Numerical modeling of stable water isotope signatures for investigations in ecohydrologic separations

Water Isotopes and Climate Workshop

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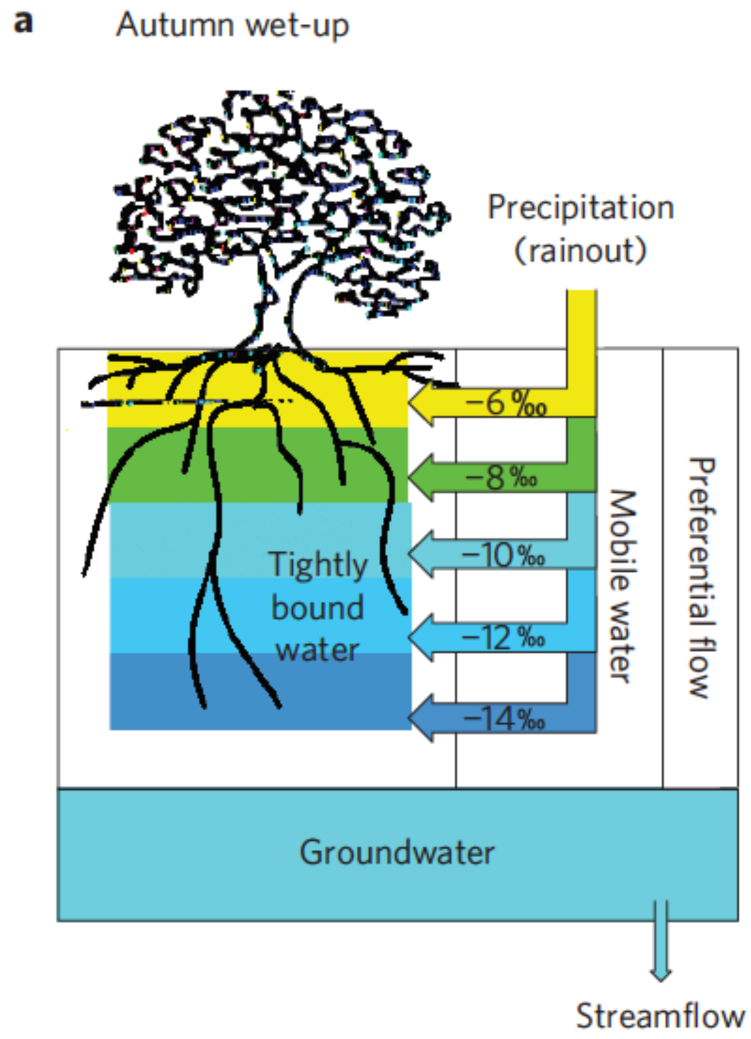
Introduction

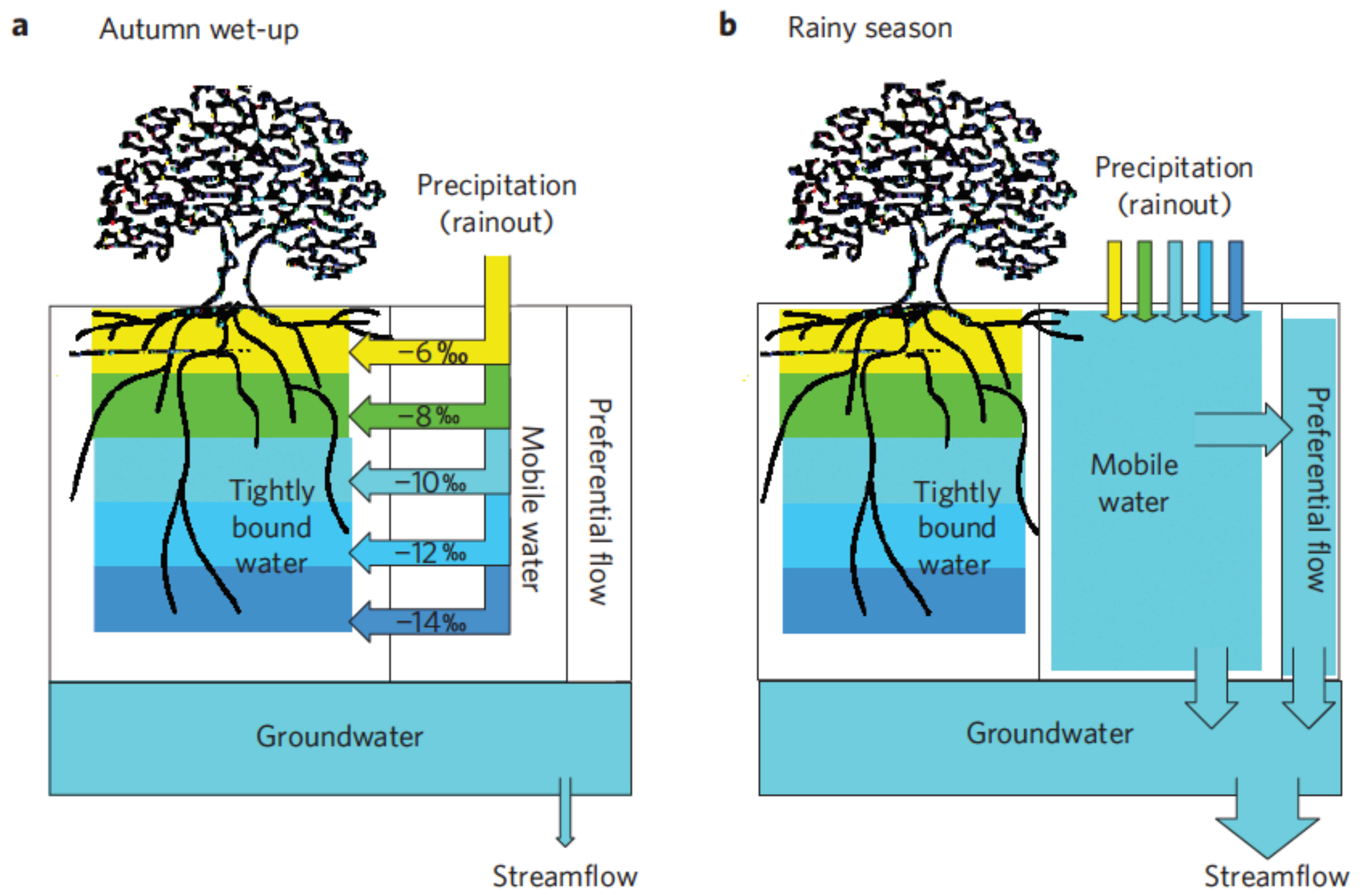
Hydrologic models often assume soil reservoirs to be well mixed

Precipitation enters the bulk soil matrix, is integrated with soil moisture, and discharged to the stream

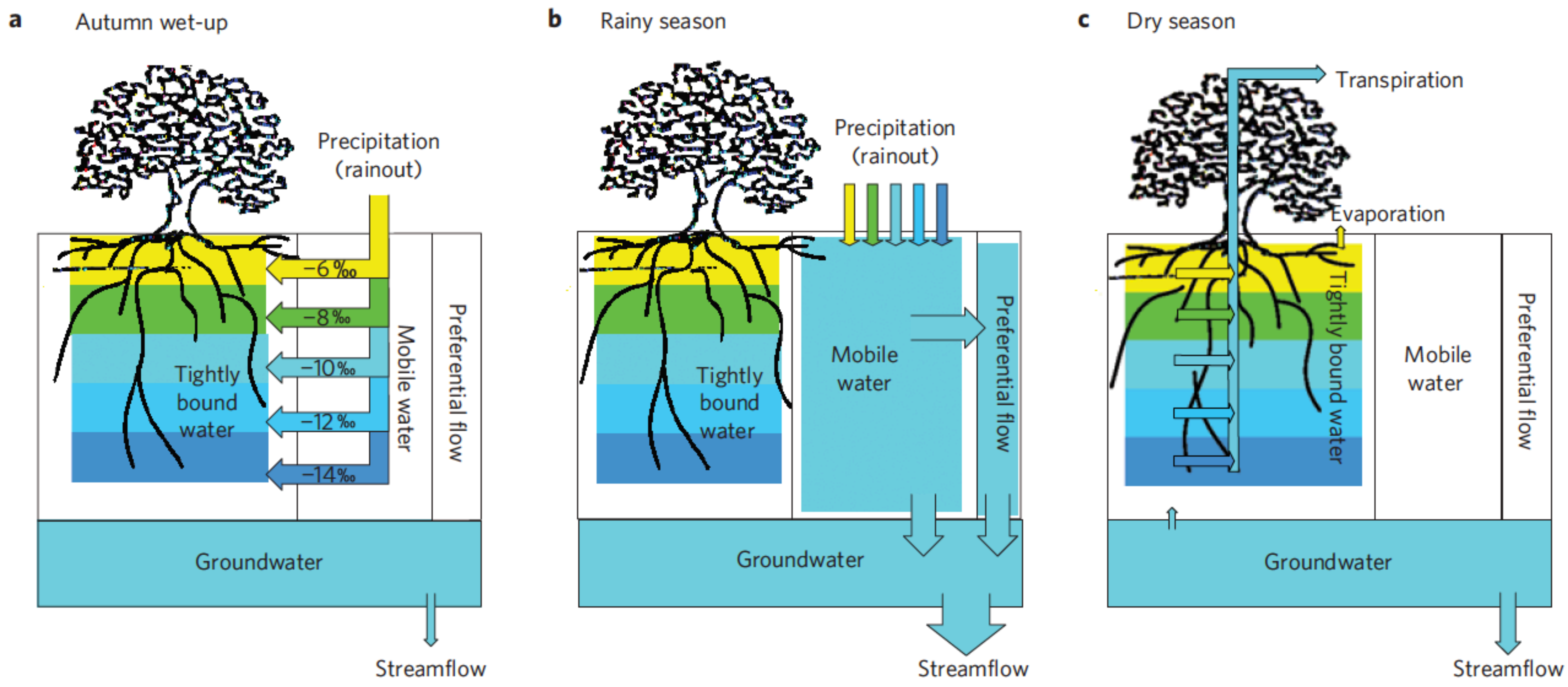
Is this true?



Brooks et al. 2009



Brooks et al. 2009



Brooks et al. 2009

Research Questions

1. Does modeling with mobile and immobile zones in soils make a difference?
    1. What are the influences on VWC?
    2. What are the influences on the transport of water isotopes?

2. How do VWC and water isotope signatures change with increasing immobile fractions of soil?

3. How are VWC and water isotope signatures influenced by the strength of exchange between the mobile and immobile zones?

HYDRUS-1D (v4.17)

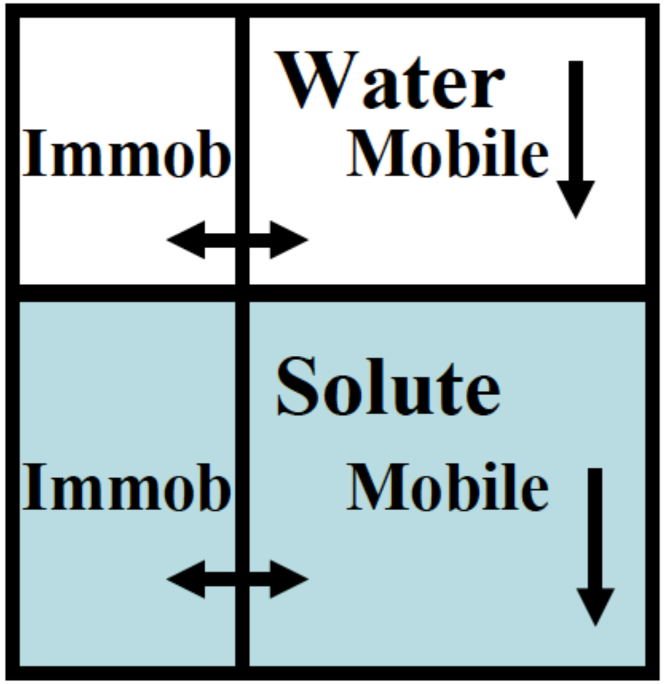
Dual-Porosity Model Configuration

- Immobile Fraction

- ω mass transfer coefficient between the fast and slow domains, driven by pressure head gradient

$$\Gamma_w = \frac{\partial \theta_{im}}{\partial t} = \omega\left[S_e^m - S_e^{im}\right]$$

c. Dual-Porosity



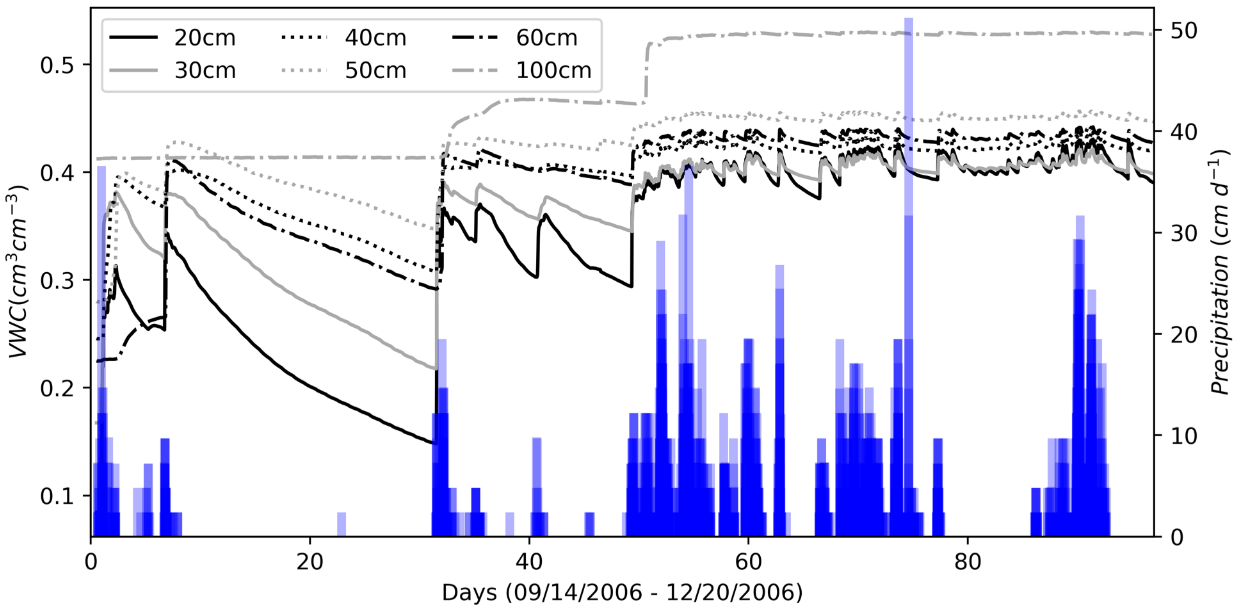
$$\theta = \theta_{im} + \theta_{mo}$$

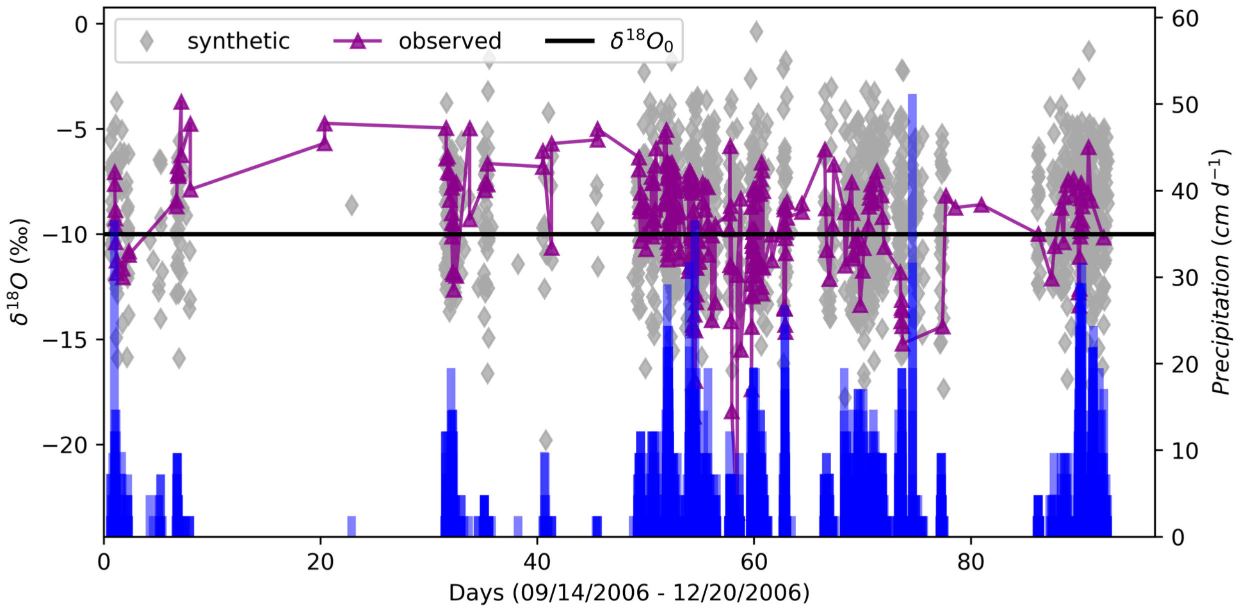
$$S = \theta_{im} c_{im} + \theta_{mo} c_{mo}$$

Šimůnek et al. 2013

Study Domain & Model Datasets

Watershed 10, H.J. Andrews Experimental Forest, OR, USA





(Hydrus-1D isotope model modifications developed by Stumpp et al. 2014)

Hydrus Model Configurations

1. Single Pore Domain

2. Pseudo- Single Pore Domain

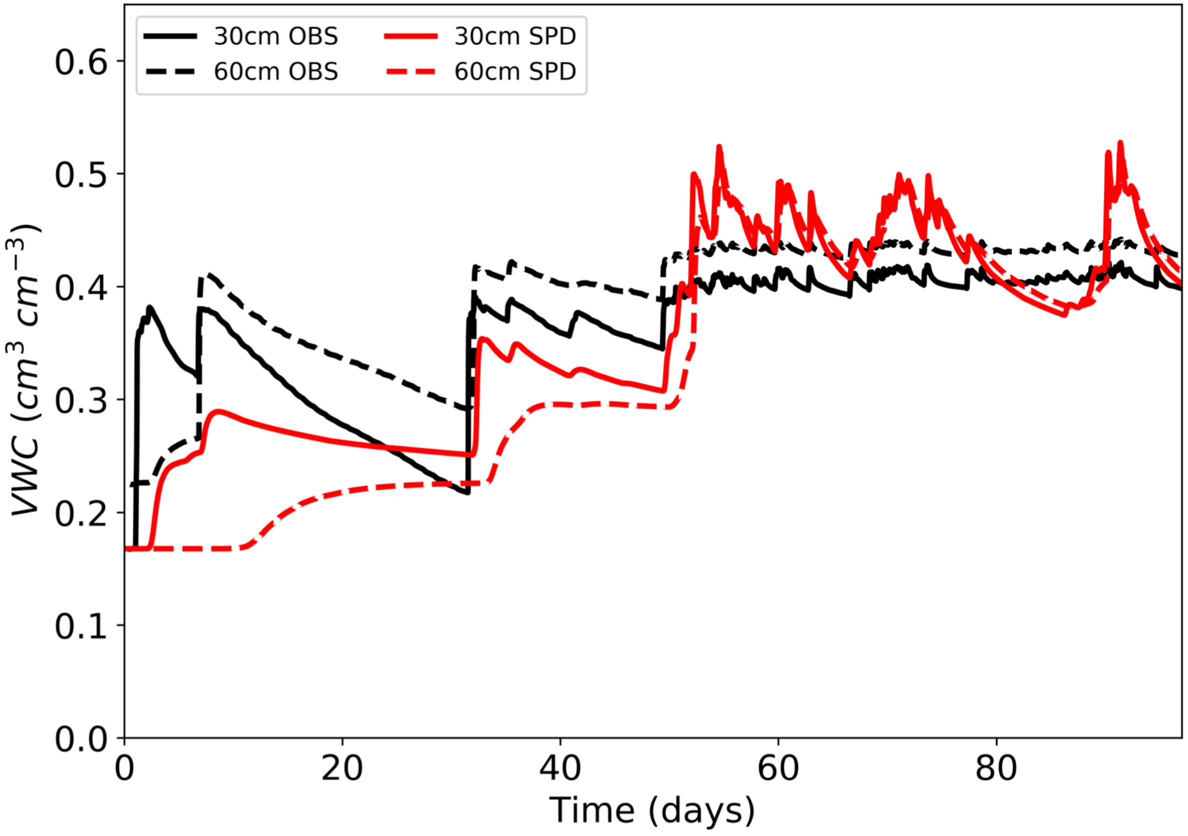
3. 9 Dual Porosity Domains

   $\text{Fraction Immobile} = [50\%, 30\%, 10\%]$

   $\omega = [1.0, 0.1, 0.01]$

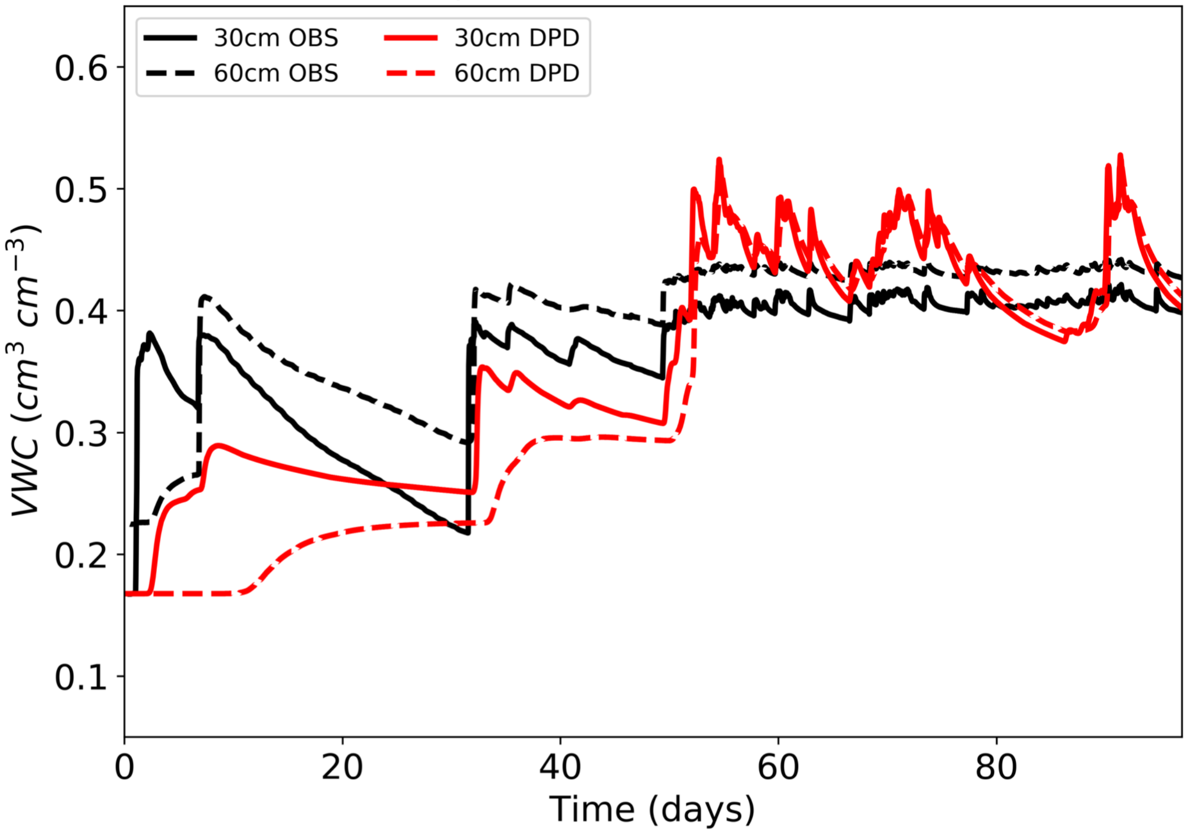
Results

Single- Pore Domain

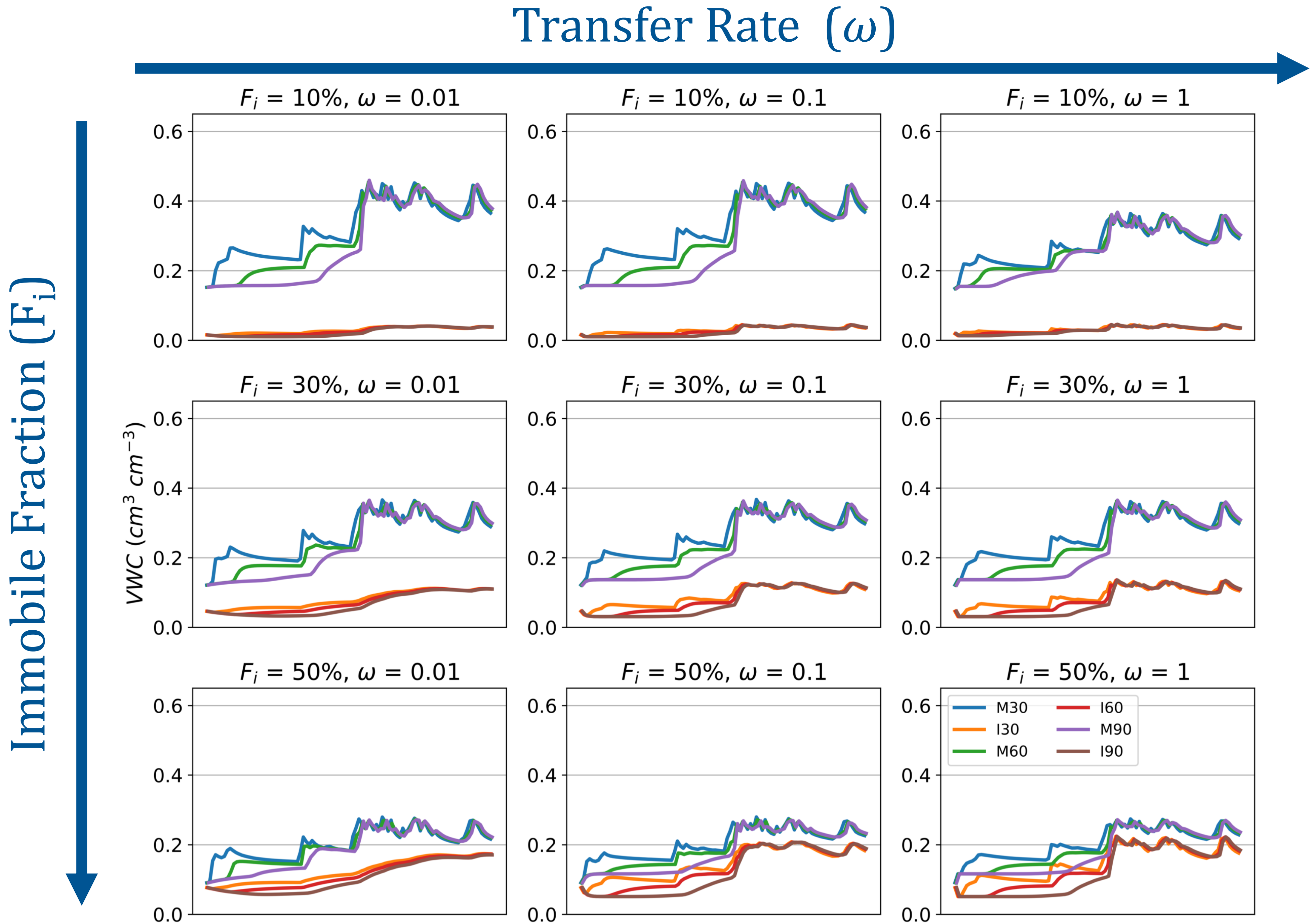


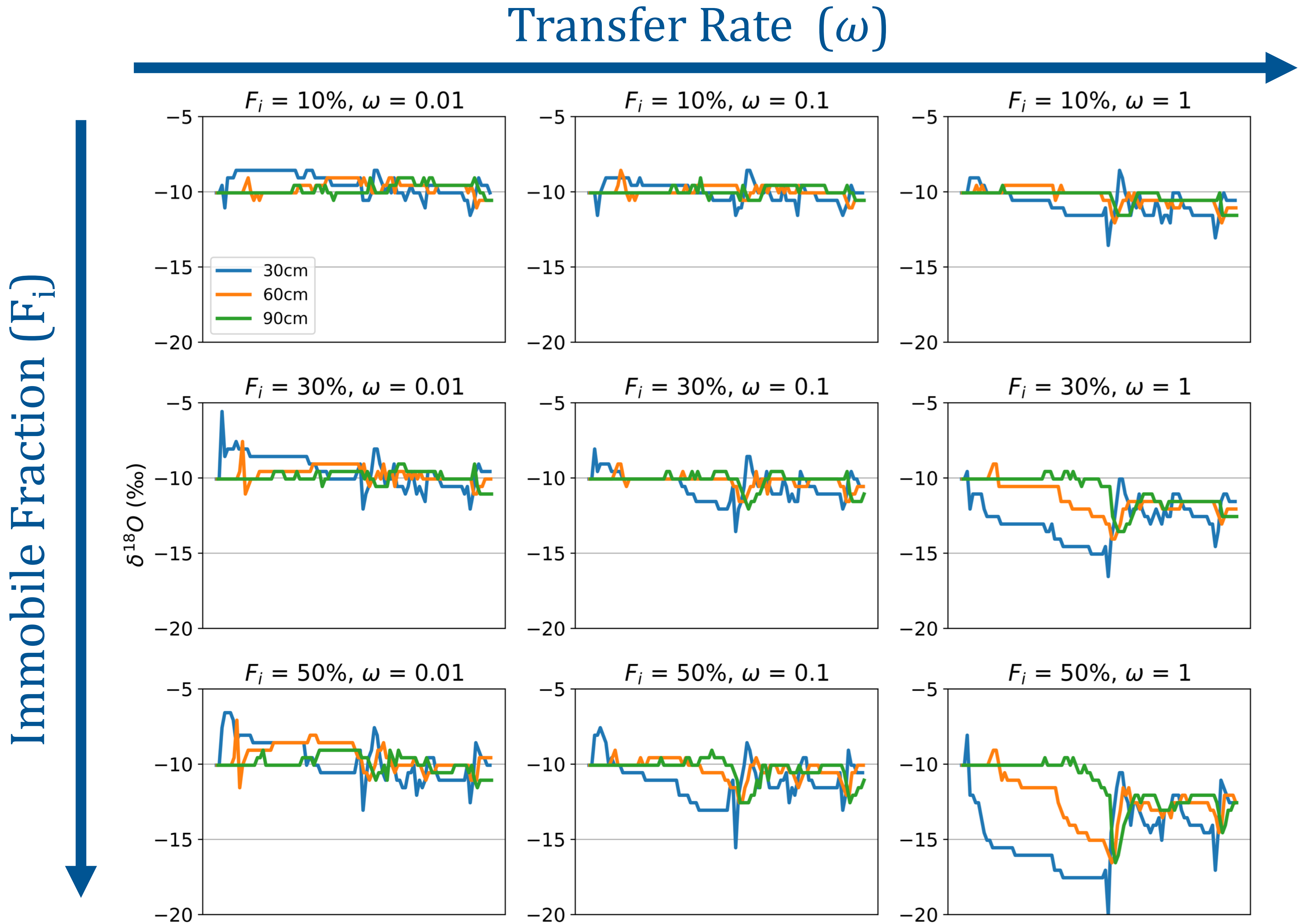
Pseudo-Single Pore Domain

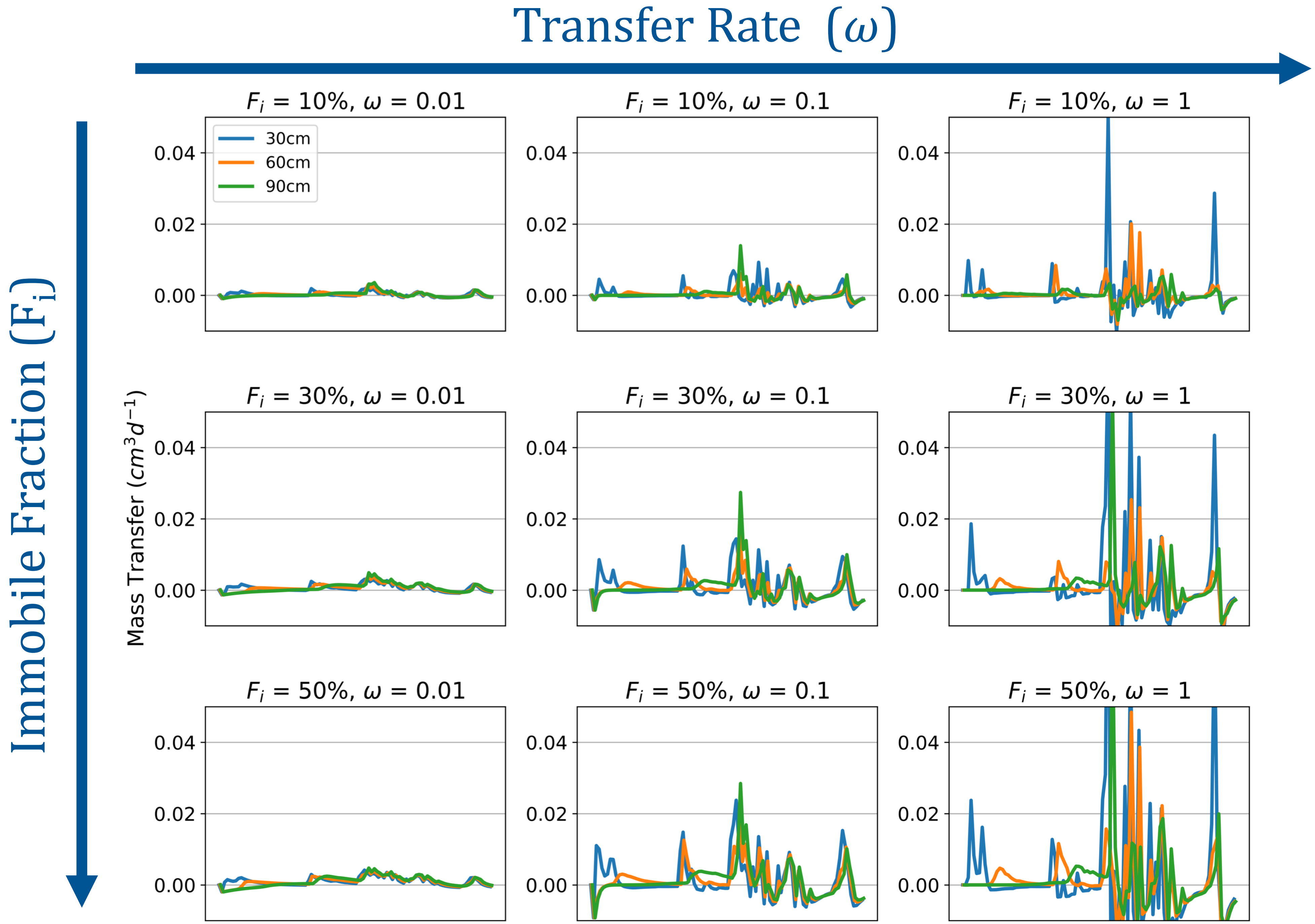
F_i = 0.002%, ω = 1.0



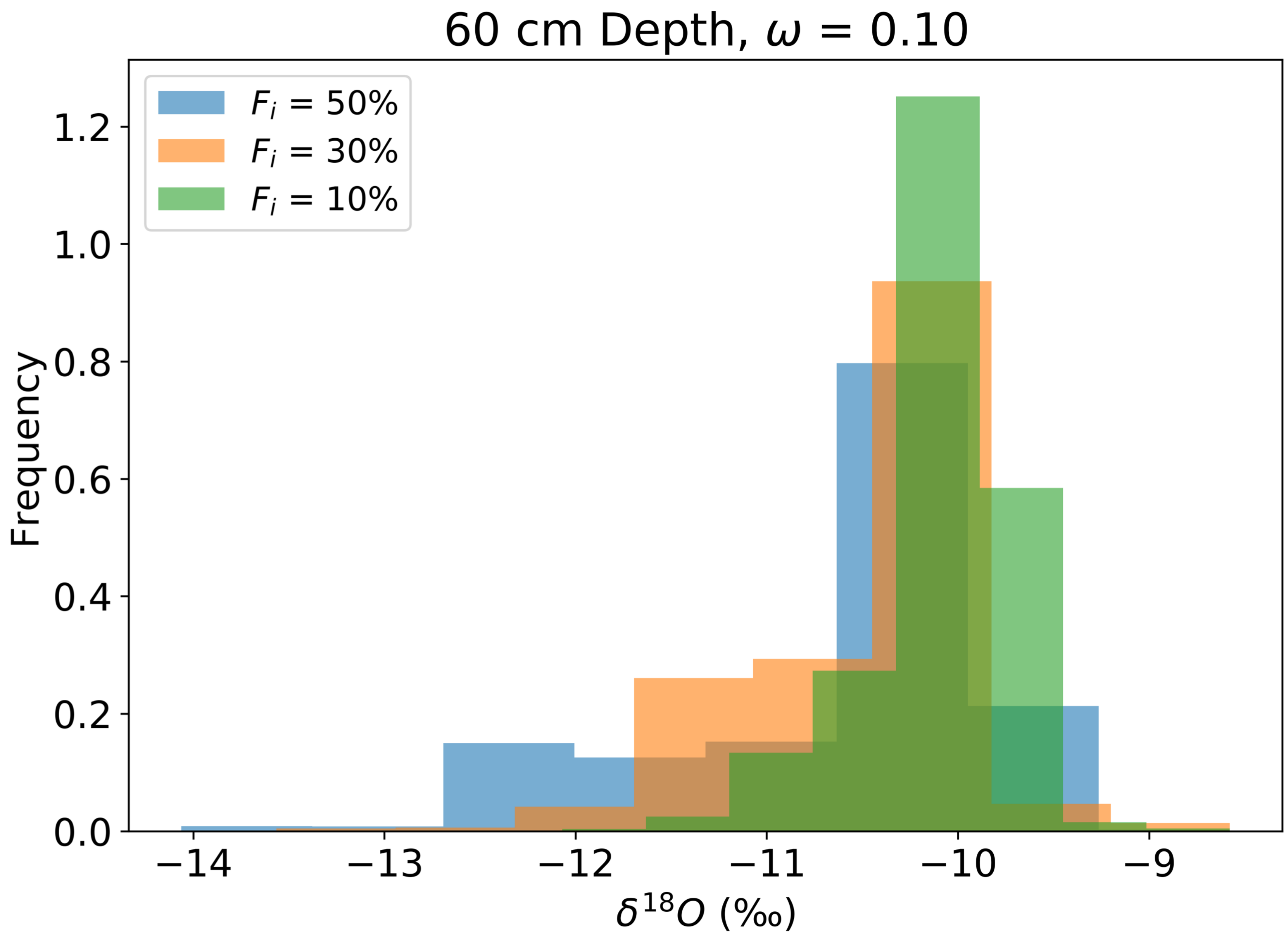
09/14/2006 – 12/20/2006


Transfer Rate (ω)
Immobile Fraction (Fi)
VWC (cm3 cm−3)
Fi = 10%, ω = 0.01
Fi = 10%, ω = 0.1
Fi = 10%, ω = 1
Fi = 30%, ω = 0.01
Fi = 30%, ω = 0.1
Fi = 30%, ω = 1
Fi = 50%, ω = 0.01
Fi = 50%, ω = 0.1
Fi = 50%, ω = 1
0.0
0.2
0.4
0.6
M30
I30
M60
I60
M90
I90


Transfer Rate (ω)
Immobile Fraction (F_i)
F_i = 10%, ω = 0.01
F_i = 10%, ω = 0.1
F_i = 10%, ω = 1
F_i = 30%, ω = 0.01
F_i = 30%, ω = 0.1
F_i = 30%, ω = 1
F_i = 50%, ω = 0.01
F_i = 50%, ω = 0.1
F_i = 50%, ω = 1
$\delta^{18}O$ (‰)
−5
−10
−15
−20
30cm
60cm
90cm



Transfer Rate (ω)
Immobile Fraction (Fi)
Mass Transfer (cm³d⁻¹)
Fi = 10%, ω = 0.01
Fi = 10%, ω = 0.1
Fi = 10%, ω = 1
Fi = 30%, ω = 0.01
Fi = 30%, ω = 0.1
Fi = 30%, ω = 1
Fi = 50%, ω = 0.01
Fi = 50%, ω = 0.1
Fi = 50%, ω = 1
30cm
60cm
90cm
0.04
0.02
0.00


60 cm Depth, ω = 0.10
F_i = 50%
F_i = 30%
F_i = 10%
Frequency
0.0
0.2
0.4
0.6
0.8
1.0
1.2
−14
−13
−12
−11
−10
−9
$\delta^{18}O$ (‰)

Conclusions

- The ensemble of modeled potential hydrologic partitions compared with observed isotope signatures suggests evidence for mobile/immobile fractions arising from ecohydrologic separations in soils
- The results provide evidence for the value of hydrologic signatures in modeling and the interpretation of subsurface transport mechanisms
- Broader implications of this work relate to understanding contaminant and solute movement through environmental systems

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