Arctic extreme seasons: Dynamics and climate change effects

Katharina Hartmuth[1], Maxi Boettcher[1], Heini Wernli[1], and Lukas Papritz[1]

[1]Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland (katharina.hartmuth@env.ethz.ch)

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Outline

1. **Arctic inter-annual variability:** A seasonal-mean perspective in the *T-P* phase space

2. **Change of Arctic inter-annual variability in a warming climate (CESM-LE, RCP8.5)**
   - Amplitude & Pathways
   - Role of weather systems

3. **Arctic extreme seasons in ERA5 and CESM**
   - Identification
   - Characteristics

(1) Arctic inter-annual variability: a seasonal-mean perspective in the *T-P* phase space

Data:

ERA5 reanalysis 1979/80-2017/18 = 39 years

CESM-LE (6h)

RCP8.5

- Historic: 1990-2000
- «End-of-century»: 2091-2100

105 ensemble members with 10/11 years each

- Midcentury periods:
  - 2031-2040
  - 2061-2070

40 ensemble members with 10 years each

- seasonal-mean anomalies
- grid points averaged over > 80°N (excl. land)

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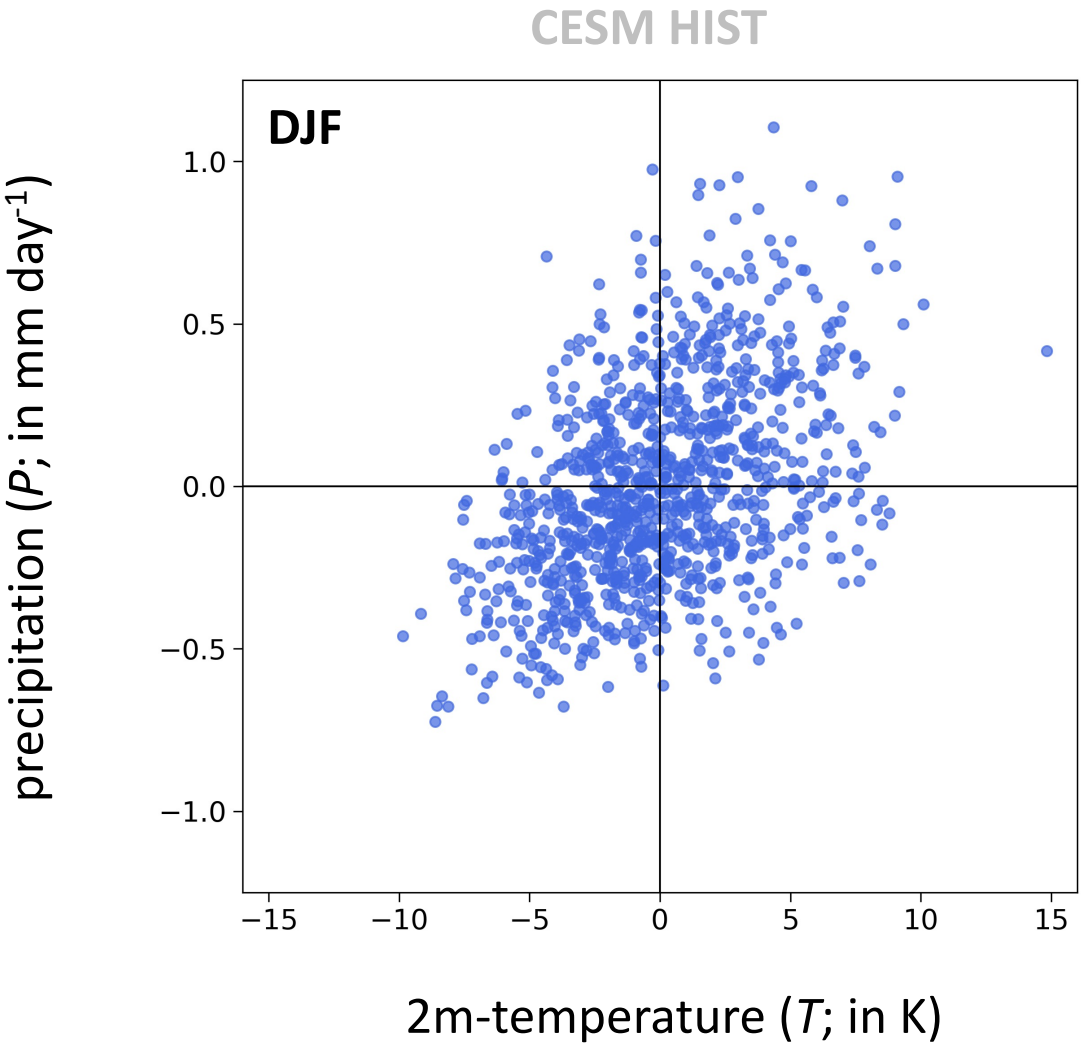
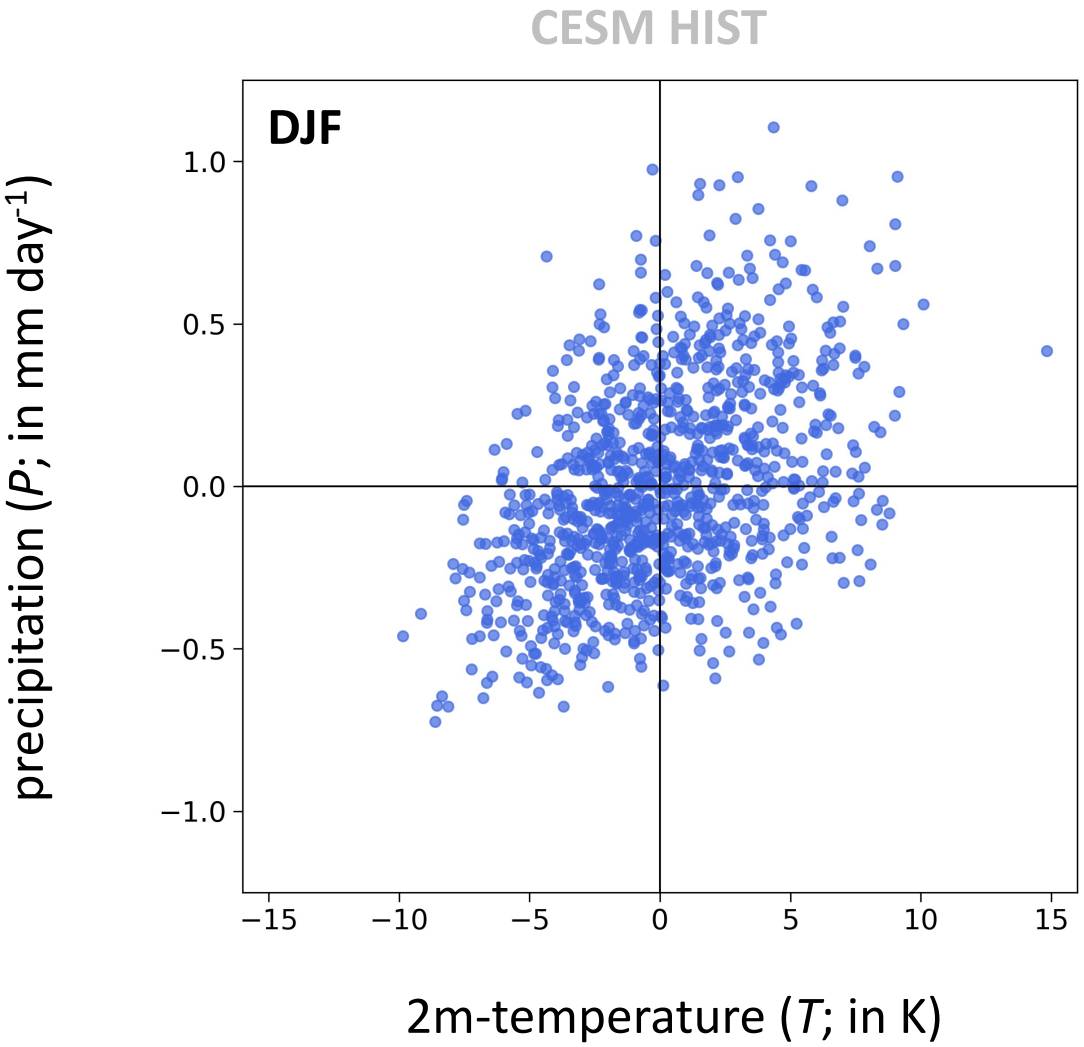


(1) Arctic inter-annual variability: a seasonal-mean perspective in the *T-P* phase space

→ How will this distribution change in the future (RCP8.5 scenario in CESM-LE) in different seasons and regions?

→ What causes Arctic extreme seasons?



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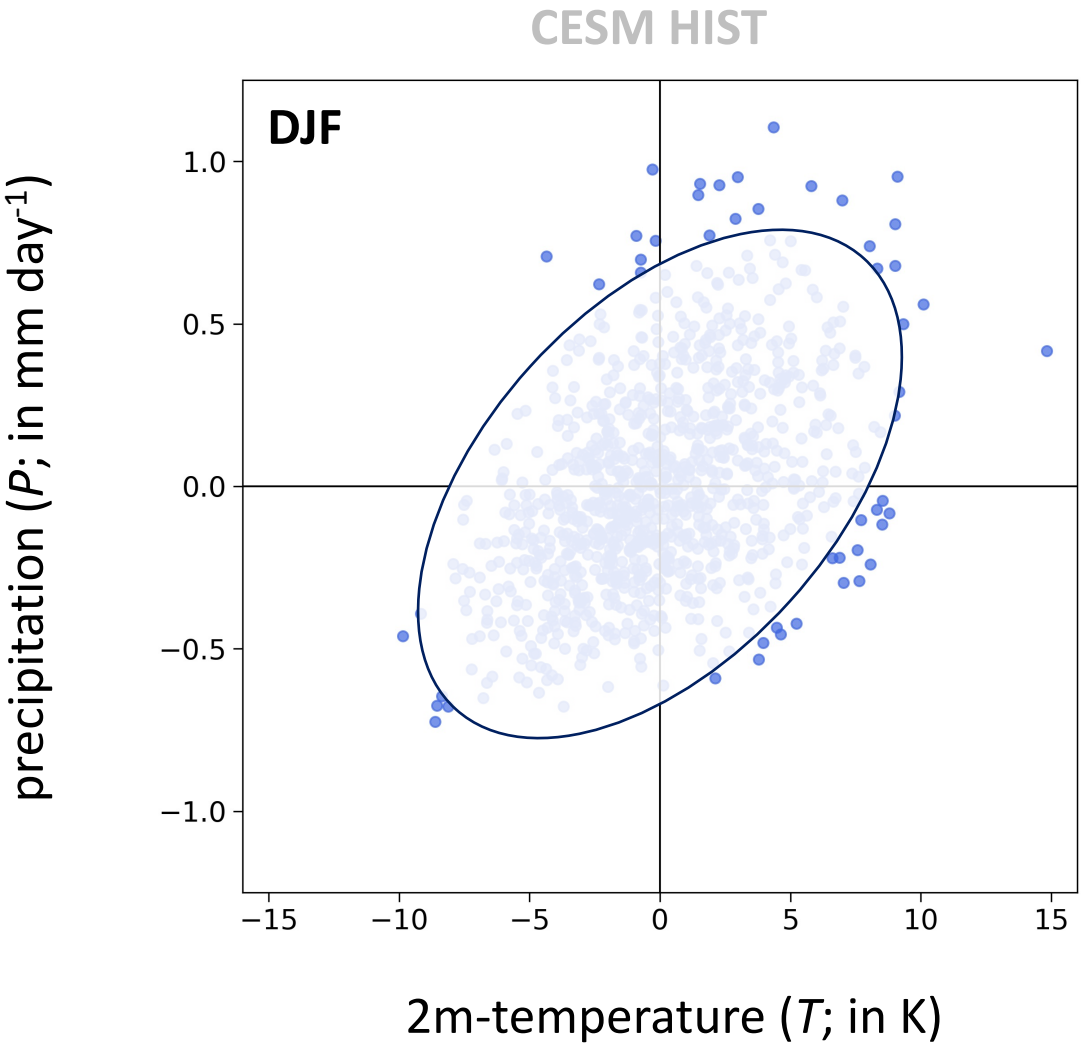

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↑

Role of weather systems?

↓

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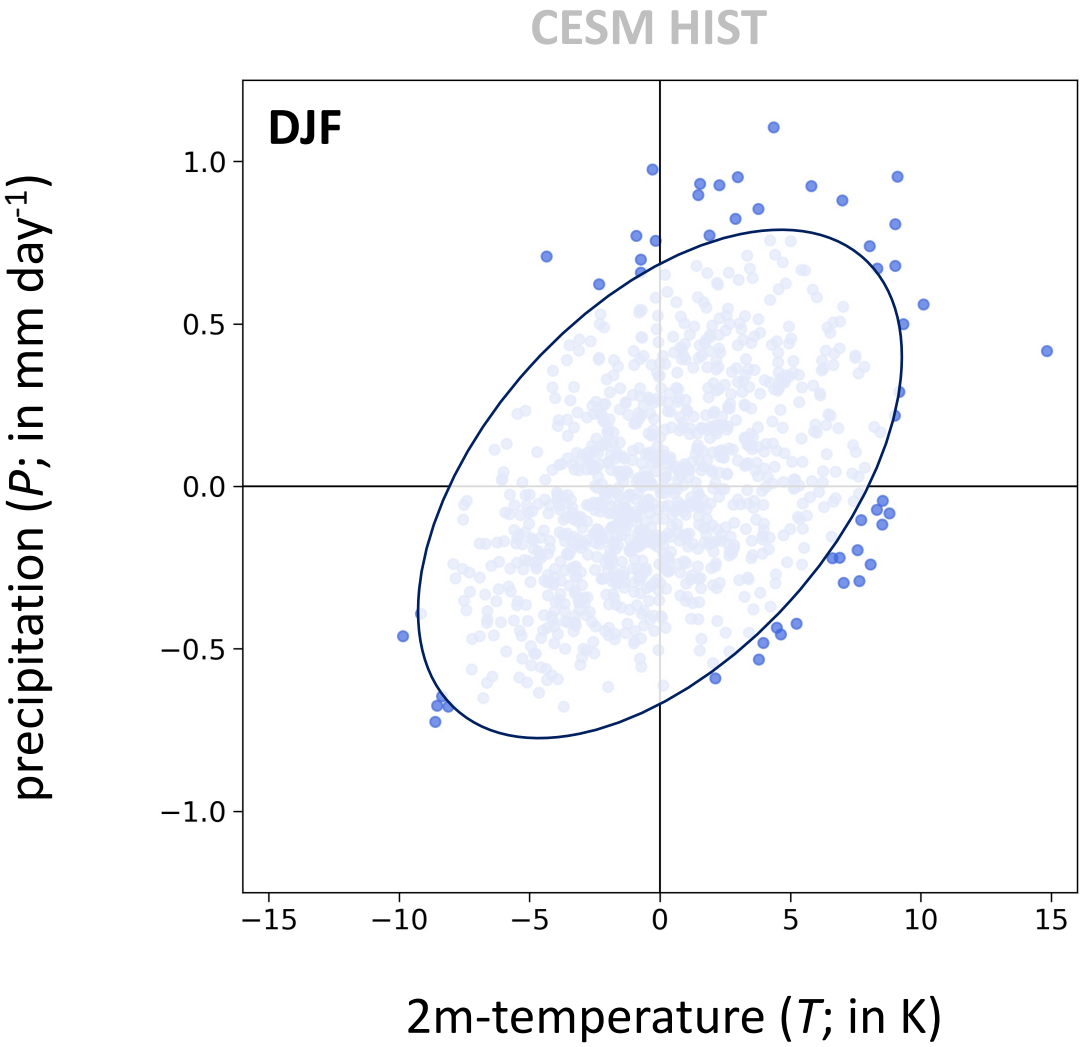
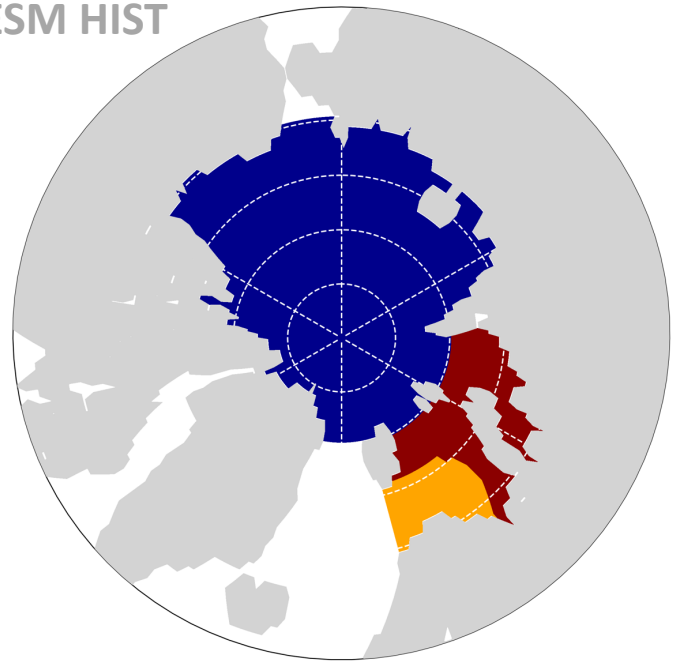


(2) Climate Change: Amplitude & Pathways

DJF
CESM HIST



Kara- & Barents Seas: $SIC_{clim} < 0.5$ **(open ocean)**

Kara- & Barents Seas: $SIC_{clim} \geq 0.5$ **(ice)**

Arctic Ocean: $SIC_{clim} \geq 0.5$ **(ice)**

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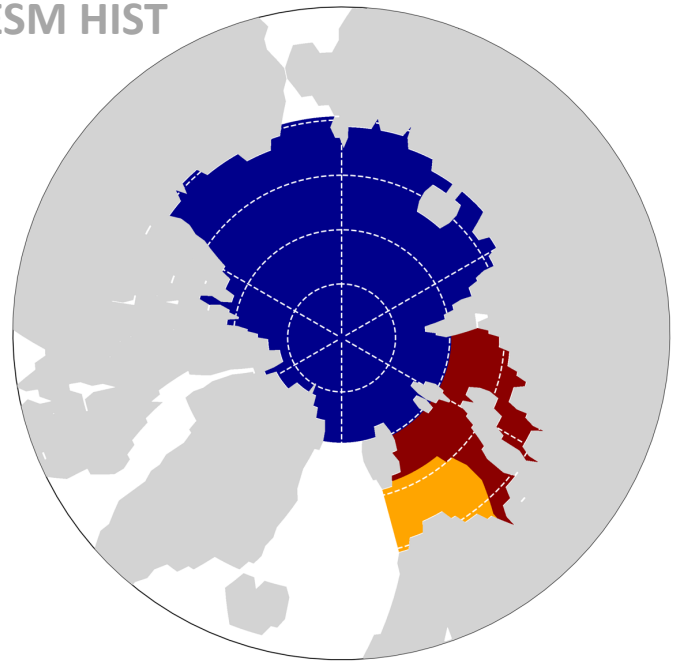

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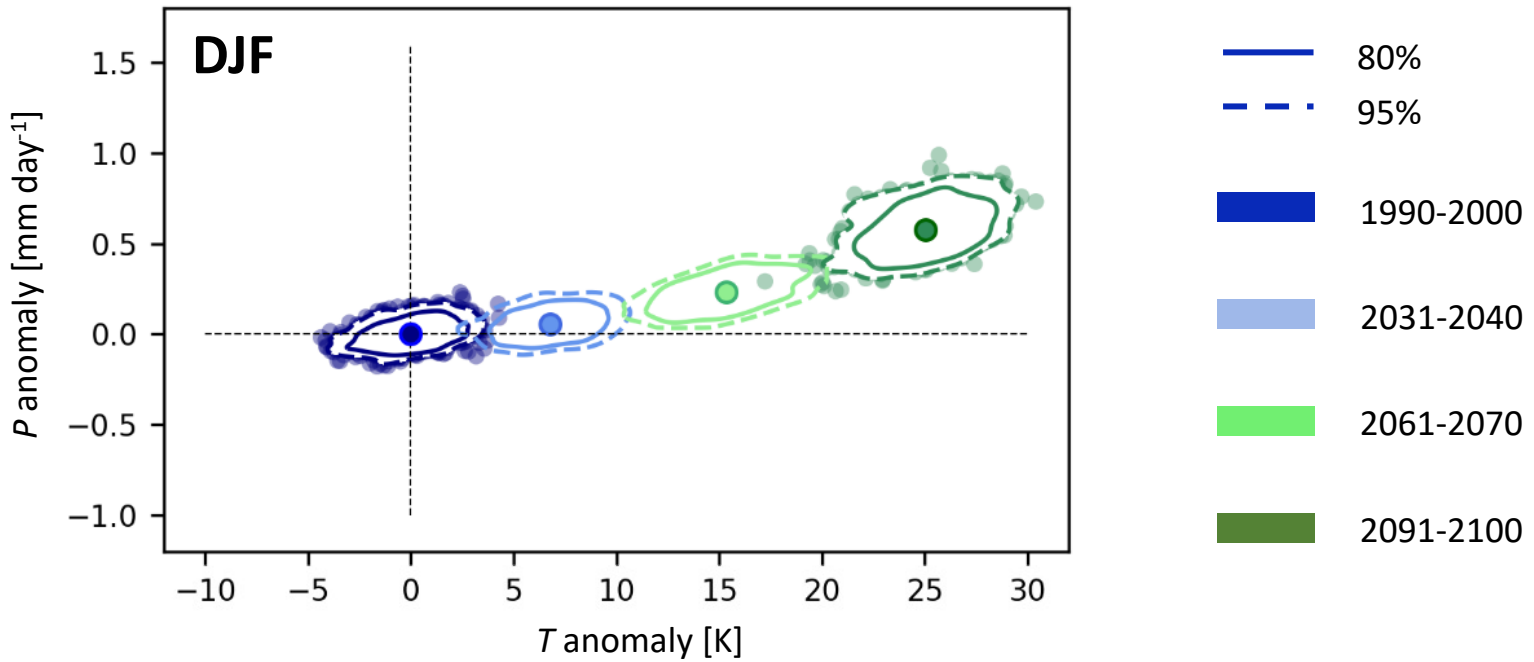
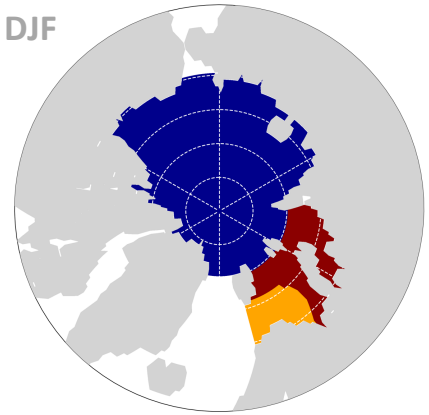
Arctic Ocean, *ice*



Anomalies are now relative to the historical (1990-2000) mean state.

(2) Climate Change: Amplitude & Pathways



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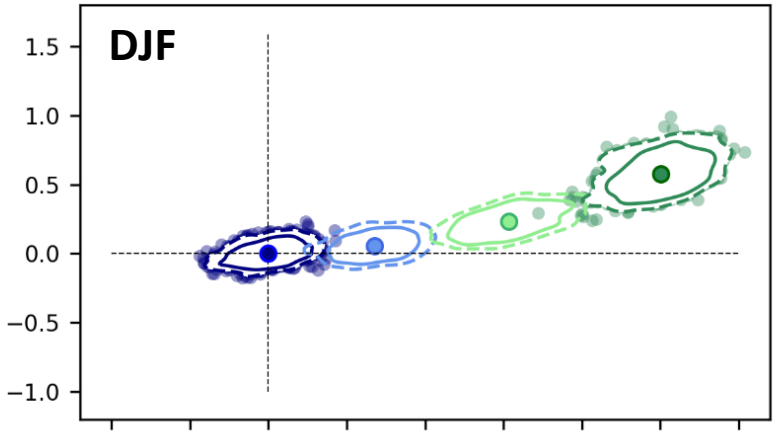
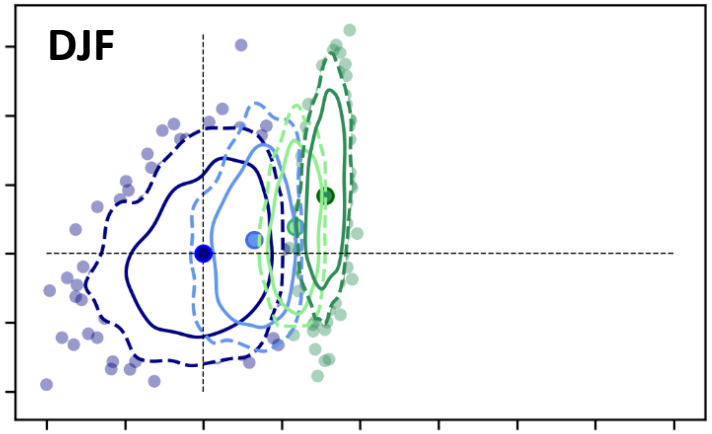


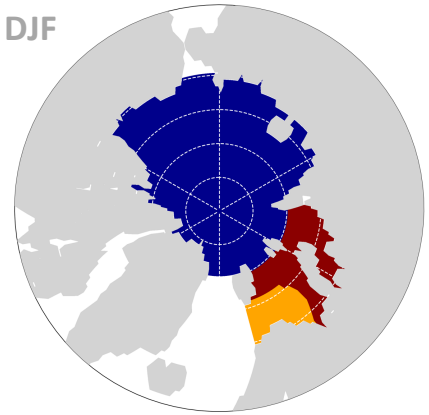
Kara- and Barents Seas, *open ocean*

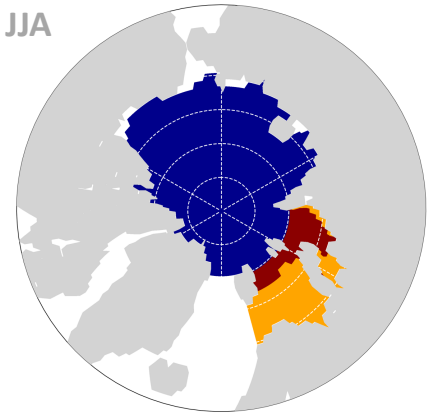


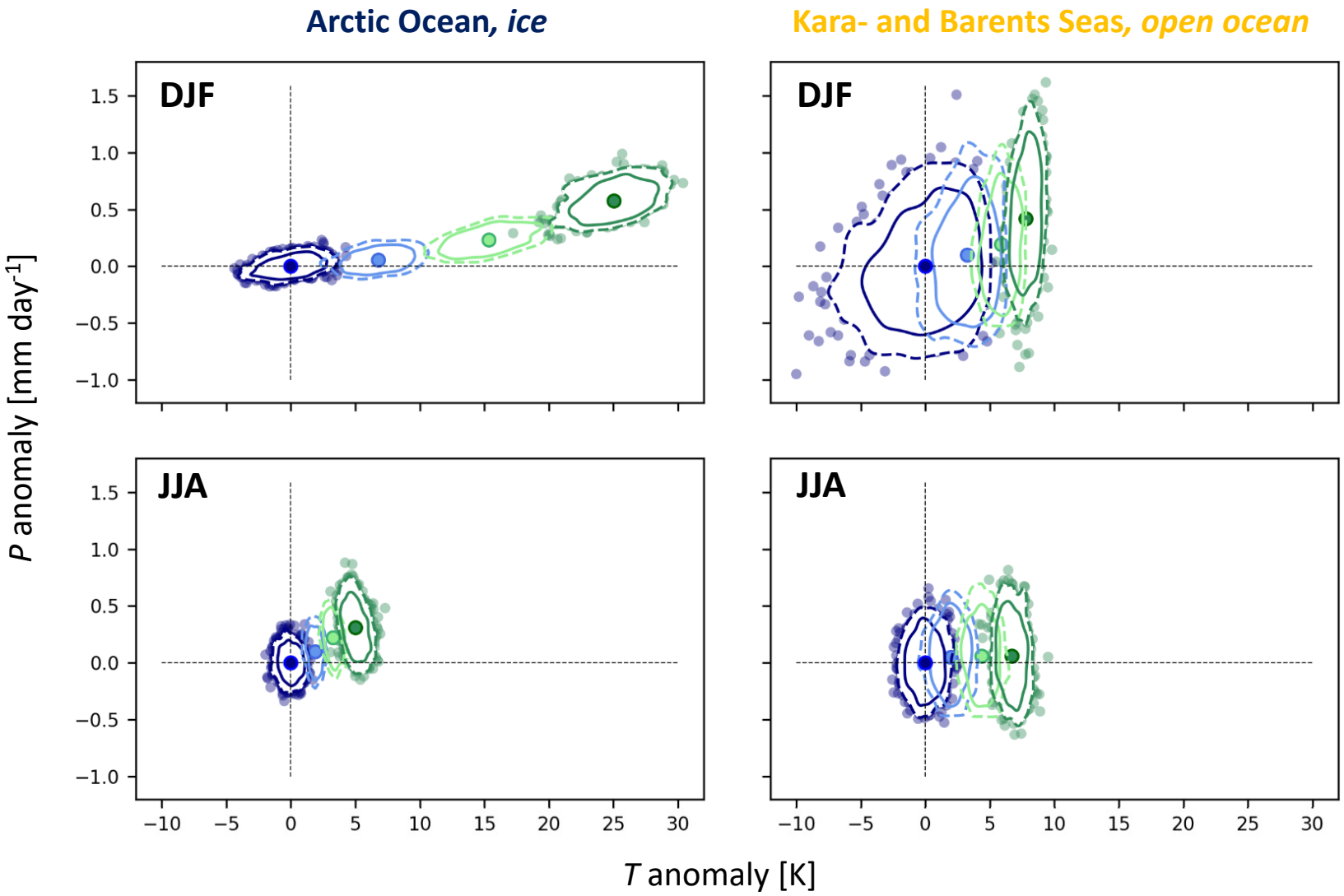
P anomaly [mm day^{-1}]

T anomaly [K]

(2) Climate Change: Amplitude & Pathways







(2) Role of (local vs. remote) weather systems for anomalous seasons

«TOP50» seasons in CESM HIST

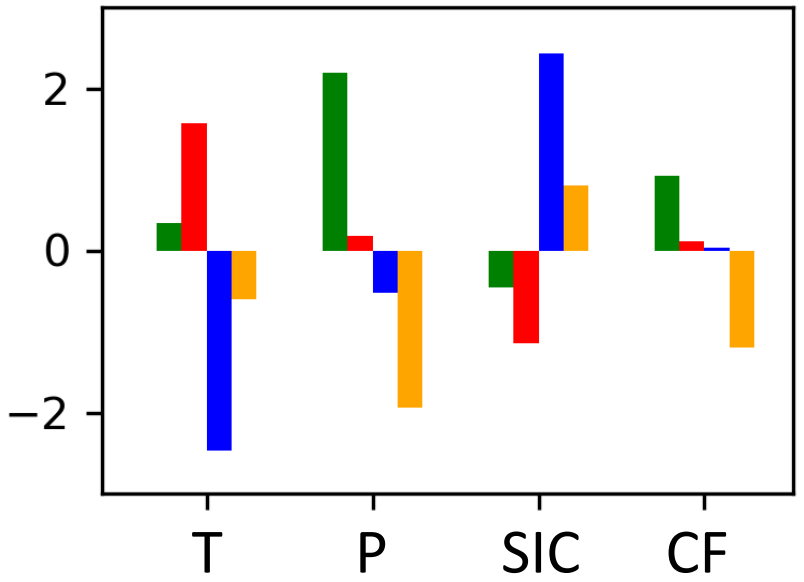
T + = 50 warmest seasons

T − = 50 coldest seasons

P + = 50 wettest seasons

P − = 50 driest seasons

Example: DJF; Kara- and Barents Seas, *open ocean*



Standardized anomaly for each «TOP50» category.

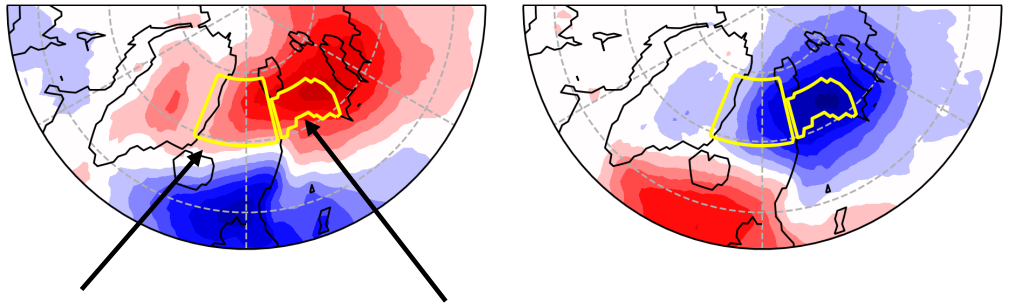
SIC = sea ice concentration; CF = cyclone frequency

(2) Role of (local vs. remote) weather systems for anomalous seasons

P +

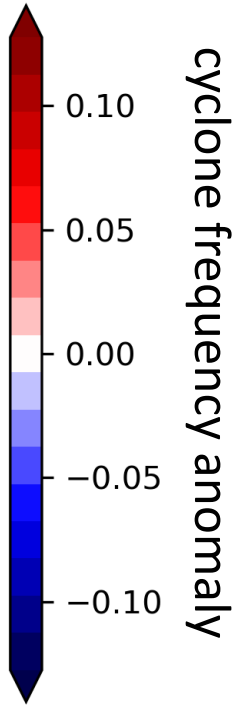
P –

HIST



remote

Kara- and Barents Seas, open ocean (DJF) = **local**



(2) Role of (local vs. remote) weather systems for anomalous seasons

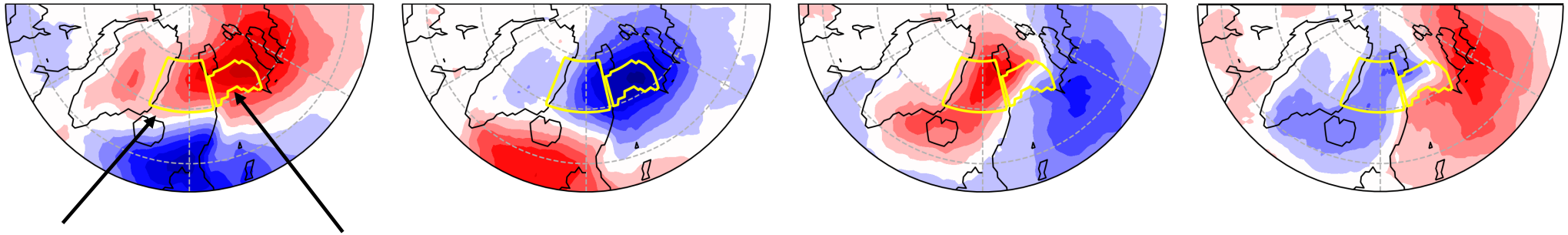
P +

P –

T +

T –

HIST



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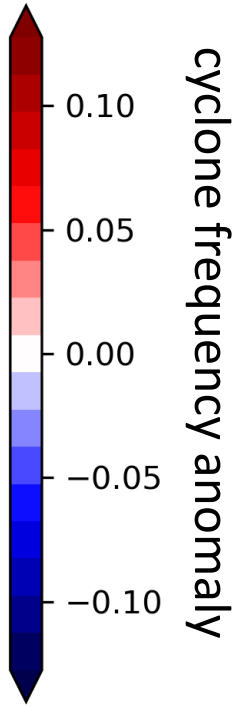

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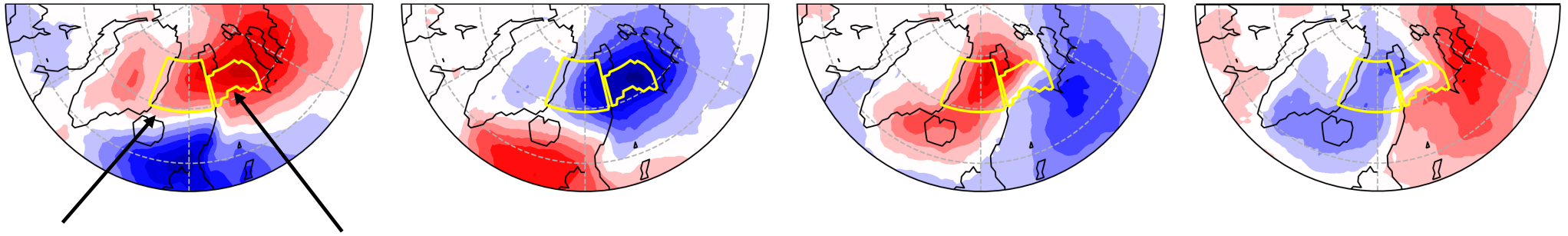
P +

P –

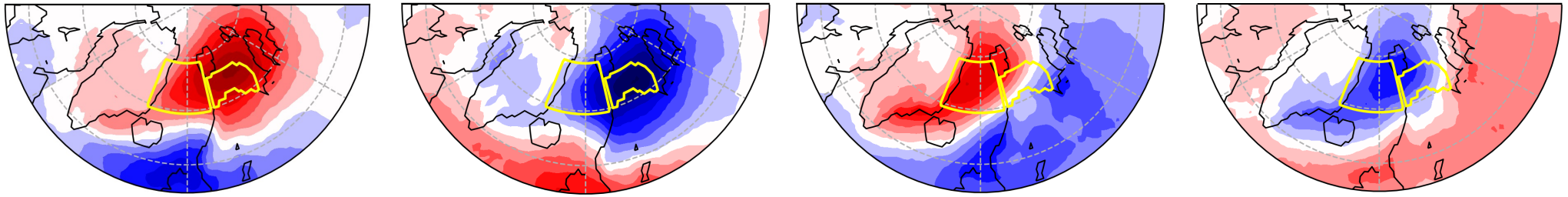
T +

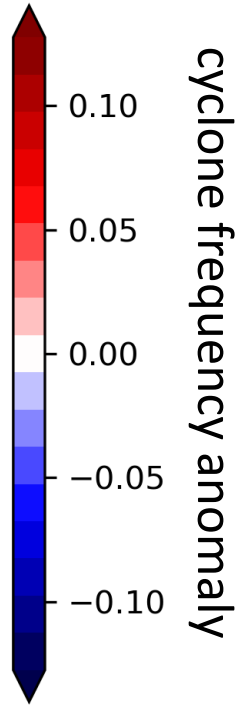
T –

HIST



EOC

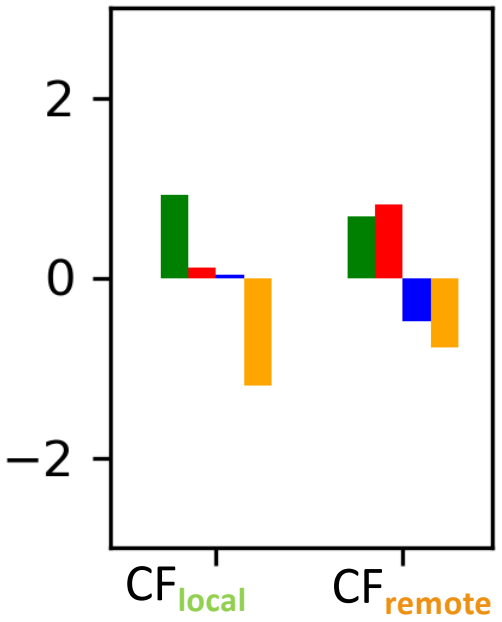




e.g. Woods et al., 2013 (GRL); Murto et al., 2022 (WCD)

(2) Role of (local vs. remote) weather systems for anomalous seasons

HIST



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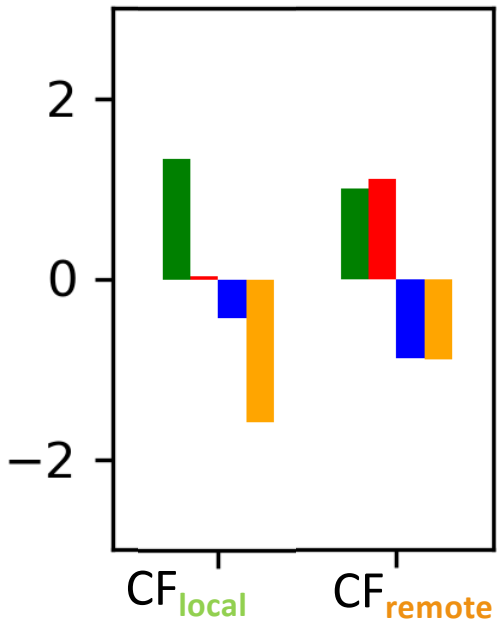

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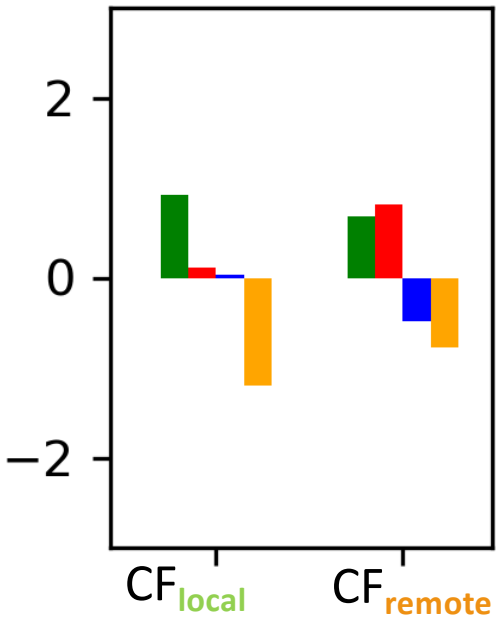

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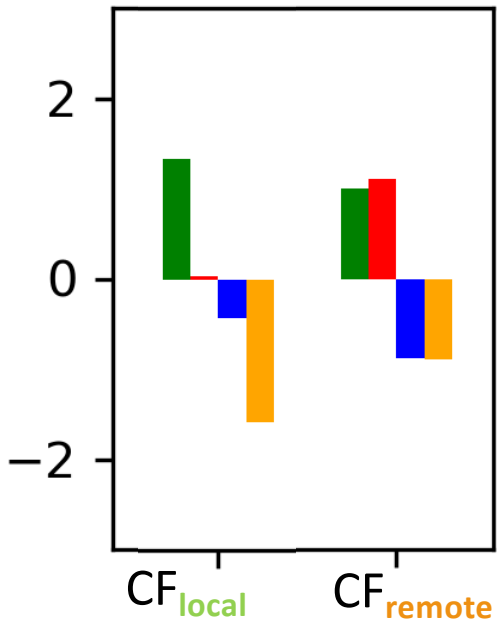


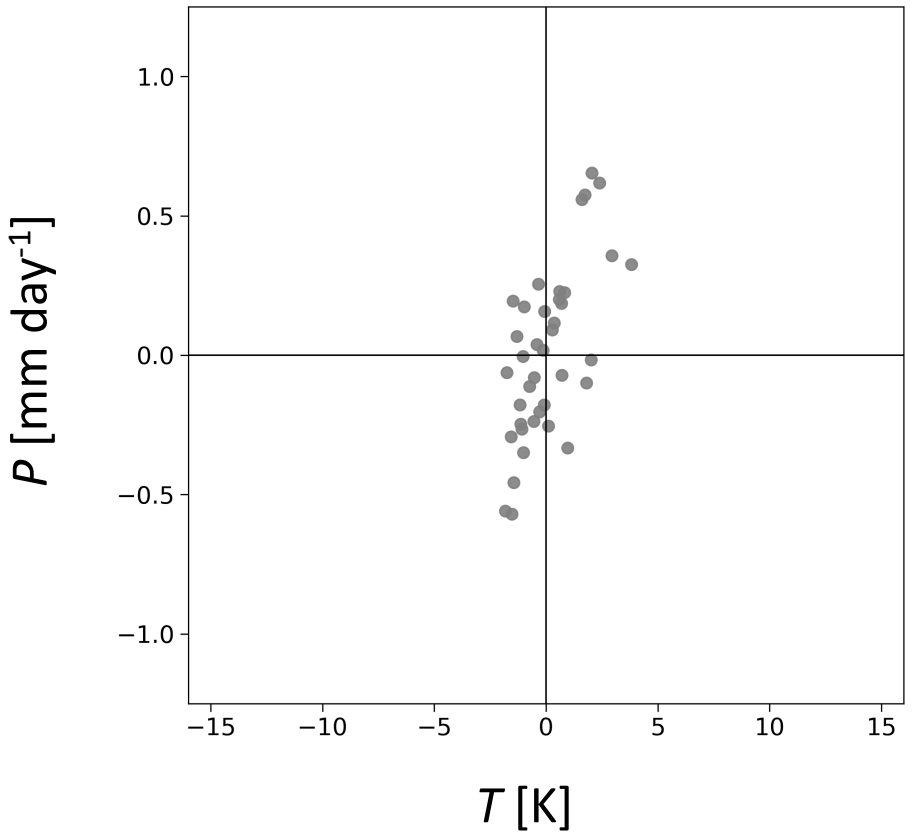
- **Local** cyclone frequency drives **seasonal *P* extremes**; **remote** cyclone frequency drives **seasonal *T* extremes**
- Similar patterns for CESM HIST and EOC
- Larger amplitude of cyclone frequency anomaly in EOC

(3) Arctic extreme seasons in ERA5 and CESM HIST

- How to objectively identify Arctic extreme seasons in a multivariate phase space?
- What are the characteristics of such seasons?
- Which processes cause Arctic extreme seasons?

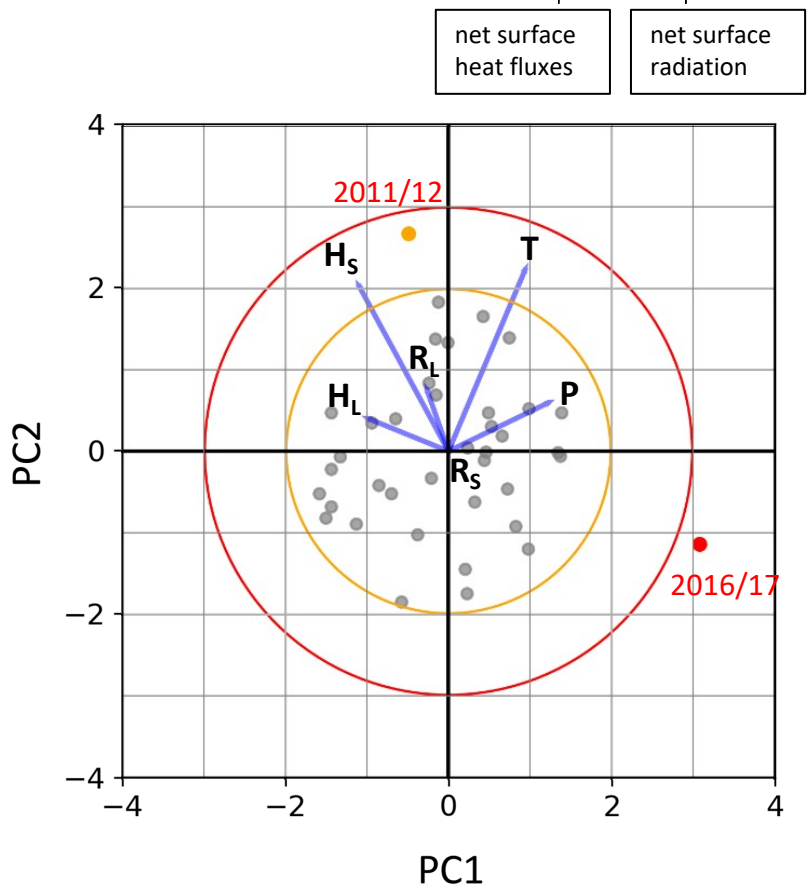
(3) Arctic extreme seasons in ERA5: Identification

T-P phase space



PCA phase space

from 6D phase space: *T, P, H_S, H_L, R_S, R_L*

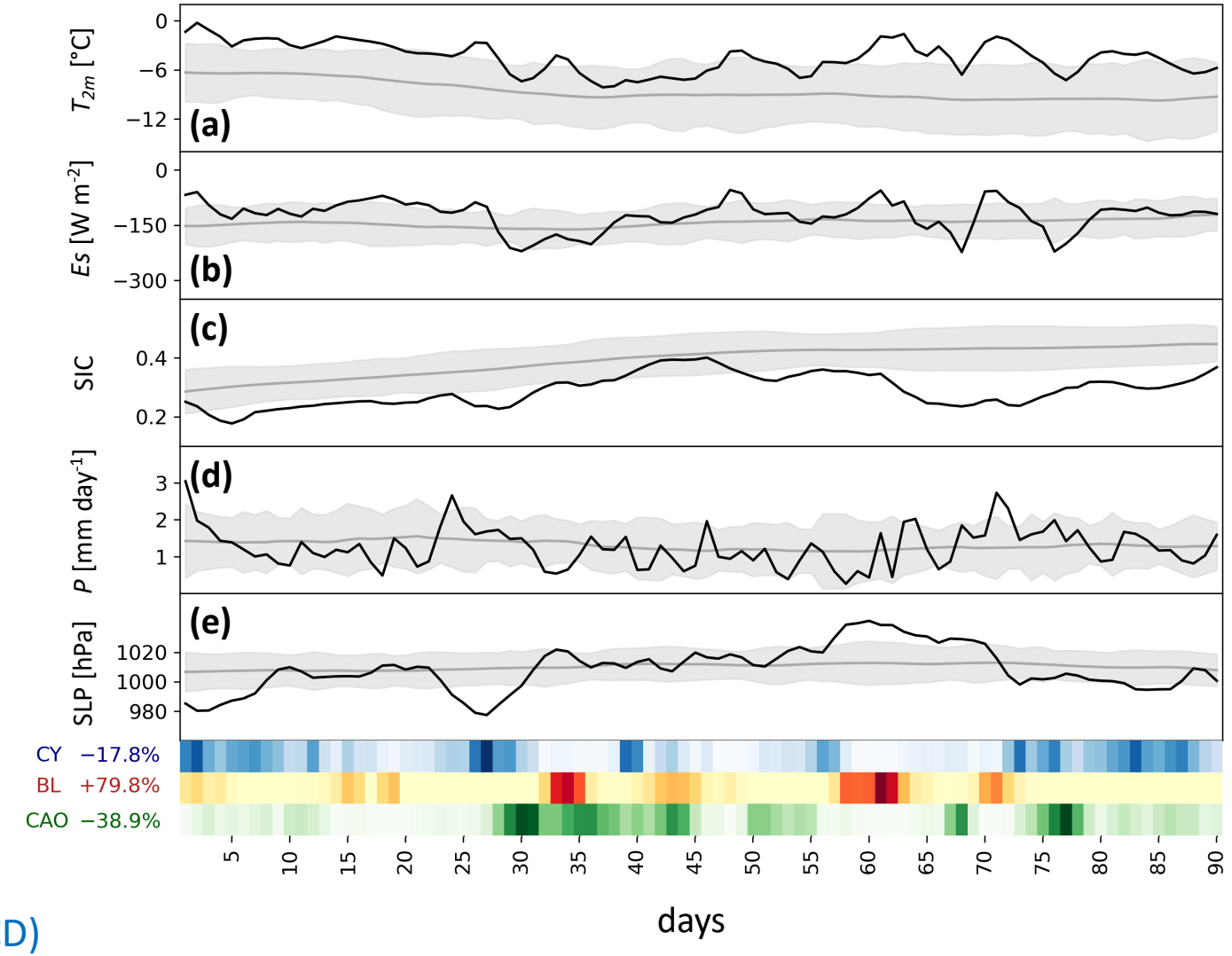


Hartmuth et al., 2022 (WCD)

(3) Arctic extreme seasons in ERA5: Characteristics

DJF 2011/12 [*T*+]

Kara- and Barents Seas



CY = cyclones
BL = blocks
CAO = cold air outbreaks

Hartmuth et al., 2022 (WCD)

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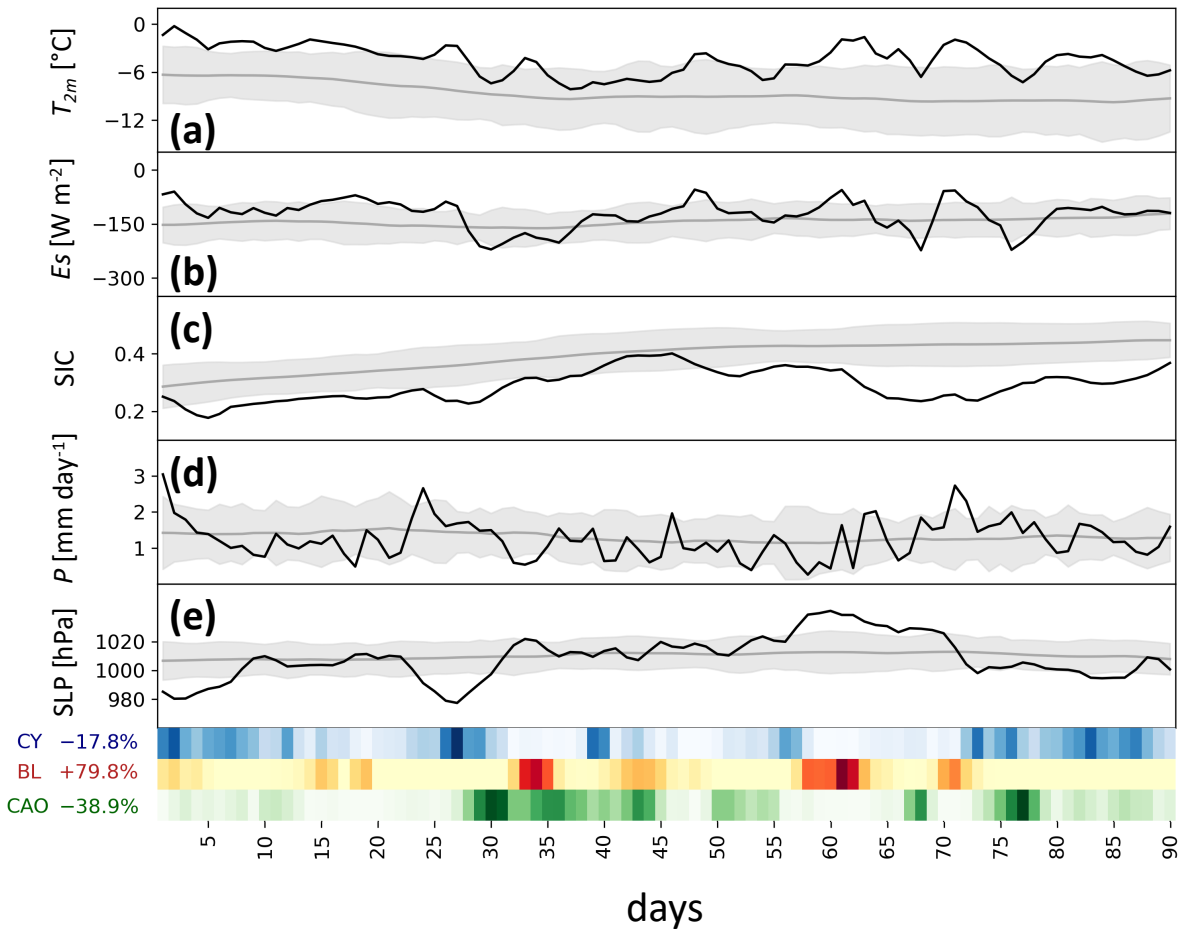

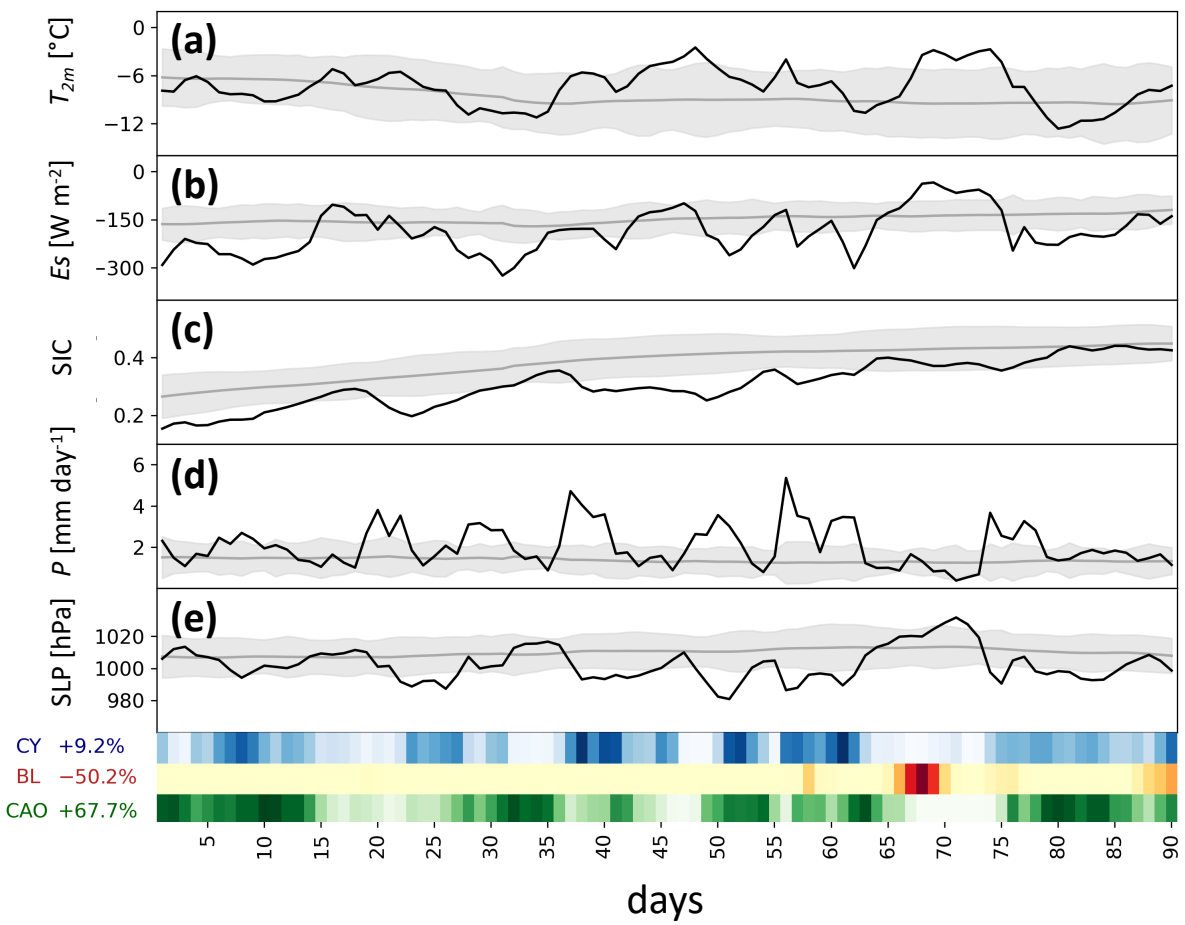

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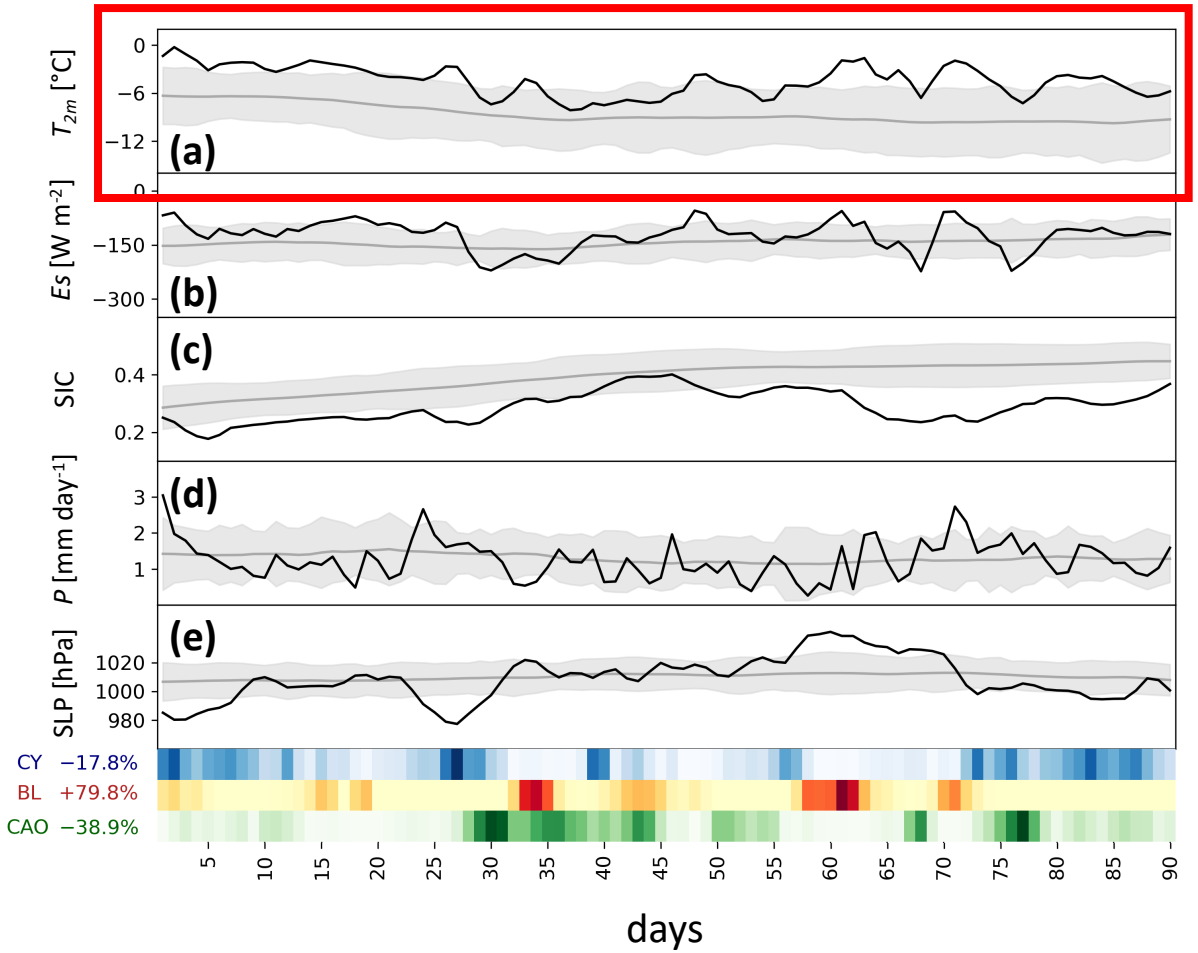

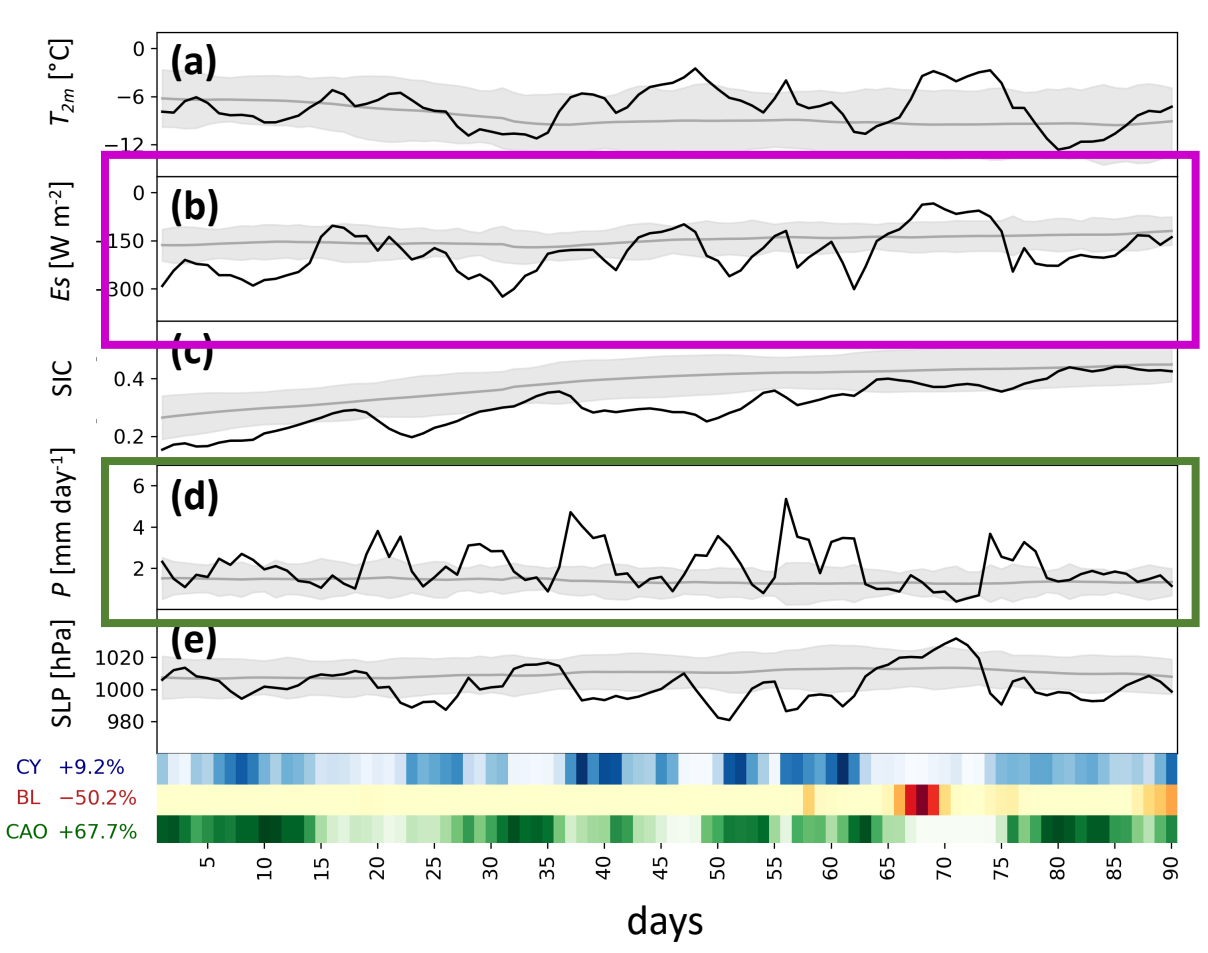

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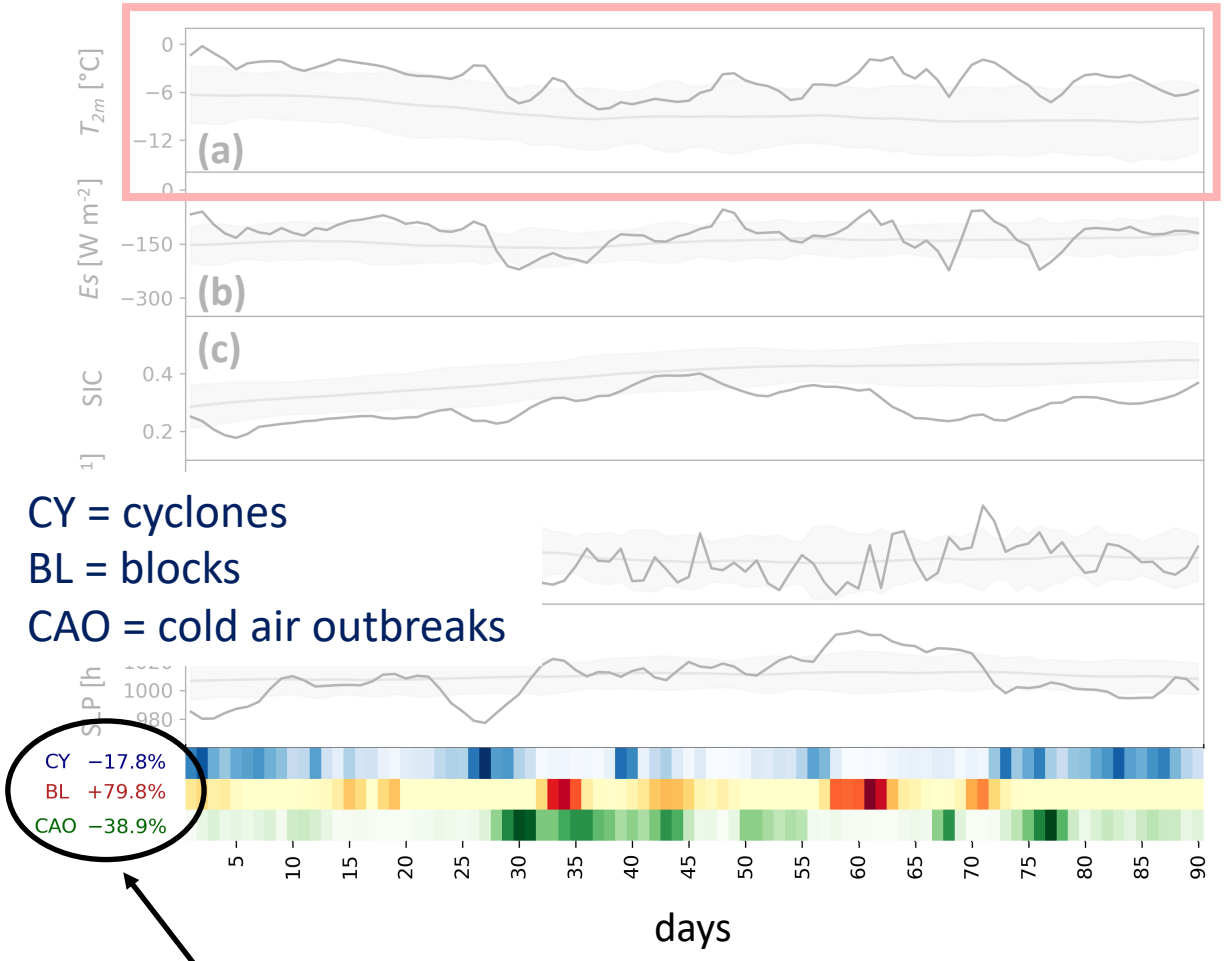
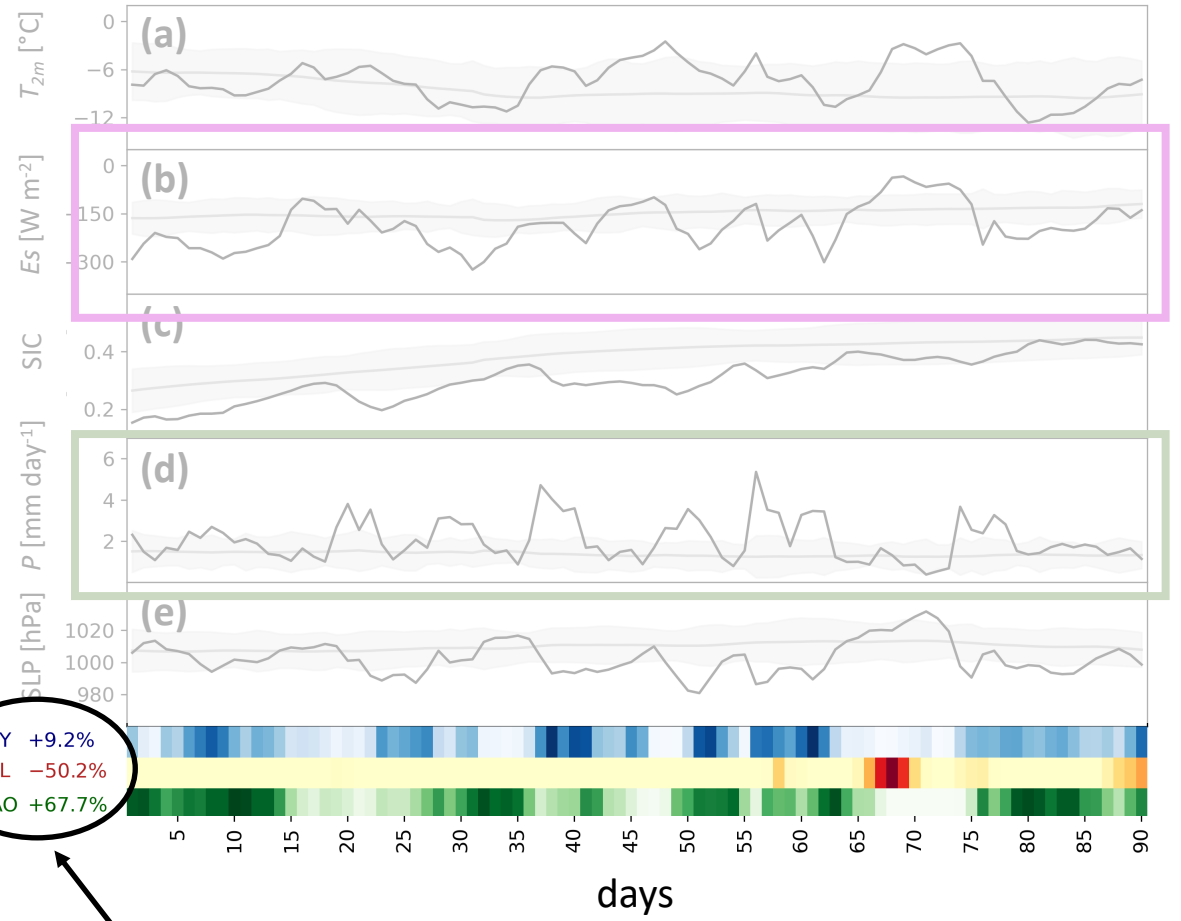


CY = cyclones
BL = blocks
CAO = cold air outbreaks

more collocated blocks, less cold air outbreaks

DJF 2016/17 [*P*+, E_S–]



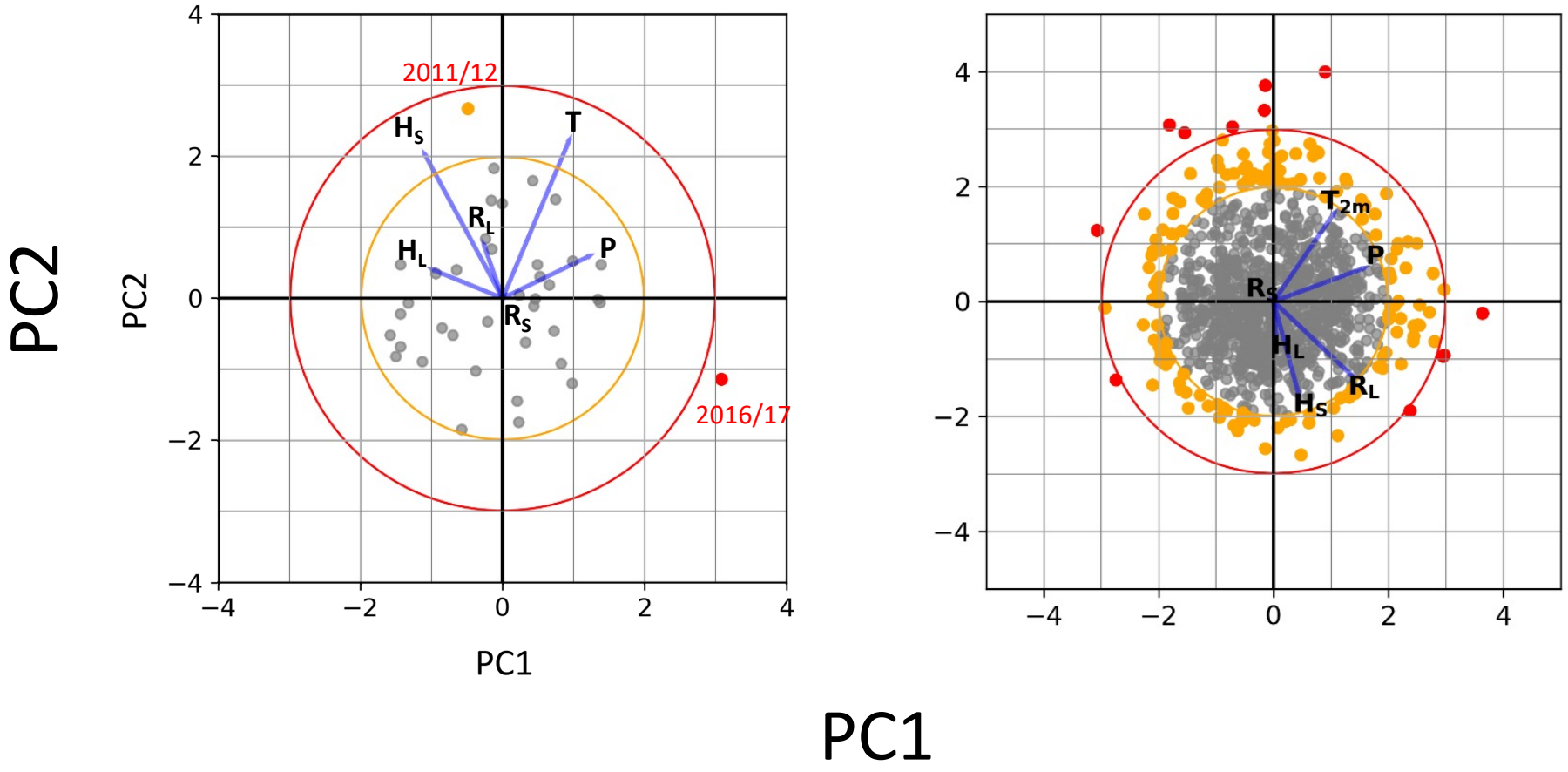
less collocated blocks, more cold air outbreaks

(3) Arctic extreme seasons in CESM HIST

ETH zürich erc

ERA5 (1979-2017)

CESM (1990-1999)



Conclusions

Arctic inter-annual variability: *T-P* phase space

- Large seasonal and regional differences
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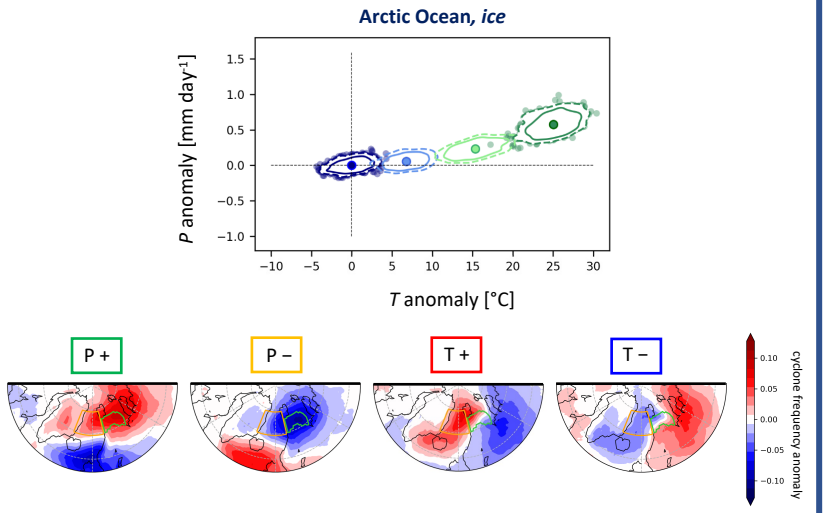
- Local (remote) weather systems have contrasting effects for seasons with large *P* (*T*) anomalies



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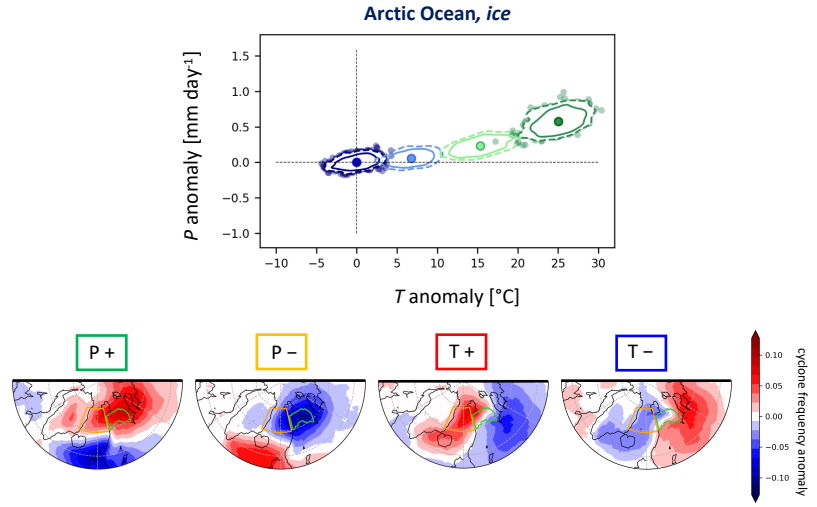
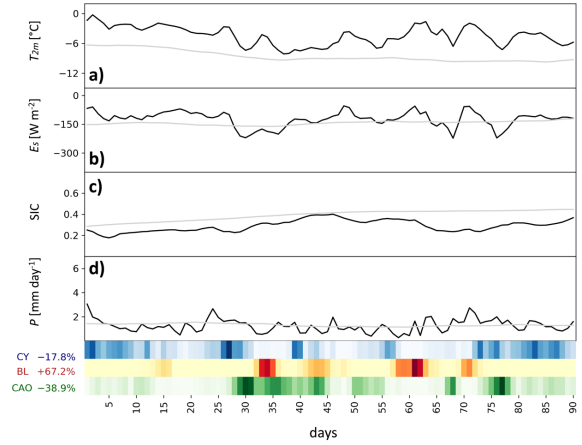


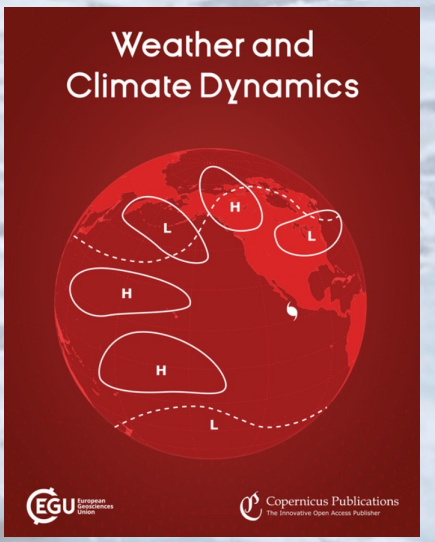
Arctic extreme seasons: 6D phase space (*T*, *P*, E_S components)

- High variability in seasonal substructure
- Extreme seasons can be driven by preconditioning (SIC, SST) and/or atmospheric variability



Thank you!

Hartmuth, K., Boettcher, M., Wernli, H., and Papritz, L., 2022. Identification, characteristics and dynamics of Arctic extreme seasons, Weather Clim. Dynam., 3, 89-111, https://doi.org/10.5194/wcd-3-89-2022



Credit: Wikimedia Commons