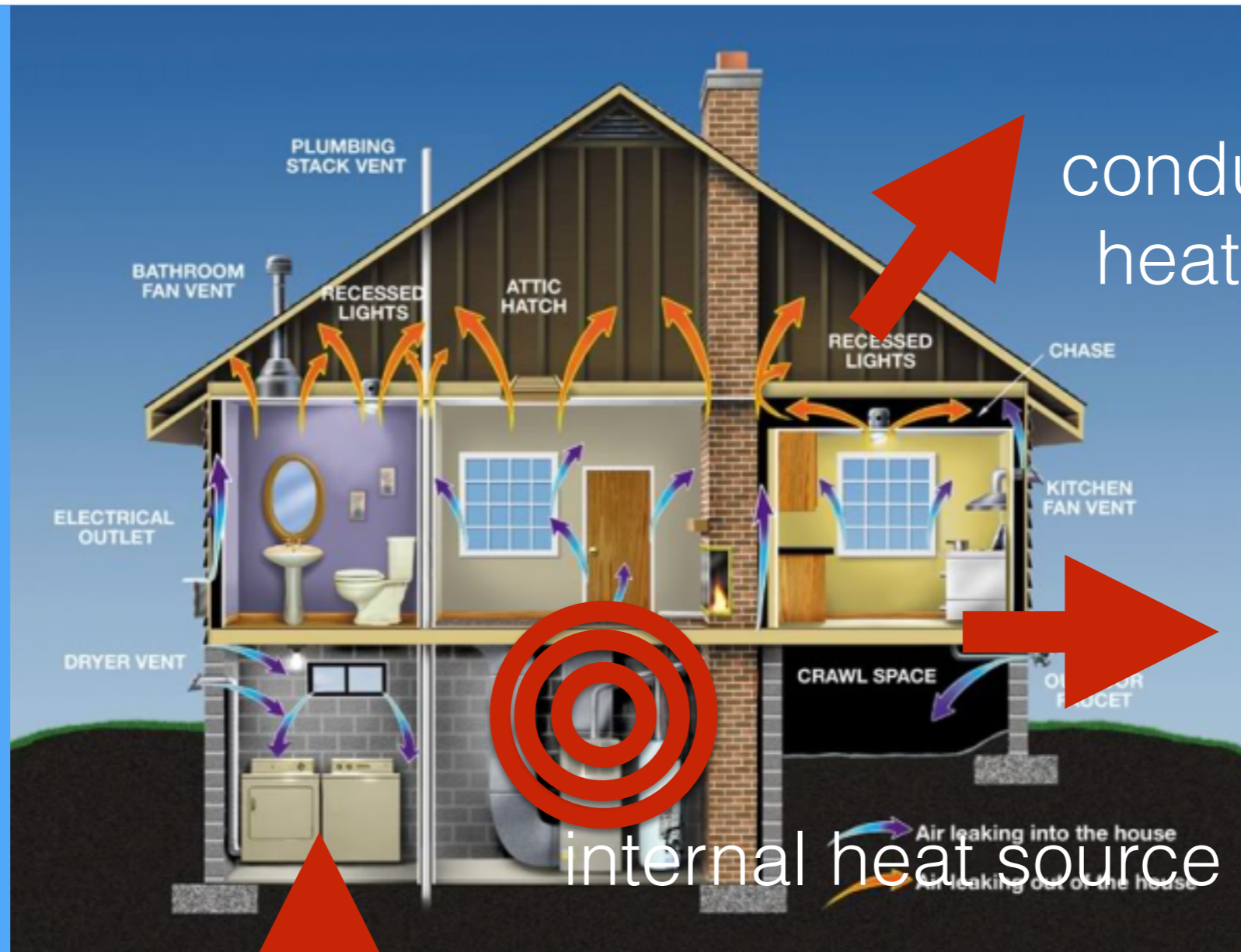


# Heat flow and serial covariance

# This week's objectives

- Carry out a **calibration** of the thermistors.
- **Explore Pandas:** read, resample and merge time series data.
- **Evaluate** your temperature time series to observe the correlation between what you measured and the outside temperature.
- **Determine** covariance and lagged covariance between your data and the outside temperature.

# Winter heat flow

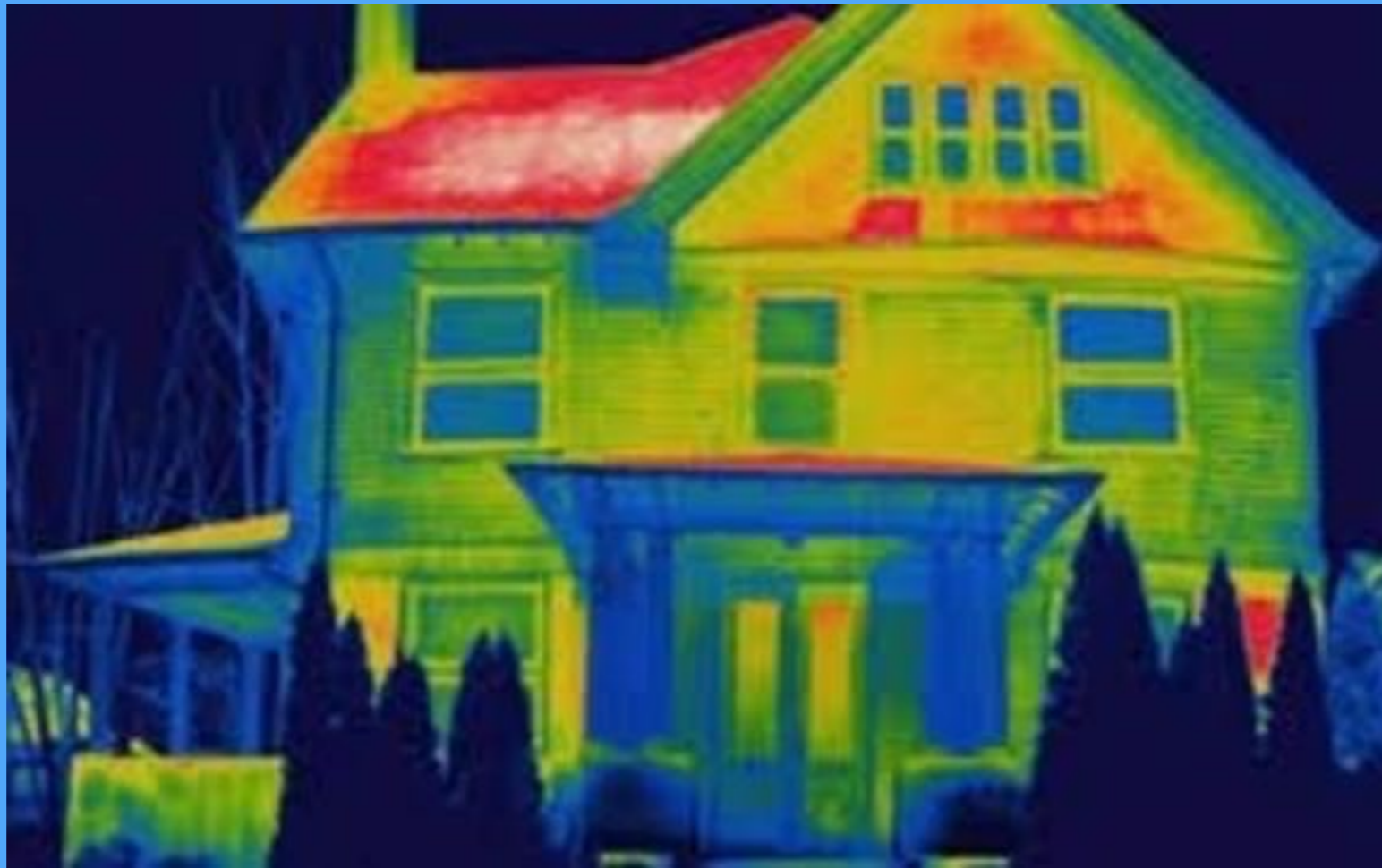


conductive  
heat loss

internal heat source

geothermal heat in

# Winter heat flow

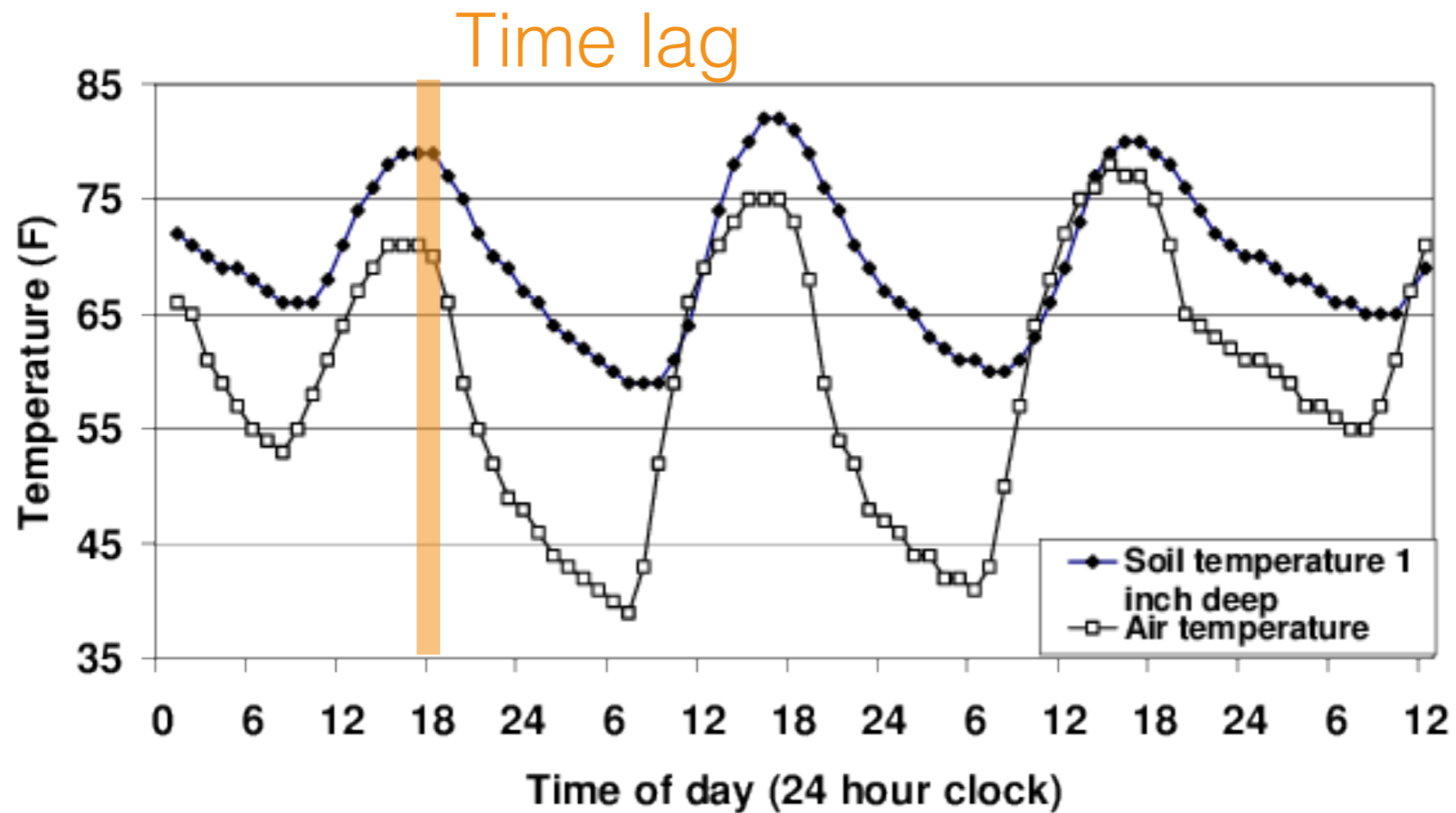


# How well-insulated is your home?

- Does the inside temperature follow the outside temperature?
- Is there a time lag, or does the inside temperature respond immediately?
- Can we quantify the insulating properties of your house?

# Example: Soil is a good insulator

## Soil and air temperature daily variation

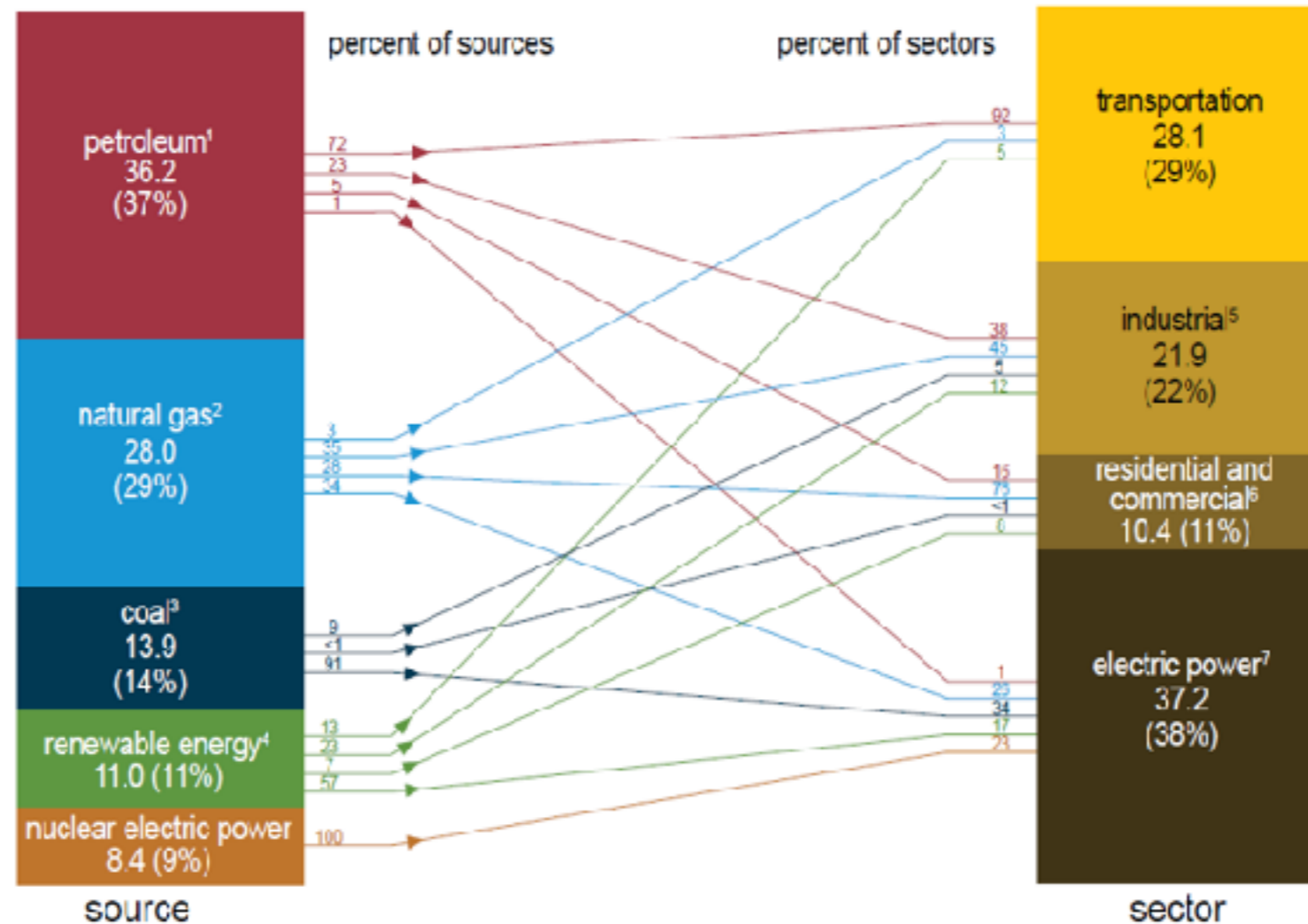




# Energy use in the US

U.S. primary energy consumption by source and sector, 2017

Total = 97.7 quadrillion British thermal units (Btu)



18% of external consumption

<sup>1</sup> Does not include biofuels that have been blended with petroleum—biofuels are included in "Renewable Energy."  
<sup>2</sup> Excludes supplemental gaseous fuels.  
<sup>3</sup> Includes -0.03 quadrillion Btu of coal coke net imports.  
<sup>4</sup> Conventional hydroelectric power, geothermal, solar, wind, and biomass.  
<sup>5</sup> Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.  
<sup>6</sup> Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.  
<sup>7</sup> Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes 0.17 quadrillion Btu of electricity net imports not shown under "source."

Notes: • Primary energy is energy in the form that it is accounted for in a statistical energy balance, before any transformation to secondary or tertiary forms of energy occurs (for example, coal is used to generate electricity). • The source total may not equal the sector total because of differences in the heat contents of total, end-use, and electric power sector consumption of natural gas. • Data are preliminary. • Values are derived from source data prior to rounding. • Sum of components may not equal total due to independent rounding.  
 Sources: U.S. Energy Information Administration, *Monthly Energy Review* (April 2018), Tables 1.3, 1.4a, 1.4b, and 2.1-2.6

# Simple heat flow solution

- If we assume no furnace,
- no geothermal heat,
- and its colder outside than inside:

$$\frac{dH}{dt} = -k\Delta H \frac{1}{dA}$$

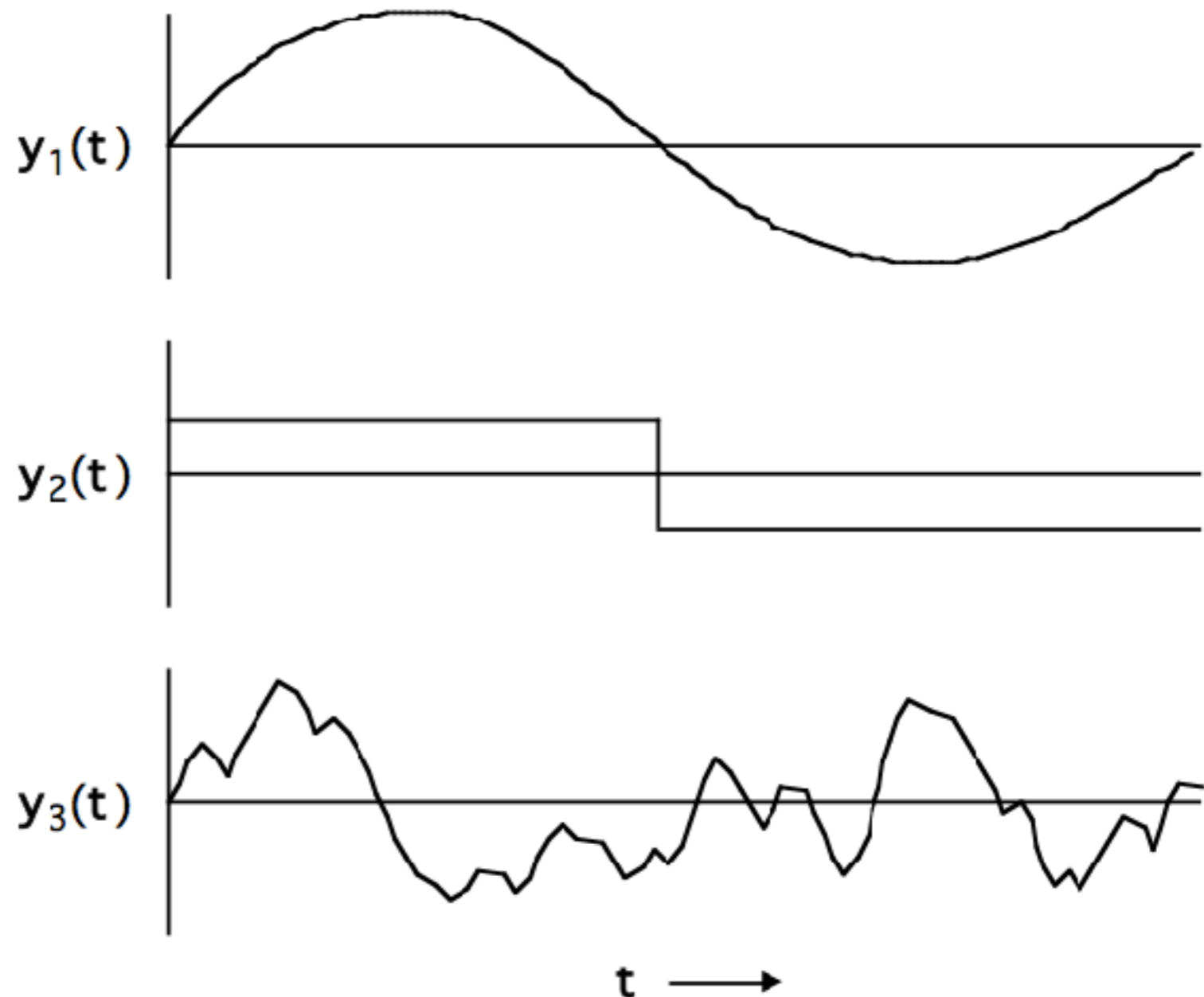
$$H = \rho C_p T$$

$$\Delta H = \rho C_p \left( T_{house} - T_{Air} \right)$$

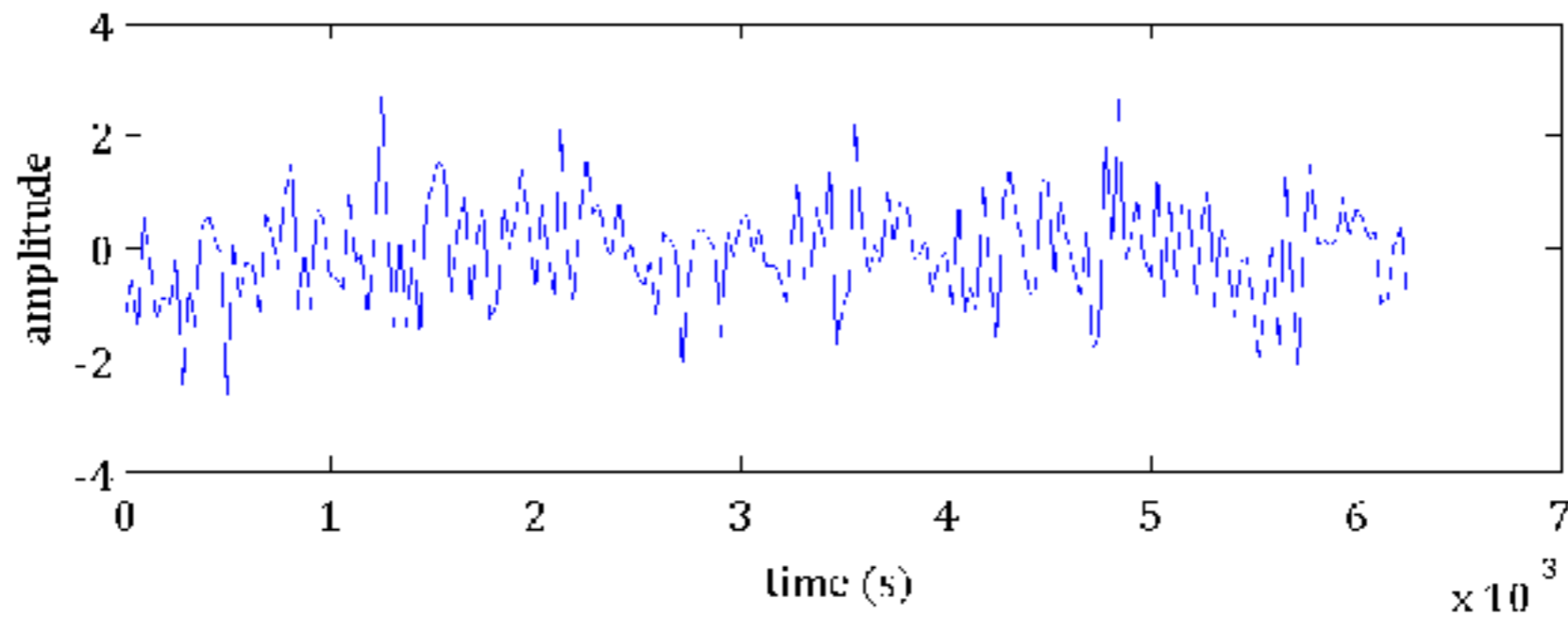
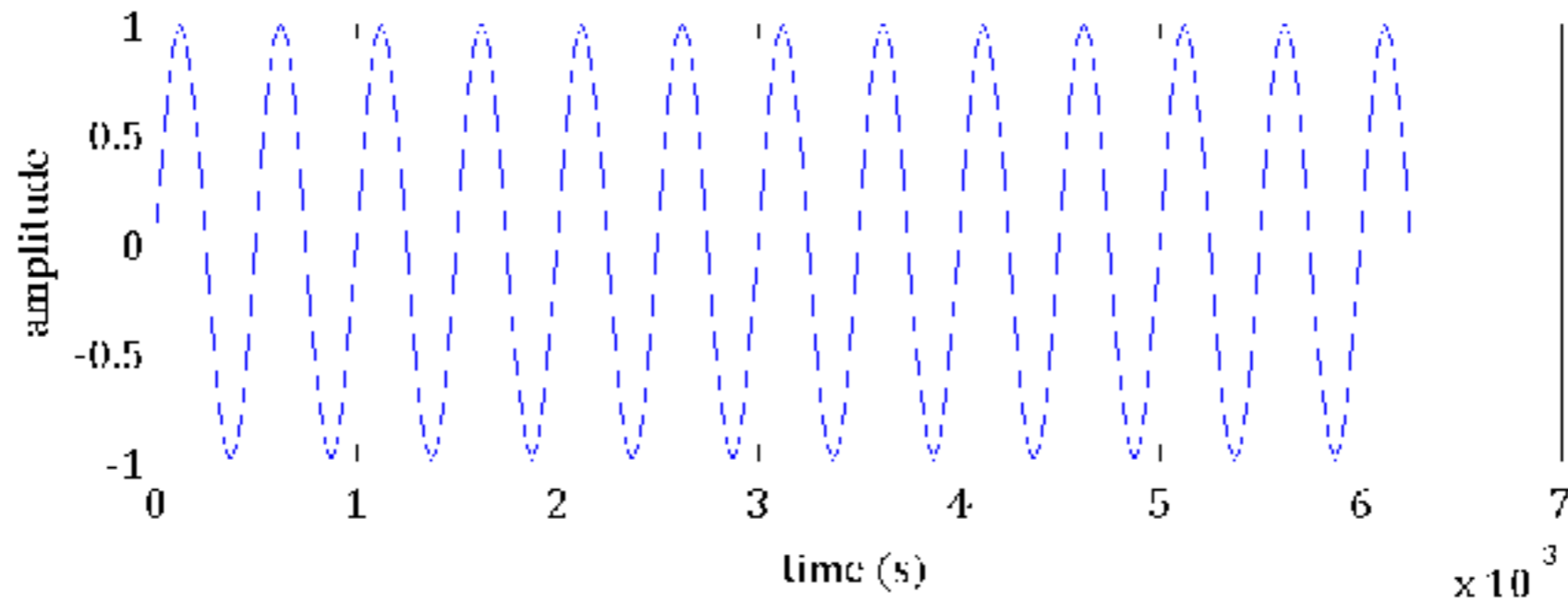


# Time Series

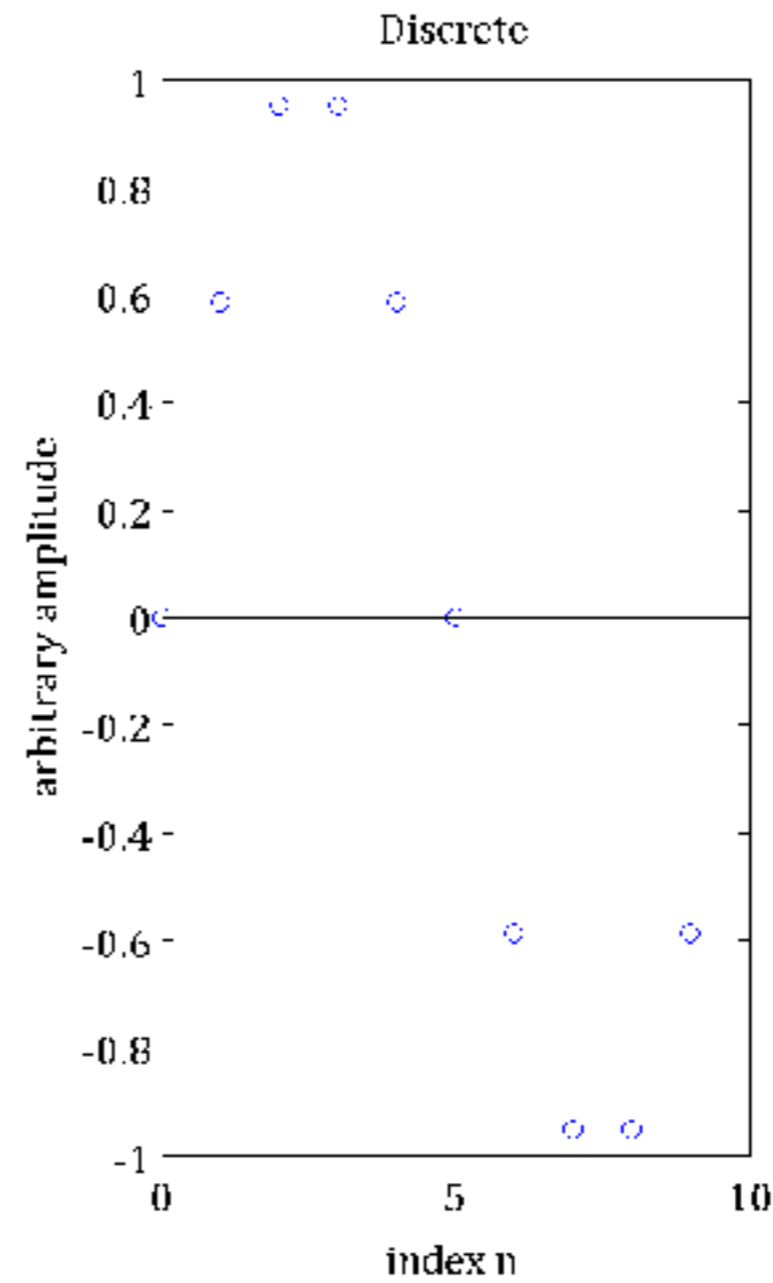
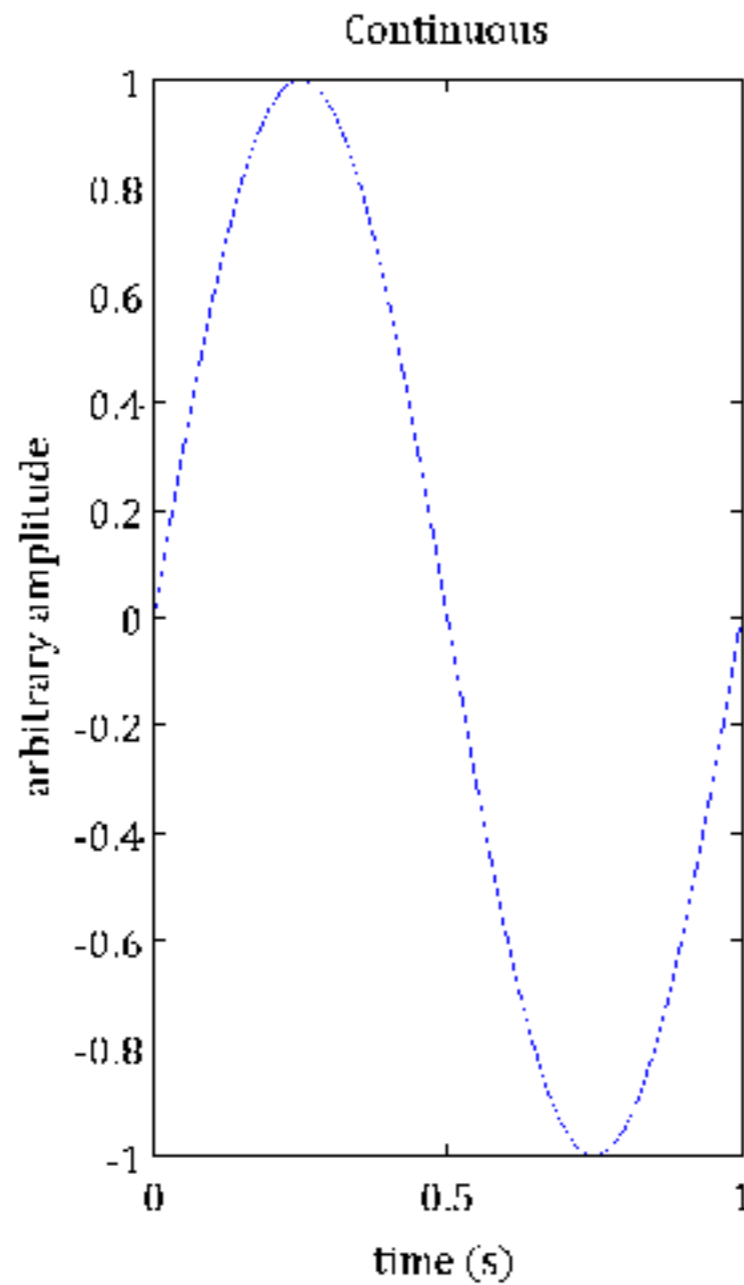
- Sequential data – often called “time series data” even when the data is actually sequential in space or other dimension. *In general time series data is any sequential data.*



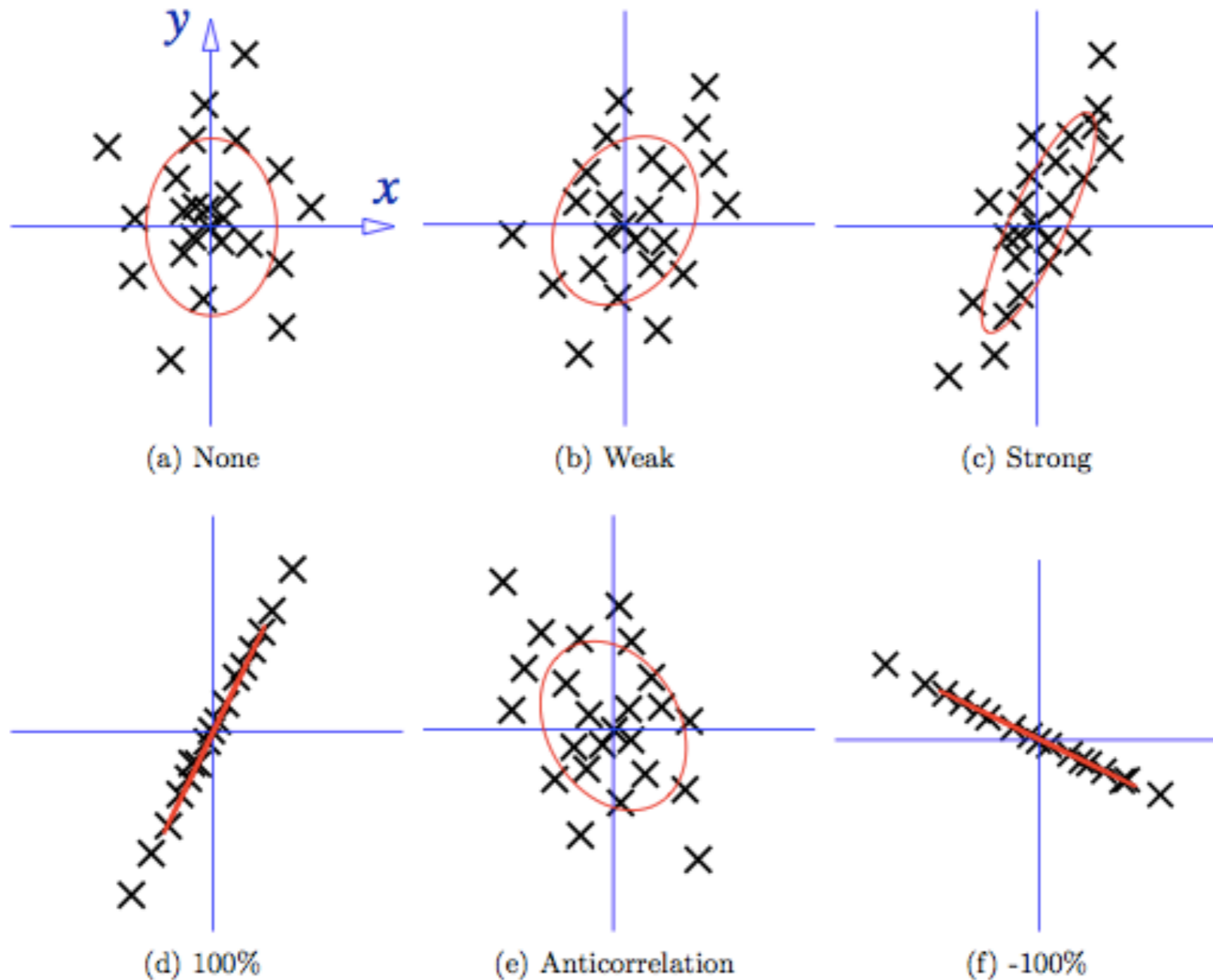
# Periodic vs. Aperiodic



# Continuous vs. discrete



# Correlation/Covariance

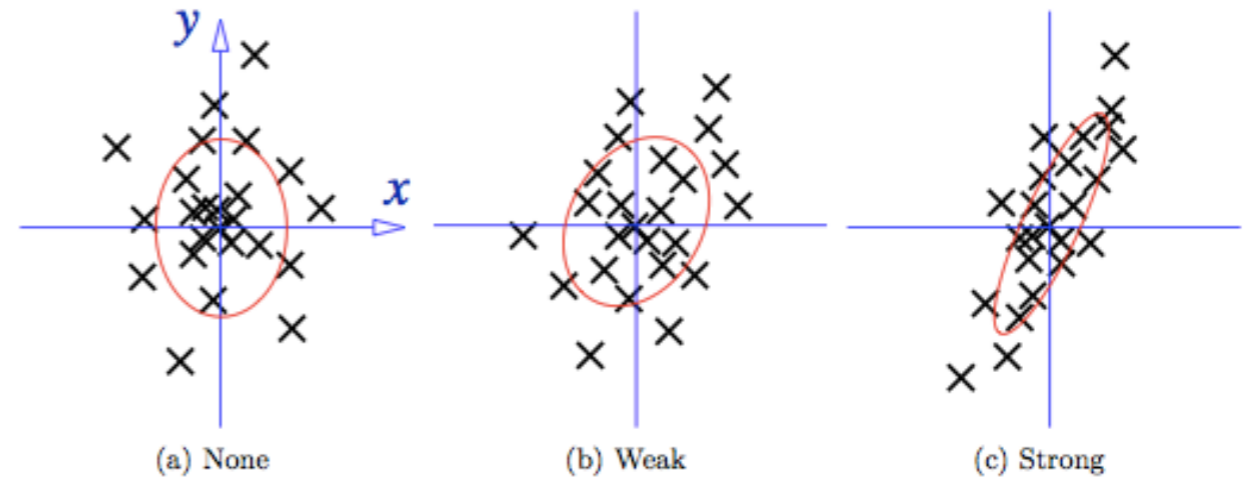


# Correlation/Covariance

- Recall Variance:  $Var[Y] = E[(Y - E[Y])^2]$

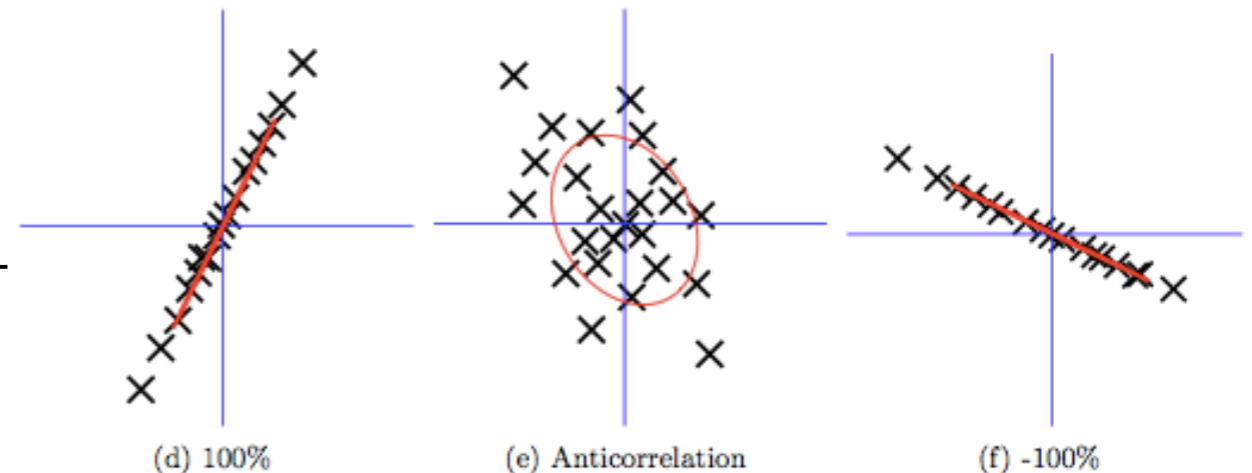
- Covariance:

$$Cov[X, Y] = E[(Y - E[Y])(X - E[X])]$$



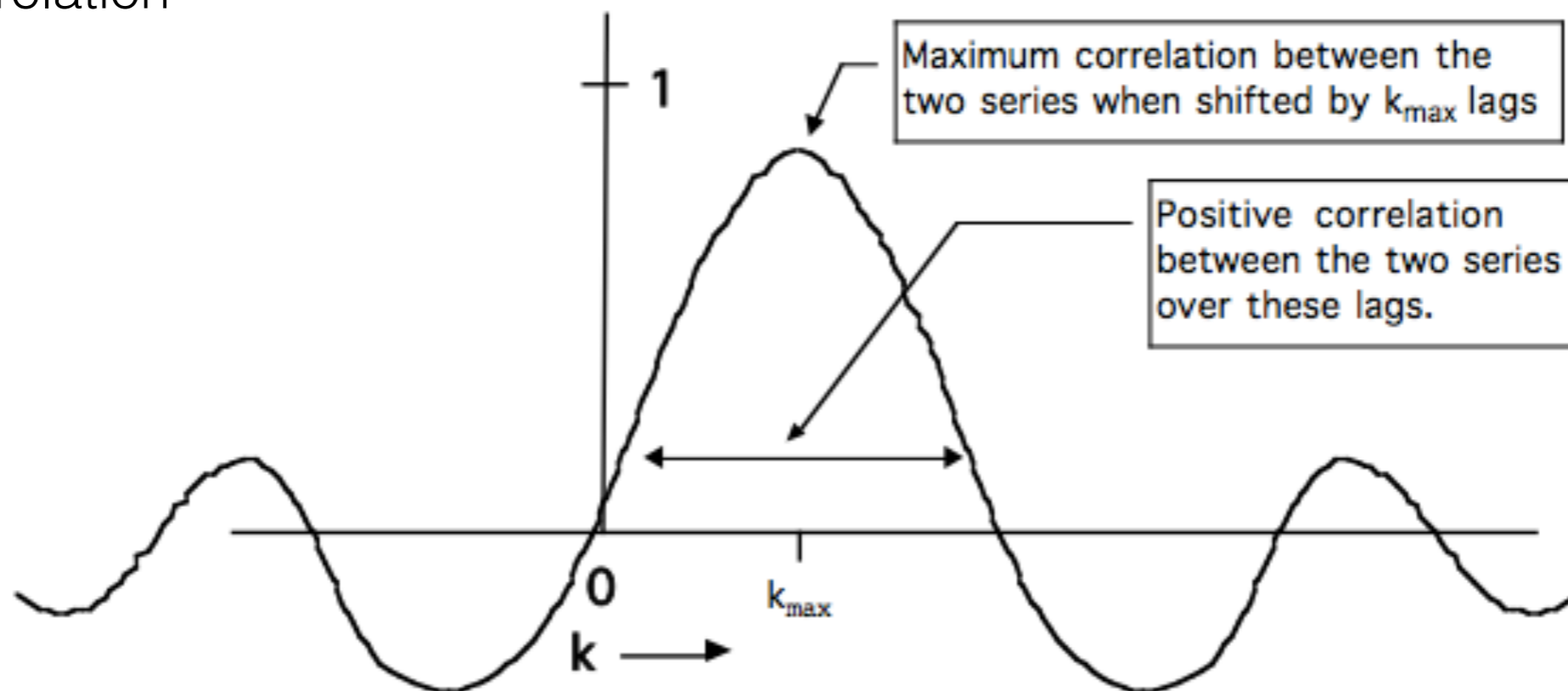
- Correlation:

$$Corr[X, Y] = \frac{E[(Y - E[Y])(X - E[X])]}{\sqrt{Var[X] \cdot Var[Y]}}$$



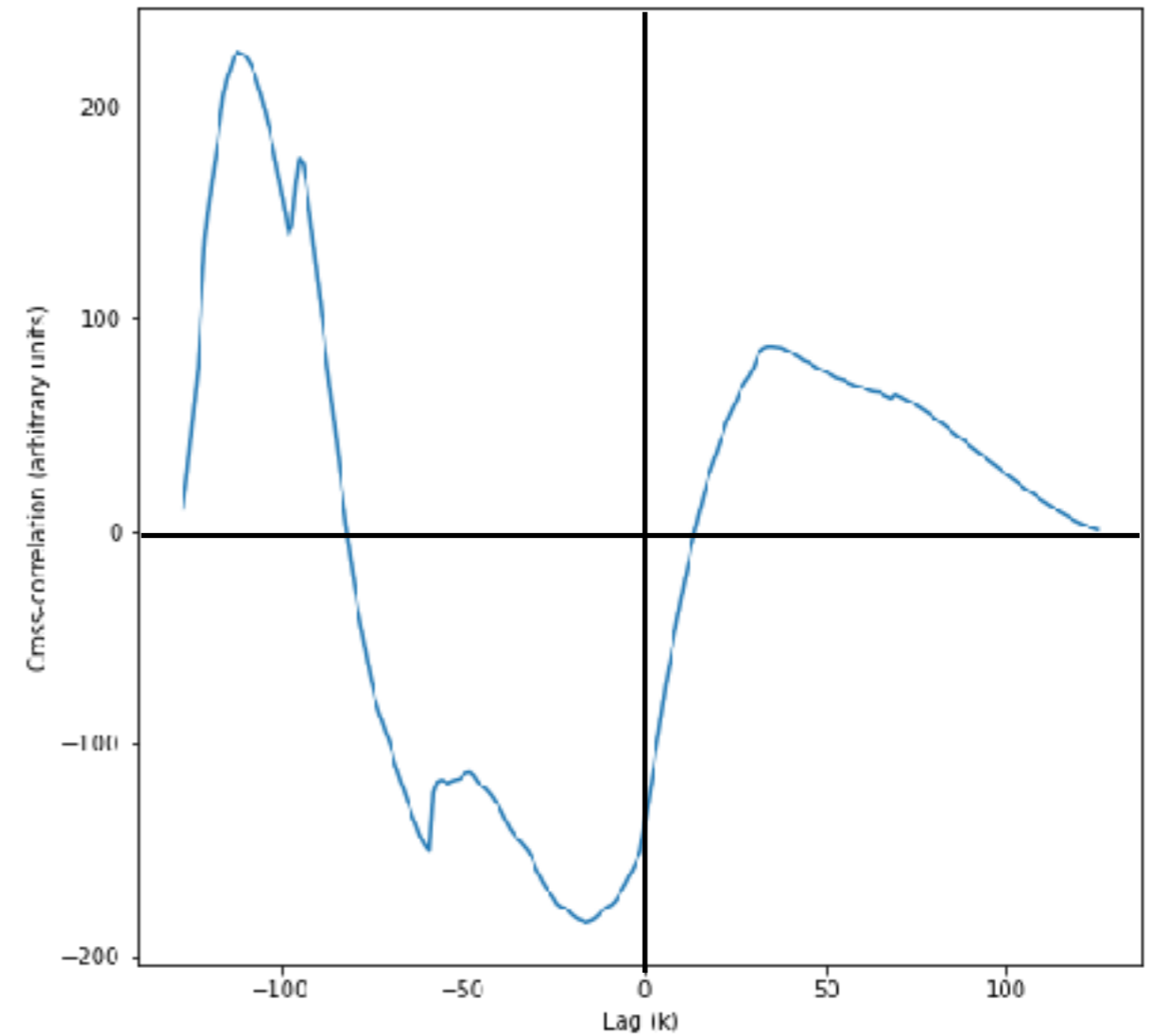
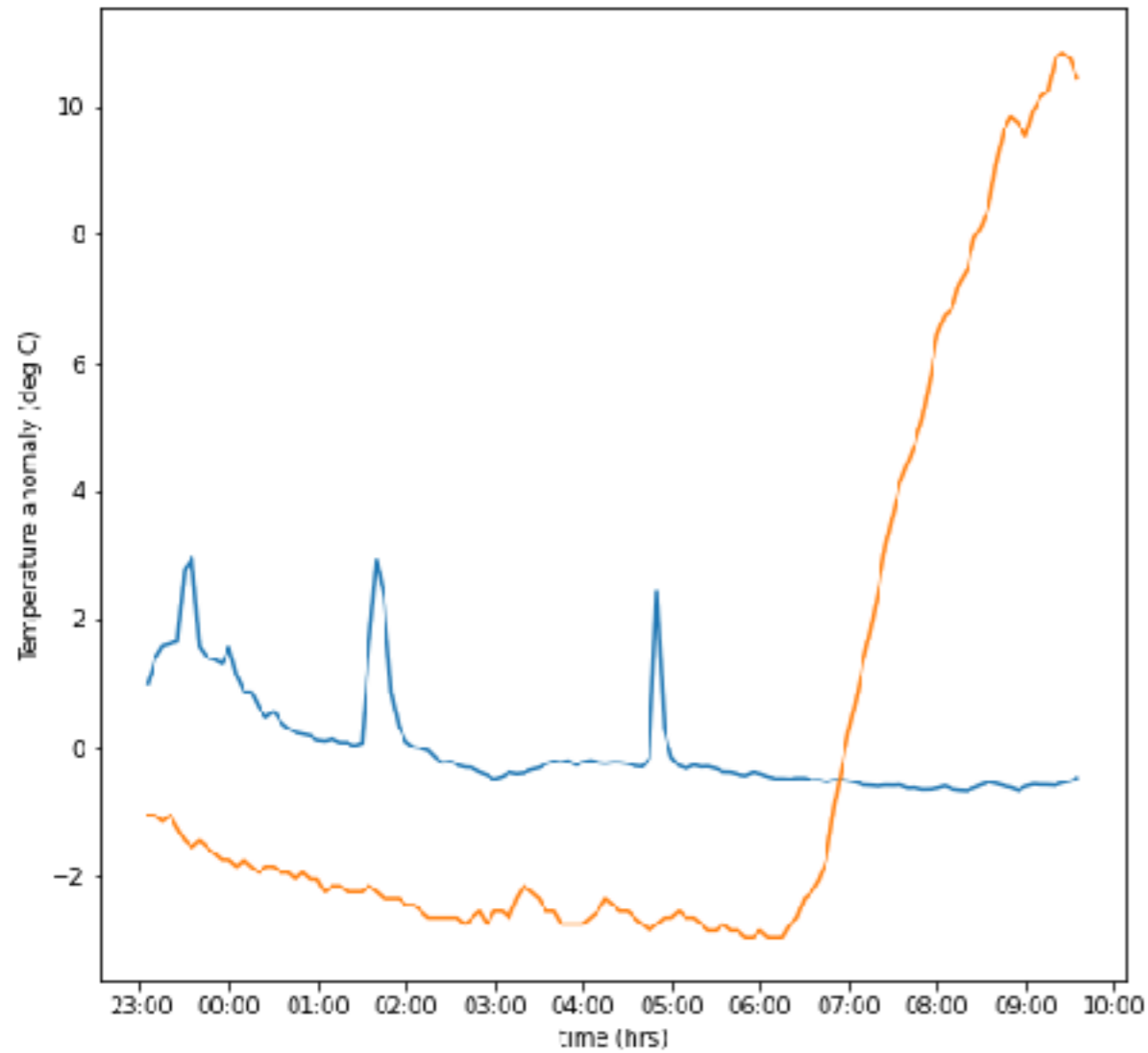
# Serial covariance

- Decorrelation length – correlation must approach zero and remain insignificantly different from zero
- Test for significance in the correlation between sequential variables
- N-3-k – because we calculate mean of both series and chose where to start the correlation



This entire time series is significantly correlated

# Example





# Time series pre-processing steps

- All timeseries analysis requires that data be evenly spaced, with a constant delta  $t$ .
- Comparison between timeseries requires both series to have the **same** delta  $t$ .
- Timeseries data must be detrended or de-meanned before carrying out analysis. Result produces mean = 0.