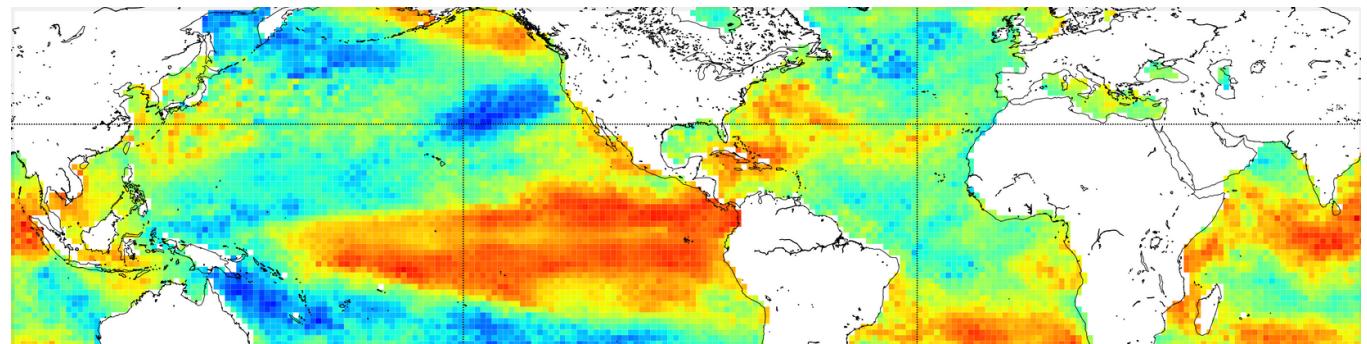
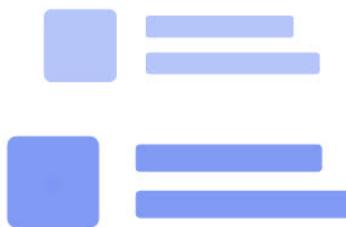


Improving sub-seasonal drought forecasting with machine learning and climate indices



Today's Agenda

this presentation will go through the following stages:



01

Intro

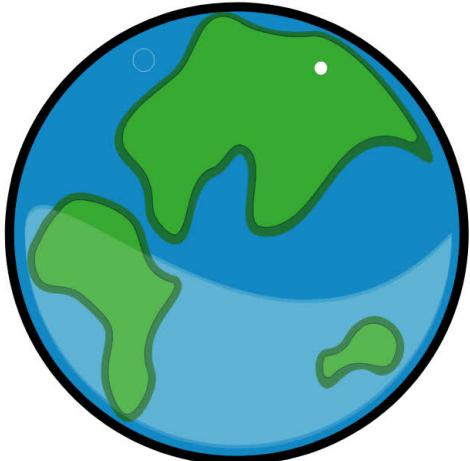
02

Context

03

Framework

Intro



- 01 What is drought
- 02 ML for Drought
- 03 The gap

Intro



- 01 What is drought
- 02 ML for Drought
- 03 The gap

a period of time in which a region experiences below-normal precipitation

Intro



- 01 What is drought
- 02 ML for Drought
- 03 The gap

Reduced soil moisture

Reduced stream flow

Crop damage

Intro



- 01 What is drought
- 02 ML for Drought
- 03 The gap

Reduced soil moisture

Reduced stream flow

Crop damage

Water shortage

Intro



The onset, extent and duration of drought are difficult to define

- 01 What is drought
- 02 ML for Drought
- 03 The gap

Intro



- 01 What is drought
- 02 ML for Drought
- 03 The gap

The onset, extent and duration of drought are difficult to define

different stakeholders have varying degrees of tolerance and resilience to these events

(Slette et al., 2019)

Intro



The onset, extent and duration of drought are difficult to define

CONTEXT
DEPENDENT

- 01 What is drought
- 02 ML for Drought
- 03 The gap

Intro

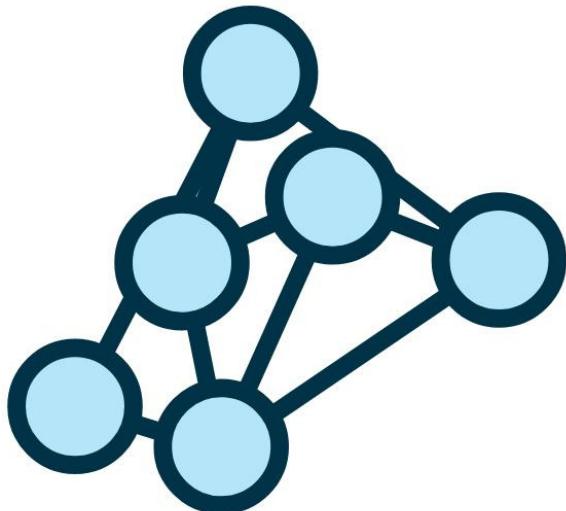


- 01 What is drought
- 02 ML for Drought
- 03 The gap

Being able to forecast
them is crucial

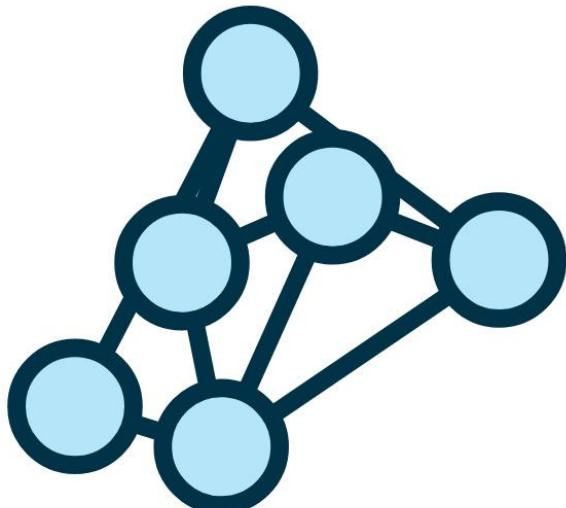
Intro

- 01 What is drought
- 02 ML for Drought
- 03 The gap



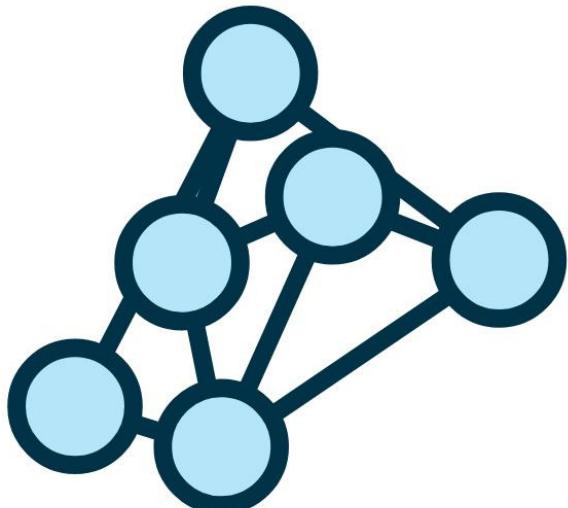
Intro

- 01 What is drought
- 02 ML for Drought
- 03 The gap



exploitation of *statistic* and *dynamic techniques* for droughts forecasting has been and is widely studied

Intro

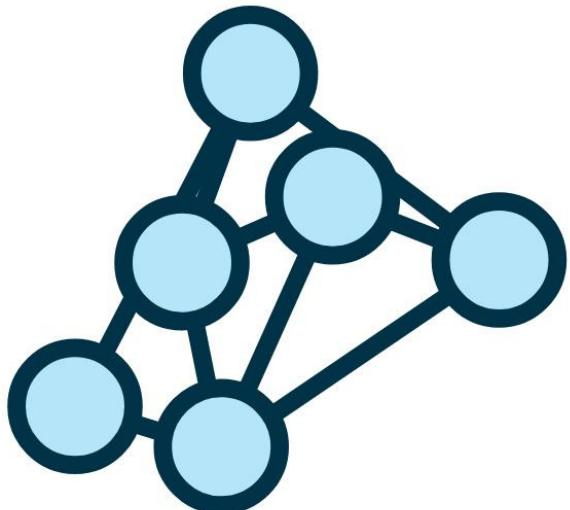


exploitation of *statistic* and *dynamic techniques* for droughts forecasting has been and is widely studied

sub-seasonal forecasting

- 01 What is drought
- 02 ML for Drought
- 03 The gap

Intro



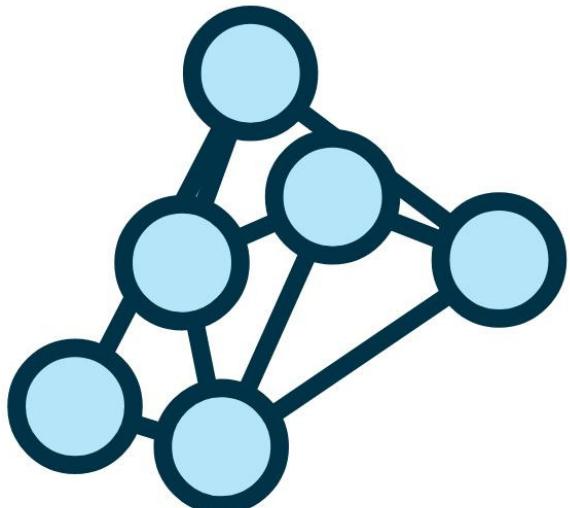
Earth observation data

Artificial Intelligence

Hardware (GPU,TPU)

- 01 What is drought
- 02 ML for Drought
- 03 The gap

Intro



- 01 What is drought
- 02 ML for Drought
- 03 The gap

Earth observation data

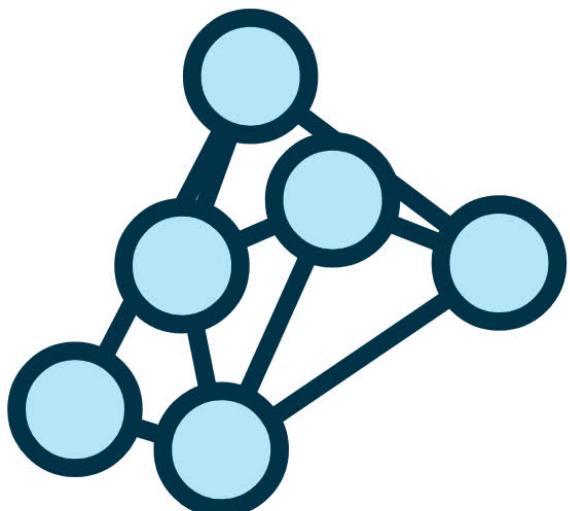
Artificial Intelligence

Hardware (GPU,TPU)

AI-based prediction models

Intro

- 01 What is drought
- 02 ML for Drought
- 03 The gap



McGovern et al. (2017)

Learn from past data

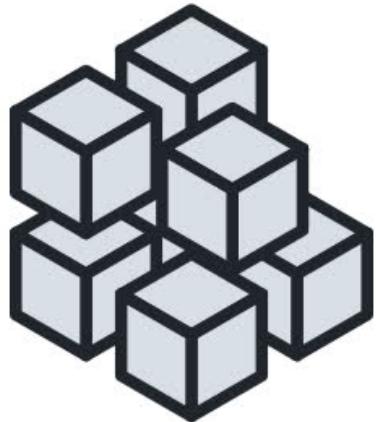
Integrate physical understanding into the models

Discover additional knowledge from the data

Handle large amounts of input variables

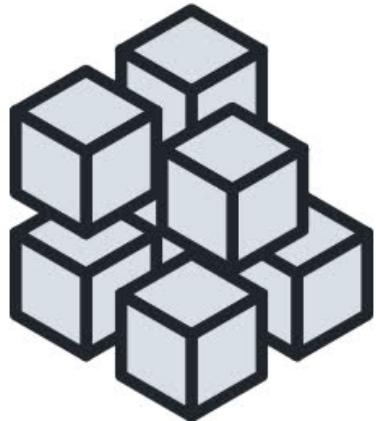
Intro

- 01 What is drought
- 02 ML for Drought
- 03 The gap



Intro

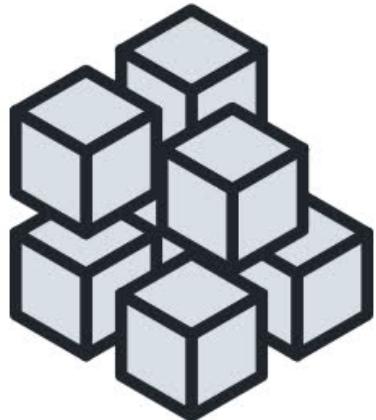
- 01 What is drought
- 02 ML for Drought
- 03 The gap



sub-seasonal
drought forecasting

Intro

- 01 What is drought
- 02 ML for Drought
- 03 The gap



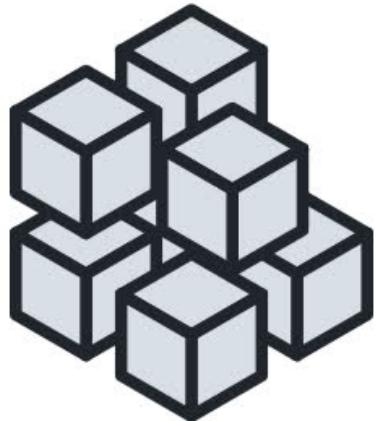
sub-seasonal
drought forecasting



AI

Intro

- 01 What is drought
- 02 ML for Drought
- 03 The gap

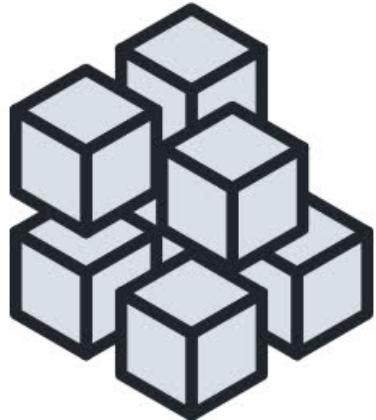


**Why to focus on sub-seasonal
lead times?**

Intro

- 01 What is drought
- 02 ML for Drought
- 03 The gap

Informative predictors



Seasonal:

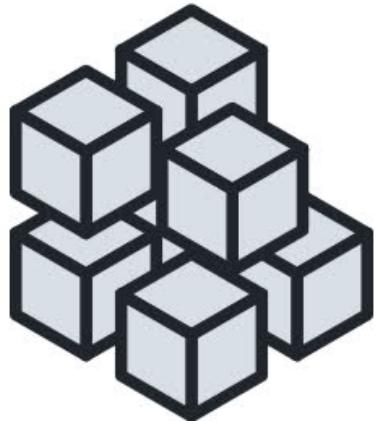
climate indices and large scale
teleconnection patterns

sub-monthly:

local variable (precipitation,
temperature)

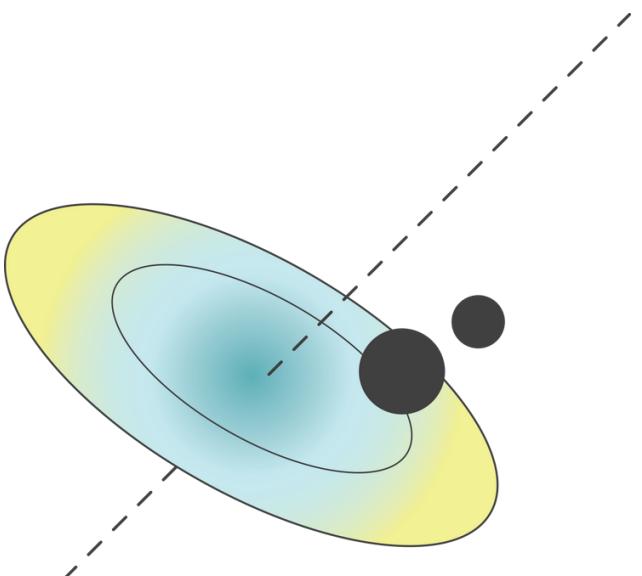
Intro

- 01 What is drought
- 02 ML for Drought
- 03 The gap



Informative predictors
sub-seasonal?

Context



- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)

Context



Machine Learning model for
sub-seasonal precipitation
forecasting

- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)

Context



precipitation forecasting



drought forecasting

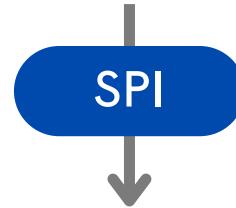
- 01 What (our goal)
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Context



- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)

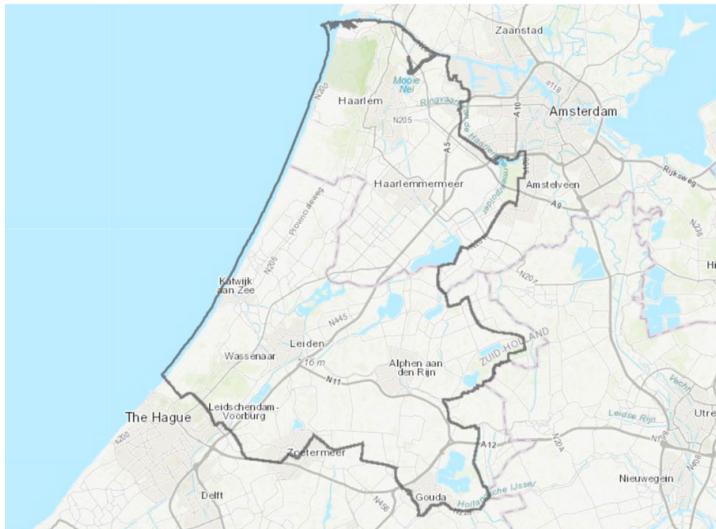
precipitation forecasting



drought forecasting

Context

- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)



Context

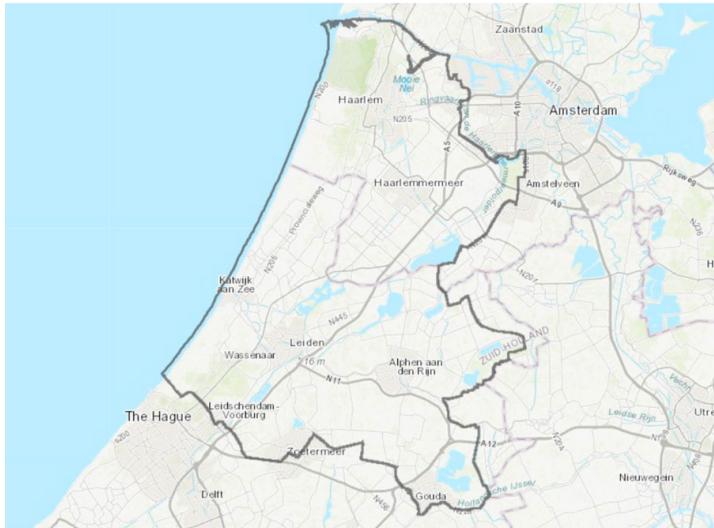
- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)



Rijnland

Context

- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)



Rijnland

small sub-catchment of 1000 km² at the very end of the Rhine delta in the Netherlands

Context



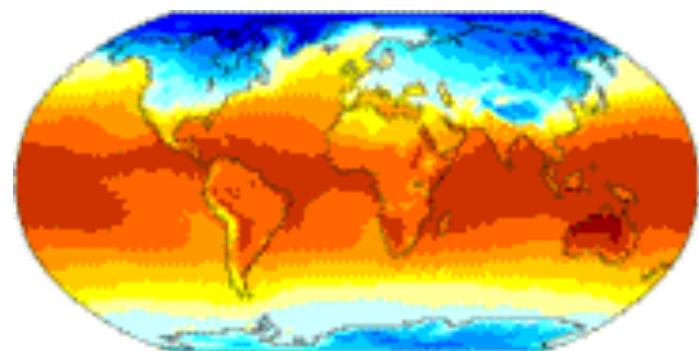
- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)

Rijnland

small sub-catchment of 1000 km² at the very end of the Rhine delta in the Netherlands

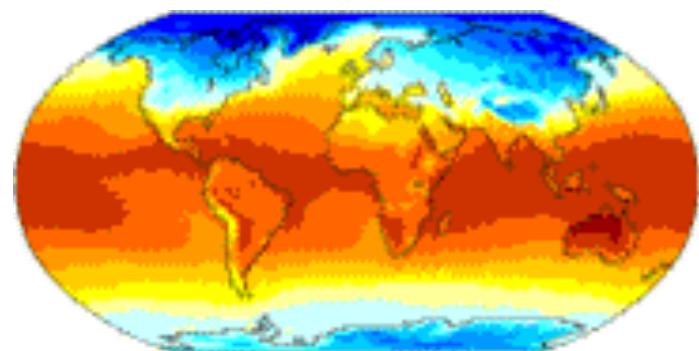
- Net precipitation deficit in the Rijnland area >150 mm
- Discharge threshold where the Rhine enters the Netherlands < 1100 m³/s

Context



- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)

Context



- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)

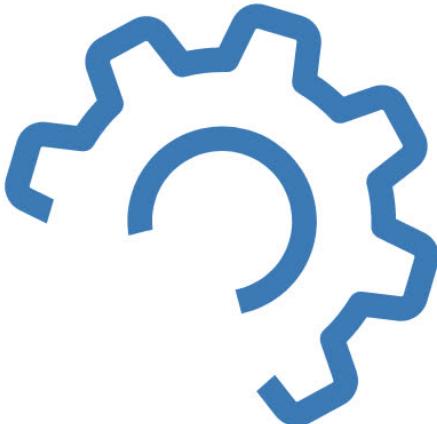
Statistical framework (NIPA)

+

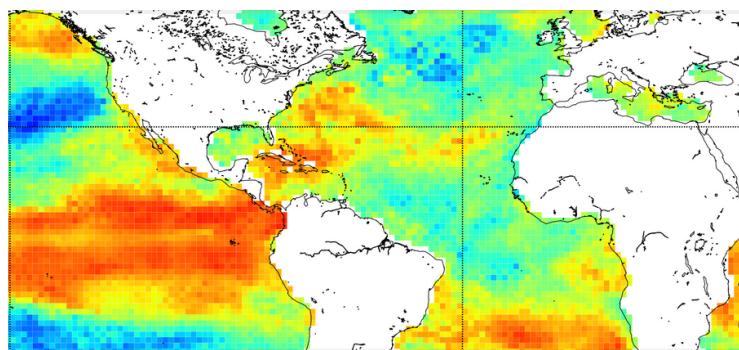
ML model (NN)

Framework

- 01 NIPA
- 02 Neural Network

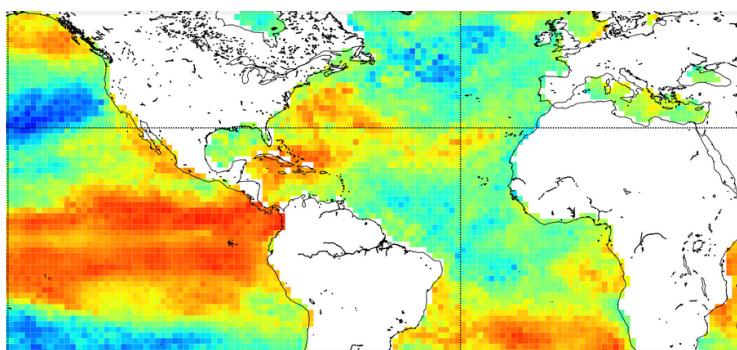


Framework



- 01 NIPA
- 02 Neural Network

Framework



- 01 NIPA
- 02 Neural Network

Nino Index Phase Analysis

Zimmerman et al. (2016)

Framework

Zimmerman et al. (2016)



- 01 NIPA
- 02 Neural Network

Nino Index Phase Analysis

Framework

Zimmerman et al. (2016)



- 01 NIPA
- 02 Neural Network

Nino Index Phase Analysis

Giuliani et al. (2019)

Framework

Zimmerman et al. (2016)



Nino Index Phase Analysis

Giuliani et al. (2019)



- 01 NIPA
- 02 Neural Network

Framework

Zimmerman et al. (2016)



Giuliani et al. (2019)



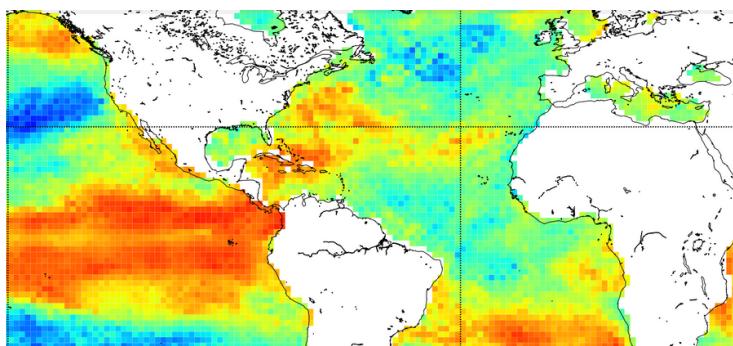
- 01 NIPA
- 02 Neural Network

Nino Index Phase Analysis

Our readaptation



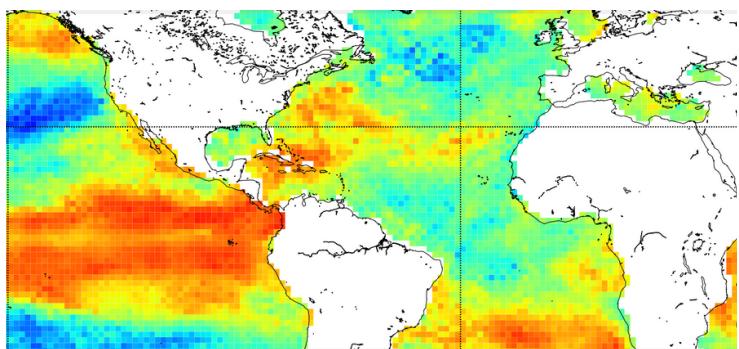
Framework



- 01 NIPA
- 02 Neural Network

NIPA is a framework that searches for links between **Global** and **Local variables** exploiting the phases of teleconnection patterns materialized by **climate indices**

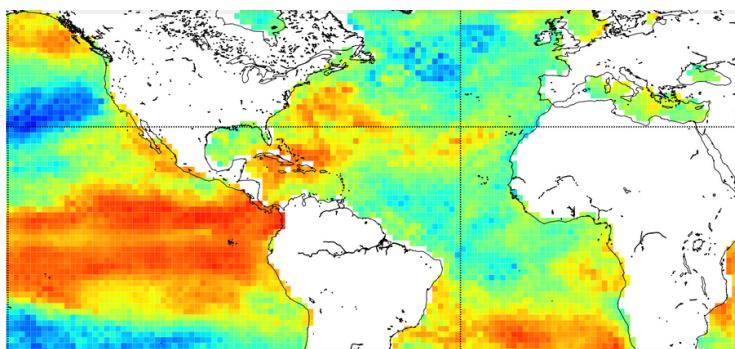
Framework



climate indices

- 01 NIPA
- 02 Neural Network

Framework



- 01 NIPA
- 02 Neural Network

climate indices

El Niño Southern Oscillation (ENSO)

North Atlantic Oscillation (NAO)

SCAndinavian oscillation (SCA)

East Atlantic oscillation (EA)

Framework

- 01 NIPA
- 02 Neural Network

climate indices
North Atlantic Oscillation (NAO)

Framework

- 01 NIPA
- 02 Neural Network

climate indices
North Atlantic Oscillation (NAO)



Framework

- above/below-normal temperatures in eastern United States and northern Europe
- above/below-normal temperatures in Greenland and southern Europe
- above/below-normal precipitation over northern Europe and Scandinavia
- above/below-normal precipitation over southern and central Europe

- 01 NIPA
- 02 Neural Network

climate indices

North Atlantic Oscillation (NAO)



Framework

- above/below-normal temperatures in eastern United States and northern Europe
- above/below-normal temperatures in Greenland and southern Europe
- above/below-normal precipitation over northern Europe and Scandinavia
- above/below-normal precipitation over southern and central Europe

- 01 NIPA
- 02 Neural Network

climate indices

North Atlantic Oscillation (NAO)



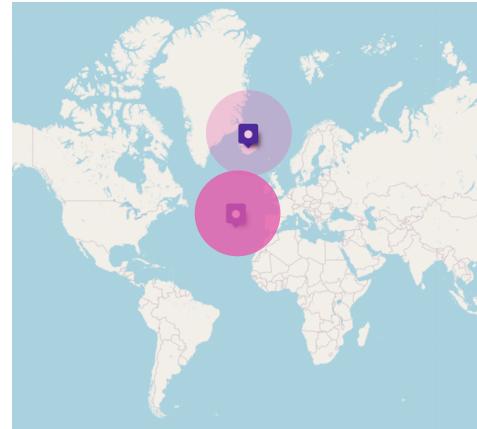
Framework

- above/below-normal temperatures in eastern United States and northern Europe
- above/below-normal temperatures in Greenland and southern Europe
- above/below-normal precipitation over northern Europe and Scandinavia
- above/below-normal precipitation over southern and central Europe

- 01 NIPA
- 02 Neural Network

climate indices

North Atlantic Oscillation (NAO)



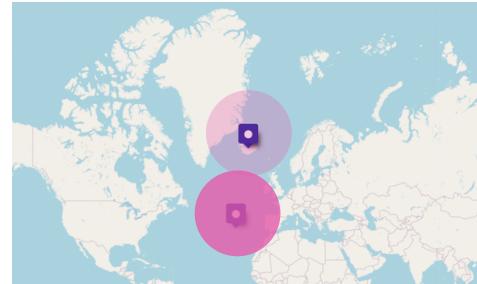
Framework

- above/below-normal temperatures in eastern United States and northern Europe
- above/below-normal temperatures in Greenland and southern Europe
- above/below-normal precipitation over northern Europe and Scandinavia
- above/below-normal precipitation over southern and central Europe

- 01 NIPA
- 02 Neural Network

climate indices

North Atlantic Oscillation (NAO)



Phases

Framework

- above/below-normal temperatures in eastern United States and northern Europe
- above/below-normal temperatures in Greenland and southern Europe
- above/below-normal precipitation over northern Europe and Scandinavia
- above/below-normal precipitation over southern and central Europe

- 01 NIPA
- 02 Neural Network

climate indices

North Atlantic Oscillation (NAO)



Phases Pos/Neg

Framework

- 01 NIPA
 - 02 Neural Network
-

Input
Data extraction
Phase segmentation
Correlation
PCA
output

Framework

● 01 NIPA

● 02 Neural Network

DATA

- Local precipitation (monthly timeseries)
- Global variable (monthly timeseries)
- Climate Index (monthly timeseries)

SETTING PARAMETERS

- Month
- Aggregation level

Input

Data extraction
Phase segmentation
Correlation
PCA
output

Framework

● 01 NIPA

● 02 Neural Network

DATA

- Local precipitation (monthly timeseries) - cumulative
- Global variable (monthly timeseries) - SLP,SST,Z500
- Climate Index (monthly timeseries) - ENSO, NAO,SCA,EA

Input

Data extraction

Phase segmentation

Correlation

PCA

output

SETTING PARAMETERS

- Month (of local precipitation)
- Aggregation level (of pre month global data)

Framework

SETTING PARAMETERS

- Month (of local precipitation)
- Aggregation level (of pre month global data)

● 01 NIPA

● 02 Neural Network

Input

Data extraction

Phase segmentation

Correlation

PCA

output

Framework

● 01 NIPA

● 02 Neural Network

SETTING PARAMETERS

- Month (of local precipitation)
- Aggregation level (of pre month global data)

Example:

- Month 1
- Aggregation level 1

local precipitation of January and
the global variable of December

Input

Data extraction

Phase segmentation

Correlation

PCA

output

Framework

● 01 NIPA

● 02 Neural Network

SETTING PARAMETERS

- Month (of local precipitation)
- Aggregation level (of pre month global data)

Example:

- Month 1
 - Aggregation level 1
-
- Month 1
 - Aggregation level 2

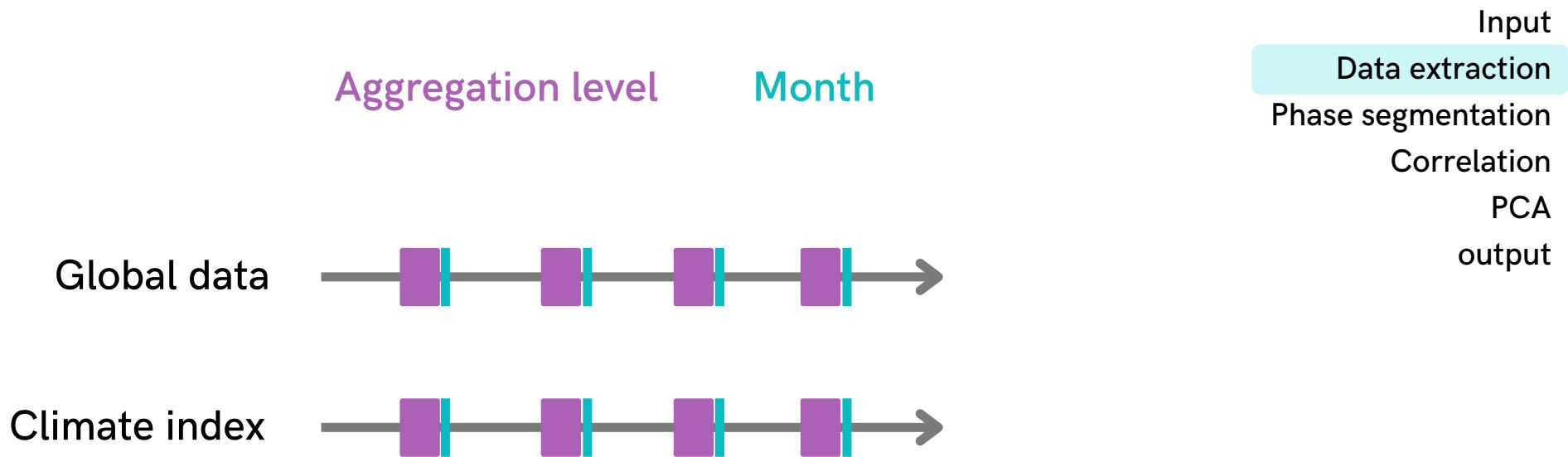
local precipitation of January and
the global variable of December

local precipitation of January and the
global variable of November + December

Input

Data extraction
Phase segmentation
Correlation
PCA
output

Framework

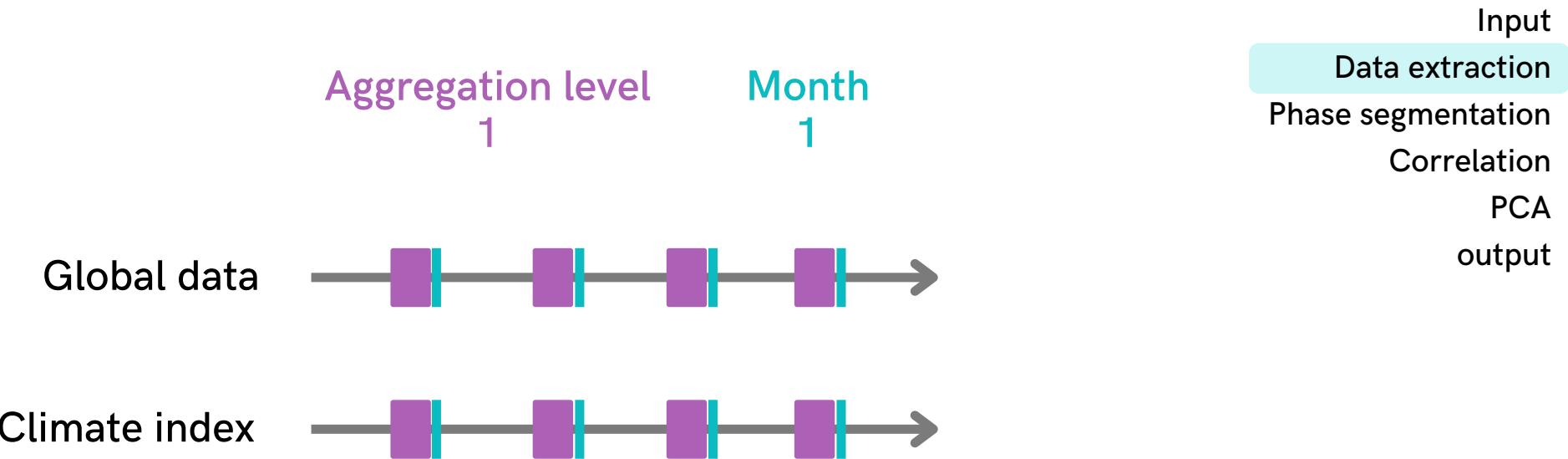


● 01 NIPA

● 02 Neural Network

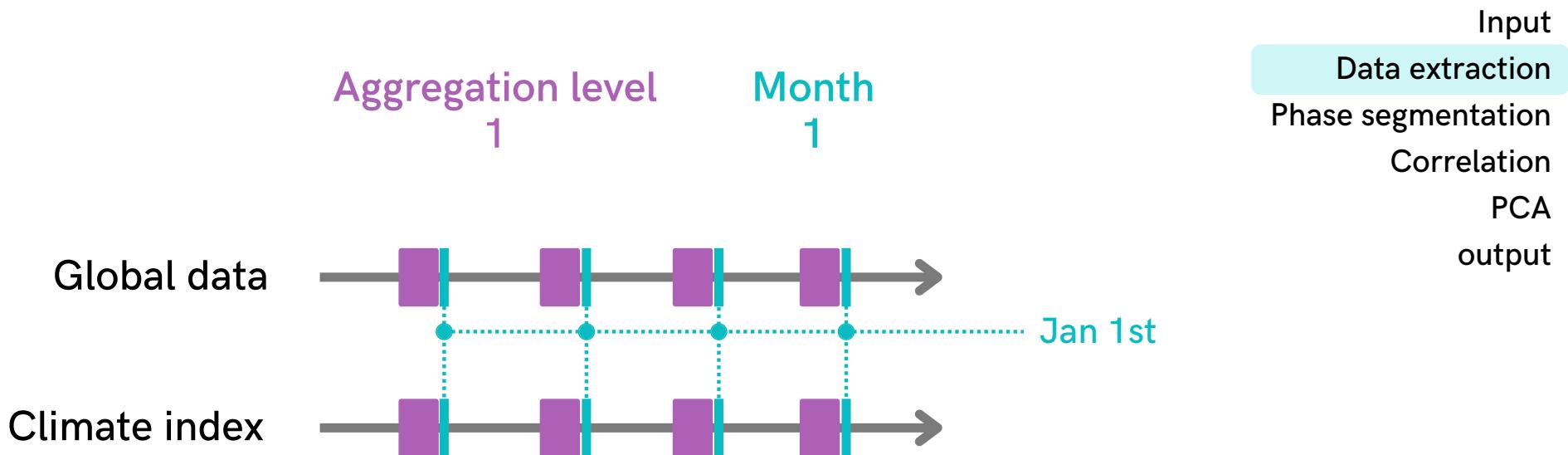
Framework

- 01 NIPA
 - 02 Neural Network
-



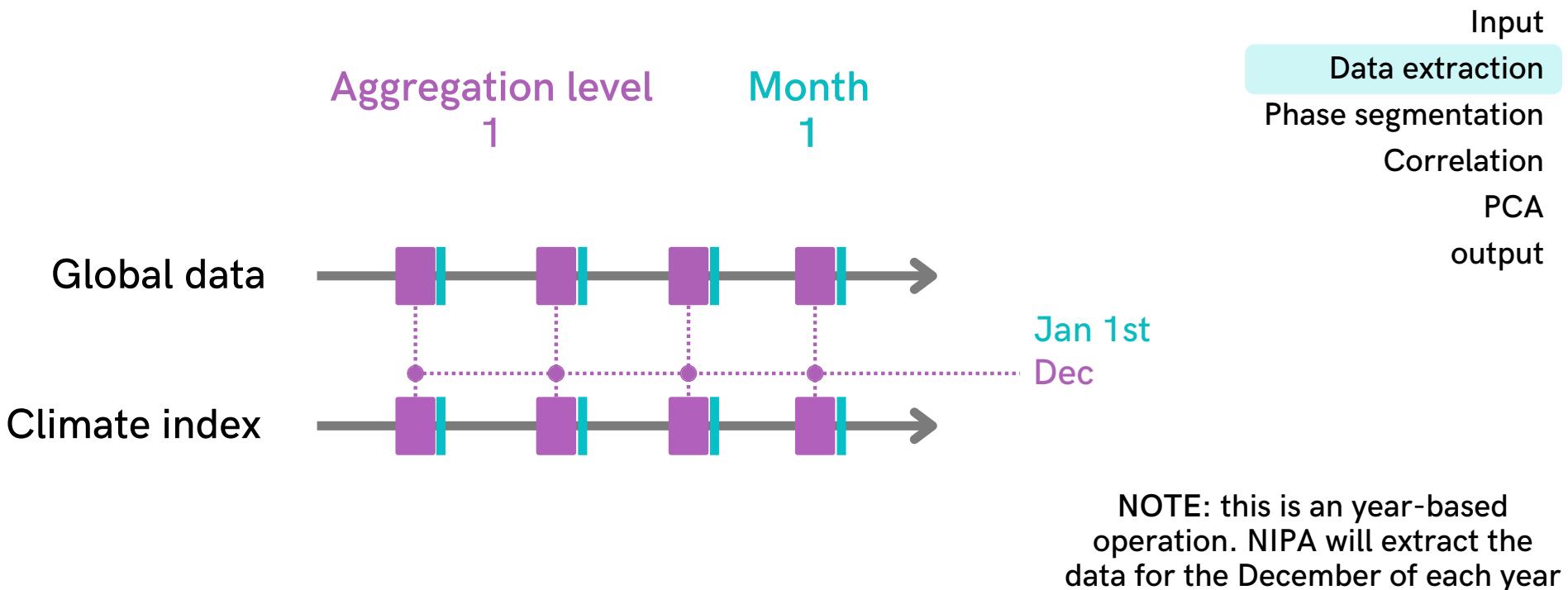
Framework

- 01 NIPA
 - 02 Neural Network
-



Framework

- 01 NIPA
 - 02 Neural Network
-



Framework

- 01 NIPA

- 02 Neural Network

Global data



Input

Data extraction

Phase segmentation

Correlation

PCA

output

Climate index



Framework

Global data



Climate index

- 01 NIPA

- 02 Neural Network
-

Input

Data extraction

Phase segmentation

Correlation

PCA

output

Framework

Global data



Climate index

- 01 NIPA

- 02 Neural Network
-

Input

Data extraction

Phase segmentation

Correlation

PCA

output

Framework

Global data



- 01 NIPA
 - 02 Neural Network
-

Input
Data extraction
Phase segmentation
Correlation
PCA
output

Framework

- 01 NIPA

- 02 Neural Network
-



Input
Data extraction
Phase segmentation
Correlation
PCA
output

Framework

- 01 NIPA
 - 02 Neural Network
-

Global data Pos  →

Global data Neg  →

Input
Data extraction
Phase segmentation
Correlation
PCA
output

Framework

- 01 NIPA

- 02 Neural Network
-

Global data Pos 

Global data Neg 

Input

Data extraction

Phase segmentation

Correlation

PCA

output

Framework

Global data Pos 
Global data Neg 

- 01 NIPA
 - 02 Neural Network
-

Input
Data extraction
Phase segmentation
Correlation
PCA
output

Framework

- 01 NIPA
 - 02 Neural Network
-

Global data Pos 

Global data Neg 

Input
Data extraction
Phase segmentation
Correlation
PCA
output

Local data 

Dec Jan 1st

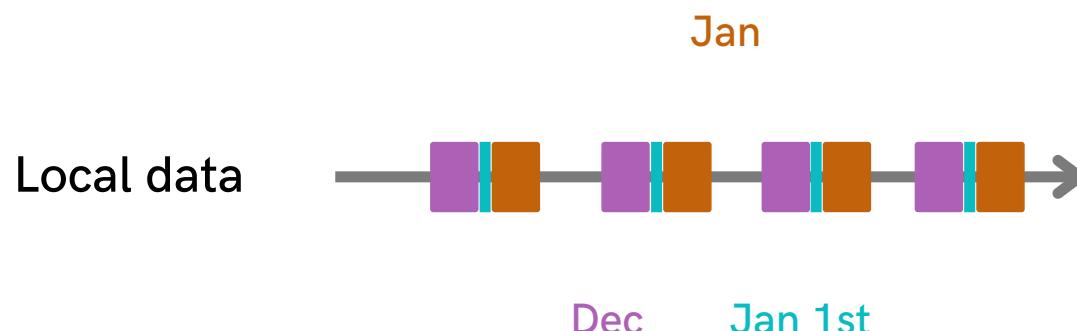
Framework

● 01 NIPA

● 02 Neural Network



Input
Data extraction
Phase segmentation
Correlation
PCA
output



Framework

● 01 NIPA

● 02 Neural Network

Global data Pos 

Global data Neg 

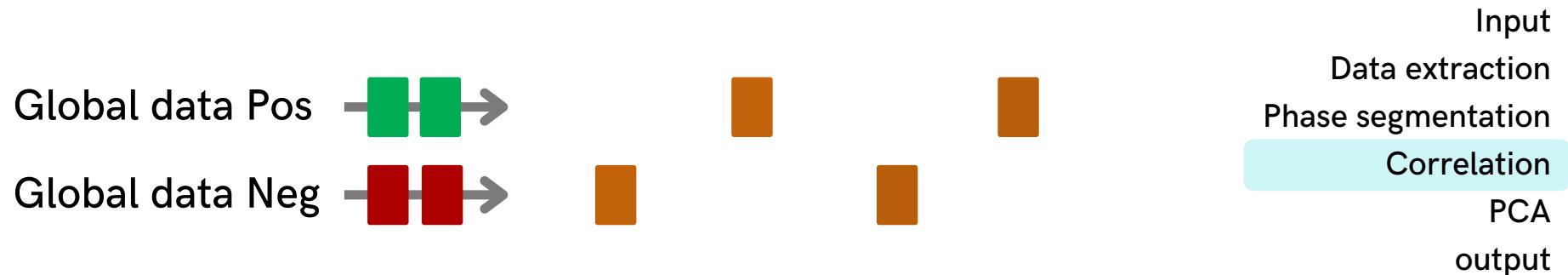
Local data 

Input
Data extraction
Phase segmentation
Correlation
PCA
output

Framework

● 01 NIPA

● 02 Neural Network



Framework

Global data Pos

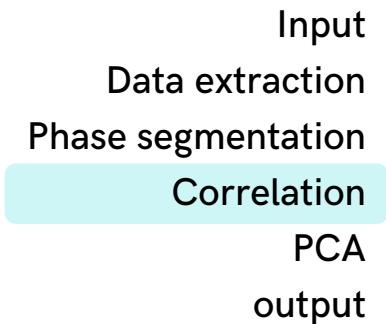


Global data Neg

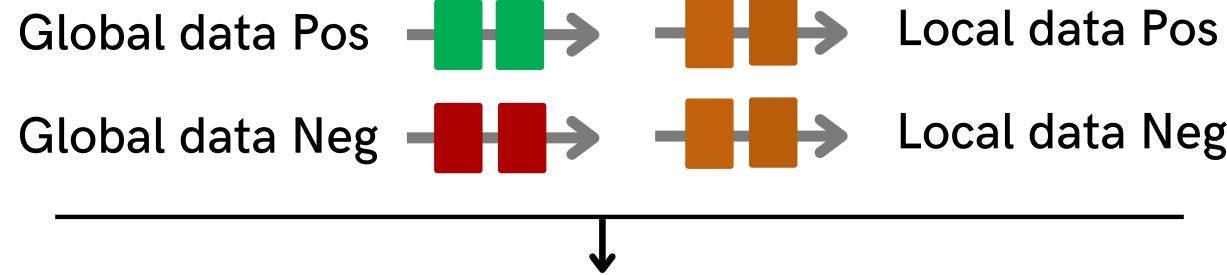


- 01 NIPA

- 02 Neural Network



Framework



- 01 NIPA
- 02 Neural Network

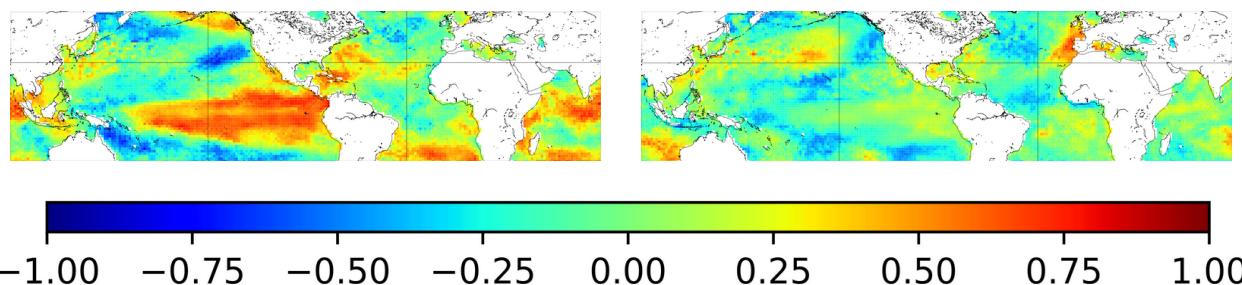
Input
Data extraction
Phase segmentation
Correlation
PCA
output

Framework

- 01 NIPA
- 02 Neural Network

Global data Pos → Local data Pos
Global data Neg → Local data Neg

Neg ↓ Pos

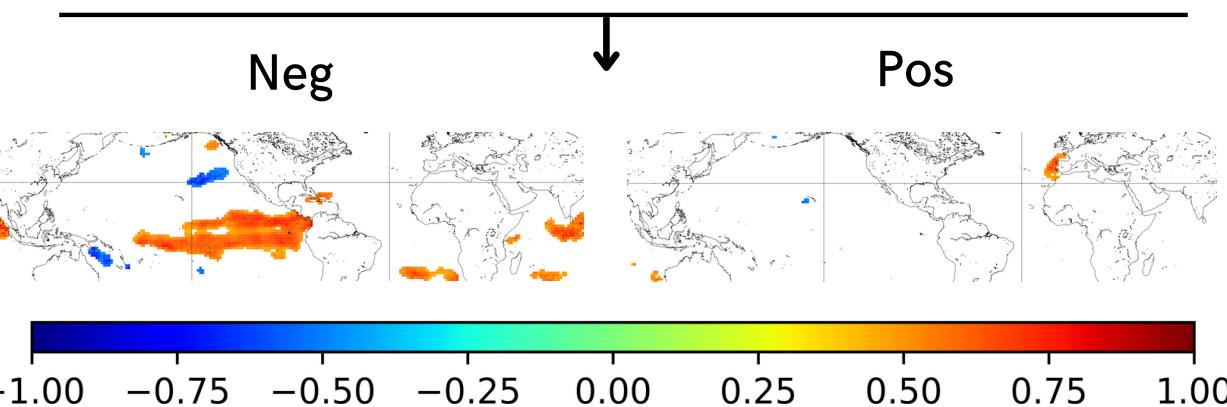


Input
Data extraction
Phase segmentation
Correlation
PCA
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Framework

- 01 NIPA
 - 02 Neural Network
-

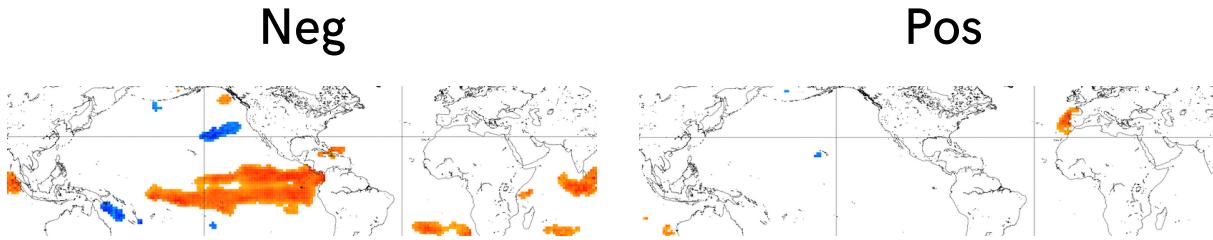
Global data Pos → Local data Pos
Global data Neg → Local data Neg



Input
Data extraction
Phase segmentation
Correlation
PCA
output

95% of
significance

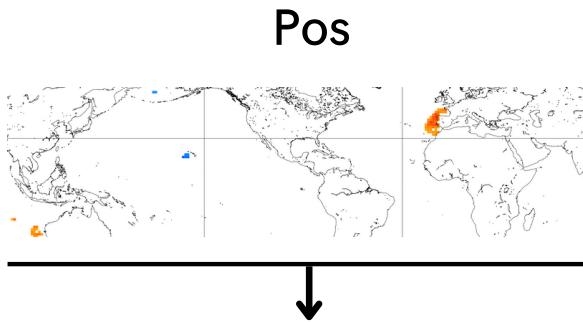
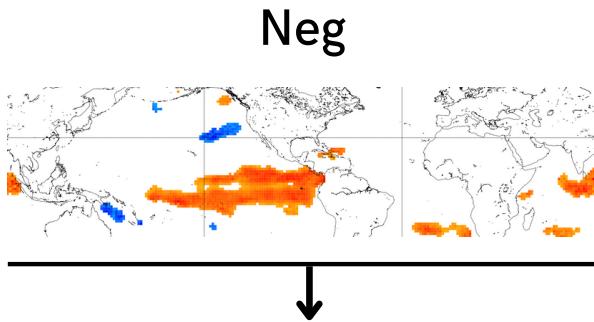
Framework



- 01 NIPA
 - 02 Neural Network
-

Input
Data extraction
Phase segmentation
Correlation
PCA
output

Framework



$$\underbrace{\begin{bmatrix} \dots \\ \vdots \\ \dots \end{bmatrix}}_{pixels} \Bigg\} year_{neg}$$

$$\underbrace{\begin{bmatrix} \dots \\ \vdots \\ \dots \end{bmatrix}}_{pixels} \Bigg\} year_{pos}$$

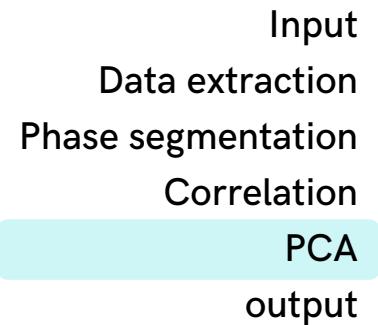
- 01 NIPA
- 02 Neural Network

Input
Data extraction
Phase segmentation
Correlation
PCA
output

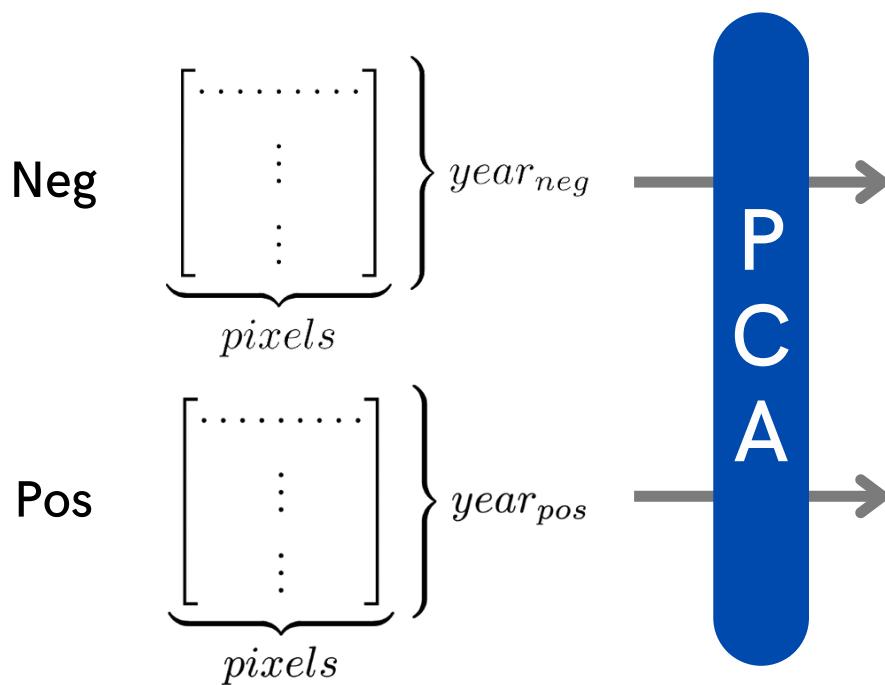
Framework

$$\begin{array}{c} \text{Neg} \\ \left[\dots \dots \dots \atop \vdots \atop \vdots \atop \vdots \right] \\ \underbrace{}_{pixels} \end{array} \left. \right\} year_{neg}$$
$$\begin{array}{c} \text{Pos} \\ \left[\dots \dots \dots \atop \vdots \atop \vdots \atop \vdots \atop \vdots \atop \vdots \right] \\ \underbrace{}_{pixels} \end{array} \left. \right\} year_{pos}$$

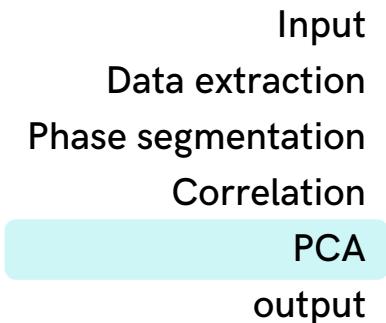
- 01 NIPA
 - 02 Neural Network
-



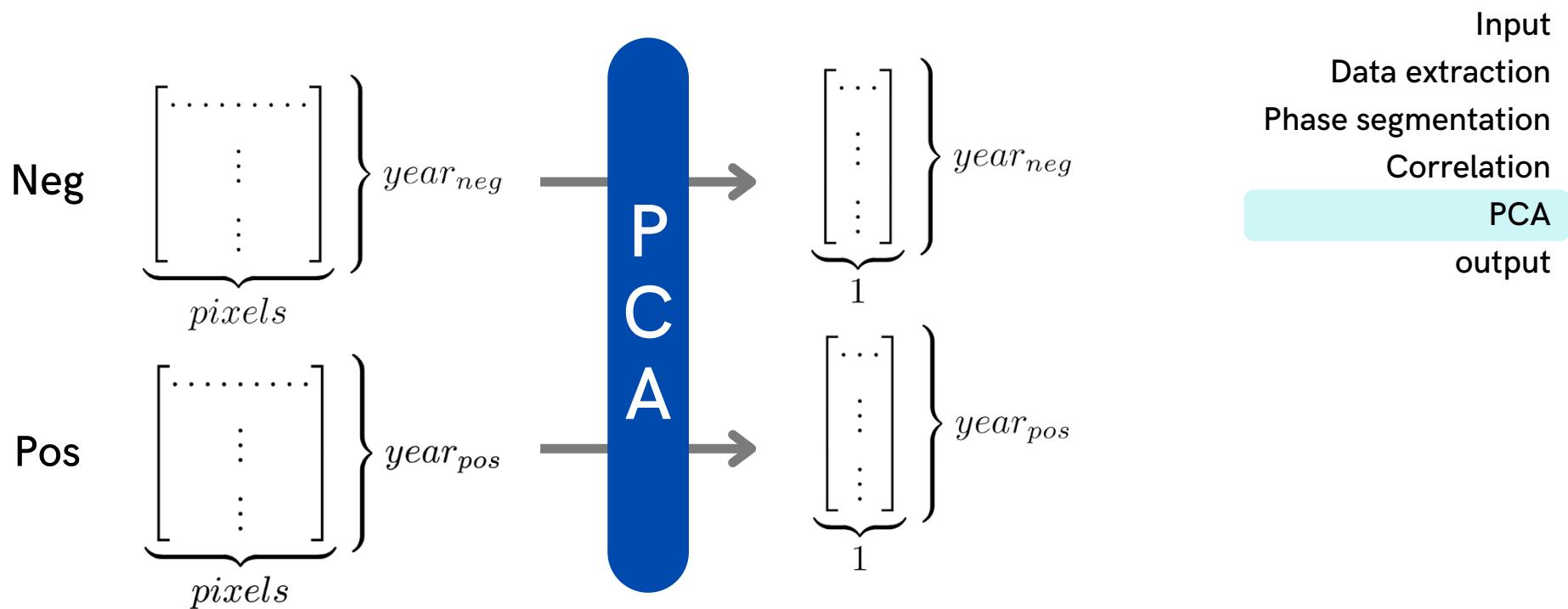
Framework



- 01 NIPA
- 02 Neural Network



Framework

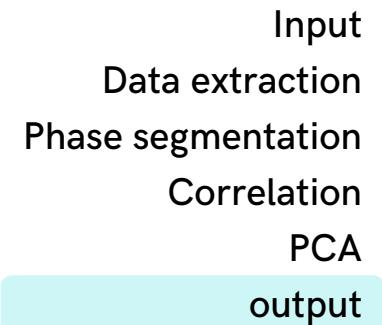


- 01 NIPA
- 02 Neural Network

Framework

PC1	phase_label
PC1 1979	1
PC1 1980	2
...	...
...	...
PC1 2021	2

- 01 NIPA
 - 02 Neural Network
-



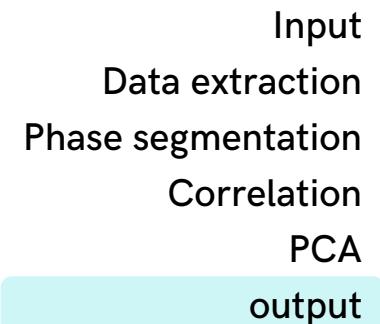
Dataset for 1
month

Framework

This procedure can be applied

- for each Month
- for each combination of:
 - Local Precipitation
 - Global Variable (SST/SLP/Z500)
- for each aggregation level of SST/SLP/Z500 (1/2/3 month)

- 01 NIPA
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Framework

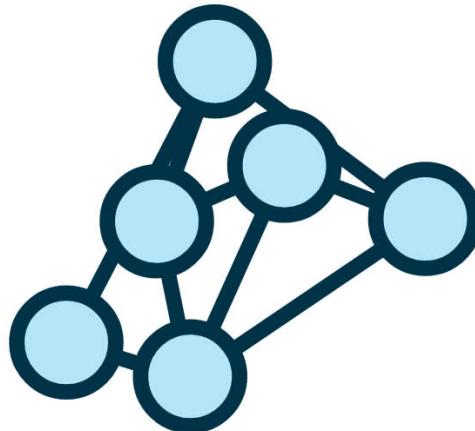
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Just entered in this step

- which are our thought on **how to proceed**
- **what has emerged** from the test

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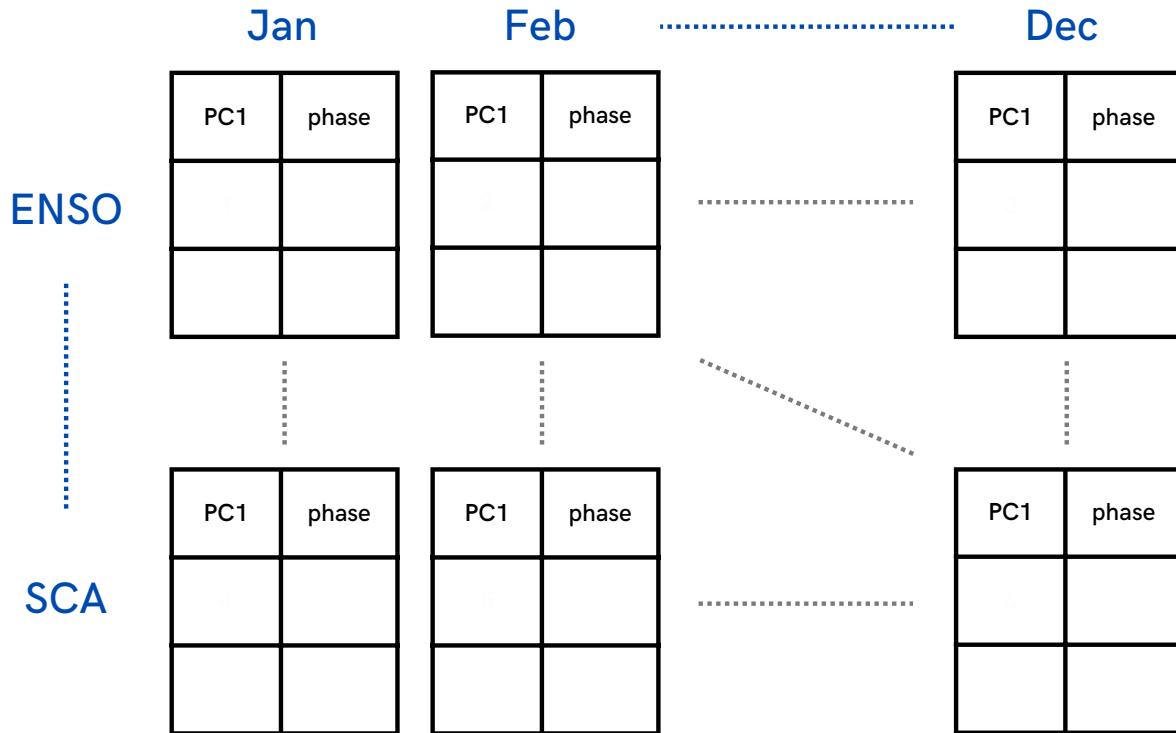
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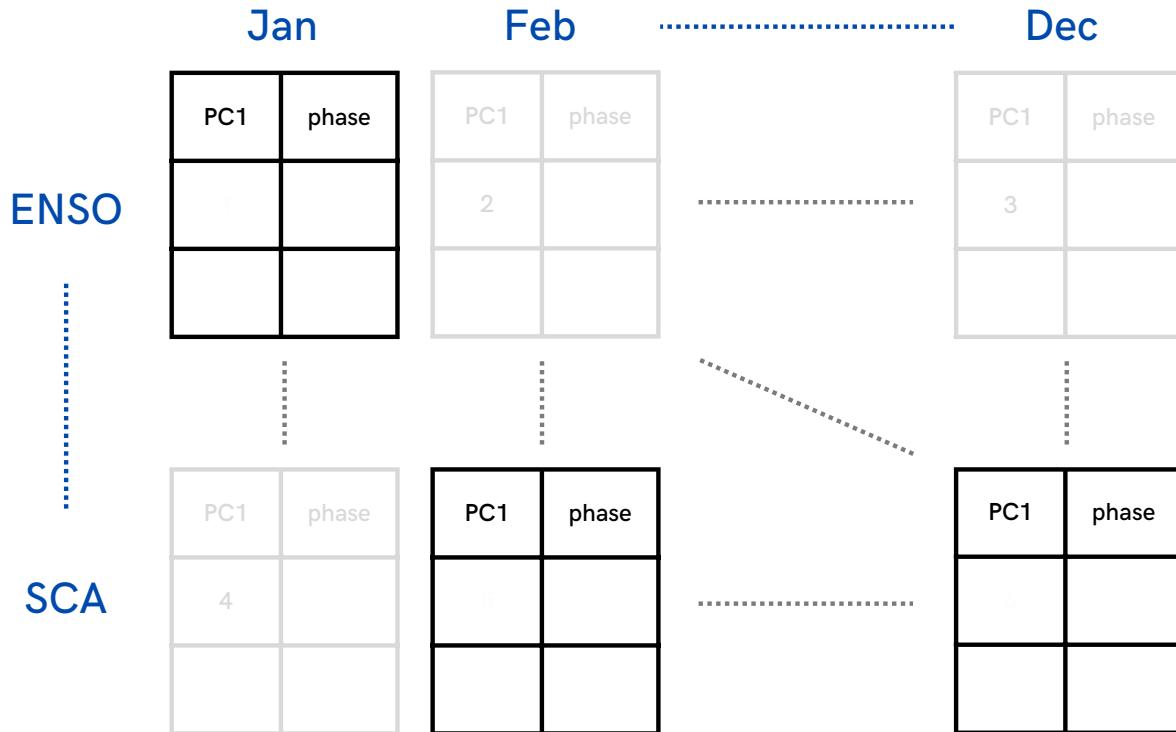
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- Skim some of the features by considering only **physical based combination**

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- Skim some of the features by considering only **physical based combination**
- Skim some of the features based on the pearson coefficients of a linear regression between **PC1** and **Local Precipitation**

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- Skim some of the features by considering only **physical based combination**
- Skim some of the features based on the pearson coefficients of a linear regression between **PC1** and **Local Precipitation**
- Skim some of the features by imposing a **minimum correlation threshold**

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- Skim some of the features by considering only **physical based combination**
- Skim some of the features based on the pearson coefficients of a linear regression between **PC1** and **Local Precipitation**
- Skim some of the features by imposing a **minimum correlation threshold**
- Consider the skimmed set of features and build **N different models for each month** and compare the **N different LOO validation errors** to choose the best one

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Inputs: (PC1, phase label);

Target: (Cumulated Local Precipitation)

Inputs: (PC1_1, PC1_2, climate state);

Target: (Cumulated Local Precipitation)

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Inputs: (PC1, phase label);

Target: (Cumulated Local Precipitation)

climate state

Inputs: (PC1_1, PC1_2, climate state);

Target: (Cumulated Local Precipitation)

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Inputs: (PC1_1, PC1_2, **climate state**);
Target: (Cumulated Local Precipitation)

climate state

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Inputs: (PC1_1, PC1_2, **climate state**);
Target: (Cumulated Local Precipitation)

climate state

Climate index 1	Climate index 2	Climate state
1	1	1
1	2	2
2	1	3
2	2	4

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- Input features:
 - SCA-SLP-1-1,
 - EA-SST-1-1,
 - climate state
- Target: Cumulative precipitation
- Hidden layers: 2
- Neurons: (3, 2)
- Activation function: ReLU
- Loss function: MSE

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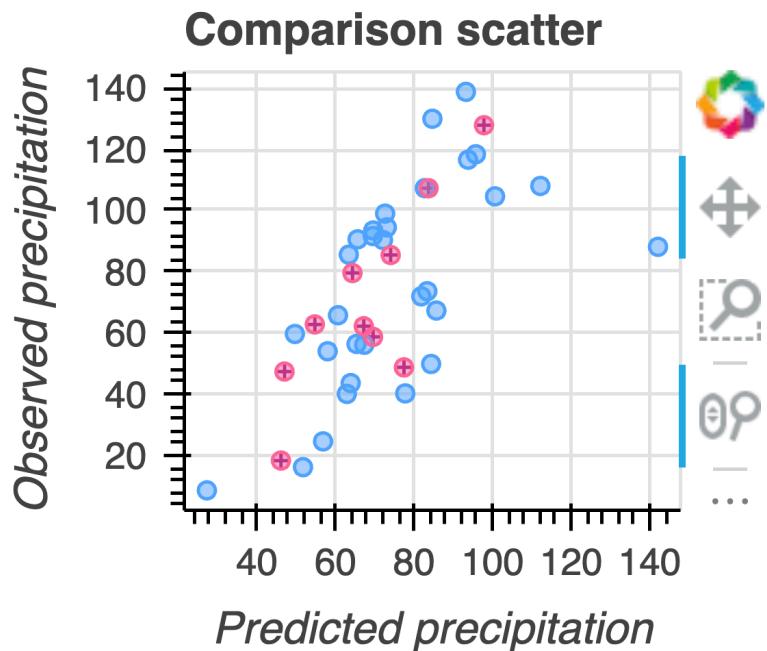
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MSE of **319.0494** on the validation set

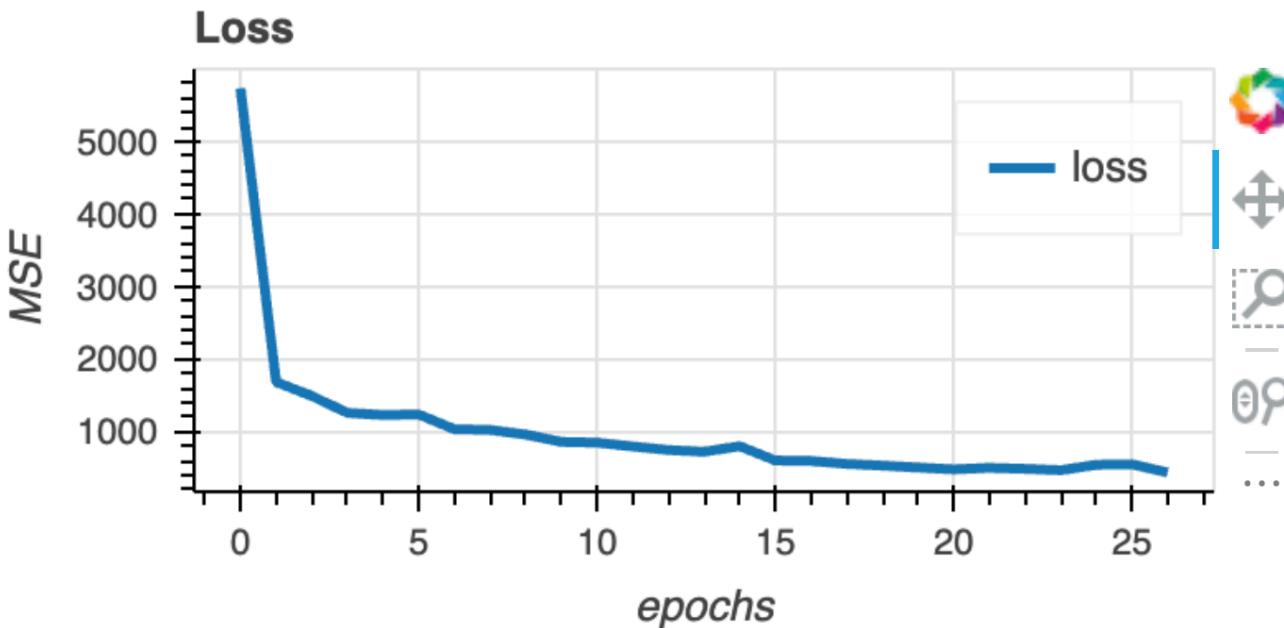
comparable with giuliani et al with ELM (374.905)

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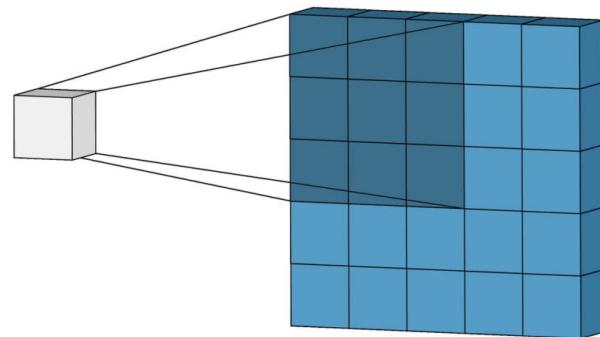
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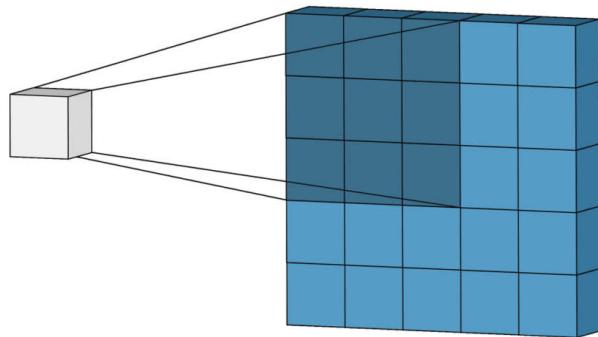
Future ideas



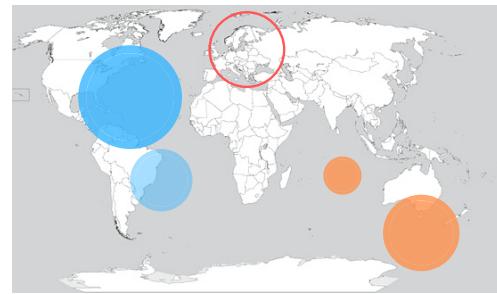
NN
↔
CNN

PC1
↔
Correlation
Map

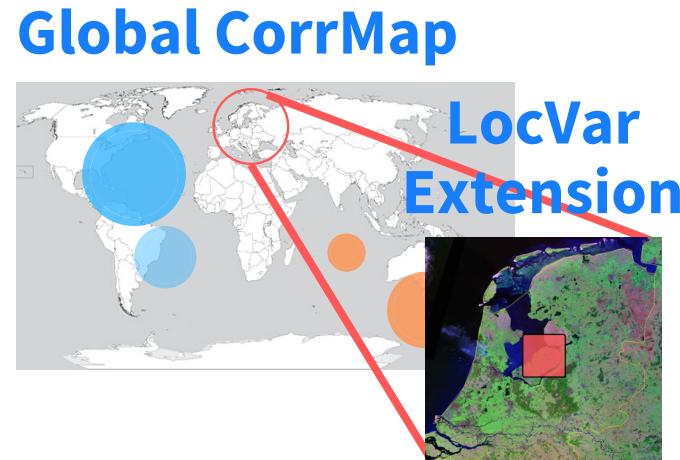
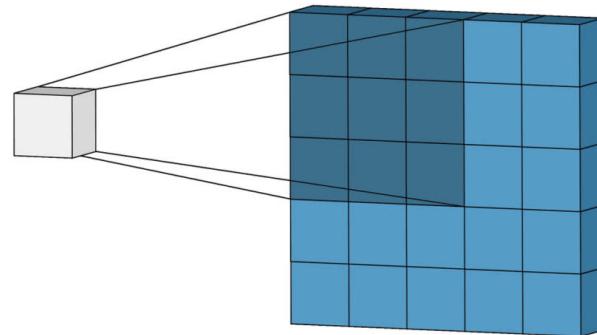
Future ideas



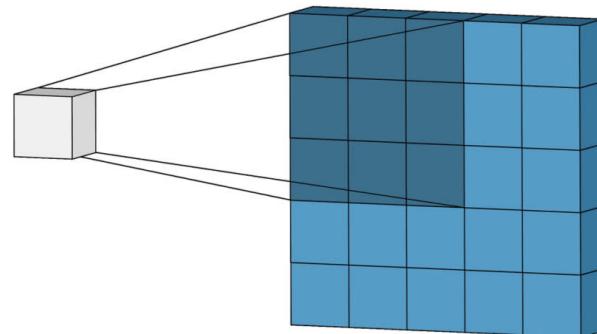
Global CorrMap



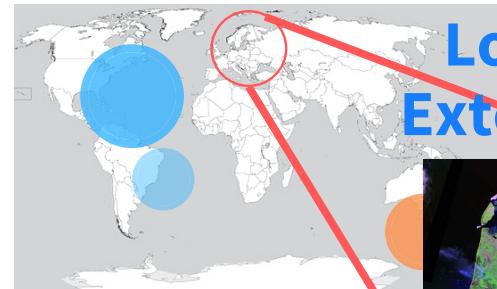
Future ideas



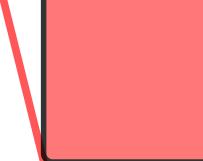
Future ideas



Global CorrMap

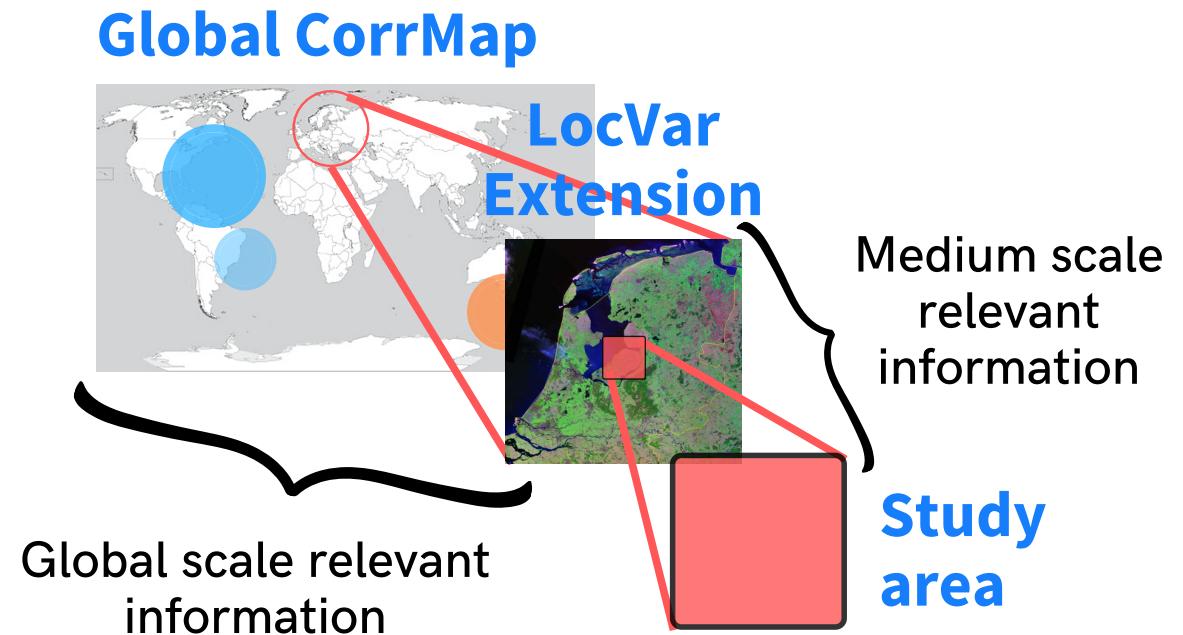
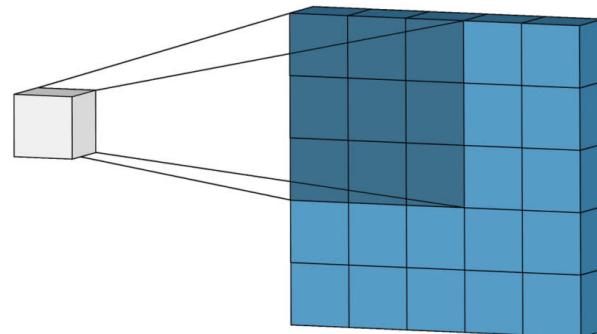


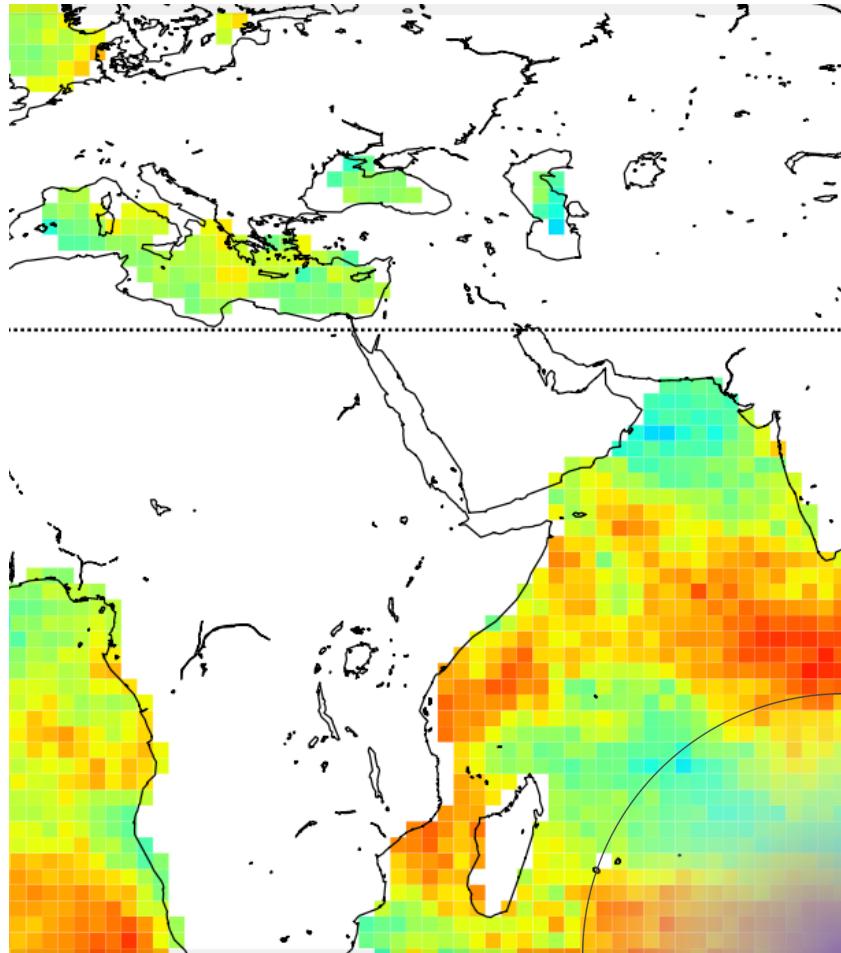
LocVar
Extension



Study
area

Future ideas





Thank you
for attending!