A Comparison Of Three Solute Transport Models Using Mountain Stream Tracer Experiments

J. R. Manson,
Stockton University,
New Jersey, USA

B. O. L. Demars,
James Hutton Institute,
Aberdeen, UK

G. M. GÃslason,
University of Iceland,
Reykjavik, Iceland

N. Friberg,
Norwegian Institute for
Water Research,
Oslo, Norway

S. G. Wallis
Heriot-Watt University,
Edinburgh, UK

J. D. Mick,
General Dynamics
Information Technology,
New Jersey, USA

J. S. Ã“lafsson
Inst. of Freshwater Fisheries,
Reykjavik, Iceland

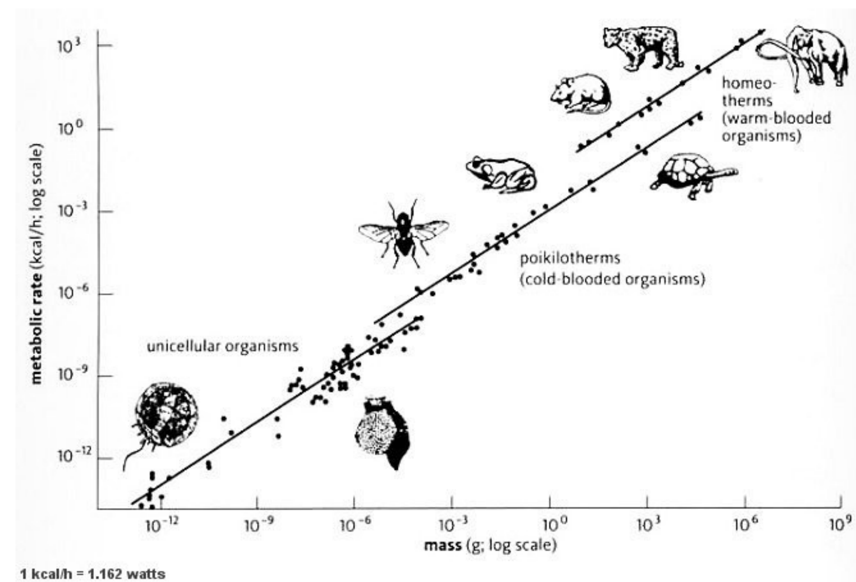
Background: stream metabolism

Is there a fundamental theoretical relationship governing the activity of biological systems?

Metabolic Ecological Theory (MTE) is a proposed extension of Keilber's Law but as yet has not been verified (observed) in complex biological systems.

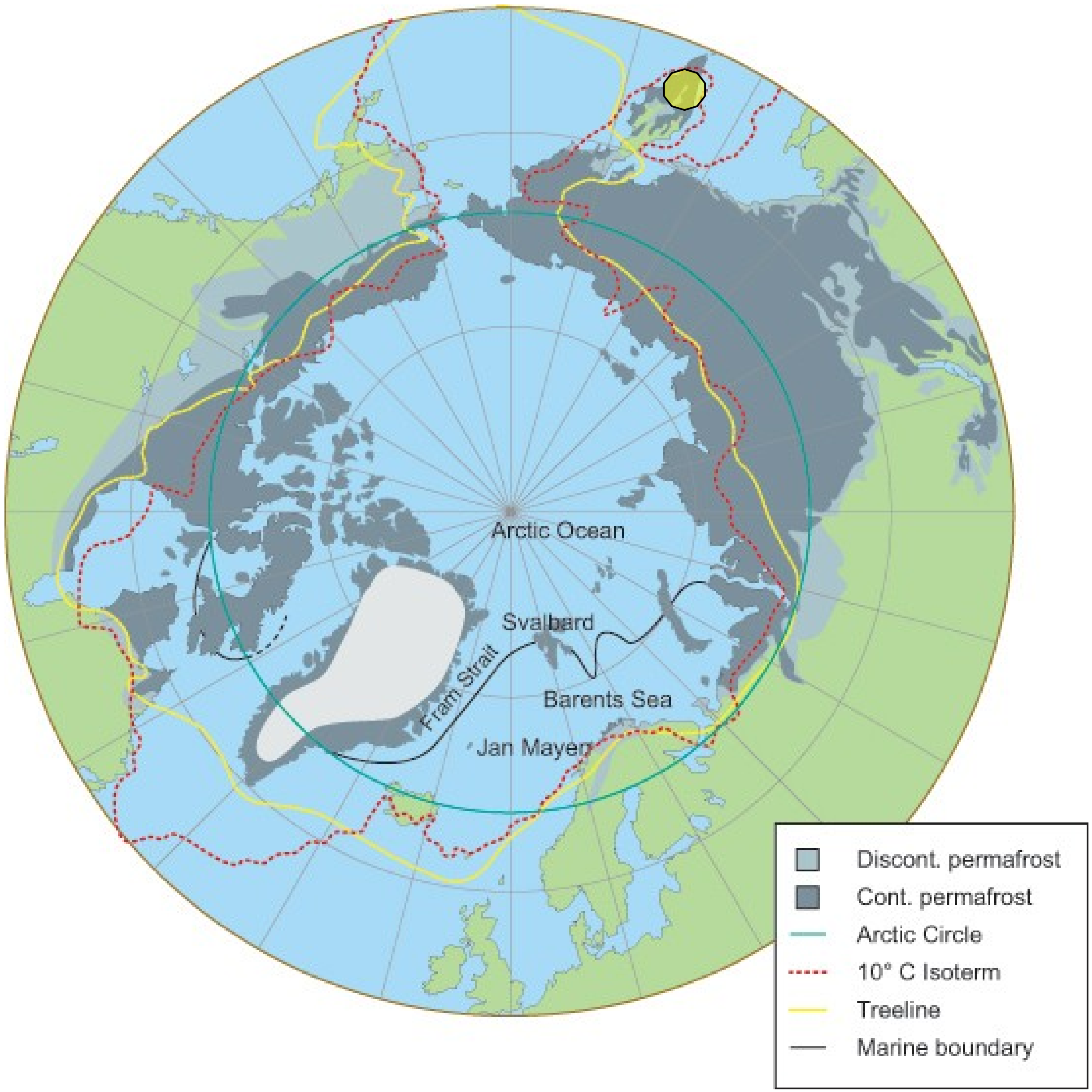
Key to verifying it would be in showing a relationship between the metabolic rate of a biological organism and temperature.

In situ this is very difficult to achieve because how can you say that all other things are held constant while temperature is varied.

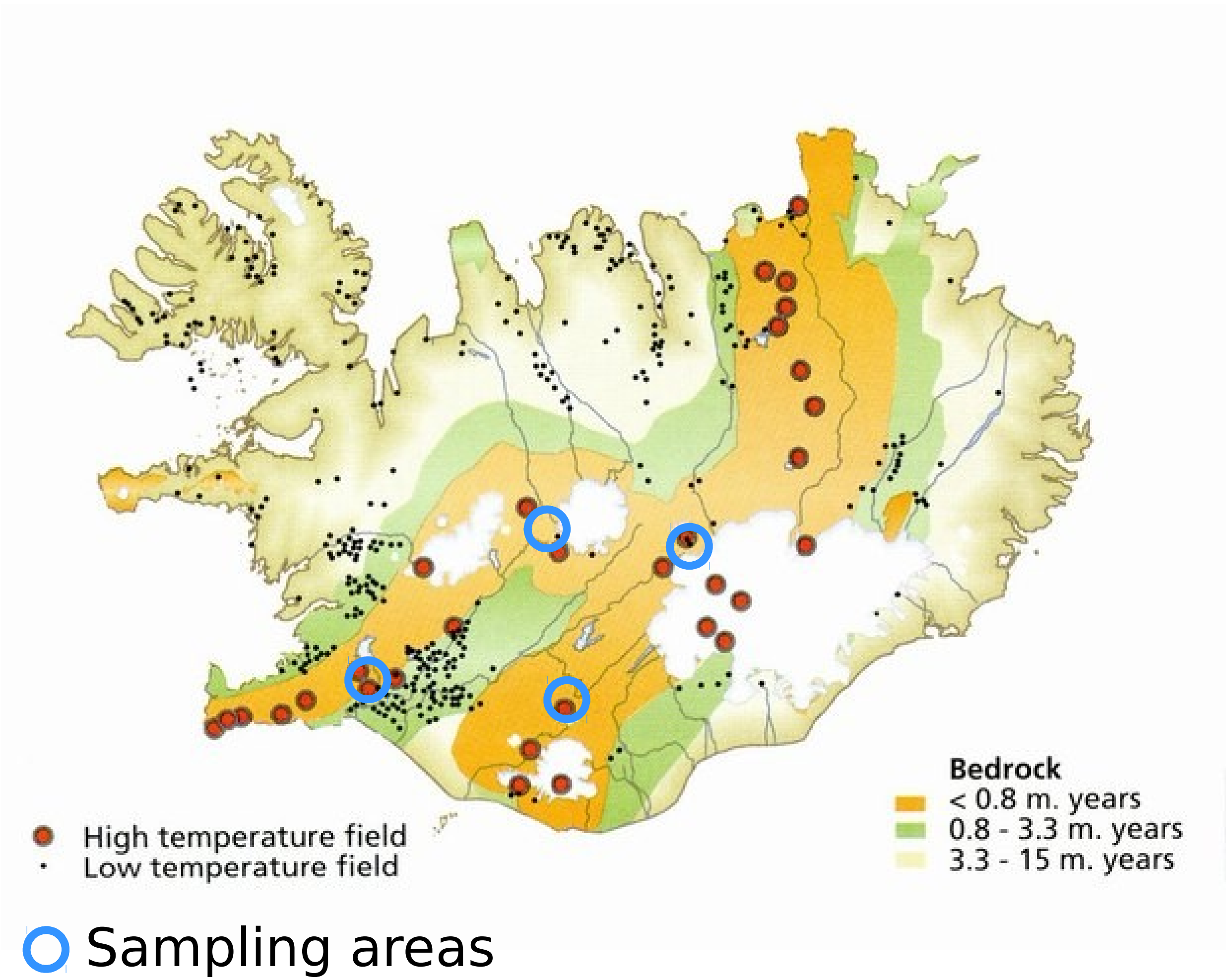


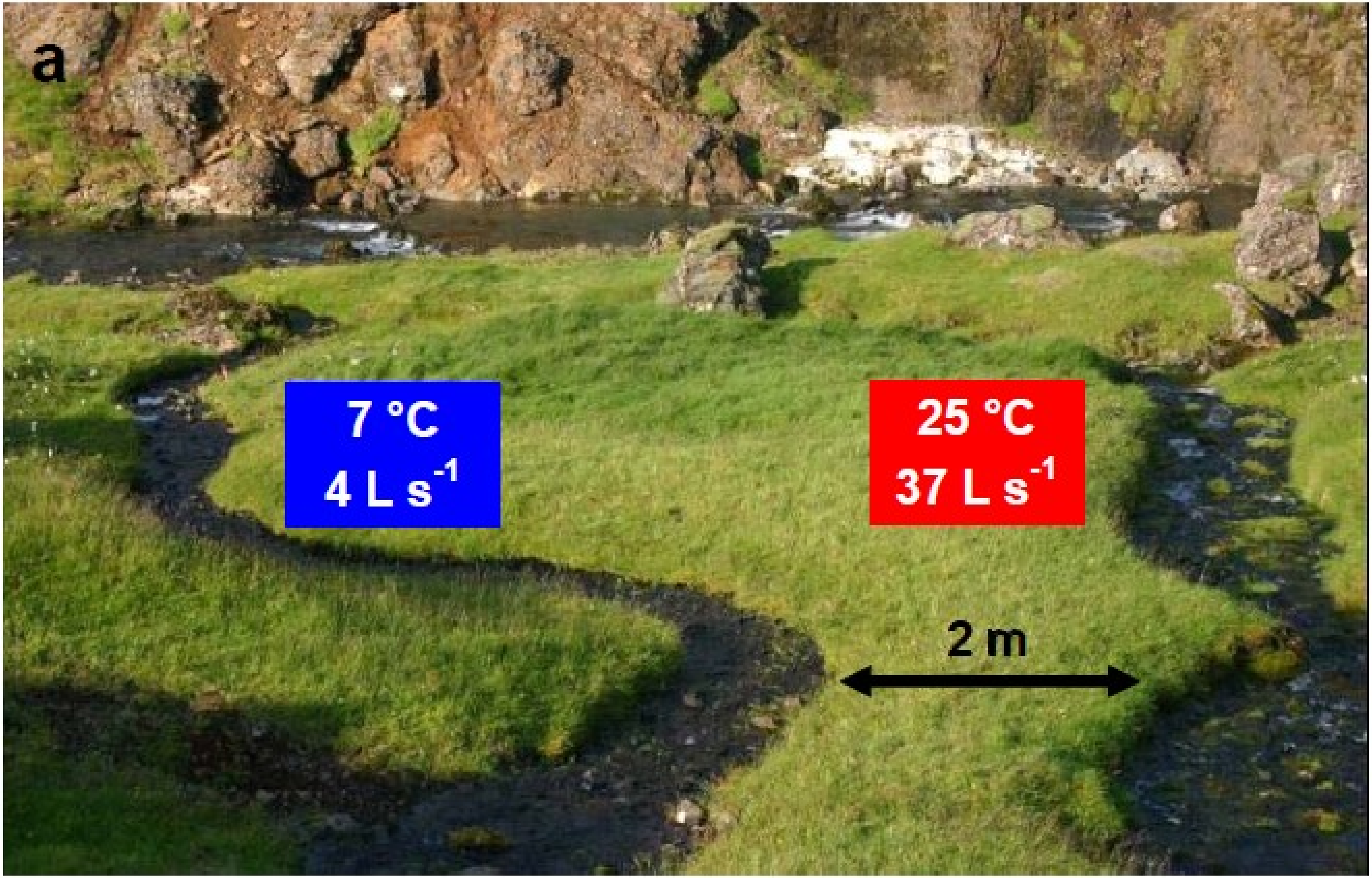
$$B = B_0 M^b e^{\frac{-E_a}{kT}}$$

Fieldwork in geothermal fields: Iceland & Kamchatka



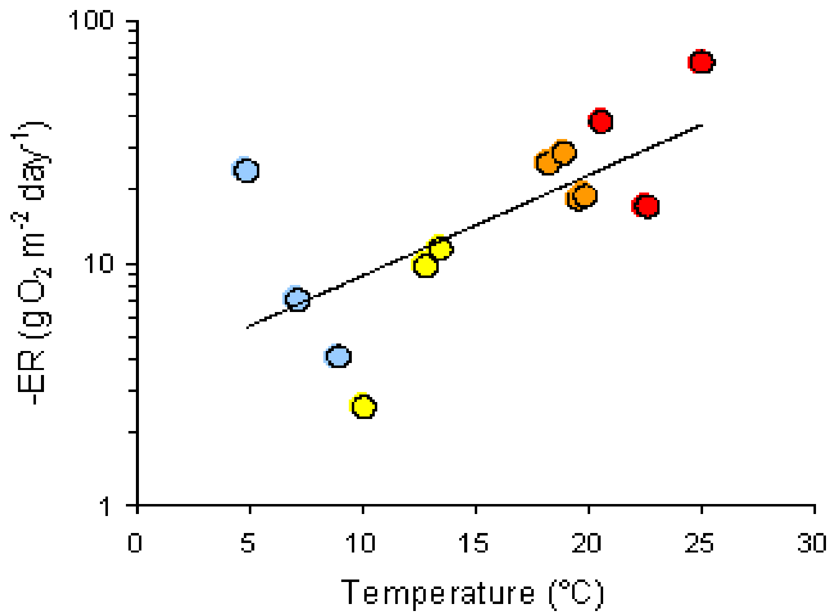
Iceland geothermal fields




a
7 °C
4 L s-1
25 °C
37 L s-1
2 m

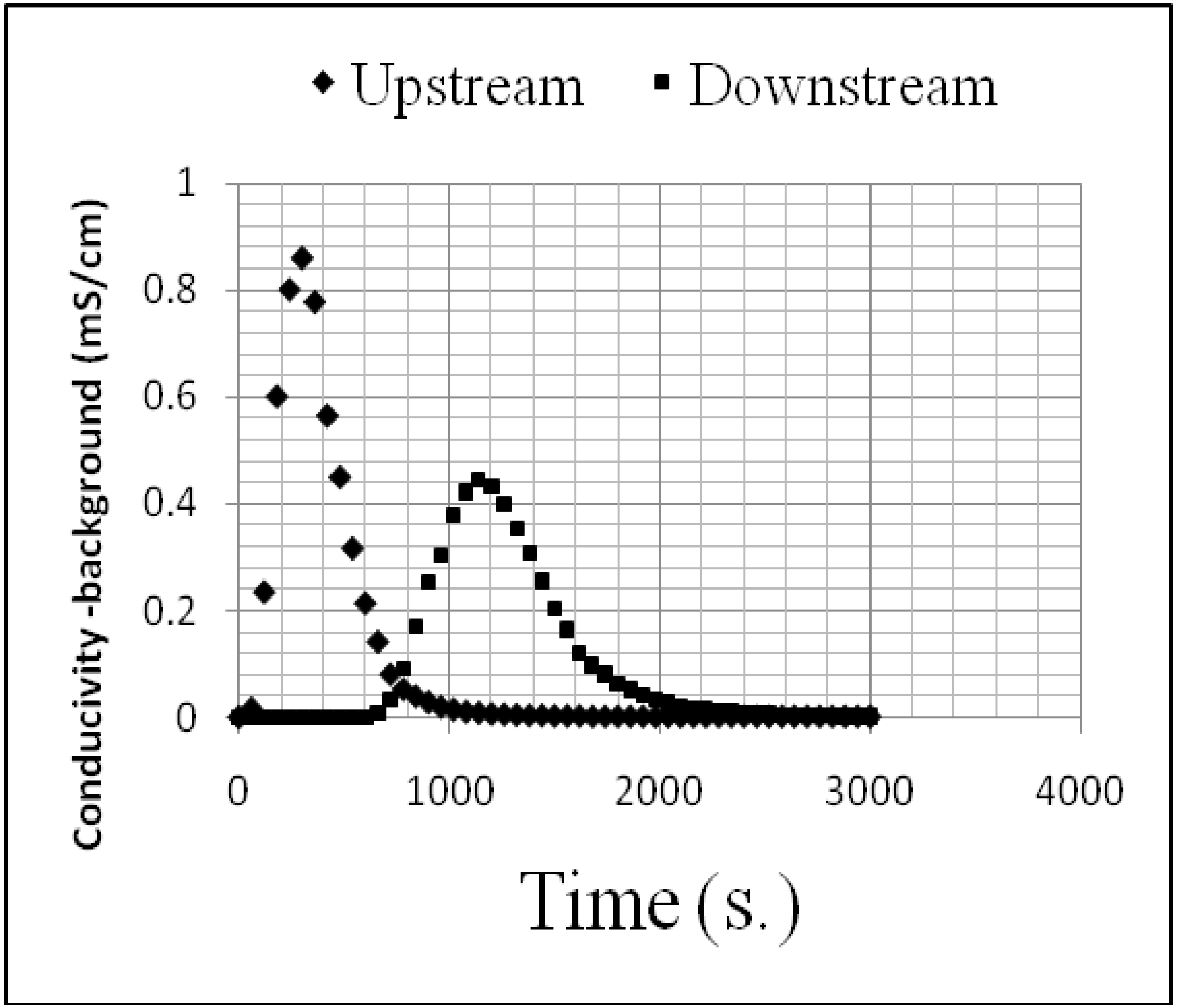
Background: stream metabolism

Metabolism



$r^2 = 0.45$

Available stream tracer data



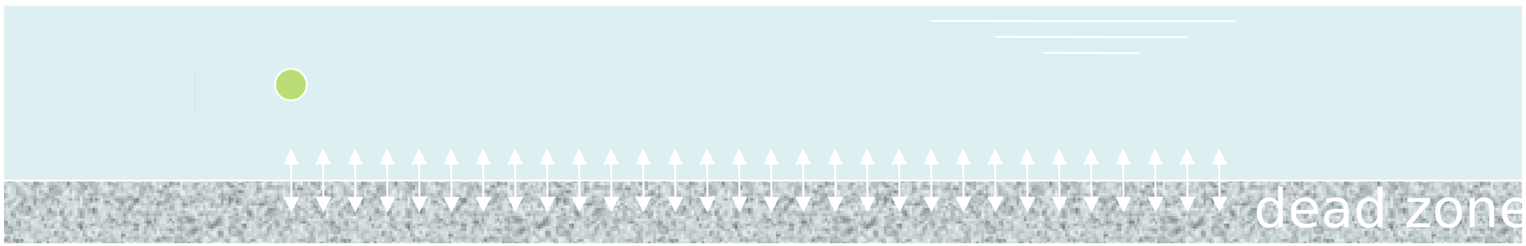
Salt tracer data sets

These were used for quantifying flow rates.

However we were able to use these for a more detailed analysis to determine stream hydraulics (transient storage volume).

“Study within a study”

Quantifying transient storage: tracer studies

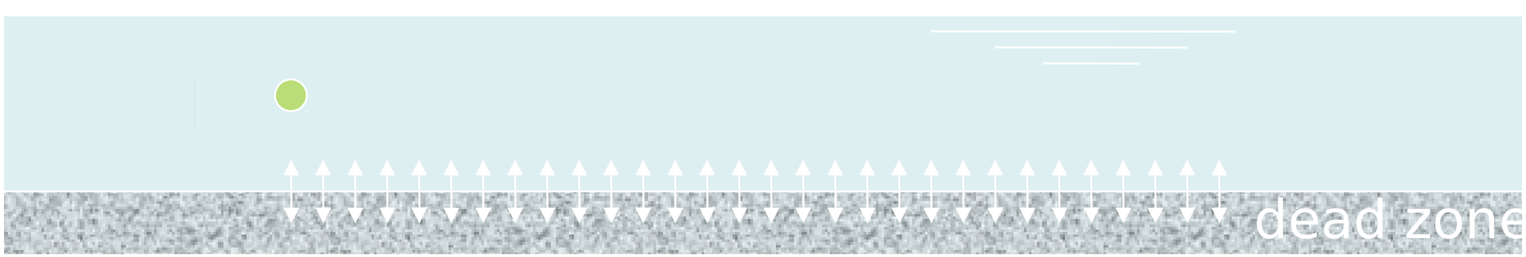


Chosen model:

Advection-dispersion with **T**ransient **S**torage **M**odel (TSM)

$$\frac{\partial c(x,t)}{\partial t} + U_{TS}\frac{\partial c(x,t)}{\partial x} = D_{TS}\frac{\partial^2 c(x,t)}{\partial x^2} + k_1\big(s(x,t) - c(x,t)\big)$$

$$\frac{\partial s(x,t)}{\partial t} = -k_2\big(s(x,t) - c(x,t)\big)$$



Quantifying transient storage: tracer studies

In much previous work the so-called Transient Storage Model (e.g. Bencala and Walters, 1983) has been fitted to tracer data in order to evaluate the parameters that quantify the transient storage process.

Although good fits to the data are often achieved, questions have been raised over how well the parameters can be identified .

Here we are motivated by the possibility of obtaining the parameters from correlations with the parameters of alternative models.

Hence we saught to explore relationships between the parameters of the Transient Storage Model, and other simpler models: the Advection Dispersion Model and the Aggregated Dead Zone Model

Simpler model 1:
Advection-**D**ispersion **M**odel (ADM)

$$\frac{\partial c(x,t)}{\partial t} + U_{AD}\frac{\partial c(x,t)}{\partial x} = D_{AD}\frac{\partial^2 c(x,t)}{\partial x^2}$$

Completely ignore transfer of mass into transient storage zone. Mass is transferred longitudinally by flow velocity and bi-directionally by differential velocity (dispersion).

Simpler model 2: **A**ggregated **D**ead **Z**one **M**odel (ADZM)

$$\frac{\partial y(t)}{\partial t} = \frac{1}{V}\left[Q_u u(t-\tau) - Q_y y(t)\right]$$

In this model all transient storage is agregated into a “dead zone” characterised by a storage volume. All advection is characterised by a simple time delay in the concentration time profile.

Model fits

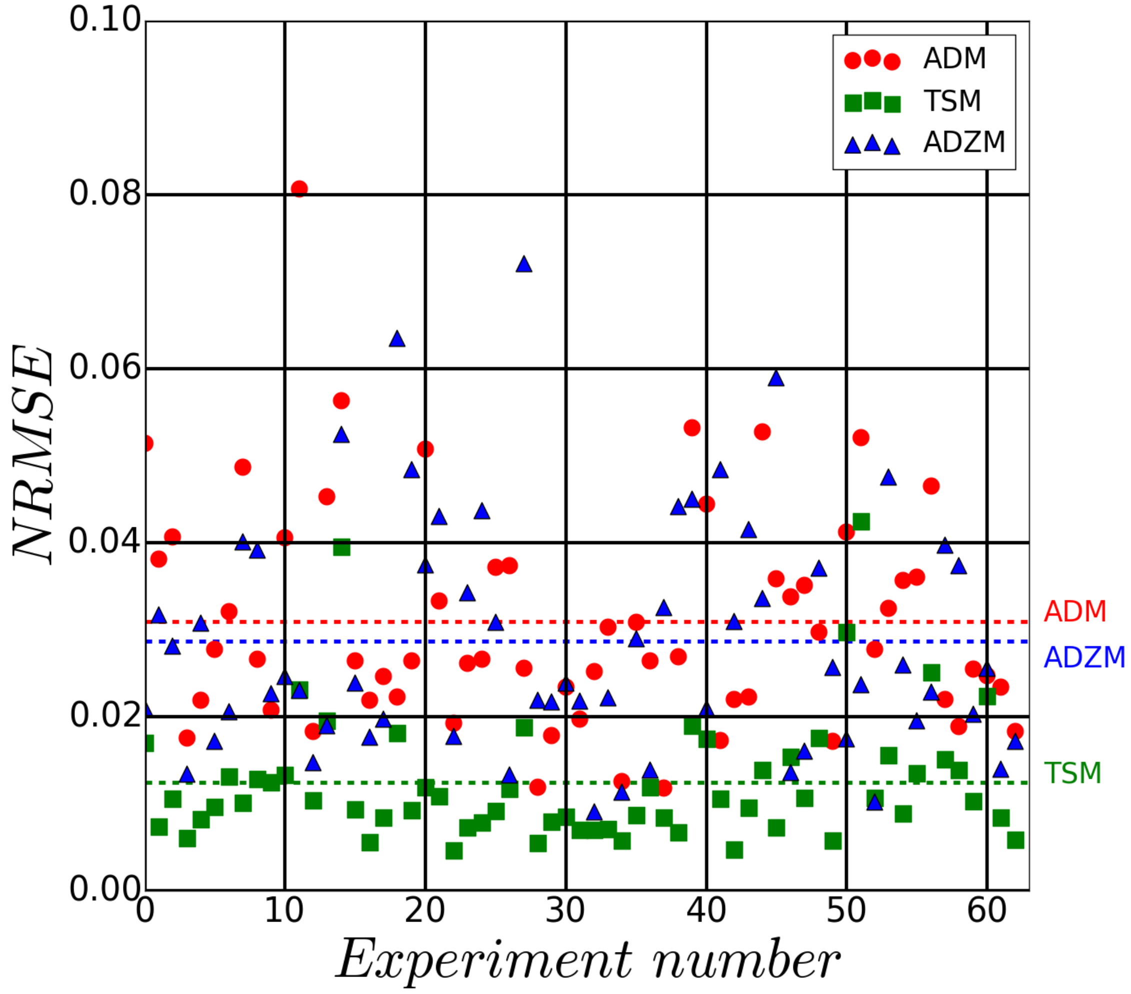
- Normalised residual mean square error

$$NRMSE = \frac{1}{\max(C_{OBS})}\left(\frac{SSR}{N}\right)^{0.5}$$

Akaike information criterion (AIC) is a measure of the relative quality of a statistical model for a given set of data.

$$AIC = 2k + N\ln\left(\frac{SSR}{N}\right)$$

So which model fits best?

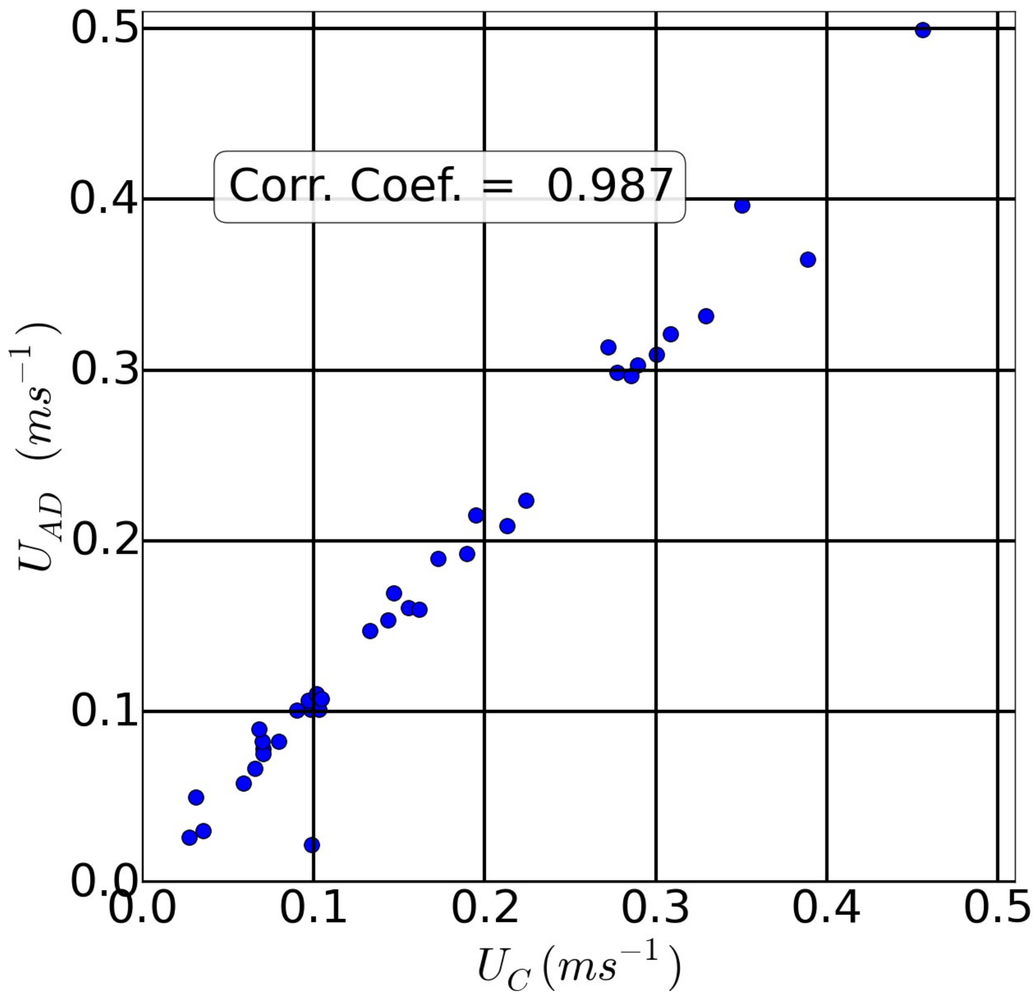


How are model parameters related to bulk transport features (i.e. centroid movement)?

Bulk transport features come from temporal moments of the concentration profiles

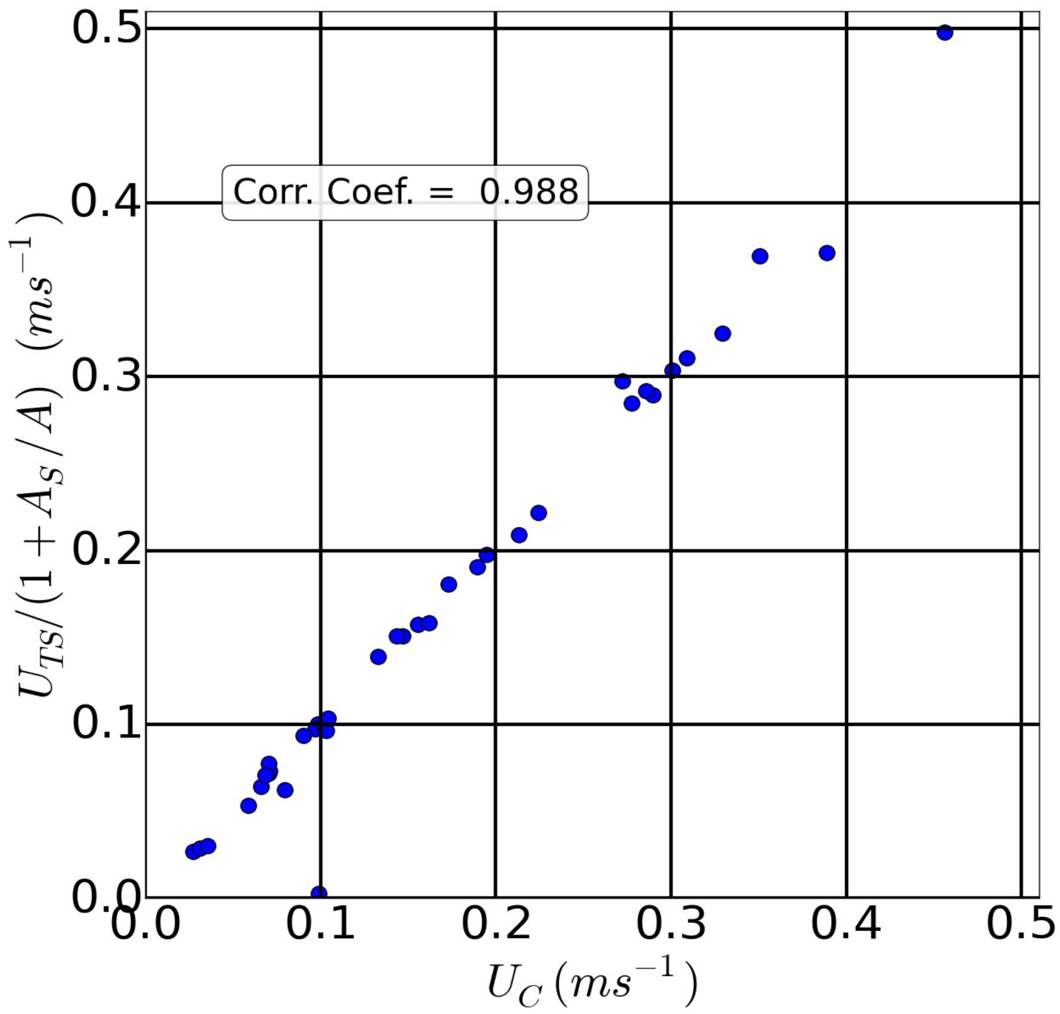
If model fits are robust we would expect certain things.

ADM:
ADM velocity & centroid velocity



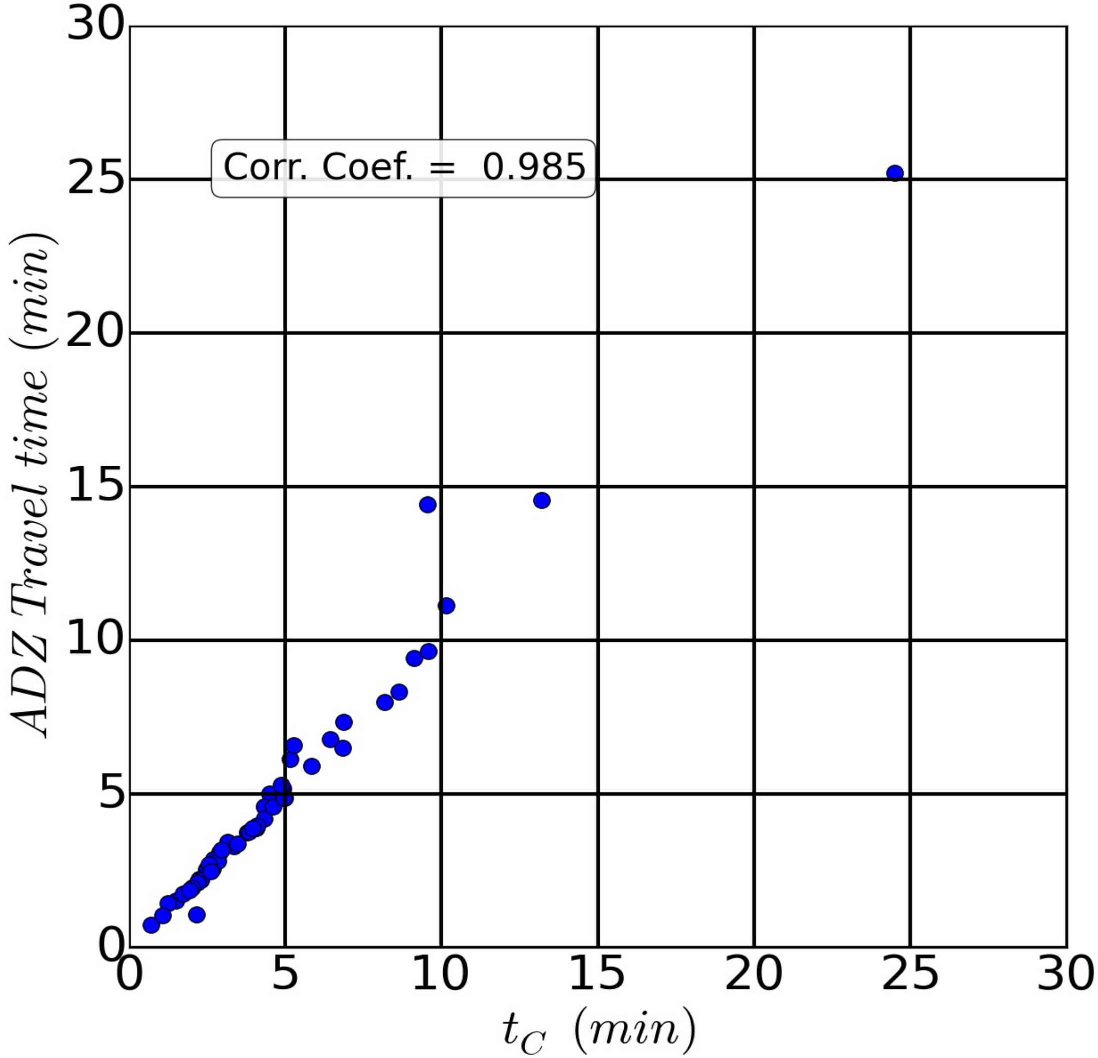
There is a one to one relationship since only advection contributes to longitudinal movement

TSM:
Corrected TSM velocity & Centroid velocity



There is a one to one relationship since both transient storage and advection contribute to longitudinal movement

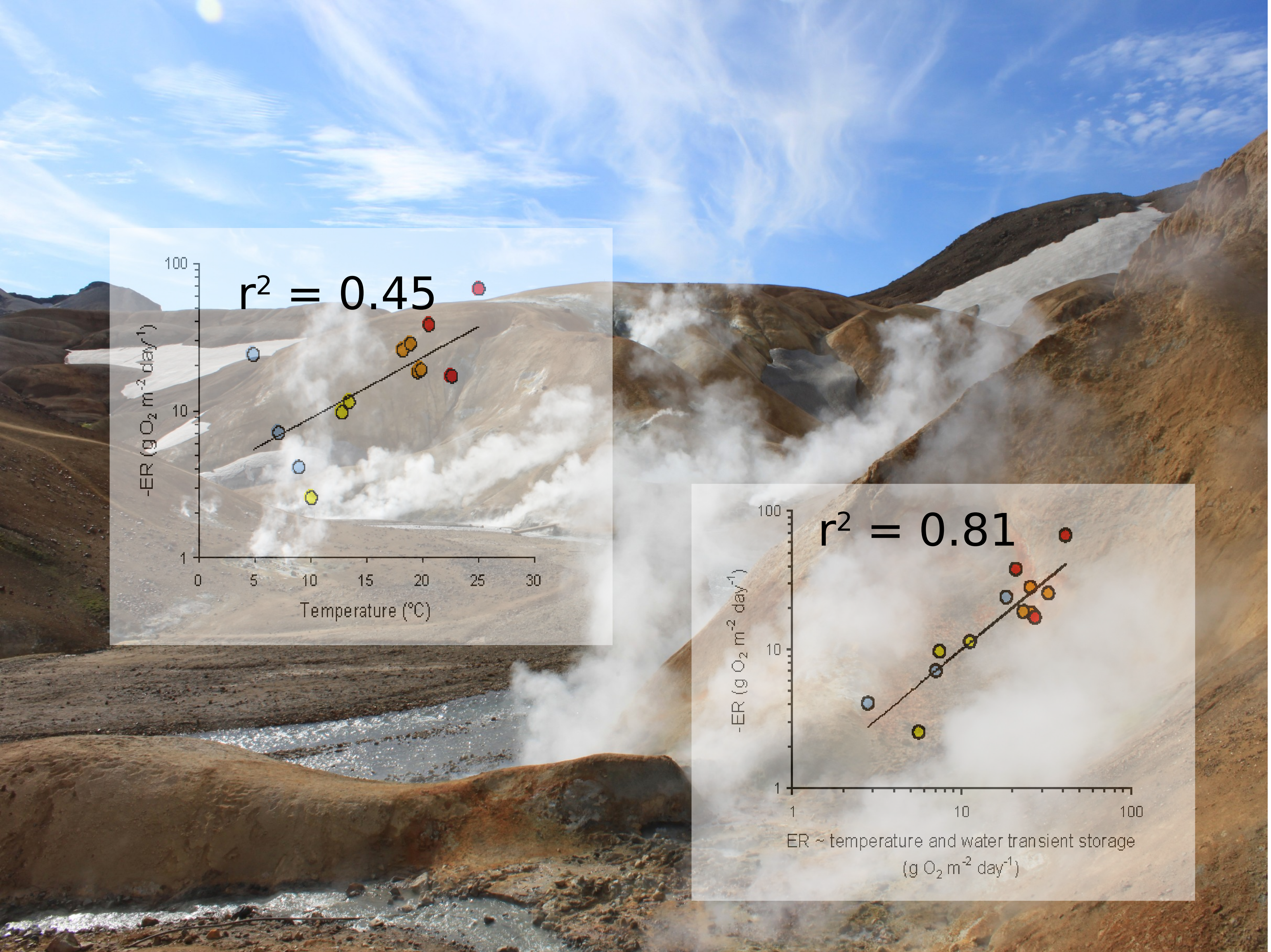
ADZM:
ADZM travel time & centroid travel time



Again there is a one to one relationship since here delay and residence contribute to longitudinal movement

- So model fits appear robust.

Now back to stream metabolism ...



r² = 0.45
-ER (g O2 m-2 day-1)
Temperature (°C)
r² = 0.81
-ER (g O2 m-2 day-1)
ER ~ temperature and water transient storage
(g O2 m-2 day-1)