Water Budget I: Precipitation Inputs

Legend (inches)
- Less than 5
- 5 to 10
- 10 to 15
- 15 to 20
- 20 to 25
- 25 to 30
- 30 to 35
- 35 to 40
- 40 to 50
- 50 to 60
- 60 to 70
- 70 to 80
- 80 to 100
- 100 to 140
- 140 to 180
- More than 180

Period: 1961-1990

Modeling performed by Christopher Daly using the PRISM model, based on 1961-1990 normals from NOAA Cooperative stations and NRCS SNOTEL sites. Sponsored by USDA-NRCS Water and Climate Center, Portland, Oregon.

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Forests and Rainfall

- Forests won’t grow where $P < 15”$ / yr
- Forest type depends strongly on rainfall quantity, type (snow, rain) and timing (summer, winter)
  - Forest type is driven by rainfall/temp.

1. Arctic Tundra
2. Boreal
3. Rocky Mt. Evergreen
4. Pacific Coast Evergreen
5. Northern Mixed
6. Eastern Deciduous
7. Coastal Plain Evergreen
8. Mexican Montane
9. Rain Forest/Selva
10. Prairie
11. Tropical Savanna
12. Cool Desert
13. Hot Desert
14. Mediterranean Scrub
What Do We Need to Know?

1. How does the atmosphere create rainfall?
   - How does the underlying process work?
   - What are the different mechanisms?

2. Atmospheric water vapor as the global air conditioning system.
   - Global and site-level energy budgets
   - We’ll come back to this as part of ET

3. How is rainfall delivered (and how does this set the stage for forest growth)?
   - Mostly discussed in the lab
   - Why is Florida so wet?
Rainfall Starts As Water Vapor

- Vapor Amount $\sim f(\text{temperature, pressure, available liquid water})$ [we’ll come back to this]
- For each temperature there is a saturation point of max water vapor partial pressure.
  - Lower for cooler air (extremely important)
  - Condensation occurs when $\text{Vapor}_{\text{actual}} \geq \text{Vapor}_{\text{max}}$
- Relative humidity is a measure of how close the water vapor partial pressure is to max.
  - $\text{RH} = \left[ \frac{\text{Vapor}_{\text{actual}}}{\text{Vapor}_{\text{max}}} \right] \times 100\%$
- Evaporation rate $\alpha \text{ RH}$
Which air mass needs to be cooled more to condense?

A) 70° and 50% relative humidity
B) 70° and 40% relative humidity
Temperature in the Atmosphere

- Air temp = f[Elevation]
- Adiabatic Lapse Rate is the rate at which (on average) temperature decreases with height.
- ~ 6.5 °C/1000 m
  - ~ 1 °F/280 ft
Atmospheric Temperature Profile
Precipitation

• Adiabatic cooling: warm air rises and cools as the pressure drops.
• Cool air has lower water vapor partial pressure so at some point (condensation elevation) it reaches saturation.
• 100% relative humidity + nucleation particles = condensation = rain or snow.
• Condensation releases latent heat, which provides energy for more lifting – the basis of thunderstorm formation.
Air Movement - Convection

• Hot air has lower density, rises and is replaced by cooler, denser air, resulting in vertical convection.

• Much of solar energy absorbed by the earth is used to evaporate water.
  – Energy stored in water vapor as latent heat.

• Convection generates rainfall.
Radiation Budget
Convection

- Land heats more quickly than water (why?)
- Generally surface winds blow onshore
- Water subsidy
  - Rain over land > ET from land
Convective Rainfall

• Rising, expanding air creates an area of relatively high pressure at the top of the convection column and a region low pressure at the surface.
  – Air flows out of high-pressure zone towards areas of low-pressure, where cool, dry air is subsiding.

• Subsiding air is compressed as it approaches the earth’s surface where it piles up and creates an area of high pressure at the surface.
  – Air flows out of this region back towards low pressure, closing the cycle.

• Why the anvil?
Mountain Rain

• The world’s rainiest spots are near mountains...why?
• Air sweeps up windward side of a mountain, air cools.
• Saturation point is reached, and moisture condenses.
• Rain falls.
• Cool, dry air descends and warms, absorbing moisture from other sources. (Rain Shadow)
Orographic Rainfall
(oro – mountain)

Rain shadow
0.46 meters per year

Air becomes warmer and drier as it descends

1,598 meters

Waialeale

World’s rainiest spot
11.8 meters per year

Cools as it rises

Prevailing winds

Moisture-laden air

Altitude (meters)

West

East
Frontal Boundary Rainfall

• **Cold Front** - Boundary formed when cooler air displaces warmer air.
  – Cold air is more dense, so it stays near the ground and pushes under warm air.

• **Warm Front** - Boundary formed when warm air displaces cooler air.
  – Warm air is less dense and slides over cool air, creating a long wedge-shaped band of clouds.
Frontal Weather
Other Precipitation

• Cloud drip
  – Cloud forest
    • Icacos PR – 432 mm/yr
    • Monte Verde CR – 350 mm/yr
  – Forests actually capture water
  – Cutting forests REDUCES stream flow
Other Precipitation

- Snow/Sleet/Hail
  - ~75% of water supply in Western US is snowmelt
  - Lake Tahoe gets 300” of snow = 30” of rain

Effect of clear cutting on snow accumulation and water outflow at Fraser, Colorado.

Fig. 6. Summary diagram showing the mean fate of precipitation on the control and harvested plots during the six post-harvest years that were monitored (1986–90 plus 1993). Mean total precipitation was 590 mm.
Global Precipitation Patterns
So...why is Florida so Wet?

• The Peninsula Effect
  – The length of the coastline means that Florida is in close contact with water at all times. The sea-breeze subsidizes the rainfall.

• The Bermuda High Pressure Zone
  – Air flows away from a high pressure zone, and one of these zones that persistently forms, the Bermuda High, forces air off the warm Atlantic ocean our direction. This keeps things wetter than they might otherwise be.
The Bermuda High

Prevailing Wind Flow
Average Rainfall Delivery

• Thought experiment
  – Tuition + living expenses to attend UF is $40,000 per year
  – What if you were given a full scholarship (worth $160,000 over 4 years), but you weren’t told:
    • When the money was coming to you?
    • How much you’d get in any given installment?

• This is a plant’s view of “average” rainfall
Describing Rainfall Delivery

• Did it rain today?
  – Rainfall is a stochastic “Poisson” process
  – We can describe the statistics of rainfall by asking about the average interval between rain events (a term we call \( \lambda \), which is both mean and variance)

• How much did it rain?
  – Rainfall amount (\( \alpha \)) – mean amount of rain from an exponential distribution

• Can get the same rainfall in different ways
  – Low interval, low amount
  – High interval, high amount
Is “Average” Rainfall Meaningful?

- Yes – but only to a point.
- Plant stress can be really different between these cases with the same annual rainfall:
Next Time...

- Evaporation
- Transpiration