# What metrics can be used to analyze Arctic – mid-latitude linkages?

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## Outlook

**Metrics related to observed relationships and processes**

- applicable metrics depend on the observations and processes

**Novel methods to analyse Arctic – mid-latitude linkages**

- clustering methods, Maximum Covariance Analysis, Causal Effect Networks, reconstruction of paleoclimatological conditions, …

**Model performance metrics**

- evaluation of model representation of, e.g., co-variability relationships and individual processes
- from linkage analysis methods to model performance metrics

**Discusssion**

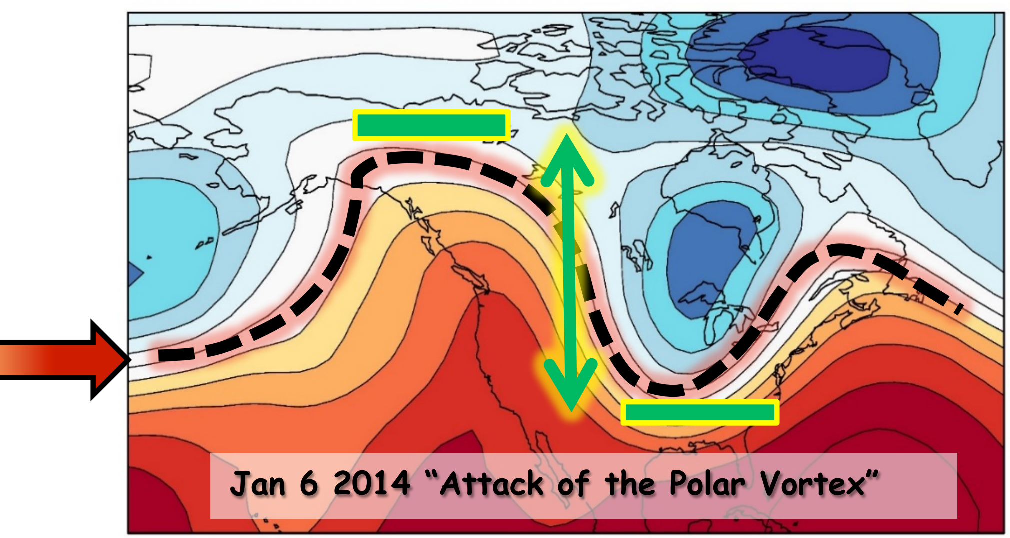
# Strength and occurrence of cold-air outbreaks and blockings

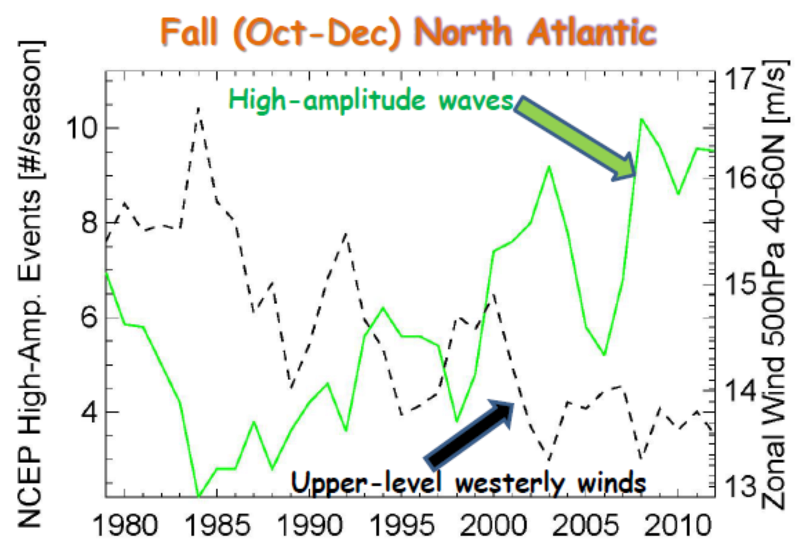
- Arctic Amplification → cold-air outbreaks less cold (Serreze et al., 2011; Screen, 2014), but at least over East Asia winter cold-air outbreaks have become more frequent, stronger and longer lasting (Kim et al. 2014, Kug et al., 2015)
- No significant trends in blocking activity in hemispherical scale (Barnes et al., 2014), but more frequent Greenland Blocking (Overland and Wang, 2010; Hanna et al., 2016)

Results may be sensitive to the exact definitions of a cold-air outbreak and a blocking

# Frequency of occurrence of high-amplitude wave patterns (HAPs)

Are HAPs happening more often?

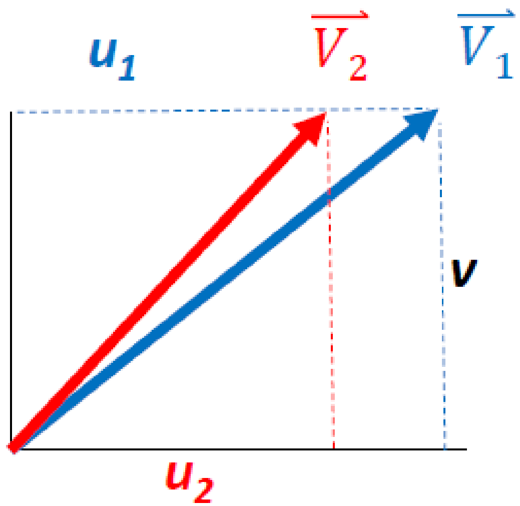


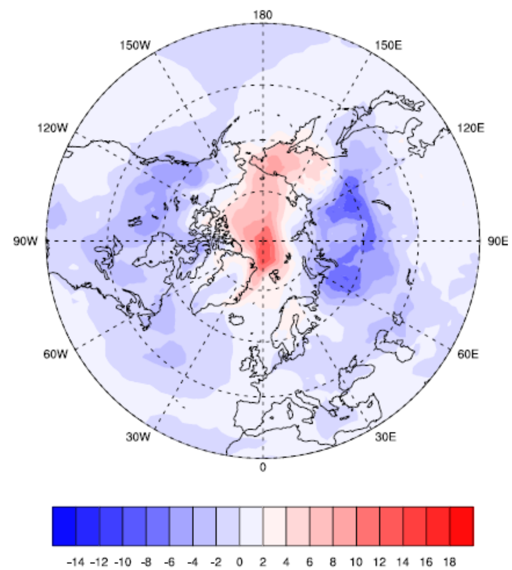



# Meridional Circulation Index (MCI)

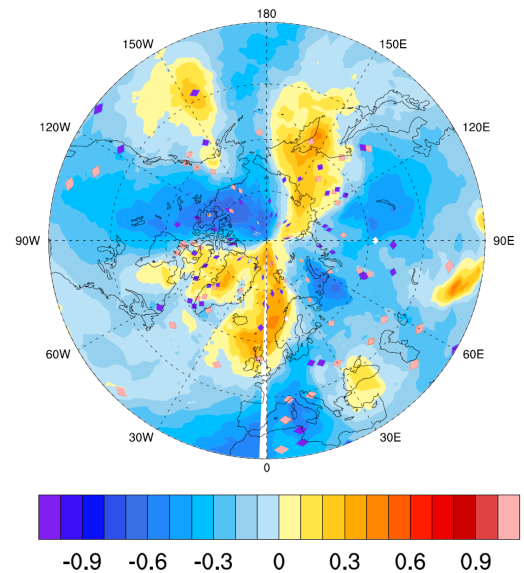
Francis and Vavrus (2015):

$$\mathrm{MCI} = \frac{v|v|}{u^2 + v^2}$$



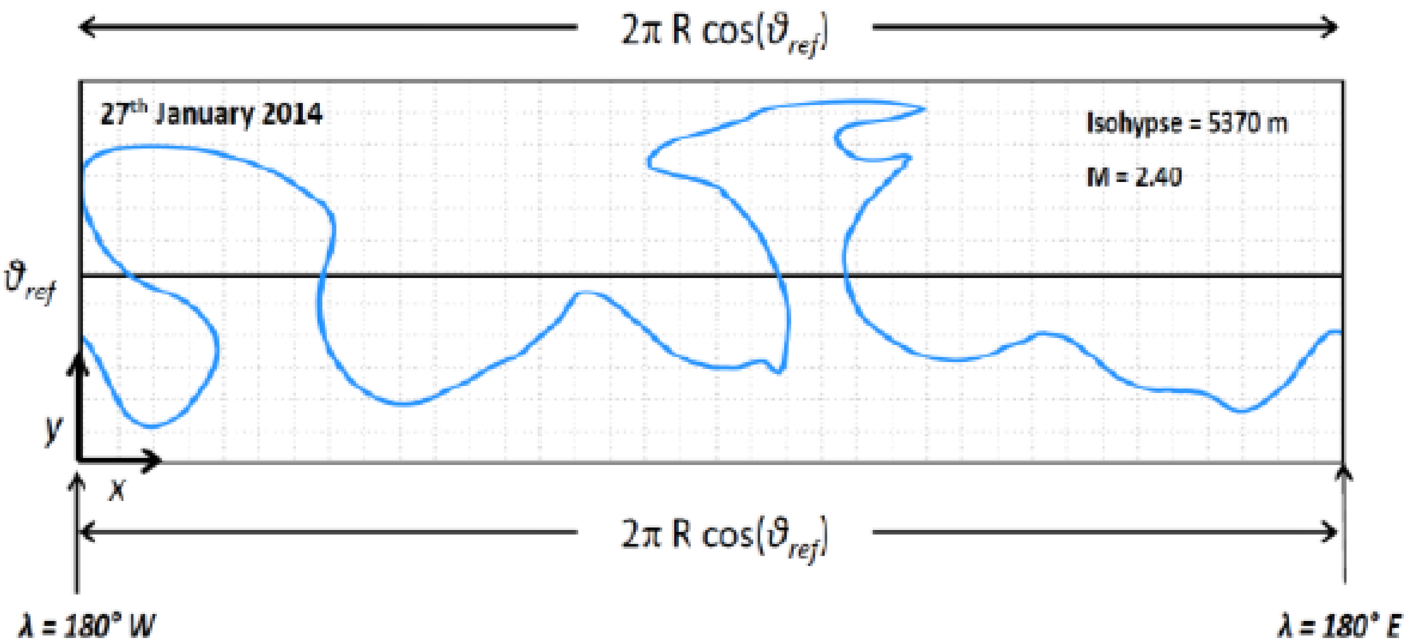

T2m anomaly




MCI

Clustering 100 largest temperature anomalies during last 10 winters into 6 groups, the most common group is the warm Arctic – cold continents pattern. It typically occurs under a specific pattern of MCI.

# Meandering Index (M)




Di Capua and Coumou (2016)

M excludes blocks, cut-off lows and highs

M calculated for the waviest contour

Strong negative correlation with AOI

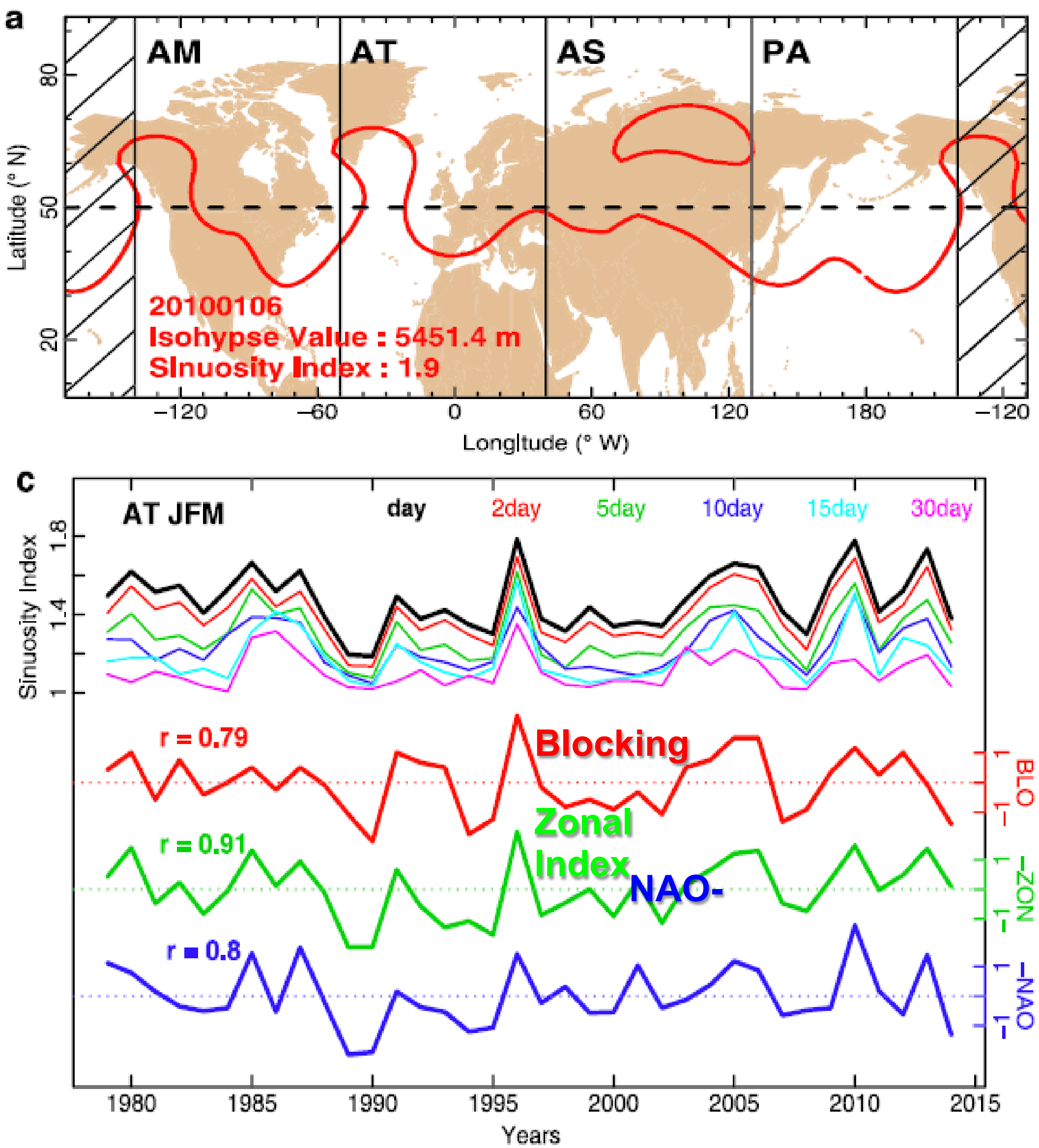
Changes in M during 1979-2015:

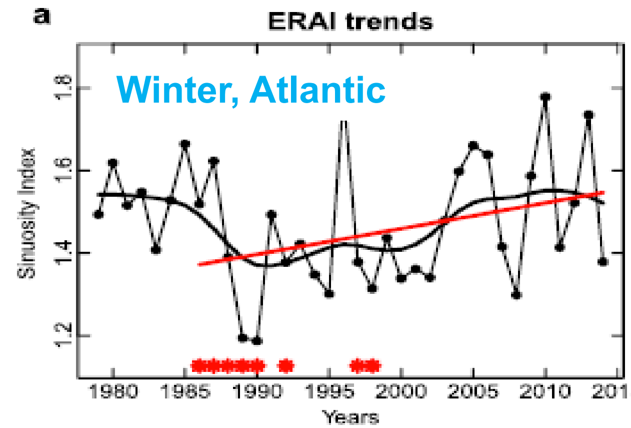
- Strong (~50%) increases in occurrence of large M in autumn and, in Mid-Pacific / N. America, in summer

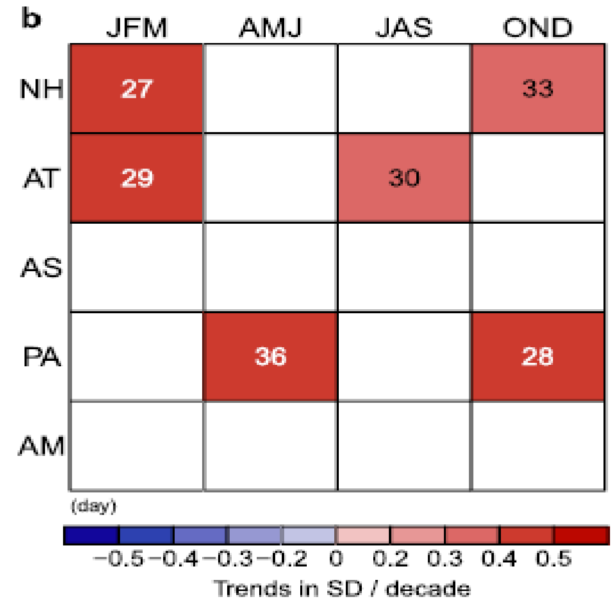
- In summer, daily trends negative; 5-day and 11-day means positive trends
=> synoptic waves weaker, planetary waves larger amplitude.

# Metrics related to observed relationships and processes linking the Arctic and mid-latitudes

## Sinuosity



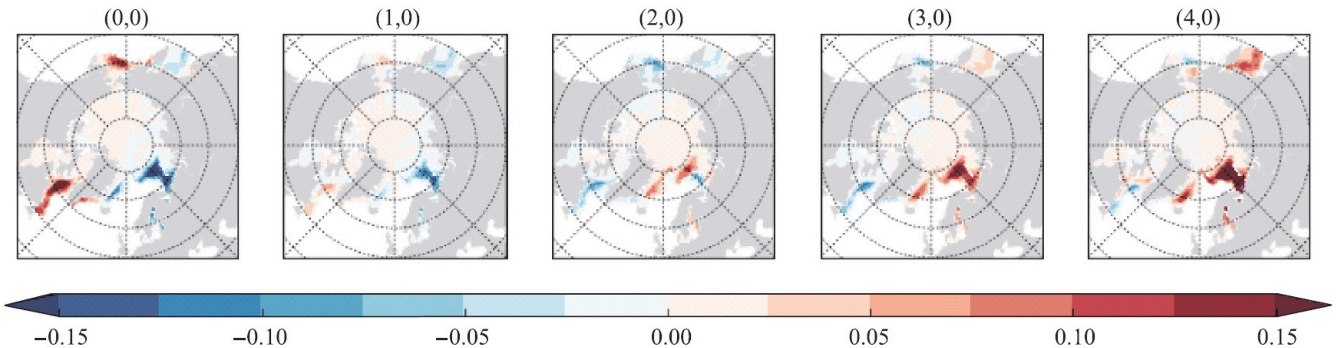




Wavier flow, consistent with F&V 2012, 2015 and Di Capua & Coumou 2016

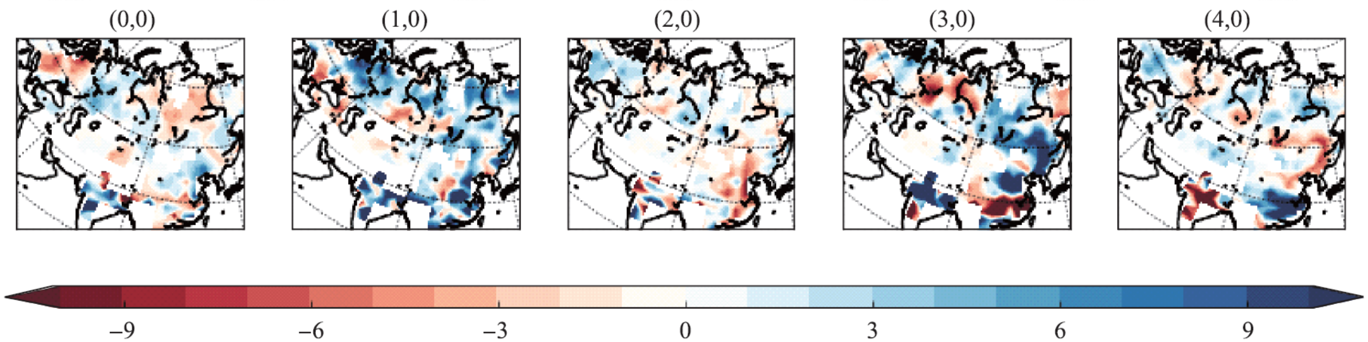
Cattiaux et al, GRL 2016

# Self-Organizing Maps (SOM)

Example: Arctic sea ice and summer precipitation in China (Uotila et al., 2014)




A five node SOM of spring (MAM) Arctic sea-ice concentration anomaly (SICA)




Detrended monthly maximum consecutive 5 day precipitation (mm) anomalies in JJA mapped to SICA.

Clustering allows application of new metrics:

Temporal changes can be divided into contributions due to changes in (a) frequency of occurrence of patterns, (b) intensity of patterns, and (c) both of them.

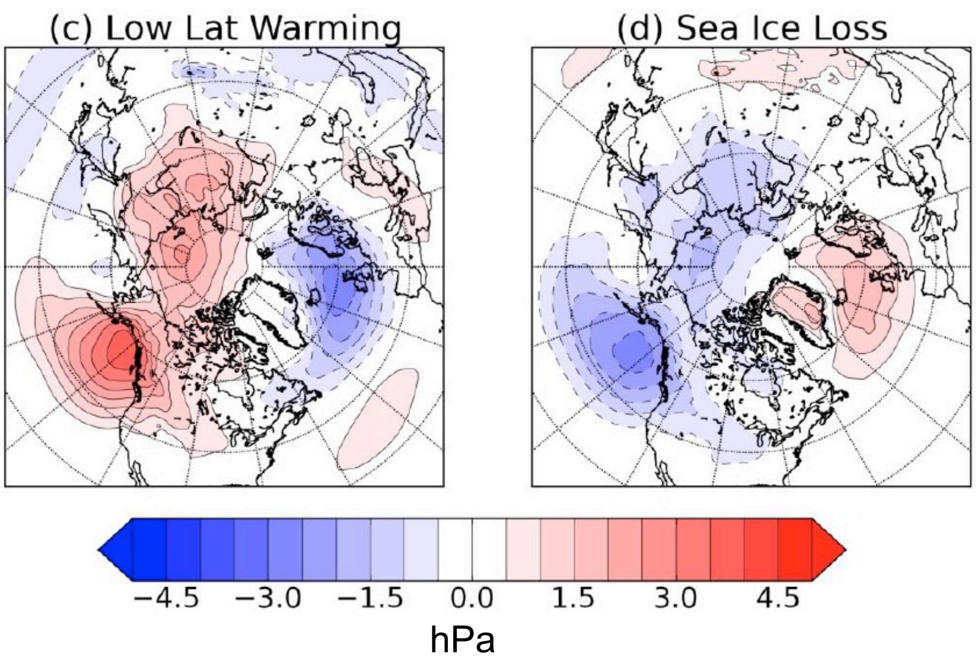
Usually applied for time series of 2D fields, but can also be applied to 1D fields: e.g. T(z) can be projected against pressure fields.

# Pattern Scaling

An approach proposed by Blackport and Kushner (2017):

The local multi-decadal mean atmospheric response is assumed to be separately proportional to the total sea ice loss and to the total low-latitude ocean surface warming.
→ estimates for the response, in a coupled climate model, to Arctic sea ice loss with low-latitude ocean temperatures fixed and vice versa.

Example: SLP response




The annual mean SLP response for the ensemble mean of CCSM4 RCP5 forcing experiments with respect to the 2032:2051 and 2052:2071 epochs.

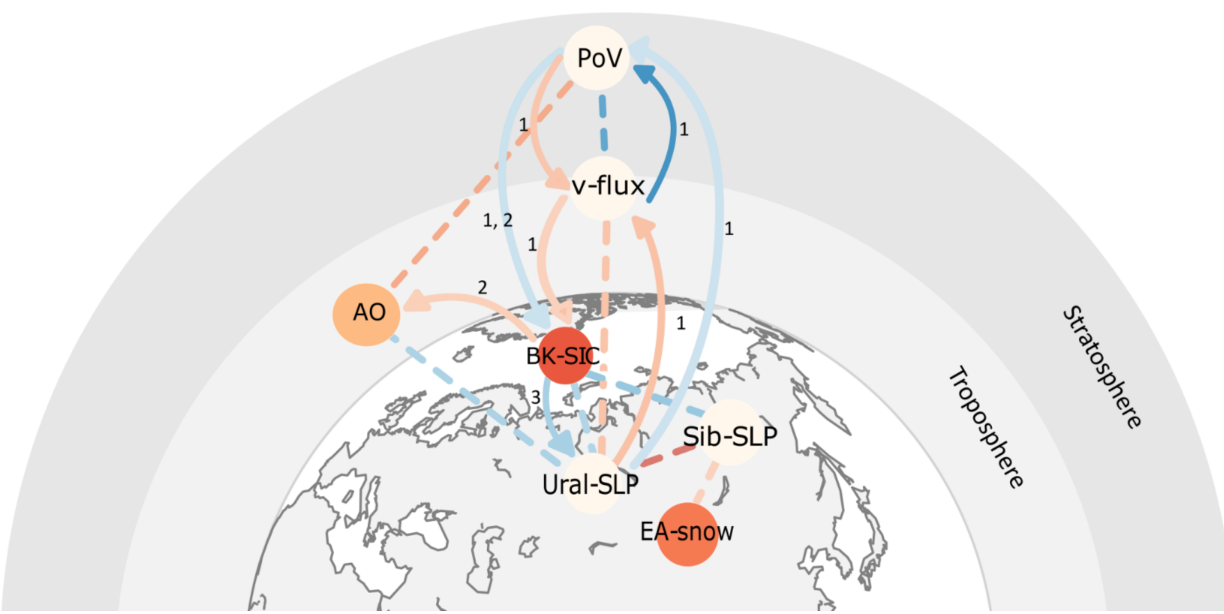
See poster by Blackport

# Novel methods to analyse Arctic – mid-latitude linkages

## Causal Effect Networks (CEN)

- CEN-algorithm is multivariate approach, which tests for conditional dependent relationships among a set of time-series and for different lags.
- Distinguishes between spurious correlations and causal relationships.
- CEN can be applied in hypothesis testing or to evaluate model data.

Example: test hypothesis about Arctic induced drivers of the Stratospheric polar vortex (e.g. Kim et al., 2014 and Cohen et al., 2014). Data: Monthly time-series in winter (DJF)




**Results:**
Reduction in Barents-Kara sea ice in fall leads to increased SLP over the Ural Mountains followed by increased vertical wave activity and a weakened stratospheric polar vortex

Kretschmer et al., 2016 (J Clim)

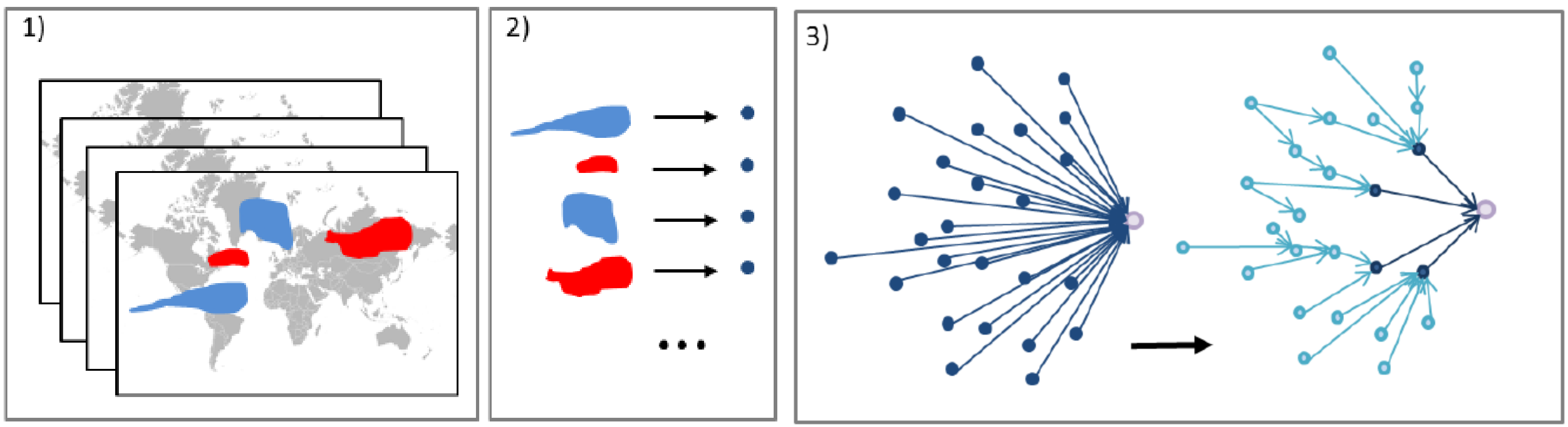
# Novel methods to analyse Arctic – mid-latitude linkages

Limitations of CEN

- Causal interpretations only possible with respect to the included time-series
- not-included external drivers might affect the network structure

→ more sophisticated method developed:

## Response-guided causal precursor detection (RG-CPD)




Detect communities in multi-variate data which correlate positively (red) or negatively (blue) with the response variable at different lead-lag times

Take area-weighted averages of all communities creating time-series of precursors.

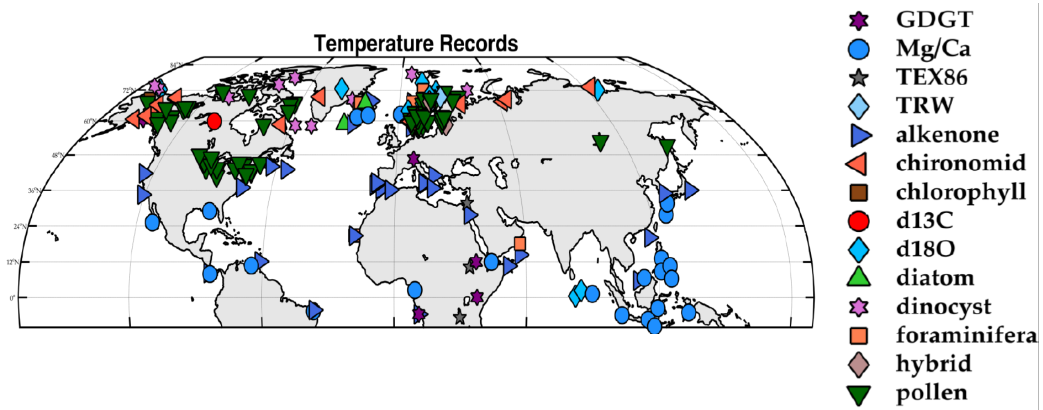
The algorithm removes all non-causal links due to common drivers, auto-correlation or indirect links.

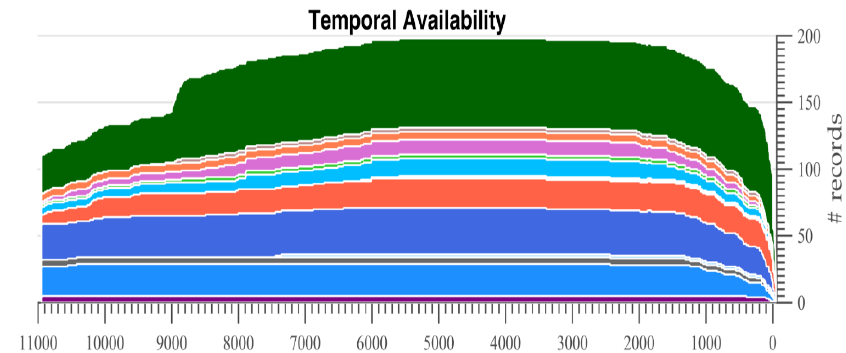
See poster by Kretschmer et al.

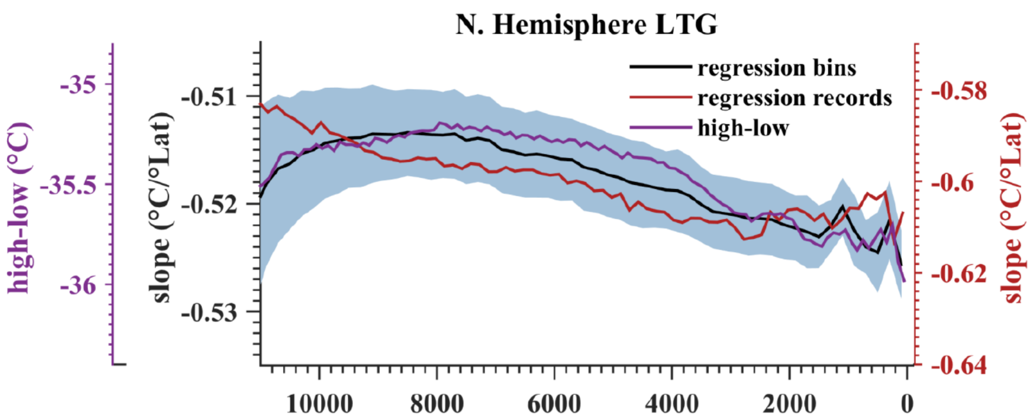
# Novel methods to analyse Arctic – mid-latitude linkages

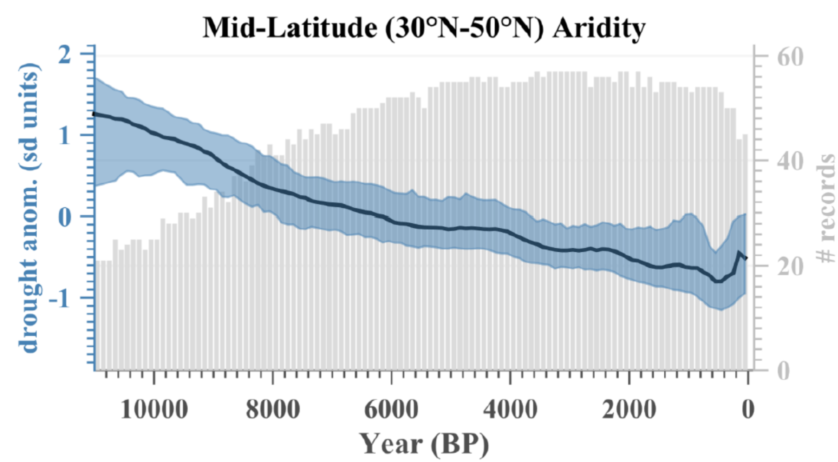
## Reconstruction of paleoclimatological conditions

**Large datasets to assess the evolution of latitudinal temperature gradients and moisture transport**




See poster by Routson et al.

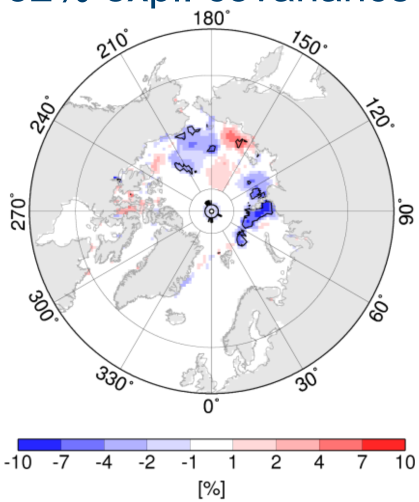
**Climate model performance metrics**

# Maximum Covariance Analysis (MCA)

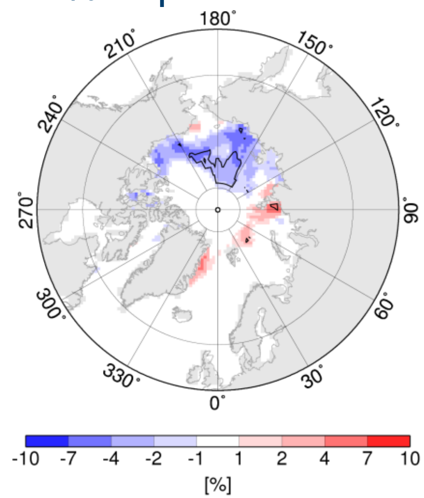
to detect atmospheric changes initiated by low sea ice conditions

Sea ice concentration Sep

**GPH 500hPa**
32% expl. covariance

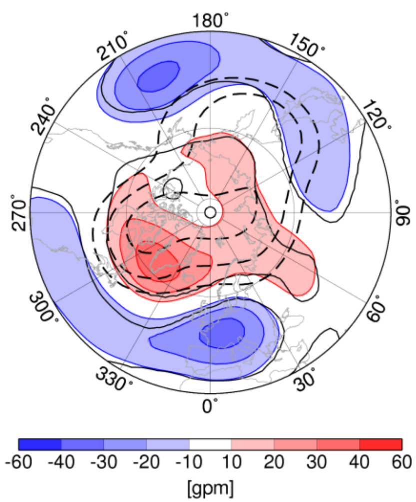



**GPH 500hPa**
37% expl. covariance

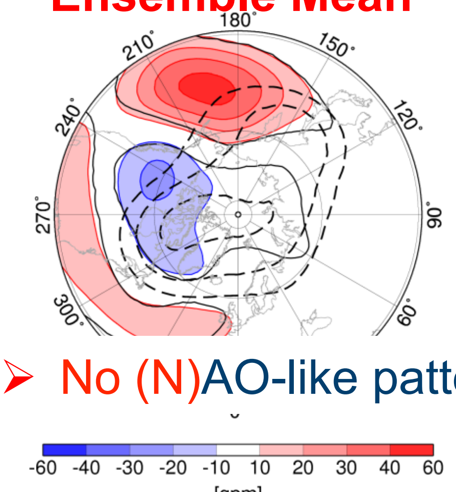



Atmospheric circulation DJF

**ERA-Interim**



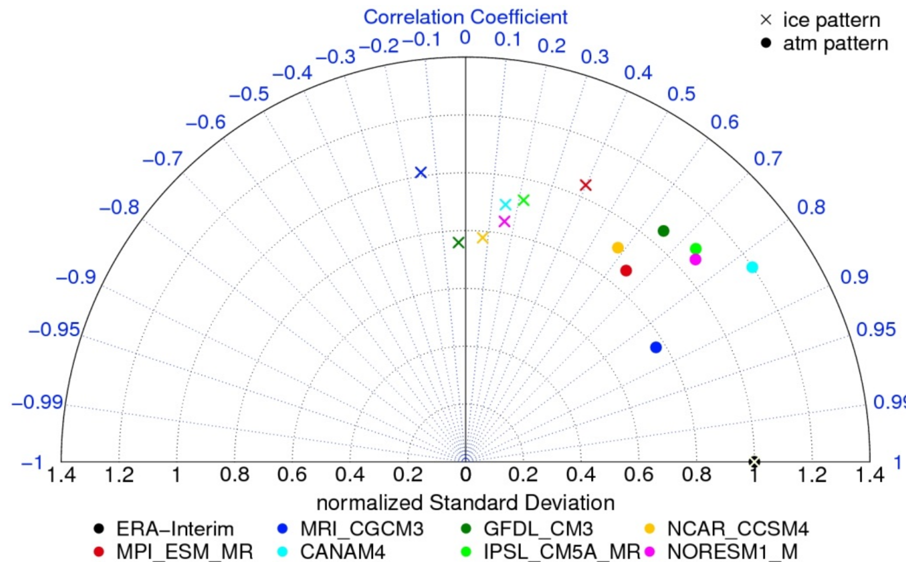

**ECHAM6-AMIP Ensemble Mean**




➢ No (N)AO-like pattern

**Metrics → Taylor Plot**

Patterns of first MCA mode
AMIP simulations (CMIP5)
Ensemble mean data
Ensemble size: 3-5 members

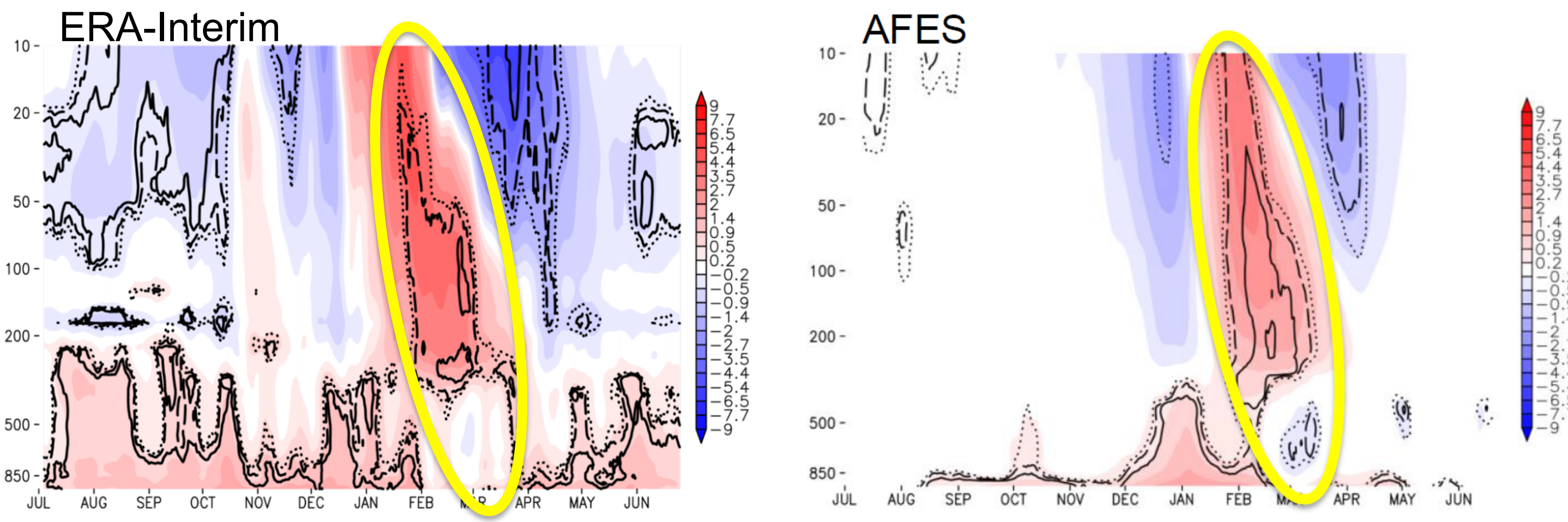



**None of these model ensembles** reproduces observed first MCA-mode with (N)AO-like winter pattern

Handorf et al., GRL 2015

# From temporal evolution method to metrics?

**Polar cap (65-85°N) mean temperature; low ice (1998-2013) minus high ice (1979-1997) years**




The strong stratospheric warming in late winter is related to weaker zonal winds and reduced upward propagation of planetary waves.

In 60-year perpetual runs with fixed sea-ice forcing, the AFES model reasonably well reproduces the temporal evolution of the Polar cap mean temperature profile.

How to define metrics? Possibilities:

- Termination
- Amplitude of change

Jaiser et al., JGR 2016

# Conclusions

● The metrics presented have yielded a lot of new information on various relationships and trends not easily detectable otherwise.

● Some metrics are sensitive to the exact practise of calculating them, as well as to inaccuracies in observations and reanalyses.

● Even if changes in certain metrics are robust, the reasons for the changes often remain unclear.

● New analysis methods have allowed novel applications of traditional metrics of climate model performance (e.g. Taylor plots).

## Way forward

● There is need for standardization of metrics so that various studies can be better intercompared.

● Novel metrics found applicable in studies based on reanalyses should be more extensively applied in evaluation of climate and NWP model performance.

● More extensive use of promising novel methods, such as CEN, RG-CPD, MCA, SOM, NARMAX, and evolutionary algorithms (the last two not yet applied in the field), some of them applicable for distinguishment between forced signals and natural variability

● Paleoclimatological data can help in better understanding Arctic – mid-latitude linkages.

## References


Barnes, E. A., E. Dunn-Sigouin, G. Masato and T. Woollings (2014). Exploring recent trends in Northern Hemisphere blocking. Geophys. Res. Lett., 41, doi: 10.1002/2013GL058745.

Blackport, R., and P. Kushner (2017). Isolating the Atmospheric Circulation Response to Arctic Sea Ice Loss in the Coupled Climate System. J. Climate. doi:10.1175/JCLI-D-16-0257.1, in press.

Cattiaux, J., Y. Peings, D. Saint-Martin, N. Trou-Kechout, and S. J. Vavrus (2016), Sinuosity of midlatitude atmospheric flow in a warming world, Geophys. Res. Lett., 43, 8259–8268, doi:10.1002/2016GL070309.

Cohen, J. et al. (2014). Recent Arctic amplification and extreme mid-latitude weather. Nat. Geosci. 7, 627–637.

Czaja, A., and C. Frankignoul (2002), Observed impact of Atlantic SST anomalies on the North Atlantic Oscillation. J. Climate, 15, 606–623, doi: 10.1175/1520-0442(2002)015<0606:OIOASA>2.0.CO;2.

Di Capua and Coumou (2016). Changes in meandering of the Northern Hemisphere circulation. Environ. Res. Lett. 11, 094028.

Francis and Vavrus (2012). Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophys. Res. Lett. 39, L06801.

Francis and Vavrus (2015). Evidence for a wavier jet stream in response to rapid Arctic warming. Environ. Res. Lett. 10, 014005.

García-Serrano, J., C. Frankignoul, G. Gastineau, and A. De La Càmara, A. (2015), On the predictability of the winter Euro-Atlantic climate: lagged influence of autumn Arctic sea ice. J. Clim., 28, 5195-5216. doi:10.1175/JCLI-D-14-00472.1

García-Serrano, J., C. Frankignoul, M.P. King, A. Arribas, Y. Gao, V. Guemas, D. Matei, R. Msadek, W. Park, and E. Sanchez-Gomez (2016), Multi-model assessment of linkages between eastern Arctic sea-ice variability and the Euro-Atlantic atmospheric circulation in current climate. Clim. Dyn., 1-23. doi:10.1007/s00382-016-3454-3

Handorf, D., R. Jaiser, K. Dethloff, A. Rinke, and J. Cohen (2015), Impacts of Arctic sea ice and continental snow cover changes on atmospheric winter teleconnections. Geophys. Res. Lett., 42, doi:10.1002/2015GL063203

Hanna, E., Cropper, T. E., Hall, R. J. & Cappelen, J. (2016). Greenland Blocking Index 1851–2015: a regional climate change signal. Int. J. Climatol. http://doi.org/brqf.

Jaiser, R., K. Dethloff, and D. Handorf (2013), Stratospheric response to Arctic sea ice retreat and associated planetary wave propagation changes, Tellus, Ser. A, 65, 19375, doi: 10.3402/tellusa.v65i0.19375.

Jaiser, R., T. Nakamura, D. Handorf, K. Dethloff, J. Ukita, K. Yamazaki (2016), Atmospheric winter response to Arctic sea ice changes in reanalysis data and model simulations. J. Geophys. Res., 121, doi: 10.1002/2015JD024679

Kim, B.-M. et al. (2014). Weakening of the stratospheric polar vortex by Arctic sea-ice loss. Nat. Commun. 5, 4646.

Kretschmer, M., Coumou, D., Donges, J. & Runge, J. (2016). Using causal effect networks to analyze different Arctic drivers of midlatitude winter circulation. J. Clim. 29, 4069-81.

Kug, J.-S. et al. (2015). Two distinct influences of Arctic warming on cold winters over North America and East Asia. Nat. Geosci. 8, 759–762.

Overland, J. E. & Wang, M. Y. (2010). Large-scale atmospheric circulation changes are associated with the recent loss of Arctic sea ice. Tellus A 62, 1–9.

Screen, J.A. (2014), Arctic amplification decreases temperature variance in northern mid- to high-latitudes, Nature Clim. Change, 4, 577-582.

Serreze MC, Barrett AP, Cassano JJ (2011) Circulation and surface controls on the lower tropospheric temperature field of the Arctic. J Geophys Res 116:D07104

Taylor, K.E. (2001), Summarizing multiple aspects of model performance in a single diagram. J. Geophys. Res., 106, 7183-7192.

Uotila, P., A. Karpechko, and T. Vihma (2014). Links between the Arctic sea ice and extreme summer precipitation in China: An alternative view. Adv. Polar Sci., 25(4), 222-233, doi:10.13679/j.advps.2014.4.00222.

Wu, Q., and X. Zhang (2010), Observed forcing-feedback process between Northern Hemisphere atmospheric circulation and Arctic sea ice coverage. J. Geophys. Res., 115, D14119, doi:10.1029/2009JD013574.