An improved practical approach for estimating catchment-scale response functions through wavelet analysis

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Abstract

Catchment-scale response functions, such as transit time distribution (TTD) and evapotranspiration time distribution (ETTD), are considered fundamental descriptors of a catchment's hydrologic and ecohydrologic responses to spatially and temporally varying precipitation inputs. Yet, estimating these functions is challenging, especially in headwater catchments where data collection is complicated by rugged terrain, or in semi-arid or sub-humid areas where precipitation is infrequent. Hence, we developed practical approaches for estimating both TTD and ETTD from commonly available tracer flux data in hydrologic inflows and outflows without requiring continuous observations. Using the weighted wavelet spectral analysis method of Kirchner and Neal [2013] for δ18O in precipitation and stream water, we specifically calculated TTDs that contribute to streamflow via spatially and temporally variable flow paths in a sub-humid mountain headwater catchment in Arizona, USA. Our results indicate that composite TTDs most accurately represented this system for periods up to approximately one month and that a Gamma TTD was most appropriate thereafter. The TTD results also suggested that some contribution of subsurface water was beyond the applicable tracer range. For ETTD and using δ18O as a tracer in precipitation and xylem waters, a Gamma ETTD type best matched the observations, and stable water isotopes were capable tracers for the majority of vegetation source waters. This study contributes to a better understanding of a fundamental question in mountain catchment hydrology; namely, how tracer input fluxes are modulated by spatially and temporally varying subsurface flow paths that support evapotranspiration and streamflow at multiple time scales.

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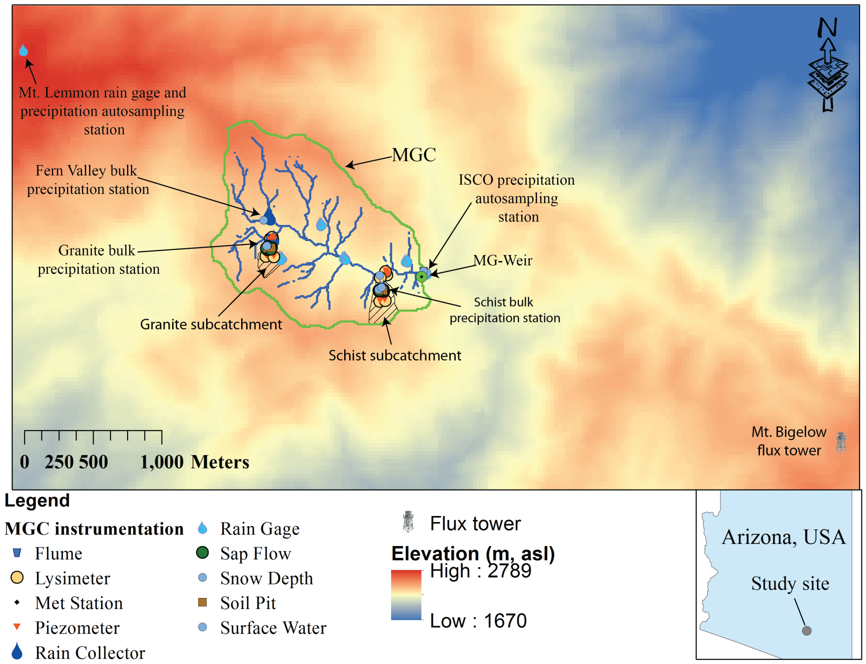
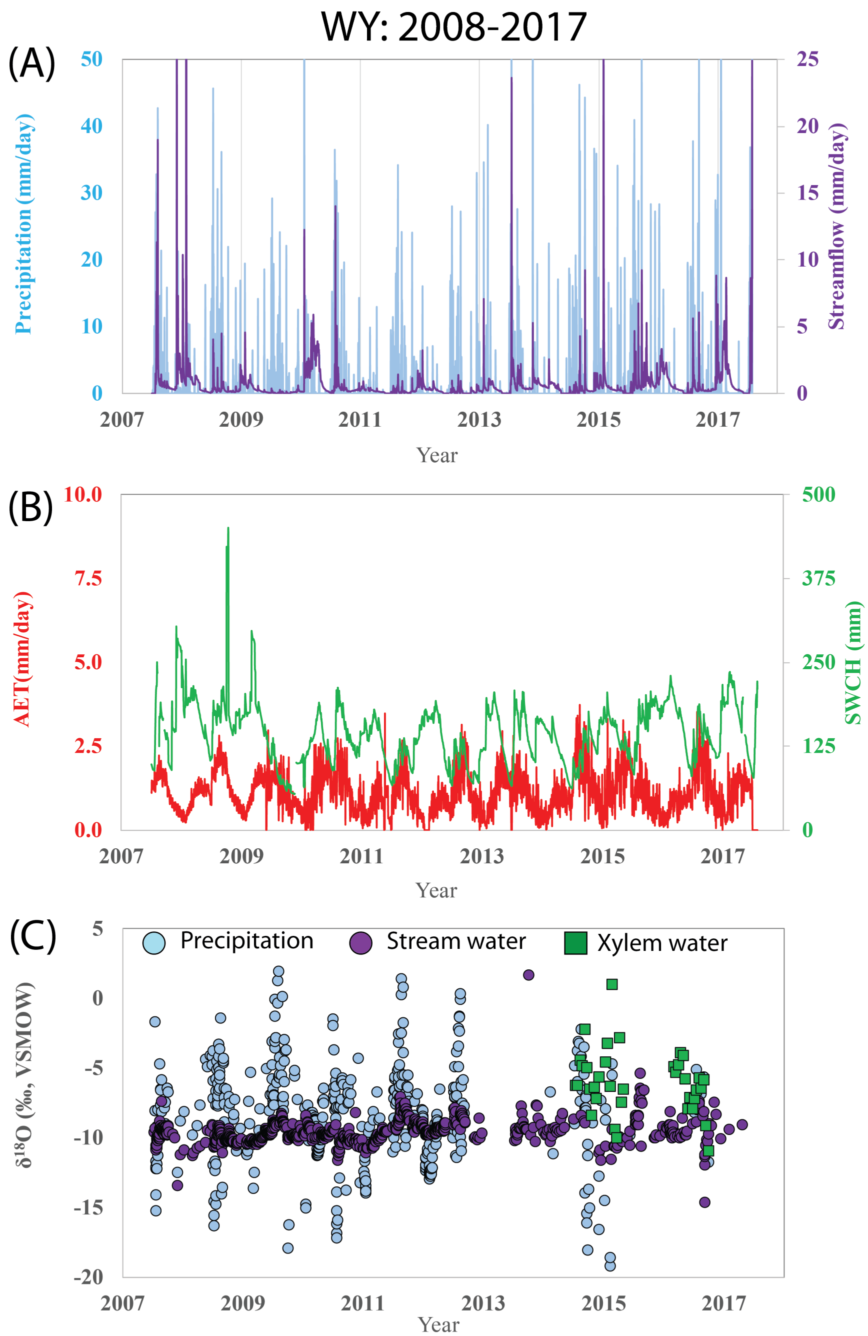
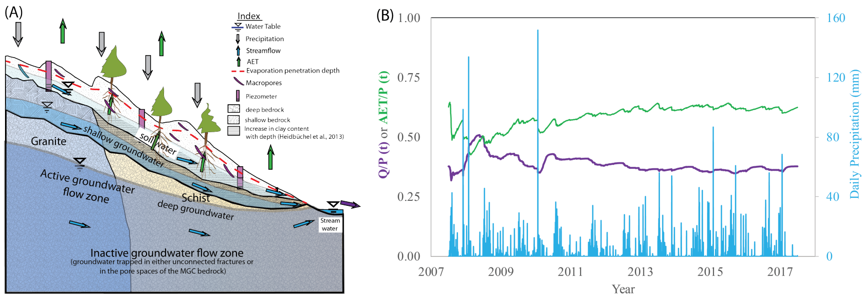
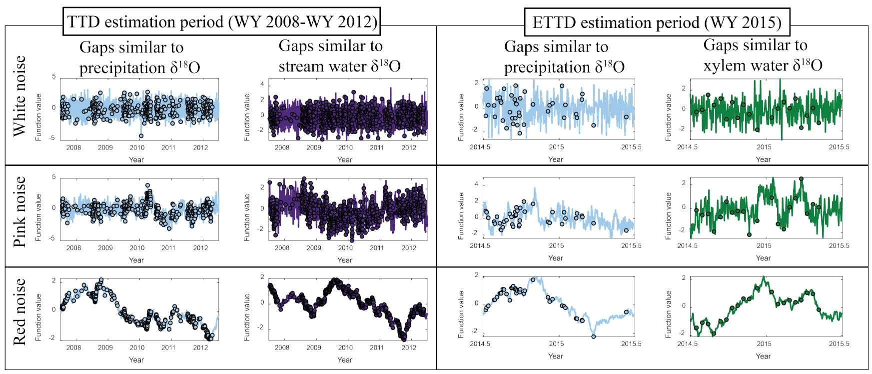
Main_text_F_T_TTD_ETTD_f.pdf available at https://authorea.com/users/371833/articles/490041-an-improved-practical-approach-for-estimating-catchment-scale-response-functions-through-wavelet-analysis


Mt. Lemmon rain gage and precipitation autosampling station
Fern Valley bulk precipitation station
Granite bulk precipitation station
Granite subcatchment
MGC
ISCO precipitation autosampling station
MG-Weir
Schist bulk precipitation station
Schist subcatchment
N
Mt. Bigelow flux tower
0 250 500 1,000 Meters
Legend
MGC instrumentation
Flume
Lysimeter
Met Station
Piezometer
Rain Collector
Rain Gage
Sap Flow
Snow Depth
Soil Pit
Surface Water
Flux tower
Elevation (m, asl)
High : 2789
Low : 1670
Arizona, USA
Study site

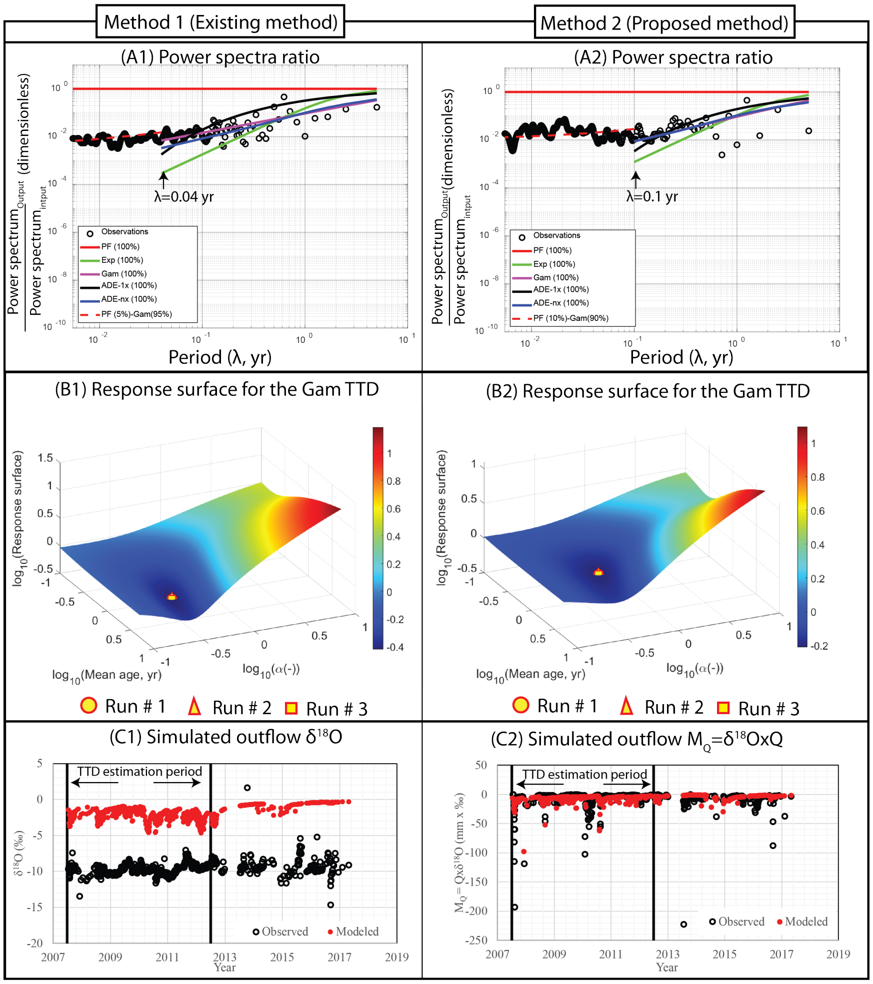

WY: 2008-2017
(A)
Precipitation (mm/day)
Streamflow (mm/day)
Year
(B)
AET(mm/day)
SWCH (mm)
Year
(C)
Precipitation
Stream water
Xylem water
δ18O (‰, VSMOW)
Year



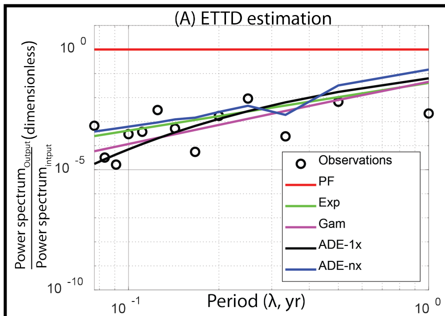
(A)
Index
Water Table
Precipitation
Streamflow
AET
Evaporation penetration depth
Macropores
Piezometer
deep bedrock
shallow bedrock
increase in clay content with depth (Heidbüchel et al., 2013)
Granite
shallow groundwater
soil water
Active groundwater flow zone
Schist
deep groundwater
Stream water
Inactive groundwater flow zone
(groundwater trapped in either unconnected fractures or in the pore spaces of the MGC bedrock)
(B)
Q/P (t) or AET/P (t)
Daily Precipitation (mm)
Year



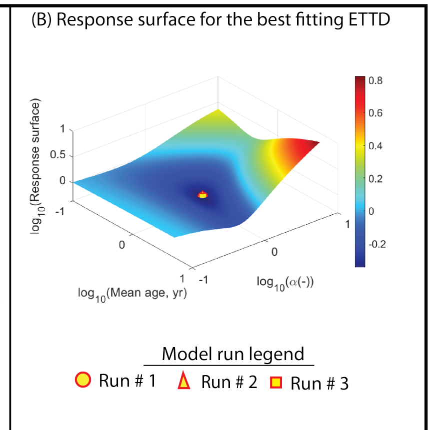
TTD estimation period (WY 2008-WY 2012)
ETTD estimation period (WY 2015)
Gaps similar to precipitation δ18O
Gaps similar to stream water δ18O
Gaps similar to precipitation δ18O
Gaps similar to xylem water δ18O
White noise
Pink noise
Red noise
Function value
Year

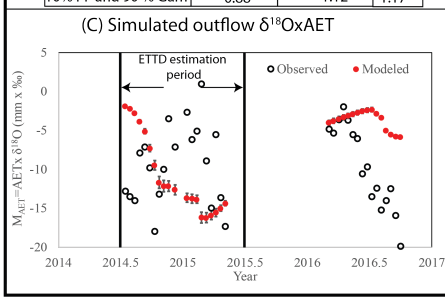


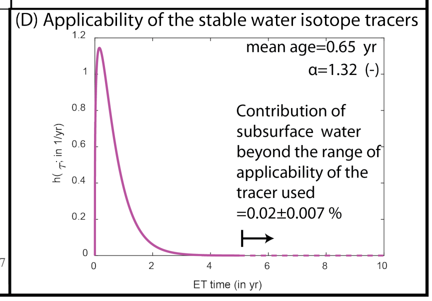
Method 1 (Existing method)
Method 2 (Proposed method)
(A1) Power spectra ratio
(A2) Power spectra ratio
Power spectrum Output / Power spectrum input (dimensionless)
λ=0.04 yr
λ=0.1 yr
Observations
PF (100%)
Exp (100%)
Gam (100%)
ADE-1x (100%)
ADE-nx (100%)
PF (5%)-Gam(95%)
PF (10%)-Gam(90%)
Period (λ, yr)
(B1) Response surface for the Gam TTD
(B2) Response surface for the Gam TTD
log10(Response surface)
log10(Mean age, yr)
log10(α(-))
Run # 1
Run # 2
Run # 3
(C1) Simulated outflow δ18O
(C2) Simulated outflow MQ=δ18OxQ
TTD estimation period
δ18O (‰)
MQ = Qxδ18O (mm x ‰)
Observed
Modeled
Year

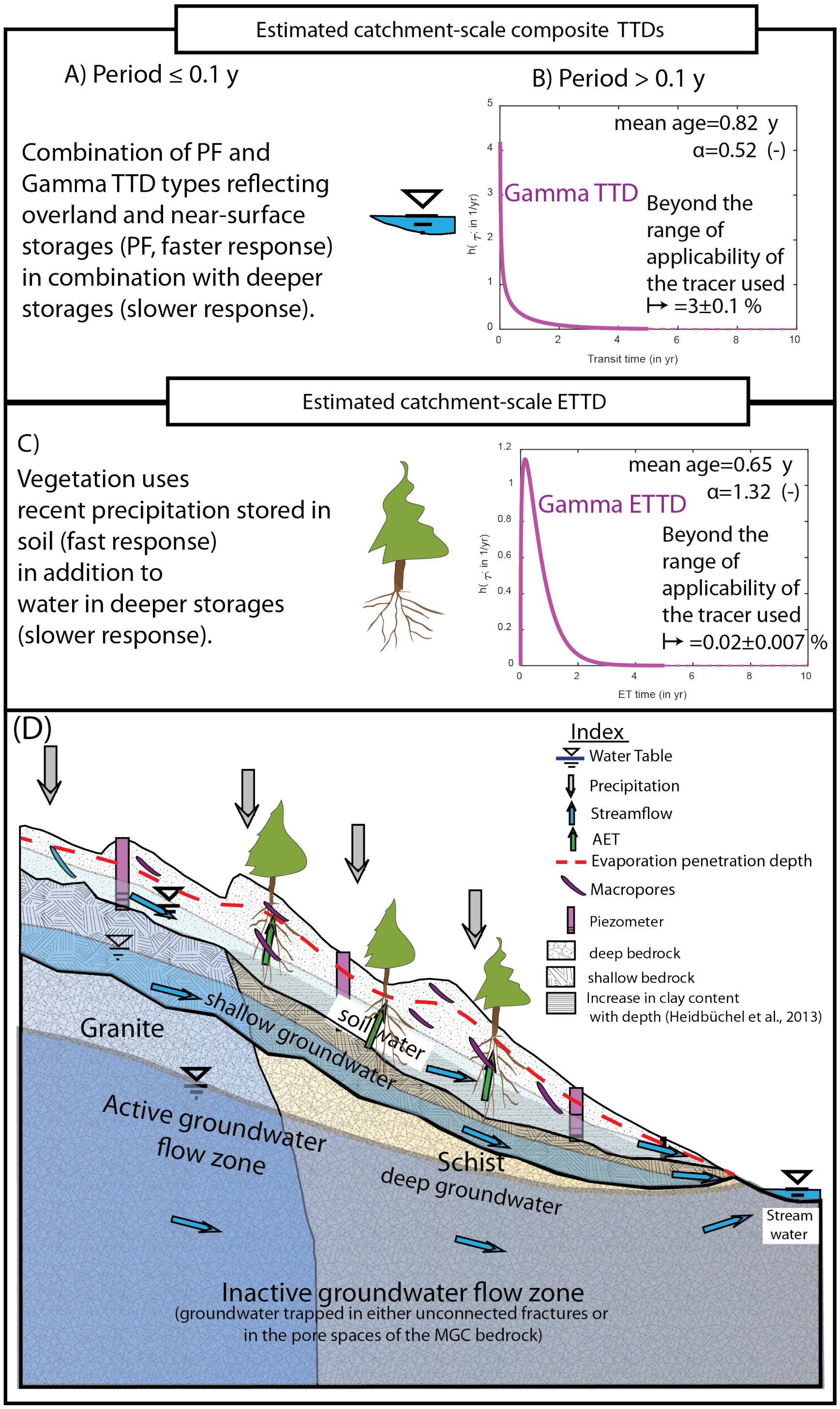


ETTD type	Parameter 1	Parameter 2	KGE'
Exp	0.77	1.00	0.48
Gam	0.65 (±0.05)	1.32 (±0.03)	0.45
ADE-1x	5.00	0.40	0.52
ADE-nx	0.34	100	0.45
10% PF and 90 % Gam	0.88	1.12	1.17









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`Table 1.xlsx` available at https://authorea.com/users/371833/articles/490041-an-improved-practical-approach-for-estimating-catchment-scale-response-functions-through-wavelet-analysis

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Table 2.xlsx available at https://authorea.com/users/371833/articles/490041-an-improved-practical-approach-for-estimating-catchment-scale-response-functions-through-wavelet-analysis