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Varying snow and vegetation signatures of surface-albedo feedback on the Northern Hemisphere land warming

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Supplementary material for this article is available online

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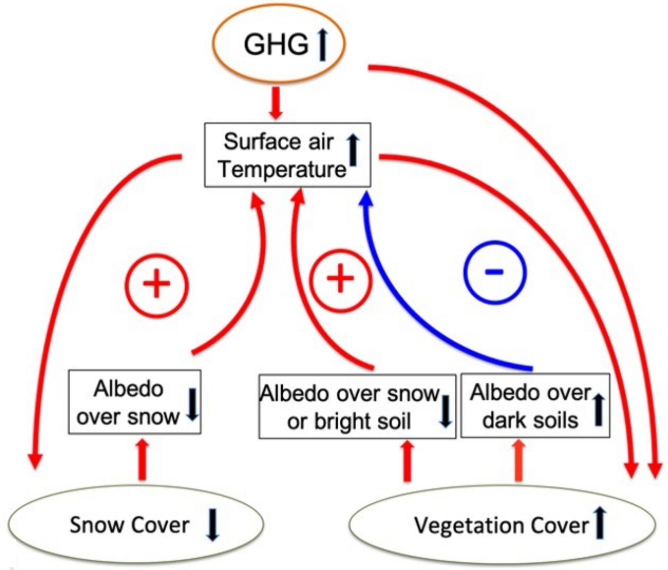

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Outline

- Method and Data
- Results of Surface Albedo Feedback (SAF) composite (1998-2012 vs. 1982-1996) analysis
  - ➢ annual mean and seasonal cycle of SAF
  - ➢ Regressions of SAF vs. Vegetation cover and Snow Extent
- Summary and Conclusions
  - ➢ Future work: observational benchmark for evaluation of CMIP6 and towards next generation ESM

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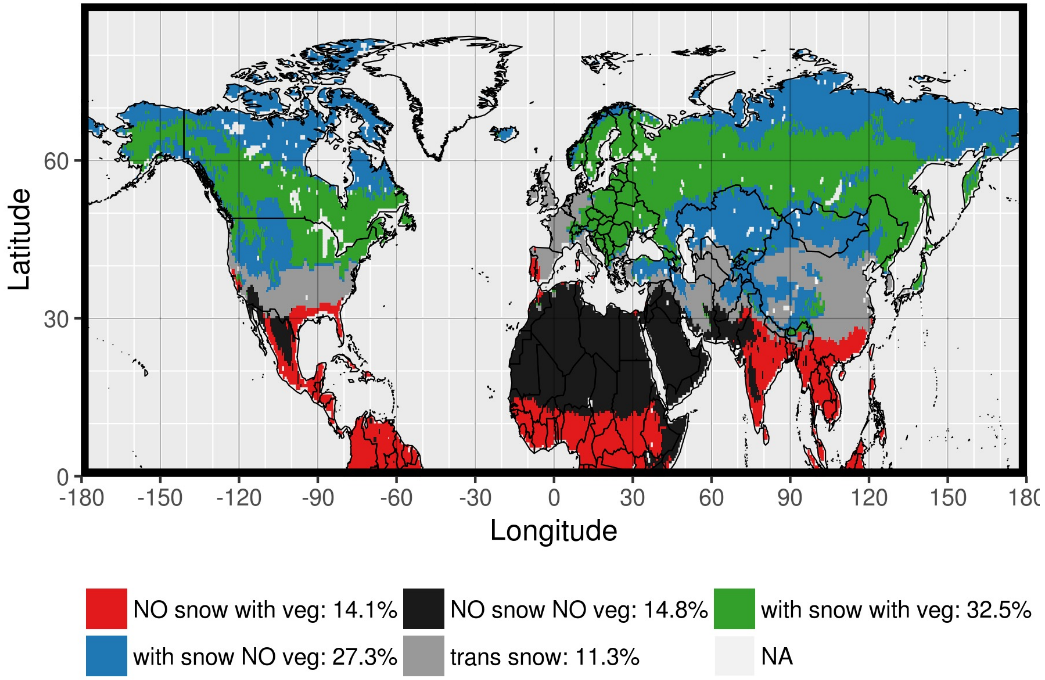
Method and Data

Alessandri et al., 2021 ERL

Method: composite analysis, domain discrimination and observational/reanalysis dataset.

The spatially varying signatures of surface-albedo feedback are identified by comparing the temporal composites of the recent [1998-2012] with historical reference [1982-1996] periods over three different NH domains that are distinguished based on the dominance of snow and/or vegetation cover.



	Producer	Spatial domain and resolution	Temporal Resolution	Period
LAI Leaf Area Index	GLCF-GLASS	Global 0.05°x0.05°	8-days	1982-2014
ALB Surface Albedo	GLCF-GLASS	Global 0.05°x0.05°	8-days	1982-2012
SE Snow Extent	NSIDC	Northern Hemisphere 180x180 EASE grid	weekly	1979-2012
T2M 2m Temperature	ERA-INTERIM	Global T255, 80km x 80km	daily	1979-present
SSRD Surface Downward short-wave radiation	ERA-INTERIM	Global T255, 80km x 80km	daily	1979-present

Thresholds:
-snow: snow cover > 10%
-no_snow: snow cover < 0.1%
-veg/no_veg: LAI >/<0.5

All the datasets homogenized over Northern Hemisphere to the same spatial (0.5°×0.5°) and temporal (8-days) resolution in the common available time range (1982-2012).

Method: definition of the surface albedo feedback (SAF)

Following earlier studies (Hall and Qu 2006, Qu and Hall 2014, Loranty *et al* 2014), the strength in the surface component of the albedo feedback is represented by the relative % change in surface albedo (***ΔALB)*** that is associated with the corresponding difference in air temperature at the surface (***ΔT2M***):

$$SAF_{ALB} = \frac{\Delta ALB \cdot 100}{ALB \cdot \Delta T2M}$$

The surface radiative energy feedback governed by albedo changes is consistently evaluated using the ratio between the composite-difference in net short-wave radiation at the surface (**SSRN**; positive downward) and the respective temperature change.

$$SAF_{SSRN} = \frac{\Delta SSRN}{\Delta T2M}$$

The composite analysis has been applied to the annual means as well as for separate monthly-means to determine the annual cycle of the surface albedo feedback. To account for the uncertainties related to random errors in the observational data and internal variability in the space/time domain of the composites, a 1000 iteration bootstrap procedure is employed for both reference (1982-1996) and recent (1998-2012) periods, as well as for their difference.

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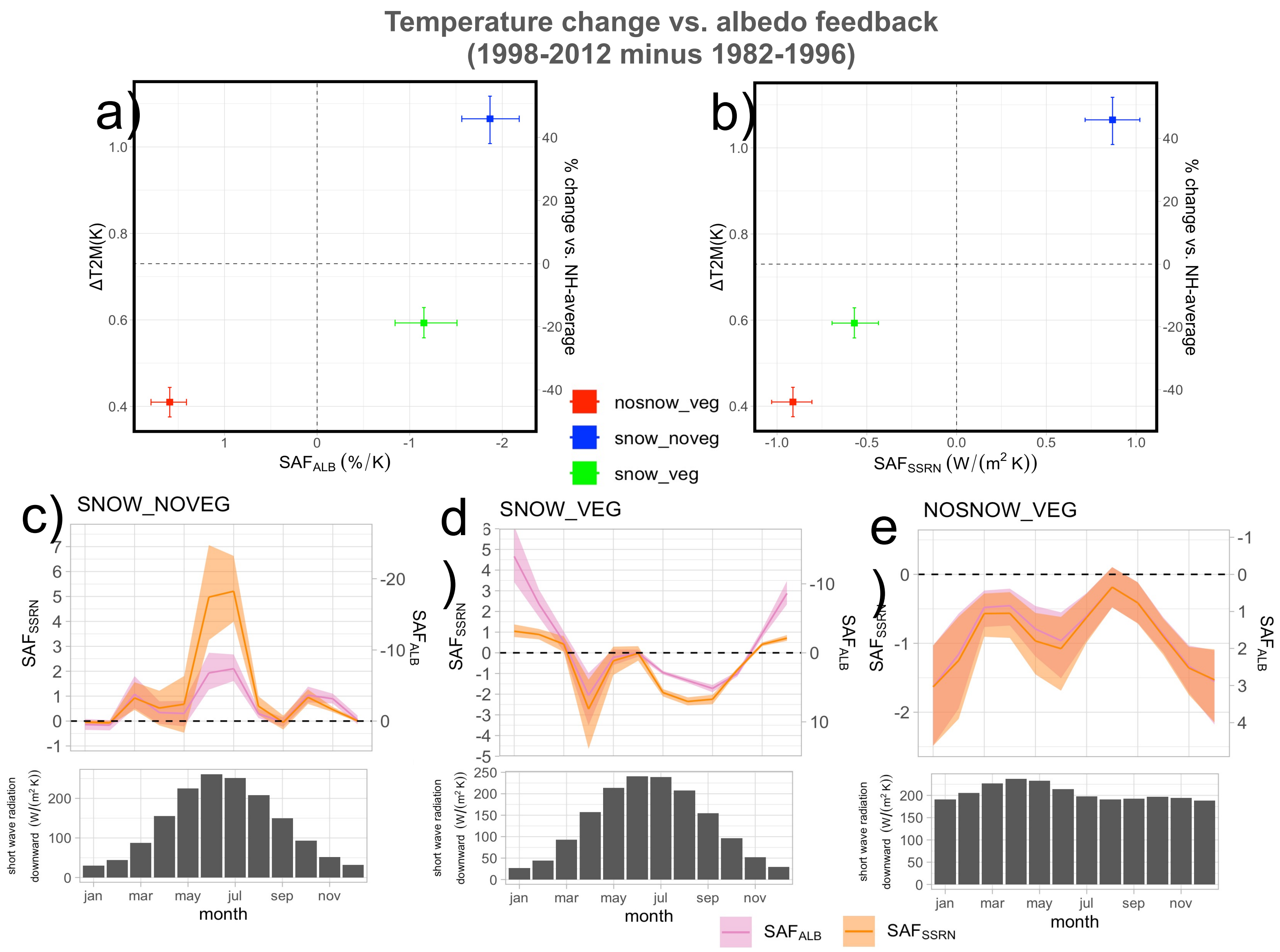
Results

Alessandri et al., 2021 ERL

Results: annual mean and seasonal cycle of SAF (1998-2012 minus 1982-1996)



Change (1998–2012 minus 1982–1996) in T2M vs SAF in terms of (a) ALB change (SAF_{ALB}) and (b) change in absorbed short wave (SAF_{SSRN}) for each considered domain. The regional temperature change relative to the average NH land domain is displayed on right y-axis. (c)–(e) Seasonal cycle of (pink) SAF_{ALB} and (orange) SAF_{SSRN} for (c) SNOW_NOVEG (d) SNOW_VEG and (e) NOSNOW_VEG. Left axis is SAF_{SSRN} ($W(m2 \cdot K)^{-1}$), right is SAF_{ALB} ($\%K^{-1}$). Inset histograms show the climatological seasonal cycle of available downward short-wave radiation (SSRD; $W\ m^{-2}$) for each month. Uncertainty of the estimates is assessed by re-sampling the grid points in each domain by a bootstrap procedure with replacement (1000 iterations). 5th and 95th percentiles of the synthetic distribution are displayed.

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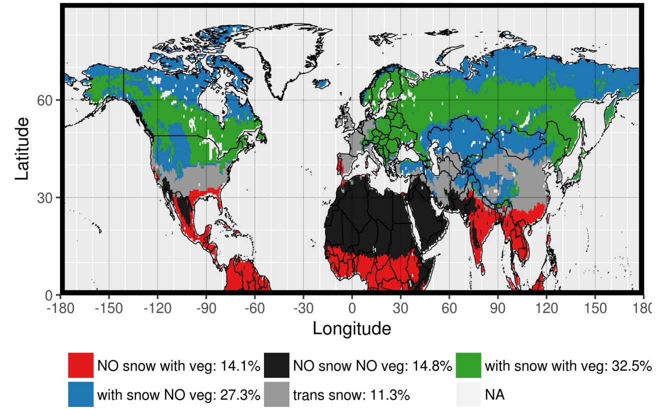
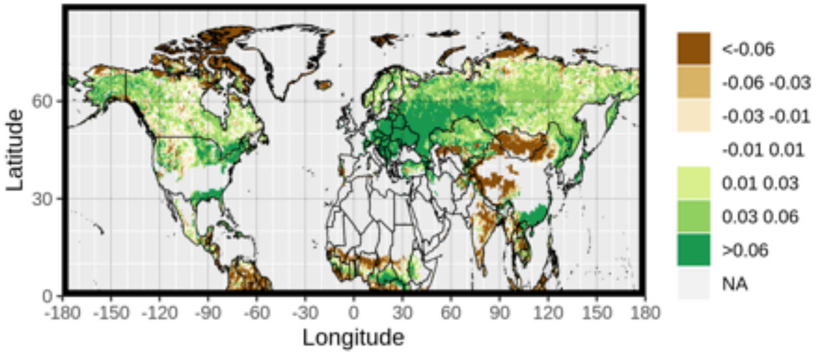
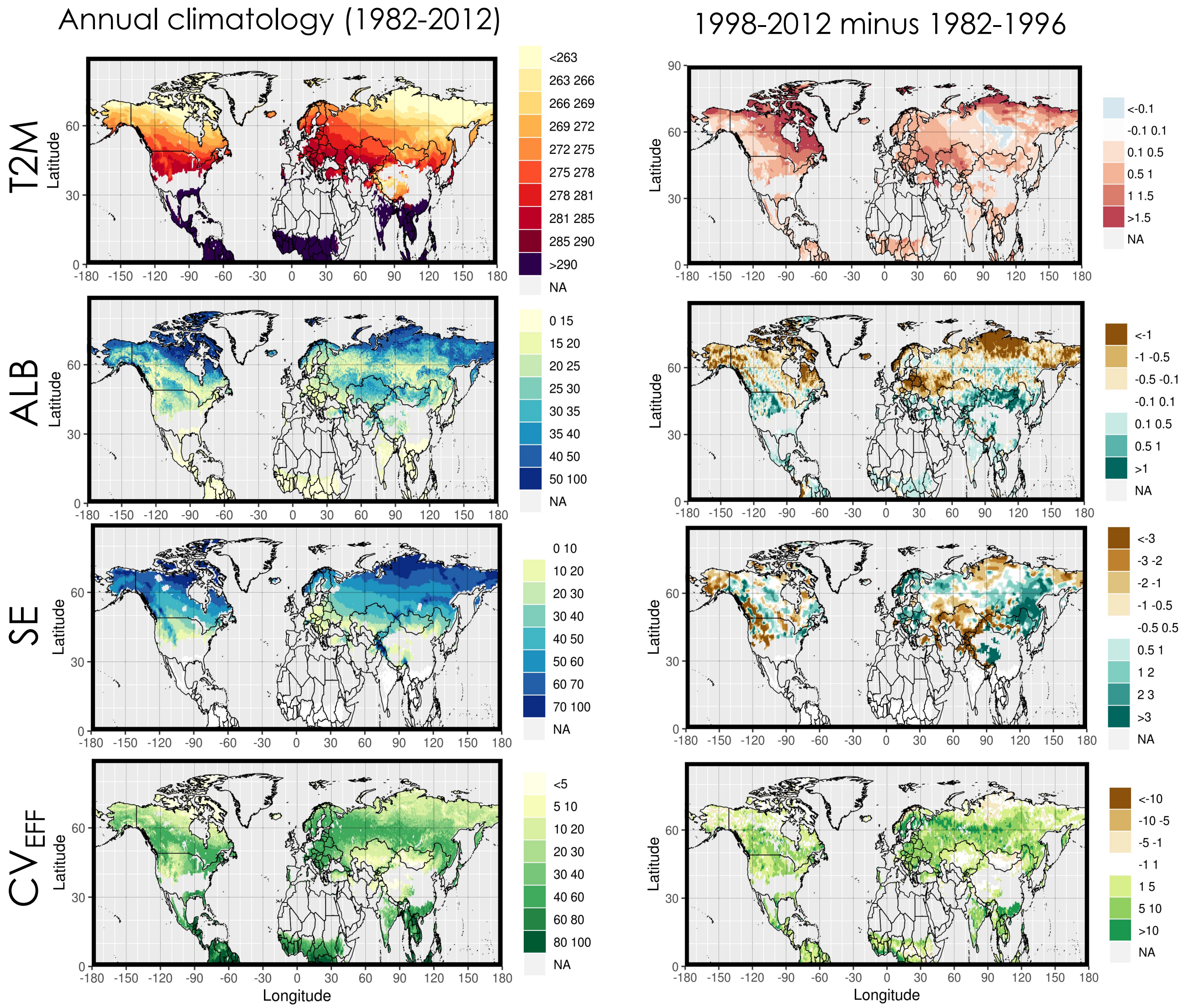
Results: annual mean climatology and change (1998-2012 minus 1982-1996 composite-map differences)



Vegetation minus Soil Albedo

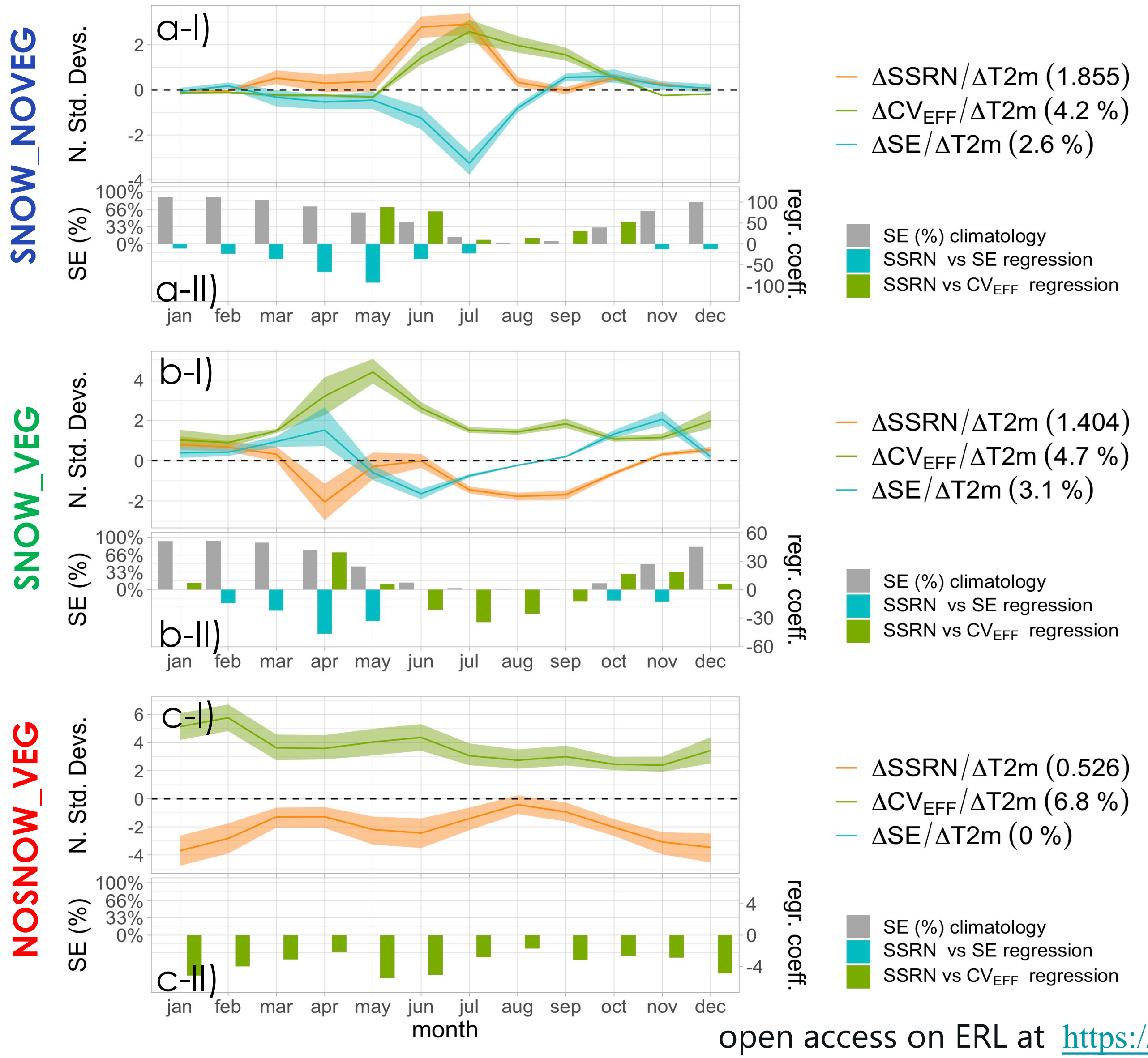


Estimates from Rechid et al., (2009)



Alessandri et al., 2021 – supplementary material at https://doi.org/10.1088/1748-9326/abd65f

Results: drivers of the SAF along the seasonal cycle – SAF_{SSRN} regressions vs. Vegetation cover (CV_{EFF}) and Snow Extent (SE)



Annual cycle of change per degree K in SSRN (SAF_{SSRN}; orange), SE (blue), and CV_{EFF} (green) for a-I) SNOW_NOVEG b-I) SNOW_VEG and c-I) NOSNOW_VEG. Normalization is performed with respect to the standard deviation of the seasonal cycle (reported in brackets in the legend). Uncertainty of the estimates is assessed by the 1000 iteration bootstrap procedure. 5th and 95th percentiles of the synthetic distribution are displayed. Panels -II report the regression coefficients of absorbed short wave changes vs. (blue) snow changes and (green) CV_{EFF} changes. Only the regression-slopes that passed statistical significance at 10% significance level are displayed. In grey the climatological seasonal cycle of fractional [%] snow extent (SE) is reported.

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Summary and conclusions

- For the first time, a 31-year (1982-2012) high-frequency observational record has been exploited to understand and quantify the strength of the surface-albedo feedback over NH lands.
- The analysis reveals and quantifies varying snow and vegetation signatures of surface-albedo feedback in the recent historical period (1998-2012 vs. 1982-1996):
  - ➢ Snow cover reduction consistently provides a large positive surface-albedo feedback on warming where snow dominates (+0.87 (CI 95%, +0.68, +1.05) $W(m2 \cdot K)^{-1}$).
  - ➢ Vegetation expansion can produce either positive or negative feedbacks in different regions and seasons depending on whether the underlying surface being replaced has higher (e.g. snow) or lower (e.g. dark soils) albedo than vegetation.
  - ➢ Overall the surface-albedo feedback is predominantly negative where vegetation dominates, therefore contrasting temperature warming (-0.67 (CI 95%, -0.53, -0.82) $W(m2 \cdot K)^{-1}$).
- The observational analysis from this work is supplying fundamental knowledge to model and predict how the surface-albedo feedback will evolve and affect the strategies for the mitigation of future climate change.

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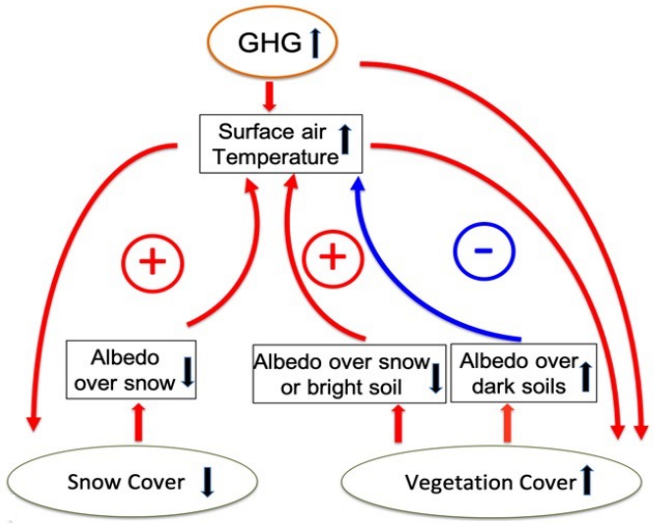
Future work

- Surface albedo feedbacks shows a large spread and divergence among the available state-of-the-art ESMs, due to uncertainties in the representation of vegetation-snow processes and the dynamics of vegetation and to uncertainties in land-cover parameters (Qu and Hall, 2014; Loranty et al., 2014; Thackeray and Fletcher, 2015; Thackeray et al., 2018).

- By exploiting the unprecedented observational benchmark to evaluate the ESMs currently engaged in CMIP6, this work will allow an improved and better constrained representation of the processes underlying surface albedo feedbacks in the next generation of ESMs.



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