

# Climate Studies

introduction to climate science

## Chapter 3

# Tools for Investigating Earth's Climate System

# Essential Questions

- Why are tools necessary for investigating the climate system?
- Which tools are useful to climate studies?
- What kind of graphical descriptors are useful for data display?
- How are descriptive statistics useful in scientific investigations?
- Why are geospatial tools appropriate for climate studies?
- How are numerical models related to statistical tools?

# Introduction

- Observational data without any kind of analysis tells us nothing
- To make sense of the vast amounts of data, **statistical analysis** is utilized
  - analysis, interpretation and presentation of large quantities of data

# Measuring Using Statistical Procedures

- Two types of statistics
  - Descriptive
    - Describes data as given- quantitatively
  - Inferential
    - Tests of hypotheses, making predictions, drawing conclusions
- Deals with uncertainty

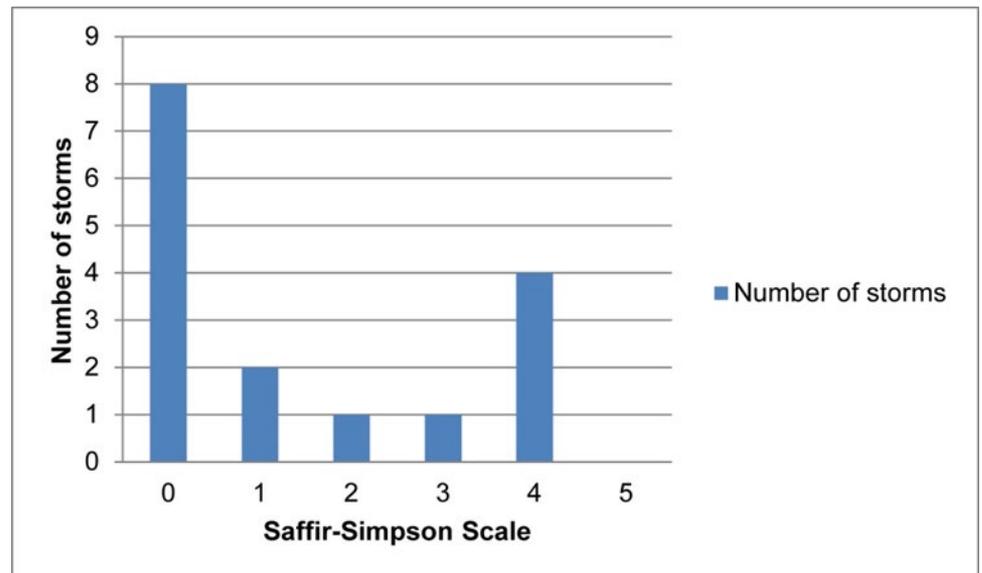
# Measuring Using Statistical Procedures

## Displays of Statistical Data

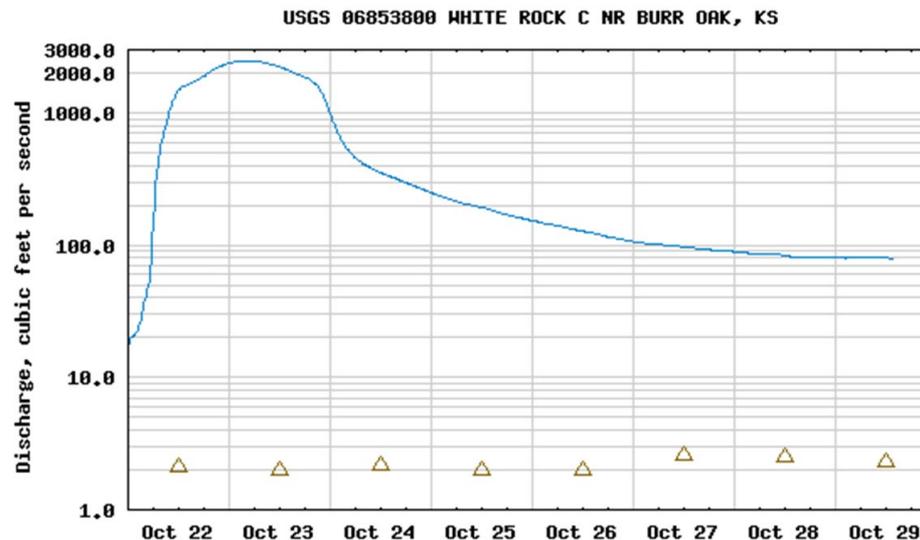
- **Frequency distribution**

- how many of each value exists in the group, within a simple, one-dimensional set of numbers

| Scale | # of times |
|-------|------------|
| 0     | 8          |
| 1     | 2          |
| 2     | 1          |
| 3     | 1          |
| 4     | 4          |
| 5     | 0          |

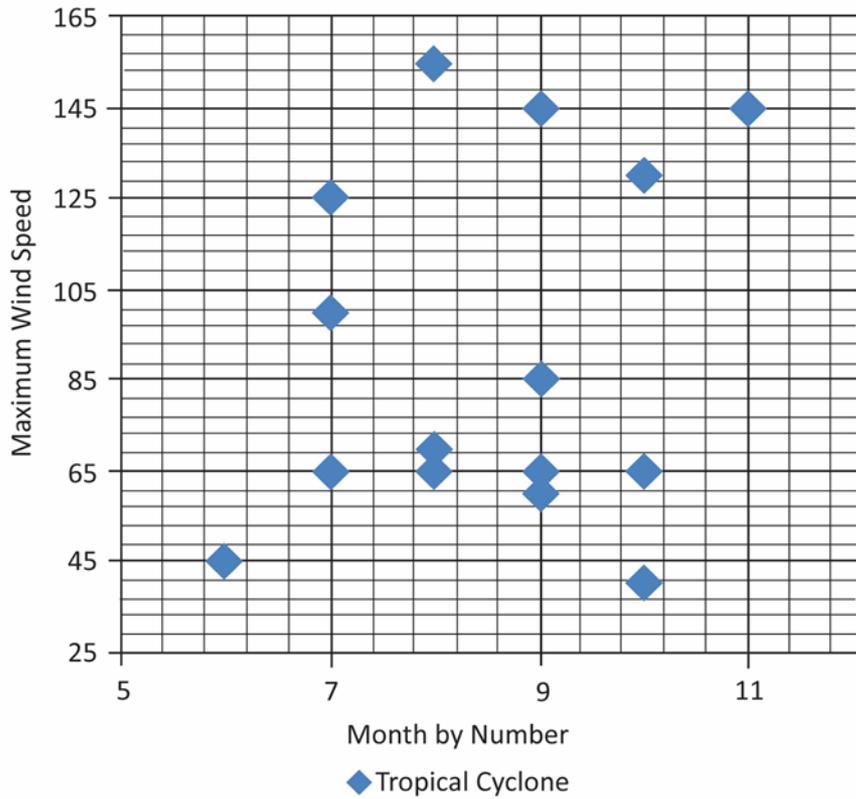


- Common standards when creating graphical representations of data
  - Axes scales should be linear (Saffir-Simpson graph) OR logarithmic (stream discharge)

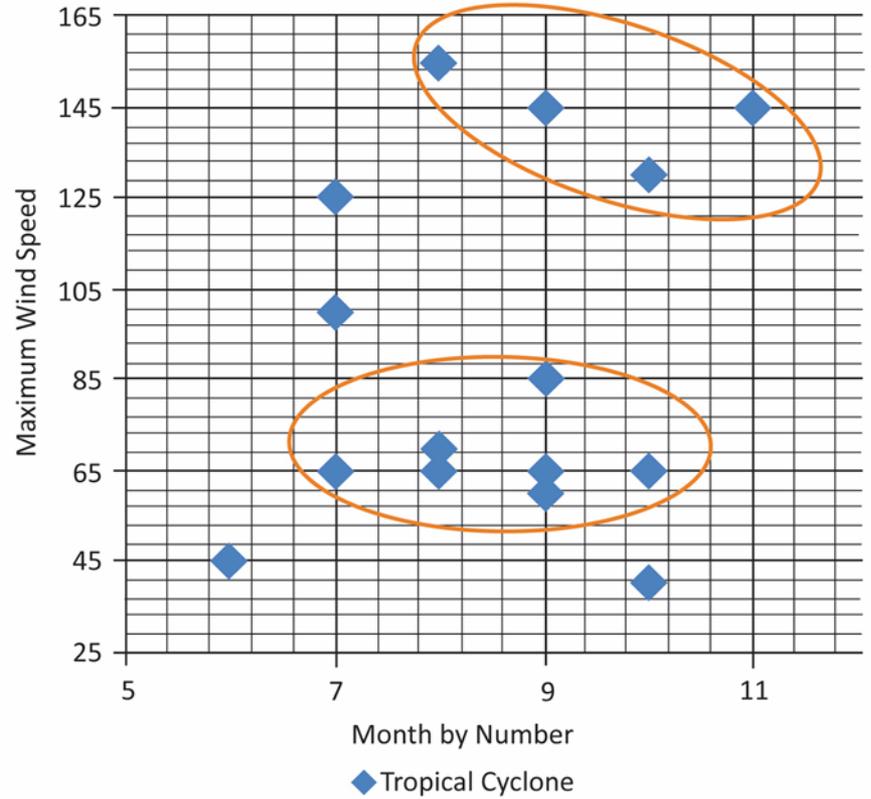


- Two dimensional data
  - Two values associated with each point
  - General relationship found by clustering of points
  - Scatter plot or scattergram used

### Scattergram



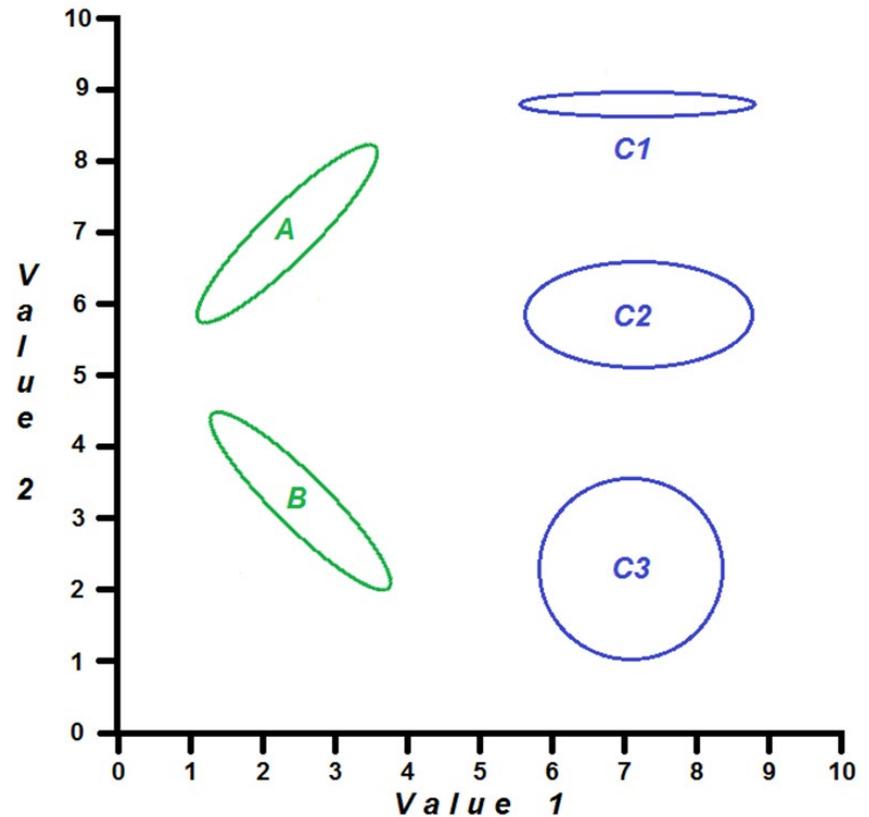
### Scattergram with identified clusters



| Storm Name | Month | Max Wind | Point     | Saffir-Simpson Category at Peak |
|------------|-------|----------|-----------|---------------------------------|
| Arthur     | 6     | 45       | (6, 45)   | 0                               |
| Bertha     | 7     | 125      | (7, 125)  | 3                               |
| Cristobal  | 7     | 65       | (7, 65)   | 0                               |
| Dolly      | 7     | 100      | (7, 100)  | 2                               |
| Edouard    | 8     | 65       | (8, 65)   | 0                               |
| Fay        | 8     | 70       | (8, 70)   | 0                               |
| Gustav     | 8     | 155      | (8, 155)  | 4                               |
| Hanna      | 9     | 85       | (9, 85)   | 1                               |
| Ike        | 9     | 145      | (9, 145)  | 4                               |
| Josephine  | 9     | 65       | (9, 65)   | 0                               |
| Kyle       | 9     | 85       | (9, 85)   | 1                               |
| Laura      | 9     | 60       | (9, 60)   | 0                               |
| Marco      | 10    | 65       | (10, 65)  | 0                               |
| Nana       | 10    | 40       | (10, 40)  | 0                               |
| Omar       | 10    | 130      | (10, 130) | 4                               |
| Paloma     | 11    | 145      | (11, 145) | 4                               |

Table 3.2 Atlantic 2008 hurricane season cyclones by month with maximum sustained wind speeds including dual-value point pair.

- Analyzed scattergram shows the type of relationship between values based upon shape of the cluster



- Pie graphs are used to represent how pieces of data relate to the data as a whole

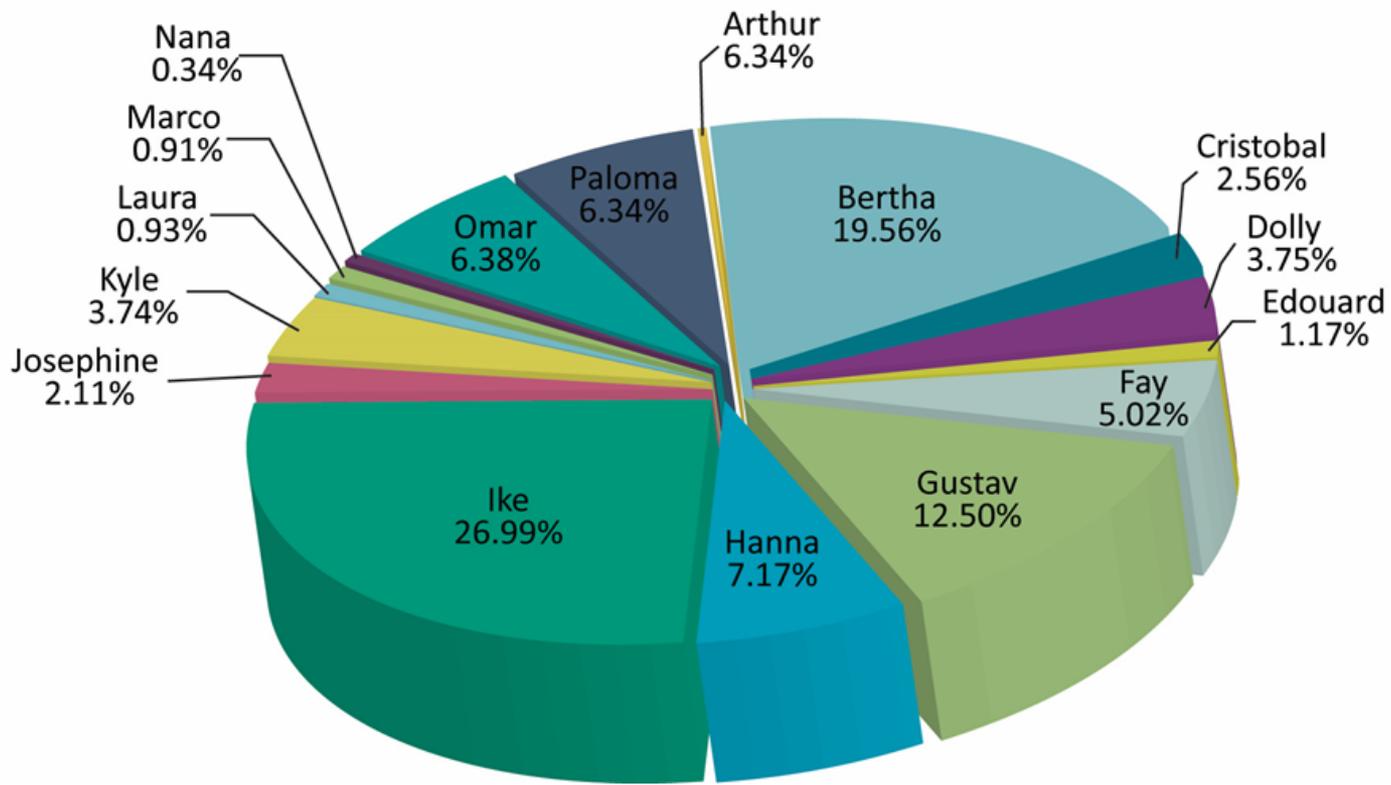
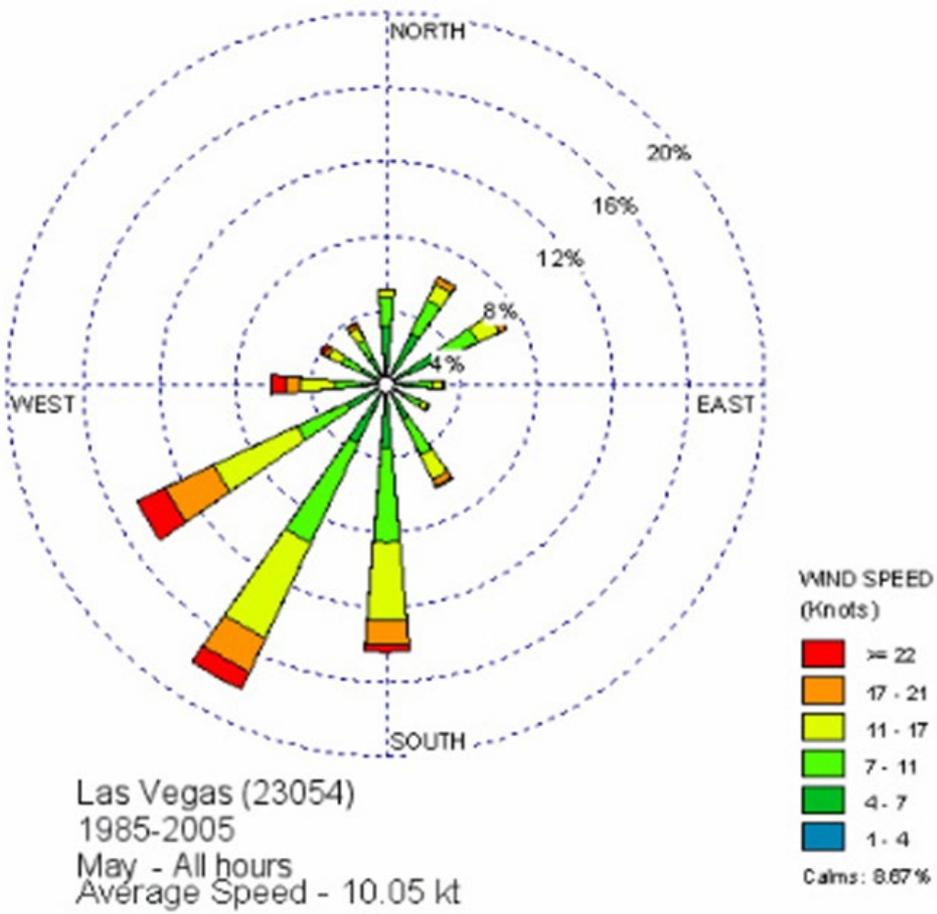


Table 3.3 2008 Atlantic tropical cyclones, their respective ACE values and the percentage of the overall total for the entire season.

| <u>Storm Name</u> | <u>ACE Value</u> | <u>Percent</u> |
|-------------------|------------------|----------------|
| Arthur            | 0.77             | 0.53           |
| Bertha            | 28.40            | 19.56          |
| Cristobal         | 3.71             | 2.56           |
| Dolly             | 5.45             | 3.75           |
| Edouard           | 1.70             | 1.17           |
| Fay               | 7.29             | 5.02           |
| Gustav            | 18.15            | 12.50          |
| Hanna             | 10.41            | 7.17           |
| Ike               | 39.19            | 26.99          |
| Josephine         | 3.07             | 2.11           |
| Kyle              | 5.43             | 3.74           |
| Laura             | 1.35             | 0.93           |
| Marco             | 1.32             | 0.91           |
| Nana              | 0.49             | 0.34           |
| Omar              | 9.27             | 6.38           |
| Paloma            | 9.20             | 6.34           |

- Information with a directional component can be displayed on a radial graph



# Measuring Using Statistical Procedures

## Descriptive Statistics

- **Descriptive statistics** - a succinct quantitative summary of the characteristics of a variable or data set
- Many types can be used
  - Each has advantages and limitations
  - Selecting the appropriate measure is the first step to understanding the data set

# Displays of Statistical Data

## Central Tendency

- Most commonly used: mean, median or mode
- **Mean** - the sum of a set of values divided by the number of observations in the same set

$$\mu = \frac{(x_1 + x_2 + x_3 + \dots x_n)}{n}$$

$\mu$  = mean value of our data set

$x_n$  = the individual values of the data set

$n$  = number of observations in the data set

# Displays of Statistical Data

## Central Tendency

- **Median** - middle value in a set of ranked observations, so there are an equal number of values above it and below it
- **Mode** - the value that occurs most frequently or appears most often in a data set

# Displays of Statistical Data

## Central Tendency

|           | <u>Mean<br/>(in.)</u> | <u>High<br/>(in.)</u> | <u>Year</u> | <u>Low<br/>(in.)</u> | <u>Year</u> | <u>1 Day Max<br/>(in.)</u> | <u>1 Day Max<br/>(date)</u> | <u>≥0.01in<br/>(# days)</u> | <u>≥0.10in<br/>(# days)</u> | <u>≥0.50in<br/>(# days)</u> | <u>≥1.00in<br/>(# days)</u> |
|-----------|-----------------------|-----------------------|-------------|----------------------|-------------|----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| January   | 0.62                  | 1.48                  | 1960        | 0.00                 | 1981        | 1.01                       | 1/3/71                      | 5                           | 2                           | 0                           | 0                           |
| February  | 0.83                  | 3.86                  | 1965        | 0.00                 | 1985        | 1.92                       | 2/27/58                     | 5                           | 2                           | 0                           | 0                           |
| March     | 1.99                  | 6.34                  | 1973        | 0.00                 | 1988        | 2.15                       | 3/23/87                     | 7                           | 4                           | 1                           | 0                           |
| April     | 2.68                  | 7.61                  | 1978        | 0.15                 | 1989        | 1.76                       | 4/21/84                     | 8                           | 5                           | 2                           | 1                           |
| May       | 4.27                  | 9.98                  | 1996        | 1.10                 | 1989        | 4.16                       | 5/6/07                      | 10                          | 7                           | 3                           | 1                           |
| June      | 4.46                  | 12.93                 | 1967        | 0.70                 | 1988        | 4.59                       | 6/24/63                     | 9                           | 6                           | 3                           | 1                           |
| July      | 3.83                  | 11.66                 | 1993        | 0.00                 | 1983        | 5.79                       | 7/26/90                     | 8                           | 5                           | 3                           | 1                           |
| August    | 3.61                  | 9.92                  | 1982        | 0.08                 | 1976        | 3.80                       | 8/15/96                     | 8                           | 5                           | 3                           | 1                           |
| September | 3.31                  | 8.61                  | 1973        | 0.28                 | 1974        | 3.06                       | 9/5/56                      | 8                           | 5                           | 2                           | 1                           |
| October   | 2.12                  | 6.08                  | 1986        | 0.05                 | 1958        | 3.50                       | 10/12/86                    | 6                           | 4                           | 1                           | 1                           |
| November  | 1.19                  | 3.65                  | 1996        | 0.00                 | 1976        | 2.09                       | 11/30/97                    | 4                           | 2                           | 1                           | 0                           |
| December  | 0.86                  | 2.48                  | 1984        | 0.04                 | 1976        | 2.20                       | 12/16/84                    | 5                           | 2                           | 0                           | 0                           |
| Annual    | 29.79                 | 44.59                 | 1986        | 17.79                | 1976        | 5.79                       | 7/26/90                     | 83                          | 51                          | 20                          | 8                           |
| Winter    | 2.32                  | 4.88                  | 2007        | 0.65                 | 1977        | 2.20                       | 12/16/84                    | 15                          | 6                           | 1                           | 0                           |
| Spring    | 8.94                  | 15.63                 | 1959        | 1.25                 | 1989        | 4.16                       | 5/6/07                      | 26                          | 16                          | 6                           | 2                           |
| Summer    | 11.91                 | 22.88                 | 1993        | 2.42                 | 1976        | 5.79                       | 7/26/90                     | 25                          | 17                          | 8                           | 3                           |
| Fall      | 6.62                  | 15.77                 | 1973        | 2.42                 | 1980        | 3.50                       | 10/12/86                    | 18                          | 11                          | 4                           | 2                           |

# Displays of Statistical Data

## Dispersion

- **Range** - the arithmetic difference between the smallest and the largest values of the group
- **Average deviation** - the average amount of spread of the numbers from the middle value

# Displays of Statistical Data

## Dispersion

| <u>Storm Name</u> | <u>ACE Value</u> | <u>Absolute Deviation</u> |
|-------------------|------------------|---------------------------|
| Arthur            | 0.77             | $ 0.77 - 9.08  = 8.31$    |
| Bertha            | 28.40            | $ 28.4 - 9.08  = 19.32$   |
| Cristobal         | 3.71             | $ 3.71 - 9.08  = 5.37$    |
| Dolly             | 5.45             | $ 5.45 - 9.08  = 3.63$    |
| Edouard           | 1.70             | $ 1.70 - 9.08  = 7.38$    |
| Fay               | 7.29             | $ 7.29 - 9.08  = 1.79$    |
| Gustav            | 18.15            | $ 18.15 - 9.08  = 9.07$   |
| Hanna             | 10.41            | $ 10.41 - 9.08  = 1.33$   |
| Ike               | 39.19            | $ 39.19 - 9.08  = 30.11$  |
| Josephine         | 3.07             | $ 3.07 - 9.08  = 6.01$    |
| Kyle              | 5.43             | $ 5.43 - 9.08  = 3.65$    |
| Laura             | 1.35             | $ 1.35 - 9.08  = 7.73$    |
| Marco             | 1.32             | $ 1.32 - 9.08  = 7.76$    |
| Nana              | 0.49             | $ 0.49 - 9.08  = 8.59$    |
| Omar              | 9.27             | $ 9.27 - 9.08  = 0.19$    |
| Paloma            | 9.20             | $ 9.20 - 9.08  = 0.12$    |

ACE Sum = 145.19  
ACE Mean = 9.08  
Deviation Sum = 120.36  
Deviation Average = 7.52

- **Variance** - square of standard deviation
  - Provides a measure of the average squared deviation
- **Standard Deviation** - common measure of the spread of the values about a middle position in a group

$$\sigma = \frac{\sqrt{\sum(x_i - \mu)^2}}{n}$$

$\mu$  = mean value

$x_i$  = individual values

$n$  = number of observations in the data set

# Displays of Statistical Data

## Dispersion

| Storm Name | ACE Value | ACE – Mean | (ACE – Mean) <sup>2</sup> |
|------------|-----------|------------|---------------------------|
| Arthur     | 0.77      | -8.31      | 69.01                     |
| Bertha     | 28.40     | 19.32      | 373.26                    |
| Cristobal  | 3.71      | -5.37      | 28.84                     |
| Dolly      | 5.45      | -3.63      | 13.18                     |
| Edouard    | 1.70      | -7.38      | 54.46                     |
| Fay        | 7.29      | -1.79      | 3.20                      |
| Gustav     | 18.15     | 9.07       | 82.27                     |
| Hanna      | 10.41     | 1.33       | 1.77                      |
| Ike        | 39.19     | 30.11      | 906.61                    |
| Josephine  | 3.07      | -6.01      | 36.12                     |
| Kyle       | 5.43      | -3.65      | 13.32                     |
| Laura      | 1.35      | -7.73      | 59.75                     |
| Marco      | 1.32      | -7.76      | 60.22                     |
| Nana       | 0.49      | -8.59      | 73.79                     |
| Omar       | 9.27      | 0.19       | 0.03                      |
| Paloma     | 9.20      | 0.12       | 0.01                      |

Sum = 1775.84

Sum ÷ 16 = 110.99

$\sigma = 10.54$

$\mu = 145.19 \div 16 = 9.08$

Initial values input for Arthur:  $\sigma = \sqrt{[\sum (0.77 - 9.08)^2] / 16} = \sqrt{[\sum (-8.31)^2] / (16)}$

All storms:

$\sigma = \sqrt{[1775.84/16]}$

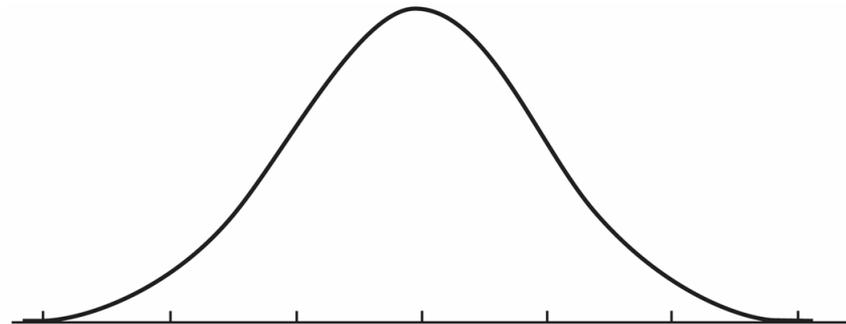
$\sigma = \sqrt{(110.99)}$

$\sigma = 10.54$

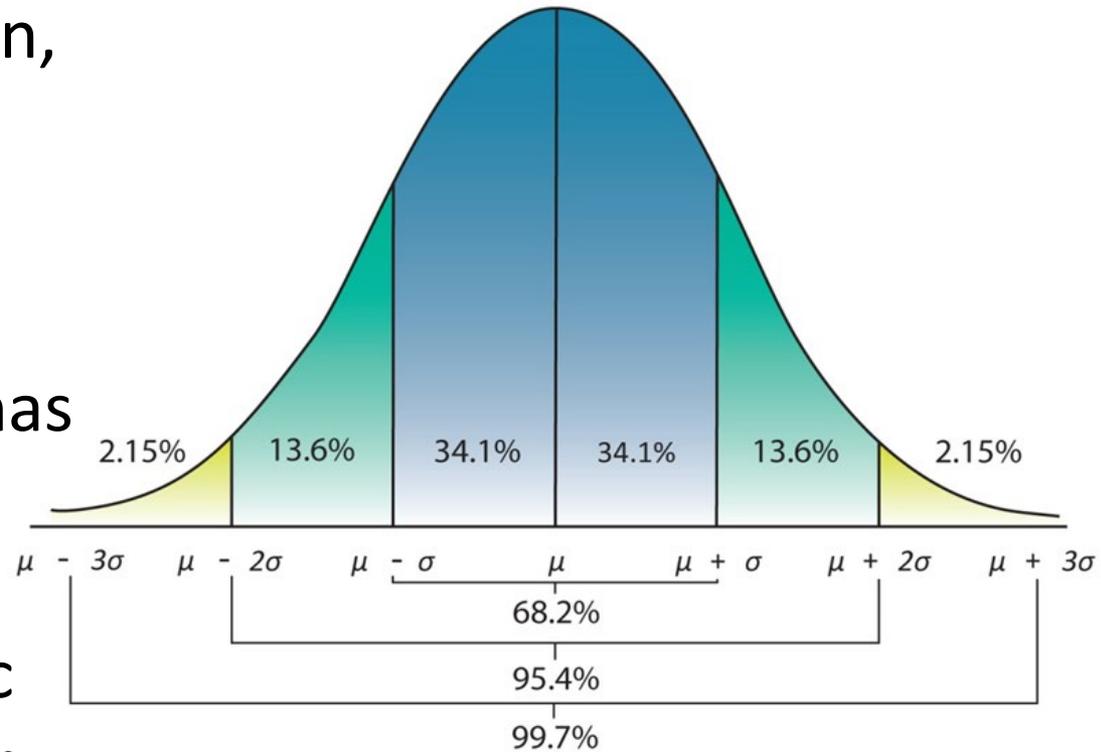
# Displays of Statistical Data

## Shape or Relative Position

- Distribution - shape of a frequency graph that is repeatable
- Most common is the normal distribution
  - Also known as the bell curve
  - Peak values most common
  - Tail values least common



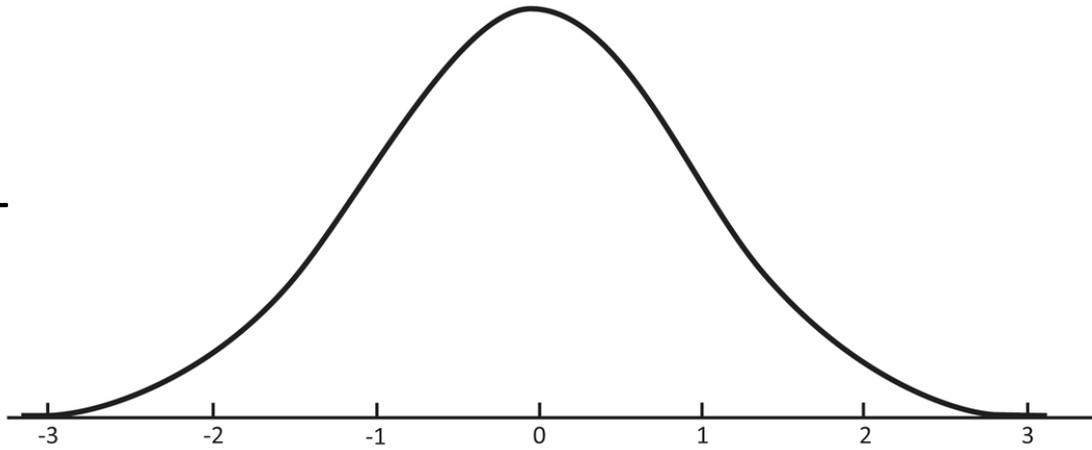
- For standard deviation, the central point is mean, median and mode
- Normal distribution has very well defined frequencies of occurrence at specific distances from center



- **Standard Score**

- mean is set to zero and each deviation is set to 1

- Indicates how many standard deviations separate a particular value from the mean of the distribution, either positive or negative, for a normal curve

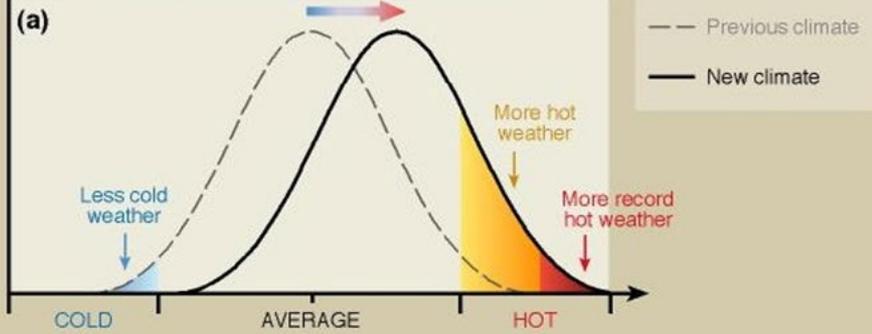


$$Z = \frac{(x - \mu)}{\sigma}$$

Z = score along horizontal axis, generally from -3 to +3  
μ = mean  
σ = standard deviation  
x = set of real values

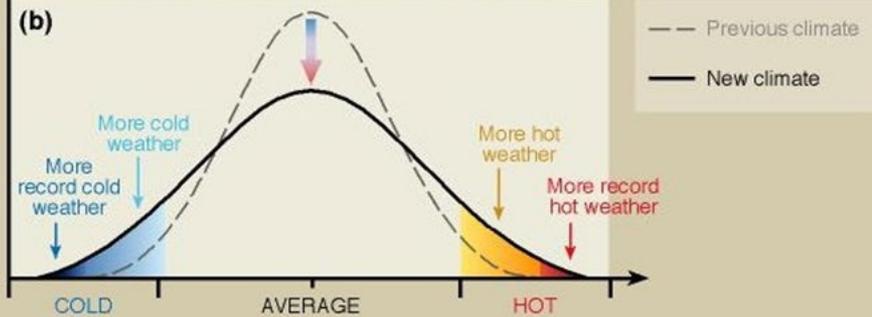
Probability of occurrence

### Increase in mean temperature



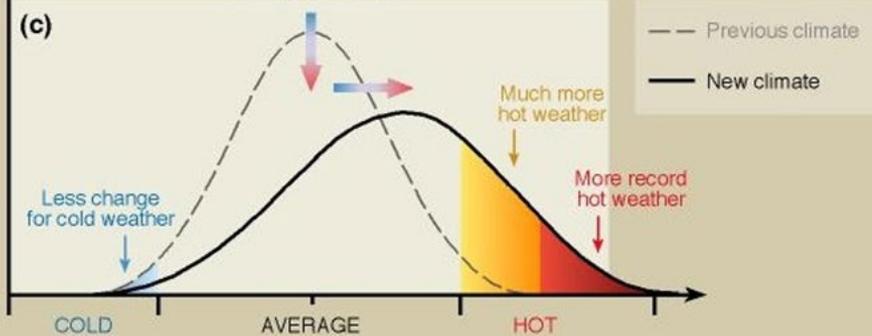
Probability of occurrence

### Increase in variance of temperature



Probability of occurrence

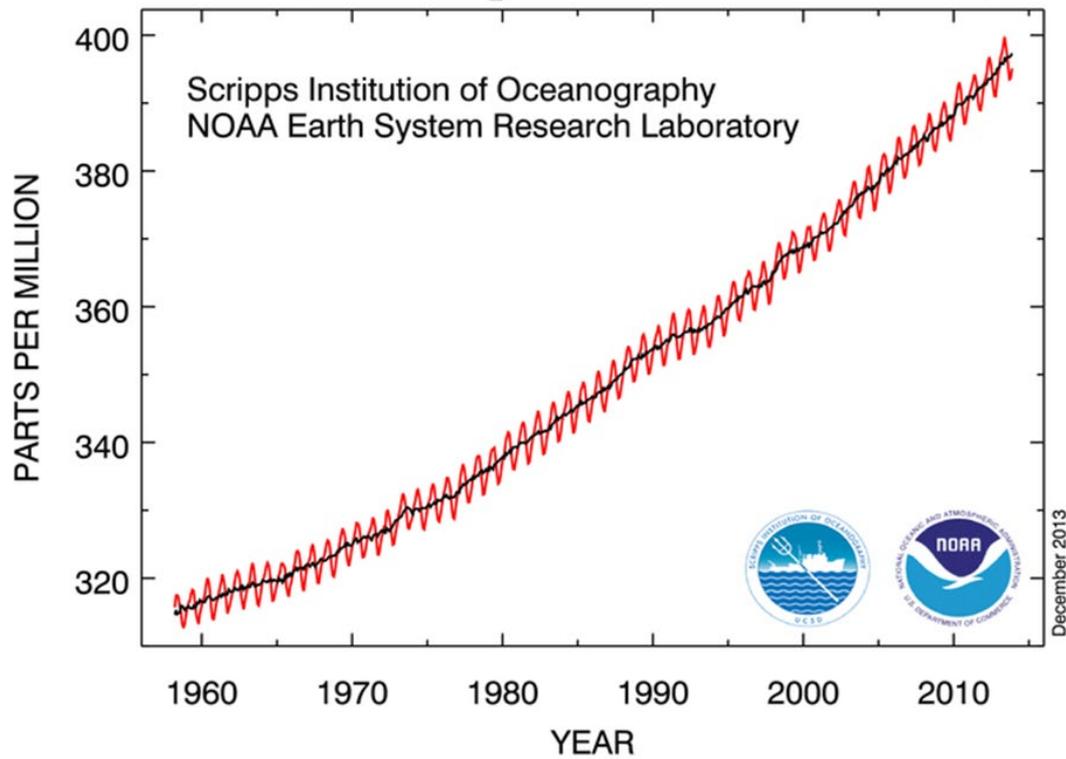
### Increase in mean and variance of temperature



- When investigating climate, time is an important factor
- **Time series** – an analysis accounting for climate observations taken over time that may have internal patterns, such as trends or seasonal variations
  - Data is often auto correlated to itself

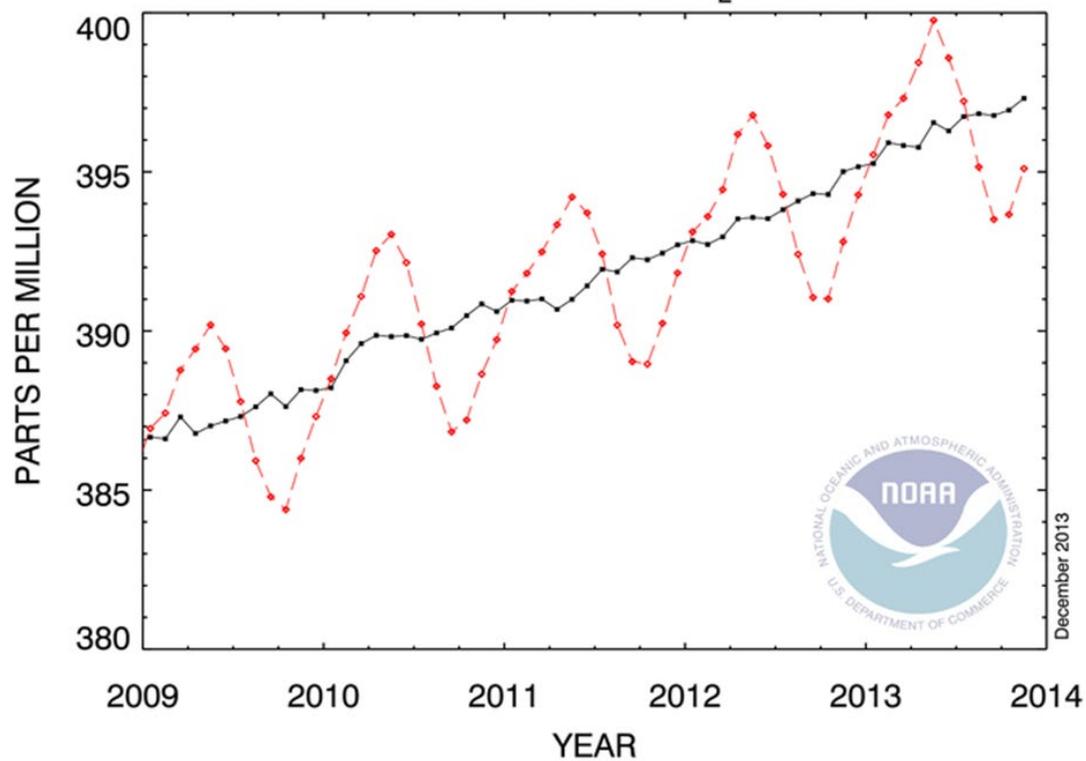
- Two major objectives in climatic time series analysis
  - Understand variation in an ECV
  - Use this understanding to forecast future changes in ECV behavior
    - Explain variations in the pattern

# Atmospheric CO<sub>2</sub> at Mauna Loa Observatory

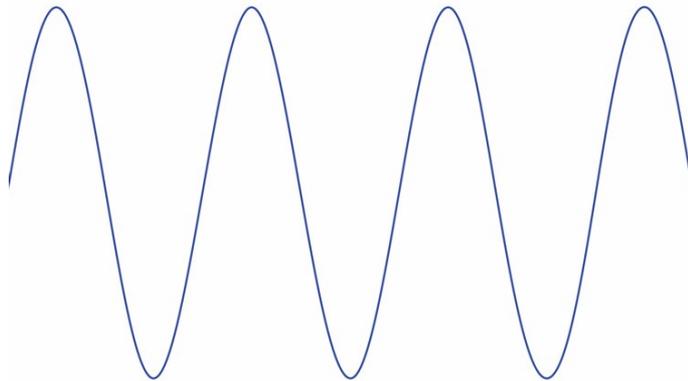


- **Trend** - the general tendency of the values to increase or decrease over time for a series
- Most linear data will utilize a line of best fit
- **Cycles** - regular fluctuations of similar magnitude and time span that can be identified in a data series
  - More complex procedures needed to handle this type of data
  - Data correction can remove seasonal cycles from data

# RECENT MONTHLY MEAN CO<sub>2</sub> AT MAUNA LOA



- The Mauna Loa data is not a pure curve
  - Peaks result from a winter build up; the rebound is slower than the decline
  - Pure cycle would be explained with a Fourier analysis
  - Resulting graph would look like the curve below



# Expected Frequency

## Recurrence Interval

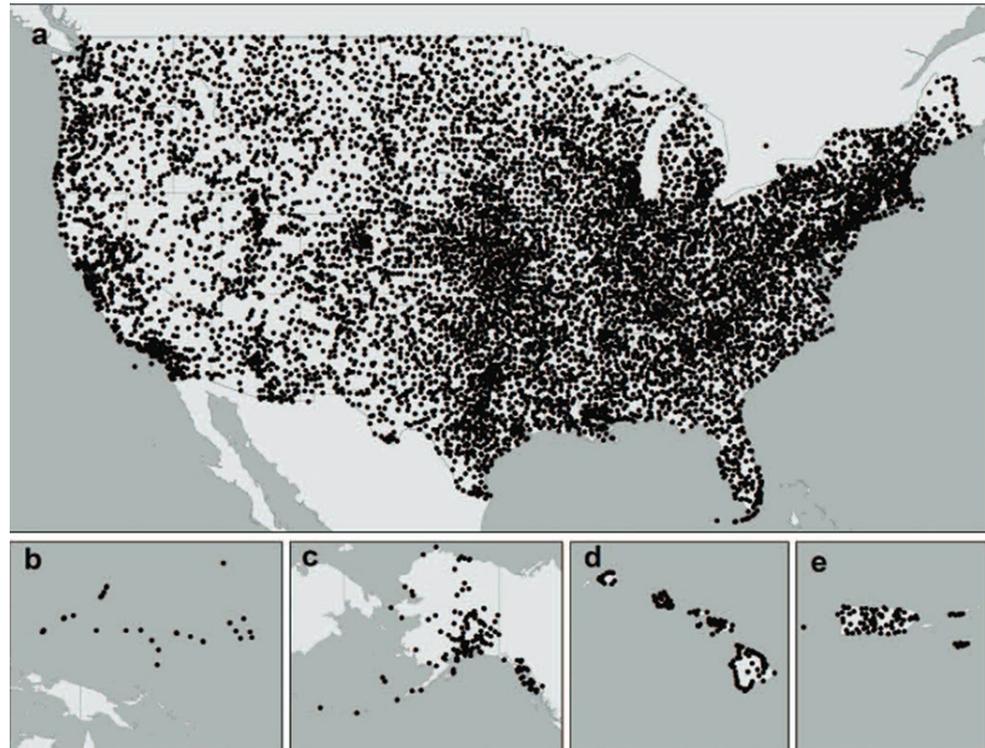
- **Recurrence interval** - statistical measure based on historic data representing the average reoccurrence of a similar event over an extended period of time
  - Commonly used with flood data

$$\text{Recurrence interval} = \frac{n}{m}$$

$n$  = number of years on record

$m$  = number of recorded occurrences of the event

- **Climate normals** - a tool used to characterize surface climate conditions at a specific location using just a couple ECVs
  - “expected values”
  - Available for approximately 9,800 sites



| Category                            | Parameter                         | Daily | Monthly | Seasonal | Annual |
|-------------------------------------|-----------------------------------|-------|---------|----------|--------|
| Averages                            | Maximum temperature               | ✓     | ✓       | ✓        | ✓      |
|                                     | Minimum temperature               | ✓     | ✓       | ✓        | ✓      |
|                                     | Mean temperature                  | ✓     | ✓       | ✓        | ✓      |
|                                     | Diurnal temperature range         | ✓     | ✓       | ✓        | ✓      |
|                                     | Heating degree days               | ✓     | ✓       | ✓        | ✓      |
|                                     | Cooling degree days               | ✓     | ✓       | ✓        | ✓      |
|                                     | Precipitation (liquid equivalent) | *     | ✓       | ✓        | ✓      |
|                                     | Snowfall                          | *     | ✓       | ✓        | ✓      |
| Standard deviations                 | Maximum temperature               | ✓     | ✓       |          |        |
|                                     | Minimum temperature               | ✓     | ✓       |          |        |
|                                     | Mean temperature                  | ✓     | ✓       |          |        |
|                                     | Diurnal temperature change        | ✓     | ✓       |          |        |
| Frequencies of threshold exceedance | Maximum temperature               | ✓     | ✓       | ✓        | ✓      |
|                                     | Minimum temperature               | ✓     | ✓       | ✓        | ✓      |
|                                     | Precipitation (liquid equivalent) | ✓     | ✓       | ✓        | ✓      |
|                                     | Snowfall                          | ✓     | ✓       | ✓        | ✓      |
|                                     | Snow depth                        | ✓     | ✓       | ✓        | ✓      |
| Percentiles                         | Precipitation (liquid equivalent) | ✓     | ✓       |          |        |
|                                     | Snowfall                          | ✓     | ✓       |          |        |
|                                     | Snow depth                        | ✓     |         |          |        |

# Geospatial Analysis

- Display of ECVs on a map
  - ECV value is spatially referenced to a geographic point
- **Geospatial climatology** - a powerful, emerging method of study that examines spatial patterns of climate and their relationships with geographic features, as defined by climate scientists at Oregon State University

- **Global positioning system (GPS)** - a satellite-based geospatial location system that uses radio frequencies to provide geographic reference information for most places on Earth, so long as at least four GPS-specific satellites are above the individual location's horizon

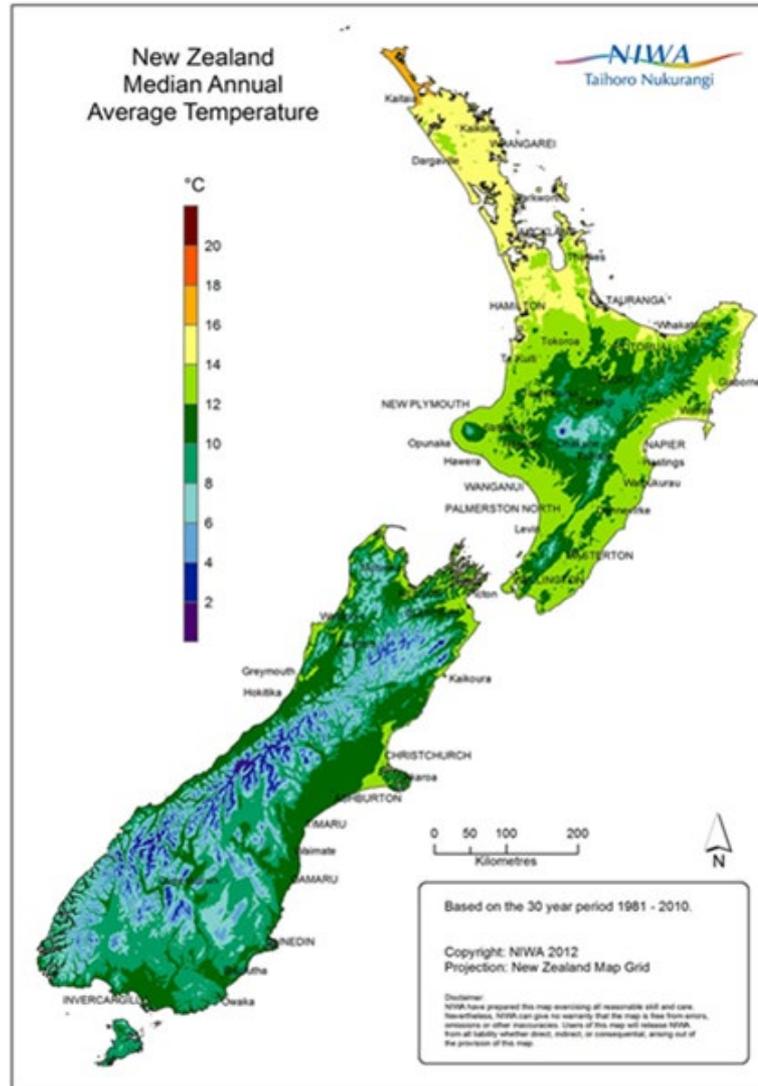
# Geospatial Analysis

## Geographic Information Systems (GIS)

- **Geographic Information Systems (GIS)** - a “system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data”
  - helps identify and predict ECV differences place to place
- Using GIS in climate mapping allows for greater interactivity with users
  - Users can get information they need efficiently without combing through a large amount of unwanted data

# Geospatial Analysis

## Climate Mapping

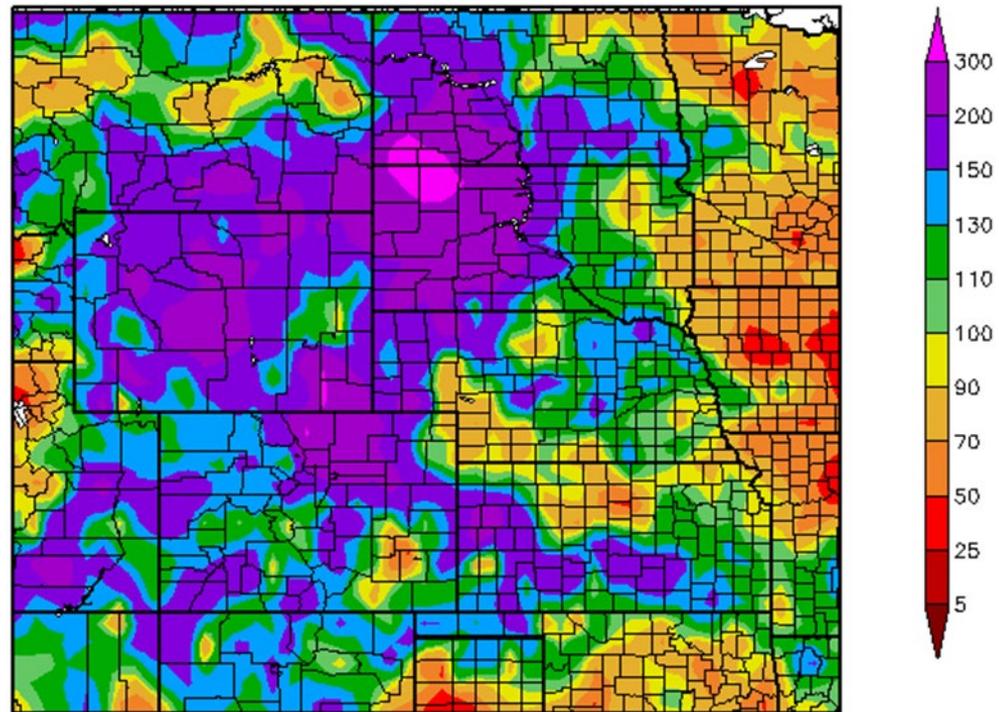


# Climate Mapping

## Applied Climate Information System (ACIS)

- **Applied Climate Information System (ACIS)** - gathers together archived climate data and presents it to the user in a visually amenable format

Percent of Normal Precipitation (%)  
8/1/2013 – 10/31/2013

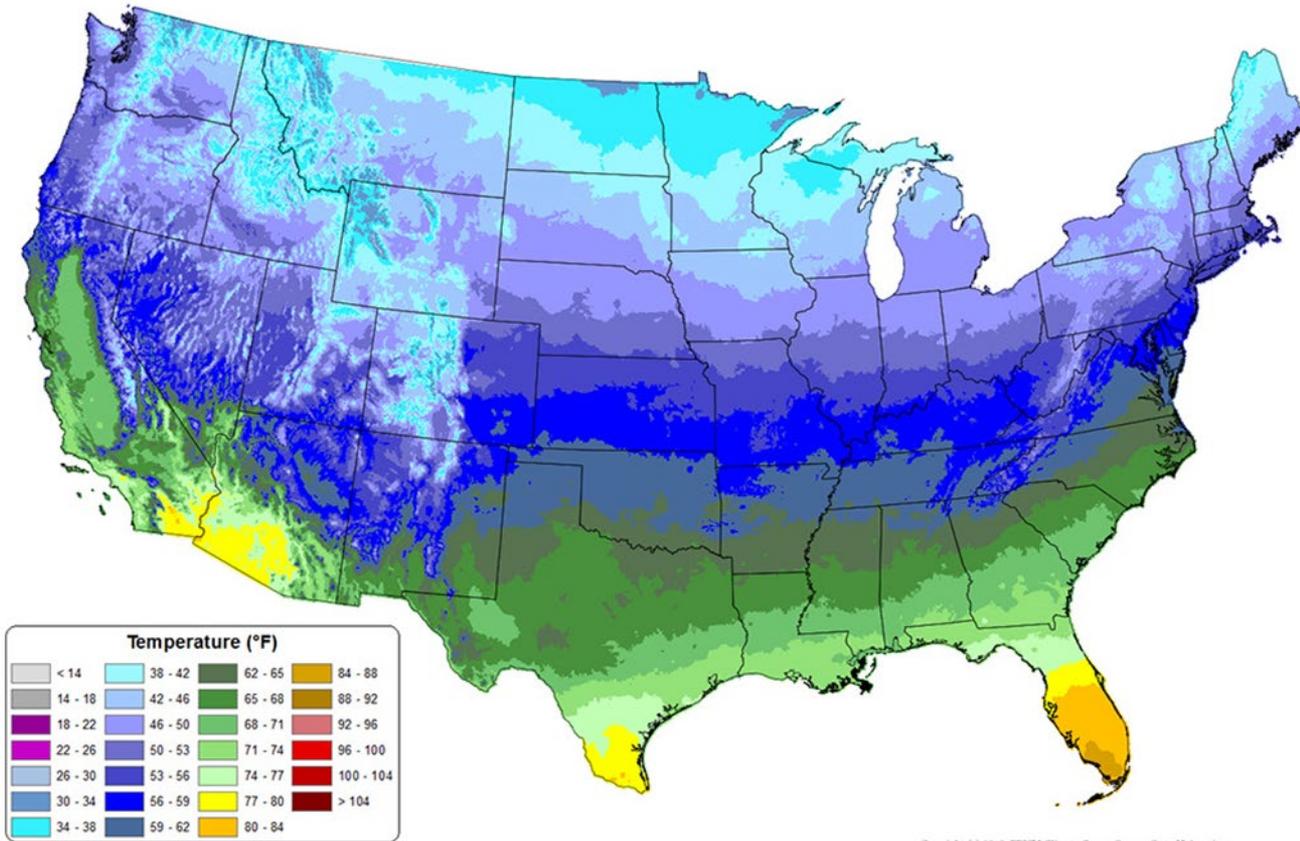


# Climate Mapping

## PRISM Project

- **Parameter-elevation Regressions on Independent Slopes Model (PRISM)** - a principal example of climate mapping, from Oregon State University, which seeks to address elevation challenges in characterizing climate analysis over complex terrain
- Climate can be greatly impacted by changes in elevation
- Previously, data was extrapolated to explain changes over elevation
- PRISM addresses elevation changes using regression analysis
  - Finer resolution in data is possible

**Average Daily Max Temperature: 01 November 2013 - 24 November 2013**  
Period ending 7 AM EST 24 Nov 2013  
(Map created 25 Nov 2013)



# Climate Classification Techniques

- **Regional climate analysis** - where scientists define clear geographic bounds to a spatial area and identify the intrinsic climatic characteristics that describe that area for a specific time
- Require a classification scheme
  - Genetic classifications deal with why climate types are where they are
  - Empirical classifications infer type from environmental impacts

- **Dynamic climatology** - assumes that Earth's climate system is governed by the well-known laws of physics (principally thermodynamics, radiative transfer, etc.) and behaves accordingly
- **Applied climatology** - a multi-disciplinary approach to “describing, defining, interpreting and explaining relationships between climate conditions and countless weather-sensitive activities” that focuses on how climatic variations affect humans and human interests

- Climate typically described in terms of normal, means and extremes in ECVs
- Alternate approach is to use air mass climatology
  - Frequency of weather types is bases for describing climatology of an area

# Climate Classification Techniques

## Köppen Classification

- **Köppen classification system** - an empirical approach to organize Earth's many regional climate zones that uses native vegetation as an indicator of regional climate as well as patterns in mean annual and monthly temperature and precipitation
- Shortcomings include that the underlying connection of vegetation to climate will be destabilized by changes in climate

# Climate Classification Techniques

## Köppen Classification

|                           |   |
|---------------------------|---|
| <b>Tropical humid (A)</b> |   |
| Af                        | tropical wet                                  |
| Am                        | tropical monsoon                              |
| Aw                        | tropical wet-and-dry                          |
| <b>Dry (B)</b>            |   |
| BS                        | steppe or semiarid (BSh, BSk)                 |
| BW                        | arid or desert (BWh, BWk)                     |
| BWn                       | foggy desert                                  |
| <b>Subtropical (C)</b>    |   |
| Cs                        | subtropical dry summer (Csa, Csb)             |
| Cw                        | subtropical dry winter                        |
| Cf                        | subtropical humid (Cfa, Cfb, Cfc)             |
| <b>Snow forest (D)</b>    |   |
| Dw                        | dry winter (Dwa, Dwb, Dwc, Dwd)               |
| Df                        | year-round precipitation (Dfa, Dfb, Dfc, Dfd) |
| Ds                        | dry summer                                    |
| <b>Polar (E)</b>          |   |
| ET                        | tundra  |
| EF                        | ice caps                                      |
| <b>Highland (H)</b>       |   |

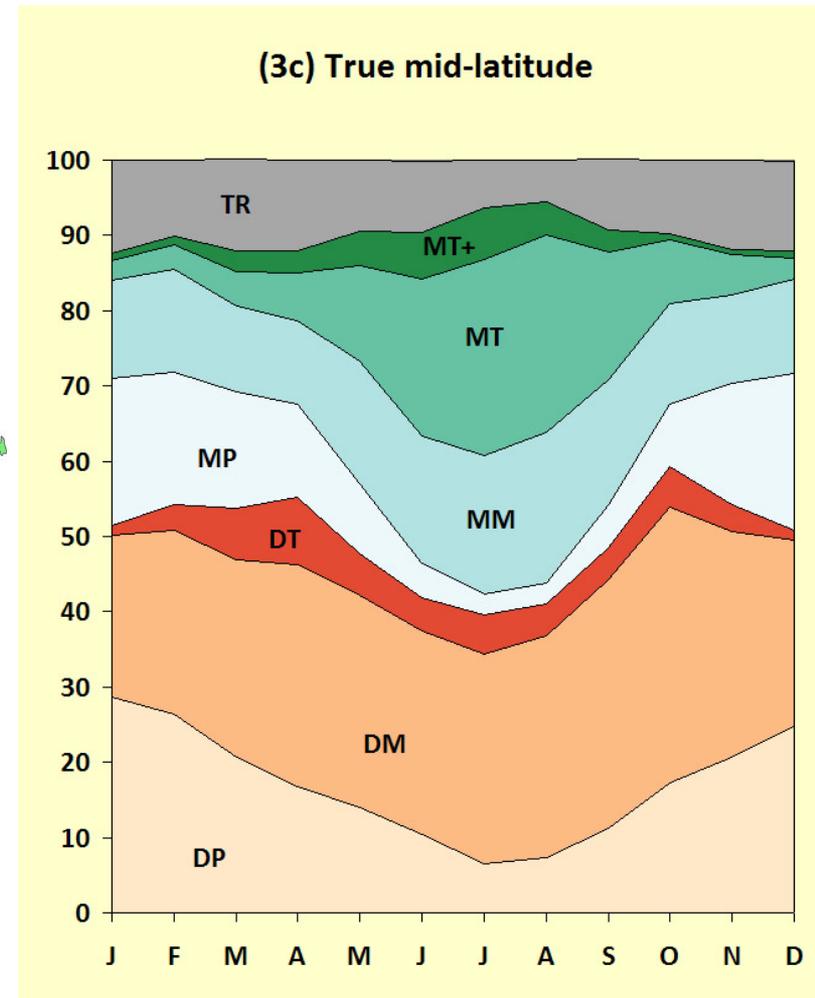
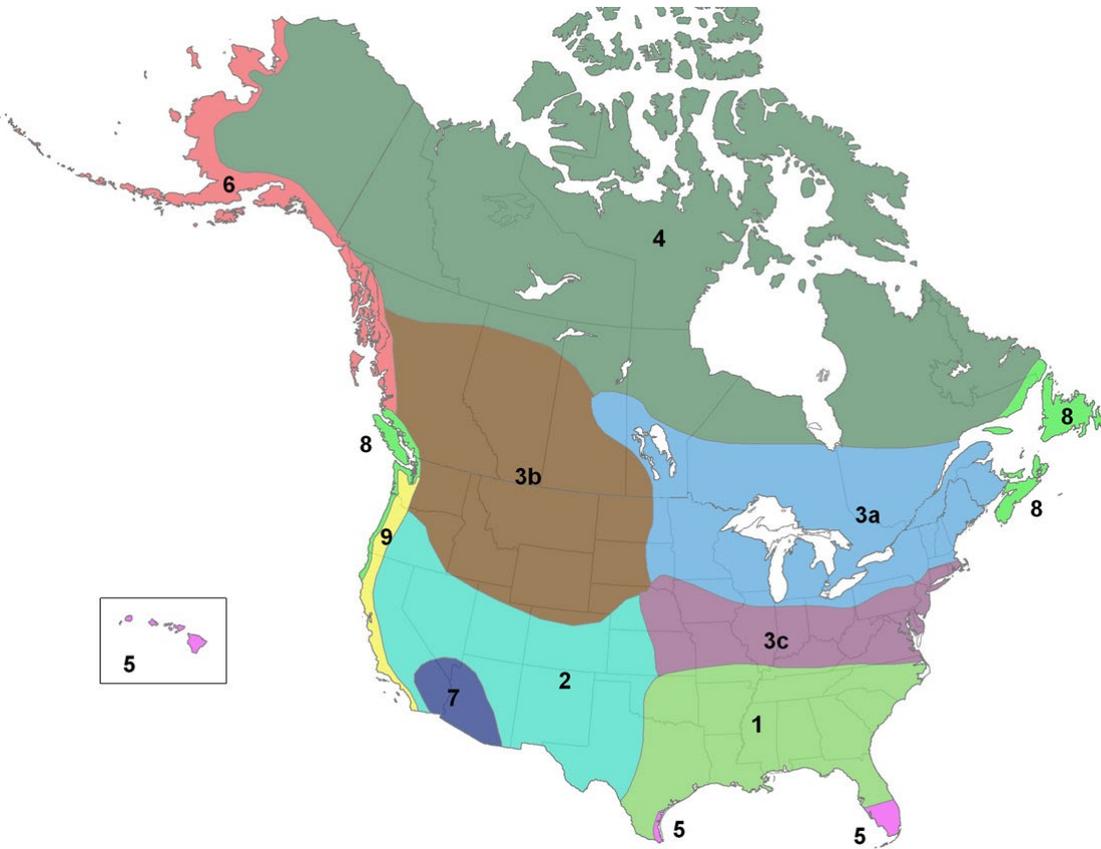
# Climate Classification Techniques

## Spatial Synoptic Classification

- **Spatial synoptic classification (SSC)** - a hybrid classification scheme based on both manual and automated processes of identifying climate types
  - Can adjust descriptors on a daily basis
  - Seed days representative of climate type from season to season are used for comparison and identification of climate type
  - Output in calendar and map format
    - Allows for extrapolation of data

# Climate Classification Techniques

## Spatial Synoptic Classification



# Big Ideas

- Quantitative tools are necessary to organize and make sense of the voluminous climate data.
- Changes in understanding and in computing capacity help advance the scientific understanding of the climate system.
- Latest advance includes GIS analysis.

# Key Terms

Statistical analysis

Frequency distribution

Descriptive statistics

Mean

Median

Mode

Range

Average deviation

Variance

Standard deviation

Standard score

Trend

Recurrence interval

Climate normal

Geospatial climatology

Global positioning system (GPS)

Geographic Information System (GIS)

Applied Climate Information System (ACIS)

Parameter-elevation Regressions on Independent Slopes Model (PRISM)

Regional climate analysis

Dynamic climatology

Applied climatology

Koppen classification system

Spatial Synoptic classification (SSC)