Demonstration of Well Response Functions

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Abstract

abstract text

1 Introduction

Load the necessary packages

```
library(RColorBrewer, warn.conflicts = FALSE)
Set1 <- brewer.pal(8, "Set1")
library(signal, warn.conflicts = FALSE)

## Loading required package:  MASS

library(kitagawa, warn.conflicts = FALSE)

## Loading required package:  kelvin
## Loading required package:  Bessel
## Loading required package:  Rmpfr
## Loading required package:  gmp
##
## Attaching package:  'gmp'
##
## The following object is masked from 'package:base':
##
##    %*%, apply, crossprod, matrix, tcrossprod

## Loading C code of R package 'Rmpfr': GMP using 64 bits per limb

##
## Attaching package:  'Rmpfr'
##
## The following object is masked from 'package:stats':
##
##    pnorm, print.integrate
##
## The following object is masked from 'package:base':
##
```

```
##    cbind, pmax, pmin, rbind
##
## Loaded kelvin (1.2.2) - Solutions to the Kelvin differential equation.
## Loaded kitagawa (2.1.0) - Spectral response of water wells
```

```
opts_knit$set(verbose = TRUE)
```

Setup some constants

```
S. <- 1e-05  # Storativity [nondimensional]
T. <- 1e-04  # Transmissivity [m**2 / s]
D. <- T./S.  # Diffusivity [m**2 / s]
Ta <- 50  # Aquifer thickness [m] #100
Hw <- z <- 50  # Depth to water table [m] #10
# Using AN01 stats from Kit Tbl 1
Rc. <- 0.075  # Radius of cased portion of well [m]
Lc. <- 570  # Length of cased portion of well [m]
Rs. <- 0.135  # Radius of screened portion of well [m]
Ls. <- 15  # Length of screened portion of well [m]
Vw. <- sensing_volume(Rc., Lc., Rs., Ls.)  # volume of fluid [m**3]
# parameters assumed by well_response: rho=1000 # density of rock [kg/m**3]
# Kf=2.2e9 # Bulk modulus of fluid [Pascals] grav=9.81 # gravitational
# acceleration [m/s**2]
rhog <- 9.81 * 1000
# Kitagawa Fig 7: Ku B / Kw Aw = 3 => Aw==4.8 at 40GPa
Ku. <- 4e+10  # Bulk modulus [Pascals]
B. <- 0.5  # Skemptons ratio [nondimensional]
# Frequencies
Q <- 10^seq(-5, 2, by = 0.05)  # [nondimensional] == z**2 omega / 2 D
lQ <- log10(Q)
omega <- omega_norm(Q, z, D., invert = TRUE)  # [Hz] == Q * 2 * Diffus / z**2
```

2 Sealed well response

2.1 Strain: Kitagawa (2011)

Kitagawa et al. (2011)

```
asP <- FALSE
wrsp <- well_response(omega, T. = T., S. = S., Vw. = Vw., Rs. = Rs., Ku. = Ku.,
    B. = B., Avs = 1, Aw = 1, as.pressure = asP)
crsp <- wrsp[["Response"]][, 2]  # complex response
# Amplitude
kGain <- Mod(crsp)/Ku./B.
# Phase
kPhs <- Arg(crsp)  # will wrap to -pi/pi
```

```r
kuPhs <- signal::unwrap(kPhs, tol = pi/30)
```

3 Open well response

3.1 Pressure head: Cooper et al (1965)

Cooper et al. (1965)

```r
ZasP <- FALSE
wrsp <- open_well_response(omega, T. = T., S. = S., Ta = Ta, Hw = Hw, model = "cooper",
    as.pressure = ZasP)
crsp <- wrsp[["Response"]][, 2]  # complex response
# Amplitude
cGain <- Mod(crsp)
# Phase
cPhs <- Arg(crsp)  # will wrap to -pi/pi
cuPhs <- signal::unwrap(cPhs, tol = pi/30)
```

3.2 Pressure head: Hsieh (1987)

Hsieh et al. (1987)

```r
wrsp <- open_well_response(omega, T. = T., S. = S., Ta = Ta, Hw = Hw, model = "hsieh",
    as.pressure = ZasP)
crsp <- wrsp[["Response"]][, 2]  # complex response
# Amplitude
hGain <- Mod(crsp)
# Phase
hPhs <- Arg(crsp)  # will wrap to -pi/pi
huPhs <- signal::unwrap(hPhs, tol = pi/30)
```

3.3 Pressure head: Liu (1989)

Liu et al. (1989)

```r
wrsp <- open_well_response(omega, T. = T., S. = S., Ta = Ta, Hw = Hw, model = "liu",
    as.pressure = ZasP)
crsp <- wrsp[["Response"]][, 2]  # complex response
# Amplitude
lGain <- Mod(crsp)
# Phase
lPhs <- Arg(crsp)  # will wrap to -pi/pi
luPhs <- signal::unwrap(lPhs, tol = pi/30)
```

3.4 Strain: Rojstaczer (1988)

Rojstaczer (1988b,a)

```
wrsp <- open_well_response(omega, T. = T., S. = S., z = z, model = "rojstaczer",
    as.pressure = asP)
crsp <- wrsp[["Response"]][, 2]  # complex response
# Amplitude
rGain <- Mod(crsp)
# Phase
rPhs <- Arg(crsp)  # will wrap to -pi/pi
ruPhs <- signal::unwrap(rPhs, tol = pi/30)
```

4 Model Comparisons

4.1 Harmonic Strain Response

4.2 Harmonic Pressure Head Responses (all open)

References

Cooper, H. H., Bredehoeft, J. D., Papadopulos, I. S., and Bennett, R. R. (1965). The response of well-aquifer systems to seismic waves. *Journal of Geophysical Research*, 70(16):3915–3926.

Hsieh, P. A., Bredehoeft, J. D., and Farr, J. M. (1987). Determination of aquifer transmissivity from Earth tide analysis. *Water Resources Research*, 23(10):1824–1832.

Kitagawa, Y., Itaba, S., Matsumoto, N., and Koizumi, N. (2011). Frequency characteristics of the response of water pressure in a closed well to volumetric strain in the high-frequency domain. *J. Geophys. Res.*, 116(B8).

Liu, L.-B., Roeloffs, E., and Zheng, X.-Y. (1989). Seismically induced water level fluctuations in the Wali Well, Beijing, China. *Journal of Geophysical Research: Solid Earth*, 94(B7):9453–9462.

Rojstaczer, S. (1988a). Determination of fluid flow properties from the response of water levels in wells to atmospheric loading. *Water Resources Research*, 24(11):1927–1938.

Rojstaczer, S. (1988b). Intermediate period response of water levels in wells to crustal strain: Sensitivity and noise level. *Journal of Geophysical Research: Solid Earth*, 93(B11):13619–13634.

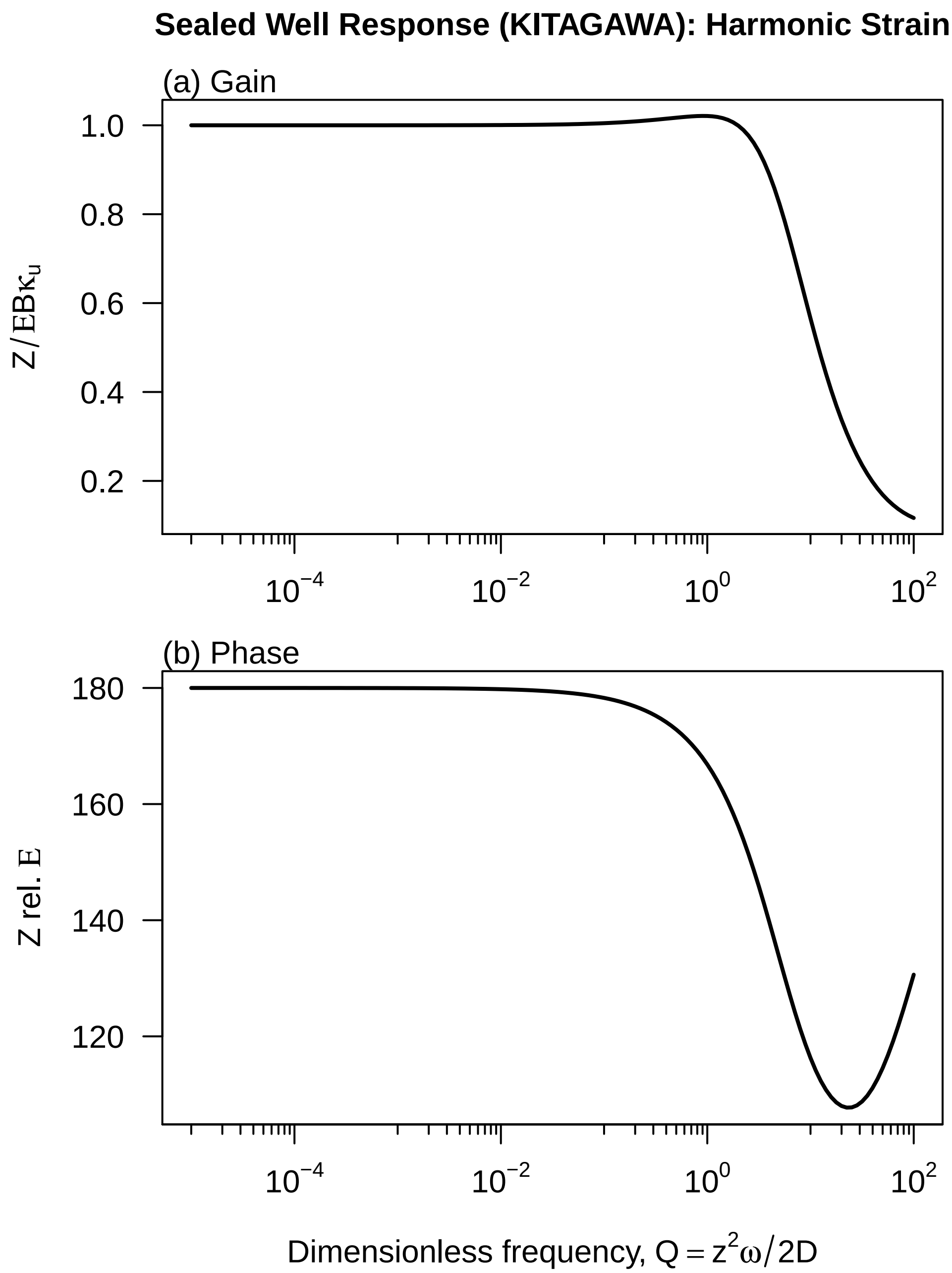

Figure 1: The response of a sealed well to harmonic areal strain using the Kitagawa model.

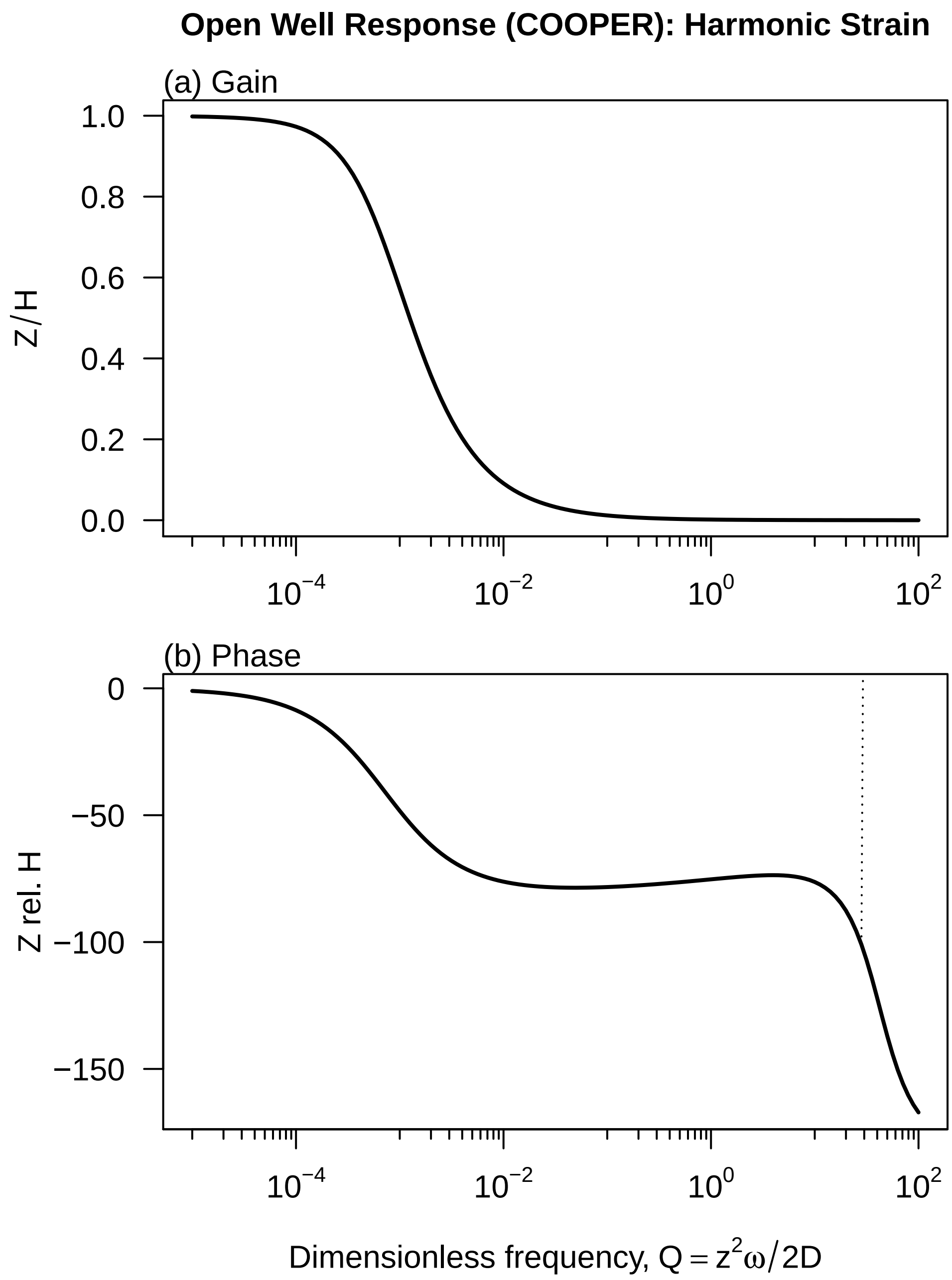

Figure 2: The response of an open well to harmonic areal strain using the Cooper model. Frequency is dimensionless, based on the well-depth z and the diffusivity D.

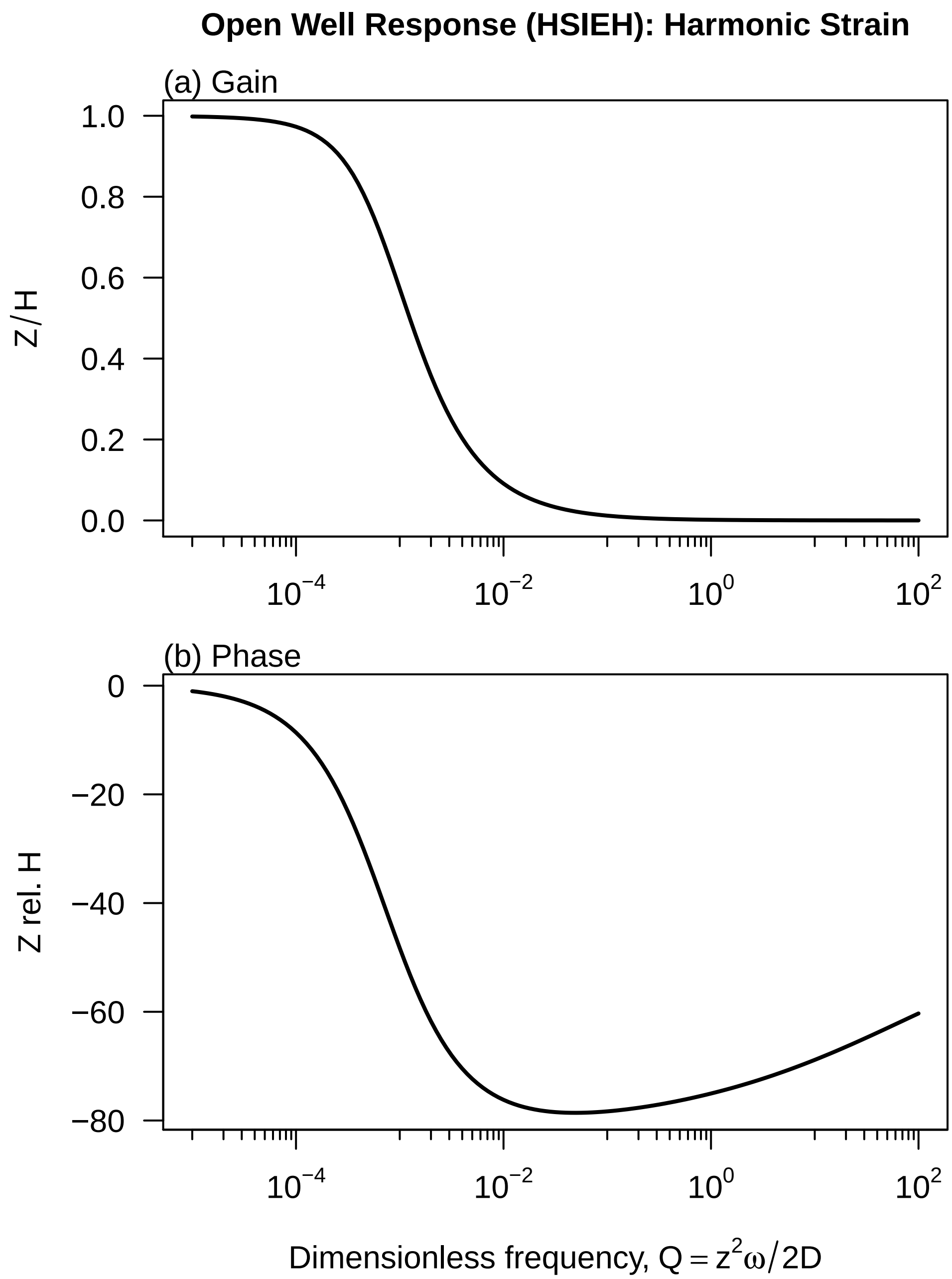

Figure 3: The response of an open well to harmonic areal strain using the Hsieh model. Frequency is dimensionless, based on the well-depth z and the diffusivity D.

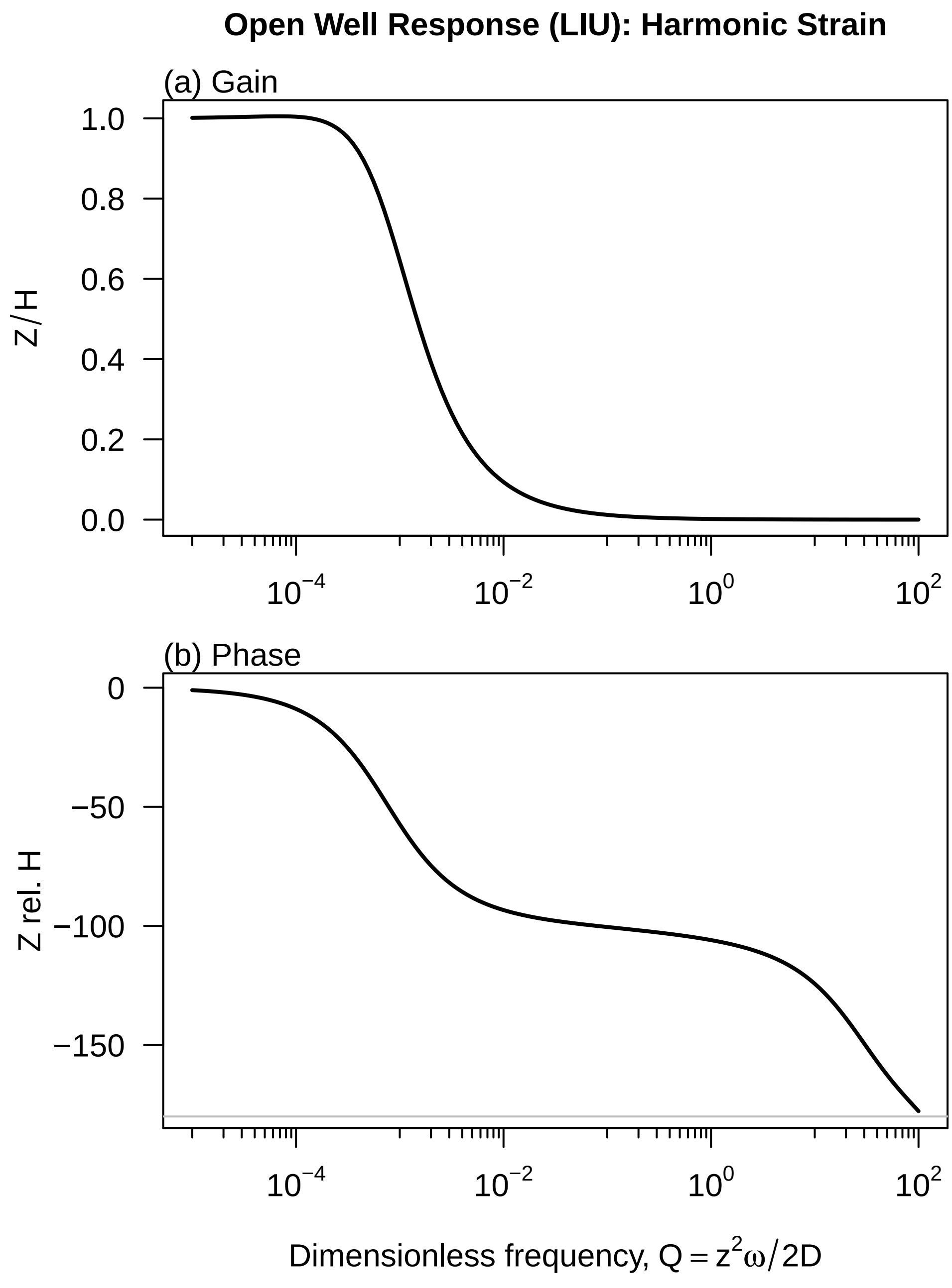

Figure 4: The response of an open well to harmonic areal strain using the Liu model. Frequency is dimensionless, based on the well-depth z and the diffusivity D.

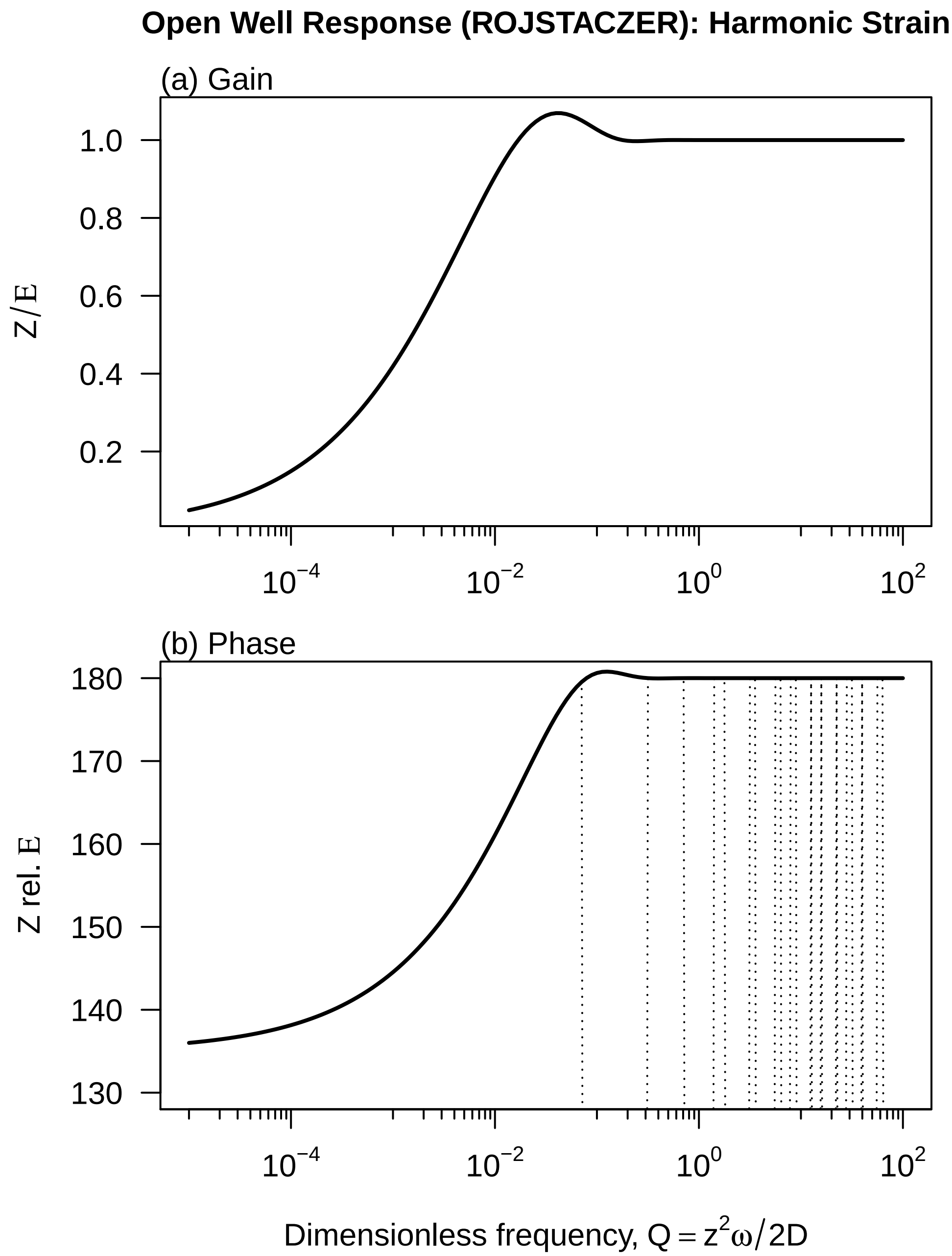

Figure 5: The response of an open well to harmonic areal strain using the Rojstaczer model. Modified from Rojstaczer (1988b, Fig. 3). Frequency is dimensionless, based on the well-depth z and the diffusivity D.

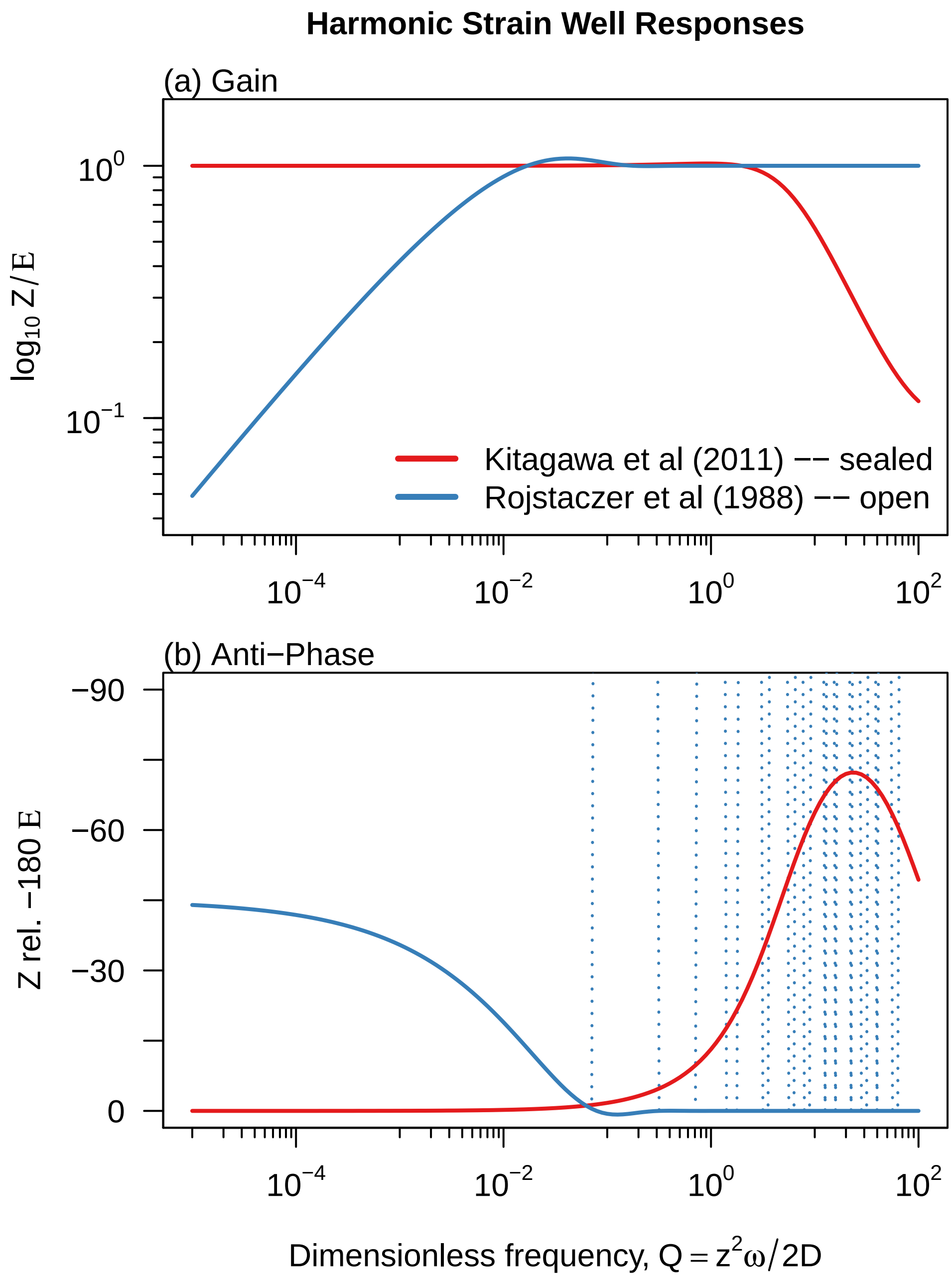

Figure 6: A comparison of harmonic strain well responses.

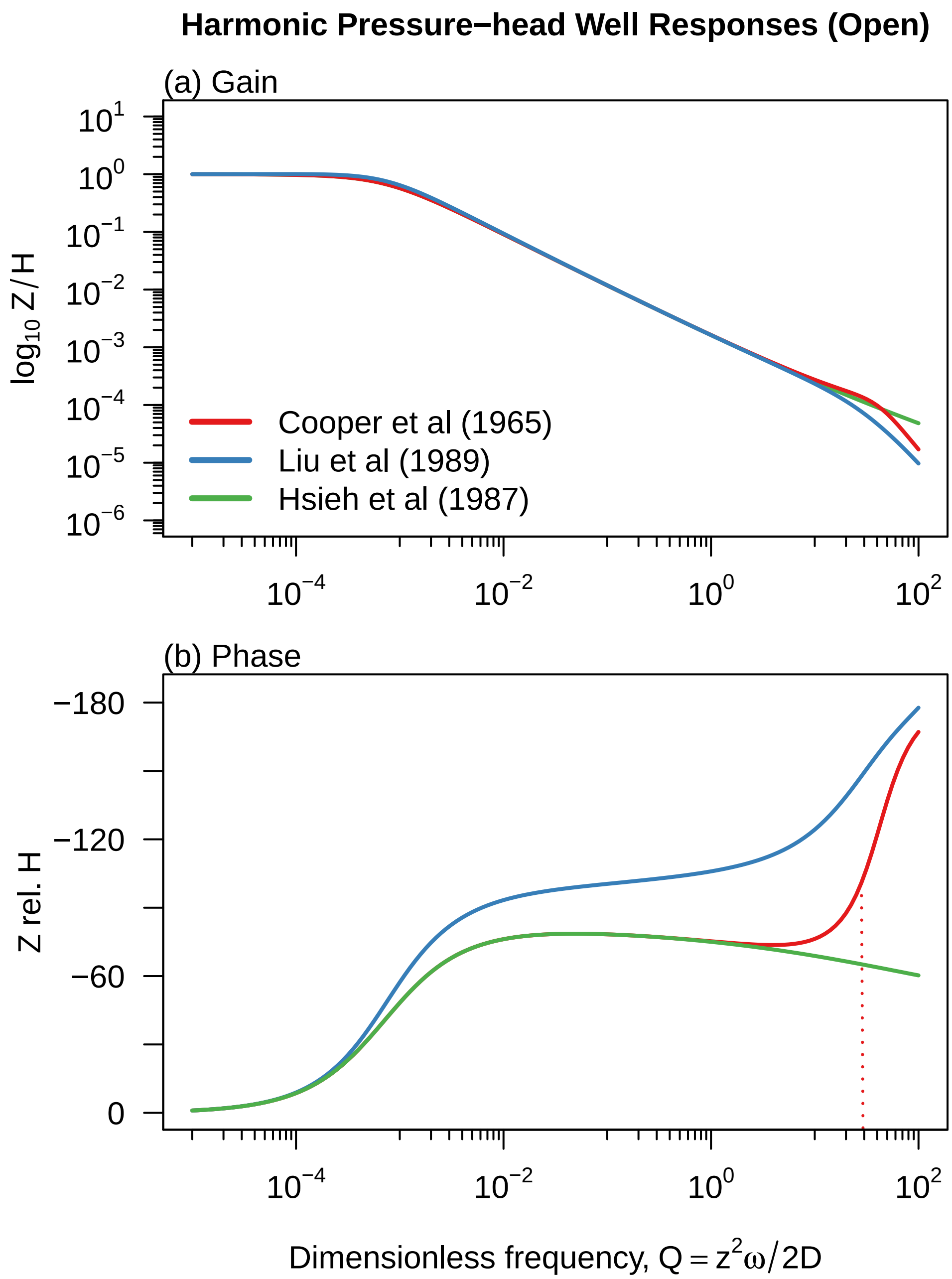

Figure 7: A comparison of harmonic pressure-head well responses (all open) from Cooper et al. (1965); Hsieh et al. (1987); Liu et al. (1989).