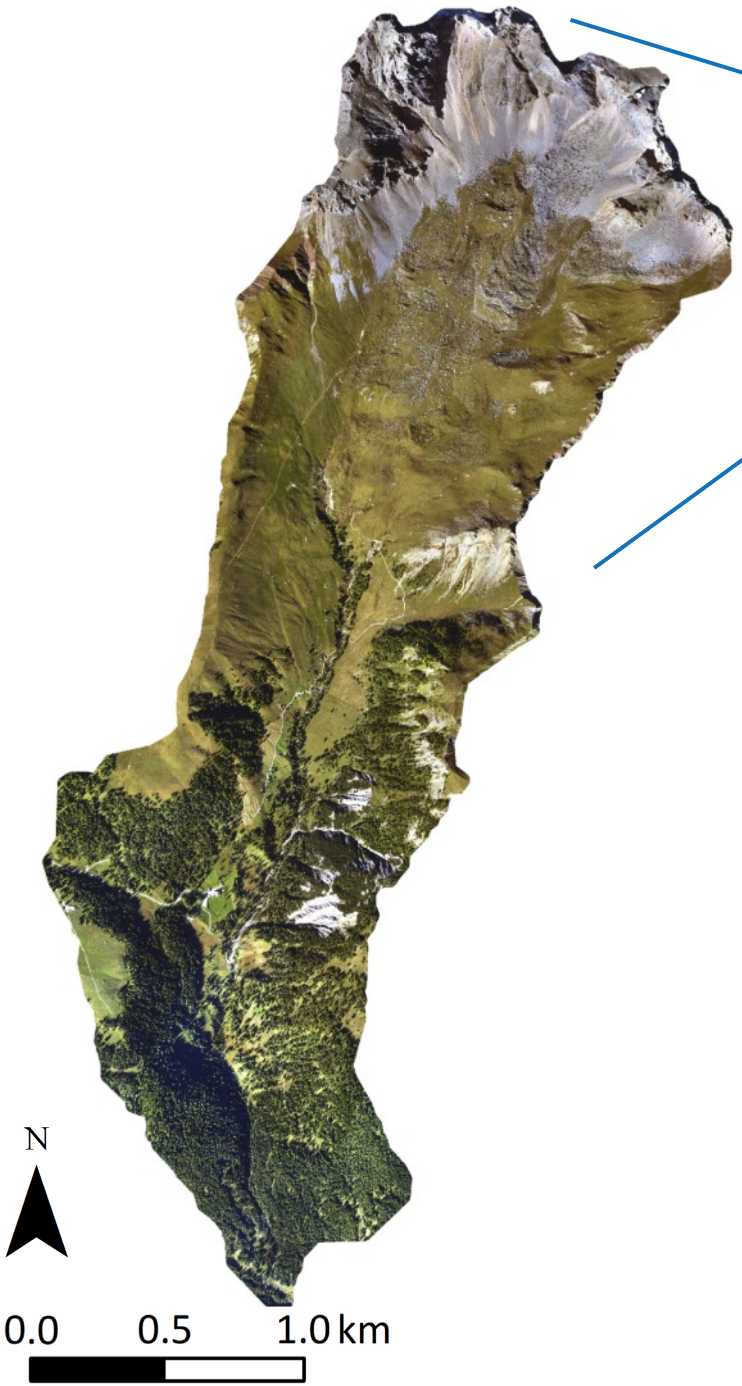
Many physiographic properties (e.g. geology, morphology and land cover) exhibit spatial heterogeneities.

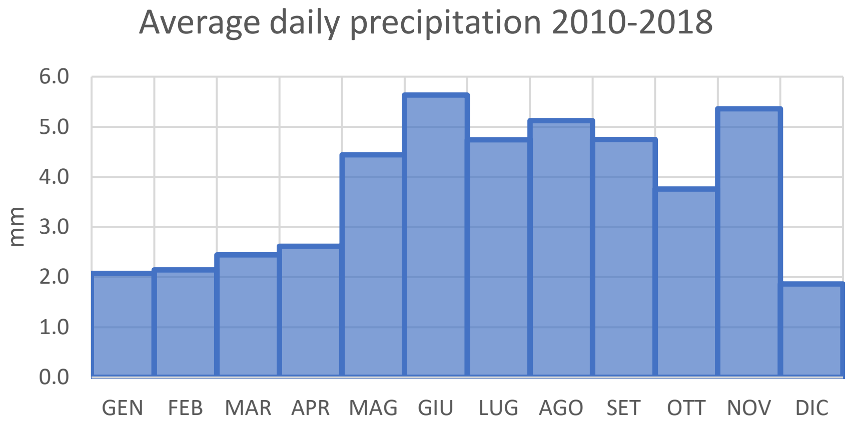
River networks incorporate these heterogeneity into recognizable spatial patterns of drainage density and temporal dynamics.

The spatial and temporal complexity of river systems could inspire many researches.

Research questions

1. What are the drivers of space-and-time variability of the river network?
2. Are spatial heterogeneities and temporal dynamics intertwined?





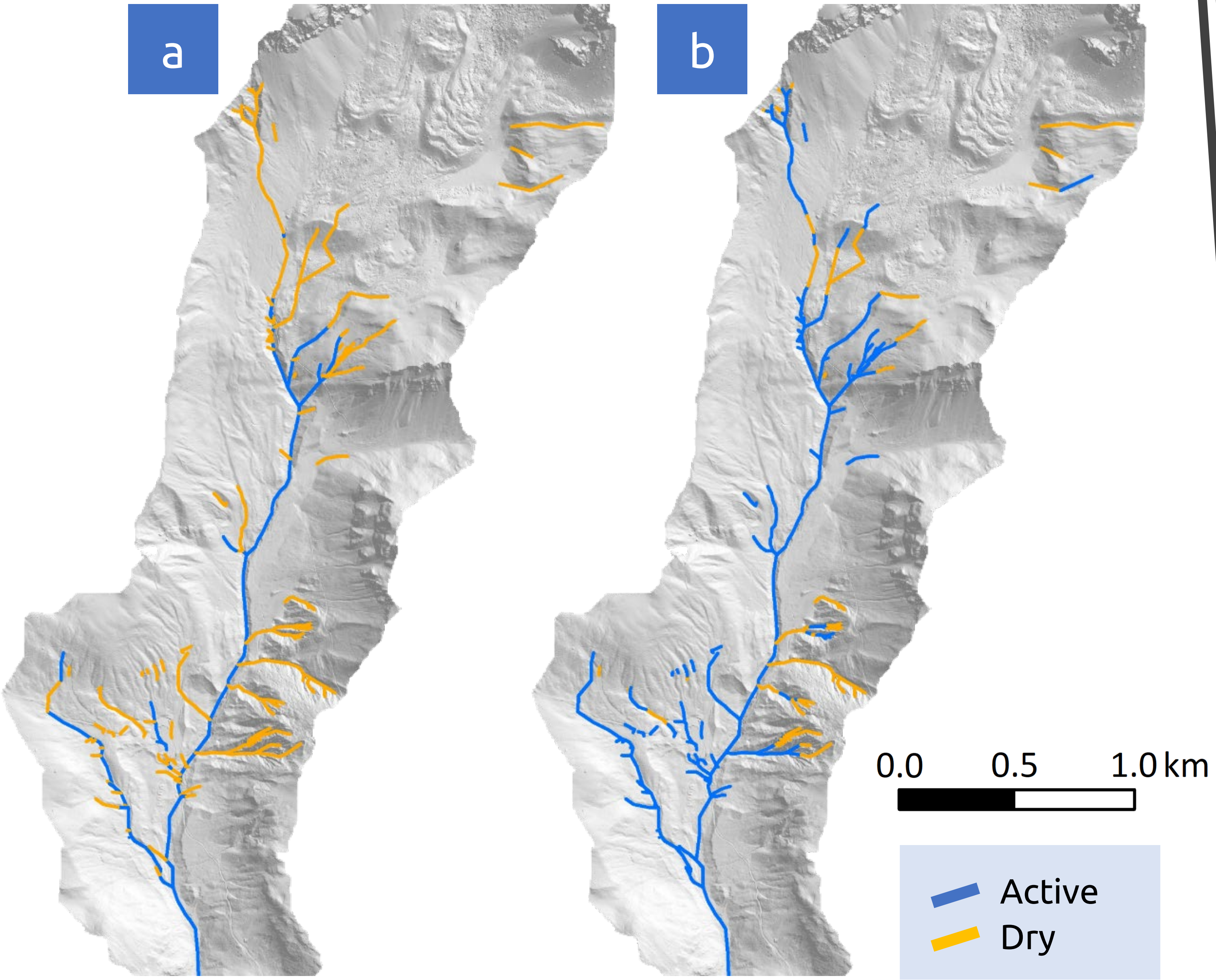
The study catchment

The Valfredda river drains a 5 km^2 catchment in the Alps of northern Italy. The elevation ranges between 1500 and 3000 m a.s.l., and the two main land covers are pasture and forest.

It has a typical alpine climate, with 1500 mm of annual precipitation distributed between long rigid winters and short rainy summers.

There are strong spatial heterogeneities in geology and physiography that dictate the shape and dynamicity of the river network.

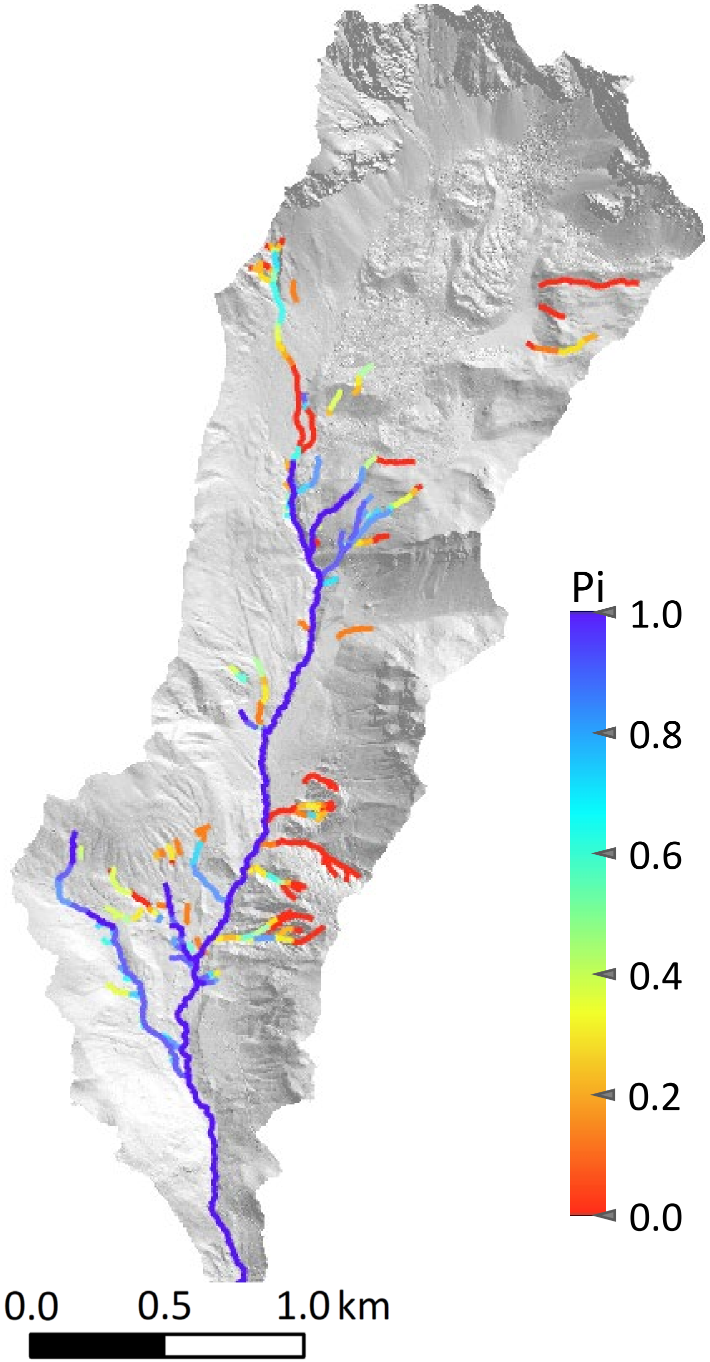
[Durighetto et al., 2020]



Network mapping

During a biweekly field campaign from July 2018 to January 2019, the active river network was mapped for 10 times in different hydrologic conditions.
The shortest surveyed network (a) was observed after a two-months recession period; 8 days later, after a 300 mm rainfall event, the network reached its maximum expansion (b). During this event, the network expanded for about 6 km by activating a lot of disconnected tributaries. This suggests that both short- and long-term precipitation dynamics play a key role in the expansion and contraction of the river network.

[Durighetto et al., 2020]



Persistency index Pi
For any network stretch i
$$P_i = \frac{\#\ of\ times\ the\ stretch\ i\ was\ active}{total\ \#\ of\ field\ surveys}$$

High Pi	Sporadic deactivation
Intermediate Pi	High dynamicity
Low Pi	Sporadic activation

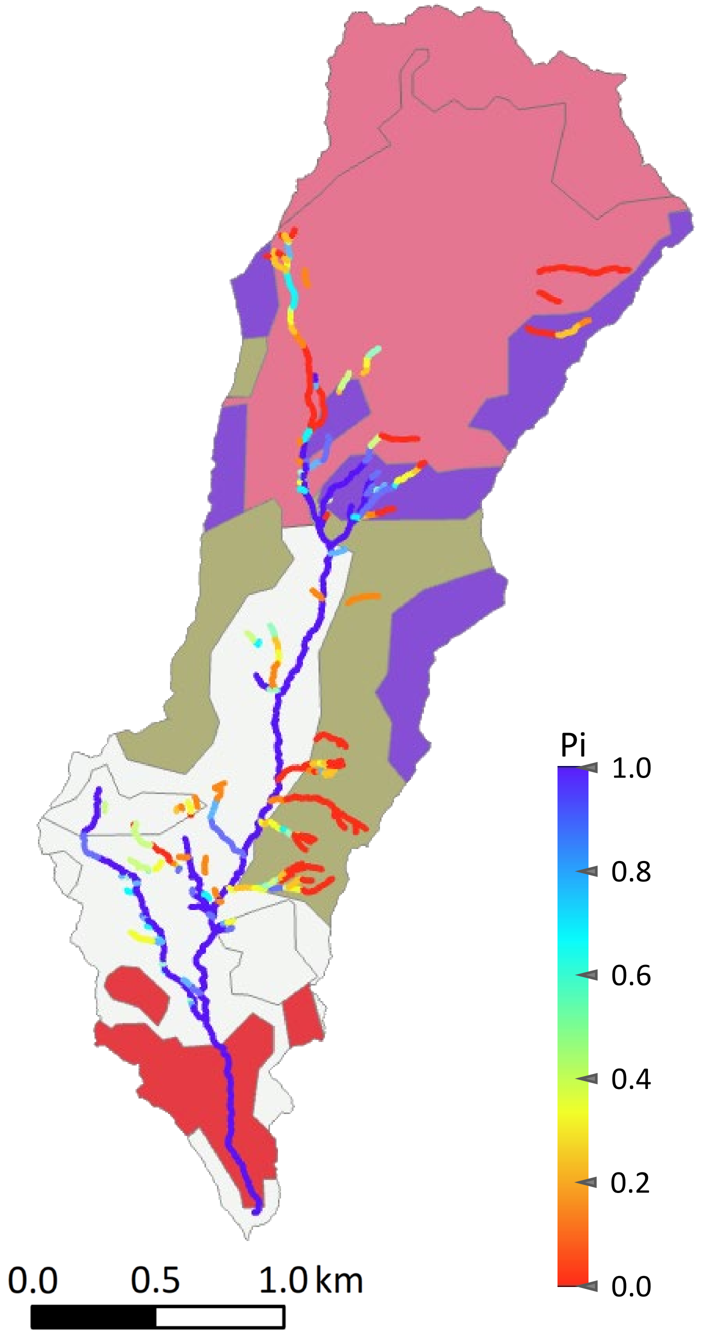
Network description

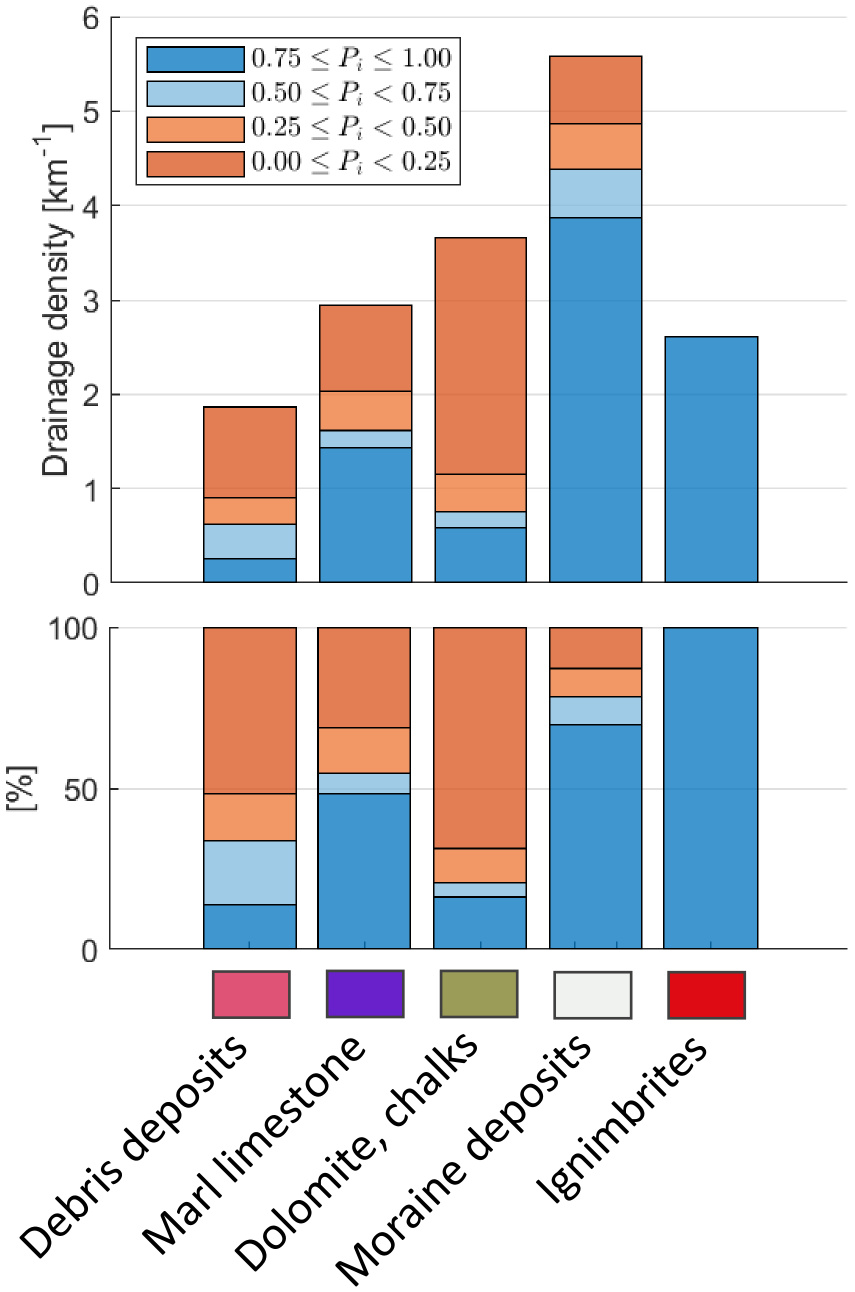
Network dynamicity can be summarized via the persistency index Pi, which indicates how often the stretch i experiences flowing water. Pi can be interpreted as the fraction of time of a stretch being active, and tells how dynamic each part of the network is.

Despite the wet climate of the study area, the permanent fraction of the network (Pi = 1) is less than 30% of the total length.

The less persistent stretches are clustered in some areas of the catchment, suggesting that local physiographic features dictate network persistence.

[Durighetto et al., 2020]



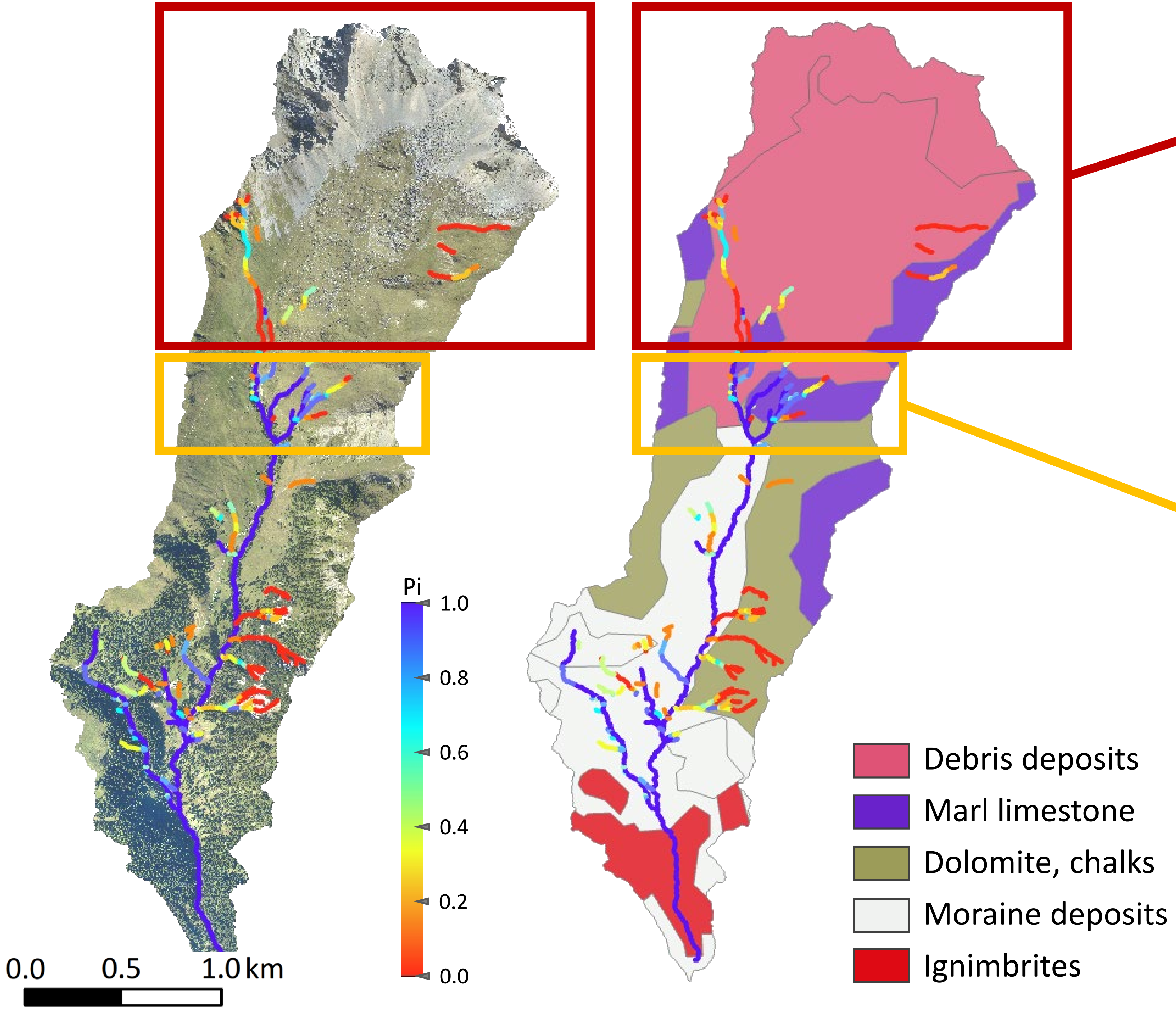


Geology driven heterogeneity

The geology and land cover present strong spatial heterogeneities.

The bar plot shows how each geologic unit is associated with a different drainage density, and a different repartition among persistencies.

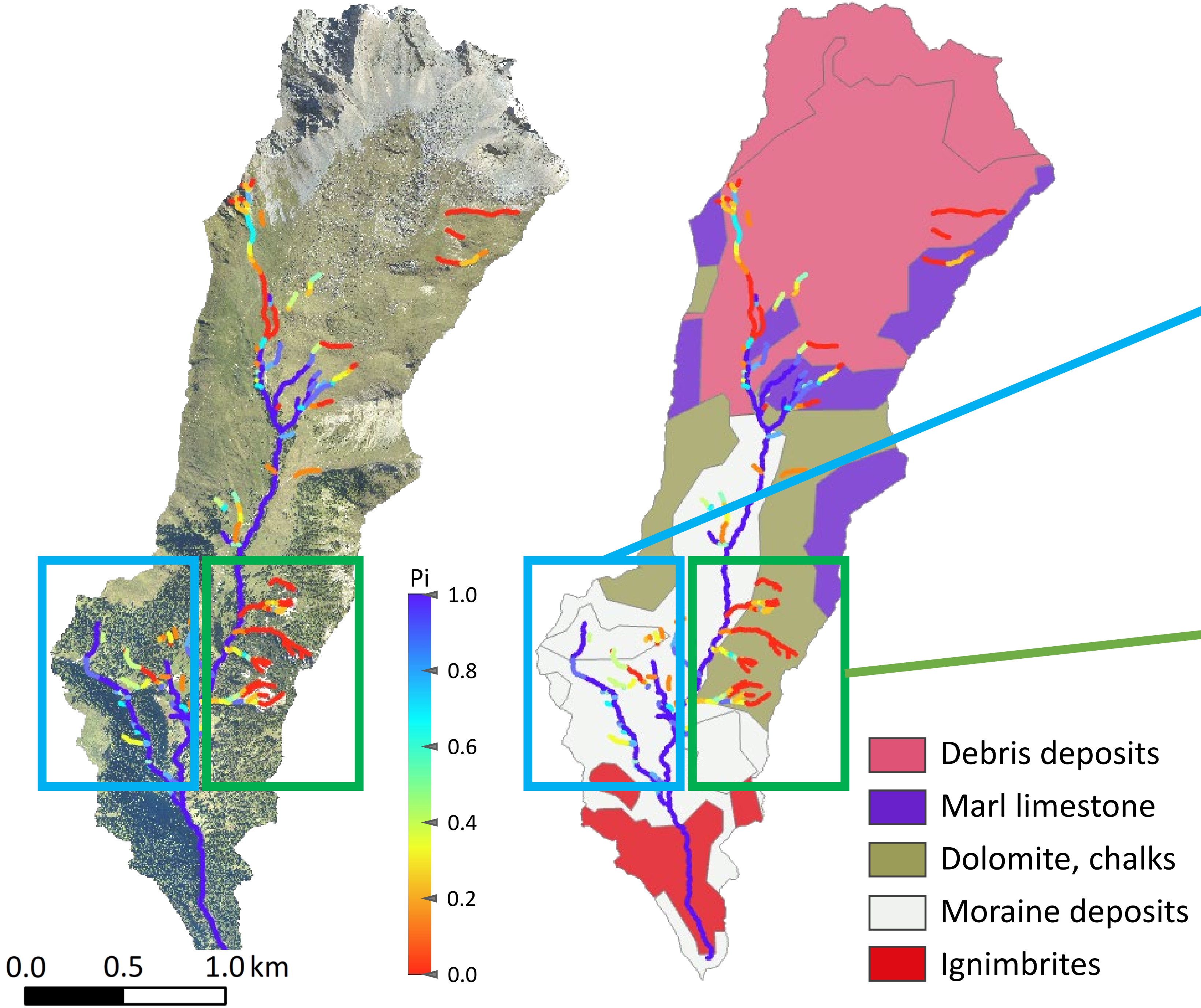
[Durighetto et al., 2020]



The northern part of the catchment is dominated by solid limestone, debris deposits and terrain depressions. Here rainfall water can be easily accumulated and infiltrated into the soil; in this area the drainage density is low, and the few channels are temporary and disconnected.

The water infiltrated above supplies some perennial sources, which generate the most persistent fraction of the network.

[Durighetto et al., 2020]



The central part of the catchment shows a much higher drainage density; here, the two sides of the main river are profoundly different.

On the western side, moraine deposits with a thick soil horizon are covered by conifers. This formation allows rainfall water to infiltrate in the root zone and be slowly released, originating quite persistent tributaries.

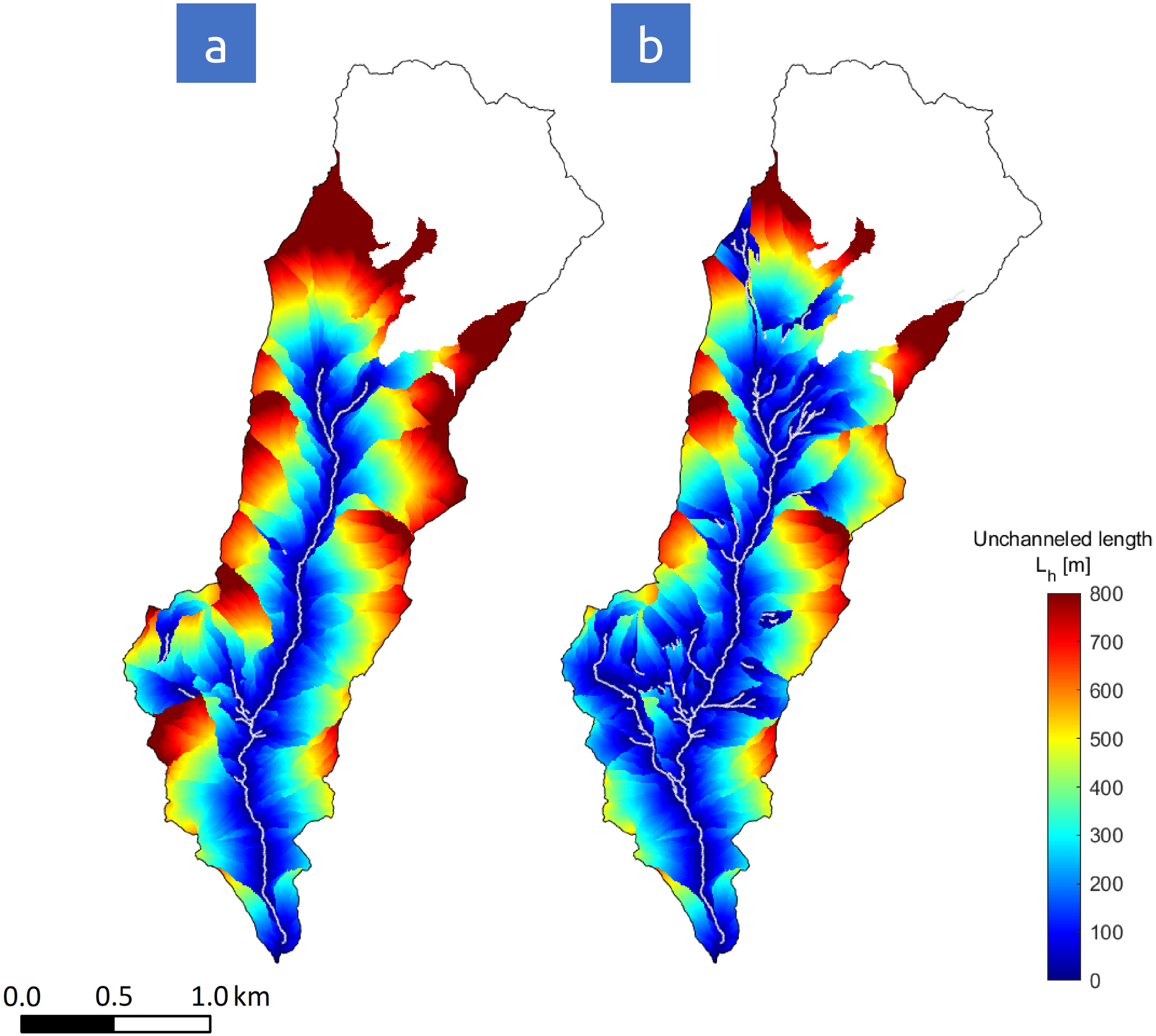
On the eastern side, instead, the dolomite bedrock is close to the surface and generates an almost impermeable surface with high slopes. Here, the hydrological response is flashy and dominated by overland flow, and the streams have very low persistence.

[Durighetto et al., 2020]

Unchanneled lengths

The spatial heterogeneity of network dynamics is reflected into the unchanneled lengths, defined as the distance, along flow directions, from any given point to the first stretch of the active network.

Unchanneled lengths can be useful in assessing: 1) hillslope to stream connectivity; 2) the local drainage density, when averaged over the auto-correlation scale [Tucker et al., 2001]; 3) the frequency distribution of water travel time [Rinaldo et al. 1995].

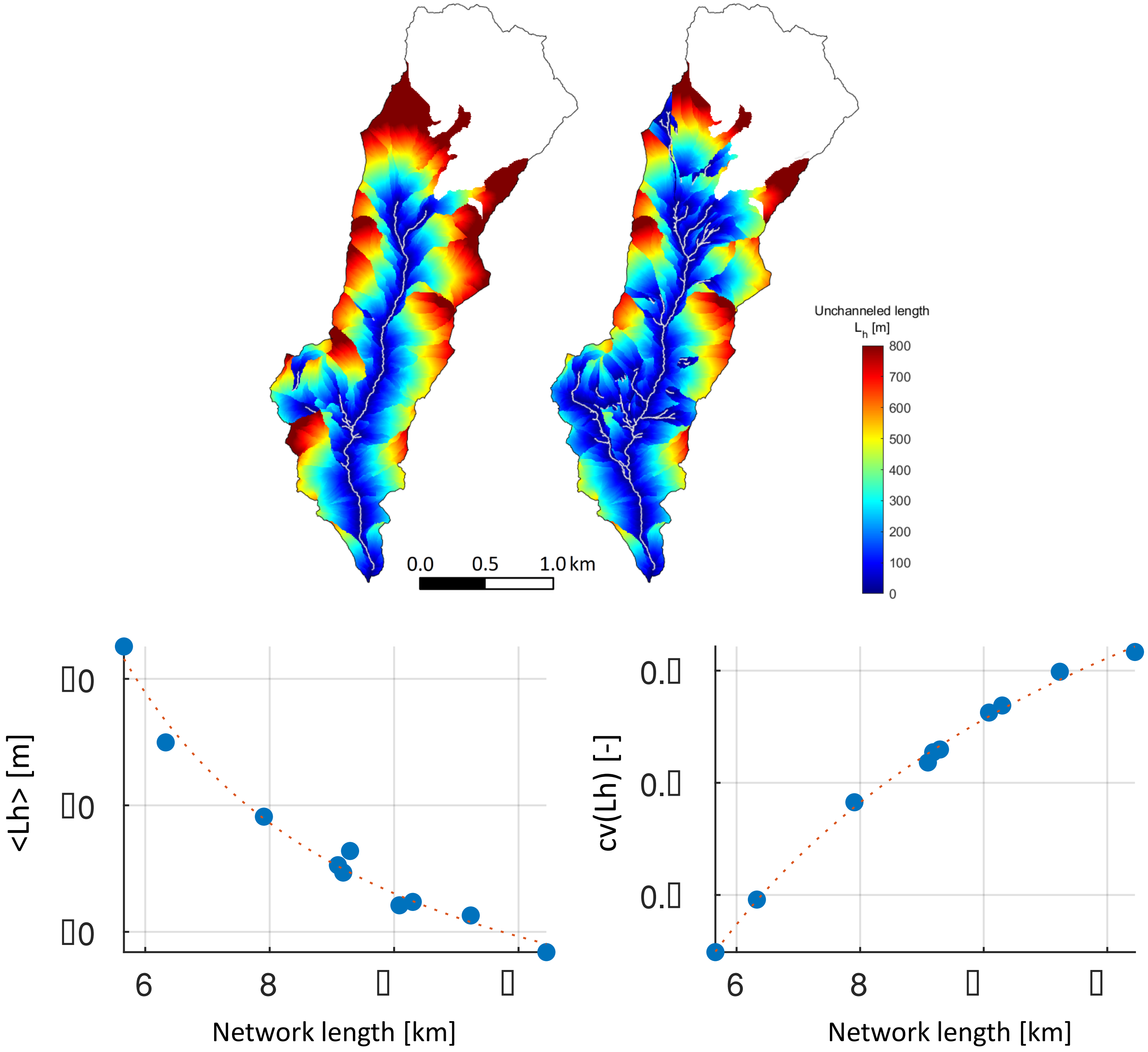


The two maps on the left show the unchanneled lengths relative to the shortest (a) and longest (b) surveyed networks.

During dry conditions (a), short and long unchanneled lengths are homogeneous troughout the catchment, while for the longest network (b) the areas with long unchanneled distances are sparser and the catchment is more heterogeneous.

Wet conditions enhance hydrological connectivity, with possible implications for the biogeochemistry of the whole catchment [Covino 2017].

[Durighetto et al., 2020]

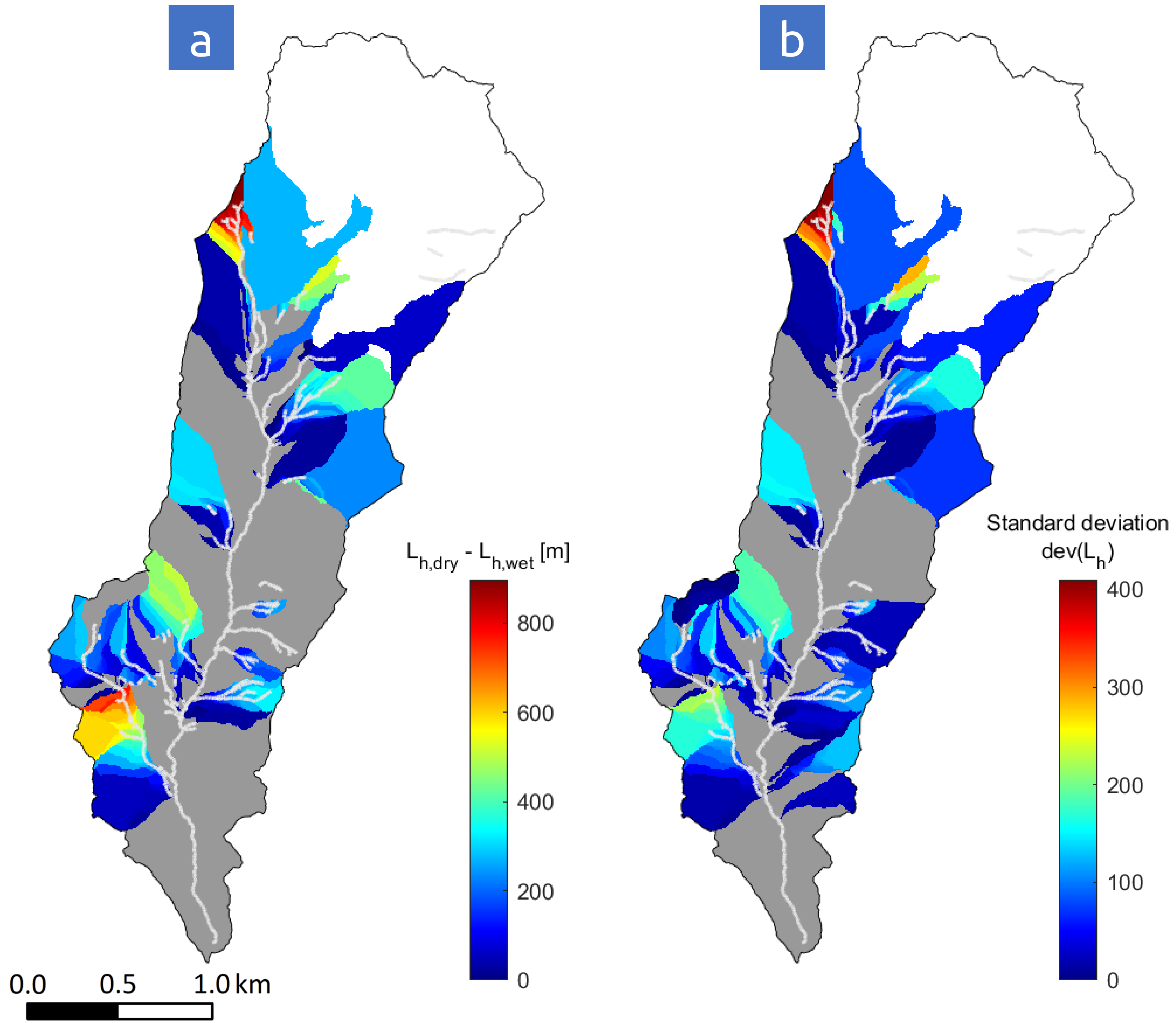


These heterogeneous dynamics are reflected in the statistics of the unchanneled lengths.

The average unchanneled length <Lh> decreases for increasing network length.

The coefficient of variation of Lh increases with network length, suggesting that network dynamics induce temporal changes also in the heterogeneity of the catchment.

[Durighetto et al., 2020]



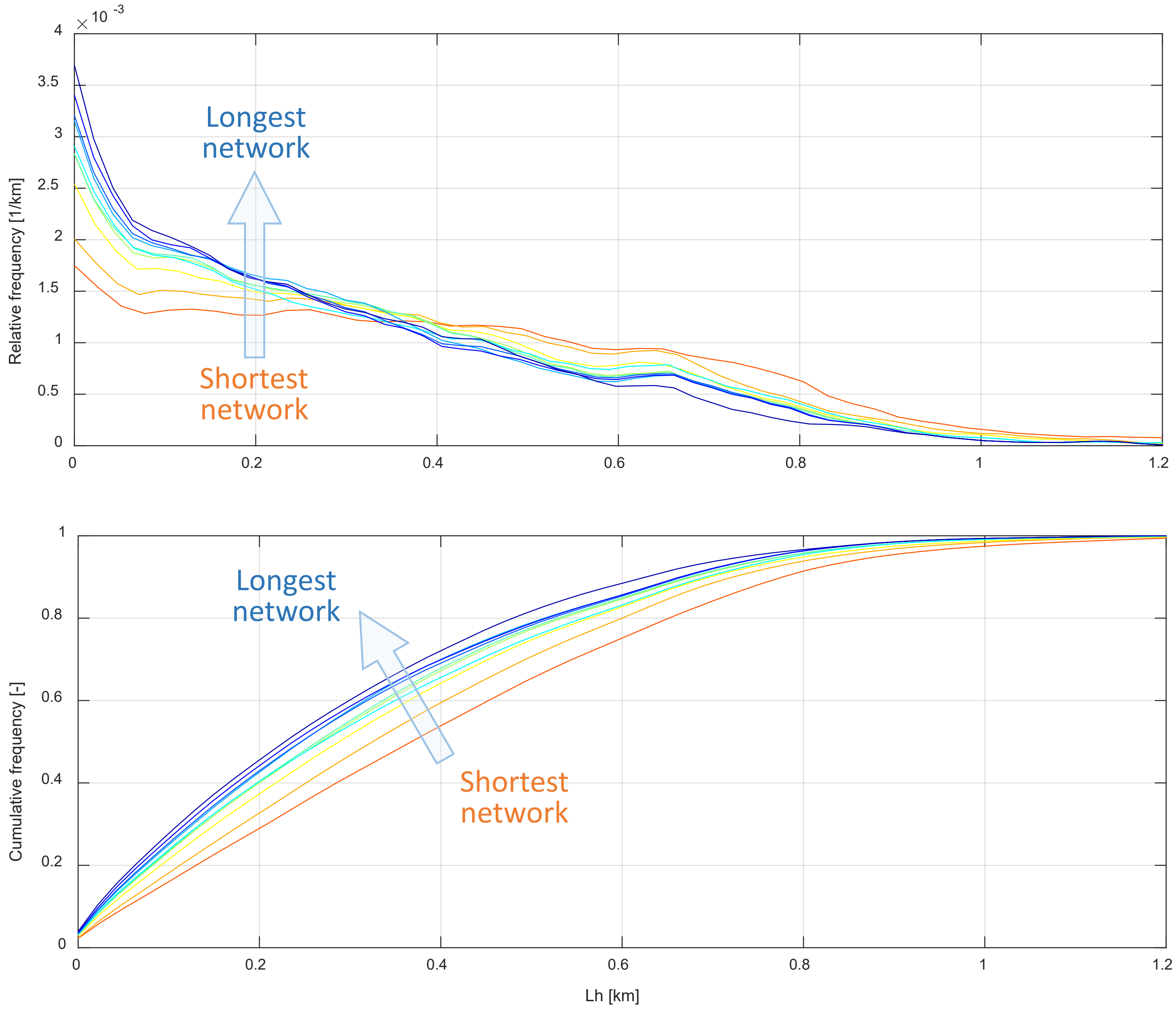
Unchanneled lengths variability

The maps show Lh difference between the shortest and longest active networks (a) and the local standard deviation (b).

Each subcatchment has a uniform dynamic of Lh, corresponding to the length of the dynamic part of the network it drains into.

More than 35% of the catchment area experiences dynamics in Lh. In these areas, the hydrological connectivity is most enhanced during wet periods. Consequently, the fraction of catchment with a particular degree of connectivity changes through time.

[Durighetto et al., 2020]



The relative and cumulative frequency distributions of the unchanneled length can serve as a proxy for assessing the shape of the travel time distribution, and its temporal variations associated with network dynamics.

The frequency distribution is more uniform for shorter networks (i.e. when only the most persistent stretches are active), and becomes more skewed as the network expands, suggesting that the activation of temporary stretches plays a key role in reducing the travel time to the outlet.

[Durighetto et al., 2020]

CONCLUSIONS

1. Geomorphology drives network geometry and persistency
2. Catchment heterogeneities are intertwined with network temporal dynamics
3. Network expansion enhances the hydrological connectivity of specific subcatchments
4. Longer networks cause more spatially heterogeneous catchments

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