Quantifying in situ climatological data coverage and human population dynamics across High Mountain Asia

James M. Thornton *et al.*

GEO MOUNTAINS
Observing Mountain Environments

Cryosphere and related hazards in High Mountain Asia in a changing climate

04 November 2022

MOUNTAIN RESEARCH INITIATIVE

ADAPTATION AT ALTITUDE
Taking Action in the Mountains

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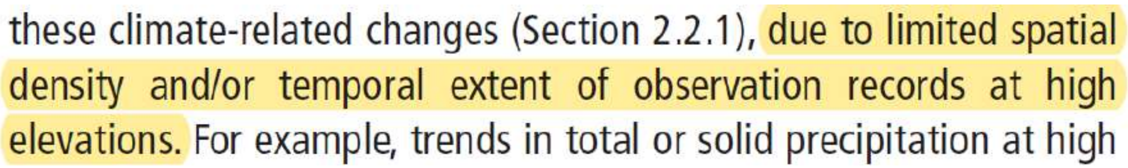
Part 1: Motivation (in brief)

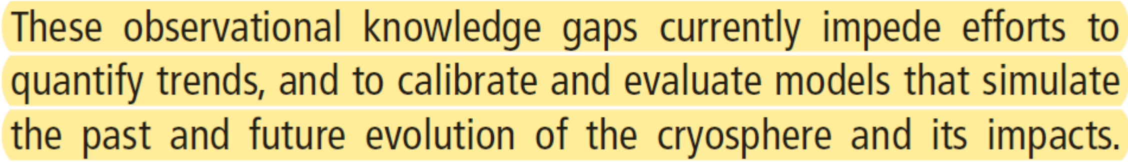
- In situ climatological observations:

“Monitoring networks are insufficient at high elevations” / “the density of stations decreases with elevation”

Hock et al. (2019)



these climate-related changes (Section 2.2.1), due to limited spatial density and/or temporal extent of observation records at high elevations. For example, trends in total or solid precipitation at high

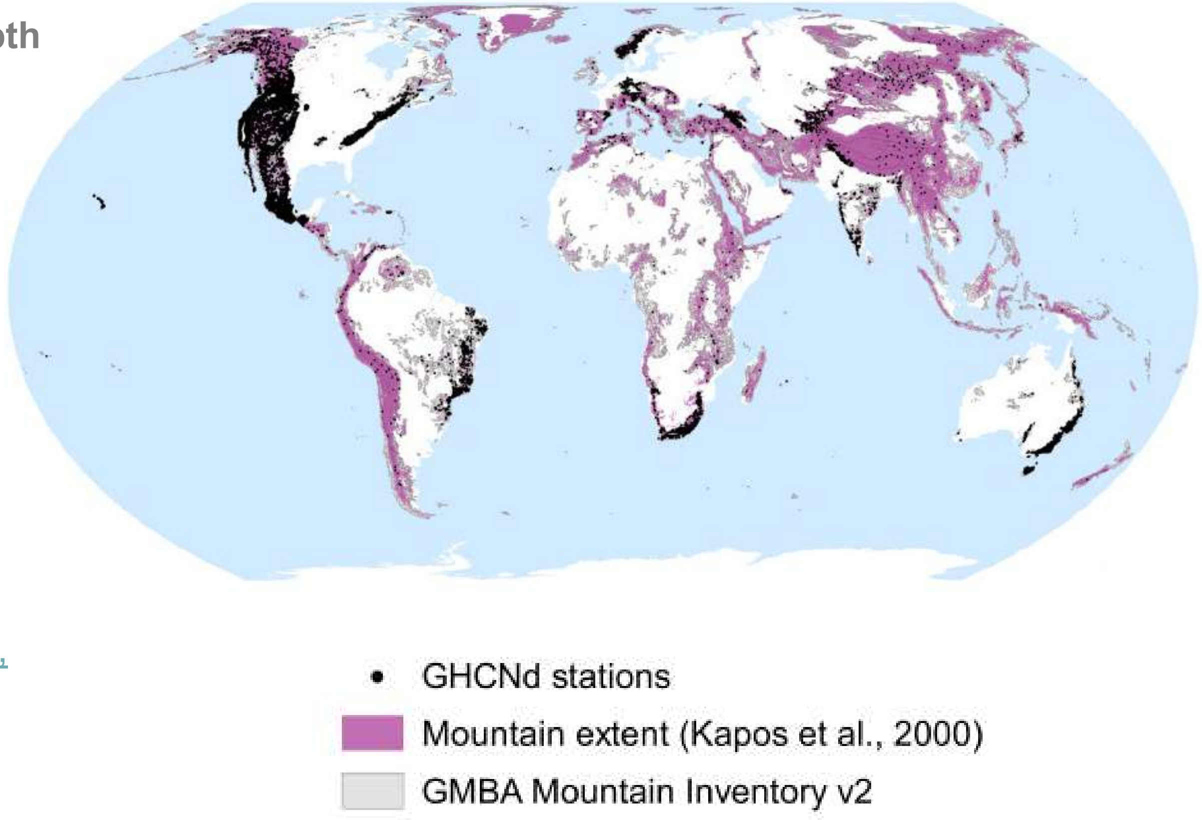


These observational knowledge gaps currently impede efforts to quantify trends, and to calibrate and evaluate models that simulate the past and future evolution of the cryosphere and its impacts.

Objectives and data

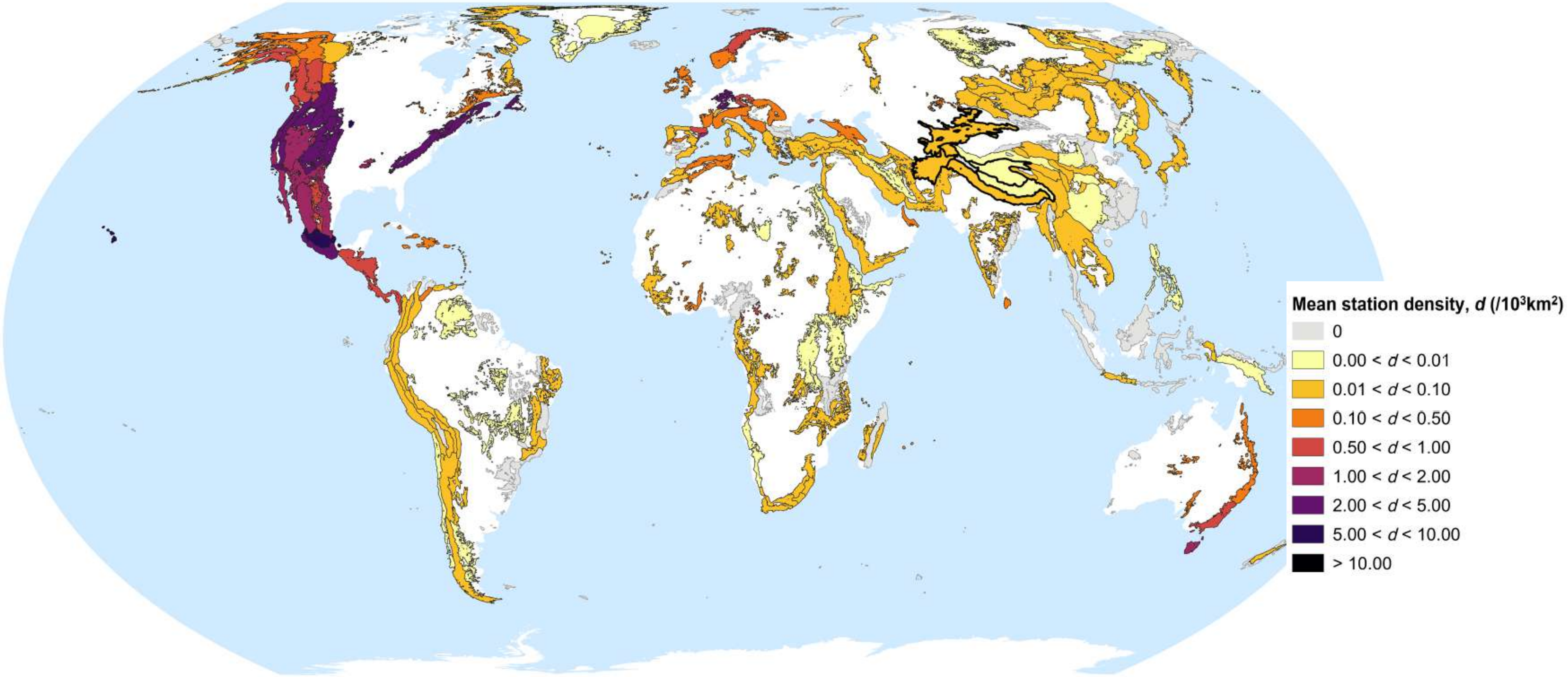
- To **quantify patterns** of in situ climatological station **record coverage** with respect to:
  - **Space**, **time**, and **elevation** (absolute coverage)
  - Three key variables; **air temperature**, **precipitation**, **snow depth**
  - Across **292 named global mountain regions** (Snethlage et al., 2022)
  - Station inventory: **Global Historical Climatological Network-Daily** (GHCNd; Menne et al., 2012)

- Also introduce additional datasets to assess **coverage metrics relative to other potential covariates,** e.g.:
  - The **Topographic Roughness Index (TRI)**
  - The **Water Tower Index (WTI)** (Immerzeel et al., 2020)
  - The **population** (Pesaresi et al., 2019) and **GDP** (Kummu et al., 2018) of corresponding downstream river catchments (GRDC, 2020)



Spatial density: Global overview

- **Mean spatial density** by mountain range, irrespective of record length, for **air temperature** (daily max):



Spatial density: Global overview

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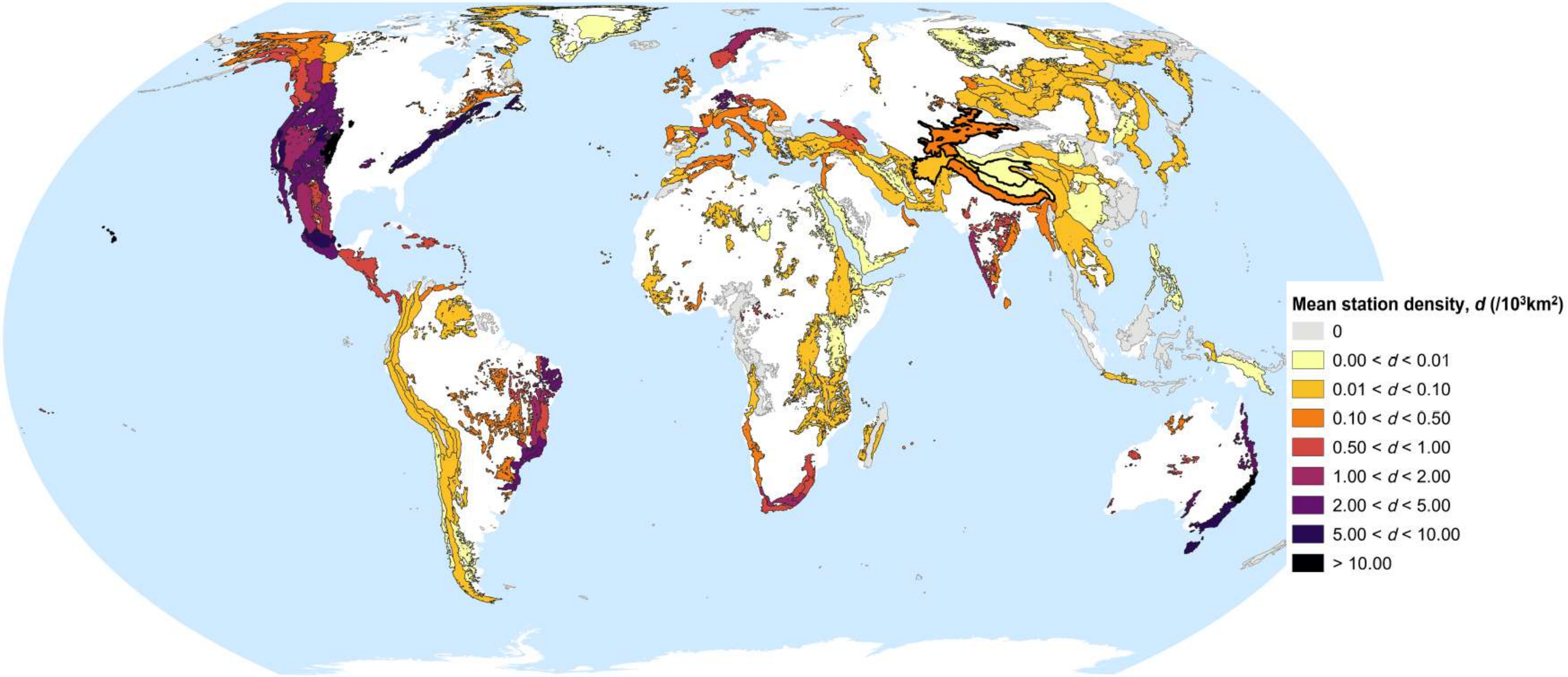
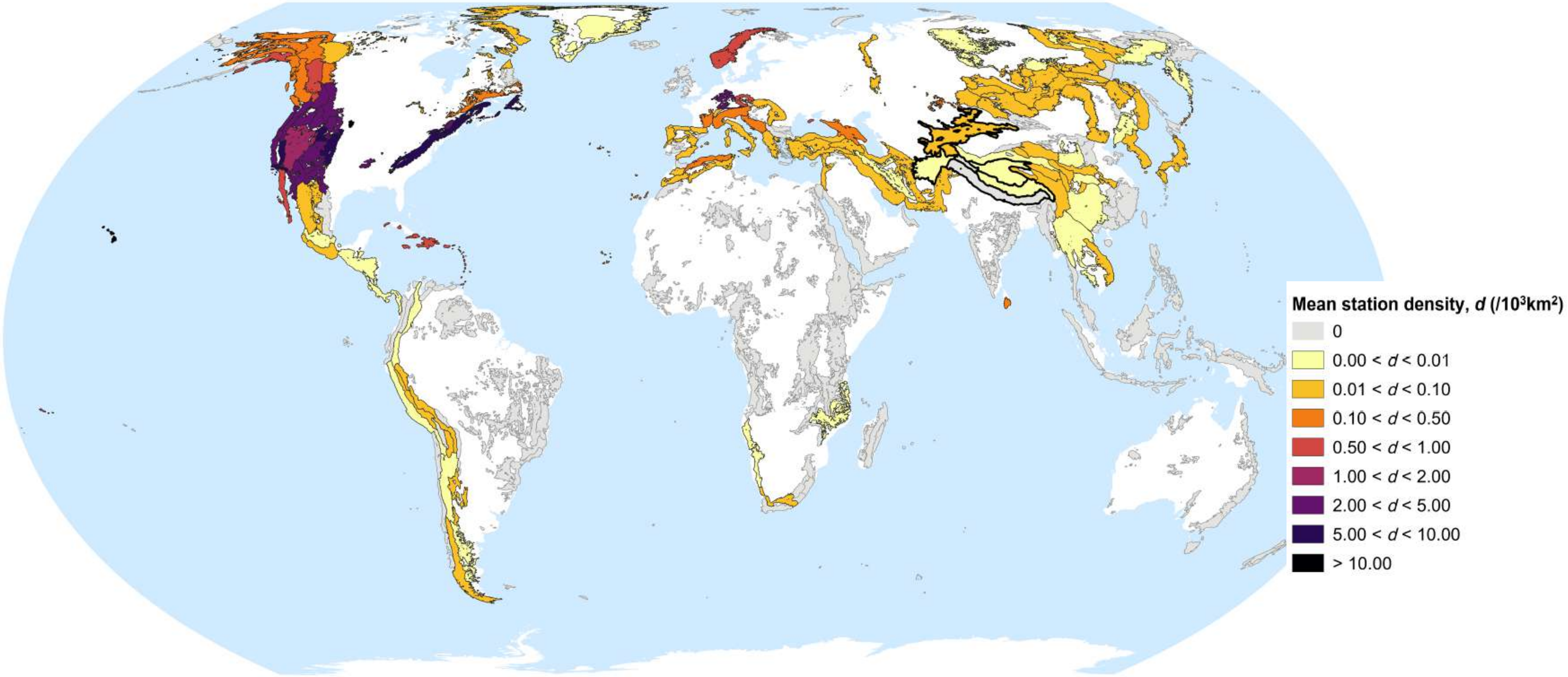
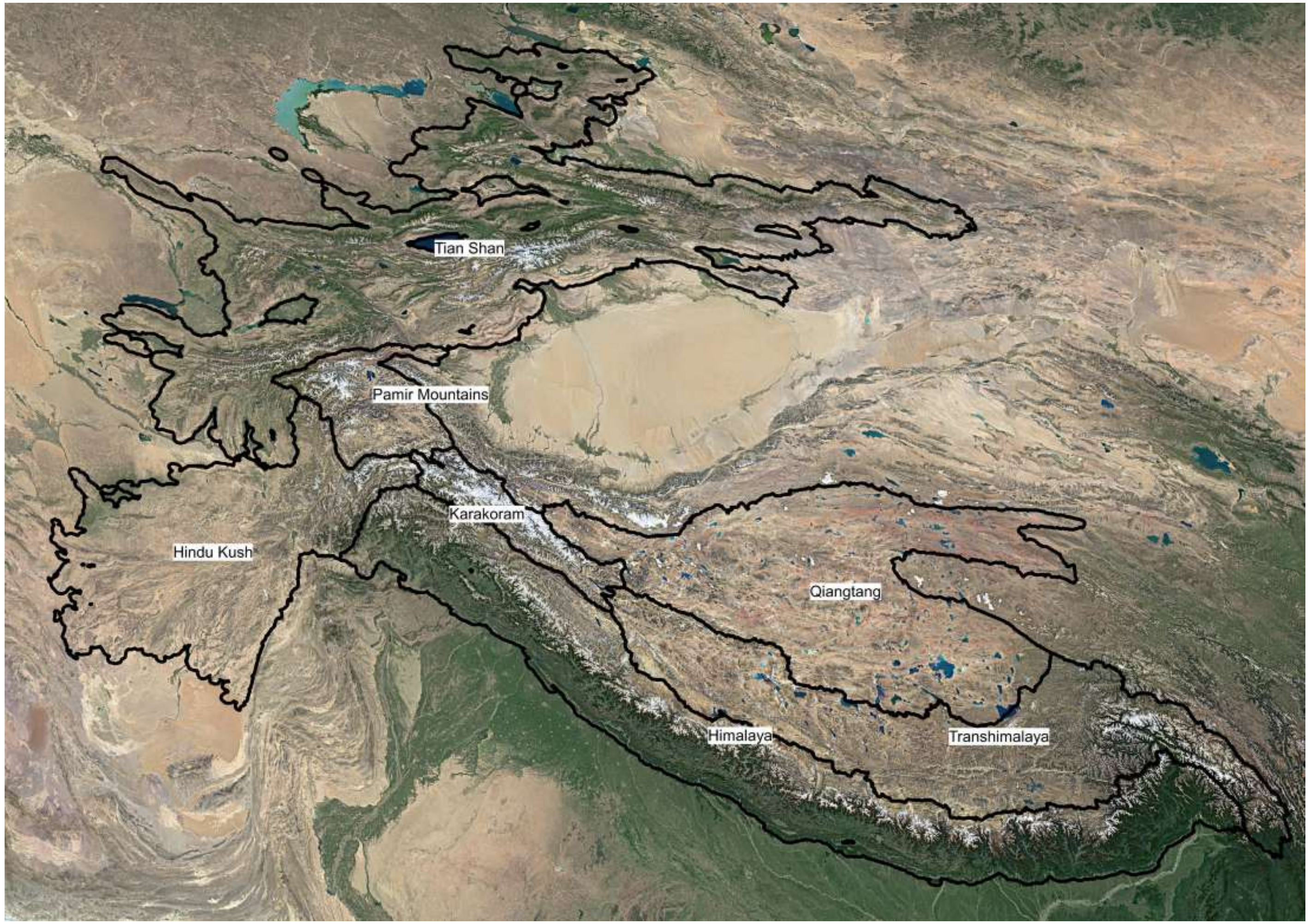


Spatial density: Global overview

- **Mean spatial density** by mountain range, irrespective of record length, for **snow depth**:



Spatial density: HMA



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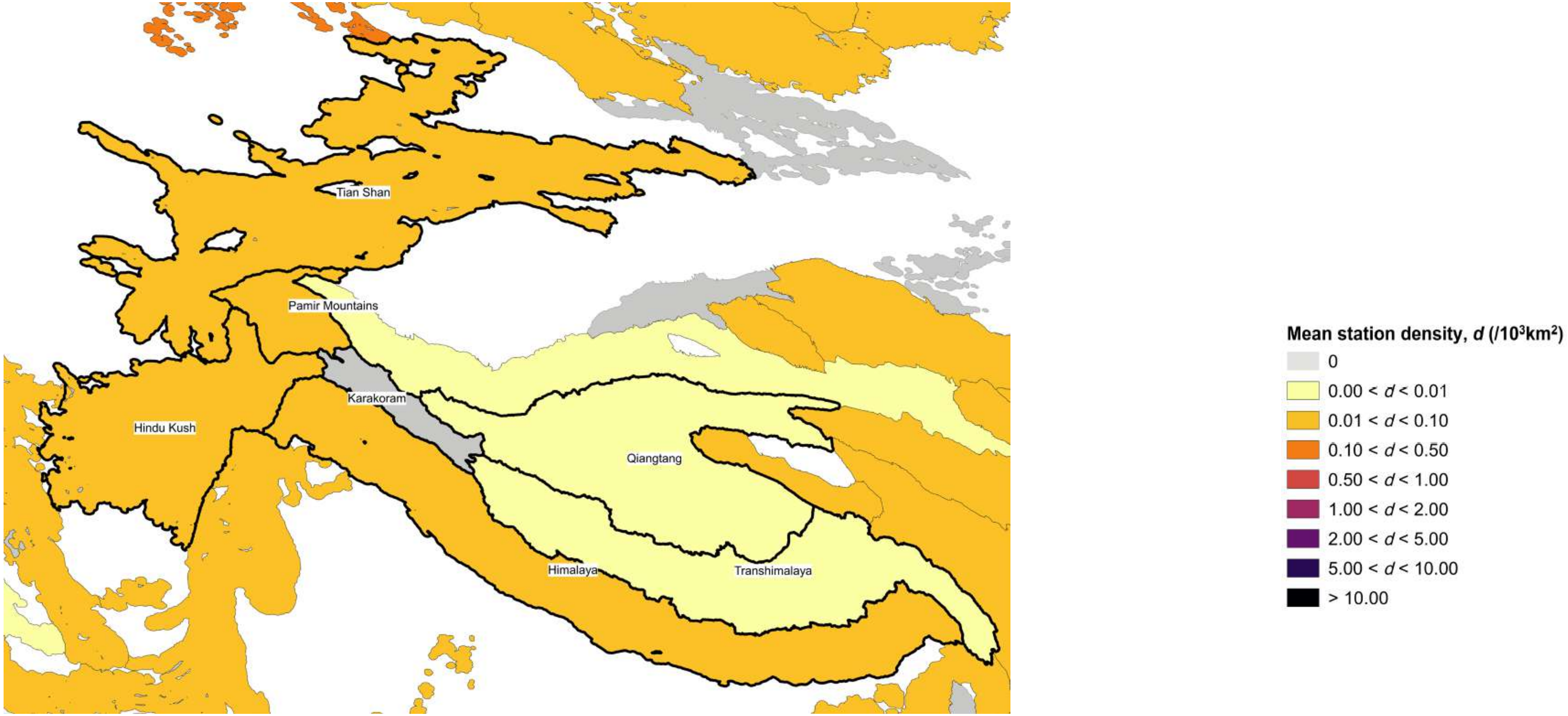

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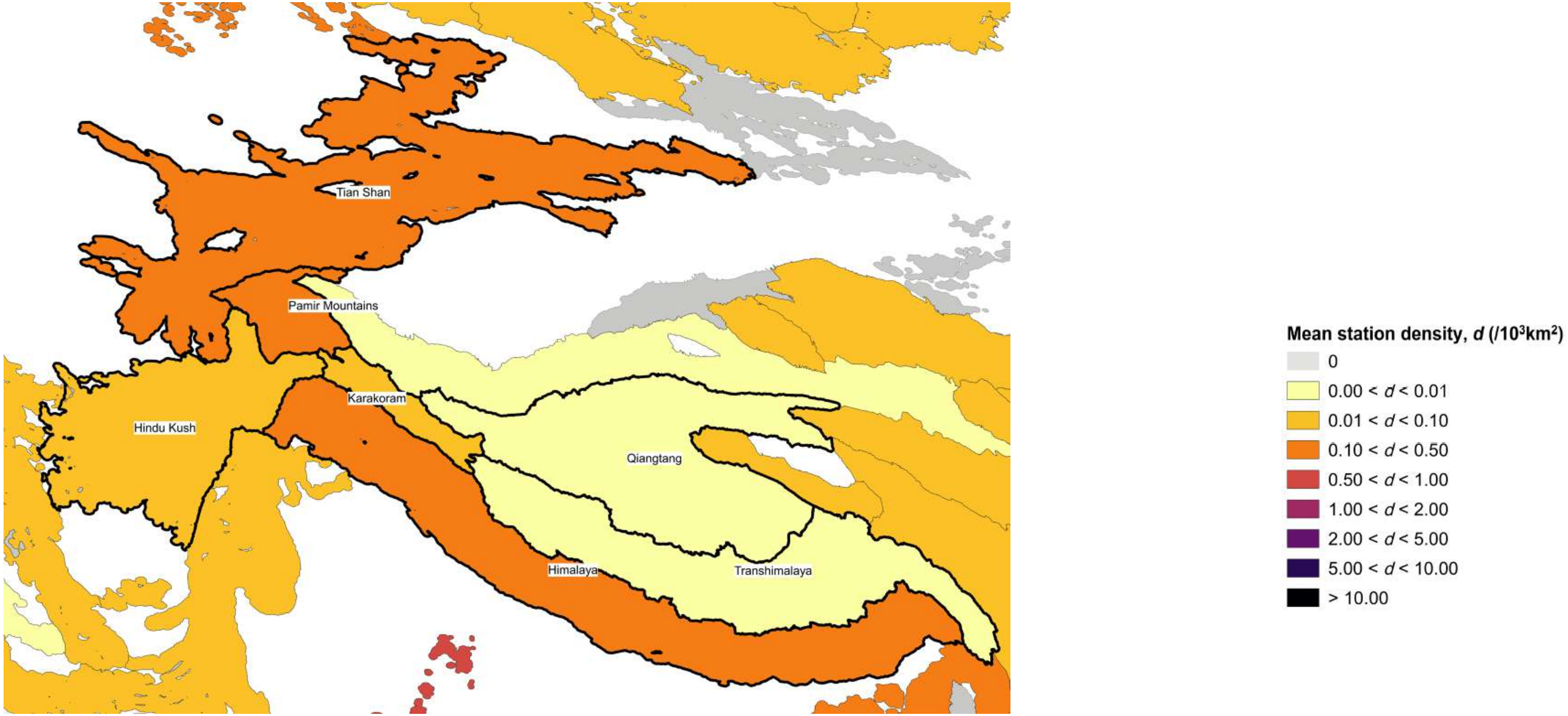

Spatial density: HMA

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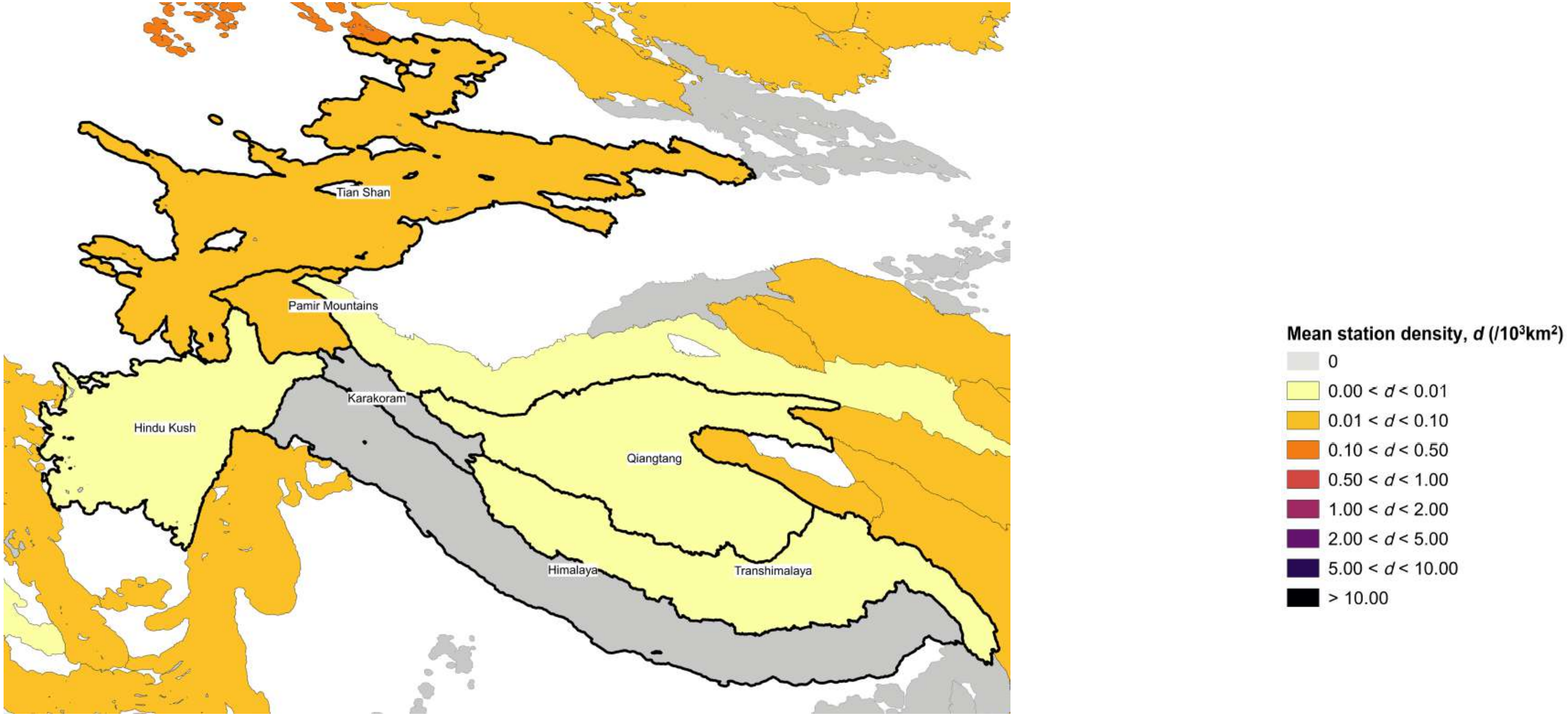
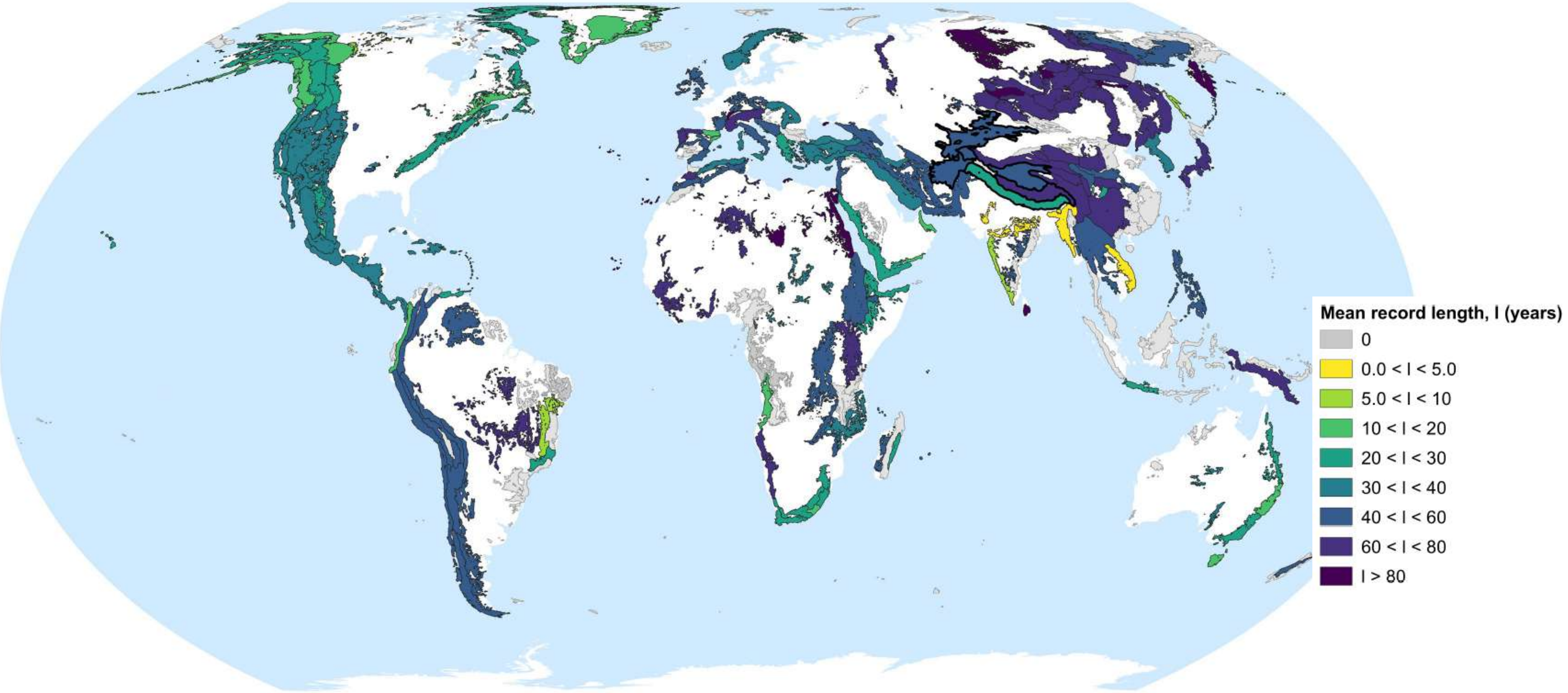


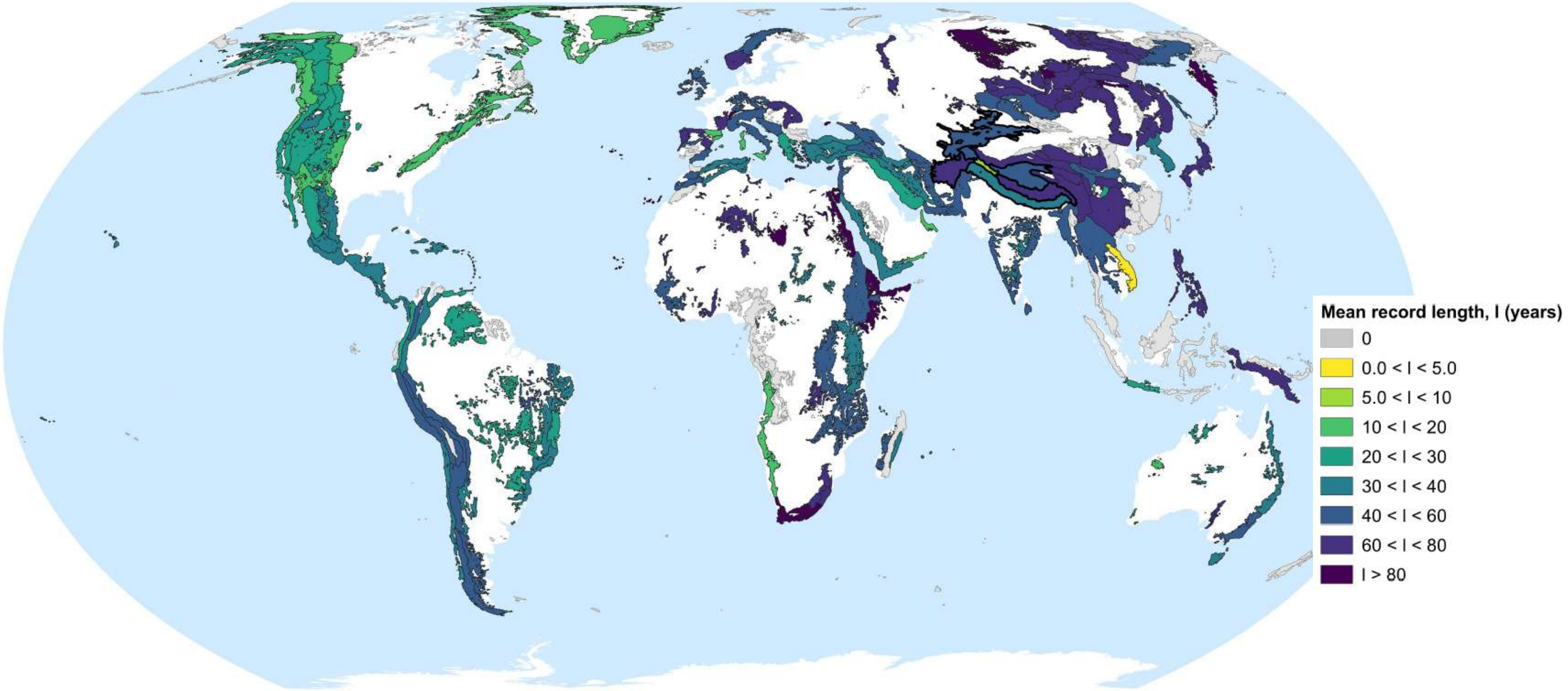
Record length: Global overview

- Mean record length by mountain range for air temperature (daily max):



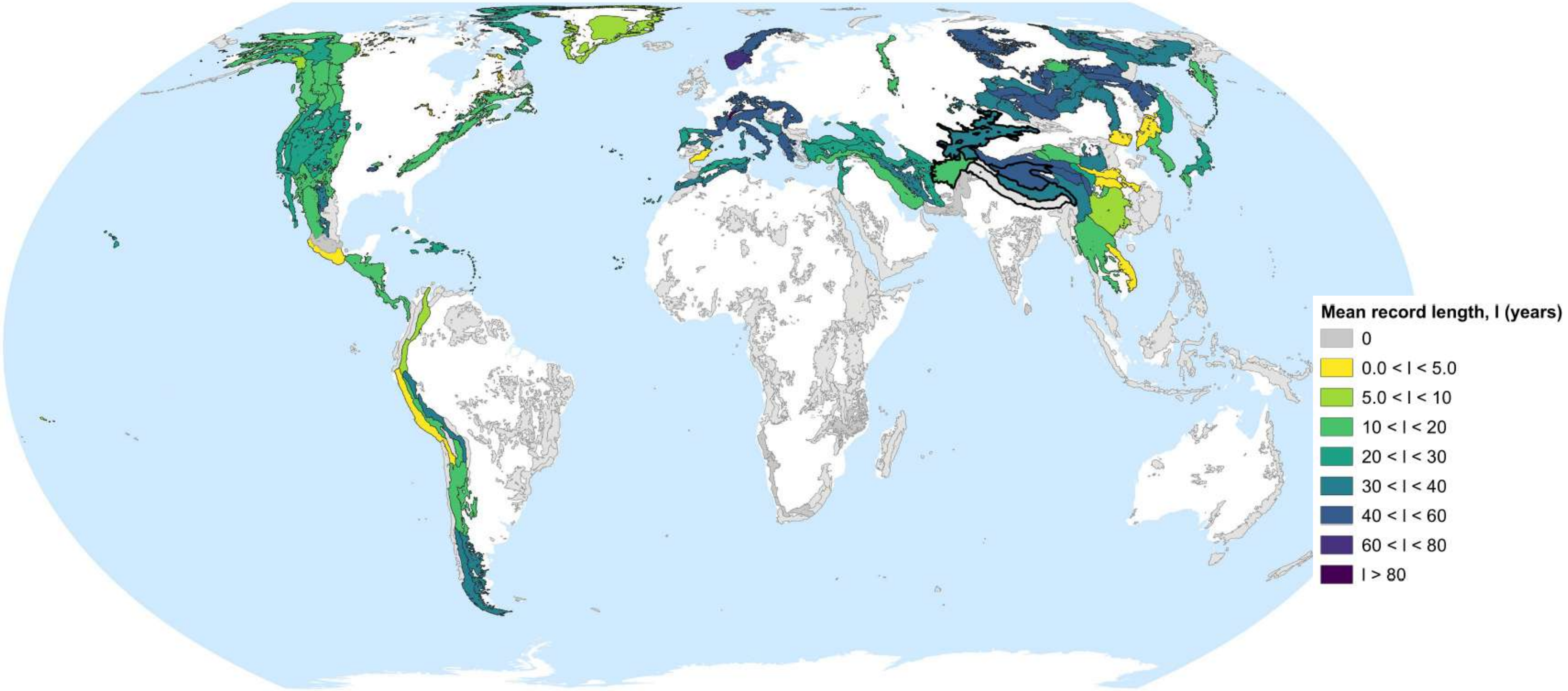
Record length: Global overview

- ❑ **Mean record length** by mountain range for **precipitation**:



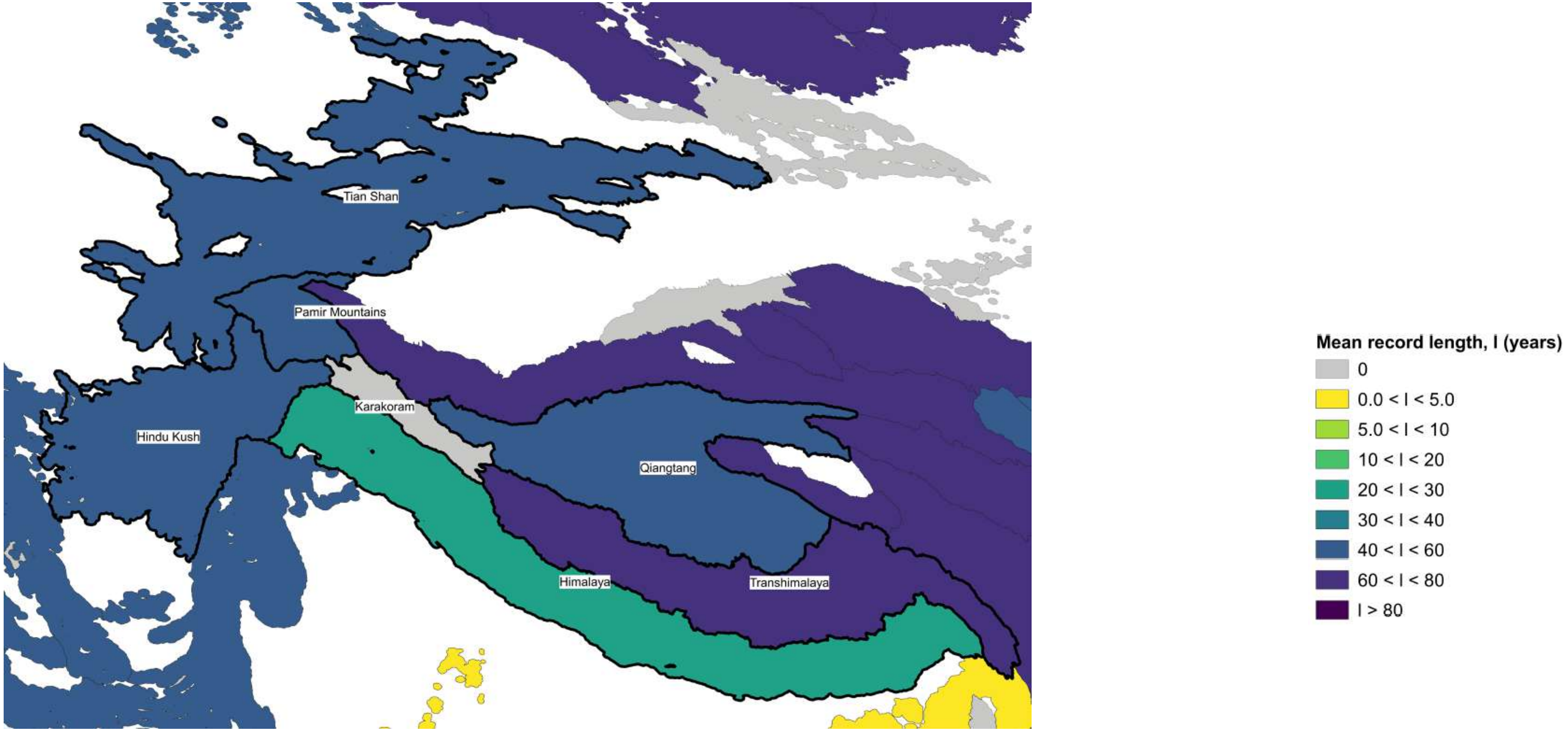
Record length: Global overview

- Mean record length by mountain range for snow depth:



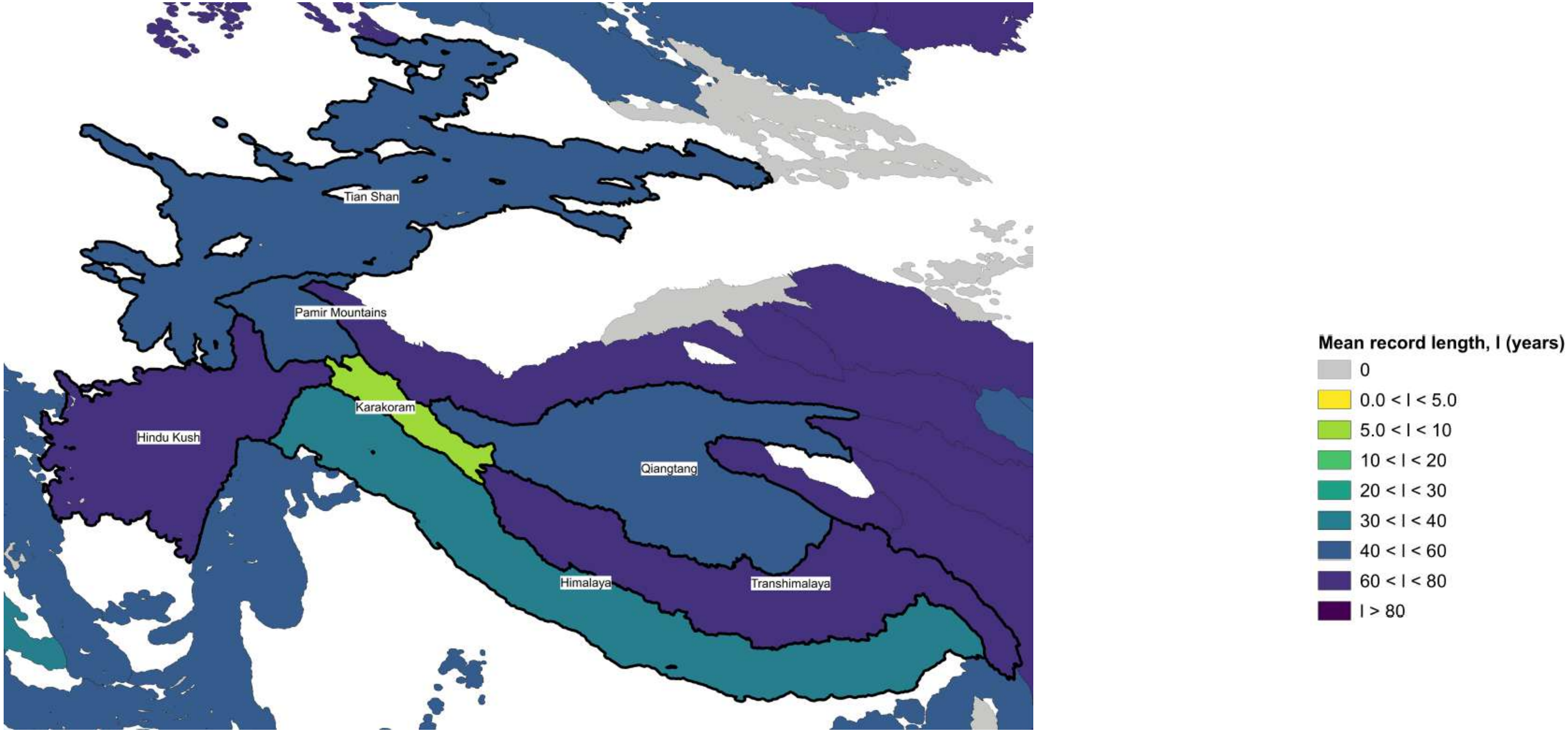
Record length: HMA

- ❑ **Mean record length** by mountain range for **air temperature** (daily max):



Record length: HMA

- Mean record length by mountain range for precipitation:



Record length: HMA

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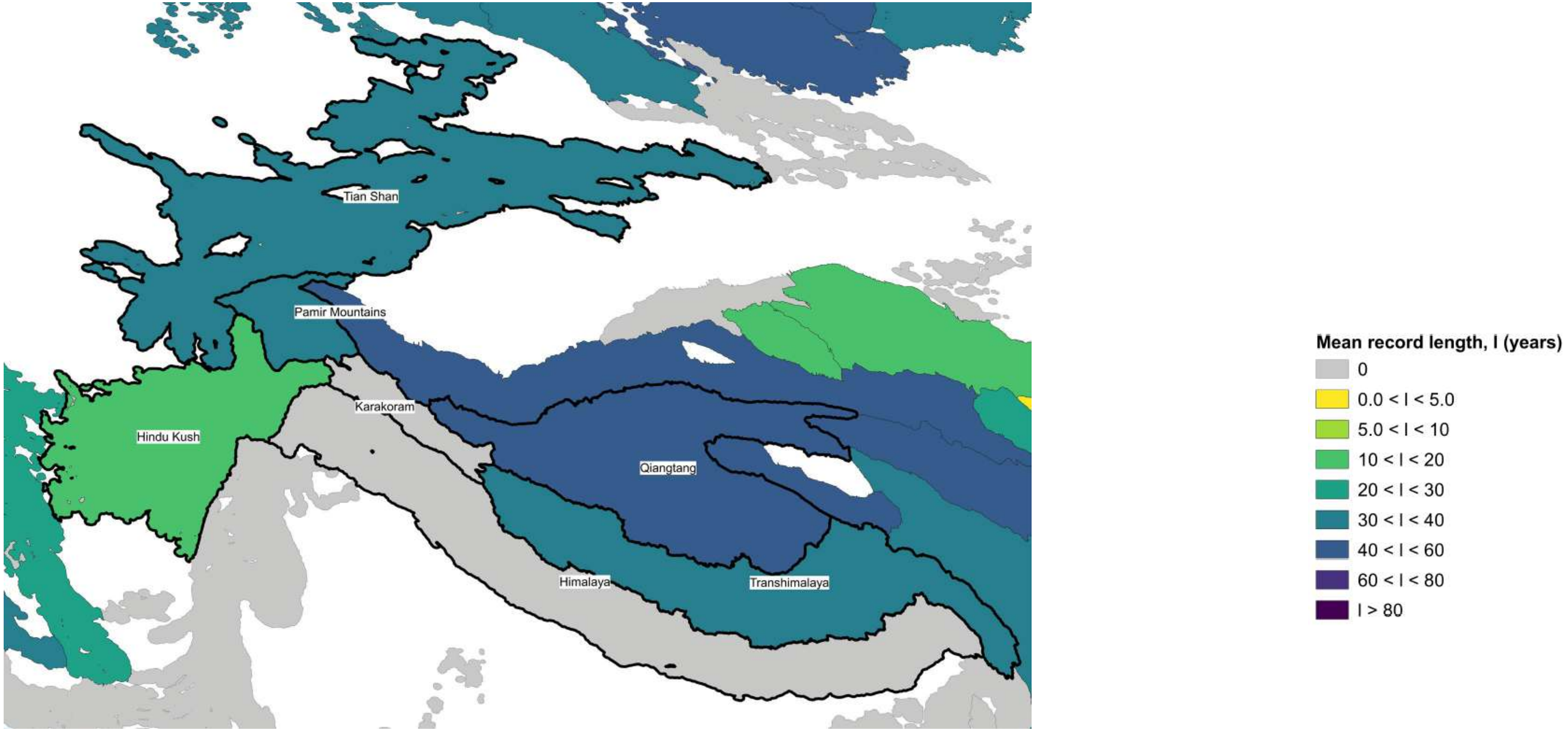
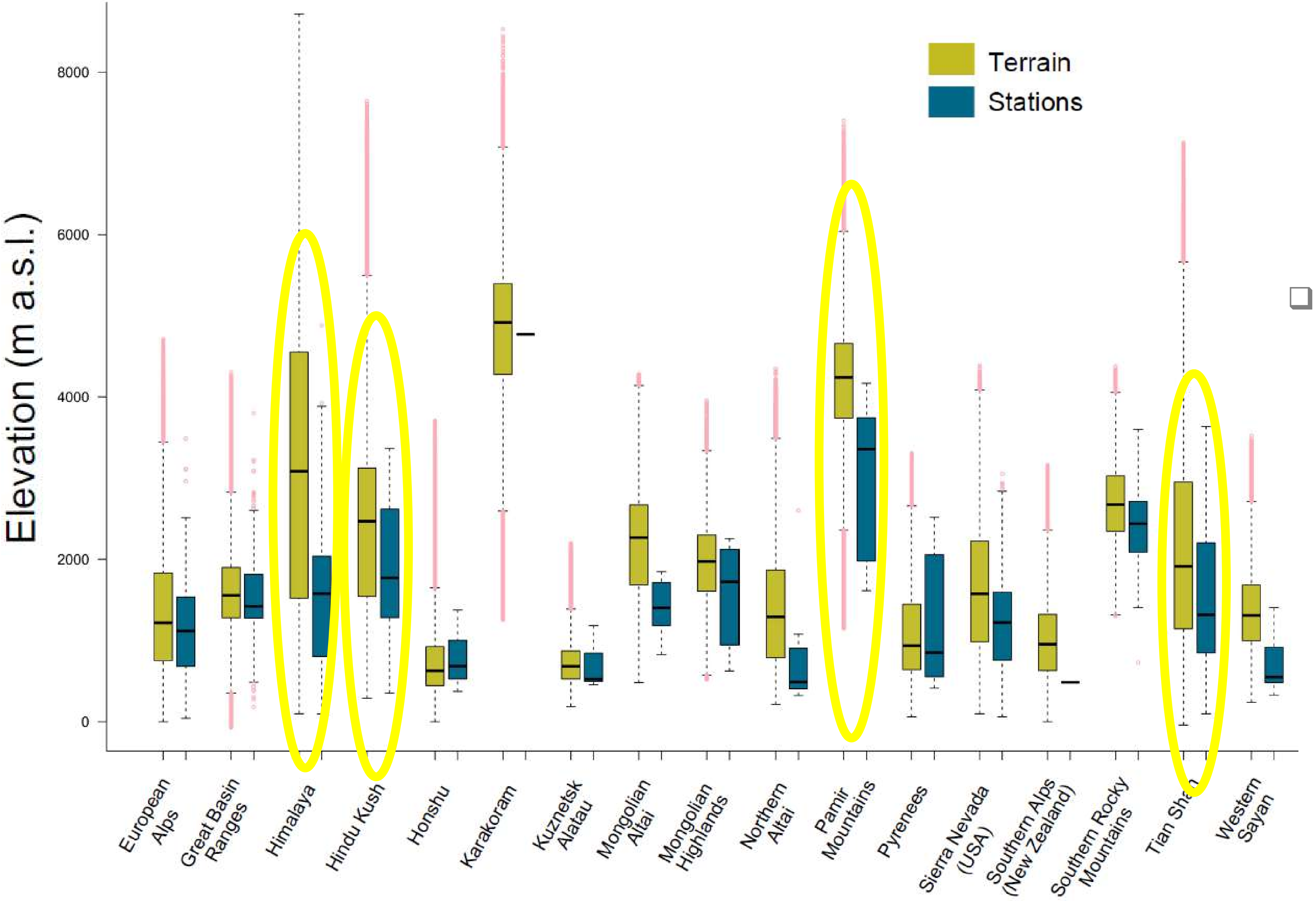
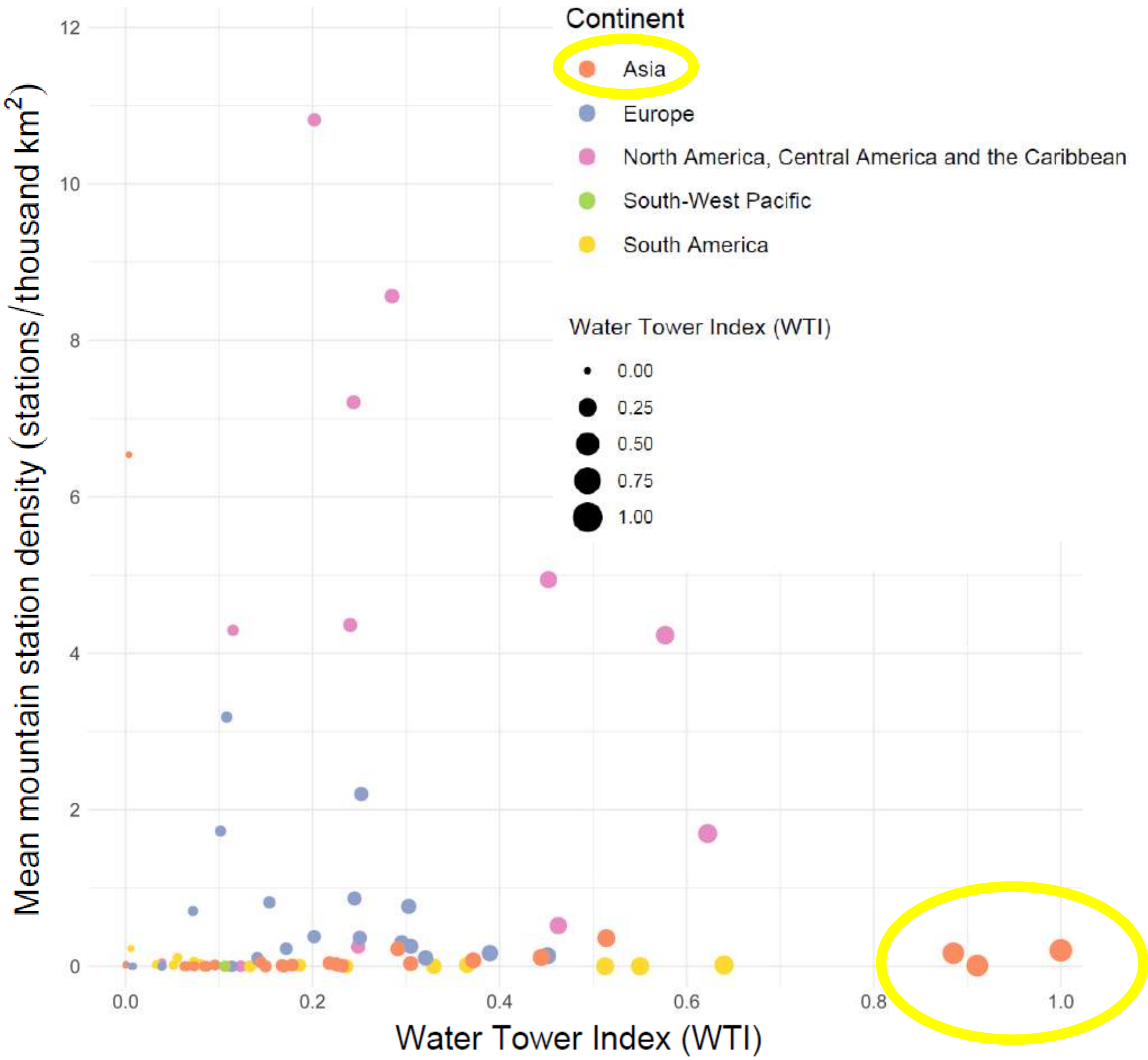


Selected results: elevational coverage



- **Elevational distribution** of **several mountain ranges** seems to be **severely under-sampled**

Water Tower Index vs. Mean station density*



*Mean station density per Water Tower Unit (WTU)

Amu Darya
Tarim Interior
Indus

GEO Mountains In Situ Inventory (v2.0)

GEO MOUNTAINS
Observing Mountain Environments

*In a **broader**, **multi-disciplinary** sense, who is measuring what, where, when, how, and why across the world's mountains?*

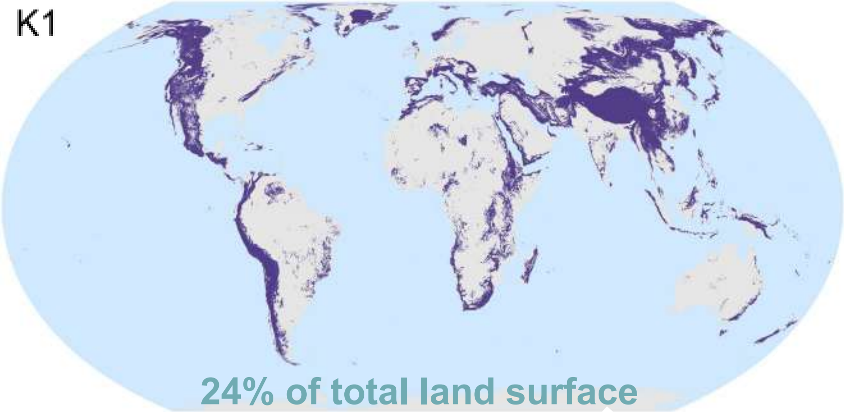
https://www.geomountains.org/resources/resources-surveys/inventory-of-in-situ-observational-infrastructure

Motivation (in brief)

- Part II: Human populations:

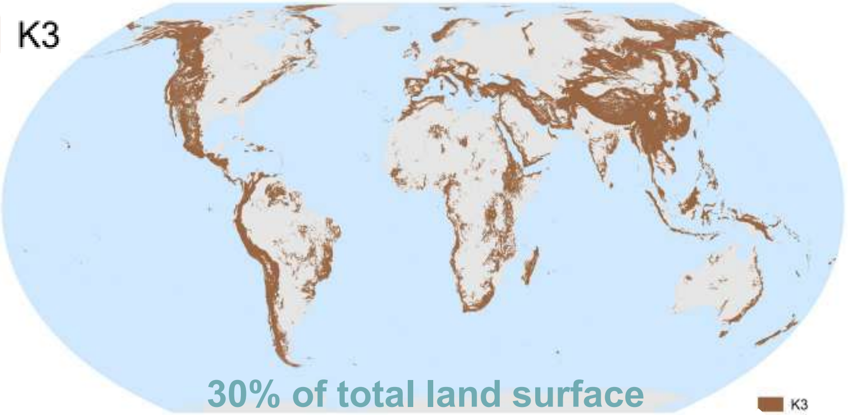
“Mountains cover X% of the global land surface and host Y million people”

K1



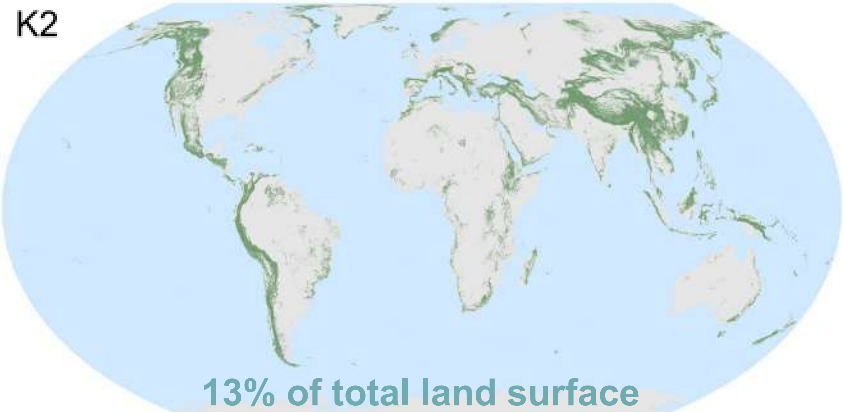
24% of total land surface

K3



30% of total land surface

K2



13% of total land surface

Objectives and data

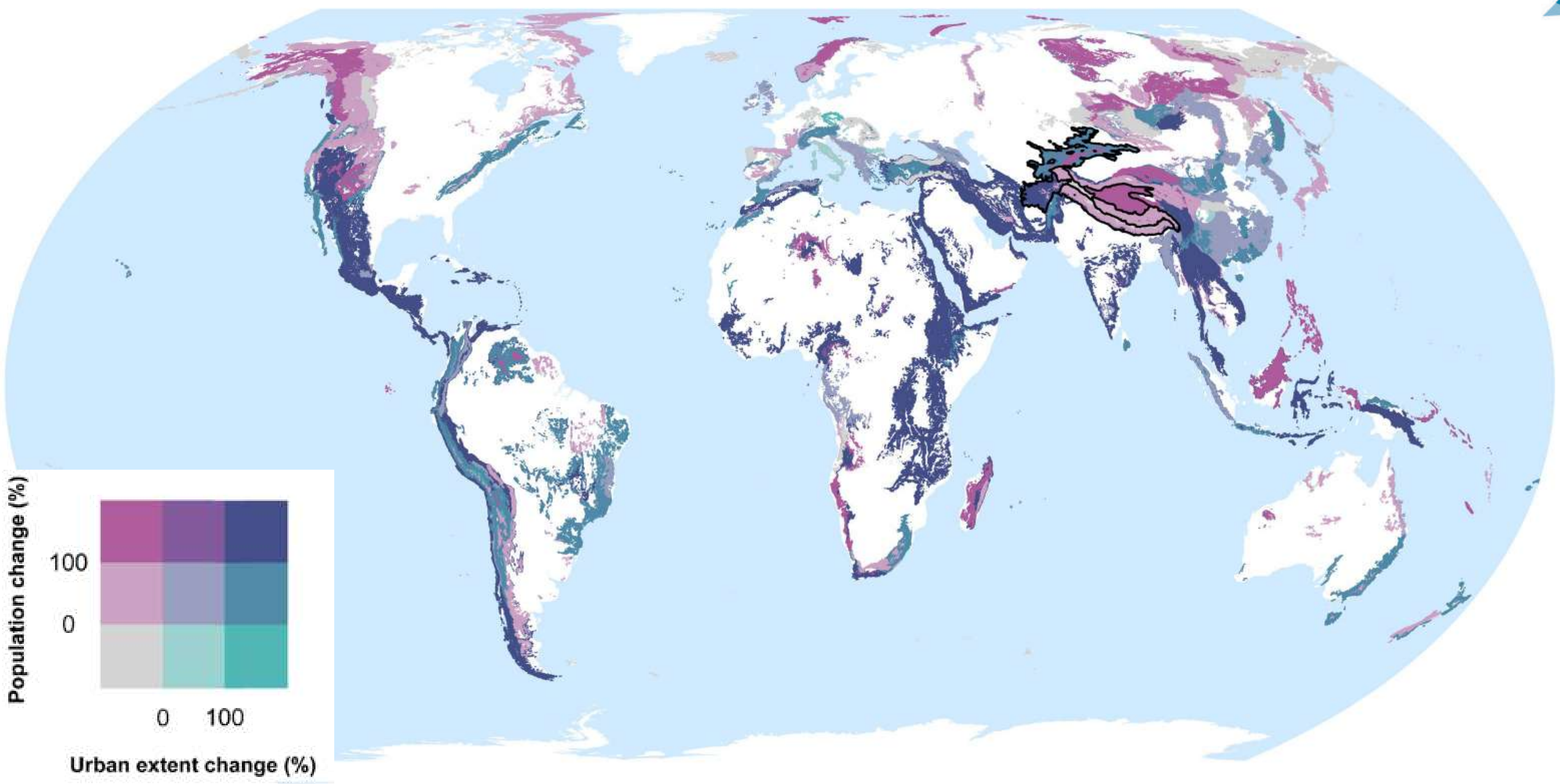
- To answer **several outstanding questions** in a **transparent** and **reproducible** fashion, e.g.:

    1. *To what extent do estimates of the global human population living in and around mountains depend on input data choices?*
    2. *How have mountain population counts and densities varied spatially and temporally over recent decades?*
    3. *How do population density estimates in mountains compare with those of their wider regions?*
    4. *Which mountainous regions are undergoing the most profound population changes?*
    5. *What proportion of the mountain population can be considered "urban", and to what extent are recent population change and urban extent change in mountains spatially related?*
    6. *To what extent are mountain population densities within individual mountain regions related to topographic, climatic, and protected-area variables, and how have these dependencies changed in time and space over recent decades?*

- A **wide variety of datasets** were applied to do this!

Population vs. urban extent change

At **“sub-mountain range-scale”** (GMBA Mountain Inventory v2), from **1975 to 2015**, according to one selected combination of population and urban extent data:



Snethladge et al. (2022), *Scientific Data*

https://ghsl.jrc.ec.europa.eu/

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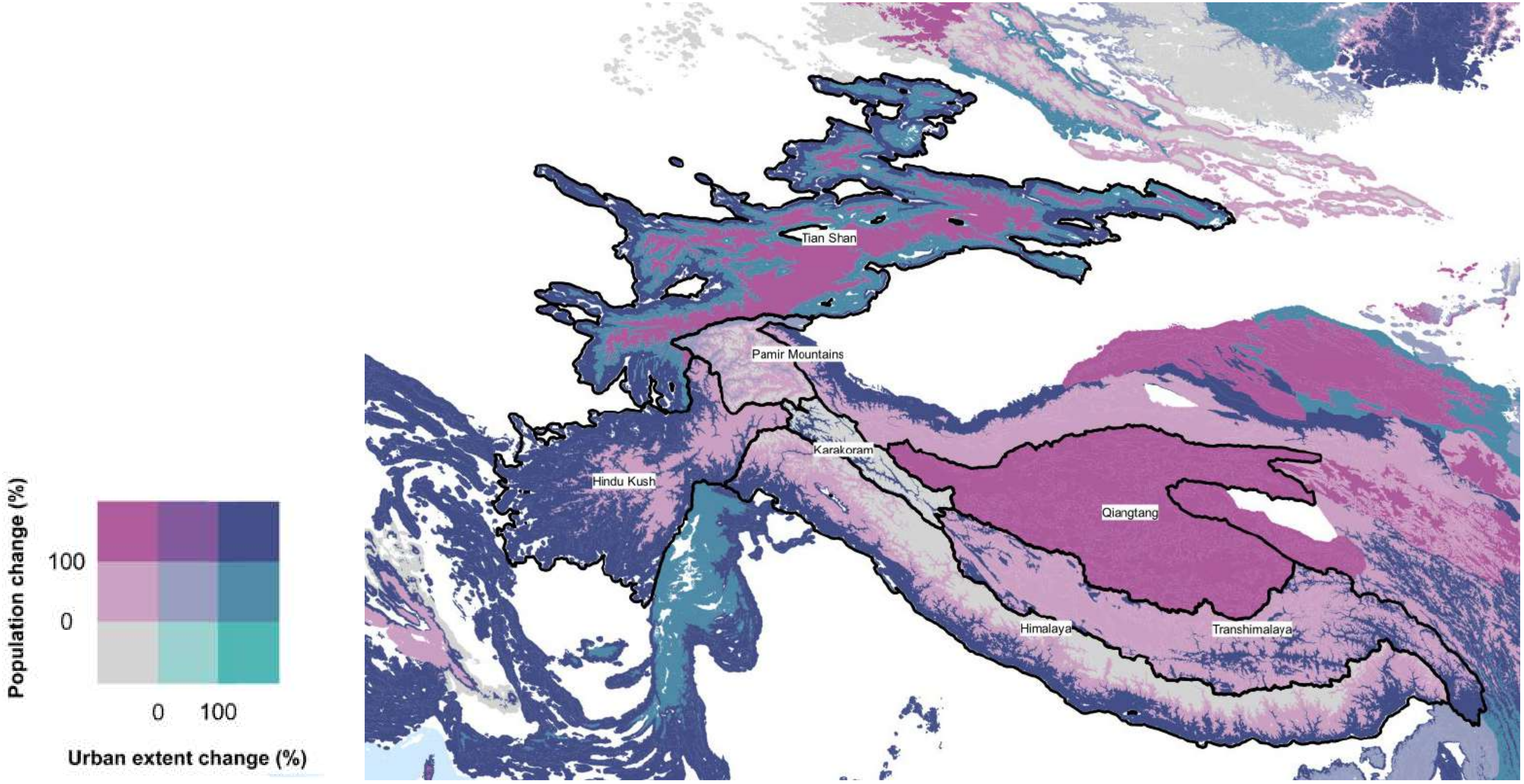


Conclusions

- We can demonstrate patterns in the coverage of easily available in situ climatological observations in HMA, not only "absolute" (spatial, temporal) but also "relative" (elevation, Water Tower Index)
    - Provides a basis for international and other organizations to better target investments and activities in fundamental climate monitoring
- Given the diversity of other (multi-disciplinary) monitoring sites, we need to continue to work together to i) better characterize their metadata (e.g. variables measured, time periods, frequencies, protocols, instrumentation etc.), and ii) try to ease access to the corresponding time-series (especially for research purposes)
- We have likewise elucidated the relationship between population and urbanization change across the region over recent decades (as well as the impact of different input dataset choices on population count and density estimates per mountain range, and associations between population densities and various environmental covariates; not shown)
- Can readily rank the HMA ranges in a global context according to these various metrics
- Open Science standards should be adhered to wherever possible

Central Asian Mountain Observatories Network (CAMON)

Network:

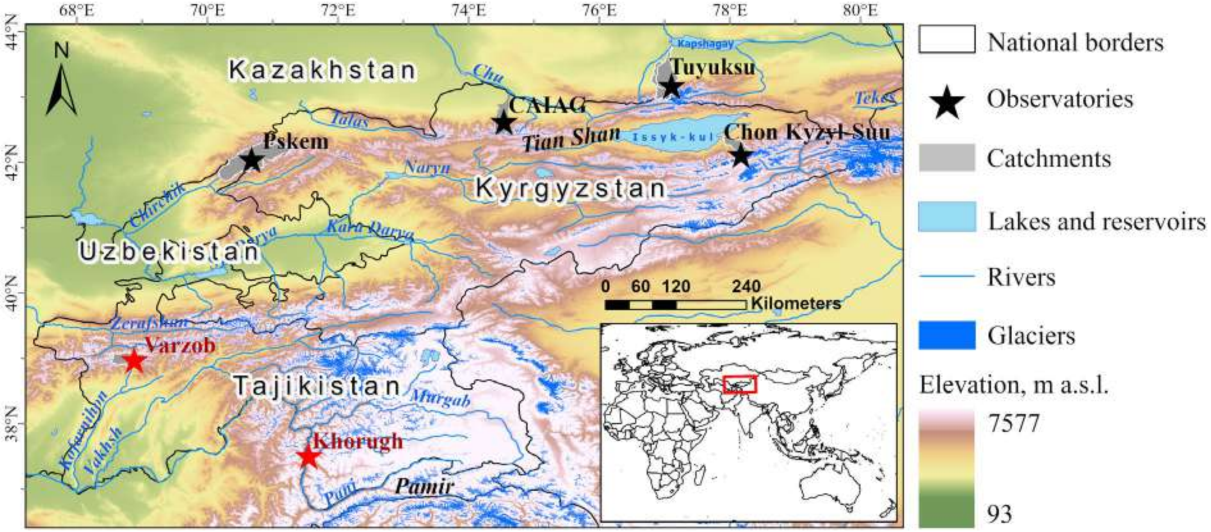
- Four sites with well established monitoring dating back to 1950s
- Two sites under development in Tajikistan

Strengths and weaknesses:

- Long-term monitoring of climate, hydrology, and state of glaciers
- Lack of socio-economic observations

Network:

- Maintain and enhance glaciological and hydro-meteorological monitoring
- Expand ecological monitoring
- Introduce socio-economic observations



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Contacts:

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Mr. Vassiliy Kapitsa, Central Asian Regional Glaciological Centre, Kazakhstan (vasil.geo@mail.ru)

GEO Mountains

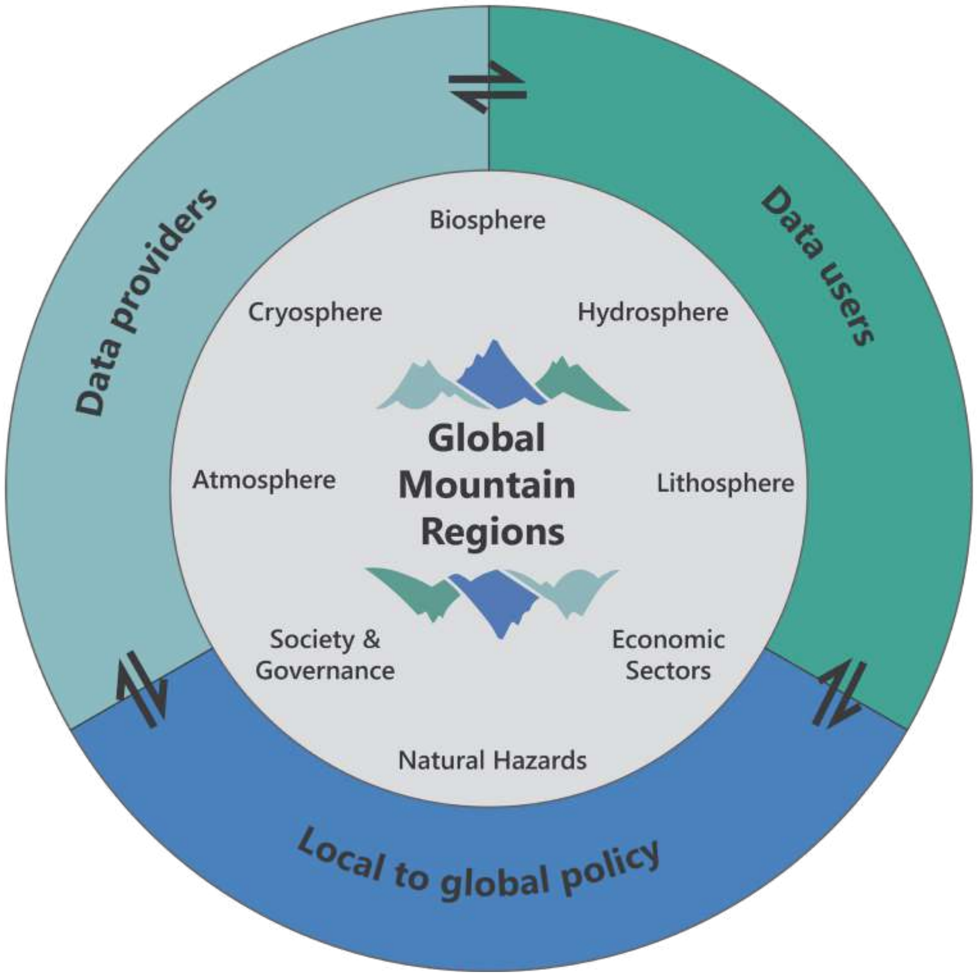
The Global Network for Observations and Information in Mountain Environments

An Initiative of the Group on Earth Observations (GEO) co-led by the Mountain Research Initiative (MRI)
& the National Research Council of Italy

Objectives:

- To increase the discoverability, accessibility, and usability of a wide range of data and information pertaining to mountains globally
- To integrate and apply such data and information for scientific, policy, and practical impact
- To build, connect, and share capacity across a community of mountain researchers, practitioners, and policy makers

All welcome!



Many thanks! Any questions?

Thornton, J. M., Pepin, N., Shahgedanova, M., & Adler, C. (2022). Coverage of in situ climatological observations in the world's mountains. *Frontiers in Climate*, 4. 10.3389/fclim.2022.814181

Thornton, J. M., Snethlage, M. A., Sayre, R., Urbach, D. R., Viviroli, D., Ehrlich, D., ... & Adler, C. (2022). Human populations in the world's mountains: Spatio-temporal patterns and potential controls. *PLOS ONE, 17*. 10.1371/journal.pone.0271466

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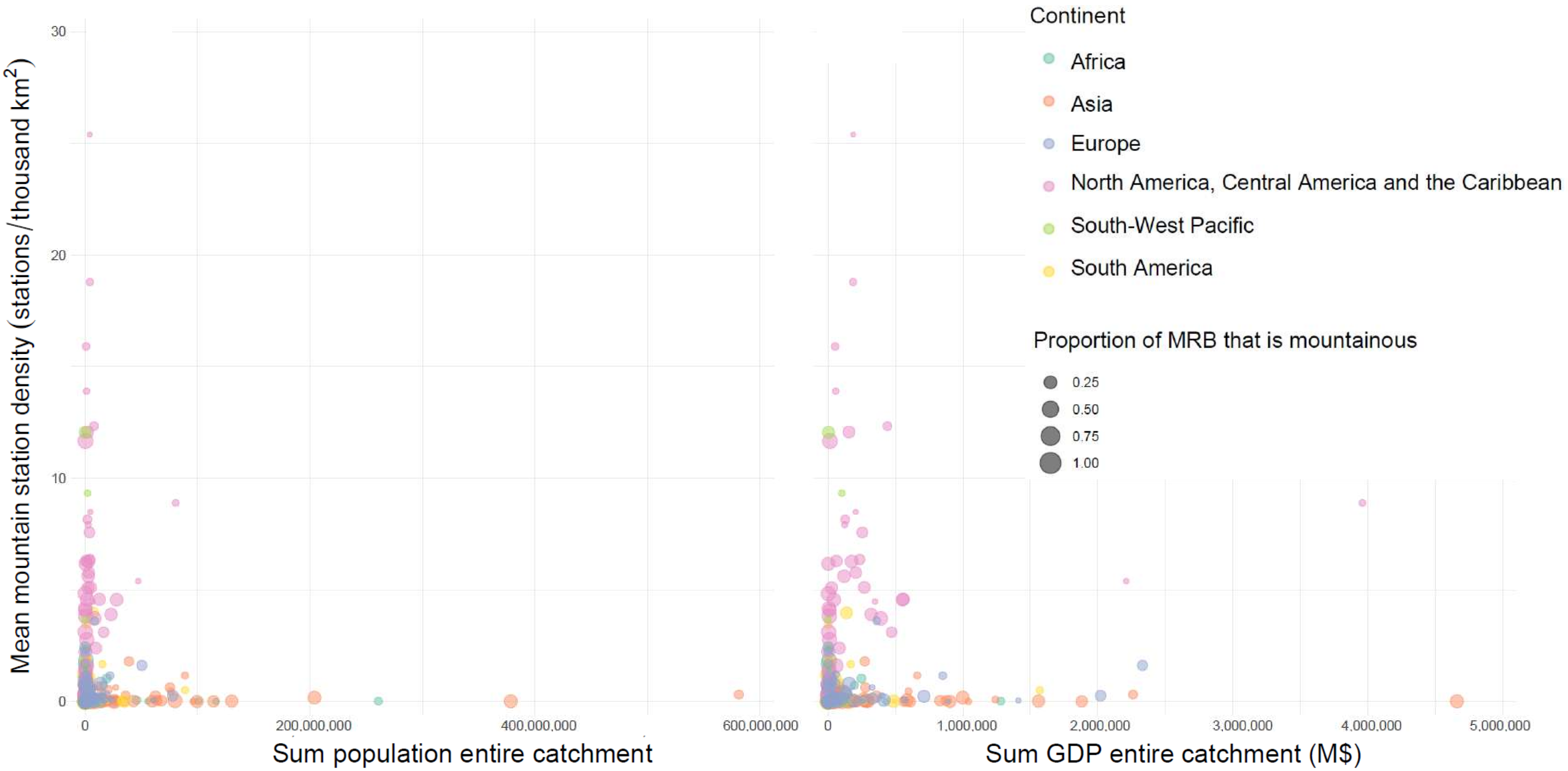
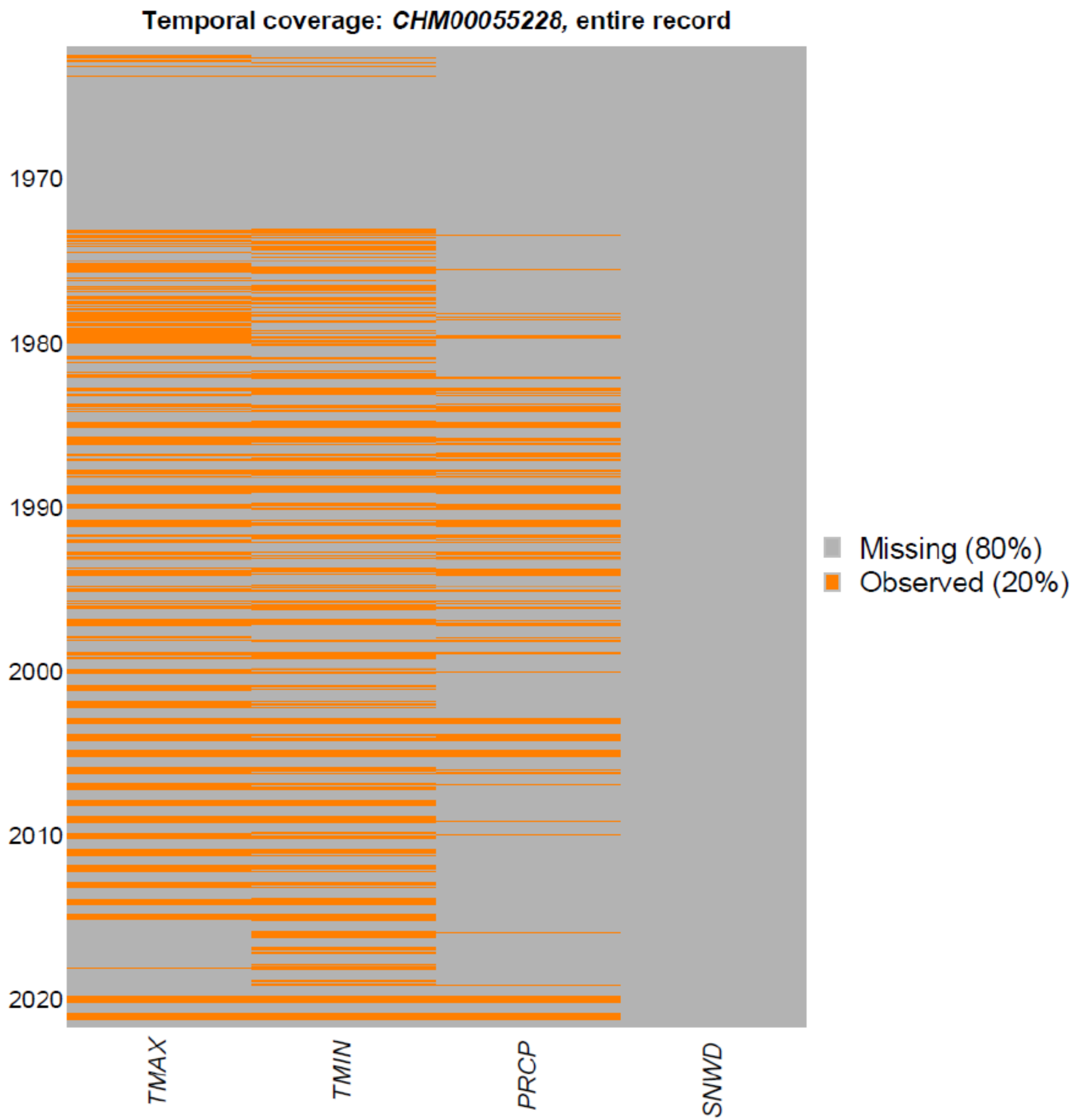
Spatial density vs. population and GDP



Detailed temporal coverage and quality information

- ❑ **R script** provided in online Supplementary Material
- ❑ Works on **any GHCNd station** (potentially useful beyond mountains)
  - ❑ e.g. **Temporal coverage**, all variables at a given station:



Detailed temporal coverage and quality information

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  - e.g. **Quality flag distribution** for a given variable at a given station: