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The Impact of Sea Ice Concentration and Sea Surface Temperature Boundary Forcing in different Experimental Setups with ECHAM6 on the changes in Northern hemisphere atmospheric circulation regimes

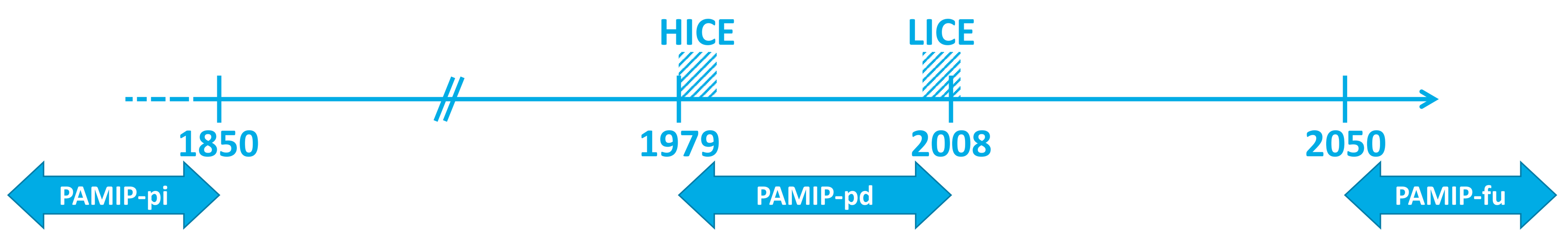
Experiments with different boundary forcing

We provide two sets of atmosphere-only ensemble simulations with ECHAM6:

1) **Recent Past Experiments** (Jaiser et al. 2023)
2) **PAMIP experiments** (Smith et al. 2019)

Recent Past Experiment

High and low sea ice conditions and low and high sea surface temperature conditions according to observed anomalies from the early 80s and late 2000s, respectively.



PAMIP Experiment

High and low sea ice conditions and low and high sea surface temperature conditions according to average present-day, pre-industrial and future conditions, respectively.

Introducing a fast interactive ozone chemistry

Polar SWIFT

- Determines the polar vortex average ozone depletion
- Based on a reduced set of coupled differential equations
- Includes a parameterization of transports
- Coupling to ECHAM6 allows for feedback processes between radiation & dynamics

Relevance of including ozone interaction

→ Changed surface or tropospheric conditions have the potential to alter wave forcing of the stratospheric polar vortex

→ Potential of future increase of winter cold extremes in the stratosphere (Von der Gathen et al. 2021)

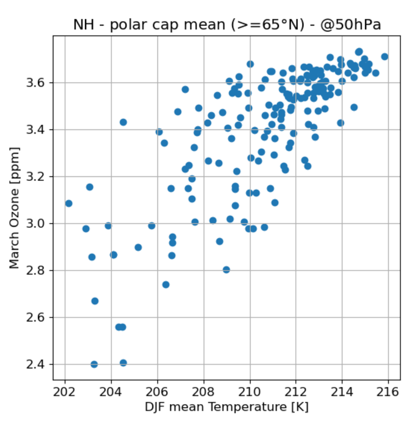


Figure 1: Dependency of spring ozone concentration on winter temperature

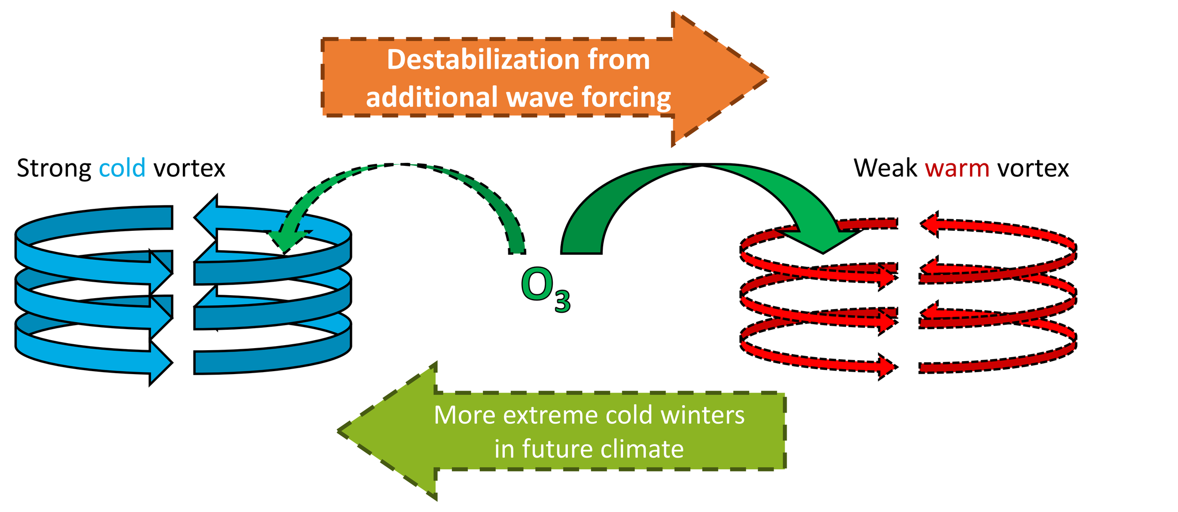


Figure 2: Scheme of potential feedbacks between the intensity of the stratospheric polar vortex and ozone concentration under future climate impacts

Hypothesis on climatological impacts

→ Higher zonal wind speed (vortex stability)

→ Increased variability of zonal wind

Analysis of tropo- and stratospheric circulation regimes

- Regimes = Preferred states of atmospheric circulation
- Regimes play a crucial role in stratospheric pathway of Arctic-midlat. Linkages
- Regimes are closely related with extremes
- Tropospheric data: daily fields of sea level pressure (SLP) anomalies over
  (1) North-Atlantic-Eurasian region (30°-90°N, 90°W-90°E)
  (2) North-Pacific region (30°-90°N, 90°E-270°E) (not shown)
- Stratospheric data: daily fields of geopot. height anomalies @50hPa north of 50°N
- k-means clustering with k=5 in a reduced state space spanned by leading EOFs
- detect changes in the frequency of occurrence

ECHAM6 reproduces observed circulation regimes

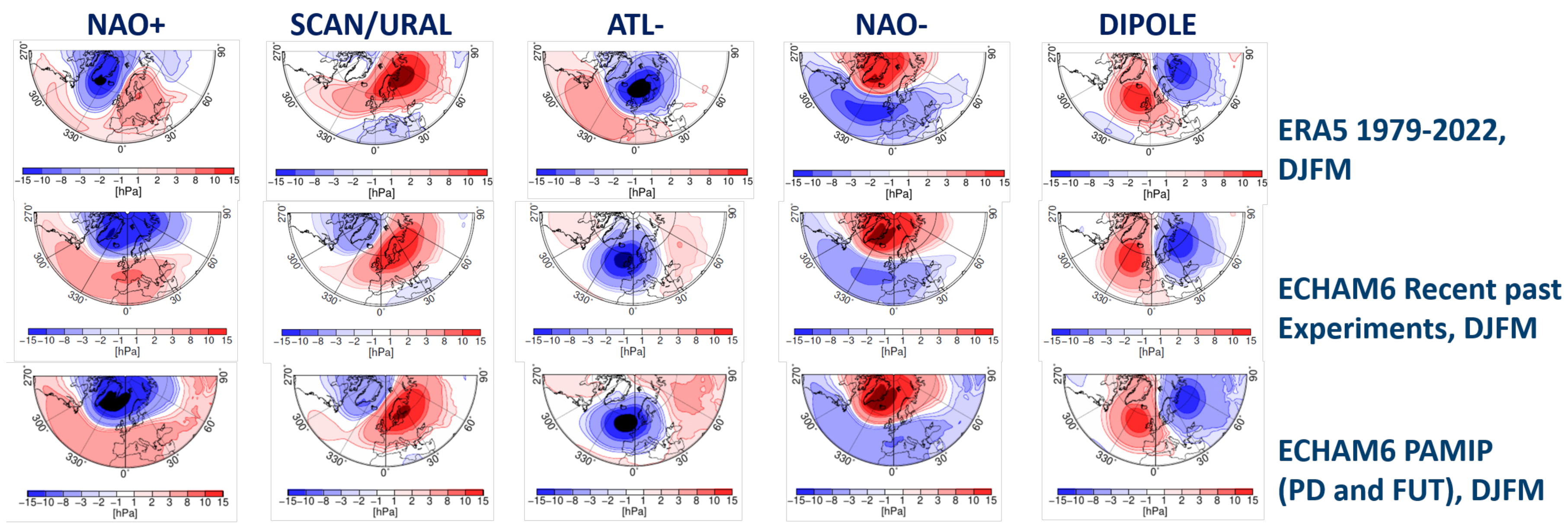


Figure 3: Tropospheric atmospheric circulation regimes over North-Atlantic-Eurasian region

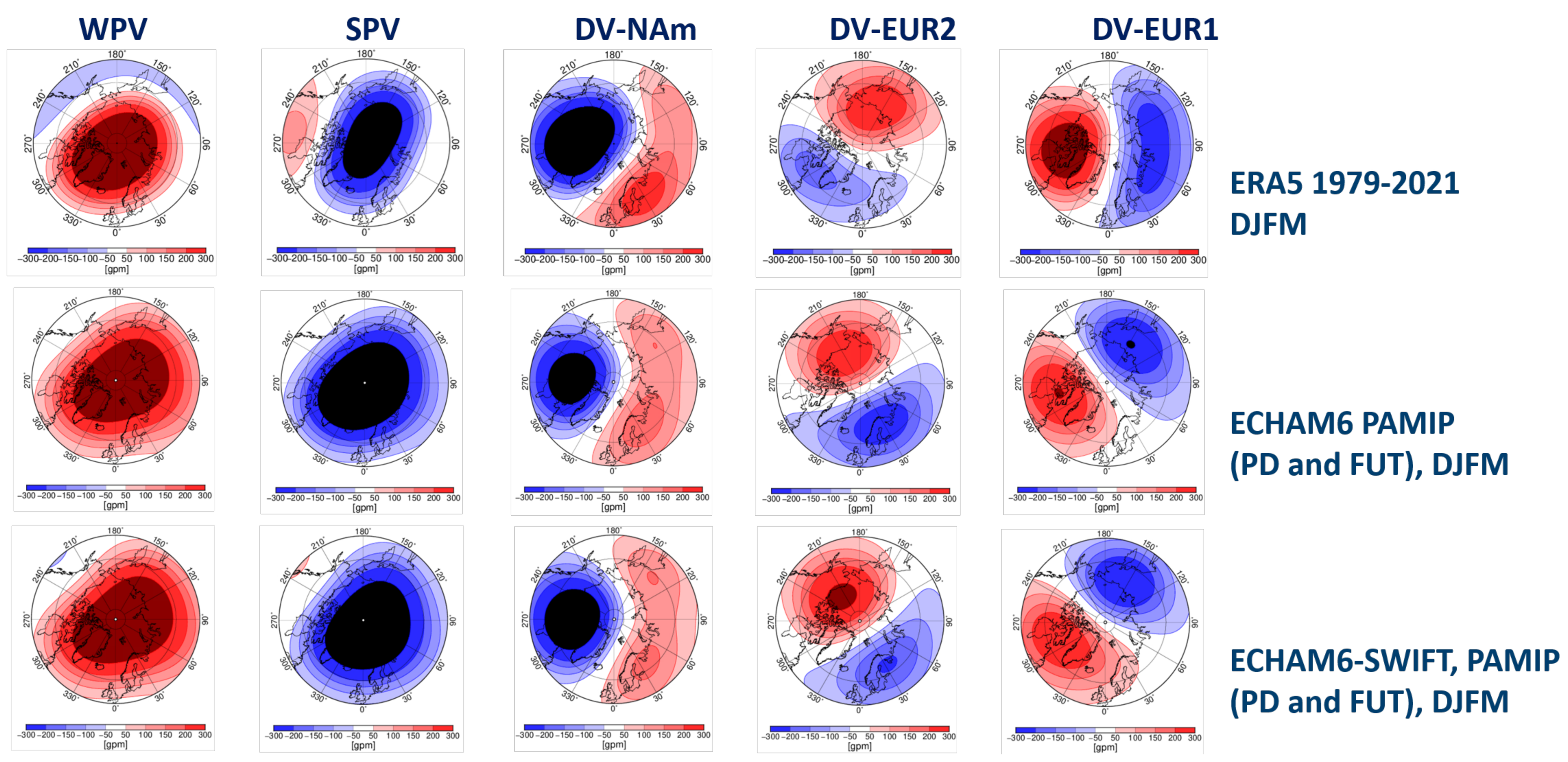


Figure 4: NH stratospheric circulation regimes, GPH@50hPa, WPV-Weak Polar Vortex, SPV-Strong Polar Vortex, DV-NAm displaced Vortex N-America, DV-EUR1/2 displaced Vortex Eurasia.

Frequency changes of stratospheric regimes

- Impact of SWIFT for different backgrounds

Figure 6: Frequency changes between sensitivity runs (in % of days), dark colors: 99% significance

	WPV		SPV		DV-NAm		DV-EUR2		DV-EUR1	
	DJ	FM	DJ	FM	DJ	FM	DJ	FM	DJ	FM
SWIFT-noSWIFT, PD SIC, PD SST (PAMIP 1.1)	0.1	–0.9	0.4	1.8	–0.9	–0.7	0	–0.9	0.5	0.7
SWIFT-noSWIFT, PI SIC, PI SST (PAMIP 1.2)	–1.3	3.1	0	–0.6	1.3	–3.7	–1.3	0.7	1.3	0.5
SWIFT-noSWIFT, PD SIC, PI SST (PAMIP 1.3)	–1	1	2.3	2.1	–0.6	–1.9	1.7	0.8	–2.4	–2
SWIFT-noSWIFT, PD SIC, FUT SST (PAMIP 1.4)	0.1	–1	3	1.8	–2.3	0.7	–2.8	–1.5	2.1	0.1
SWIFT-noSWIFT, PI SIC, PD SST (PAMIP 1.5)	–2.8	1.6	–0.8	1	–3.1	–0.9	2.4	–3.1	4.3	1.4
SWIFT-noSWIFT, FUT SIC, PD SST (PAMIP 1.6)	–0.9	–1.6	0.9	–0.2	–0.4	0.6	1	–1.4	–0.6	2.7

- Impact of SIC and SST changes

Figure 7: Frequency changes between sensitivity runs (in % of days), dark colors: 99% significance

	WPV		SPV		DV-NAm		DV-EUR2		DV-EUR1	
	DJ	FM	DJ	FM	DJ	FM	DJ	FM	DJ	FM
Changes between late and early period	3.7	9.9	–5.5	–8.7	–8.6	–4.3	7.4	–0.2	3.1	3.2
SIC changes FUT and PD, PAMIP, PD SST	0.4	–2	–4	–0.3	1.5	1.7	0.8	0.5	1.2	0.1
SIC changes FUT and PD, PAMIP, SWIFT	–0.7	–2.1	–1.5	–1.9	1.1	2.2	1.9	0.3	–0.7	1.4
SST changes FUT and PD, PAMIP, PD SIC	–1.9	–1.8	–2.1	–0.3	–0.1	–1.5	–0.1	1.2	4.1	2.4
SST changes FUT and PD, PAMIP, SWIFT	–2.5	–1.4	1	0	–1.9	0.3	–2.6	–0.8	5.9	1.9

Results and conclusions: Stratospheric regimes

Impact of Polar SWIFT for various PAMIP experiments

- Impact depends strongly on background conditions
- Most coherent response for SPV (strong vortex regime)
  → Increase in occurrence in SWIFT exp → agreement on hypothesis

Response to SST and SIC changes

- SIC changes mostly project on decrease in WPV and SPV and increase in DV-Nam
- SST changes mostly project on decrease in WPV and increase in DV-EUR1
- SPV response to SST changes different in ECHAM6-SWIFT

Frequency changes of tropospheric regimes

- Impact of SIC and SST changes

Figure 5: Frequency changes between sensitivity runs (in % of days), dark colors: 99% significance

	NAO+		SCAN/URAL		ATL-		NAO-		DIPOLE	
	DJ	FM	DJ	FM	DJ	FM	DJ	FM	DJ	FM
Changes between late & early period ERA-I	–1.9	–3	7	–6.6	–0.9	0.5	–0.2	5.8	–4	3.3
Changes between late & early period ERA5	–1.6	–1	5.5	–8.2	–1	0.4	–0.1	3.8	–4.5	4.9
SIC changes recent past, SST from 2000s	–2.4	–1.4	1	0.4	–0.4	1.2	2.1	–1.8	–0.3	1.6
SST changes recent past, SIC from 2000s	–3.7	–1.3	4.3	1.2	–4.6	–3	5.6	0.8	–1.5	2.3
SIC changes FUT and PD, PAMIP, PD SST	–2.5	2.6	3.1	–0.4	–0.8	1.4	1.1	–5.1	–0.9	1.5
SIC changes FUT and PD, PAMIP, SWIFT	–1	–1.4	1.5	–1.4	0.3	1.6	0.3	1.2	–1.1	0
SST changes FUT and PD, PAMIP, PD SIC	3.8	3	–1.7	–2.1	–1.4	1.1	–3.1	–4.7	2.4	2.6
SST changes FUT and PD, PAMIP, SWIFT	3.3	2.2	–1.3	–0.3	–1.1	–1.3	–3.3	–2.5	2.5	1.9

Results and conclusions: Tropospheric regimes

Recent Past Experiments: Occurrence changes in regime occurrences

- Increase in SCAN in DJ for **SST** changes → Initiation of stratospheric pathway possible
- No increase in NAO- in late winter, but increase in early winter
  Weaker dependence of EP flux changes on blocking changes in the SCAN/Ural region in ECHAM6 → Initiation of a stratospheric pathway more unlikely
- Increase in NAO+ for SST- and SIC changes
- Increase in DIPOLE in late winter for SST and SIC changes

PAMIP Experiments

- Increase in SCAN in DJ for **SIC** changes → Initiation of stratospheric pathway possible
- No increase in NAO- in late winter, except for ECHAM6-SWIFT for **SIC** changes
  → Hint on improvement of stratospheric pathway??
- Strong impact of **SST** changes
  → Coherent changes: Increase in NAO+ , DIPOLE, mostly decrease in SCAN, NAO-, ATL-

Changes in occurrence frequency depend on SST- and SIC-changes in a nonlinear way

Literature

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