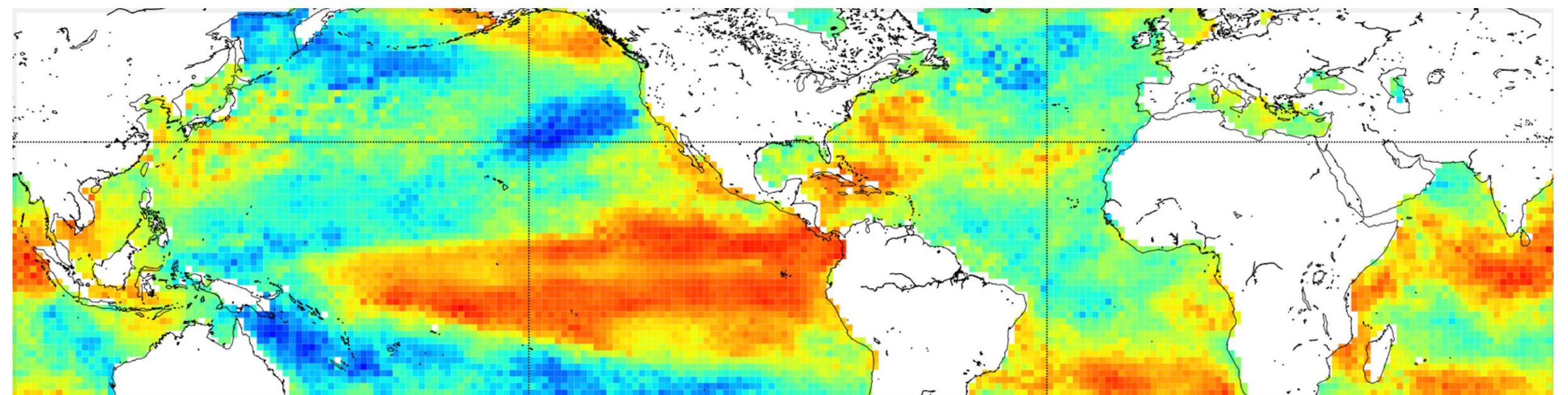


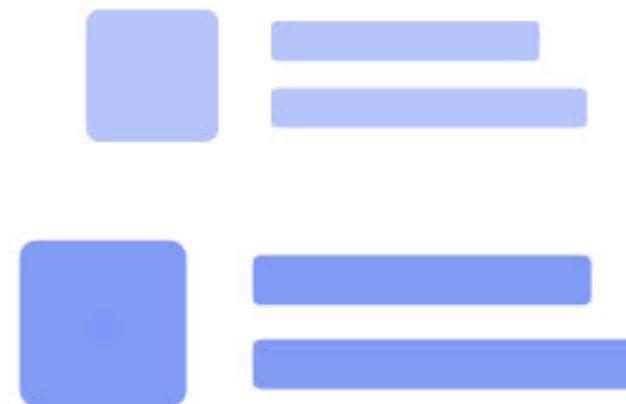
Improving sub-seasonal drought forecasting with machine learning and climate indices

IHE Delft, 03/11/2022



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

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



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

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

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



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

CONTEXT
DEPENDENT

Intro

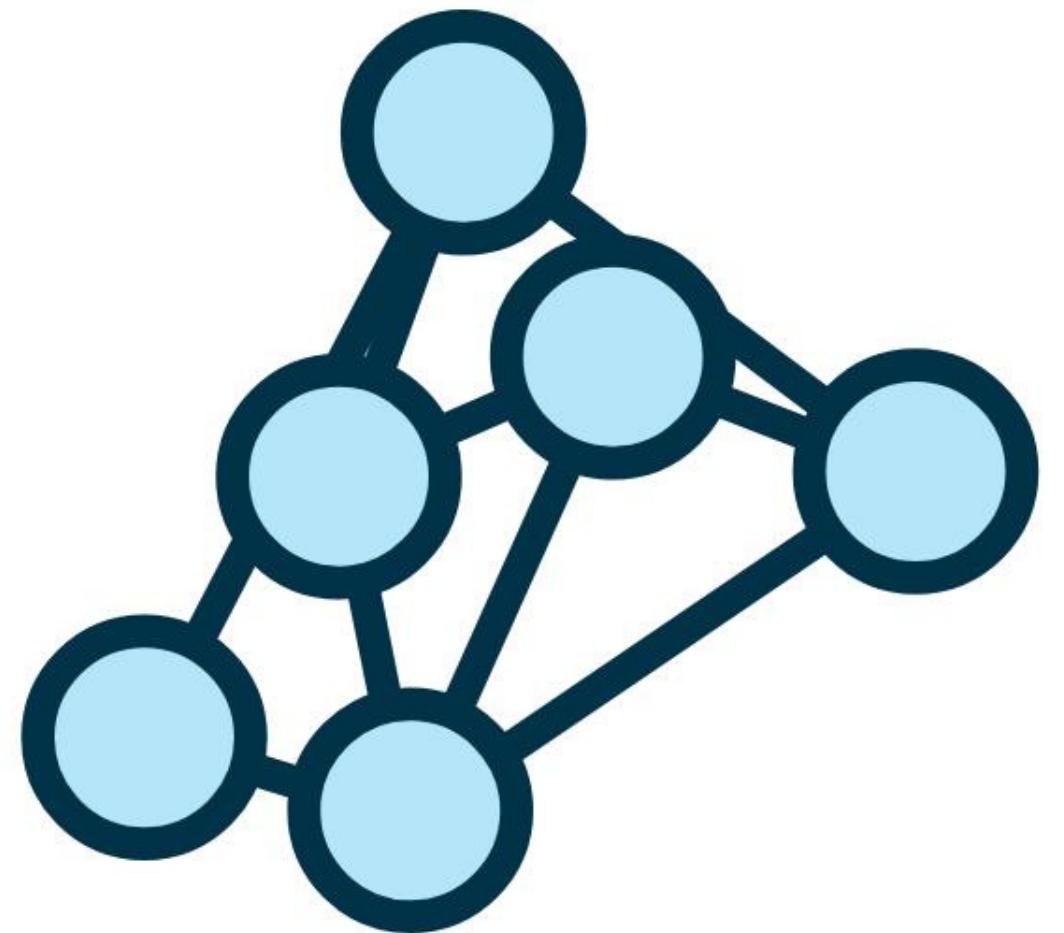
- 01 What is drought
- 02 ML for Drought
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Being able to forecast
them is crucial

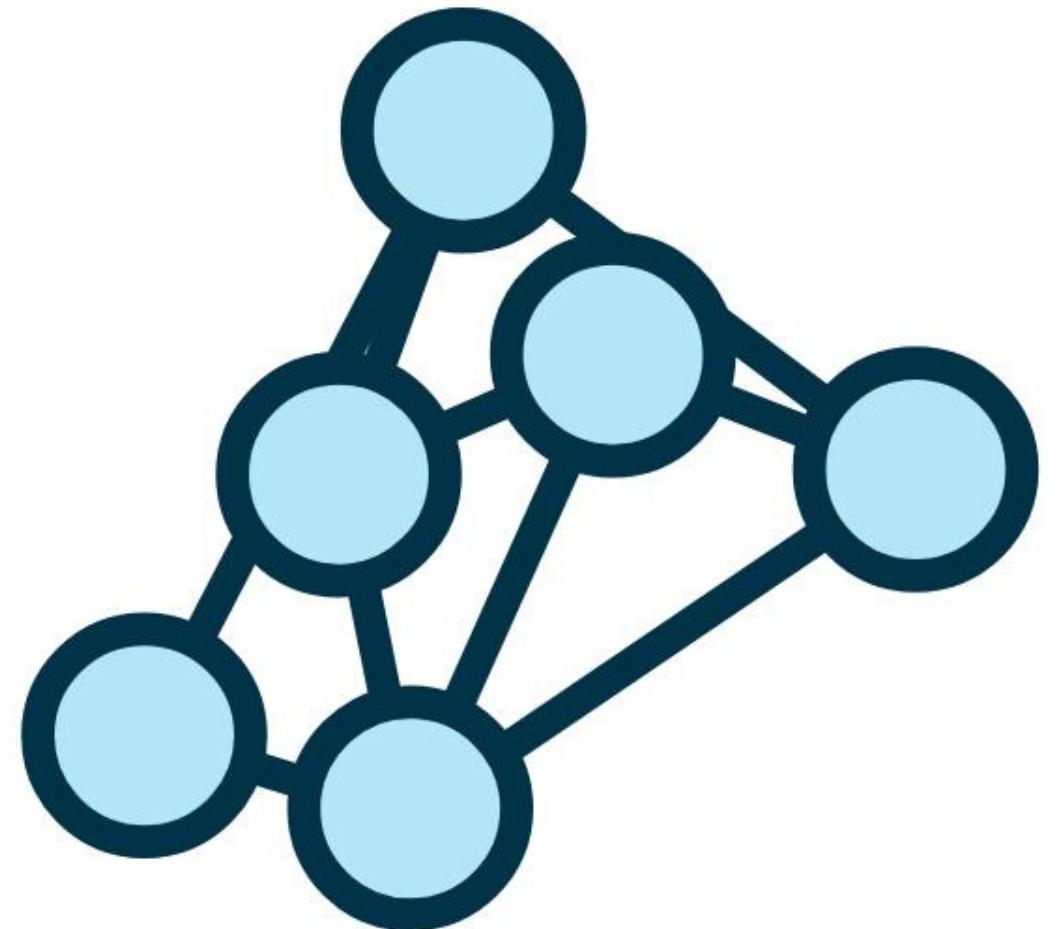
Intro

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



Intro

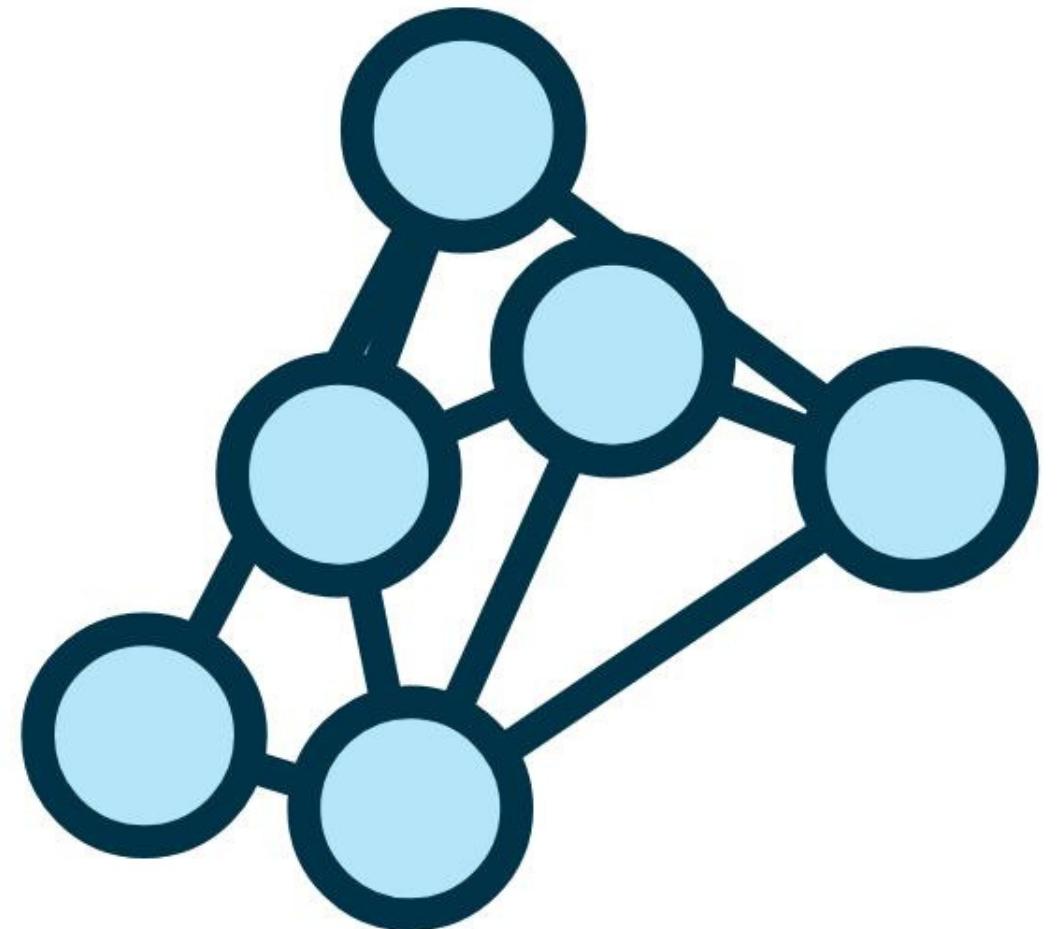
- 01 What is drought
- 02 ML for Drought
- 03 The gap



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

Intro

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

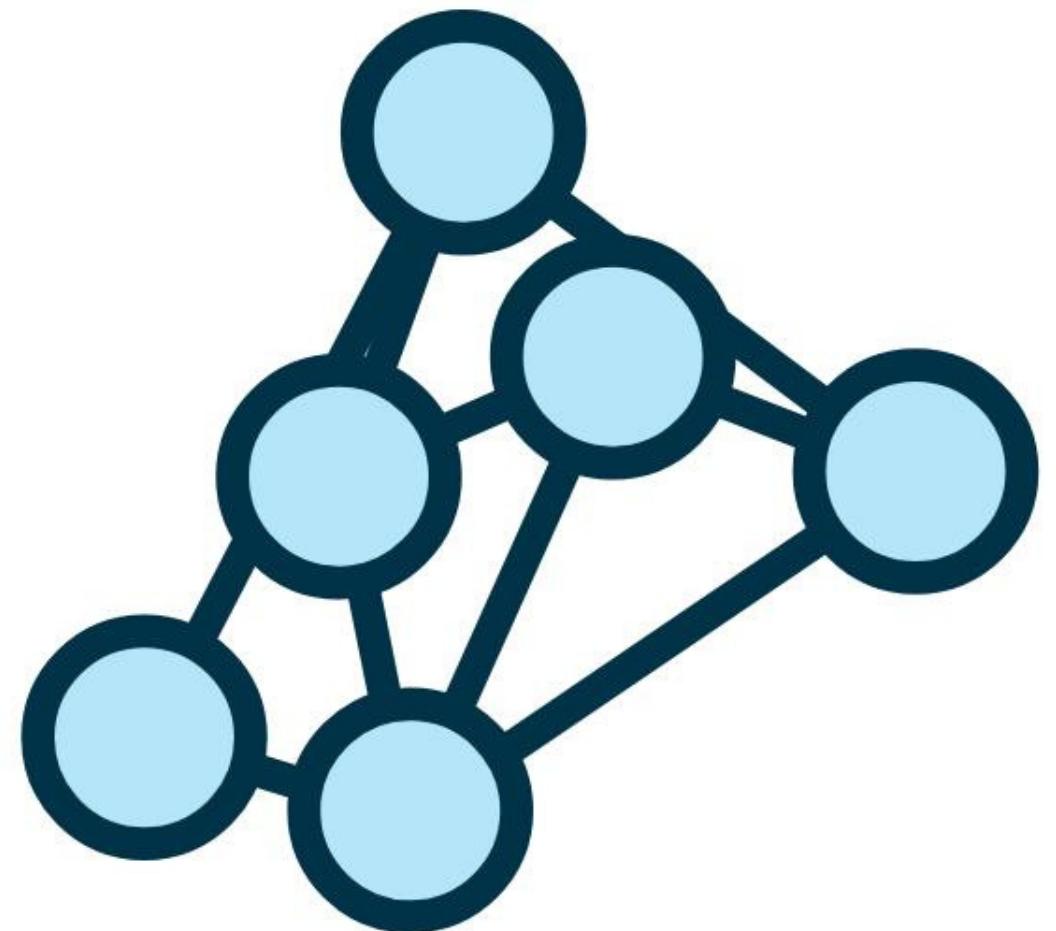


exploitation of *statistic* and *dynamic techniques* for droughts forecasting has been and is widely studied

sub-seasonal forecasting

Intro

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



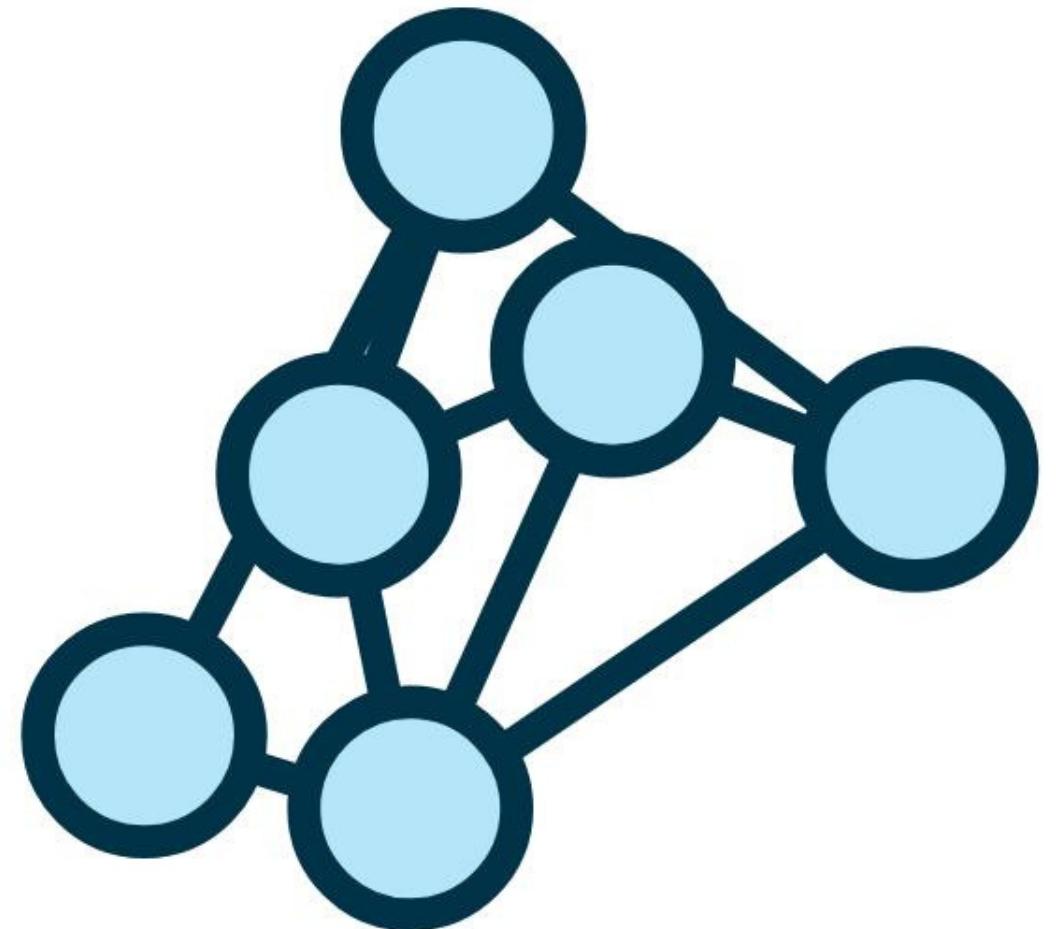
Earth observation data

Artificial Intelligence

Hardware (GPU,TPU)

Intro

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



Earth observation data

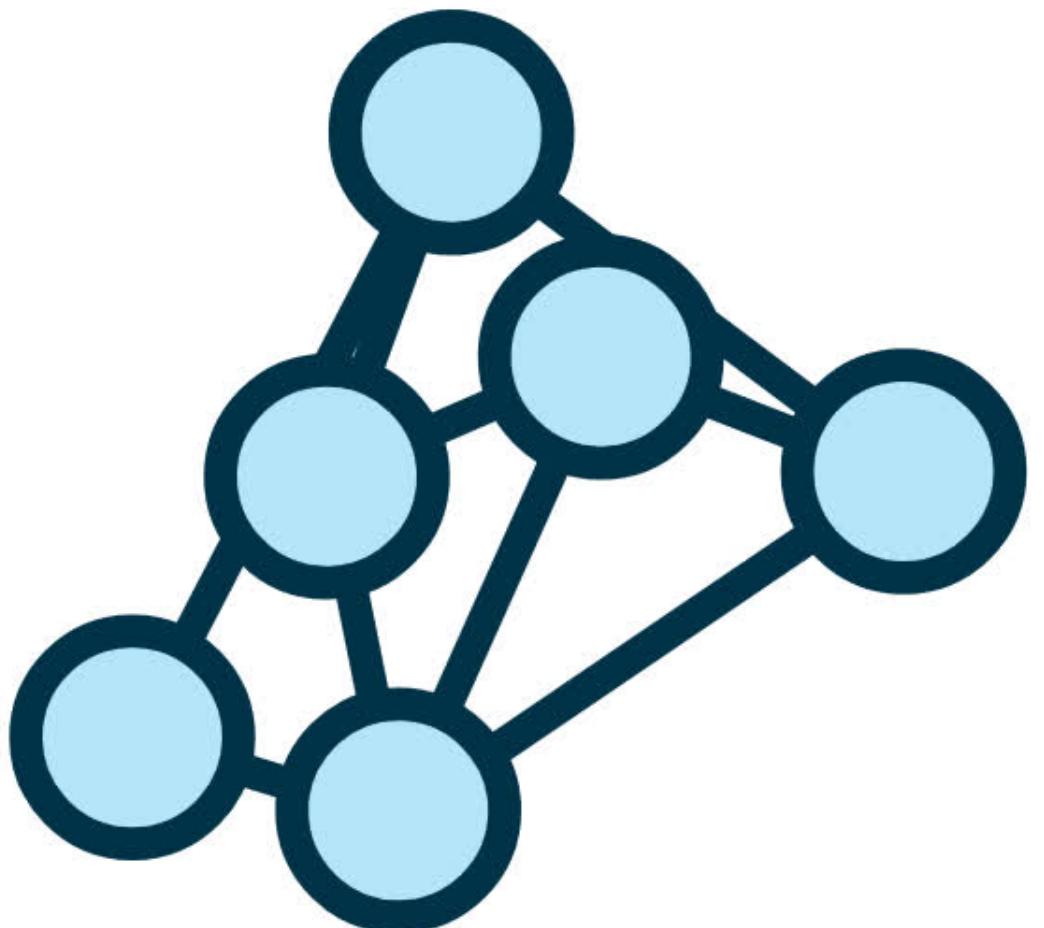
Artificial Intelligence

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

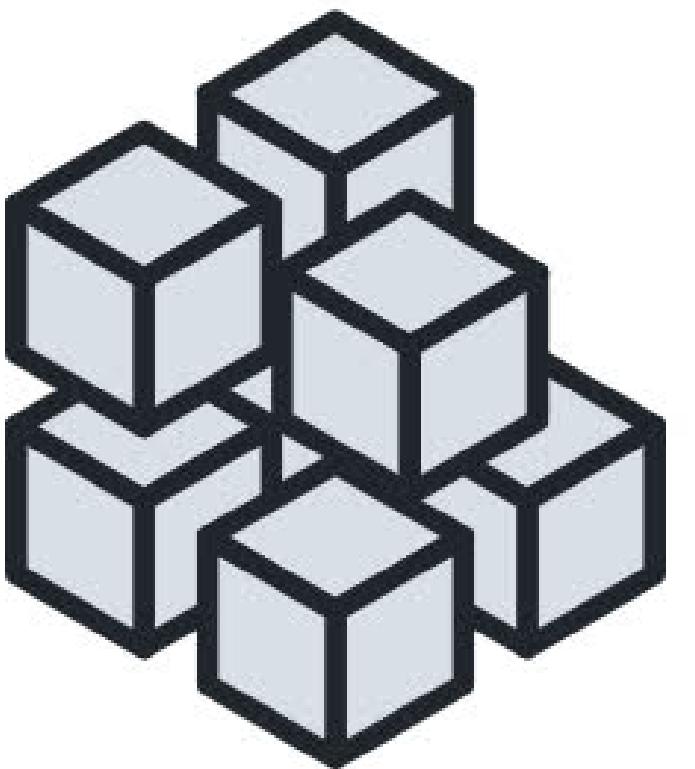
Integrate physical understanding into the models

Discover additional knowledge from the data

Handle large amounts of input variables

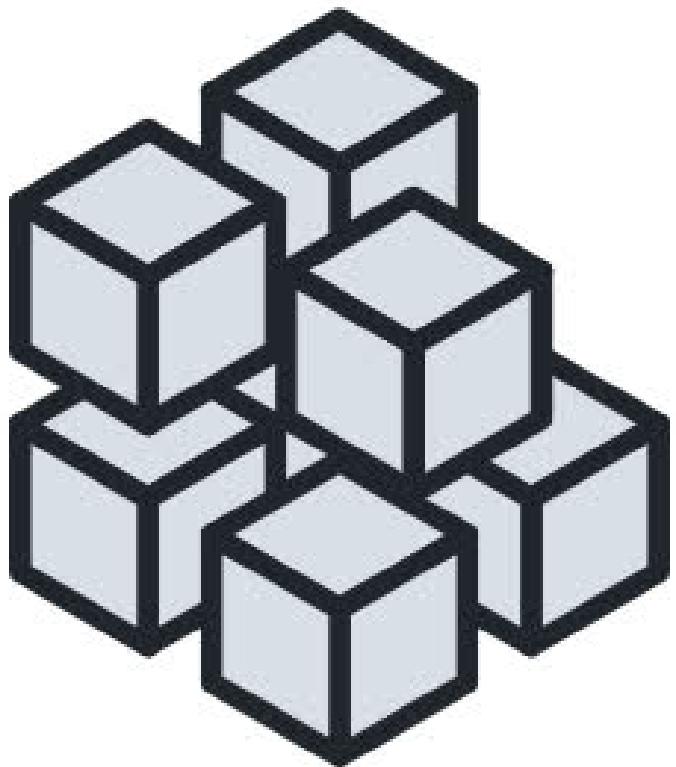
Intro

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



Intro

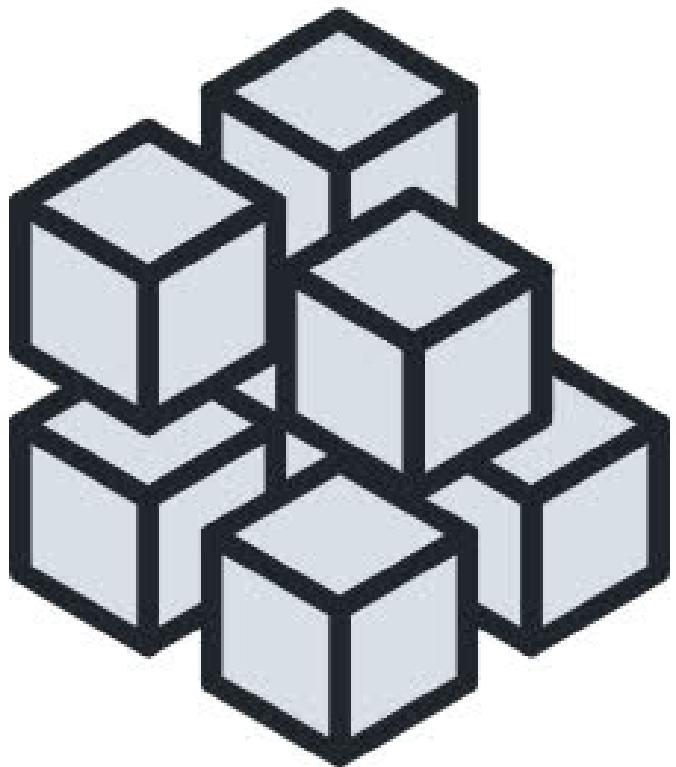
- 01 What is drought
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- 03 The gap



**sub-seasonal
drought forecasting**

Intro

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

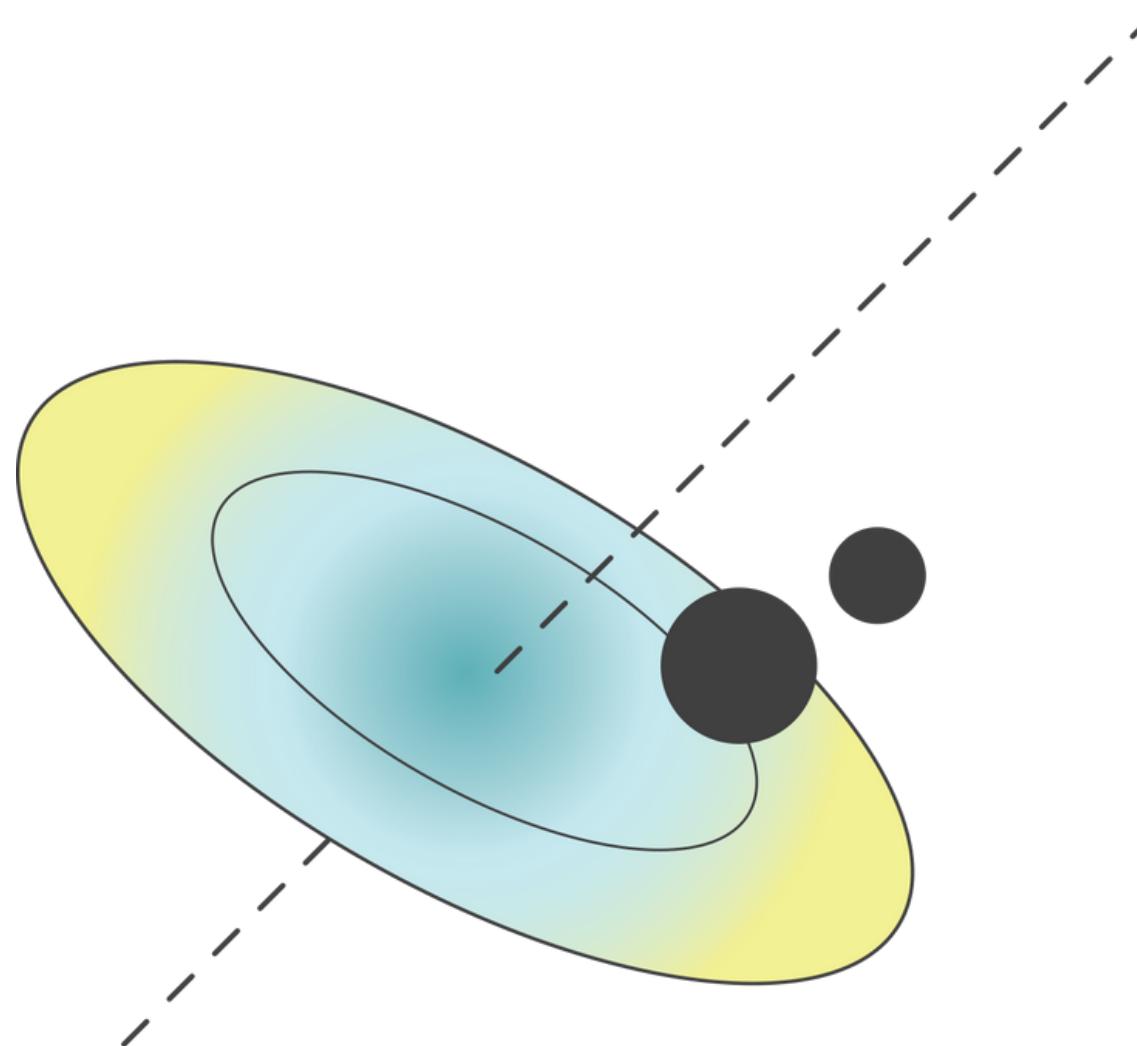


**sub-seasonal
drought forecasting**



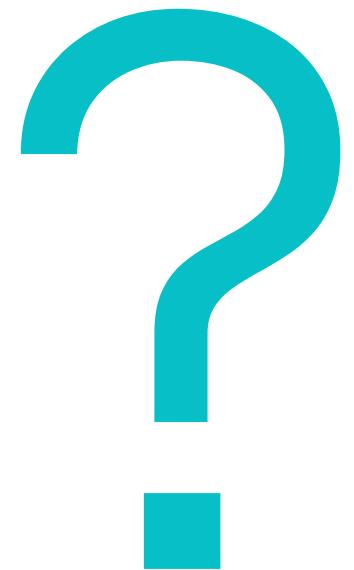
AI

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

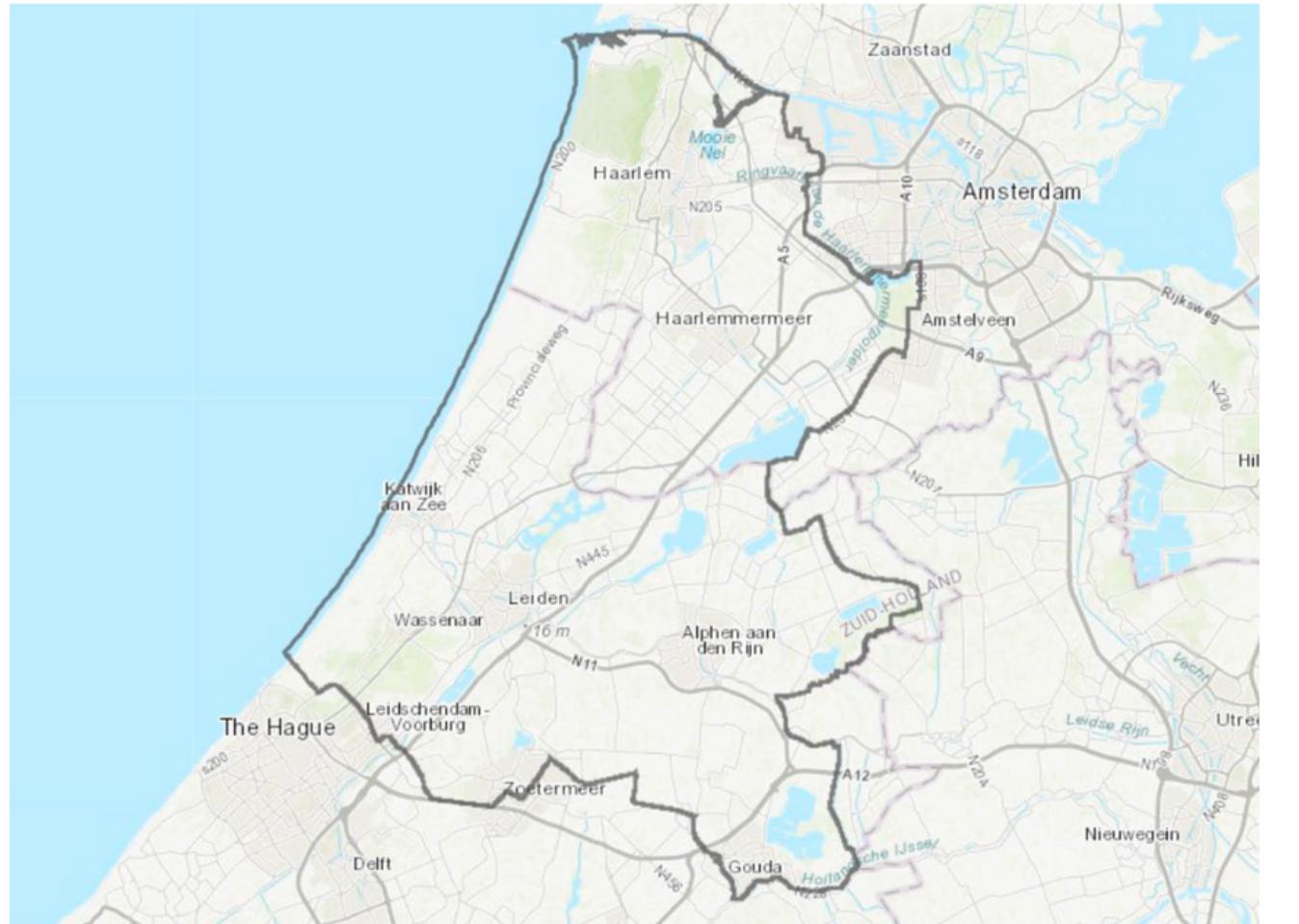
- 01 What (our goal)
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- 03 How (the framework)



Context

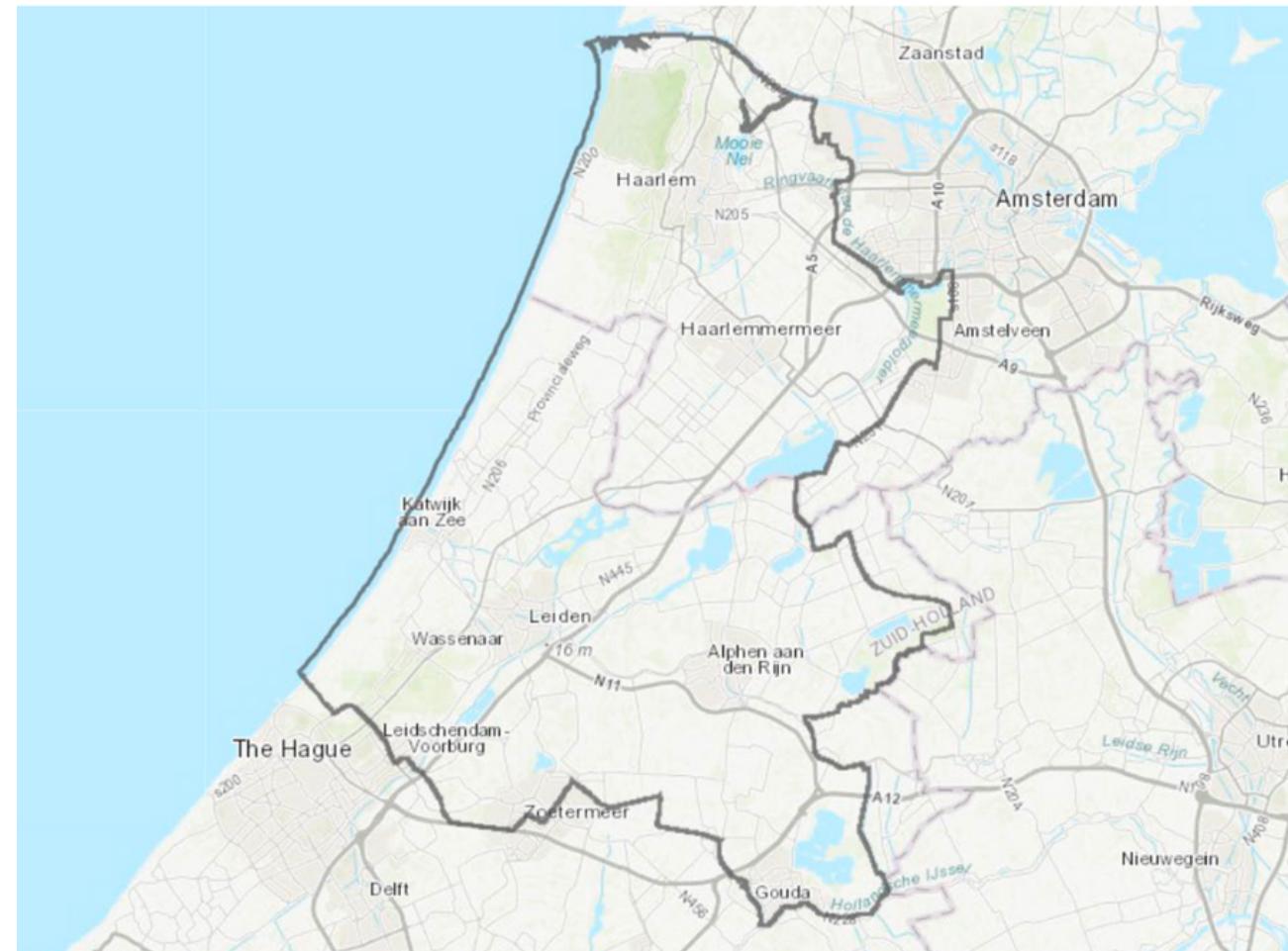
- 01 What (our goal)
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- 03 How (the framework)

Rijnland



Context

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

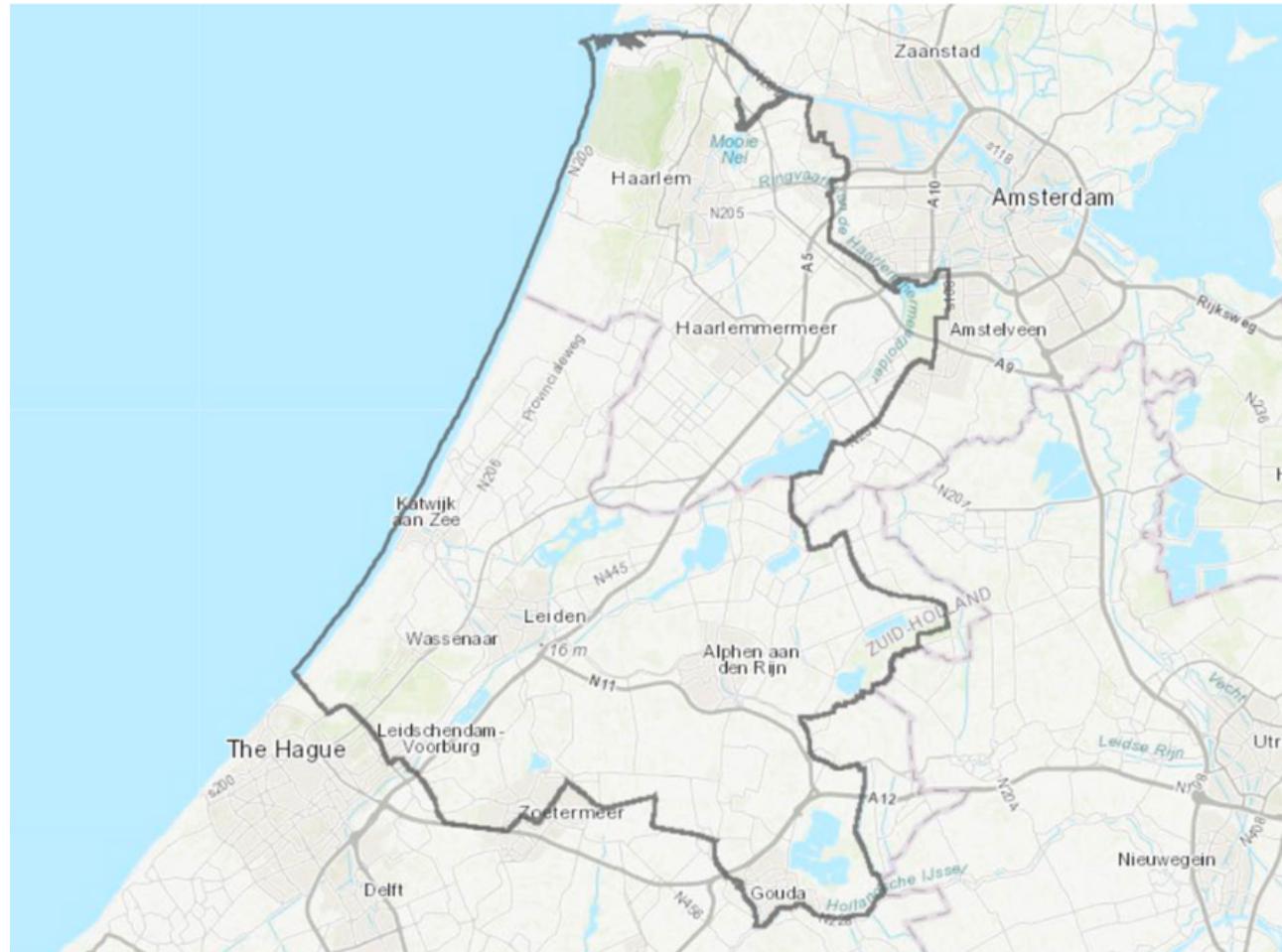


Rijnland

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)

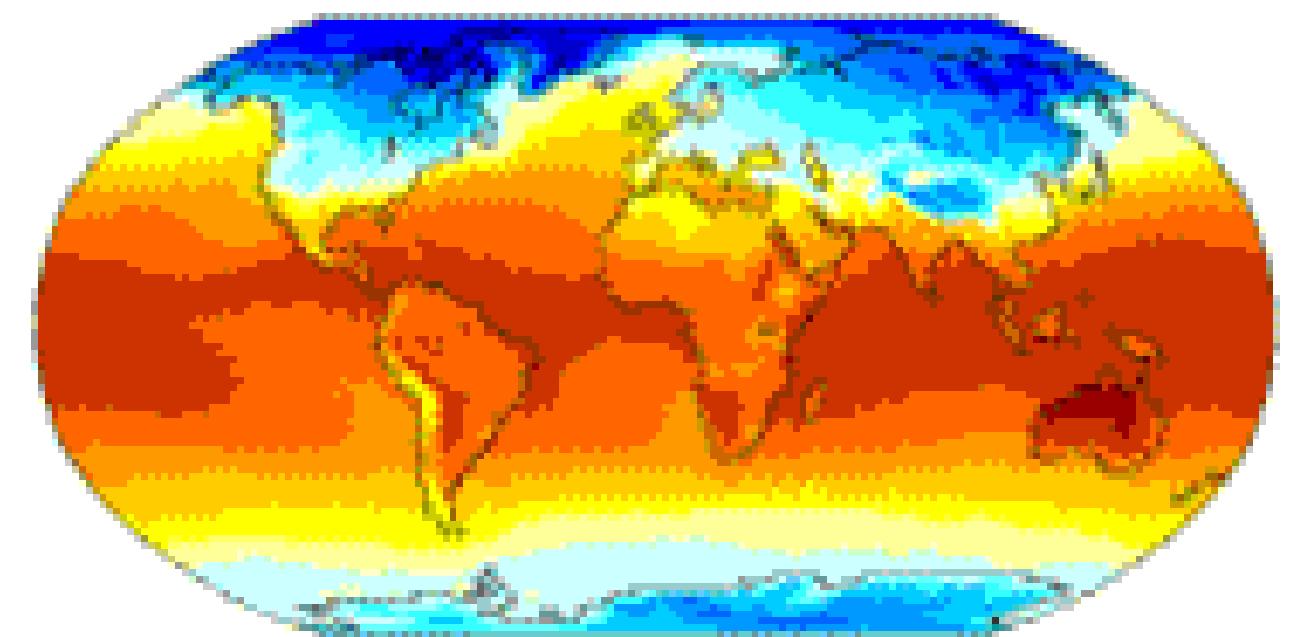


Rijnland

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

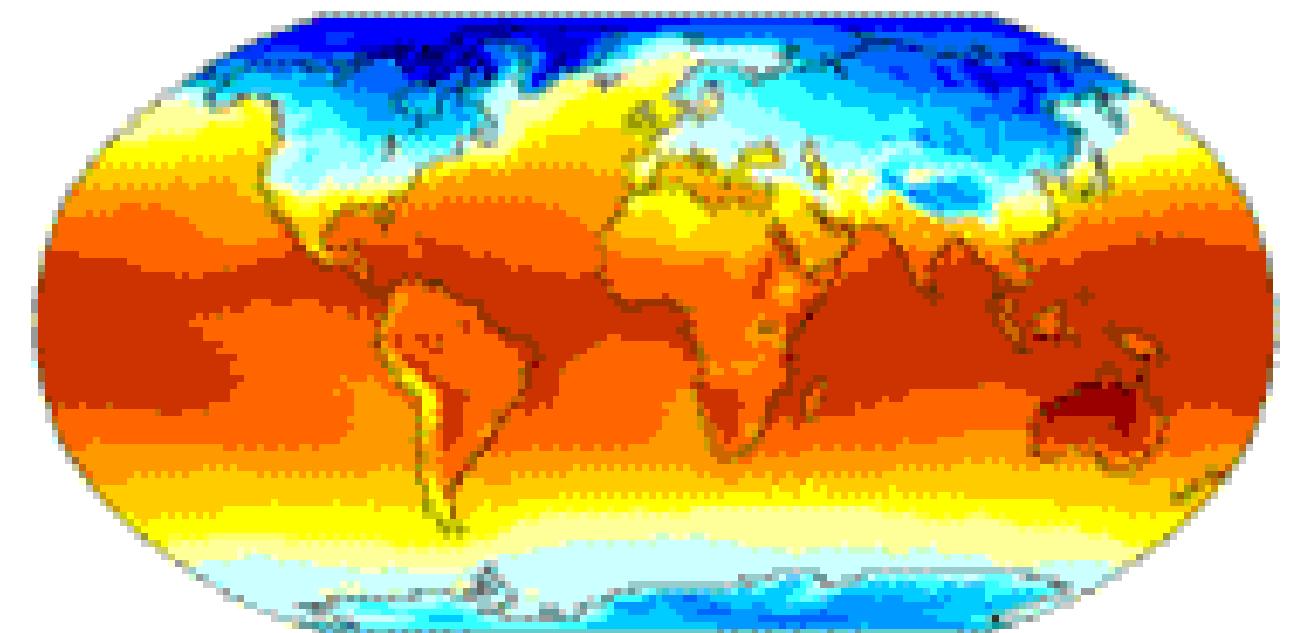
- Net precipitation deficit in the Rijnland area >150 mm
 - Discharge threshold where the Rhine enters the Netherlands < 1100 m³/s

Context



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

Context



Statistical framework (NIPA)
+
ML model (NN)

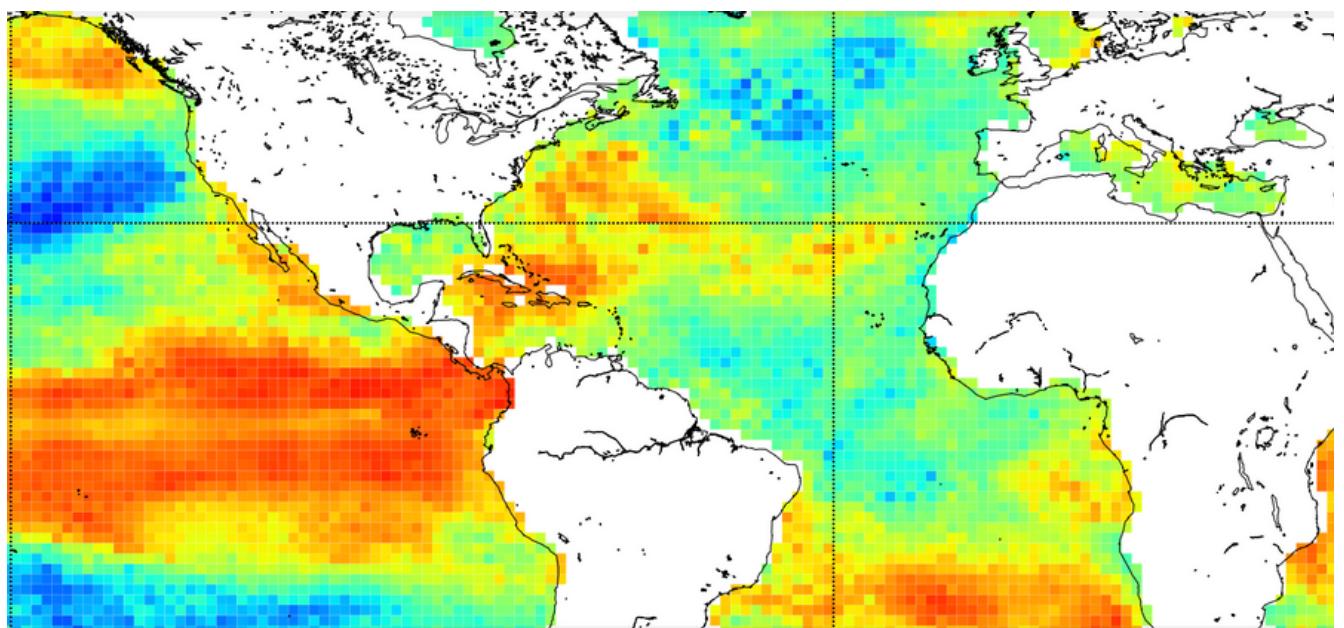
- 01 What (our goal)
- 02 Where (study area)
- 03 How (the framework)

Framework

- 01 NIPA
- 02 Neural Network



Framework



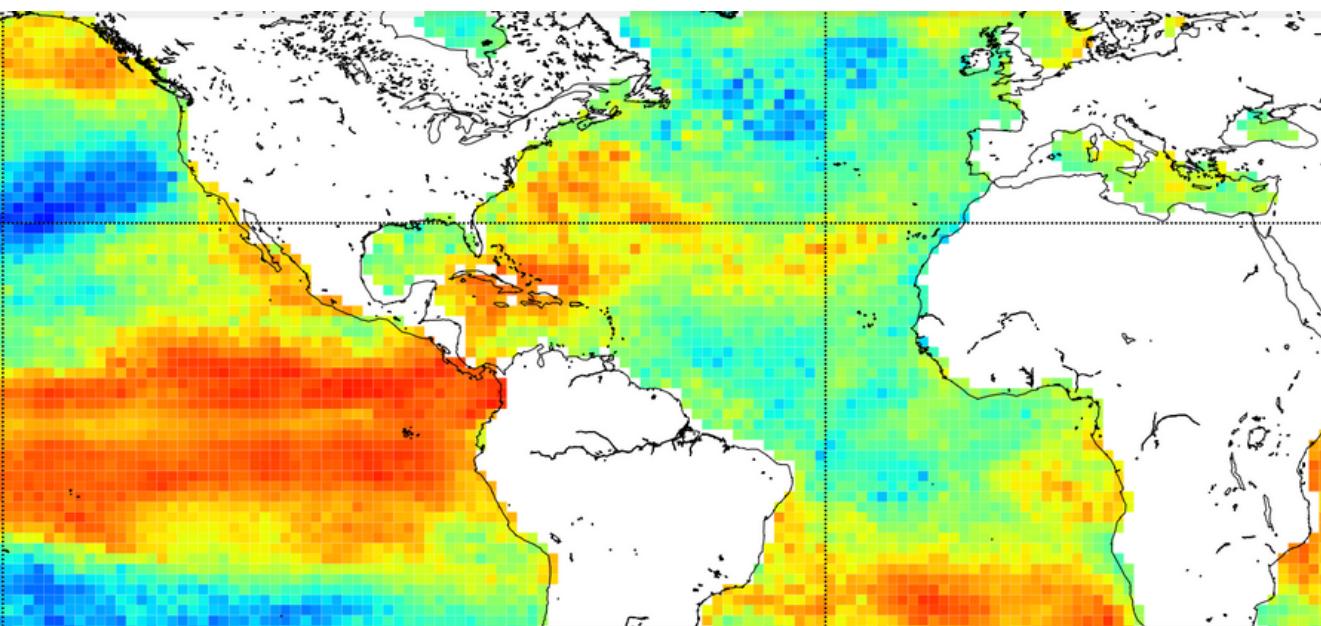
- 01 NIPA
- 02 Neural Network

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)

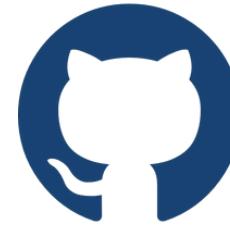


- 01 NIPA

- 02 Neural Network

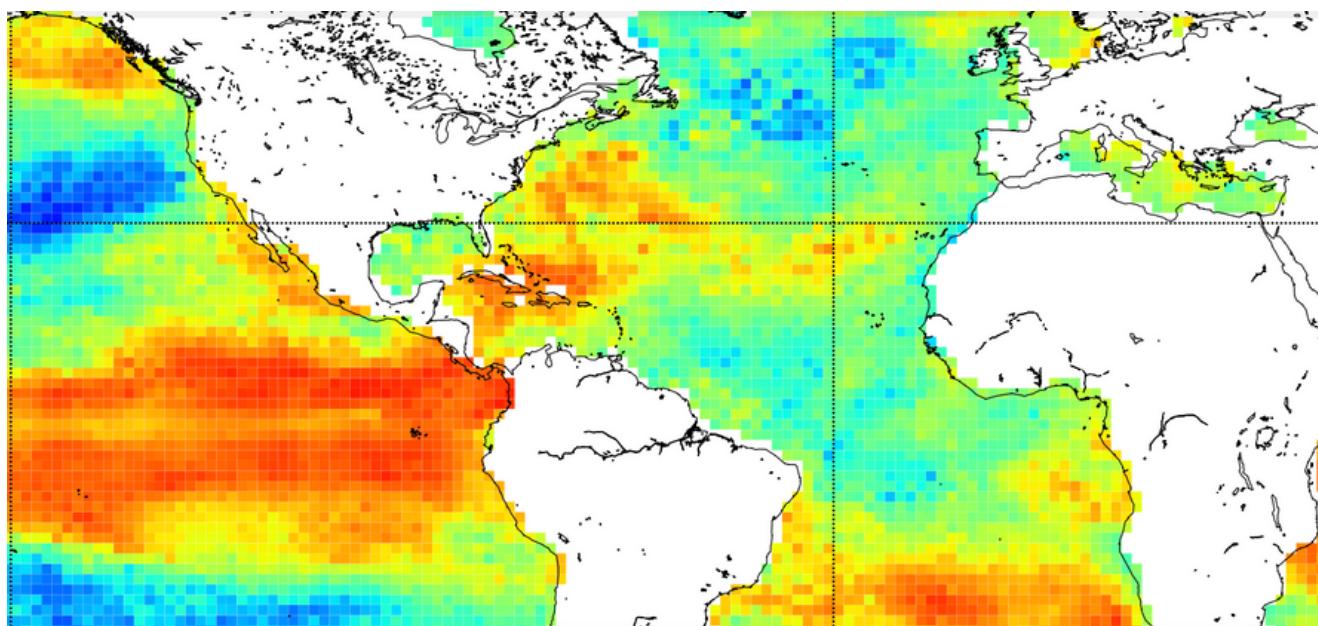
Nino Index Phase Analysis

Our readaptation



Framework

- 01 NIPA
- 02 Neural Network

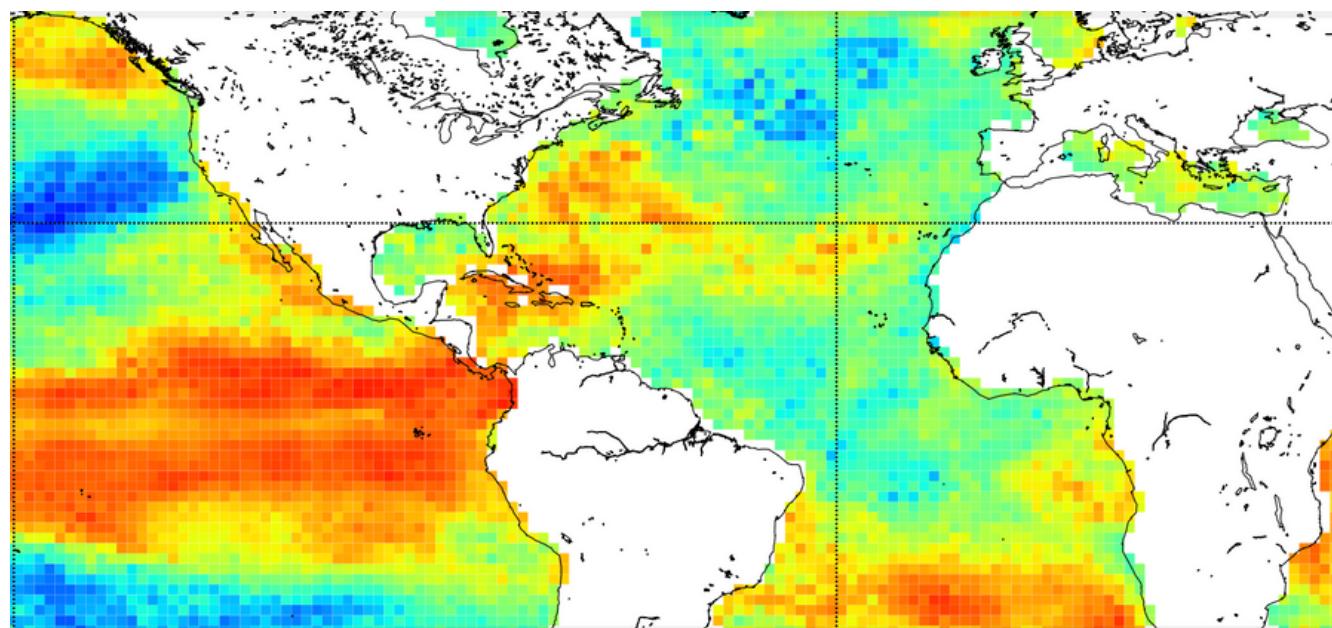


NIPA is a framework that searches for links between **Global** and **Local variables** exploiting the phases of teleconnection patterns materialized by **climate indices**

Framework

- 01 NIPA
- 02 Neural Network

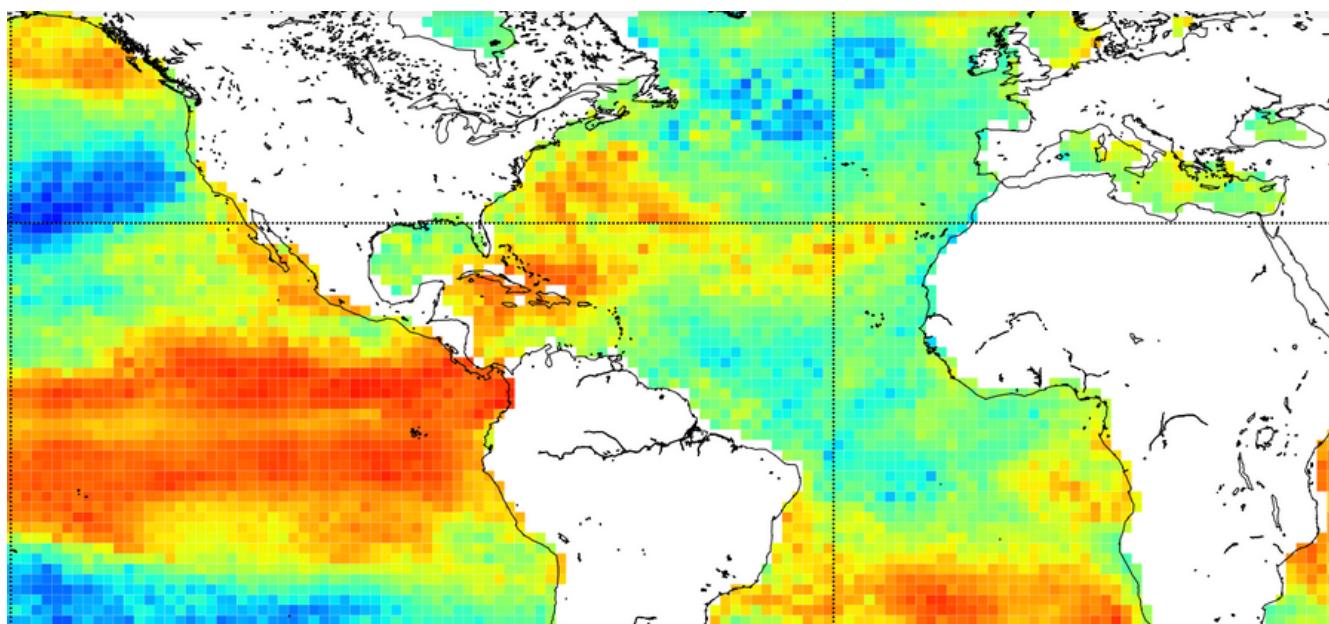
climate indices



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

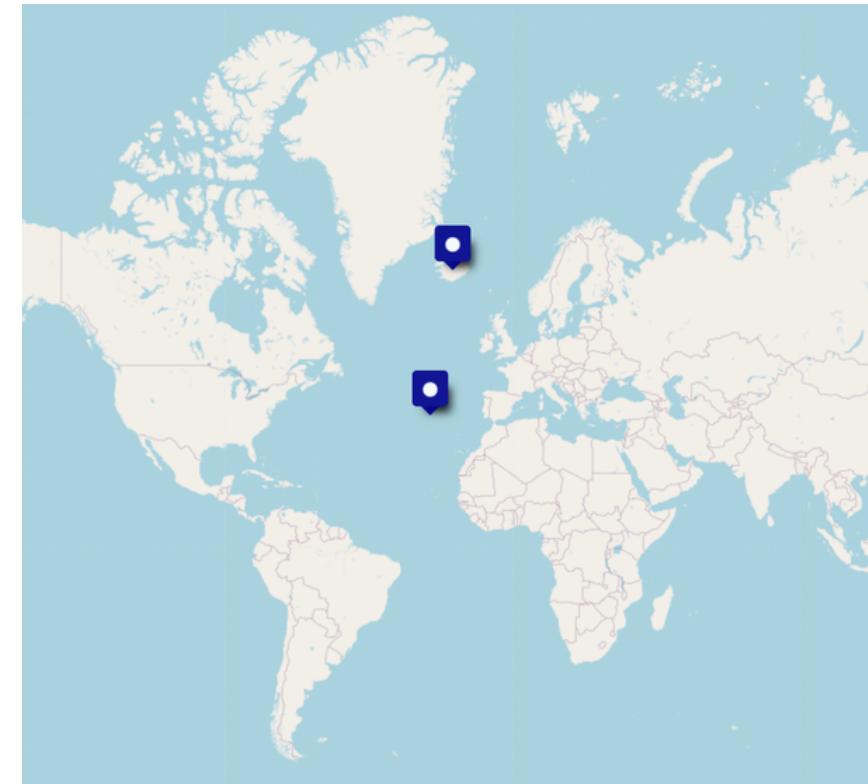
climate indices

North Atlantic Oscillation (NAO)

Framework

- 01 NIPA
- 02 Neural Network

climate indices
North Atlantic Oscillation (NAO)



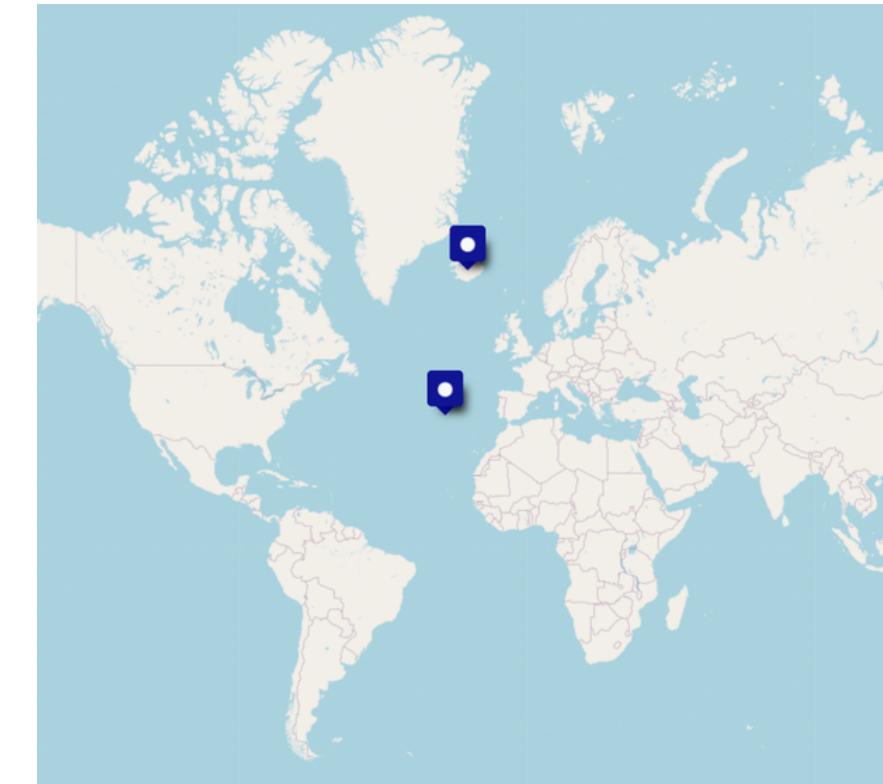
Framework

- 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
- **above/below-normal precipitation** over northern Europe and Scandinavia
- **above/below-normal precipitation** over southern and central Europe

climate indices

North Atlantic Oscillation (NAO)



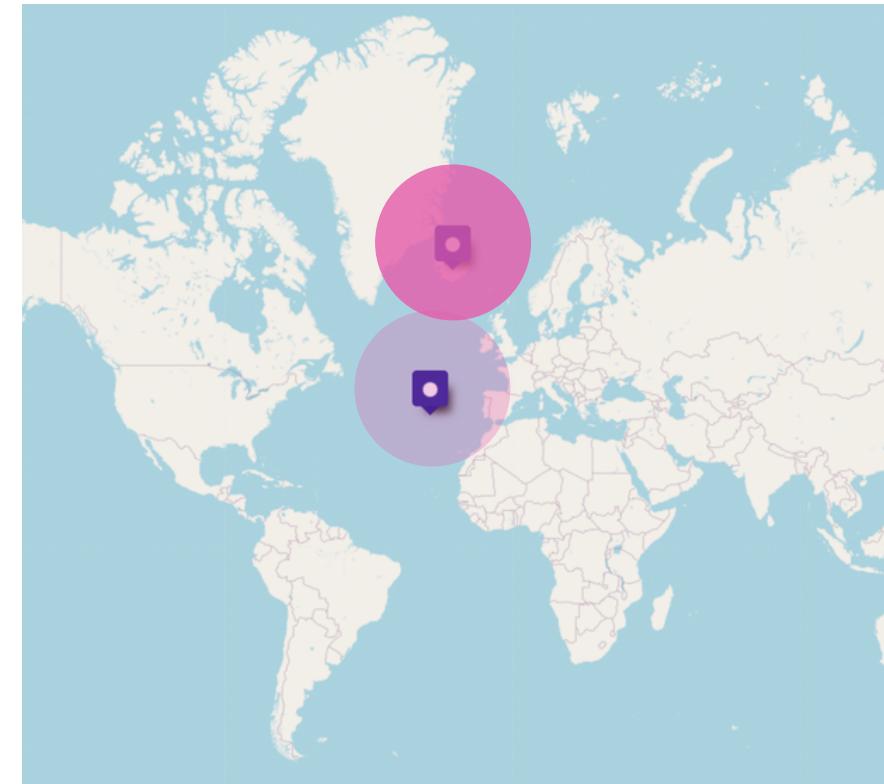
Framework

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

- 01 NIPA
- 02 Neural Network

climate indices

North Atlantic Oscillation (NAO)



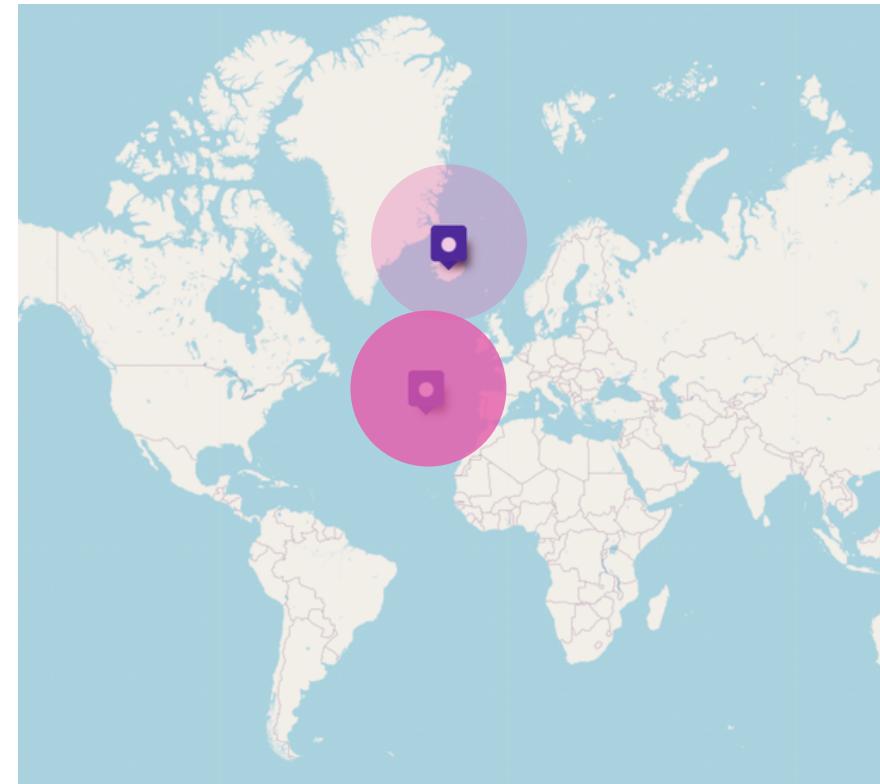
Framework

- 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)



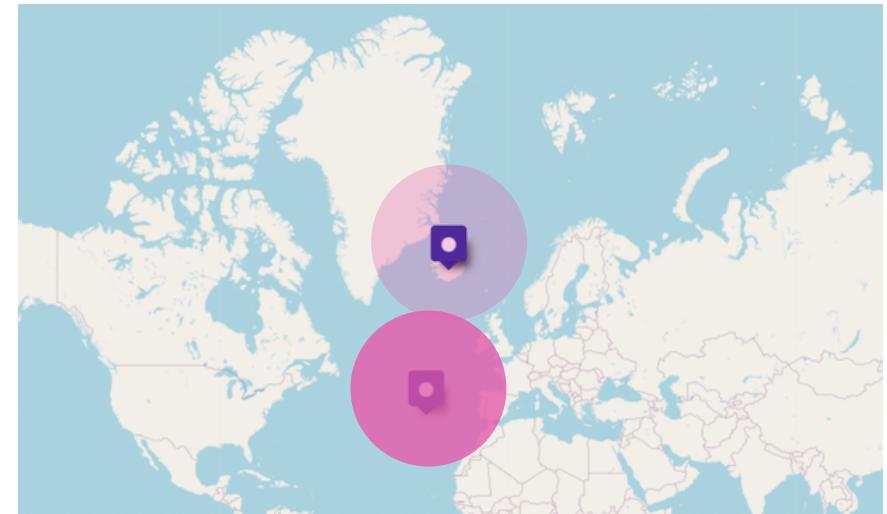
Framework

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

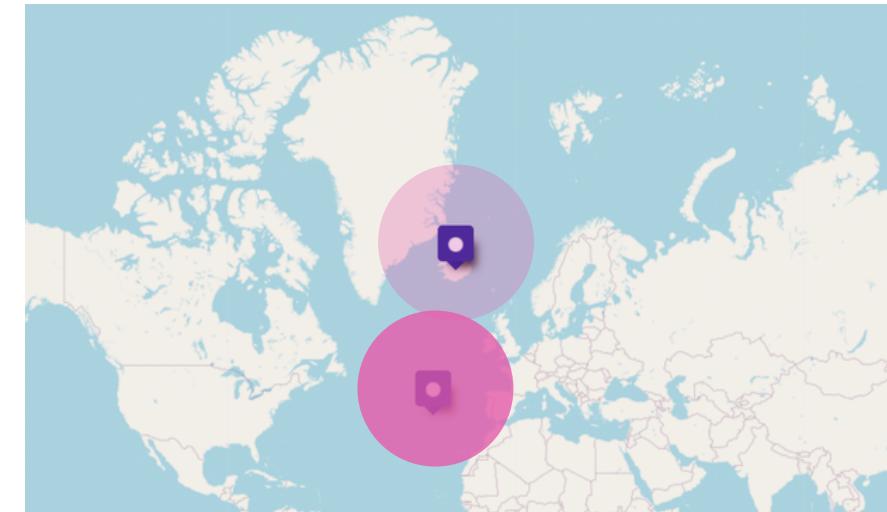
Framework

- 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** local precipitation of **January** and the global variable of **December**
- Month **1** local precipitation of **January** and the global variable of **November + December**

Input

Data extraction

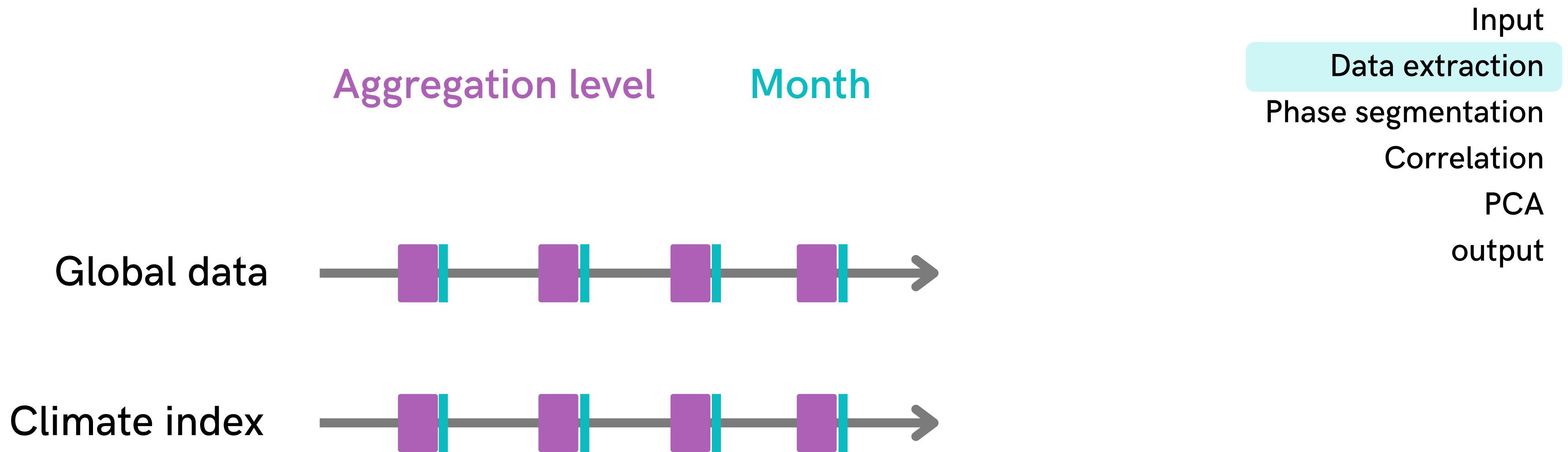
Phase segmentation

Correlation

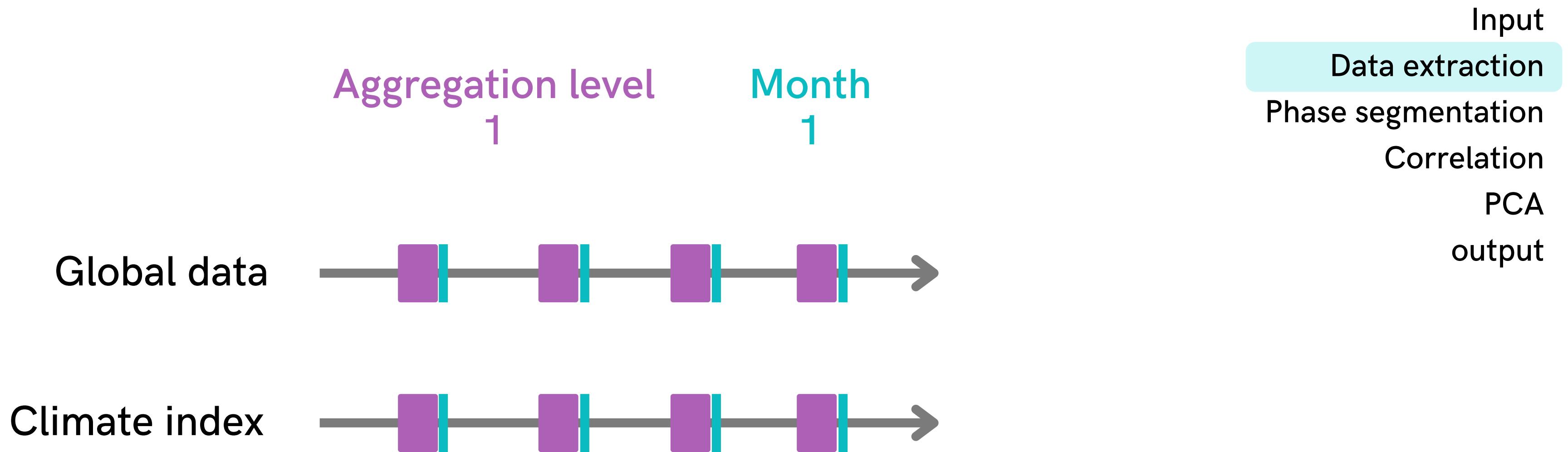
PCA

output

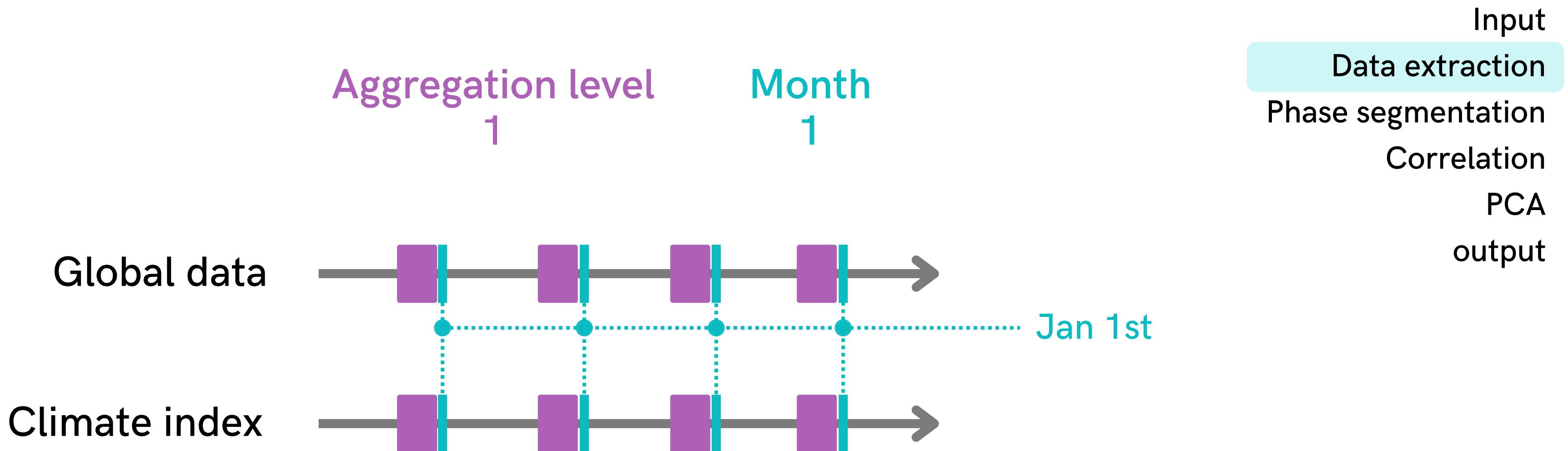
Framework



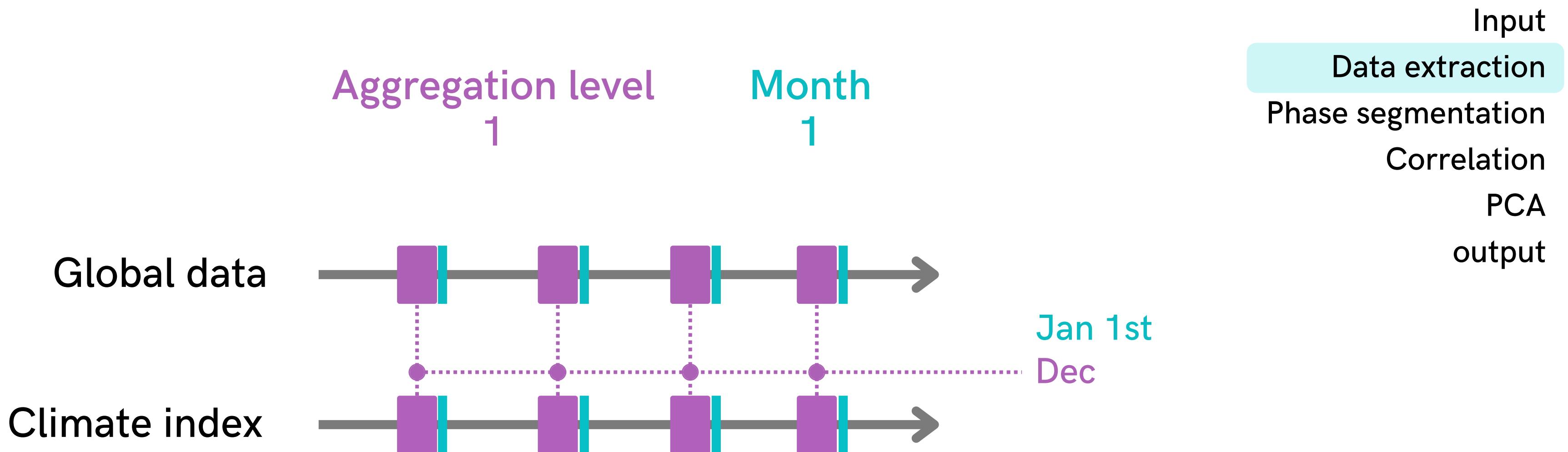
Framework



Framework



Framework

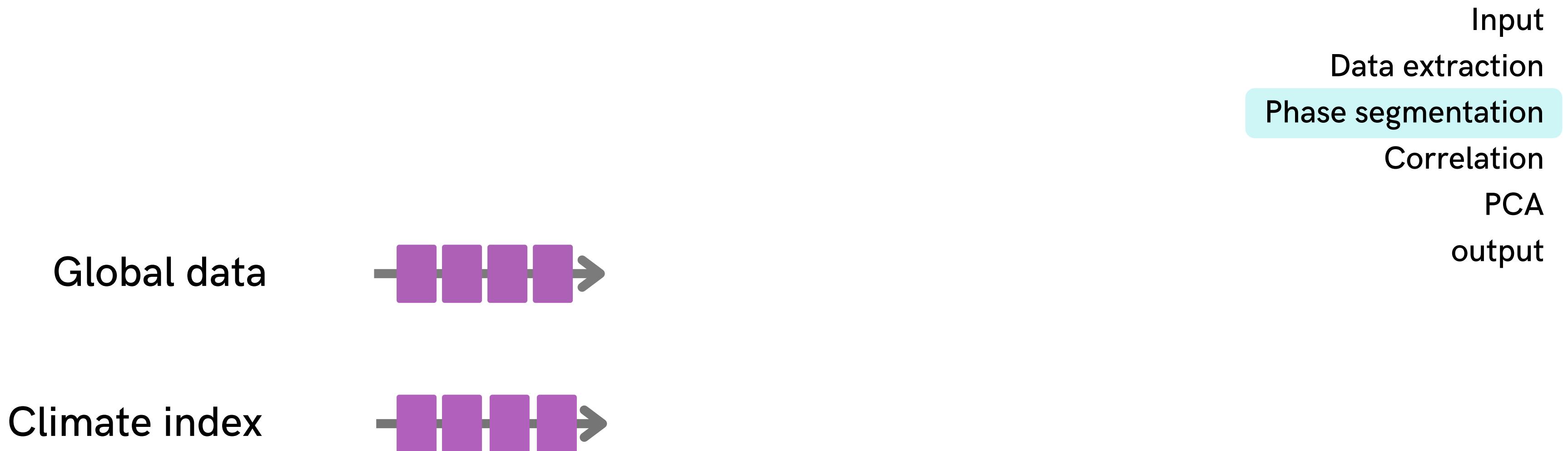


NOTE: this is an year-based operation. NIPA will extract the data for the December of each year

Framework

- 01 NIPA

- 02 Neural Network



Framework



- 01 NIPA

- 02 Neural Network

Framework

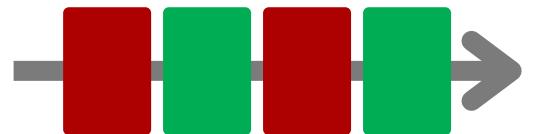


- 01 NIPA

- 02 Neural Network

Framework

Global data



- 01 NIPA
 - 02 Neural Network
-

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

Global data Pos 

Global data Neg 

Input

Data extraction

Phase segmentation

Correlation

PCA

output

Framework

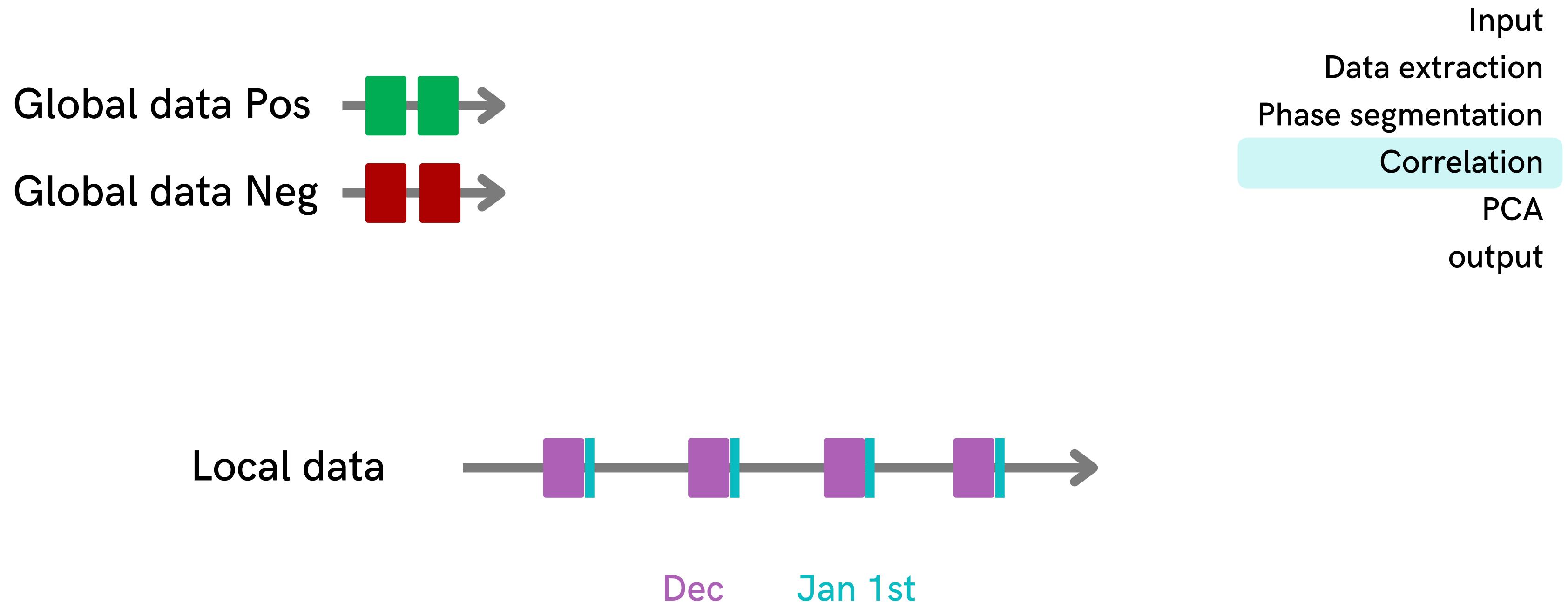
Global data Pos 
Global data Neg 

- 01 NIPA
- 02 Neural Network

Input
Data extraction
Phase segmentation
Correlation
PCA
output

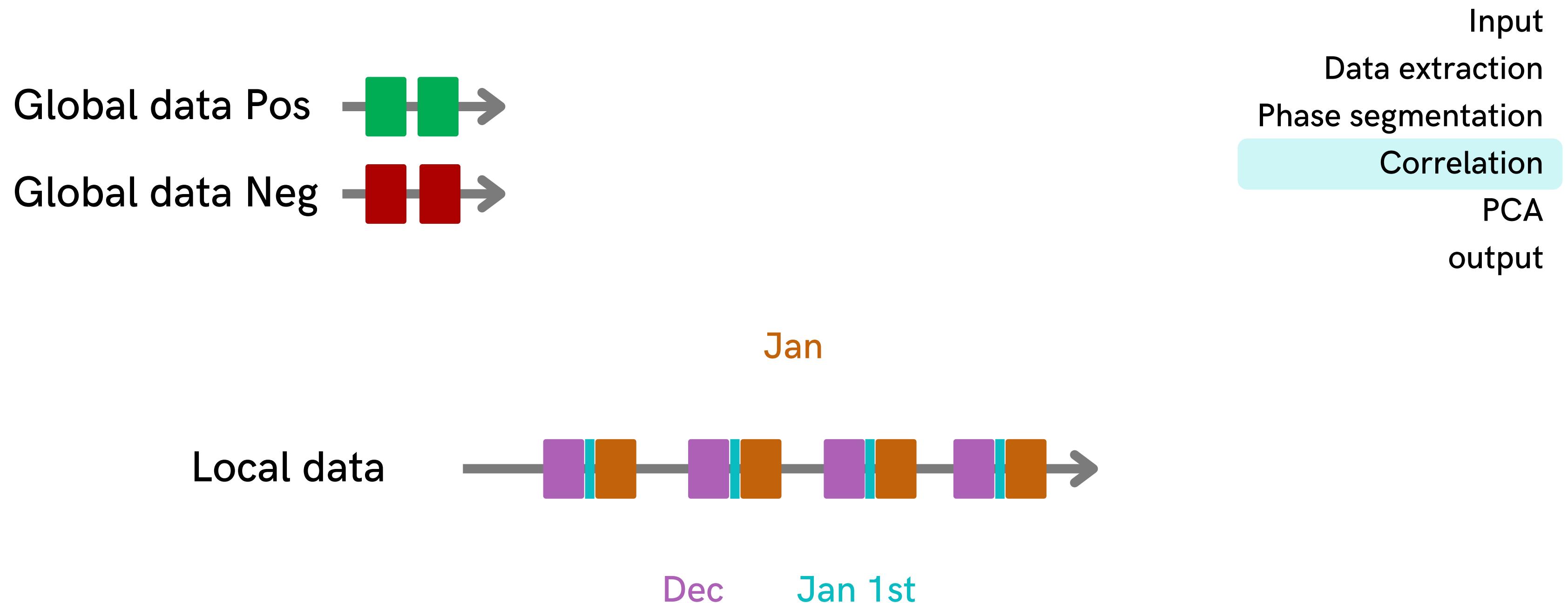
Framework

- 01 NIPA
 - 02 Neural Network
-



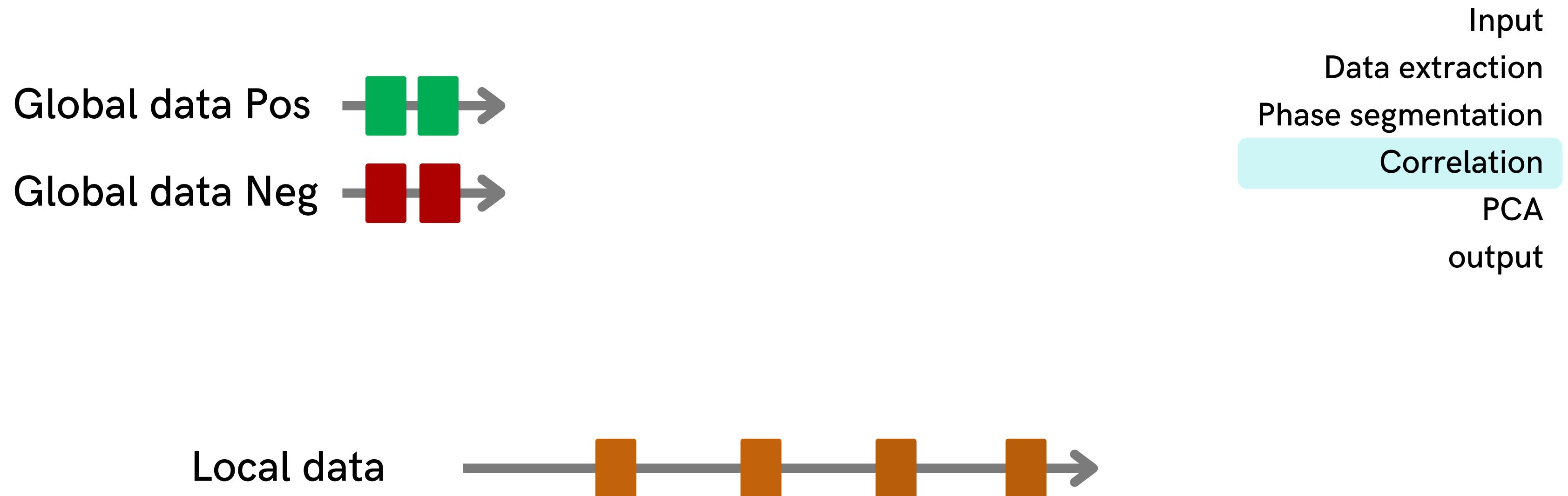
Framework

- 01 NIPA
 - 02 Neural Network
-

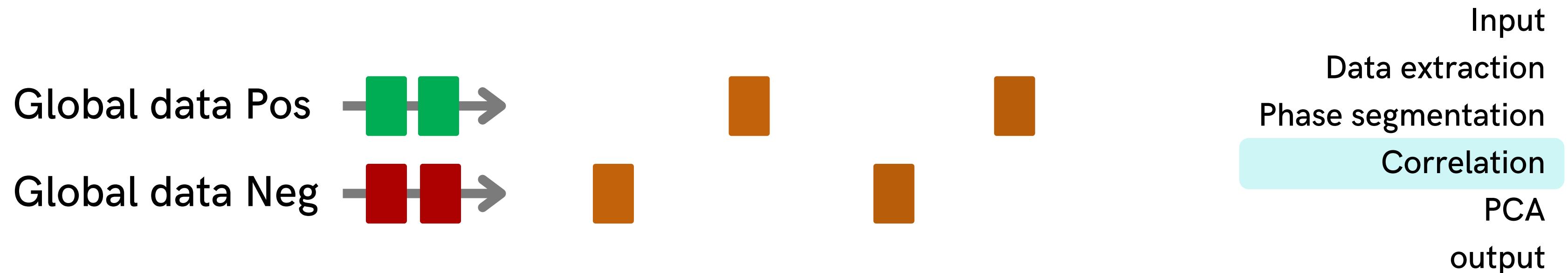


Framework

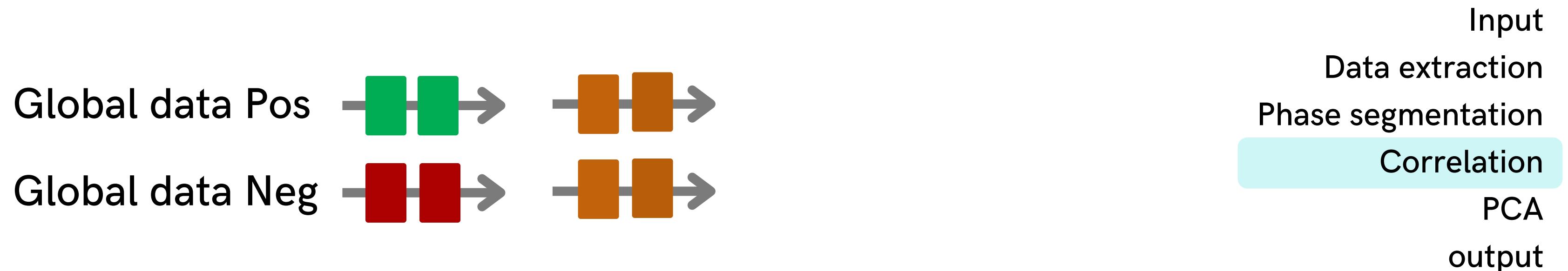
- 01 NIPA
 - 02 Neural Network
-



Framework



Framework



Framework

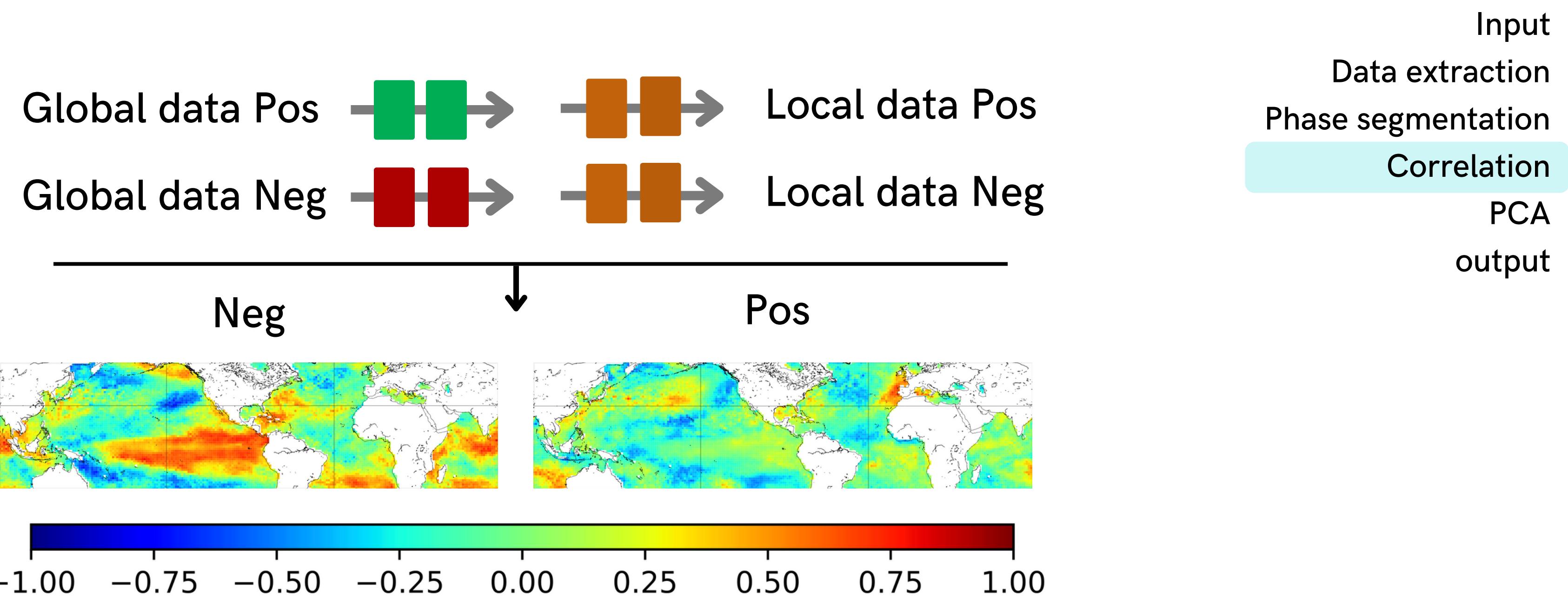


- 01 NIPA

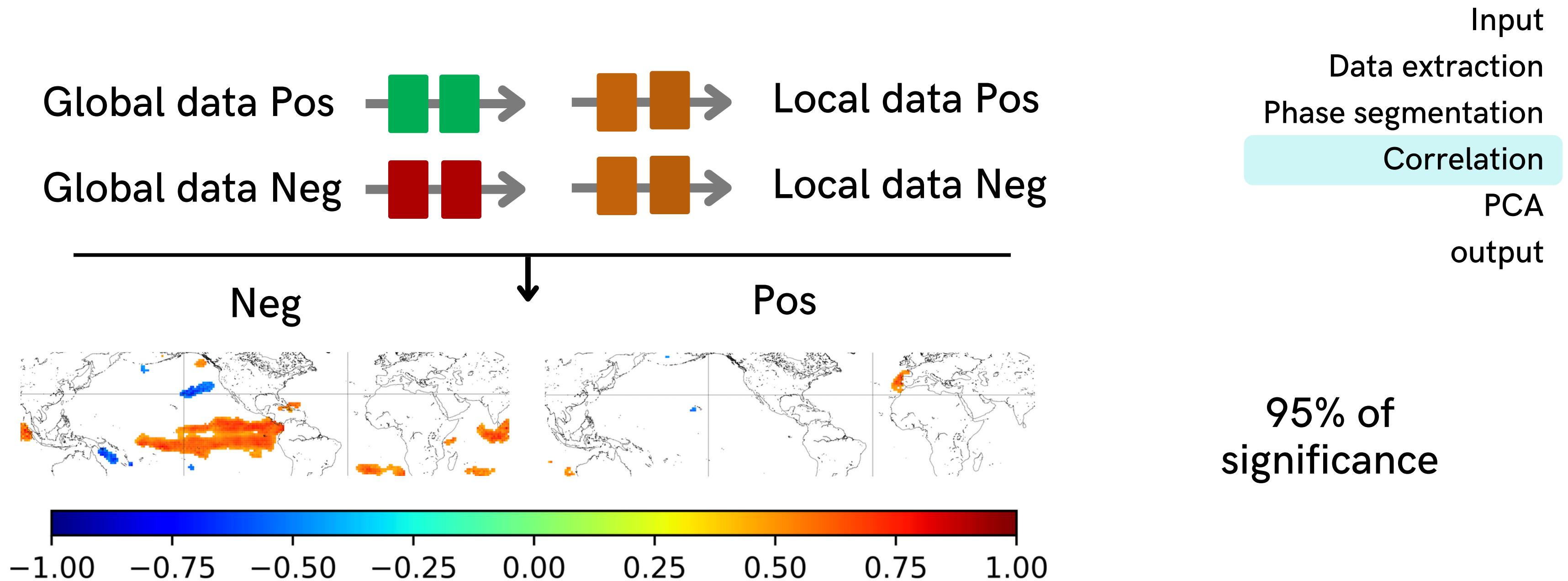
- 02 Neural Network

Framework

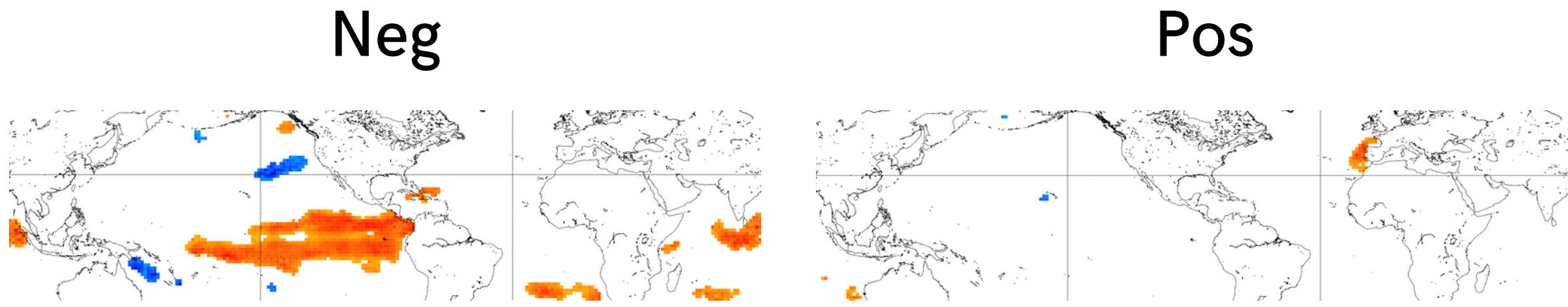
- 01 NIPA
- 02 Neural Network



Framework



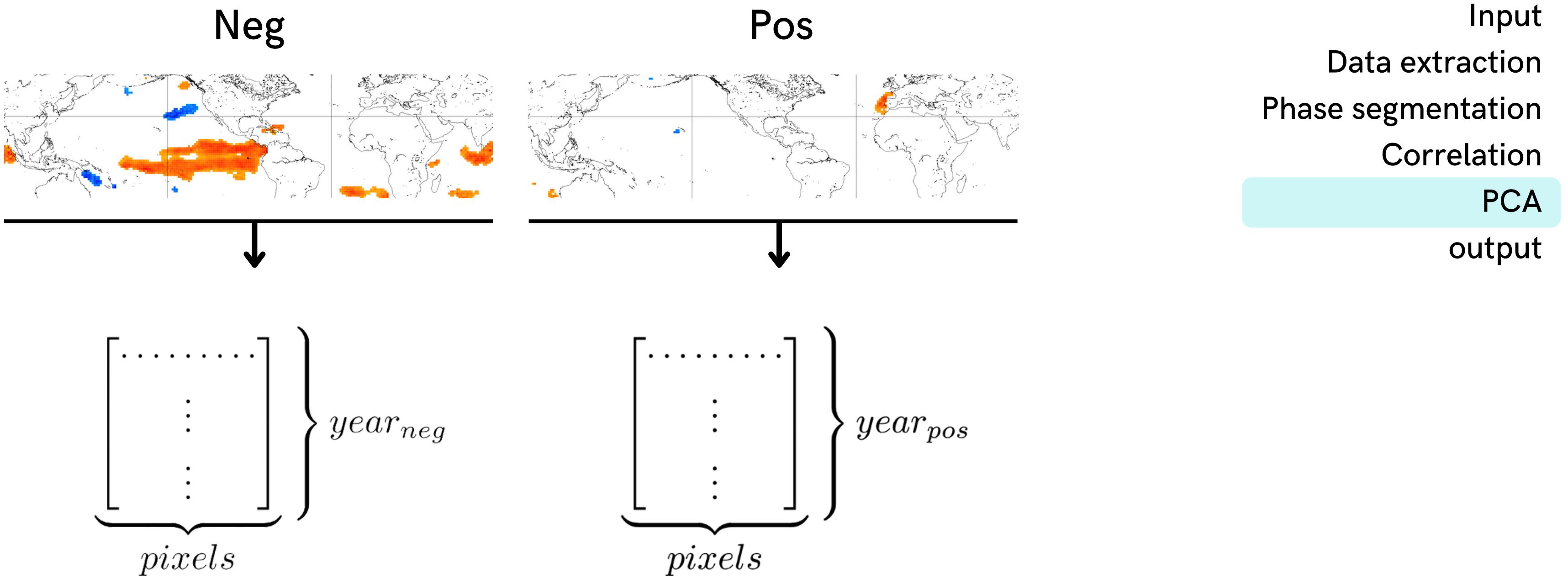
Framework



- 01 NIPA
- 02 Neural Network

Input
Data extraction
Phase segmentation
Correlation
PCA
output

Framework

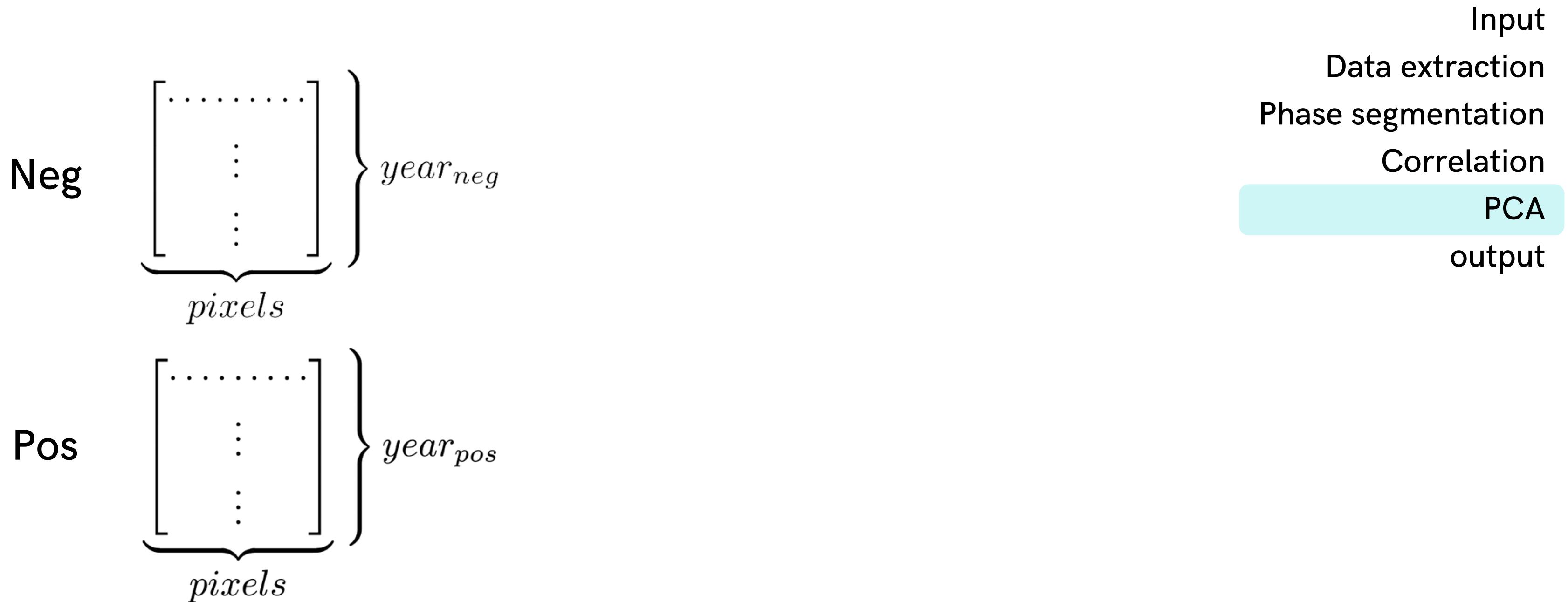


- 01 NIPA
- 02 Neural Network

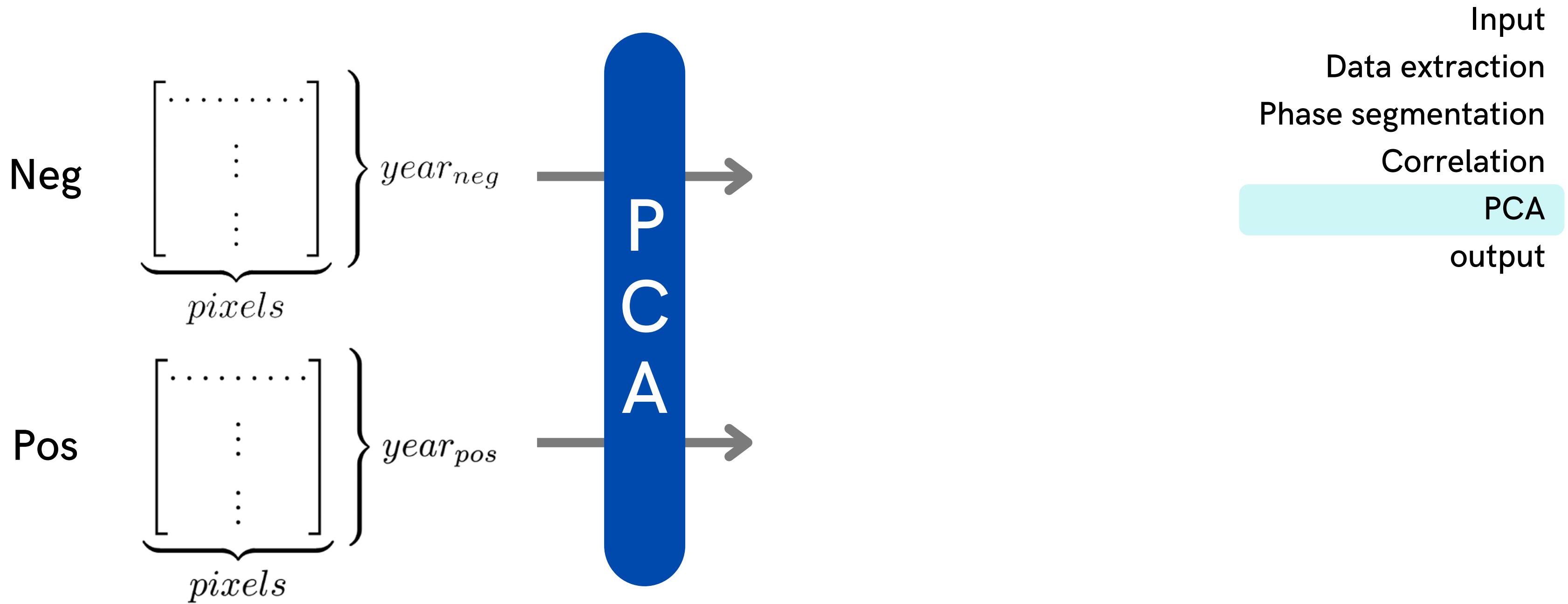
Framework

- 01 NIPA

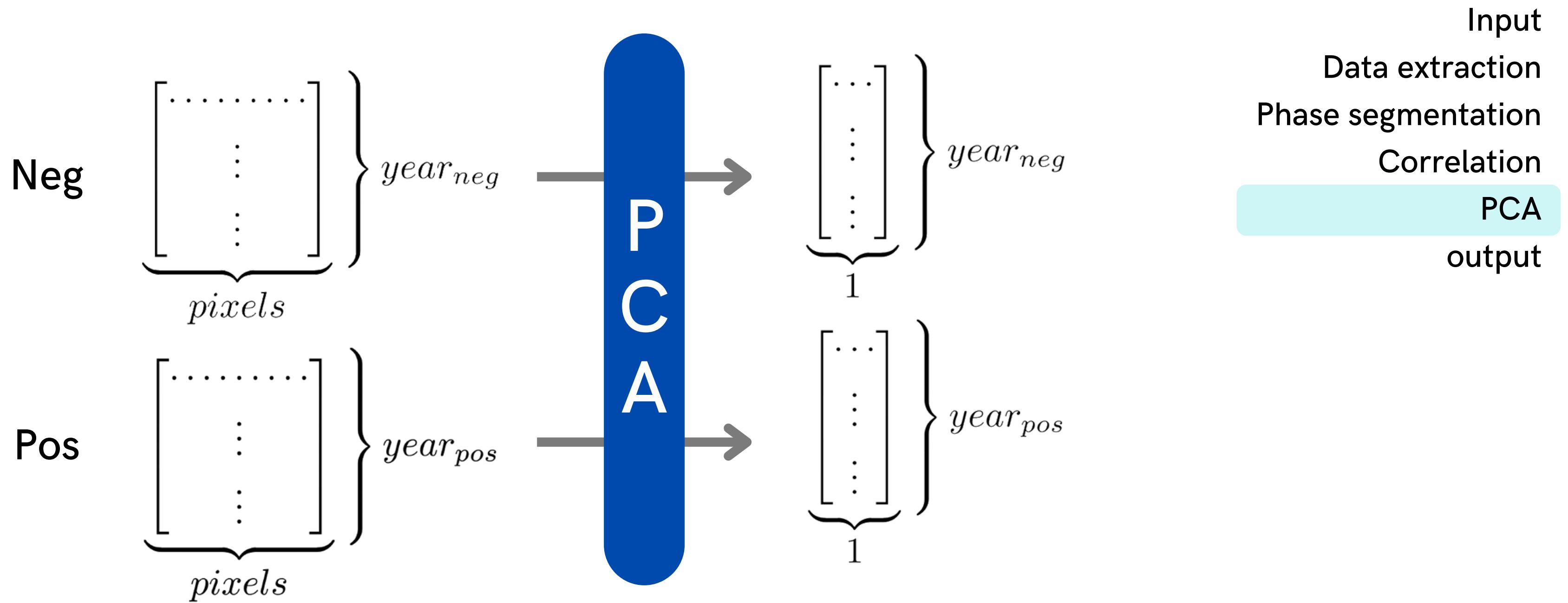
- 02 Neural Network



Framework



Framework



Framework

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

Input
Data extraction
Phase segmentation
Correlation
PCA
output

- 01 NIPA
 - 02 Neural Network
-

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

● 02 Neural Network

Input

Data extraction

Phase segmentation

Correlation

PCA

output

Framework

- 01 NIPA
 - 02 Neural Network
-

Framework

- 01 NIPA
 - 02 Neural Network
-

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

Framework

- 01 NIPA
 - 02 Neural Network
-

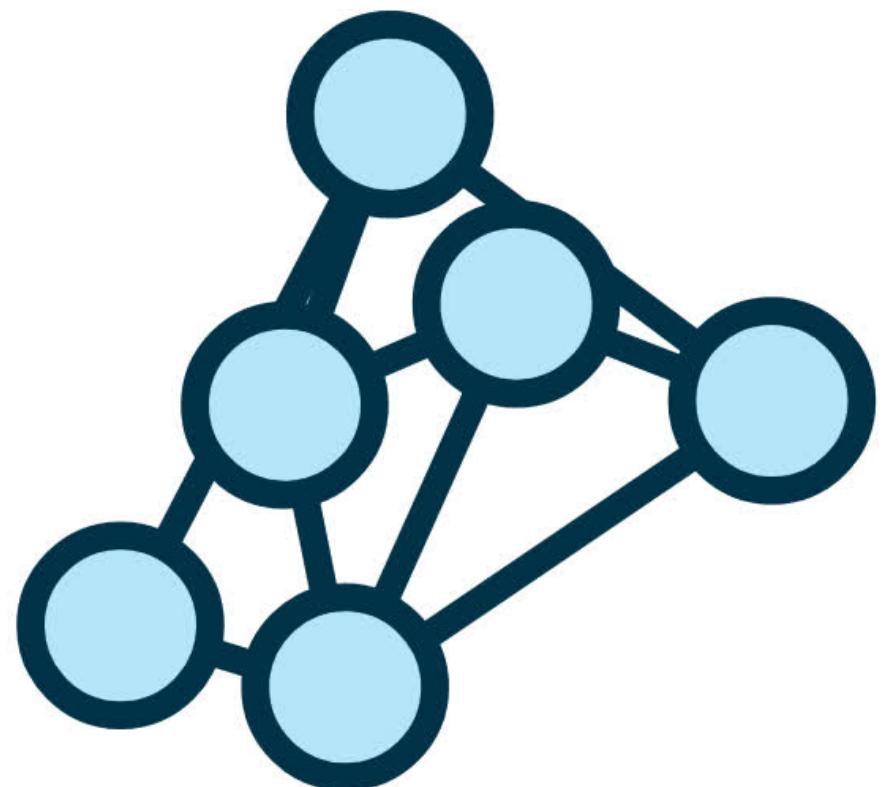
Disclaimer

Link with NIPA

Our ideas

Model creation

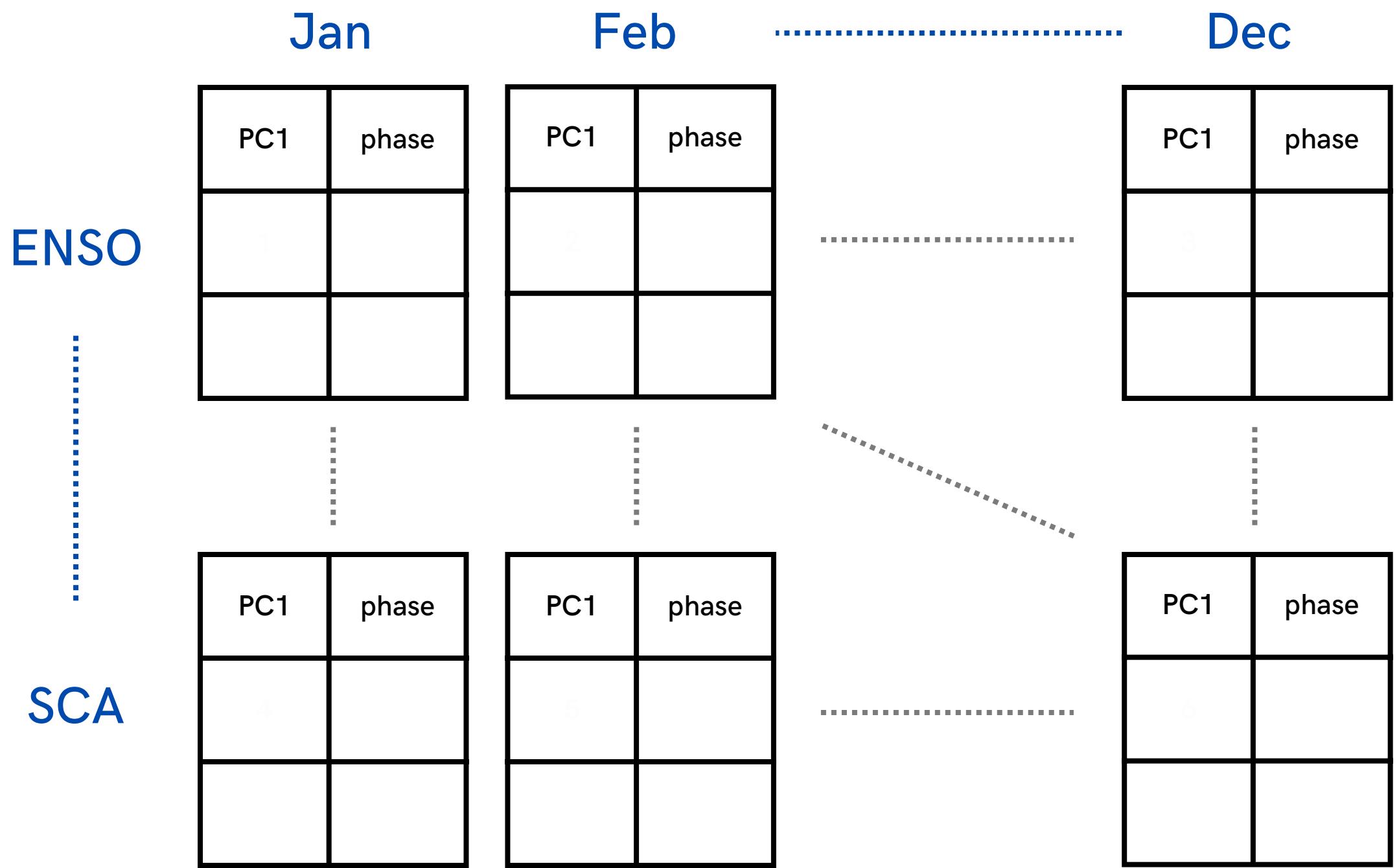
A raw result



Just entered in this step

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

Framework



- 01 NIPA
- 02 Neural Network

Disclaimer

Link with NIPA

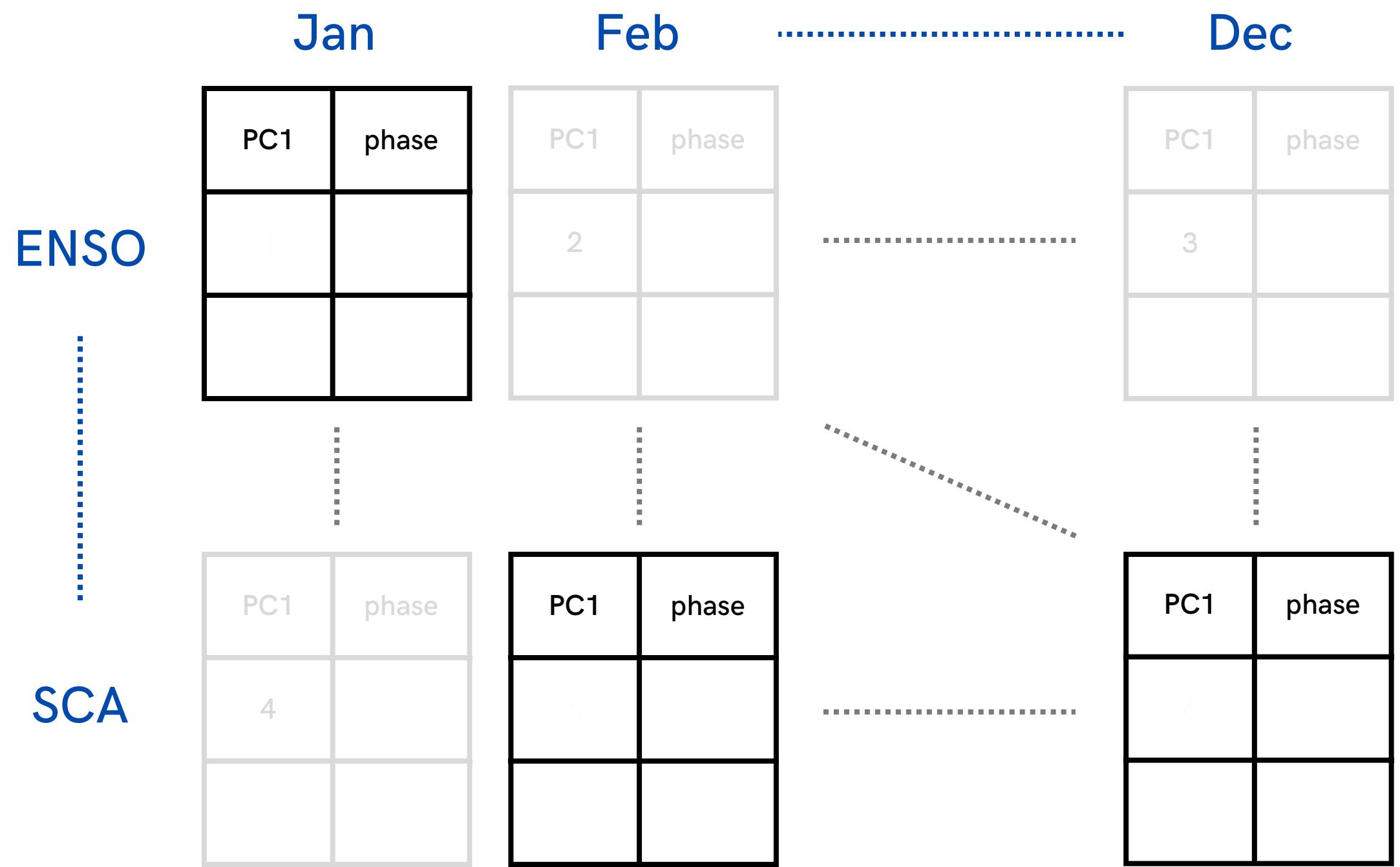
Our ideas

Model creation

A raw result

- 01 NIPA
 - 02 Neural Network
-

Framework



Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

Framework

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

- 01 NIPA
 - 02 Neural Network
-

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

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**

- 01 NIPA
- 02 Neural Network

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

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**

- 01 NIPA
- 02 Neural Network

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

Framework

- 01 NIPA
 - 02 Neural Network
-

- 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

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

Framework

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

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

- 01 NIPA
 - 02 Neural Network
-

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

Framework

- 01 NIPA
 - 02 Neural Network
-

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

climate state

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

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

Framework

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

climate state

- 01 NIPA
 - 02 Neural Network
-

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

Framework

- 01 NIPA
 - 02 Neural Network
-

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

climate state

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

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

Framework

- Input features:
 - SCA-MSLP-1-1,
 - EA-SST-1-1,
 - climate state
- Target: Cumulative precipitation
- Hidden layers: 1
- Nodes: 10
- Activation function: ReLU
- Loss function: MSE

- 01 NIPA
- 02 Neural Network

Disclaimer

Link with NIPA

Our ideas

Model creation

A raw result

Framework

- 01 NIPA
 - 02 Neural Network
-

Disclaimer

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Our ideas

Model creation

A raw result

MSE of 319.049 on the validation set

comparable to giuliani et al with ELM (374.9050)

Framework

- 01 NIPA
 - 02 Neural Network
-



Disclaimer

Link with NIPA

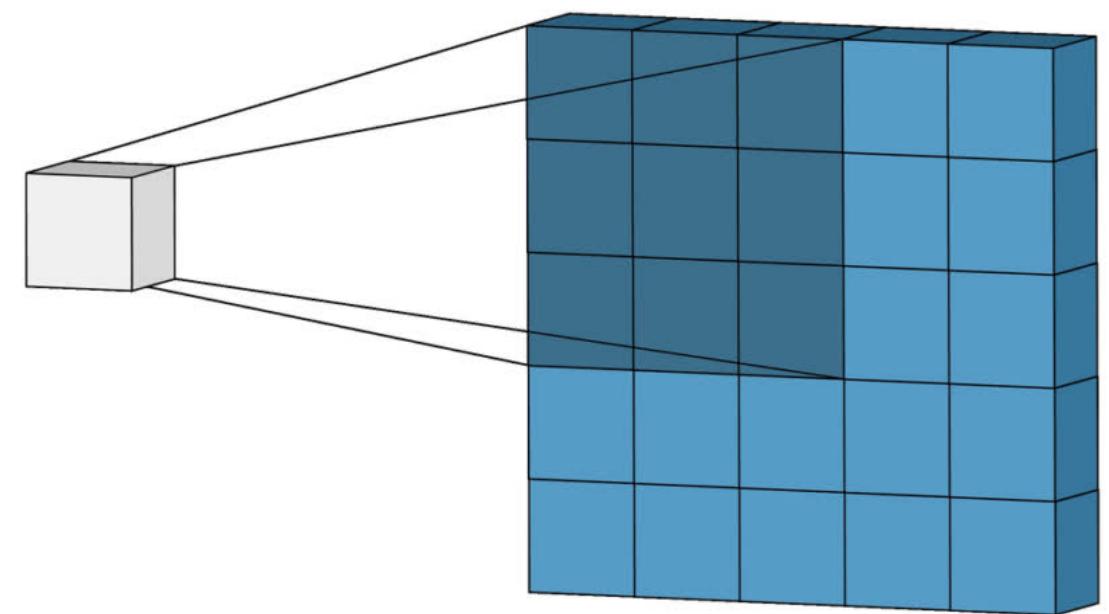
Our ideas

Model creation

A raw result

Run
Pen

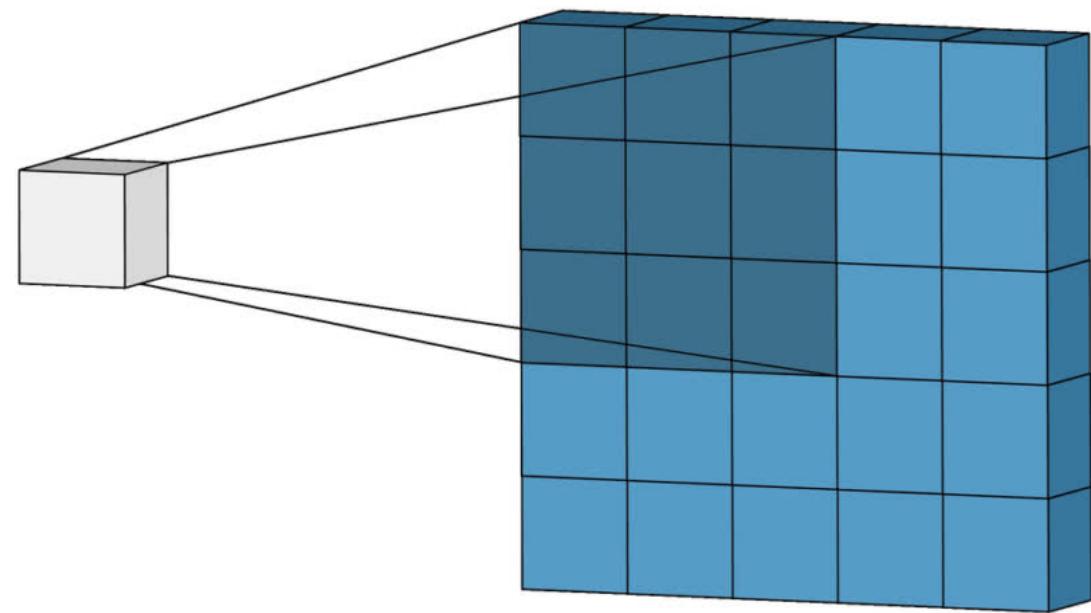
Future ideas



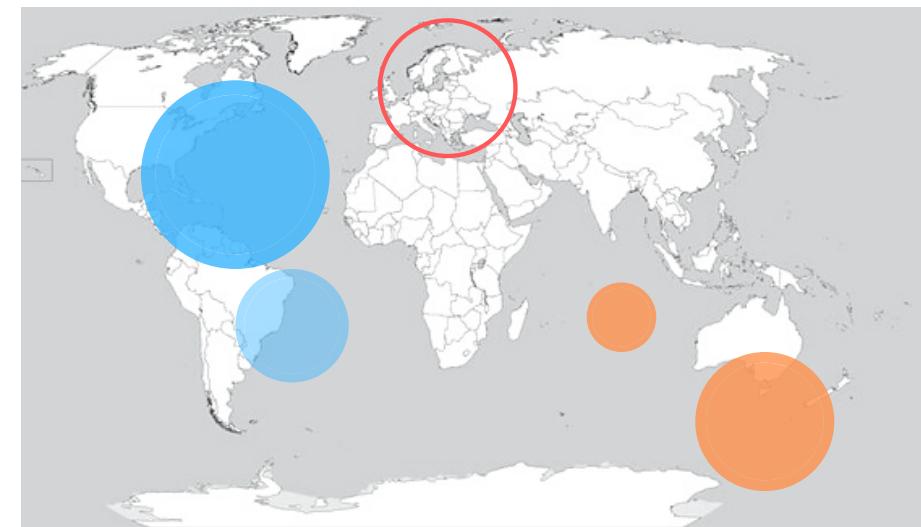
NN
↔
CNN

PC1
↔
**Correlation
Map**

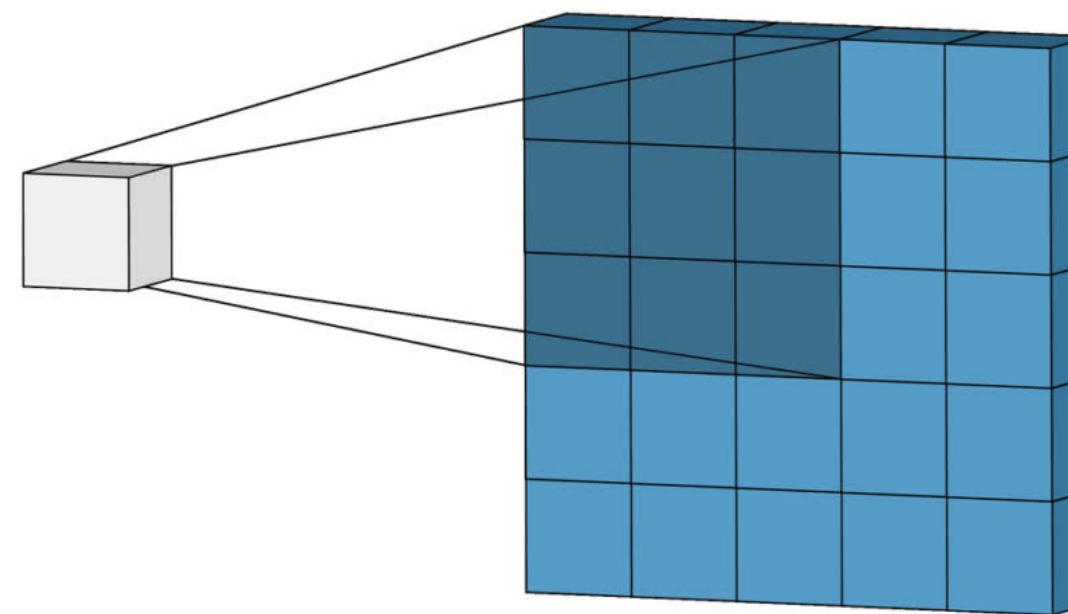
Future ideas



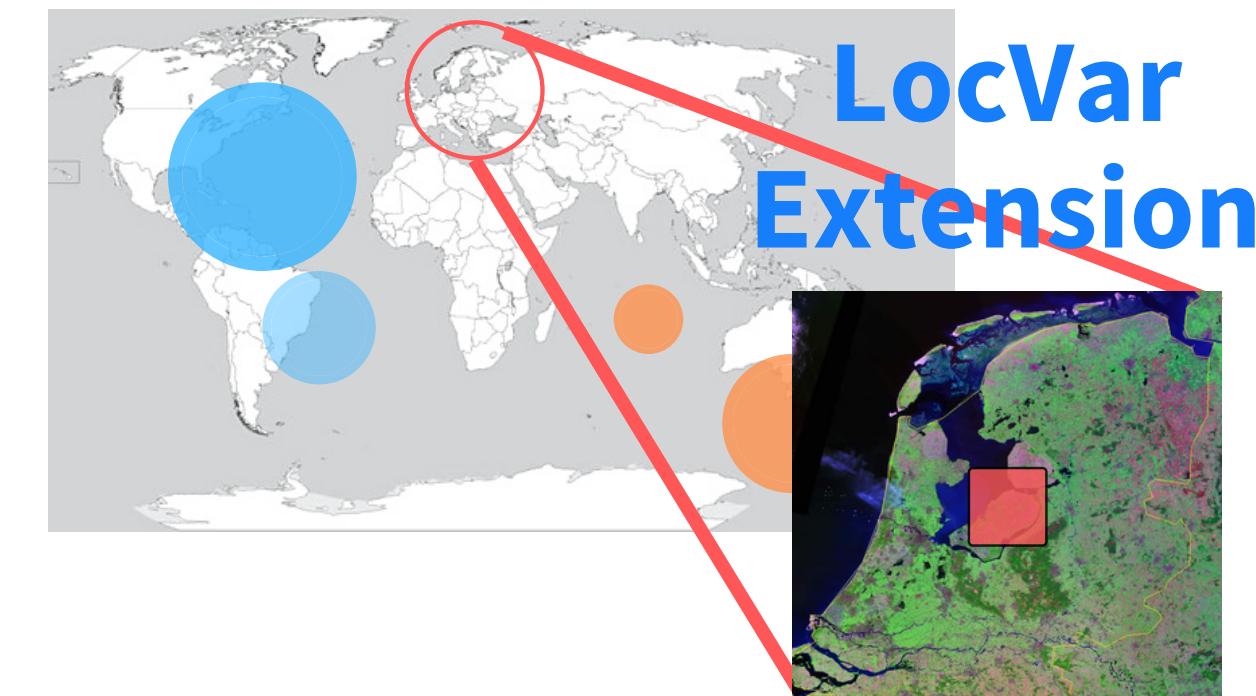
Global CorrMap



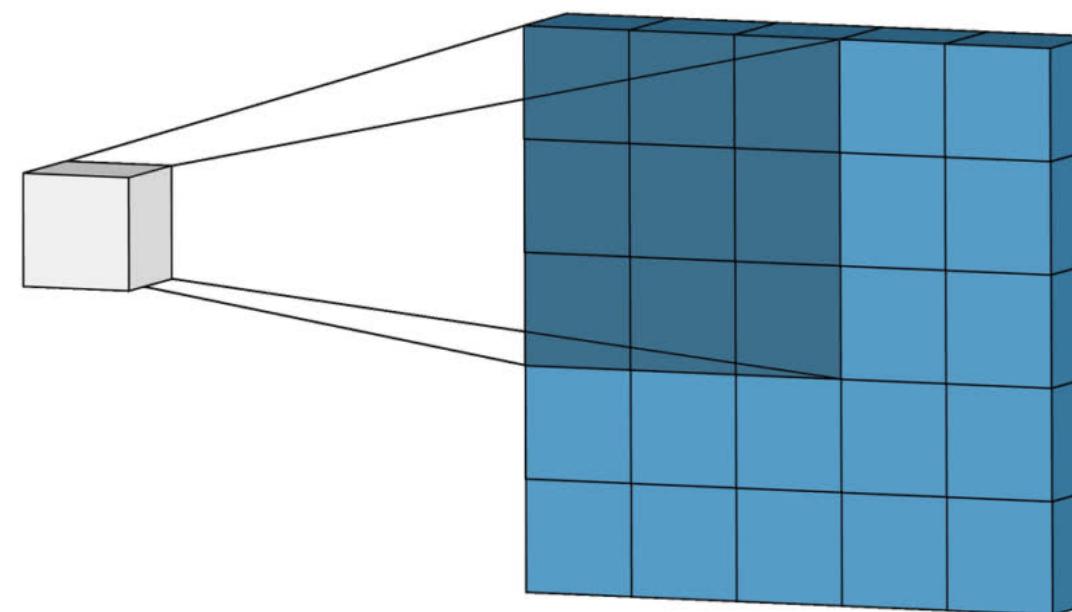
Future ideas



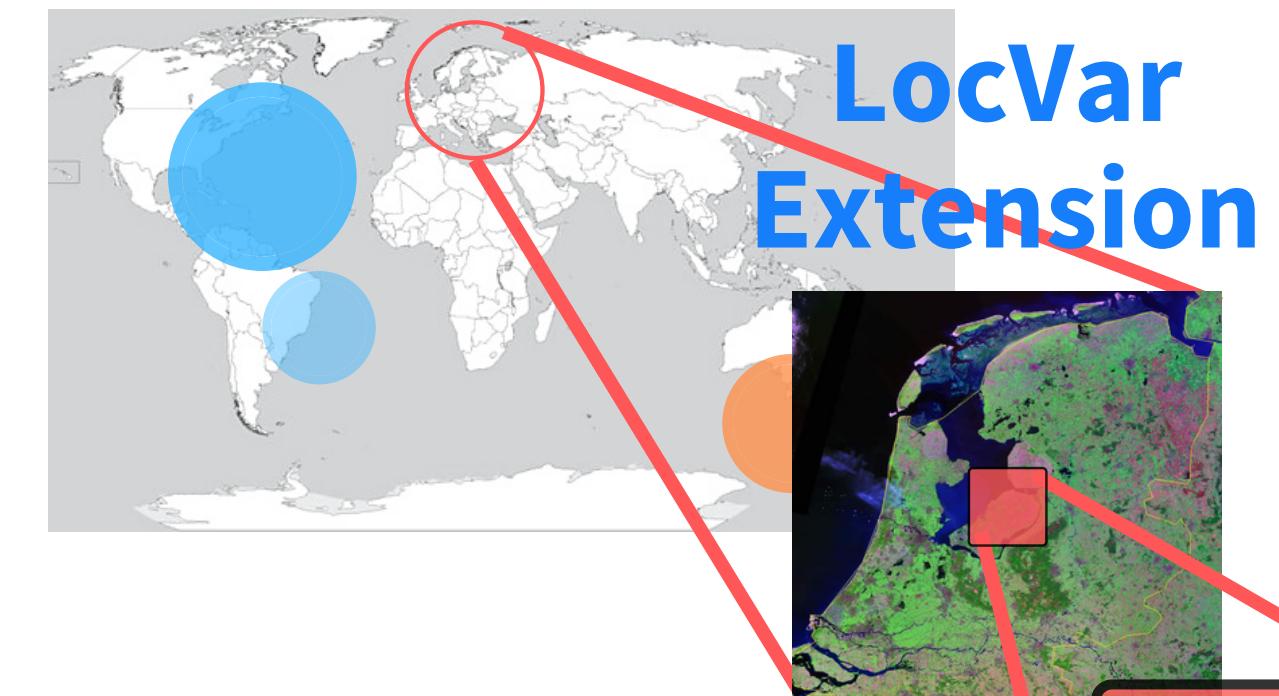
Global CorrMap



Future ideas



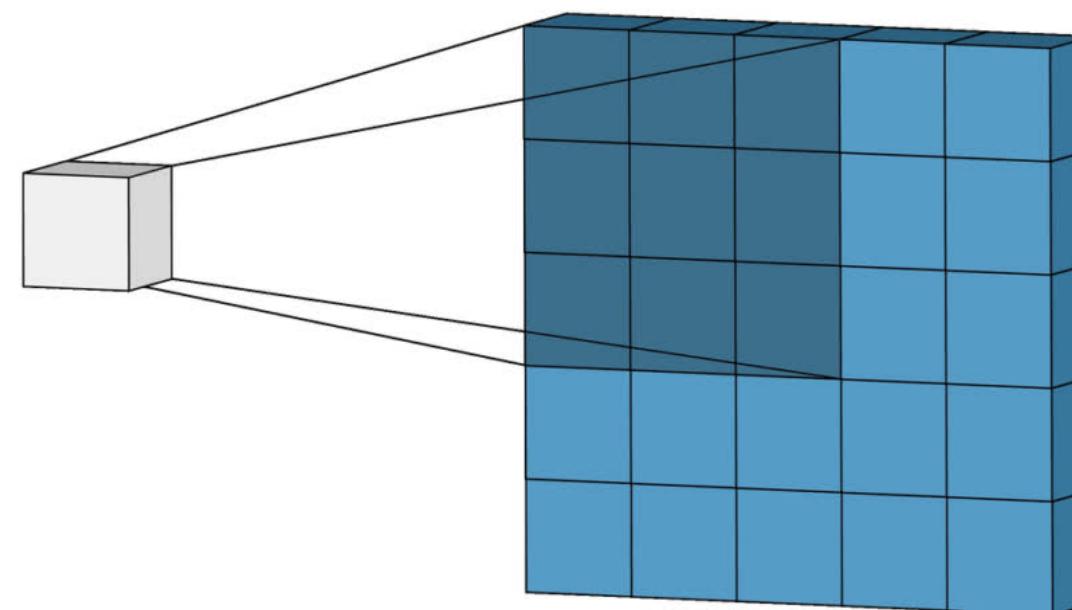
Global CorrMap



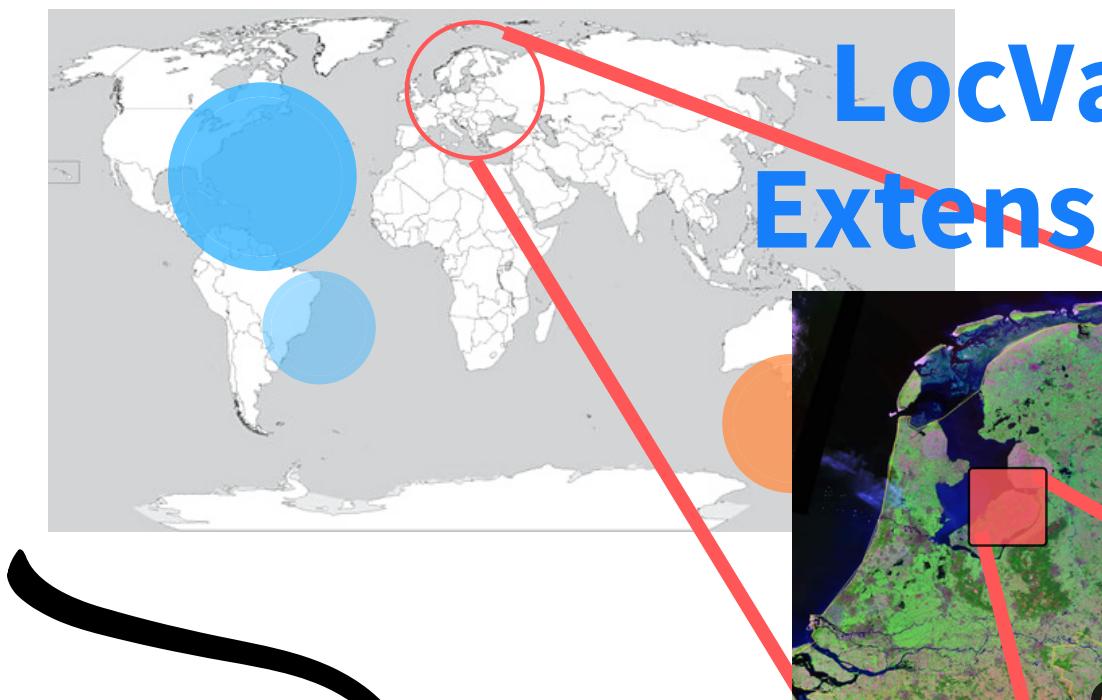
**LocVar
Extension**

**Study
area**

Future ideas



Global CorrMap

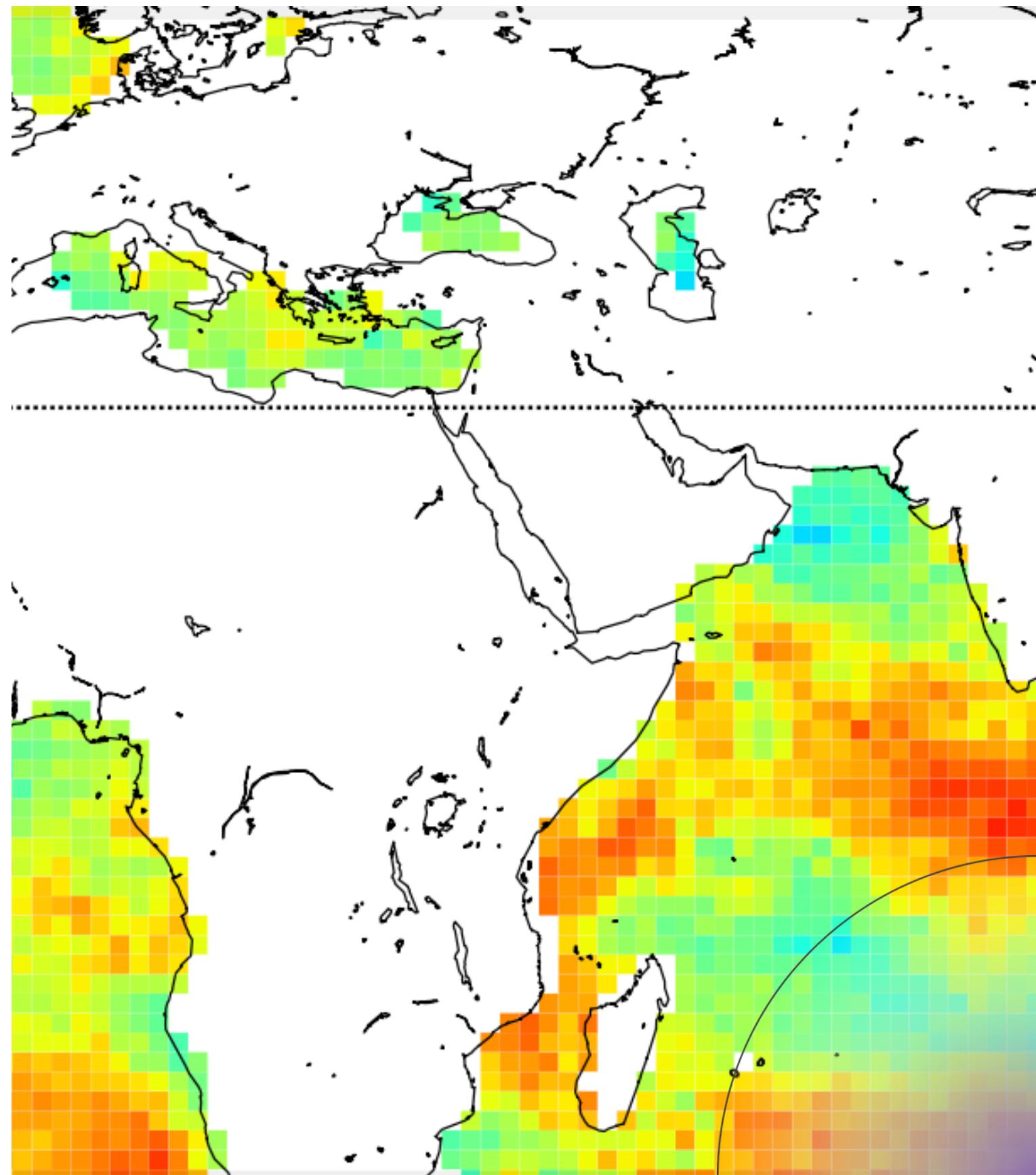


Global scale relevant
information

**LocVar
Extension**

Medium scale
relevant
information

**Study
area**



Thank you
for attending!