

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 # Skemptions coeff
WR <- well_response(omega, T. = T., S. = S., Vw. = Vw., Rs. = Rs., Ku. = Ku.,
  B. = B., Avs = 1, Aw = 1) #4.8)
rsp <- WR[["Response"]]
# Amplitude
kGain <- rsp[, 2] * rhog/Ku./B.
# Phase
kPhs <- rsp[, 3] # 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., Papadopoulos, 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.

Sealed Well Response (KITAGAWA): Harmonic Strain

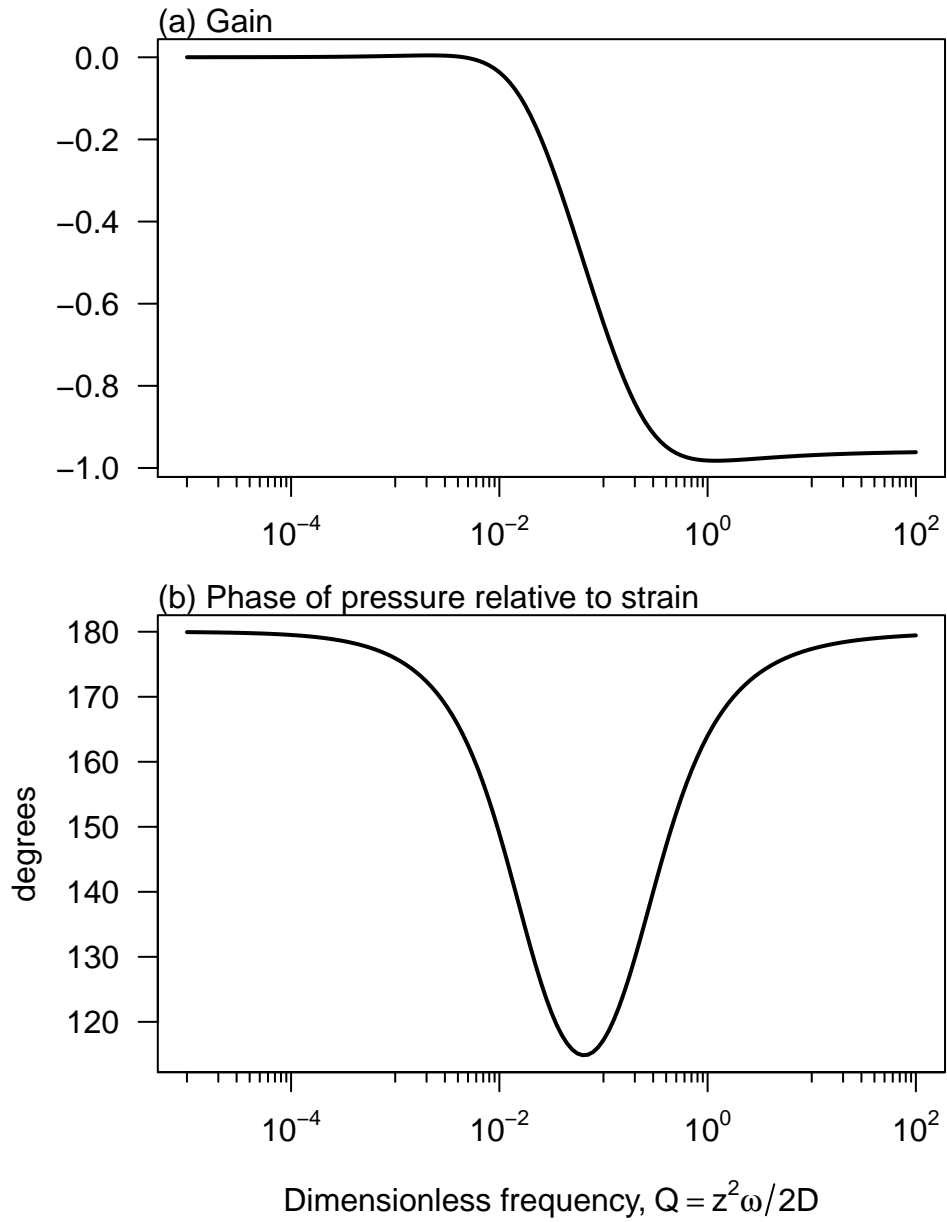


Figure 1: The response of a sealed well to harmonic areal strain using the Kitagawa model.

Open Well Response (COOPER): Harmonic Strain

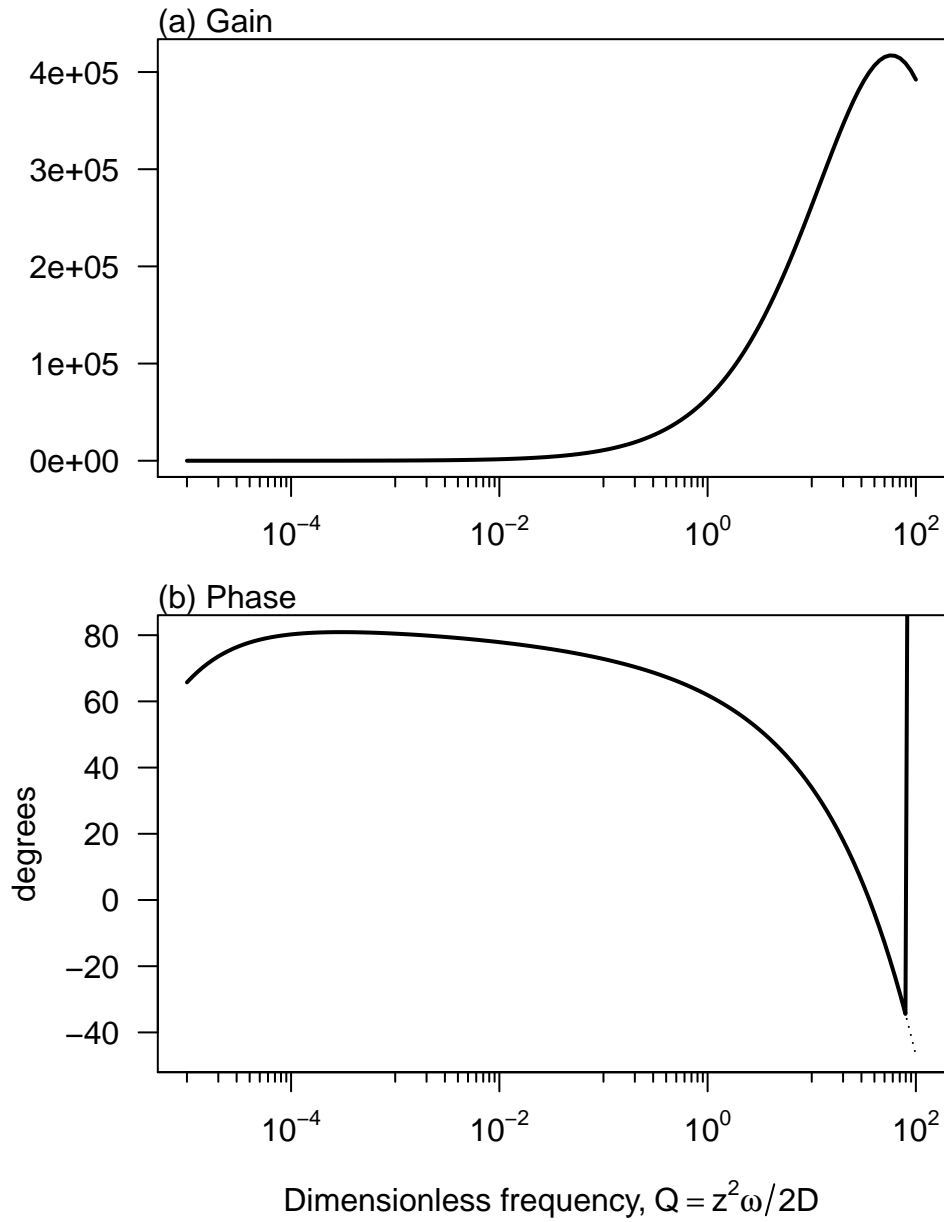


Figure 2: The response of an open well to harmonic areal strain using the Cooper model.

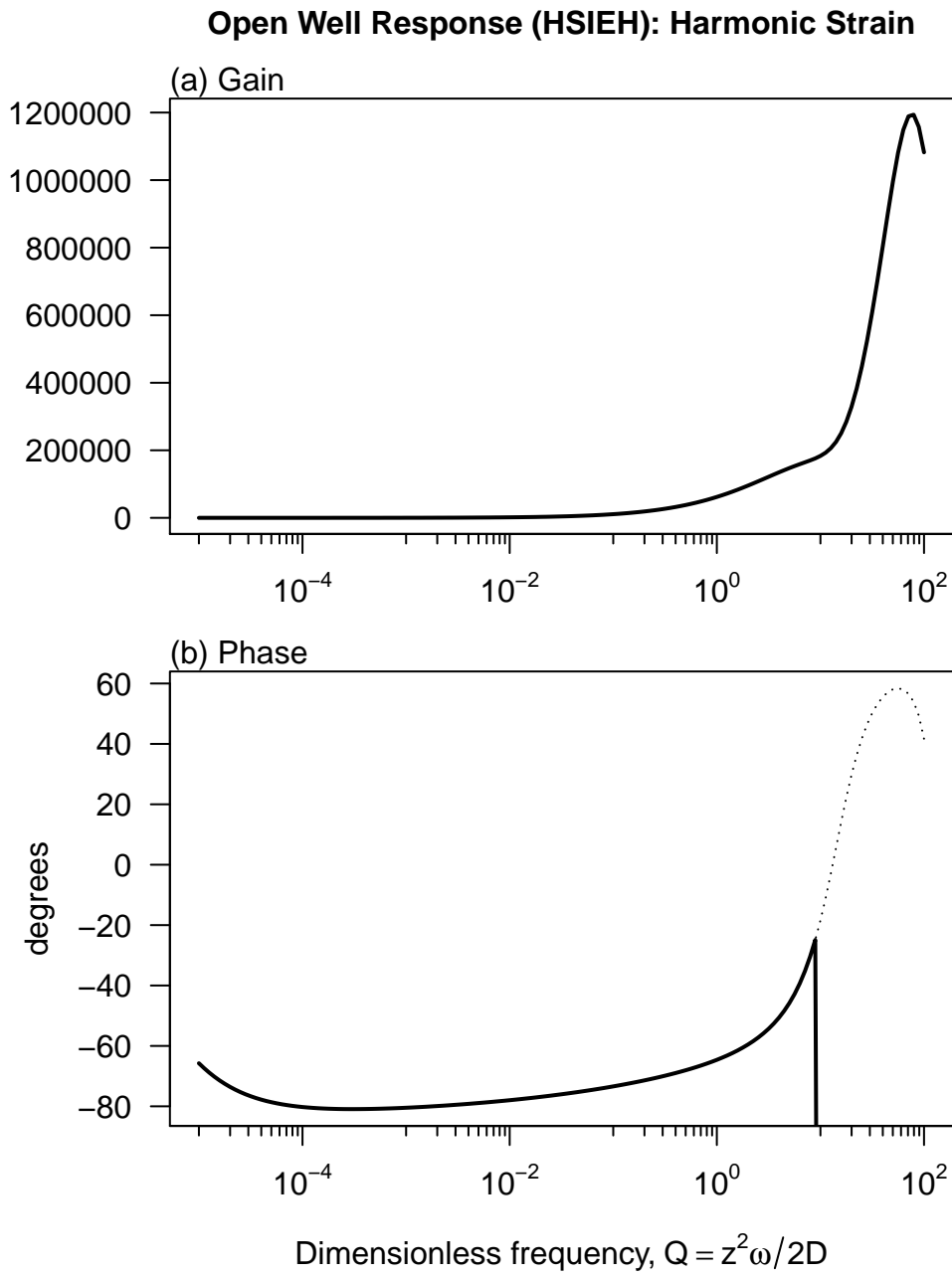


Figure 3: The response of an open well to harmonic areal strain using the Hsieh model.

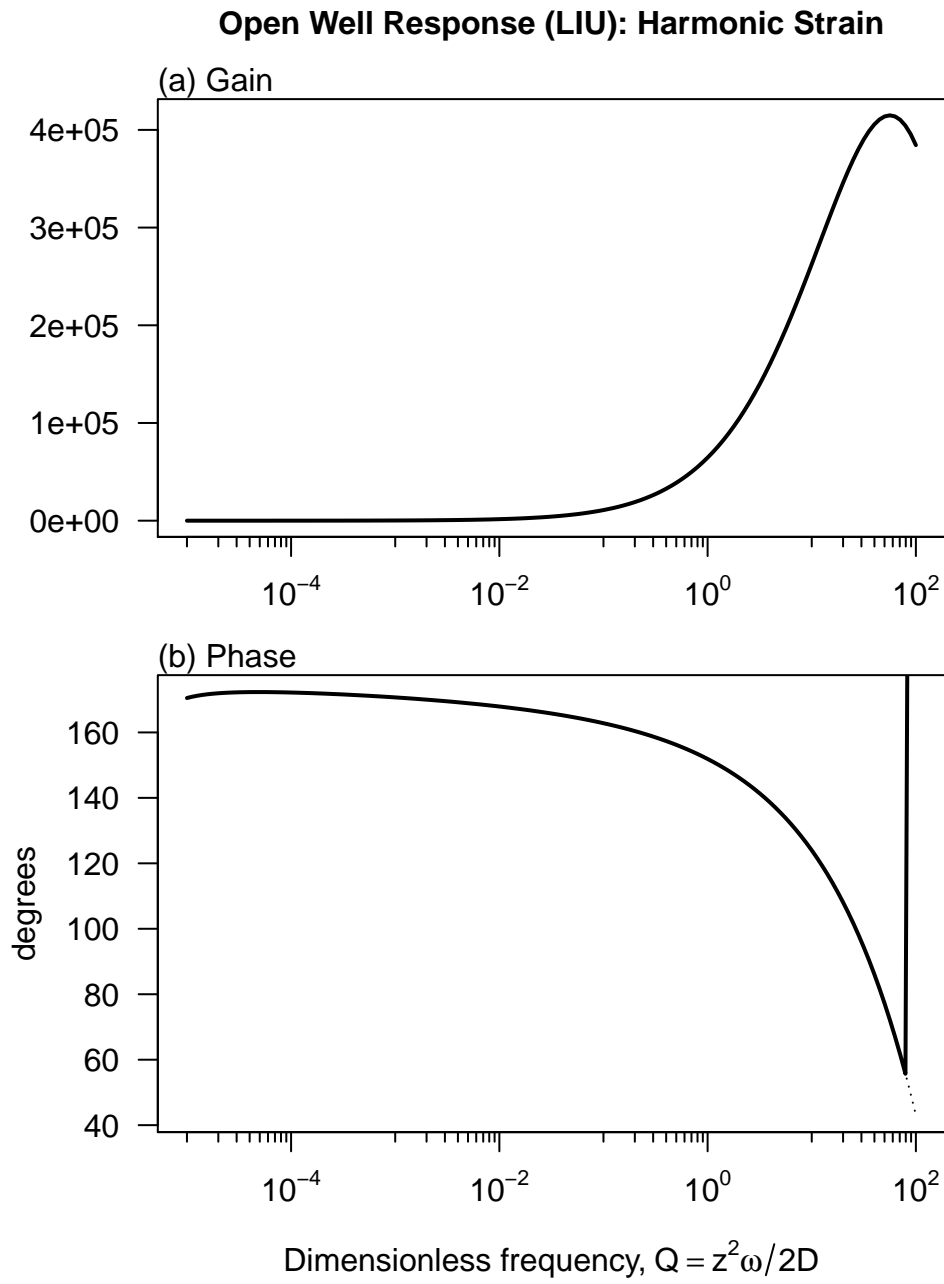


Figure 4: The response of an open well to harmonic areal strain using the Liu model.

Open Well Response (ROJSTACZER): Harmonic Strain

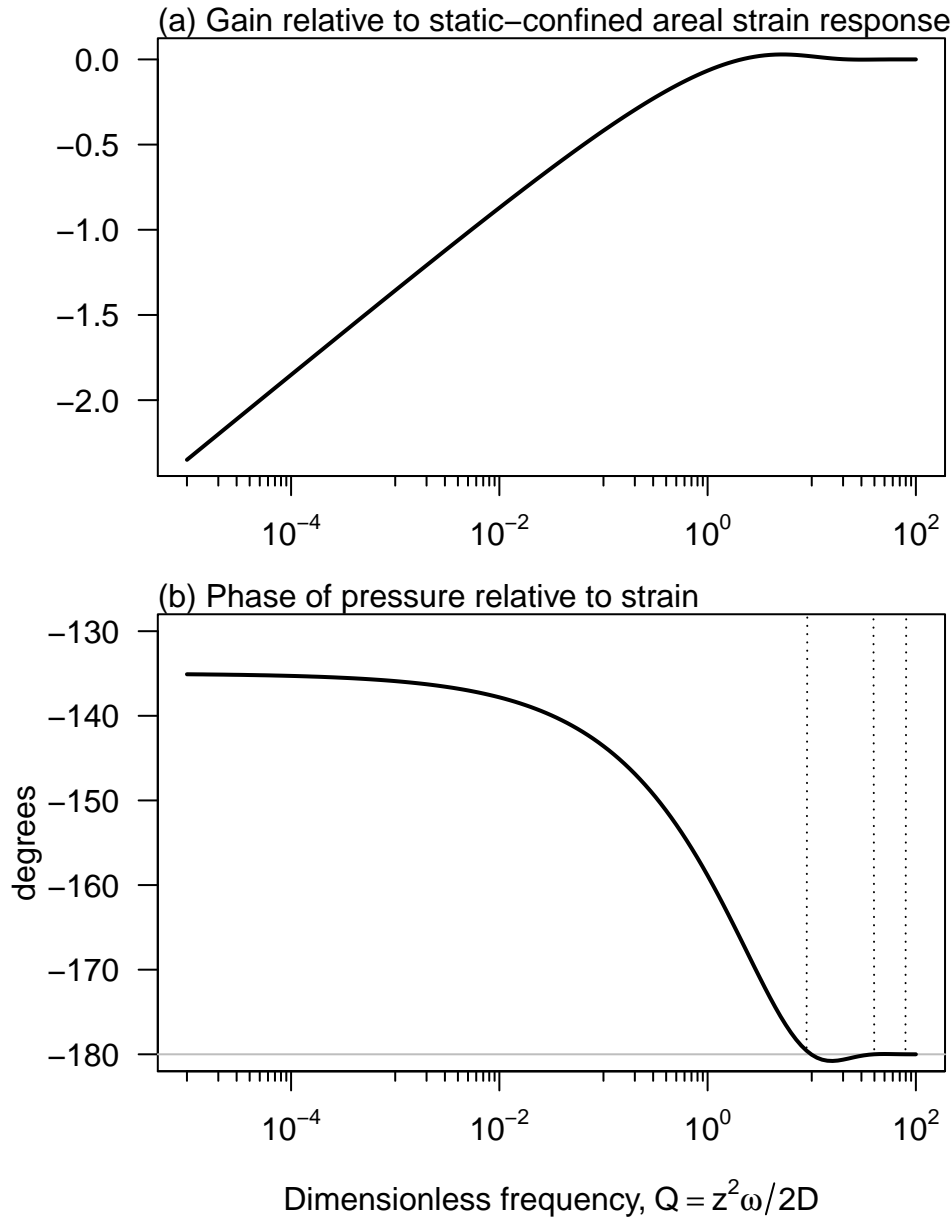


Figure 5: The response of an open well to harmonic areal strain using the Rojstaczer model. Modified from Rojstaczer (1988b, Fig. 3). Frequency is dimensionless, based on the well-depth z and the diffusivity D .

Harmonic Strain Well Responses

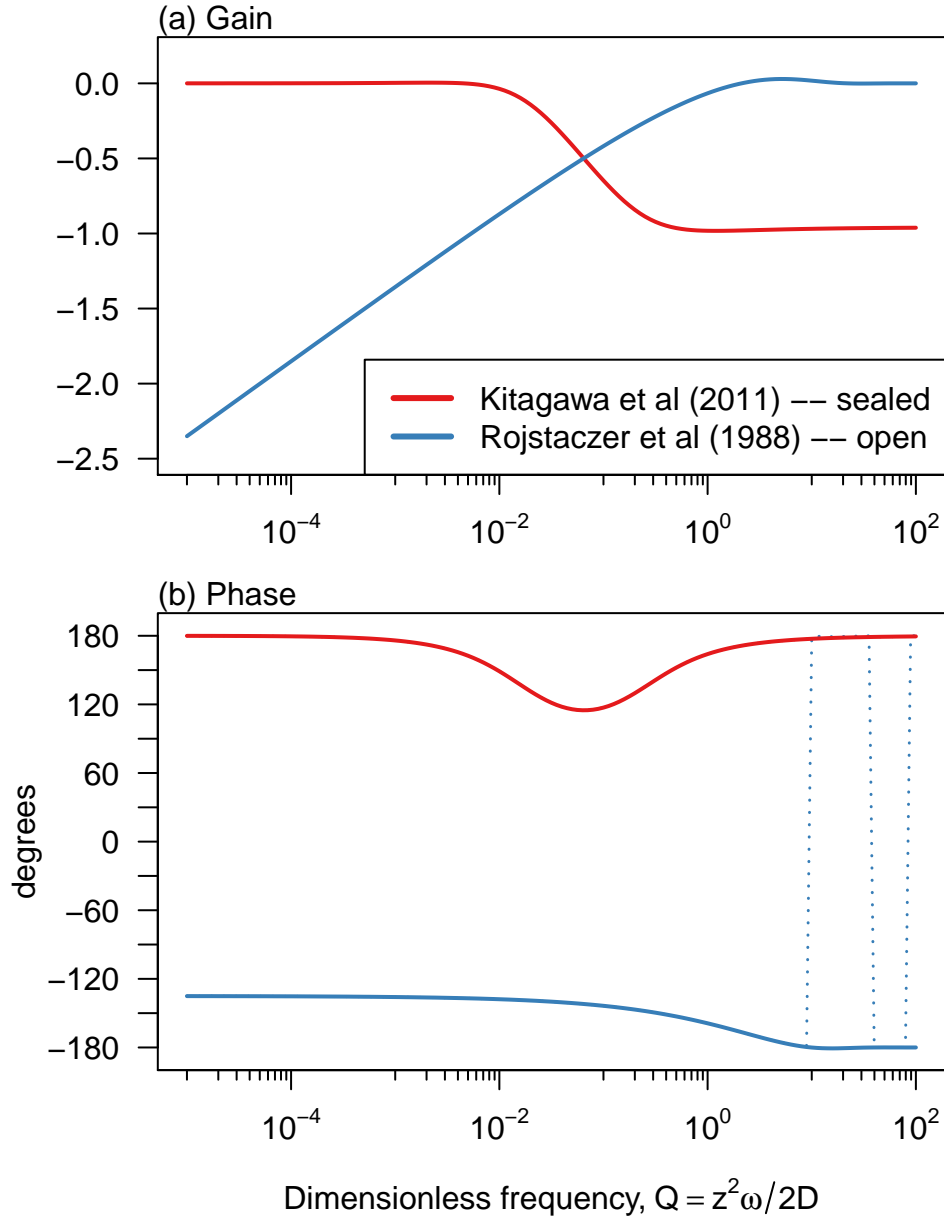


Figure 6: A comparison of harmonic strain well responses.

Harmonic Pressure-head Well Responses (Open)

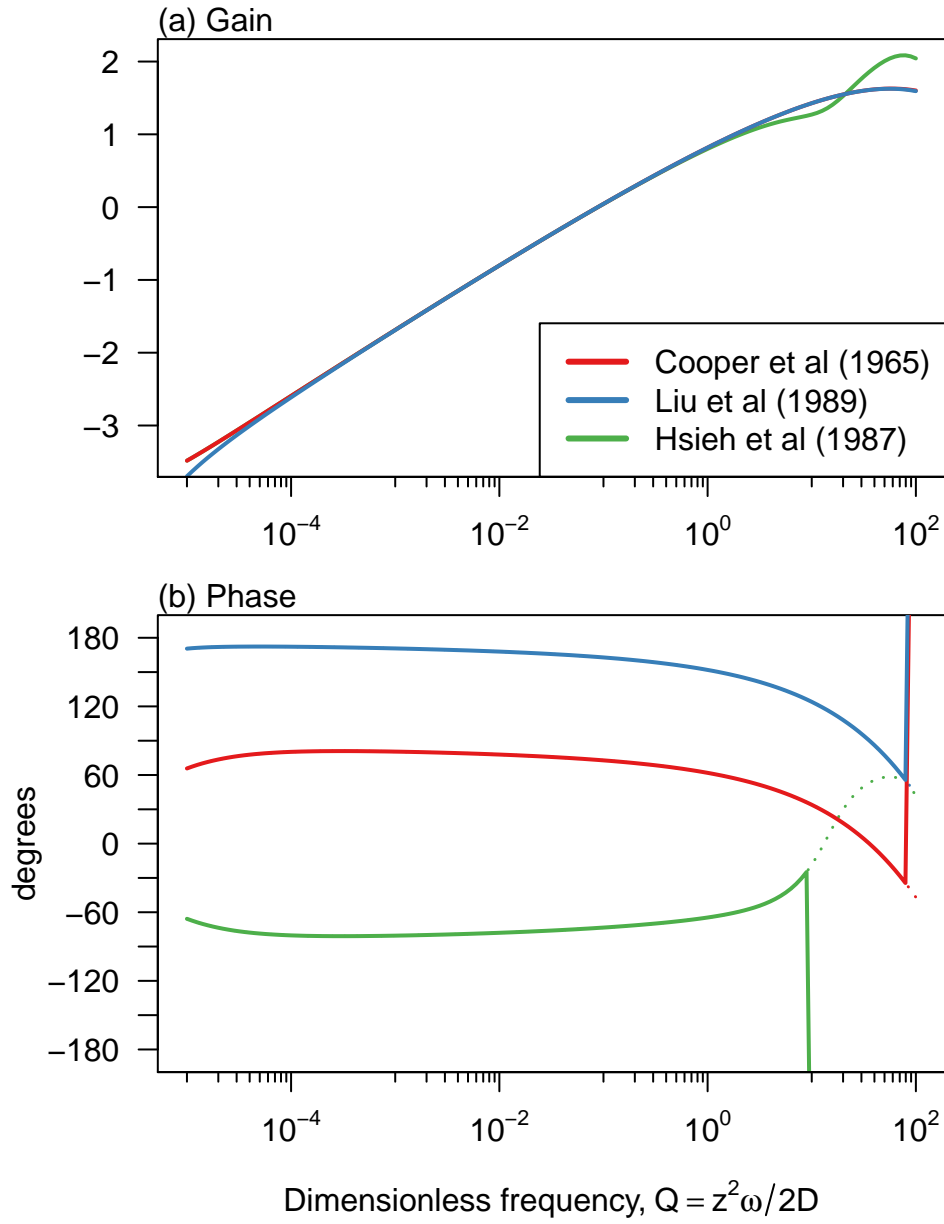


Figure 7: A comparison of harmonic pressure-head well responses (all open).