Elevation-dependent warming in European mountains and its possible causes

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Motivation

Warming at high elevations is faster in comparison with surrounding lowlands in the world's highest mountains (Himalaya, Andes, Rocky Mountains). In Europe, enhanced warming with increasing elevation was documented only for spring in specific regions of the Alps. The aim of this contribution is to detect the existence of the relationship between temperature trends and elevation in different mountain regions in Europe and describe the mechanism of the relationship via changes in atmospheric circulation and sunshine duration.

Data and methods

- Period 1981-2010
- 6 regions: the Alps, Spain, Norway, Central Europe, Black Sea region, Slovenia and Croatia
- The trend magnitude was estimated with linear regression using the method of least squares; the statistical significance of trends was tested by the non-parametric Mann-Kendall trend test
- Causes of elevation-dependent temperature trends were studied in detail in selected parts of the year in the individual regions

Temperature trends:

- Daily maximum and minimum temperature (TX and TN, respectively)
- 86 stations from ECA&D representing different elevations (see **Fig. 1**)
- Annual course of trends is based on trends of 30-day sliding seasons shifting during the year with a step of 1 day (see **Fig. 2**)

Circulation indices:

- Daily sea-level pressure from NCEP/NCAR reanalysis
- Circulation indices computed for individual regions (**Fig. 5**) are: flow direction, flow strength, and vorticity (based on the Jenkinson-Collison method)
- Histograms of the circulation indices are shown in **Figs. 4, 8, 9** for three decades: 1981-1990, 1991-2000, and 2001-2010

Sunshine characteristics:

- Daily sunshine duration (SS) available at 60 % of stations

i) trends of sunshine duration
ii) trends of the number of sunny and overcast days (defined as days with more than 80% or less than 20% of maximum sunshine duration for the selected day) (**Fig. 3, 6, 7**)

Snow characteristisc:

- snow depth (SD) available at 50% of stations
- trends of the number of days with snow cover (SD≥2cm) (**Fig. 3, 6, 7**)

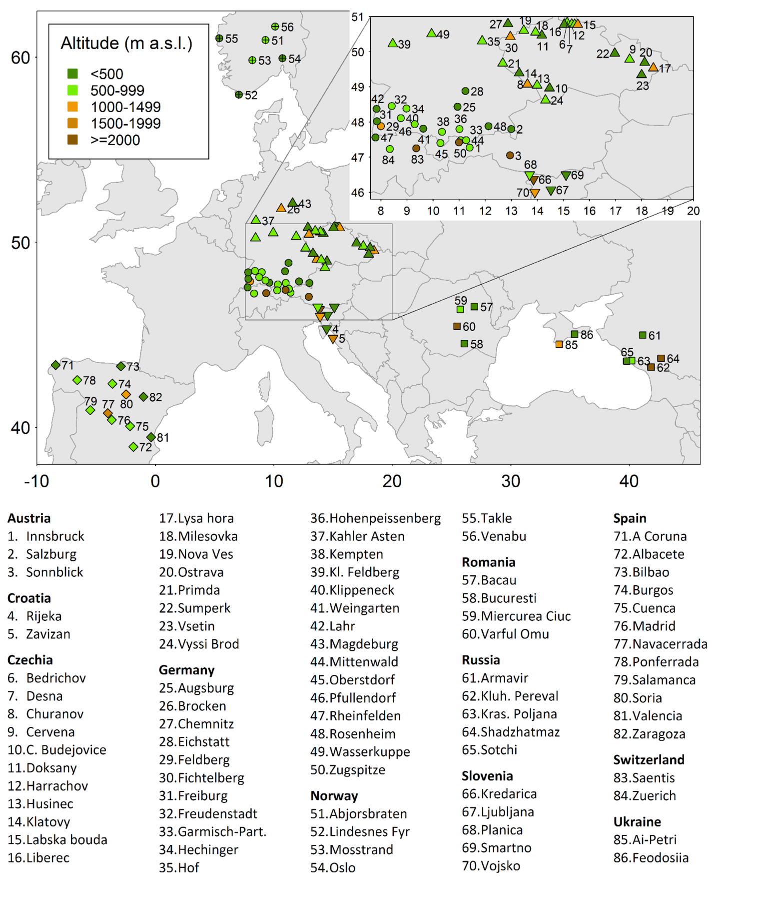
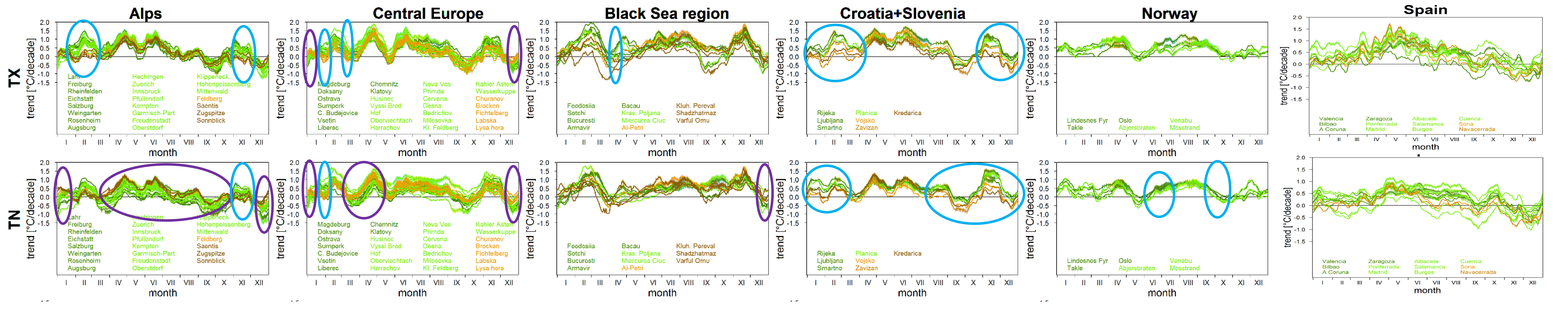


Fig. 1 Map of stations. Colours represent altitude of stations, symbols are regions.

Relationship between elevation and temperature trends

Fig. 2 Annual course of temperature trends for 30-day seasons at stations in individual regions. The colour scale as in Fig. 1 is used to displayeach station's altitude. The seasons are displayed by the position of their 15th day.



Alps:

Dependence varies within the year:

- positive relationship (larger trends at higher altitudes) exists for TN from March to October, in December and in January;
- negative relationship was uncovered in November and for TX also in February and March.

Central Europe:

Dependence is not clear, some middle-altitude stations have even higher trends than stations located above 1000 m a.s.l.

- Some indications of positive dependence exist in December, in the first half of January, and from March to April particularly for TN;
- negative relationship exists only during a short period at the turn of January and February, and for TX in March.

Black Sea region:

Dependence is not clear, the position of stations by the sea or in mountain valleys may affect the magnitude of trends, also the distance between stations is enormous. There are no data of SS an SD that would support any relationship.

- A short period of positive relationship exists for TN at the end of December;
- some indications of negative relationship exist for TX in the first half of April.

Croatia + Slovenia:

Dependence is clear in the cold part of the year but no dependence exists during spring and summer.

- Negative relationship dominates for both TX and TN from November to March, and for TN the same dependence is obvious also from August to October.

Norway:

The position of stations inland or at the coast plays a more important role than their altitude, the dependence exists only for TN.

- Negative relationship for TN was detected in June, July, and at the turn of September and October.

Spain:

No dependence of the temperature trends on altitude exists in any part of the year neither for TX nor TN.

Elevation-enhanced warming in the Alps

March 16 – April 24 in the Alps

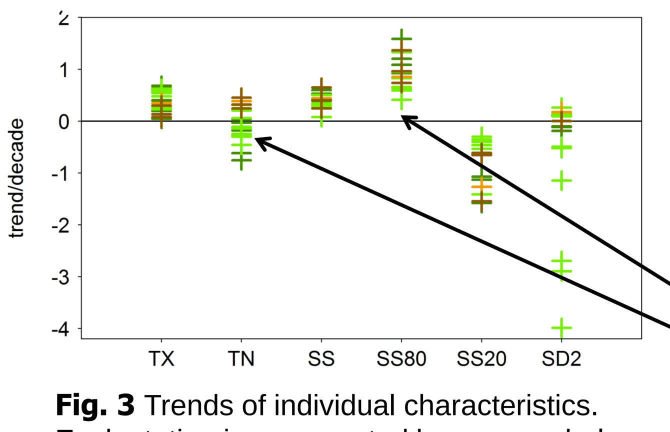


Fig. 3 Trends of individual characteristics. Each station is represented by one symbol (cross), and colours represent the altitude of stations. SS80: number of clear days, SS20:number of overcast days, SD2: days with snow cover.

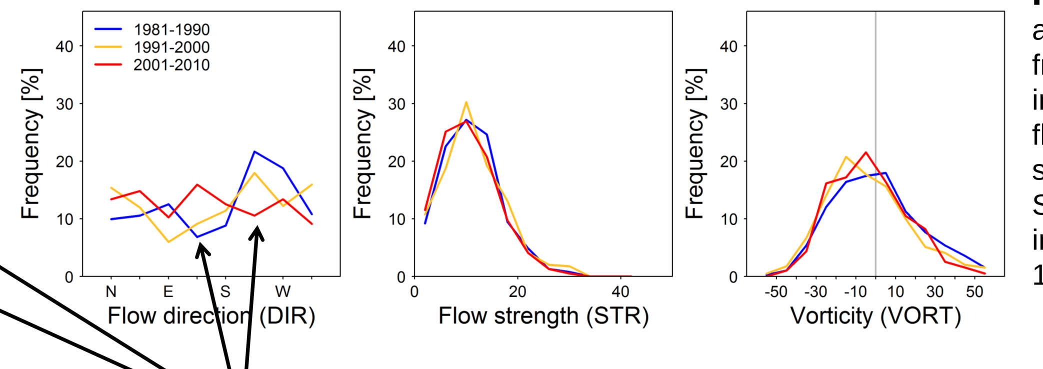


Fig. 4 Changes of atmospheric circulation from March 16 to April 24 in the Alps. Histograms of flow direction, flow strength, and vorticity from SLP are shown for individual decades in 1981-2010.

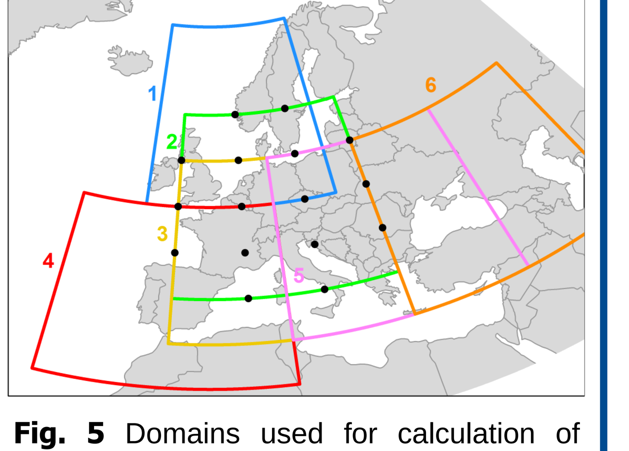


Fig. 5 Domains used for calculation of circulation indices

TN increase at high elevations is related to increasing sunshine and changes in flow direction from southwesterly to southeasterly. Lower humidity associated with the influx of dry air probably leads to clear sky both during the day and at night that increase TX but decrease TN in lowlands.

Decreasing trends with increasing elevation in Central Europe and Croatia+Slovenia

January 10 –February 16 in Central Europe, Croatia and Slovenia

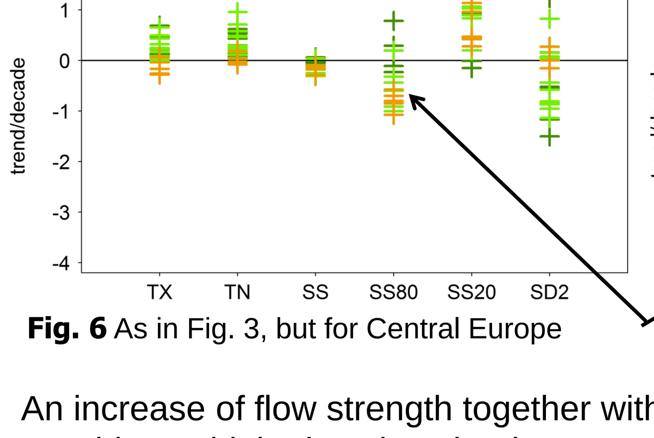


Fig. 6 As in Fig. 3, but for Central Europe

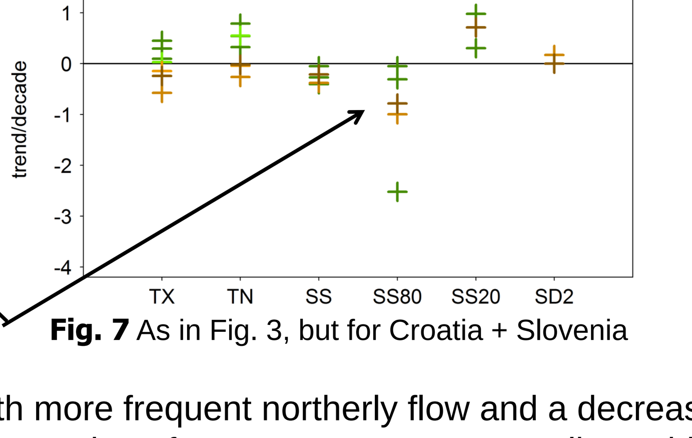


Fig. 7 As in Fig. 3, but for Croatia + Slovenia

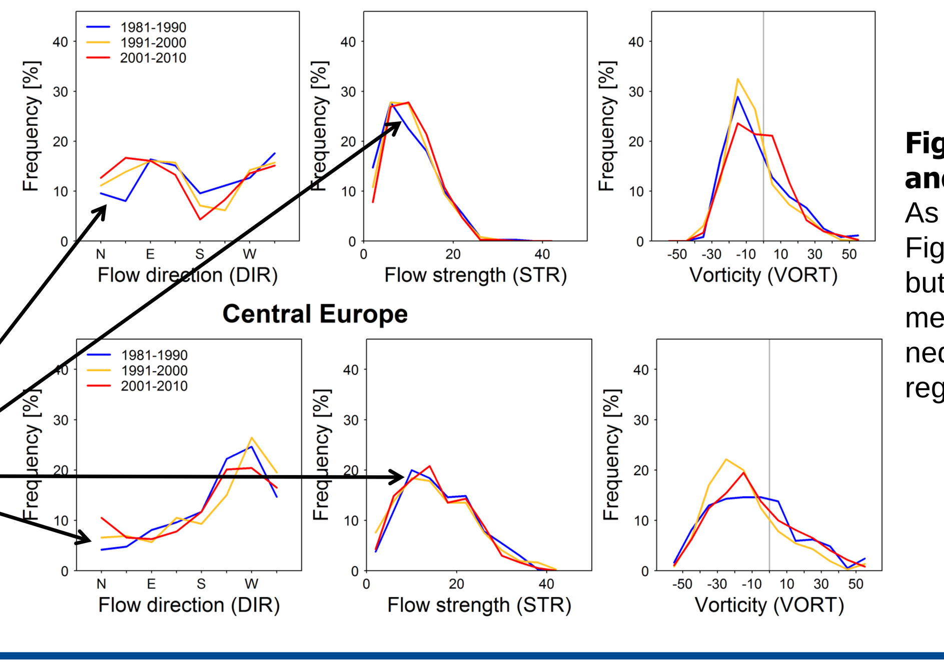


Fig. 8 and 9 As in Fig. 4, but for mentioned regions

An increase of flow strength together with more frequent northerly flow and a decrease of sunshine at high elevations leads to a stagnation of temperature or even cooling, while lowlands are warming at the same time.

Conclusions

- **There is no evidence of general elevation dependence of temperature trends in any of the six studied European regions, relationship exists only in selected parts of the calendar year in individual regions**
- **Decrease of temperature trends with increasing elevation is more frequent than enhanced warming**
- **There is no relationship between temperature trends and elevation in Spain**
- **Differences in temperature trends at lowlands and high elevations are frequently linked to changes in sunshine**
- **The mechanism how changes of atmospheric circulation affect the temperature trends is difficult to interpret**

Acknowledgements

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