Teleconnection Phenomena in Climate Network via Sea Surface Temperature Datasets

Daekyung Lee, Heetae Kim, Jong-Min Park, Eun Lee*

KENTECH
Korea Institute of Energy Technology

부경대학교
PUKYONG NATIONAL UNIVERSITY

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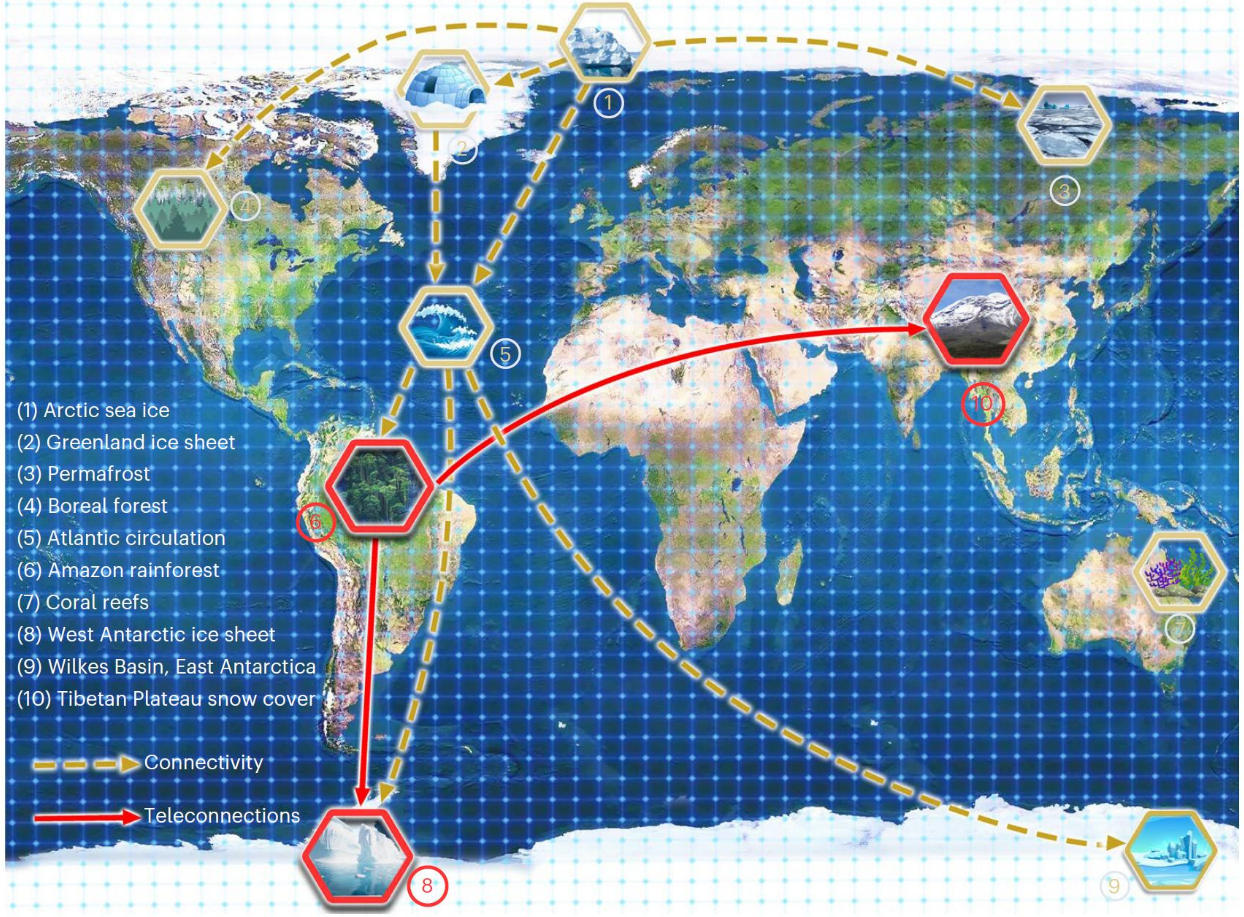
Correlation of climate phenomena

- Climate phenomena in various regions of the world are connected to each other
- Observing inter-regional climate correlation using data such as air and ocean temperature

Correlation of climate phenomena



- Climate phenomena in various regions of the world are connected to each other
- Observing inter-regional climate correlation using data such as air and ocean temperature

Previous researches on teleconnection

LETTER

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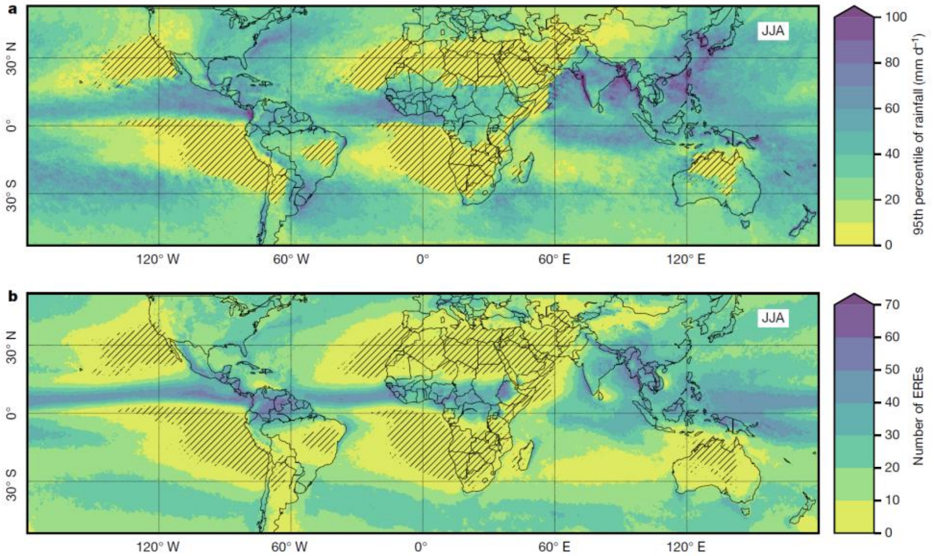
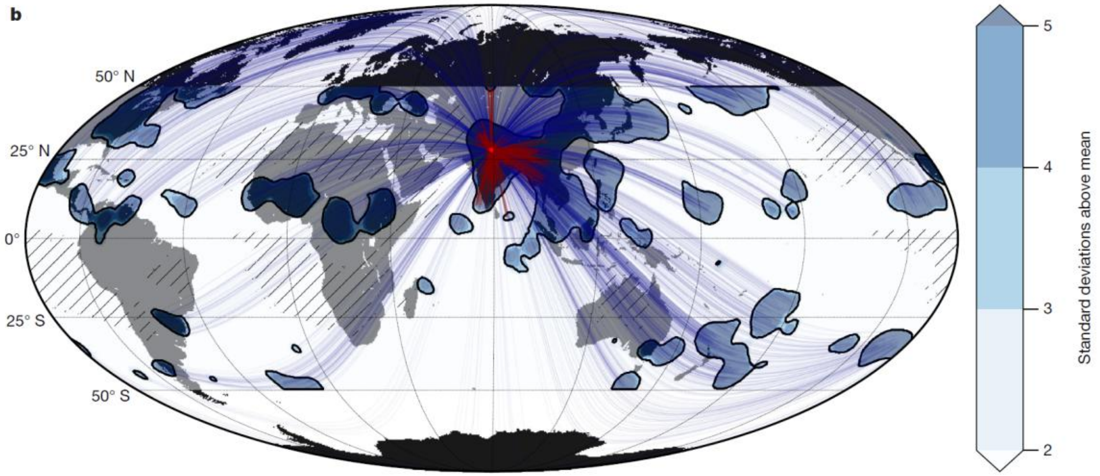
Complex networks reveal global pattern of extreme-rainfall teleconnections

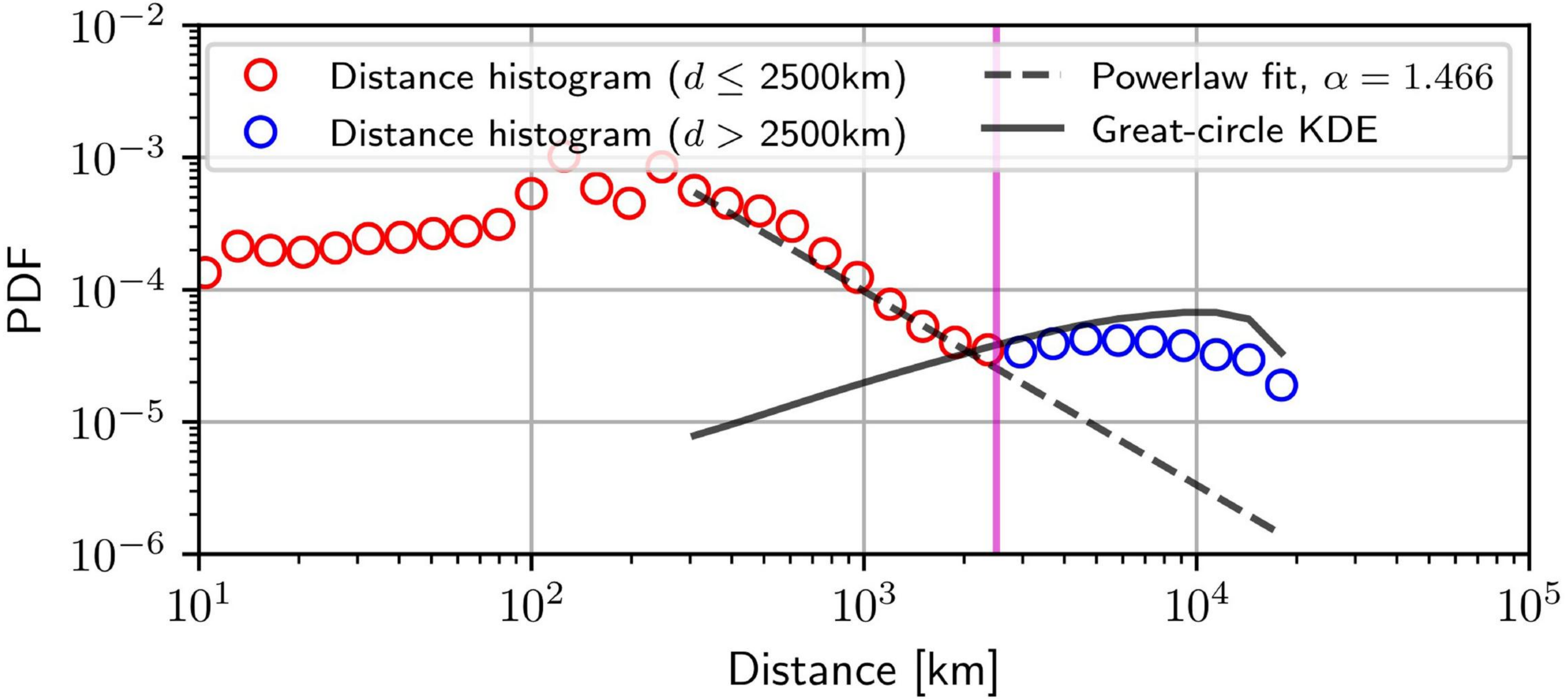
Niklas Boers[1,2]*, Bedartha Goswami[2,7], Aljoscha Rheinwalt[3,7], Bodo Bookhagen[3], Brian Hoskins[1,4] & Jürgen Kurths[2,5,6]





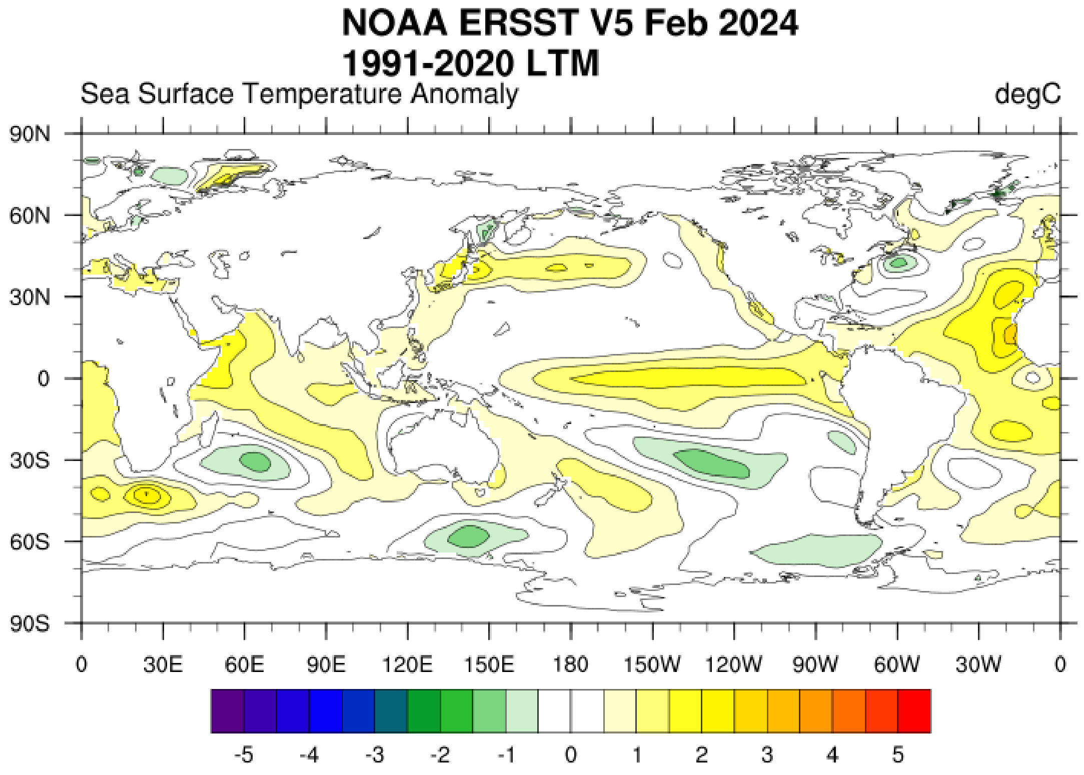
- 2019 Nature paper: Observing teleconnection in global precipitation data
- Synchronization analysis of intense rainfall events (ERE) where high rainfall is observed in a specific region
- Inter-regional correlation is measured through the number of times EREs in two regions occur together
- Many significant correlations are observed even at longer distances →Teleconnection

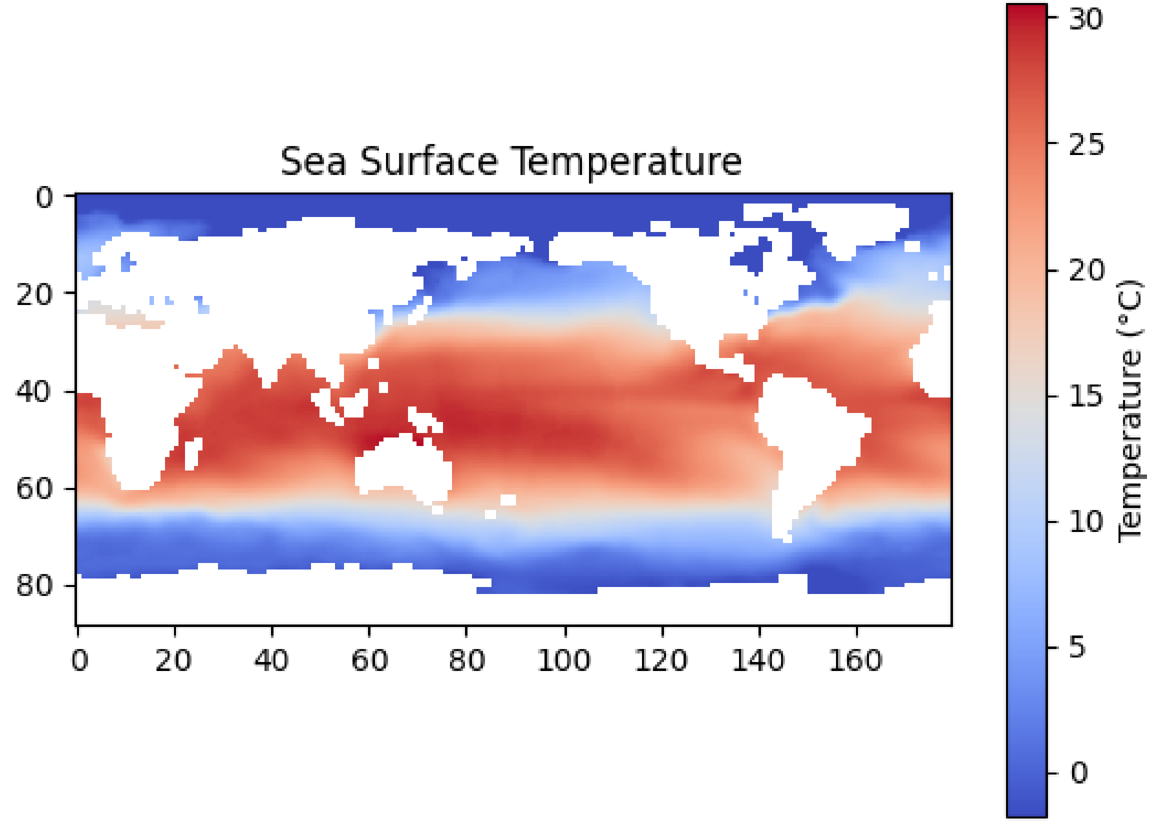
Previous researches on teleconnection



- Synchronization frequency of EREs in distant regions
- The frequency of synchronization decreases as the distance increases
- But increases again at the 2500 km boundary.
- Teleconnection phenomenon that occurs starting at 2500 km

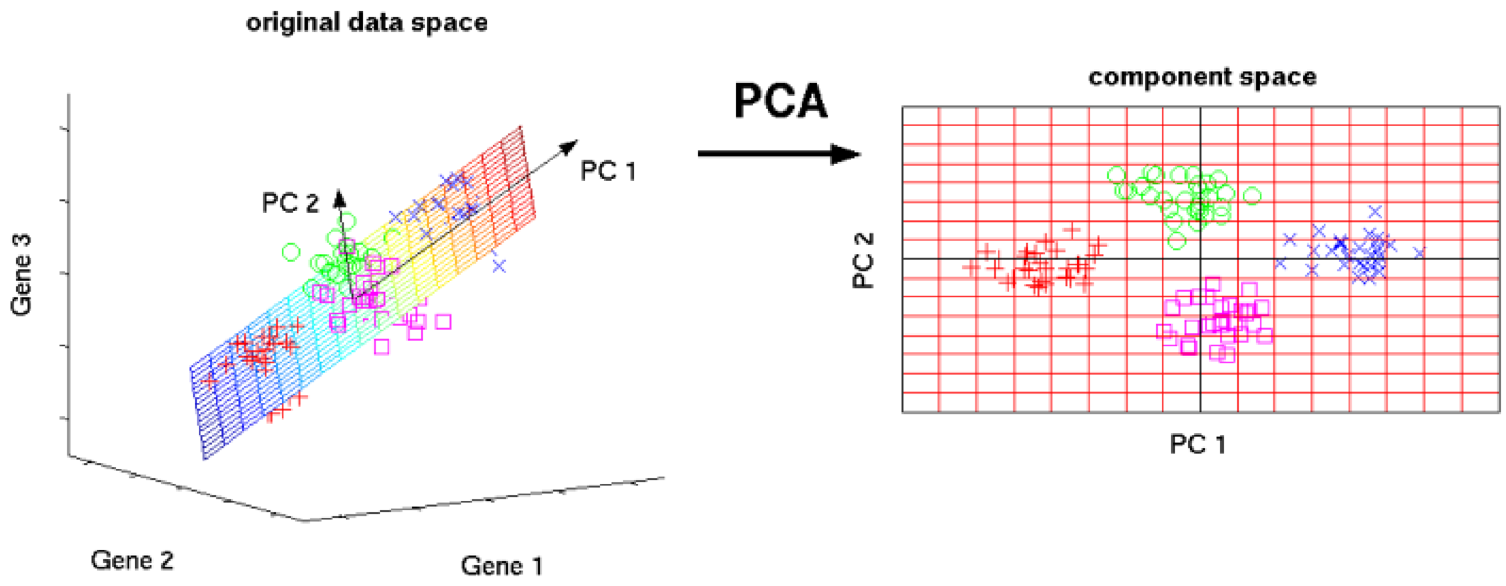
Sea-surface dataset





- Observe climate phenomena occurring in the ocean through sea surface temperature data
- Data source: National Oceanic and Atmospheric Administration (NOAA).
- Temperature measurement data at monthly intervals (89x180) (1854-present).
- Cross-verified data based on various data accumulated through buoys, ships, etc.

Raw data analysis

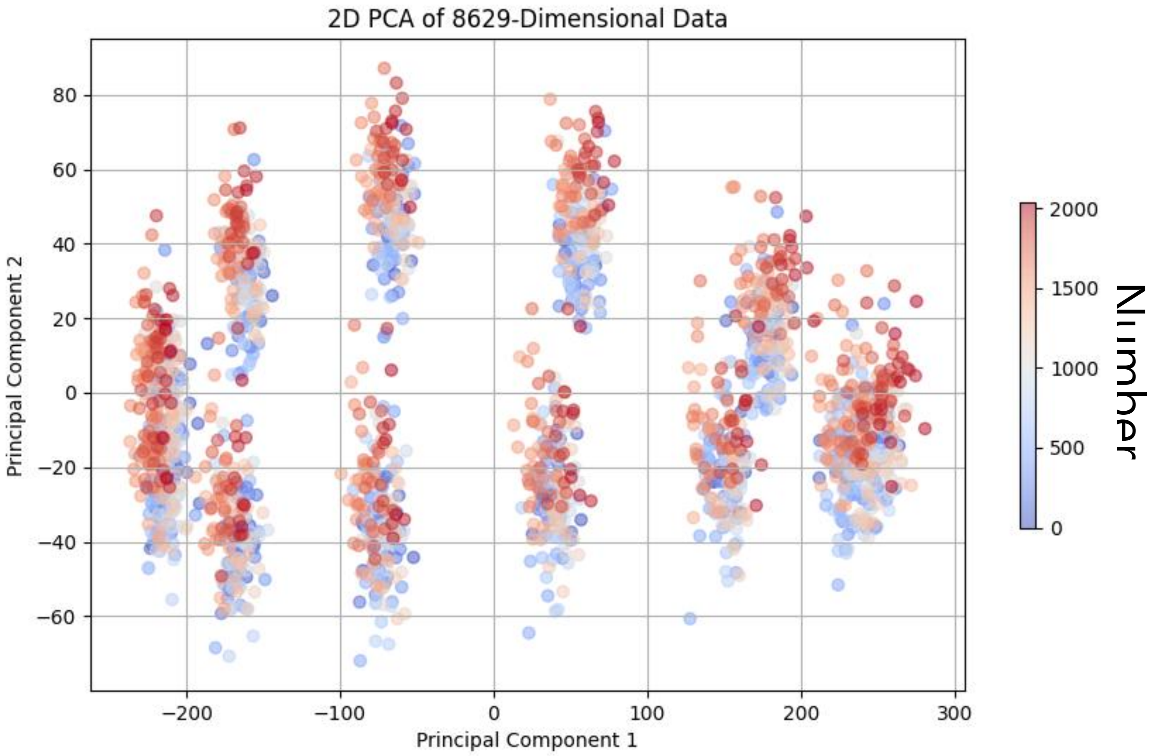


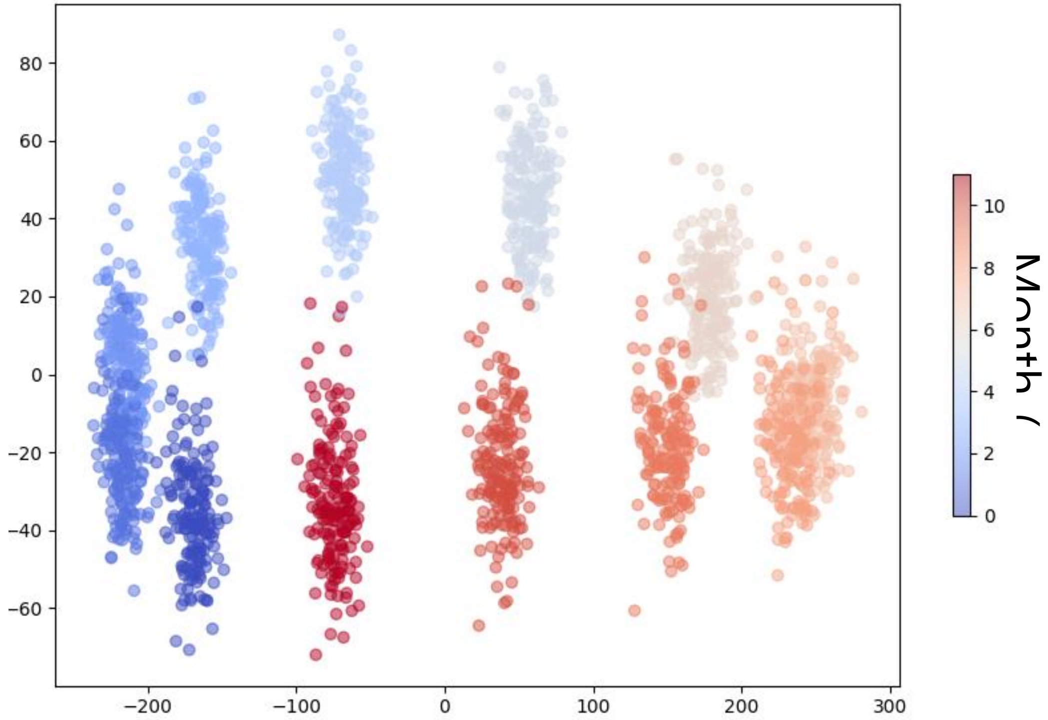
T temperature data for N locations
→ T points in N dimensions

Projection onto the plane where N-dimensional points are best distinguished

- PCA analysis: Observe the distribution of temperature data for each location at each time
- Projection onto the top two principal axes

Raw data analysis

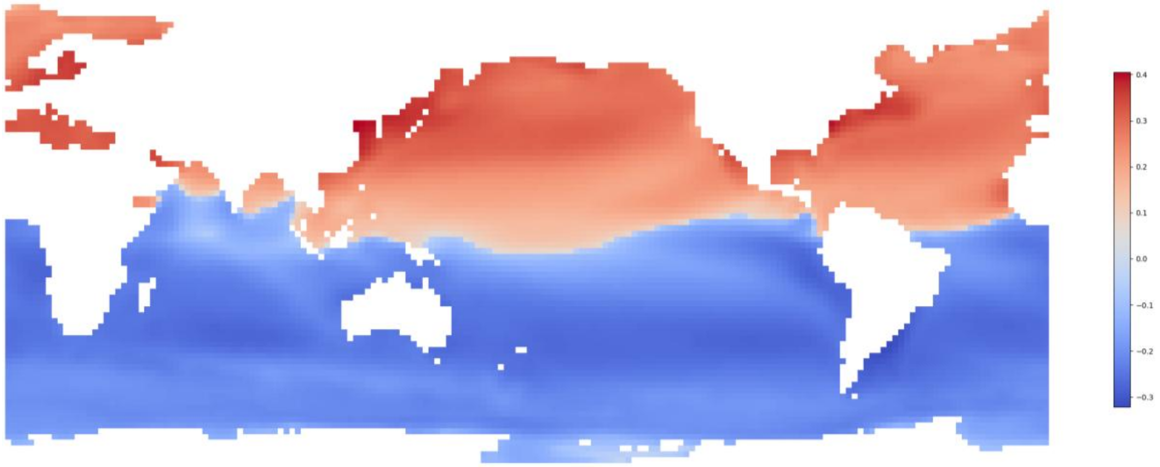




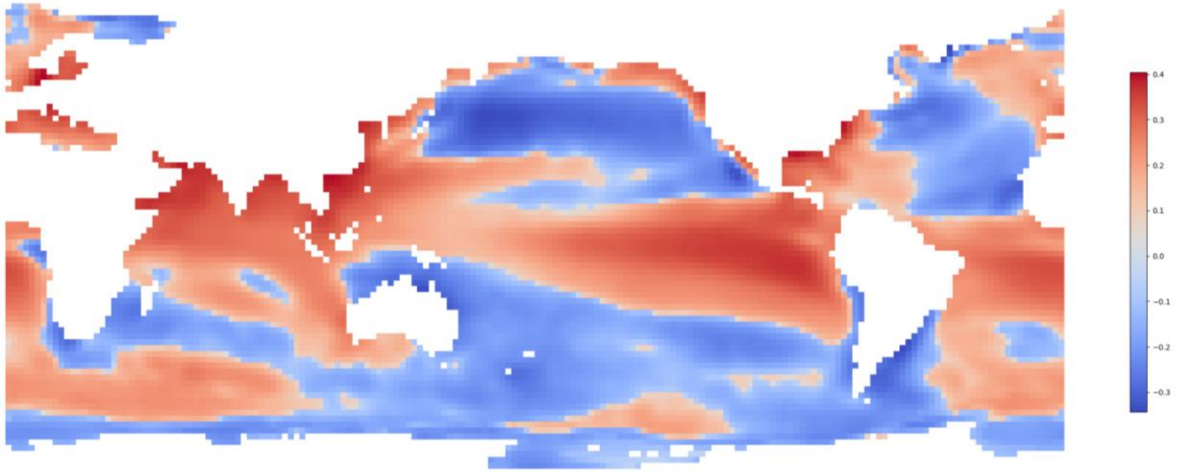
- Distribution on two principal axes obtained by PCA on raw data
- It is divided into 12 chunks representing each month.
- As time passes, the component of the second axis increases → Global warming?

Raw data analysis

1st axis

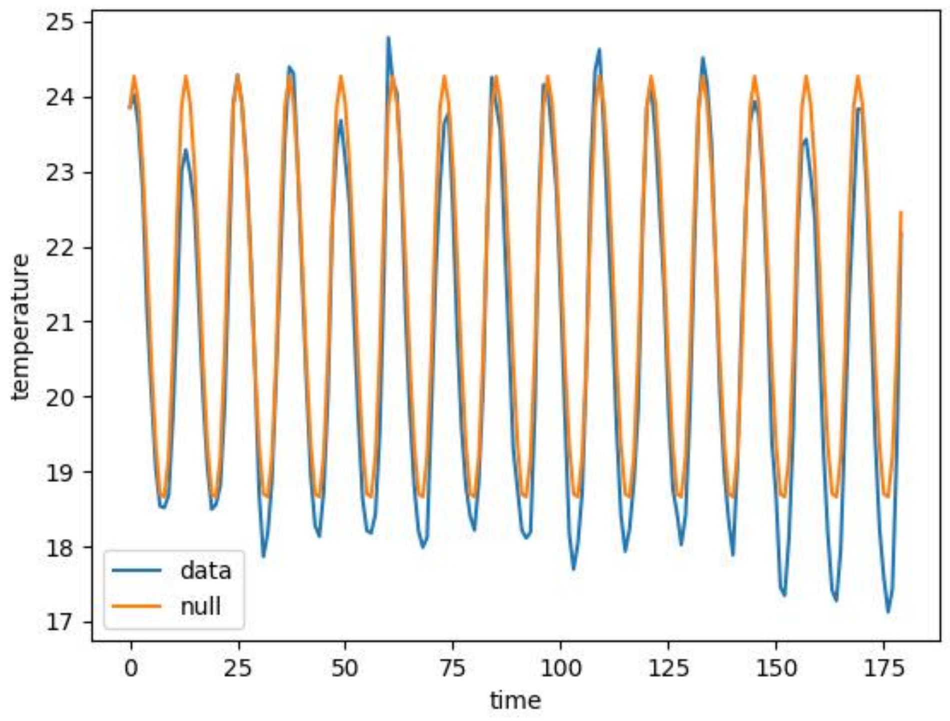


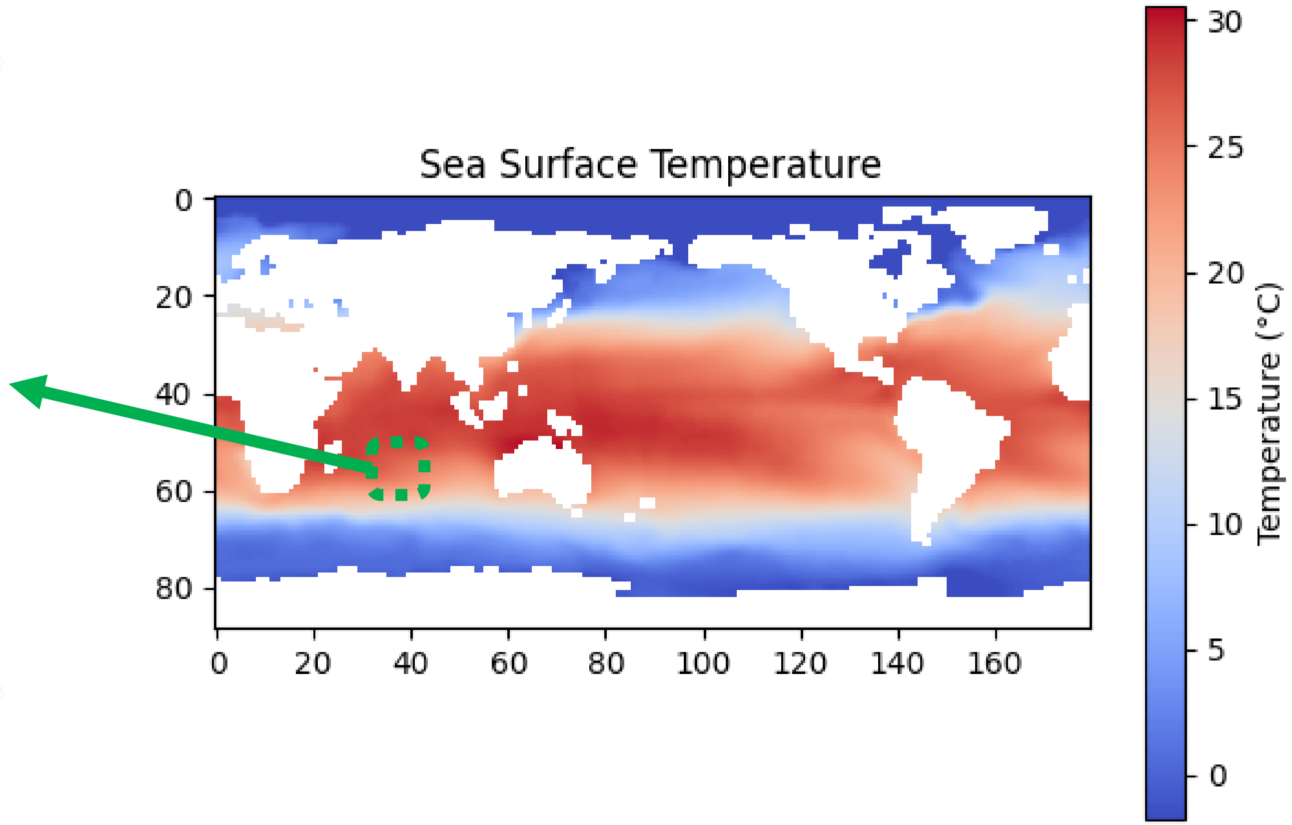
2nd axis



- Top two principal component vectors from PCA analysis
- First vector: Temperature patterns that help distinguish between seasons (variance contribution 0.83)
- Second vector: Clusters of temperature change (0.03)

Sea-surface dataset





- Eliminates macro trends with monthly averages over the entire period for each location
- Use the difference between the current data and monthly trend over the entire measurement period.
- Focuses on the propagation of fluctuations at each location relative to the overall climate change pattern.

Heat equation

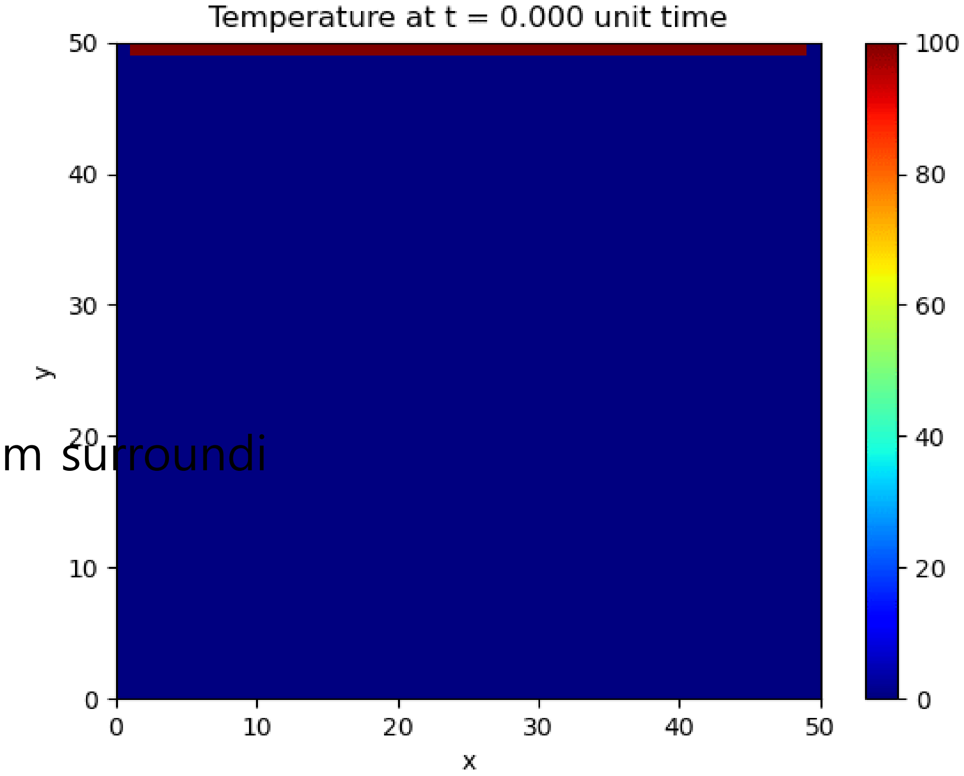
Heat equation

$$\frac{dT}{dt} = D\nabla^2 T$$

therm
al con
ductivi
ty

Temperature difference from surroundi
ng area

The temperature in
your area changes



- Approach the relationship between sea surface temperature changes using the heat equation
- The temperature of each point changes depending on the temperature difference from surrounding points.

Heat equation

Heat equation

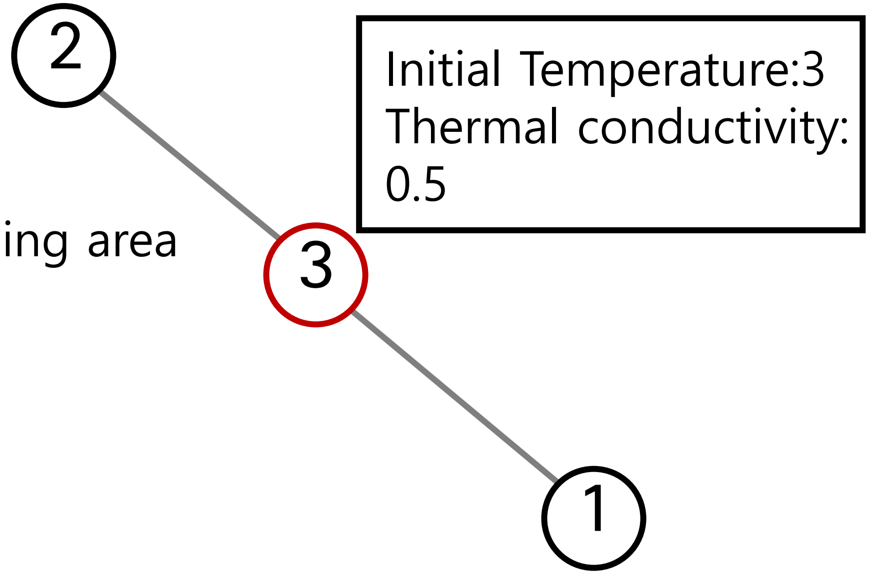
thermal conductivity

$$\frac{dT}{dt} = D\nabla^2 T$$

Temperature difference from surrounding area

The temperature change of target point

Ex) Temperature changes in the network



- Application of heat equation to network structure
- The center follows the temperature of surrounding nodes.

Heat equation

Heat equation

$$\frac{dT}{dt} = D\nabla^2 T$$

thermal conductivity

Temperature difference from surrounding area

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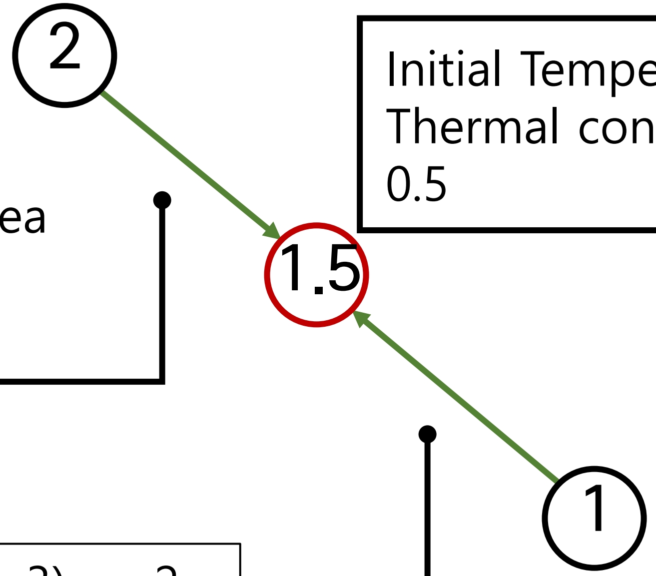
Ex) Temperature changes in the network



Initial Temperature:3
Thermal conductivity: 0.5

Temperature difference: (2-3) = -1
Impact: -1 X 0.5 = -0.5

Temperature difference: (1-3) = -2
Impact: -2 X 0.5 = -1

- Application of heat equation to network structure
- The center follows the temperature of surrounding nodes.
- Total temperature change: -1.5
- The temperature difference is reflected as much as the thermal conductivity of the target node.

Heat equation

Method

Heat equation

$$\frac{dT}{dt} = D\nabla^2 T$$

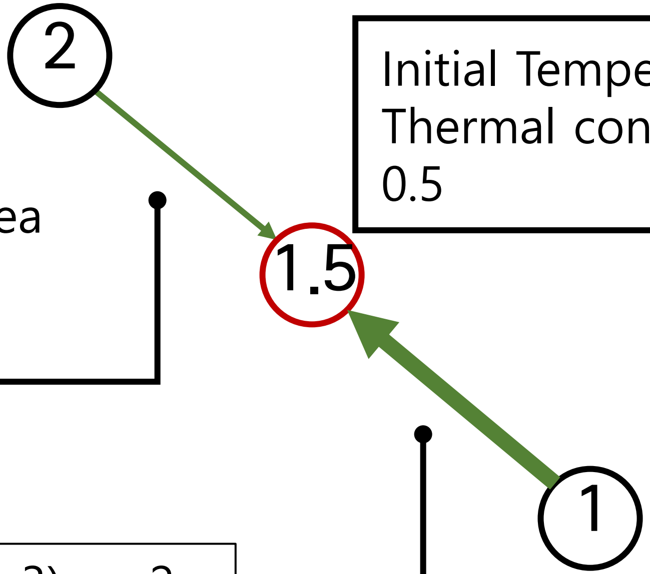
thermal conductivity

Temperature difference from surrounding area

The temperature change of target point

Ex) Temperature changes in the network

Initial Temperature:3
Thermal conductivity: 0.5



Temperature difference: (2-3) = -1
Impact: -1 X 0.5 = -0.5

Temperature difference: (1-3) = -2
Impact: -2 X 0.5 = -1

- However, in sea surface temperature, the conductivity may vary depending on the direction
- Introducing a general heat equation that relaxes symmetry

Heat equation

Heat equation

thermal conductivity

$$\frac{dT}{dt} = D\nabla^2 T$$

Temperature difference from surrounding area

The temperature change of target point

Generalized heat equation

$$T_i(t+\tau) - T_i(t) = \sum_j W_{ij} T_j$$

Generalized interaction matrix
(influence of position j on i)

Temperature at location j at time t

- 불연속적인 데이터에 대한 일반화 열방정식
- 행렬 W_{ij}는 위치 j와의 온도차가 i의 온도에 미치는 영향을 의미
- 목표: 해수면의 온도 데이터 $T(t)$ 를 입력값으로 이용해 이를 잘 설명하는 W_{ij}를 탐색

Heat equation

Generalized heat equation

$$E_i = \left(T_i(t+\tau) - T_i(t) - \sum_j W_{ij} T_j\right)^2$$

actual temperature change

predicted value

$$T_i(t+\tau) - T_i(t) = \sum_j W_{ij} T_j$$

Generalized interaction matrix
(influence of position j on i)

Temperature at location j at time t

$$W_{ij}(n+1) = W_{ij}(n) - \frac{dE}{dW_{ij}(n)}$$

- Take the square of the difference between both sides as the error function
- Searching for W that minimizes this error function.
- Initialize and update the W matrix appropriately to minimize the error.
- Allows correlation between all locations, even if they are not close

Heat equation

$$E_i = \left(T_i(t+\tau) - T_i(t) - \sum_j W_{ij}T_j\right)^2$$

Update W_{ij} such that E decreases

$$W_{ij}(n+1) = W_{ij}(n) - \frac{dE_i}{dW_{ij}(n)}$$

$$= W_{ij}(n) - \left(\frac{\partial E_i}{\partial W_{ij}} + \frac{\partial W_{ii}}{\partial W_{ij}}\frac{\partial E_i}{\partial W_{ii}}\right)$$

$$= W_{ij}(n) - 2\sqrt{E_i}\,(T_i - T_j)$$

Secondary change $(W_{ij} \rightarrow W_{ii} \rightarrow E)$

$$\frac{dT_i}{dt} = \sum_j W_{ij}T_j$$

$If\ all\ T_j = T,$

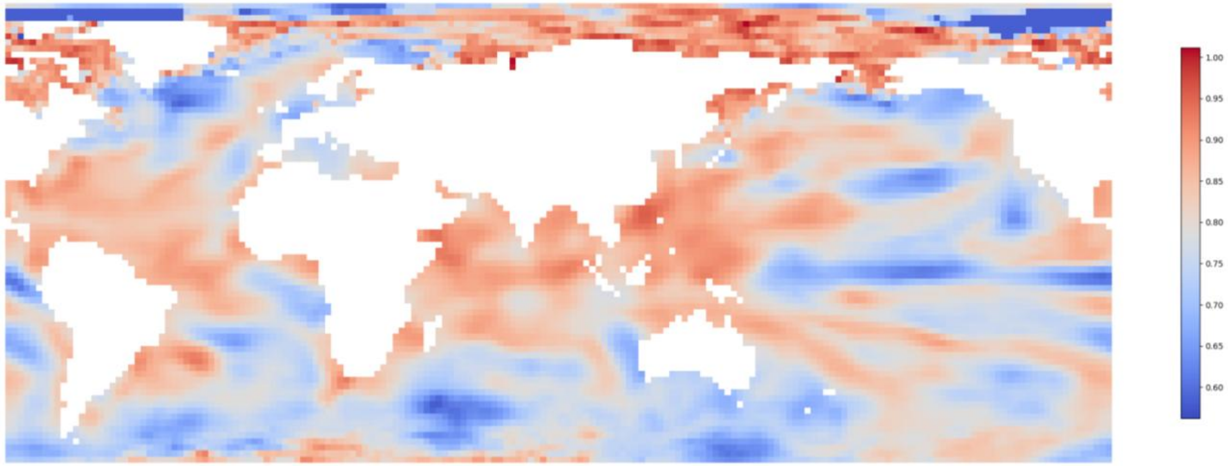
$$0 = \sum_j W_{ij}T$$

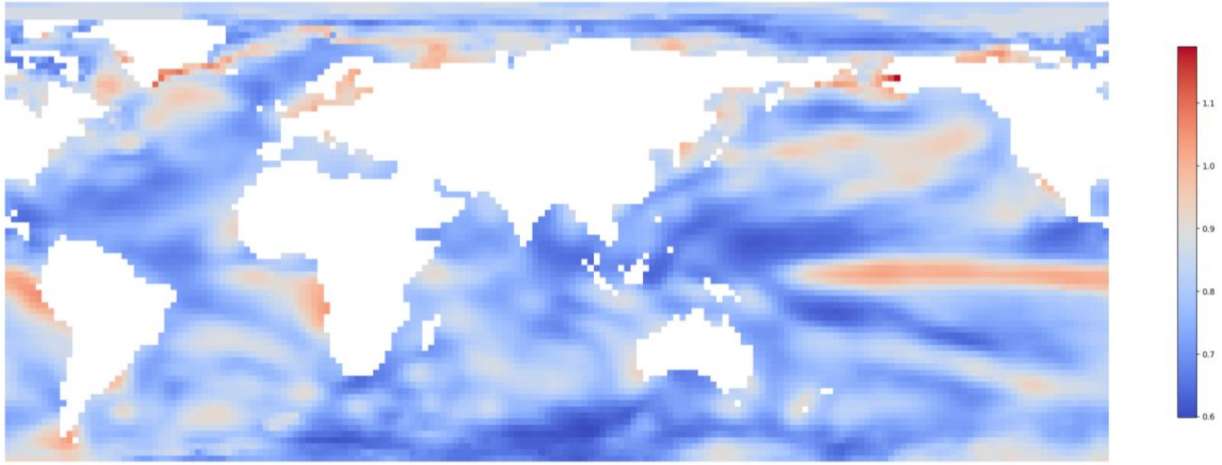
- Take the square of the difference between both sides as the error function
- Searching for W that minimizes this error function.
- Initialize and update the W matrix appropriately to minimize the error.
- Allows correlation between all locations, even if they are not close

Flow analysis

$$S_i^{\text{in}} = \sum_j W_{ij} = total\ inflow$$

$$S_i^{\text{out}} = \sum_j W_{ji} = total\ outflow$$





- Influence of each region achieved through optimization
- Left: Total influence (sensitivity) from temperatures in other regions
- Right: Total influence on temperature of different regions

Flow analysis

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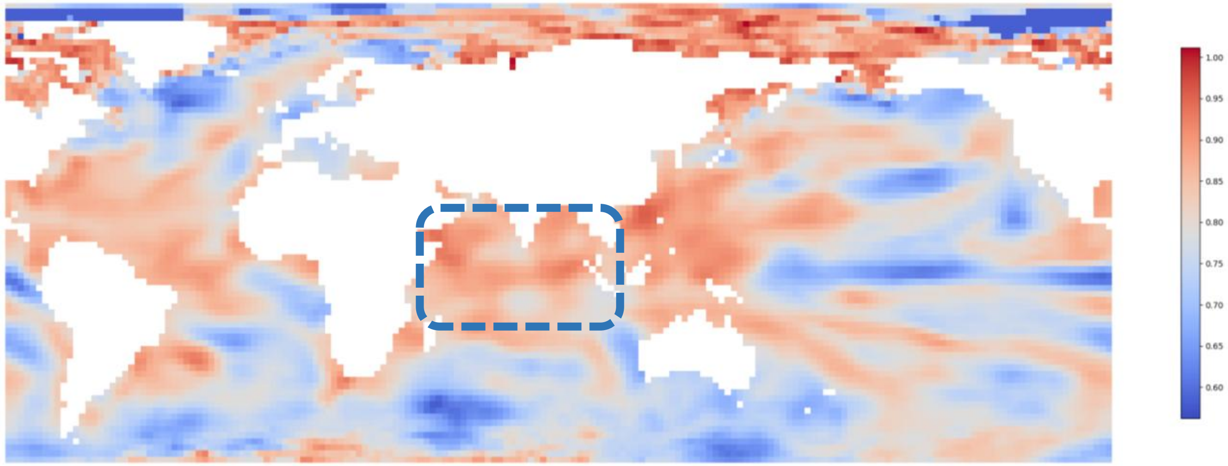
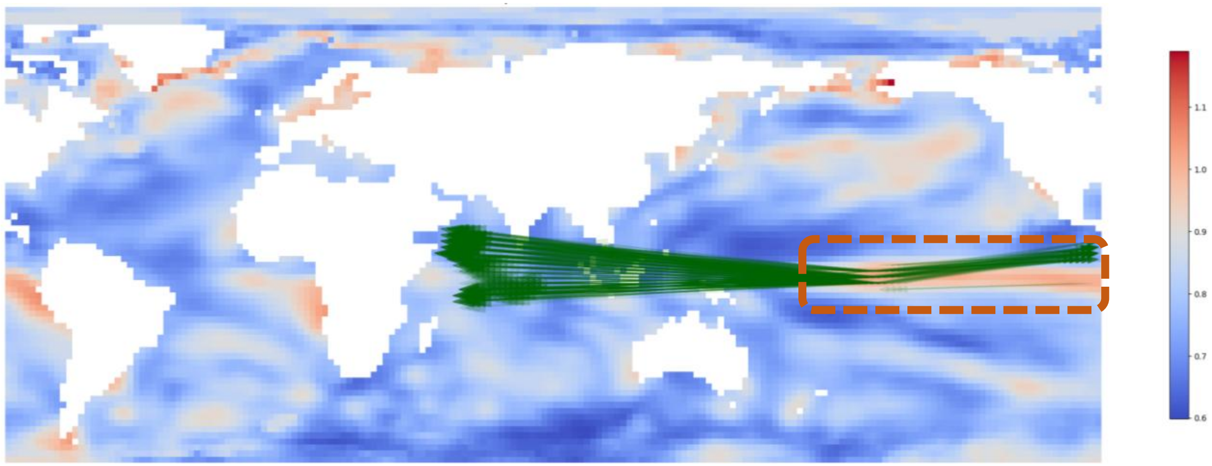
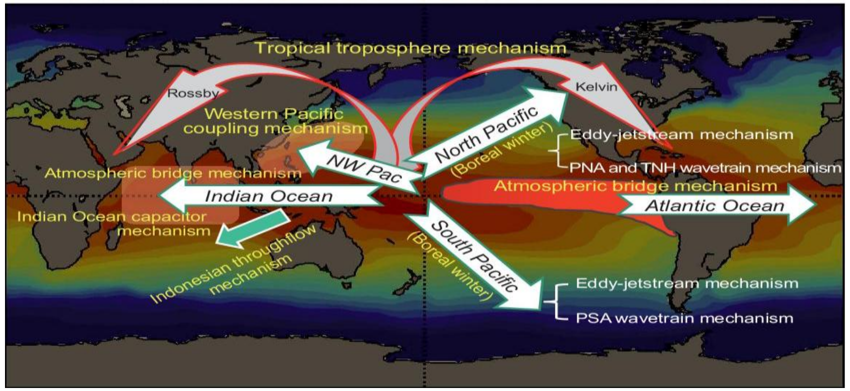




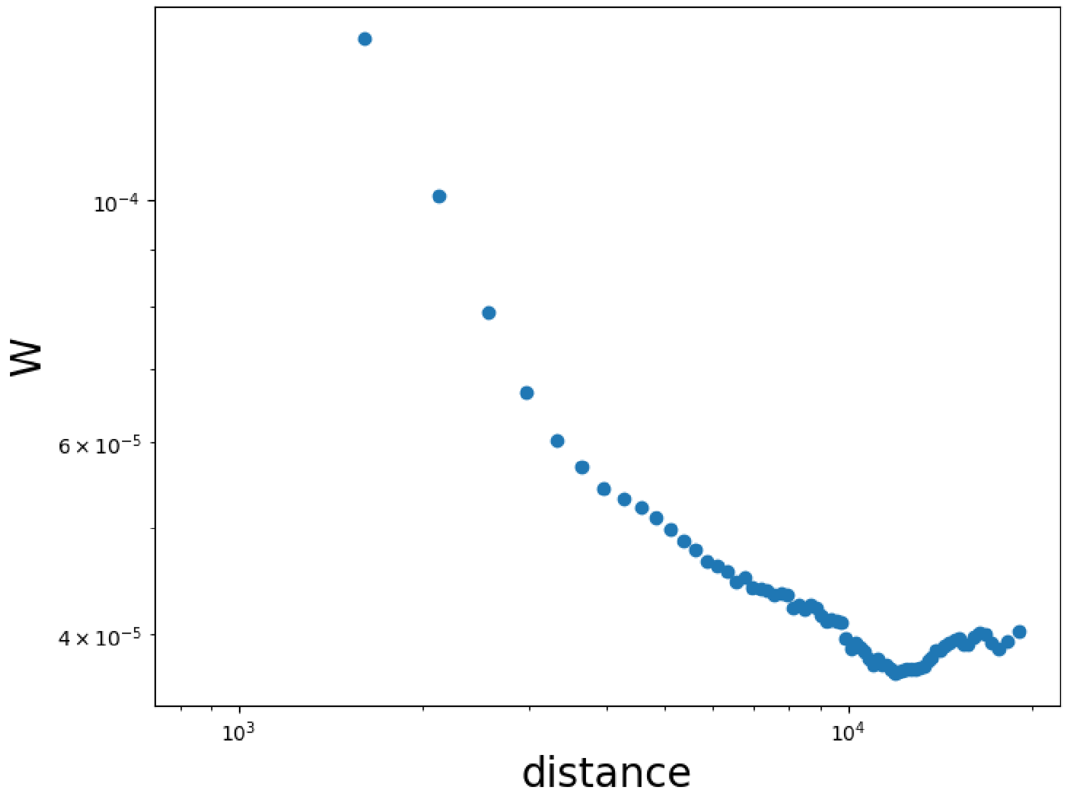
ENSO Teleconnection Mechanisms

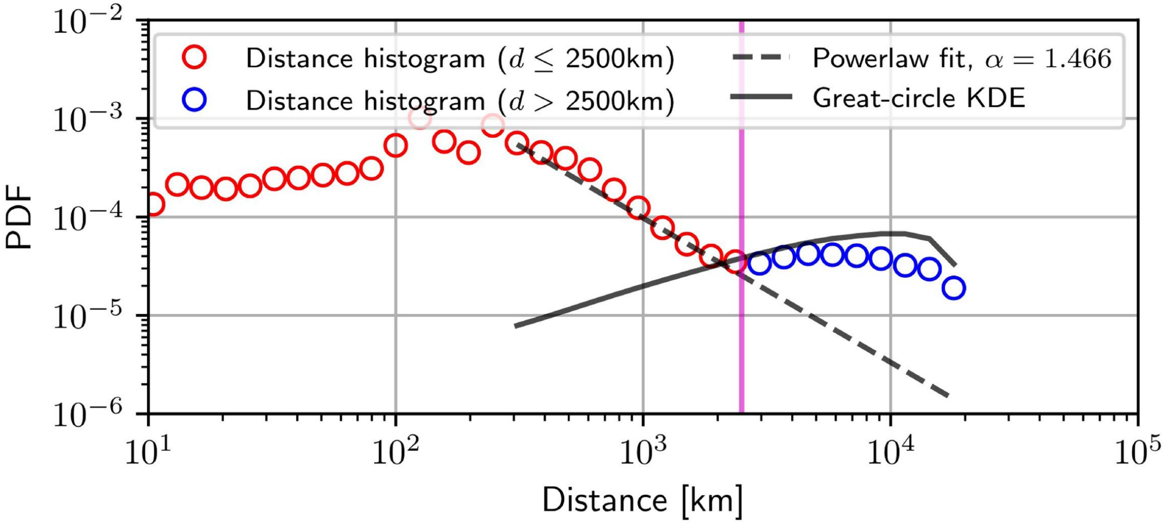


- Influence of each region achieved through optimization
- Left: Total influence (sensitivity) from temperatures in other regions
- Right: Total influence on temperature of different regions
- Similar to the ENSO pattern found in existing climate-related studies

Flow analysis

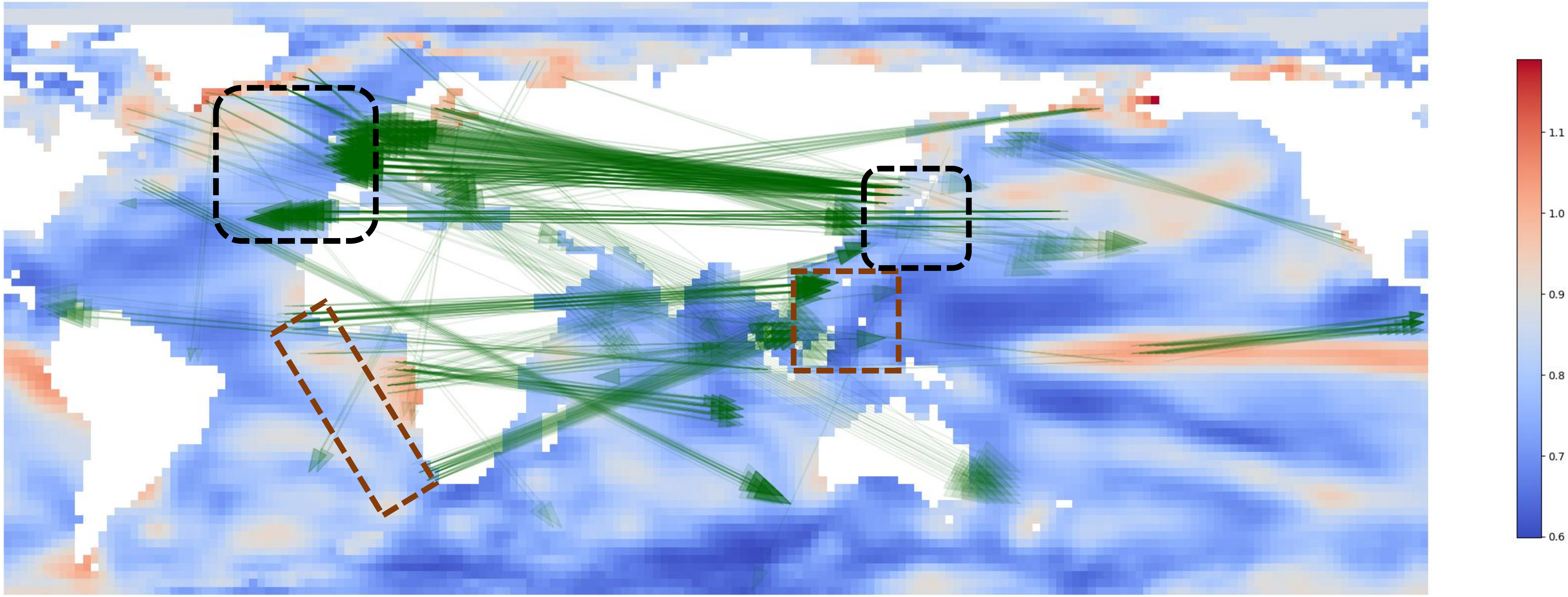
Result





- Change of W as a function of distance
- It changes slightly from around 4,000km and rebounds above 10,000km.
- Consistent with other researches on teleconnection

Flow analysis



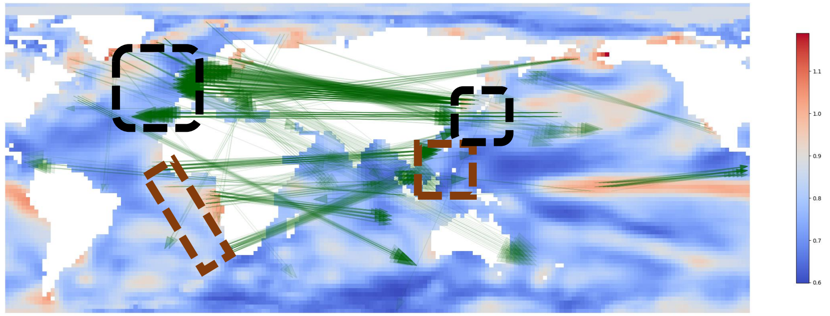
- Top 500 of all connections over 7000km
- Macro flows: West coast of Africa →Southeast Asia, Northeast Asia → Western Europe
- Need for cross-validation with existing context on ocean current circulation

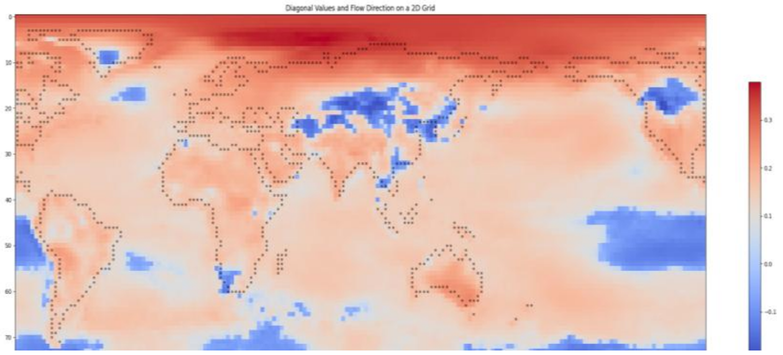
Summary

- Teleconnection observation and analysis using sea surface temperature data
- Extract macroscopic patterns from sea level data through PCA analysis
- Analyzing correlations through generalized heat equations
- Building a network of influence through time series data of temperature
- Observe teleconnection patterns over distance
- Observation of climate correlations through analysis of influence networks

Future Works

- Climate correlation analysis at various time scales (〉1 year)
- Applying analytical methodologies to air temper ature data
- Comparison and integration of climate phenome na from atmospheric and ocean temperature
- Apply other methodologies such as percolation a nd eigenvector analysis





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