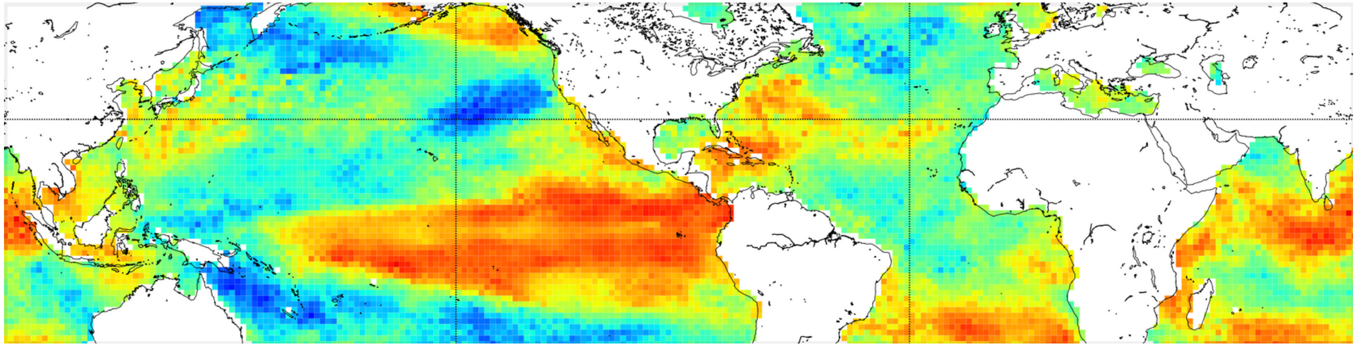
Improving sub-seasonal drought forecasting with machine learning and climate indices

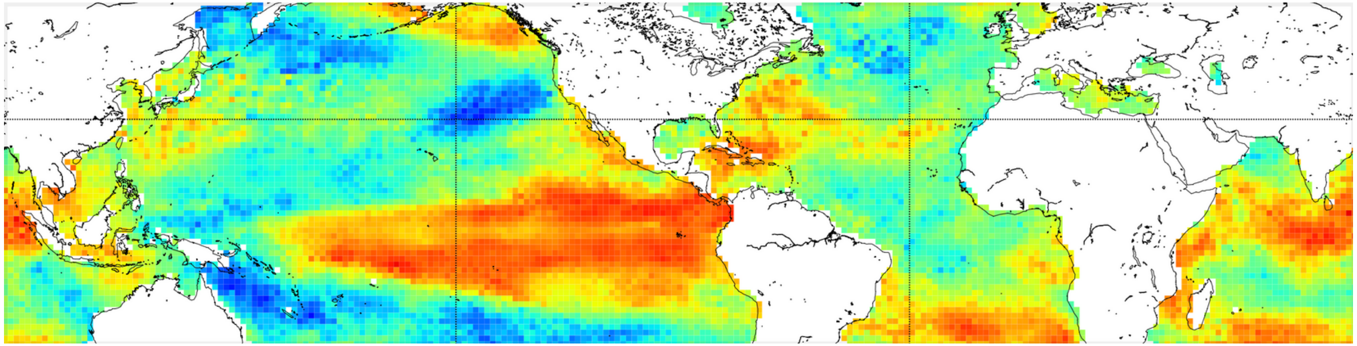
BOSSO FRANCESCO



IHE Delft, 03/11/2022

you can find the slides here!

BOSSO FRANCESCO



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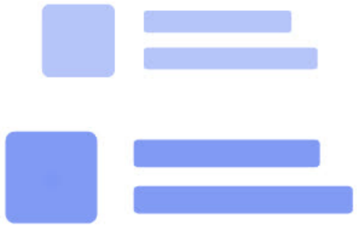
Today's Agenda

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

Meteorological Drougt

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

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Reduced soil moinsture,Reduced stream flow,Crop damage

Water shortage

Intro

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

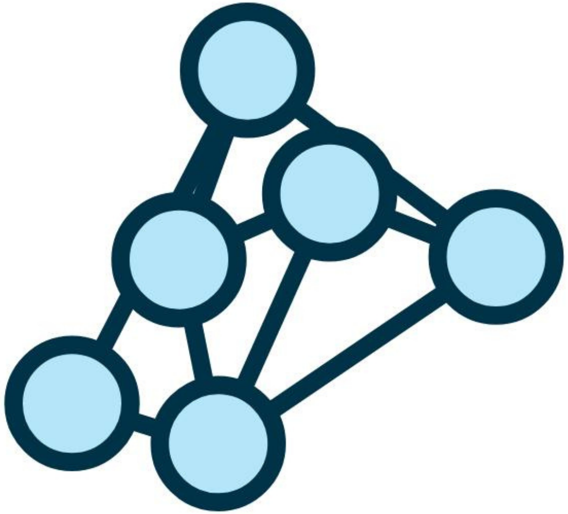
The onset, extent and duration of drought are difficult to define

different stakeholders have varying degrees of tolerance and resilience to these events (Slette et al., 2019)

Intro

Being able to forecast them is crucial

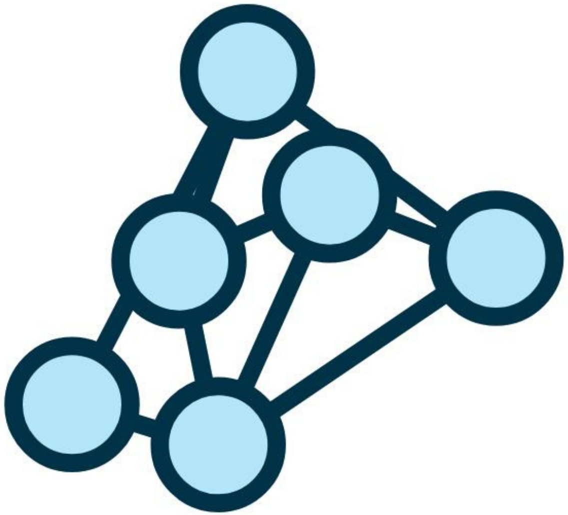
Intro



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

sub-seasonal forecasting

Intro



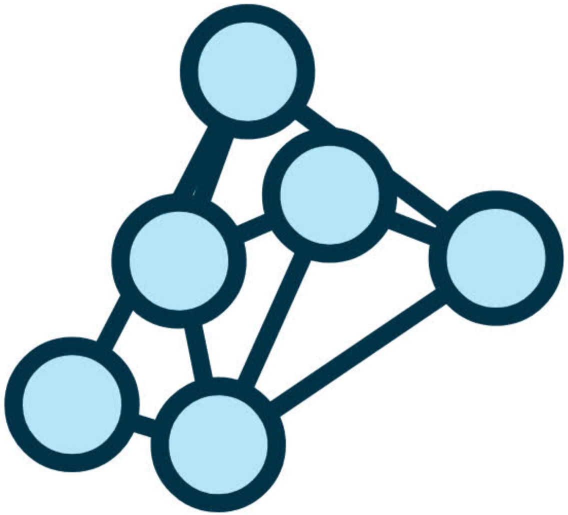
Earth observation data

Artificial Intelligence

Hardware (GPU,TPU)

AI-based prediction models

Intro



McGovern et al. (2017)

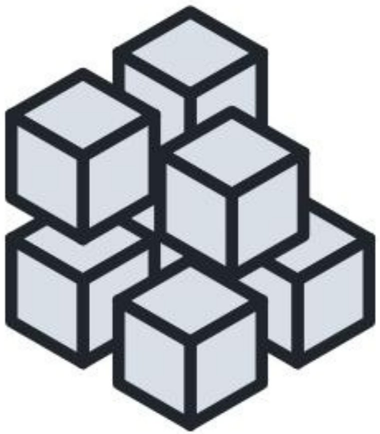
Learn from past data

Integrate physical understanding into the models

Discover additional knowledge from the data

Handle large amounts of input variables

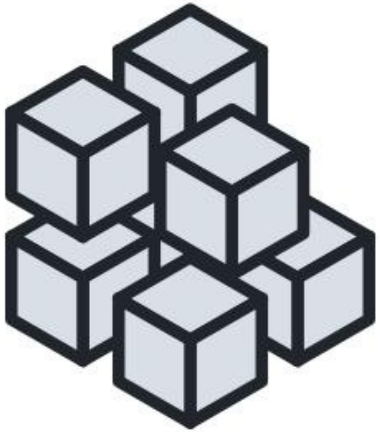
Intro



sub-seasonal drought forecasting ⟷ AI

Why to focus on sub-seasonal lead times?

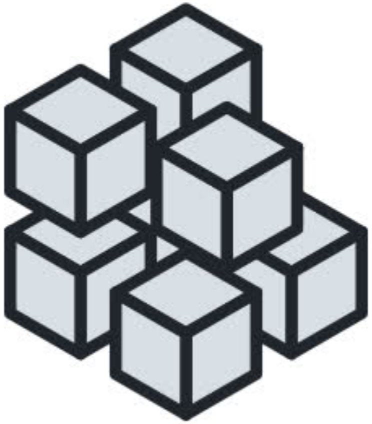
Intro



Informative predictors

Seasonal:
climate indices and large scale teleconnection patterns
short-medium term:
local variable (precipitation, temperature)

Intro

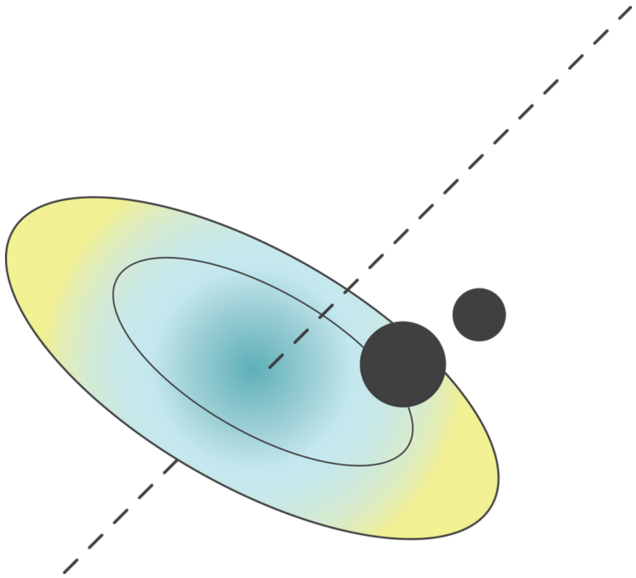


Informative predictors

sub-seasonal?

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)

?

Machine Learning model for sub-seasonal precipitation forecasting

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precipitation forecasting

↓

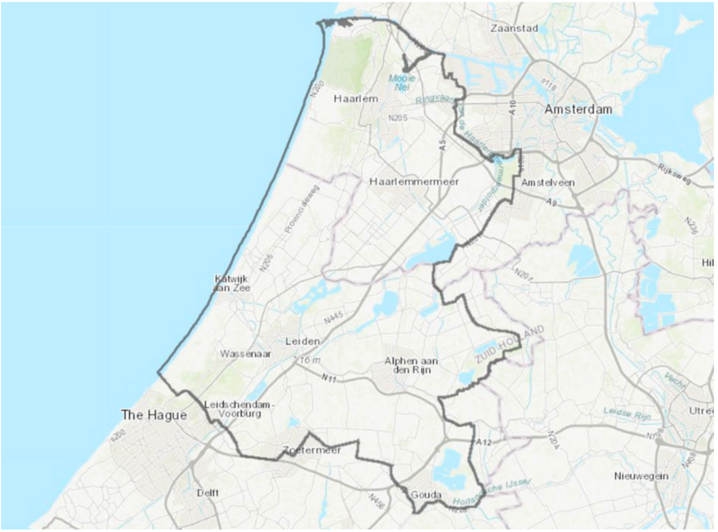
SPI

↓

drought forecasting

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

water board of Rijnland is able to forecast drought at bi-weekly lead times. The goal is to extend it to a month

Context

Extreme Event definition

- Meteorological drought
- Occurrence of drought (binary or multi-class or precipitation prediction)
- Decision trigger: SPI
- Lead time: 30 days

Input variables selection

- Climate State Intelligence (Giuliani et al., 2019) extended for sub-seasonal forecasts to identify teleconnections (NIPA)

ML algorithm

- NN for drought prediction on a single cell (precipitation forecasting or SPI classification) – input form NIPA and target in a single cell

Performance assessment

- Depending on the kind of model: MSE, hitrate, ...

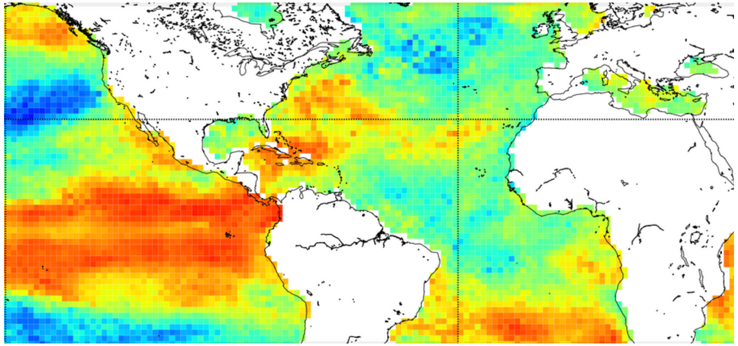
Framework

- 01 NIPA
- 02 Neural Network

Framework

- **01 NIPA**
- 02 Neural Network

Nino Index Phase Analysis



Zimmerman et al. (2016)

↓

Giuliani et al. (2019)

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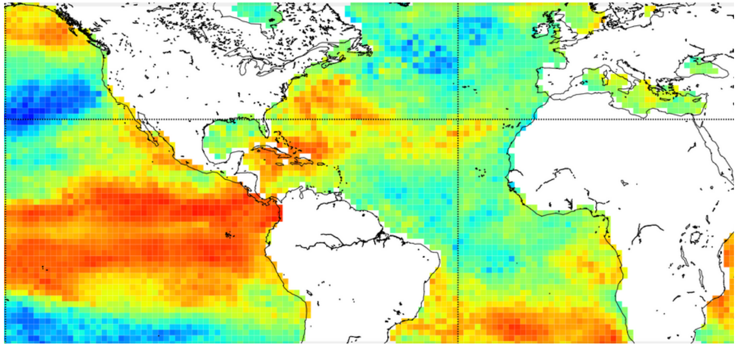
Our readaptation

01 NIPA

02 Neural Network

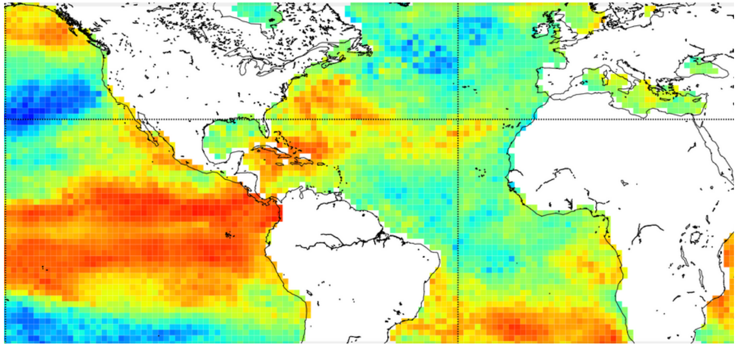
Framework



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

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)

- 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

Framework

- 01 NIPA
- 02 Neural Network

- above/below-normal temperatures in eastern United States and northern Europe
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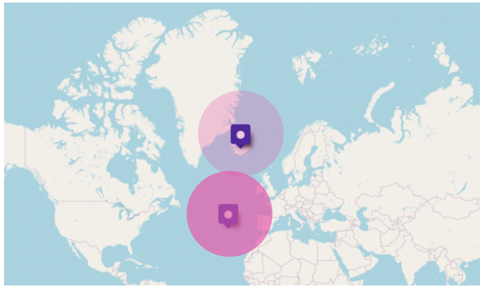
climate indices

North Atlantic Oscillation (NAO)



Phases Neg

Framework

- 01 NIPA
- 02 Neural Network

- above/below-normal temperatures in eastern United States and northern Europe
- above/below-normal temperatures in Greenland and southern Europe
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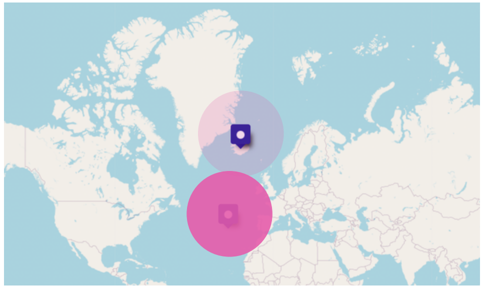
climate indices

North Atlantic Oscillation (NAO)



Phases Pos

Framework

DATA

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

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)

Example:

- Month 1
- Aggregation level 1

local precipitation of January and the global variable of December

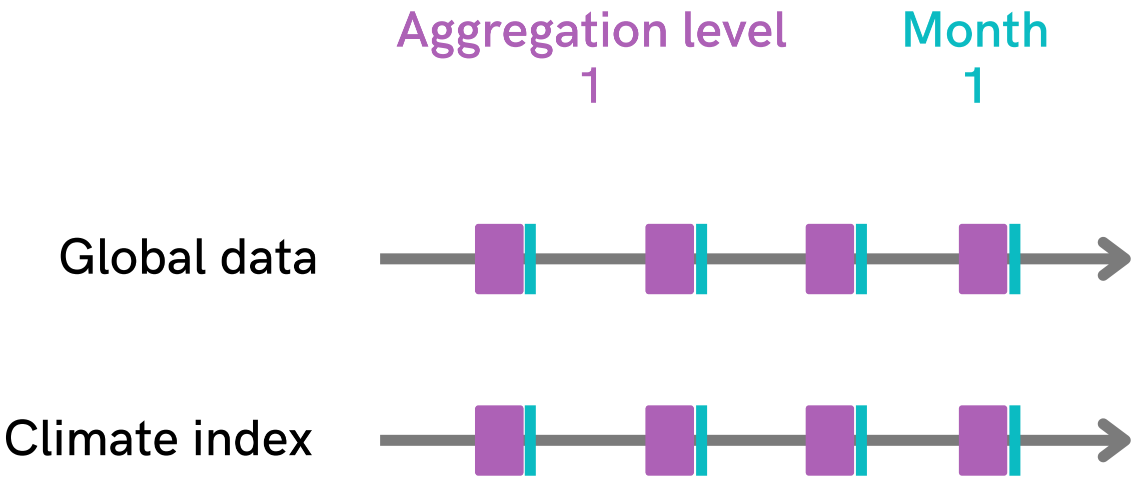
- Month 1
- Aggregation level 2

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

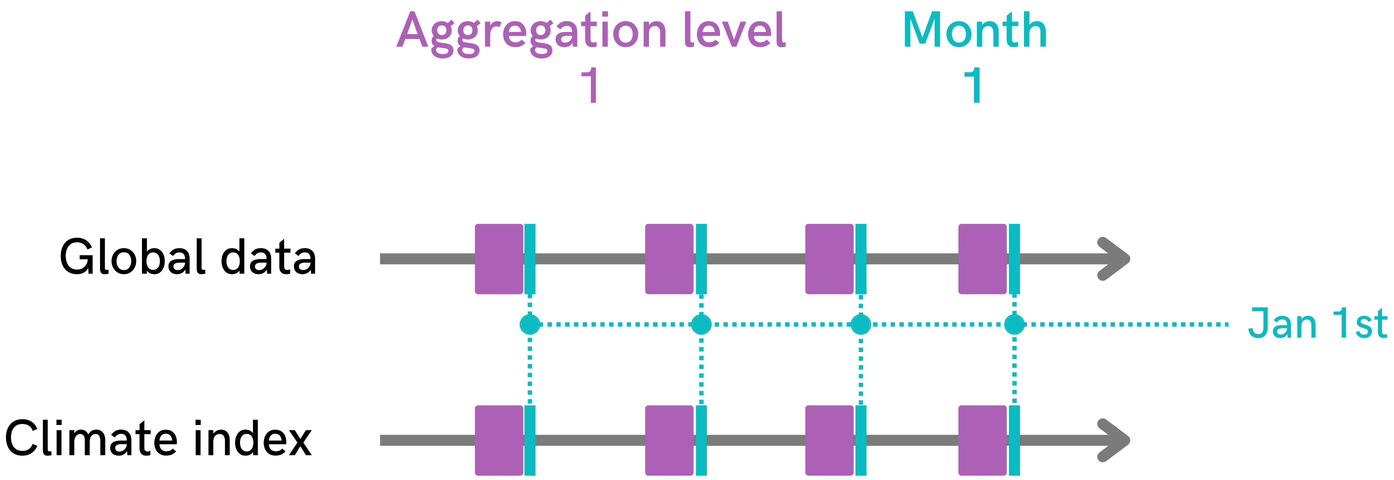
Framework

- 01 NIPA
- 02 Neural Network

Input
Data extraction
Phase segmentation
Correlation
PCA
output



Framework



Aggregation level
1
Month
1
Global data
Climate index
Jan 1st

Framework

- 01 NIPA
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Input
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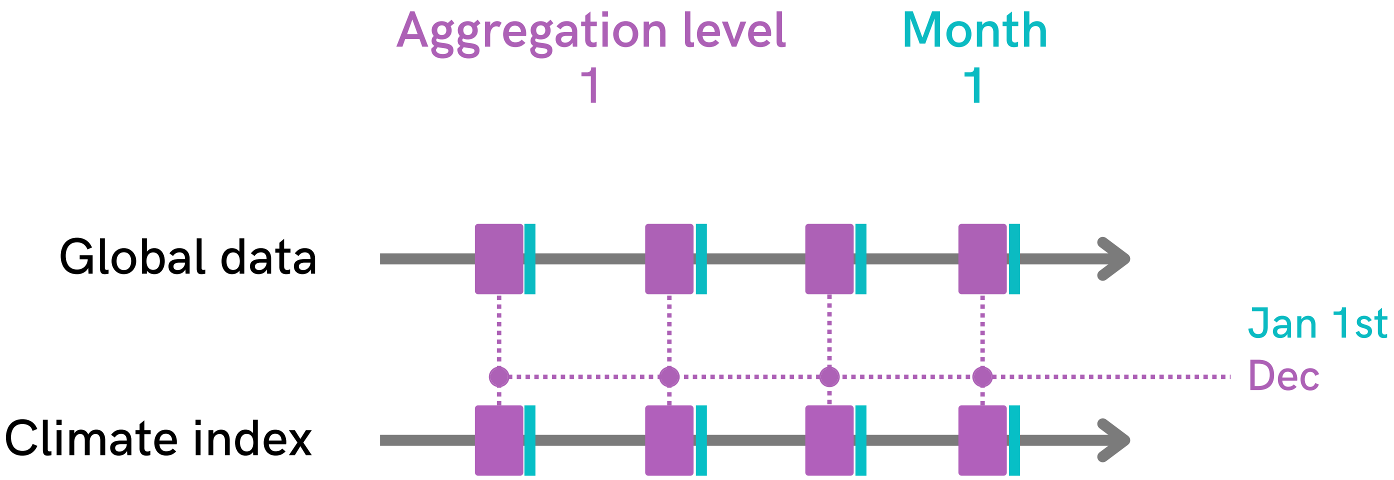


NOTE: this is an year-based operation. NIPA will extract the data for the December of each year

Framework

Input

Data extraction

Phase segmentation

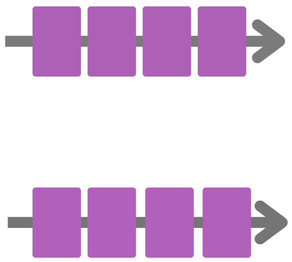
Correlation

PCA

output

Global data

Climate index



Framework

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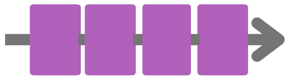
Global data

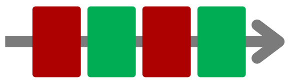


Climate index

Framework

- Input
- Data extraction
- Phase segmentation
- Correlation
- PCA
- output

Global data



Climate index

Framework

01 NIPA

02 Neural Network

Input

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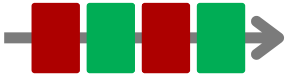
Global data



Framework

01 NIPA

02 Neural Network

Input

Data extraction

Phase segmentation

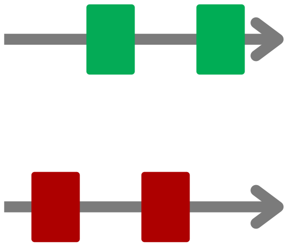
Correlation

PCA

output

Global data Pos

Global data Neg



Framework

01 NIPA

02 Neural Network

Input

Data extraction

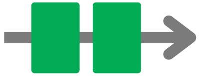
Phase segmentation

Correlation

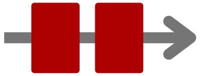
PCA

output

Global data Pos



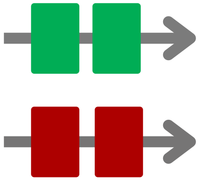
Global data Neg



Framework

Global data Pos

Global data Neg



Input

Data extraction

Phase segmentation

Correlation

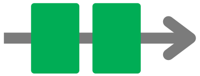
PCA

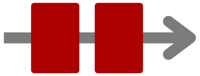
output

Framework

- 01 NIPA
- 02 Neural Network

Input
Data extraction
Phase segmentation
Correlation
PCA
output

Global data Pos 

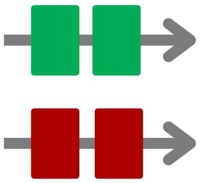
Global data Neg 

Local data 

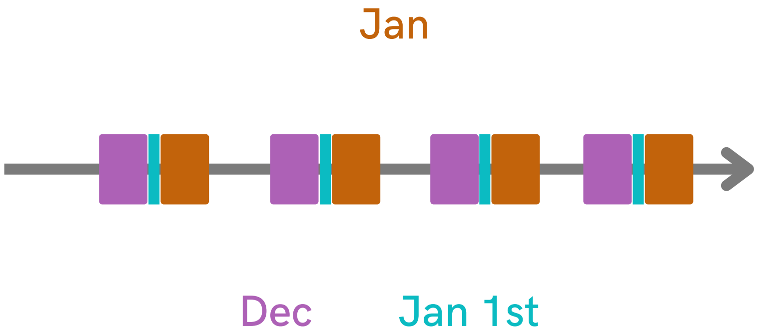
Framework

Global data Pos

Global data Neg



Local data

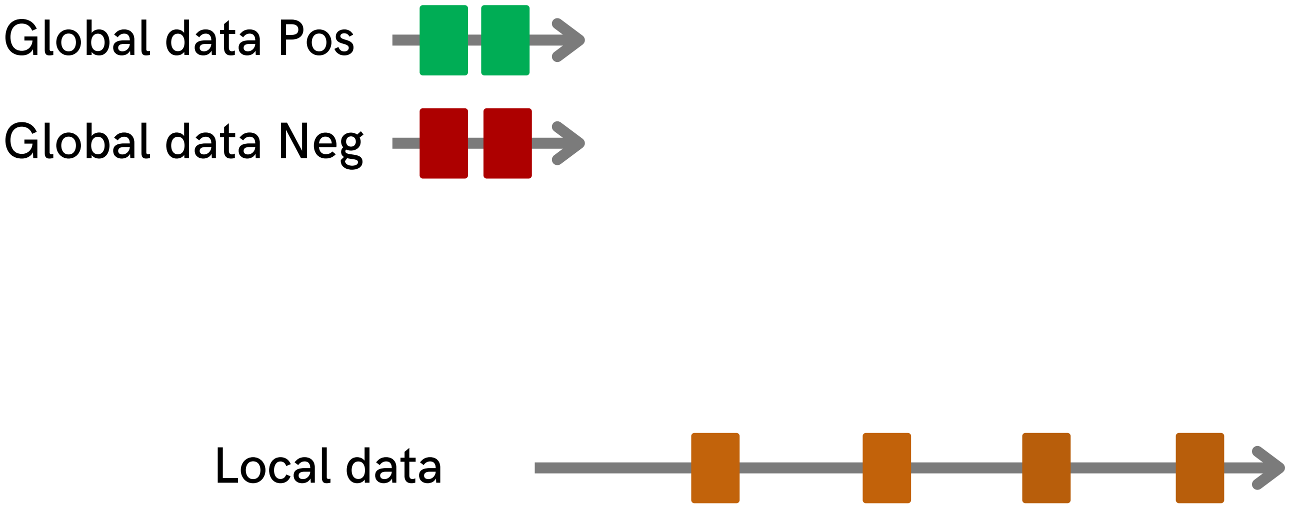


Framework

01 NIPA

02 Neural Network

Input
Data extraction
Phase segmentation
Correlation
PCA
output



Framework

- 01 NIPA
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Input
Data extraction
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PCA
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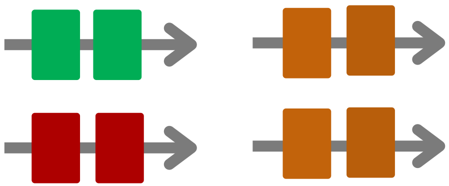
Global data Pos

Global data Neg

Framework

Global data Pos

Global data Neg



● 01 NIPA

● 02 Neural Network

Input

Data extraction

Phase segmentation

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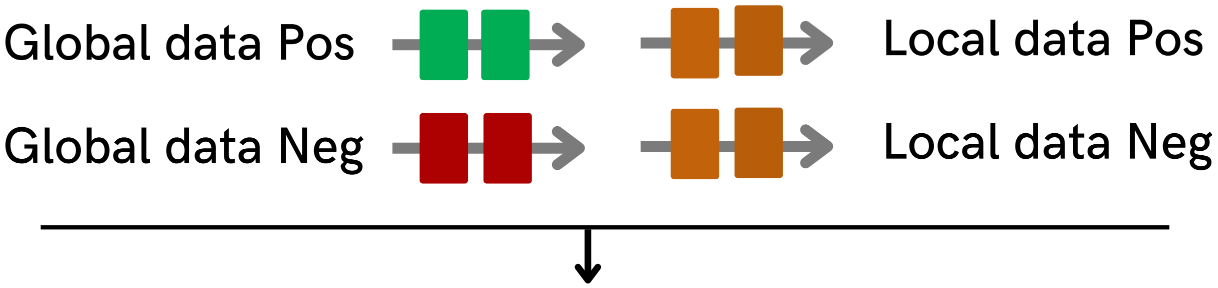
PCA

output

Framework



01 NIPA

02 Neural Network

Input

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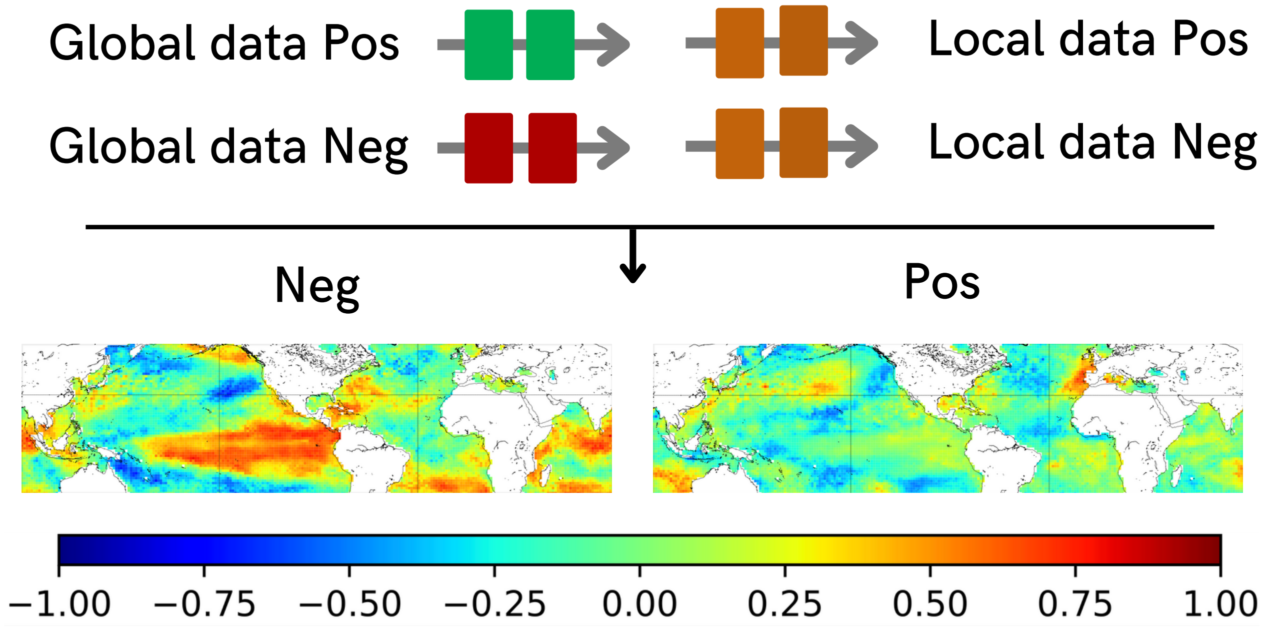
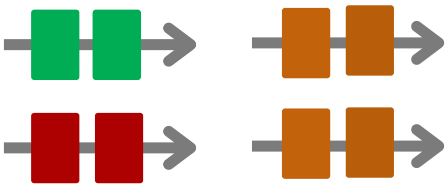
Framework


Global data Pos
Global data Neg
Local data Pos
Local data Neg
Neg
Pos
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00

Framework

Global data Pos

Global data Neg

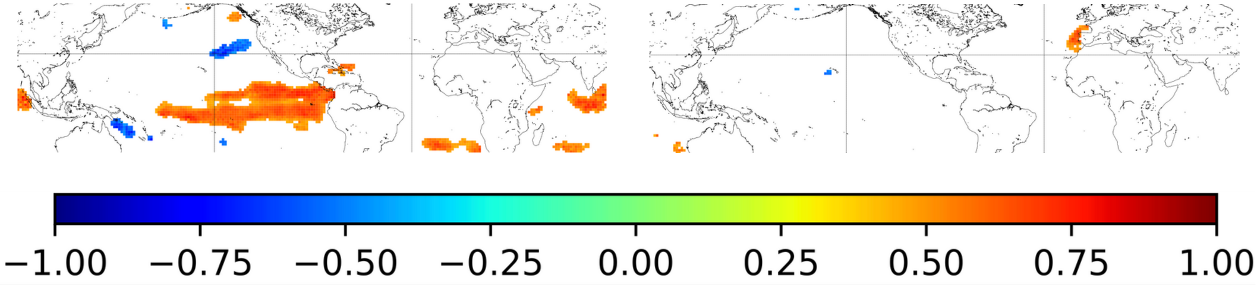


Local data Pos

Local data Neg

Neg

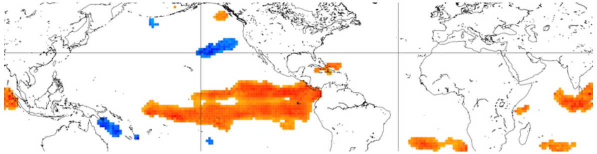
Pos



95% of significance

Framework

Neg



Pos

- 01 NIPA
- 02 Neural Network

Input
Data extraction
Phase segmentation
Correlation
PCA
output

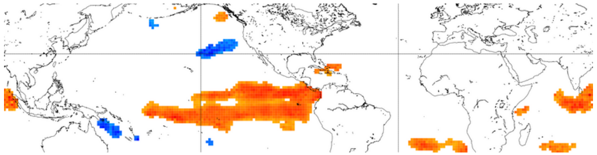
Framework

01 NIPA

02 Neural Network

- Input
- Data extraction
- Phase segmentation
- Correlation
- **PCA**
- output

Neg



$$\underbrace{\begin{bmatrix} \cdots\cdots\cdots \\ \vdots \\ \vdots \end{bmatrix}}_{pixels} \left.\vphantom{\begin{bmatrix} \cdots \\ \vdots \\ \vdots \end{bmatrix}}\right\} year_{neg}$$

Pos

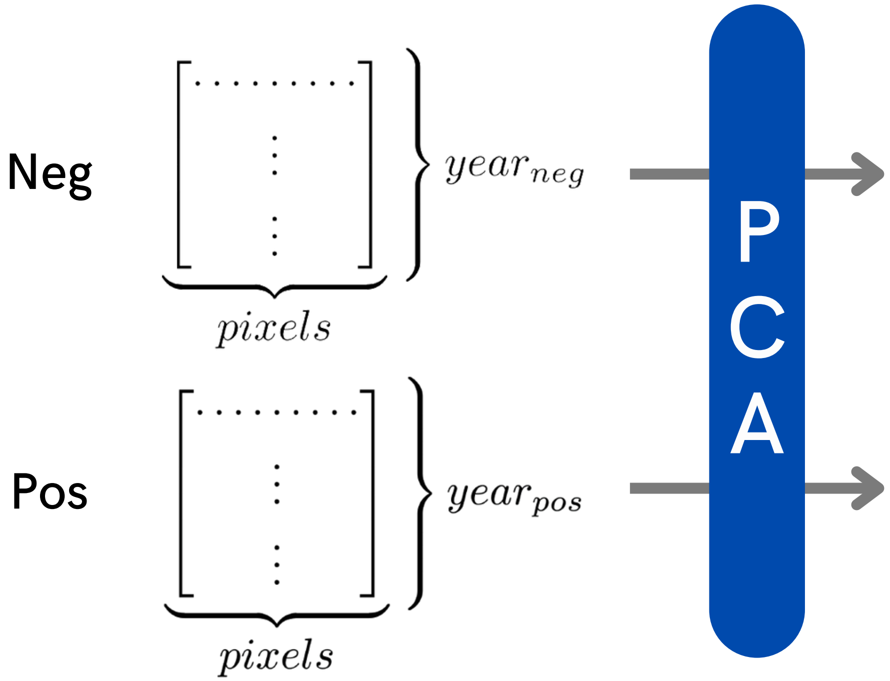
$$\underbrace{\begin{bmatrix} \cdots\cdots\cdots \\ \vdots \\ \vdots \end{bmatrix}}_{pixels} \left.\vphantom{\begin{bmatrix} \cdots \\ \vdots \\ \vdots \end{bmatrix}}\right\} year_{pos}$$

Framework

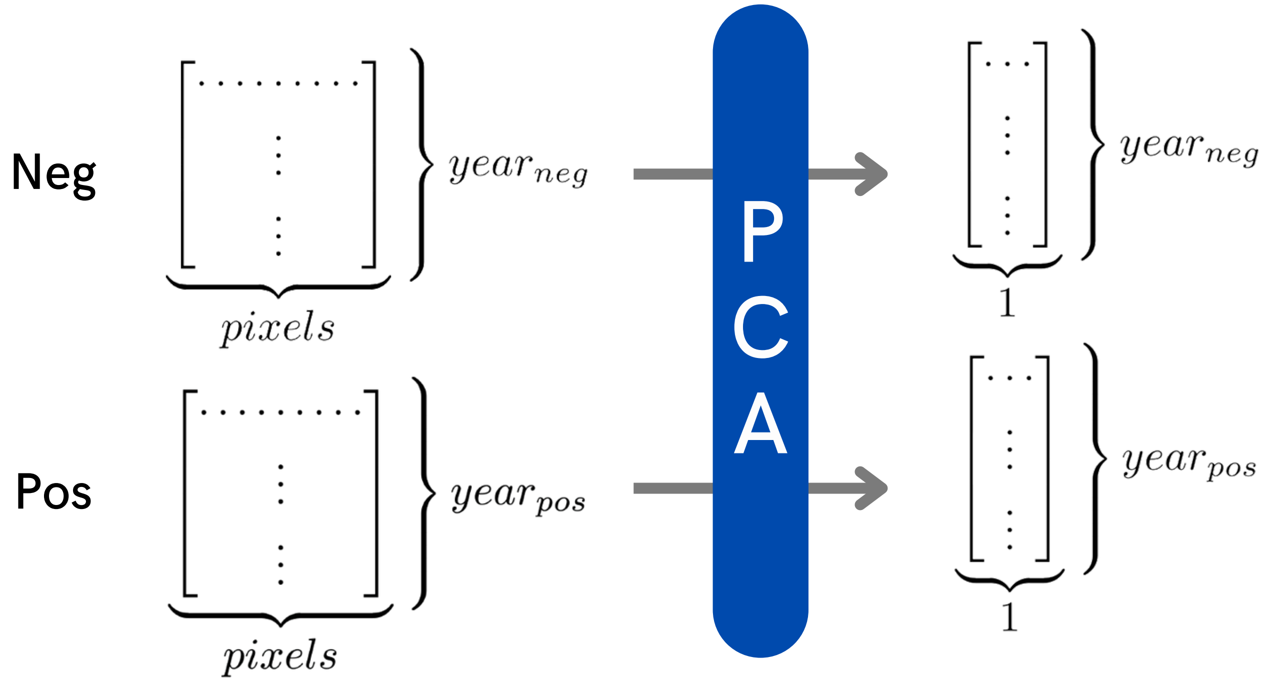
Neg $\underbrace{\left.\begin{bmatrix} \cdots\cdots\cdots \\ \vdots \\ \vdots \end{bmatrix}\right\} year_{neg}}_{pixels}$

Pos $\underbrace{\left.\begin{bmatrix} \cdots\cdots\cdots \\ \vdots \\ \vdots \end{bmatrix}\right\} year_{pos}}_{pixels}$

Framework



Framework



Neg
$year_{neg}$
$pixels$
Pos
$year_{pos}$
$pixels$
PCA
$year_{neg}$
1
$year_{pos}$
1

Framework

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

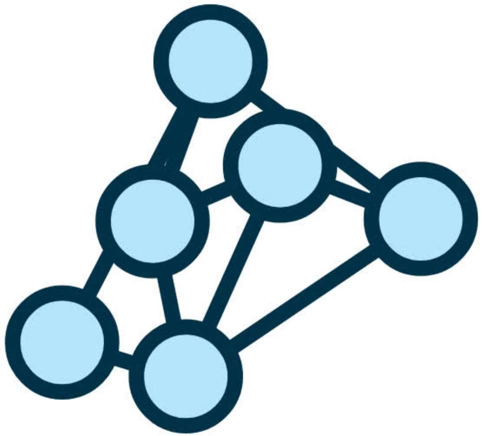
Dataset for 1 month

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)

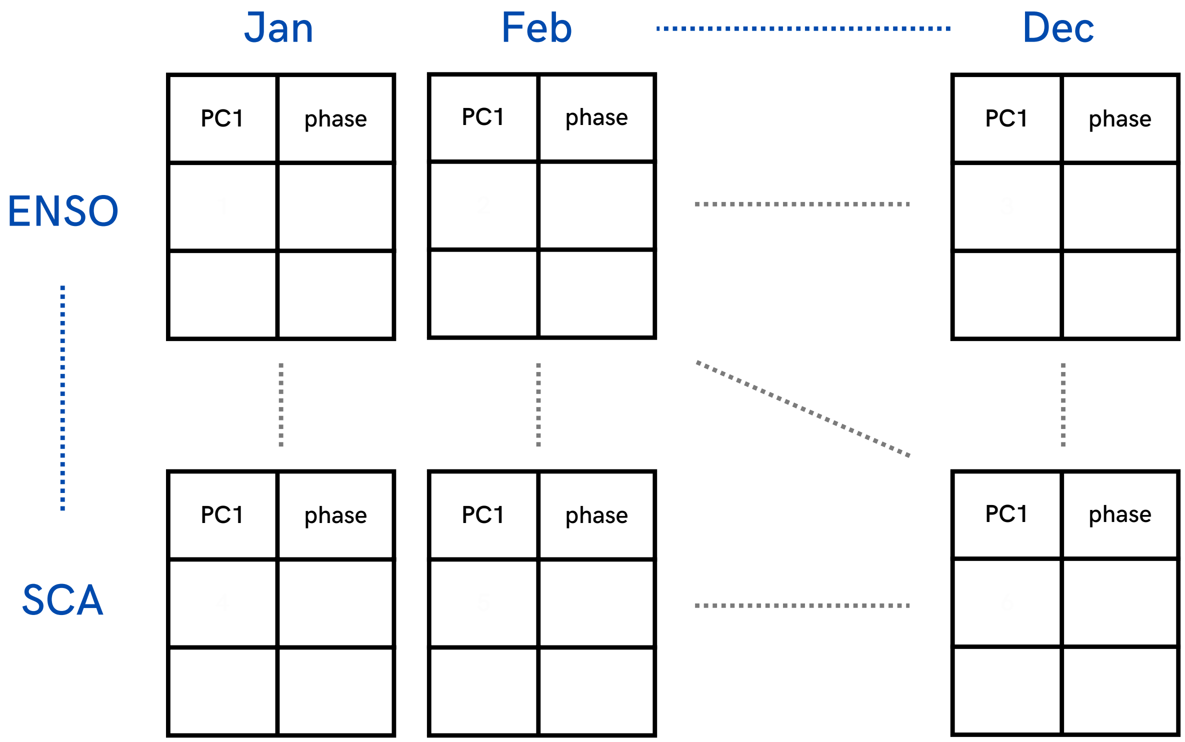
Framework



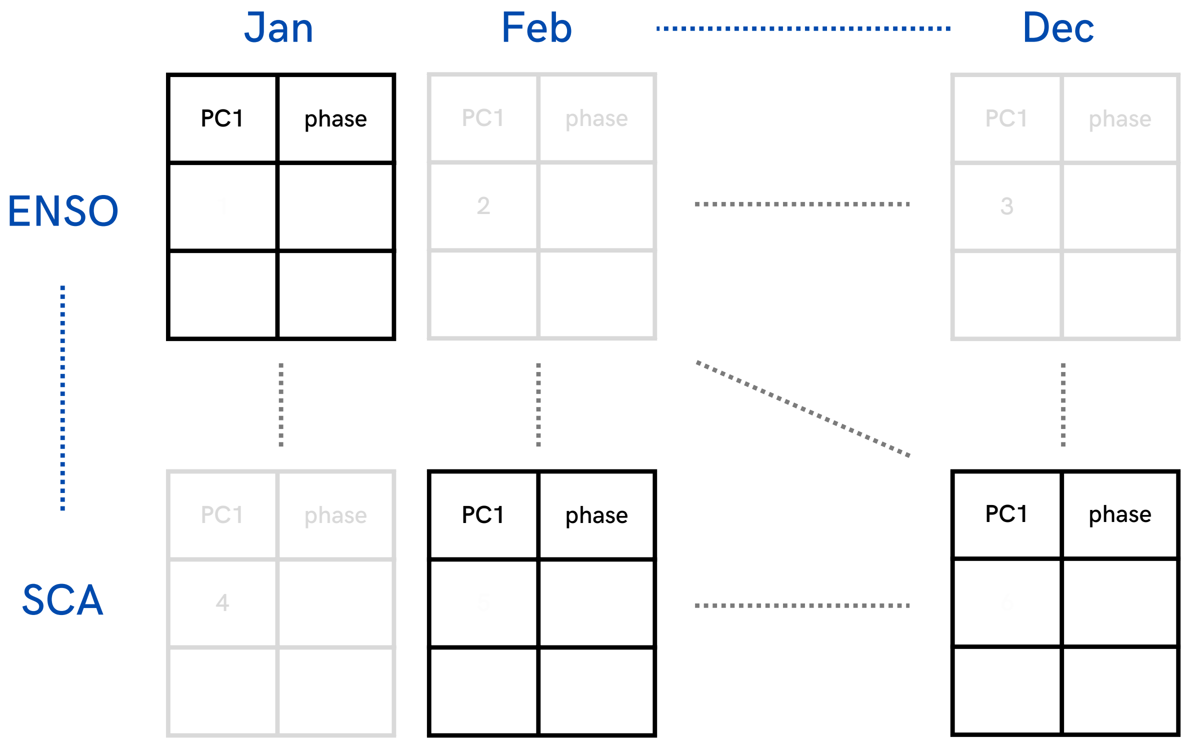
Just entered in this step

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

Framework


Jan
Feb
Dec
ENSO
SCA
PC1
phase
PC1
phase
PC1
phase
PC1
phase
PC1
phase
PC1
phase

Framework



Framework

- 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

Framework

Inputs: (PC1, phase label);
Target: (Cumulated Local Precipitation)

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

Framework

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

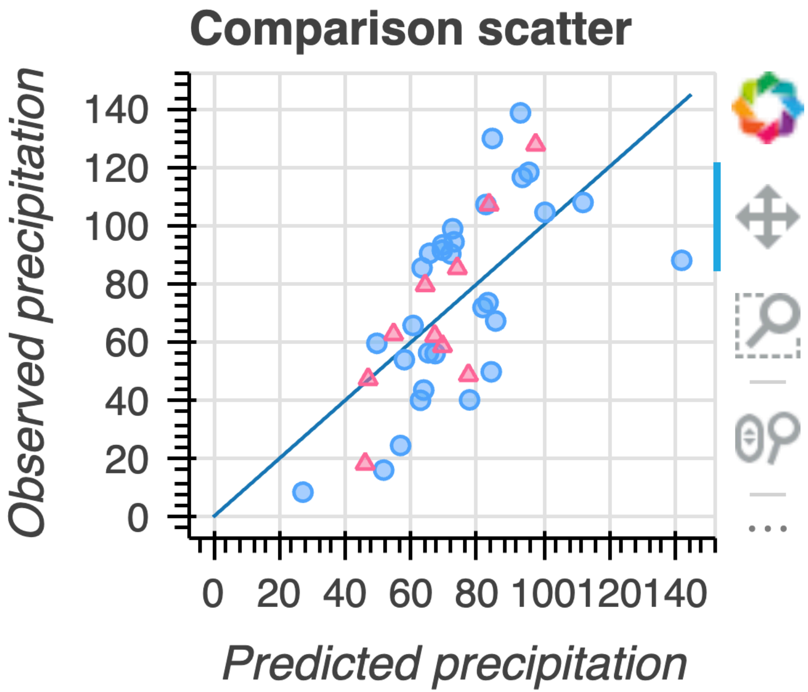
climate state

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

Framework

- 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

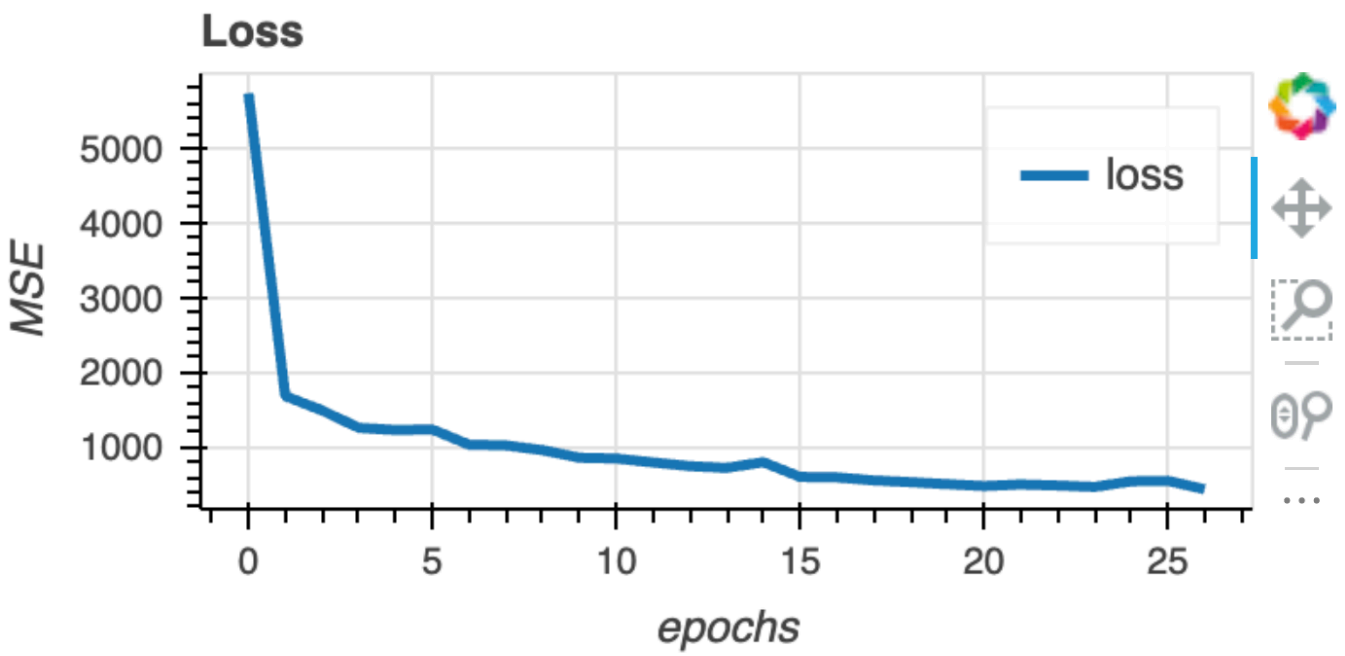
Framework



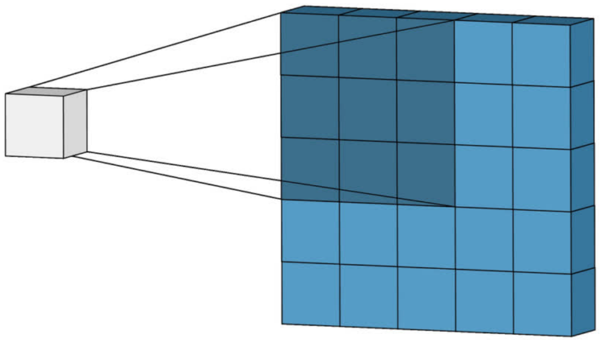
MSE of 319.0494 on the validation set

comparable with giuliani et al with ELM (374.905)

Framework



Future ideas



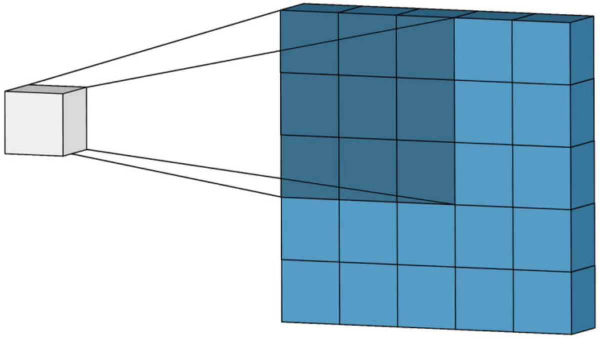
NN

CNN

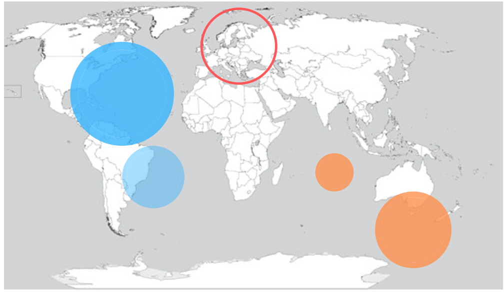
PC1

Correlation Map

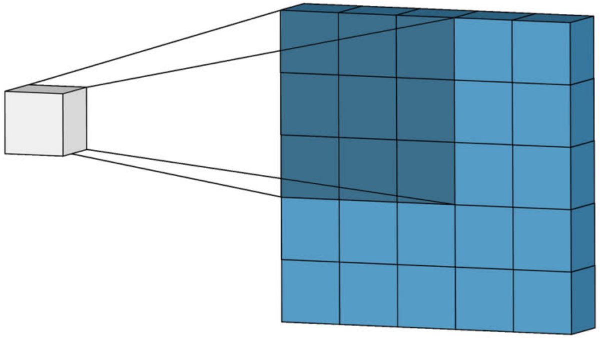
Future ideas

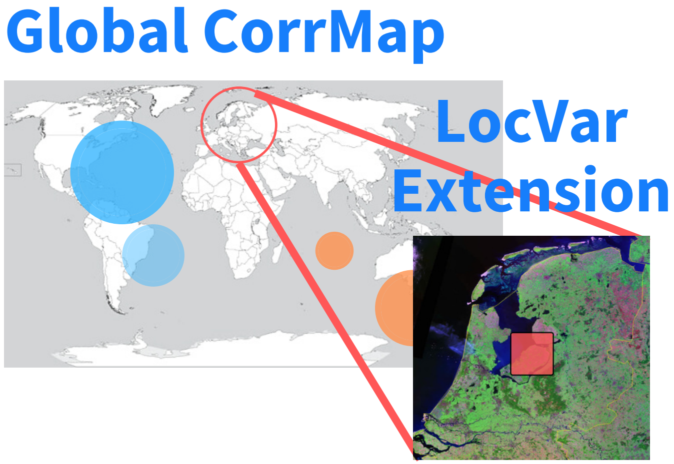


Global CorrMap

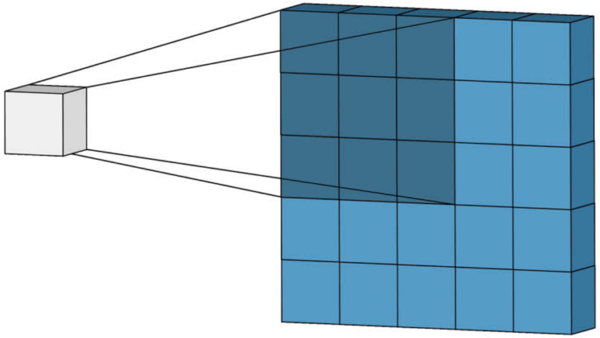


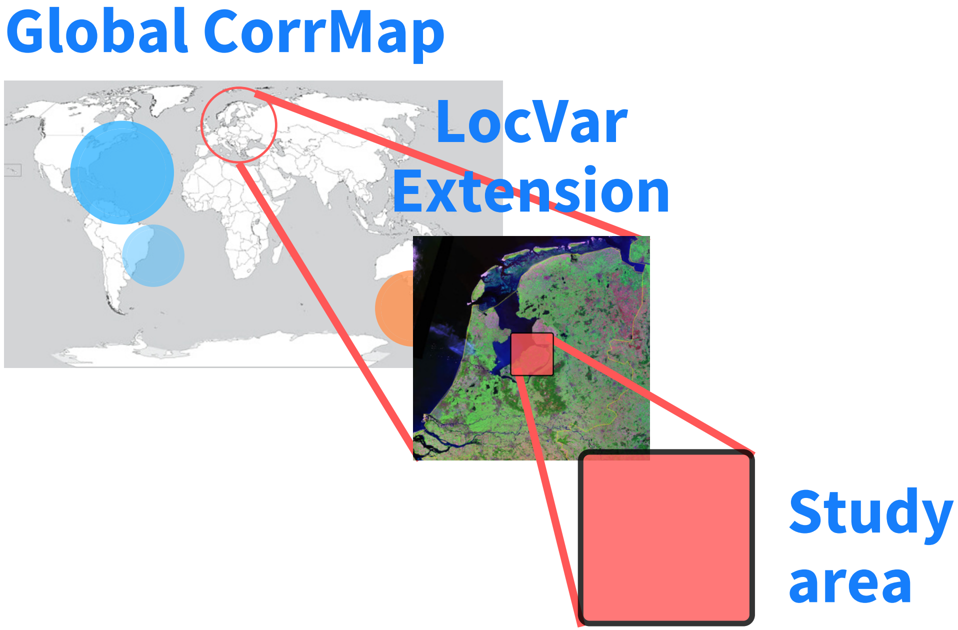
Future ideas



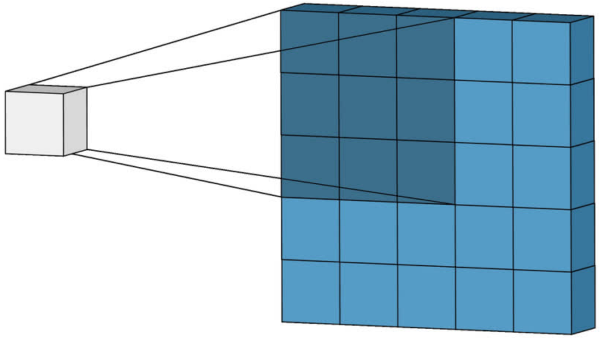


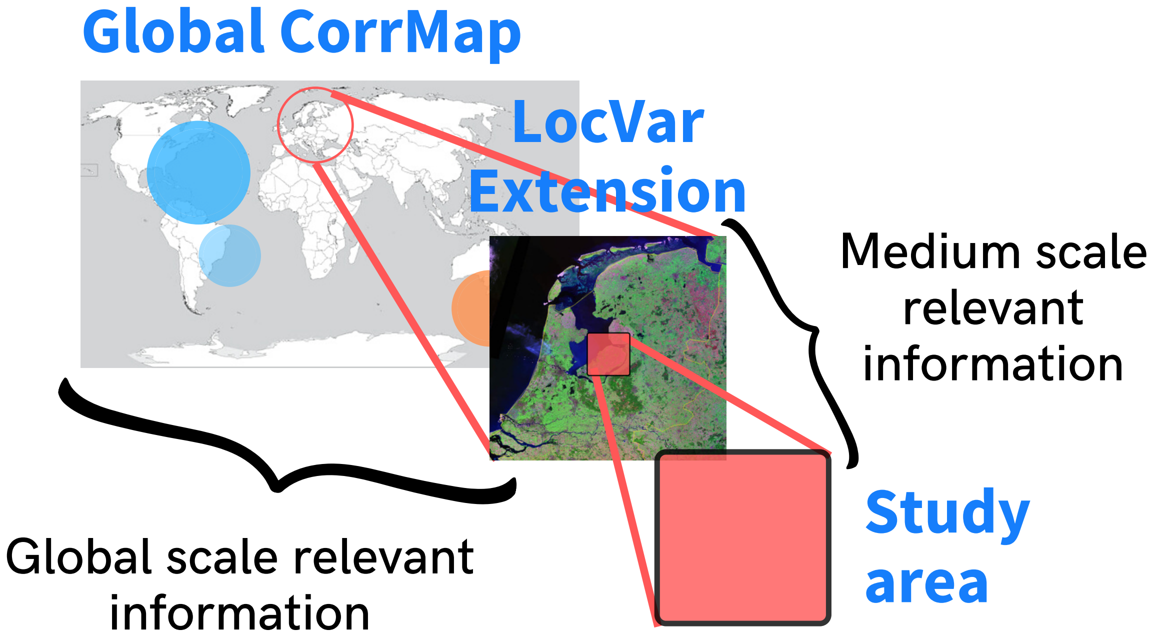
Future ideas

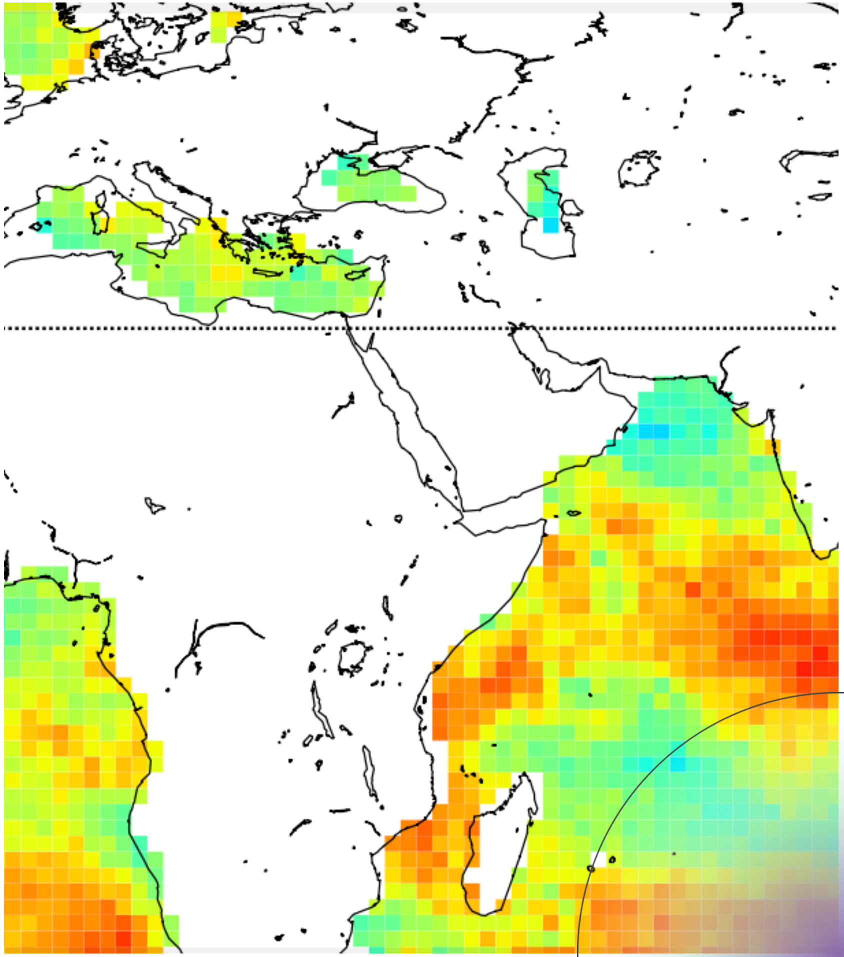




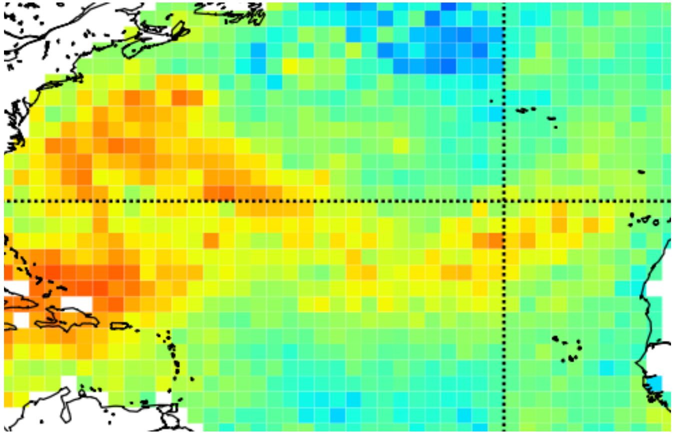
Future ideas







Thank you for attending!



you can find the slides here!

Zimmerman et al. (2016)

Giuliani et al. (2019)

Our readaptation