# WHAT MATTERS WHEN AND WHERE FOR ANOMALOUS DISPERSION/DIFFUSION

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## ANOMALOUS DISPERSION

The classical Lagrangian model of Fickian dispersion/diffusion is given by Brownian motion of fluid particles representing contaminant migration. Brownian motion is defined via three conceptual assumptions about the distribution of (spatial) displacements. Anomalous dispersion/diffusion occurs when one or more of these assumptions fails. Or, equivalently, anomalous dispersion takes place if one or more of the following holds:

- The displacements are interdependent.
- The displacements are nonstationary.
- The displacements are not normally distributed.

Anomalous behavior associated with such a violation has been observed in a variety of application areas including surface and subsurface hydrology. Anomalous dispersion/diffusion can create significant problems in efforts to characterize contaminant transport and design remediation strategies that protect groundwater resources.

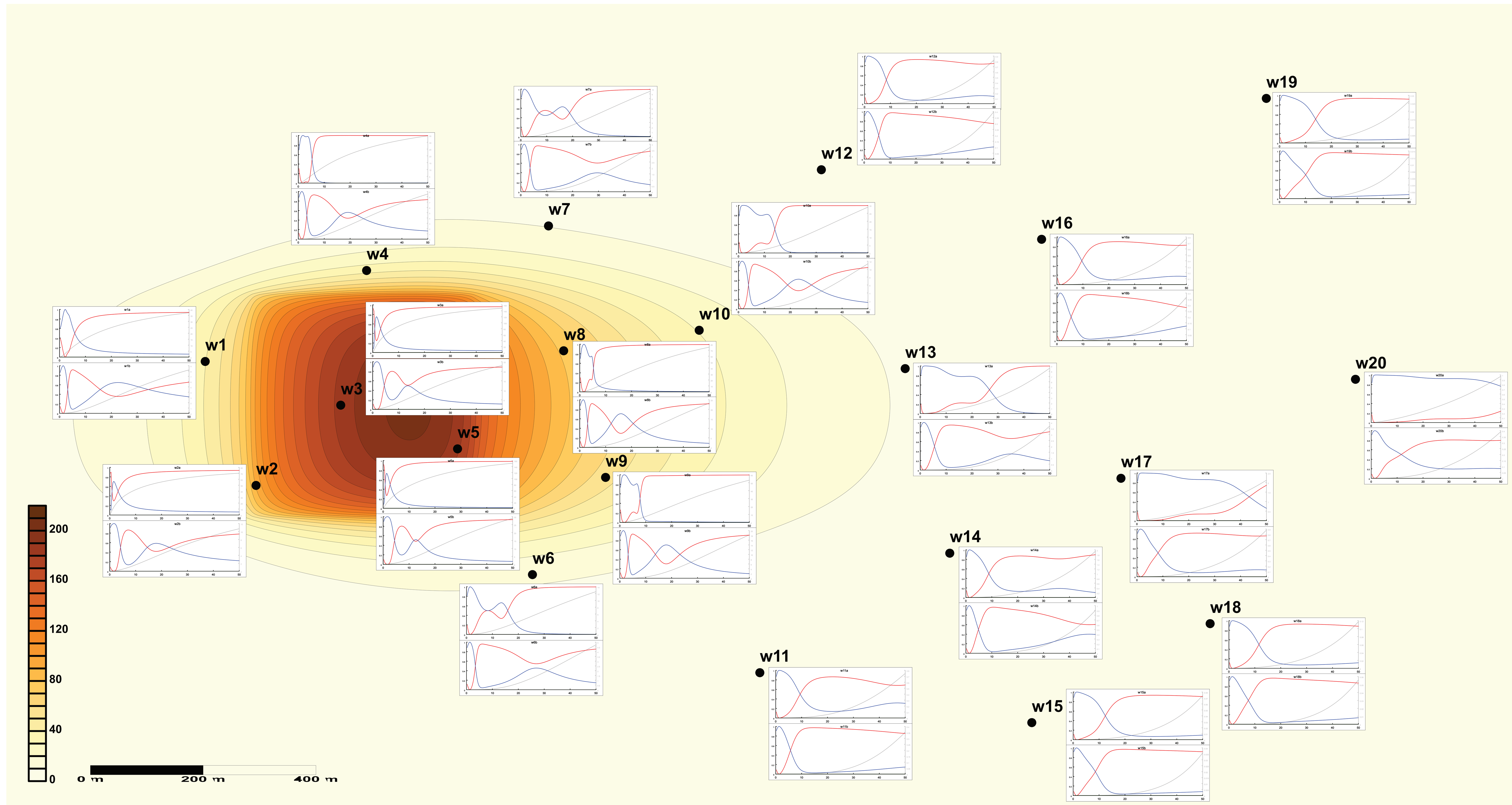
## QUESTIONS

- When/where does periodic (with period 1 year) nonstationarity impact concentrations?
- When/where do heavy-tailed dispersion impact concentrations?
- When/where do long range correlations impact concentrations?
- What data needs to be collected to identify different types of anomalous dispersion?

## REFERENCES

1. O'Malley and Vesselinov, "Analytical solutions for three-dimensional reaction-advection-dispersion with anomalous dispersion" (in review)
2. MADS: http://mads.lanl.gov

## SENSITIVITY ANALYSIS




## SIMULATIONS

An analytical solution was derived for the concentration using the methodology in [1]:

$$C(\mathbf{x},t) = \frac{M}{n||B||(t_2-t_1)}\int_0^t \chi_{(t_1,t_2)}(t-\tau)e^{-\lambda\tau}\left\{[F_X(x-x_1-v\tau,\mathfrak{C}(\tau))-F_X(x-x_2-v\tau,\mathfrak{C}(\tau))]\right.$$
$$\times[F_Y(y-y_1,\mathfrak{C}(\tau))-F_Y(y-y_2,\mathfrak{C}(\tau))]$$
$$\left.\times\,[F_Z(z-z_1,\mathfrak{C}(\tau))-F_Z(z-z_2,\mathfrak{C}(\tau))]\right\}d\tau \quad (1)$$

where $F_X(x,t)$, $F_Y(y,t)$, and $F_Z(z,t)$ are the CDFs of fractional, symmetric $\alpha$-stable Lévy motions with different spread parameters in each of the coordinate directions. The stability parameter, $\alpha$ was uniformly distributed between 1.1 and 2. The Hurst exponent was uniformly distributed between 1/2 and 1. The clock was specified to be $\mathfrak{C}(t) = t + 2\pi A\sin(\pi t/2)$ and $A$ was uniformly distributed between $-1/2$ and 1/2. The sensitivity analyses were performed with 1,000,000 forward runs to compute accurate sensitivity coefficients. The analyses were performed using the code MADS (Model Analyses for Decision Support; http://mads.lanl.gov).

## CONCLUSIONS

- Nonstationarity in dispersion rates with period 1 year has little impact
- Heavy tails are important at early times and at the plume edge
- Long-range correlations are important at long times
- Collect data at early times/plume edges to determine tail behavior
- Collect data at later times/plume interior to determine correlations