Signatures and time scales of the stable isotope network in the Shale Hills Critical Zone Observatory

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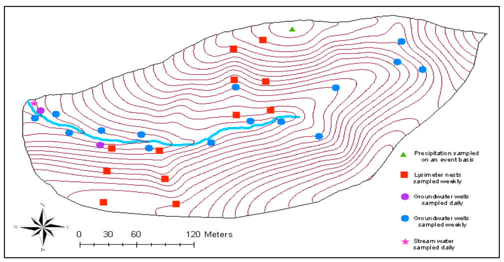
Introduction

The Shale Hills stable isotope network offers the opportunity to research and use stable isotope signatures covering the entire hydrologic cycle. The goal of the research is to identify flow paths and time scales of water from precipitation input to the watershed through stream flow output. Singular Spectrum Analysis is used to determine dominant "modes" and processes affecting the stable isotope dynamics of the system. Ultimately the stable isotope network, real time hydrologic network, real time soil moisture network, real time groundwater network and sap flow network will be used to quantitatively estimate the mean age of the water in the watershed.

Field Site

The Shale Hills Watershed Unit was established in 1961 in the Valley and Ridge province of Central Pennsylvania. The watershed, shown below, is 19 acres in size, with an average relief of 100'. Rose Hill shale underlies the entire study area. Soils on the watershed average 56" in depth, ranging from 18" to 24" on the upper slopes and ridge tops to over 100" in portions of the valley floor. The soils are primarily silt loams and shaley silt loams, and soil moisture storage at field capacity is 14.1". The oak-hickory cover type dominates the watershed while an oak-hemlock community exists in the moist valley floor areas.



Sampling Plan

- •Precipitation sampled on an event basis using an Eigenbrodt NSA 181/S
  - •Collects when it senses precipitation
  - •Contains two sets of four bottles each
    - •First bottle collects for 30 minutes
    - •Bottles two through four collect for six hours each
- •Soil water sampled weekly using four transects of suction cup lysimeter nests
  - •Two transect's each on the north and south slope
    - •One transect on the planar hill slope, and one on a swale
    - •Nest's at valley floor, mid-slope, and ridge top
    - •Nest's have lysimeters spaced 10-20 cm apart from the ground surface to "bedrock"
- •Groundwater sampled weekly at 13 wells, and daily at two wells using ISCO automatic samplers
  - •13 weekly wells range from nine to 15 feet deep
    - •Screened four feet into "bedrock"
  - •Two daily wells are 10 feet and nine feet deep
    - •Unscreened; water is pumped from the base of each well
- •Stream water sampled daily at the outlet using an ISCO automatic sampler
- •Vegetation sampled synoptically across the watershed


Eigenbrodt NSA 181/S


Suction cup lysimeters

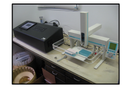

Groundwater well


Streamwater ISCO

Isotopes

DLT-100 Liquid-Water Stable Isotope Analyzer

- •Laser-absorption spectroscopy
  - •Off-Axis Integrated Cavity Output Spectroscopy (Off-Axis ICOS)
  - •Creates path lengths of 2.5km in a 25cm cell
- •Measures absolute abundances of ^{18}O and ^{2}H
- •Reproducibility of 0.1‰ for ^{18}O and 0.5‰ for ^{2}H
- •Able to run approximately 30 samples per day
  - •One mL per sample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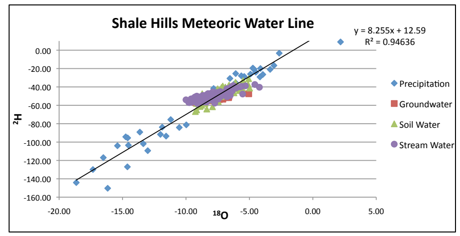


- •Shale Hills local meteoric water line comparable to local meteoric water lines from Northeastern United States
- •Stream water, groundwater, and soil water areclosely related
  - •The three reservoirs depart slightly from the meteoric line indicating evaporation, and possibly effects due to snow
- •Samples collected from 03/28/2008 – 10/22/2008

Age Model

An age model is being produced by Duffy (in review) to determine the continuous mean age of the water in the watershed. The premise behind the model is that it is possible to analyze moments of the concentration distribution function, in accordance with Delhez et al (1999). The stable isotope signatures will be used as inputs to the model along with some hydrologic variables. The stable, nonlinear, fully coupled system of equations is:

$$dV/dt = Q_i - Q$$

$$dC/dt = Q_i/V(C_i - C) + \Gamma_C$$

$$D\alpha/dt = C - \alpha \bullet Q_i/V + \Gamma_\alpha$$

$$A(t) = \alpha(t)/C(t)$$

where Q_i and Q are inflow and outflow; C is the zeroth moment of the concentration distribution function; Γ is sources and sinks; α is the age concentration; and A is the mean age.

References

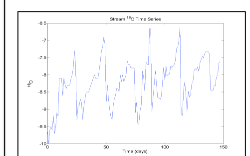
Delhez, Eric J.M., Campin, Jean-Michel, Hirst, Anthony C., Deleersnijder, Eric. "Toward a general theory of the age in ocean modelling." Ocean Modelling 1 (1999): 17-27.

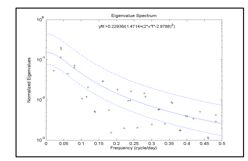
Vautard, Robert, Yiou, Pascal, Ghil, Michael. "Singular-spectrum analysis: A toolkit for short, noisy chaotic signals." Physica D 58 (1992): 95-126.

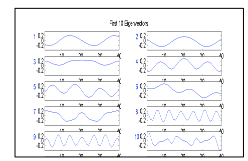
Singular Spectrum Analysis

Singular spectrum analysis was carried out on a daily stream water ^{18}O time series, collected from 03/28/2008 – 08/22/2008. A Matlab code written by Eric Breitenberger, and modified by Tongying Shun and Kris Sedmera, following the paper by Vautard, Yiou, and Ghil (1992), was used to carry out the analysis.

Singular spectrum analysis embeds a regularly sampled time series, then determines spectral data by diagonalizing the lag-covariance matrix that is Toeplitz in structure. Eigenvalues represent the amount of variance accounted for in the time series by the accompanying eigenvector, which represent an oscillation in the time series. If a pair of eigenvalues account for the same amount of variance and are at the same frequency, and the eigenvectors are in phase quadrature, then they represent a significant oscillation of the time series. From the eigenvalues and eigenvectors it is possible to calculate principal components and to reconstruct the time series. The difference between singular spectrum analysis and other spectral techniques is that eigenvectors are data adaptive, instead of being fixed as sines and cosines.







The original time series for stream ^{18}O shows variability, but singular spectrum analysis was unable to discern a significant oscillation. A window length of 40 was used for this analysis. All eigenvectors that account for a significant amount of variance in the time series fall within the red noise filter. Eigenvectors one and two have a 23 day period, which can be roughly discerned in the original record, but they do not explain the same amount of variance, and the eigenvectors are not in phase quadrature. It is likely that the time series was too short to be able to discern any significant oscillations.

Conclusion

The Shale Hills Stable Isotope Network samples the entire hydrologic cycle, making it possible to study and visualize otherwise closed-off reservoirs. From the meteoric water line it is obvious that precipitation is somehow filtered before it becomes soil water, groundwater, and stream water. An evaporative signal is recognized in the soil water, groundwater, and stream water, and it is very likely that vegetation is also affecting these reservoirs. Unfortunately no time series is long enough yet to be able to discern any significant oscillations using singular spectrum analysis. It is apparent though that there is variability in the stream ^{18}O time series, and it therefore should be possible to determine oscillations in that series.