Tracers and Isotopes in Urban Hydrology

What is a hydrologic tracer?

- Any substance that can be used for tracking water movement is a *tracer*
- An *ideal tracer* behaves exactly as the traced material behaves
- A *conservative tracer* does not have sources or sinks (decay, sorption, or precipitation) in the system
- *Environmental tracers* exist in the system, *applied tracers* are added by scientists to study

Example of an applied (dye) tracer for studying groundwater-stream interactions

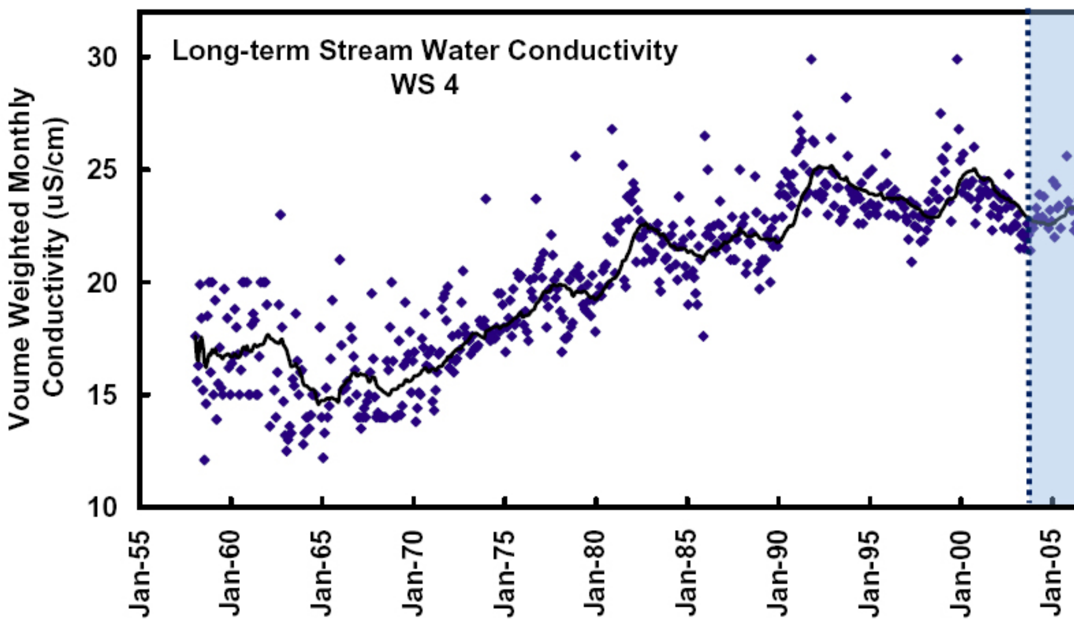
This tracer is non-conservative because it gets metabolized.

Environmental tracers

- Naturally occurring substances
- Anthropogenic signals
  - CFCs in atmosphere and groundwater → date groundwater recharge
  - Caffeine, hormones, pharmaceuticals → "emerging contaminants" that can identify wastewater
  - Disinfection by products from wastewater treatment process
  - Fecal coliform

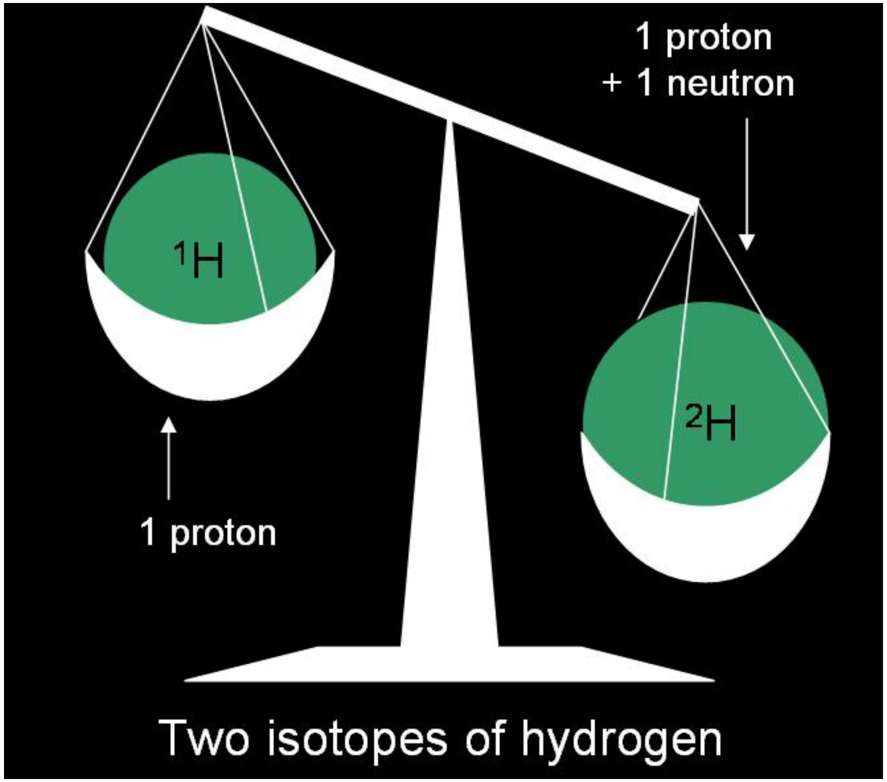
Environmental tracers: Conductivity

- Electrical conductivity –the measure of how a material accommodates the transport of electric charge.
  - In water, it varies with the amount and type of dissolved ions.
  - It varies with temperature, so we normalize and call it *specific conductance*.



Isotopes as Environmental Tracers

- Isotopes are the same element, but with different numbers of neutrons.
- Two groups of isotopes:
  - **Radioactive:** atoms that spontaneously break down their nuclei to form other isotopes
  - **Stable:** do not spontaneously break down to form other isotopes



Radioactive Isotopes in hydrology

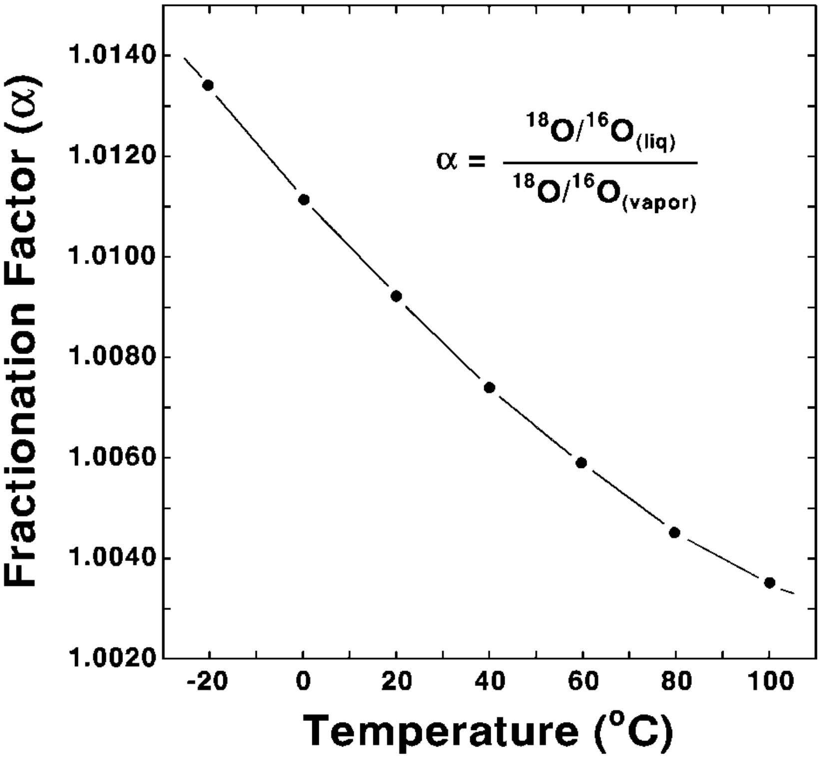
- Age of groundwater
- Measure groundwater flow rates
- Tracers for groundwater movement

- Choose isotopic system:
  - Half-life of radioisotope
  - Reactivity of isotope in system of interest

Stable Isotopes In Hydrology

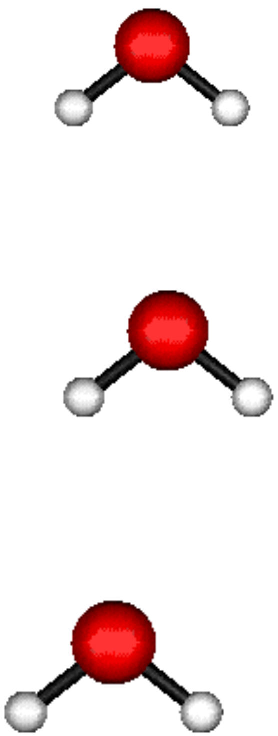
- Changes in isotope ratios in environment from physical, chemical, and biological processes due to mass differences between isotopes

Figure 6-4. Variation of the isotope fractionation factor for oxygen, as a function of temperature, during the evaporation of water. Note that with increasing temperature the fractionation factor approached 1.0000. Values from Dansgaard (1964).



Stable Isotopes Tracing the Hydrologic Cycle

- Stable Isotopes of H_2O
  - ^{1}H, ^{2}H (^{2}D), ^{16}O, ^{17}O, ^{18}O
- Vibrational frequency (energy) differences
- Provide characteristic fingerprint of origin
- Applications in hydrogeology
  - Provenance of water
  - Identify processes that formed waters
  - Separating hydrographs into "old" and "new" water



Characteristic vibrations of H_2O

Animations courtesy of E. Schauble (UCLA)

Isotopic Fractionation

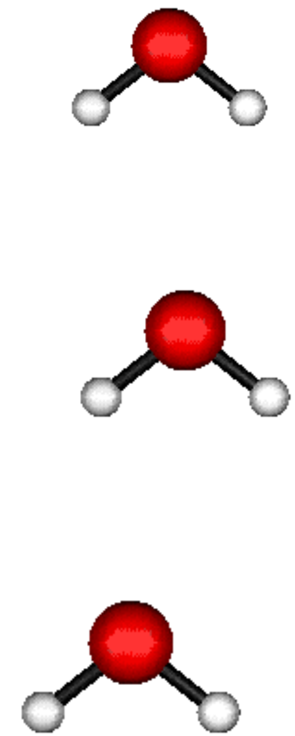
- Detectable change in the ratio of an isotopic pair-due to geologic processes (partitioning of isotopes)
- **Due to mass differences of isotopes**—affect vibrational frequency of atom which affects ability to make (& break) bonds w/ surrounding environment

- Examples
  - Evaporation-precipitation of rain
  - Dissolution & precipitation of crystals in fluid
  - Exchange reactions: liquid-gas and liquid-crystal
  - Separation due to reaction rates (kinetic rates)

Isotope Ratio notation

$$\delta^{18}O = \left[\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right] \times 1,000$$

- δ = value ‰ ‘per mil’
- Positive vs. negative delta values
- Isotopically heavy vs. light



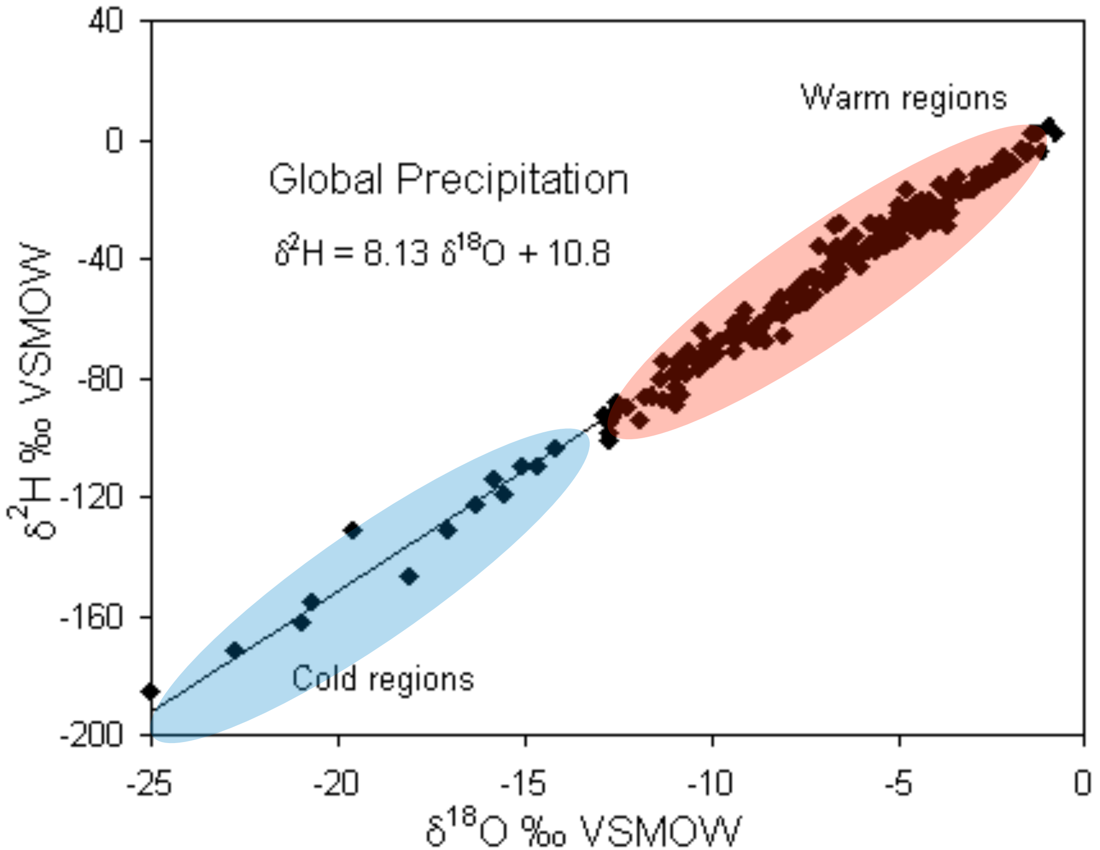
Characteristic vibrations of H_2O

Animations courtesy of E. Schauble (UCLA)

Precipitation: Equilibrium & the "Global Meteoric Water Line"

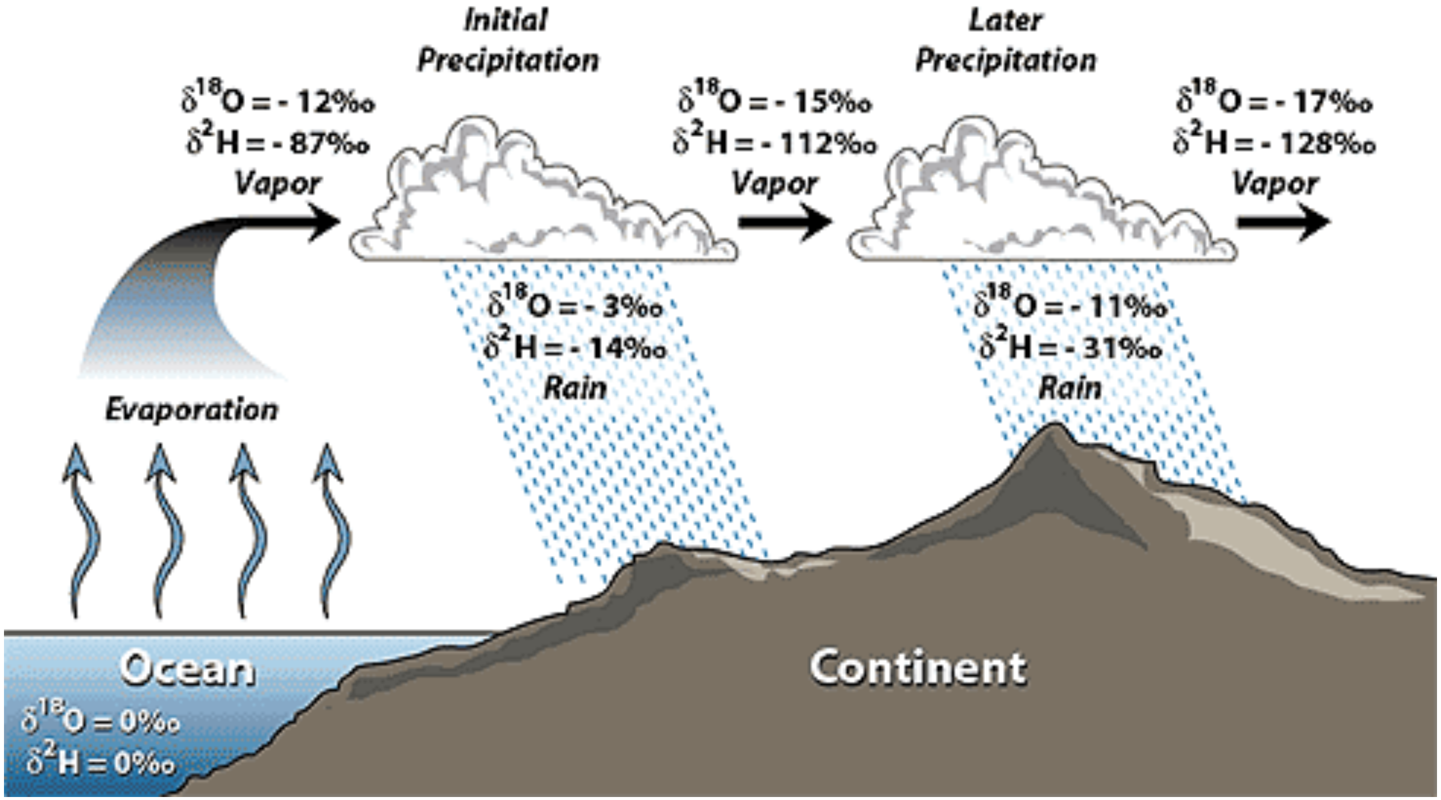
Sam Epstein and Toshiko Maveda,1953

Harmon Craig (1961) defined the relationship between ^{18}O and ^{2}H in worldwide fresh surface waters.



Craig (1961); Rozanski et al. (1992)

Precipitation: Rainout effect

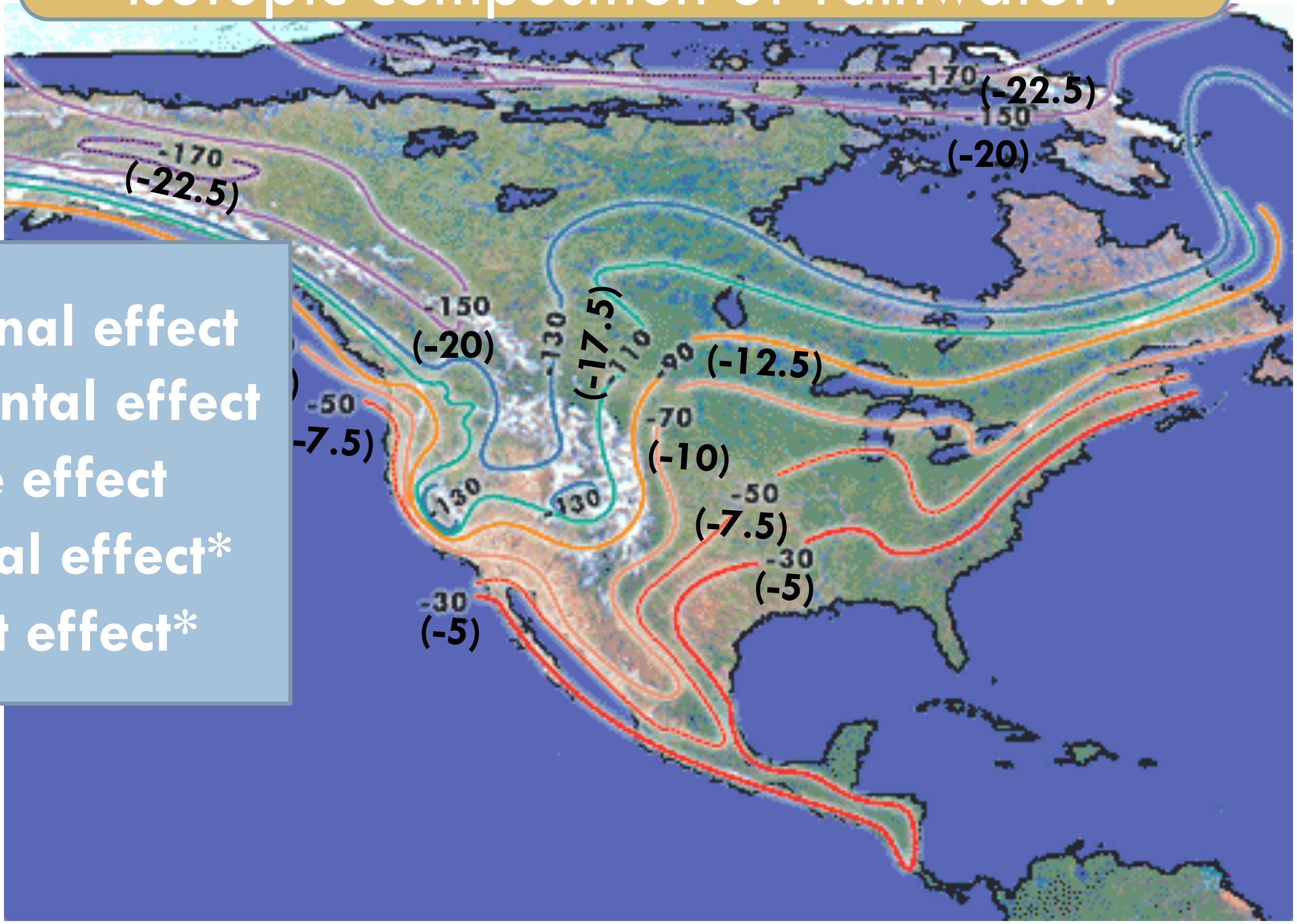


Contours of δD and $\delta^{18}O$ in rainwater

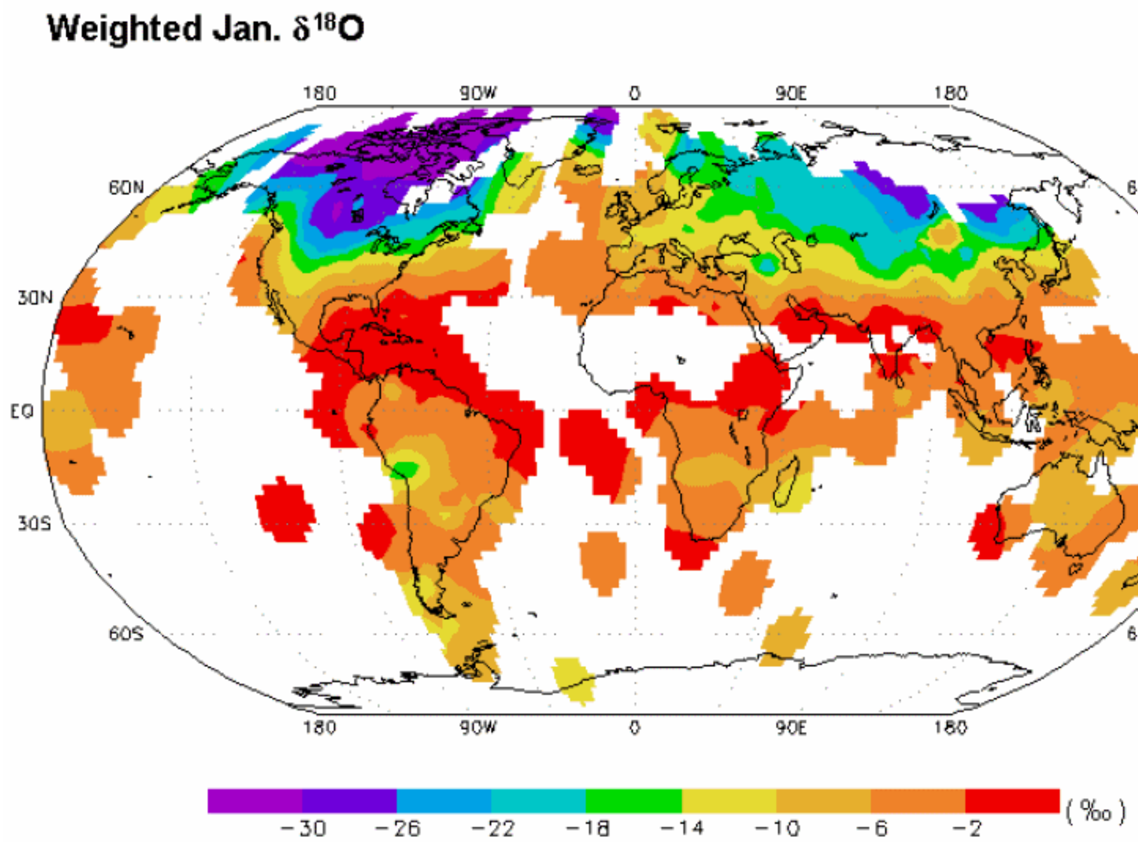
What patterns do we see in the isotopic composition of rainwater?

1) latitudinal effect
2) continental effect
3) altitude effect
4) seasonal effect*
5) amount effect*

($\delta^{18}O$ values in parentheses)



Global pattern $\delta^{18}O$ in rainwater



http://www.iaea.org/programmes/ripc/ih/iaea_waterloo_gnipmaps/iaea_waterloo.htm

IAEA/University of Waterloo

Other effects

- Global Temperature Trend (from Dansgaard, 1964)
  - δ18O = 0.69 *Taverage* – 13.6
  - δD = 5.6 *Taverage* – 100
- Distance/Continentality Effect
  - Wintertime δ18O -3 permil / 1000 km
  - Summertime δ18O -1.5 permil / 1000 km
- Latitude Effect
  - δ18O -0.5 permil per degree of latitude
- Altitude Effect
  - Varies, δ18O -0.2 to -1 per 1000 km
- Amount Effect and Seasonal Effects vary…

Use of O and H isotopes to help solve geochemical/hydrologic modeling problems

- Source of water
  - Rainwater – new or old
  - Evaporated water
  - Recharge at a certain altitude
  - Age of water
- Mixing of waters
  - Leakage from lakes, rivers, aquifers
  - Groundwater – surface water interactions
  - Contributions of snowmelt
- Salinization mechanism (plot of d vs concentration)
  - Evaporates surface water
  - Seawater
  - Dissolved evaporites
  - Mixing with connate brines
  - Reaction with rocks

Evaporation: Humidity & Local Meteoric Water Lines