The Hydrosphere:

Lecture 5: Precipitation

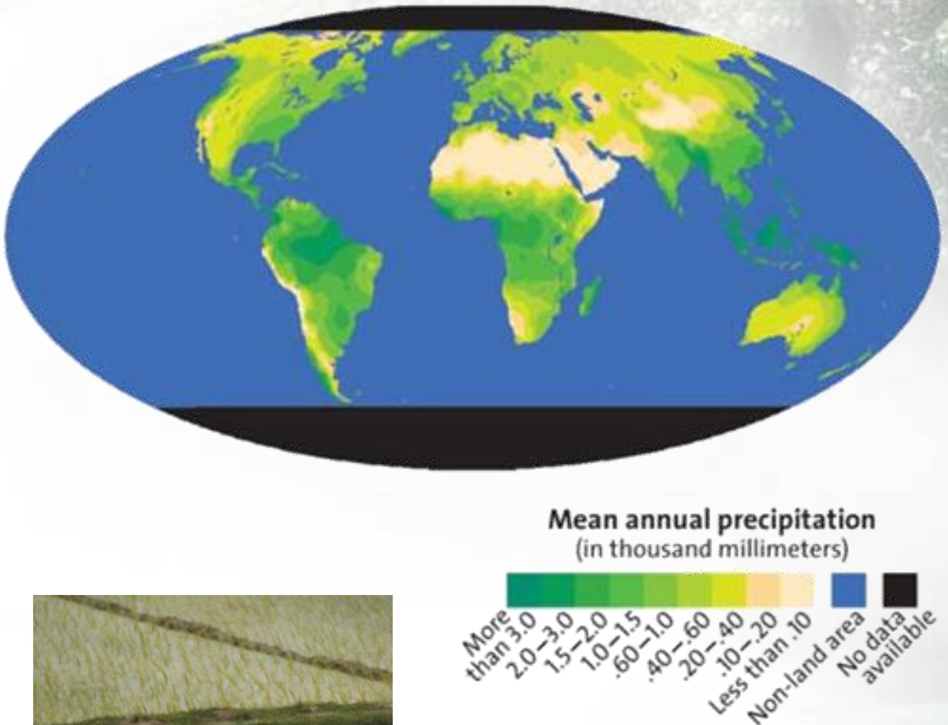
Precipitation Defined

Precipitation: Particles of liquid water or ice that fall from the atmosphere and may reach the ground.

Precipitation: water falling from the atmosphere to the earth.

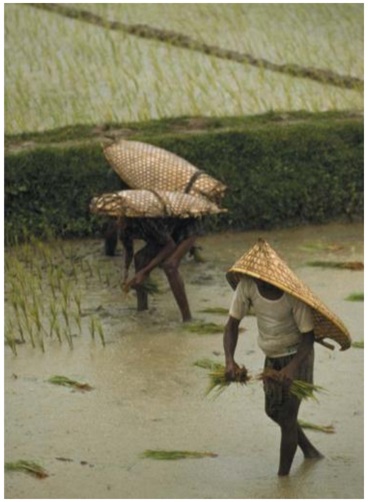
- Rainfall
- Snowfall
- Hail, sleet

- Requires lifting of air mass so that it cools and condenses.



2.6 mm/day, 949 mm/yr

- Single strongest variable driving hydrologic processes
- Formed water vapor in the atmosphere
- As air cools its ability to 'hold' water decreases and some turns to liquid or ice-i.e. glass condensation

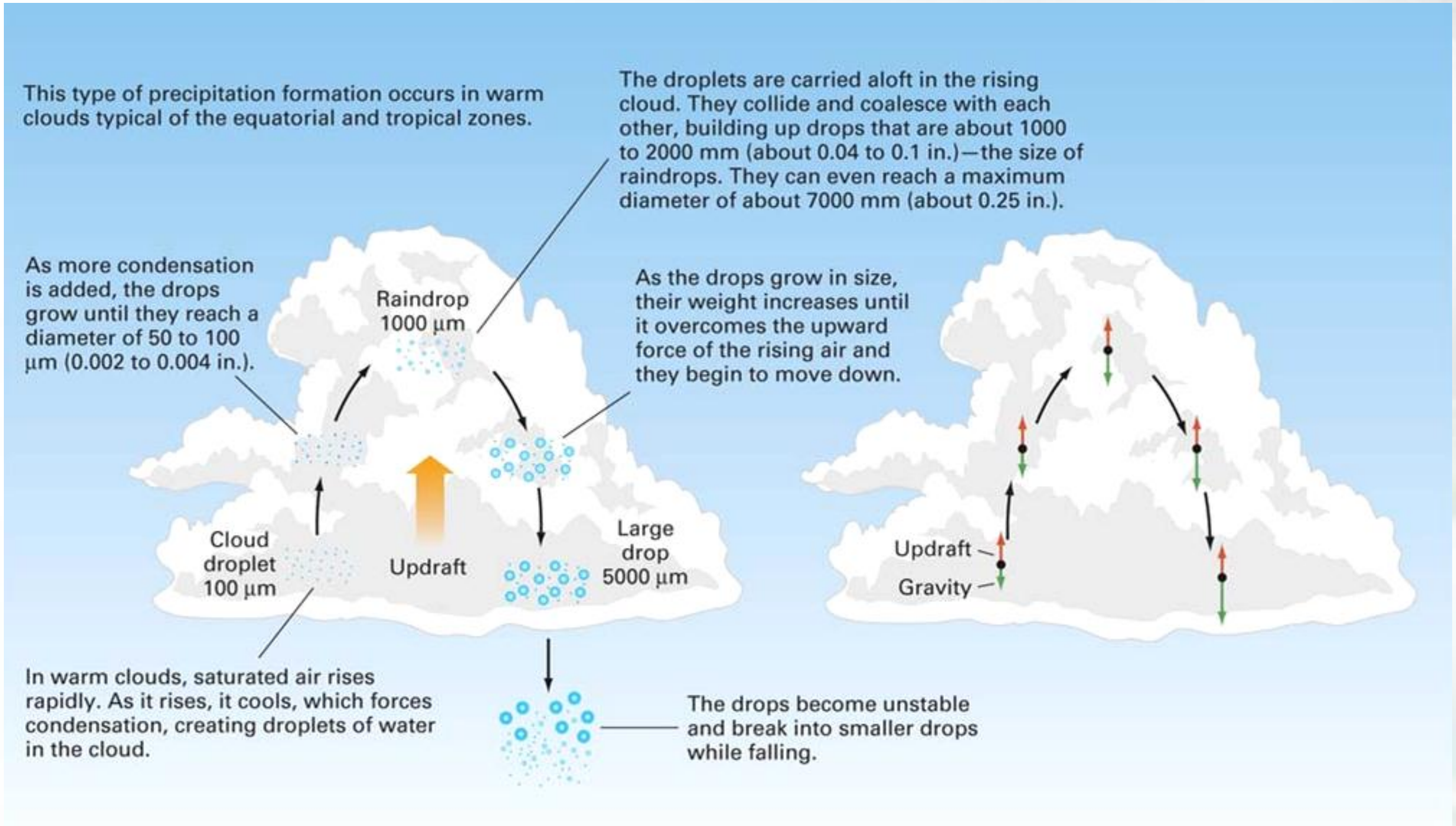


Precipitation

Types of Precipitation

- Rain
- Snow
- Hail
- Ice storm

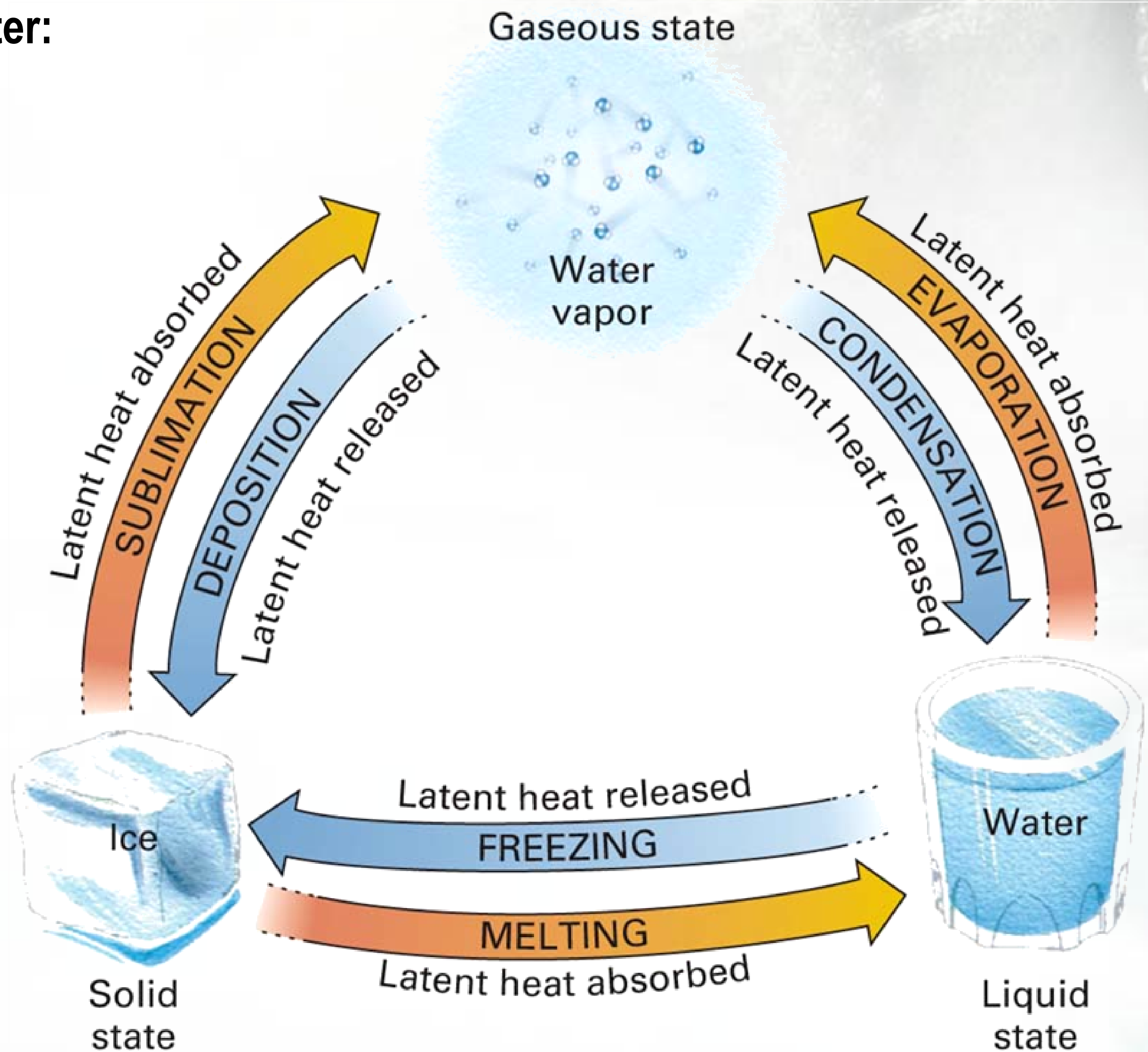
Precipitation → Liquid (Rainfall)
Precipitation → Solid (Ice) → Snow (vapor condensed to ice)
Solid (Ice) → Hail (water condensed to ice)



Water and the Hydrosphere

Three States of Water:

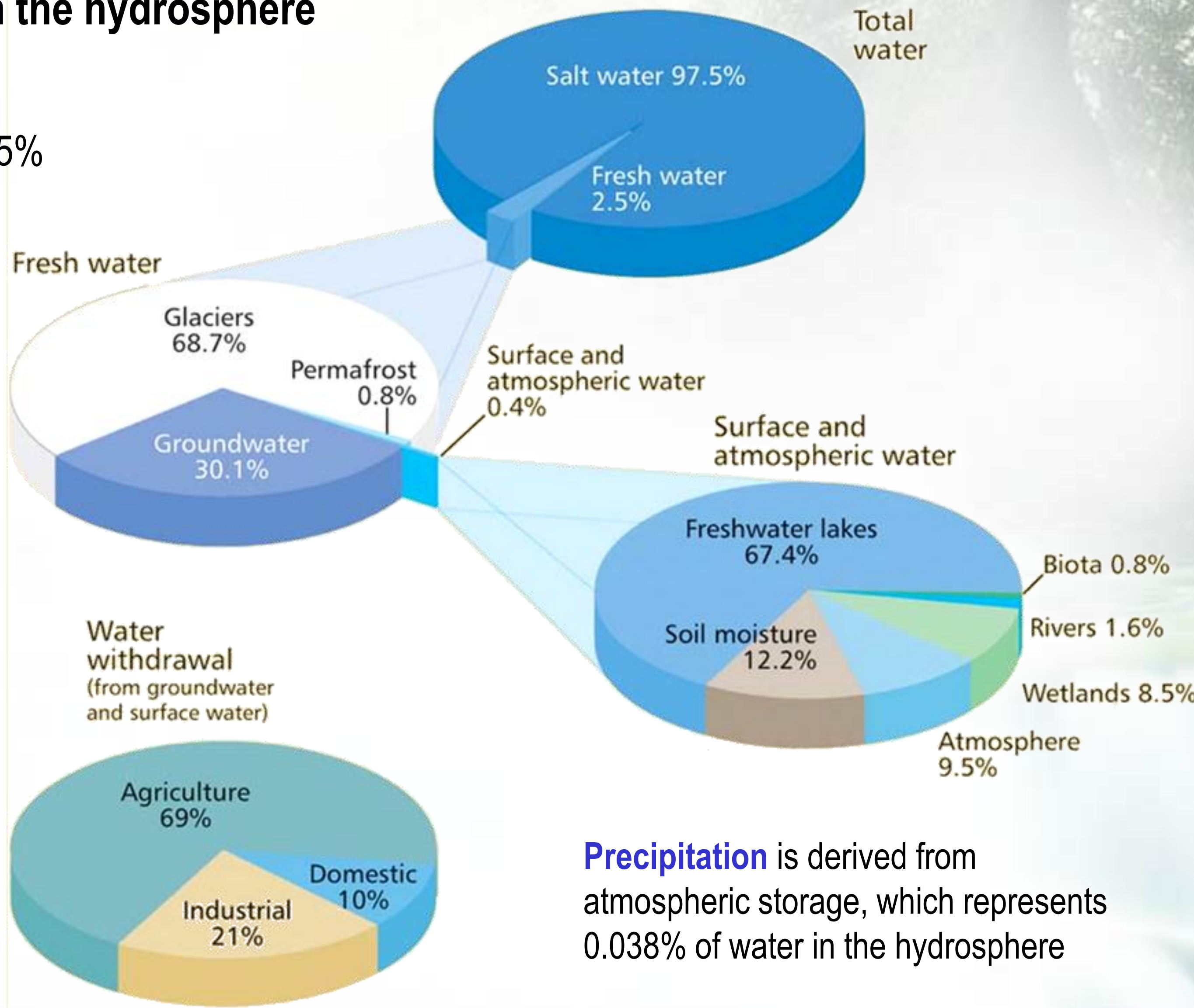
- •Solid (ice)
- •Liquid (water)
- •Gas (vapor)



Water and the Hydrosphere

Distribution of water in the hydrosphere

- Oceans: 97.5%
- Fresh water: 2.5%

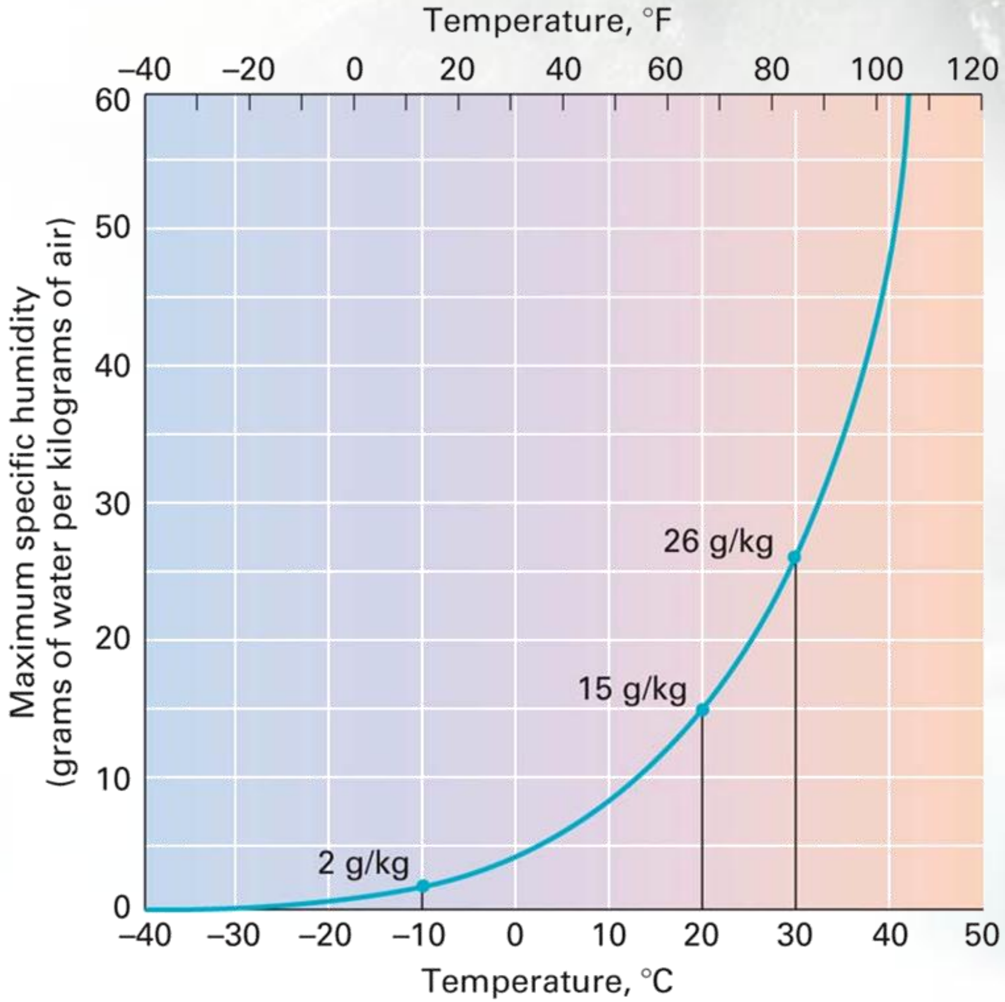


Precipitation is derived from atmospheric storage, which represents 0.038% of water in the hydrosphere

Humidity

Humidity: the amount of water vapor in the air

The maximum quantity of moisture that can be held in the air depends on air temperature



Visualizing Physical Geography
Copyright © 2008

Humidity

Relative Humidity: compares the amount of water vapor present in the air to the maximum amount that the air can hold at that temperature

Expressed as a percentage:

At 100% relative humidity, air is *saturated.*

Relative Humidity changes when:

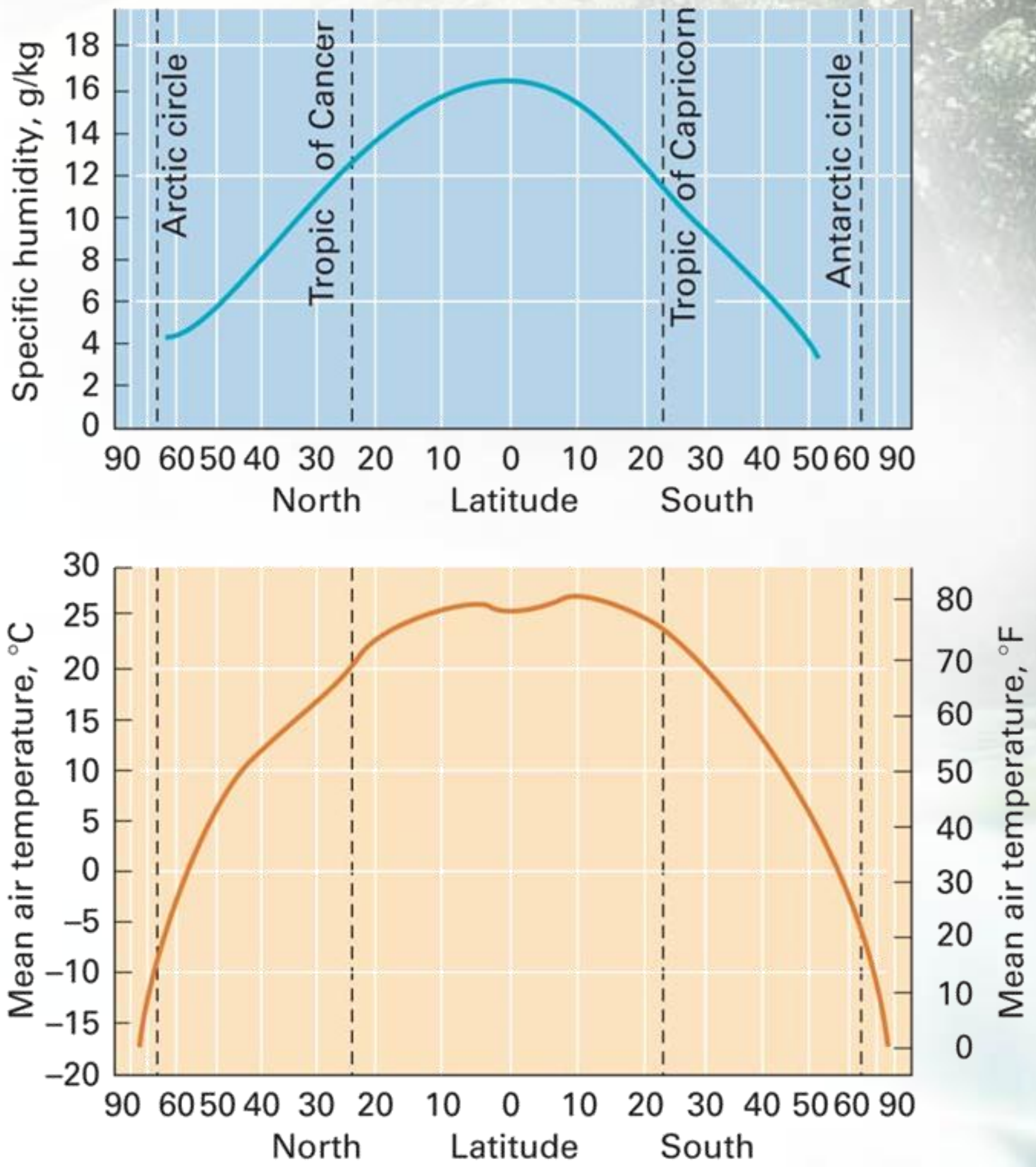
1. Atmosphere gains or loses water vapor
   - Evaporation
2. Temperature changes
   - Lower temperature→ relative humidity rises
   - Raise temperature→ relative humidity decreases

Humidity

Specific Humidity: actual quantity of water held by a parcel of air

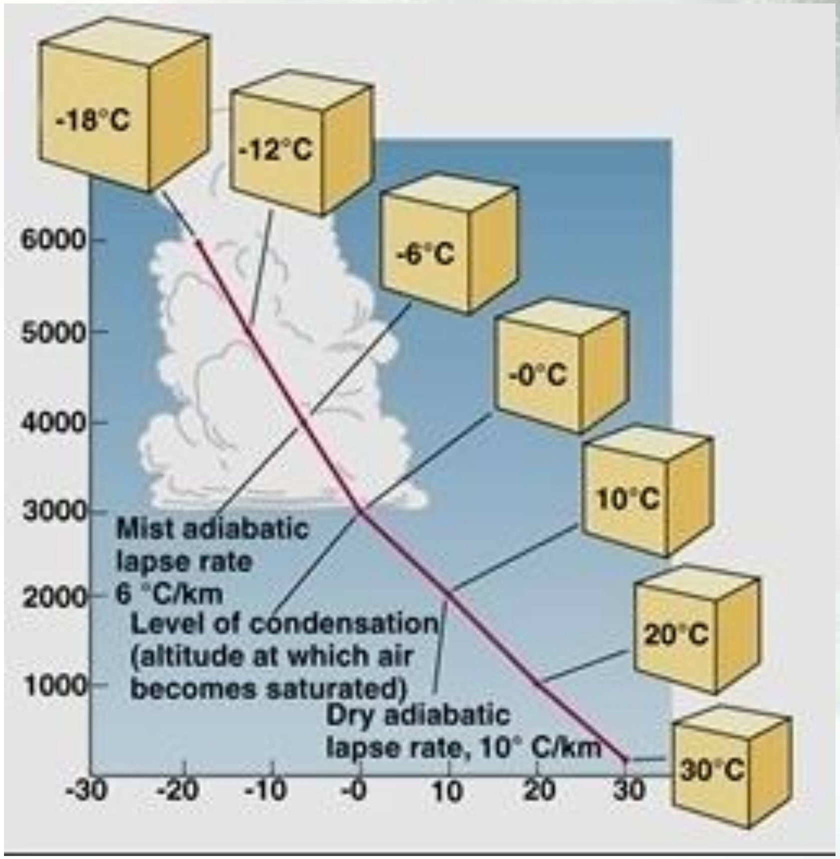
- Grams of water vapor per kilogram of air (g/kg)
- Highest in equatorial zones
- Lowest near poles

Dew-point temperature: temperature at which air with a given humidity will reach saturation when cooled without changing its pressure



The Adiabatic Process

Adiabatic Principle**:** the physical principle that a gas cools as it expands and warms as it is compressed



Change in temperature:

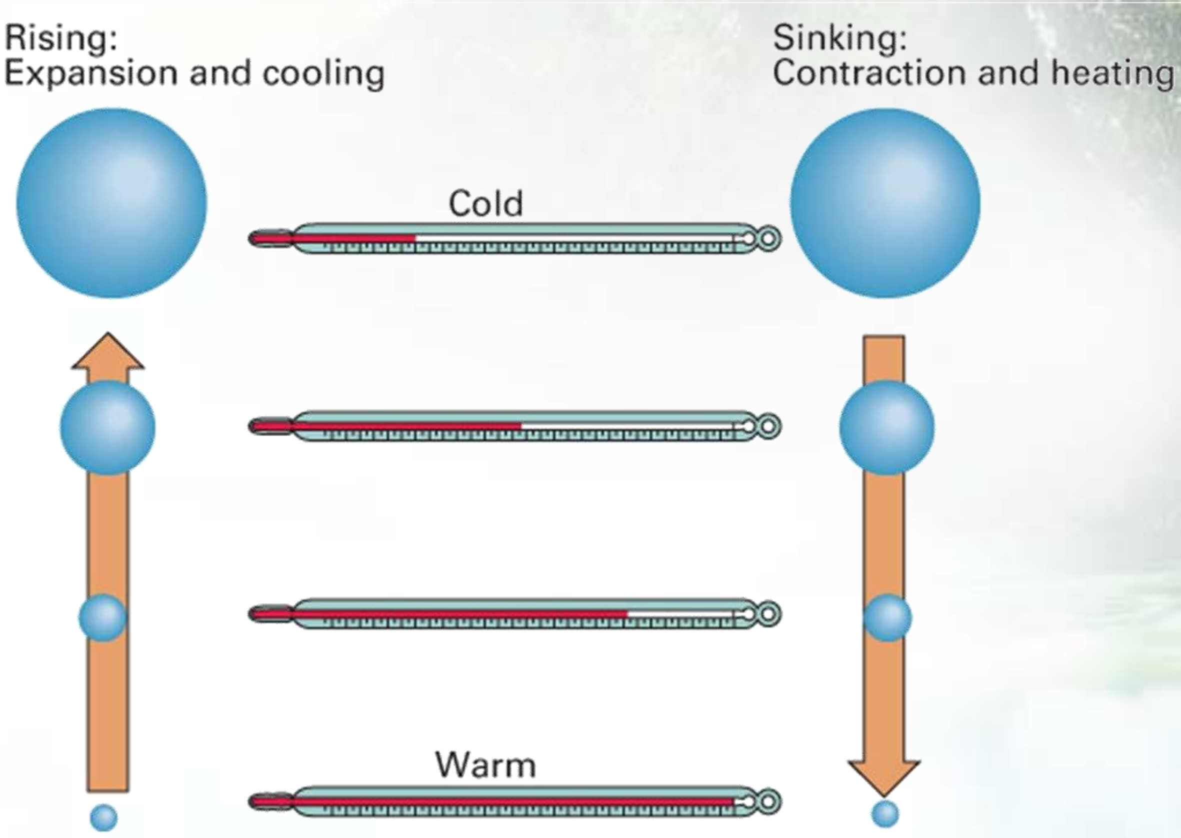
- caused only by a change in pressure
- <u>not</u> caused by heat flowing in or out of the gas

The Adiabatic Process

Atmospheric pressure decreases with altitude so...

As a parcel of air rises
→pressure on the parcel decreases
→air expands and cools

As a parcel of air descends
→pressure on the parcel increases
→air is compressed and warms



The Adiabatic Process

***Dry adiabatic lapse rate*:** rate at which rising air is cooled by expansion when no condensation i occurring:

10º C per 1000 m

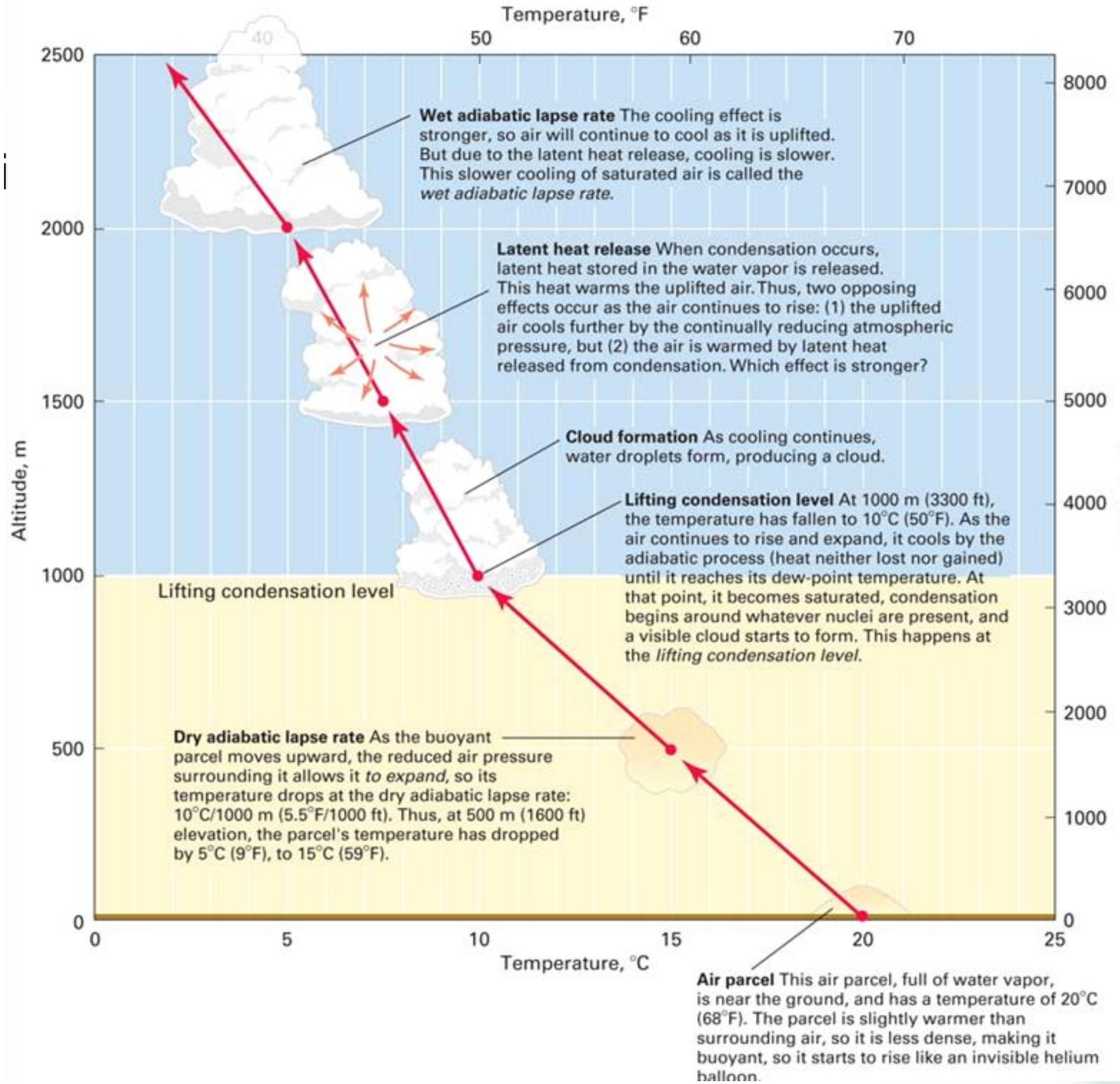
(5.5 º F per 1000 feet)

***Wet adiabatic lapse rate*:** rate at which rising air is cooled by expansion when condensation is occurring:

Ranges from

4-9º C per 1000 m

(2.2-4.9º F per 1000 feet)

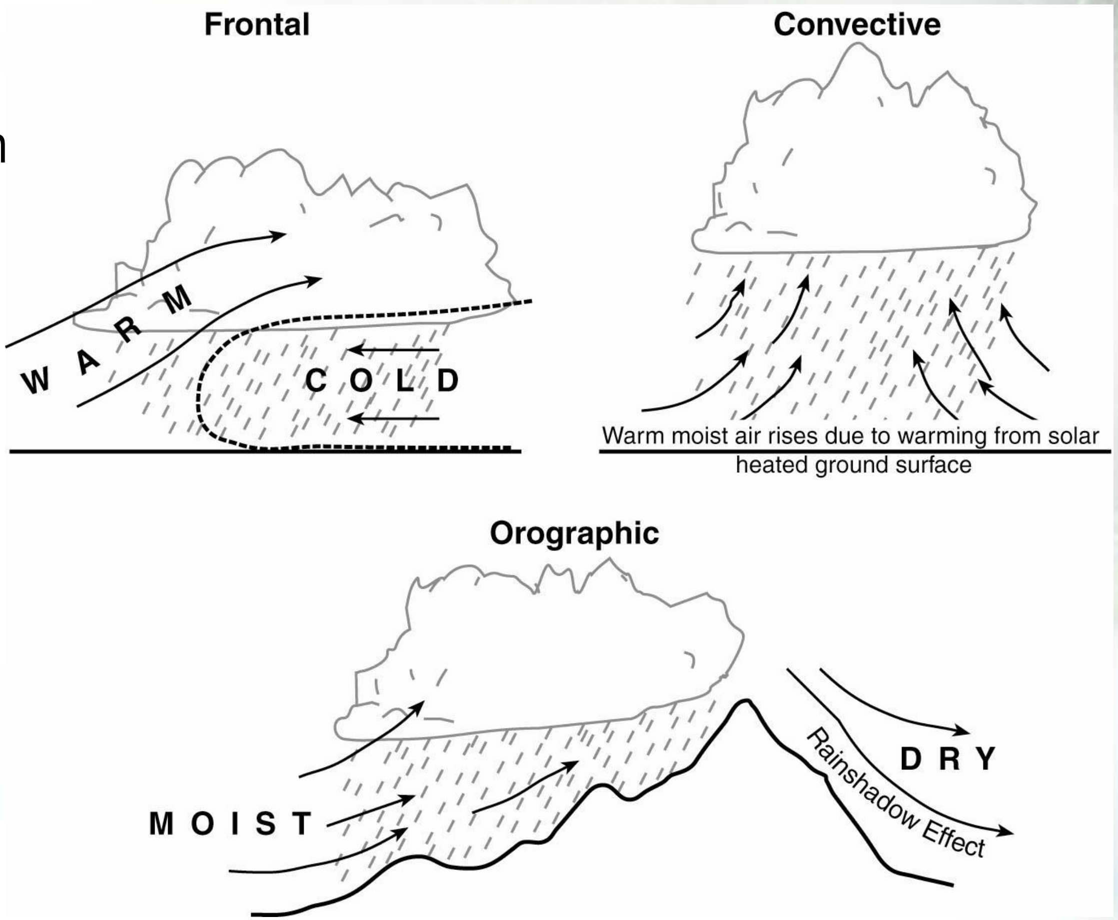


Precipitation

To form precipitation, air must move upward and chill by adiabatic processes.

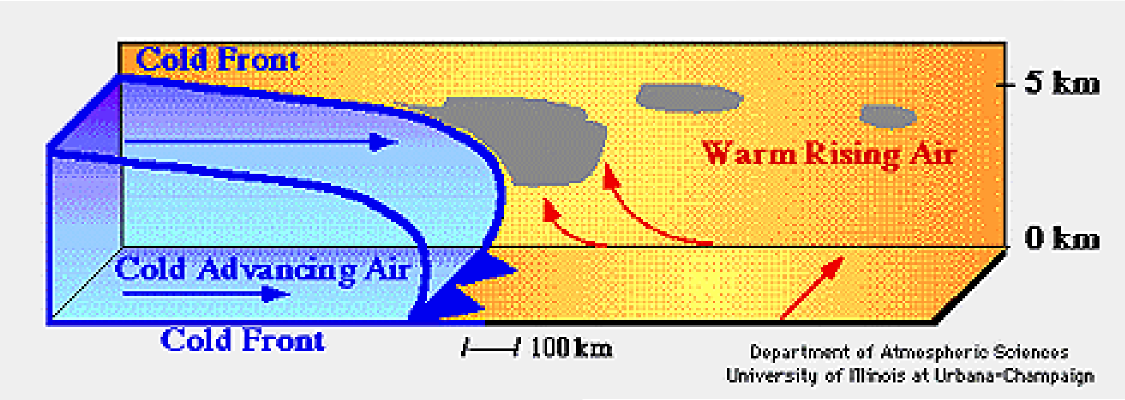
Four ways for air to move upward:

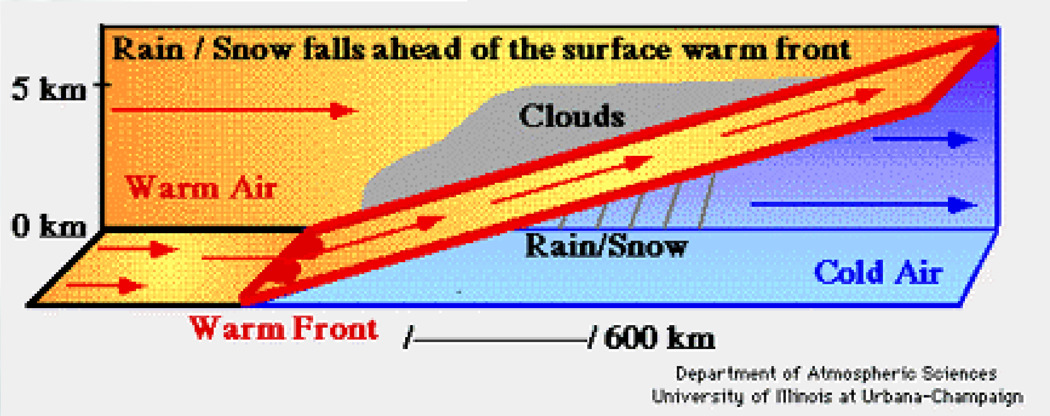
1. Orographic precipitation
2. Convectional precipitation
3. Cyclonic precipitation
4. Convergence



Definitions

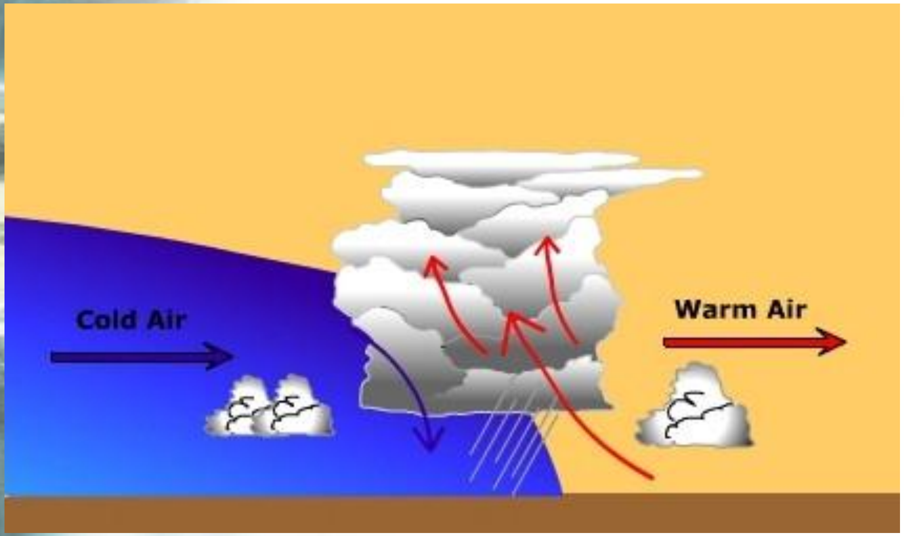
- **Air mass**: A large body of air with similar temperature and moisture characteristics over its horizontal extent.
- **Front**: Boundary between contrasting air masses.
- **Cold front**: Leading edge of the cold air when it is advancing towards warm air.
- **Warm front**: leading edge of the warm air when advancing towards cold air.



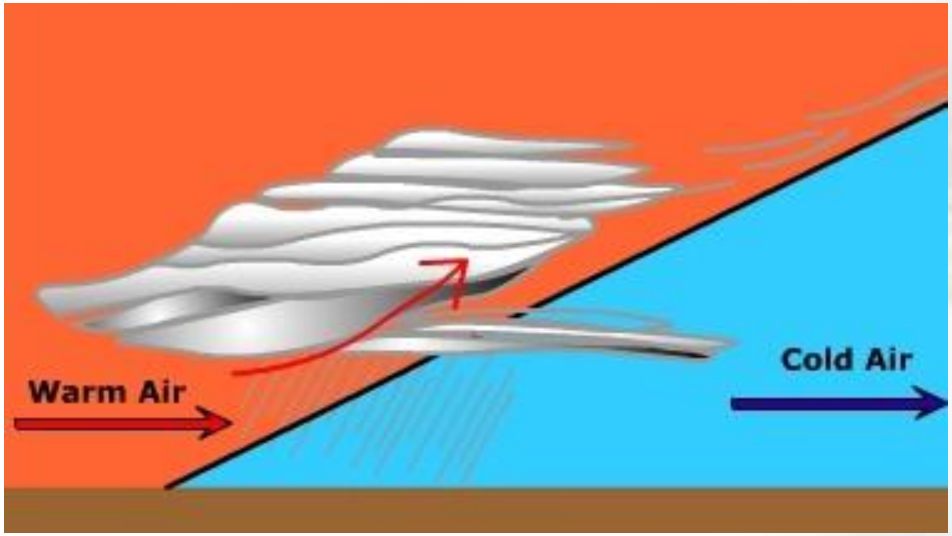


Frontal Lifting

- **Air mass**: A large body of air with similar temperature and moisture characteristics over its horizontal extent.
- Boundary between air masses with different properties is called a ***front***
- ***Cold front*** occurs when cold air advances towards warm air
- ***Warm front*** occurs when warm air overrides cold air



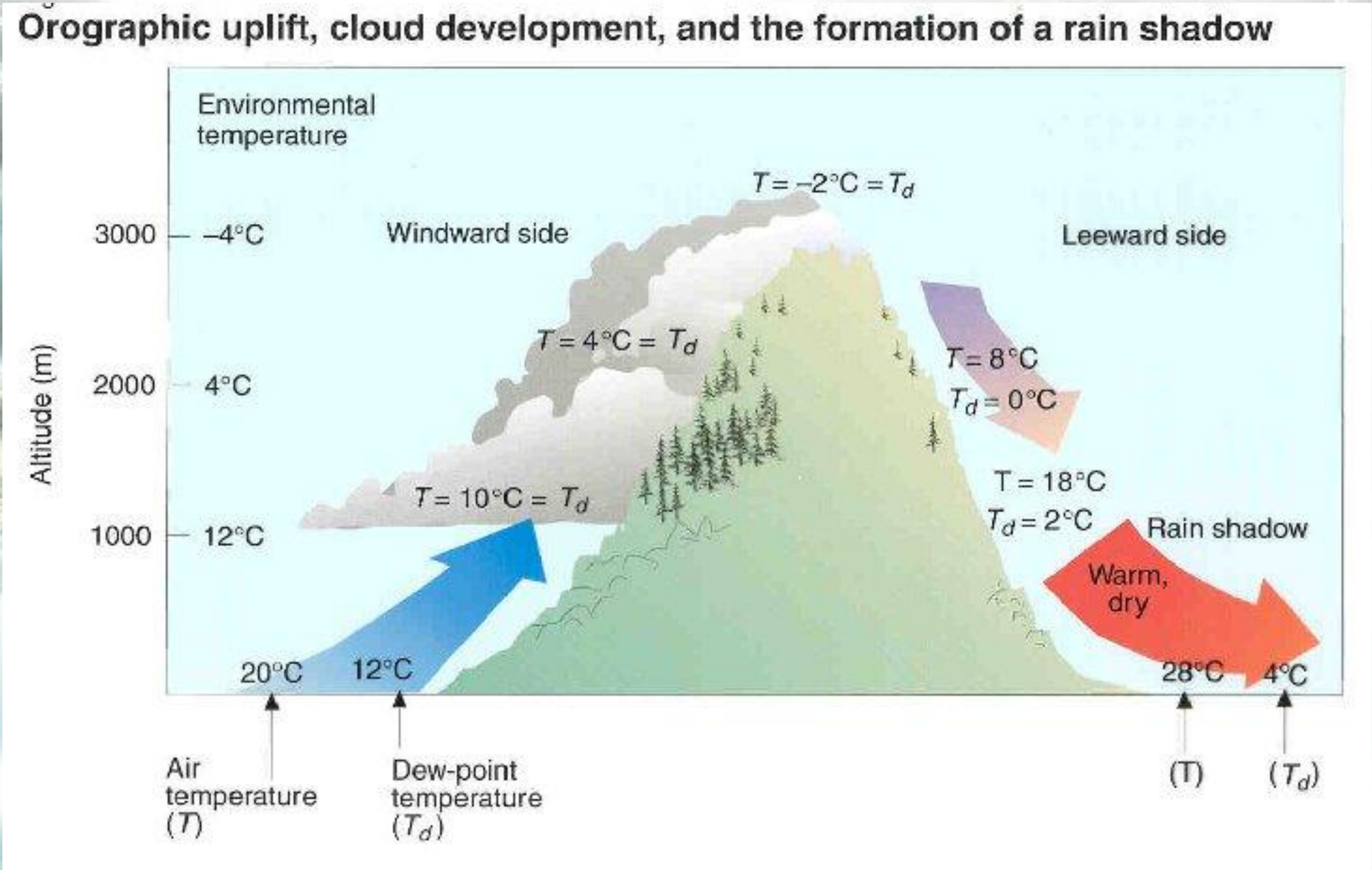
Cold front (produces cumulus cloud)



Cold front (produces stratus cloud)

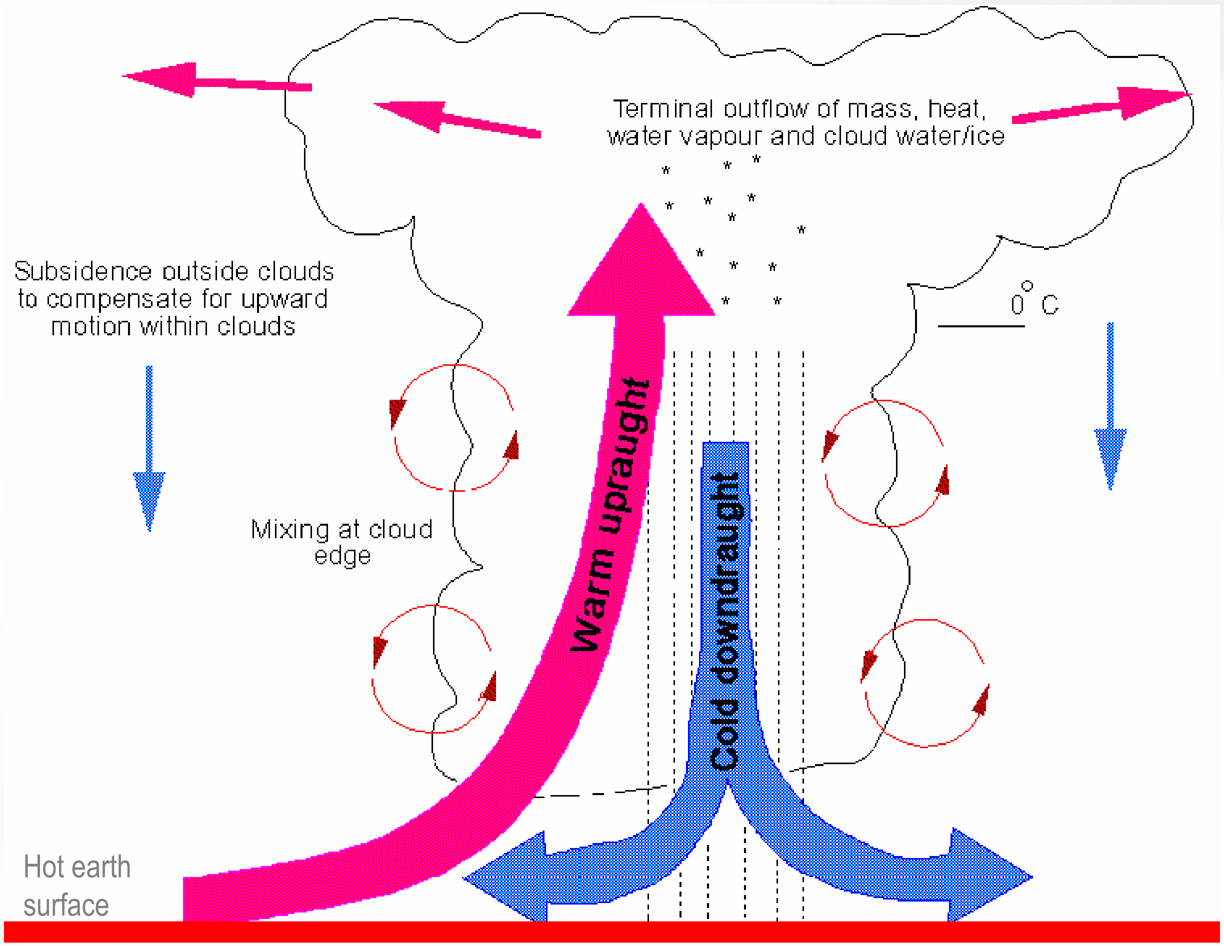
Orographic lifting

Orographic uplift occurs when air is forced to rise because of the physical presence of elevated land.



Convective lifting

Convective precipitation occurs when the air near the ground is heated by the earth's warm surface. This warm air rises, cools and creates precipitation.

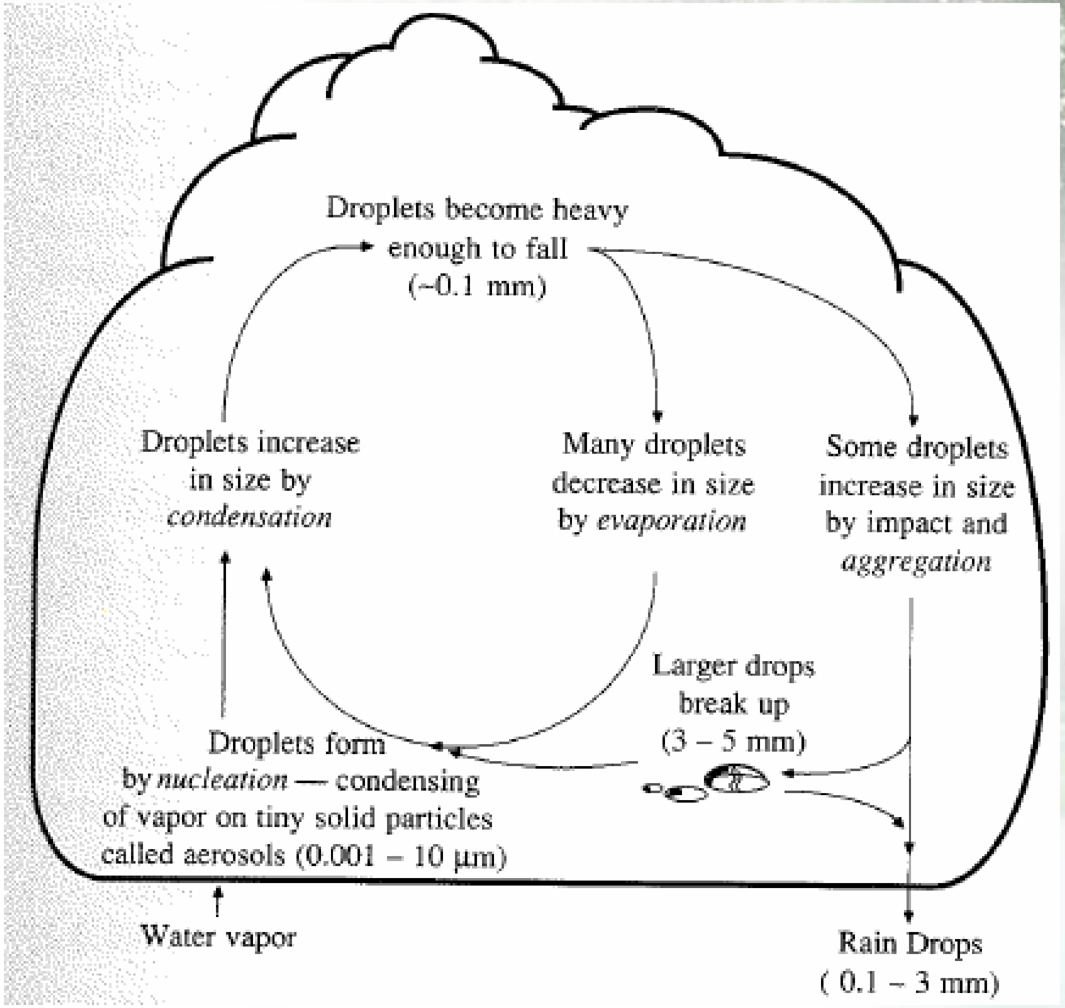


Condensation

- **Condensation** is the change of water vapor into a liquid. For condensation to occur, the air must be at or near saturation in the presence of condensation nuclei.
- **Condensation nuclei** are small particles or aerosol upon which water vapor attaches to initiate condensation. Dust particulates, sea salt, sulfur and nitrogen oxide aerosols serve as common condensation nuclei.
  - Size of aerosols range from **10^{-3} to 10 mm**.

Precipitation formation

- Lifting cools air masses so moisture condenses
- Condensation nuclei
  - Aerosols
  - water molecules attach
- Rising & growing
  - 0.5 cm/s sufficient to carry 10 μm droplet
  - Critical size (~0.1 mm)
  - Gravity overcomes and drop falls



Forces acting on rain drop

Three forces acting on rain drop

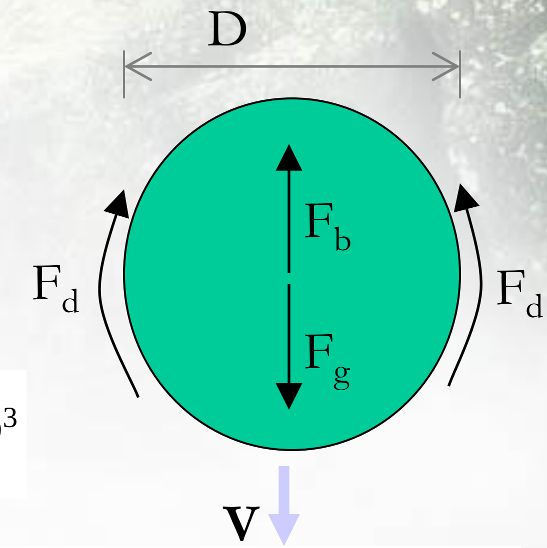
- Gravity force due to weight
- Buoyancy force due to displacement of air
- Drag force due to friction with surrounding air

$$Volume = \frac{\pi}{6} D^3$$

$$Area = \frac{\pi}{4} D^2$$

$$F_g = \rho_w g \frac{\pi}{6} D^3$$

$$F_b = \rho_a g \frac{\pi}{6} D^3$$

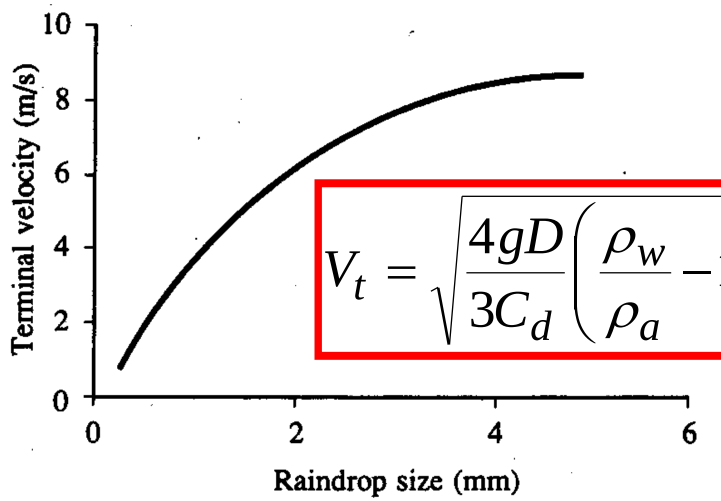


$$F_d = C_d \rho_a A \frac{V^2}{2} = C_d \rho_a D^2 \frac{\pi}{4} \frac{V^2}{2}$$

Terminal velocity: velocity at which the forces acting on the raindrop are in equilibrium.

- If released from rest, the raindrop will accelerate until it reaches its terminal velocity

At standard atmospheric pressure (101.3 kpa) and temperature (20ºC), r_w = 998 kg/m3 and r_a = 1.20 kg/m3

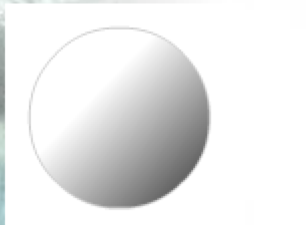


$$V_t = \sqrt{\frac{4gD}{3C_d}\left(\frac{\rho_w}{\rho_a} - 1\right)}$$

- Raindrops are spherical up to a diameter of 1 mm
- For tiny drops up to 0.1 mm diameter, the drag force is specified by Stokes law

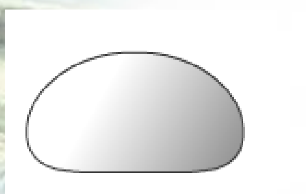
Raindrop Shape

Radius < 2 mm



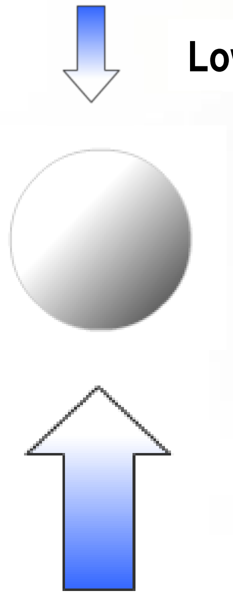
Round shape maintained during free fall

Radius 2-5 mm



Shape affected by surface tension & hydrodynamic forces

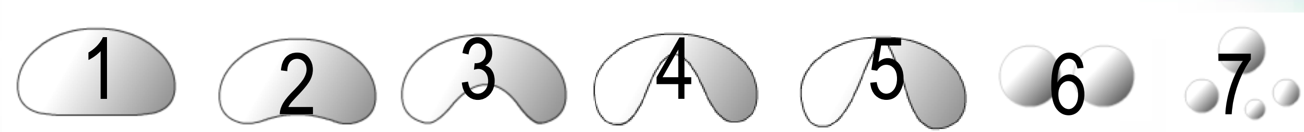
Flow direction of a raindrop



Because air pressure exceeds surface tension, raindrop begins to break into smaller droplets by a number of process.

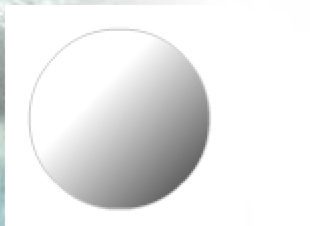
round shape maintained during free fall

Radius > 5 mm



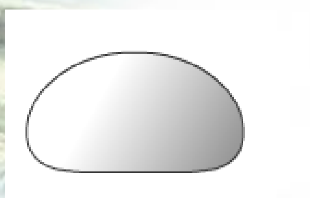
Raindrop Shape

Radius < 2 mm

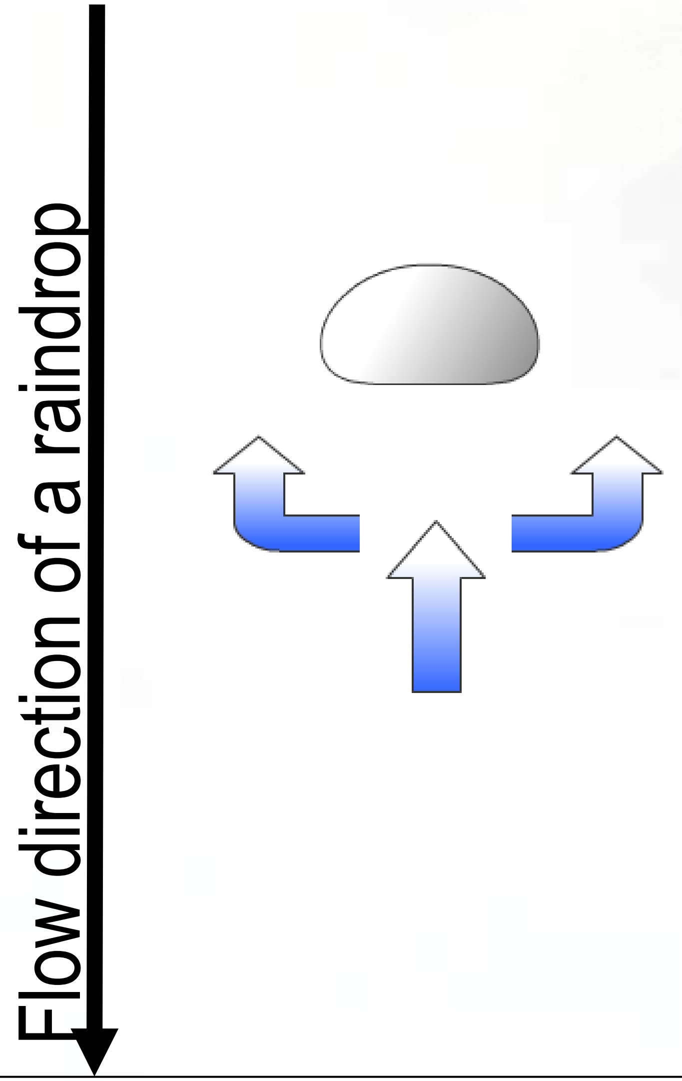


Round shape maintained during free fall

Radius 2-5 mm

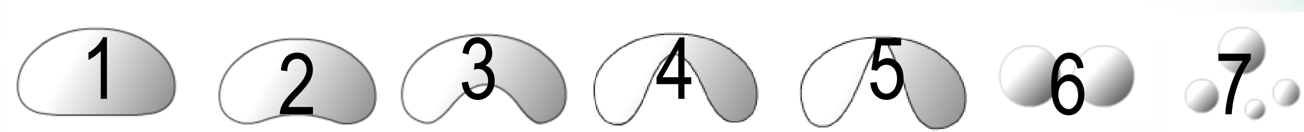


Shape affected by surface tension & hydrodynamic forces



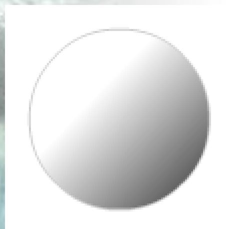
Less air pressure thus flattens bottom and sides bulge

Radius > 5 mm of a sphere with the same mass



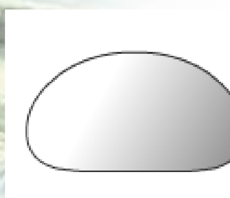
Raindrop Shape

Radius < 2 mm

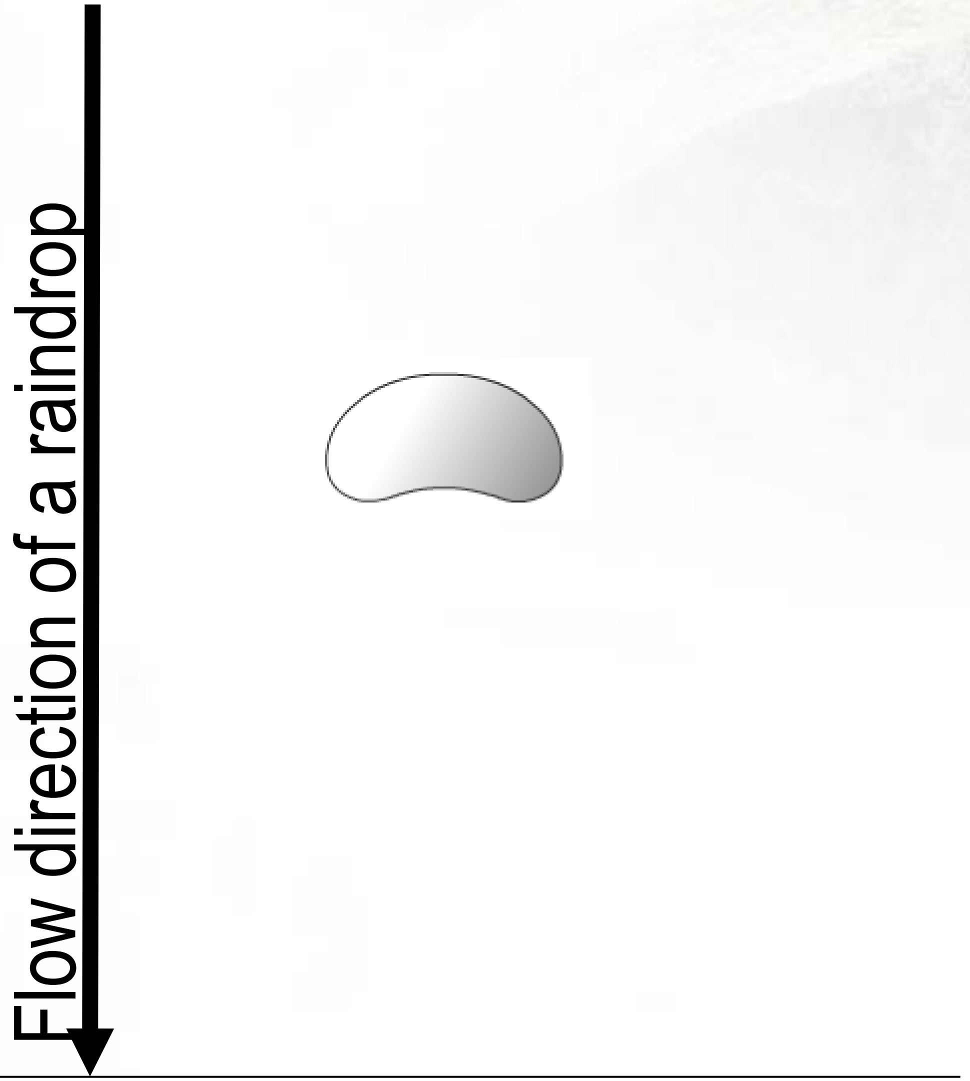


Round shape maintained during free fall

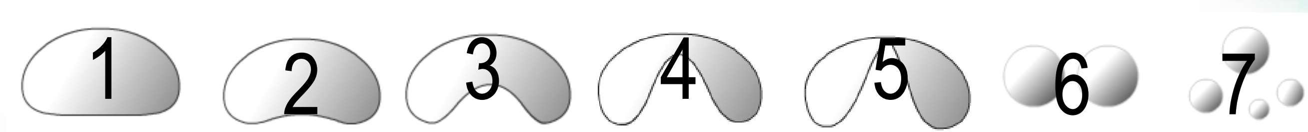
Radius 2-5 mm



Shape affected by surface tension & hydrodynamic forces

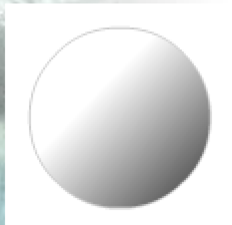


Radius > 5 mm of a sphere with the same mass



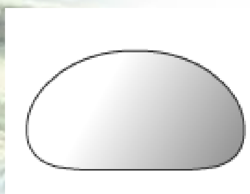
Raindrop Shape

Radius < 2 mm

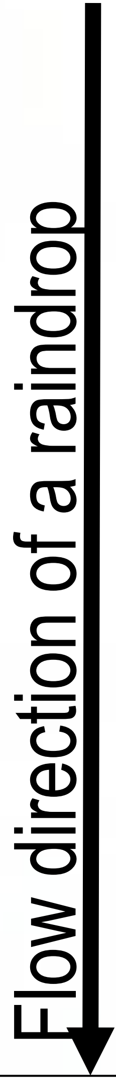


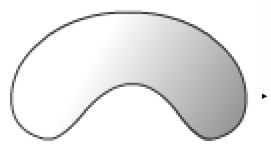
Round shape maintained during free fall

Radius 2-5 mm



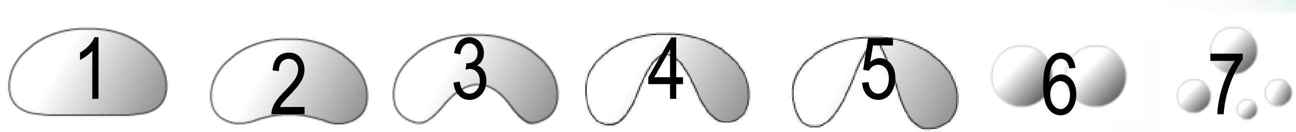
Shape affected by surface tension & hydrodynamic forces





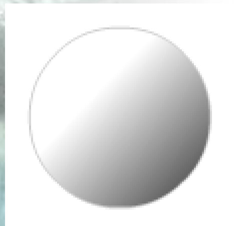
Raindrop splits into droplets due to air pressure.

Radius > 5 mm of a sphere with the same mass



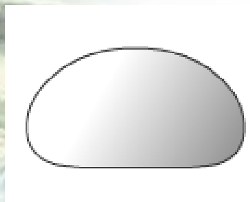
Raindrop Shape

Radius < 2 mm



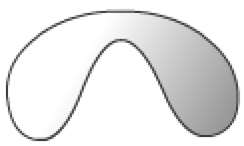
Round shape maintained during free fall

Radius 2-5 mm

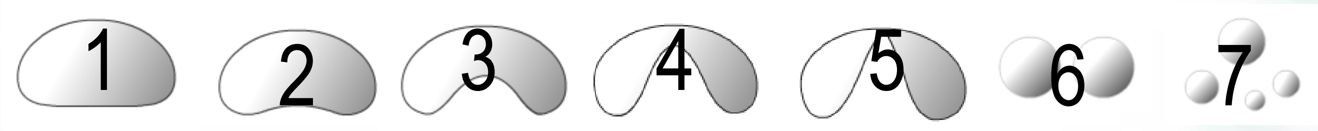


Shape affected by surface tension & hydrodynamic forces

Flow direction of a raindrop

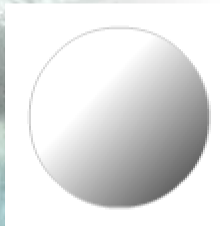


Radius > 5 mm of a sphere with the same mass



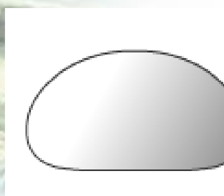
Raindrop Shape

Radius < 2 mm

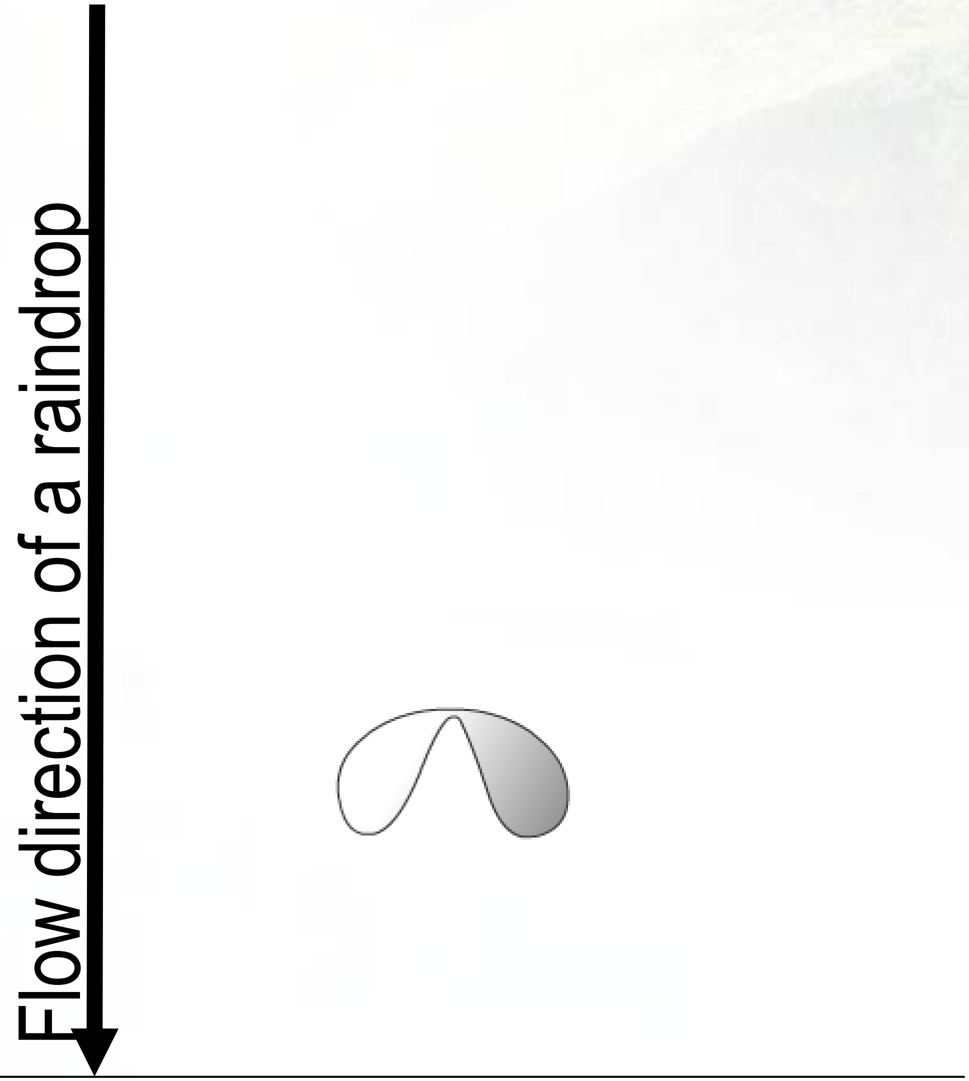


Round shape maintained during free fall

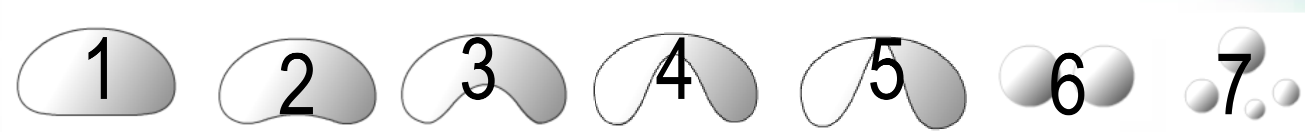
Radius 2-5 mm



Shape affected by surface tension & hydrodynamic forces

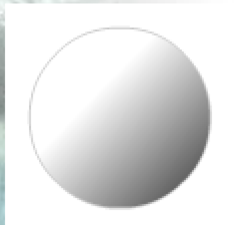


Radius > 5 mm of a sphere with the same mass



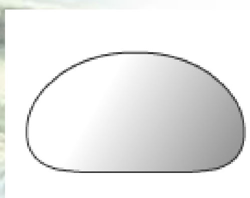
Raindrop Shape

Radius < 2 mm



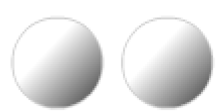
Round shape maintained during free fall

Radius 2-5 mm

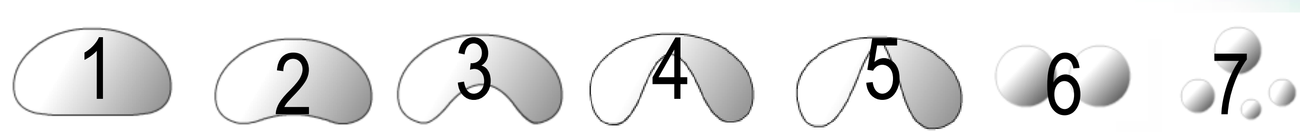


Shape affected by surface tension & hydrodynamic forces

Flow direction of a raindrop

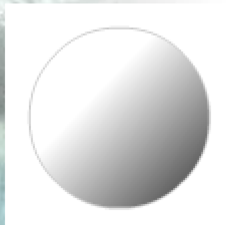


Radius > 5 mm of a sphere with the same mass



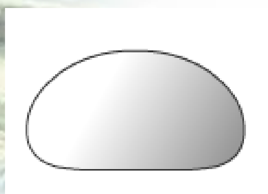
Raindrop Shape

Radius < 2 mm



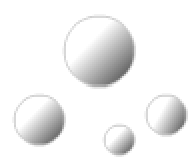
Round shape maintained during free fall

Radius 2-5 mm



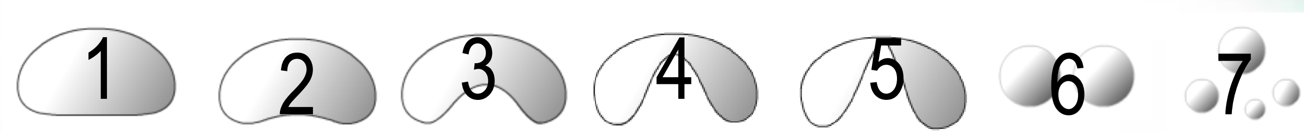
Shape affected by surface tension & hydrodynamic forces

Flow direction of a raindrop



Raindrop retains its spherical shape due to its water surface tension.

Radius > 5 mm of a sphere with the same mass

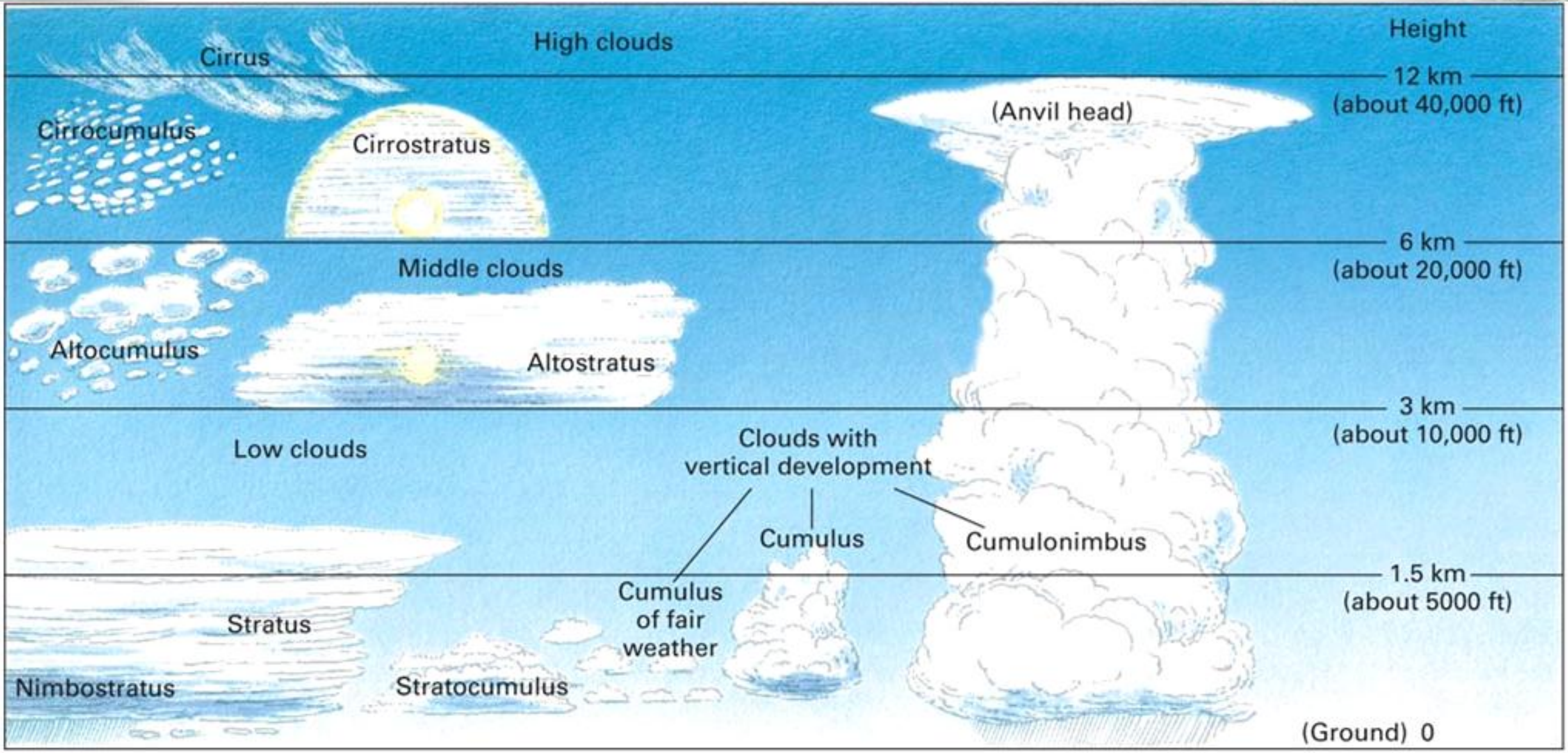


Clouds

Clouds consist of water droplets, ice crystals, or both

Condensation nucleus: a tiny bit of solid matter (aerosol) in the atmosphere, on which water vapor condenses to form a tiny water droplet

Clouds



Cloud Families: High clouds, middle clouds, low clouds, clouds of vertical development

Clouds

Cumulus Clouds

Cumuliform clouds: globular masses of cloud, associated with parcels of rising air

Clouds

Stratus Clouds

Stratiform clouds: **blanket-like, cover large areas**

Clouds

Cirrus Clouds

Cirrus clouds: high, thin, wispy clouds composed of ice crystals

Clouds

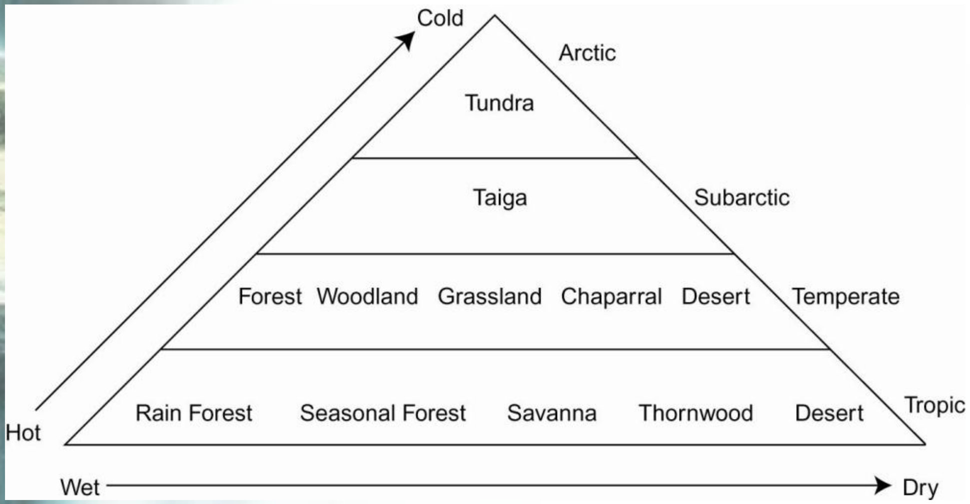
Fog is a cloud layer at or close to Earth's surface

Image ID: wea03250, NOAA's National Weather Service (NWS) Collection
Photographer: LCDR Mark Wetzler, NOAA Corps
http://www.photolib.noaa.gov/htmls/wea03250.htm

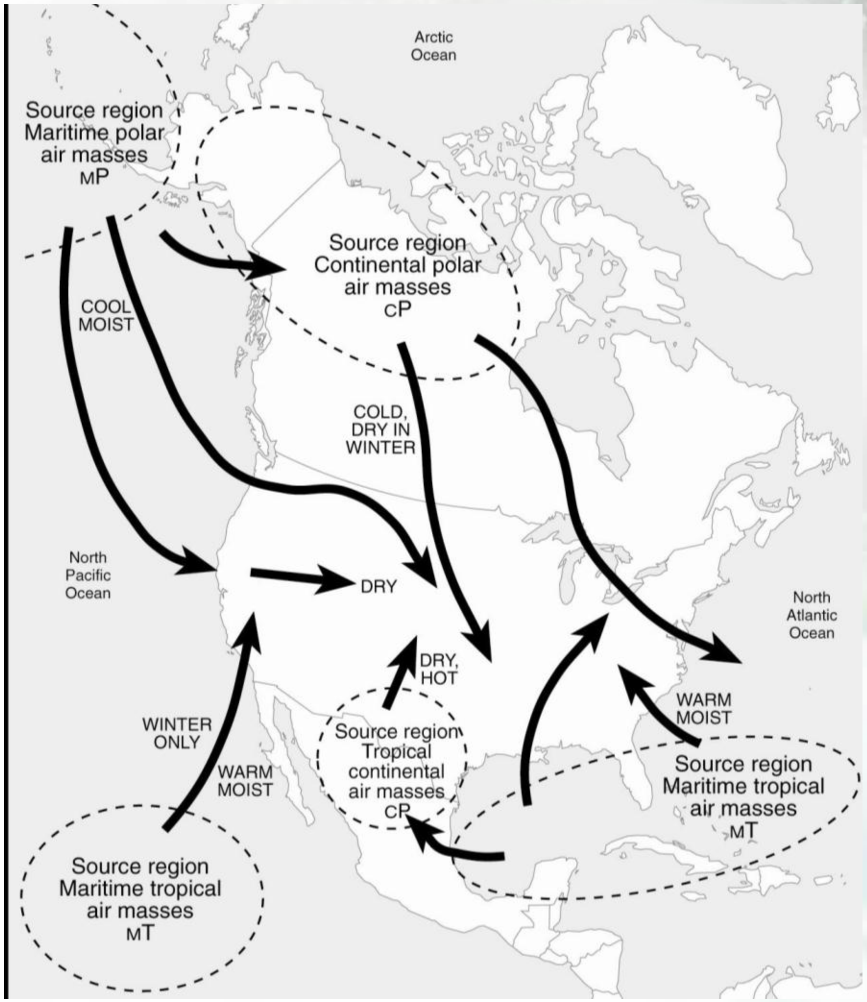
- *Radiation fog*: formed when temperature of the air at ground level falls below dew point
- *Advection fog*: forms when warm moist air moves over a cold surface
  - Common over oceans ("sea fog")

Weather Patterns

- Weather (day to day) vs. climate (years-decades and patterns)
- What are hydrologists most concerned with?
- Climate and geography result in biome classification



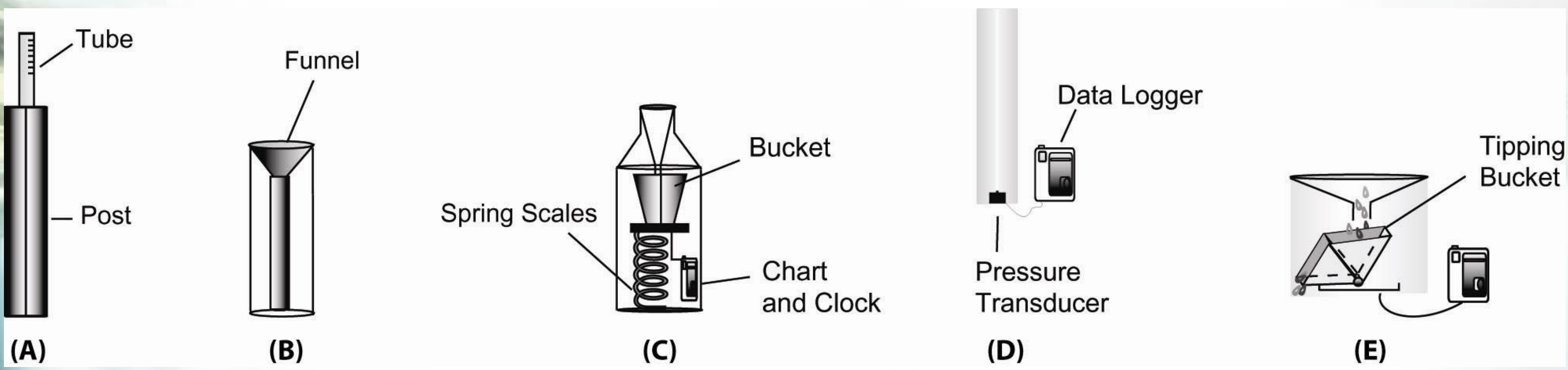
Moisture Sources for U.S.A.



What if you need to know the rainfall in a catchment?

Measure it yourself….

- Type of rain gauges?
- Where to put gauges?
- How many gauges?
- How do you map it?

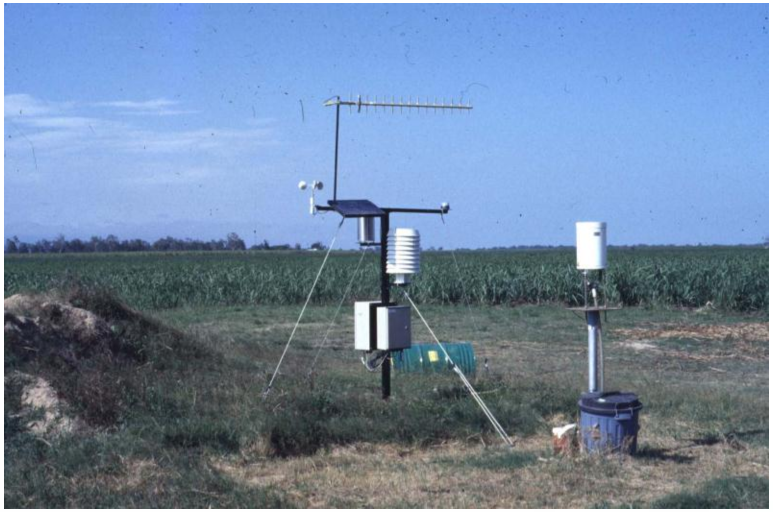


Methods of Measuring Rainfall: Manual

- Often have a funnel opening into a cylinder gauge.
- Come in a variety of shapes and sizes
- Calculate the rainfall (in mm) by dividing the volume of water collected by the area of the opening of the cup. (The gauge marking often accounts for this).

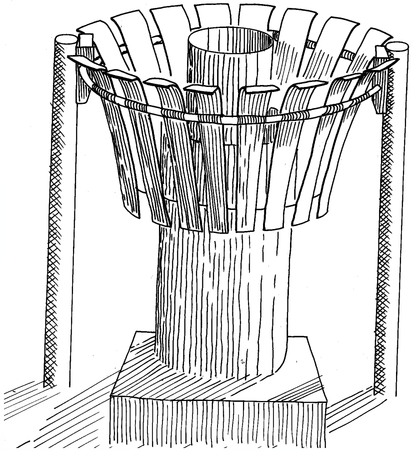
Methods of Measuring Rainfall: Remote

- Tipping bucket rain gauge -The bucket tips when precipitation of 0.2 mm, 0.5 mm, 1.0 mm has been collected. Each tip is recorded by a data logger.
- Weather Station - Records rainfall, but also evaporation, air pressure, air temperature, wind speed and wind direction (so can be used to estimate evapotranspiration)
- Radar - Ground-based radar equipment can be used to determine how much rain is falling and where it is the heaviest.

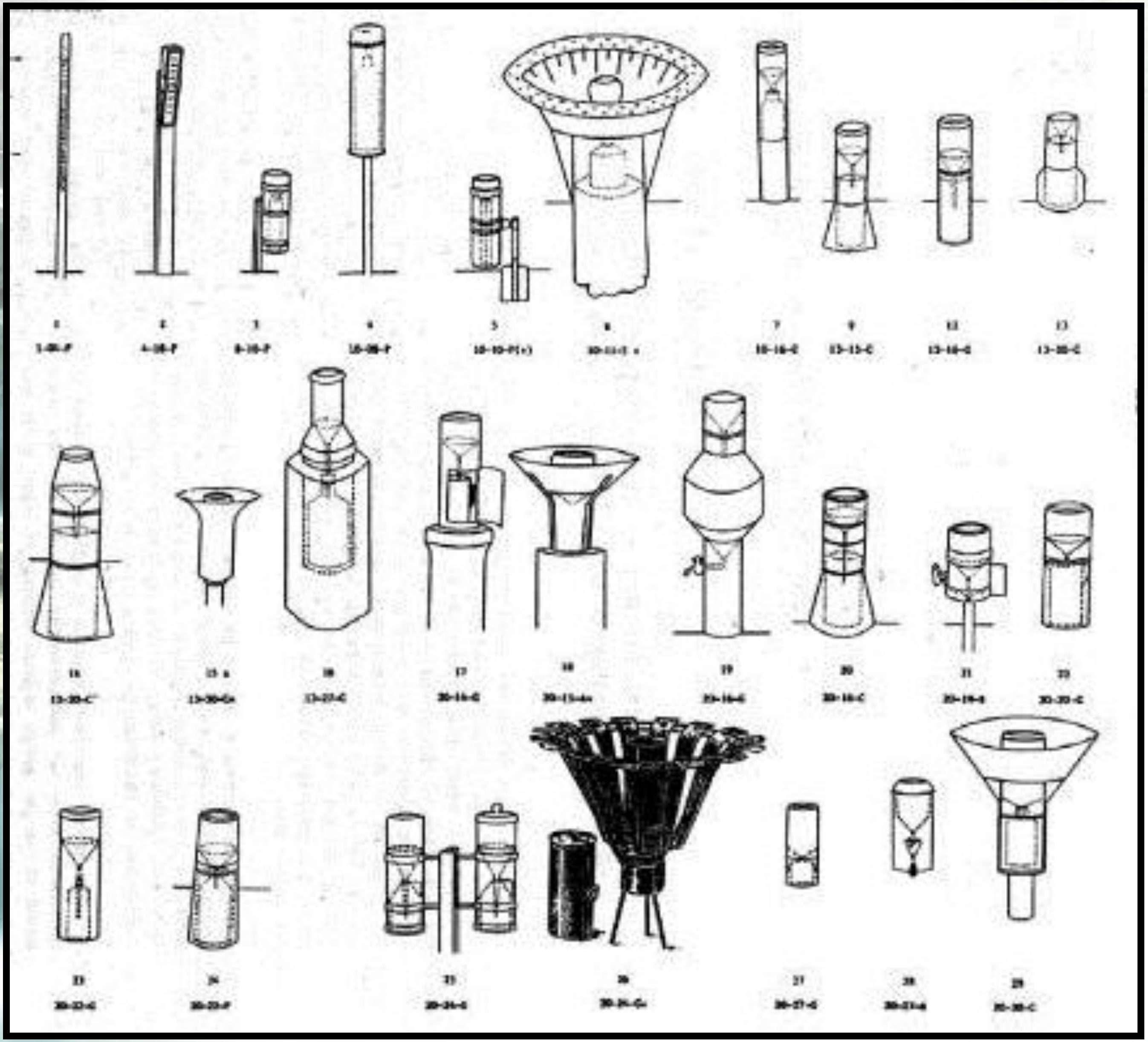


Precipitation Gauges

- Tipping Bucket: Automatically tips when a certain amount of precipitation accumulates inside of it. Total precipitation is determined by the number of tips.
- Weighing Gauge: Tall and typically cone-shaped. It collects all types of precipitation continuously into a bucket. Its weight presses down on a scale, and every 15 minutes, a hole is punched in a ticker tape or a marking is made on paper by pen to record the bucket's weight. This is useful for hourly collections.
- Optical Gauge: Measures precipitation rate proportional to a disturbance to a beam between a light-emitting diode and a sensor.



Precipitation Gauges of the World



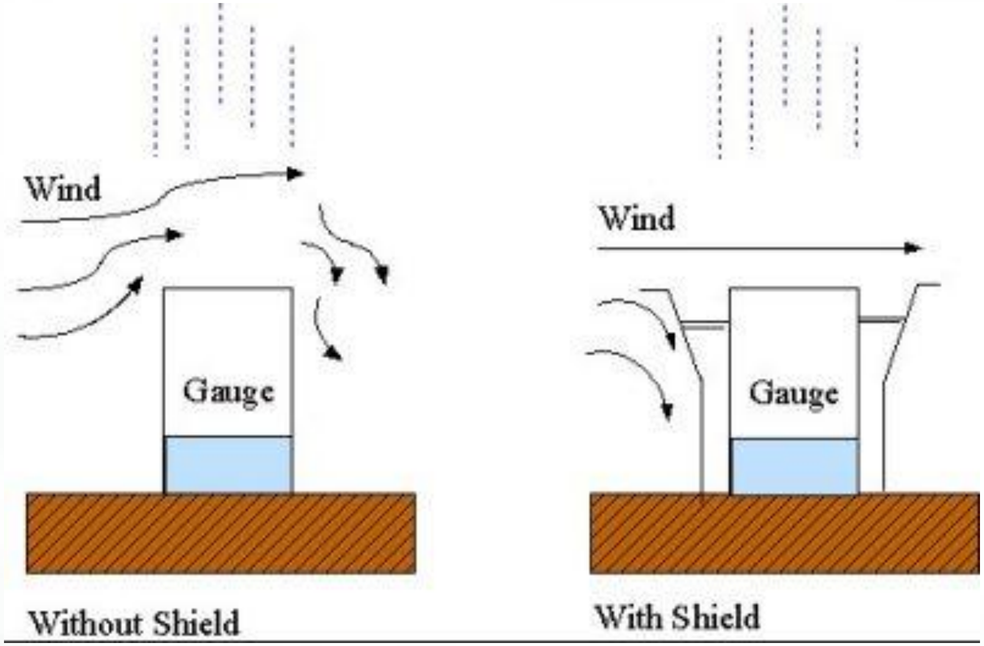
~50 types of National Standard gauges

(Sevruk et al., 1989)

Placement of Rain Gauges

Gauges are affected by wind pattern, eddies, trees and the gauge itself, therefore it is important to have the gauge located and positioned properly.

- 1m above ground level is standard - all gauges in a catchment should be the same height
- 2 to 4 times the distance away from an isolated object (such as a tree or building) or in a forest a clearing with the radius at least the tree height or place the gauge at canopy level
- shielded to protect gauge in windy sites or if obstructions are numerous they will reduce the wind-speed, turbulence and eddies.



Number and Distribution of Gauges

- The **distribution** of gauges **should not be random**.
  - only fixed characteristics of areas can be sampled randomly. Random events **must** be sampled by a systematic arrangement of sampling points

- Practical considerations of access and exposure mean that some pragmatism is required in designing a network.
  - It is useful to locate gauges so that **isohyetal maps** can be drawn. Some gauges need to be near, or outside the catchment boundary in order to cover the catchment completely.

Need to consider:

- size of area
- prevailing storm type
- form of precipitation
- topography
- aspect
- season

Number of Gauges

Depends on Storm type

- **Cyclonic storms** (large areas, low intensities) -small number of gauges may be O.K.
- **Convective storms** (local, intense, uneven distribution) - denser network needed. Convective storms may have seasonal dominance -need to consider this as well.
- **Orographic** rainfall due to mountains (not fronts) -may need denser network than flatter area.

Size of area	Number of gauges
2	16 hectares
3	40 hectares
10	8 km^2
15	16 km^2
50	160 km^2
300	1600 km^2
1000+	16,000 km^2

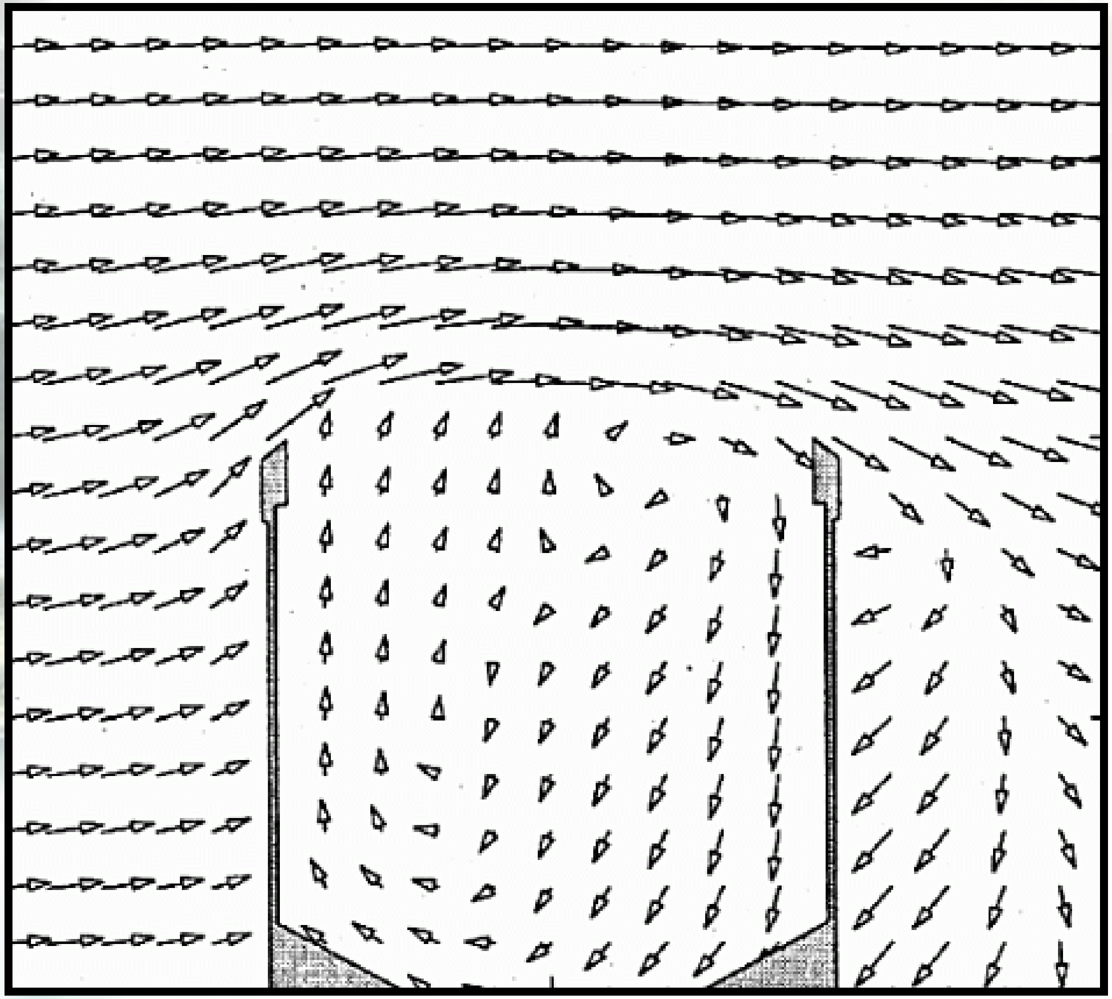
Problems with US Network

- Gauge Type and Shielding Inhomogeneous in time and space
- Trend towards Recording Gauges
- Relocations frequently occur
- 1st order stations located mainly at airports
- Inhomogeneous in gauge density: low gauge density in Western US and mountainous areas – difficult to support higher resolution gridding
- The unshielded 8” has large wind-induced undercatch, especially for solid precipitation

ASOS Heated Tipping Bucket (HTB) Gauge

- The HTB is replacing many of the standard 8” gauges
- Increased Inhomogeneity in time and space
- Mid 1990’s is period of greatest change

Wind-Induced Undercatch



Nespor and Sevruk, 1999

- Influencing Factors:
  - Wind speed
  - Temperature
  - Gauge type
  - Gauge height
  - Windshield
  - Exposure

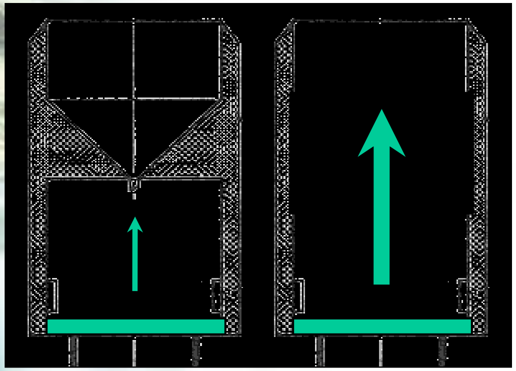
Undercatch of Precipitation

Wind-Induced Undercatch	Snow: 10 to >50% Rain: 2 to 10%
Wetting Losses	2 to 10%
Evaporation Losses	0 to 4%
Treatment of Trace Precipitation as Zero	Significant in Cold Arid Regions
Splash-out and splash-in	1 to 2%
Blowing and Drifting Snow	??

Sevruk, 1982

Other Sources of Errors

- Obstruction (ideally in a clearing surrounded by trees)
- Occult Precipitation: fog drip and rime
- Observer Errors: random, systematic, and gross
- Errors due to differences in observation time (ideally midnight)
- Instrument Malfunction
- Specific to Recording Gauges – bad calibration…
- Tampering / Vandalism
- Observation Record Inhomogeneity – changes in instrumentation, site, and local environment



Evaporation Loss:
- Gauge type
- Climate
- Measurement Methodology

Wetting Loss

Influencing Factors:
- Gauge type
- Climate
- Measurement Methodology

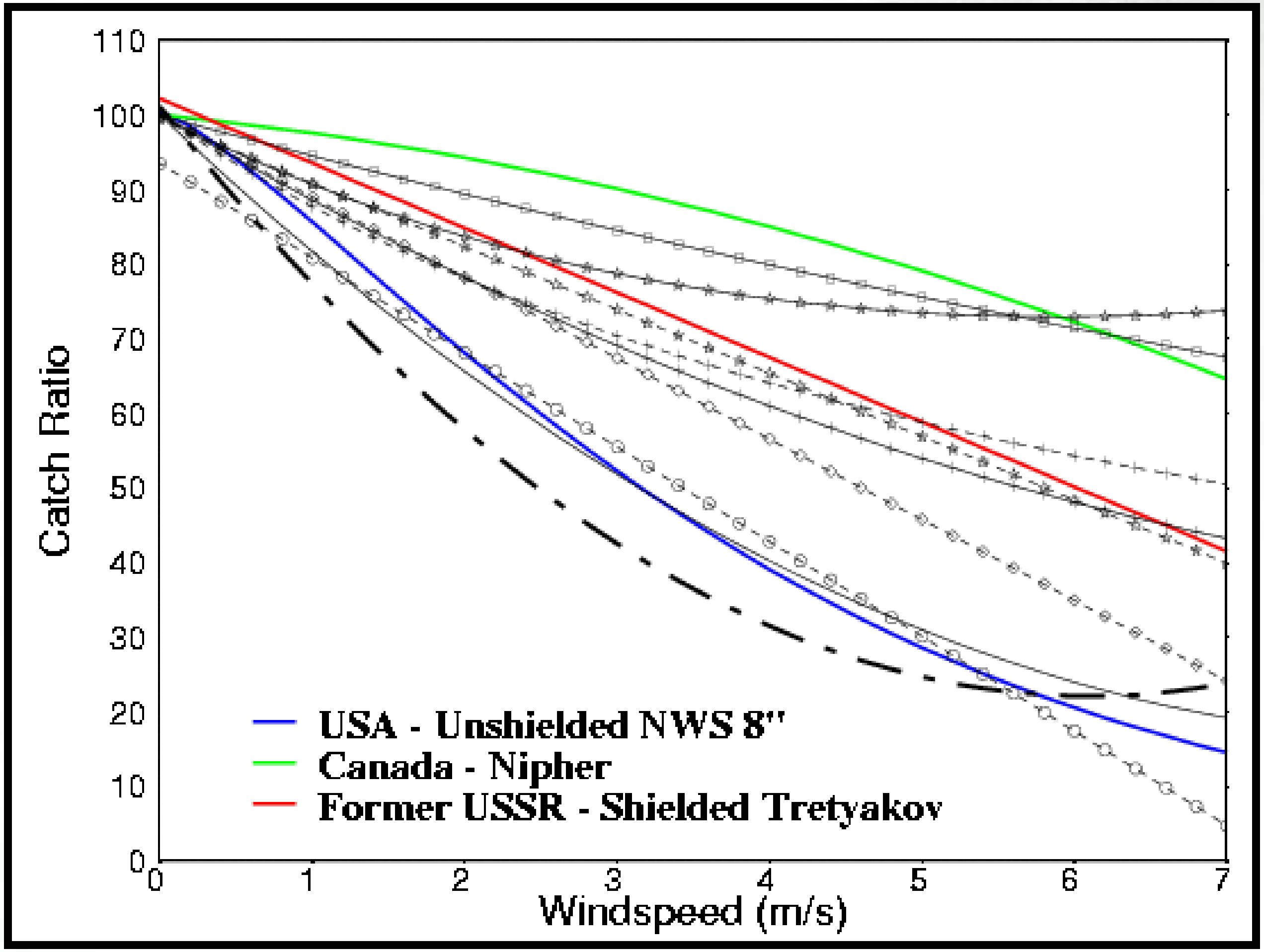
Double-Fenced International Reference (DFIR)


UCAR

- Encloses the Shielded Tretyakov Gauge

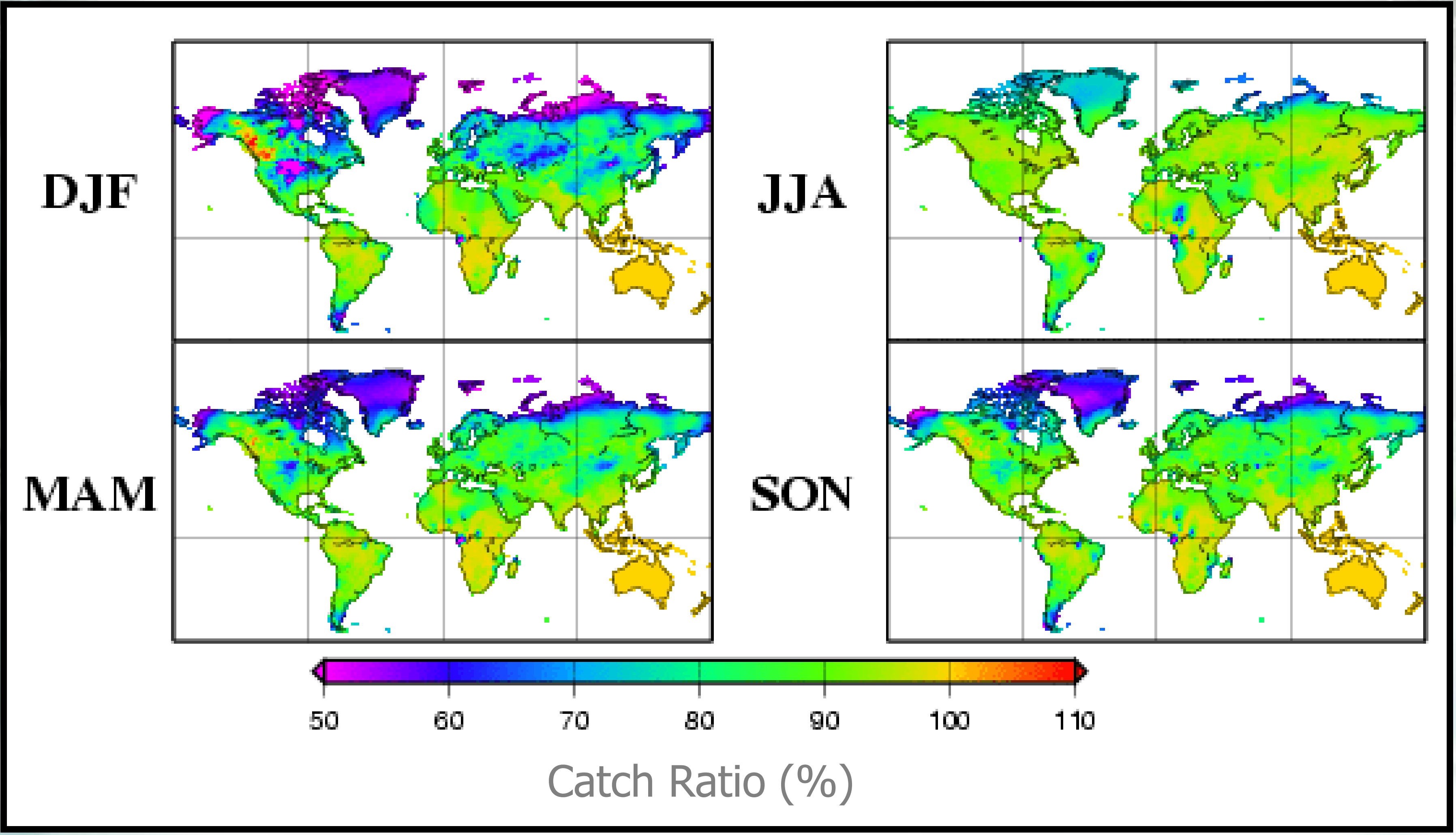
- Catches 92 to 96% of bush gauge snowfall

Results



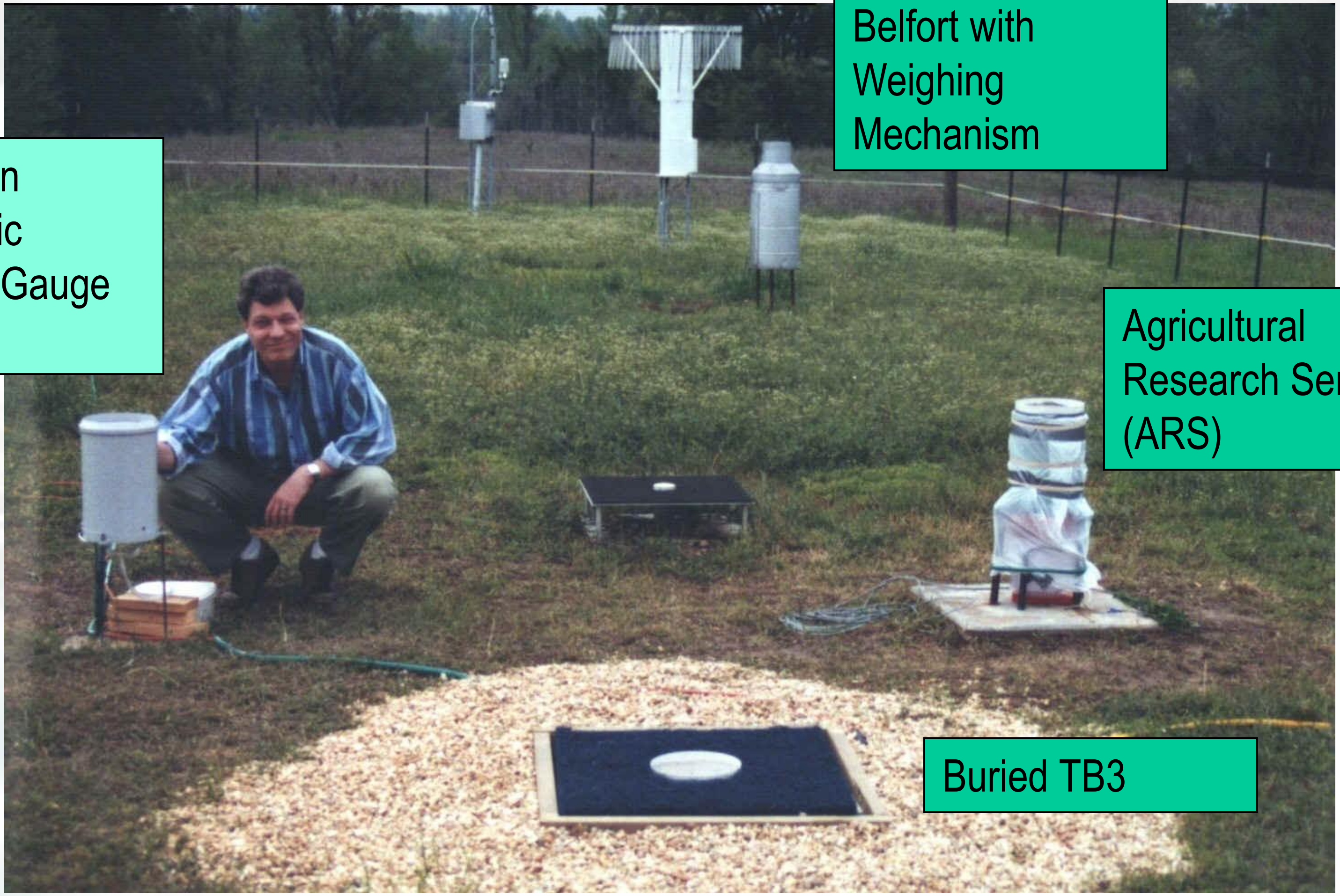
CATCH RATIO (CR) = $\dfrac{\text{Measured Precipitation}}{\text{True Precipitation}}$

Gridded Catch Ratios



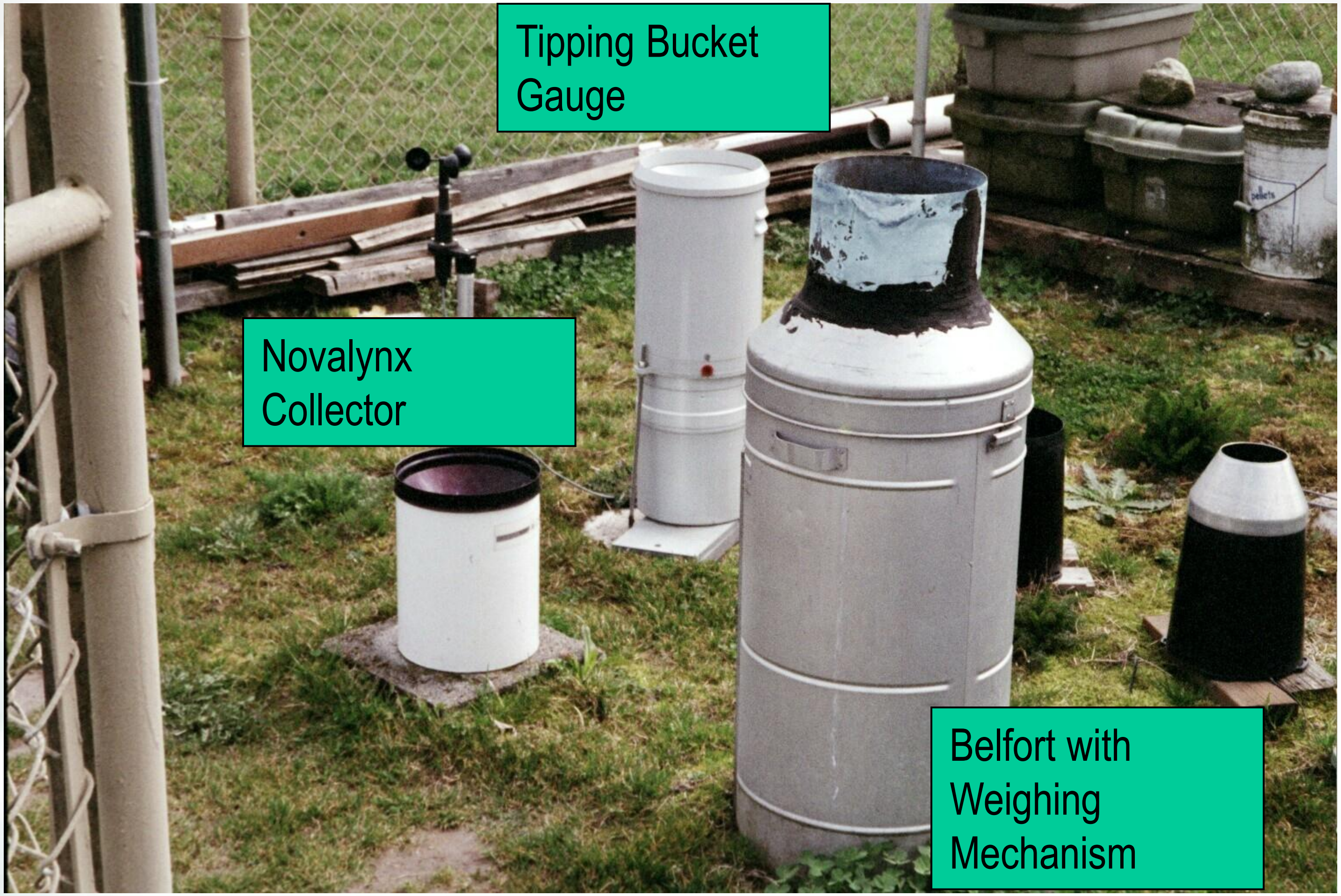
Smaller-Scale Studies

- Mississippi: Lisa Sieck, Steve Burges



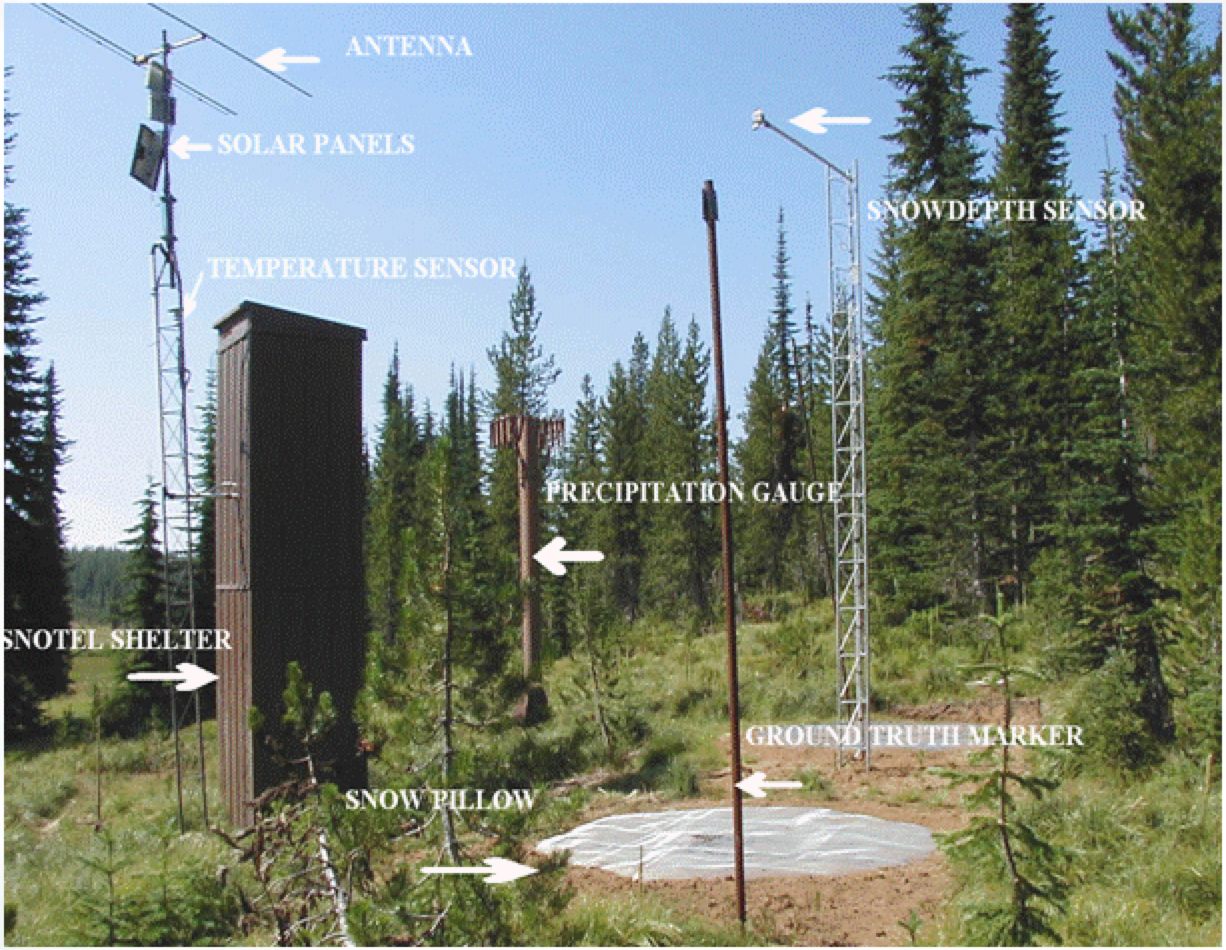
Smaller-Scale Studies

- Urban Horticulture Center Gauges: Steve Burges

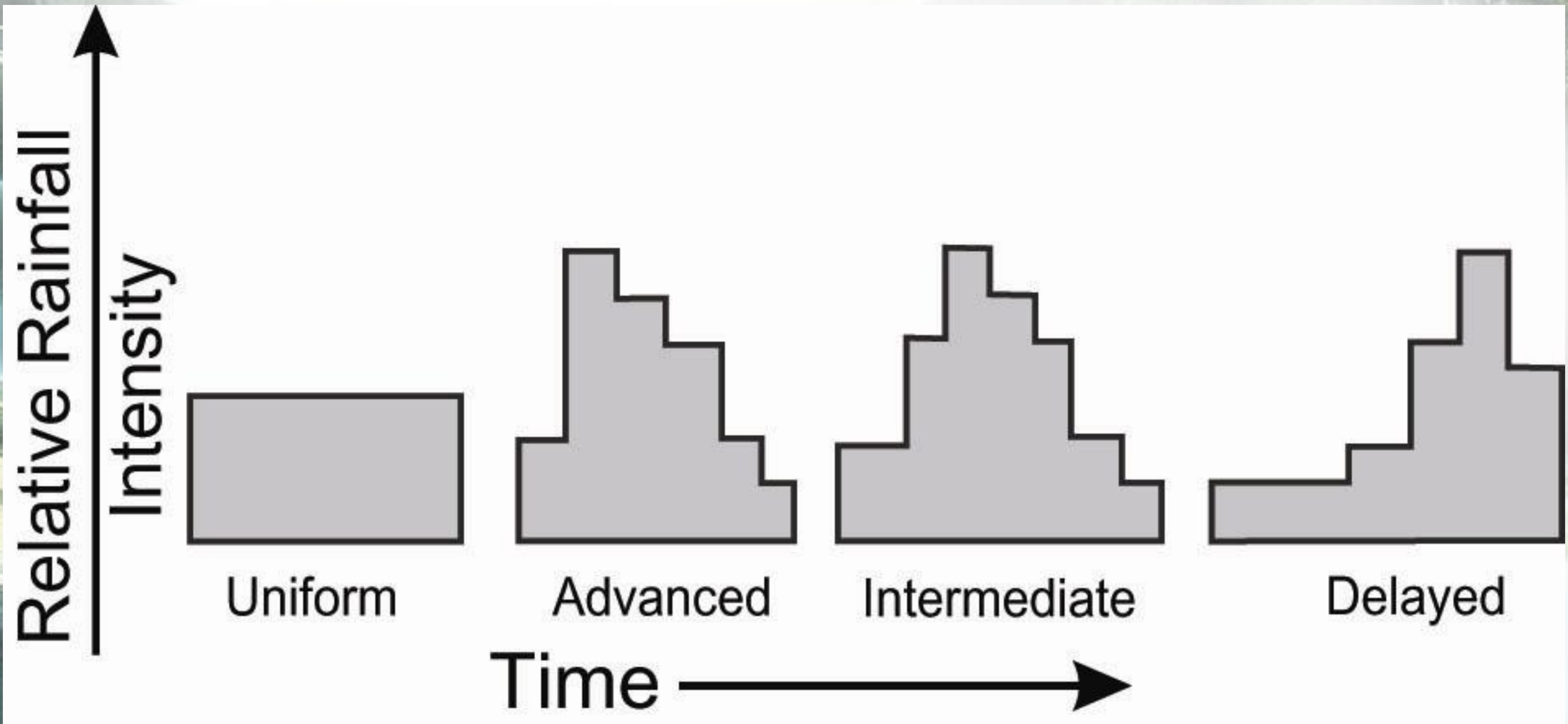


Snow Measurement

- Determine the water equivalent
- 5%-60% of snow depth may be water equivalent-- "density"
- Snow pillows use antifreeze solution and pressure measurement to measure water equivalent



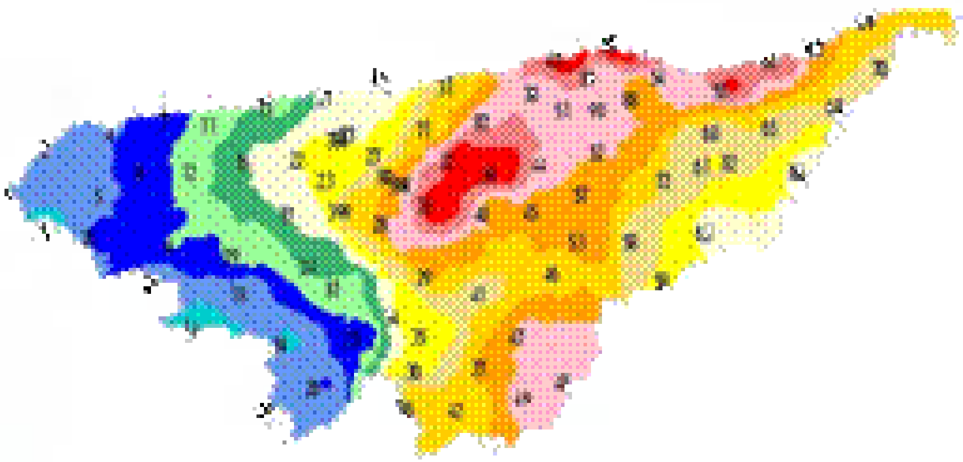
Storm Patterns (Histograms)



Methods of averaging rainfall data

- Arithmetic average
- Theissen polygons
- Isohyetal method

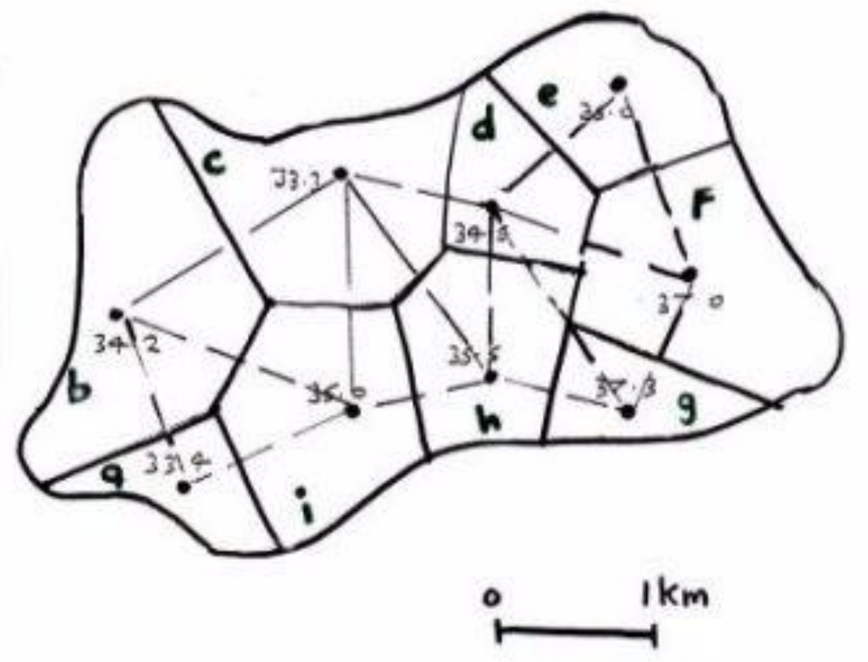
Although, most of these calculations are done with computer mapping programs, it is still useful to understand these methods.



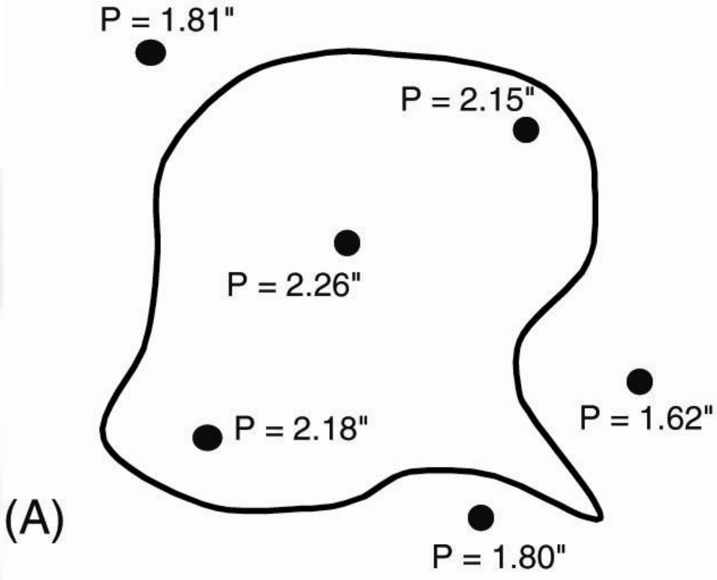
Thiessen method for Mapping Rainfall

This involves determining the area of influence for each station, rather than assuming a straight-line variation. It is easier than the isohyetal method but less accurate

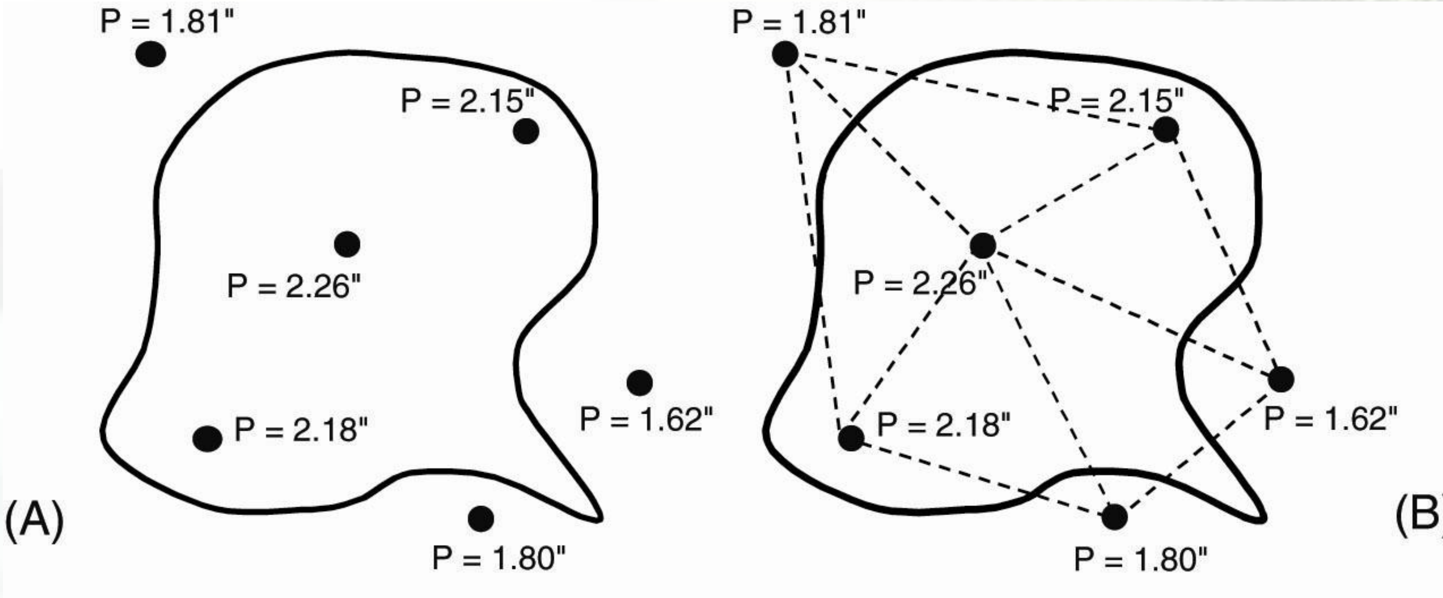
- Locate all rainfall stations on a base map and record the rainfall amount.
- Connect each station by straight lines with the several nearest stations to form a series of triangles.
- Erect perpendicular bisectors on each of these lines and extend them to the intersect with other bisectors, thus forming a series of irregular polygons



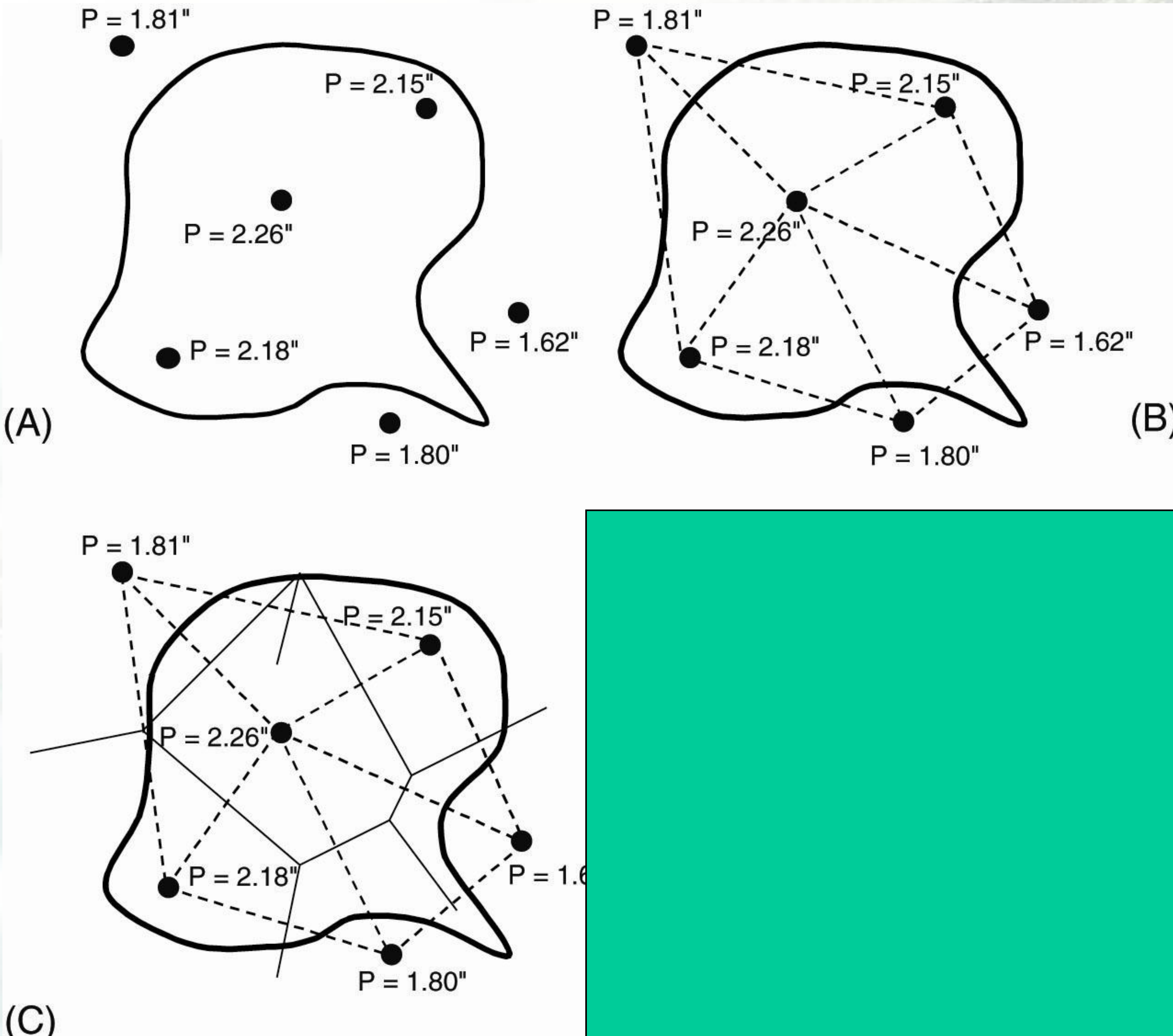
Thiessen Method for Average Rain



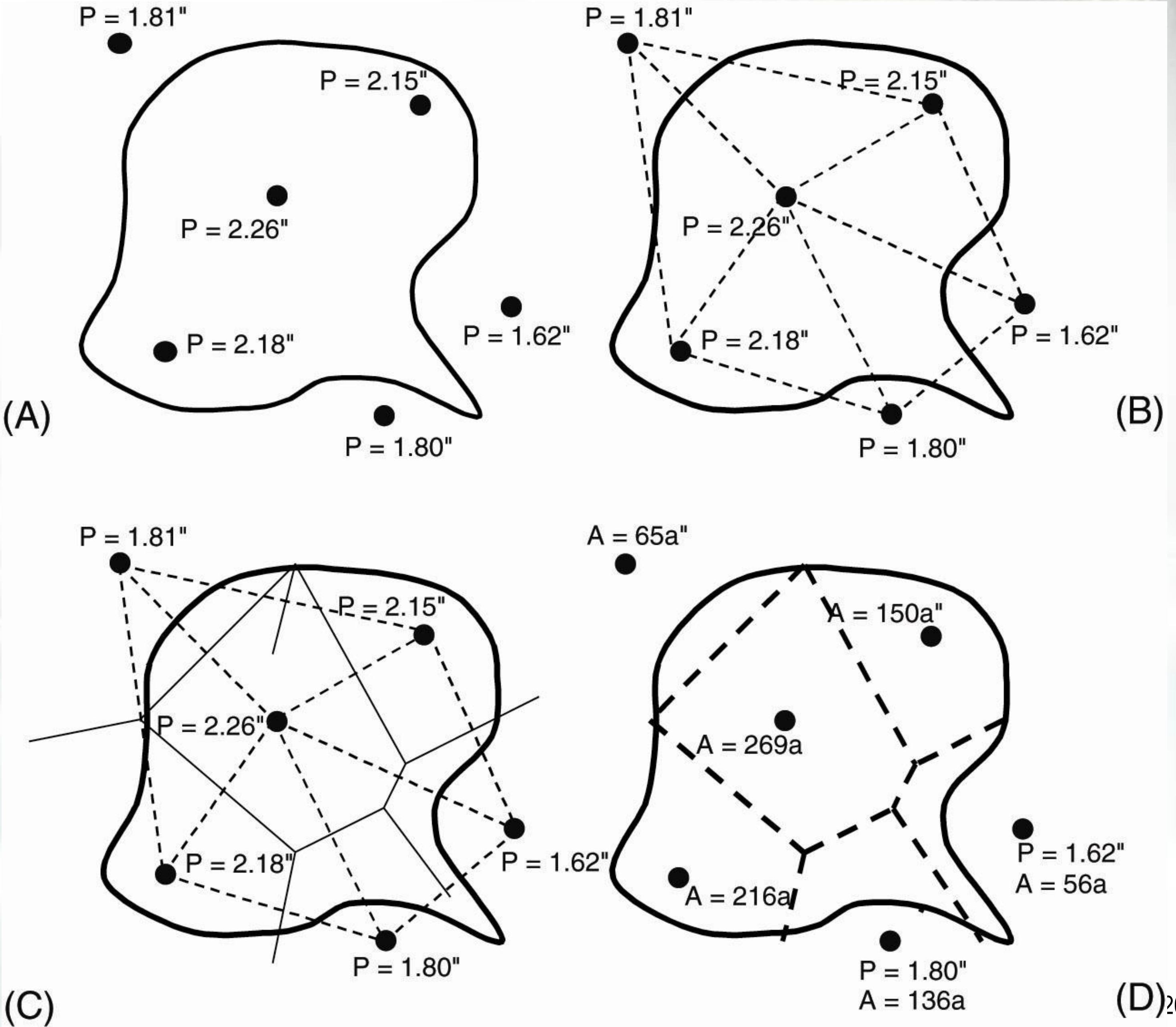
Thiessen Method for Average Rain



Thiessen Method for Average Rain



Thiessen Method for Average Rain



Thiessen method for Mapping Rainfall

Measure the fraction of the catchment area in each polygon (called the Thiessen constant), multiply by the rainfall catch at the station within the polygon and sum to get the catchment average.

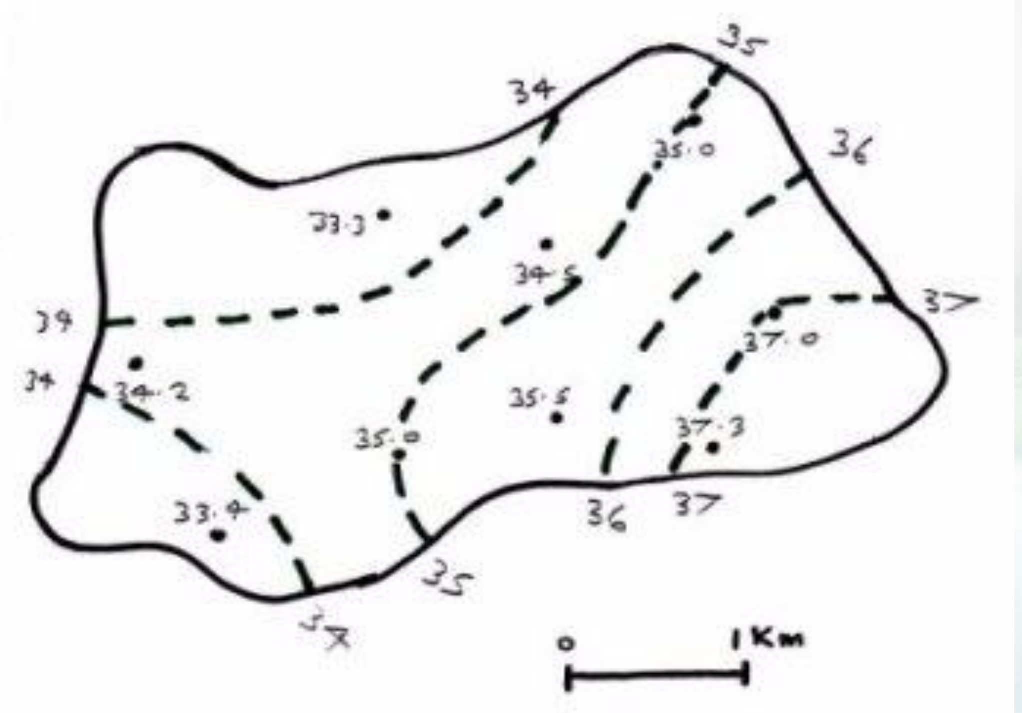
Rainfall Station	A Thiessen Constant (Fractional Area)	B Rainfall in Each Polygon	A*B Weighted average
A	0.144	33.4	4.81
B	0.110	34.2	3.76
C	0.104	33.3	3.46
D	0.133	34.5	4.59
E	0.132	35.0	4.62
F	0.113	37.0	4.18
G	0.064	37.3	2.39
H	0.105	35.5	3.73
I	0.103	35.0	3.60
Sum Total	**1.00**		**35.14**

Isoheyetal method for Mapping Rainfall

The most basic method of representing the spatial distribution. This is generally the **most accurate** method but is also the most **laborious**.

- Locate all rainfall stations on a base map and record the rainfall amount.

- Draw isohyets (lines of equal rainfall) by proportioning the distances between adjacent gauges according to differences in catch.



Isoheyetal method for Mapping Rainfall

- Then calculate the mean precipitation for the area corresponding to each isohyet.
- Calculate the fraction of catchment area under each isohyet, multiply by the mean precipitation for that area and sum to get the catchment average.

Isohyets Upper	Lower	A Mean Rainfall On Area	B Area Between Isohyets (ha)	A*B Weighted Mean Rainfall
38	37	37.5	130	4875
37	36	36.5	150	5475
36	35	35.5	300	10650
35	34	34.5	450	15525
34	33	33.5	200	6700
Total			**1230**	**43225**

Mean Rainfall = 35.14 i.e. from (43225/1230)

Methods of determining missing data

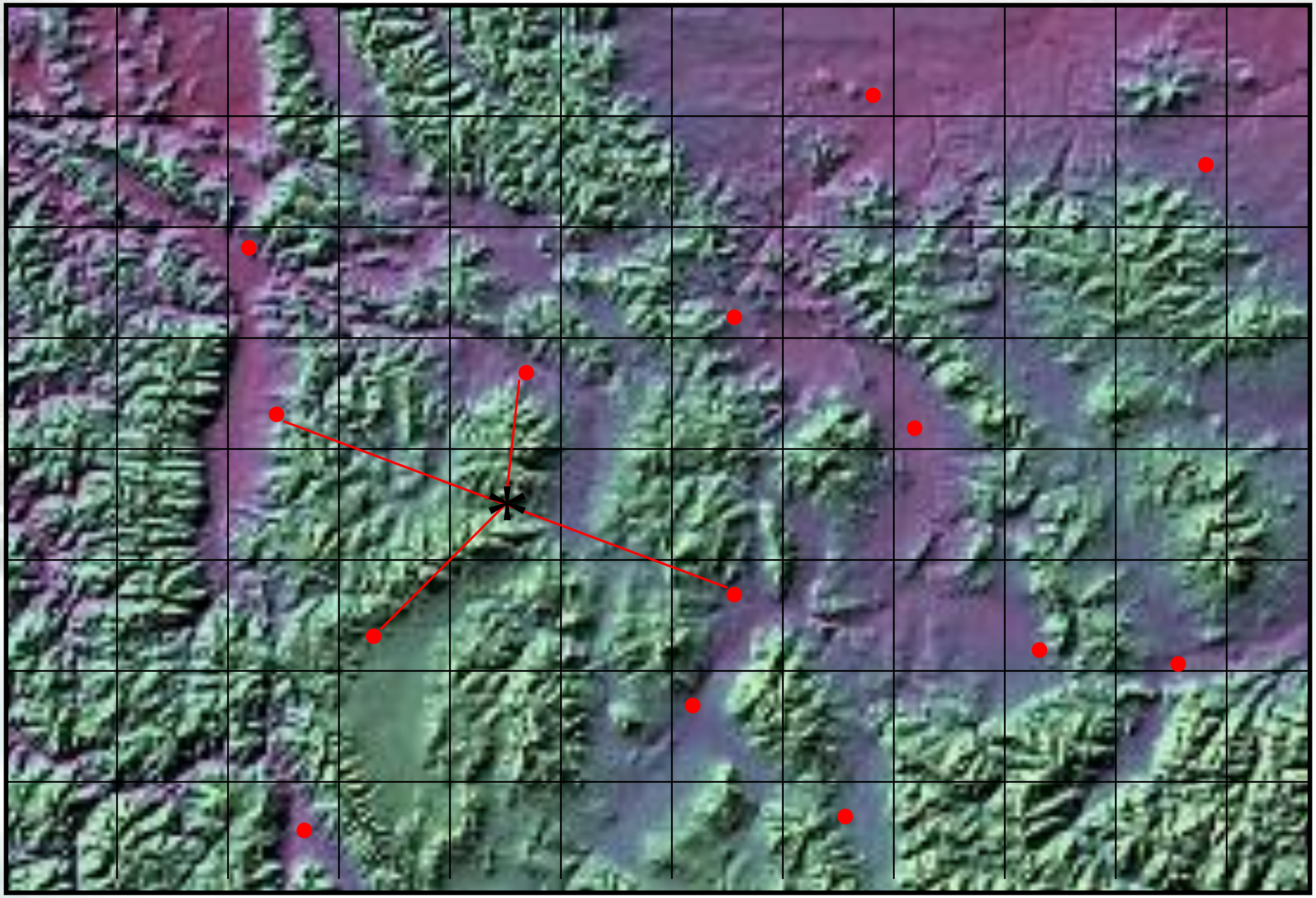
In the examples station X is the station with data missing

- **Arithmetic average** - assign it to station X
- **Normal ratio method** -
  - get observed rainfall at surrounding stations
  - These are weighted by the ratio of the normal annual rainfall at station X and normal annual rainfall at that station.

$$P_x = \frac{1}{n}\left(\sum_{i=1}^{n} P_i \frac{N_x}{N_i}\right)$$

- **Inverse distance squared**
  - The closer a station is to station X the greater the weight assigned to that station's precipitation.
  - The inverse of the squared distance between a station and station X is used as a weighting factor in determining the rainfall at station X.

Interpolation from Valley Gauges



Computer Mapping Methods

- Other mapping programs such as SURFER or GIS program ARCVIEW can be used to map rainfall at the different measurement locations.
- Maps of rainfall can be produced by using the statistical analysis packages that come with the program. Statistical methods include nearest neighbour, inverse distance weighting or kriging (which uses variogram analysis).
- The statistical methods produce a grid over the specified area of a specific size. The influence of the actual rainfall measurement is determined for each grid node to produce a rainfall amount at each node.

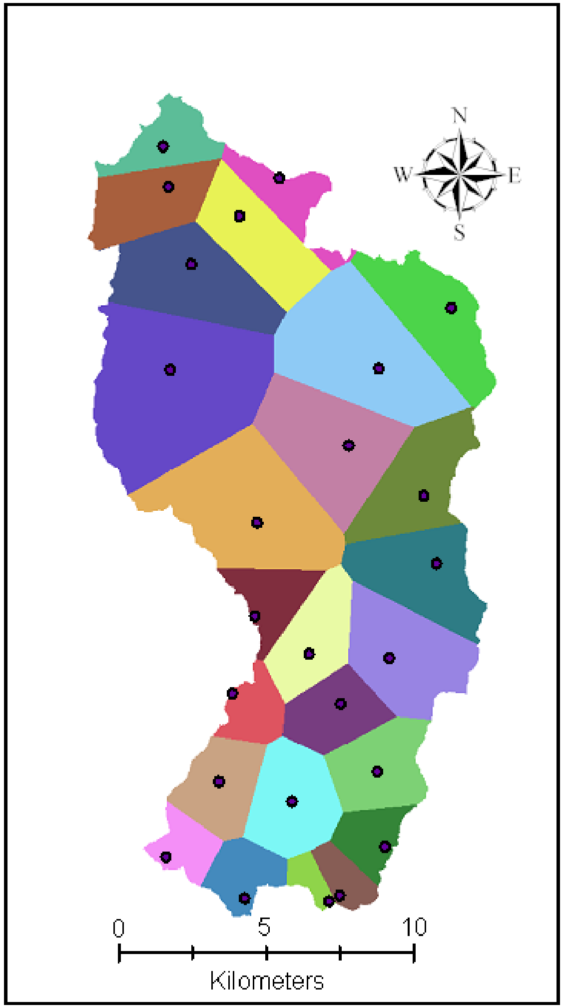
Rainfall interpolation in GIS

- Data are generally available as points with precipitation stored in attribute table.

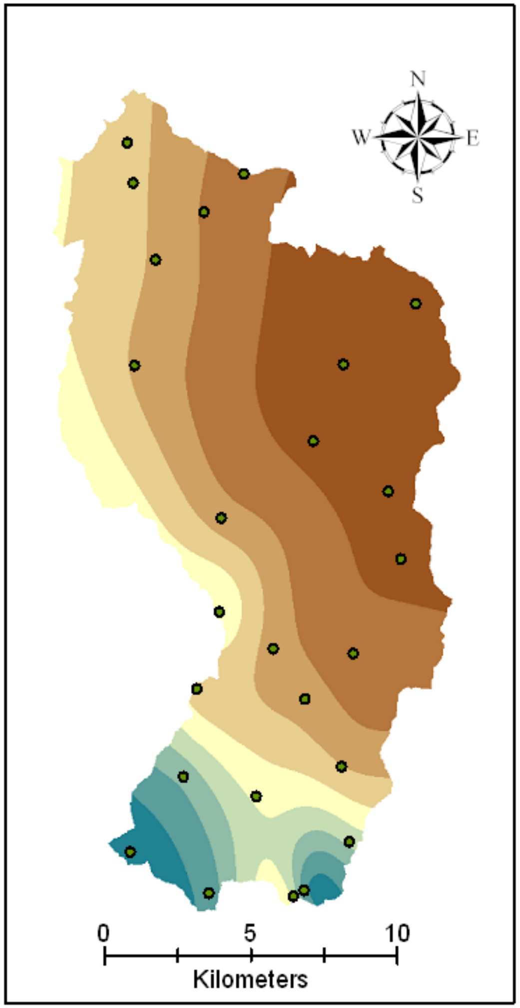
Attributes of reyprecip.txt

staid	long	lat	anntot	jan	feb
p012	-116.827040151	43.296918	558.62	83.58	40.71
p015	-116.778195562	43.287189	359.82	48.27	23.7
p023	-116.824585572	43.284514	546.35	69.92	44.7
p024	-116.79488694	43.275550	407.04	65.24	30.4
p033	-116.815215733	43.260925	504.02	83.5	38.9
p049	-116.706133516	43.247226	223.71	21.64	16.41
p053	-116.824105883	43.228522	507.89	57.88	43.0
p057	-116.736588983	43.228723	236.61	24.15	18.7

Rainfall maps in GIS



Nearest Neighbor "Thiessen" Polygon Interpolation



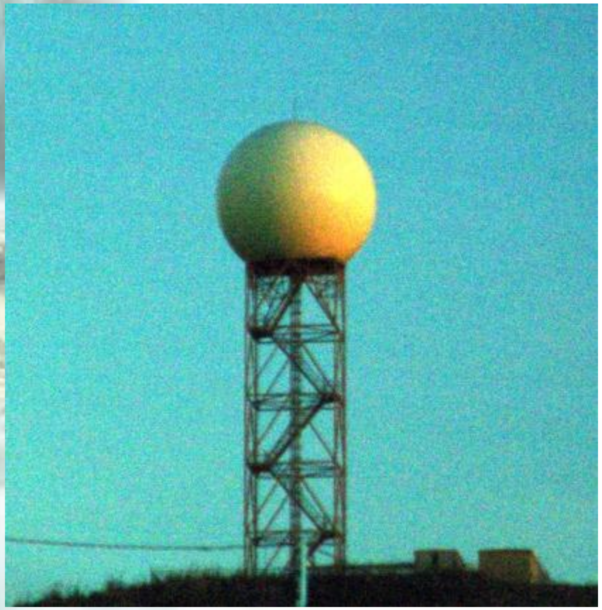
Spline Interpolation

Problems with Gridded Data

- Uniformity of Station Density
  - Global precipitation – higher density in more developed countries
- Gauge Type Uniformity
  - If not uniform, station data should be first be corrected for undercatch – specific to each gauge type
- Station Representation – Do the stations used for gridding adequately represent the precipitation spatial patterns?
  - US stations mainly at airports
  - Stations located in valleys – orographic effects

Radar Precipitation

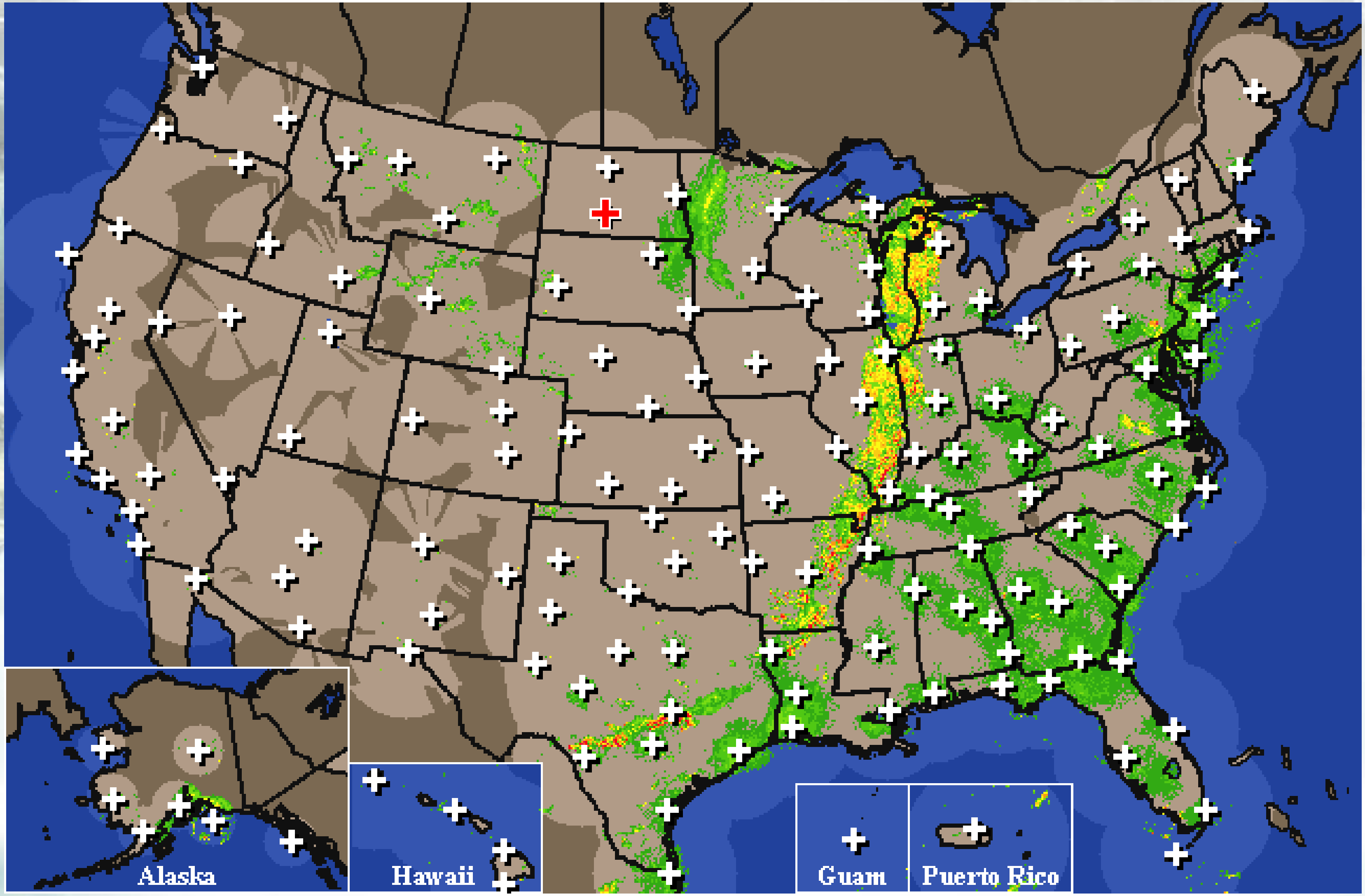
- **NEX**t generation **RAD**ar: is a doppler radar used for obtaining weather information
- A signal is emitted from the radar which returns after striking a rainfall drop
- Returned signals from the radar are analyzed to compute the rainfall intensity and integrated over time to get the precipitation



NEXRAD Tower

Working of NEXRAD

US NEXRAD “Gaps” (West)



Satellite Precipitation

- **Infrared**
  - GOES 11 and 12
- **Microwave**
  - DMSP SSM/I
  - NOAA AMSU-A
  - NOAA AMSU-B
  - NASA AMSR-E
- **Satellite Radar**
  - NASA TRMM

Satellites are superior to alternative methods with respect to coverage and calibration.

Satellites supplement ground radar and rain gauges- they are all interconnected.

GOES products are superior to microwave due to higher temporal and spatial resolution.

Microwave products have more robust scientific theory than GOES.

A combination of microwave and infrared theory is promising for the future.

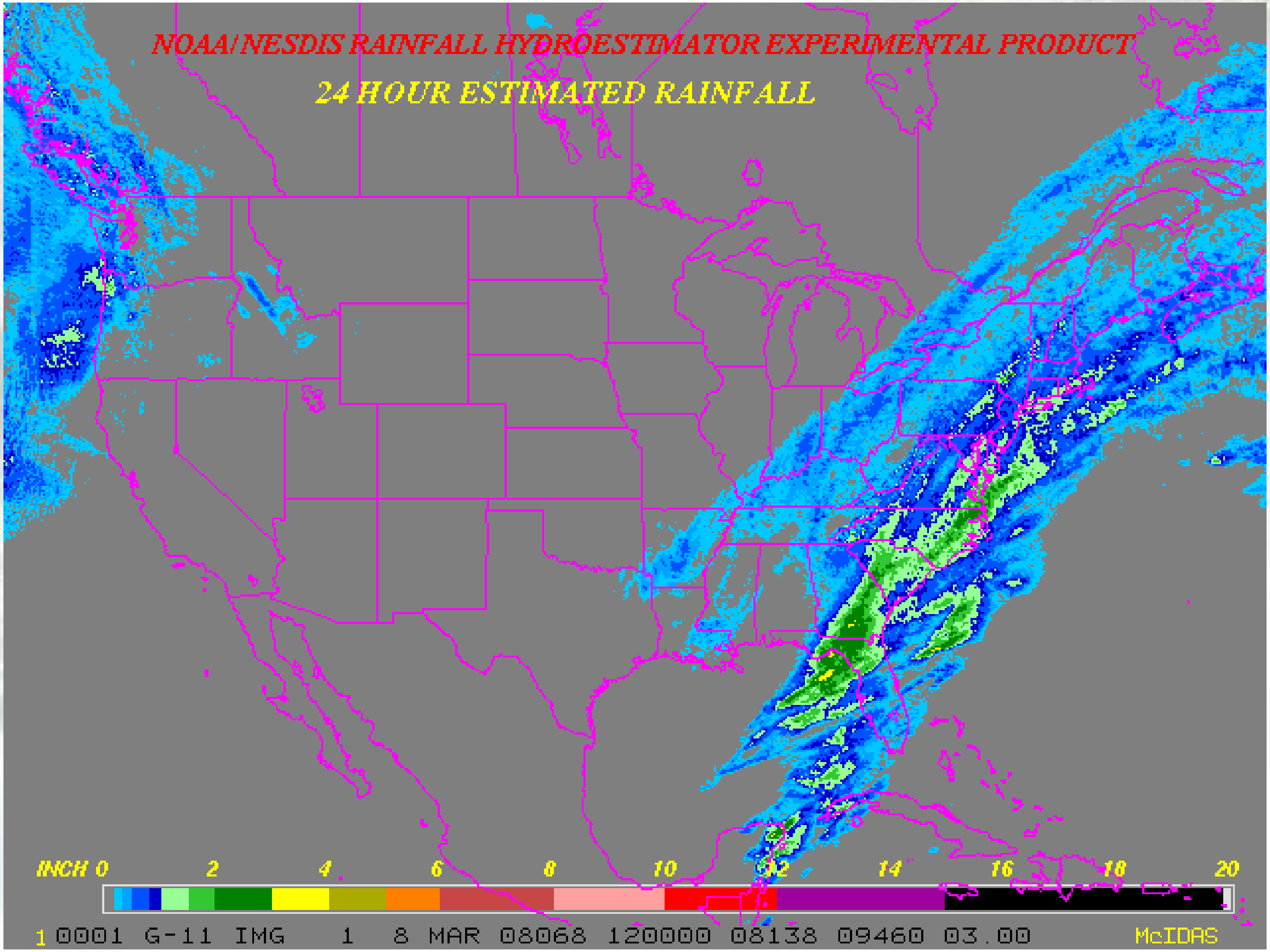
Infrared Theory

- Relationship between cloud-top temperature, cloud-top thickness, and precipitation:
  - Colder cloud-top temperatures imply higher and thicker clouds, which imply heavier precipitation
- Relationship between changes in cloud-top surface and precipitation
  - Vertically growing clouds are associated with precipitation while decaying clouds are not

Microwave Theory

- Direct relationship between ice in cold clouds and precipitation
  - Ice scatters terrestrial radiation back down to the surface, making microwave imagery appear “cold” where ice clouds are present (passive)
- Direct relationship between water content in clouds and precipitation
  - Water in clouds emits microwave radiation, making microwave imagery relatively “warm” where high water content clouds are present (passive)

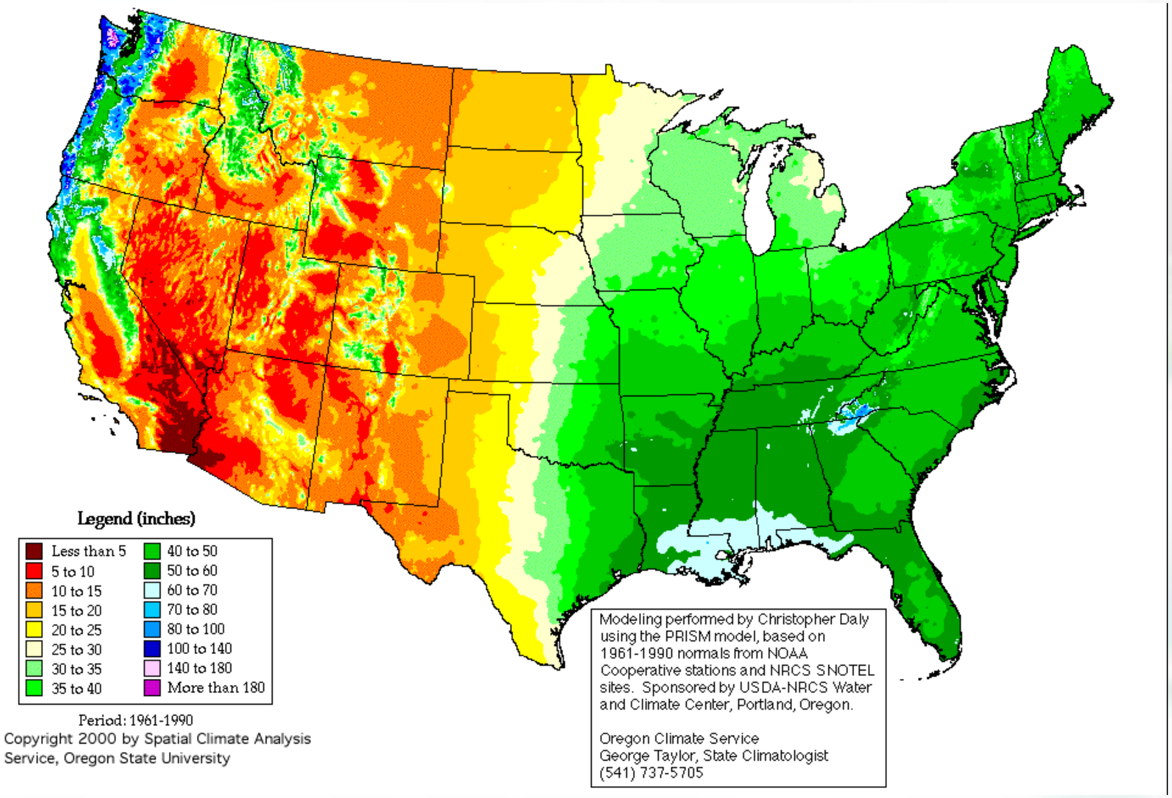
Example 24-hr Total



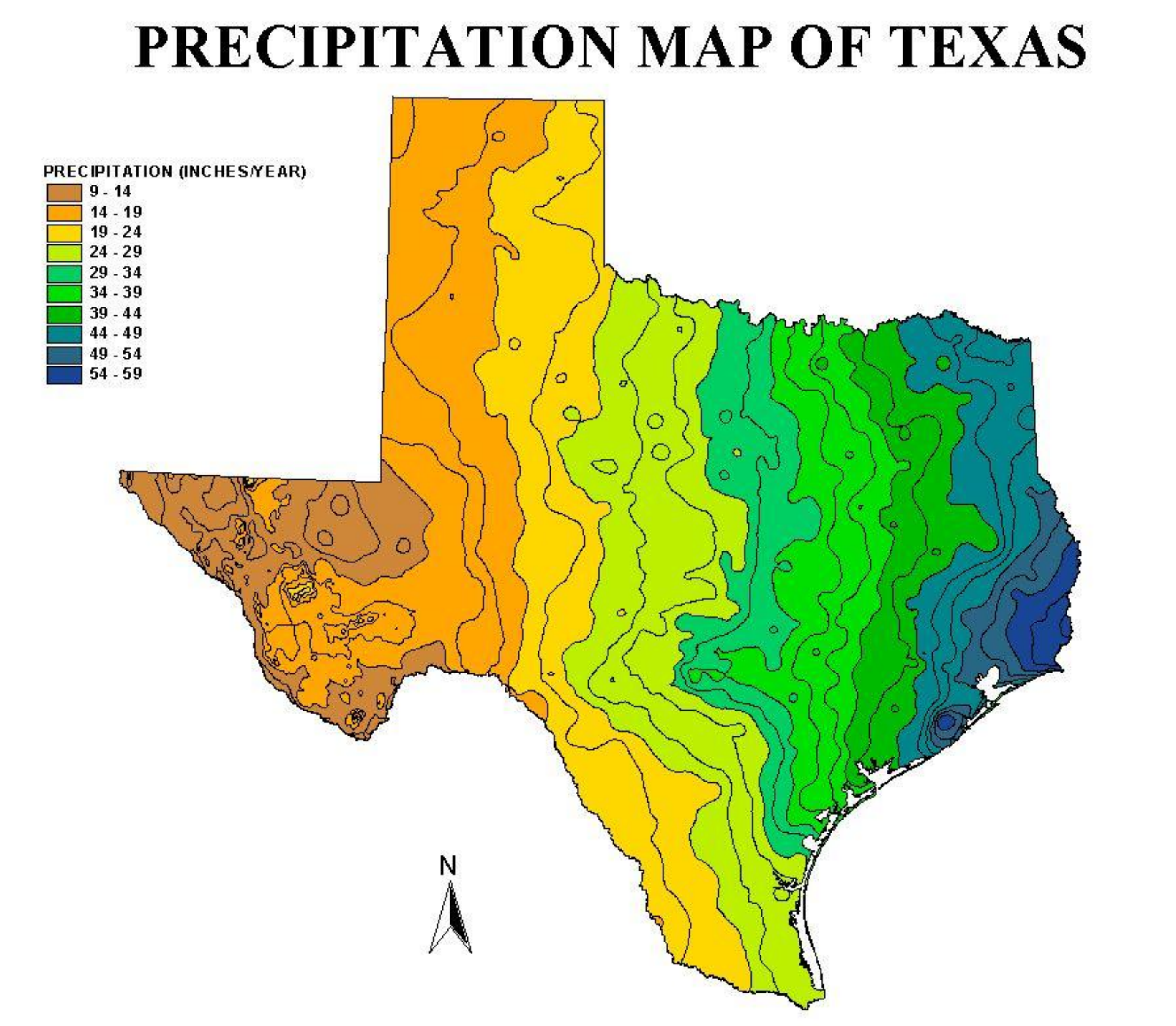
http://www.star.nesdis.noaa.gov/smcd/emb/ff/auto.html

Precipitation Variation

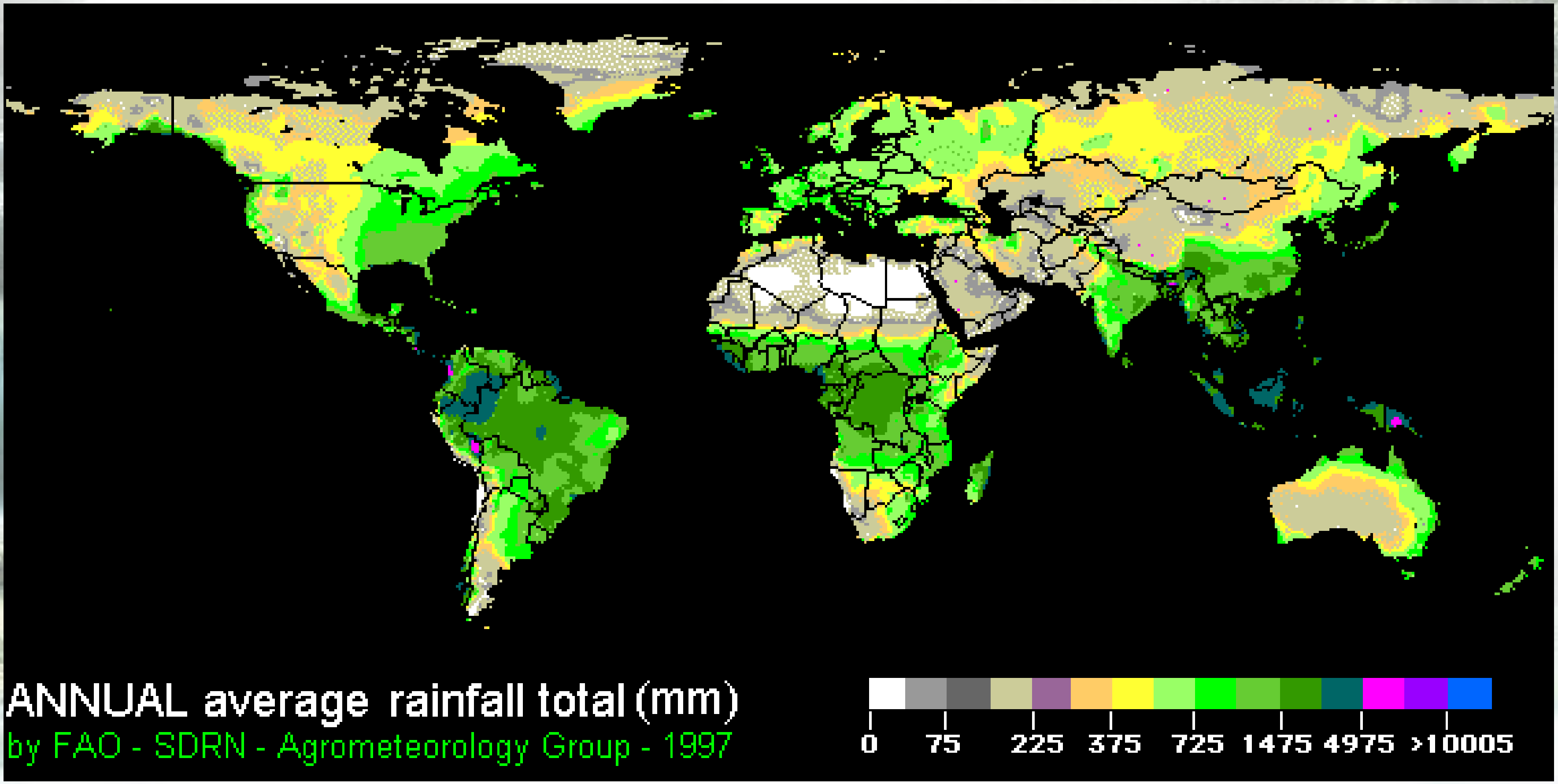
- Influenced by
  - Atmospheric circulation and local factors
    - Higher near coastlines
    - Seasonal variation – annual oscillations in some places
    - Variables in mountainous areas
    - Increases in plains areas
    - More uniform in Eastern US than in West



Texas Rainfall Maps



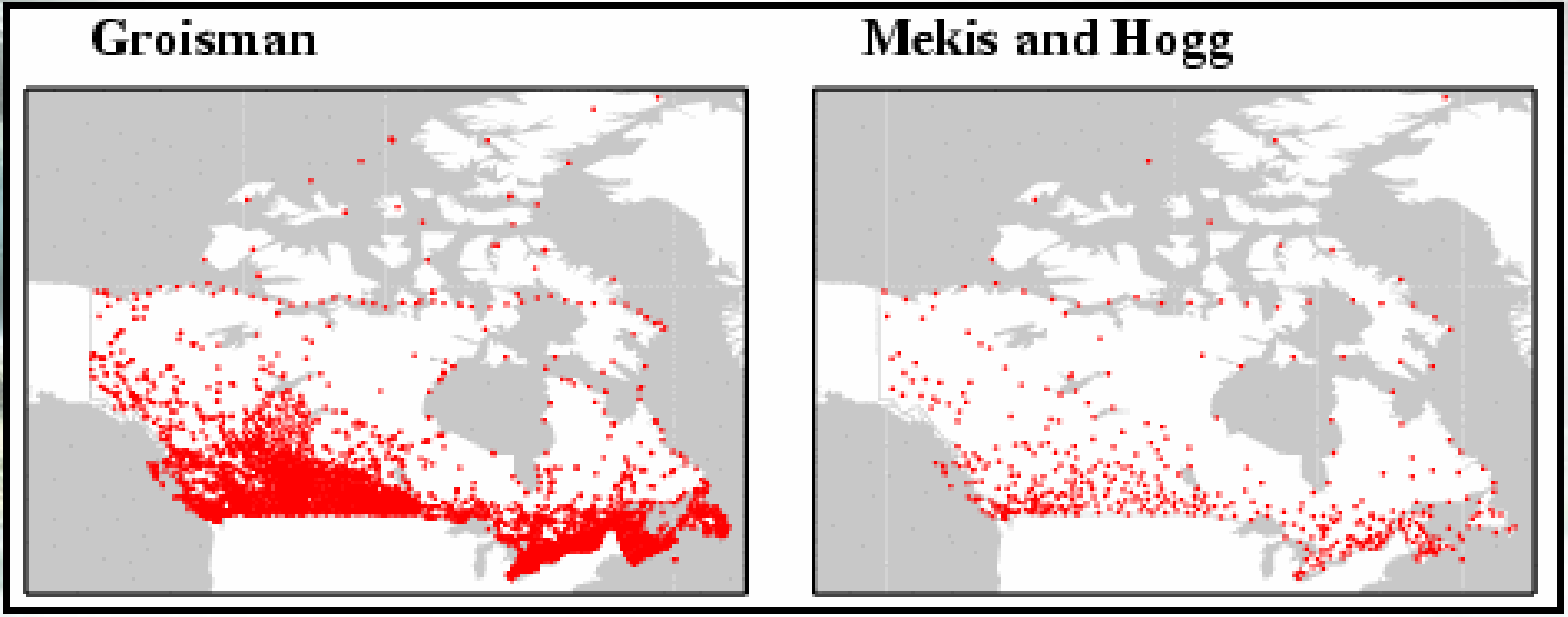
Global precipitation pattern



Global Gridded Data

Legates 1987	Willmott and Matsuura 2001	CRU 0.5 2000	GPCC 1994	GPCP 1997 (Merged data)
½ degree	½ degree	½ degree	1 degree	1 degree / 2½ degree
monthly Climatol. 1920-1980	monthly Series 1950-1999	monthly Series 1901-1998	monthly Series 1986-1999	1dd -daily 1997-2000 v2 -monthly 1979-2000
Bias-Adjusted	NA	NA	In progress	Bias-Adjusted

Canadian Gauge-Corrected Data
(Monthly Station Data)

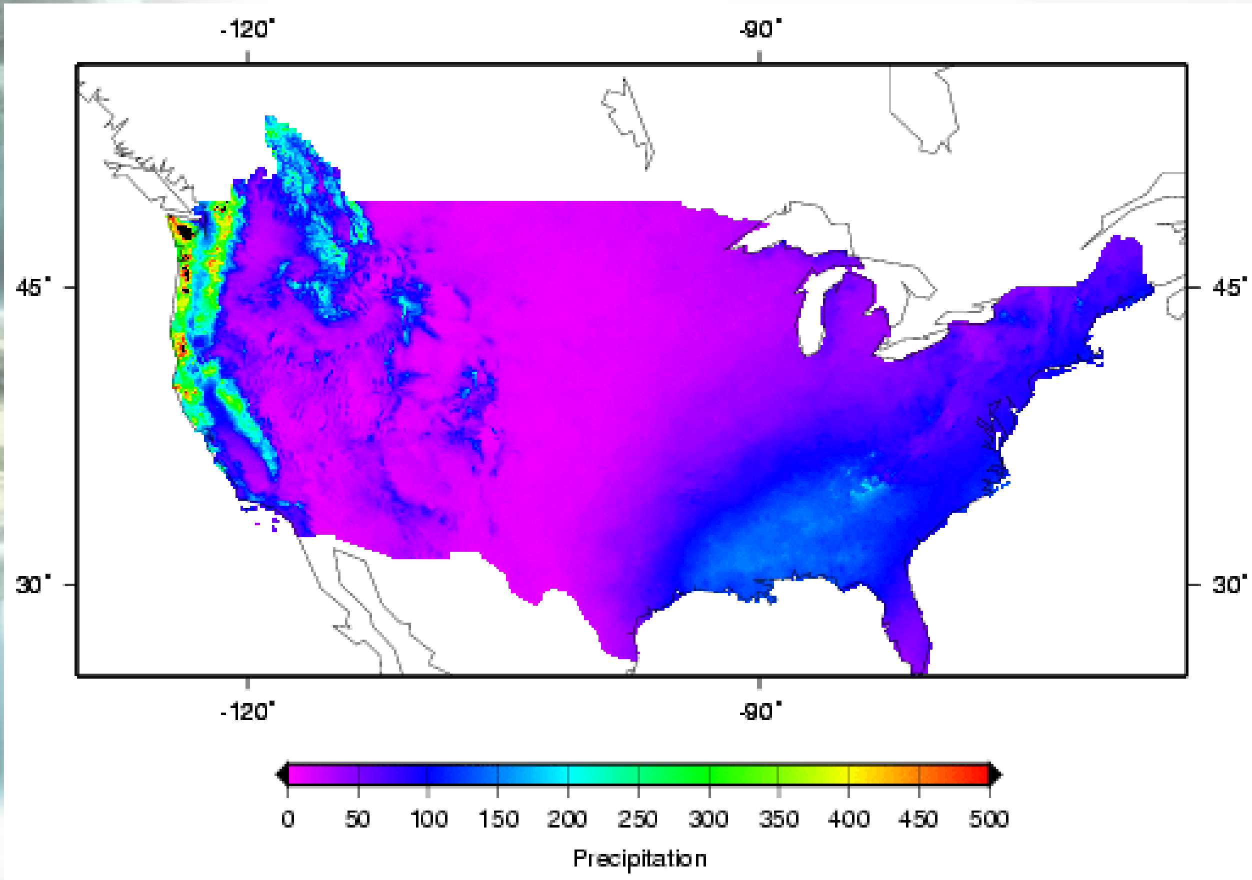


- 6,692 stations, through 1990
- Wetting, wind-induced undercatch
- Assumed CR = 90%

- 495 stations, through 1999
- Wetting, wind-induced, trace undercatch
- Utilized WMO Results

PRISM

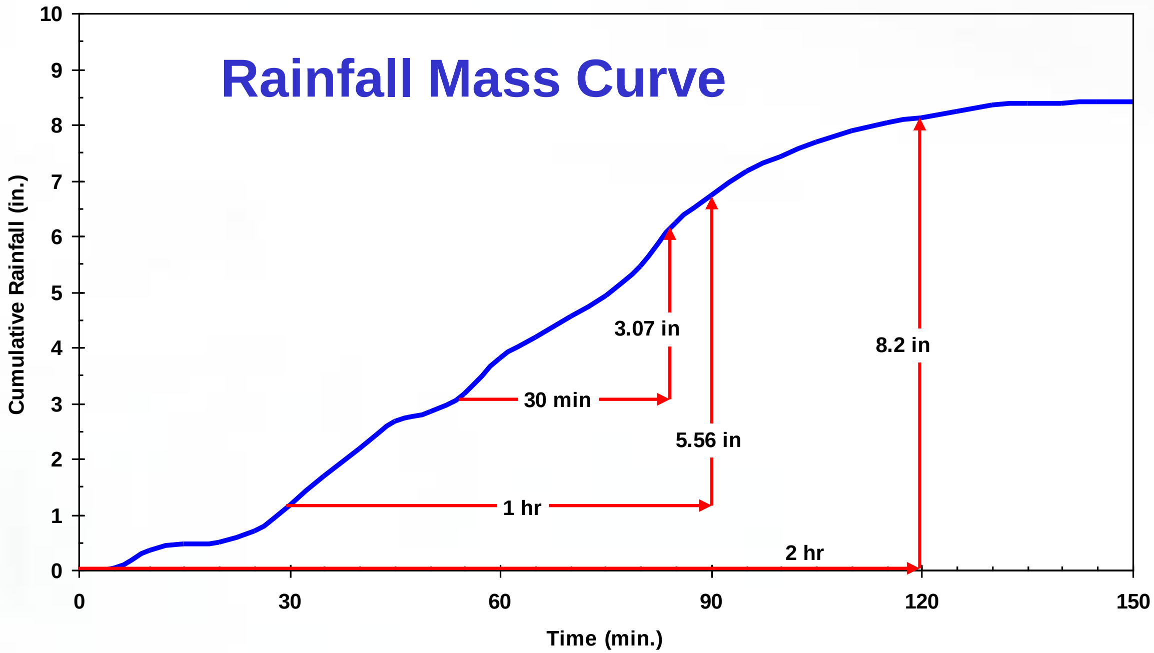
(**P**arameter-elevation **R**egressions on **I**ndependent **S**lopes **M**odel)



- 2.5 minute
- 1961-1990 clim
- Topographic facets
- Regresses P against elevation on each facet
- All 50 states, Puerto Rico, Mainland China, Taiwan, and Mongolia

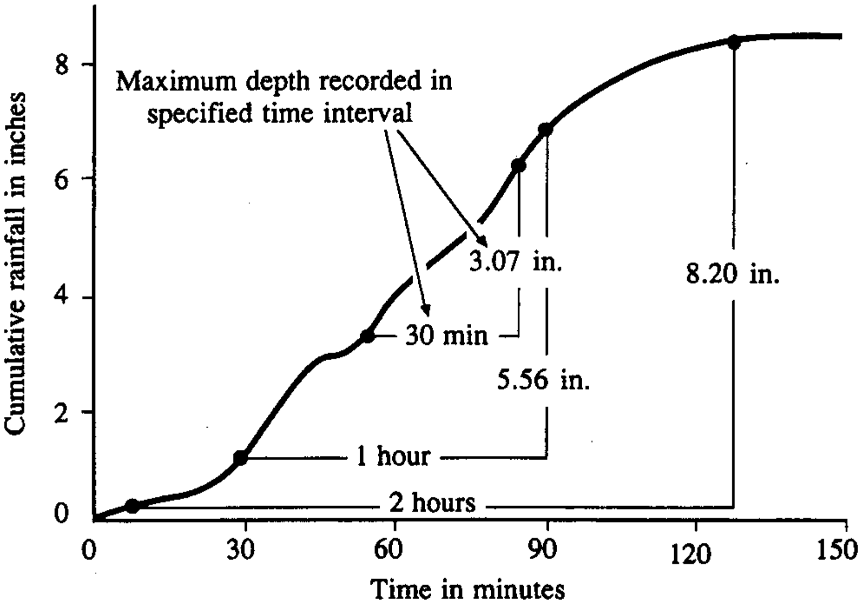
Temporal Representation

- **Rainfall hyetograph** – plot of rainfall depth or intensity as a function of time
- **Cumulative rainfall hyetograph or rainfall mass curve** – plot of summation of rainfall increments as a function of time
- **Rainfall intensity** – depth of rainfall per unit time



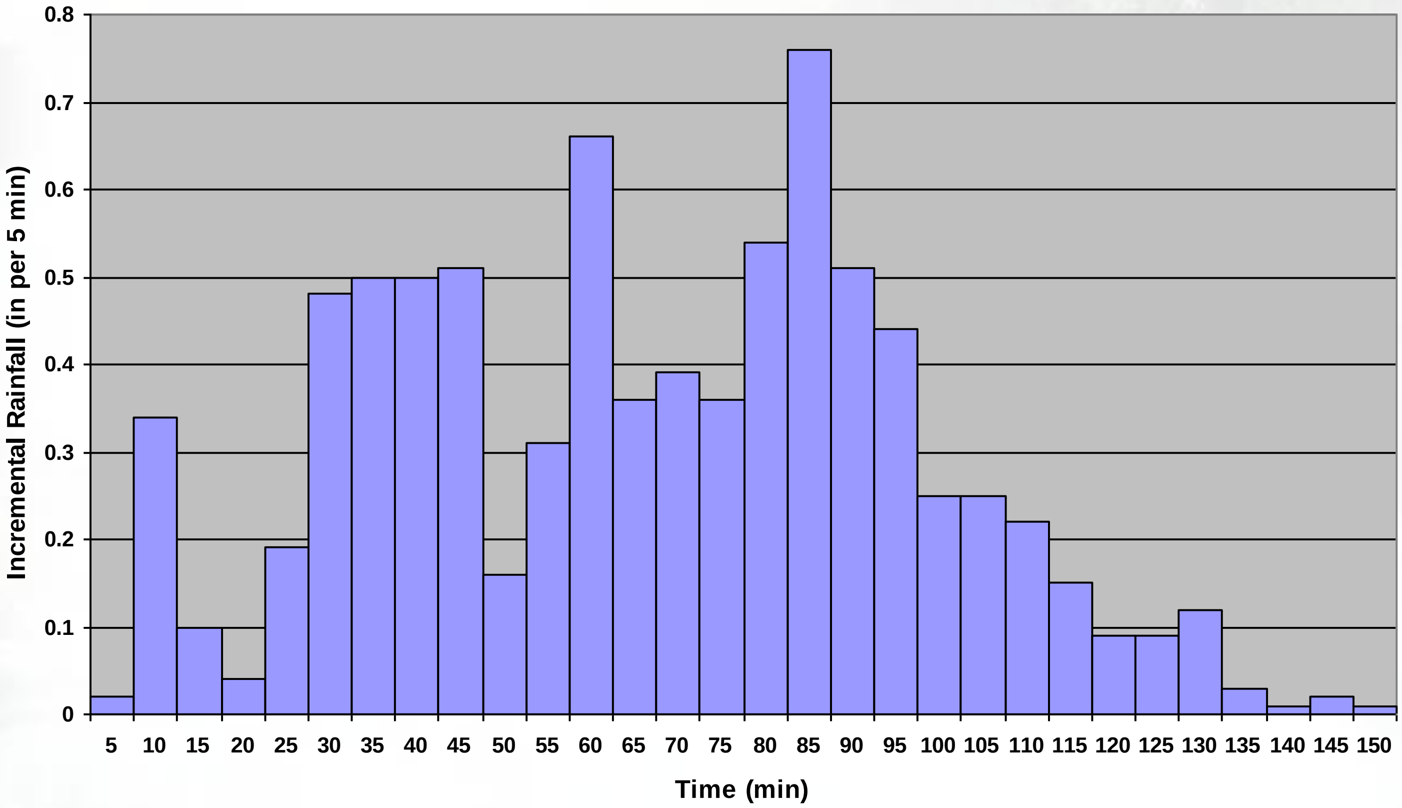
Extreme Rainfall

			Running Totals		
Time (min)	Rainfall (in)	Cumulative Rainfall (in)	30 min	1 h	2 h
0		0			
5	0.02	0.02			
10	0.34	0.36			
15	0.1	0.46			
20	0.04	0.5			
25	0.19	0.69			
30	0.48	1.17	1.17		
35	0.5	1.67	1.65		
40	0.5	2.17	1.81		
45	0.51	2.68	2.22		
50	0.16	2.84	2.34		
55	0.31	3.15	2.46		
60	0.66	3.81	2.64	3.81	
65	0.36	4.17	2.5	4.15	
70	0.39	4.56	2.39	4.2	
75	0.36	4.92	2.24	4.46	
80	0.54	5.46	2.62	4.96	
85	0.76	6.22	3.07	5.53	
90	0.51	6.73	2.92	5.56	
95	0.44	7.17	3	5.5	
100	0.25	7.42	2.86	5.25	
105	0.25	7.67	2.75	4.99	
110	0.22	7.89	2.43	5.05	
115	0.15	8.04	1.82	4.89	
120	0.09	8.13	1.4	4.32	8.13
125	0.09	8.22	1.05	4.05	8.2
130	0.12	8.34	0.92	3.78	7.98
135	0.03	8.37	0.7	3.45	7.91
140	0.01	8.38	0.49	2.92	7.88
145	0.02	8.4	0.36	2.18	7.71
150	0.01	8.41	0.28	1.68	7.24
Max. Depth	**0.76**		**3.07**	**5.56**	**8.2**
Max. Intensity	**9.12364946**		**6.14**	**5.56**	**4.1**



(*b*)

Incremental Rainfall



Rainfall Hyetograph

EOS 656/EVPP 652/GEOG 570 - **The Hydrosphere**

Homework #4: Precipitation

1) Obtain a picture of a precipitation gage in its native environment. Evaluate its placement with respect to all possible error sources, and hypothesize on the effect of these errors on precipitation measurement.
2) Find several relatively long precipitation gage time series from the same area (HydroDesktop may be a good source), and analyze one of the station's consistency using a mass curve.
3) Compare a gage time series with a nearby NEXRAD radar precipitation timeseries. Are they very different?