How is snow cover in global mountain area changing? Detection of snow cover and snow phenology changes by using MODIS imagery over 2000 – 2018

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Motivation

Recent studies showed that temperature increase in mountains doubles the global average, and it intensifies with elevation (Pepin et al., 2015).

Changes in snow cover and related phenology (duration, onset and melt) have a critical role in mountain environment, and are strictly related to water availability in downstream areas.

To better understand these changes, observations from surface stations, remotely sensed data, and model simulations have been extensively exploited on several mountain areas in the most recent decades (Beniston et al., 2018; Hammond et al., 2018; Mote et al., 2018).

These studies indicate that mountain areas are undergoing relevant changes related to snowpack, even though the results, being conducted with different data sets and time frame, cannot be compared directly to retrieve a global view of snow change in mountains.

Beniston, M., et al., .The European mountain cryosphere: a review of its current state, trends, and future challenges, The Cryosphere 12, 759-794, (2018) https://doi.org/10.5194/tc-12-759-2018.
Hammond, J.C., Saavedra, F.A., Kampf, S. K. Global snow zone maps and trends in snow persistence 2001–2016. *Int J Climatol*. **38**, 4369–4383 (2018). https://doi.org/10.1002/joc.5674
Mote, P.W. Li, S., Lettenmaier, D. P., Xiao, M., Engel, R. Dramatic declines in snowpack in the western US, *Climate and Atmospheric Science* **1:2** (2018); doi:10.1038/s41612-018-0012-1.
Pepin, N. et al. Elevation-dependent warming in mountain regions of the world. *Nat Clim Change*, **5**, 424:430 (2015).

Objectives

This study assesses and investigates the status of changes in snow cover and related phenology in global mountain ranges by using MODIS imagery data from 2000 to 2018 at 500 m ground resolution (Notarnicola, 2020).

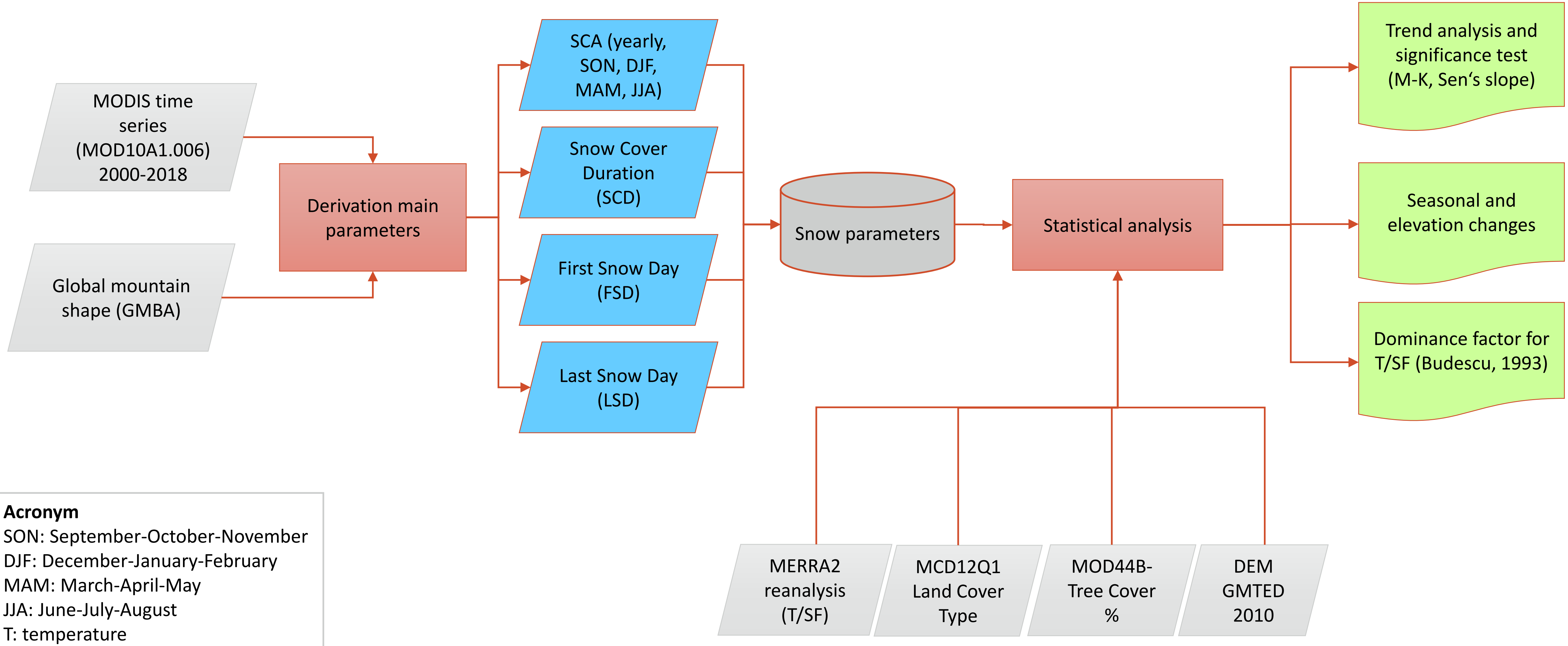
The analysis on global mountain ranges is carried out with the aim to improve the knowledge on snow changes, with the following research questions:

- What is the status in mountains areas at global level in the last two decades?
- Are there seasonal and elevation patterns?
- Which is the impact of main meteorological parameters (temperature, snowfall)?
- Is there a specific snow onset and melt dynamics?
- What are the „hotspots“ of snow cover changes from 2000 to 2018?

Notarnicola C., "Hotspots of snow cover changes in global mountain regions over 2000-2018", Remote Sens. Environ. 243 (2020), 111781

Methodology with GEE platform

All calculations were carried out in the Google Earth Engine (GEE) platform

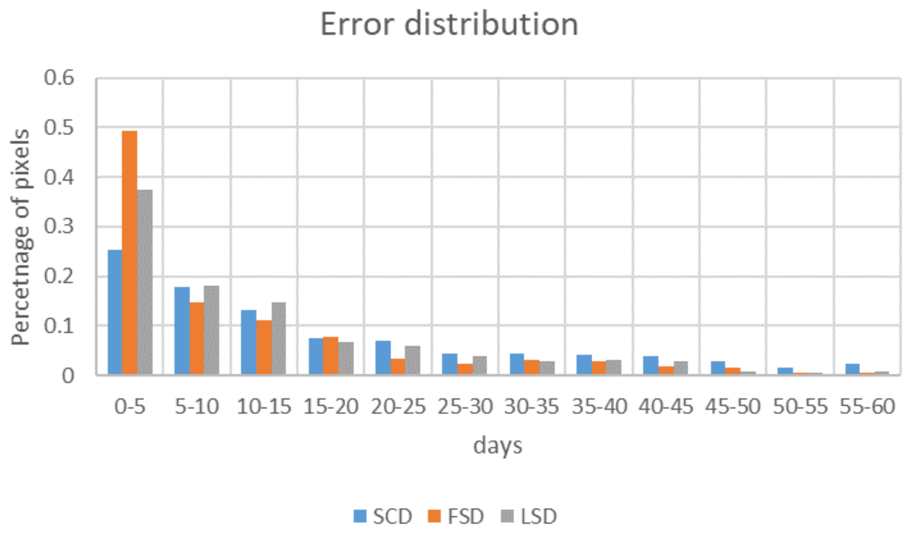


Acronym
SON: September-October-November
DJF: December-January-February
MAM: March-April-May
JJA: June-July-August
T: temperature
SF: snowfall
MK: Man-Kendall statistics

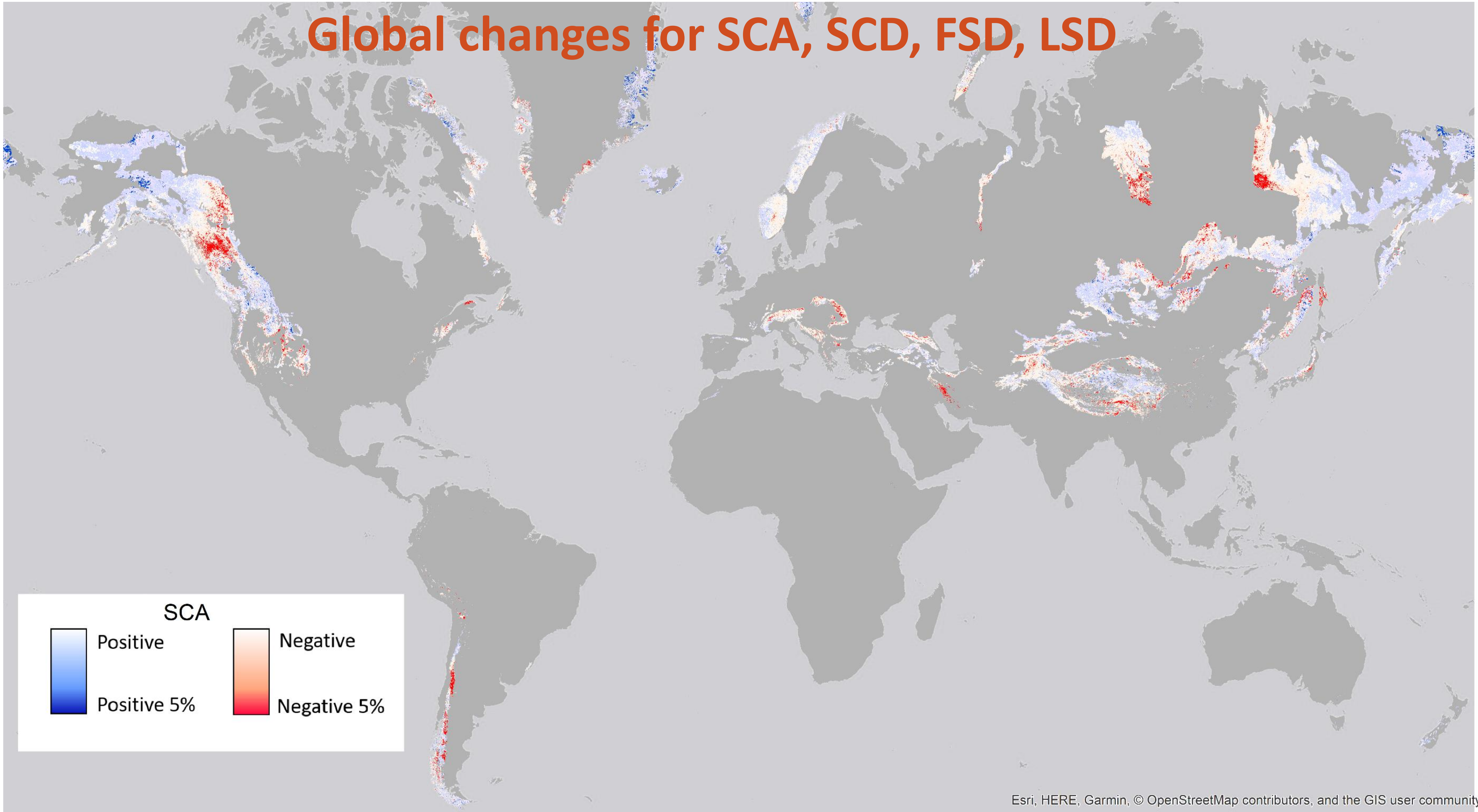
Validation of snow phenology parameters

	SCD			FSD			LSD			
	R	MAE (day)	Bias (day)	R	MAE (day)	Bias (day)	R	MAE (day)	Bias (day)	N.points
Total	0.84**	21.1	-3.1	0.93**	11.1	4.7	0.89**	13.9	-2.2	466
Regions										
North America (USA, Canada)	0.80**	20.2	7.1	0.82**	11.1	7.0	0.75**	11.9	3.9	222
Asia (China, Russia)	0.90**	17.7	-5.3	0.85**	9.5	-3.1	0.66**	14.9	-10.8	124
Europe	0.96**	12.7	-4.9	0.89**	6.5	1.0	0.89**	12.4	-7.3	38
Norway	0.83**	39.9	-37.6	0.26*	18.9	-17.9	0.70**	24.2	-22.4	54
Argentina	0.83**	12.5	-5.5	0.84**	9.7	-0.18	0.90**	8.1	-2.4	28
Missing values (%)										
<40%	0.80**	10.9	-2.7	0.90**	8.9	-2.6	0.89**	9.2	-2.4	23
40%-50%	0.84**	19.4	3.3	0.94**	13.6	9.4	0.93**	13.8	-0.3	51
50%-60%	0.90**	18.4	8.7	0.67**	10.1	3.7	0.68**	15.4	3.03	123
60%-70%	0.81**	18.2	-2.7	0.85**	9.2	1.6	0.80**	9.9	-0.7	191
>70%	0.79**	34.4	-26.7	0.85**	16.4	12.7	0.59**	23.0	-15.7	78
Latitude										
30°-40° N	0.93**	17.9	9.2	0.89**	10.9	6.3	0.69**	13.6	6.6	79
40°-50° N	0.84**	19.5	5.8	0.72**	9.3	3.7	0.82**	12.0	2.3	160
50°-60° N	0.88**	18.4	0.2	0.89**	10.7	-3.0	0.65**	17.5	0.9	52
> 60°N	0.74**	26.0	-20.0	0.50**	13.7	8.4	0.62**	16.0	-12.9	147
30°-40° S	0.83**	12.5	-5.5	0.84**	9.7	-0.2	0.90**	8.1	-2.4	28

** indicates results which are significant at 1% level, * indicates results that are significant at 10%
N. Points: each point represents a full time series covering the hydrological year



Global changes for SCA, SCD, FSD, LSD



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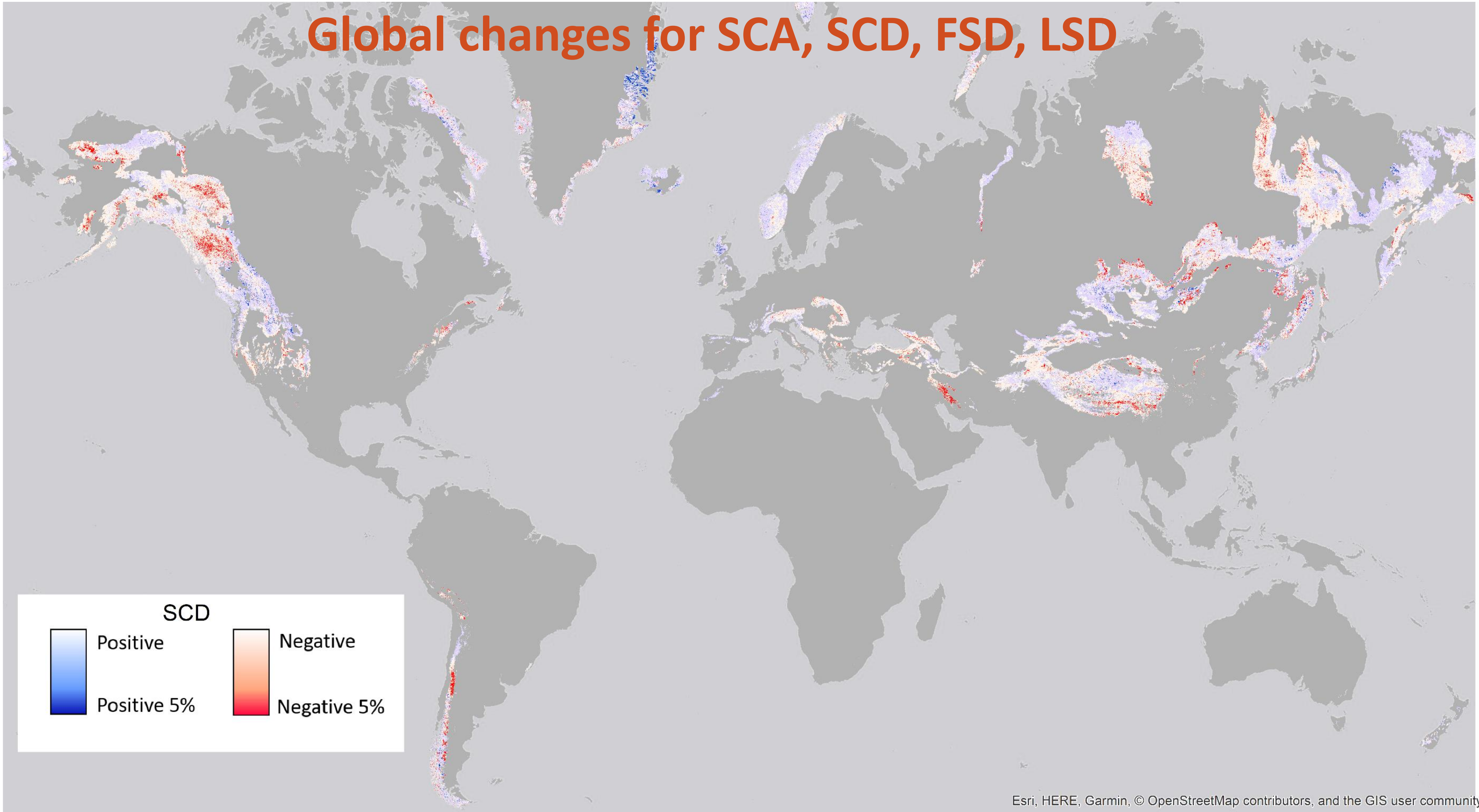

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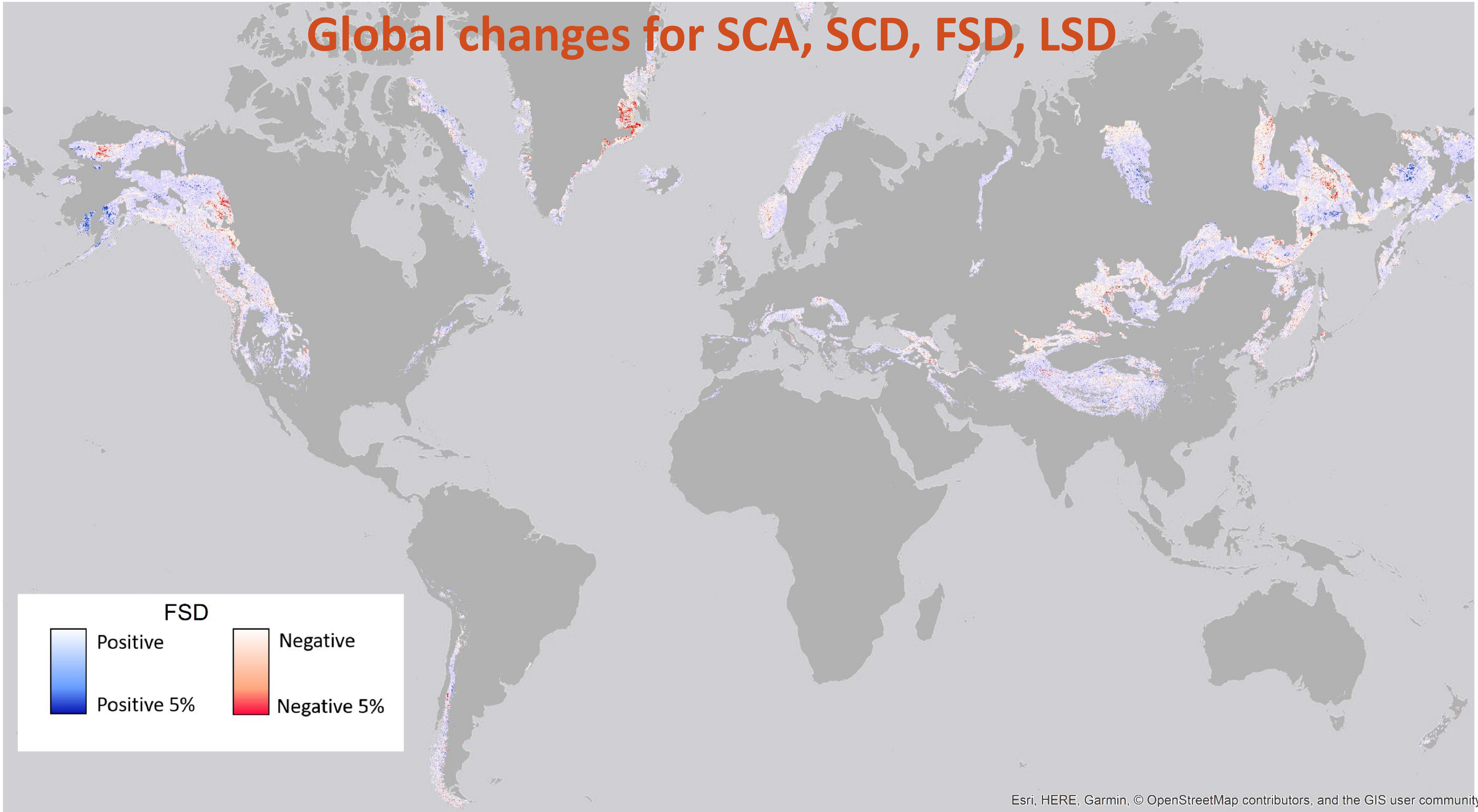

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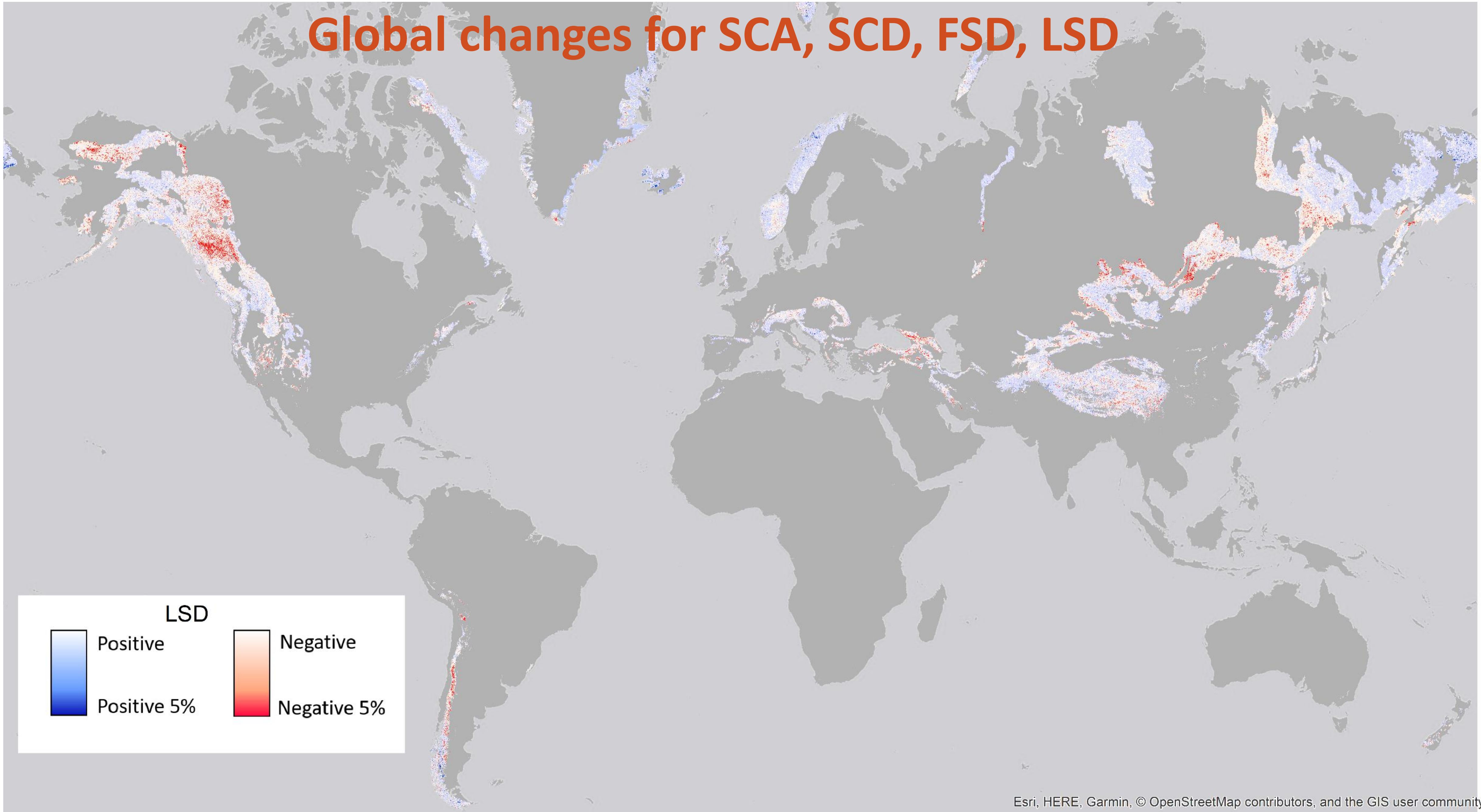
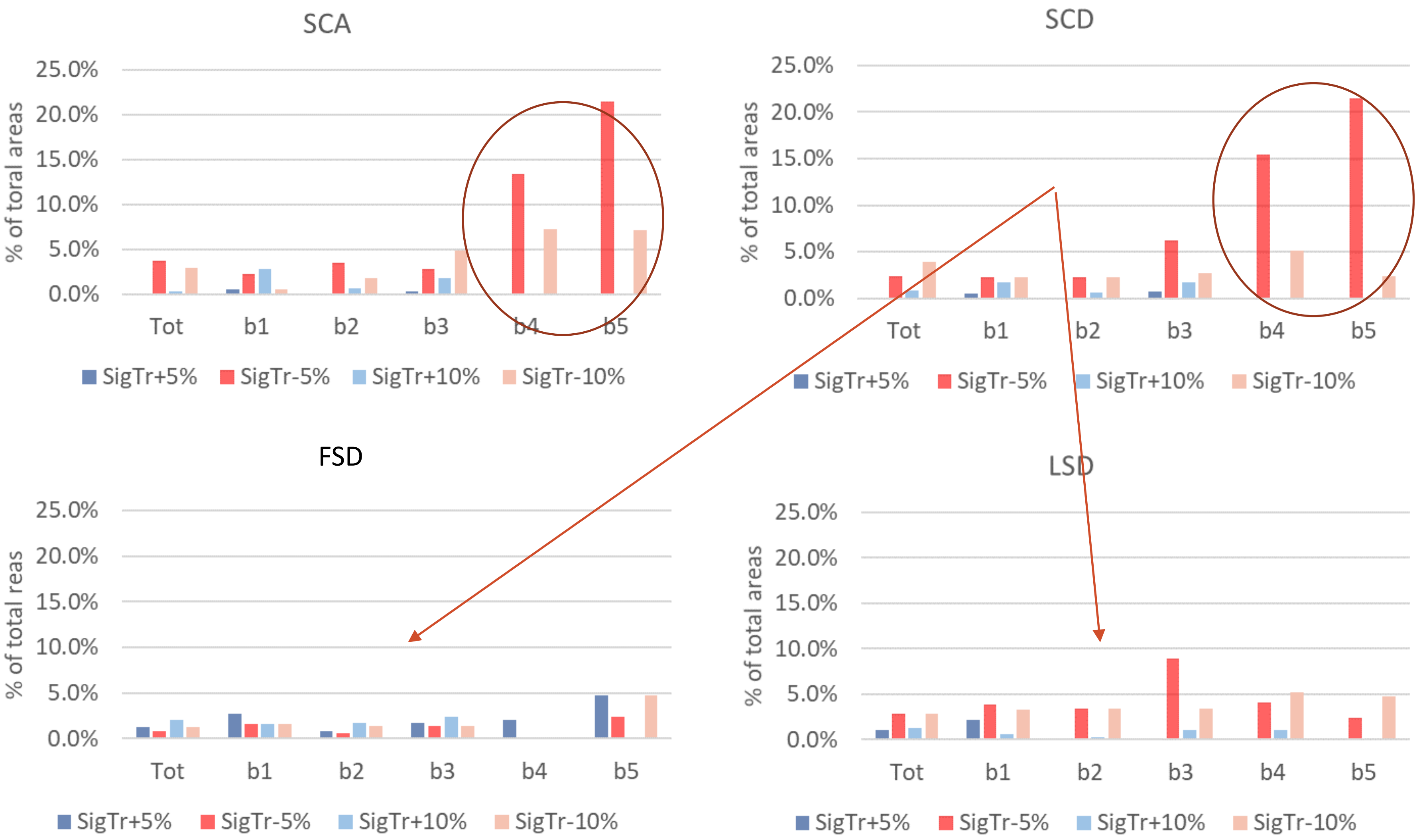


What are the elevation patterns?



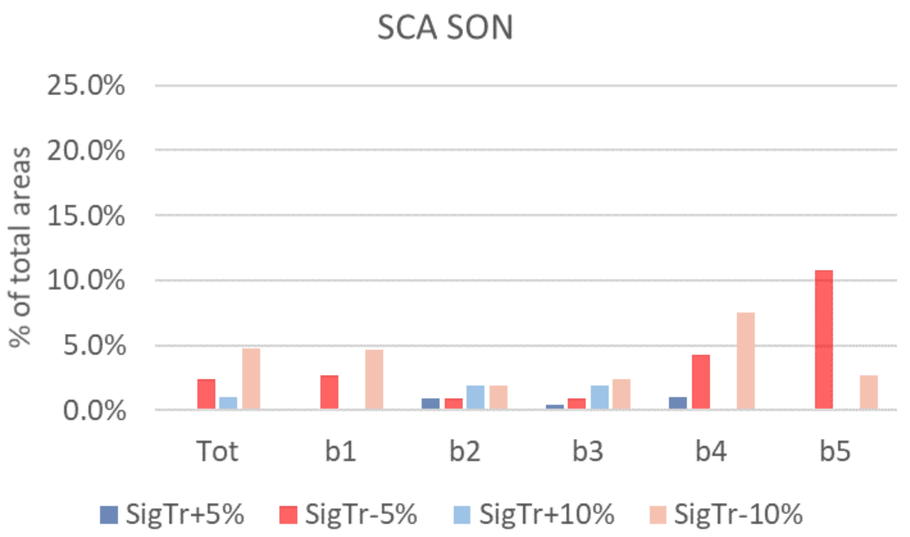
At elevetion higher than 4000m, mainly negative changes are detected

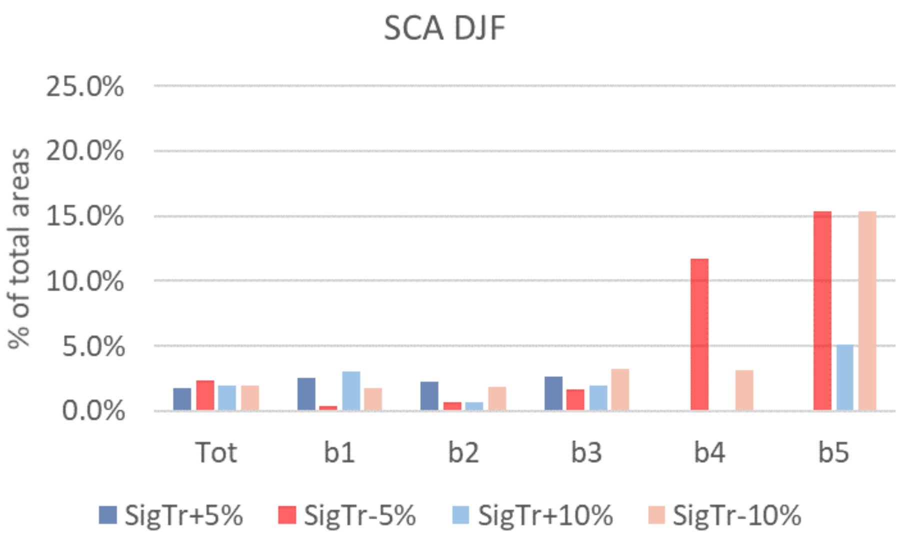
In 58% of areas with significant trends, SCD changes are significantly related to both FSD and LSD variations.

While in 54% of area, SCD changes are stronger correlated to LSD than to FSF.

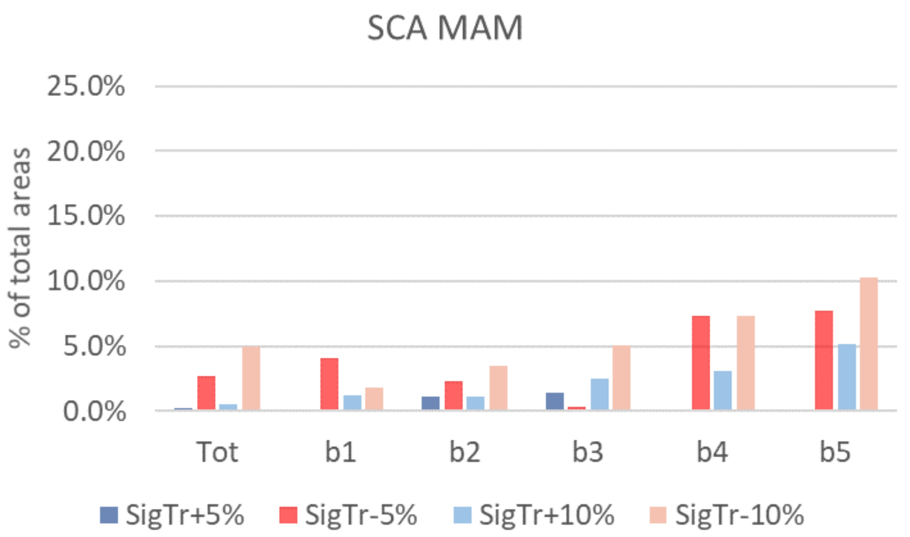
b1: 300-1000m, b2: 1000-2500m, b3: 2500-4000m, b4: 4000-5500m, b5: > 5500m.

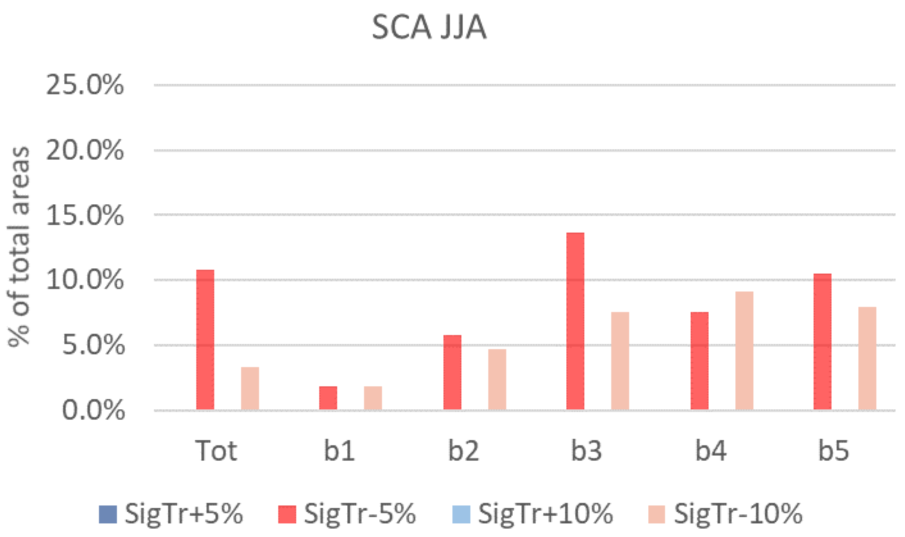
What are the seasonal patterns?





During December-January-February (DJF), some areas show positive trends up to 4000 m.

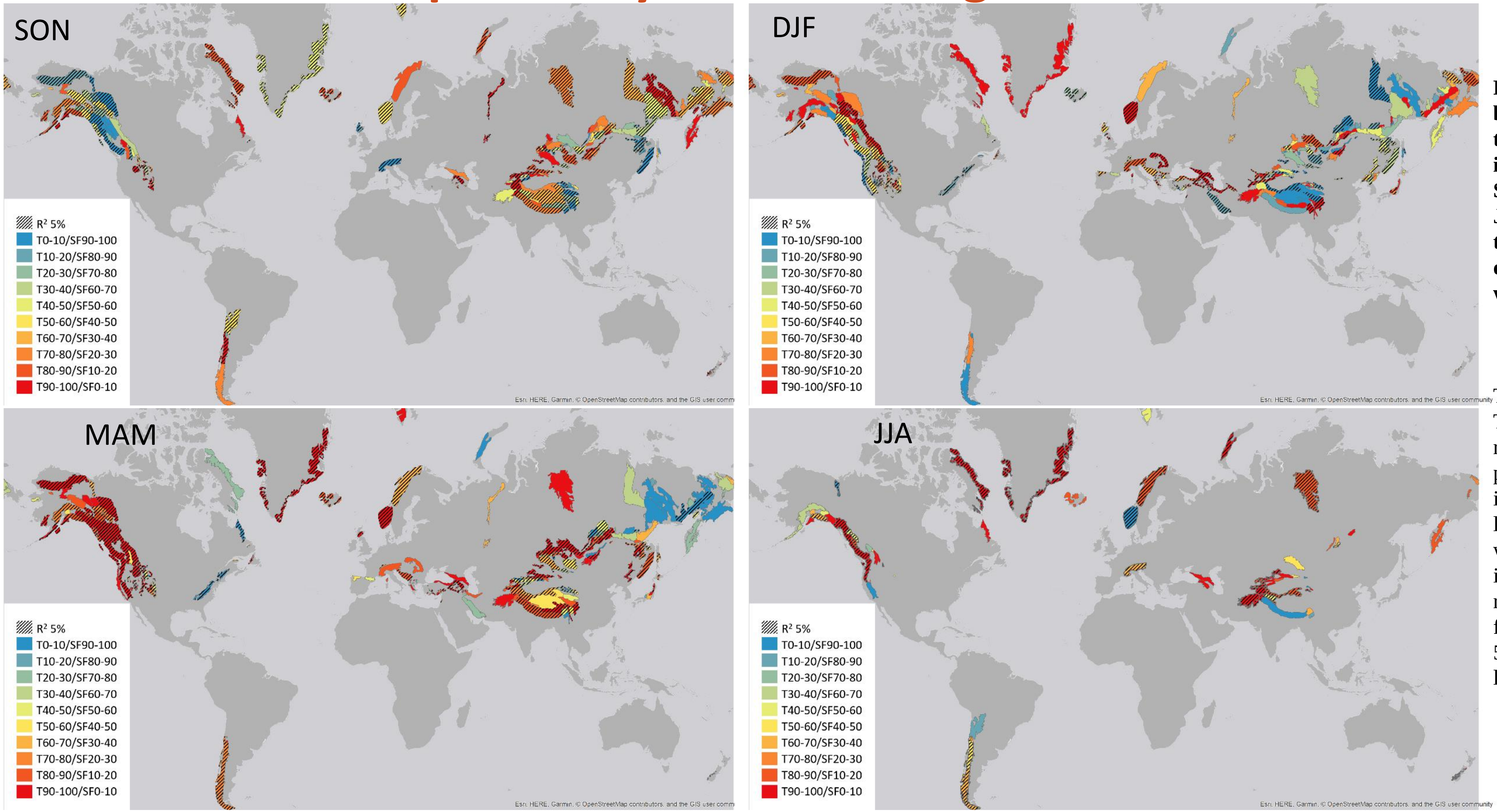




The period June-July-August (JJA) is characterized by negative trends, all located in the Northern Hemisphere but one in South America

b1: 300-1000m, b2: 1000-2500m, b3: 2500-4000m, b4: 4000-5500m, b5: > 5500m.

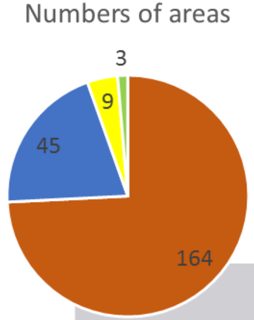
Dependency on meterological factors



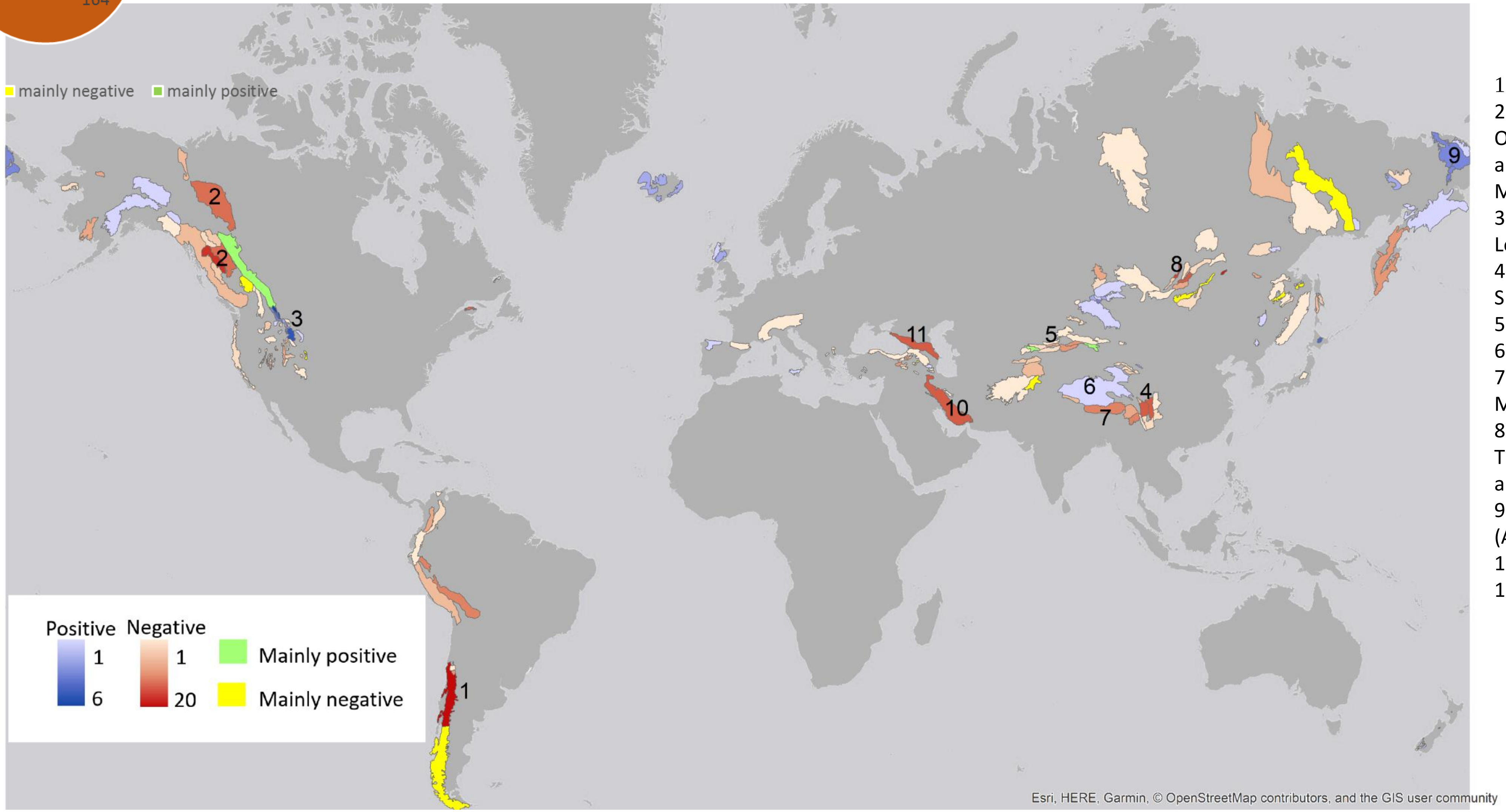
Relationship between SCA and the variables T, SF in the periods SON, DJF, MAM, JJA, as results of the general dominance weights approach.

The importance of T and SF is reported in percentage as indicated in the legend. The areas with crossed bars indicate that the relationships are found significant at 5% significance level.

Hotspots of snow cover changes in global mountain regions over 2000-2018



Numbers of areas with only negative, positive, mainly negative, and mainly positive changes for the different analyzed parameters (SCA, SCD, FSD, LSD at different elevations and periods)



1 SouthAmerica-02
2 Skeena Mountains, Omineca Mountains, and Mackenzie Mountains
3 Flathead Range and Lewis Range
4 Daxue Shan and Shaluli Shan
5 TienShan
6 Tibetan Plateau
7 Nyainqentanglha Mountains
8 Baykal'skiy Khrebet, Tungirskiy Khrebet and Ikatskiy Khrebet
9 Chukotskiy (Anadyrskiy) Khrebet
10 Zagros Mountain
11 Greater Caucasus

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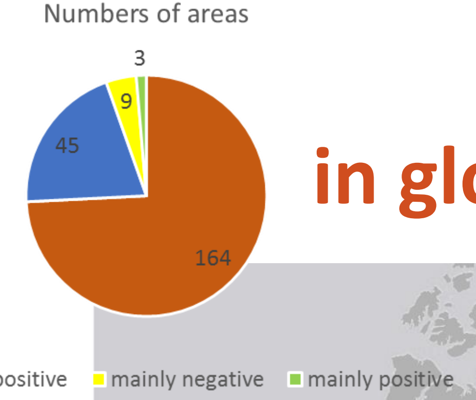

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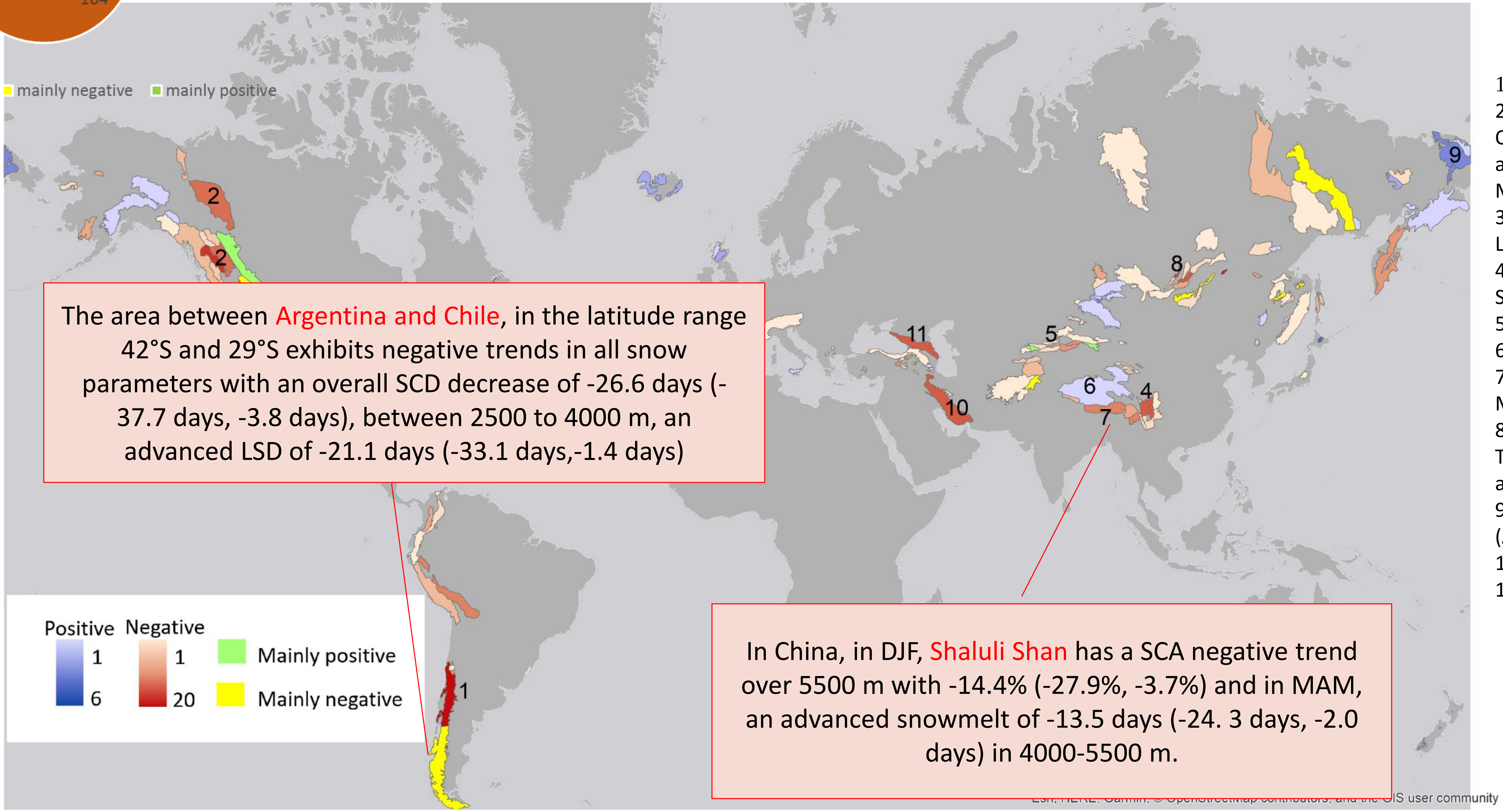

The area between Argentina and Chile, in the latitude range 42°S and 29°S exhibits negative trends in all snow parameters with an overall SCD decrease of -26.6 days (-37.7 days, -3.8 days), between 2500 to 4000 m, an advanced LSD of -21.1 days (-33.1 days,-1.4 days)

In China, in DJF, Shaluli Shan has a SCA negative trend over 5500 m with -14.4% (-27.9%, -3.7%) and in MAM, an advanced snowmelt of -13.5 days (-24. 3 days, -2.0 days) in 4000-5500 m.

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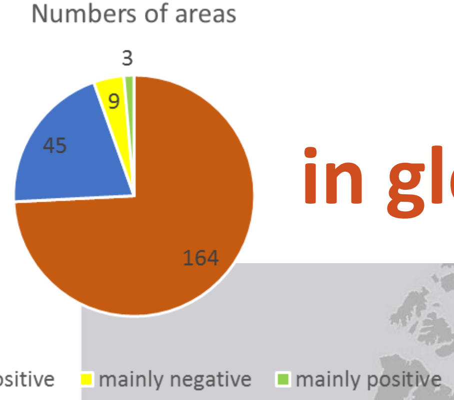
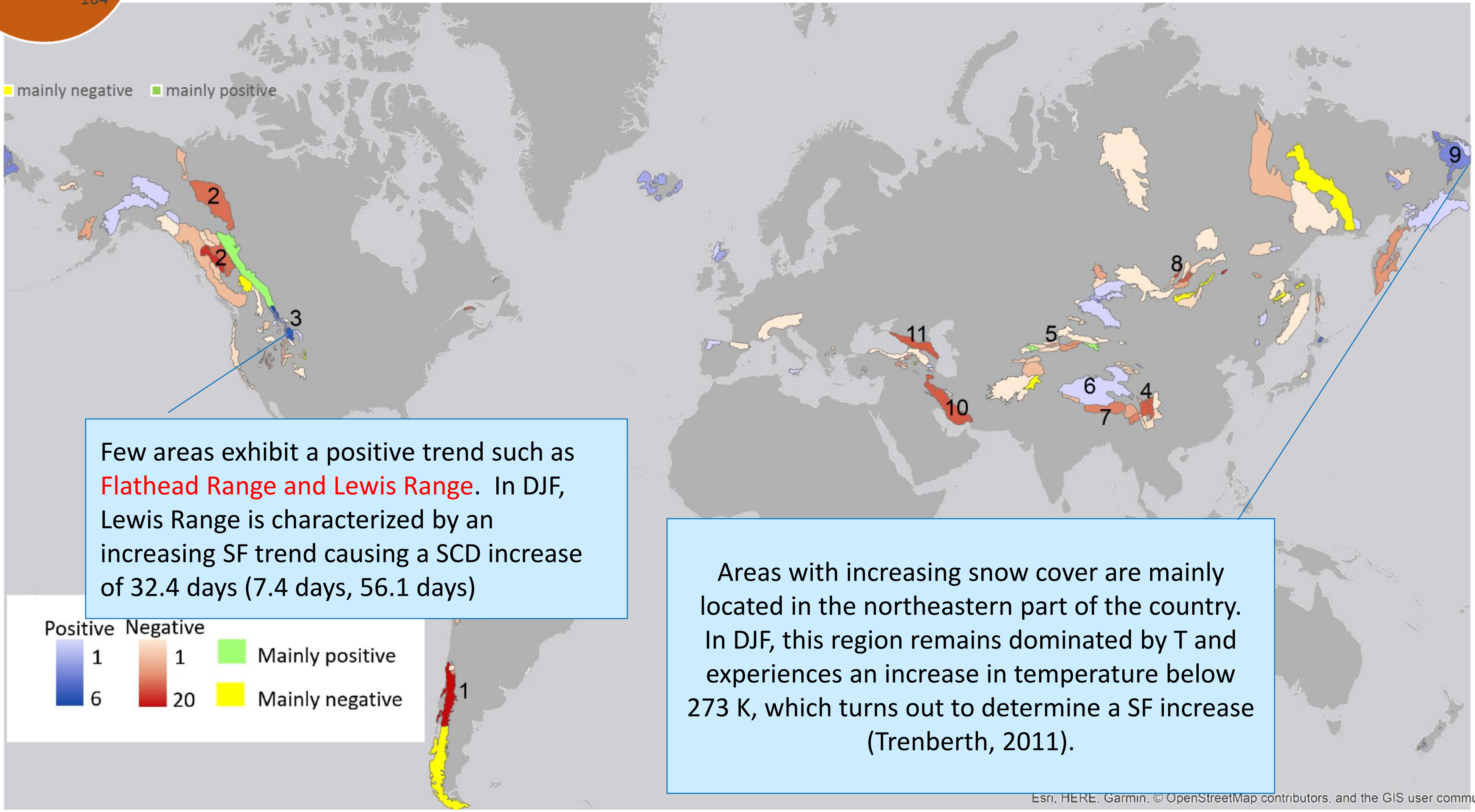


Numbers of areas with only negative, positive, mainly negative, and mainly positive changes for the different analyzed parameters (SCA, SCD, FSD, LSD at different elevations and periods)



Few areas exhibit a positive trend such as Flathead Range and Lewis Range. In DJF, Lewis Range is characterized by an increasing SF trend causing a SCD increase of 32.4 days (7.4 days, 56.1 days)

Areas with increasing snow cover are mainly located in the northeastern part of the country. In DJF, this region remains dominated by T and experiences an increase in temperature below 273 K, which turns out to determine a SF increase (Trenberth, 2011).

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Trenberth K. E. Changes in precipitation with climate change. Climate Research, 47, 123-138 (2011) doi:10.3354/cr00953

Conclusions and next steps

Main findings

By using MODIS images from 2000 to 2018, this work analyzes the variation in snow cover, and snow phenology (onset, melt and accumulation) in global mountain ranges (Notarnicola, 2020).

- around 78% of the global mountain areas are undergoing a snow decline
- snow cover duration decreases up to 43 days, and a snow cover area decreases up to 13%.
- Anticipation of snowmelt (days/y) is larger than snow onset delay (days/y) in the analyzed time period
- few areas show positive changes with snow cover duration increase up to 32 days, and snow cover area increase up to 11%, mainly during wintertime in Northern Hemisphere.
- from 4000 m upward only negative changes are detected in the analyzed parameters.

Next steps

- Update snow parameters (data are freely available)
- Introduce the dynamics of snow albedo in relation to snow onset and melt changes
- Understand the snow changes in relation to global circulation atmosphere dynamics
- Understand the relationship with vegetation phenology

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