Profile "smearing" in long residence time rivers

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Introduction

H.T. Odom (1957) was the first to recognize that the spring-fed rivers of North Florida make excellent model analogs because they exhibit large diel variation in metabolism while their boundary concentration remains temporally stable.

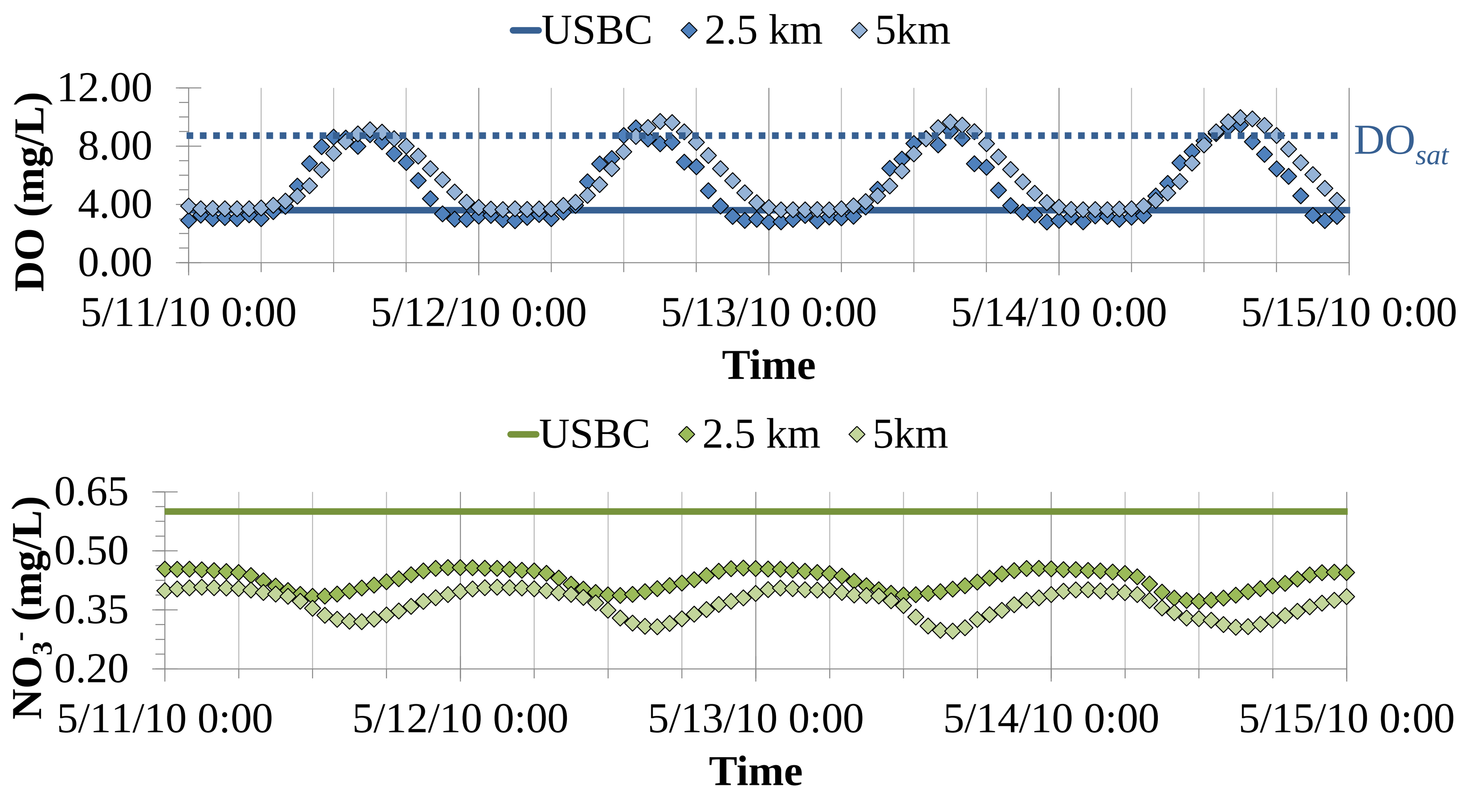

Figure 1. Diel DO and NO_3^- profiles from Ichetucknee River.

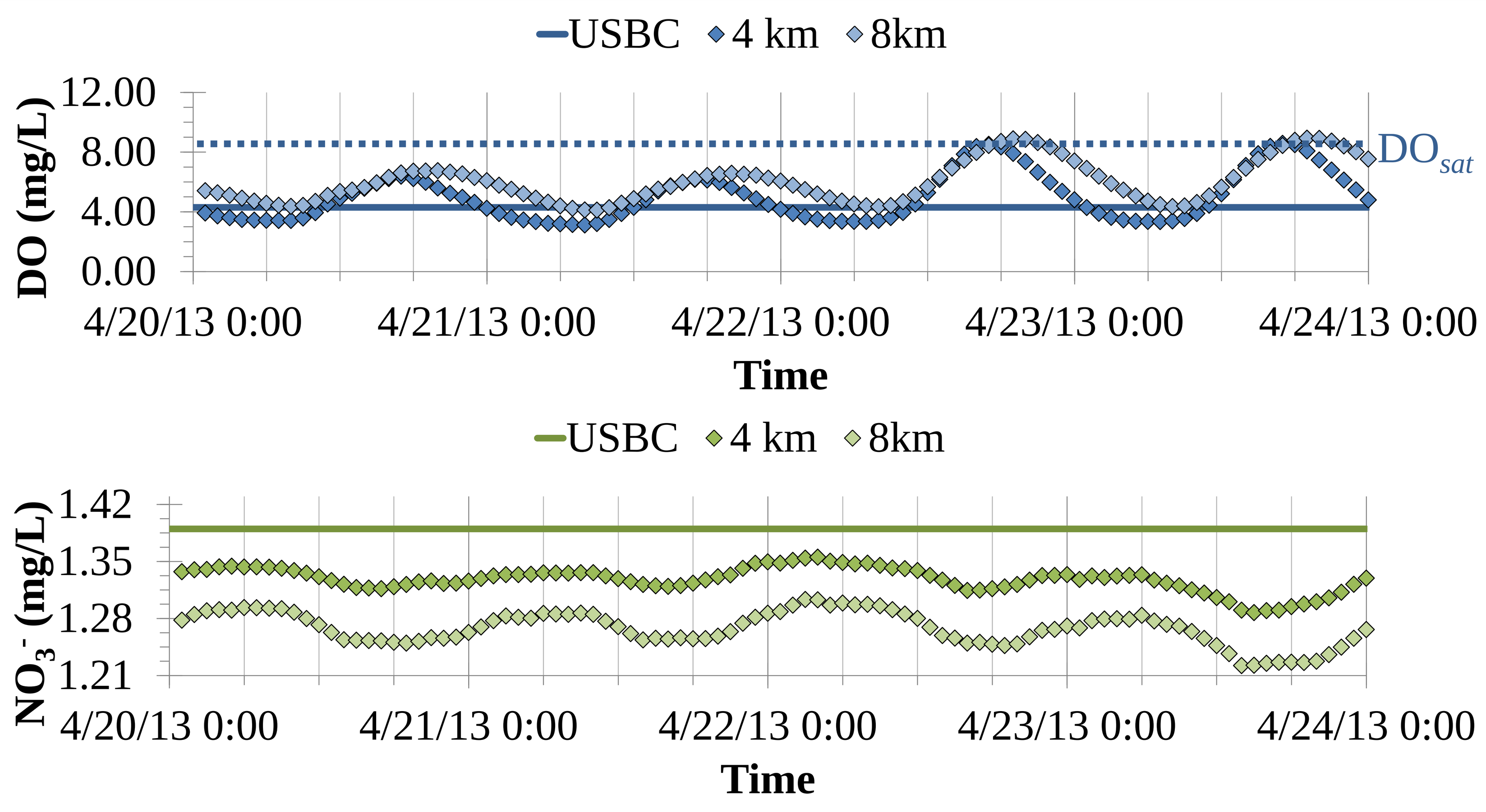

Figure 2. Diel DO and NO_3^- profiles from Silver River.

Some interesting observations

- Increased mean residence time (due to greater travel time) delays the timing of the signals. For example, note the peaks in DO occur after solar noon (and in 8 km Silver River profile after the sun has set).
- Increased distribution of residence times (due to dispersion and transient storage) causes a "smearing" of older and younger water along the flowpath, attenuating the magnitude of diel variability.
- Re-aeration along the flowpath further decreases the magnitude of diel variability in the DO signal by gradually "erasing" upstream effects.

What signals might we expect in longer rivers?

- Unfortunately even the longest spring-fed rivers are only on the order of 10 km long with residence times on the order of half a day. Thus predicting the sort of signals we might observe in longer residence time rivers requires projection using a reactive transport model.

Methods

Modeling was performed using a one-dimensional reactive transport model based off the advection, dispersion and transient storage equations (Bencala and Walters 1983). Reactive terms were added to both the channel and storage zone (Runkle 2007).

$$\frac{\partial C}{\partial t} = -\frac{Q}{A}\frac{\partial C}{\partial x} + D\frac{\partial^2 C}{\partial x^2} + \alpha(C_s - C) - k_C C^{n_C}$$

$$\frac{\partial C_s}{\partial t} = \alpha\frac{A_S}{A}(C - C_s) - k_S C^{n_S}$$

Simplification of the model required making certain assumptions

- Channel processes were driven by assimilation and zero-order. Therefore k_C was a function of insolation (modeled as a half sine wave) and $n_C = 0$.
- Storage zone processes were heterotrophic, first-order and time invariant. Therefore k_S was constant and $n_S = 1$.
- Re-aeration (DO model only) was a product of the saturation deficit and the re-aeration rate constant k. k was modeled as a function of stream velocity using an empirical formula derived for spring-fed rivers (Knight 1980).

$$k = 0.0604u + 0.0929$$

The model was calibrated using data from the Silver River. We performed a pulse release of Rhodamine WT and positioned fluorometers to record the breakthrough curve at the 4 km and 8 km station.

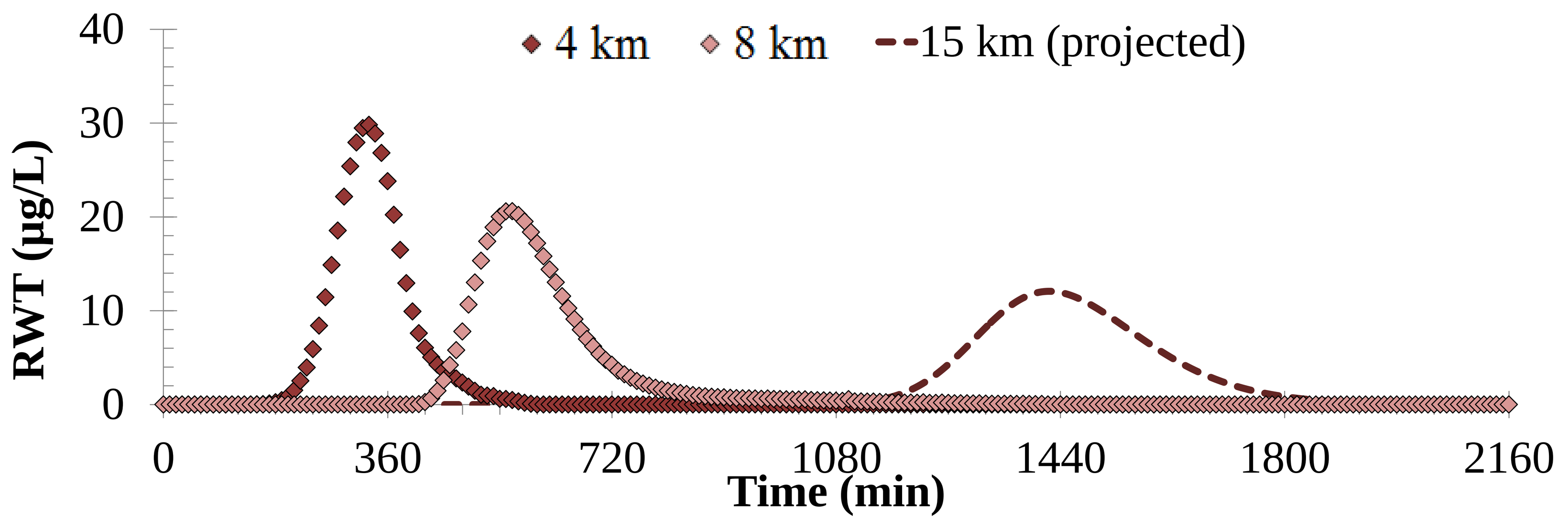

Figure 3. RWT Breakthrough curves for Silver River

Because RWT is a conservative tracer we could set the reactive parameters equal to zero and fit the model to the breakthrough curve to estimate the hydraulic parameters (A, A_S, and α). The reactive parameters were then fit using the observed DO and NO_3^- signals.

Results

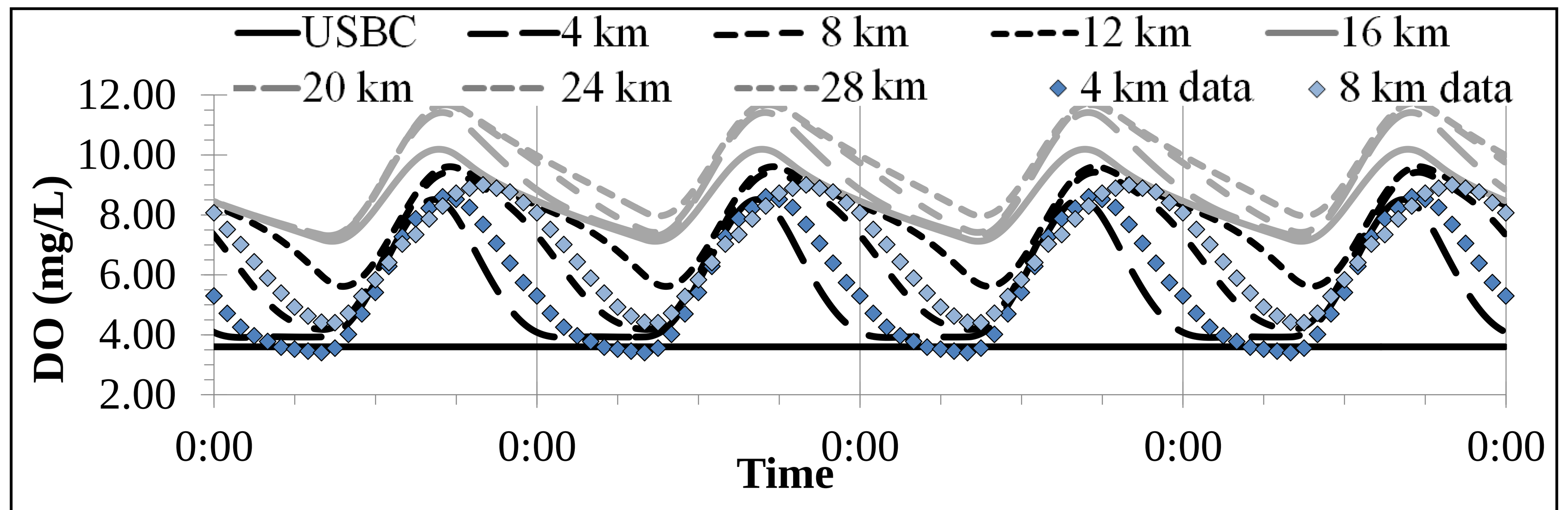

Figure 4. Results of DO Simulation

The DO model does only a fair job of fitting observed profiles, particularly in regards to timing of peaks. We note several potential reasons

- Incorrect re-aeration. Changing re-aeration could shift the timing of the peaks (Chapra et al. 1991). However this would also require changing GPP to maintain correct amplitude of the signal.
- Assuming that respiration is constant over 24 hours. Respiration may be temporally variable in response to labile C availability (Heffernan and Cohen 2010).

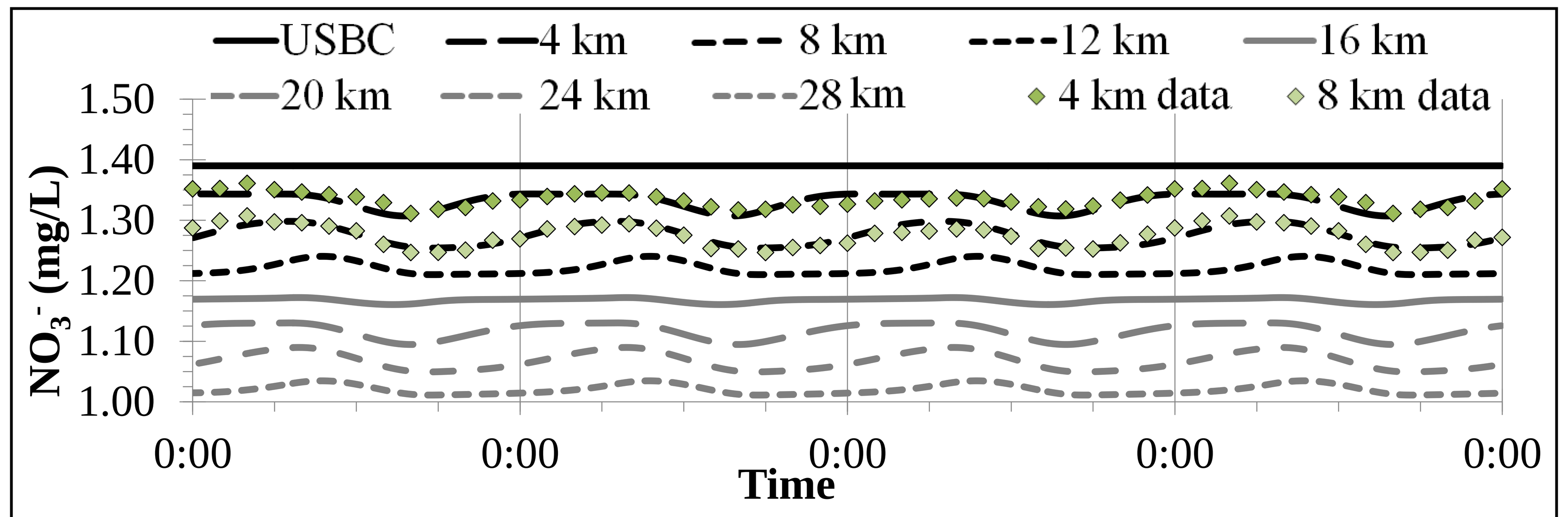

Figure 5. Results of NO3- Simulation

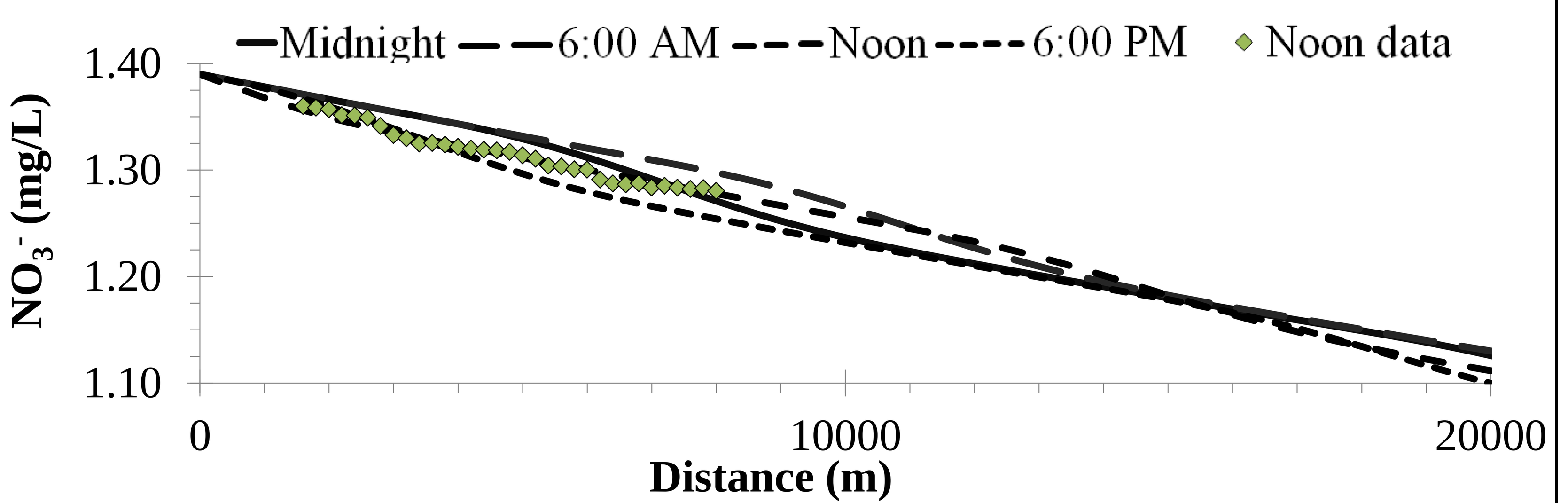

Figure 4. Simulated NO_3^- Longitudinal Profile

The NO_3^- model on the other hand dose a better job of fitting observed profiles, leading us to conclude the shortcomings of the DO model are not being driven by hydraulics. We also note several interesting features

- Diel variability initially increases with downstream distance but then begins to decline until the signal matches the USBC at approximately 15 km.
- We observe a similar trend in the longitudinal profile (Fig 4).
- Note 15 km is the distance with mean residence time of 24 hrs (Fig 3).
- Thus all water parcels have been acted on by exactly one full daily cycle; though the order of processes varies, the net effect is approximately equal.
- Using the two-station method, sensors placed 15 km apart would show offset but identical signals, leading one to incorrectly assume that removal is time invariant (all dissimilatory).