EGU General Assembly online, 4-8 May 2020

Nonlinear components in global climate teleconnections

Jiří Mikšovský

Department of Atmospheric Physics, Charles University, Prague, Czech Republic
Global Change Research Institute, Czech Academy of Sciences, Brno, Czech Republic

jiri@miksovsky.info

Principal Questions

How prominent are nonlinear components in global teleconnection patterns pertaining to major internal climate oscillatory modes?

How to best capture them?

Nonlinearity estimation approaches tested

Asymmetry in regression mappings

Measuring nonlinearity from differences of regression coefficients pertaining to different phases of the predictors

Mutual information

General nonparametric measure of relationships between time series, both linear and nonlinear

Local linear models

Representation of nonlinear links through segmentation of the space of predictors

Main conclusions

Nonlinearities prominent in some setups, but vary strongly with location or season of the year

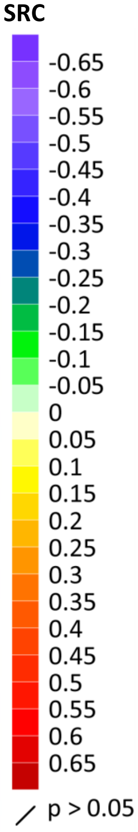
Even though different nonlinearity detection techniques are sensitive to different aspects of nonlinearity, common patterns do appear

Starting point: Linear temperature response patterns

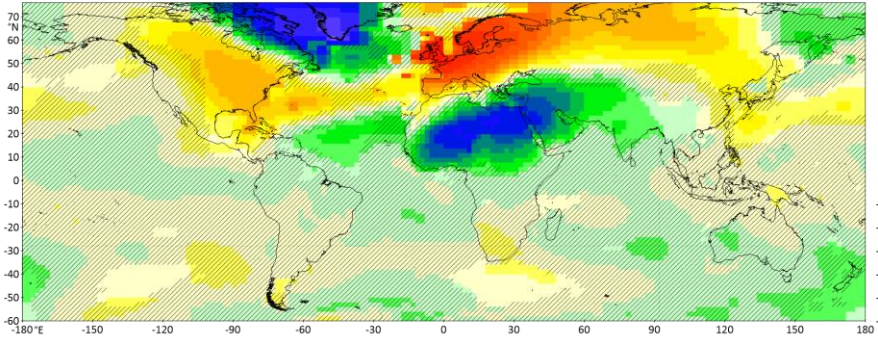
Target data: GISTEMP monthly temperatures, 1901-2015, 2°x 2° resolution

Explanatory variables: Indices of major climate oscillations (NAO, ENSO, AMO, PDO)

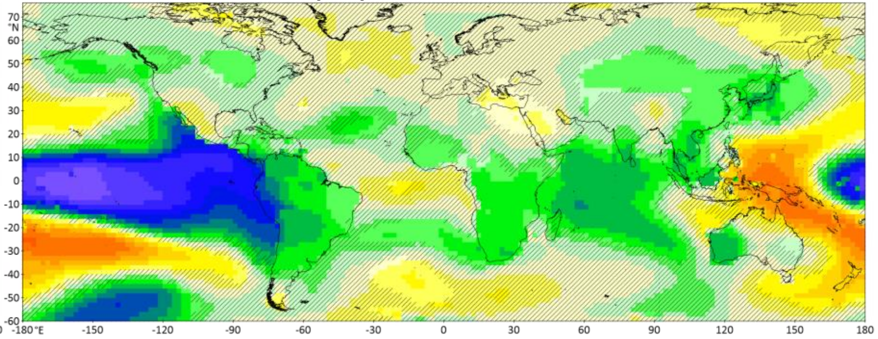
Analysis setup: Multiple linear regression (MLR), statistical significance estimated through moving block bootstrap, results presented as **standardized regression coefficients (SRCs)**



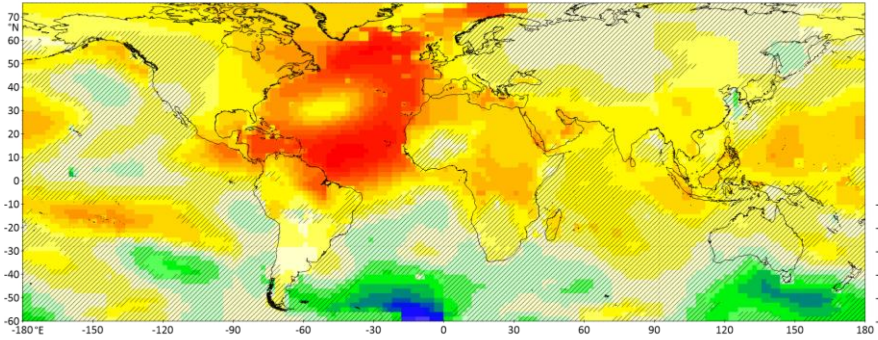
North Atlantic Oscillation (NAO)



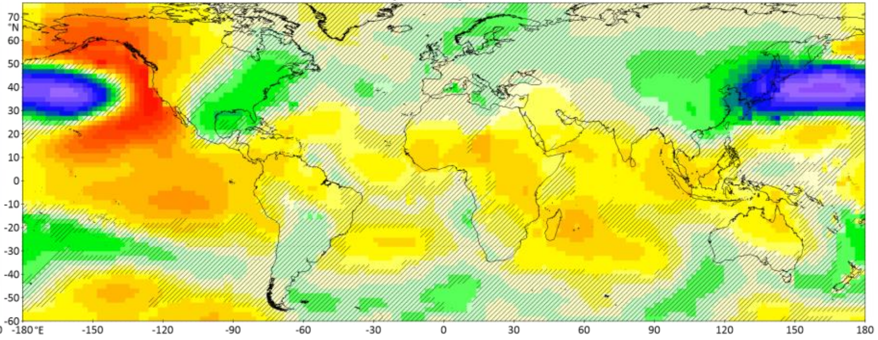
Southern Oscillation (SO)



Atlantic Multidecadal Oscillation (AMO)



Pacific Decadal Oscillation (PDO)

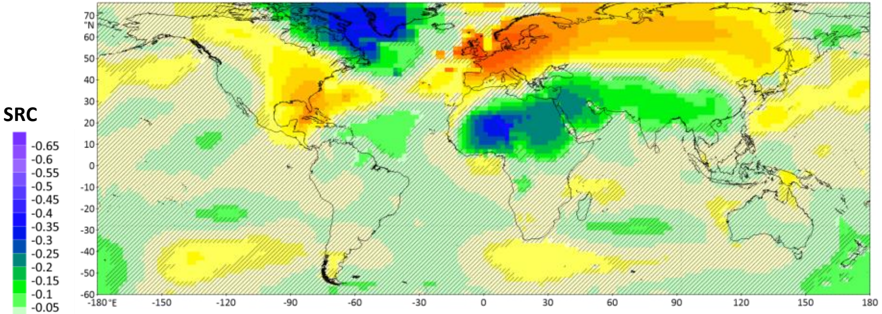


Asymmetry in regression-estimated responses

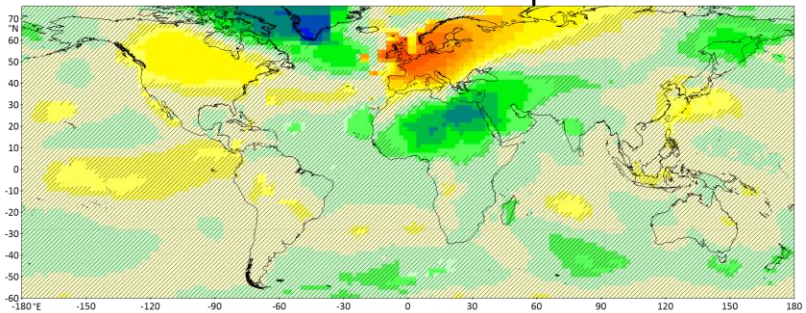
Predictor: NAO index

Several regions with distinctly different temperature responses during positive/negative phase of NAO, indicative of noteworthy deviation from linearity

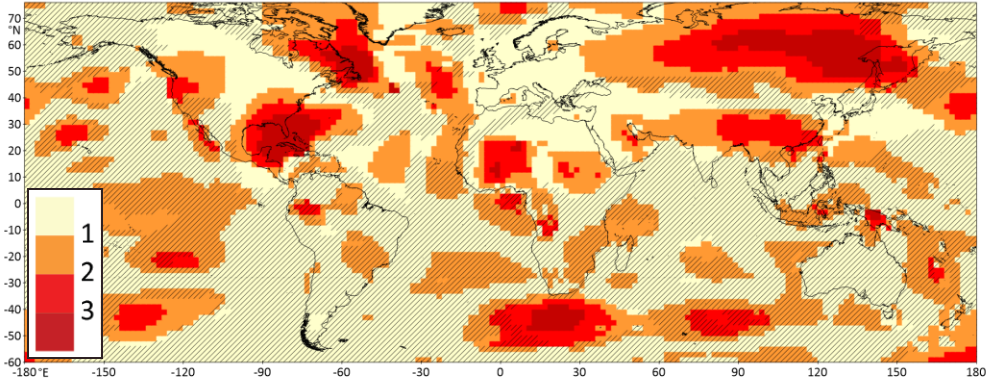
North Atlantic Oscillation - NAO+ phase



North Atlantic Oscillation - NAO- phase



Asymmetry expressed from regression coefficients (c) and their st. deviations (s) as: $T = \frac{|c_+ - c_-|}{(s_+^2 + s_-^2)^{1/2}}$

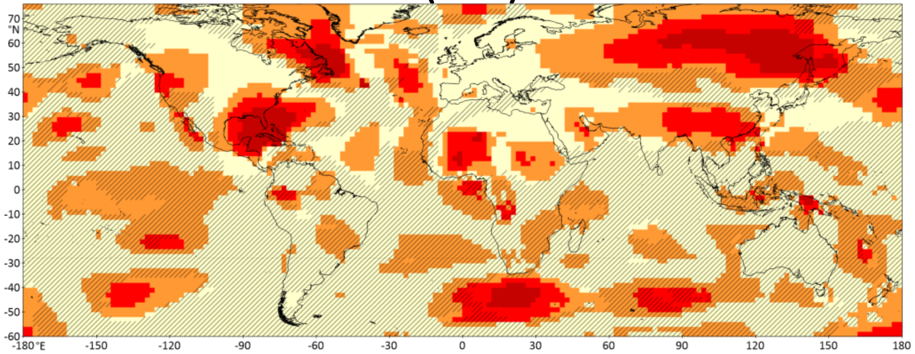


Hatching: Response statistically significant for neither of the NAO phases (95% level)

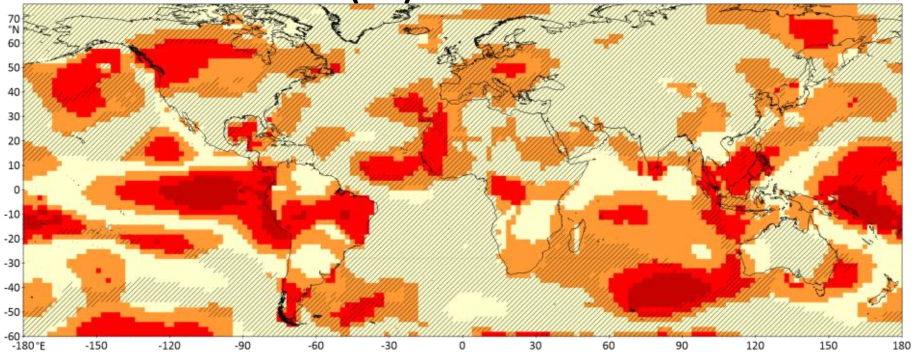
Asymmetry in regression-estimated responses

$$T = \frac{|c_+ - c_-|}{(s_+^2 + s_-^2)^{1/2}}$$

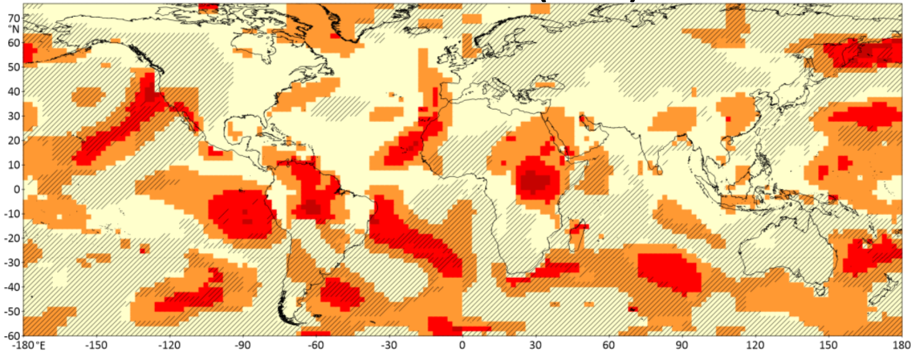
North Atlantic Oscillation (NAO)



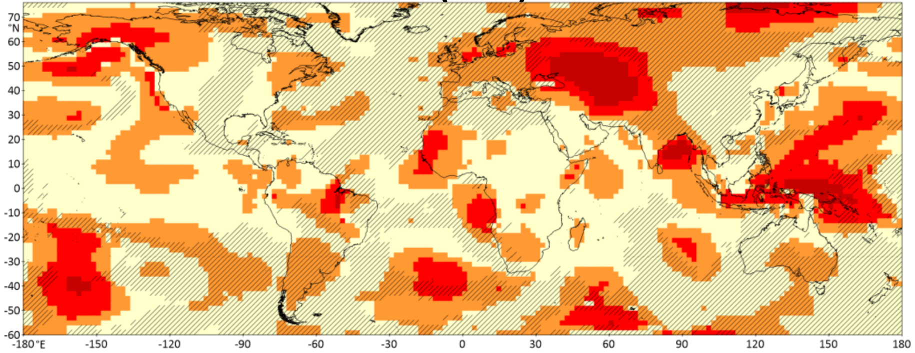
Southern Oscillation (SO)



Atlantic Multidecadal Oscillation (AMO)

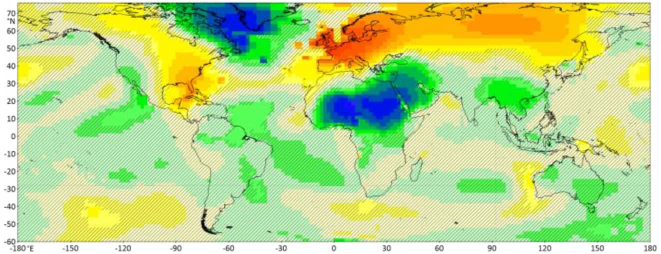


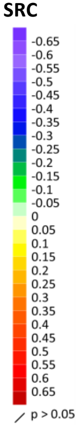
Pacific Decadal Oscillation (PDO)



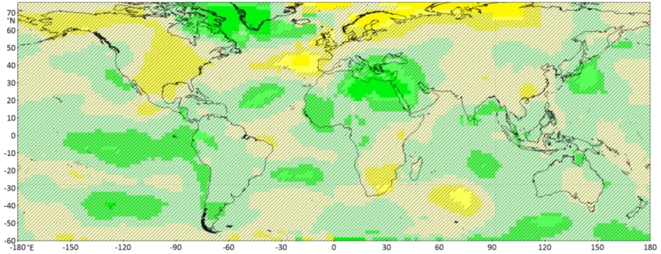
More segments, better resolution?

North Atlantic Oscillation - highly positive phase

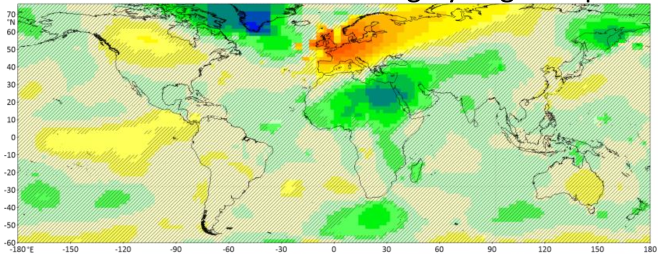




North Atlantic Oscillation - neutral phase



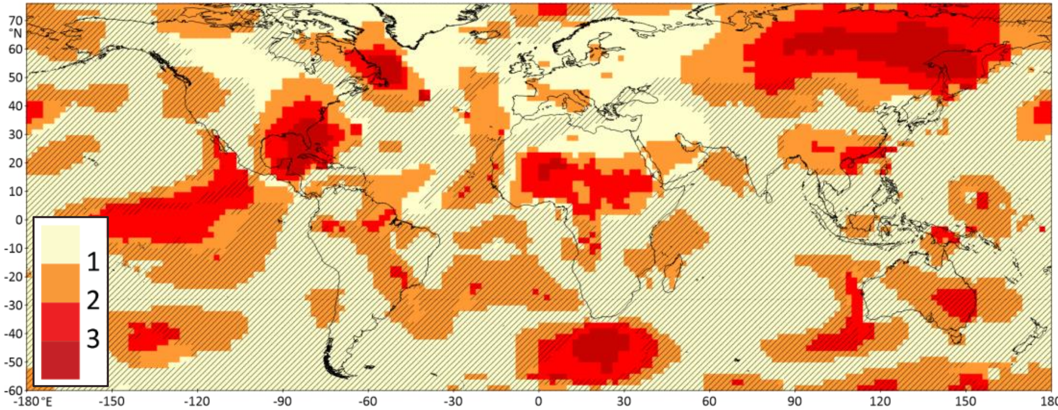
North Atlantic Oscillation - highly negative phase



Although some deviations from linearity become more prominent when smaller-sized categories are used, other diminish due to higher uncertainty associated with lower number of samples used in each of the partial data segments

Asymmetry of coefficients obtained for highly positive and highly negative phases of NAO:

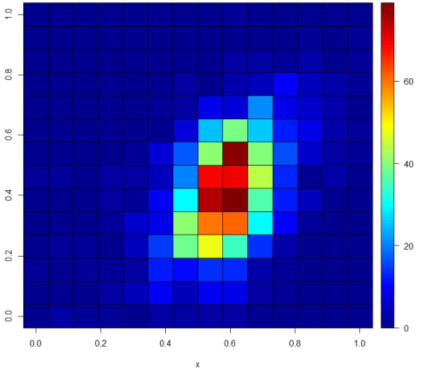
$$T = \frac{|c_{++} - c_{--}|}{(s_{++}^2 + s_{--}^2)^{1/2}}$$



Mutual information (MI):

General dependence measure, based on information entropy

Marginal & joint probabilities of the two series compared

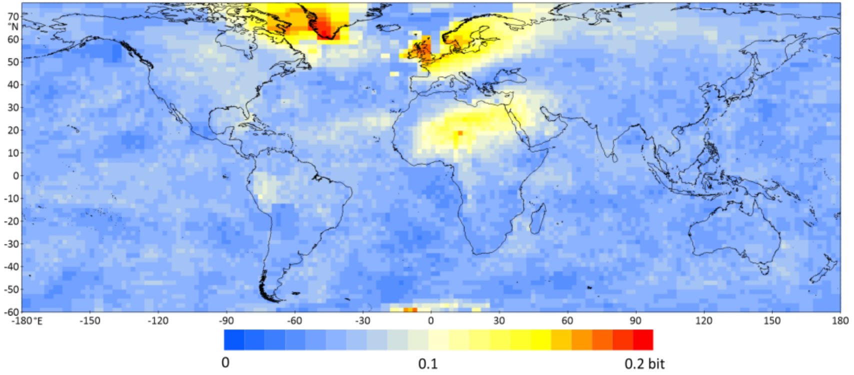


Calculation of mutual information

$$MI(X,Y)= \sum\sum_{x,y} p(x,y) ln\left(\frac{p(x,y)}{p(x)p(y)}\right)$$

Mutual information distribution example

North Atlantic Oscillation index vs. **temperature**

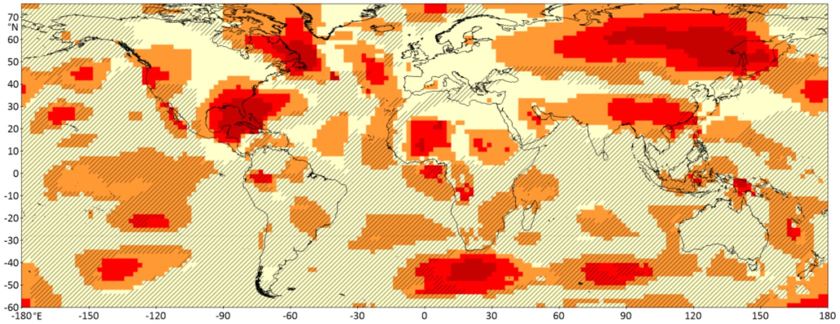


Nonlinearity testing: Degree and statistical significance of nonlinearity estimated by comparing the values of mutual information to an ensemble of results obtained for **surrogate data**, i.e. datasets created by randomizing the phases in the Fourier spectra of the time series, preserving their linear properties while randomizing their nonlinear components

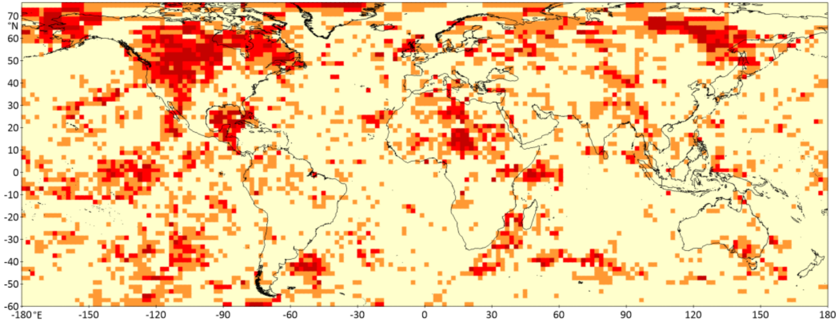
Nonlinearity magnitude:

Regression coefficients asymmetry vs. nonlinearity via MI

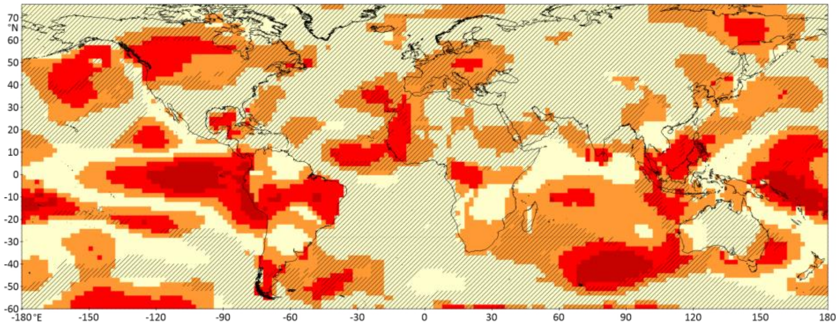
Asymmetry of regression coefficients, NAO



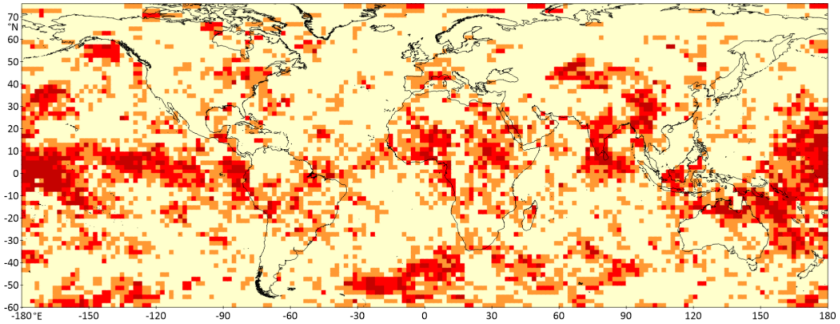
Mutual information, NAO

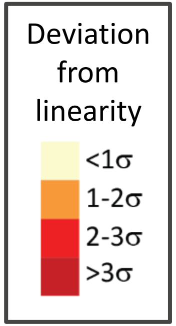


Asymmetry of regression coefficients, SO



Mutual information, SO





Local linear models:

Nonlinearity-sensitive generalization of multiple linear regression

An extension of the concept of multiple linear regression, approximating relationships in a generally nonlinear system through application of high number of **locally linear mappings on mutually overlapping segments of the space of predictors**

Individual regression model is created for each of the *N* data point in the series and calibrated using certain number (< *N*) of predictand-predictor(s) pairs pertaining to similar states of the underlying dynamical system

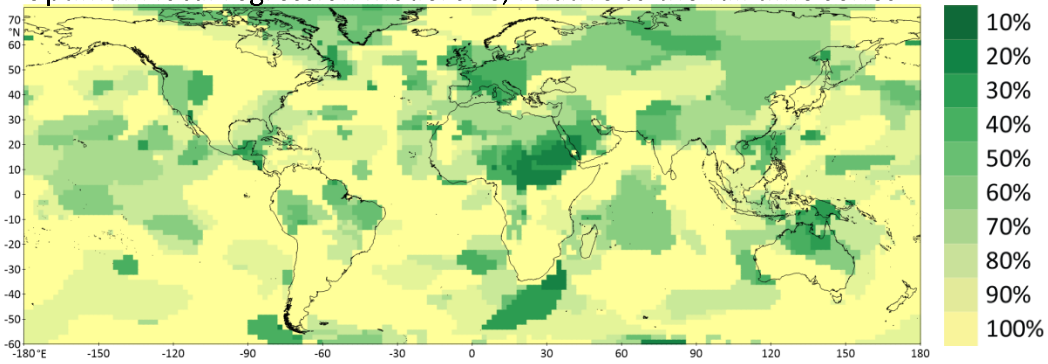
Similarity of individual states is measured as a distance of the vectors of **selector variables** (here represented by one or more of the predictors, i.e. scalar indices of NAO, SO, AMO and PDO)

Key model design parameter: Size of the local neighborhood, measured here in % of the full dataset size and optimized individually for each target grid point

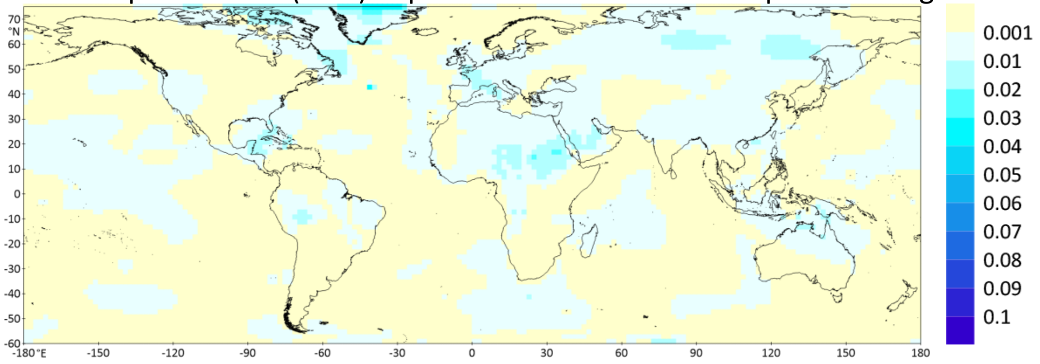
Local linear models

Selector variable: NAO index only

Optimum local regression model size, relative to the full time series

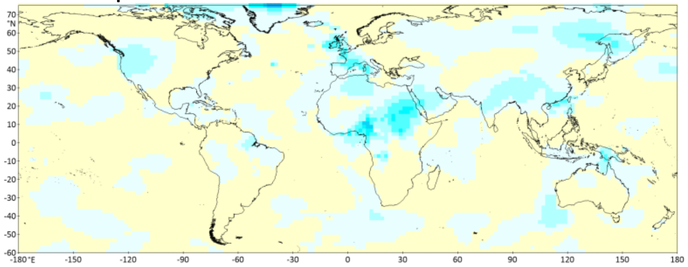


Mean squared error (MSE) improvement relative to multiple linear regression

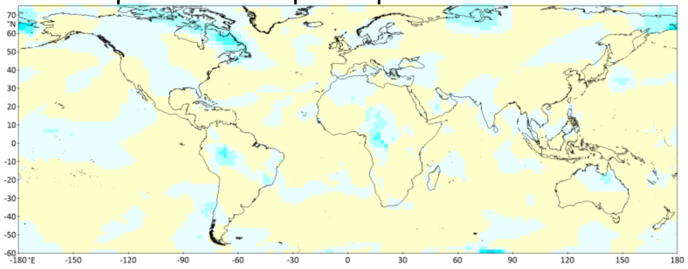


Only minor improvement over MLR, even in regions with distinct asymmetry of regression coefficients pertaining to NAO+ and NAO-

MSE improvement: October-March



MSE improvement: April-September

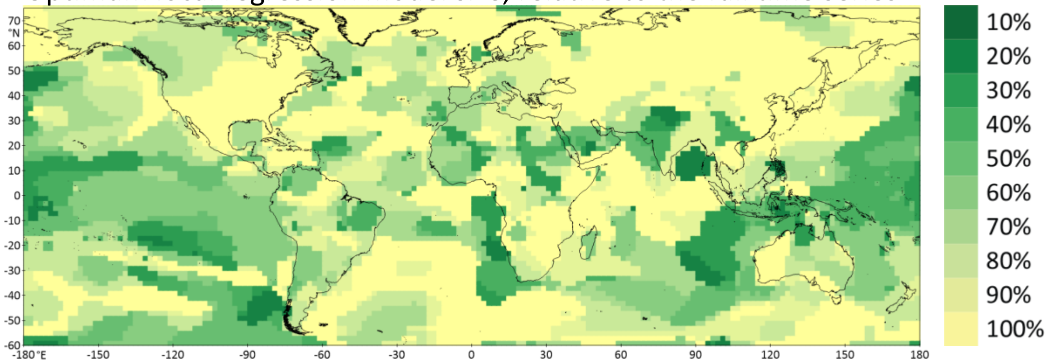


Local linear models

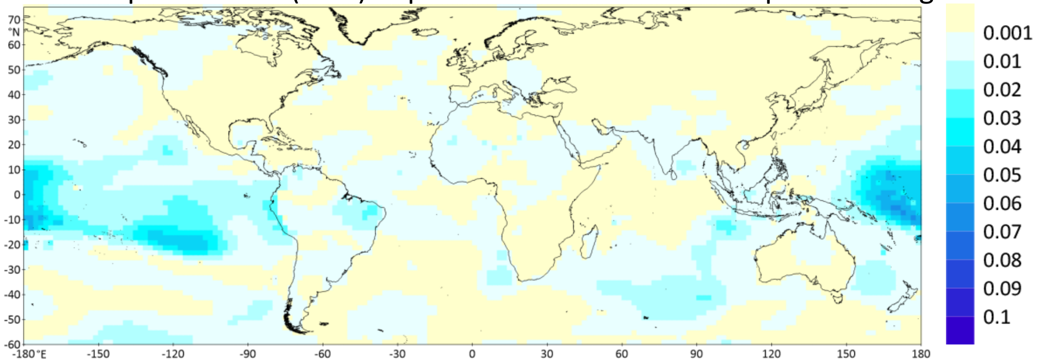
Selector variable: SO index only

Substantial improvement over MLR especially in the equatorial Pacific, some gains also in South America, southern Asia and over southern Indian Ocean

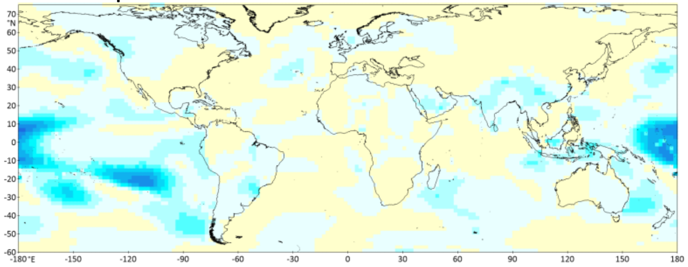
Optimum local regression model size, relative to the full time series



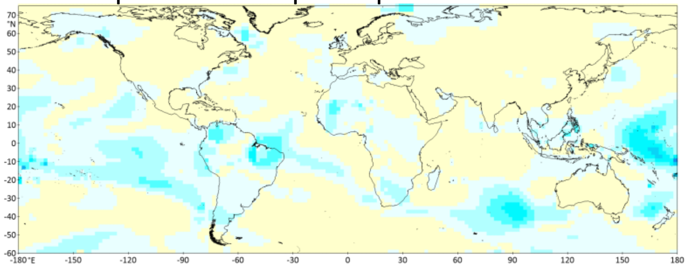
Mean squared error (MSE) improvement relative to multiple linear regression



MSE improvement: October-March



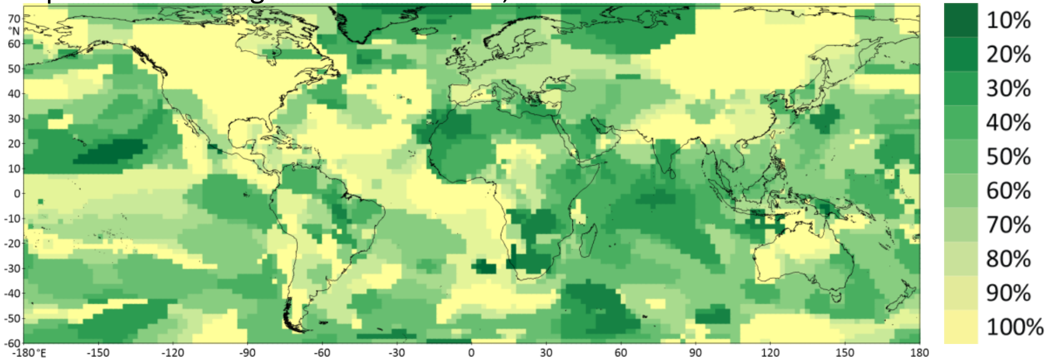
MSE improvement: April-September



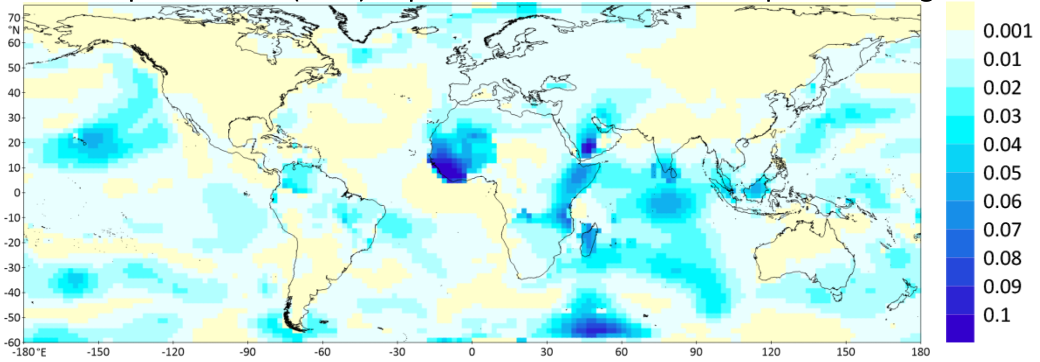
Local linear models

Selector variable: AMO index only

Optimum local regression model size, relative to the full time series

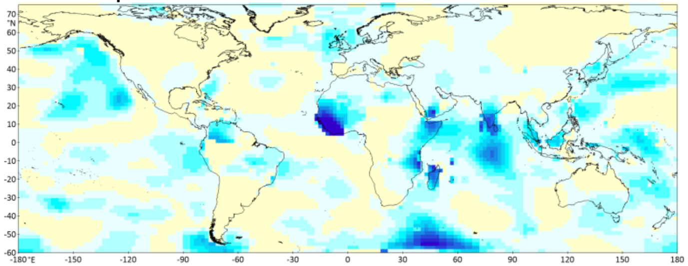


Mean squared error (MSE) improvement relative to multiple linear regression

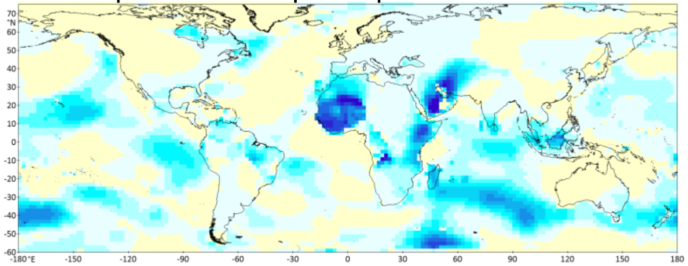


Substantial gains especially in Africa, as well as over the Indian Ocean and several adjacent regions

MSE improvement: October-March



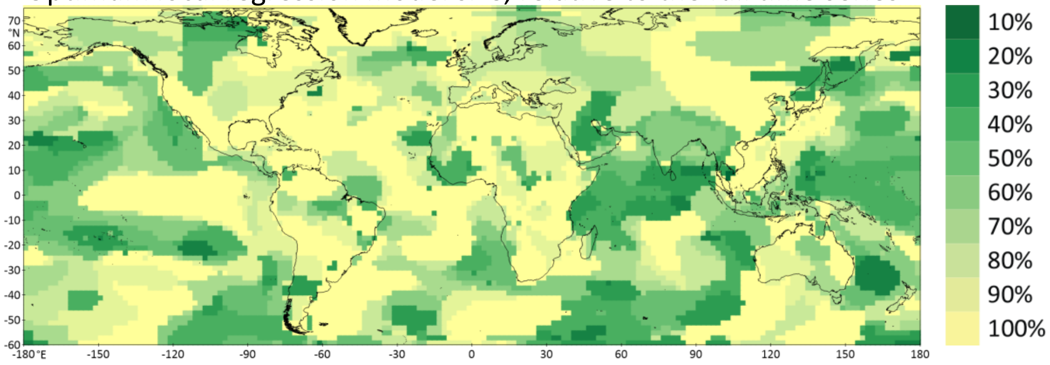
MSE improvement: April-September



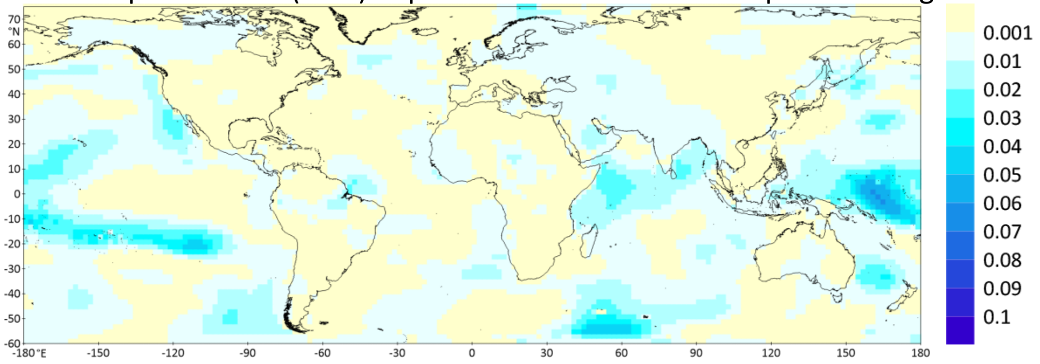
Local linear models

Selector variable: PDO index only

Optimum local regression model size, relative to the full time series

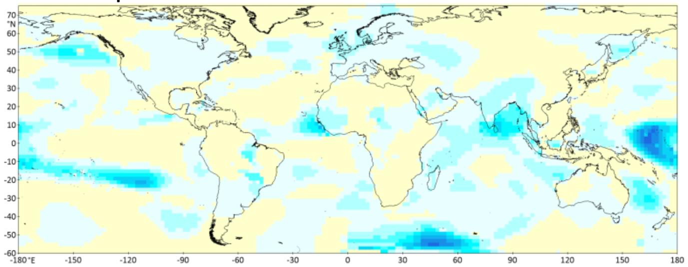


Mean squared error (MSE) improvement relative to multiple linear regression

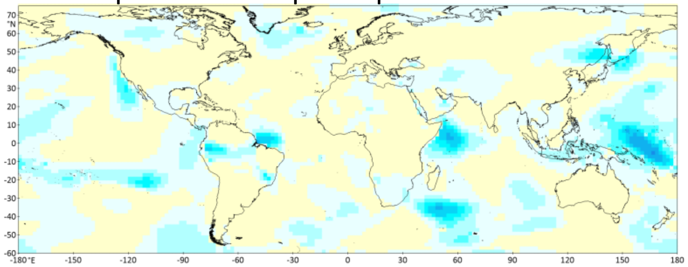


Improvement over MLR notable especially over western tropical Pacific, minor gains indicated for some more distant teleconnections as well

MSE improvement: October-March



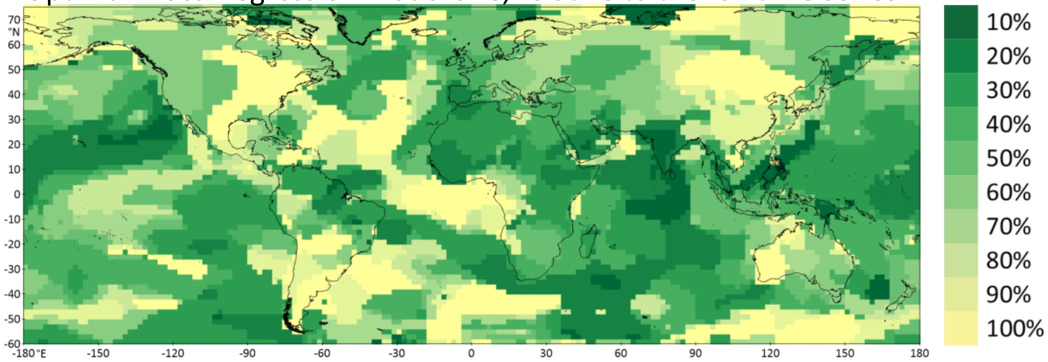
MSE improvement: April-September



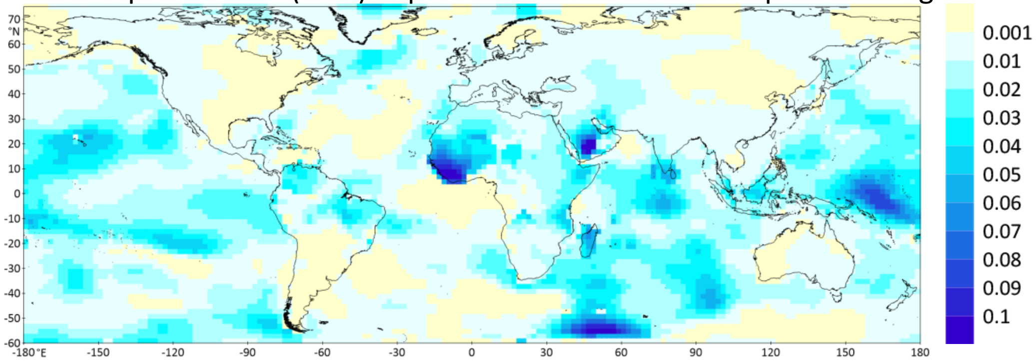
Local linear models

Selector variable: Multi-component (NAO, SO, AMO & PDO indices)

Optimum local regression model size, relative to the full time series

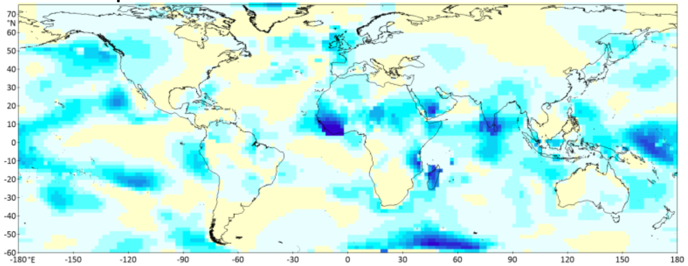


Mean squared error (MSE) improvement relative to multiple linear regression

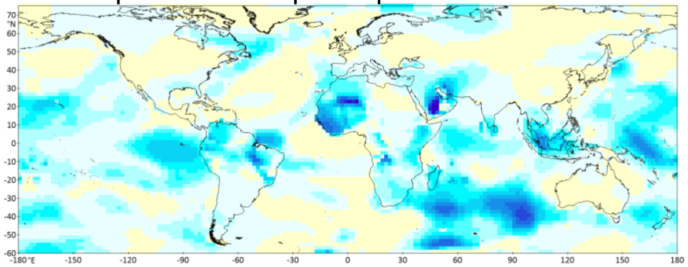


Improvement over MLR prominent in numerous areas, underscoring potential gain from application of nonlinear mappings

MSE improvement: October-March



MSE improvement: April-September



Conclusions

Nonlinearities are not universally detectable in all the links and teleconnections, but can be noteworthy for some regions and seasons

Even when deviations from linearity are statistically significant, nonlinearity-sensitive techniques may not provide major practical improvement over their linear counterparts (e.g. in terms of substantial increase of variance explained)

Different nonlinearity detection/capture techniques reflect different aspects of the links studied - their specific choice should reflect nature of the task at hand

Additional potentially relevant issues to be considered

Effects of seasonality: individual seasons or months are associated with specific links; suitable seasonal division may however differ from region to region

Time-delayed responses

Cross-predictor (cross-teleconnection) interactions

Thank you

jiri@miksovsky.info