Climate Growth Analysis for Whitebark Pine

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Load Packages

TO DO LIST

Load Data

```
dat_all <- read_csv(here::here("tree-H", "data", "processed", "final_df.csv"))
str(dat_all)
```

```
## spc_tbl_ [20,450 x 18] (S3: spec_tbl_df/tbl_df/tbl/data.frame)
##  $ TRE_CN             : chr [1:20450] "20T634" "20T634" "20T634" "20T634" ...
##  $ PLOT_CN            : chr [1:20450] "40421037010690" "40421037010690" "40421037010690" "4042103701
##  $ year               : num [1:20450] 1897 1898 1899 1900 1901 ...
##  $ RW                 : num [1:20450] 0.69 0.73 0.68 0.54 0.62 0.7 0.62 0.65 0.52 0.61 ...
##  $ dataset            : chr [1:20450] "FIA" "FIA" "FIA" "FIA" ...
##  $ MEASYEAR           : num [1:20450] 2020 2020 2020 2020 2020 2020 2020 2020 2020 2020 ...
##  $ DIA                : num [1:20450] 8.4 8.4 8.4 8.4 8.4 8.4 8.4 8.4 8.4 8.4 ...
##  $ Z                  : num [1:20450] 2.94 3 3.05 3.09 3.14 ...
##  $ JulAug_tmax        : num [1:20450] -0.454 0.292 -0.765 -0.465 1.277 ...
##  $ pJulAug_tmax       : num [1:20450] -0.531 -0.45 0.293 -0.76 -0.46 ...
##  $ AprMay_tmax        : num [1:20450] 1.137 -0.195 -1.52 0.597 0.881 ...
##  $ pAprMay_tmax       : num [1:20450] -2.22 1.14 -0.19 -1.51 0.6 ...
##  $ JulSep_ppt         : num [1:20450] -0.983 -0.931 -0.817 -1.423 -0.644 ...
##  $ pJulSep_ppt        : num [1:20450] -0.0642 -0.9807 -0.9285 -0.815 -1.4195 ...
##  $ pJulSep_JulSep_ppt : num [1:20450] -0.714 -1.306 -1.193 -1.529 -1.411 ...
##  $ prevJun_currAug_ppt: num [1:20450] 635 720 647 486 587 ...
##  $ meantemp           : num [1:20450] -0.36 -0.36 -0.36 -0.36 -0.36 ...
##  $ precip             : num [1:20450] -1.13 -1.13 -1.13 -1.13 -1.13 ...
##  - attr(*, "spec")=
##   .. cols(
##   ..   TRE_CN = col_character(),
##   ..   PLOT_CN = col_character(),
##   ..   year = col_double(),
##   ..   RW = col_double(),
##   ..   dataset = col_character(),
##   ..   MEASYEAR = col_double(),
##   ..   DIA = col_double(),
##   ..   Z = col_double(),
##   ..   JulAug_tmax = col_double(),
##   ..   pJulAug_tmax = col_double(),
##   ..   AprMay_tmax = col_double(),
##   ..   pAprMay_tmax = col_double(),
##   ..   JulSep_ppt = col_double(),
##   ..   pJulSep_ppt = col_double(),
```

```
##   ..   pJulSep_JulSep_ppt = col_double(),
##   ..   prevJun_currAug_ppt = col_double(),
##   ..   meantemp = col_double(),
##   ..   precip = col_double()
##   .. )
##  - attr(*, "problems")=<externalptr>
```

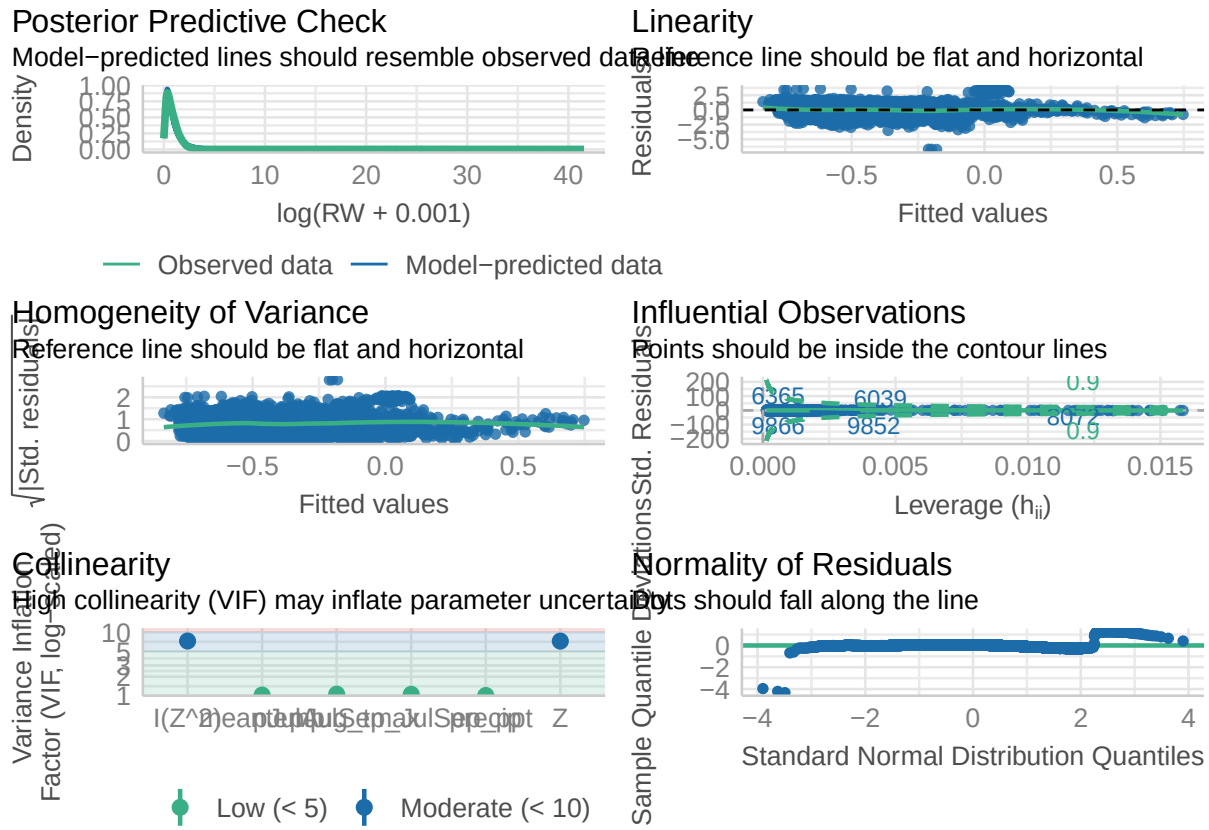
Model Building

fixed effects models

```
# model with MAP/MAT aggregated time varying precip and previous summer tmax
mod_climate_01 <- lm(log(RW + 0.001) ~ Z + I(Z^2) + pJulSep_JulSep_ppt + pJulAug_tmax + precip + meantem
     data = dat_all)
summary(mod_climate_01)
```

```
##
## Call:
## lm(formula = log(RW + 0.001) ~ Z + I(Z^2) + pJulSep_JulSep_ppt +
##     pJulAug_tmax + precip + meantemp, data = dat_all)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -6.7273 -0.5305  0.0430  0.5402  3.6923
##
## Coefficients:
##                       Estimate Std. Error t value Pr(>|t|)
## (Intercept)          0.0942659  0.0256346   3.677 0.000237 ***
## Z                   -0.1257342  0.0057287 -21.948  < 2e-16 ***
## I(Z^2)               0.0054435  0.0002975  18.297  < 2e-16 ***
## pJulSep_JulSep_ppt   0.0253617  0.0085707   2.959 0.003092 **
## pJulAug_tmax        -0.0063818  0.0086355  -0.739 0.459913
## precip               0.0846738  0.0076485  11.071  < 2e-16 ***
## meantemp            -0.0069810  0.0136625  -0.511 0.609391
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.8589 on 10380 degrees of freedom
##   (10063 observations deleted due to missingness)
## Multiple R-squared:  0.05635,    Adjusted R-squared:  0.0558
## F-statistic: 103.3 on 6 and 10380 DF,  p-value: < 2.2e-16
```

```
check_model(mod_climate_01) ###Best model with AIC
```

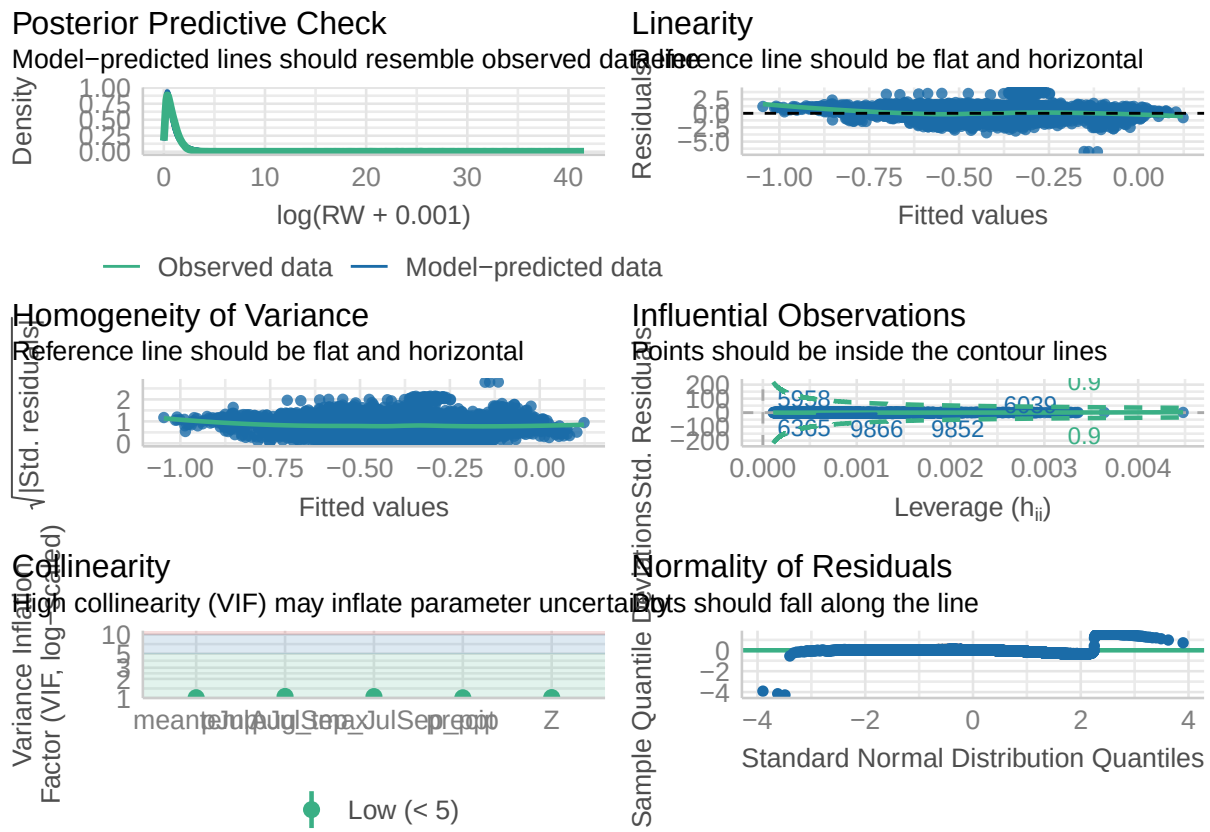



```r
mod_climate_01_sq <- lm(log(RW + 0.001) ~ Z + pJulSep_JulSep_ppt + pJulAug_tmax + precip + meantemp,
    data = dat_all)
summary(mod_climate_01_sq)
```

```
##
## Call:
## lm(formula = log(RW + 0.001) ~ Z + pJulSep_JulSep_ppt + pJulAug_tmax +
##     precip + meantemp, data = dat_all)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -6.7925 -0.5381  0.0405  0.5416  4.0249
##
## Coefficients:
##                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)        -0.241583   0.018179 -13.289  < 2e-16 ***
## Z                  -0.028538   0.002179 -13.100  < 2e-16 ***
## pJulSep_JulSep_ppt  0.022470   0.008706   2.581  0.00986 **
## pJulAug_tmax       -0.011543   0.008769  -1.316  0.18807
## precip              0.078965   0.007764  10.171  < 2e-16 ***
## meantemp           -0.035369   0.013791  -2.565  0.01034 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.8726 on 10381 degrees of freedom
##   (10063 observations deleted due to missingness)
```

```
## Multiple R-squared:  0.02591,    Adjusted R-squared:  0.02544
## F-statistic: 55.23 on 5 and 10381 DF,  p-value: < 2.2e-16
```

```
check_model(mod_climate_01_sq) ###Best model with AIC
```

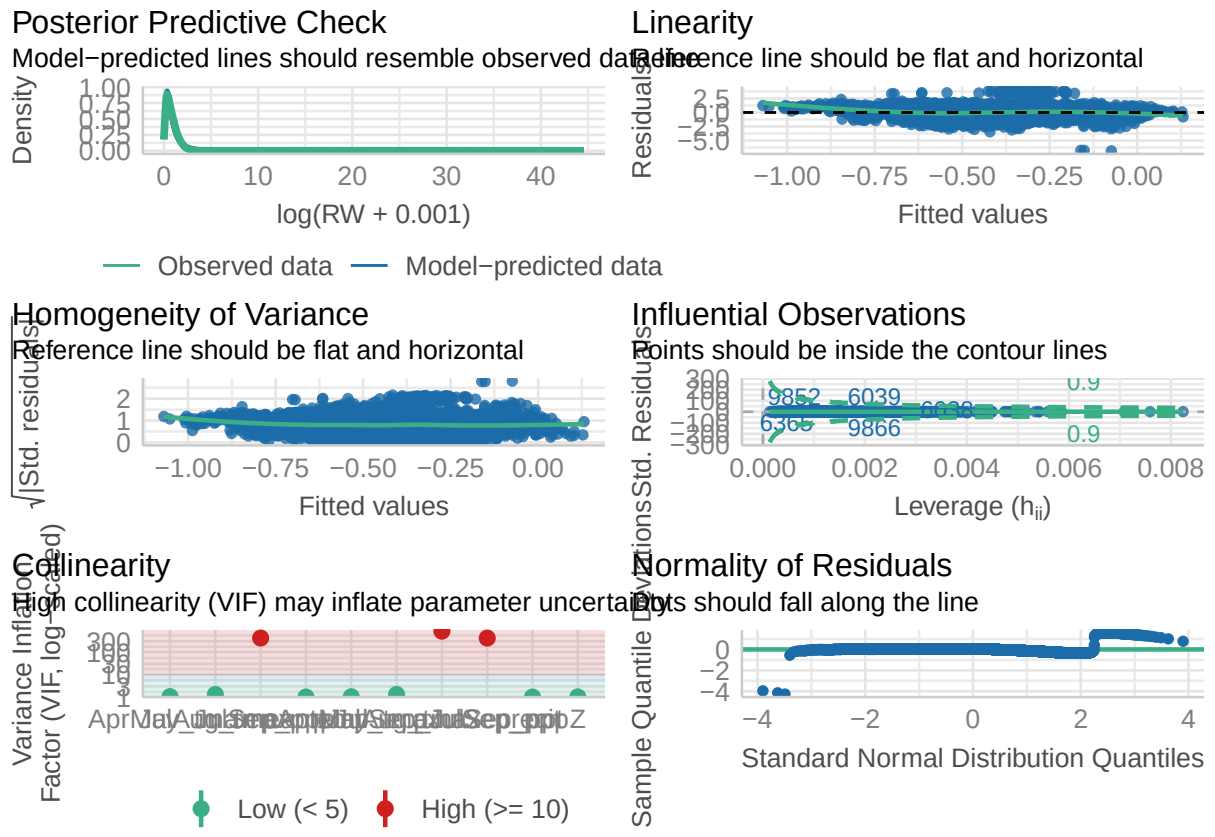



```
# all model terms, no quadratic for size
mod_climate_02 <- lm(log(RW + 0.001) ~ Z + JulAug_tmax + pJulAug_tmax + AprMay_tmax + pAprMay_tmax +
                       JulSep_ppt + pJulSep_ppt + pJulSep_JulSep_ppt + precip + meantemp,
                     data = dat_all)
summary(mod_climate_02)
```

```
##
## Call:
## lm(formula = log(RW + 0.001) ~ Z + JulAug_tmax + pJulAug_tmax +
##     AprMay_tmax + pAprMay_tmax + JulSep_ppt + pJulSep_ppt + pJulSep_JulSep_ppt +
##     precip + meantemp, data = dat_all)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -6.8340 -0.5368  0.0425  0.5419  4.0760
##
## Coefficients:
##                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)        -0.238774   0.018201 -13.119   <2e-16 ***
## Z                  -0.028883   0.002185 -13.218   <2e-16 ***
## JulAug_tmax         0.017287   0.009669   1.788   0.0738 .
## pJulAug_tmax       -0.011043   0.009769  -1.130   0.2583
```

```
## AprMay_tmax         -0.008980   0.009161  -0.980   0.3270
## pAprMay_tmax         0.004794   0.009073   0.528   0.5973
## JulSep_ppt           0.354229   0.172050   2.059   0.0395 *
## pJulSep_ppt          0.368929   0.172474   2.139   0.0325 *
## pJulSep_JulSep_ppt -0.488953   0.246905  -1.980   0.0477 *
## precip               0.079003   0.007763  10.177   <2e-16 ***
## meantemp            -0.034299   0.013796  -2.486   0.0129 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.8724 on 10376 degrees of freedom
##   (10063 observations deleted due to missingness)
## Multiple R-squared:  0.02695,    Adjusted R-squared:  0.02601
## F-statistic: 28.73 on 10 and 10376 DF,  p-value: < 2.2e-16
```

```
check_model(mod_climate_02)
```




```
confint(mod_climate_02, method = "Wald")
```

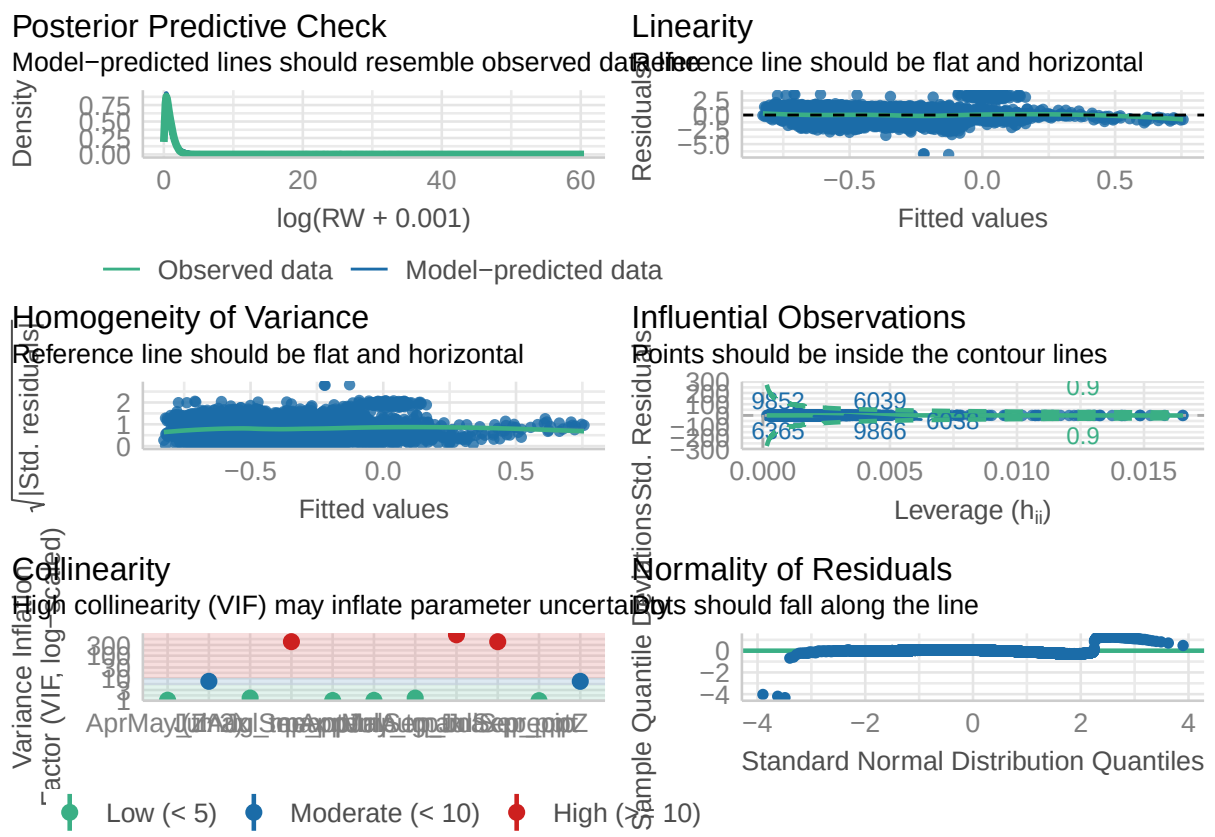
```
##                          2.5 %       97.5 %
## (Intercept)        -0.274451227 -0.203096069
## Z                  -0.033165928 -0.024599347
## JulAug_tmax        -0.001665235  0.036239689
## pJulAug_tmax       -0.030191966  0.008105097
## AprMay_tmax        -0.026936347  0.008977265
## pAprMay_tmax       -0.012990992  0.022578732
## JulSep_ppt          0.016976694  0.691480935
```

```
## pJulSep_ppt          0.030846731  0.707012040
## pJulSep_JulSep_ppt -0.972934830 -0.004970333
## precip               0.063786723  0.094219454
## meantemp            -0.061342010 -0.007255006
```

```
mod_climate_02_sq <- lm(log(RW + 0.001) ~ Z + I(Z^2) + JulAug_tmax + pJulAug_tmax + AprMay_tmax + pAprMa
                        JulSep_ppt + pJulSep_ppt + pJulSep_JulSep_ppt + precip + meantemp,
                      data = dat_all)
summary(mod_climate_02_sq)
```

```
##
## Call:
## lm(formula = log(RW + 0.001) ~ Z + I(Z^2) + JulAug_tmax + pJulAug_tmax +
##     AprMay_tmax + pAprMay_tmax + JulSep_ppt + pJulSep_ppt + pJulSep_JulSep_ppt +
##     precip + meantemp, data = dat_all)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -6.7808 -0.5324  0.0399  0.5443  3.7512
##
## Coefficients:
##                       Estimate Std. Error t value Pr(>|t|)
## (Intercept)          0.0994143  0.0256742   3.872 0.000109 ***
## Z                   -0.1267306  0.0057398 -22.079  < 2e-16 ***
## I(Z^2)               0.0054726  0.0002976  18.387  < 2e-16 ***
## JulAug_tmax          0.0234755  0.0095213   2.466 0.013695 *
## pJulAug_tmax        -0.0060864  0.0096176  -0.633 0.526849
## AprMay_tmax         -0.0113334  0.0090164  -1.257 0.208789
## pAprMay_tmax         0.0030407  0.0089297   0.341 0.733475
## JulSep_ppt           0.3158770  0.1693351   1.865 0.062154 .
## pJulSep_ppt          0.3317506  0.1697513   1.954 0.050689 .
## pJulSep_JulSep_ppt -0.4299079  0.2430114  -1.769 0.076909 .
## precip               0.0846892  0.0076459  11.076  < 2e-16 ***
## meantemp            -0.0056902  0.0136664  -0.416 0.677154
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.8586 on 10375 degrees of freedom
##   (10063 observations deleted due to missingness)
## Multiple R-squared:  0.05765,    Adjusted R-squared:  0.05665
## F-statistic:  57.7 on 11 and 10375 DF,  p-value: < 2.2e-16
```

```
check_model(mod_climate_02_sq)
```




```
confint(mod_climate_02_sq, method = "Wald")
```

```
##                           2.5 %       97.5 %
## (Intercept)          0.0490878319  0.149740760
## Z                   -0.1379817633 -0.115479532
## I(Z^2)               0.0048891512  0.006056018
## JulAug_tmax          0.0048119311  0.042139117
## pJulAug_tmax        -0.0249387309  0.012765865
## AprMay_tmax         -0.0290072464  0.006340440
## pAprMay_tmax        -0.0144631573  0.020544526
## JulSep_ppt          -0.0160524545  0.647806410
## pJulSep_ppt         -0.0009946277  0.664495815
## pJulSep_JulSep_ppt  -0.9062571846  0.046441301
## precip               0.0697018642  0.099676547
## meantemp            -0.0324790297  0.021098678
```

```
#only quadratic term
mod_climate_03_sq <- lm(log(RW + 0.001) ~ Z + I(Z^2) + pJulSep_JulSep_ppt + pJulAug_tmax + pAprMay_tmax
                    data = dat_all)
summary(mod_climate_03_sq)
```

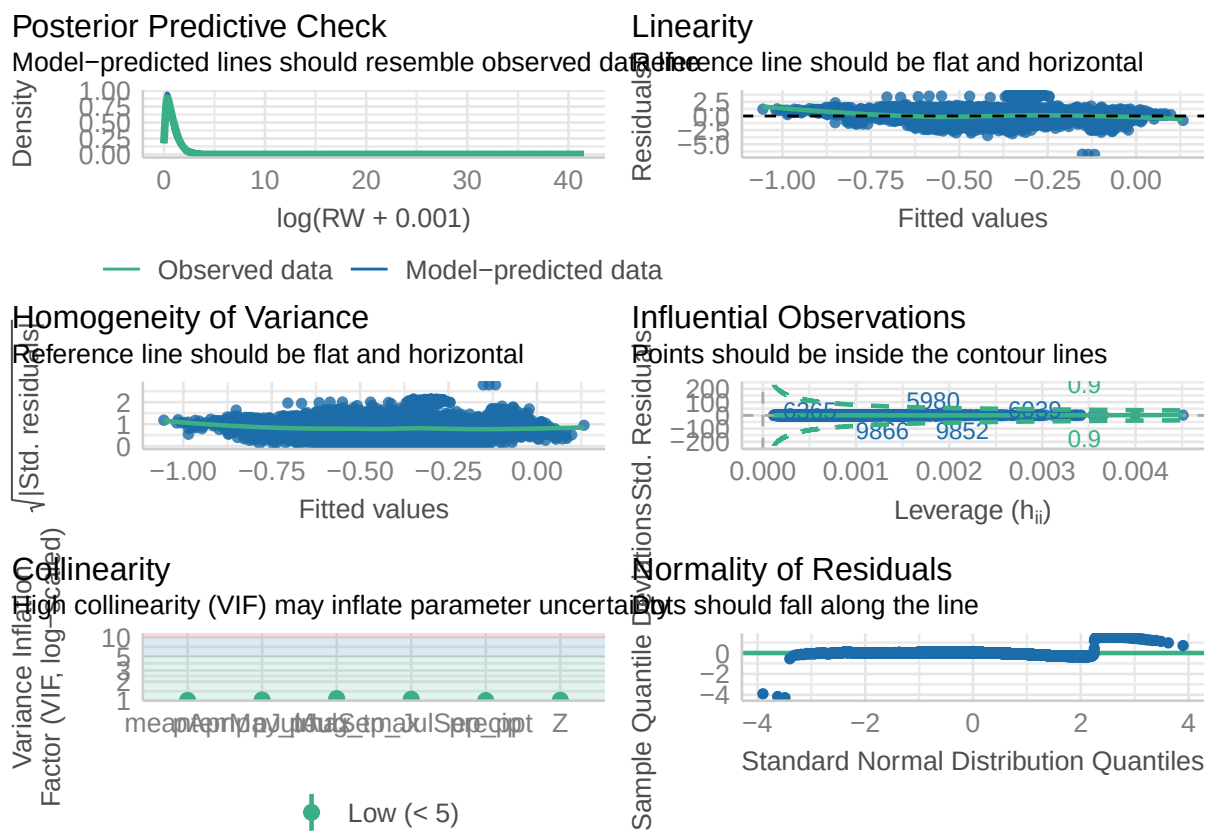
```
##
## Call:
## lm(formula = log(RW + 0.001) ~ Z + I(Z^2) + pJulSep_JulSep_ppt +
##     pJulAug_tmax + pAprMay_tmax + precip + meantemp, data = dat_all)
##
## Residuals:
```

```
##     Min      1Q  Median      3Q     Max
## -6.7258 -0.5306  0.0429  0.5396  3.6894
##
## Coefficients:
##                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)         0.0940874  0.0256393   3.670 0.000244 ***
## Z                  -0.1256965  0.0057297 -21.938  < 2e-16 ***
## I(Z^2)              0.0054424  0.0002975  18.292  < 2e-16 ***
## pJulSep_JulSep_ppt  0.0255429  0.0085823   2.976 0.002925 **
## pJulAug_tmax       -0.0068960  0.0087254  -0.790 0.429348
## pAprMay_tmax        0.0036591  0.0088697   0.413 0.679951
## precip              0.0846606  0.0076489  11.068  < 2e-16 ***
## meantemp           -0.0069112  0.0136641  -0.506 0.613014
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.859 on 10379 degrees of freedom
##   (10063 observations deleted due to missingness)
## Multiple R-squared:  0.05636,    Adjusted R-squared:  0.05573
## F-statistic: 88.56 on 7 and 10379 DF,  p-value: < 2.2e-16
```

```
#only linear term for size
mod_climate_03 <- lm(log(RW + 0.001) ~ Z + pJulSep_JulSep_ppt + pJulAug_tmax + pAprMay_tmax + precip + m
                     data = dat_all)
summary(mod_climate_03)
```

```
##
## Call:
## lm(formula = log(RW + 0.001) ~ Z + pJulSep_JulSep_ppt + pJulAug_tmax +
##     pAprMay_tmax + precip + meantemp, data = dat_all)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -6.7905 -0.5375  0.0420  0.5418  4.0208
##
## Coefficients:
##                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)        -0.241740   0.018182 -13.295  < 2e-16 ***
## Z                  -0.028512   0.002179 -13.084  < 2e-16 ***
## pJulSep_JulSep_ppt  0.022720   0.008718   2.606  0.00917 **
## pJulAug_tmax       -0.012249   0.008859  -1.383  0.16682
## pAprMay_tmax        0.005034   0.009011   0.559  0.57639
## precip              0.078948   0.007764  10.168  < 2e-16 ***
## meantemp           -0.035266   0.013792  -2.557  0.01057 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.8727 on 10380 degrees of freedom
##   (10063 observations deleted due to missingness)
## Multiple R-squared:  0.02594,    Adjusted R-squared:  0.02538
## F-statistic: 46.07 on 6 and 10380 DF,  p-value: < 2.2e-16
```

```
check_model(mod_climate_03) ###Best model with AIC
```



checking, and plotting fixed effects models

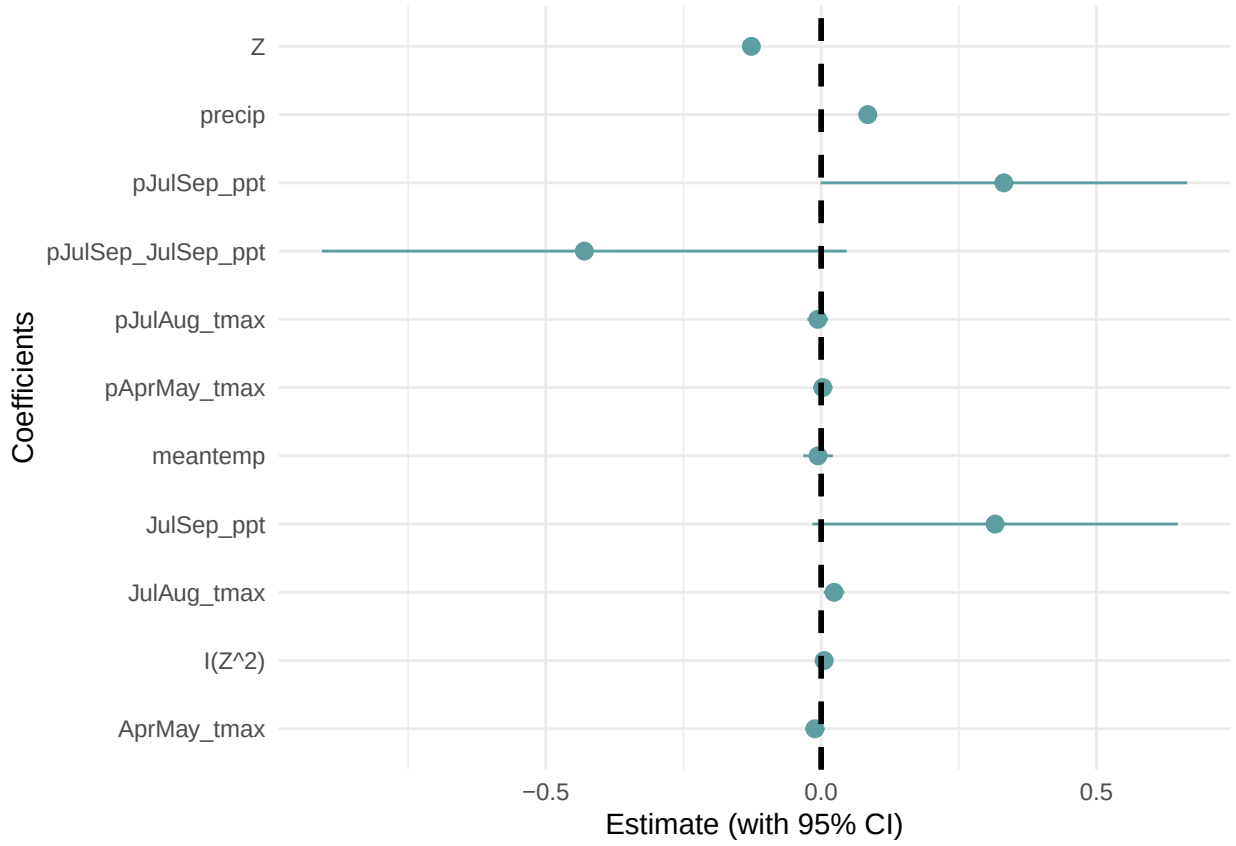
```
############### Checking models with AIC ########################
AIC(mod_climate_01, mod_climate_01_sq, mod_climate_02, mod_climate_02_sq, mod_climate_03, mod_climate_03
```

```
##                    df      AIC
## mod_climate_01      8 26327.45
## mod_climate_01_sq   7 26655.15
## mod_climate_02     12 26654.12
## mod_climate_02_sq  13 26323.06
## mod_climate_03      8 26656.84
## mod_climate_03_sq   9 26329.28
```

```
 #model 2sq has lowest AIC

#best model with AIC is Model 4
model_summary_02_sq <- tidy(mod_climate_02_sq, conf.int = TRUE) %>%
  filter(term != "(Intercept)")

ggplot(model_summary_02_sq, aes(x = term, y = estimate, ymin = conf.low, ymax = conf.high)) +
  geom_pointrange(color = "cadetblue") +
  coord_flip() +  # Flip coordinates for a horizontal plot
  geom_hline(yintercept = 0, color = "black", linetype = "dashed", size = 1) +
  labs(x = "Coefficients", y = "Estimate (with 95% CI)") +
  theme_minimal()
```

```
## Warning: Using `size` aesthetic for lines was deprecated in ggplot2 3.4.0.
## i Please use `linewidth` instead.
```

```
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
## generated.
```



mixed effects models

```
variable_ppt <- c("JulSep_ppt", "pJulSep_ppt", "pJulSep_JulSep_ppt", "prevJun_currAug_ppt")
variable_tmax <- c("JulAug_tmax", "pJulAug_tmax", "AprMay_tmax", "pAprMay_tmax")
f4 <- as.formula(paste("log(RW + 0.001) ~ Z + I(Z^2) + meantemp + precip", paste(c(variable_ppt, variabl

# terms with only linear size
mod_climate_RE <- lmer(
  log(RW + 0.001) ~ Z  + pJulAug_tmax + pAprMay_tmax +
                          pJulSep_JulSep_ppt + precip + meantemp +
    (1 + Z | TRE_CN),
  data = dat_all,
  control = lmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 200000))
)

mod_climate_RE@beta
```

```
## [1]  0.03198406 -0.03249942 -0.03723338  0.01390445  0.01806844  0.13145511
## [7]  0.03105341
```

```
summary(mod_climate_RE)
```

```
## Linear mixed model fit by REML ['lmerMod']
```

```
## Formula:
## log(RW + 0.001) ~ Z + pJulAug_tmax + pAprMay_tmax + pJulSep_JulSep_ppt +
##     precip + meantemp + (1 + Z | TRE_CN)
##    Data: dat_all
## Control: lmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
## REML criterion at convergence: 11619
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -17.1934  -0.5099   0.0632   0.5778   3.9795
##
## Random effects:
##  Groups   Name        Variance Std.Dev. Corr
##  TRE_CN   (Intercept) 1.38085  1.1751
##           Z           0.04001  0.2000   -0.73
##  Residual             0.16057  0.4007
## Number of obs: 10387, groups:  TRE_CN, 111
##
## Fixed effects:
##                     Estimate Std. Error t value
## (Intercept)         0.031984   0.136171   0.235
## Z                  -0.032499   0.019274  -1.686
## pJulAug_tmax       -0.037233   0.004219  -8.824
## pAprMay_tmax        0.013904   0.004159   3.343
## pJulSep_JulSep_ppt  0.018068   0.004080   4.429
## precip              0.131455   0.068297   1.925
## meantemp            0.031053   0.122960   0.253
##
## Correlation of Fixed Effects:
##             (Intr) Z      pJlAg_ pAprM_ pJS_JS precip
## Z           -0.611
## pJulAug_tmx  0.028 -0.034
## pAprMay_tmx -0.003  0.005 -0.142
## pJlSp_JlSp_  0.006 -0.007  0.227  0.048
## precip       0.083 -0.002 -0.002  0.000 -0.001
## meantemp     0.550 -0.004  0.001  0.001 -0.001  0.043
```

```
# terms with quadratic and lienar size

mod_climate_R_sq <- lmer(
  log(RW + 0.001) ~ Z + I(Z^2) + pJulAug_tmax + AprMay_tmax  +
                        pJulSep_JulSep_ppt + precip + meantemp +
    (1 + Z | TRE_CN),
  data = dat_all,
  control = lmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 200000))
)

summary(mod_climate_R_sq)
```

```
## Linear mixed model fit by REML ['lmerMod']
## Formula:
## log(RW + 0.001) ~ Z + I(Z^2) + pJulAug_tmax + AprMay_tmax + pJulSep_JulSep_ppt +
##     precip + meantemp + (1 + Z | TRE_CN)
##    Data: dat_all
```

```
## Control: lmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
## REML criterion at convergence: 11412.9
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -17.3761  -0.5072   0.0565   0.5794   3.9719
##
## Random effects:
##  Groups   Name        Variance Std.Dev. Corr
##  TRE_CN   (Intercept) 2.06398  1.4367
##           Z           0.04513  0.2124   -0.75
##  Residual             0.15644  0.3955
## Number of obs: 10387, groups:  TRE_CN, 111
##
## Fixed effects:
##                       Estimate Std. Error t value
## (Intercept)        -0.5114589  0.1671892  -3.059
## Z                   0.1340459  0.0230684   5.811
## I(Z^2)             -0.0135624  0.0008743 -15.513
## pJulAug_tmax       -0.0317752  0.0041314  -7.691
## AprMay_tmax         0.0035970  0.0040607   0.886
## pJulSep_JulSep_ppt  0.0096672  0.0040536   2.385
## precip              0.1236972  0.0801858   1.543
## meantemp            0.1079824  0.1445753   0.747
##
## Correlation of Fixed Effects:
##             (Intr) Z      I(Z^2) pJlAg_ AprMy_ pJS_JS precip
## Z           -0.644
## I(Z^2)       0.200 -0.464
## pJulAug_tmx  0.012 -0.002 -0.055
## AprMay_tmax -0.003  0.006 -0.008  0.027
## pJlSp_JlSp_  0.029 -0.063  0.122  0.228 -0.014
## precip       0.077  0.001 -0.007  0.000  0.000 -0.002
## meantemp     0.516  0.018 -0.046  0.005  0.002 -0.007  0.042
```

check model and viz mixed effects mdoels

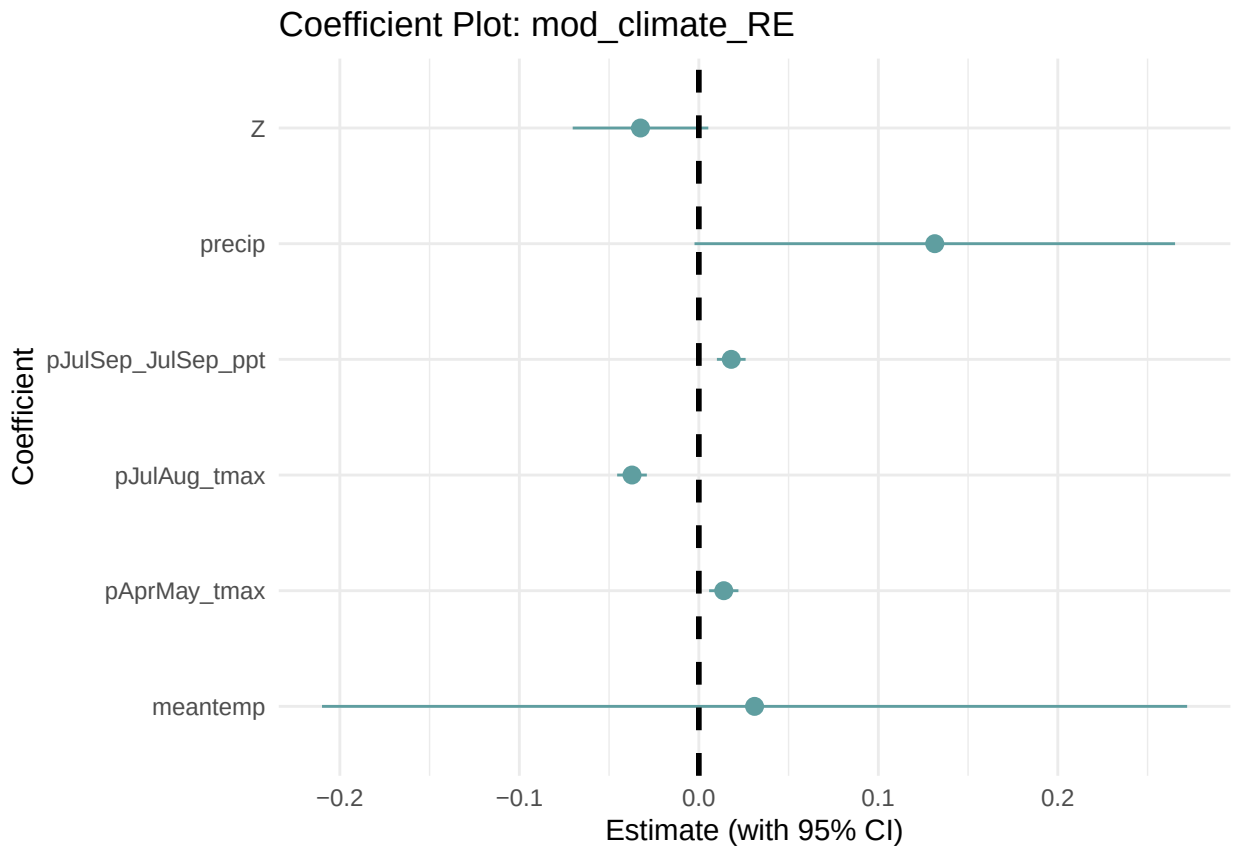
```
library(broom.mixed)
anova(mod_climate_RE, mod_climate_R_sq) # squared Z is better model with AIC
```

```
## refitting model(s) with ML (instead of REML)
```

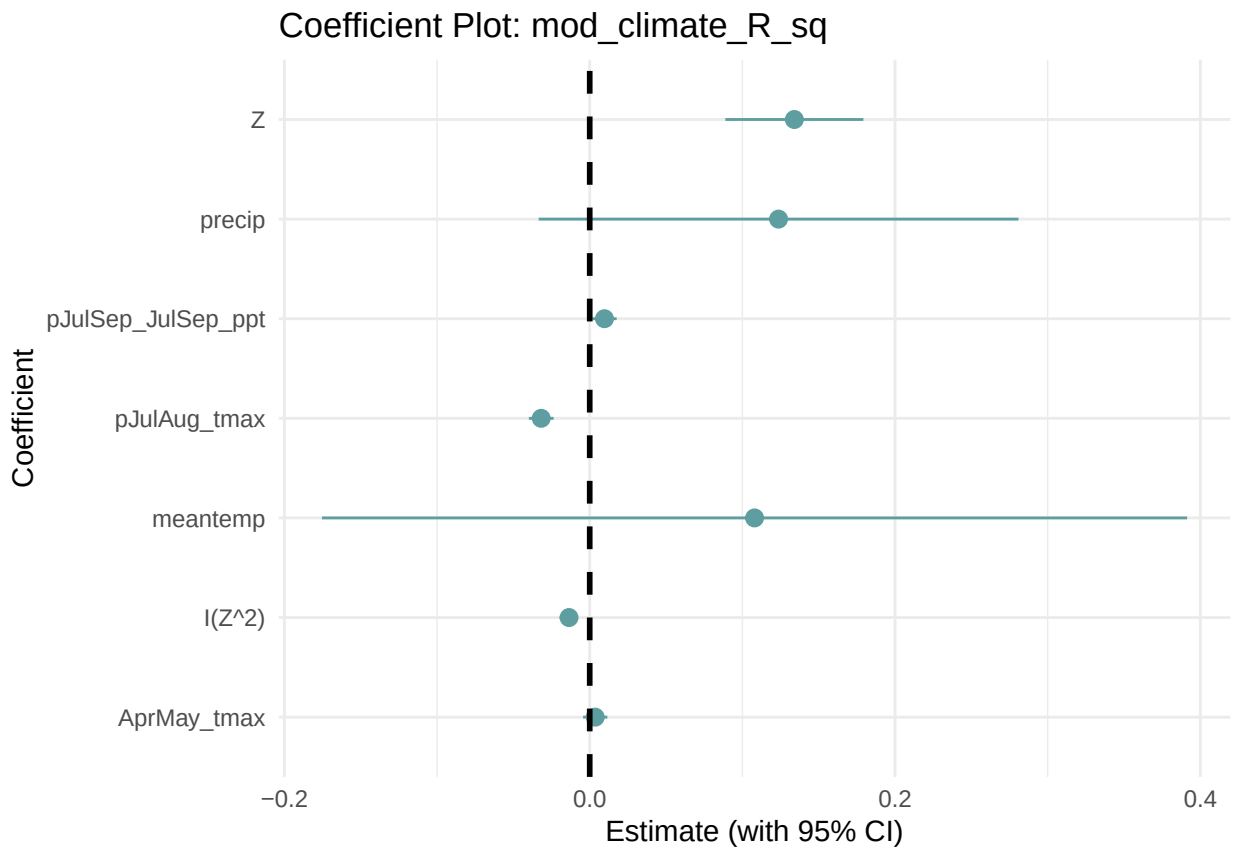
```
## Data: dat_all
## Models:
## mod_climate_RE: log(RW + 0.001) ~ Z + pJulAug_tmax + pAprMay_tmax + pJulSep_JulSep_ppt + precip + mea
## mod_climate_R_sq: log(RW + 0.001) ~ Z + I(Z^2) + pJulAug_tmax + AprMay_tmax + pJulSep_JulSep_ppt + pr
##                  npar   AIC   BIC  logLik deviance  Chisq Df Pr(>Chisq)
## mod_climate_RE     11 11598 11678 -5788.2    11576
## mod_climate_R_sq   12 11383 11470 -5679.4    11359 217.43  1  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
model_summary_RE <- broom.mixed::tidy(mod_climate_RE, conf.int = TRUE) %>%
  filter(effect == "fixed", term != "(Intercept)")
```

```r

# Plot the coefficients for mod_climate_RE
ggplot(model_summary_RE, aes(x = term, y = estimate, ymin = conf.low, ymax = conf.high)) +
  geom_pointrange(color = "cadetblue") +
  coord_flip() +
  geom_hline(yintercept = 0, linetype = "dashed", color = "black", size = 1) +
  labs(title = "Coefficient Plot: mod_climate_RE",
       x = "Coefficient",
       y = "Estimate (with 95% CI)") +
  theme_minimal()
```

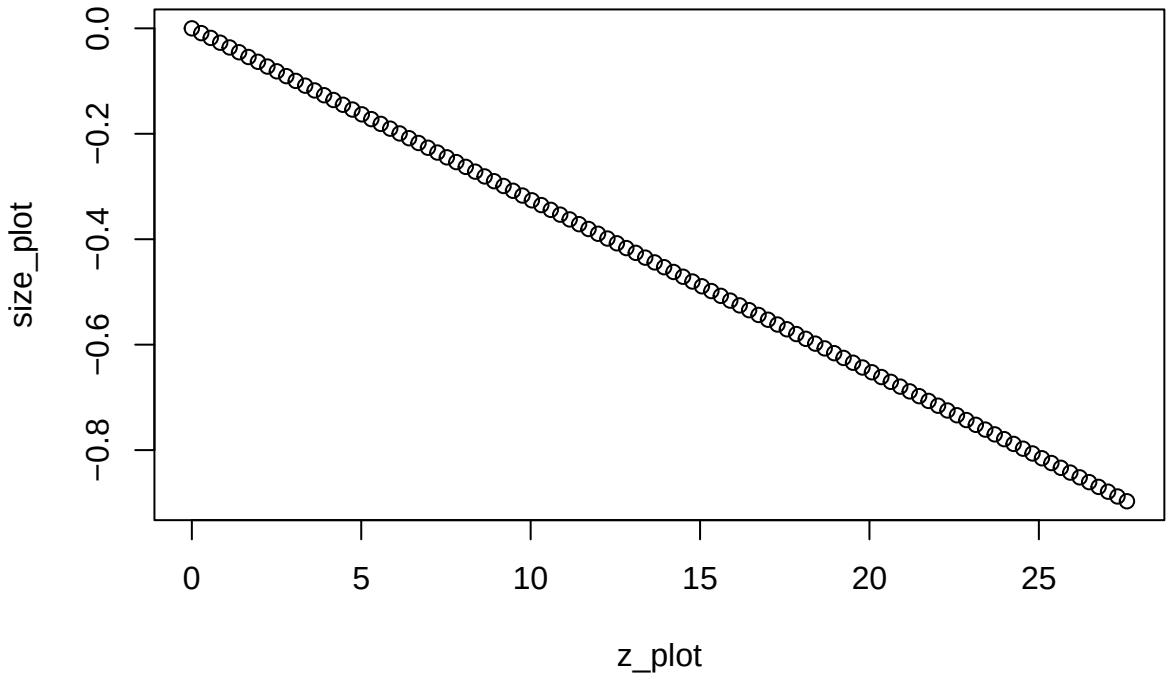



```r
# Tidy the mod_climate_R_sq model with confidence intervals
model_summary_R_sq <- broom.mixed::tidy(mod_climate_R_sq, conf.int = TRUE) %>%
  filter(effect == "fixed", term != "(Intercept)")

# Plot the coefficients for mod_climate_R_sq
ggplot(model_summary_R_sq, aes(x = term, y = estimate, ymin = conf.low, ymax = conf.high)) +
  geom_pointrange(color = "cadetblue") +
  coord_flip() +
  geom_hline(yintercept = 0, linetype = "dashed", color = "black", size = 1) +
  labs(title = "Coefficient Plot: mod_climate_R_sq",
       x = "Coefficient",
       y = "Estimate (with 95% CI)") +
  theme_minimal()
```

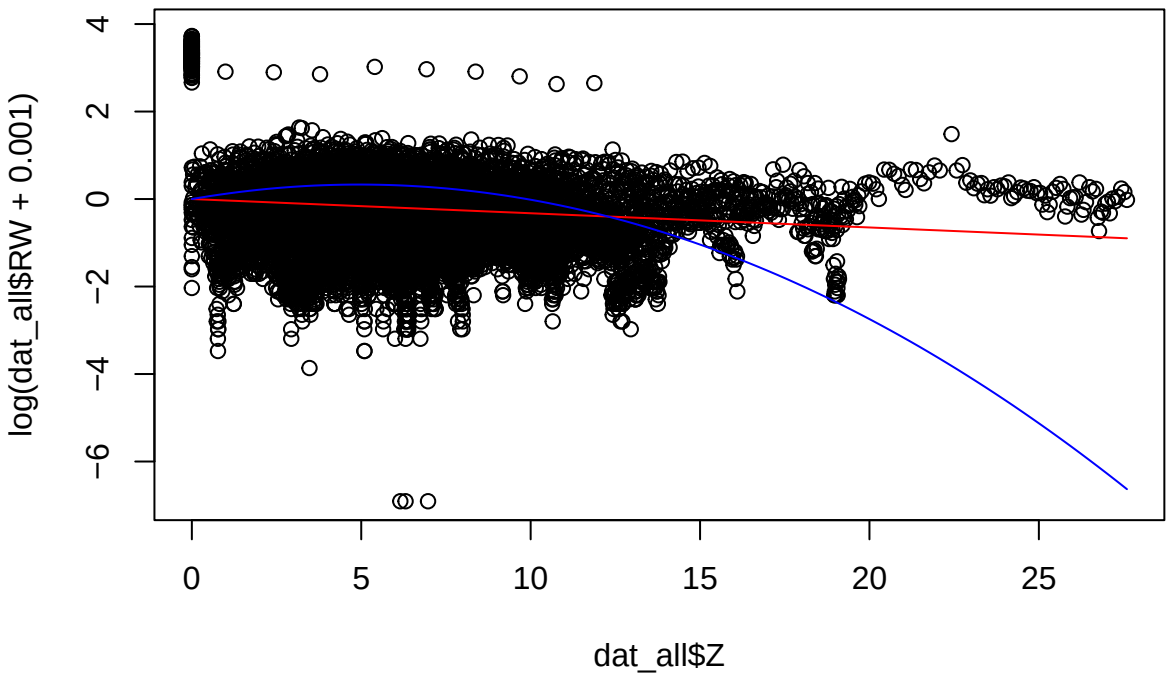


plotting growth functions linear and quadratic on data

```
z_plot <- seq(min(dat_all$Z, na.rm = TRUE), max(dat_all$Z, na.rm = TRUE), length.out = 100)
size_plot <- z_plot * mod_climate_RE@beta[2]
size_plot_sq <- z_plot * mod_climate_R_sq@beta[2] + z_plot^2 * mod_climate_R_sq@beta[3]
plot(size_plot ~ z_plot)
```




```
plot(log(dat_all$RW + 0.001) ~ dat_all$Z)
lines(size_plot~z_plot, col = "red")
lines(size_plot_sq~z_plot, col = "blue")
```



mixed effects model with interaction terms

```
mod_climate_RE_int <- lmer(
  log(RW + 0.001) ~ Z +
    precip * pJulSep_JulSep_ppt +
    meantemp * pJulAug_tmax +
    meantemp * pAprMay_tmax +
    (1 + Z | TRE_CN),
  data = dat_all,
  control = lmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 200000))
)

mod_climate_RE_int_sq <- lmer(
  log(RW + 0.001) ~ Z + I(Z^2) +
    precip * pJulSep_JulSep_ppt +
    meantemp * pJulAug_tmax +
    meantemp * pAprMay_tmax +
    (1 + Z | TRE_CN),
  data = dat_all,
  control = lmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 200000))
)

summary(mod_climate_RE_int)
```

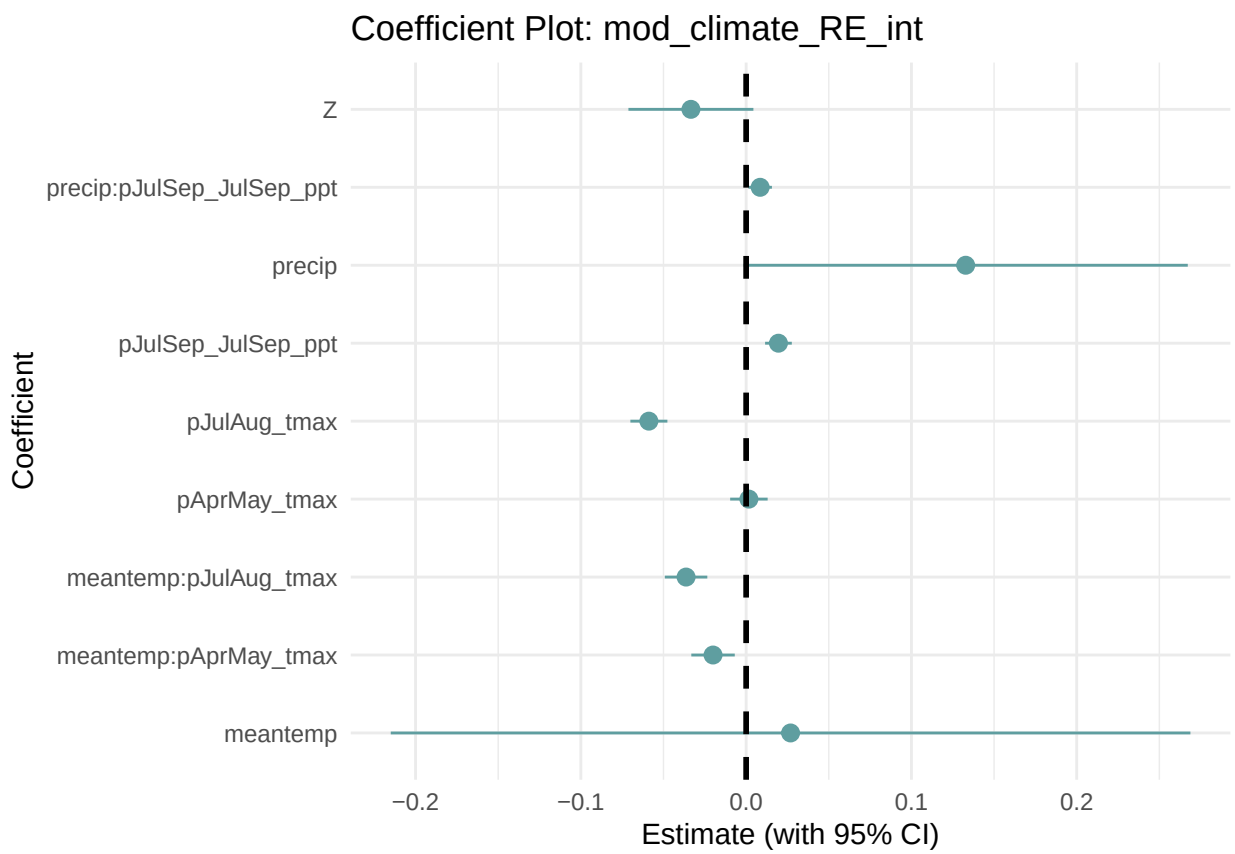
```
## Linear mixed model fit by REML ['lmerMod']
## Formula: log(RW + 0.001) ~ Z + precip * pJulSep_JulSep_ppt + meantemp *
##     pJulAug_tmax + meantemp * pAprMay_tmax + (1 + Z | TRE_CN)
```

```
##    Data: dat_all
## Control: lmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
## REML criterion at convergence: 11594.7
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -17.3209  -0.5072   0.0639   0.5736   4.0051
##
## Random effects:
##  Groups   Name        Variance Std.Dev. Corr
##  TRE_CN   (Intercept) 1.39035  1.1791
##           Z           0.04006  0.2002   -0.73
##  Residual             0.15982  0.3998
## Number of obs: 10387, groups:  TRE_CN, 111
##
## Fixed effects:
##                             Estimate Std. Error t value
## (Intercept)                 0.032251   0.136633   0.236
## Z                          -0.033405   0.019286  -1.732
## precip                      0.132837   0.068553   1.938
## pJulSep_JulSep_ppt          0.019556   0.004118   4.749
## meantemp                    0.026891   0.123420   0.218
## pJulAug_tmax               -0.058840   0.005713 -10.300
## pAprMay_tmax                0.001672   0.005784   0.289
## precip:pJulSep_JulSep_ppt   0.008486   0.003626   2.340
## meantemp:pJulAug_tmax      -0.036337   0.006558  -5.541
## meantemp:pAprMay_tmax      -0.020025   0.006702  -2.988
##
## Correlation of Fixed Effects:
##             (Intr) Z      precip pJS_JS mentmp pJlAg_ pAprM_ p:JS_J mn:JA_
## Z           -0.610
## precip       0.083 -0.002
## pJlSp_JlSp_  0.006 -0.007  0.000
## meantemp     0.550 -0.004  0.043 -0.001
## pJulAug_tmx  0.019 -0.019 -0.002  0.157  0.005
## pAprMay_tmx -0.003  0.004  0.000  0.045 -0.001 -0.128
## prcp:JS_JS_ -0.001  0.001  0.009  0.150 -0.001 -0.011  0.012
## mntmp:pJlA_ -0.001  0.009 -0.001 -0.013  0.006  0.676 -0.090 -0.020
## mntmp:pApM_  0.000  0.000  0.000  0.013 -0.003 -0.086  0.697 -0.001 -0.144
```

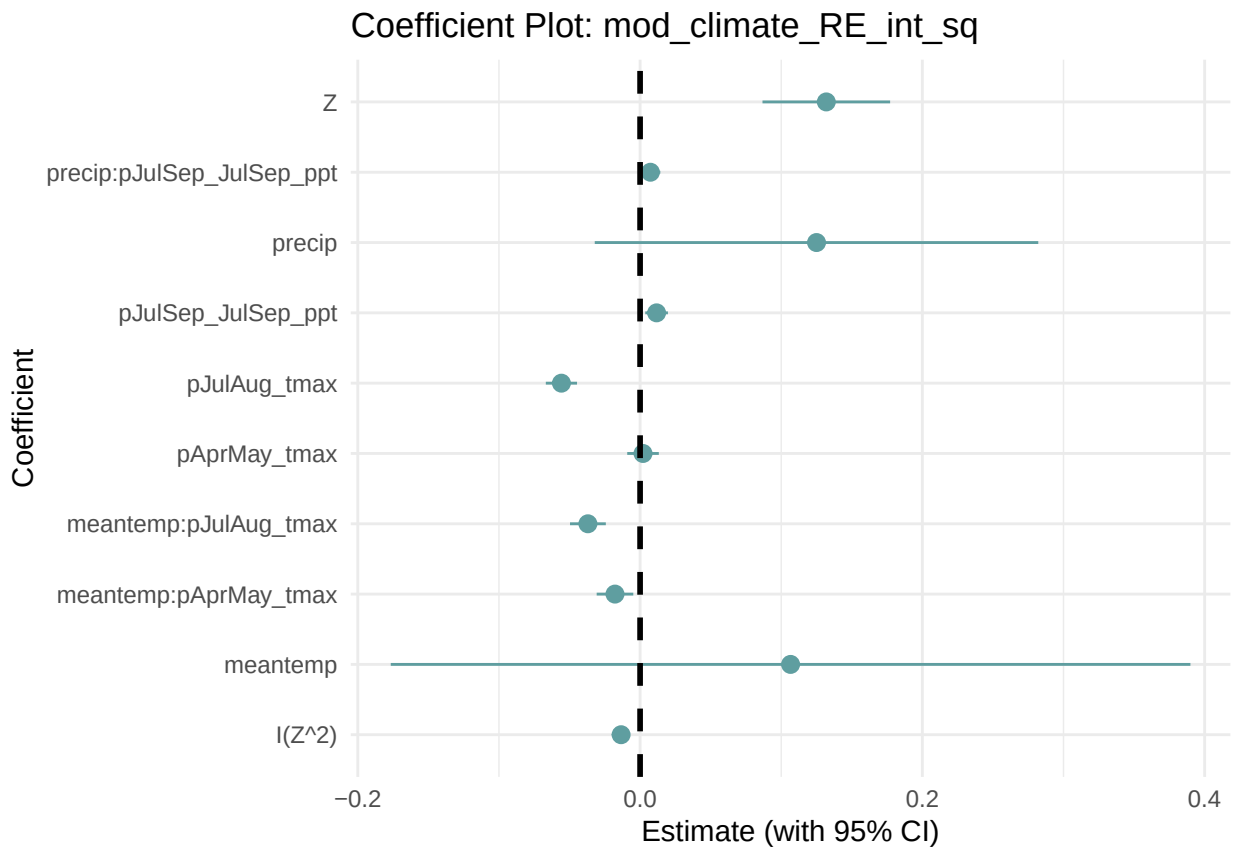
viz of mixed effects model with interaction terms

```r
model_summary_RE_int_summary <- broom.mixed::tidy(mod_climate_RE_int, conf.int = TRUE) %>%
  filter(effect == "fixed", term != "(Intercept)")

# Create the coefficient plot
ggplot(model_summary_RE_int_summary, aes(x = term, y = estimate, ymin = conf.low, ymax = conf.high)) +
  geom_pointrange(color = "cadetblue") +
  coord_flip() +
  geom_hline(yintercept = 0, linetype = "dashed", color = "black", size = 1) +
  labs(title = "Coefficient Plot: mod_climate_RE_int",
       x = "Coefficient",
       y = "Estimate (with 95% CI)") +
```

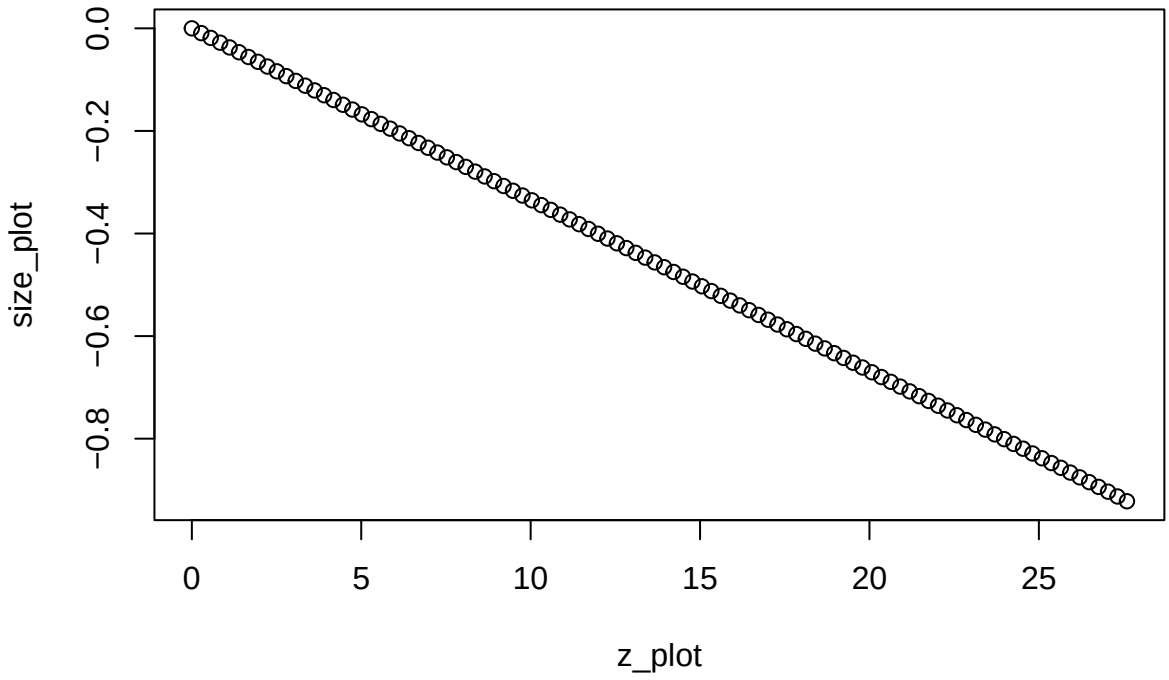
```
  theme_minimal()
```



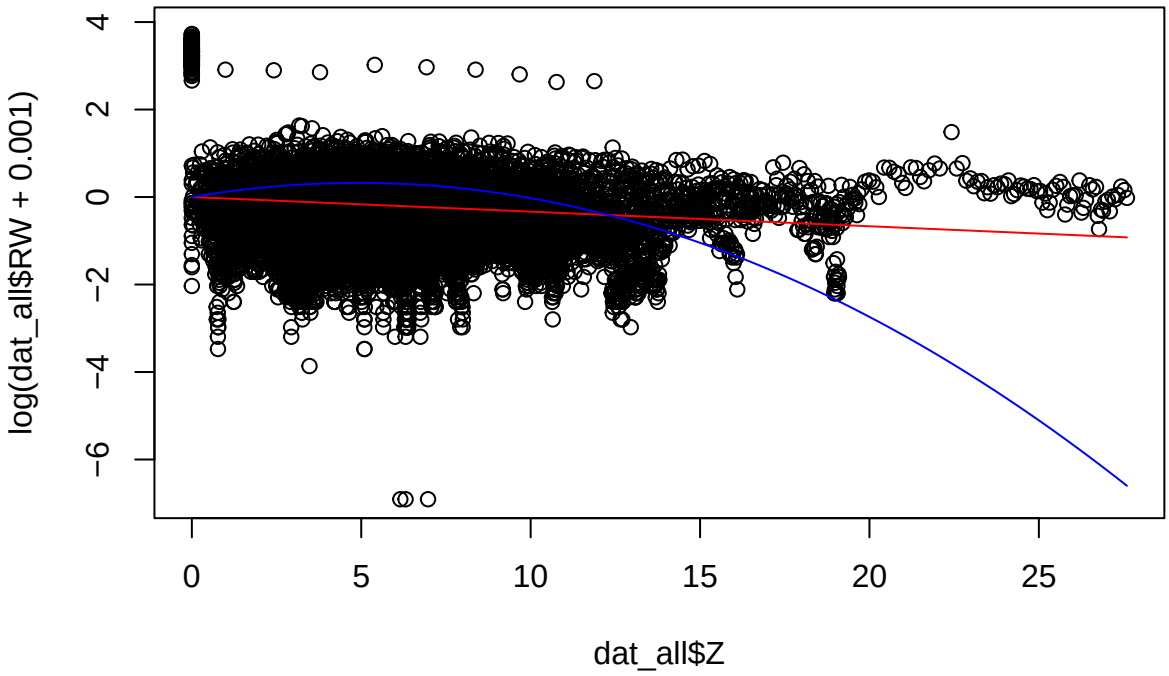

```
model_summary_RE_int_sq_summary <- broom.mixed::tidy(mod_climate_RE_int_sq, conf.int = TRUE) %>%
  filter(effect == "fixed", term != "(Intercept)")

# Create the coefficient plot
ggplot(model_summary_RE_int_sq_summary, aes(x = term, y = estimate, ymin = conf.low, ymax = conf.high))
  geom_pointrange(color = "cadetblue") +
  coord_flip() +
  geom_hline(yintercept = 0, linetype = "dashed", color = "black", size = 1) +
  labs(title = "Coefficient Plot: mod_climate_RE_int_sq",
       x = "Coefficient",
       y = "Estimate (with 95% CI)") +
  theme_minimal()
```




```
z_plot <- seq(min(dat_all$Z, na.rm = TRUE), max(dat_all$Z, na.rm = TRUE), length.out = 100)
size_plot <- z_plot * mod_climate_RE_int@beta[2]
size_plot_sq <- z_plot * mod_climate_RE_int_sq@beta[2] + z_plot^2 * mod_climate_RE_int_sq@beta[3]
plot(size_plot ~ z_plot)
```




```
plot(log(dat_all$RW + 0.001) ~ dat_all$Z)
lines(size_plot~z_plot, col = "red")
lines(size_plot_sq~z_plot, col = "blue")
```


log(dat_all$RW + 0.001)
4
2
0
−2
−4
−6
0
5
10
15
20
25
dat_all$Z