Using Isotopes to Understand Coupled Hydrological & Biological Processes

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Introduction

Understanding hydroecological connections is difficult!
Isotopes can help!

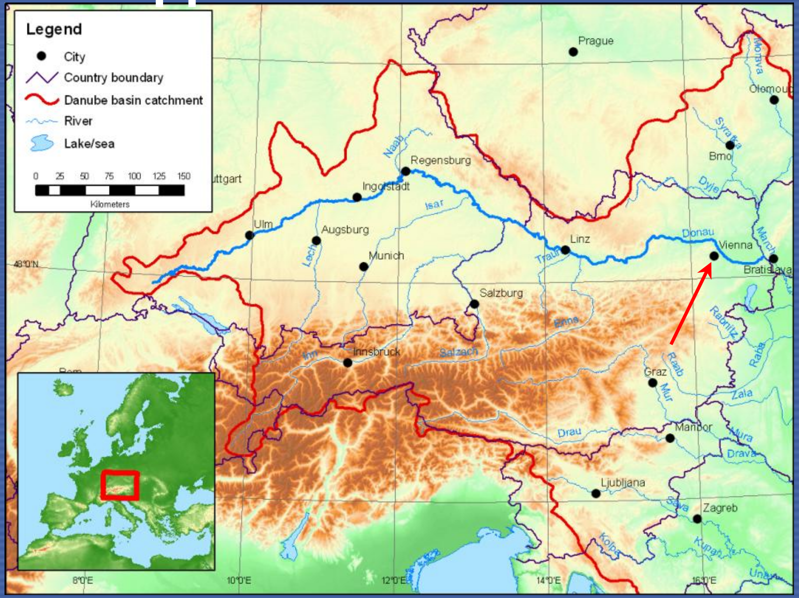
Discuss isotope examples from two main areas

- **Radioactive Isotopes**
  - **Focus on water residence times**
- **Stable Isotopes**
  - **Focus on soil & the unsaturated zone**

Radioactive Isotope Applications to Hydroecology

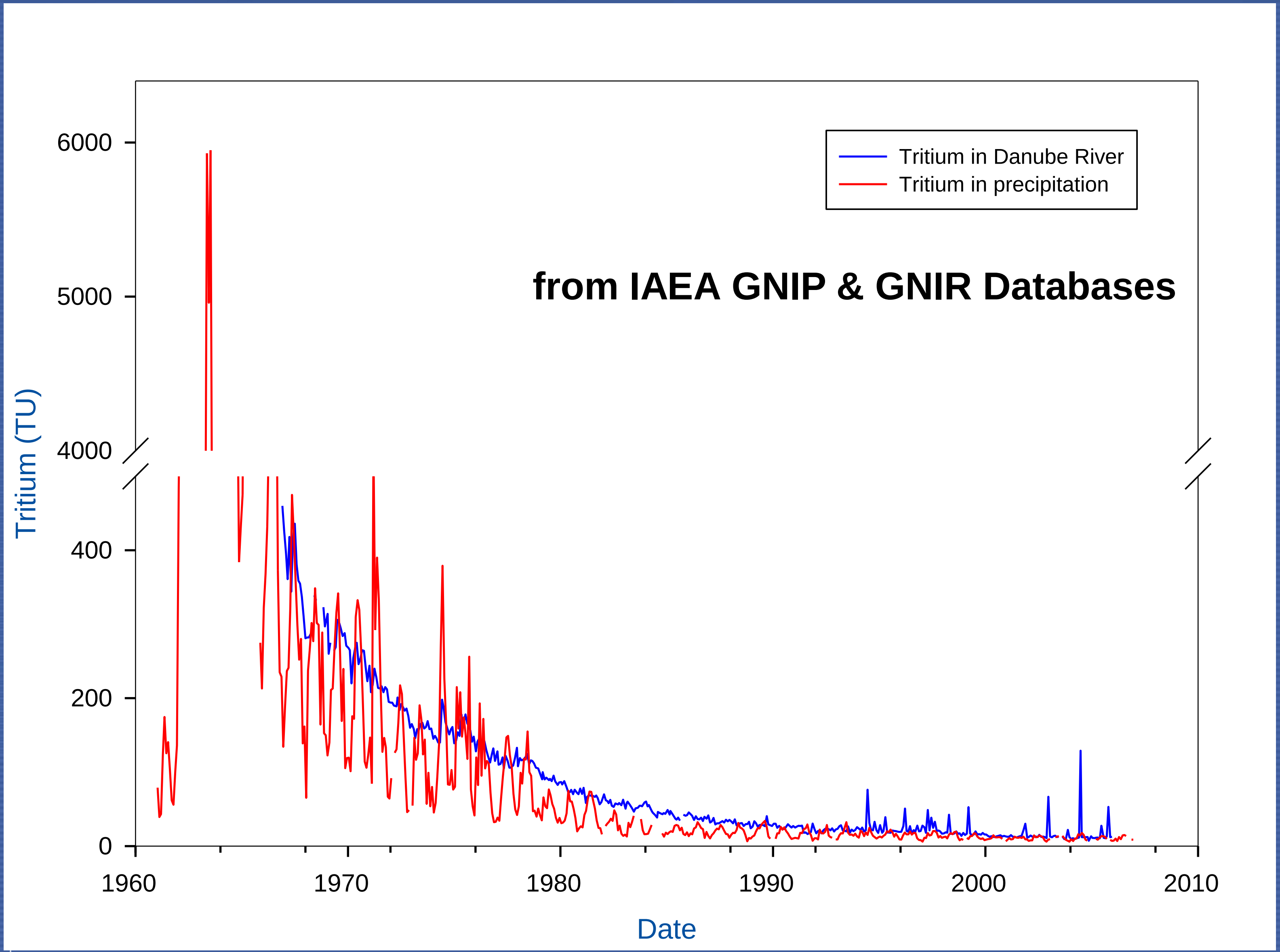
- Radioisotopes (e.g., carbon-14 and tritium) used to “label” ecohydrological processes
- Radioisotopes are underappreciated for understanding cycle or residence times
  - e.g., groundwater residence times in aquifers can be long affecting biogeochemical processes at the river basin scale for many years.

Upper Danube Basin

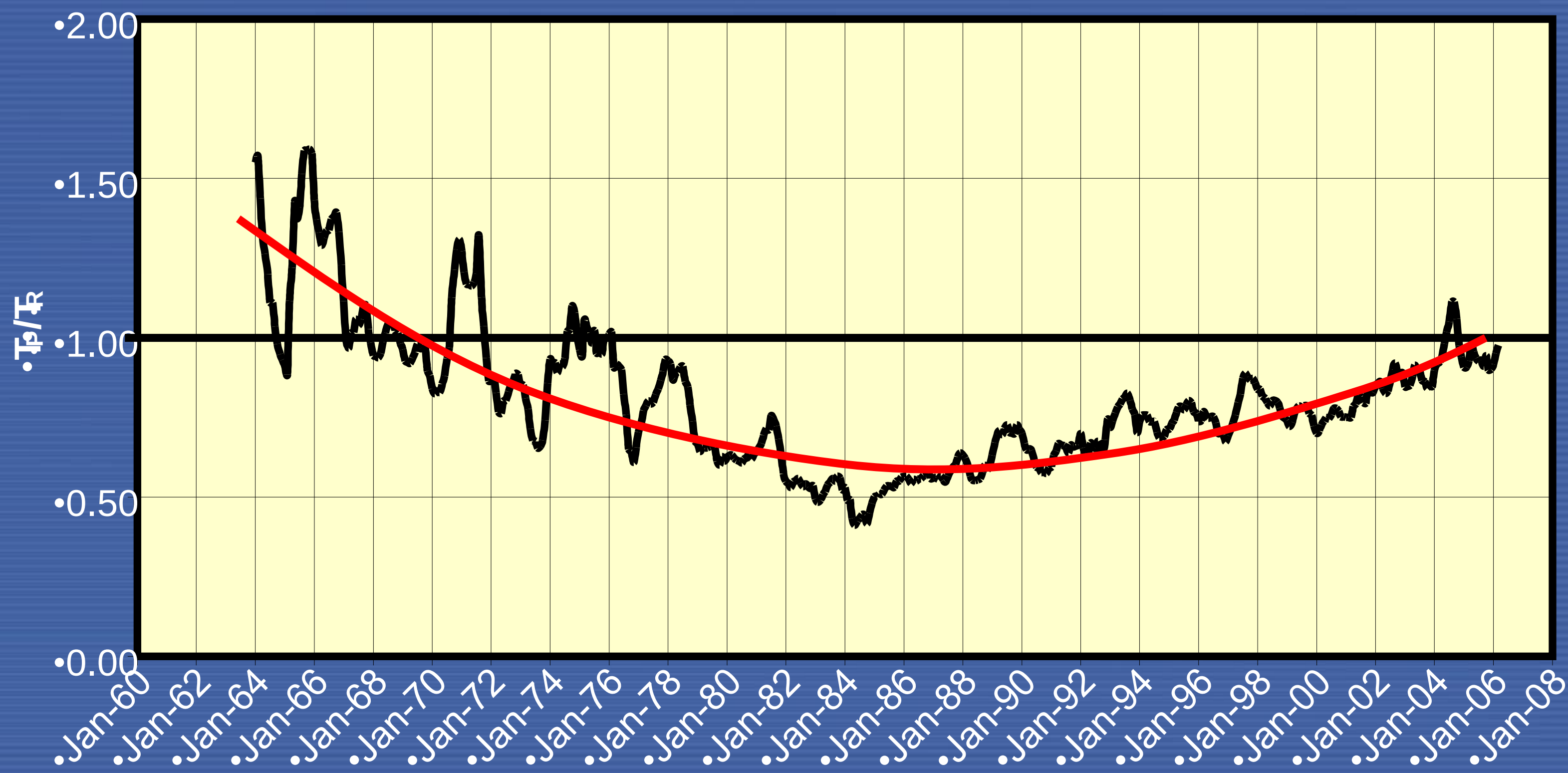


- Examine water residence times of the upper Danube using tritium measurements of precipitation and river flow

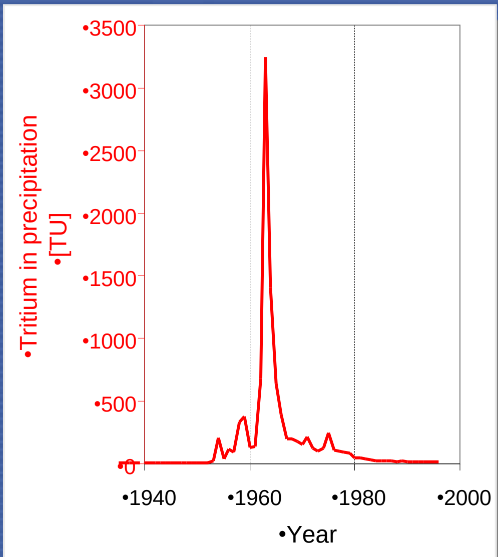
Precipitation & Danube Tritium (Vienna, 1960-2008)

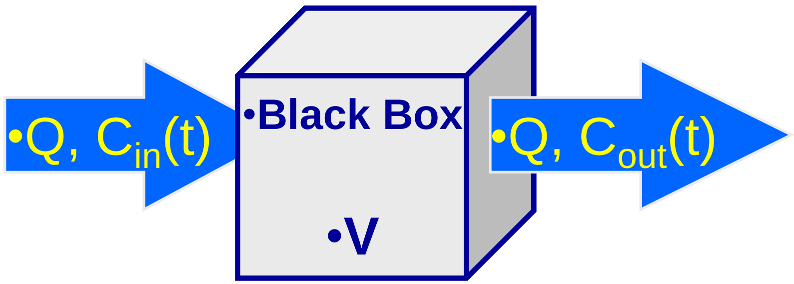


Time evolution of the T_P/T_R ratio in the Upper Danube

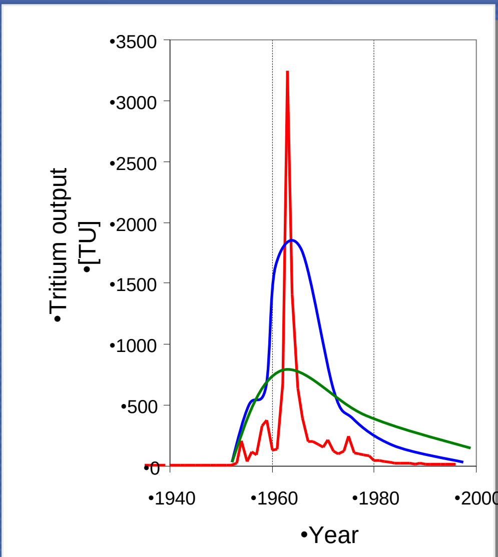


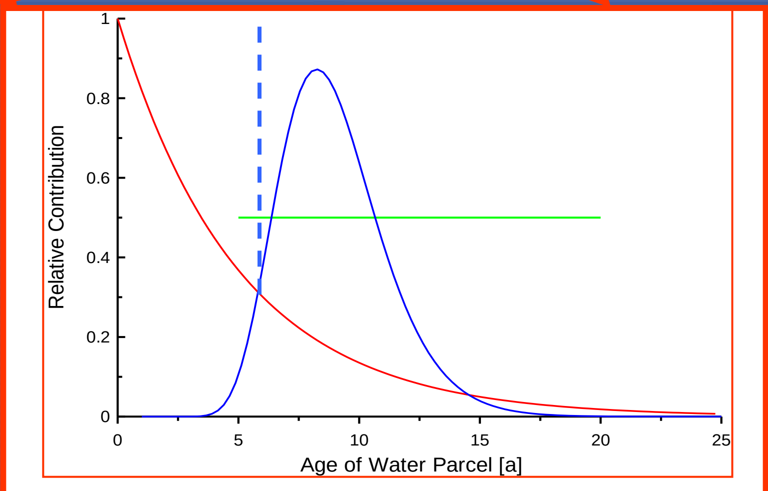
Lumped Parameter Modelling



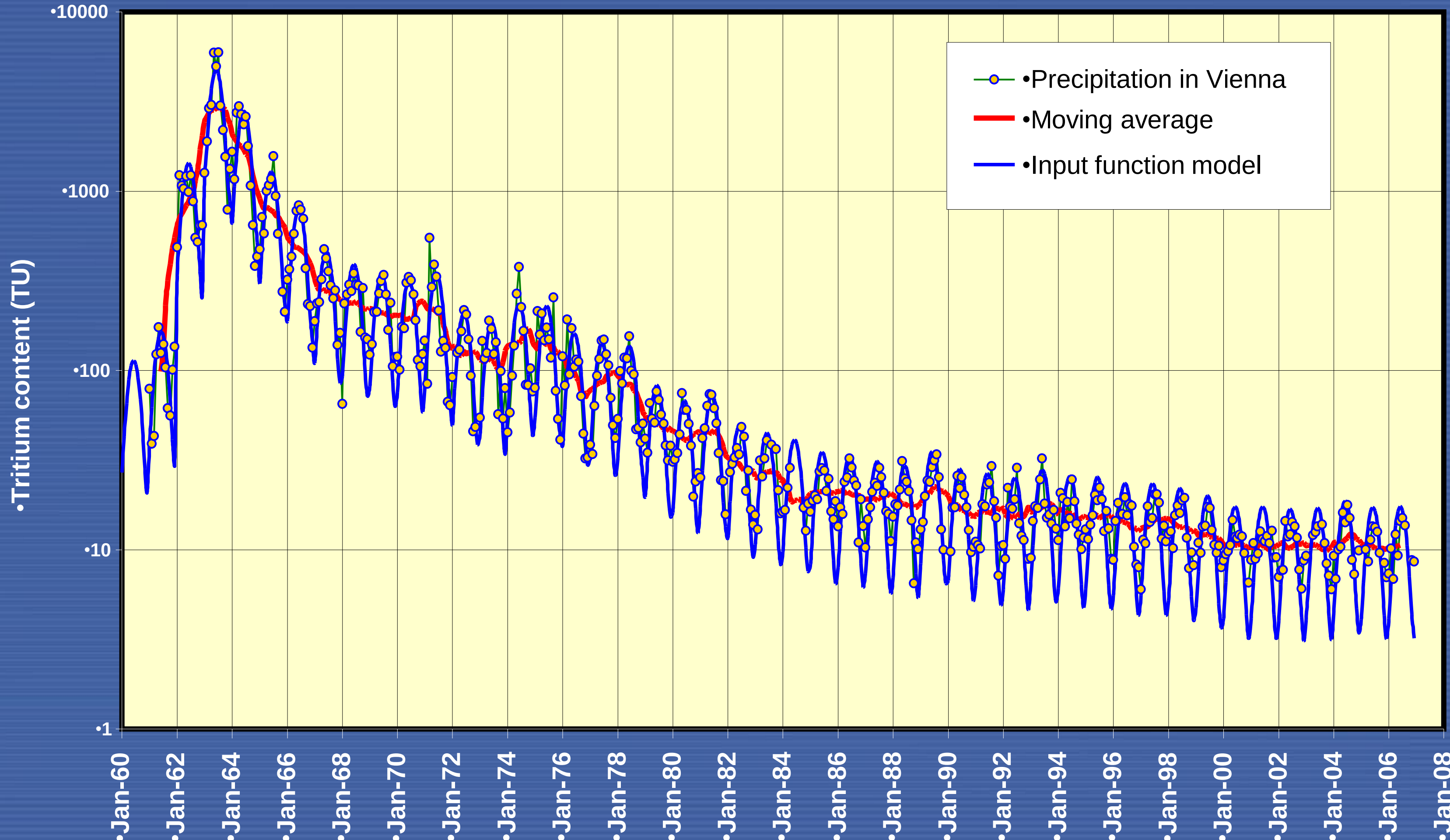


$$C_{out}(t) = \int_{-\infty}^{t} C_{in}(t')\, g(t-t')\, e^{-\lambda(t-t')}\, dt'$$





Tritium in Vienna Precipitation (1960-2008)



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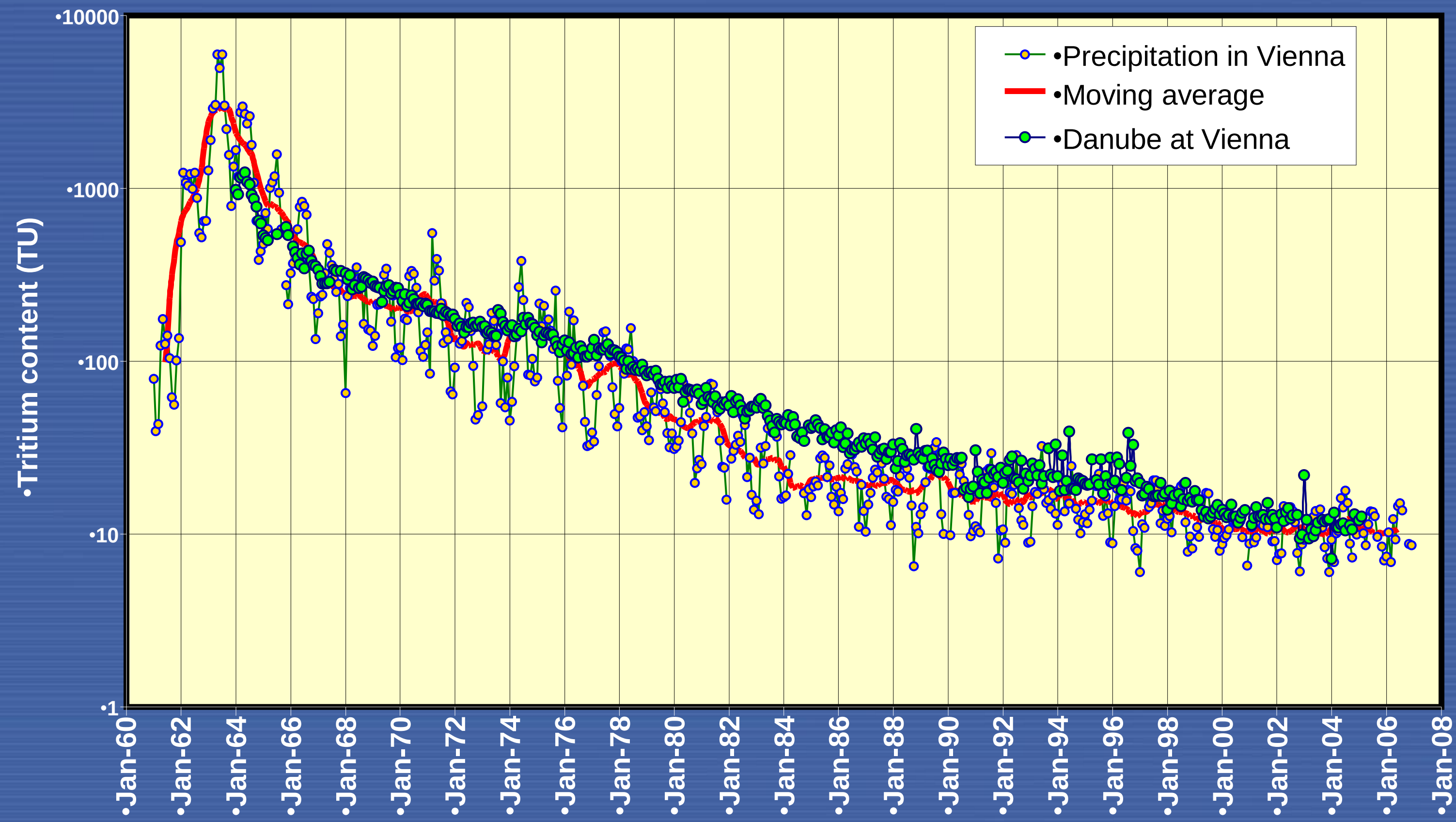
Danube Tritium (Vienna, 1960-2008)



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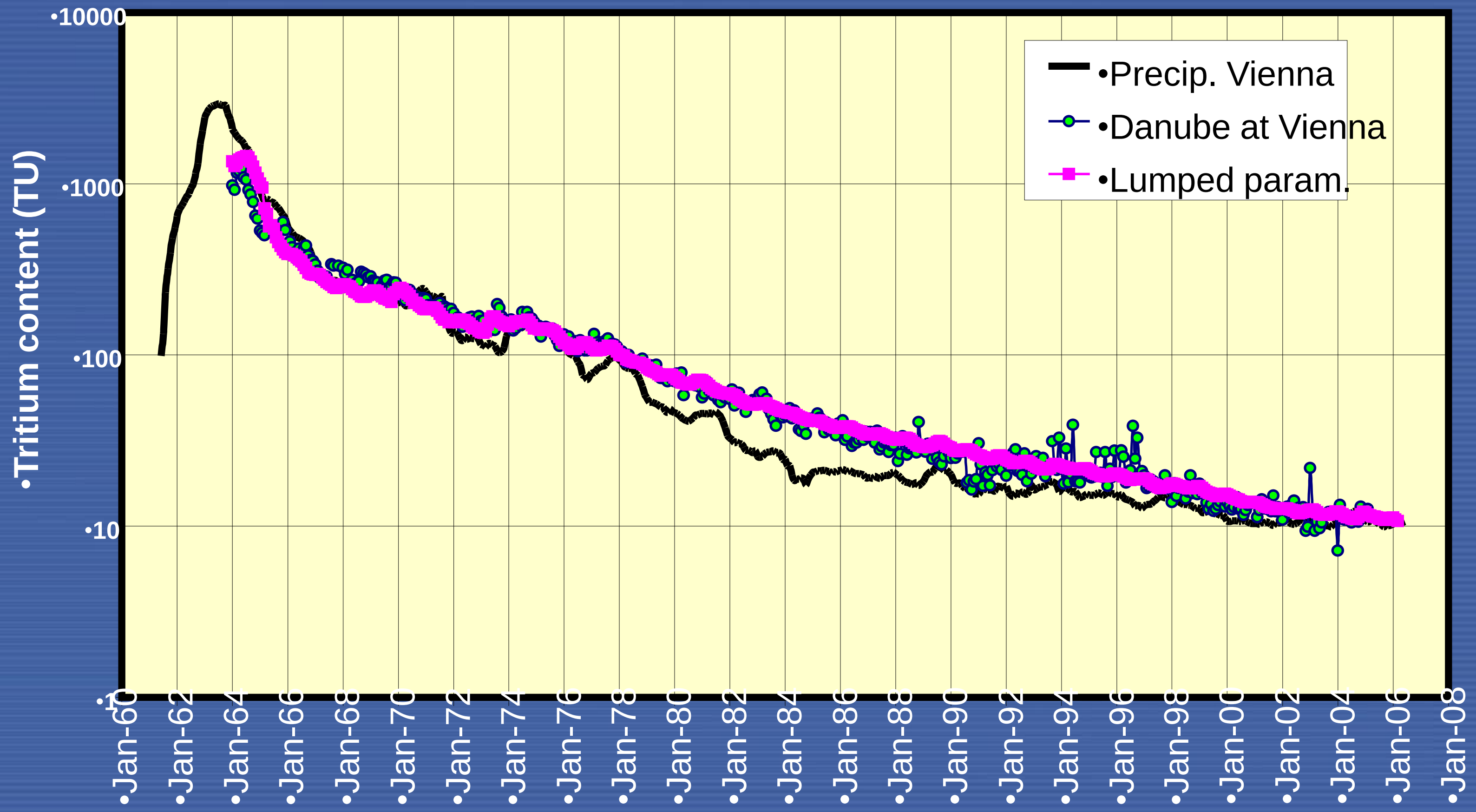
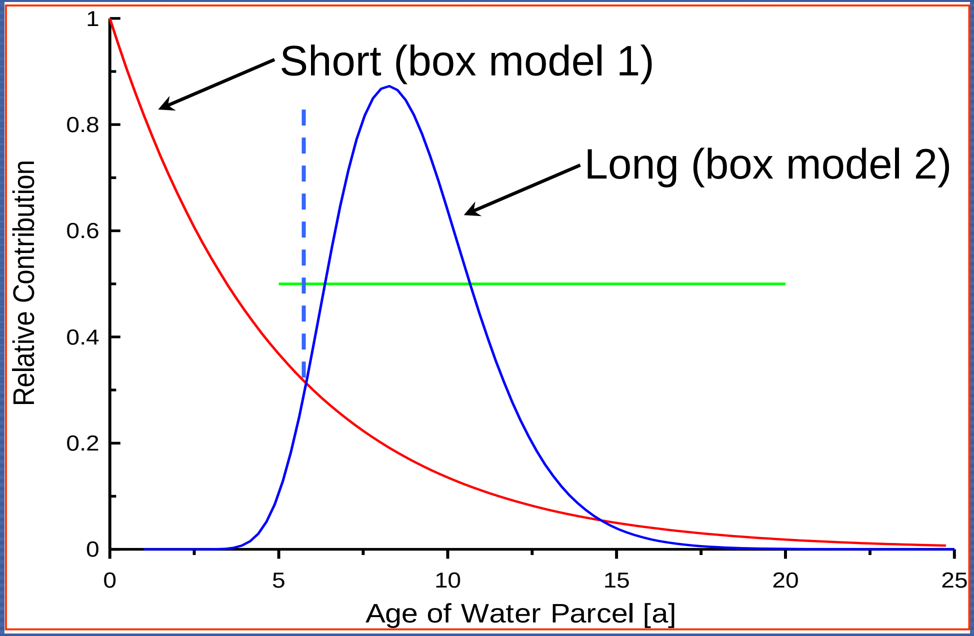
Modelled Danube Tritium (Lumpy)



Model Results

- **A two-box model provided the best fit.**
  - **a short residence time component (piston flow assumption) and a longer residence time component (exponential flow assumption)**
- **60% "short" residence time component (mean residence time of 0.75 years)**
- **40% "long" residence time" component (mean residence time of 15 years)**
- **Average combined residence time is about 6 years.**

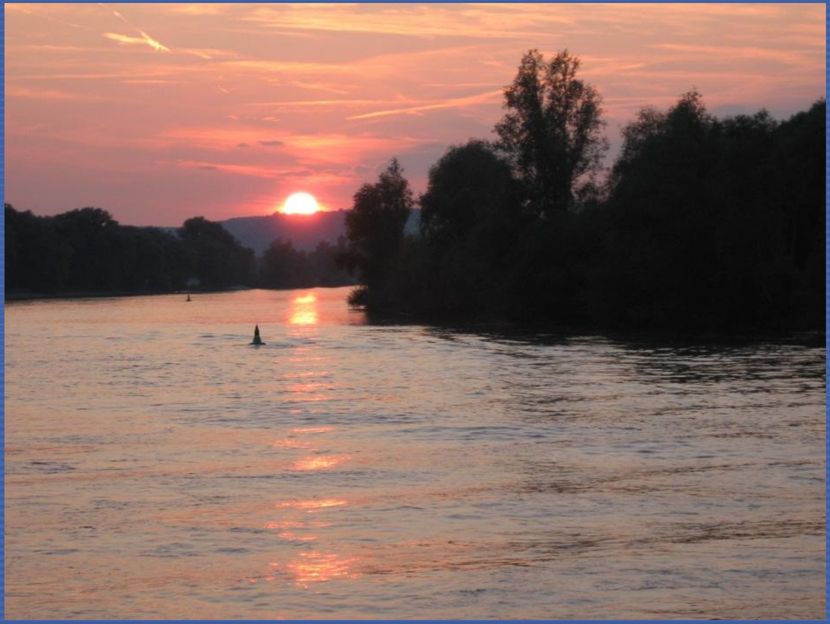


Implications of Model Results

What do these results mean ecologically?

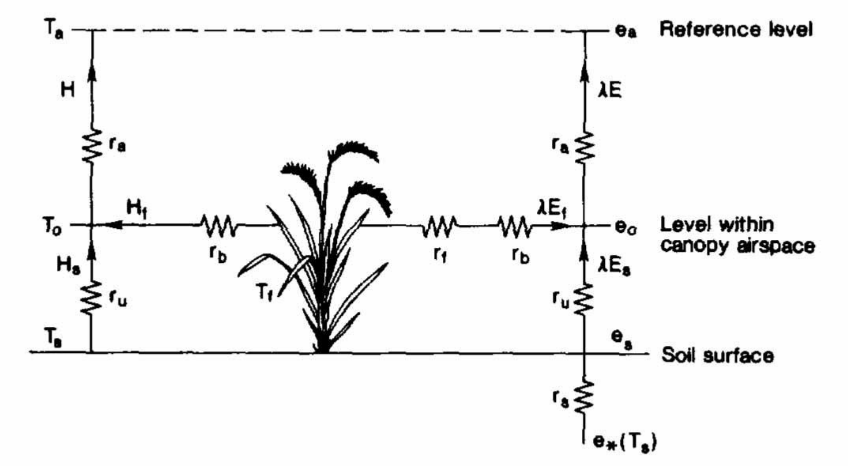
- Changes to biogeochemical and pollutant sources may take “on average” 6 years to become apparent in Vienna river water & over a decade to substantially decrease

- Estimations of residence/ cycle times are crucial at the basin scale & radio-isotopes are invaluable for this



Stable Isotopes (deuterium & oxygen-18)

- **Stable isotopes are increasingly used to understand processes involving water along the plant/soil/atmosphere continuum**
- **In agriculture they are being used to improve water use efficiency**
- **Understand plant/water interactions in natural landscapes (ecohydrology)**
  - e.g., evaporation & evapotranspiration partitioning
  - where plants get their water
  - deep percolation
  - climate variability



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Where do plant get their water?

- **Trees next to streams get their water from the stream right?**
  - Wrong, they get it from groundwater!

    - Dawson & Ehleringer, 1991, Nature

  - Stable isotopes can be used to define where plants get their water

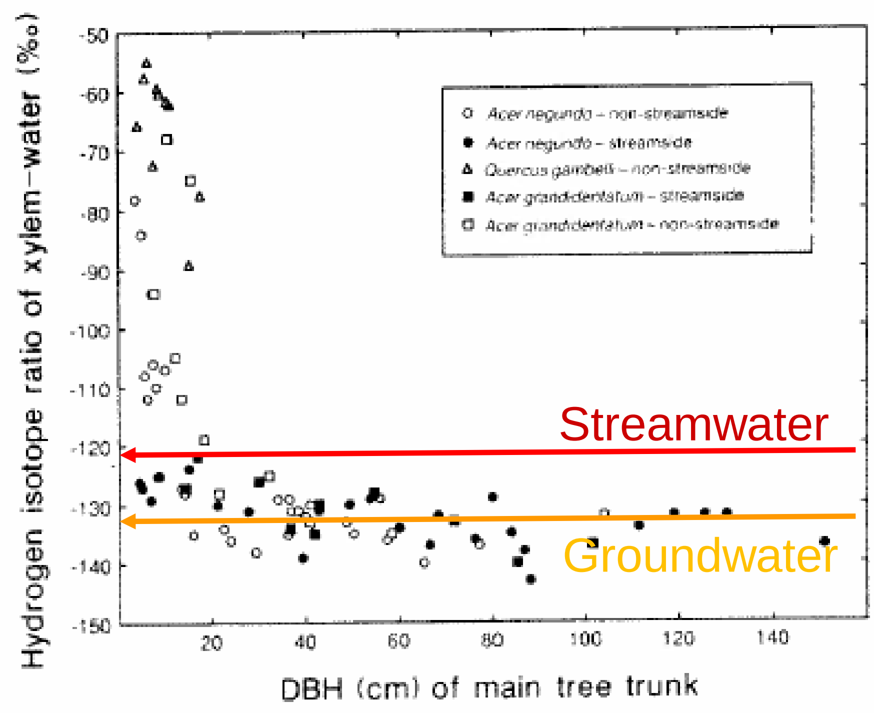
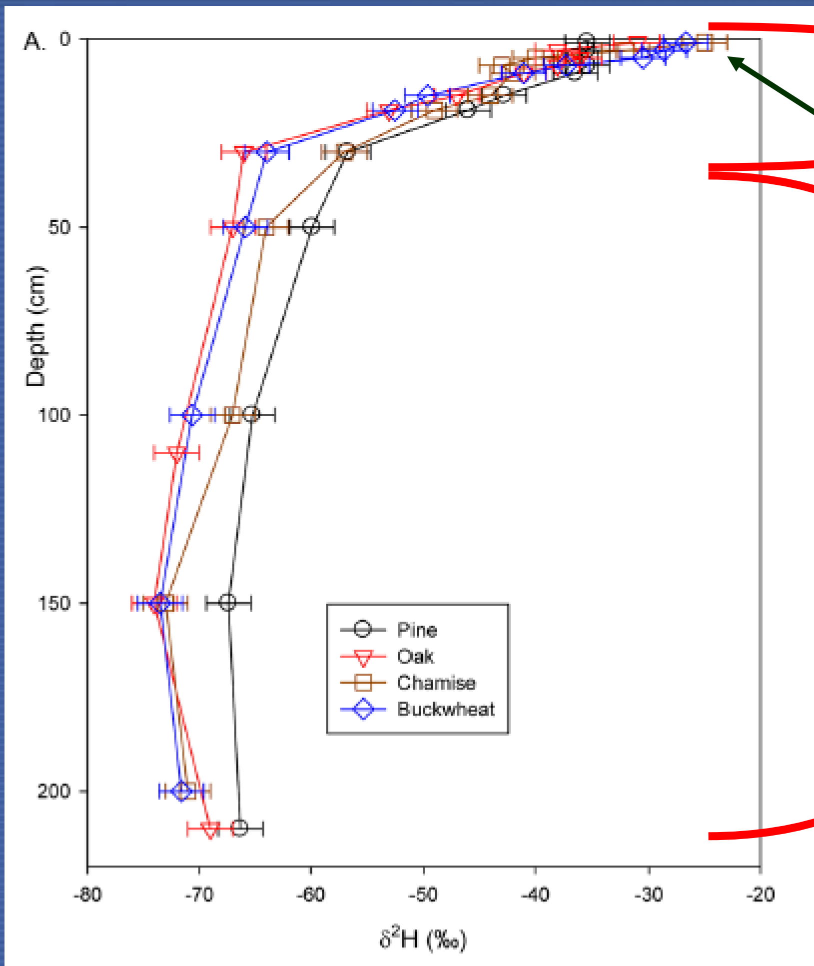


FIG. 2 The hydrogen isotope ratio (δD in ‰) obtained from xylem sap of three common streamside (closed symbols) and adjacent non-streamside (open symbols) tree species in the Red Butte Canyon Research Natural Area in 1989 as a function of the diameter at breast height (DBH) of the main trunk. Mean δD values of stream water (from Fig. 1) and local well water (see text) were -121.4 ± 0.7‰ and -132.3 ± 2.6‰ respectively. Methods are outlined in the text and in ref. 10.

Vadose Zone Stable Isotopes



Zone of mixed vapor/liquid flow

Maximum isotope value is at the evaporation front

Zone of liquid flow

Chaparral Ecosystem Isotope Profiles

San Dimas, California Monocultures

Newman & Graham, 2008, VZJ

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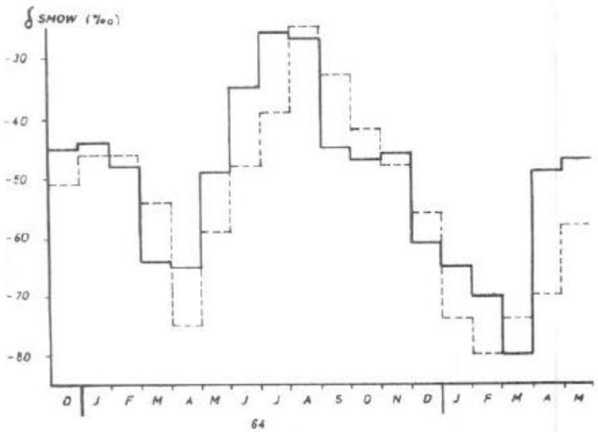
Zimmerman et al. (1967, IAEA Symp. Series)

- A classic paper on vadose zone & ecohydrological stable isotope studies
- Percolation with tritium
- Evaporation & percolation with stable isotopes
    - Model for 2nd stage evaporation
- Plants (generally) don't fractionate soil water during root uptake - a powerful concept!



Seasonal variation of deuterium content in the soil water of a grass-covered sandy soil near Heidelberg
Solid line = samples from 0 - 10 cm depth
Broken line = samples from 10 - 20 cm depth

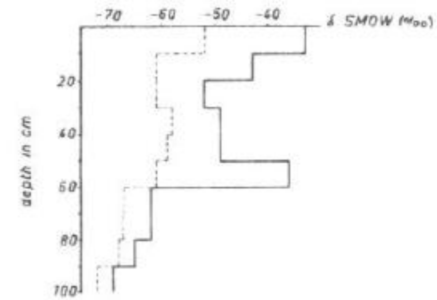
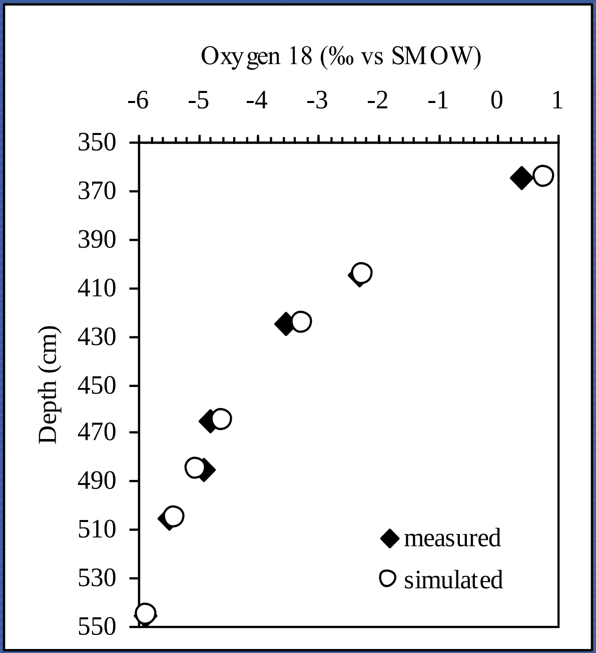


FIG. 12. Deuterium content of soil water from two cores taken simultaneously from two neighbouring proving grounds on loamy soil at Gießen. (Soil sampled 8 June, 1964.) The solid-line histogram refers to the bare area, the broken line to the grass-covered one. The bare area contains on the average about 10‰ more deuterium.

Isotope estimation of 2nd Stage Evaporation Rates (Allison & Barnes, 1983, Nature)



Chakir et al. Tunisian profile fit

- Depth profiles of isotopes can quantify 2nd stage evaporation
- For bare soil or sparse vegetation
- Iteratively fit the bulge and steady state region using:
- $(\delta-\delta_{res}) = (\delta_{ef}-\delta_{res})\exp(-f(z)/\check{z})$ &
- $\check{Z}= \theta_{ave}\tau D/E$
- Where δ are the delta values at a given depth, at the evaporation front and at depth respectively, f(z) depth fn for variable water content, ž is the decay length, θ is the ave. water content, and D is the diffusion coefficient of HDO in liquid water.

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Evaporation estimates for multiple events from a single borehole (Chakir et al. Tunisia)

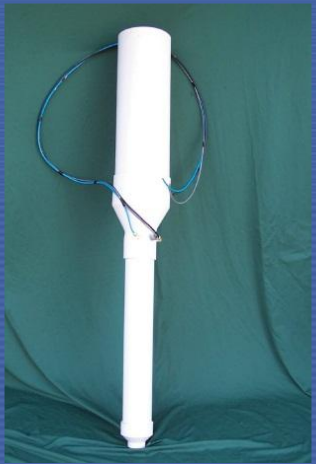
Phase	Thickness of the soil above the phase (cm)	Evaporation rate (mm/year)		Mean Evaporation rate (mm/year)
		τ=0.6	τ=0.67	
A	50	20,7	23,2	22,0
B	175	15,6	17,4	16,5
C	280	10,2	11,4	10,8
D	345	11,0	12,3	11,7
E	200	6,4	7,2	6,8

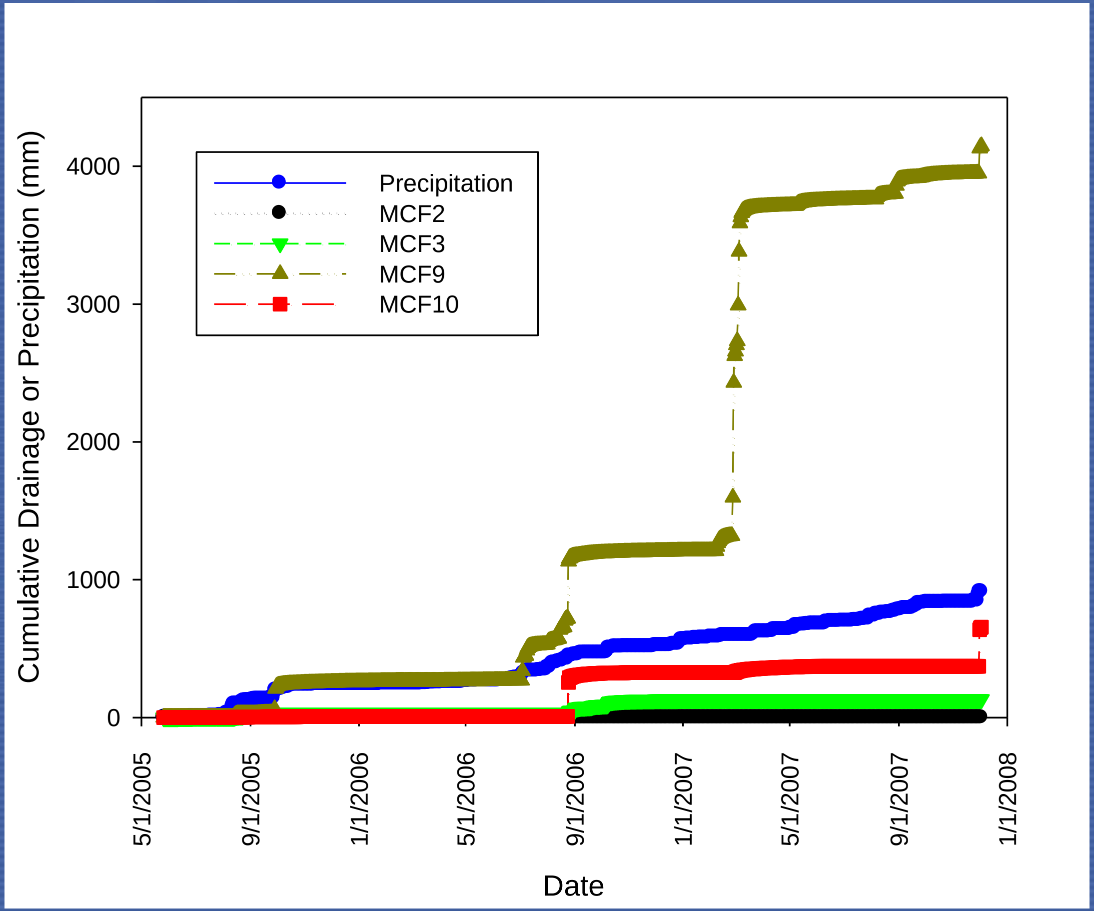
Vadose Zone Sampling for Isotopes (deuterium and oxygen-18)

- **Direct sampling of vadose water in field**
- Suction cups
- Zero tension samplers
- Passive wick lysimeters (flux and water samples)
- Passive wicks for snowmelt percolation (Frisbee et al., 2010, pts. 1 & 2, HP)
- No extraction necessary
- Difficult to sample deeper vadose zone

Cumulative percolation at 1 meter depth using flux meters in a semiarid arroyo in New Mexico

- Multiple flux meters can be used to understand study site spatial variability
- New Mexico results show the importance of topography on percolation
- for more information see Gee et al., WRR 2008

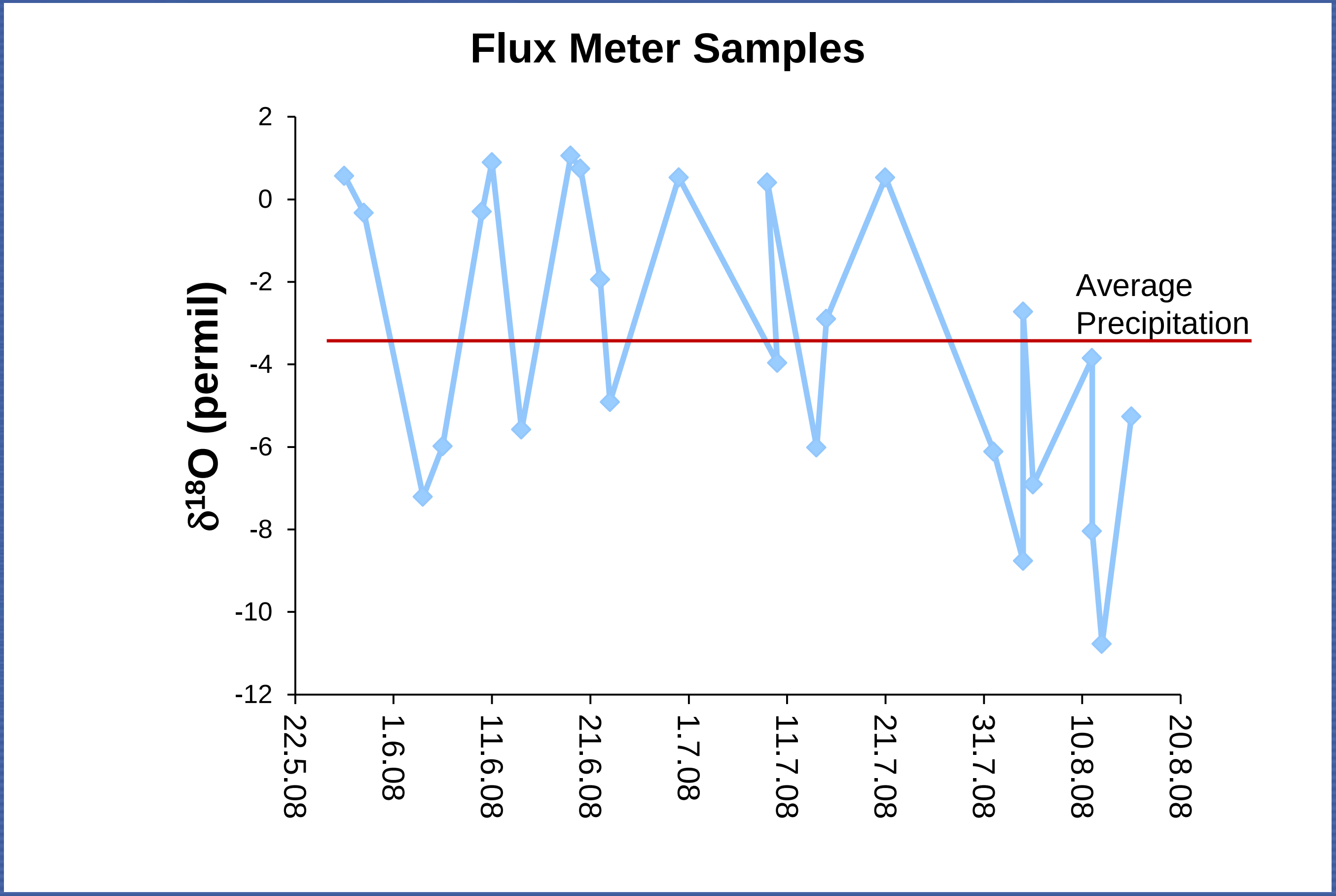




Flux meters for stable isotope sampling

- **Cotton field percolation at 1 meter depth, Indus Basin, Pakistan**

- **Isotope results show effects of transient percolation & subsequent evaporation events**



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Vadose Zone Sampling for Isotopes (deuterium and oxygen-18)

"Indirect" sampling by collecting soil, sediments, or rock from the vadose zone

- Hand augering
- Coring with drill rig or direct push system
- Can sample very deep profiles
- Good storage potential
- Requires extraction

Soil sample extraction for isotopes

- **Cryogenic Vacuum Distillation**
- **Azeotropic Distillation**
- **Both methods are tedious & are often problematic (see e.g., Araguas-Araguas, 1995, J. of Hydr.)**

- **There may now be a better way!**

from Naveed Iqball

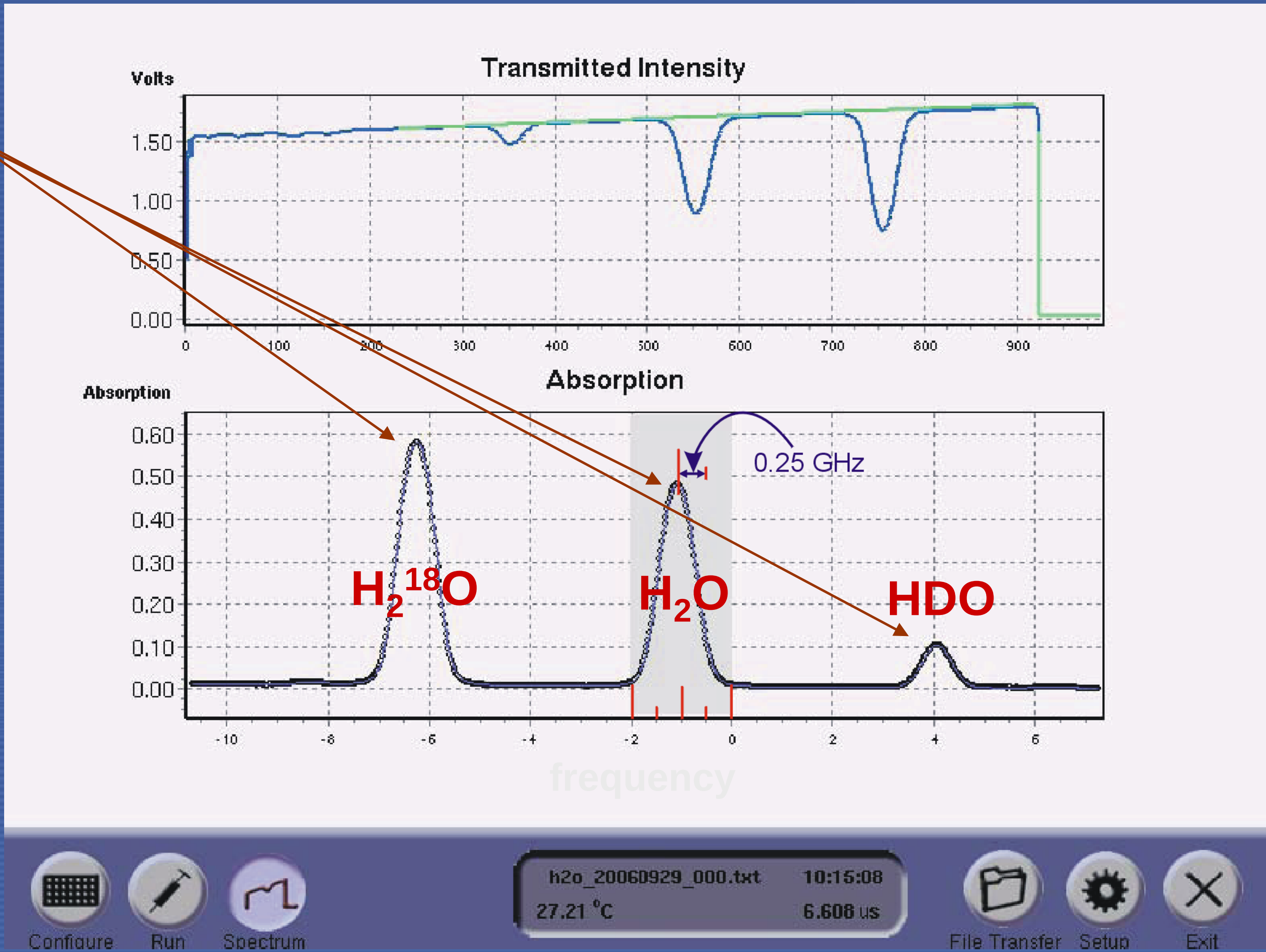
Recent Development

- A better way for soil/core porewater isotope analyses?
- Equilibration method for soil samples using an laser stable isotope analyzer for water vapor (Wassenaar et al., 2008, EST)
  - In field, put sample in zip top bag, in lab fill with dry air, equilibrate
  - Using transfer line with needle, pump air directly into instrument
  - up to 30 samples/day

- This method is much less prone to problems than traditional extraction methods & is faster & easier

Example Laser Spectrum

- **Each type of water molecule has a unique optical absorption**



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Conclusions

- Isotopes can be a powerful approach for addressing a broad range of hydro-ecological problems
  - Evaporation and evapotranspiration partitioning
  - Deep percolation
  - Residence/cycle times using radioactive isotopes
  - Many others

Thank You!