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# Temperature monitoring in mountain regions using reanalyses: Lessons from the Alps

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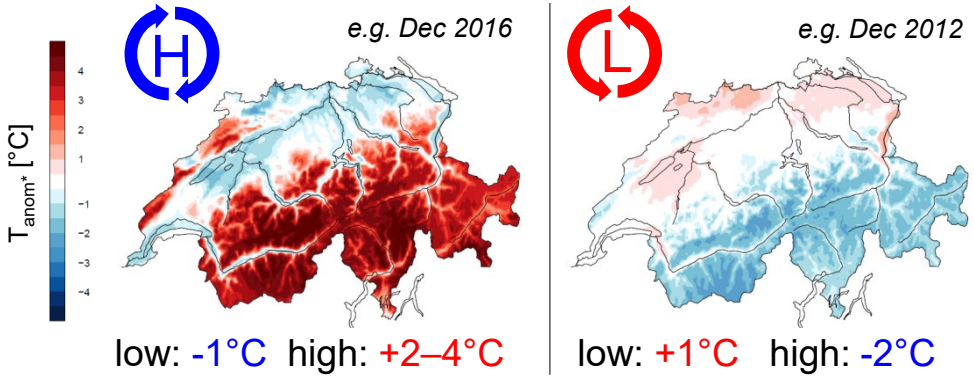
# Motivation



→ *topography–flow interaction creates elevation dependent temperature anomalies*

*monthly anomaly maps*



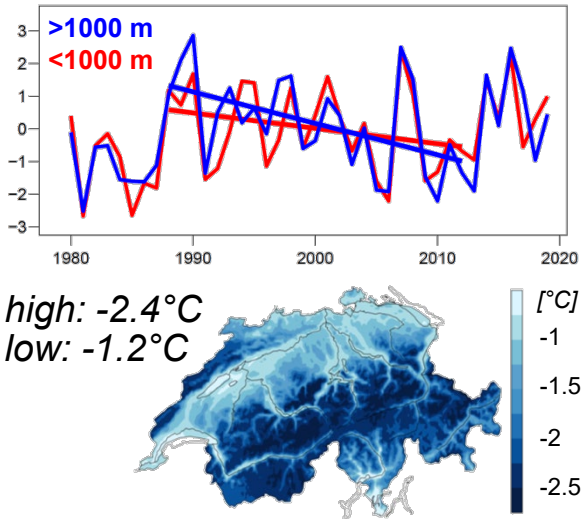

low: -1°C high: +2–4°C

low: +1°C high: -2°C

→ *Can modern reanalyses adequately represent the elevation effects?*

*short-term trends*

*1988-2012 winter cooling*




*e.g. Bader & Fukutome (2015)*

* wrt 1981-2010

# Data and methods

**> variable** monthly/seasonal 2m temperature (T2m) anomalies (e.g. wrt 1981-2010)

**> «reanalyses»**

30-60 km (global)

ECMWF **ERA5**
**0.25°**, 1979-2018

~10 km ~5-6 km *regional (Europe)*

UERRA **HARMONIE**
**0.11°**, 1961-2018

DWD COSMO-**REA6**
**0.055°** (~6 km), 1995-2017

ECA&D **E-OBS** HOM
**0.1°**, 1950-2018 (v19.0e)

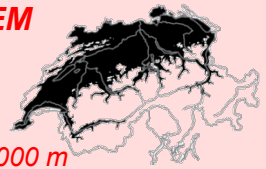
**MESCAN**-SURFEX
**5.5 km**, 1961-2017

**> benchmark**

MeteoSwiss swissmean **(OBS)** homogenized, temp. consistent (Begert & Frei, 2018)

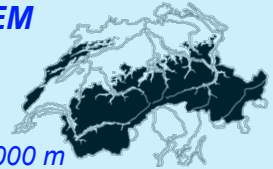
**> evaluation domains**

*Swiss low elev. mean*
***LEM***



*<1000 m*

*Swiss high elev. mean*
***HEM***



*>1000 m*

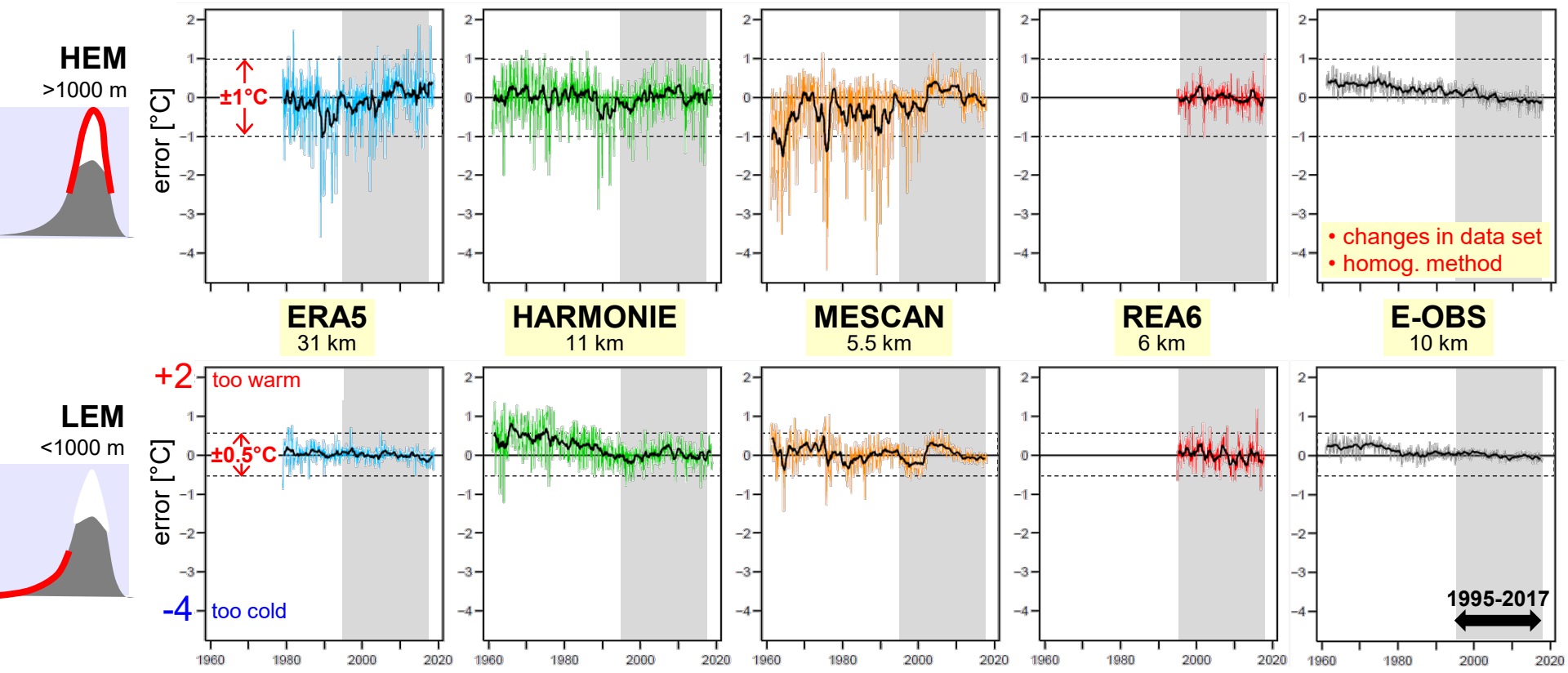
**> methods**

evaluation: mean abs. errors (MAE)

trends: Theil-Sen slope, Mann-Kendall significance test

# Temporal evolution of errors

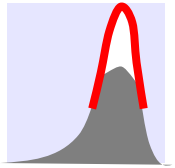
monthly T2m anomalies, error = rea-OBS



# Error «sizes» 1995-2017

Percentage of months with a certain absolute error (total 276 months)

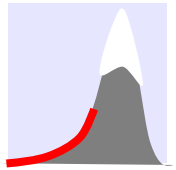
**HEM**
>1000 m



| *"rank"* | *abs. error [K]* | *<.25* | *.25 – .5* | *.5 – 1* | *1 – 2* | *>2* |
|---|---|---|---|---|---|---|
| 1 | **REA6** | 73 | 21 | 5 | <1 | . |
| 2 | **MESCAN** | 59 | 23 | 15 | 2 | <1 |
| 3 | **HARMONIE** | 51 | 32 | 14 | 3 | . |
| 4 | **ERA5** | 46 | 26 | 20 | 8 | <1 |
| | *E-OBS* | *90* | *9* | *<1* | . | . |

→ high-res. better, REA6 best @ high elevations

**LEM**
<1000 m

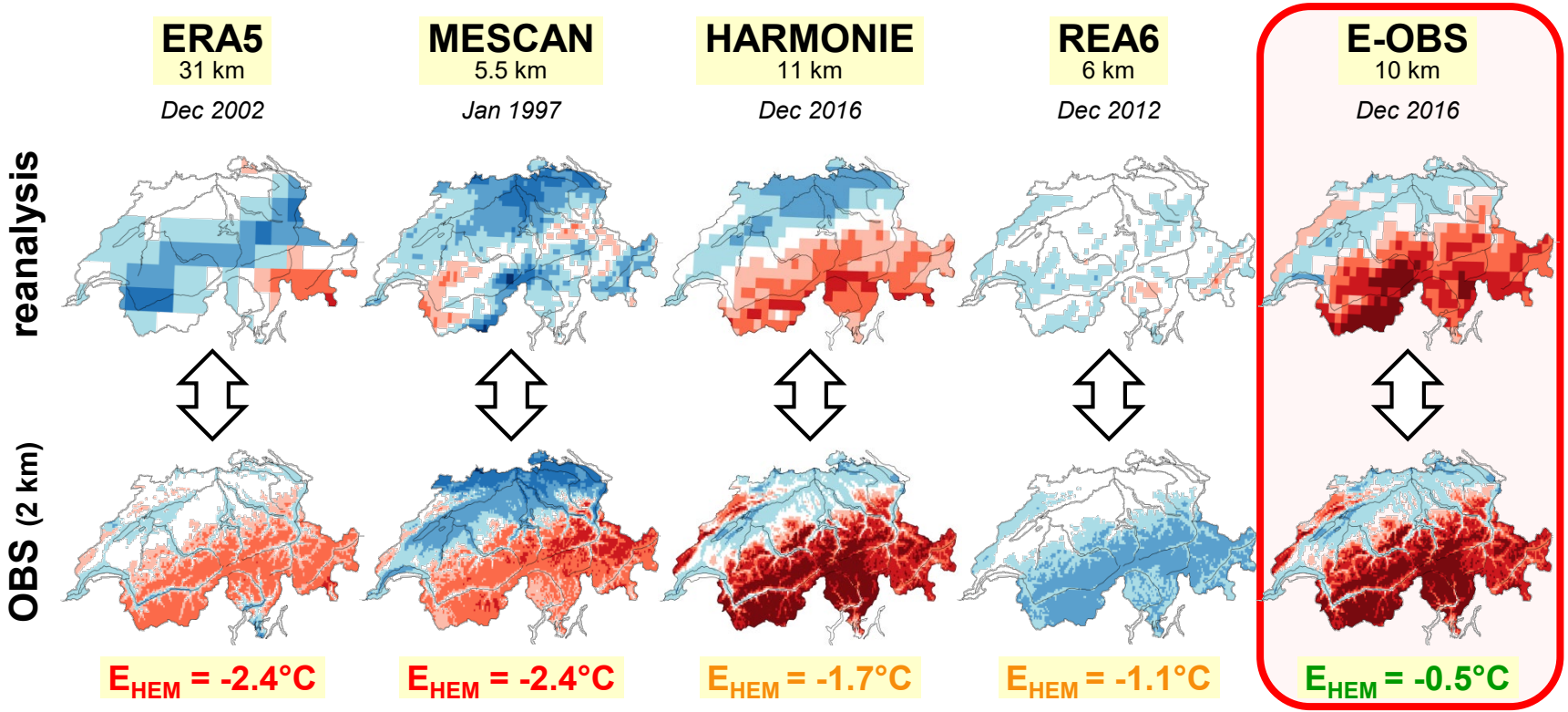


| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | **ERA5** | 93 | 6 | 1 | . | . |
| 2 | **HARMONIE** | 76 | 17 | 7 | . | . |
| 3 | **MESCAN** | 72 | 25 | 3 | . | . |
| 4 | **REA6** | 69 | 24 | 7 | <1 | . |
| | *E-OBS* | *100* | . | . | . | . |

→ ERA5 clearly best @ low elevations!

# Anomaly maps of «worst» months

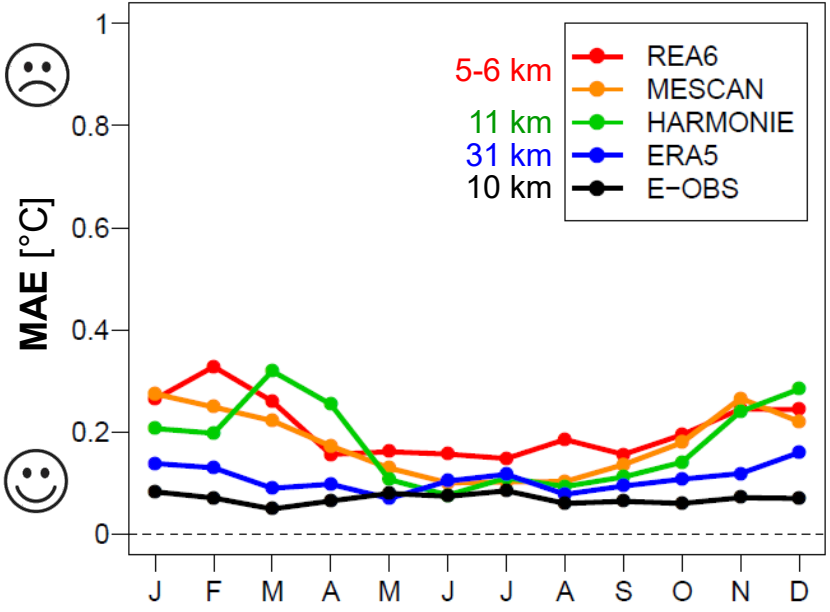




# Seasonality of errors

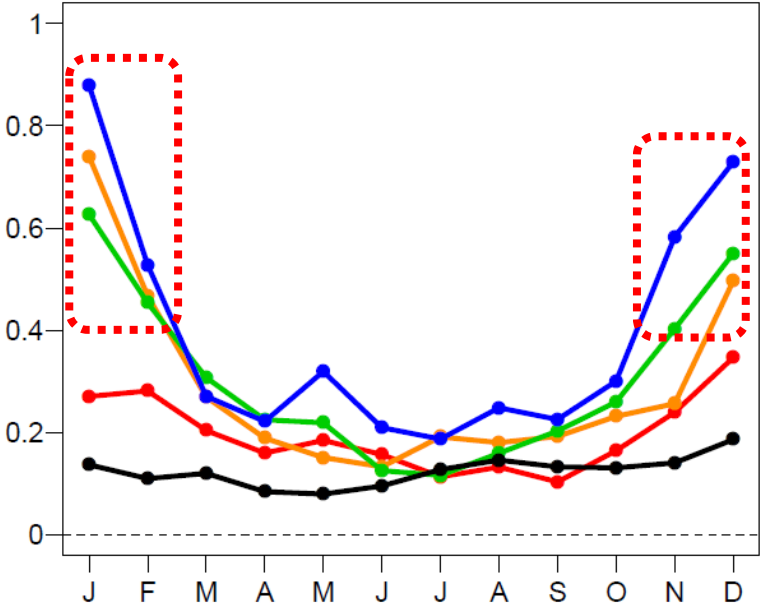


**low altitudes** (LEM <1000 m)




→ weak seasonality, ERA5 better than high-resolution regional renalyses

**high altitudes** (HEM >1000 m)

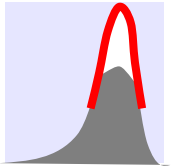



→ large errors in winter, REA6 best, ERA5 lags behind!

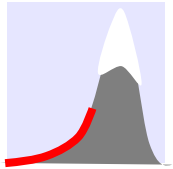
*data: 1995-2017*

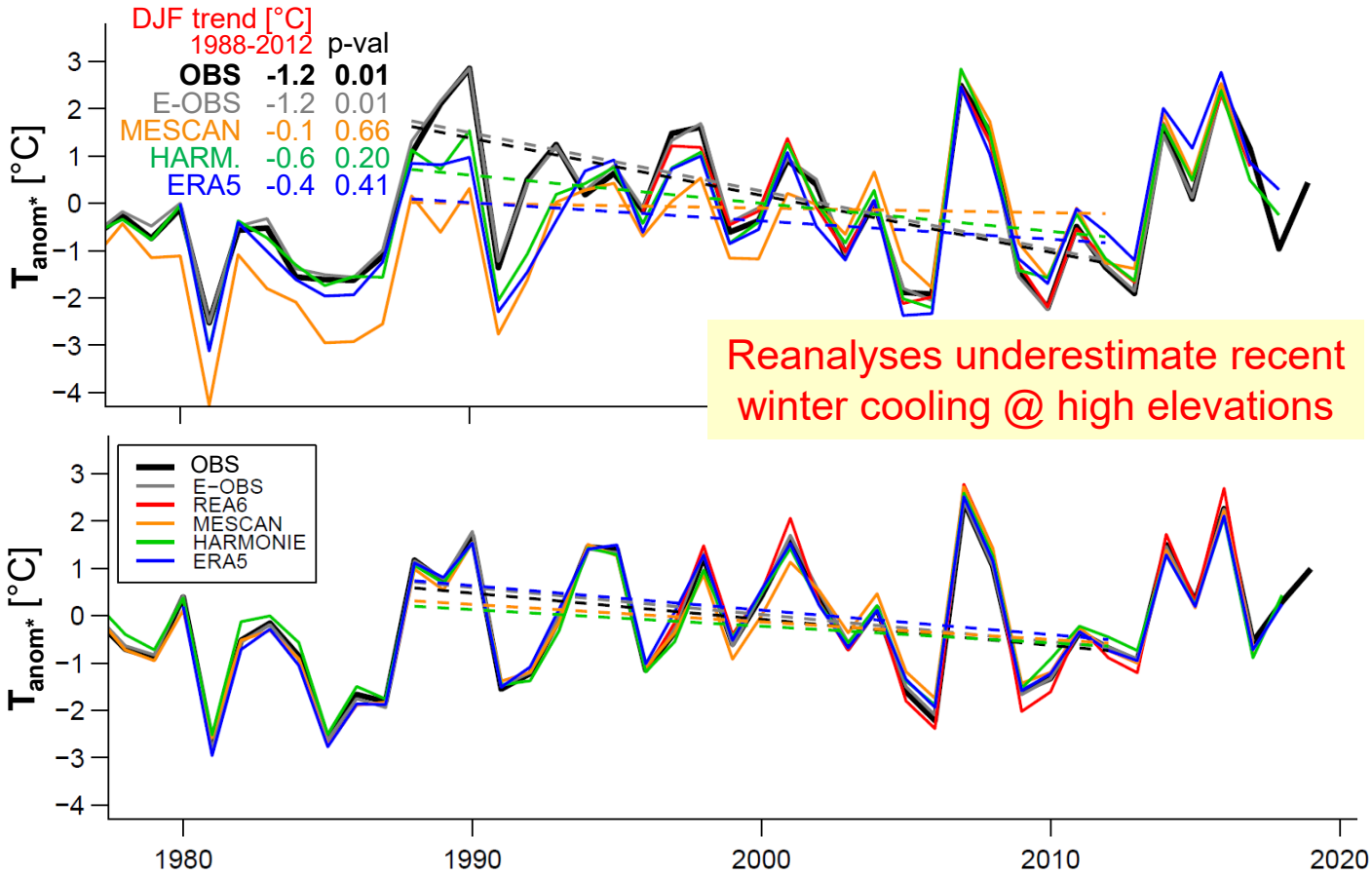
# Winter temperature evolution 1979-2018

**HEM**
>1000 m



**LEM**
<1000 m





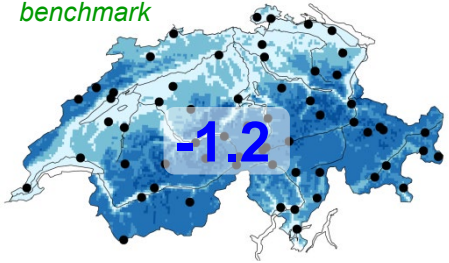

Reanalyses underestimate recent winter cooling @ high elevations

* wrt 1995-2017

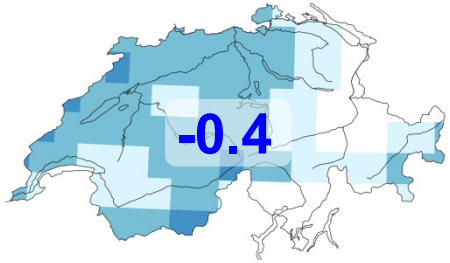
# Maps of winter temp. trends 1988-2012

DJF Theil-Sen trends [°C / 10 yrs]

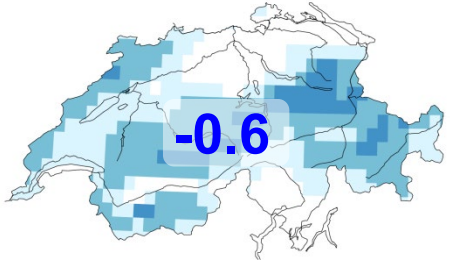
**OBS**
2 km (hom & temp cons, 61 sta)
*benchmark*

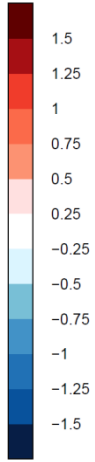



**ERA5**
0.25° (~31 km)

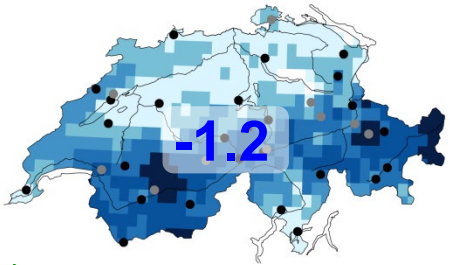



**HARMONIE**
0.11° (~11 km)

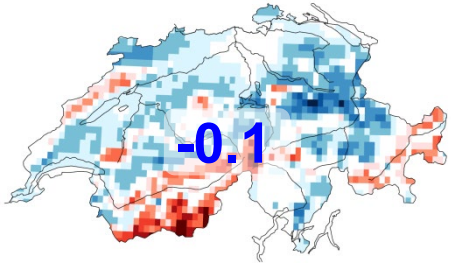



**E-OBS**
v19.0e 0.1° (~10 km) (26-35 sta.)




**MESCAN**
5.5 km



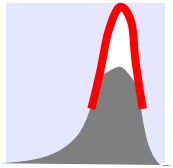

***obs data sets***

***reanalyses***

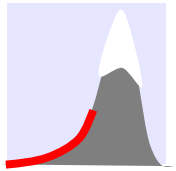
# «Running» winter temperature trends

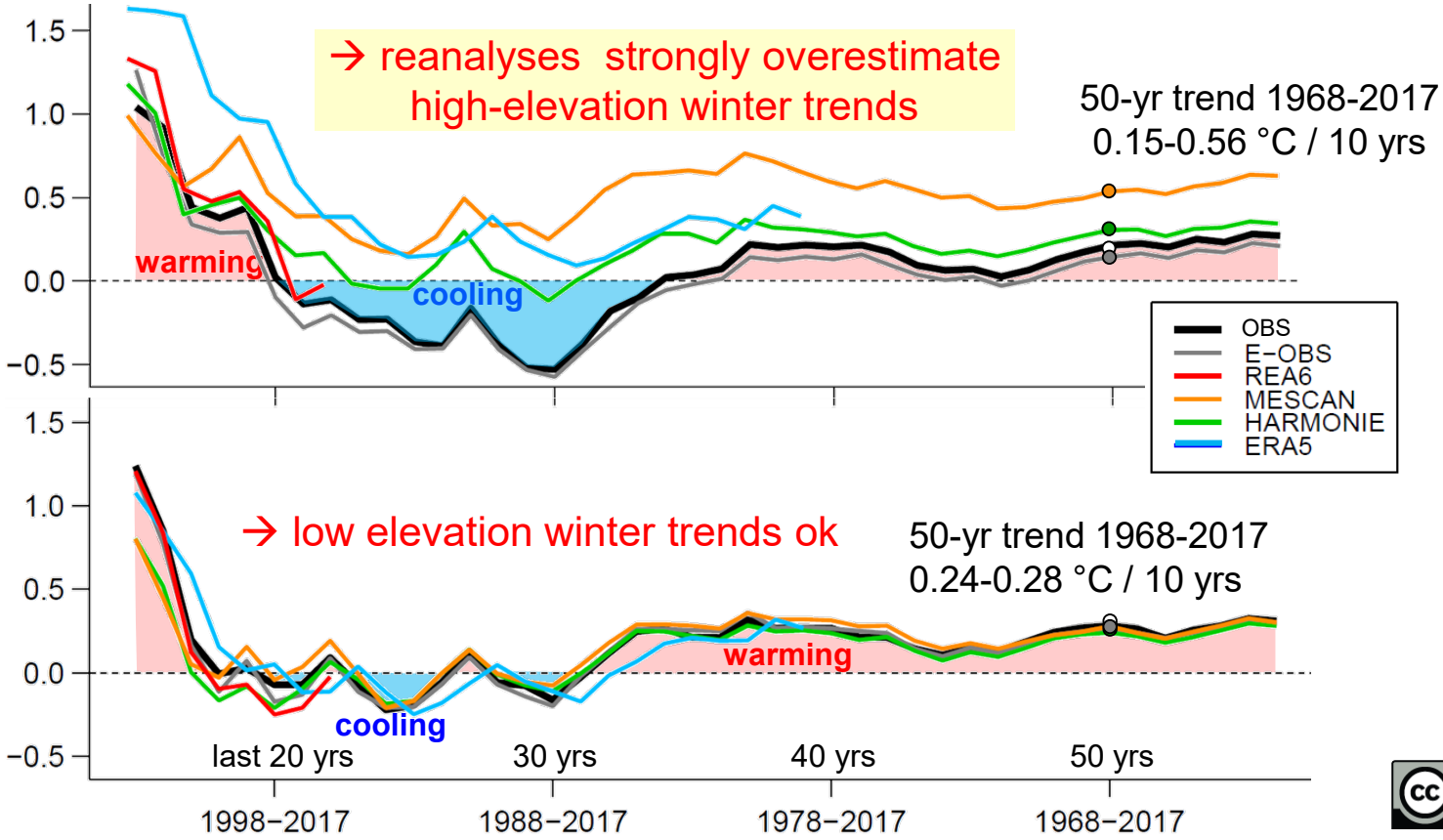
DJF running windows (last 15-57 yrs), Theil-Sen trends [°C / 10 yrs]

**HEM**
>1000 m



**LEM**
<1000 m

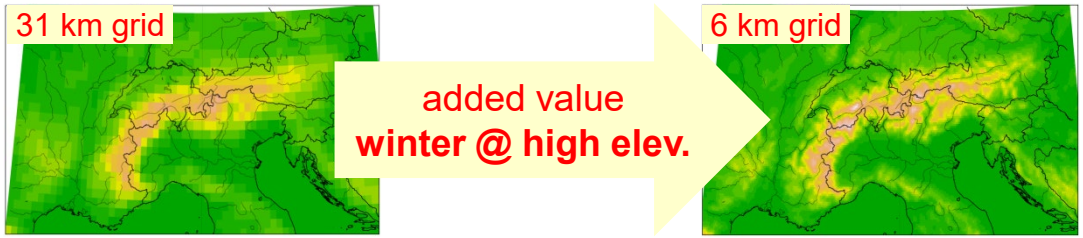





* wrt 1995-2017

# Conclusions

- All reanalyses work well at foothills and in summer
- Problematic are high elevations in winter, where also trends are strongly overestimated (and recent cooling underestimated), E-OBS HOM works very well
- High spatial resolution can help at high elevations in winter but assimilation of near-surface temperature remains challenging




*smooth ridge*
*no Alpine valleys*

complex mountain range
main valleys visible

***upcoming…***
*ERA5-land @9km?*
*C3S reanalysis @5.5km?*

**more information:**

Scherrer SC 2020 Environ. Res. Lett. 15 044005, https://doi.org/10.1088/1748-9326/ab702d