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
```

2 Sealed well response

2.1 Strain: Kitagawa (2011)

Kitagawa et al. (2011)

```
# some constants Kitagawa Fig 7 and Tab 1
S. <- 1e-06  # Storativity [nondimensional]
T. <- 1e-06  # Transmissivity [m**2 / s]
D. <- T./S.  # Diffusivity [m**2 / s]
Rs. <- 0.135  #
z <- 1
# Nondimensional frequencies
Q <- 10^seq(-5, 2, by = 0.05)  # == z**2 omega / 2 D
lQ <- log10(Q)
omega <- omega_norm(Q, z, D., invert = TRUE)  # == Q * 2 * Diffus / z**2
# calculate response Fig 7 Ku B / Kw Aw = 3 => Aw==4.8 at 40GPa Using AN01
# stats
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.)  # m**3
# parameters assumed by well_response: rho=1000, kg/m**3 Kf=2.2e9, Pa
# grav=9.81, m/s2
rhog <- 9.81 * 1000
Ku. <- 4e+10  # Bulk modulus
B. <- 0.5  # Skemptons coeff
wrsp <- well_response(omega, T. = T., S. = S., Vw. = Vw., Rs. = Rs., Ku. = Ku.,
    B. = B., Avs = 1, Aw = 1)  #4.8)
crsp <- wrsp[["Response"]][, 2]  # complex response
# Amplitude
kGain <- Mod(crsp) * rhog/Ku./B.
# Phase
kPhs <- Arg(crsp)  # will wrap to -pi/pi
kuPhs <- signal::unwrap(kPhs, tol = pi/30)
```

3 Open well response

3.1 Pressure head: Cooper et al (1965)

Cooper et al. (1965)

```
wrsp <- open_well_response(omega, T. = T., S. = S., model = "cooper")

## Warning:  water column height 'Hw' not given.  using default
## Warning:  aquifer thickness 'Ta' not given.  using default
## Warning:  this model has not yet been verified.

crsp <- wrsp[["Response"]][, 2]  # complex response
# invalid above Q ~ 30 crsp[Q>=30] <- NA 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)

```
wrsp <- open_well_response(omega, T. = T., S. = S., model = "hsieh")

## Warning:  water column height 'Hw' not given.  using default
## Warning:  aquifer thickness 'Ta' not given.  using default
## Warning:  this model has not yet been verified.

crsp <- wrsp[["Response"]][, 2]  # complex response
# invalid above Q ~ 30 crsp[Q>=30] <- NA 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)

```
wrsp <- open_well_response(omega, T. = T., S. = S., model = "liu")

## Warning:  water column height 'Hw' not given.  using default
## Warning:  aquifer thickness 'Ta' not given.  using default
## Warning:  this model has not yet been verified.
```

```
crsp <- wrsp[["Response"]][, 2]  # complex response
# invalid above Q ~ 30 crsp[Q>=30] <- NA 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 = FALSE)
crsp <- wrsp[["Response"]][, 2]  # complex response
# Amplitude
As <- 0.05  # cm/nE
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.

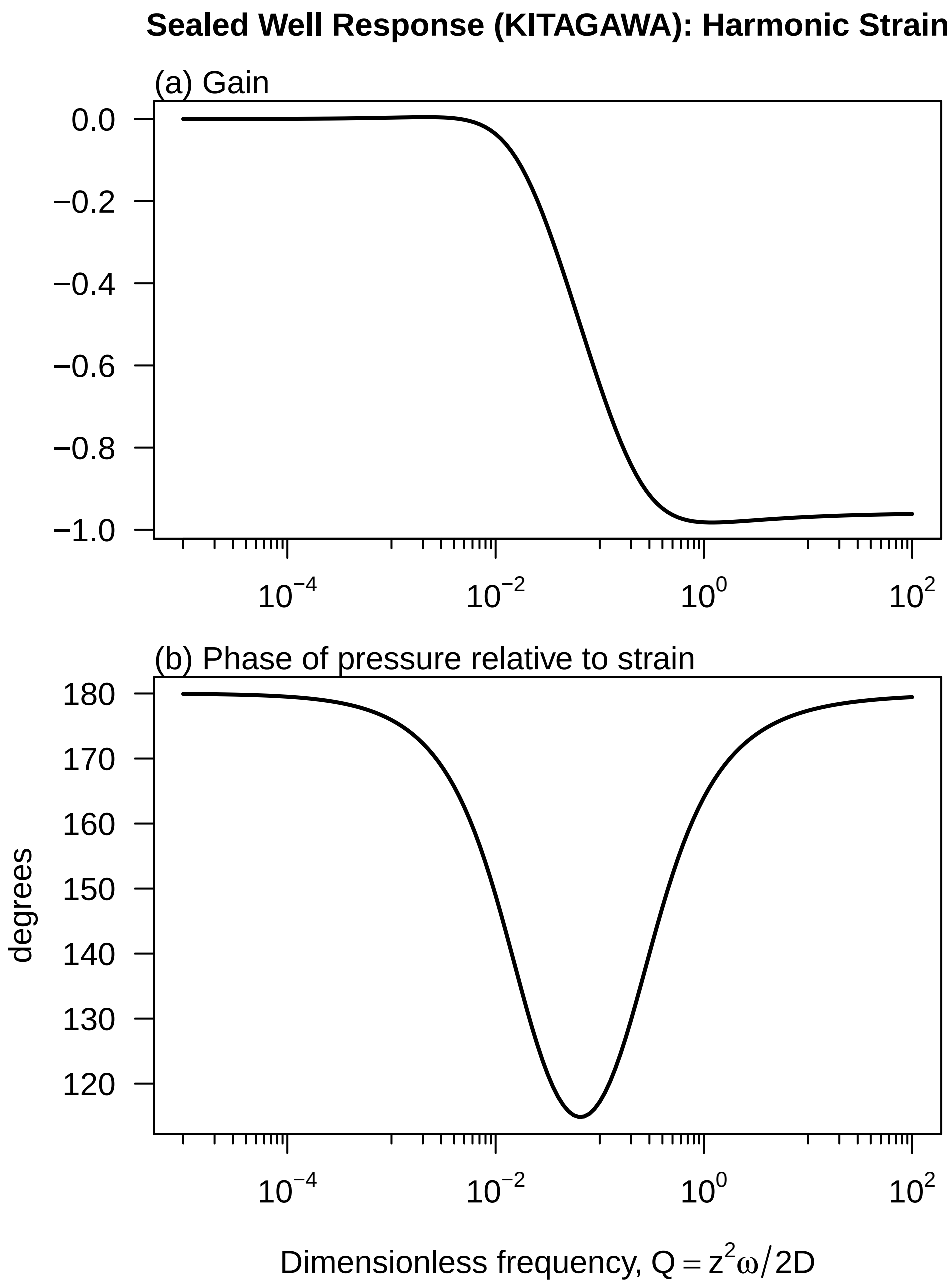

Figure 1: The response of a sealed well to harmonic areal strain using the Kitagawa model.

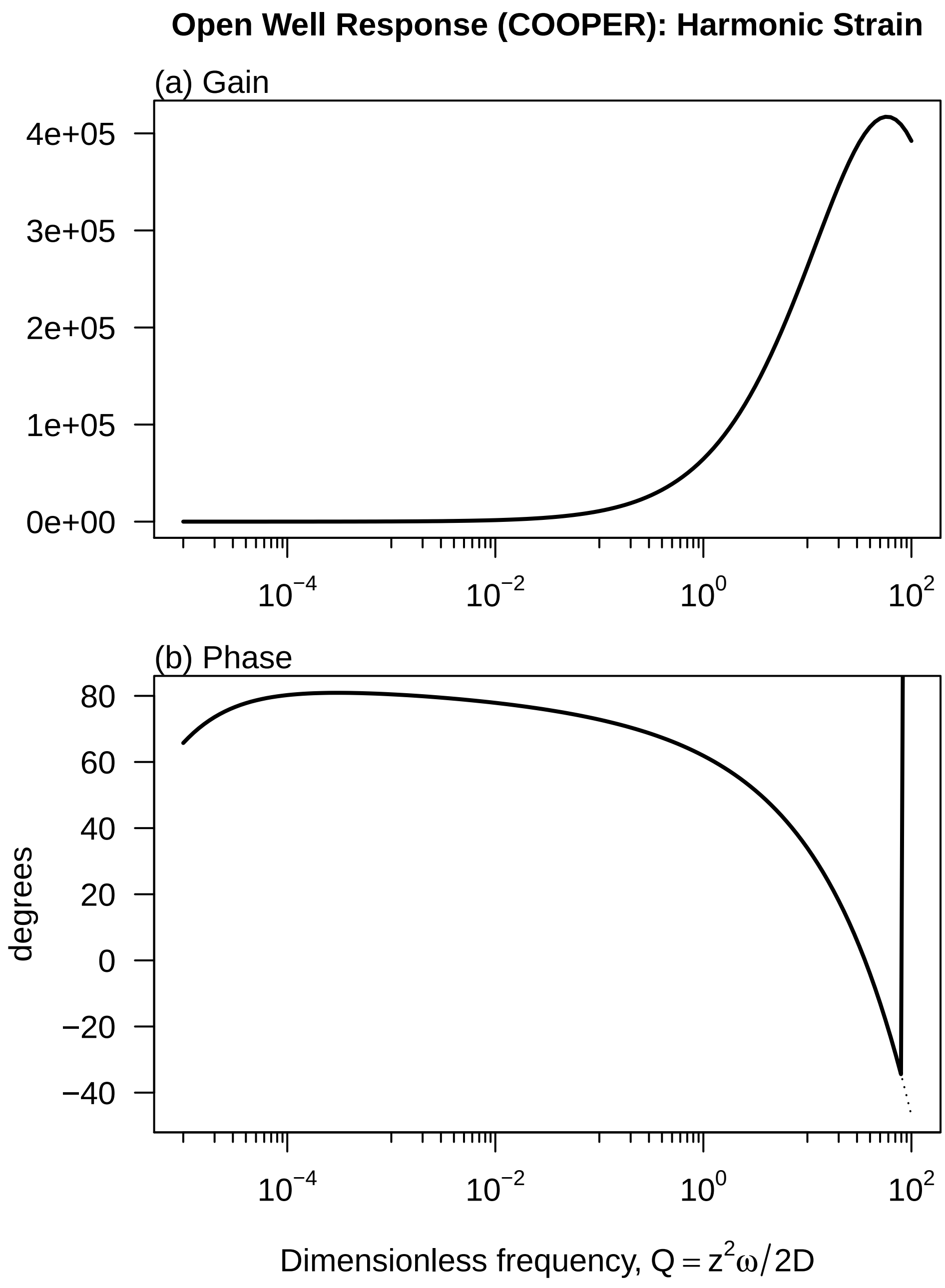

Figure 2: The response of an open well to harmonic areal strain using the Cooper model.

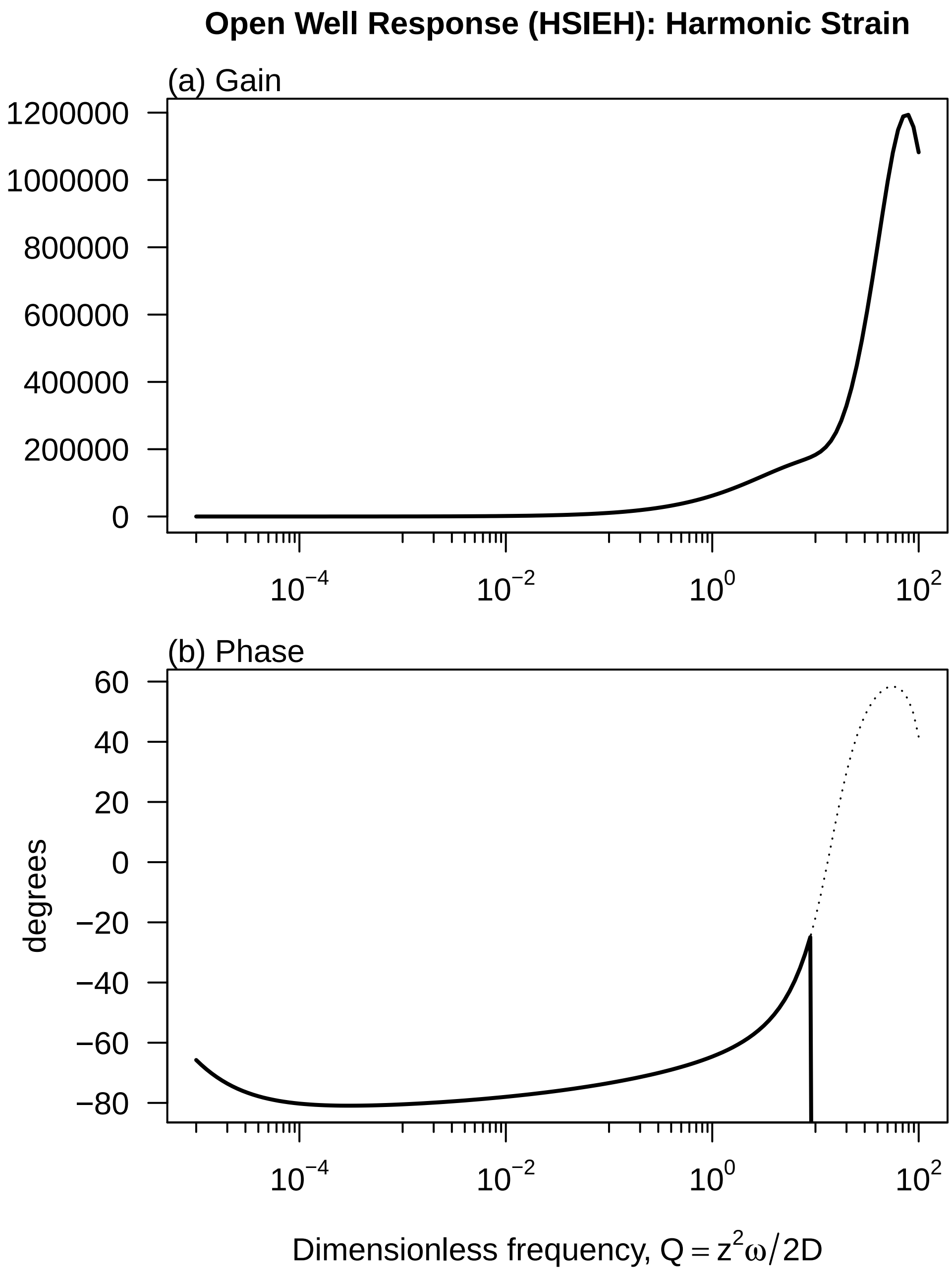

Figure 3: The response of an open well to harmonic areal strain using the Hsieh model.

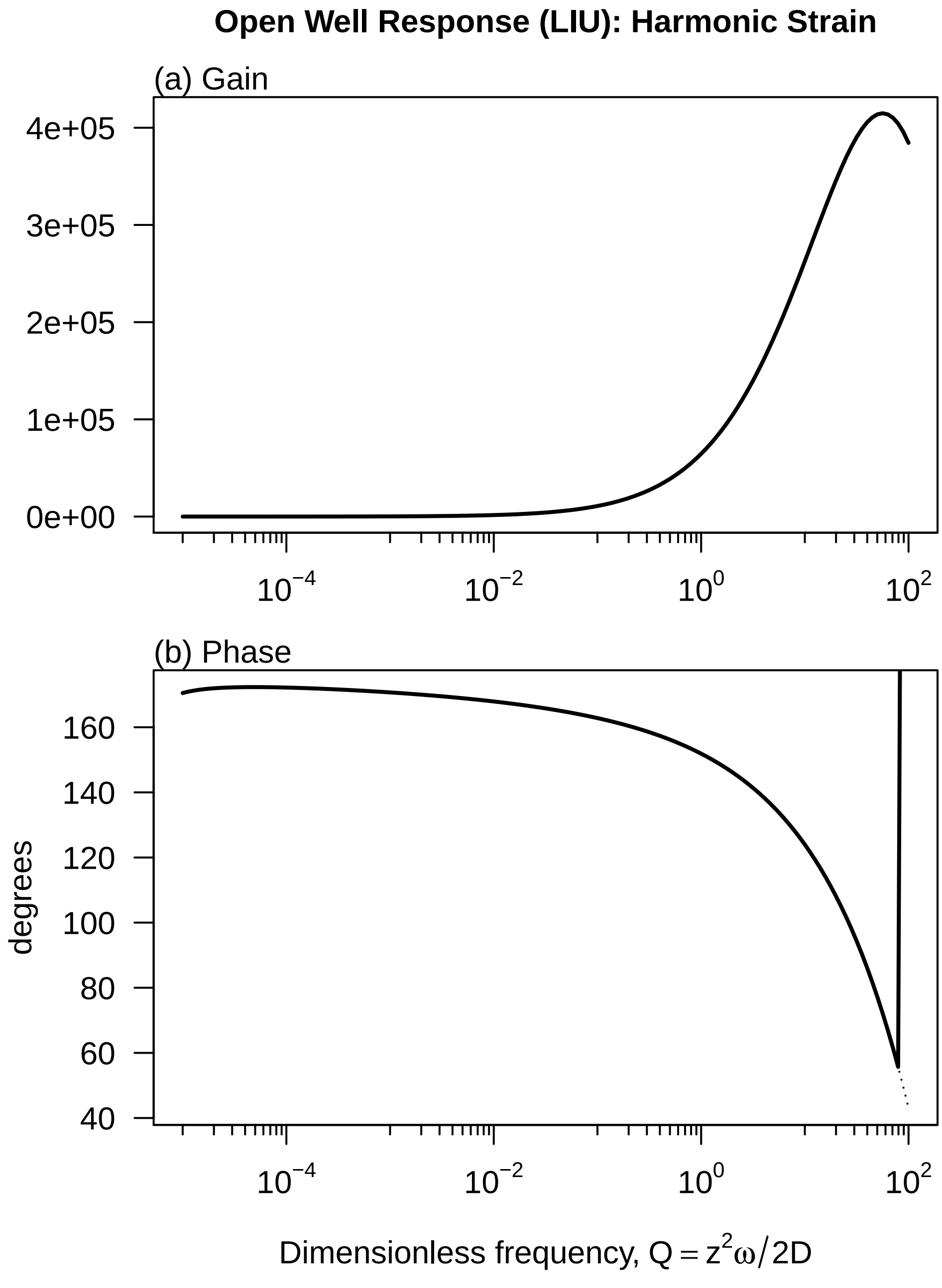

Figure 4: The response of an open well to harmonic areal strain using the Liu model.

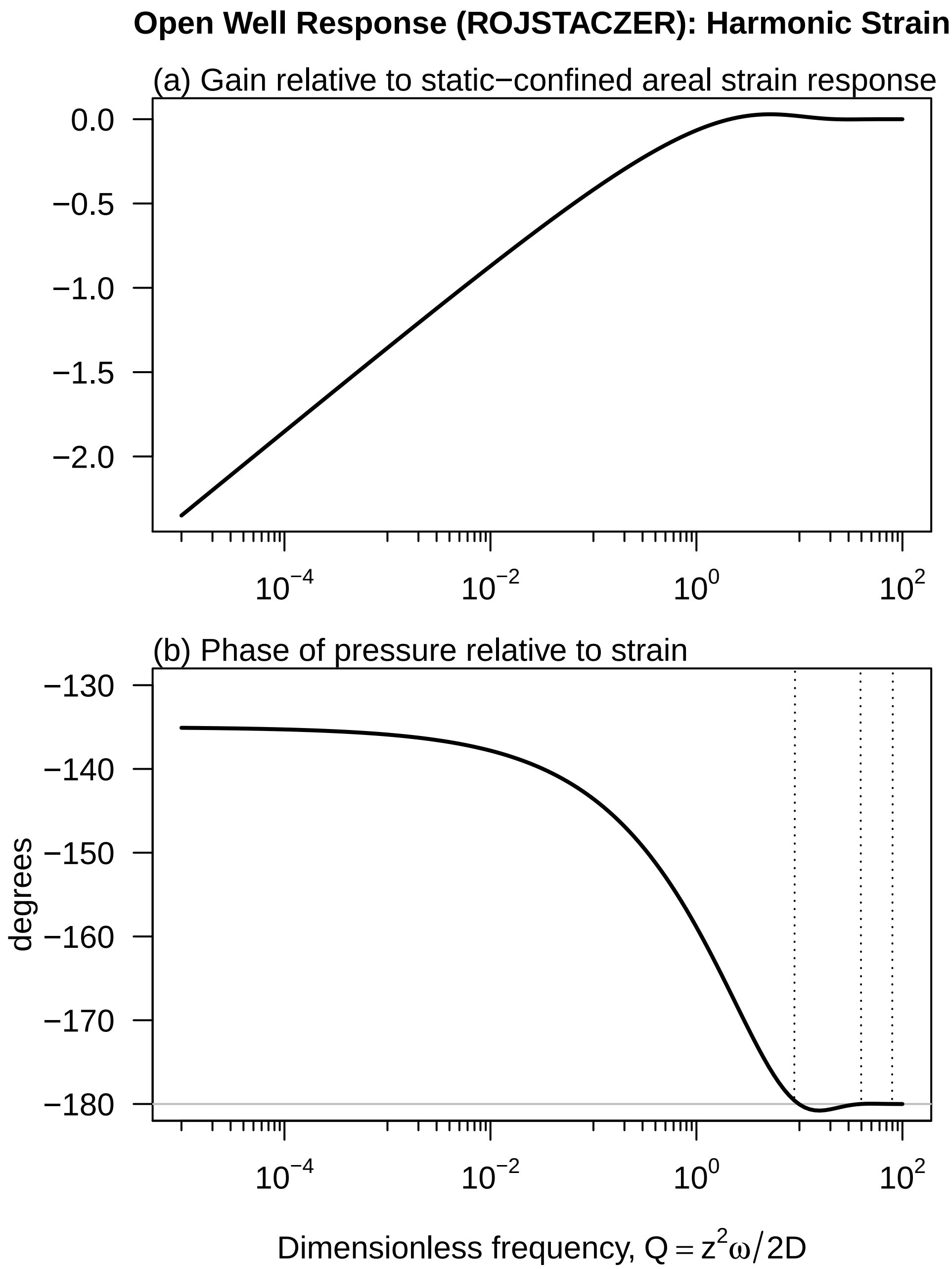

Figure 5: The response of an open well to harmonic areal strain using the Rojstaczer model. Modified from Rojstaczer (1988b, Fig. 3). Frequency is dimensionless, based on the well-depth z and the diffusivity D.

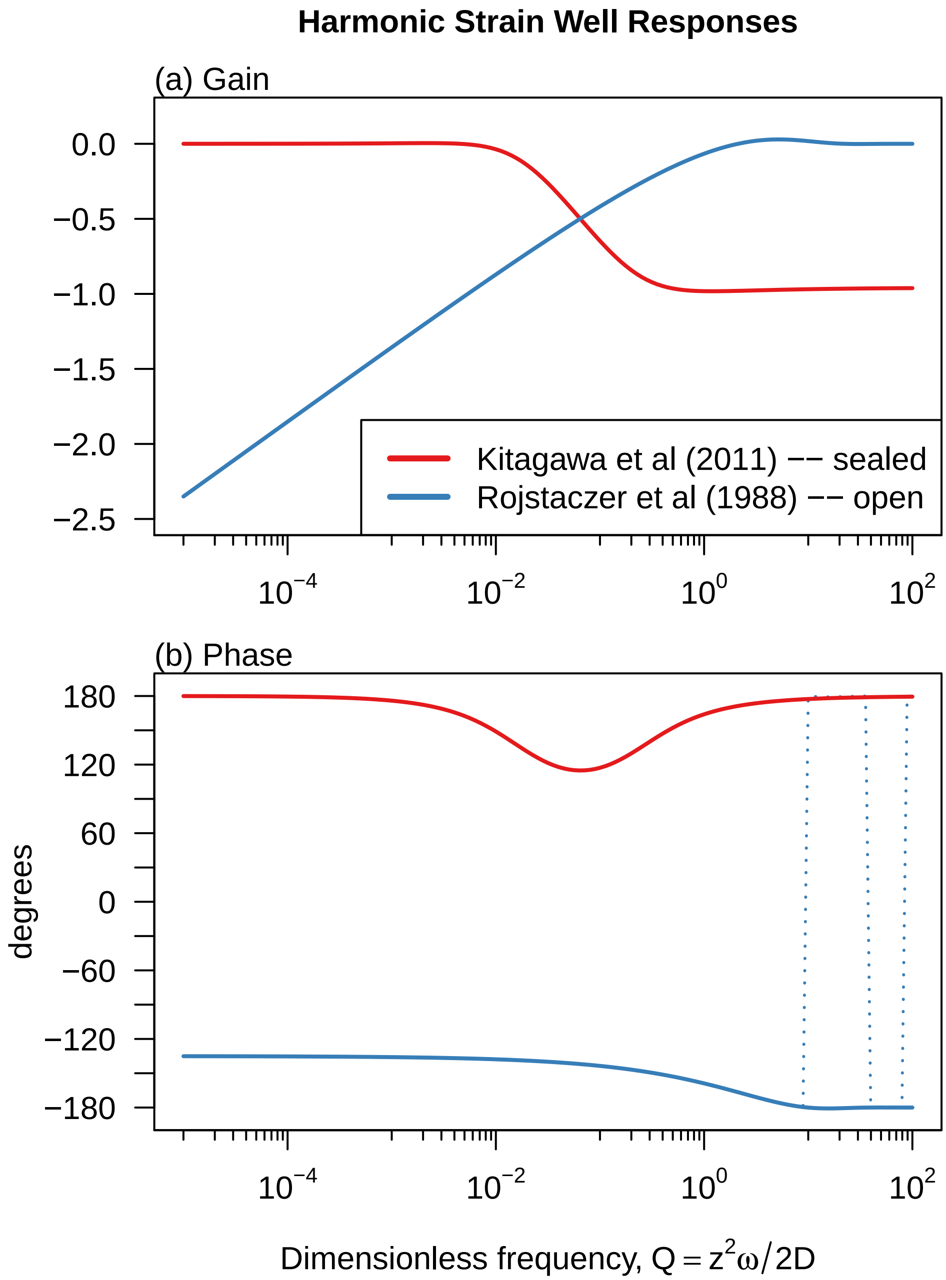

Figure 6: A comparison of harmonic strain well responses.

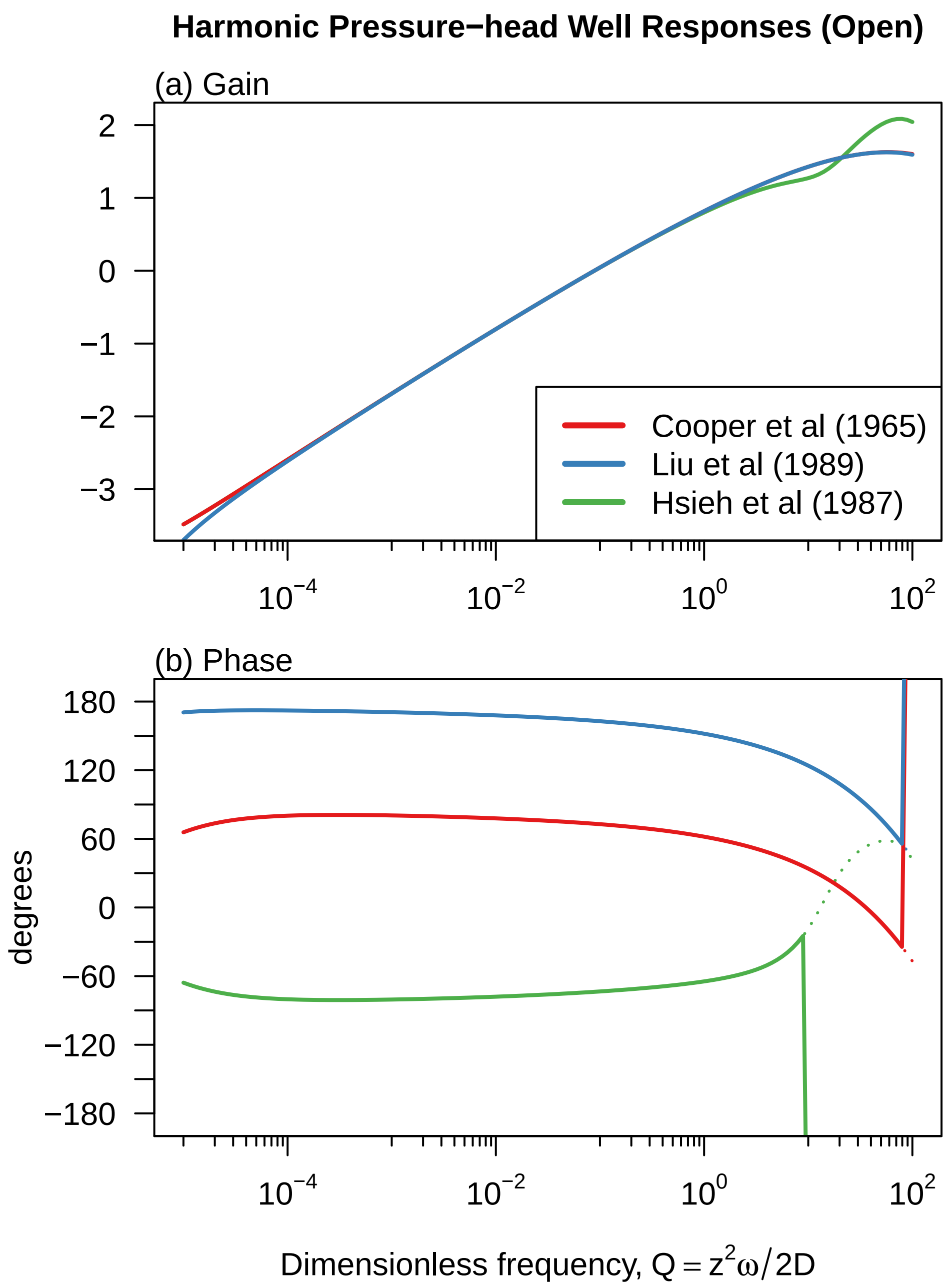

Figure 7: A comparison of harmonic pressure-head well responses (all open).