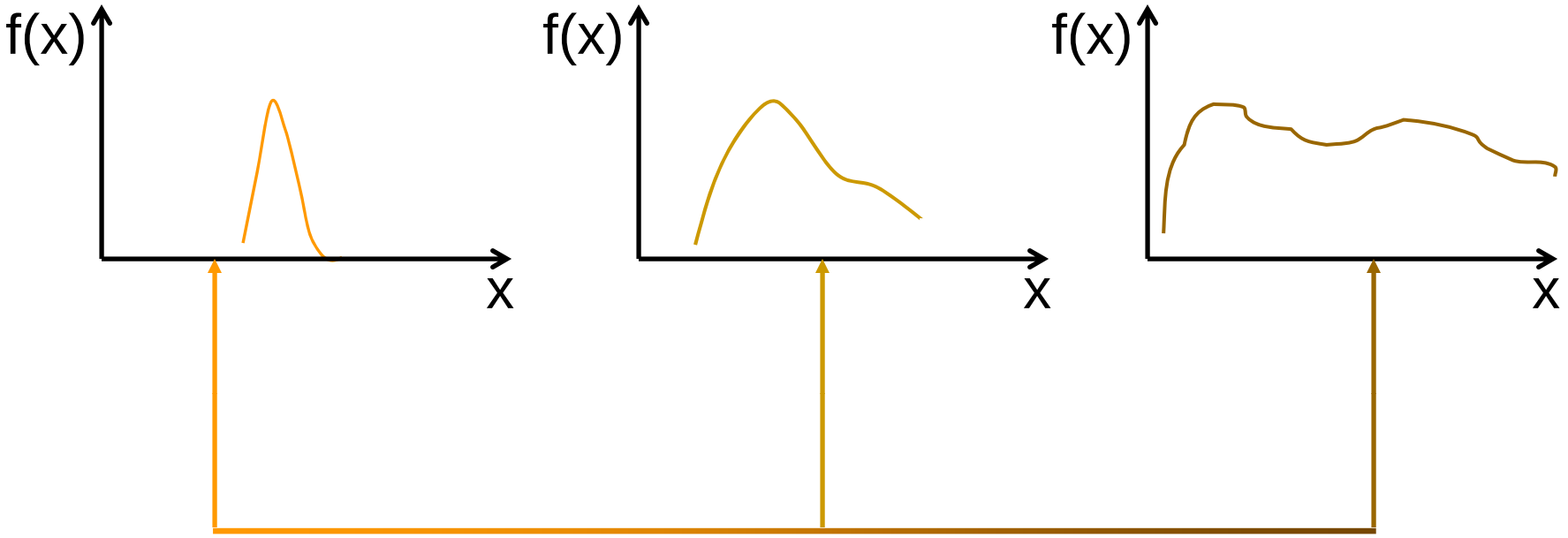
Advanced Data assimilation strategies Status and Plans

Outline:

- Overview of the approach
- Applications
- Future work
- Thanks to Xingyuan, Haruko, Glenn and Mark!

Data assimilation in a nutshell



Small (but irreducible) uncertainty

Continuum of states

Large uncertainty

Probabilistic analysis: conditional simulation & geostatistics

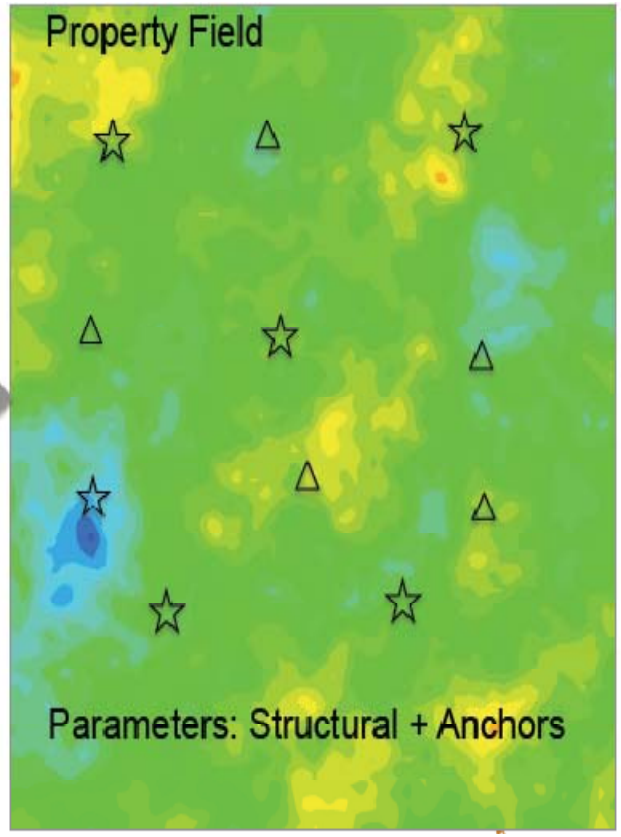
Method of Anchored Distributions (MAD) [Rubin et al.,2010]

Multi-Scale Multi-Type Data

Type A:
local, direct/regression
e.g., K, grain size, …

Type B:
Nonlocal, indirect
e.g., pumping test,
tracer test, …

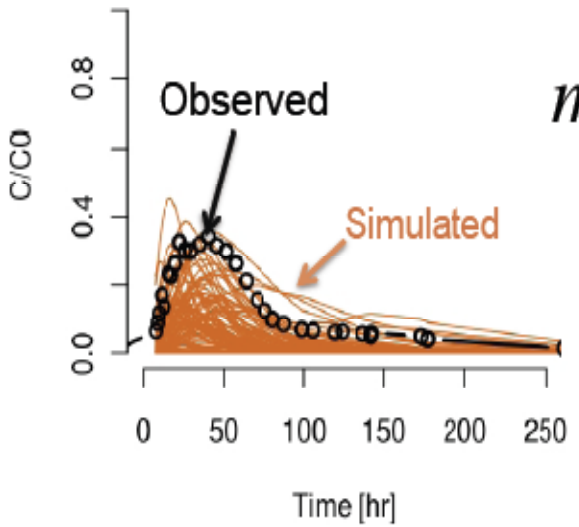
MAD



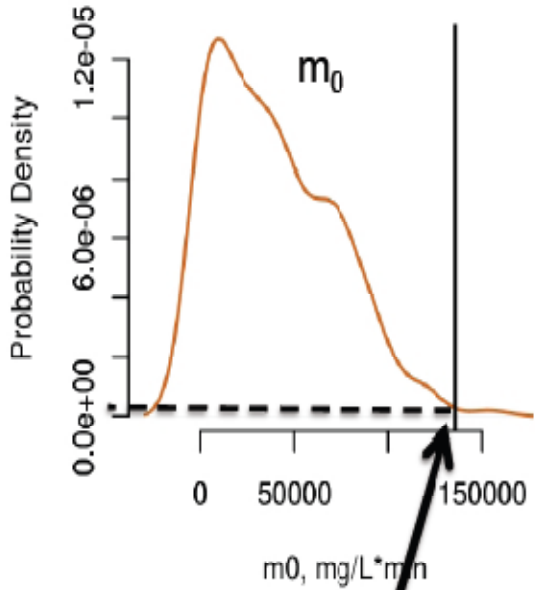
Data types employed thus far:

- Constant-rate injection tests
- EBF
- Lithology
- The March 2009 tracer test (zero- and first-order moments in several wells)

Likelihood Calculation



$$m_0 = \int_0^{\infty} c(t)dt$$



Temporal moments reduce data dimension

$$\mathbf{z}_{\text{tracer}} = \left(m_0^1, m_0^2, \ldots, m_0^n\right)$$

Likelihood: $p(\mathbf{z}_{\text{tracer}} \mid \theta, \vartheta)$

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Locations of data used for our analysis[1]

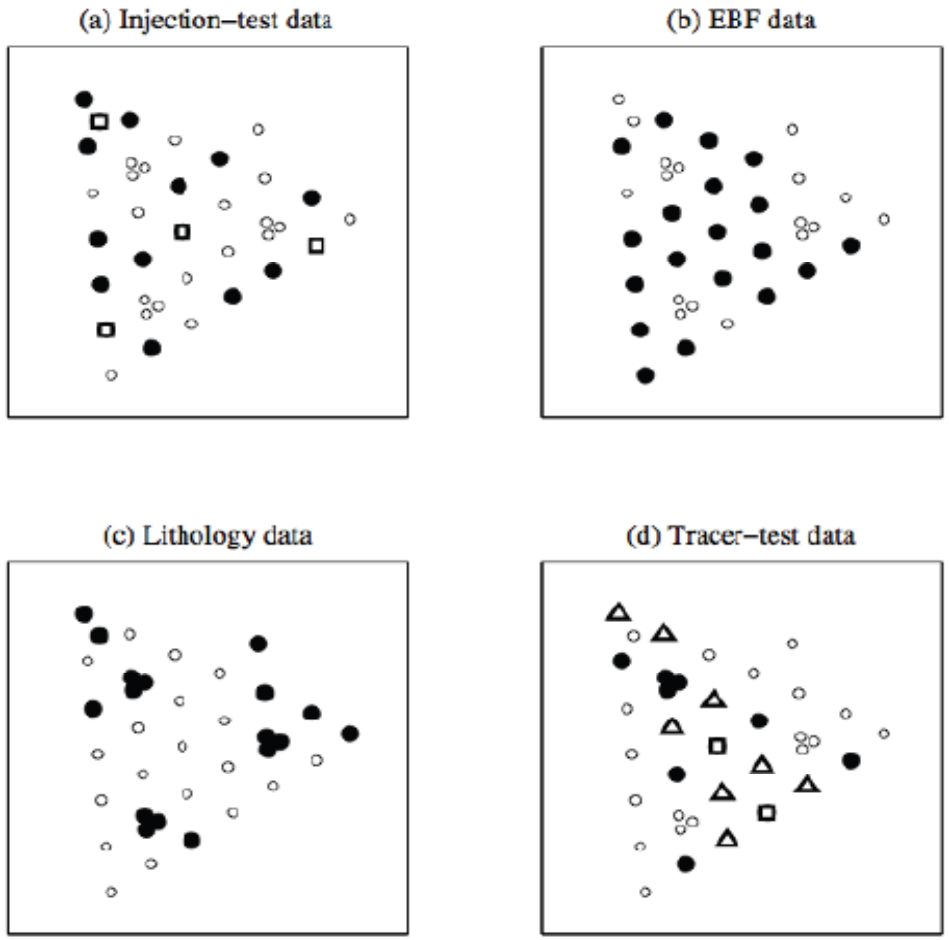
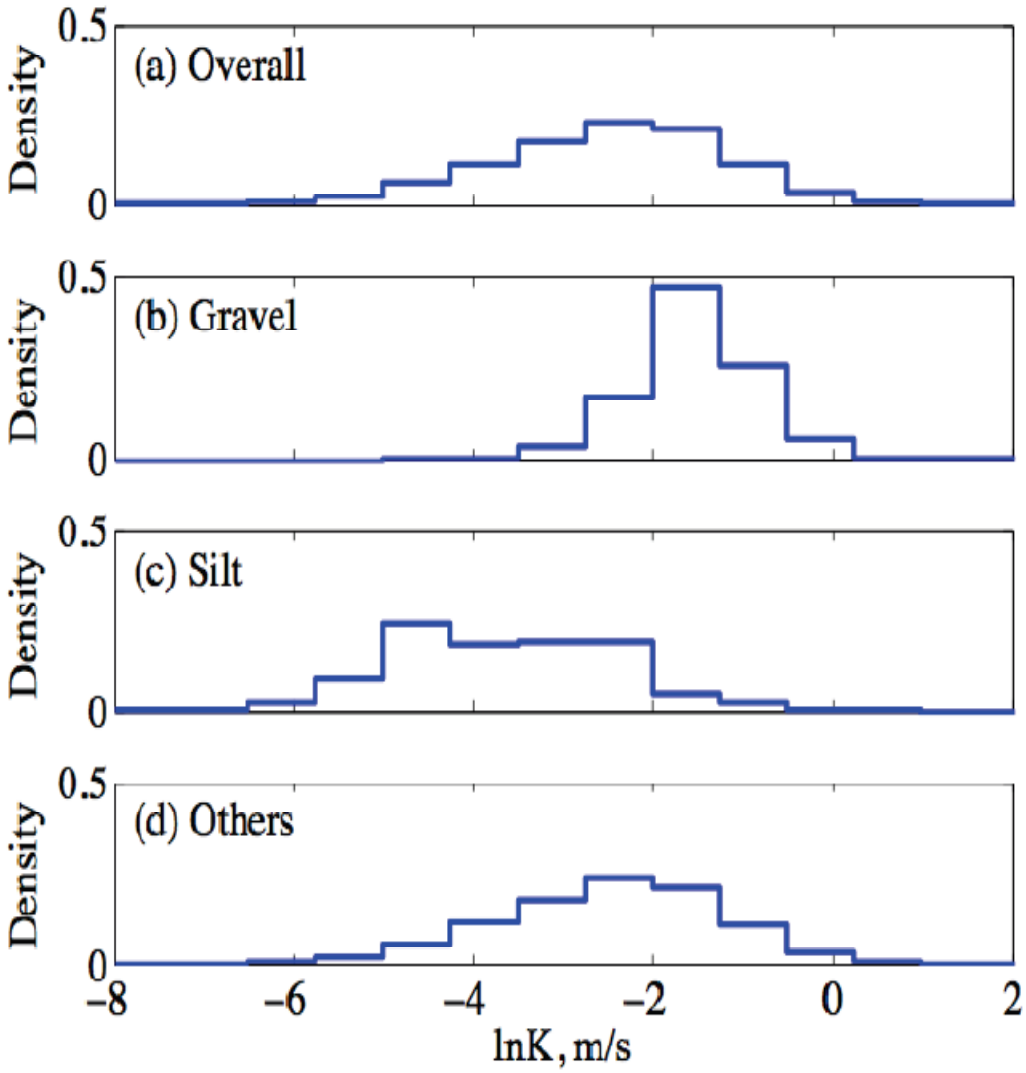


Figure 4.2: Data locations in the well plot: (a) injection-test data, (b) EBF data, (c) lithology data and (d) tracer-test data. In (a), the black circles are the wells used for observation, and the white squares are the wells used for injection and observation. The subset of the observation wells are used for each injection test. In (d), the black circles are the training-set wells at which M_1 was used, the white squares are the training-set wells at which both M_1 and M_1/M_0 were used, and the white triangles are the testing-set wells.

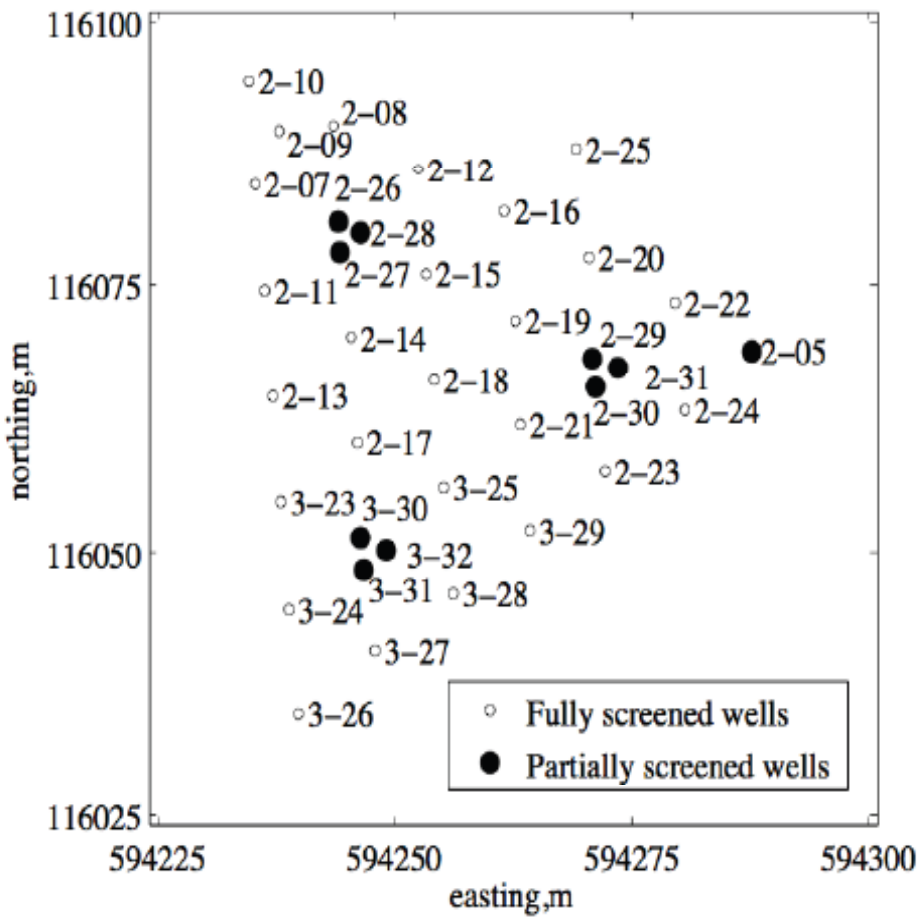
[1] Not all available Data used for inversion

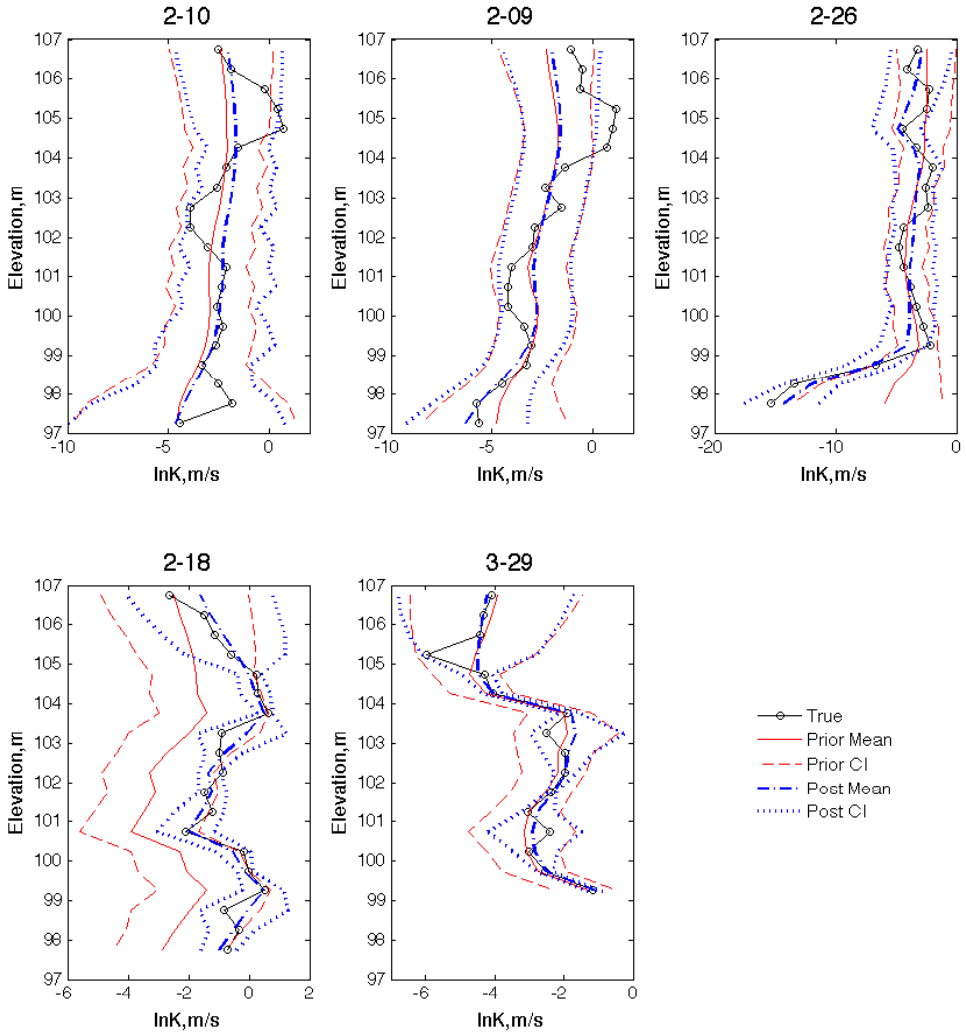
From Haruko Murakami's thesis

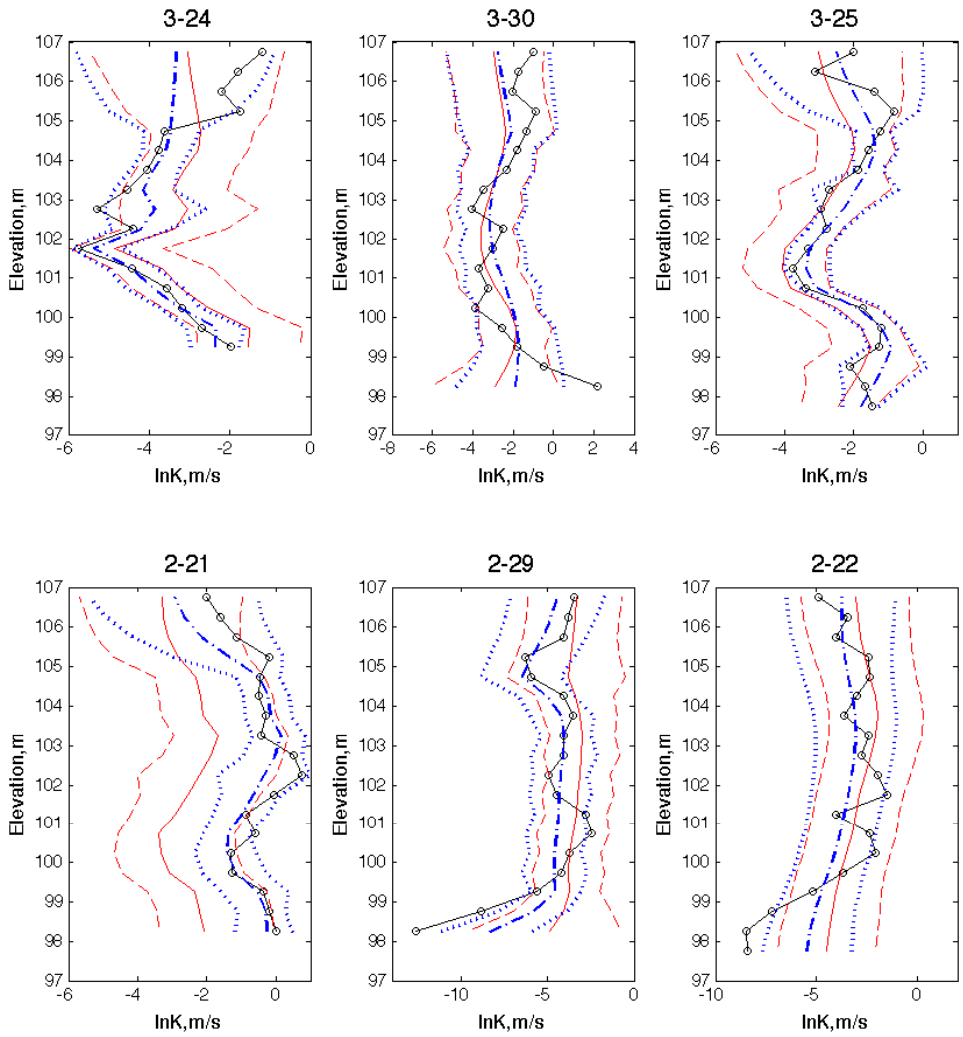


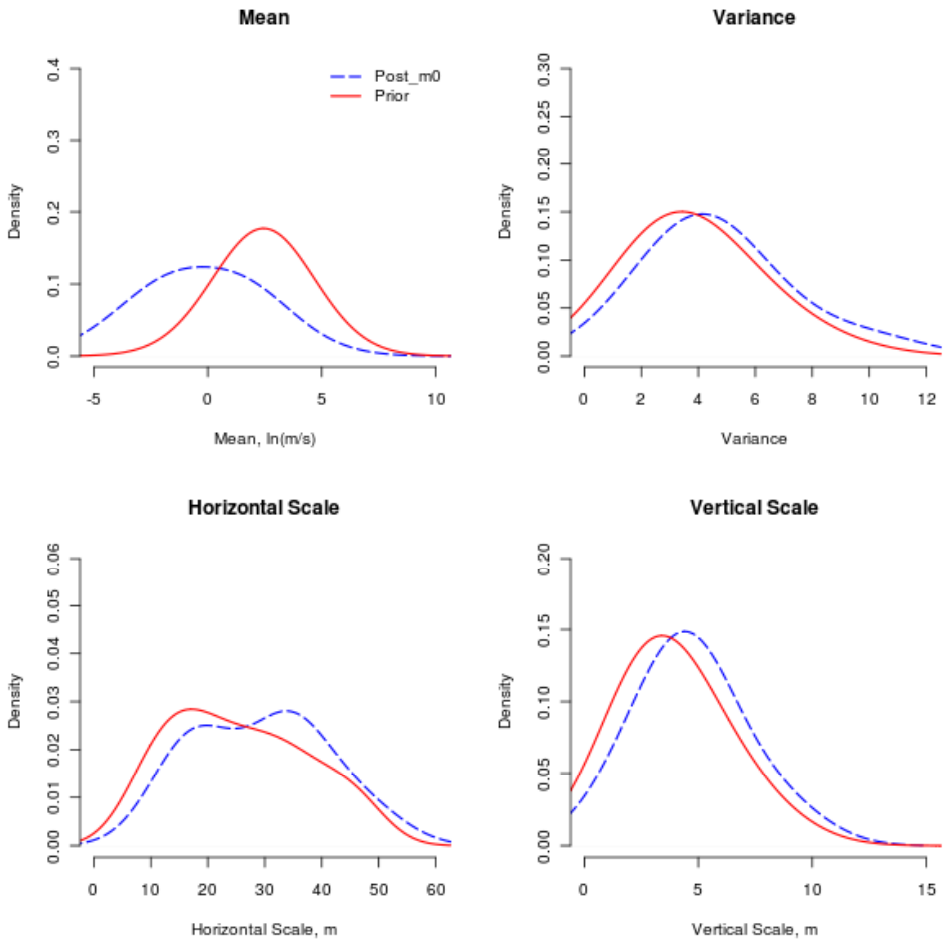
From Haruko Murakami's thesis

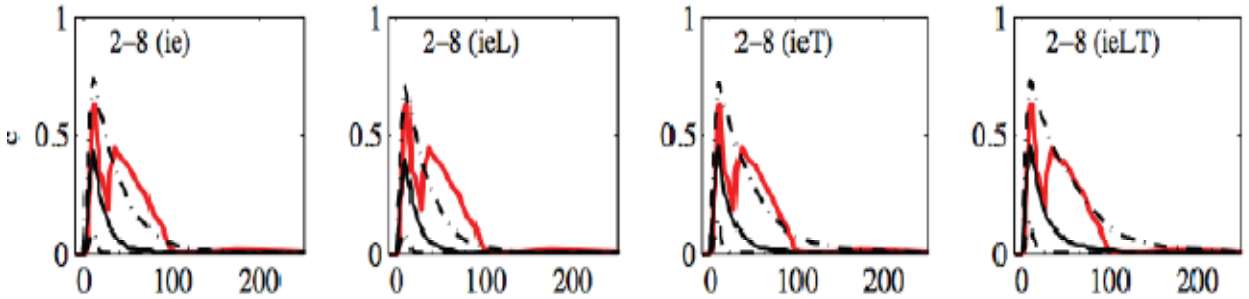
Figure 4.3: Overall distribution of ln$K$ and distributions of ln$K$ in each lithology conditioned on the injection-test and EBF data. Others include sandy gravel, gravelly sand and sand.

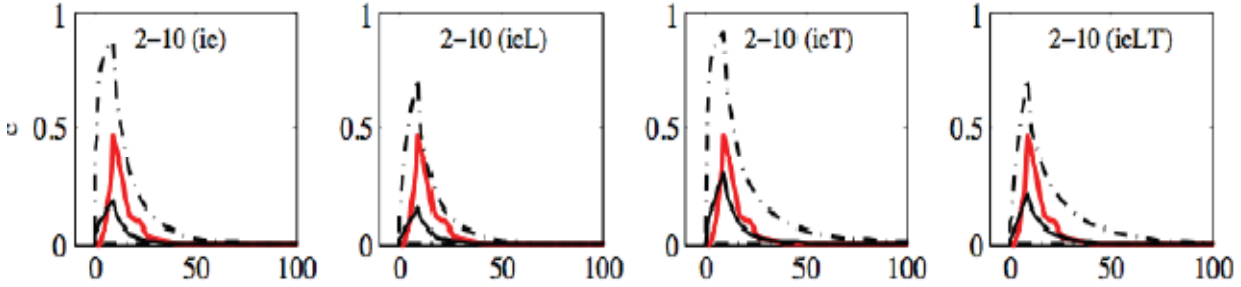

116100
116075
116050
116025
northing,m
594225
594250
594275
594300
easting,m
2–10
2–08
2–09
2–25
2–12
2–07
2–26
2–16
2–28
2–20
2–27
2–15
2–11
2–22
2–19
2–29
2–14
2–05
2–18
2–31
2–13
2–30
2–24
2–21
2–17
2–23
3–23
3–30
3–25
3–29
3–32
3–31
3–28
3–24
3–27
3–26
Fully screened wells
Partially screened wells


2-10
2-09
2-26
2-18
3-29
Elevation,m
lnK,m/s
True
Prior Mean
Prior CI
Post Mean
Post CI


3-24
3-30
3-25
2-21
2-29
2-22
Elevation,m
lnK,m/s

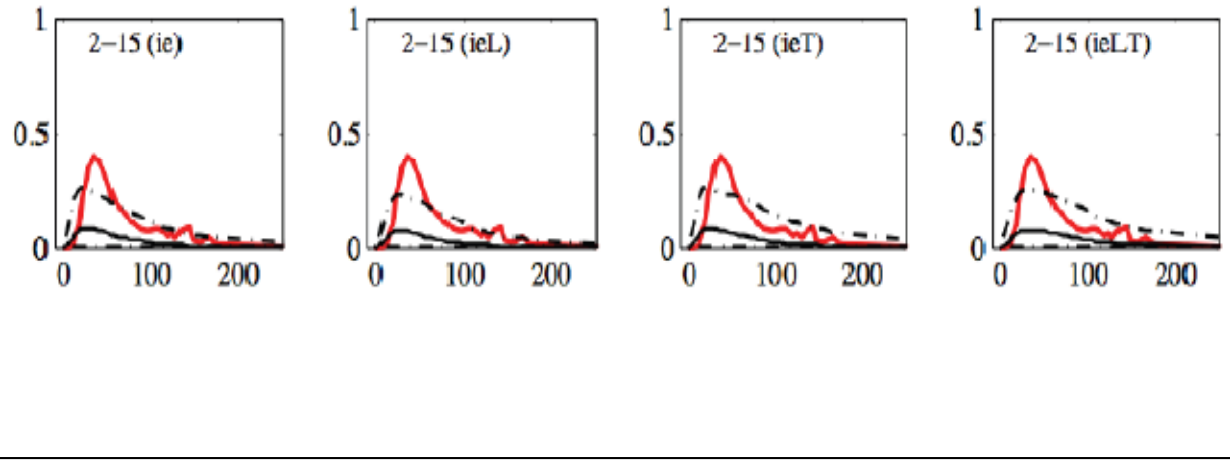

Mean
Post_m0
Prior
Density
0.0
0.1
0.2
0.3
0.4
-5
0
5
10
Mean, ln(m/s)
Variance
Density
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0
2
4
6
8
10
12
Variance
Horizontal Scale
Density
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0
10
20
30
40
50
60
Horizontal Scale, m
Vertical Scale
Density
0.00
0.05
0.10
0.15
0.20
0
5
10
15
Vertical Scale, m

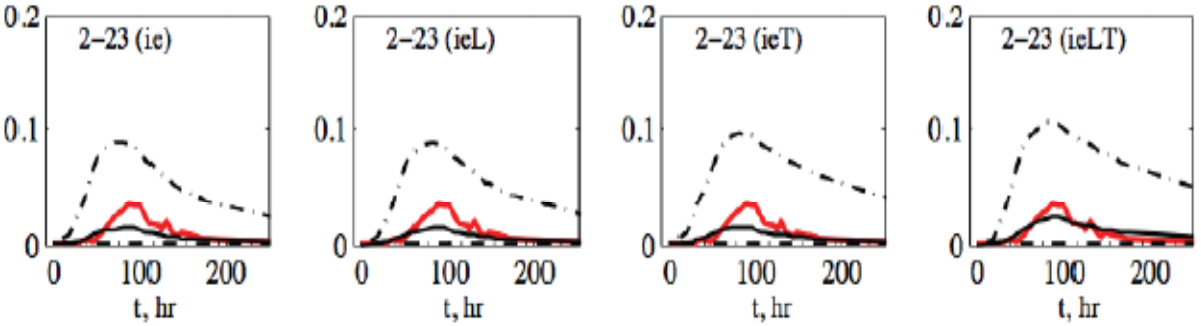


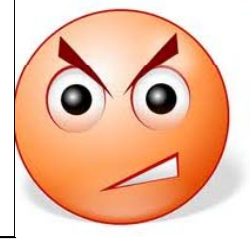


(**ie**): injection tests and EBF; (**ieLT**): injection tests, EBF, lithology and tracer tests

From Haruko Murakami's thesis

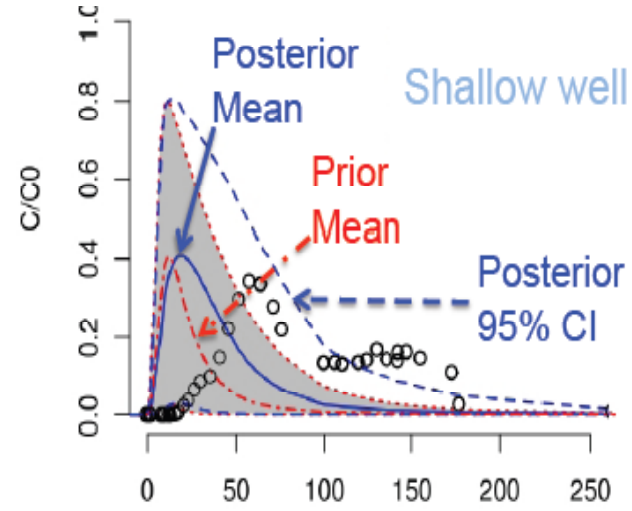


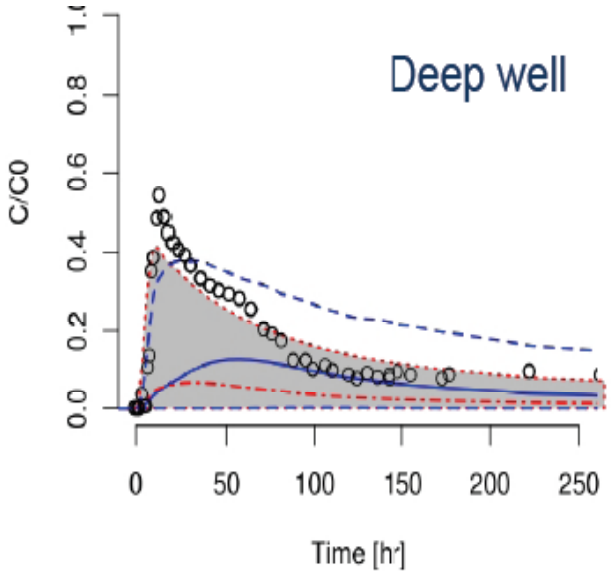


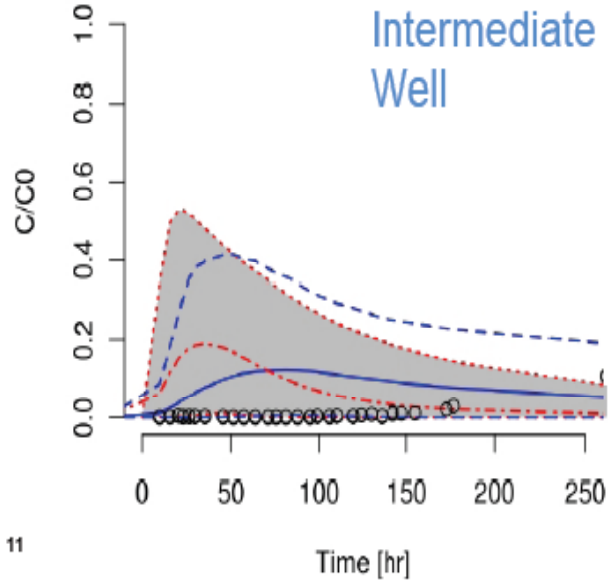


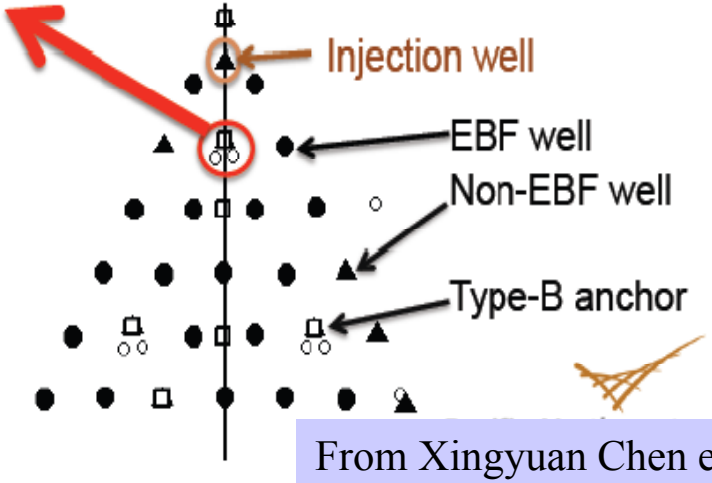
(**ie**): injection tests and EBF; (**ieLT**): injection tests, EBF, lithology and tracer test

From Haruko Murakami's thesis

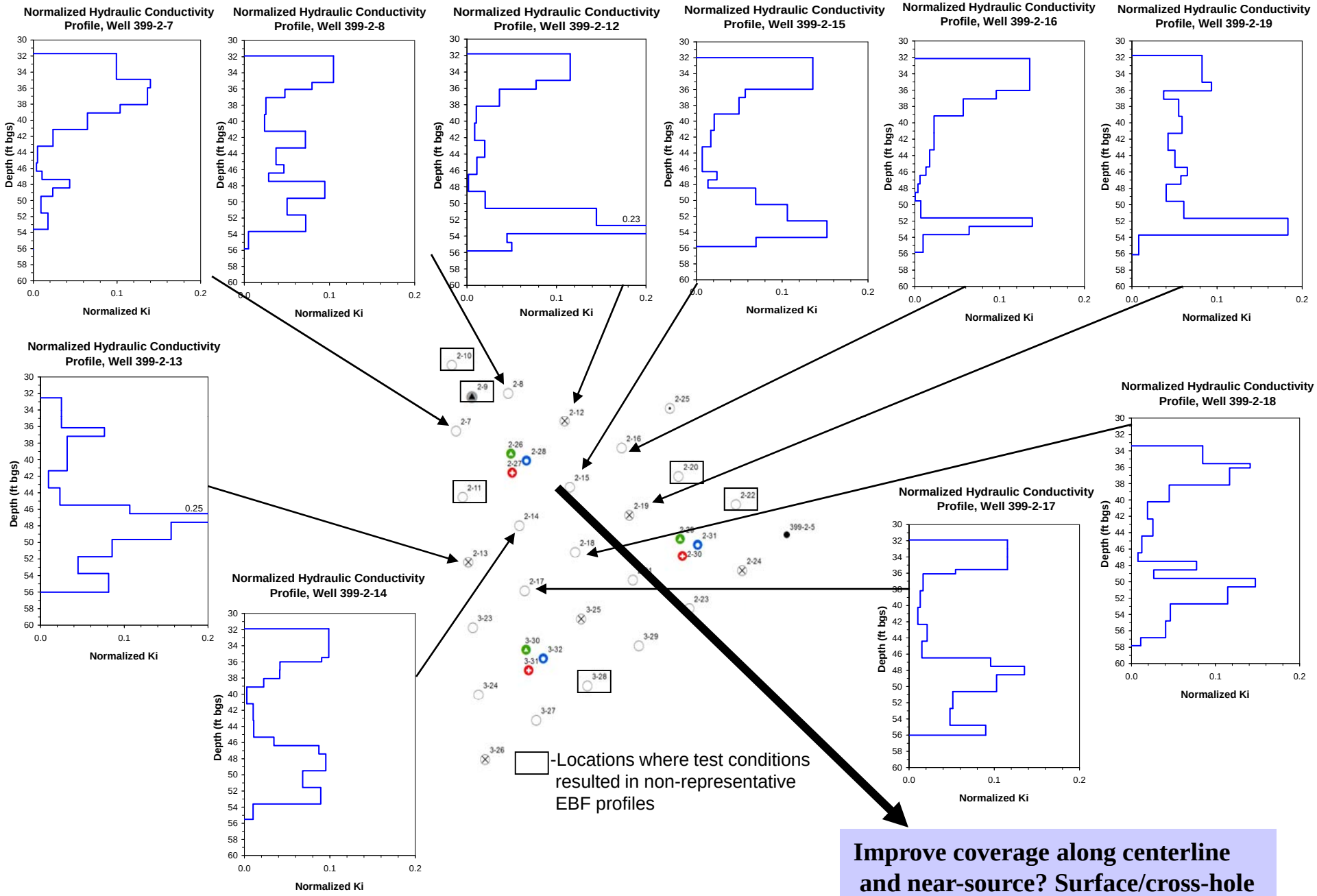




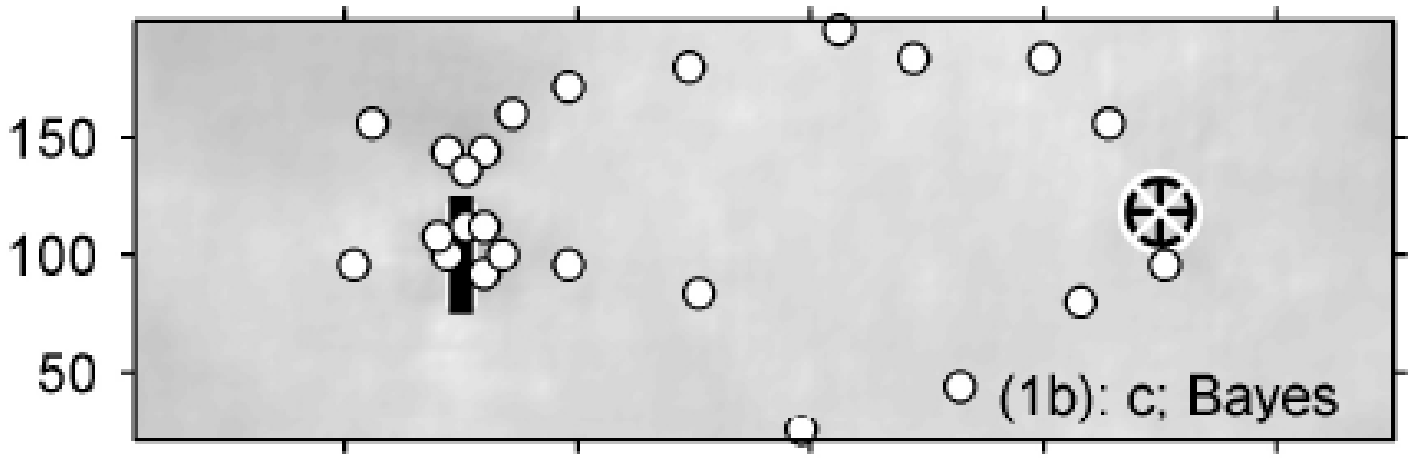




From Xingyuan Chen et al., in preparation


Normalized Hydraulic Conductivity Profile, Well 399-2-7
Normalized Hydraulic Conductivity Profile, Well 399-2-8
Normalized Hydraulic Conductivity Profile, Well 399-2-12
Normalized Hydraulic Conductivity Profile, Well 399-2-15
Normalized Hydraulic Conductivity Profile, Well 399-2-16
Normalized Hydraulic Conductivity Profile, Well 399-2-19
Normalized Hydraulic Conductivity Profile, Well 399-2-13
Normalized Hydraulic Conductivity Profile, Well 399-2-14
Normalized Hydraulic Conductivity Profile, Well 399-2-17
Normalized Hydraulic Conductivity Profile, Well 399-2-18
Depth (ft bgs)
Normalized Ki
0.23
0.25
-Locations where test conditions resulted in non-representative EBF profiles
Improve coverage along centerline and near-source? Surface/cross-hole could be useful here

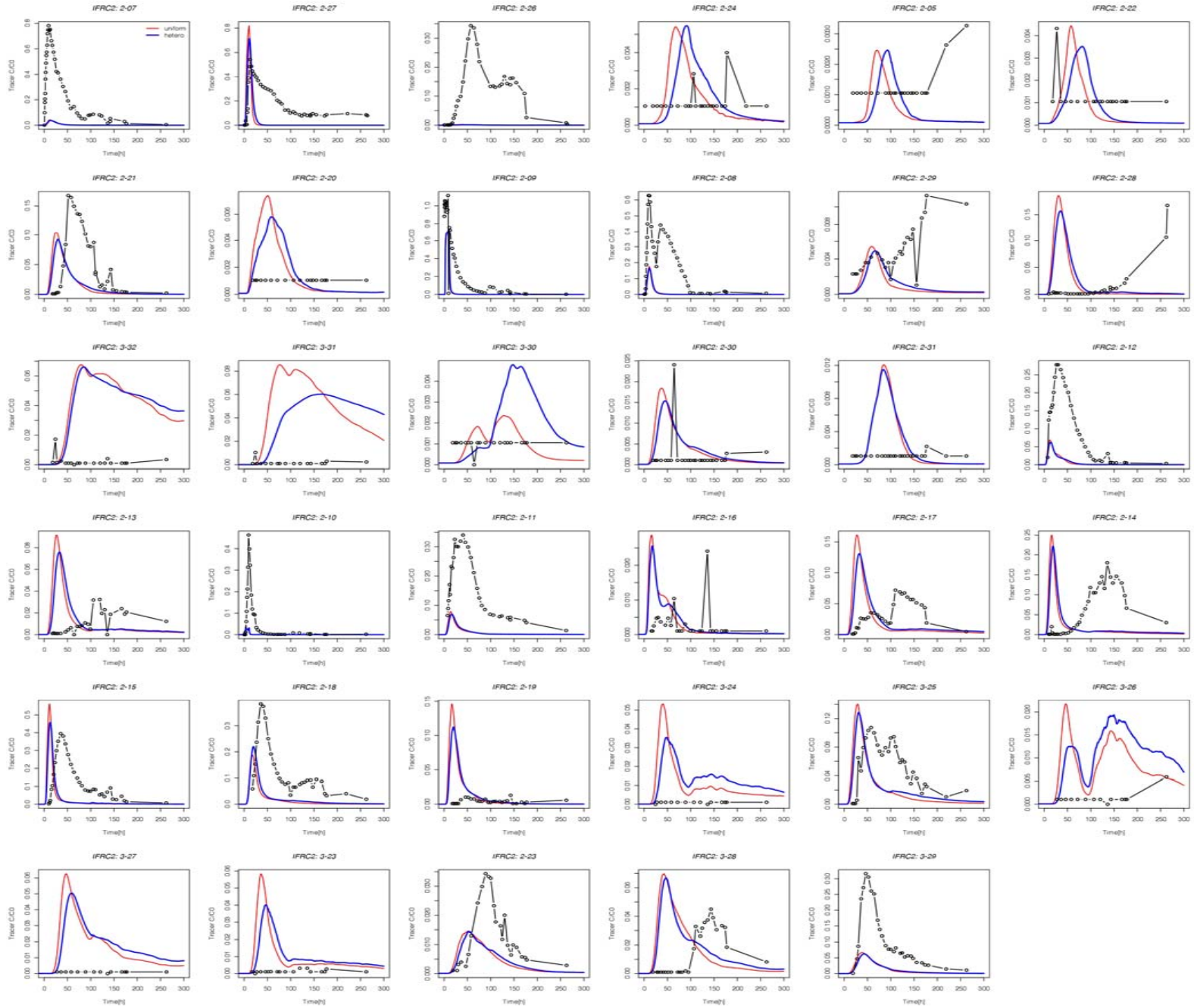
On the significance of near-source characterization



From: Nowak, Rubin and De Barros, WRR, 2010

Issues and Current Work

- Concern about uncertainty in boundary conditions.
- Vertical borehole flows – less of a concern for the March 2009 experiment?
- Started a second round of interpretation of the March 2009 experiment: more data to be used.
- Enhancing near-source characterization should be considered. Also along centerline.
- Petrophysical models: benchmark established for perm-lithology correlation.
- Preliminary tests conducted on impact of recharge, initial conditions and variable porosity field on modeled BTCs. Variable porosity appears to be a potentially significant factor.


IFRC2: 2-07
uniform
hetero
IFRC2: 2-27
IFRC2: 2-26
IFRC2: 2-24
IFRC2: 2-05
IFRC2: 2-22
IFRC2: 2-21
IFRC2: 2-20
IFRC2: 2-09
IFRC2: 2-08
IFRC2: 2-29
IFRC2: 2-28
IFRC2: 3-32
IFRC2: 3-31
IFRC2: 3-30
IFRC2: 2-30
IFRC2: 2-31
IFRC2: 2-12
IFRC2: 2-13
IFRC2: 2-10
IFRC2: 2-11
IFRC2: 2-16
IFRC2: 2-17
IFRC2: 2-14
IFRC2: 2-15
IFRC2: 2-18
IFRC2: 2-19
IFRC2: 3-24
IFRC2: 3-25
IFRC2: 3-26
IFRC2: 3-27
IFRC2: 3-23
IFRC2: 2-23
IFRC2: 3-28
IFRC2: 3-29
Tracer C/C0
Time[h]