

Identification, characteristics, and dynamics of Arctic extreme seasons

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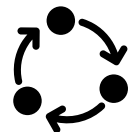
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Outline:

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Motivation & Research Questions



Method

- Data and definition of Arctic sub-regions
- Identification of extreme seasons



Case Studies

- Seasonal substructure
- Synoptic overview
- Analysis DJF 11/12
- Analysis DJF 16/17
- Surface preconditioning



Summary

→ go to abstract

→ view preprint (currently under review for WCD)

→ contact the authors

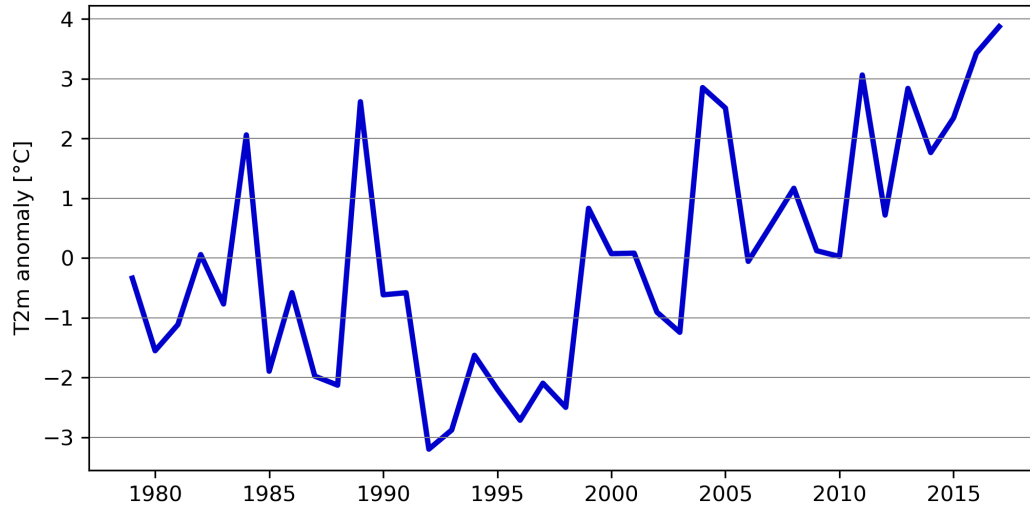


Figure 1: Seasonal T_{2m} anomaly (DJF) for $> 80^{\circ}\text{N}$ (ERA5 reanalysis data, ECMWF).

Why in the Arctic?

- Rapid surface warming and sea-ice decline in last decades → **Arctic Amplification**
- Large internal variability

Arctic Extreme Season =

Combination of considerable seasonal anomalies of several parameters over a sizable area in the Arctic region. Here, we focus on surface variables, namely, 2m-temperature, surface energy balance and freshwater fluxes, which are strongly linked to air-sea and air-ice interactions.

Research Questions:

- How can extreme seasons be defined objectively in Arctic sub-regions?
- Which dynamical processes determine their sub-structure?
- What is the role of surface preconditioning for the formation of extreme seasons?

Data: ERA5 reanalysis data from ECMWF

- DJF 1979/80 to SON 2018
 - Hourly atmospheric fields and short-range forecasts spatially interpolated to a $0.5^\circ \times 0.5^\circ$ horizontal grid
- In this project we consider anomalies defined as deviations from a transient climatology. The transient climatology is computed using a 21-day running-mean filter and 9-year running mean.

Division of Arctic in distinct sub-regions:

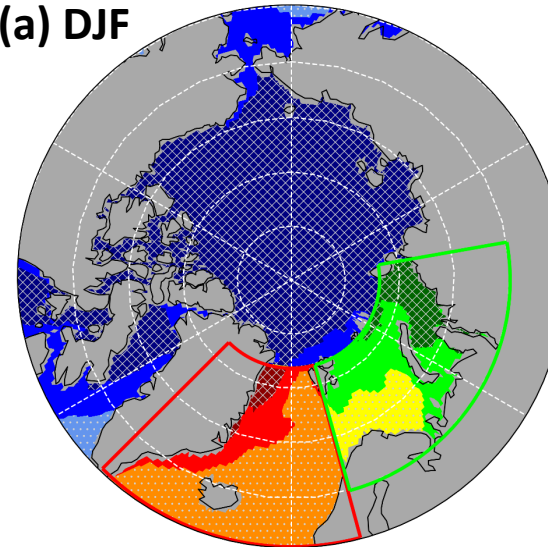
- Nordic Seas (**NO**), Kara-Barents Seas (**KB**) and remaining Arctic poleward of 60°N (**AR**)
- Considering surface conditions according to the climatological sea ice concentration (SIC_{clim})

Ice (I): $\text{SIC}_{\text{clim}} > 0.9$

Sea (S): $\text{SIC}_{\text{clim}} < 0.1$

Mixed (M): $0.1 \leq \text{SIC}_{\text{clim}} \leq 0.9$

(a) DJF



(b) JJA

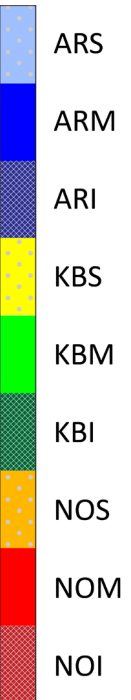
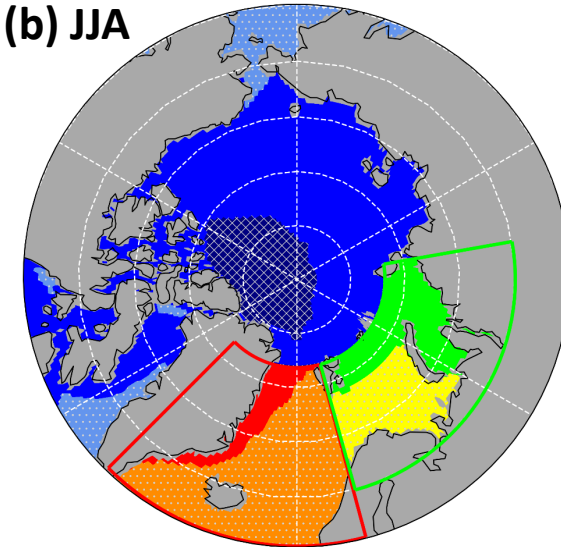


Figure 2: Sub-regions defined based on sea ice criterion (color) for (a) DJF and (b) JJA.

Arctic extreme seasons during the ERA5 period are defined for each sub-region by analysing the seasonal-mean anomalies of six parameters: **2m-temperature (T_{2m})**, **surface sensible heat flux (H_s)**, **surface latent heat flux (H_L)**, **surface solar radiation (R_s)**, **surface thermal radiation (R_L)** and **precipitation (P)**. For further analysis, we define the sum of the surface energy balance components as $H_s + H_L + R_s + R_L = E_s$.

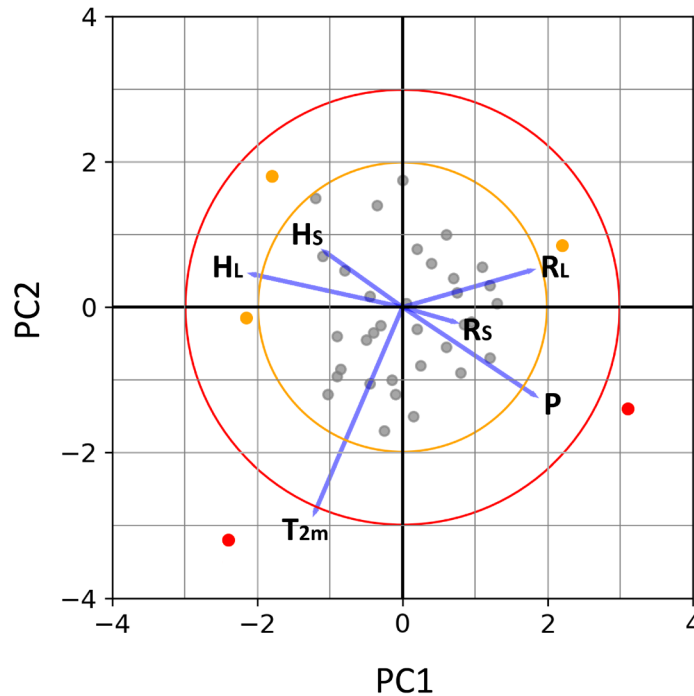


Figure 3: Schematic PCA biplot for a specific region and season with PC1 along the x-axis and PC2 along the y-axis. Grey dots represent single seasons, red (orange) dots show extreme (anomalous) seasons. Blue lines represent the projections of the original parameters onto the first two principal components. Values of $d_M=2$ and $d_M=3$ are shown by orange and red circles, respectively.

PCA analysis: [as variables are often correlated, dependent on the surface conditions]

- 39 seasonal-mean anomalies for DJF, MAM, JJA & SON, respectively
- Normalization with the intra-seasonal standard deviation (scaling variables H_s , H_L , R_s , R_L by the maximum standard deviation of the individual parameters)
- Reducing to 2-dimensional space
- Define anomalous and extreme seasons, respectively, according to their combination of PC1 and PC2

$$\text{Mahalanobis distance in PC biplot: } d_M = \sqrt{\frac{PC1^2}{\sigma_1^2} + \frac{PC2^2}{\sigma_2^2}}$$

Extreme seasons = seasons with $d_M > 3$
Anomalous seasons = seasons with $d_M > 2$ } per sub-region

PCA results

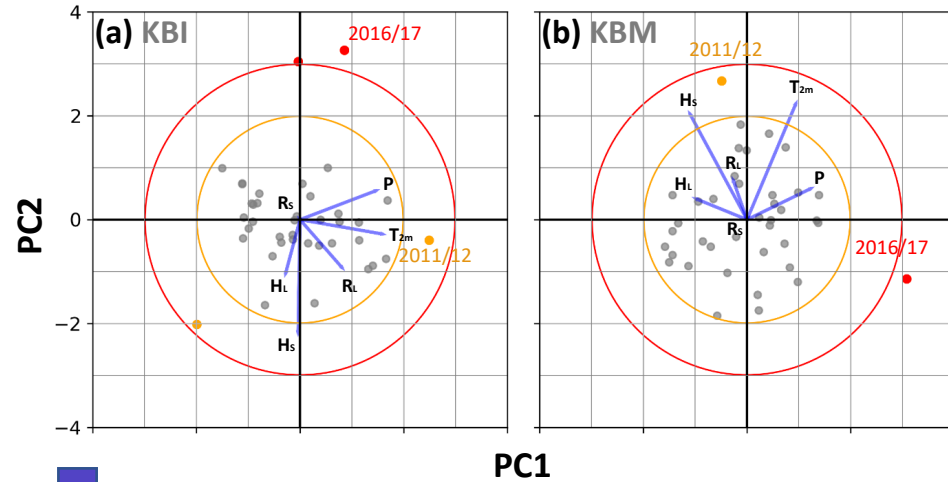


Figure 4: PCA biplot for sub-regions (a) KBI and (b) KBM in DJF.

Extreme winter 2016/17 in KBI, KBM and KBS

Anomalous winter 2011/12 in KBI and KBM

→ Different location in PCA biplot (seasons are nearly orthogonal) implies fundamentally different involved processes leading to the «unusualness» of both seasons.

Seasonal-mean anomalies

Seasonal-mean absolute anomaly = seasonal mean of the absolute daily anomalies

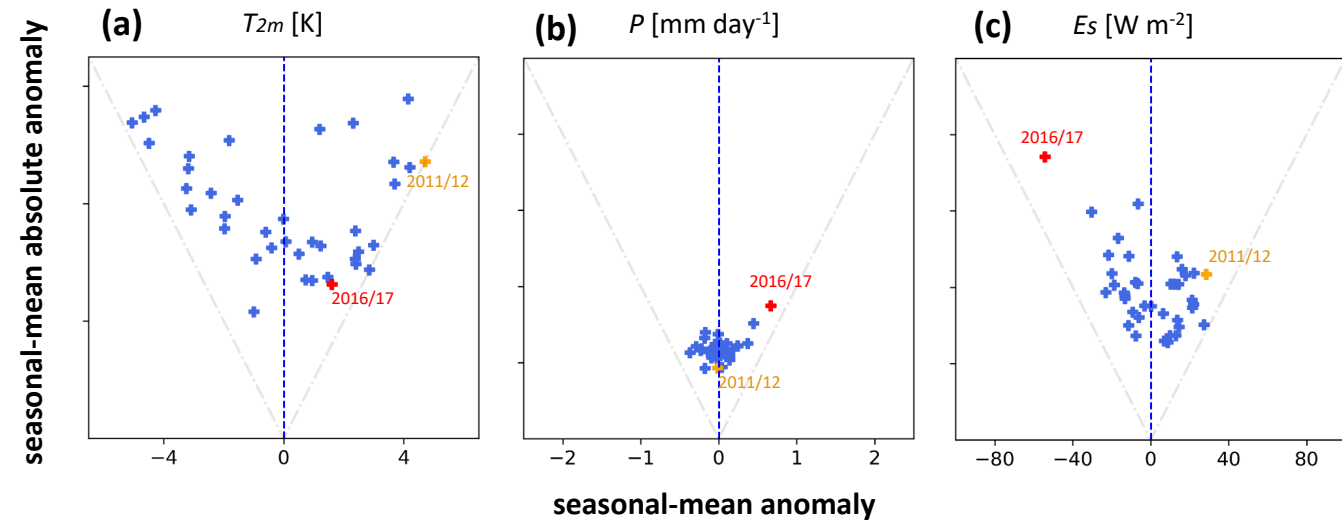


Figure 5: Seasonal-mean anomalies (along x-axis) vs. seasonal-mean absolute anomalies (along y-axis) in DJF for (a) T_{2m} (K), (b) P (mm day^{-1}) and (c) E_s (W m^{-2}) in sub-region KBM. Red (orange) markers represent extreme (anomalous) seasons. The stippled grey line marks where the seasonal-mean anomaly equals the seasonal-mean absolute anomaly.

→ Both seasons show outliers, although in different combinations of parameters and with varying signs.

DJF 11/12: positive seasonal-mean T_{2m} and E_s anomaly

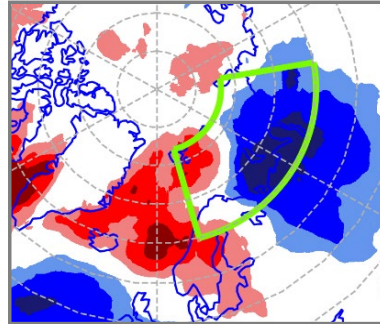
DJF 16/17: positive seasonal-mean P and negative seasonal-mean E_s anomaly

DJF 2011/12

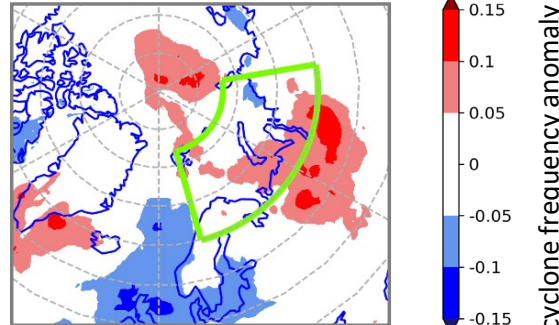
→ Have a more detailed look at this season.

- Enhanced **cyclone frequency** in **Nordic Seas** (Fig. 6a)
→ advection of warm air masses
- Reduced **cyclone frequency** in **Kara-Barents Seas** (Fig. 6a)
→ reduced amount of cold air outbreaks (CAOs)
- Recurrent **blocks over Ural mountains** (Fig. 6c)
→ maintaining T_{2m} anomaly

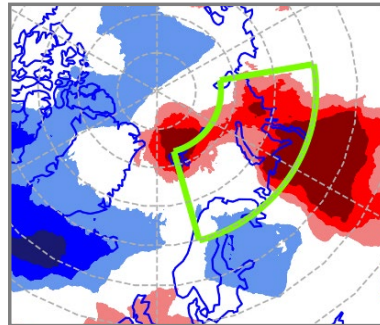
(a) DJF 2011/12



(b) DJF 2016/17



(c) DJF 2011/12



(d) DJF 2016/17

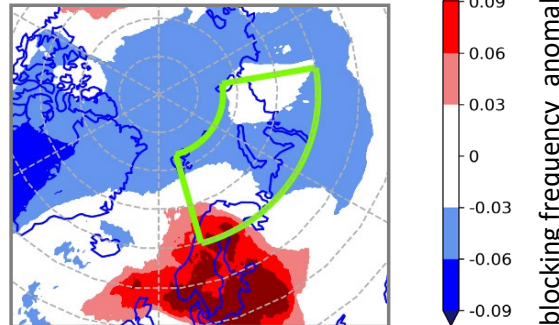


Figure 6: Seasonal-mean cyclone frequency (a,b) and blocking frequency (c,d) anomalies for DJF 2011/12 (a,c) and DJF 2016/17 (b,d). Region of the Kara-Barents Seas is marked with green contour.

DJF 2016/17

→ Have a more detailed look at this season.

- Enhanced **blocking frequency** **over Scandinavia** (Fig. 6d)
→ several warm episodes
- Frequent **passage of cyclones** (Fig. 6b)
→ frequent CAOs (cold sector), further facilitated by reduced SIC and warm ocean temperatures
→ frequent precipitation events and warm episodes

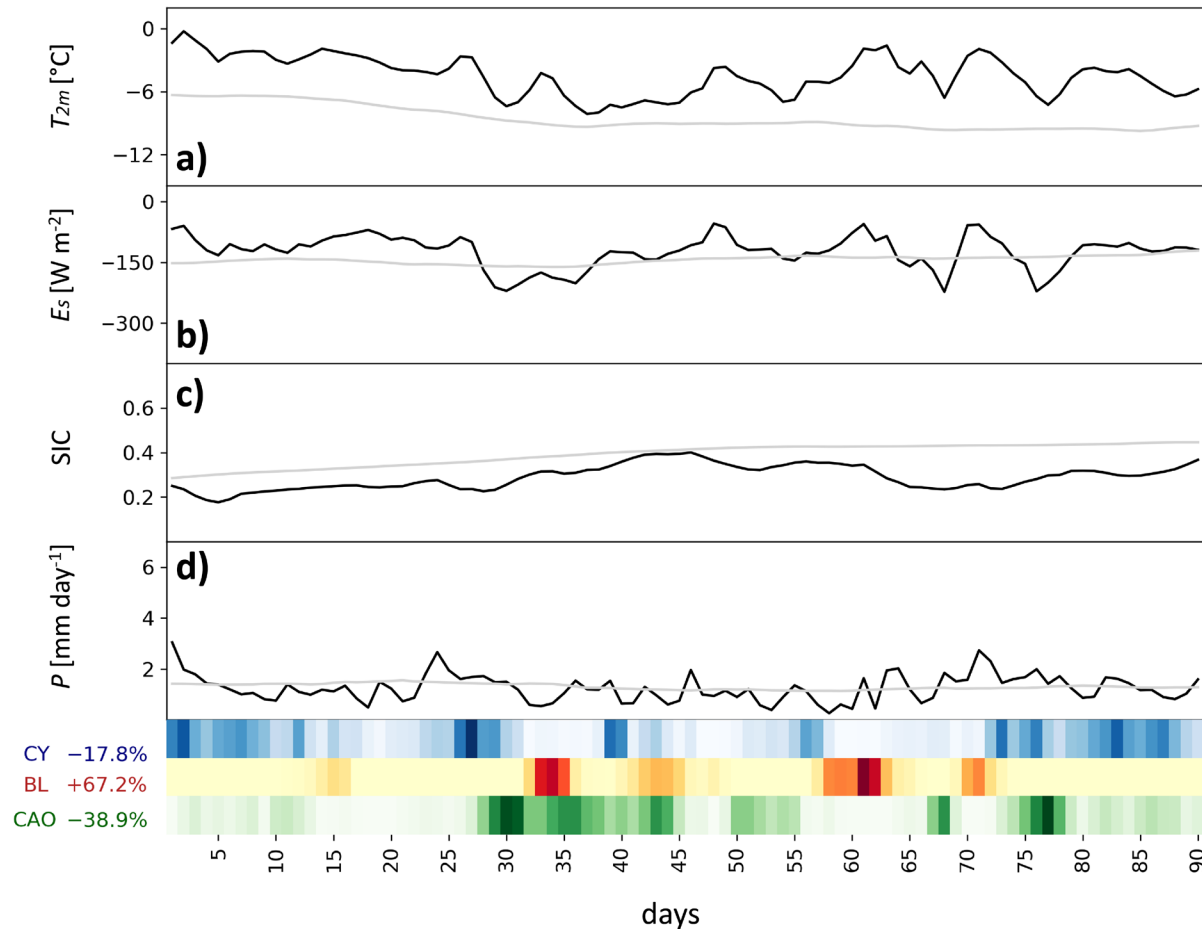


Figure 7: Time series of daily-mean (a) T_{2m} (in °C), (b) E_s (in $W\ m^{-2}$), (c) SIC and (d) P ($mm\ day^{-1}$) averaged in the region of the Kara-Barents Seas (KBI, KBM, and KBS) in DJF 2011/12 (black lines). The transient climatology is shown by grey lines. Blue, orange and green heatmaps show the daily-mean coverage of the region by cyclones, blocks and cold air outbreaks, respectively (the darker the color the higher the coverage). Relative frequency anomalies of the three weather systems are given in percentages. The horizontal axis indicates days since the start of the season with day 1 corresponding to 01 December.

Characteristics:

- Continuously **positive T_{2m} anomaly** (largest seasonal-mean anomaly in the study period)
- Continuously **negative sea-ice concentration (SIC) anomaly**
- Positive E_s anomaly**

Synoptic situation:

- Repeated passage of **cyclones** in the Nordic Seas
→ transport of warm and moist air masses into the region
- Strongly **reduced CAO** frequency
→ favors persistence of above average T_{2m}
- Several **blocking episodes**
→ coincide with peaks in T_{2m} and E_s

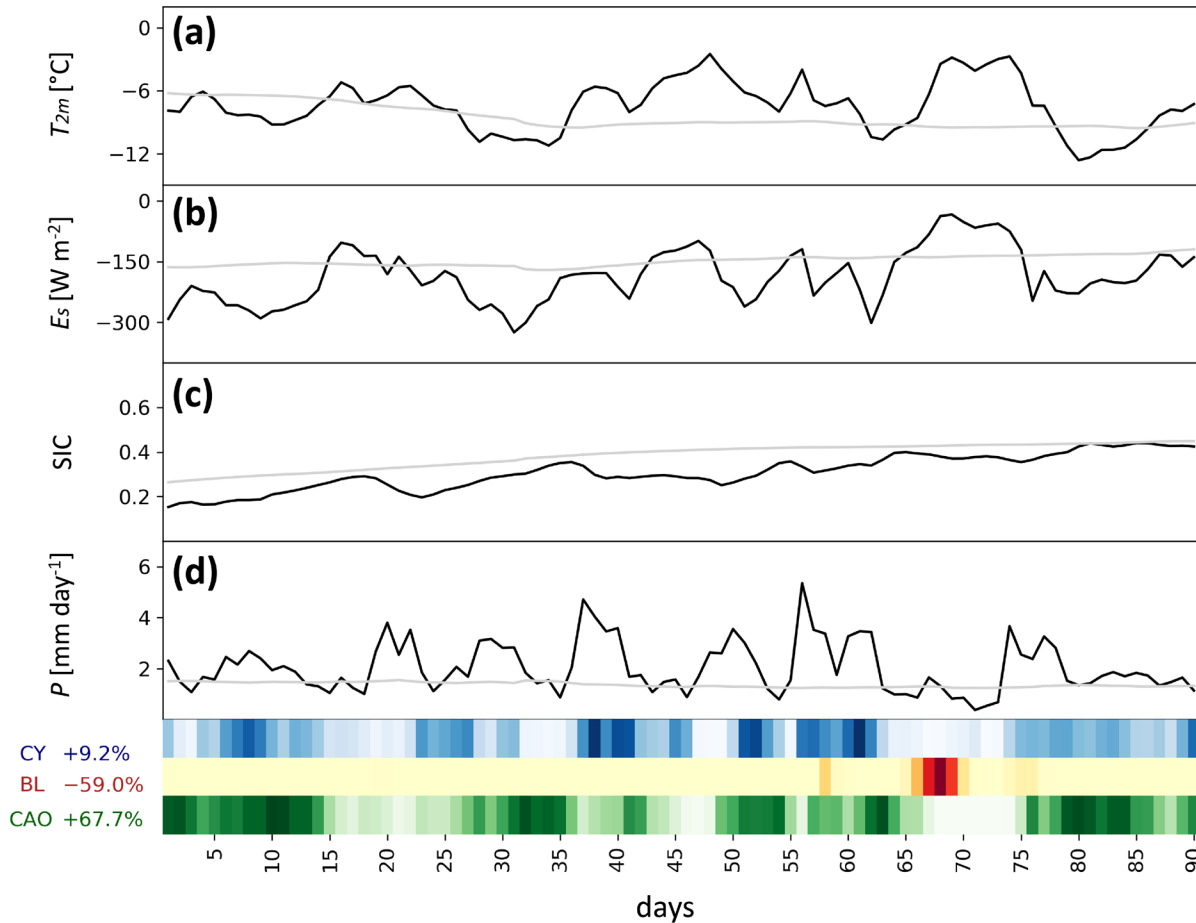


Figure 8: Time series of daily-mean (a) T_{2m} (in $^{\circ}\text{C}$), (b) E_s (in W m^{-2}), (c) SIC and (d) P (mm day^{-1}) averaged in the region of the Kara-Barents Seas (KBI, KBM, and KBS) in DJF 2016/17 (black lines). The transient climatology is shown by grey lines. Blue, orange and green heatmaps show the daily-mean coverage of the region by cyclones, blocks and cold air outbreaks, respectively (the darker the color the higher the coverage). Relative frequency anomalies of the three weather systems are given in percentages. The horizontal axis indicates days since the start of the season with day 1 corresponding to 01 December.

Characteristics:

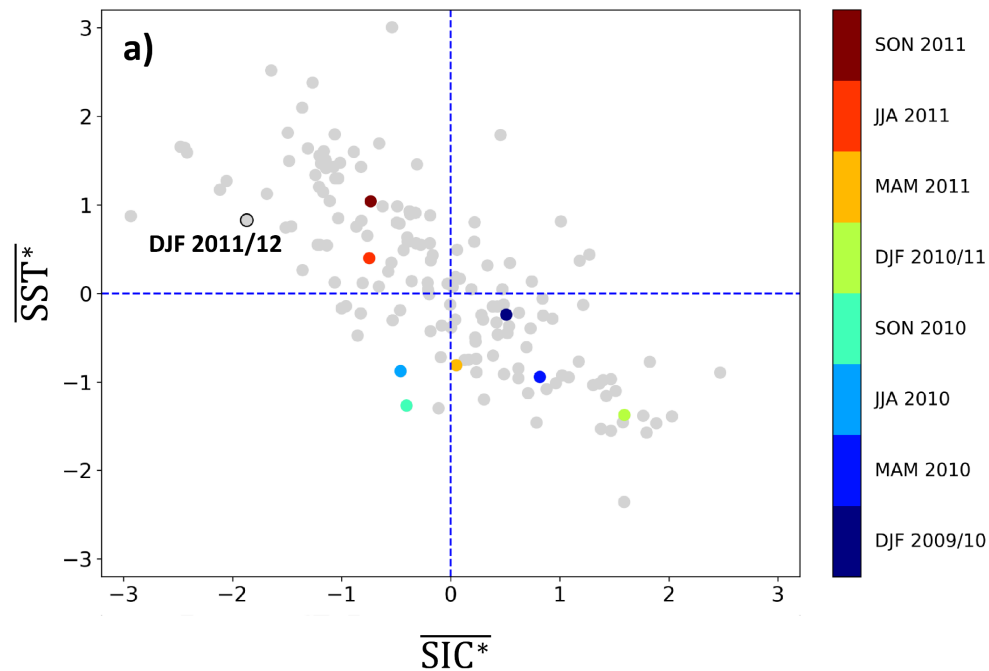
- Strongly **positive P anomaly** (wettest winter in the Kara-Barents Seas in the study period)
- Strongly **negative E_s anomaly**
- Continuously **negative SIC anomaly**

Synoptic situation:

- Repeated passage of **cyclones**
 - several episodic precipitation events
 - strong decrease in SIC (associated wind field pushes sea ice edge further to the North)
- **Large number of CAO events & strongly negative (positive) SIC (SST) anomalies at the beginning of the season**
 - strongly negative anomaly in surface heat fluxes

[SST: sea surface temperature; not shown in plot]

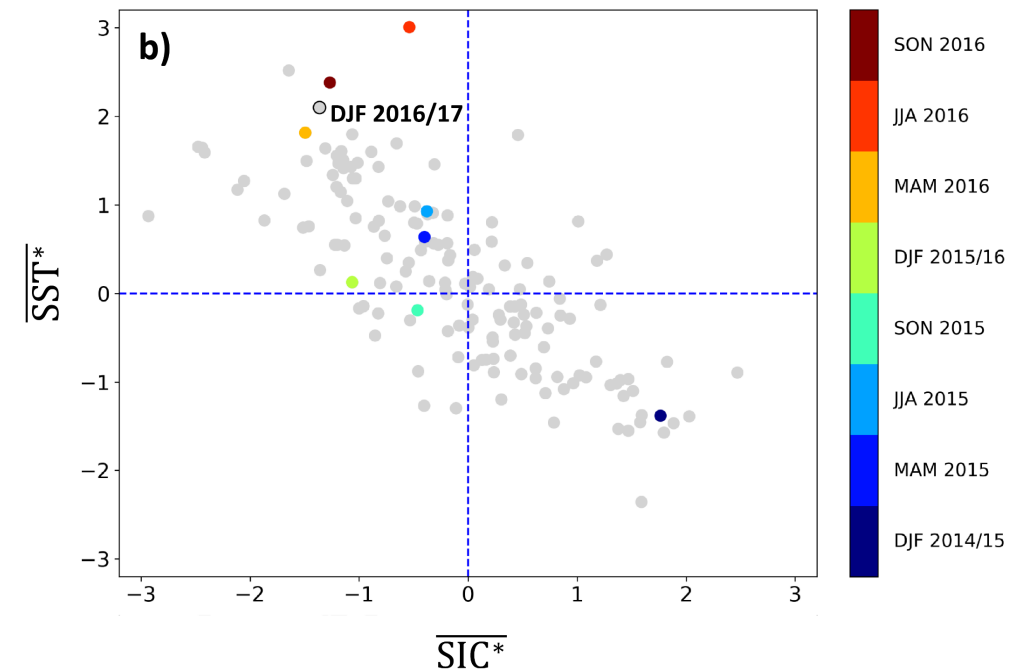
Figure 9: Standardized seasonal-mean anomalies of SIC (along x-axis) and SST (along y-axis) in the Kara-Barents Seas for the entire study period (grey dots) including all seasons. Colored dots highlight the eight seasons preceding **(a)** the anomalous winter 2011/12 and **(b)** the extreme winter 2016/17.



DJF 2011/12

- Normal SIC and SST at the beginning of the season (Fig. 7c)
- No significant SIC/SST anomalies in spring and summer 2011 (Fig. 9a) in this region

→ No surface preconditioning



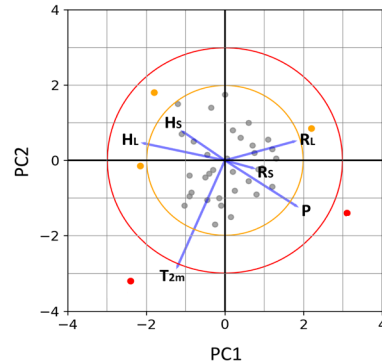
DJF 2016/17

- Low SIC and high SST at the beginning of the season (Fig. 8c)
- Persistent negative SIC and positive SST anomalies throughout the preceding 1.5 years (Fig. 9b)

→ Surface preconditioning

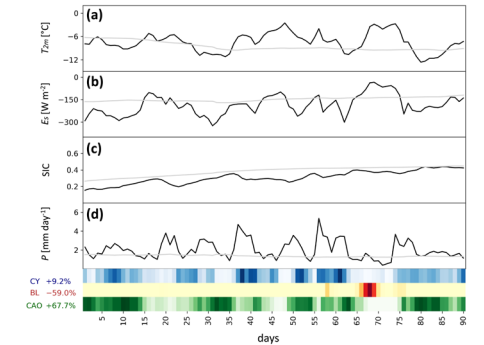
Identification:

- Based on a PCA as combination of the seasonal-mean anomalies of several surface parameters, considering varying surface conditions.



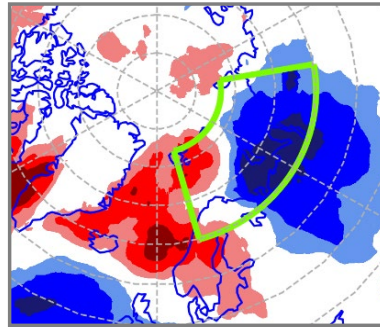
Substructure:

- Highly variable, extreme seasons can show «continuous anomaly in one parameter» or «combination of several noticeable anomalies».



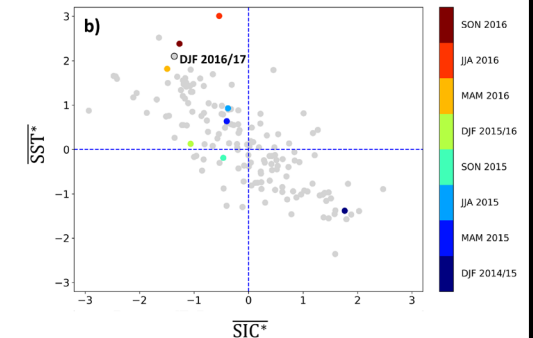
Synoptic Processes:

- Recurrent synoptic events can strongly affect entire seasons.
- CAO frequency strongly influences anomalies in T_{2m} and the surface energy balance due to the impact on air-sea intercation.



Surface Preconditioning:

- Large SIC and SST anomalies at beginning of a season can cause it to be extreme, predominantly in regions with varying sea ice coverage.



Fazit:

Our study shows that extreme seasonal conditions in the Arctic are spatially heterogenous, related to different near-surface parameters, and caused by different synoptic-scale weather systems, potentially in combination with surface preconditioning due to anomalous ocean and sea ice conditions at the beginning of the season.