Causal evaluation of Arctic-midlatitude processes in CMIP6 model simulations

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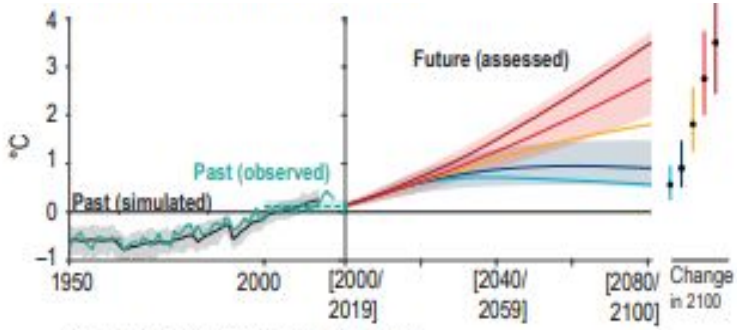
“What happens in the Arctic does not stay in the Arctic”

NATO Parliamentary Assembly
Brussels, 17 May 2017

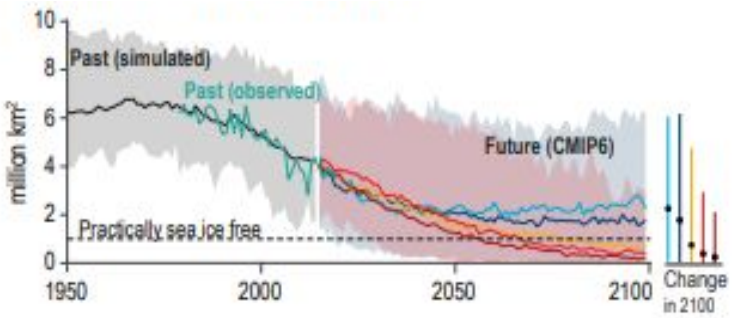
Climate change in the Arctic

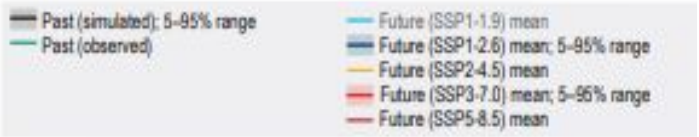
***IPCC, 2021, AR6*.**

Global surface air temperature



Arctic September sea ice area





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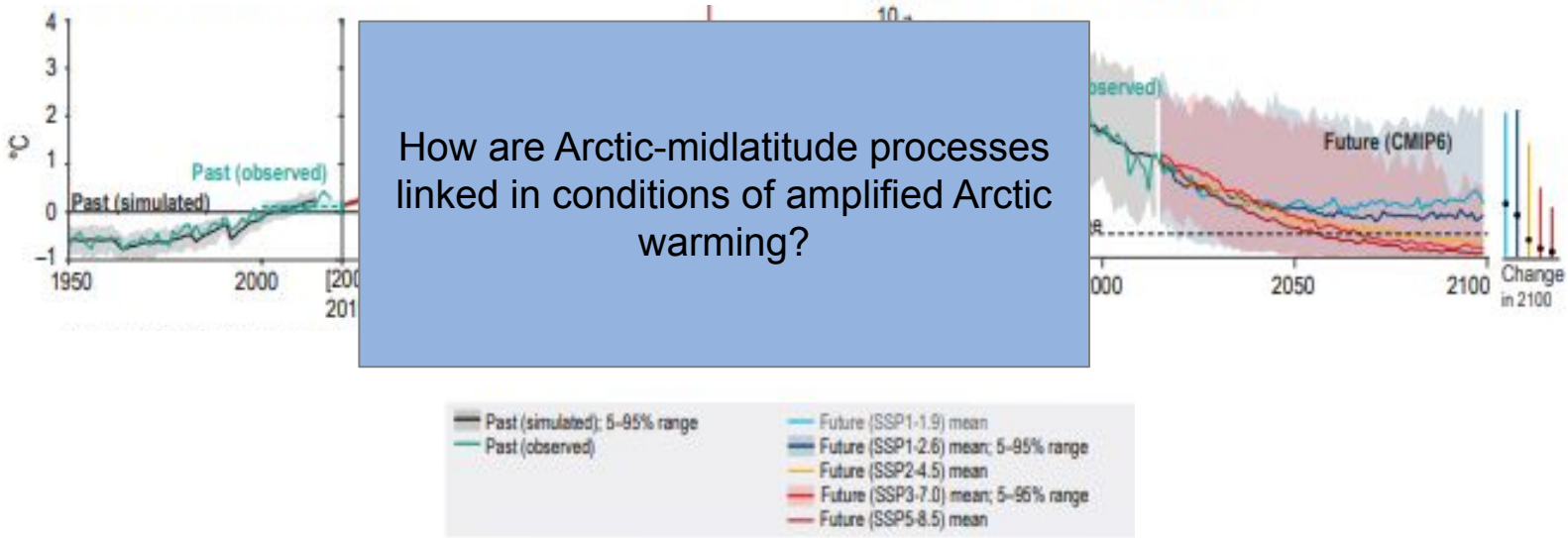
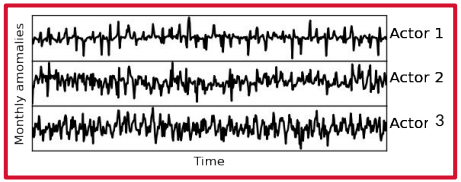


How are Arctic-midlatitude processes linked in conditions of amplified Arctic warming?

Causal Discovery or PCMCI

(1) Choose variables

(2) Calculate area-weighted spatial average



(3) Apply algorithm

PCMCI

***Runge et al.**, 2019*
Github: ***Tigramite***

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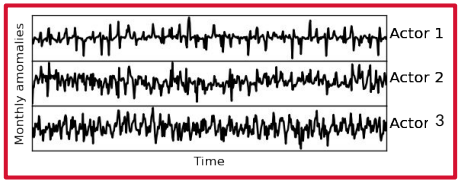

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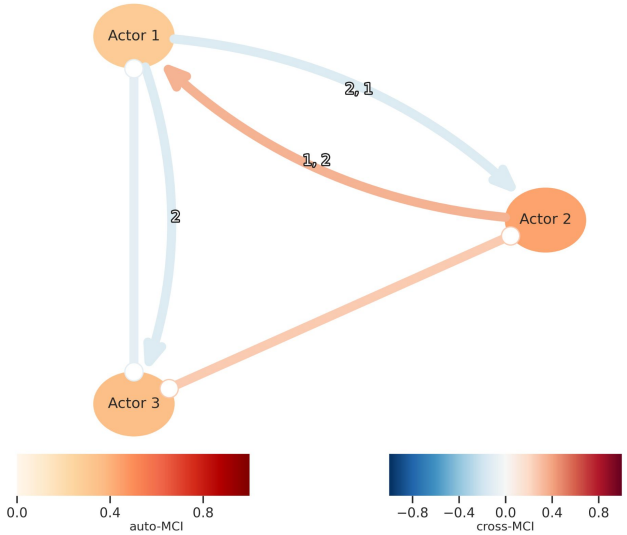

Causal graph as an example with 3 actors:

- auto-MCI: colored nodes;
- cross-MCI: colored links;
- straight lines: instantaneous links;
- curved lines: causal links;
- number: lags (in months) for causal links.

Potential processes/actors

Actor	Area	Label
Air Temperature	65-90°N, zm	TAS
Sea Ice Area Fraction	70-80°N, 30-105°E	BK-SIC
	50-60°N, 140-160°E	Ok-SIC
Sea Level Pressure	45-70°N, 40-85°E	Ural-SLP
	40-65°N, 85-120°E	Sib-SLP
	45-80°N, 160-260°E	Aleut-SLP
Heat Flux	45-75°N, zm, 100hPa	vflux
Polar Vortex	65-90°N, zm, 100-10hPa	PV
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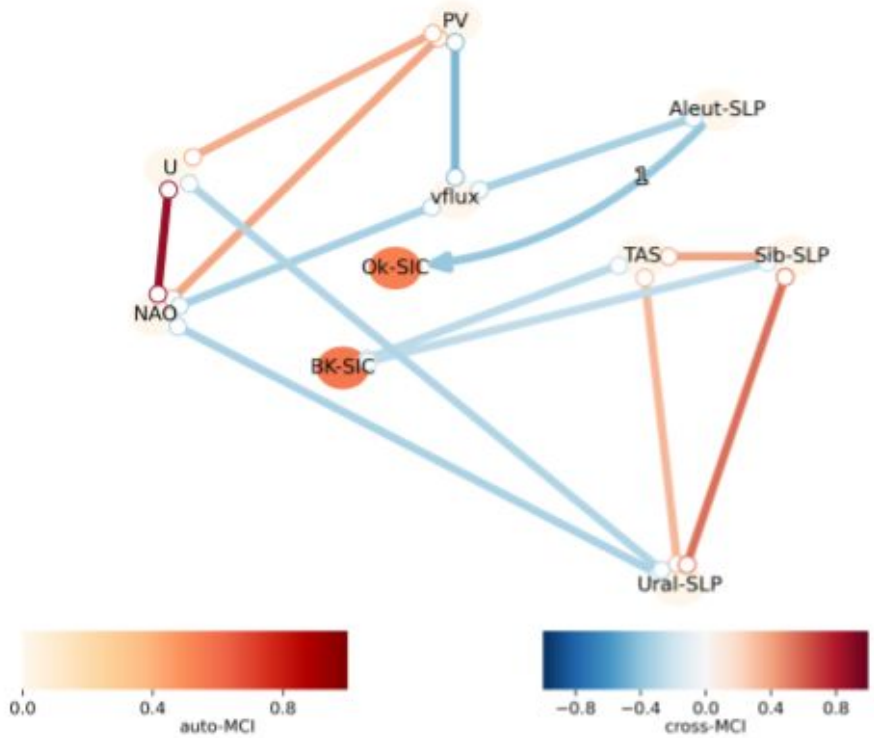
Data sources

- OBS: **ERA5** (*Hersbach et al., 2020*) and **HadISST** (*Rayner et al., 2003*), 1979-2019
- **CMIP6** 19 models (*Eyring et al., 2016, O'Neill et al., 2016*):
  - Historical (1979-2019)
  - SSP5-8.5 (2059-2099)
- Monthly mean data
- December-January-Februaries (**DJF**s) but max time delay 5 months

Causal analysis, DJFs

ERA5 & HadISST 1979-2019



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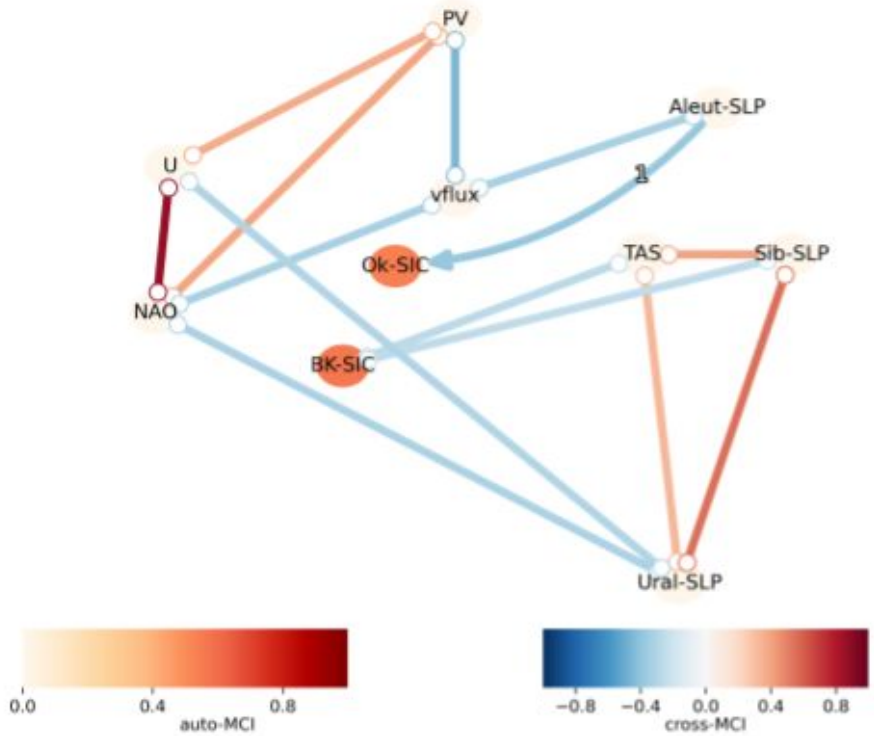
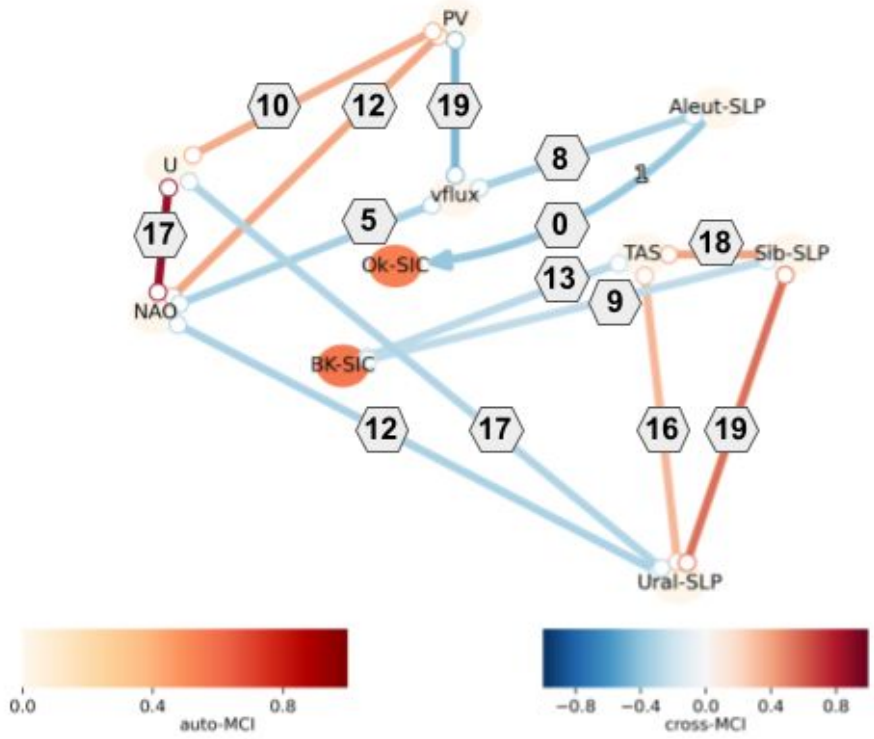


Link	*Reference*
TAS and BK-SIC	*Cohen et al., Nature Climate Change, 2020*
TAS and Ural-, Sib-SLP	*Luo et al., Journal of Climate, 2016*
Ural-SLP and Sib-SLP	*Tyrlis et al.,Quarterly Journal of the Royal Met. Society, 2020*
Sib-SLP and BK-SIC	*Siew et al., Weather and Climate Dyn., 2020*
vflux - PV	*Kretschmer et al., Journal of Climate,* 2016
PV and NAO, U	*Smith et al., Nature communications, 2022*
Aleut-SLP and Ok-SIC	*Ogi et al., Journal of Climate, 2015*

Causal analysis, DJFs

CMIP6 historical 1979-2019



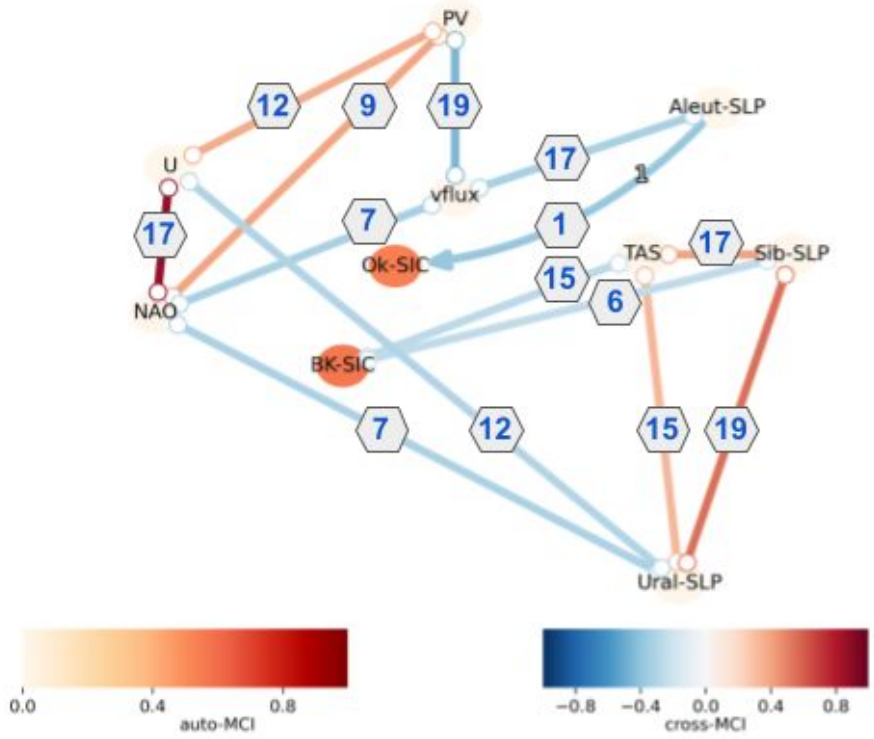
19

Majority of the links are detected in most of analysed CMIP6 historical simulations, except:

- NAO and vflux 5
- vflux and Aleut-SLP 8
- Aleut-SLP and Ok-SIC 0

Causal analysis, DJFs

CMIP6 SSP5-8.5 2059-2099



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Majority of the links are detected in most of analysed CMIP6 historical and SSP5-8.5 simulations, except:

- NAO and vflux 5 → 7
- vflux and Aleut-SLP 8 → 17
- Aleut-SLP and Ok-SIC 0 → 1

Conclusions

- Causal Discovery is a useful supervised Machine Learning tool that goes beyond correlation analysis to study complex systems;
- Majority of CMIP6 historical simulations:
  - **detect** observed links in the:
    - troposphere: TAS and BK-SIC(**13**/19); TAS and Ural- (**16**/19), Sib-SLP (**18**/19); NAO and U(**17**/19);
    - stratosphere: vflux and PV (**19**/19).
  - **do not detect**:
    - vflux and Aleut-SLP (**8**/19);
    - causal link from Aleut-SLP to Ok-SIC (but **6**/19 models show instantaneous link).
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Thank you