# On the Synergistic Climatic Effects of Covarying Major Mountain Range Topographies

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# Key Points

- **Covarying major mountain range topography leads to synergistic climatic effects/non-linear changes in regional climate.**
- **Reducing the height of Himalaya-Tibet has little effect on Andean climate; Reducing the height of the Andes has significant effects on the climate in Himalaya-Tibet, esp. when Himalaya-Tibet is above 50%-75% of its modern height.**
- **The palaeotopography of the Andes ought to be considered as a contributor of climate change in palaeoclimate or palaeoaltimetry studies of Himalaya-Tibet.**

# Summary

The interpretation of Earth surface archives often requires consideration of distant off-site events. One such event is the surface uplift of Earth's major mountain ranges, which affects climate and the Earth's surface globally. In this study, the individual and synergistic climatic effects of topographic changes in major mountain ranges are explored with a series of General Circulation Model (GCM) experiments and analyses of atmospheric teleconnections. The GCM experiments are forced with different topographic scenarios for Himalaya-Tibet (TBT) and the Andes (ADS), while environmental boundary conditions are kept constant. The topographic scenarios are constructed by successively lowering modern topography to 0% of its modern height in increments of 25%. This results in a total of 5 topographic scenarios for TBT (tbt100, tbt075, tbt050, tbt025, tbt000) and ADS (ads100, ads075, ads050, ads025, ads000). TBT scenarios are then nested in ADS scenarios, resulting in a total of 25 experiments with unique topographic settings. The climate for each of those 25 scenarios is simulated with the GCM ECHAM5-wiso. We then explore possible synergies and distant impacts of topographic changes by testing the hypothesis that varying ADS has no effect on simulated climate conditions in the TBT region (c_tbt) and vice versa. This can be expressed as the null hypothesis c_tbt(ads100) = c_tbt(ads075) = c_tbt(ads050) = c_tbt(ads025) = c_tbt(ads000) for each of the 5 TBT scenarios, and vice versa. We conduct Kruskal-Wallis tests for a total of 10 treatment sets to address these hypotheses. The results suggest that ADS climate is mostly independent of TBT topography changes, whereas TBT climate is sensitive to ADS topography changes when TBT topography is high, but insensitive when TBT topography is strongly reduced. Analyses of atmospheric pressure fields suggest that TBT height acts as a control on cross-equatorial atmospheric processes and modifies the impact of ADS topography on northern hemisphere climate. These results dictate a more careful consideration of global (off-site) conditions in the interpretation of Earth surface records.

# Problem

Topographies of major mountain ranges influence both local and global climate, which impacts the interpretation of various geological Earth surface archives. In this study we address the questions:

- **What is the magnitude of climate change (on- and off-site) cause by covarying major mountain range topographies, specifically the Andes and Himalaya/Tibet?**
- **Can non-linearities and synergistic climatic responses be detected as mountain range topographies are covaried?**

# Method: GCM Topography Experiments

## Generalised Circulation Model (GCM) Topography Experiments:

- 5 **Andes (ads)** topographic scenarios (100%,75%,50%,25%,0%)
- 5 **Himalaya/Tibet (tbt)** topographic scenarios (100%,75%,50%,25%,0%)
- nested scenarios (covarying mountain ranges) => 25 experiments

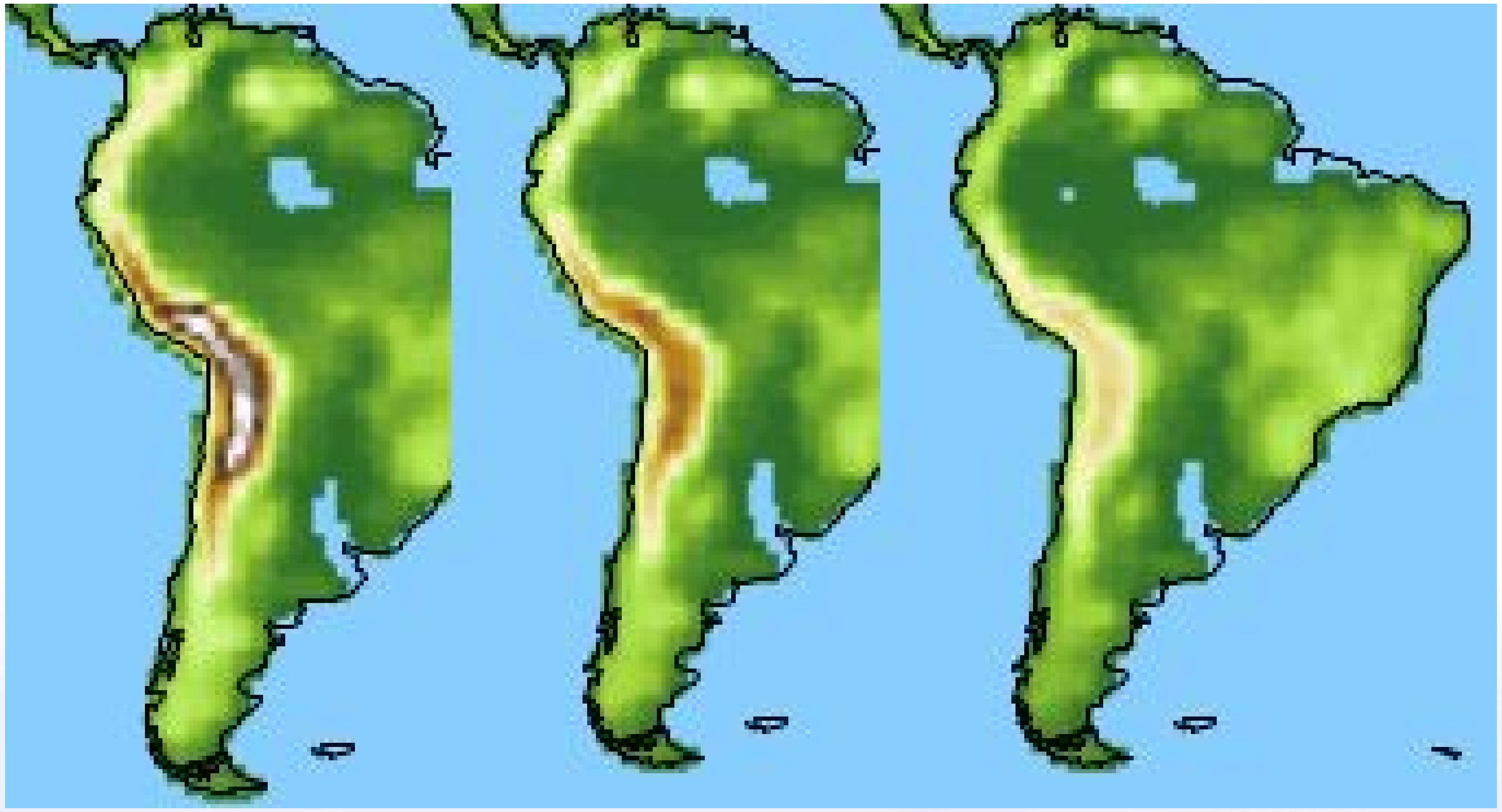

Fig. 1 Example configurations of topography for the Andes as used in the GCM as topographic forcing: A-1.0, A-0.75 and A-0.25 (l.-r.) correspond to 100%, 75% and 25% of the modern height of the Andes respectively.

# Method: Regional Climate Responses

**Regional climates c(ads) and c(tbt)** are assessed by variables (separately):

1. 2m air temperature (t-2m)
2. Precipitation (prec)
3. Near surface zonal wind speeds (u10m)
4. Near surface meridional wind speeds (v10m)
5. $\delta^{18}O$ in precipitation ($\delta^{18}O$)

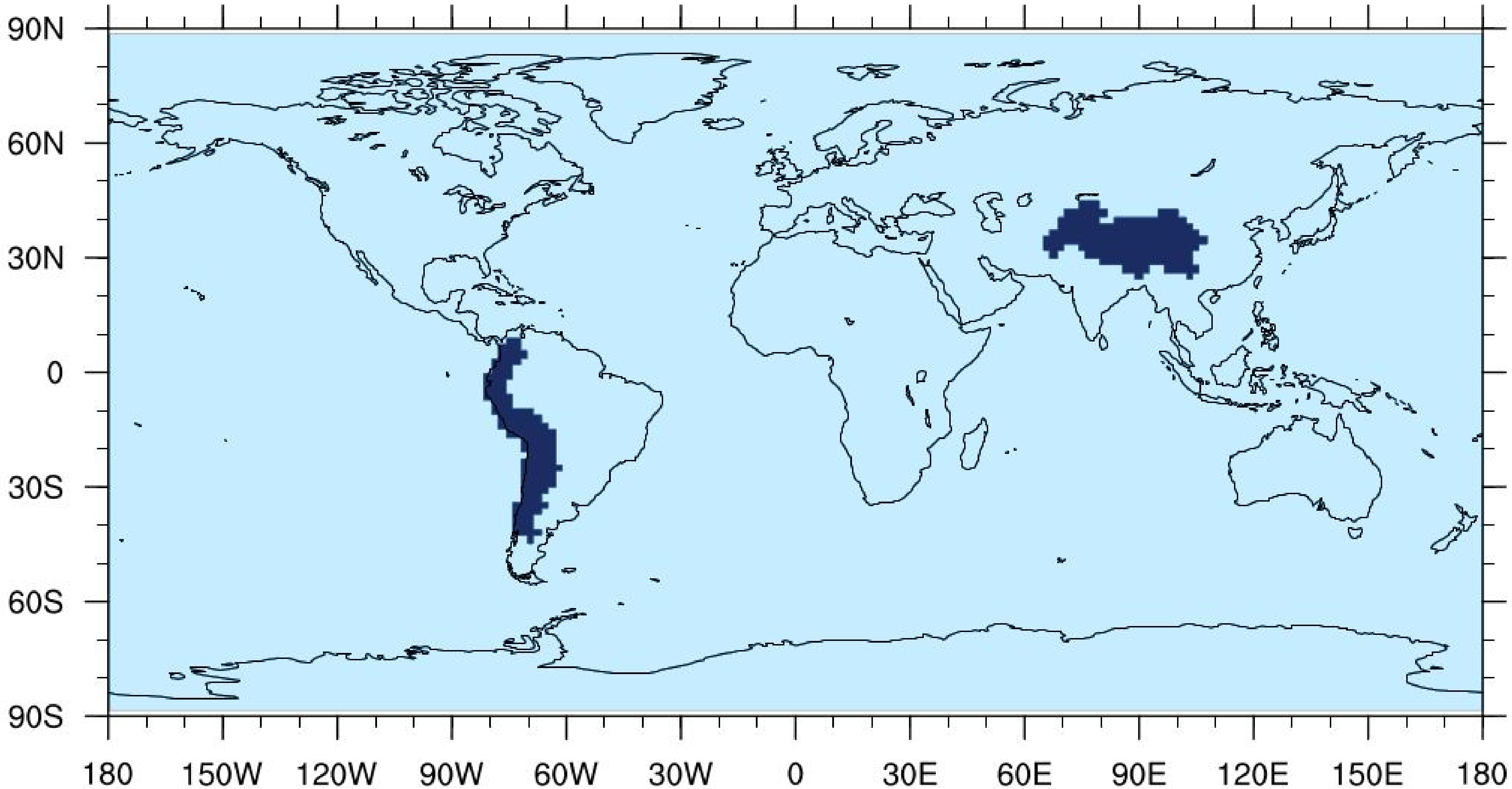


Fig. 2 Altitude-based masks that define regional boundaries for climate change assessment.

# Method: Regional Climate Responses

**For each Andes scenario ("treatment sets"):**

$H_0 = c(ads)_{tbt100} = c(ads)_{tbt075} = c(ads)_{tbt050} = c(ads)_{tbt025} = c(ads)_{tbt000}$

**For each Himalaya/Tibet scenario ("treatment sets"):**

$H_0 = c(tbt)_{ads100} = c(tbt)_{ads075} = c(tbt)_{ads050} = c(tbt)_{ads025} = c(tbt)_{ads000}$

=> Kruskall Wallis tests per grid box

=> **sensitivity to $\Delta H_{(ads/tbt)}$** = no. of rejected hypotheses in region

# Results: Climate Sensitivity Index

**For each Andes scenario:**

$H_0 = c(ads)_{tbt100} = c(ads)_{tbt075} = c(ads)_{tbt050} = c(ads)_{tbt025} = c(ads)_{tbt000}$

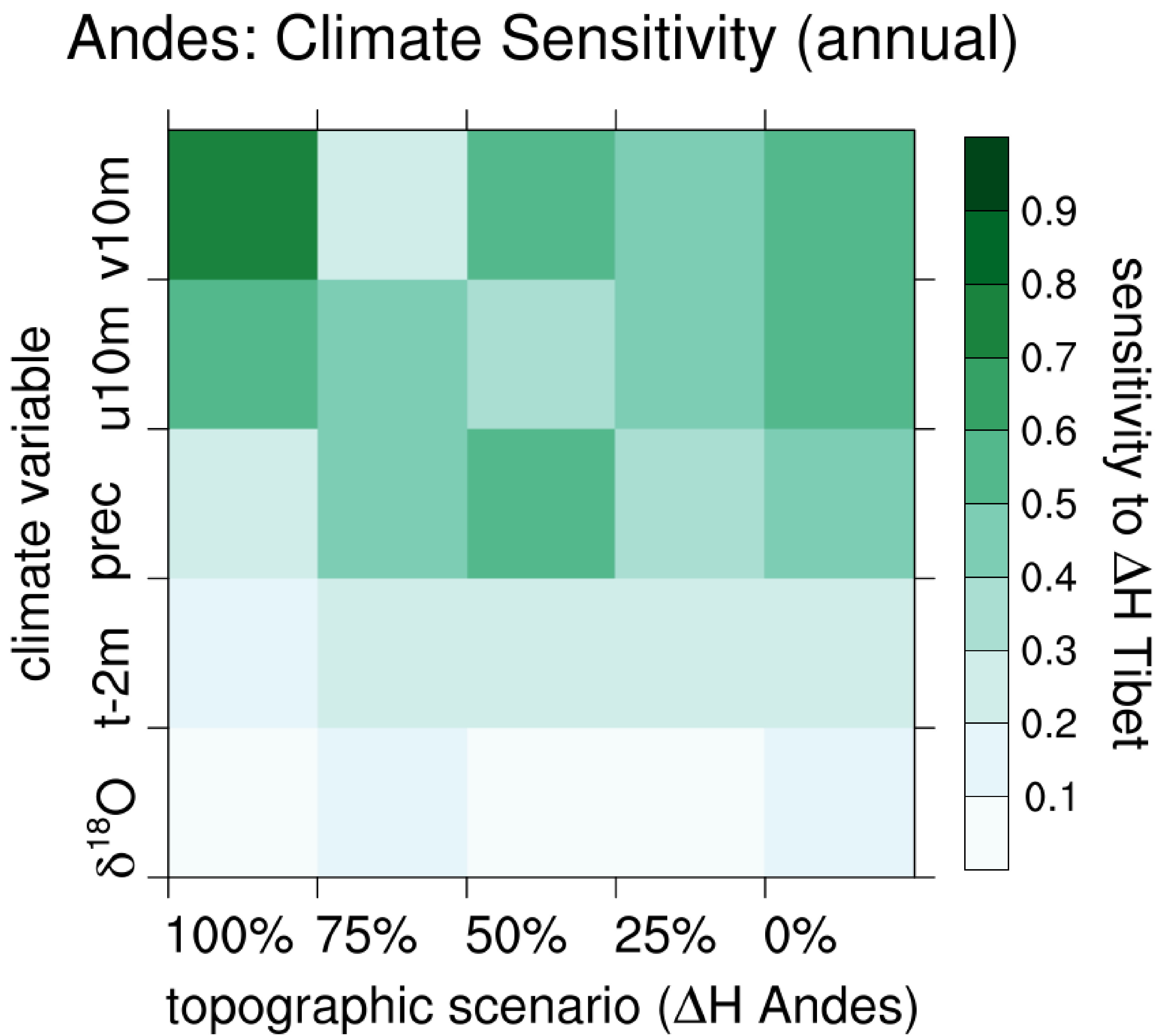


Fig. 3 The KW-test based index values for the sensitivity of Andean climate to changes in Himalaya/Tibet topography are relatively low for virtually all topographic scenarios of the Andes (x-axis) and variables (y-axis).
This suggests that altitude changes in the Himalaya-Tibet region have little or no effect on Andean climate, no matter the altitude of the Andes.

# Results: Climate Sensitivity Index

**For each Himalaya/Tibet scenario:**

$H_0 = c(tbt)_{ads100} = c(tbt)_{ads075} = c(tbt)_{ads050} = c(tbt)_{ads025} = c(tbt)_{ads000}$

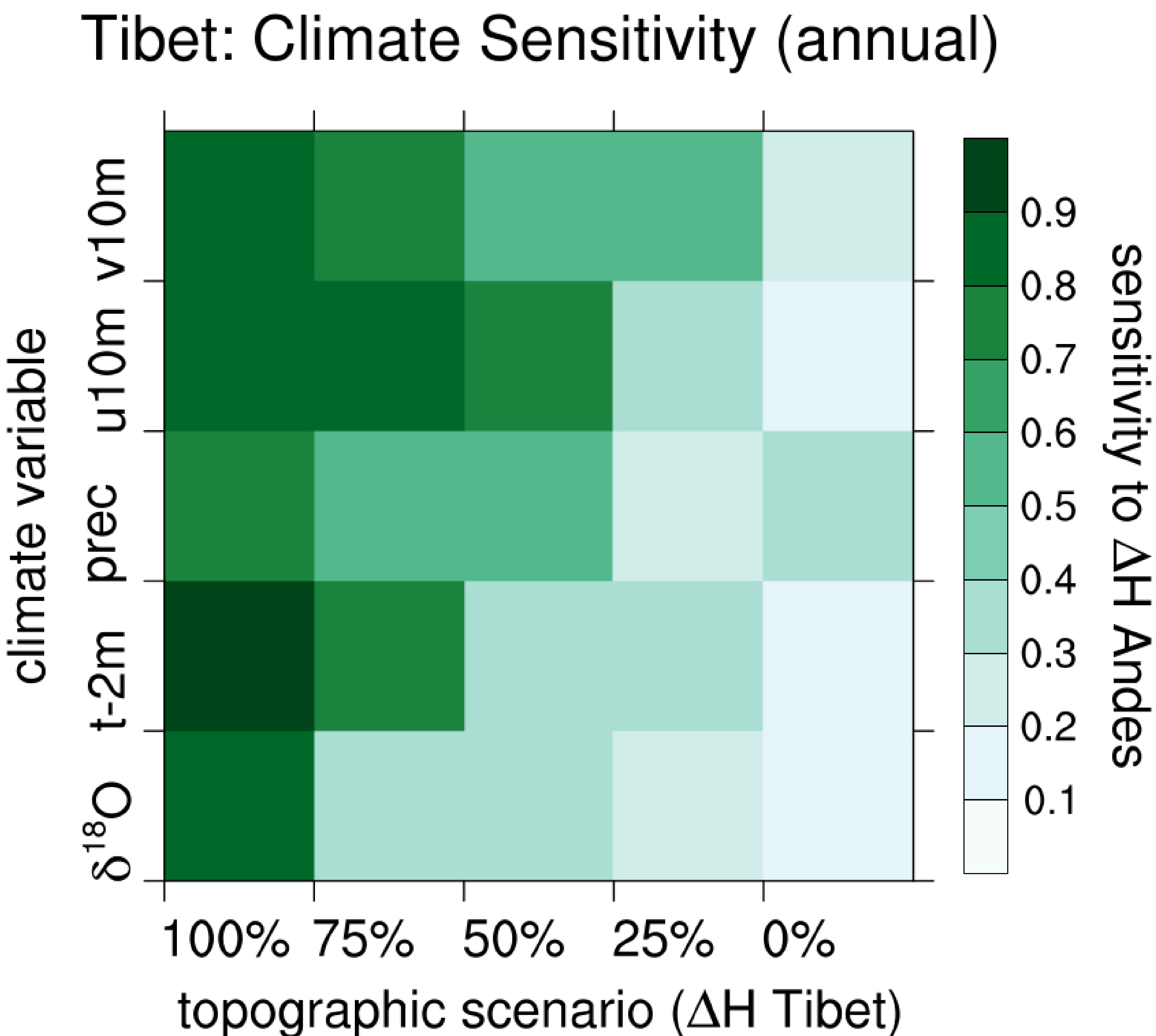


Fig. 4 The KW-test based index values for the sensitivity of Himalaya/Tibet climate to changes in Andean topography are relatively low for low-altitude scenarios of Himalaya/Tibet and high for high altitude scenarios of Himalaya/Tibet.
This suggests that altitude changes in the Andes have little or no effect on Himalaya/Tibet climate when Himalaya/Tibet is low, but a significant effect when Himalaya/Tibet is high.

# Results: Difference Maps

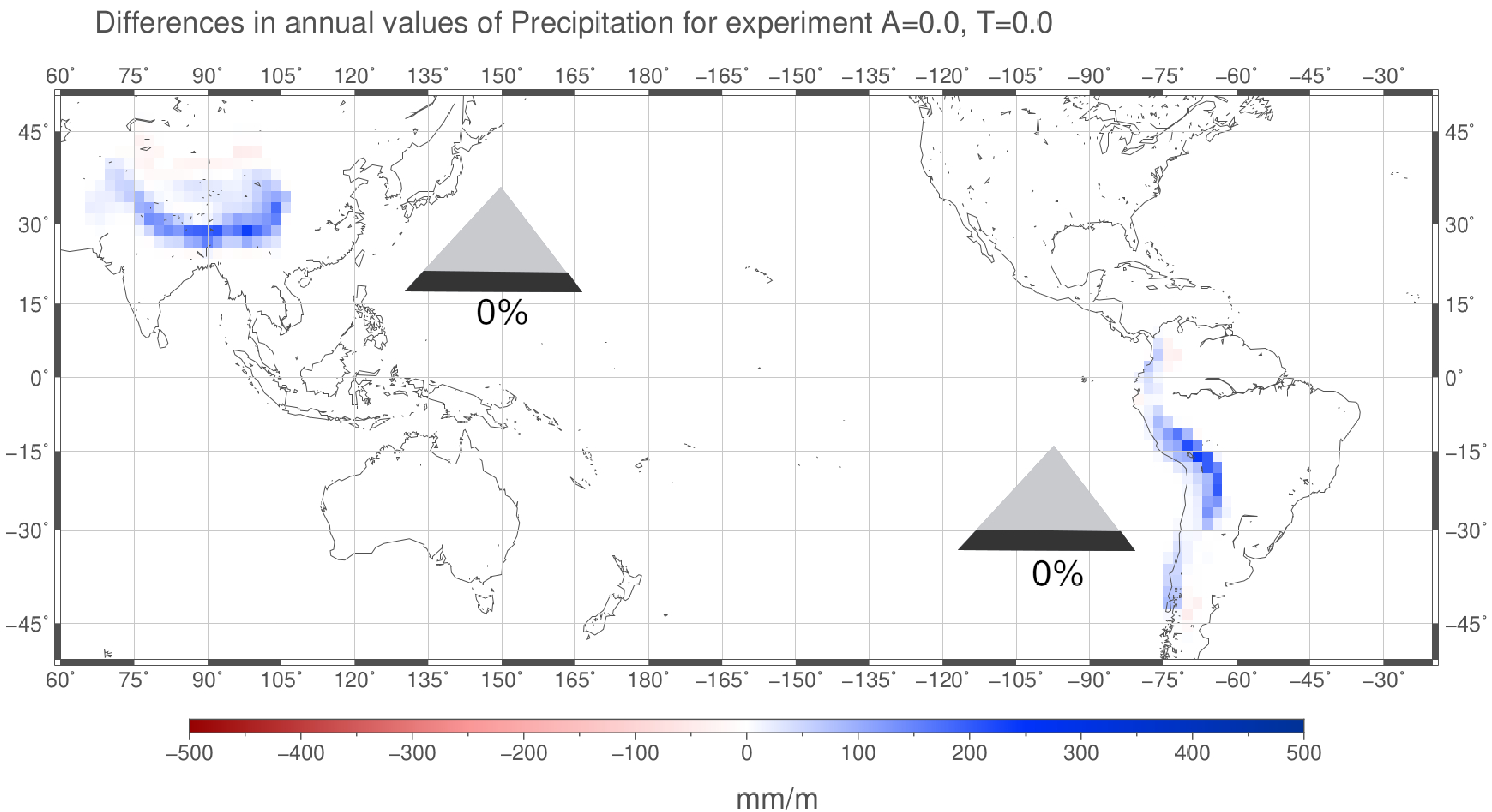


Fig. 5 The precipitation difference is calculated by subtracting simulation output for the shown topographic scenario (A=0.0, T=0.0) from the reference simulation (full topography).

# Results: Difference Maps

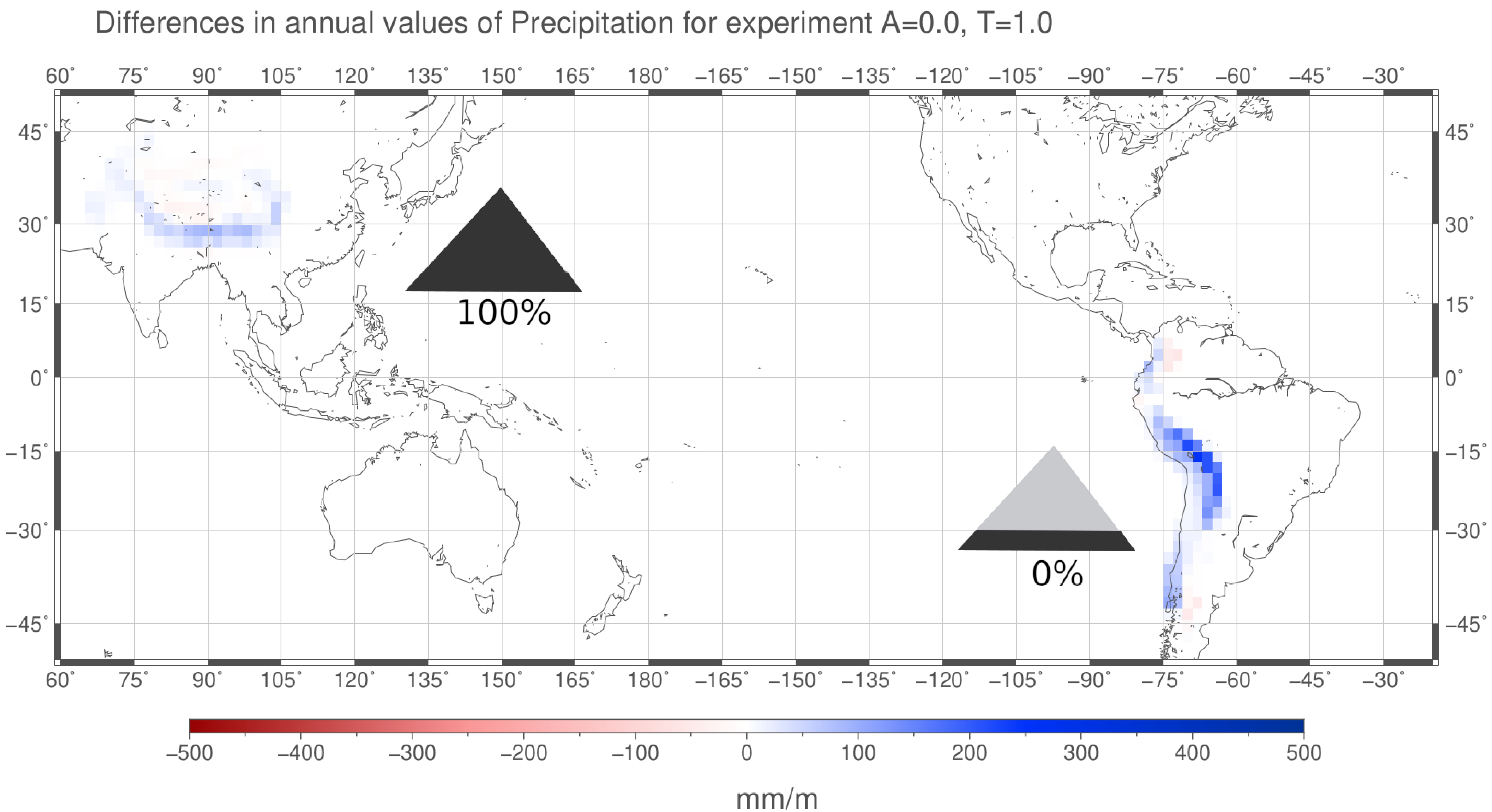


Fig. 6 The precipitation difference is calculated by subtracting simulation output for the shown topographic scenario (A=0.0, T=1.0) from the reference simulation (full topography). Removing the Andes reduces precipitation in Himalaya/Tibet by up to ca. 100 mm/m.

# Results: Difference Maps

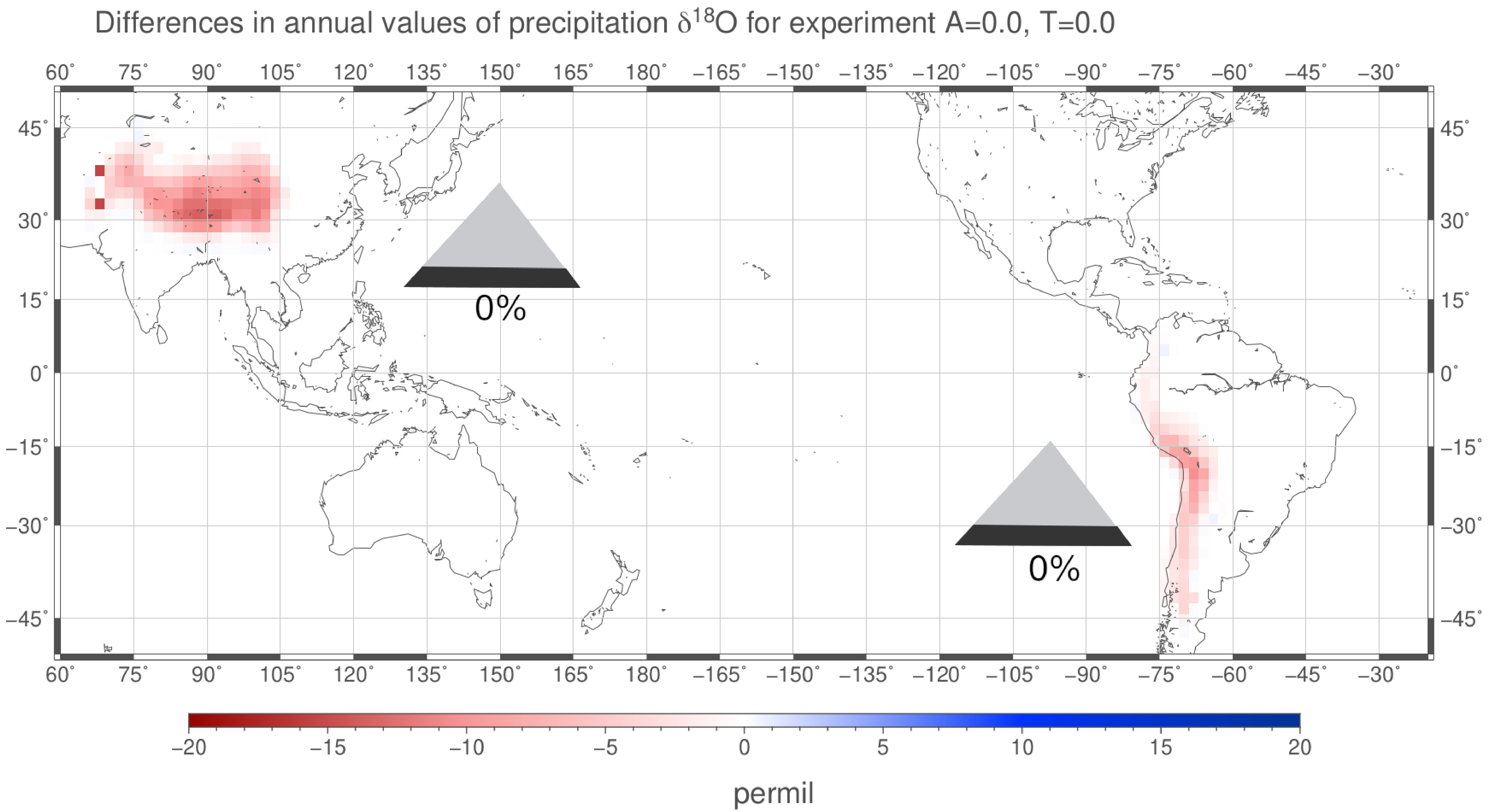


Fig. 7 The precipitation $\delta^{18}O$ difference is calculated by subtracting simulation output for the shown topographic scenario (A=0.0, T=0.0) from the reference simulation (full topography).

# Results: Difference Maps

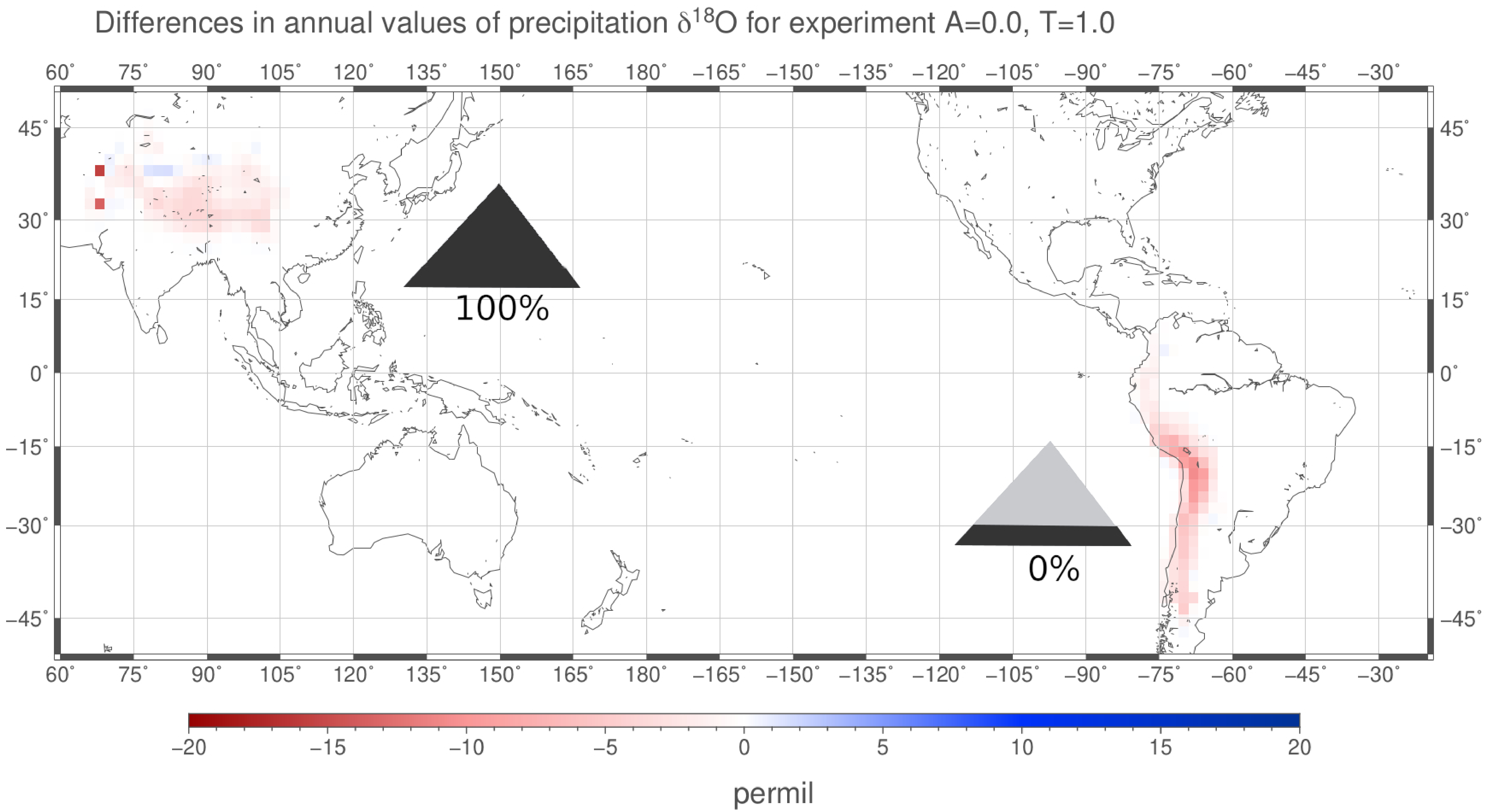


Fig. 8 The precipitation $\delta^{18}O$ difference is calculated by subtracting simulation output for the shown topographic scenario (A=0.0, T=1.0) from the reference simulation (full topography). Removing the Andes reduces precipitation $\delta^{18}O$ in Himalaya/Tibet by up to ca. 4 permil.

# Take Away

- Covarying major mountain range topography leads to synergistic climatic effects/non-linear changes in regional climate.
- Reducing the height of Himalaya-Tibet has little effect on Andean climate; Reducing the height of the Andes has significant effects on the climate in Himalaya-Tibet, esp. when Himalaya-Tibet is above 50%-75% of its modern height.
- The palaeotopography of the Andes ought to be considered as a contributor of climate change in palaeoclimate or palaeoaltimetry studies of Himalaya-Tibet.

# Outlook

**Investigation of mechanisms**: Preliminary analyses of simulated pressure fields suggest the relevance of the Eurasian Wave Train and the role of Asian topography on it.