Impact of the model resolution on the simulation of elevation-dependent warming in the Tibetan Plateau-Himalayas, Greater Alpine Region, and Rocky mountains

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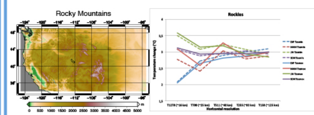
The enhancement of warming rates with elevation, the so-called elevation-dependent warming (EDW), is one of the clearest regional expressions of global warming (Pepin et al., 2015). Sentinels of climate and environmental changes, mountains have experienced more rapid and intense warming rates in the recent decades, leading to serious impacts on mountain ecosystems and downstream societies, some of which are already occurring. Here we use historical and scenario simulations of one state-of-the-art global **climate model run at five different spatial resolutions, from 125 km to 16 km**, to explore the existence and possible drivers of EDW in three different mountain regions of the world – **the Colorado Rocky Mountains, the Greater Alpine Region and the Tibetan Plateau-Himalayas,** in order to **1) investigate the impact of increasing model resolution on the representation of EDW**, and **2) highlight possible differences in EDW drivers in different mountain regions.** Preliminary results indicate that **the existence of EDW is quite coherently simulated throughout all model resolution but the EDW strength and drivers may differ from one resolution to another**. We identify changes in **albedo and downward thermalradiation** as being the most important processes for EDW, in all three areas considered and in all seasons.

1. The SPHINX PROJECT

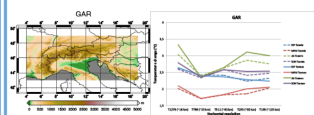
- Climate SPHINX (Stochastic Physics HIgh resolutioN eXperiments) project is a **multi-ensemble and multi-resolution** simulation campaign aimed at evaluating the sensitivity of present and future climate to model resolution and stochastic parameterisation (Davini et al., 2016; http://sansone.to.isac.cnr.it/sphinx/).
- The **EC-Earth Earth-System Model** (http://www.ec-earth.com) is used to explore the impact of a stochastic physics scheme in a large ensemble of **30-year climate integrations**
  - Historical simulations, from **1979 to 2008**
  - Future projections, from **2039 to 2068,** under the **RCP 8.5** scenario
- at five different horizontal resolutions for the atmosphere (AMIP experiments)
  - **T159 (~125 km), T255 (~80 km), T511 (~40 km), T799 (~25 km), T1279 (~16 km)**
- Several members are run for each resolution: **20 at T159 and T255; 12 at T511; 6 at T799 and 2 at T1279**. Half of the members are run with the **stochastic physics** activated and the other half without. The introduction of randomness into the physical parameterization schemes allows to include small-scale processes in the coarse resolution models and represents an alternative approach to the operation of increasing the spatial resolution of numerical models (Davini et al., 2016 and references therein)

In this study we consider the multi-member mean of base and stochastic physics simulations at each resolution.

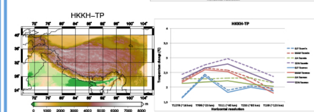
2. Study areas and projected rates of warming



US Rocky mountains: -125°E-95°E, 34°N-49°N
- Seasonality in warming rates is not captured at 80 and 125 km
- At 16 km the greatest warming is observed in JJA, followed by SON, MAM and DJF
- Daily asymmetry in warming rates is well visible in MAM (*Δtasmax > Δtasmin*) and DJF (*Δtasmin > Δtasmax)*



Greater Alpine Region: 4°E-19°E, 43°N-49°N
- Greatest warming in JJA (more in *tasmax* than in *tasmin*) followed by, in order of strength, SON, DJF and MAM.
- Daily asymmetry in warming rates observed only in JJA at almost all resolutions (*Δtasmax > Δtasmin*)

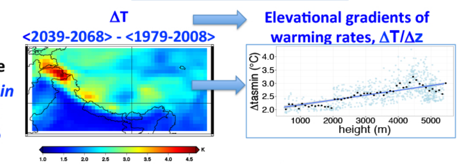


Tibetan Plateau-Himalayas: 70°E-105°E, 25°N- 40°N
- Greatest warming in SON at all resolutions, lowest in DJF (3 out of 5 resolutions)
- Daily asymmetry in warming rates (*Δtasmin > Δtasmax*), particularly emphasized in SON and JJA

For each area: (Left) ***Topographic map*** *from a high-resolution DEM (0.008° resolution lat-lon); (Right)* ***warming rates (difference between the 2039-2068 climatology and the 1979-2008 climatology)*** *for the minimum and maximum temperatures, in the 4 seasons and at the 5 model resolutions (x-axis)*

3. Methodology (Palazzi et al., 2016)

Assessment of EDW



Max and Min temperature separately analysed

Seasonal analysis (DJJ, MAM, JJA, SON)

EDW drivers

- Temperature change at the surface is primarily a response to the energy balance → factors that increase the net flux of energy to the surface would lead to EDW
- We consider the model variables whose change may be related to the temperature change

Change in:
- **Δalbedo** – Albedo
- **Δhuss** – near-surface specific humidity
- **Δrlds** – surface downward longwave radiation
- **Δrsds** – surface downward shortwave radiation

Normalized change in:
- **$\Delta huss/huss_0$** – near-surface specific humidity
- **$\Delta rlds/rlds_0$** – surface downward longwave radiation
- **$\Delta rsds/rsds_0$** – surface downward shortwave radiation

Δalbedo, Δhuss, Δrlds, Δrsds, Δhuss/huss0, Δrlds/rlds0, Δrsds/rsds0 are EDW drivers if

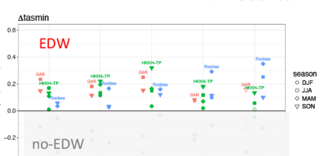
1. **They exhibit a dependence on elevation, as the temperature change does**
2. **The sign of this dependence is consistent with the amplification of the warming rate at higher elevations (dT/dz > 0)**

$$\frac{\Delta driver}{\Delta z} > 0$$

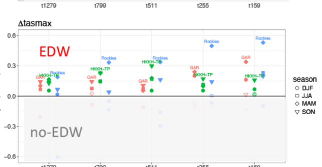
(Δalbedo → -Δalbedo)

3. **They are spatially positively correlated with the temperature changes even when the dependence on the elevation is removed**

4. Results: EDW



EDW in *tasmin*
- Rockies: max EDW in MAM (at all resolutions except T1279)
- HKKH-TP: max EDW in SON (except at T1279)
- GAR: max EDW in JJA at T1279-T511



EDW in *tasmax*
- Rockies: max EDW in MAM
- HKKH-TP: max EDW in SON (except at T1279)
- GAR: max EDW in SON at T1279-T511 and in MAM at T255-T159

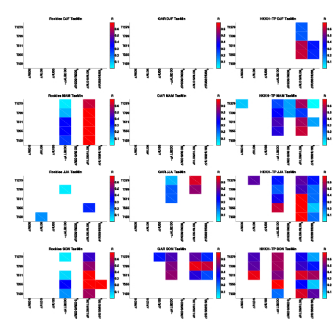
Elevational gradients of the seasonal temperature (tasmin, top; tasmax, bottom) change for the different EC-Earth resolutions, reported in the x-axis. The open symbols represent statistically non-significant elevational gradients of warming rates. See also the Table below.

		TasMin					TasMax				
		t1279	T799	T511	T255	T159	T1279	T799	T511	T255	T159
DJF	HKKH-TP	Y	Y	Y	Y	-	Y	Y	Y	Y	Y
	GAR	N	N	N	N	N	N	N	N	Y	Y
	Rockies	N	N	N	N	N	Y	N	N	N	N
		T1279	T799	T511	T255	T159	T1279	T799	T511	T255	T159
MAM	HKKH-TP	Y	Y	Y	Y	N	Y	Y	Y	Y	-
	GAR	N	N	N	N	-	Y	-	Y	Y	Y
	Rockies	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
		T1279	T799	T511	T255	T159	T1279	T799	T511	T255	T159
JJA	HKKH-TP	Y	Y	Y	Y	Y	Y	Y	Y	Y	-
	GAR	Y	Y	Y	-	-	Y	Y	Y	-	-
	Rockies	N	Y	N	Y	Y	N	N	N	-	Y
		T1279	T799	T511	T255	T159	T1279	T799	T511	T255	T159
SON	HKKH-TP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	GAR	Y	Y	Y	Y	-	Y	Y	Y	-	-
	Rockies	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

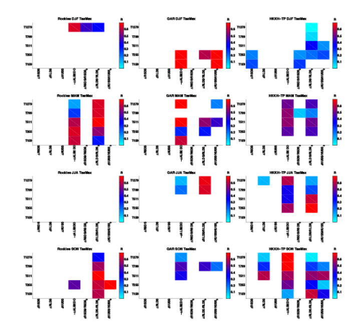
Cases where EDW (i.e., enhanced warming rates with elevation) is detected (Y) or not (N). A hyphen denotes non-significant elevational gradients of warming rates.

5. Results: EDW drivers

Minimum temperature



Maximum temperature



Correlation coefficient, R, ***between the change of each driver and the minimum (left) or maximum (right) temperature change. The variables are altitude-detrended and standardized.*** *Blank cells correspond to cases in which* ***1)*** *there is no EDW (dT/dz <0),* ***2)*** *EDW is not statistically significant (p>0.05),* ***3)*** *d(driver)/dz <0 or not statistically significant,* ***4)*** *R is not statistically significant . Only positive correlations are displayed.*

The figures show the main drivers of EDW, for all regions, seasons and model resolutions, according to the criteria defined in panel 3. The plotted value of the correlation coefficient provides a measure of the strength of the correlation of a given driver with the temperature change and of its role as a driver of EDW.

Next step*: setting up a multiple linear regression model in which the different drivers are used as predictors of the change in minimum and maximum temperature change, to assess the relative importance of the various drivers (and of their combinations) to EDW (as in Palazzi et al., 2016)*

6. Conclusions

- **If the model predicts EDW in one season and region, the signal is coherent throughout all resolutions** in spite of the large range of spatial scales resolved.
- **The EDW strength may differ from one resolution to another**. In general each study area shows a different dependence of the EDW intensity on the resolution. No clear pattern emerges.
- **In most cases if a variable proves to be a driver of EDW this is true for all the different resolutions (but the relative importance of one variable may change from one resolution to another).**
- The more frequent EDW drivers throughout the regions and seasons are changes in **albedo** and **downward thermal radiation**. Especially for *tasmin, specific humidity also seems to play a role in the HKKH-TP, while in the Rockies and in the GAR its role is only evident in SON.*

Cited bibliography

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