

# Causality in The Earth System

Addressing The Climate Change Issues

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Ridho Rahmadi, Center of Data Science UII.



UNIVERSITAS  
ISLAM  
INDONESIA

# Table of Contents

1 | 31

Data Science's First Page

Causal Modeling

Causality in The Earth System

Climate Change and Global Warming

Addressing Issues Via Causal Modeling

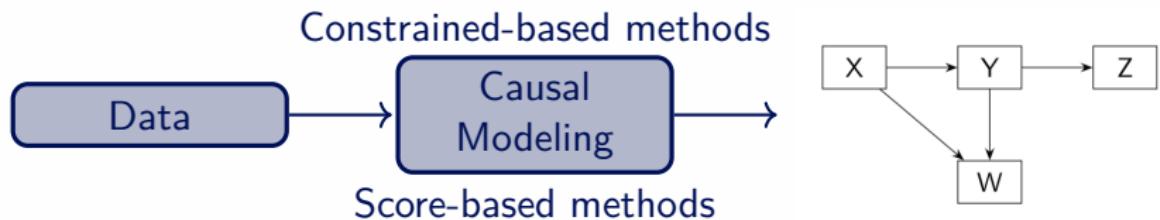
Methodological Challenges

Data science is **to seek** values from data, and **to orchestrate** them into **meaningful models**

# Perspectives in Data Science

Problem	Activity	Questions	Examples
Association $P(y x)$	Seeing	What is? How would seeing $X$ change my belief in $Y$ ?	What does a symptom tell me about a disease?
Intervention $P(y do(x), z)$	Doing	What if? What if I do $X = x$ ?	What if I take aspirin, will my headache be cured?
Counterfactual $P(y_x x', y')$	Imagining	Why? Was it $X$ that caused $Y$ ? What if I had acted differently?	What if I had not been smoking the past 2 years?

# Causal Modeling



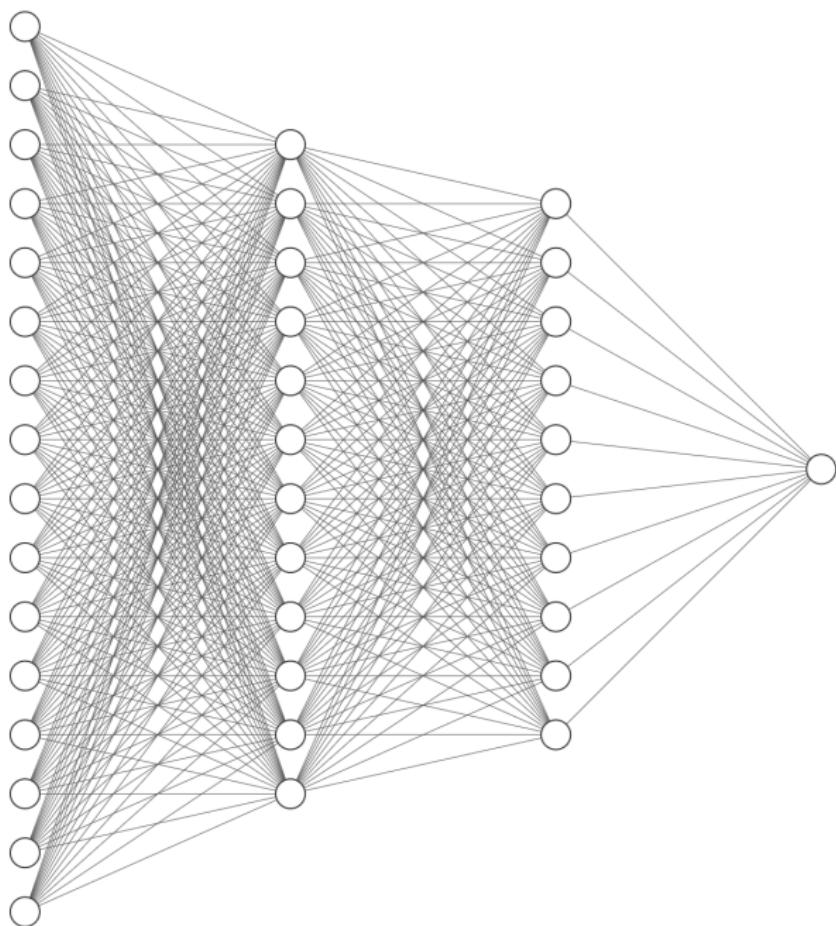


*An Illustration of a causal mechanism*

Source: [invisibledisabilities.org](http://invisibledisabilities.org)

## Why causal modeling?

- It complements standard Statistics approaches to better interpret result
- Many problems require understanding in underlying mechanisms
- It provides **explanation**, while machine and deep learning models are relatively difficult to explain
- It accommodates important parts of human's reasoning, i.e., what if? what would have been?

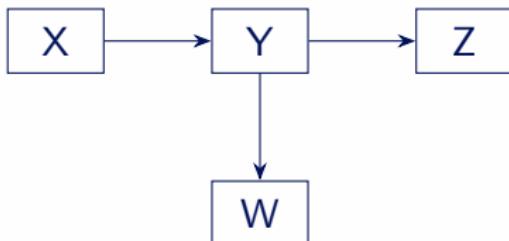


Input Layer  $\in \mathbb{R}^{16}$

Hidden Layer  $\in \mathbb{R}^{12}$

Hidden Layer  $\in \mathbb{R}^{10}$

Output Layer  $\in \mathbb{R}^1$



$P(X \perp\!\!\!\perp Z | Y)$ ,  $X$  and  $Z$  are independent given  $Y$ ;  
 $P(X \perp\!\!\!\perp W | Y)$ ,  $X$  and  $W$  are independent given  $Y$ .

A causal model provides explanation, how thing works, not only a black box with a *magic* result yet difficult to explain.

# Causality in The Earth System

## The Atmosphere

This part of the Earth System includes the mixture of gases that surround the planet.

## The Biosphere

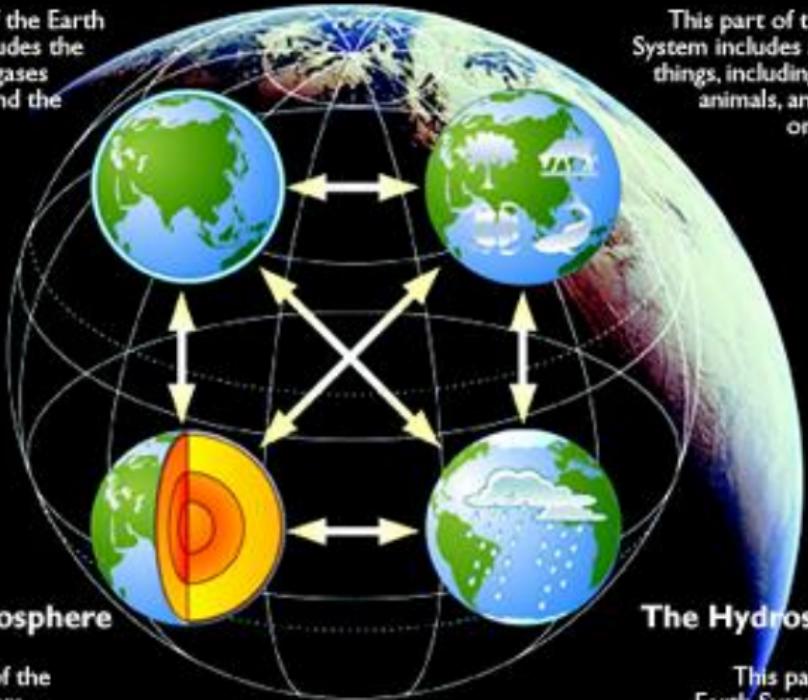
This part of the Earth System includes all living things, including plants, animals, and other organisms.

## The Geosphere

This part of the Earth System includes the crust, mantle, and inner and outer core.

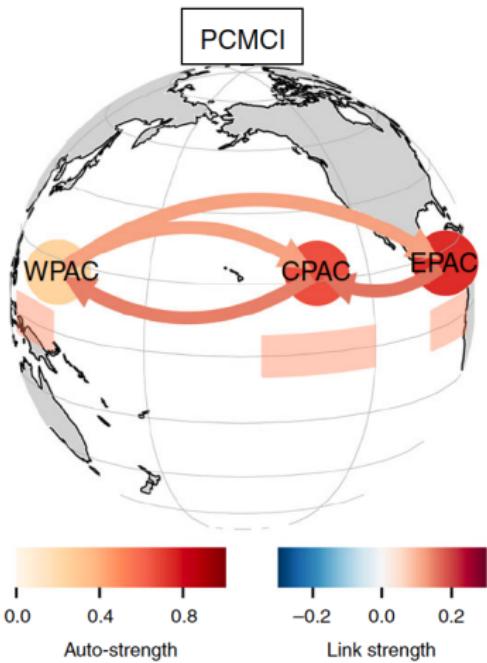
## The Hydrosphere

This part of the Earth System is the planet's water, including oceans, lakes, rivers, ground water, ice, and water vapor.

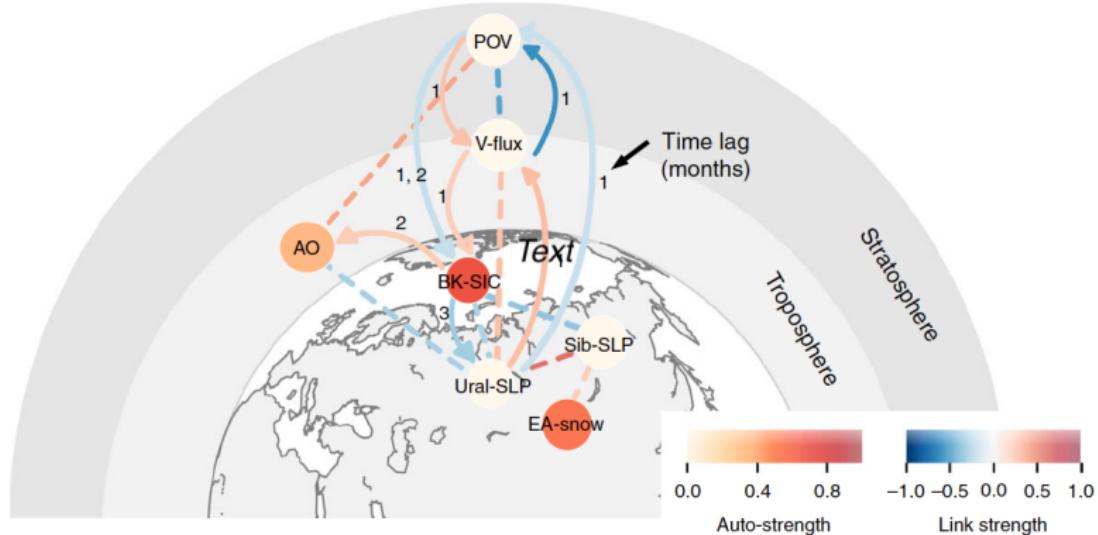


## Examples of application

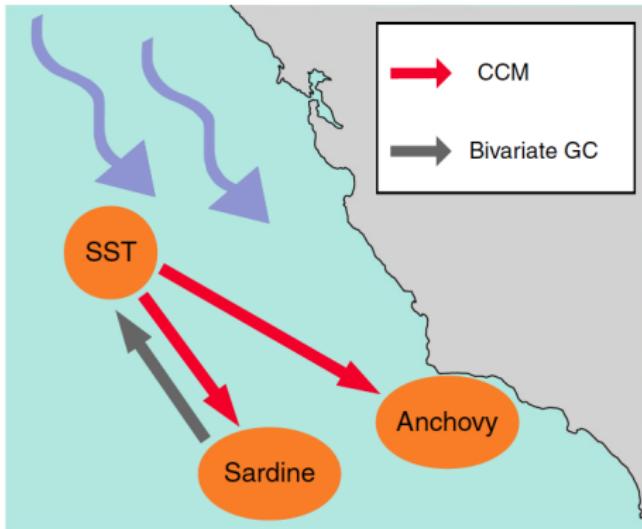
Based on Runge, Jakob, et al. "Inferring causation from time series in Earth system sciences." Nature communications 10.1 (2019): 1-13.



**Tropical climate example.** Anomalous warm surface air in the East Pacific is carried westward by trade winds across the Central Pacific. Then the moist air rises towards the upper troposphere over the West Pacific and the circulation is closed by the cool and dry air sinking eastward across the entire tropical Pacific.



**Artic climate example.** Barents and Kara sea ice concentrations (BK-SIC) are detected to be important drivers of mid-latitude circulation, influencing winter Arctic Oscillation (AO) via tropospheric mechanisms and through processes involving vertical wave activity fluxes (v-flux) and the stratospheric Polar vortex (PoV).



**Ecology example.** Convergent cross mapping (CCM) shows that sardine and anchovy abundances are both affected by sea surface temperatures (SSTs).

# Climate Change and Global Warming

Main source: NASA Global Climate Change

## Definitions

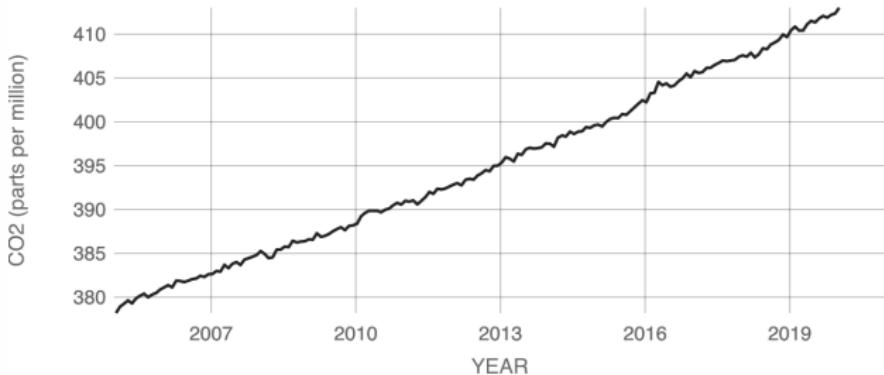
**Climate change** refers to changes in Earth's climate system which

- results in new weather patterns
- remain in place for an extended period of time

**Global Warming** refers to the long-term rise in the average temperature of the Earth's climate system.

The current warming trend is extremely likely to be **the result of human activity** since the mid-20th century.

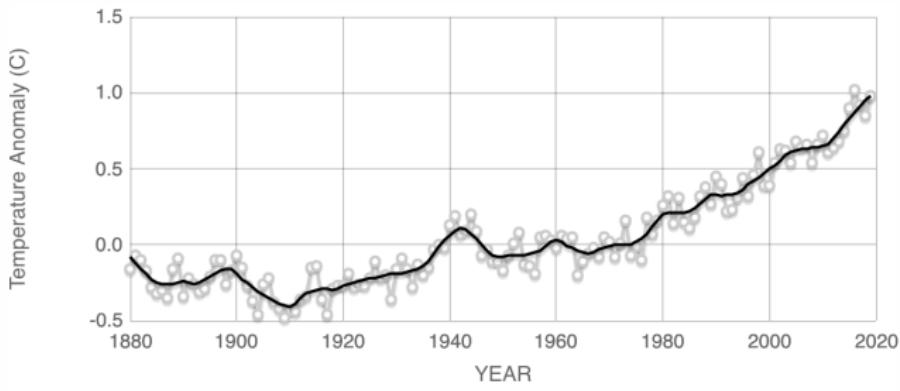
## Evidence: Carbon Dioxide



Source: climate.nasa.gov

- Ocean absorbs 25% of the CO<sub>2</sub> that humans create from burning fossil fuels (oil, coal, and natural gas)
- If too much, the ocean is becoming more acidic, e.g., the animals may not be able to make strong shells

## Evidence: Global Temperature Rise



Source: climate.nasa.gov

- Nineteen of the 20 warmest years all have occurred since 2001
- A change driven largely by increased carbon dioxide and other human-made emissions
- The year 2016 ranks as the warmest on record ( $1.02^{\circ}\text{C}$ ). [link]

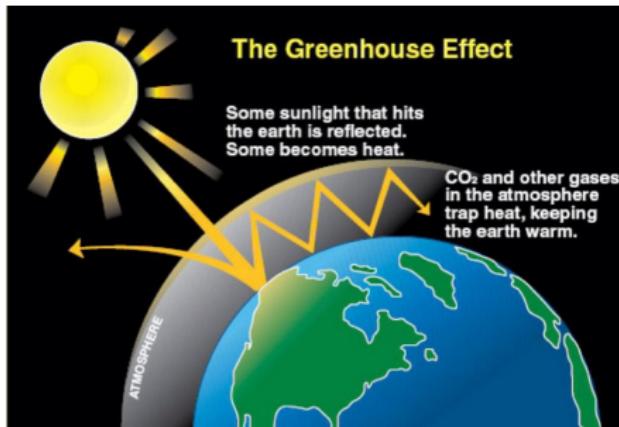
## Evidence: Warming Oceans



Source: climate.nasa.gov

- Arctic sea ice declines 12.85 percent per decade.
- Krill like to breed in really cold water near sea ice; instability in the entire food chain.
- Algae cannot carry out photosynthesis

## Finding Causes?



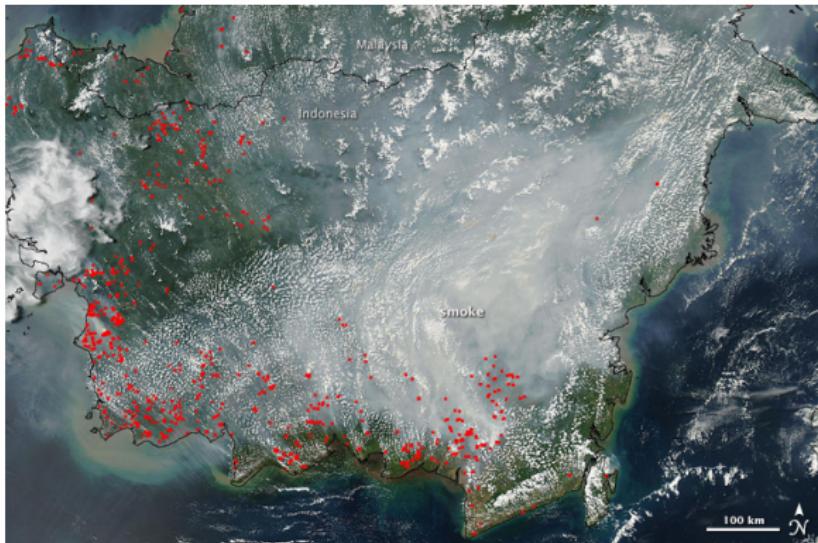
**Human activities** change the natural greenhouse via e.g.,

- burning fossil fuels (coal, oil)
- deforestation, e.g., for agriculture, industry, increases concentrations of greenhouse gases

Climate Change and Global Warming

## Deforestation in Indonesia

21 | 31



Borneo, 2009.

# Deforestation in Indonesia



Borneo, 20019.

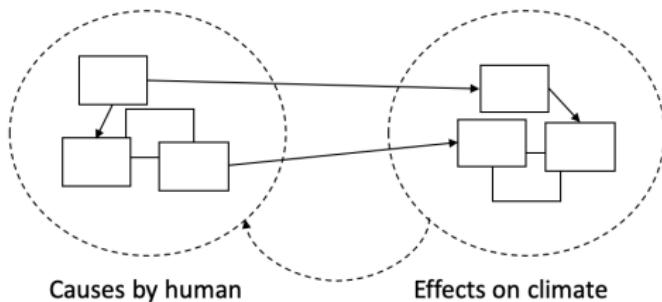
1. Global climate is projected to continue to change over this century and beyond, depending primarily on the amount of heat-trapping gases emitted globally
2. Temperatures will continue to rise
3. Frost-free season will lengthen
4. Changes in precipitation patterns
5. More droughts and heat waves
6. Hurricanes will become stronger and more intense
7. Sea level will rise 1-4 feet by 2100
8. Arctic likely to become ice-free

## Effects in Indonesia

- Temperatures in Indonesia to increase by 0.8 C by 2030
- In 2019, half of Jakarta was beneath sea level, with some neighborhoods sinking as fast as 27cm a year
- Continued carbon emissions and unlicensed groundwater extraction, is predicted to immerse 95% of Northern Jakarta by 2050
- Changes in rainfall patterns have an adverse impact on Indonesian agriculture, due to shorter rainy seasons
- Crop losses and adverse impacts to fisheries in 2007
- Impact on Indonesia's fishermen in 2020

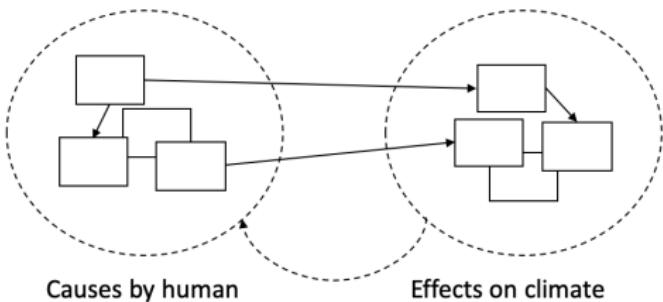
- It is currently the world's fifth biggest emitter of greenhouse gases
- The commitment under the Paris agreement: cutting emissions from deforestation by 29 percent below business-as-usual projections by 2030.
- BUT, The government plans to build more than 100 coal-fired power plants, and expand the production of palm oil for local biofuel consumption, which will involve further deforestation of carbon-rich tropical forests.

## Linking causes to effects



- Variable *cluster* on the left of indicates human activity (& related factors) that causes
- Cluster on the right represents possible effects on climate
- Modeling causal relations within and/or between the two clusters is of interest

## Linking causes to effects



- Cluster of causes should also focus on *other factors*, e.g., culture motivation in deforestation
- The arc from effect cluster to the cause cluster represents impact of climate change on human, which is also important

# Methodological Challenges

## Challenges

### Process:

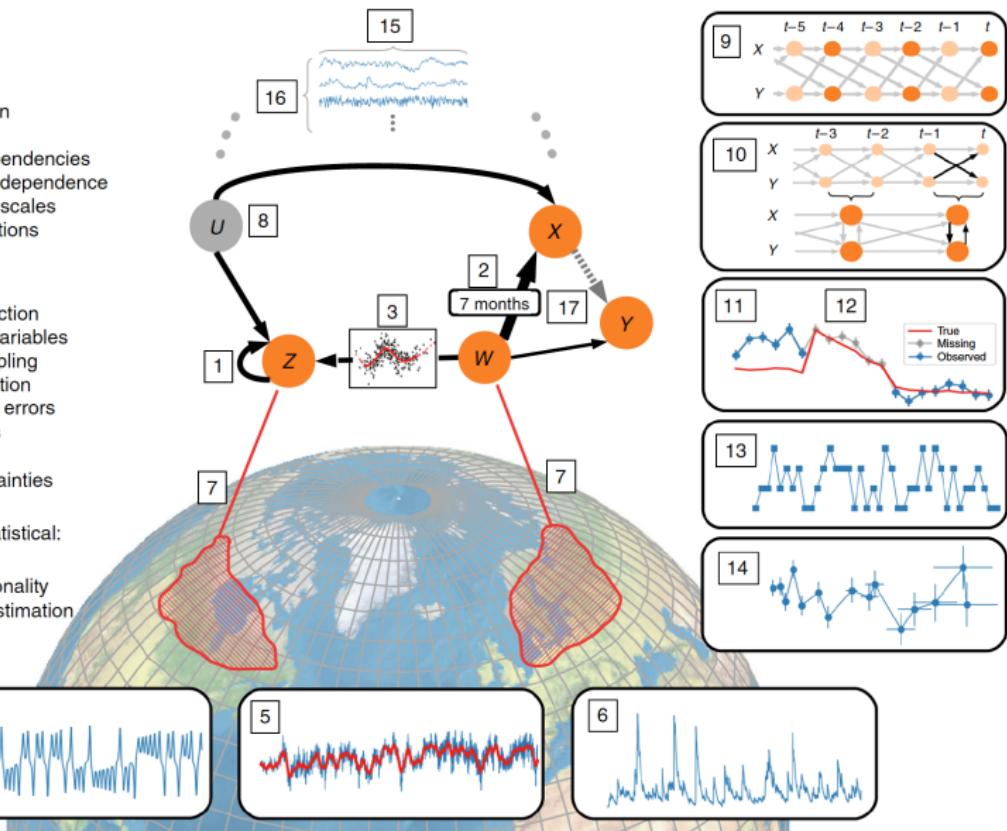
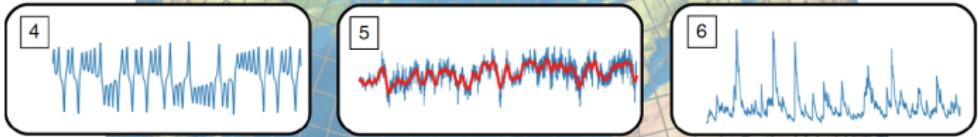
- 1 Autocorrelation
- 2 Time delays
- 3 Nonlinear dependencies
- 4 Chaotic state-dependence
- 5 Different time scales
- 6 Noise distributions

### Data:

- 7 Variable extraction
- 8 Unobserved variables
- 9 Time subsampling
- 10 Time aggregation
- 11 Measurement errors
- 12 Selection bias
- 13 Discrete data
- 14 Dating uncertainties

### Computational/statistical:

- 15 Sample size
- 16 High dimensionality
- 17 Uncertainty estimation



## Useful Sources

30 | 31

- <https://www.data.gov/climate/>
- <https://climate.nasa.gov/>
- <https://climate.nasa.gov/interactives/climate-time-machine>

Terima Kasih!  
[ridho.rahmadi@uii.ac.id](mailto:ridho.rahmadi@uii.ac.id)  
08112951304