HYDROGEOLOGY (GEO 451)

جيولوجيا المياه (جيو ٤٥١)

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MARKING SCHEME

• Weekly Assignments	5%
• Midterm Examination	5%
• Practical Examination	20%
• Final Examination	70%

LITERATURE

- **FETTER (2001):**

  Applied Hydrogeology, 4th edition

- **DOMENICO & SCHWARZ (1990):**

  Physical and Chemical Hydrogeology Wiley & Sons

- **MONTGOMERY C.W. (1992):**

  Environmental Geology. WCB, Wm.C. Brown publishers

CONTENT LIST

Press Release WHO

World Water Day - 22 March 01

- More than one billion people drink unsafe water
- 2.4 billion, 40% of the human race are without adequate sanitation
- 3.4 million people, mostly children, die every year of water-related diseases, more than one million from malaria alone
- On contrary „only“ 50.000 to 100.000 people die due to geo hazards (volcanoes, floods, earthquakes)

Press Release WHO

World Water Day - 22 March 01

- Clearly, a problem of this magnitude cannot be solved overnight
- But simple, inexpensive measures, both individual and collective, are available that will provide clean water for millions and millions of people in developing countries
- Now, not in 10 or 20 years
- One of them is to learn something about hydrogeology

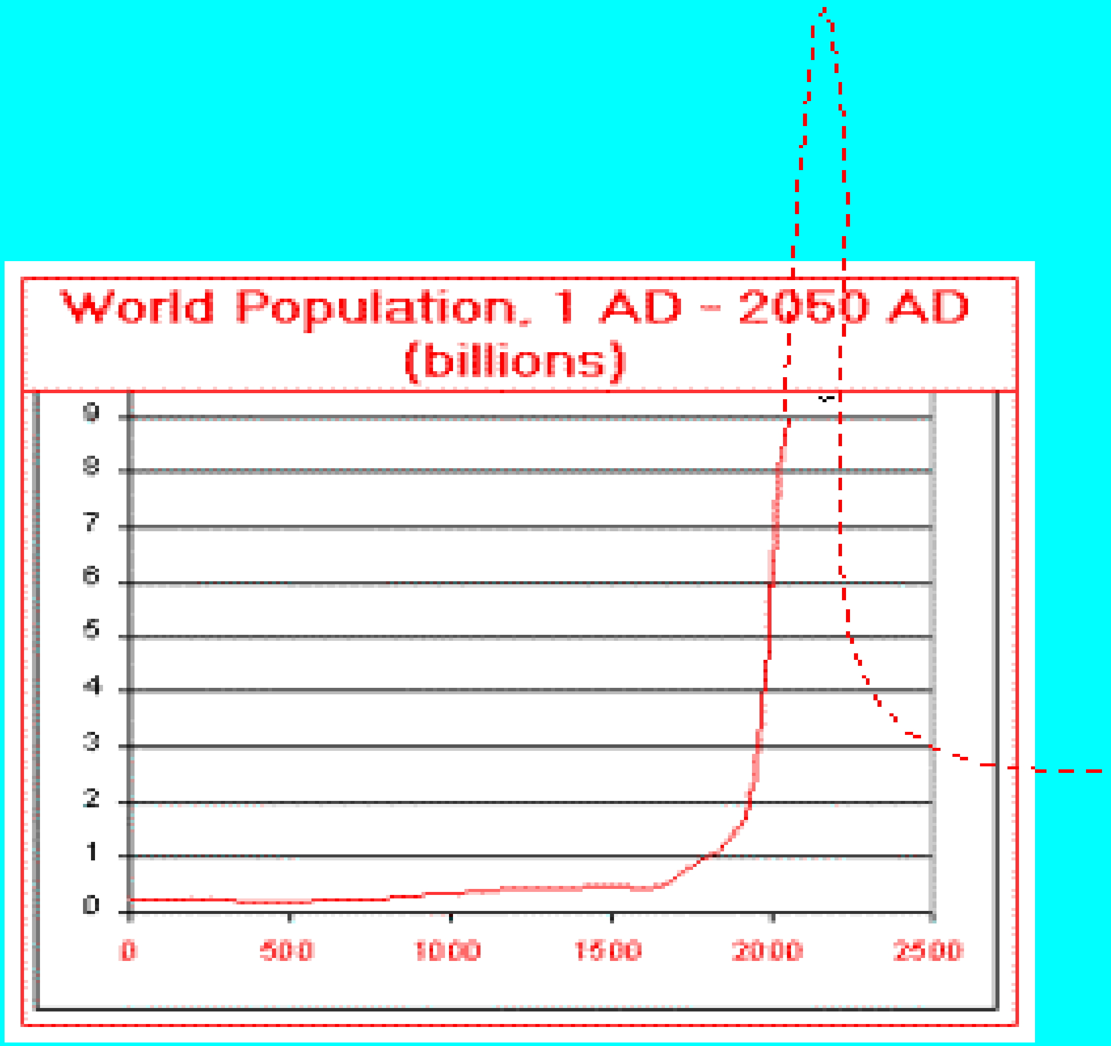
Water consumption per person and day

- Native living Bedouins 15 .. 20 L/day
- Germany 150-200 L/day
- Citizen in Saudi Arabia 450 L/day

- Drinking water humid climate 2 L/day
- Drinking water arid climate 8 L/day

- Rest: shower, bath, laundry, sanitation, small scale industry

World population growth



How much water is needed for the production of:

1 t paper	70 t of water *
1 t steel	100 t of water *
1 t maize	950 t of water
1 t wheat	1425 t of water
1 t rice	3800 t of water
1 t beef	28500 t of water

* Tap water

Ground water: a vulnerable resource

- Not believed until the 60´s
- Increase of nitrate in shallow aquifers after the Second World War
- Increase of PBSM-concentration in shallow aquifers since 1960
- Contaminations due to abandoned or uncontrolled landfills and hazardous chemicals
- Contaminations caused by accidental spills

Ground water: a vulnerable resource ?

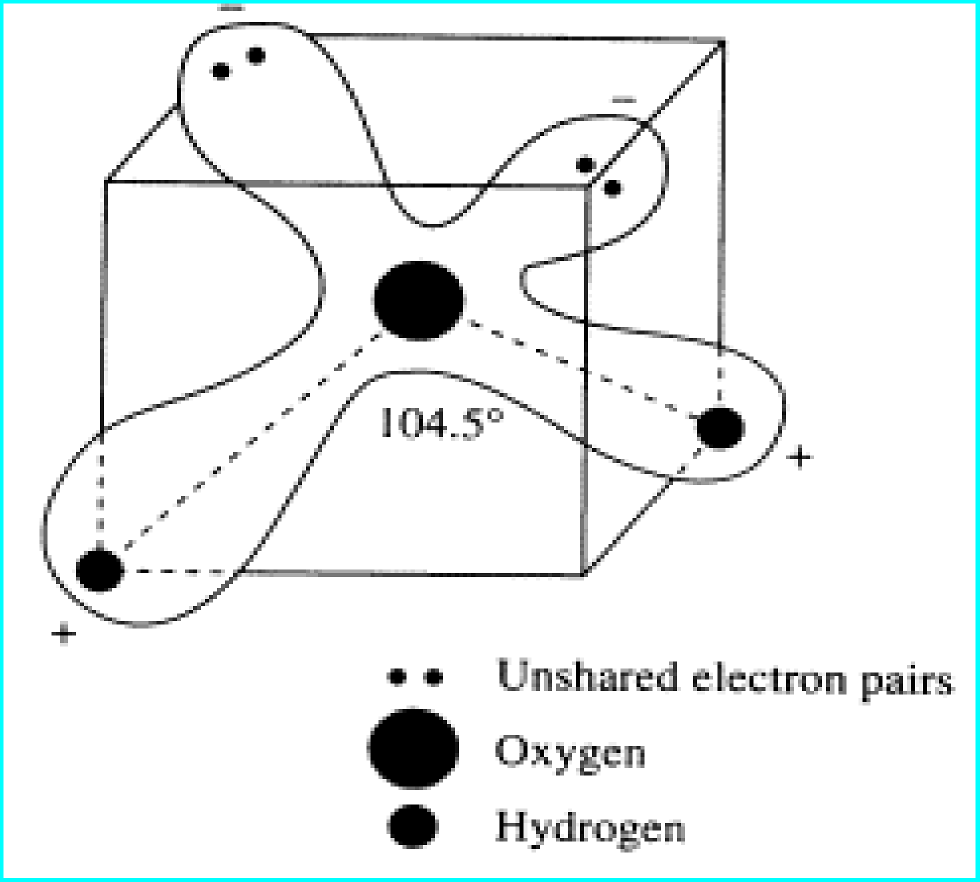
- Yes

- In humid climate and industrialized countries due to quality problems
- In semi arid and arid climate both to quality and quantity problems

- and finally: you may „repair“ surface water within a few years, but ground water remediation takes decades and centuries...

Why is water so special ?

- Four electrons are in a position as far away from the nuclei (oxygen and hydrogen)
- While the other four are forming the covalent binding between oxygen and the two hydrogen nuclei; two electrons are close to the oxygen nucleus.
- Dipole


−
−
104.5°
+
+
Unshared electron pairs
Oxygen
Hydrogen

Why is water so special ?

- Not only in ice, but also in liquid state, water molecules form clusters
- Thus the formula of water is not H2O...

Temperature	Factor	Formula
0 ° C	130	$H_{260}O_{130}$
20 °C	90	$H_{180}O_{90}$
70 °C	60	$H_{120}O_{60}$

Because of cluster structure...

- Water has the highest evaporation heat and melting heat of all liquids
- High energy demand for evaporation
- Energy release due to condensation processes (thunderstorms, tornados, hurricanes,...)

Because of cluster structure...

- High specific thermal capacity (only liquid ammonium has a higher thermal capacity)
- Buffering temperature changes
- Ocean, lakes and rivers
- Using of ground water for geothermal purposes, heat mining

Because of cluster structure...

- Highest surface tension of all liquids (72 dyn/cm at 25 °C)
- Drop size
- Erosion progress
- Sedimentation
- Forming aquifers

Dissociation of water forming H+ and OH-

- Best solvent in the world...
- Solution of minerals
- High salinity
  - e.g. 36 g/l L in the ocean
  - e.g. 700 g/L in the Dead Sea (Jordan Rift)

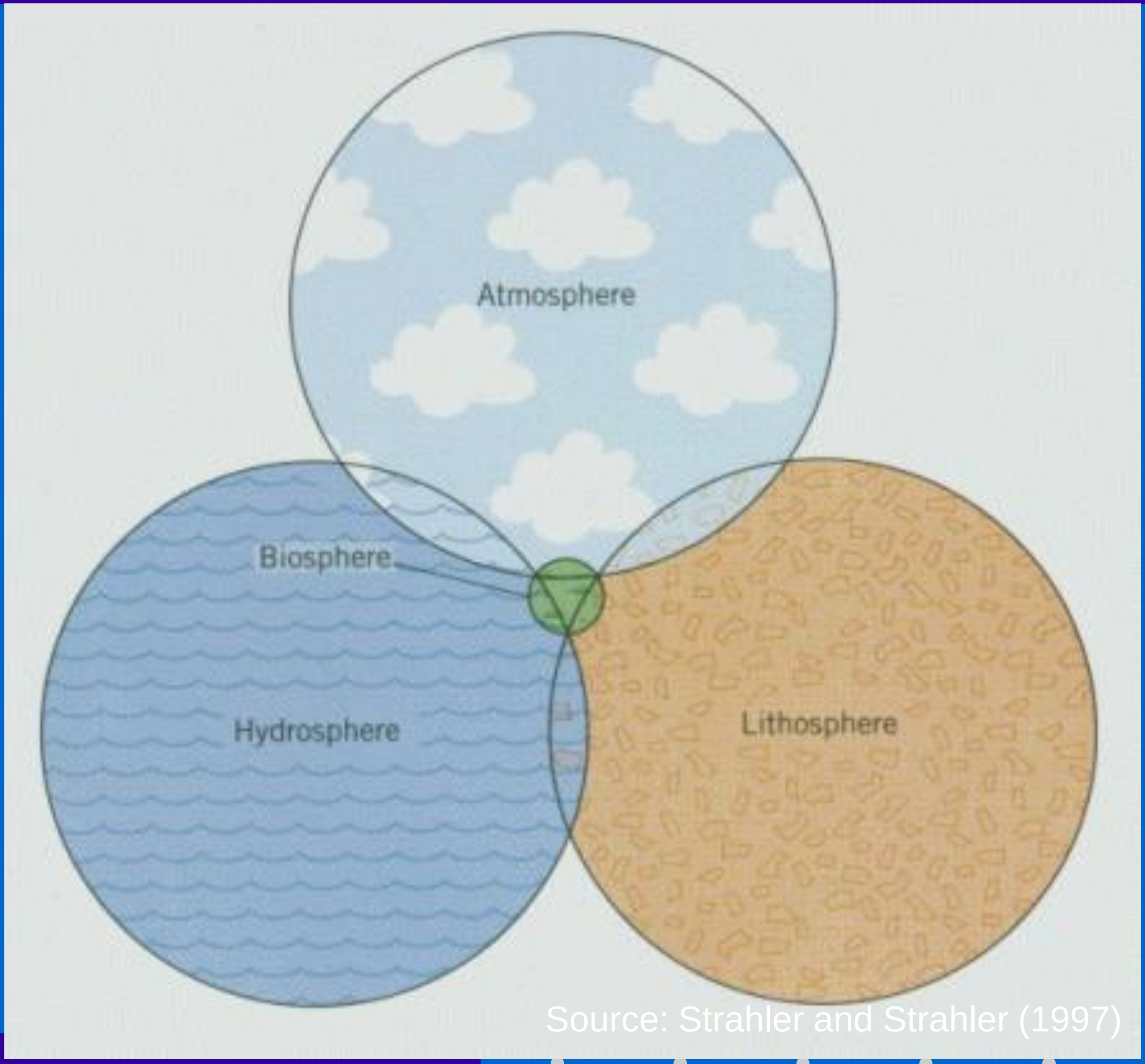
Maximum density at 4 °C

- Surface waters do not freeze from the ground
- Consequences to fishes and water born organism

Water: gas, liquid, solid

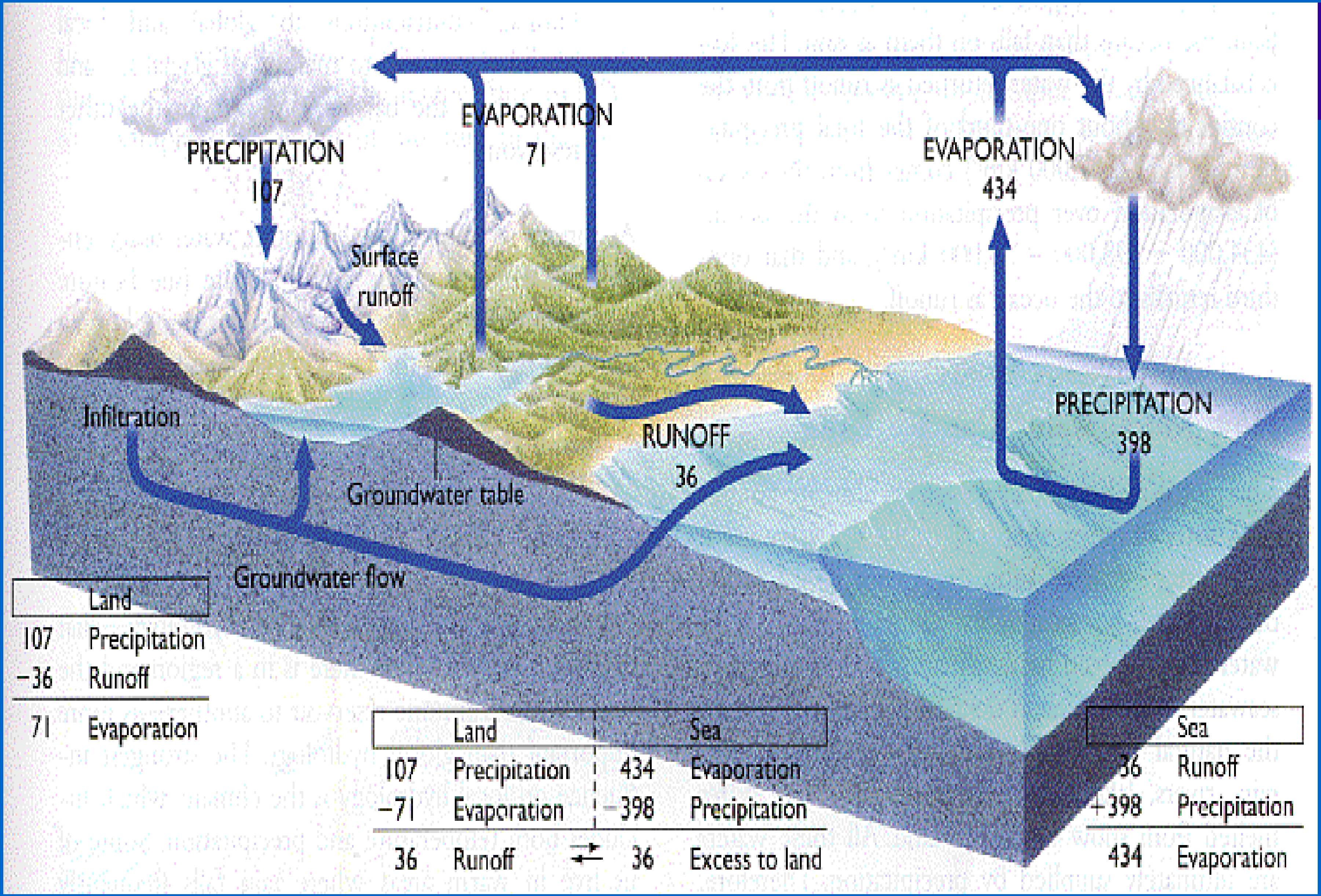
- Expansion at freezing (frost weathering)
- Regional and global water transport due to evaporation and precipitation

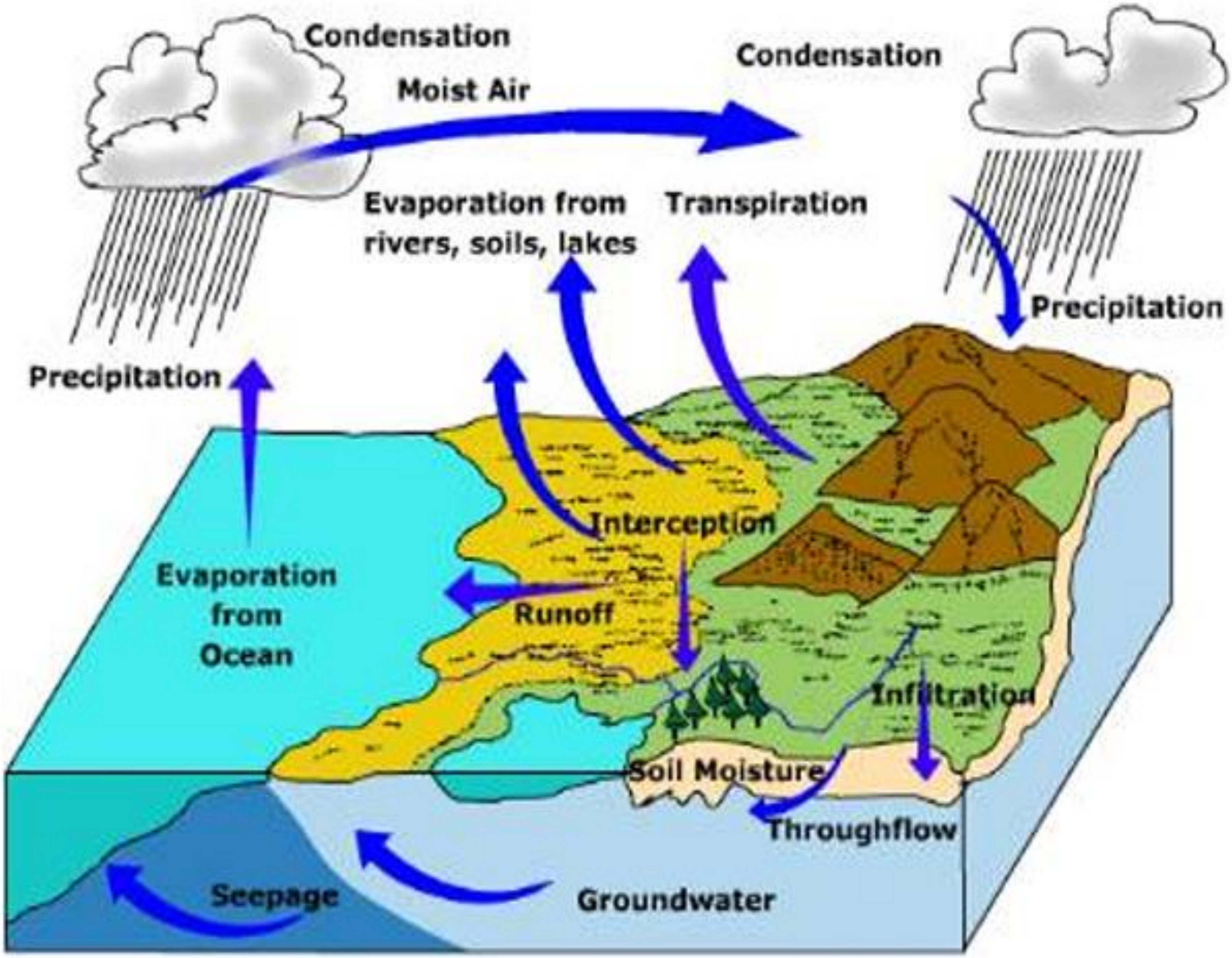
Natural systems operate within 4 great realms, or spheres, of the Earth



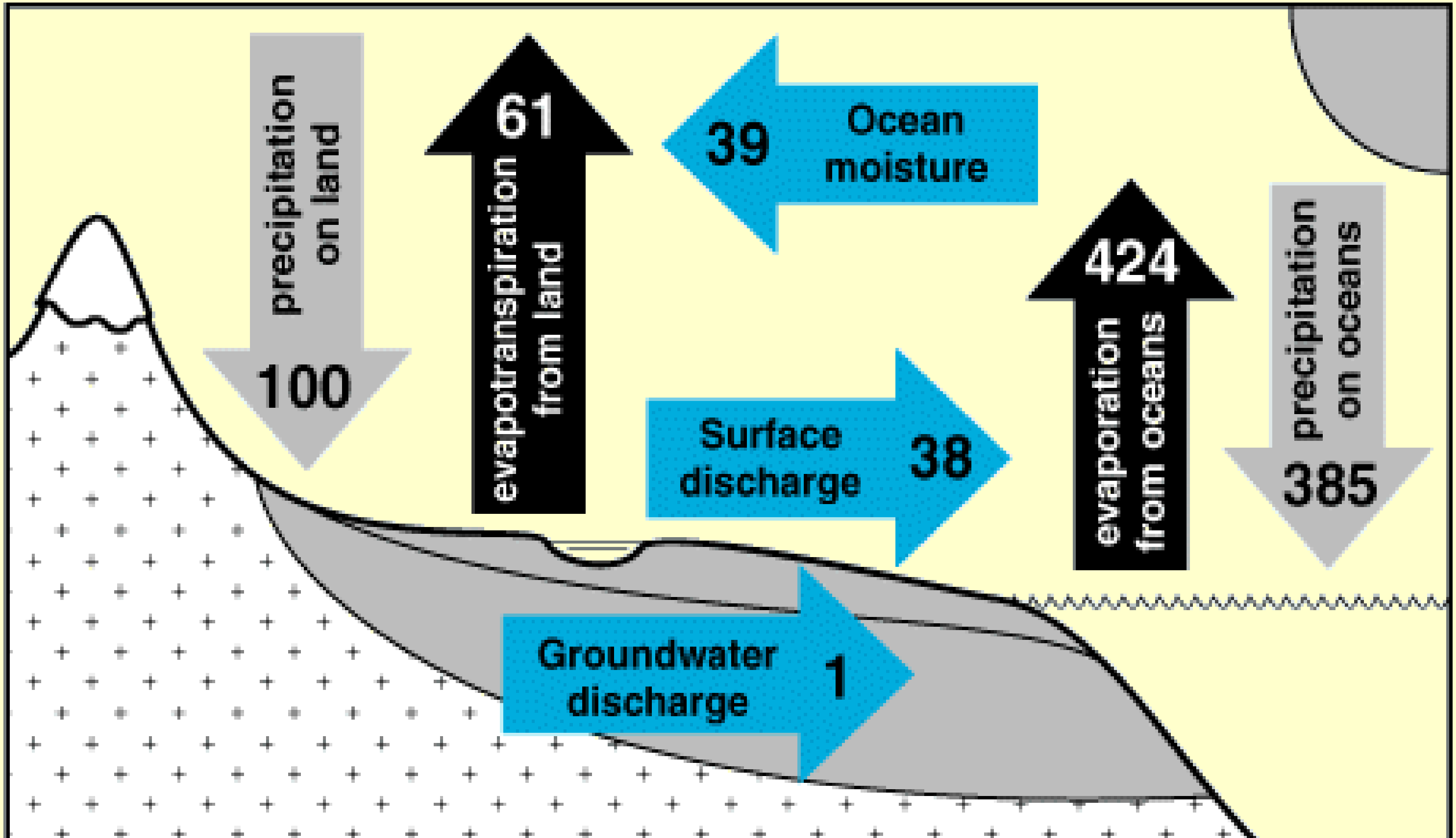
Source: Strahler and Strahler (1997)

Hydrologic cycle = energy cycle




Condensation
Moist Air
Condensation
Evaporation from
rivers, soils, lakes
Transpiration
Precipitation
Precipitation
Interception
Evaporation
from
Ocean
Runoff
Infiltration
Soil Moisture
Throughflow
Seepage
Groundwater

GLOBAL WATER BALANCE



Flows within the hydrological cycle. Units are relative to the annual precipitation on land surface (100 = 119,000 km^3 yr^{-1}). Black arrows depict flows to the atmosphere, gray arrows depict flows to the land or oceans, and blue arrows indicate lateral flows. Source: Hornberger et al. (1998)

Water resources of the world

Compartment	10^{14} tons	%
Atmosphere	0.13	0.0008
Oceans	13700	79.65
Pore water and ground water	3300	19.19
Ice	200	1.16
Surface water	0,3	0.002
bound in minerals	20000	-
evapotranspiration per year	5	-

Classification of water

Compartment	Type of water
Atmosphere	Vapour rainfall, Snow, hail
Earth surface	Snow, ice, dew rivers, lakes, oceans, water in plants
Unsaturated zone 3 phase system: gas - rock – water	water in roots soil water seepage water
Saturated zone 2 phase system: (rock - water *)	ground water water bound in minerals fluid inclusions

To understand the hydraulic cycle

- **one has to understand:**
- Evaporation and evapotranspiration
- Meteorological phenomena
- Surface run off and infiltration processes
- Ground water flow
- Geochemical processes

Elements of the Hydrologic Cycle

- Condensation
- Precipitation
- Evaporation
- Transpiration
- Interception
- Infiltration
- Percolation
- Runoff

SURFACE ENERGY BALANCE

- **According to the 1st law of thermodynamics, radiant energy received at the land surface must be conserved.**

- **Net radiant energy arriving across a boundary of a system must be balanced by other energy fluxes across the boundary and the net change in energy held within the volume.**

- **The energy may change among it possible forms**
  - **radiant**
  - **thermal**
  - **kinetic**
  - **potential**

Sensible heat:

Quantity of heat held by an object that can be sensed by touch or feel, and can be measured by a thermometer.

Increase temperature - increase sensible heat

***Sensible heat transfer* occurs by conduction. Heat flows from warmer to cooler substance.**

Latent heat:

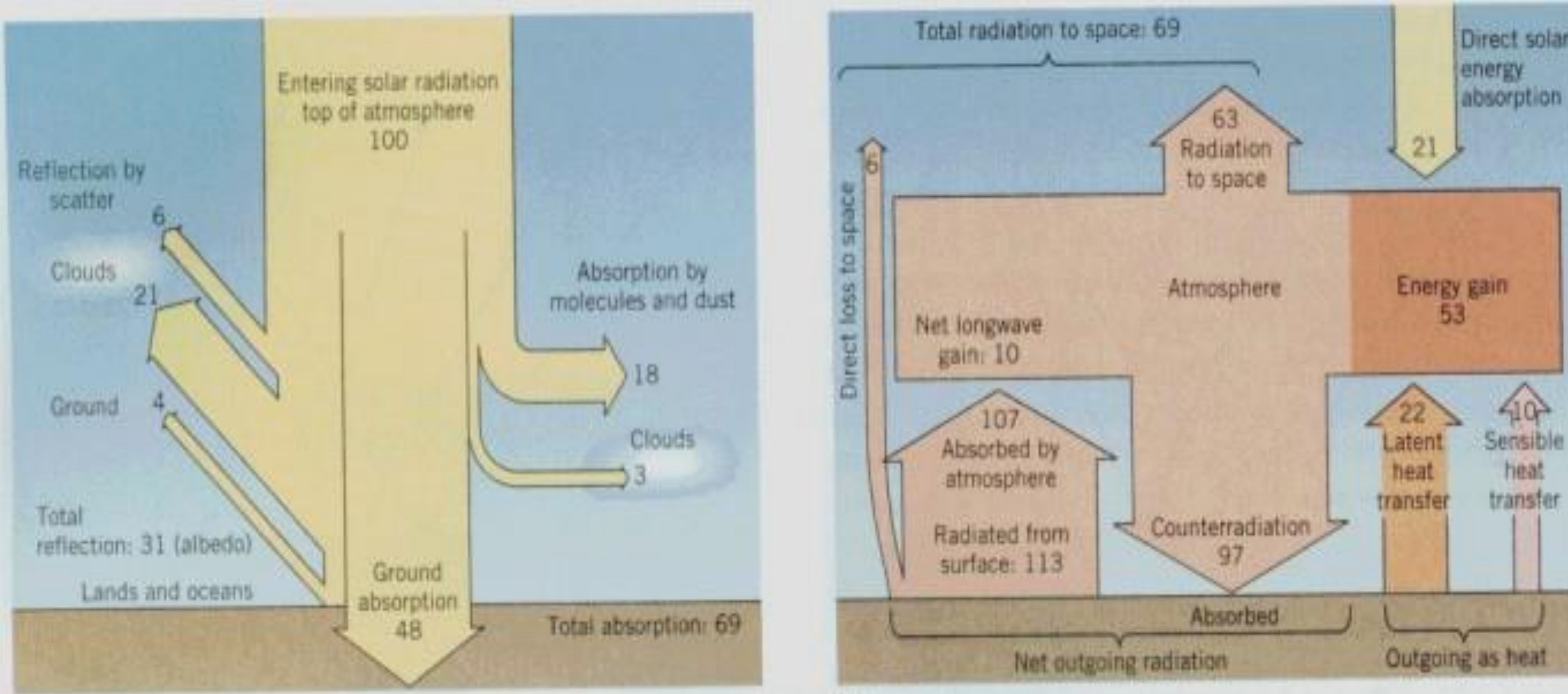
Hidden heat - absorbed or released when a substance changes phase.

***Latent heat transfer* occurs when water evaporates from land (add energy) and when vapour condenses (release energy).**

Cool surface when evaporate / heat surface when condense

Heat may also be transferred within a substance by convection:
mixing of gas or liquid

GLOBAL ENERGY BALANCE



(a) (b)

Figure 2.15 Diagram of the global energy balance. Values are percentage units based on total insolation as 100. The rate of incoming solar radiation is shown in (*a*), while (*b*) shows longwave energy flows occurring among the surface, atmosphere, and space. The transfers of latent heat, sensible heat, and direct solar absorption that balance the budget for earth and atmosphere are shown on the right side of (*b*).

Source: Strahler and Strahler (1997)

SURFACE ENERGY BALANCE

$$Q^* = Q_H + Q_E + Q_G$$

where

Q^* = net solar radiation

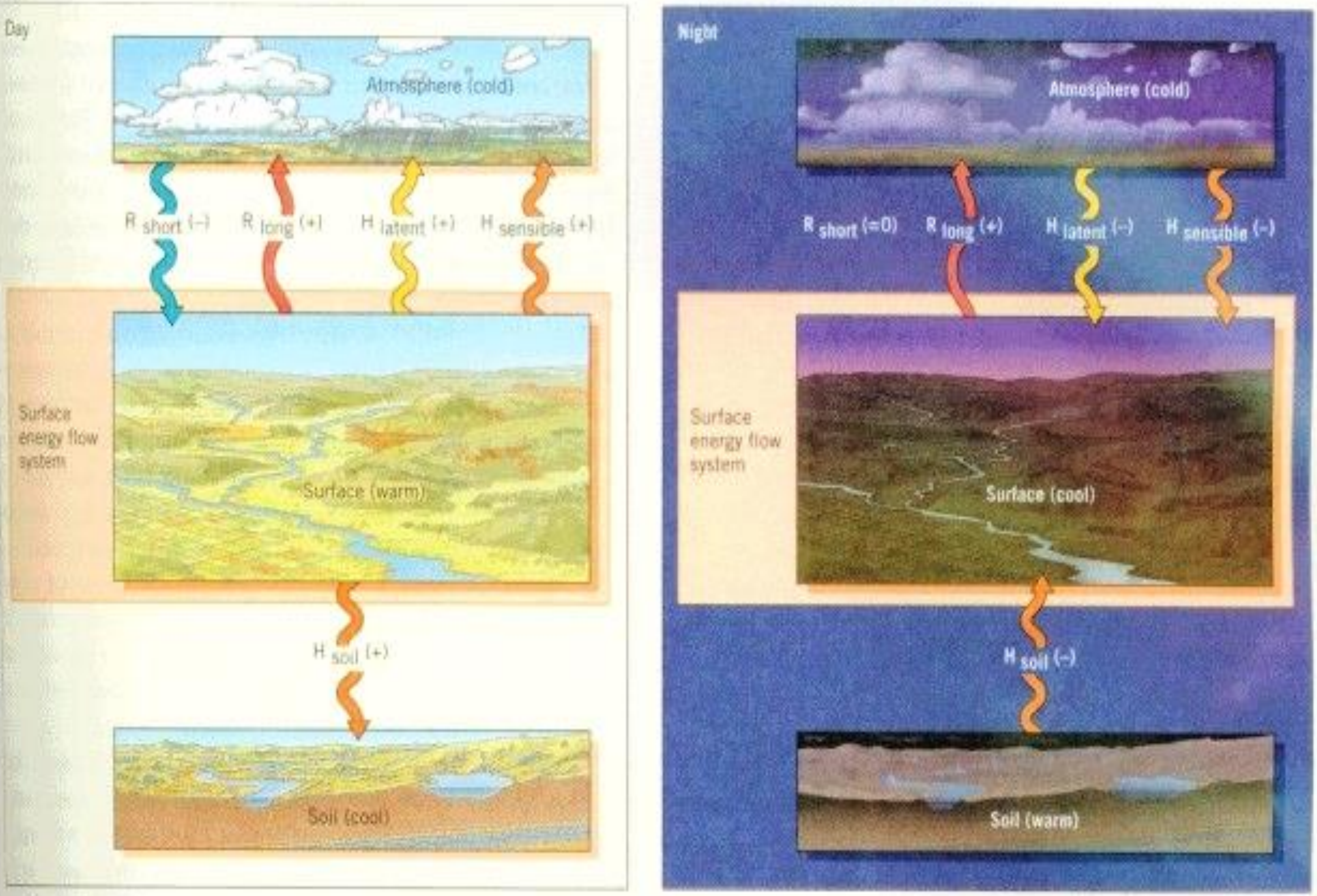
Q_H = sensible heat flux

Q_E = latent heat flux

Q_G = ground heat flux

units are $W\ m^{-2}$

Surface energy balance for a typical day and night



Diagrams of the surface energy balance equation for typical day and night conditions.

Source: Strahler and Strahler (1997)

PRECIPITATION

- Before we begin examining precipitation we must understand some basic climatic elements and physical processes
  - Humidity
  - Adiabatic process

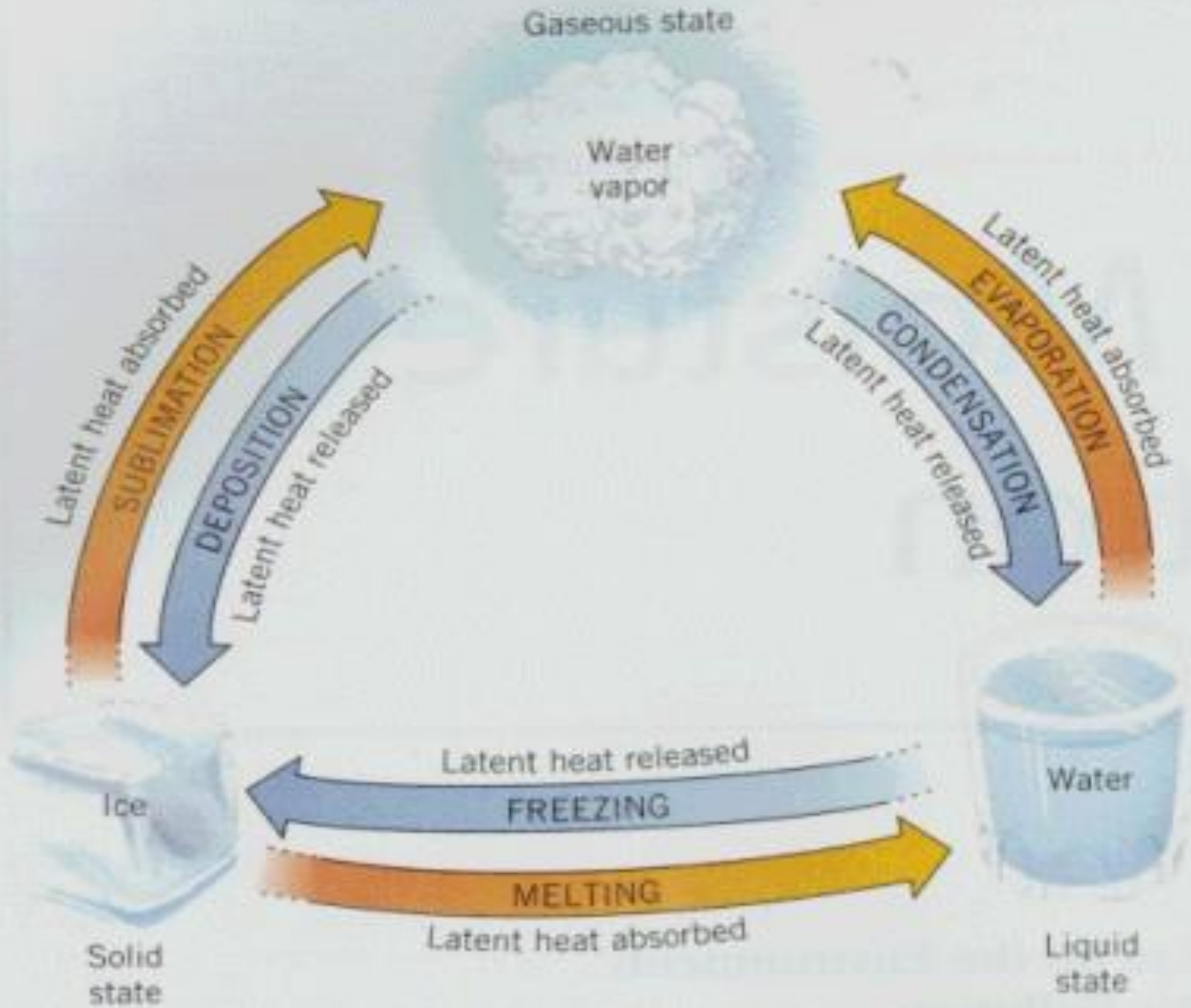


Figure 4.1 A schematic diagram of the three states of water. Arrows show the ways that any one state can change into either of the other two states. Heat energy is absorbed or released, depending on the direction of change.

Source: Strahler and Strahler (1997)

HUMIDITY

- The amount of water vapour in the air is generally referred to as humidity

  - Relative humidity
  - specific humidity

Specific Humidity

- Measure of the actual amount of water vapour in the air
  - mass of water vapour in a given mass of air [M M^{-1}]
  - q commonly expressed as g kg^{-1}

- often used to describe an air mass
  - e.g., Cold dry air over arctic regions in winter may have a specific humidity as low as 0.2 g kg^{-1}.

    Warm, moist air over equatorial regions often hold up to 18 g kg^{-1}.

- Maximum specific humidity function of air temperature

$0^oC \approx 5$ g kg^{-1}

$10^oC \approx 9$ g kg^{-1}

$20^oC \approx 15$ g kg^{-1}

$30^oC \approx 26$ g kg^{-1}

Relative Humidity

- An every day expression of the water vapour content in the air is the relative humidity (RH%)
  - defined as the amount of water vapour present relative to the amount held at saturation
    - example: if air holds 12 g of water at 20^{o}C

      RH = 12 g kg^{-1} / 15 g kg^{-1} = 80%
- Humidity equal 100% $\Rightarrow$ air is saturated

- Change in relative humidity can happen in two ways:
  - evaporation (add water vapour to air)
  - a change in temperature (capacity of air to hold water a function of temperature)

- Note: RH does not indicate actual amount of water vapour in the air

How is humidity measured?

Sling psychrometer –

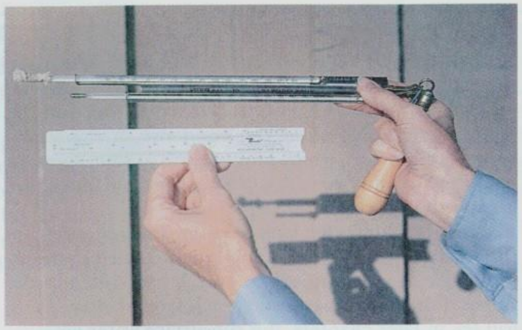


Figure 4.6 A standard sling psychrometer. Pictured below the psychrometer is a sliding scale that enables rapid determination of relative humidity from wet and dry bulb readings.

difference between wet and dry bulb temperature

- evaporation from wet bulb will cool temperature

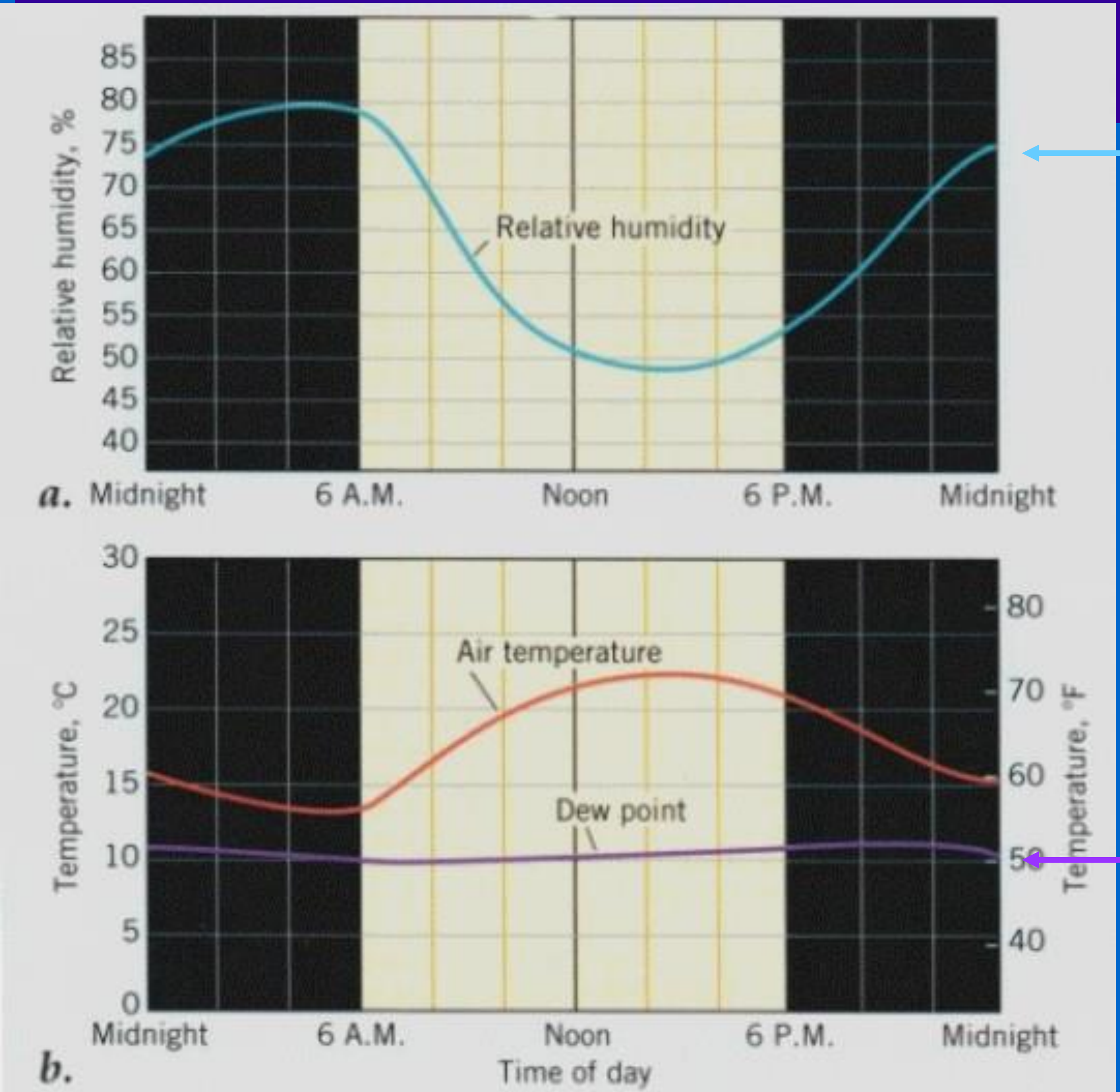
-use sliding scale to obtain RH

Relative Humidity Sensor

Figure 3.2 (*a*) A thermometer shelter. This white wooden louvered box houses maximum-minimum thermometers and other instruments. (*b*) A maximum-minimum temperature instrument system appears on the left side of this photo. To the right is a large recording rain gauge.

- material absorbs water depending on humidity
- water affects the ability of the metal to hold an electric charge, which is converted to RH

How does humidity typically vary during day?



Source: Strahler and Strahler (1997)

Relative humidity: Percent saturation

Dew point: Temperature at which saturation occurs

- Given ample water vapour is present in a mass of air, how is that related to precipitation?

- In other words, how is water vapour turned into liquid or solid particles that fall to earth?

  - Answer is natural cooling of air

  - since the ability or air to hold water vapour is dependent on temperature, the air must give up water if cooled to the dew point and below.

- How is air chilled sufficiently to produce precipitation?
  - Night time (radiational) cooling
  - uplifting of air parcel and associated changes in pressure and temperature (adiabatic process)

Radiational Cooling

- Ground surface can become quite cold on a clear night through loss of longwave radiation

- Still air near surface can be cooled below the condensation point
  - dew
  - frost
  - fog

- Mechanism not sufficient to form precipitation

CLOUDS

- Once you have moisture - clouds can form
- Clouds are made up of water droplets or ice particles suspended in air
  - diameter in the range of 20 to 50 μm
- Each cloud particle formed on a condensation nuclei
  - crystalline salt from evaporation of sea water spray
  - dust (clay particle)
  - pollution
- above -12°C still have liquid water (supercooled)
- below - 40°C formed entirely of ice particles (6-12 km altitude)

4 Families of clouds arranged by height - high, middle, low and vertical

2 major classes on basis of form

Stratiform (layered) - Cumuliform (globular)

- Blanket like and cover large areas
- Formed when large air layer forced to surrounding air gradually rise, cooling and condensing
- Can produce abundant snow or rain

- Small to large parcels of rising air because warmer than
- Thundershowers

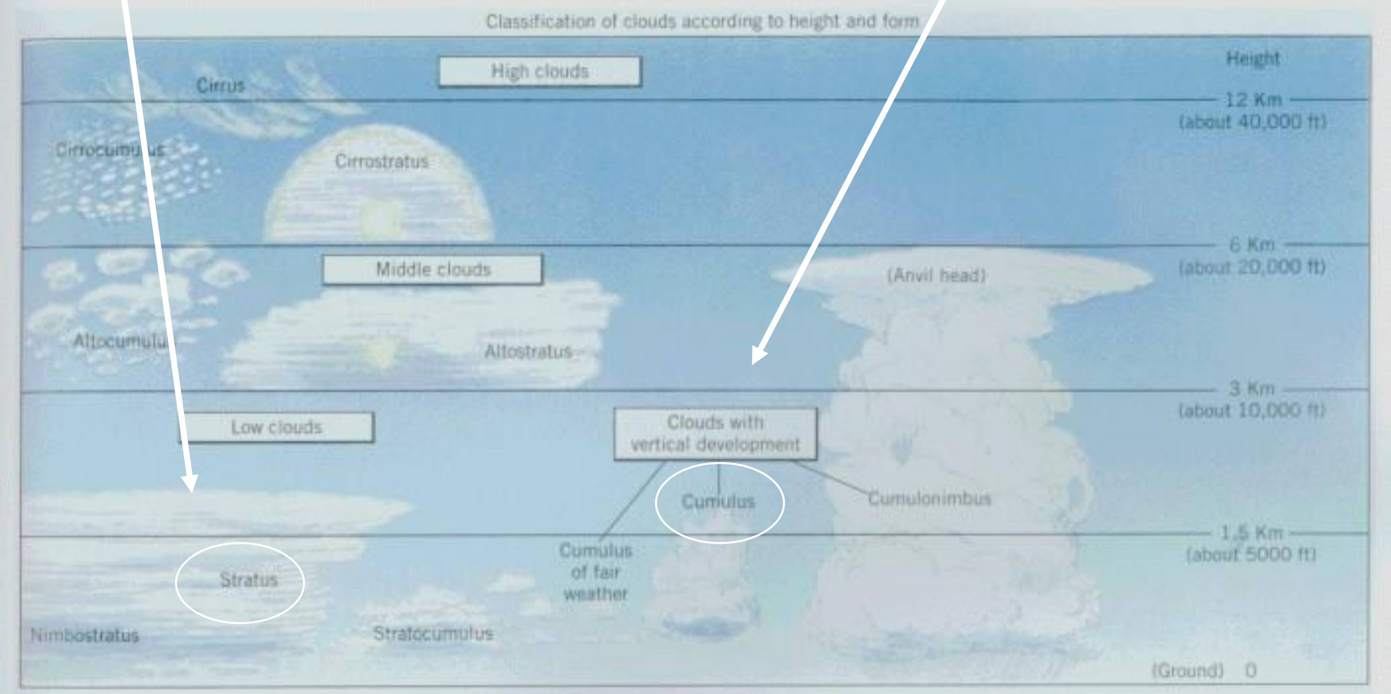


Figure 4.11 Clouds are grouped into families on the basis of height. Individual cloud types are named according to their form.

- radiation fog
- advection fog
- sea fog

Precipitation

Form in two ways:

Coalescence process

- Cloud droplets collide and coalesce into larger water droplets that fall as rain
- grows by added condensation and attain a diameter of 50-100 µm and with collision grow to 500 µm (drizzle) and up to 1000 to 2000 µm (rain drops)

Ice crystal process

- Ice crystals from and grow in a cloud that contains a mixture of both ice crystals and water droplets
- ice crystals collide with supercooled water and further coalesce to produce snow

PRECIPITATION PROCESS

- Air that is moving upward will be chilled by the adiabatic process to saturation and then condensation and eventually precipitation

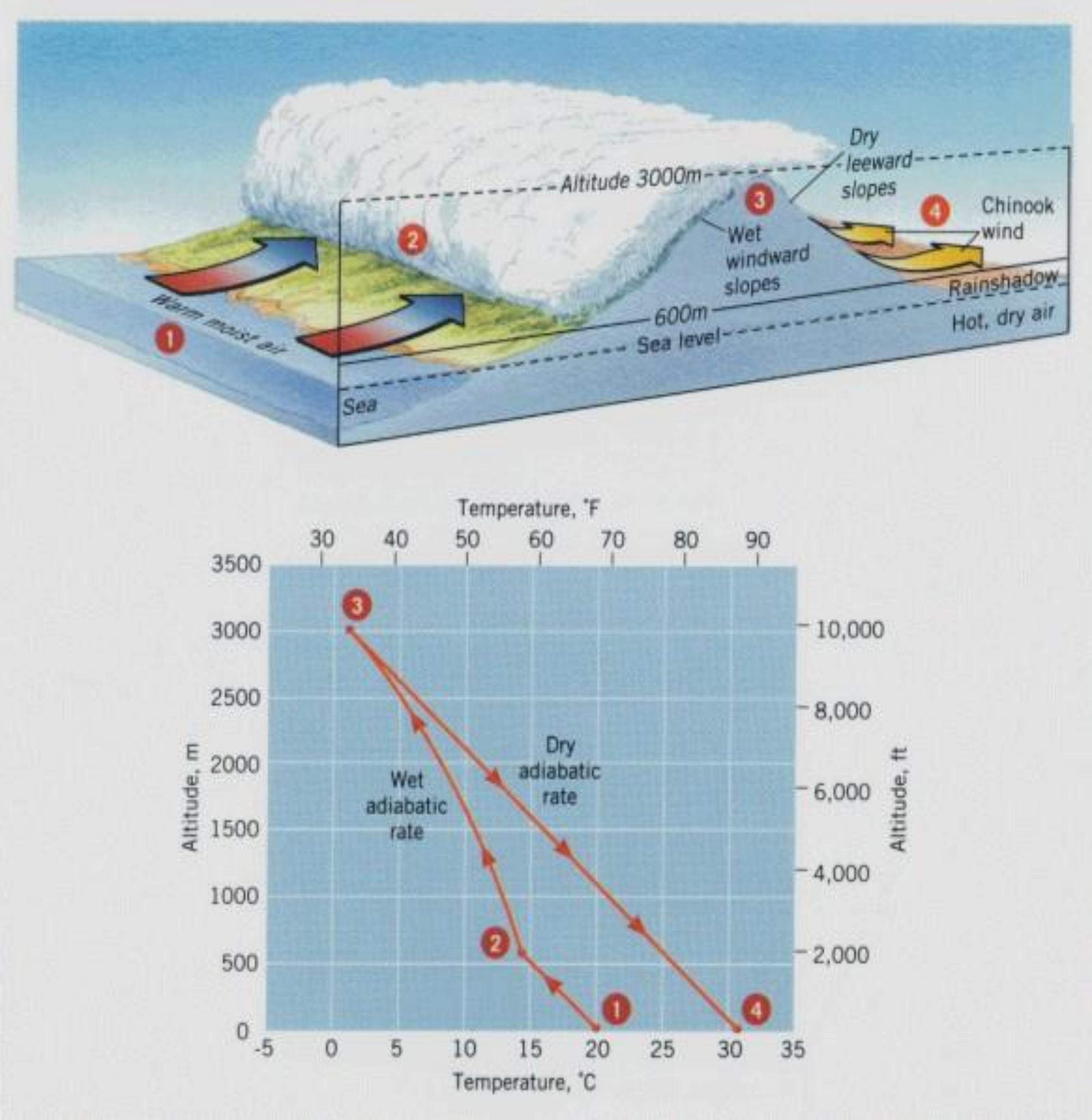
- However, what causes air to move upward?

- Air can be moved upward in 3 ways
  - Orographic precipitation: air forced up side of mountain
  - Convectional precipitation: unequal heating of surface
  - Cyclonic precipitation: movement of air masses over each other

Orographic (related to mountain) Precipitation

1

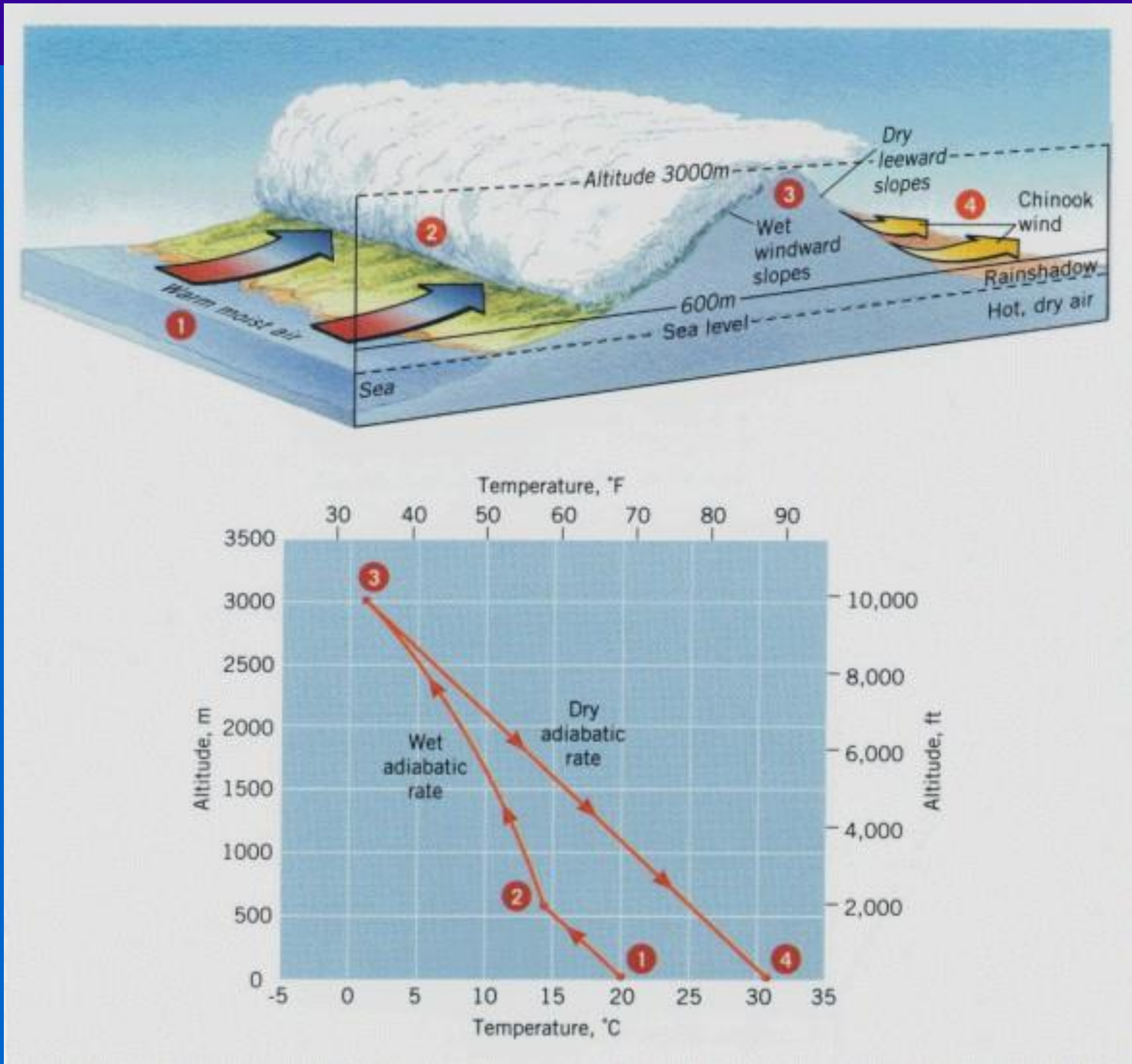
- Moist air arrives at coast after passing over ocean
- Air rises on windward side of range and is cooled at the dry adiabatic lapse rate
- Cooling sufficient and condensation level reached and clouds form
- latent heat release to surrounding air as form water droplets



Orographic (related to mountain) Precipitation

2

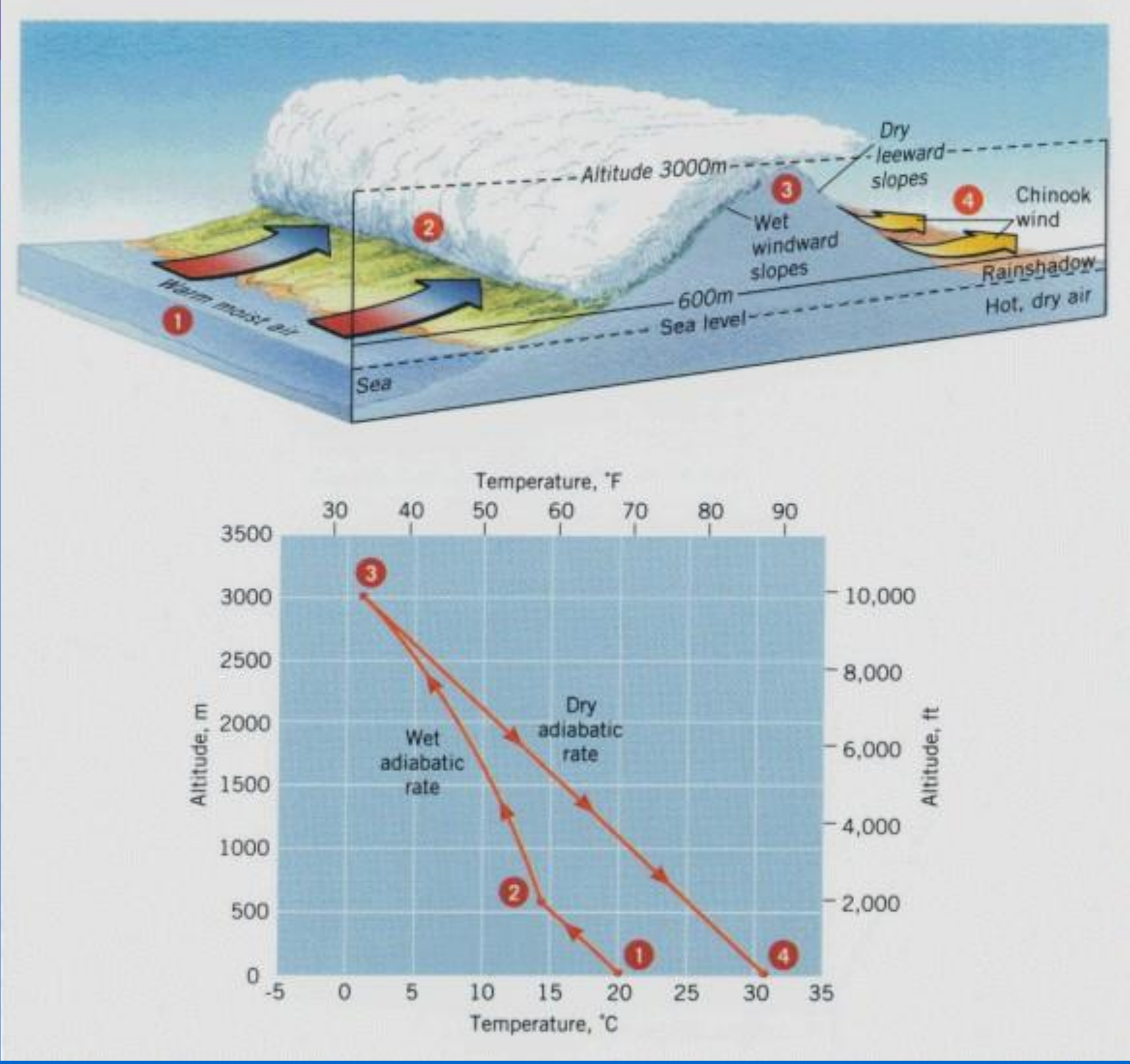
- **Cooling now proceeds at wet adiabatic lapse rate**
- **Eventually precipitation begins**
- **Heavy precipitation**



Orographic (related to mountain) Precipitation

3

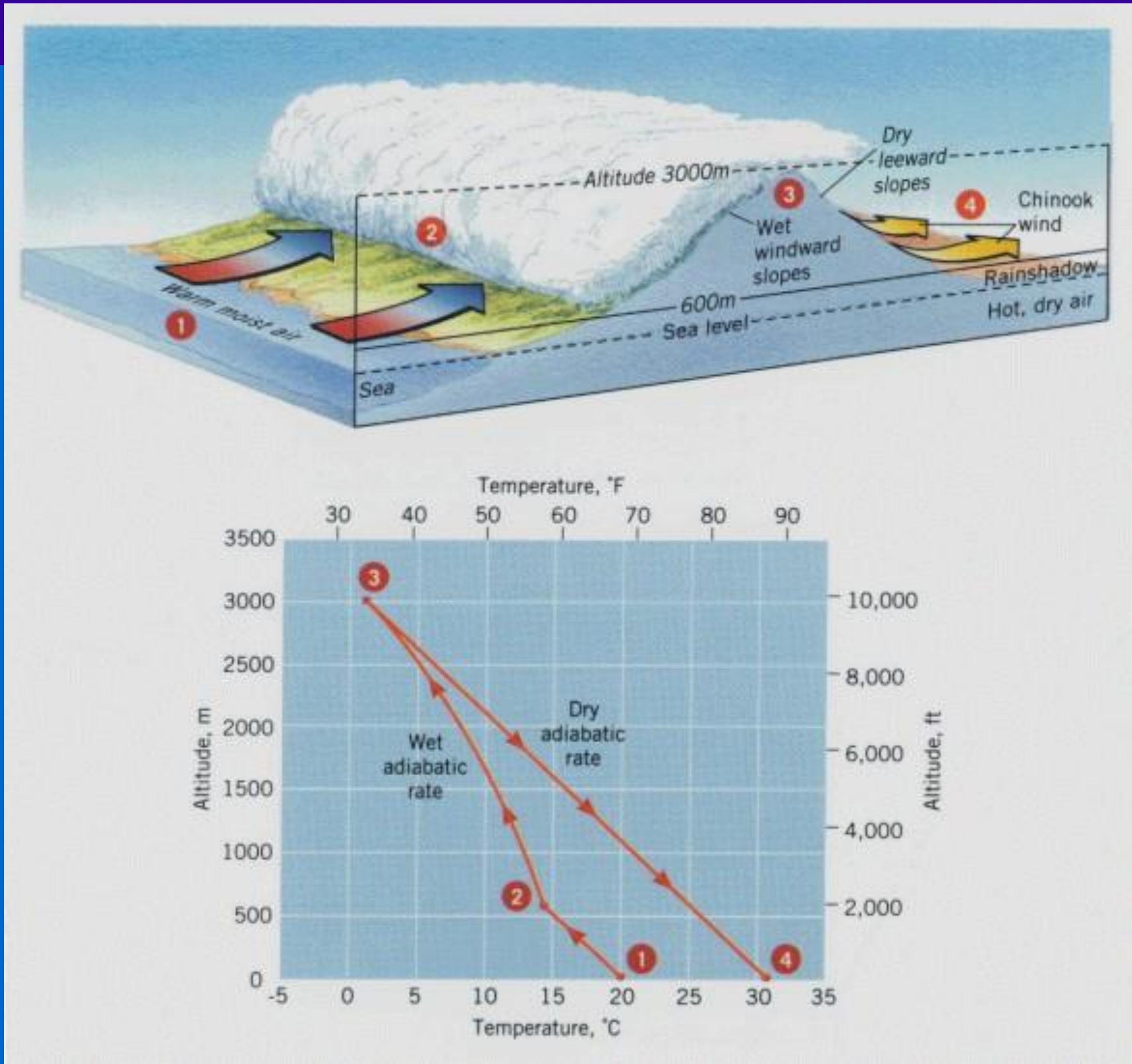
- Air begins to descend down the leeward side of the range
- Air compresses as it descends and warms according to adiabatic principle
- Cloud droplets and ice crystals evaporate or sublimate
- Air clears rapidly
- Air continues to warm as it descends



Orographic (related to mountain) Precipitation

4

- Air has reached base of mountain
- Hot and dry air since moisture has been removed on the uphill journey
- *Rain shadow* on far side of mountain (desert)
- *Chinook* - warm dry air



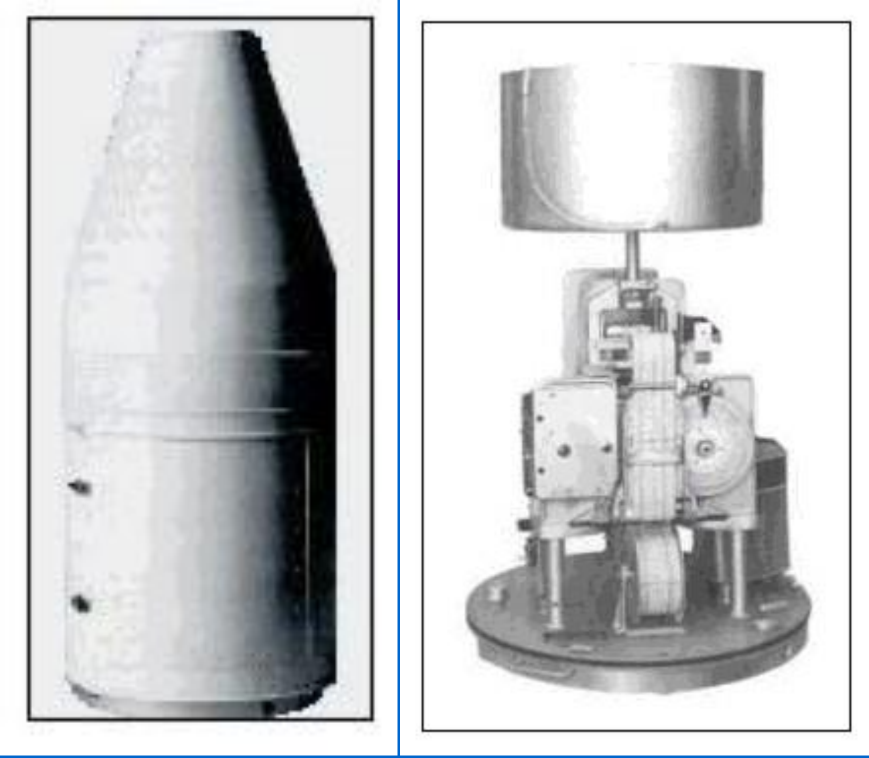
POINT MEASUREMENT OF PRECIPITAION

Recording gauges

- Weighing gages:
  - collect rain and snow (melted)
  - calibrated to read depth of precipitation (mm)
  - snow pillow

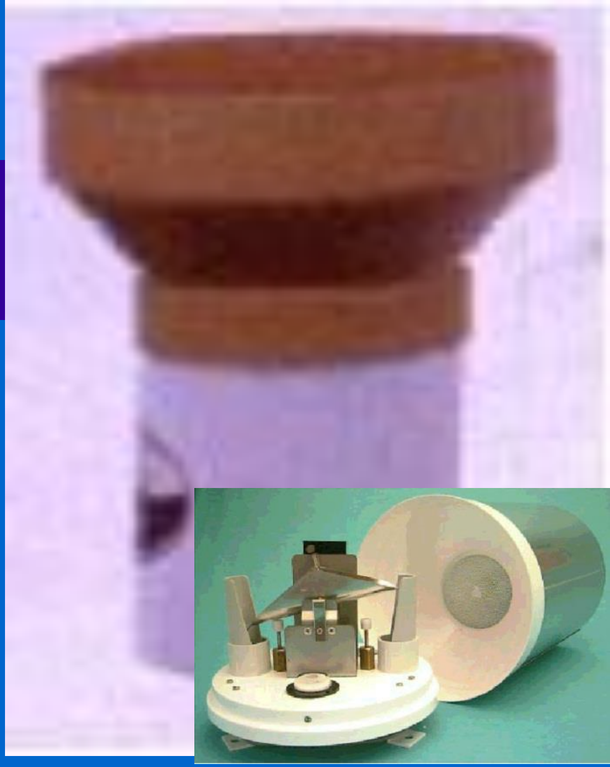
- Tipping bucket rain gauge:
  - 2 small buckets on a fulcrum
  - when one fills it tips and the other start collecting rain
  - tipping activates electronic switch

- Optical sensors:
  - measure distance to surface of water or snow



Belfort weighing precipitation gauge

Typical rain gauge



Tipping bucket rain gauge

Wind shielded snow gauge

Nipher snow gauge

Actual evapotranspiration

TURC: $ETA = P / [0.9 + (P/J)^2]^{0.5}$ $J = 300 + 25*T + 0.05*T^3$

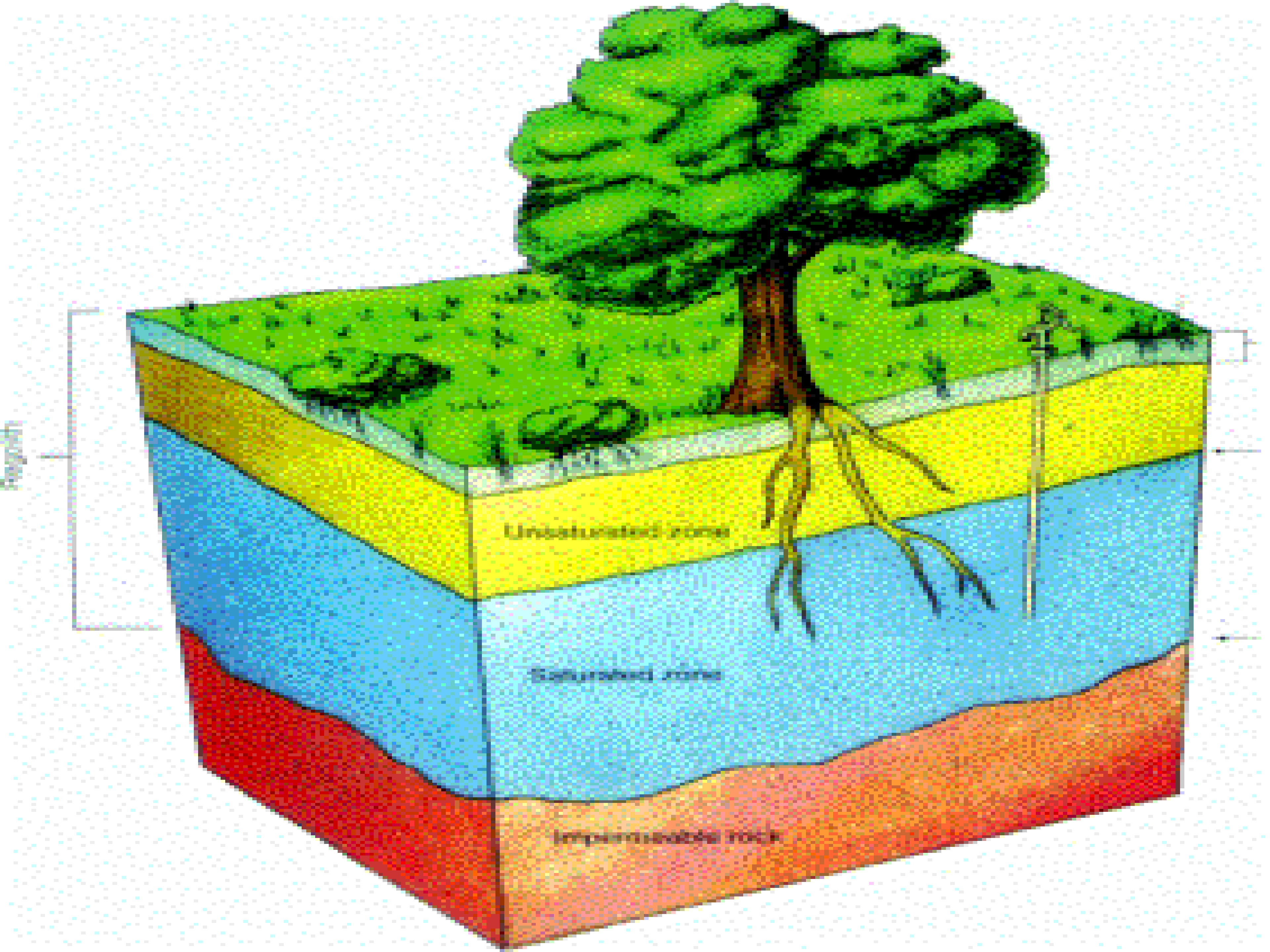
with P = mean annual precipitation [mm]; T = mean annual temperature [°C]

COUTAGNE: $ETA = P - \lambda * P^2$ $\lambda = 1 / (0.8 + 0.14 * T)$

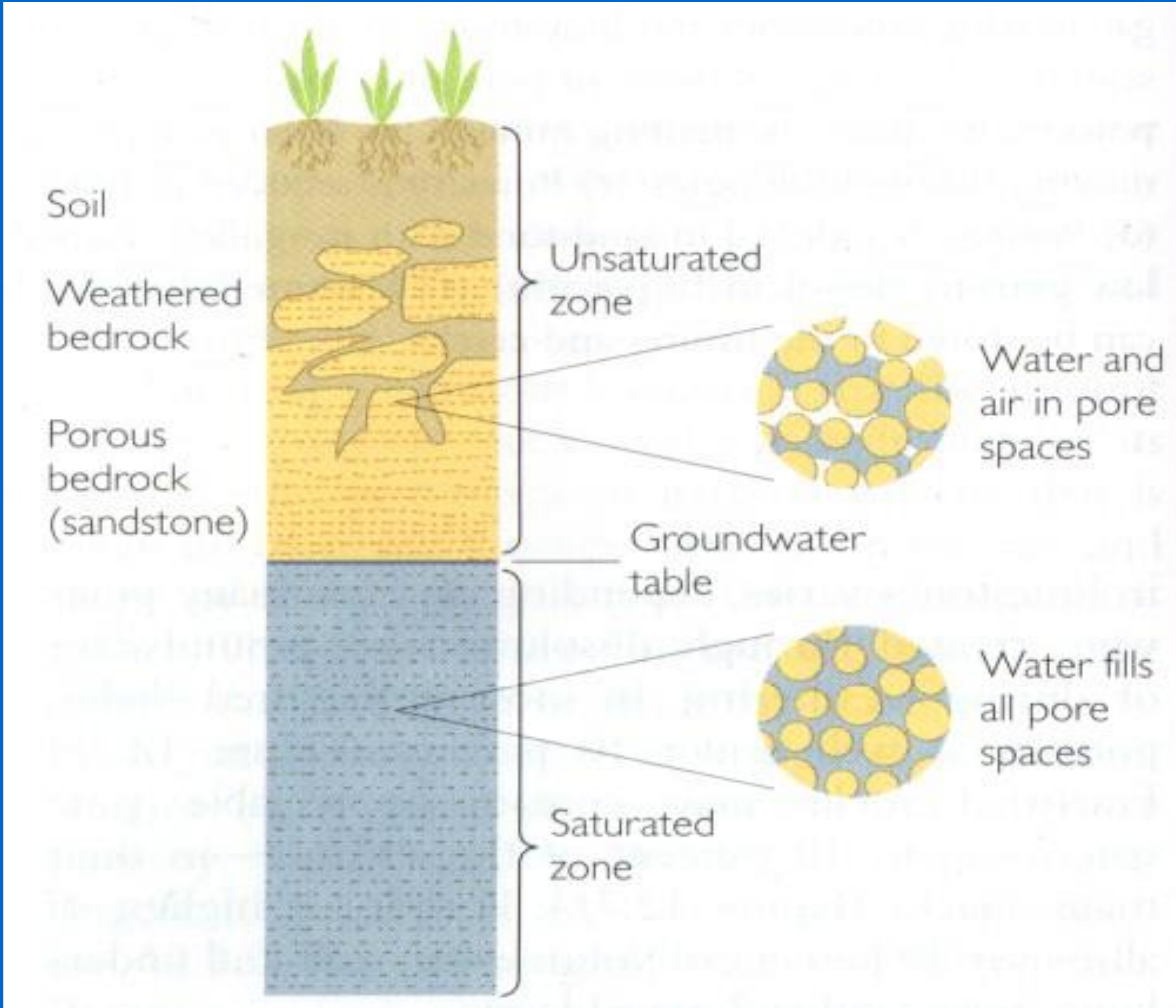
with P = mean annual precipitation [m]; T = mean annual temperature [°C]

- **Definition of soil:**
  Uppermost part of the surface sediment characterized by high biological activity
- **Unsaturated zone:**

  If part of the pores are filled with air
- **Saturated zone:**
  If all subsurface pores and fissures are filled with water and this water is able to move



Unsaturated zone
Saturated zone
Impermeable rock


Soil
Weathered bedrock
Porous bedrock (sandstone)
Unsaturated zone
Water and air in pore spaces
Groundwater table
Water fills all pore spaces
Saturated zone

Water Profile

Unsaturated

- Soil Water
- Intermediate Vadose Water
- Capillary Water

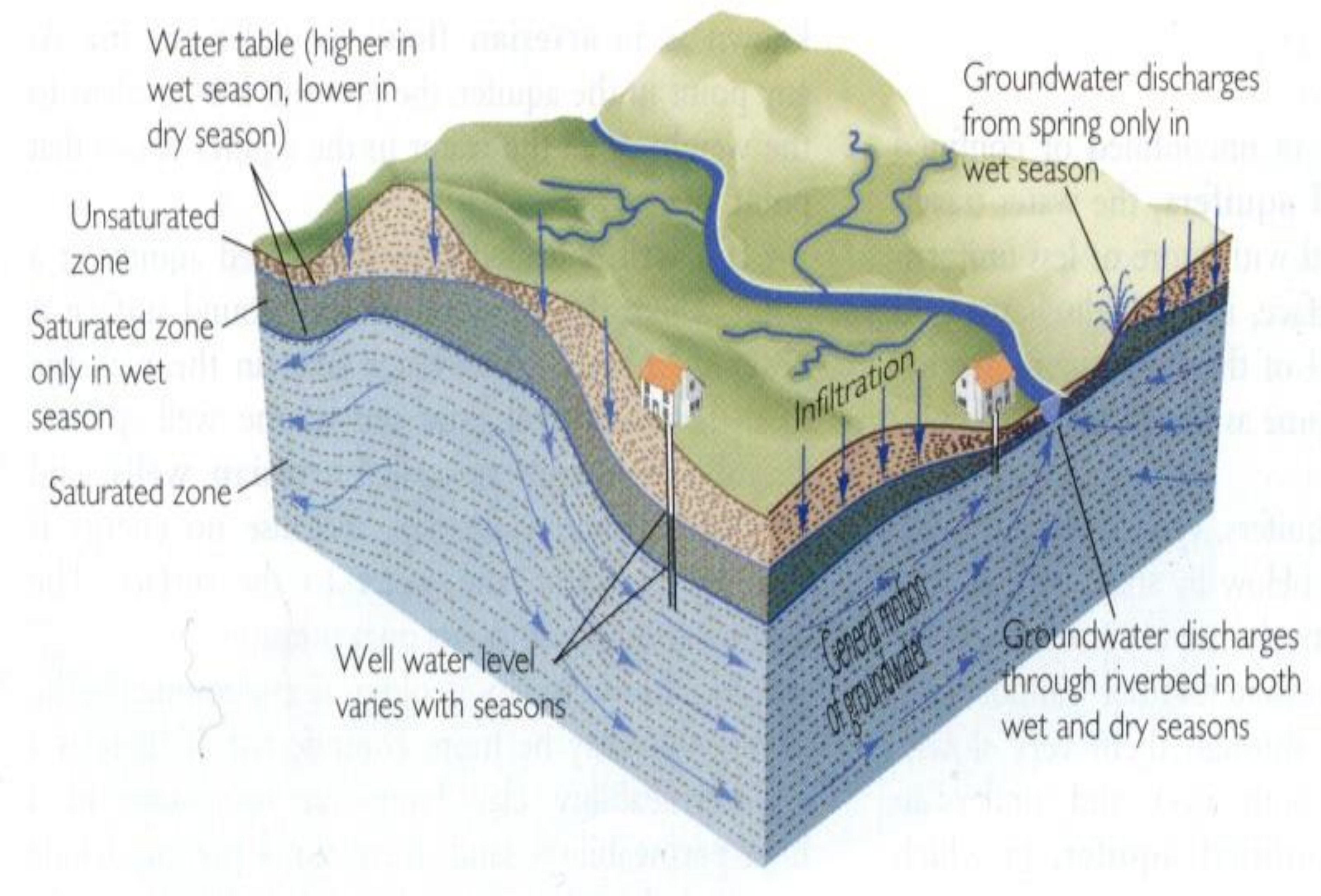
Saturated

- Groundwater
- Water in Unconnected Pores

Interstitial Zone

- Bound Water in Minerals

Water Table & Groundwater Flow



Subsurface Flow

- **Infiltration**
- **flow entering at the ground surface**
- **Percolation**
- **vertical downward unsaturated flow**
- **Interflow**
- **sub-horizontal unsaturated and perched saturated flow**
- **Groundwater flow**
- **sub-horizontal saturated flow**