# Statistical models for pH

Sasha D. Hafner

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Sort out missing data.

```
dfsumm(ds[, c('e.rel.24', 'app.method', 'man.source', 'man.dm', 'man.ph', 'air.temp.24', 'wind.2m.24')])
```

```
##
##  1899 rows and 7 columns
##  1846 unique rows
##                    e.rel.24 app.method man.source  man.dm  man.ph air.temp.24 wind.2m.24
## Class               numeric     factor     factor numeric numeric     numeric    numeric
## Minimum           -0.00222         bc        cat    0.55    3.29       -4.18      0.409
## Maximum               5.16         ts     sludge    62.2    9.22        28.8       9.69
## Mean                 0.255        bss       mink    5.56    7.45        13.2       3.12
## Unique (excld. NA)    1736          7          9     421     180        1222       1446
## Missing values         146         34          0      34     292         262        149
## Sorted               FALSE      FALSE      FALSE   FALSE   FALSE       FALSE      FALSE
```

```
dfsumm(ds2[, c('e.rel.24', 'app.method', 'man.source', 'man.dm', 'man.ph', 'air.temp.24', 'wind.2m.24')])
```

```
##
##  452 rows and 7 columns
##  452 unique rows
##                    e.rel.24 app.method man.source  man.dm  man.ph air.temp.24 wind.2m.24
## Class               numeric     factor     factor numeric numeric     numeric    numeric
## Minimum           0.000662         bc        cat       1     6.4      -0.656      0.586
## Maximum                  1         ts     sludge    11.9     8.5        24.2       9.69
## Mean                 0.234         cs       conc    5.87    7.42          13       3.32
## Unique (excld. NA)     449          4          2     199      66         390        400
## Missing values           0          0          0       0       0           0          0
## Sorted               FALSE      FALSE      FALSE   FALSE   FALSE       FALSE      FALSE
```

```
dfsumm(ds3[, c('e.rel.24', 'app.method', 'man.source', 'man.dm', 'man.ph', 'air.temp.24', 'wind.2m.24')])
```

```
##
##  56 rows and 7 columns
##  56 unique rows
##                    e.rel.24 app.method man.source  man.dm  man.ph air.temp.24 wind.2m.24
## Class               numeric     factor     factor numeric numeric     numeric    numeric
## Minimum           0.00176         bc        cat     1.9     4.3        4.56       1.51
## Maximum             0.832         ts     sludge    10.8     7.9        21.3       5.54
## Mean                0.154        bss        mix    6.52    6.38        11.3       3.21
## Unique (excld. NA)     56          2          2      22      18          28         28
## Missing values          0          0          0       0       0           8          8
## Sorted               FALSE      FALSE      FALSE   FALSE   FALSE       FALSE      FALSE
```

```r
ds2 <- subset(ds2, !is.na(air.temp.24) & !is.na(wind.2m.24))
ds3 <- subset(ds3, !is.na(air.temp.24) & !is.na(wind.2m.24))
ds2$e.rel.24[is.na(ds2$e.rel.24)] <- ds2$e.rel.final[is.na(ds2$e.rel.24)]
ds2$inst <- factor(ds2$inst)
ds3$inst <- factor(ds3$inst)
```

Linear model, all data, no institute effects.

```r
m0a <- lm(e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 + wind.2m.24, data = ds)
summary(m0a)
```

```
##
## Call:
## lm(formula = e.rel.24 ~ app.method + man.source + man.dm + man.ph +
##     air.temp.24 + wind.2m.24, data = ds)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.75637 -0.09740 -0.02486  0.06116  1.13462
##
## Coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept)     -0.0249140  0.0661376  -0.377 0.706458
## app.methodbss   -0.2443416  0.0241907 -10.101  < 2e-16 ***
## app.methodbsth  -0.1766495  0.0117970 -14.974  < 2e-16 ***
## app.methodcs    -0.2096294  0.0328553  -6.380 2.44e-10 ***
## app.methodos    -0.2757403  0.0193278 -14.267  < 2e-16 ***
## app.methodpi    -0.3454680  0.0961448  -3.593 0.000339 ***
## app.methodts    -0.1976293  0.0182106 -10.852  < 2e-16 ***
## man.sourceconc  -0.0488932  0.1663371  -0.294 0.768850
## man.sourcemink  -0.0528119  0.0432163  -1.222 0.221914
## man.sourcemix   -0.0430041  0.0311323  -1.381 0.167412
## man.sourceother -0.0469466  0.0217118  -2.162 0.030779 *
## man.sourcepig   -0.1227268  0.0116177 -10.564  < 2e-16 ***
## man.dm           0.0176359  0.0015265  11.553  < 2e-16 ***
## man.ph           0.0280204  0.0083427   3.359 0.000806 ***
## air.temp.24      0.0046197  0.0009215   5.013 6.09e-07 ***
## wind.2m.24       0.0096749  0.0029755   3.252 0.001177 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1652 on 1311 degrees of freedom
##   (572 observations deleted due to missingness)
## Multiple R-squared:  0.4086, Adjusted R-squared:  0.4018
## F-statistic: 60.38 on 15 and 1311 DF,  p-value: < 2.2e-16
```

```r
drop1(m0a, test = 'F')
```

```
## Single term deletions
##
## Model:
## e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 +
##     wind.2m.24
##             Df Sum of Sq    RSS     AIC F value    Pr(>F)
## <none>                   35.774 -4763.0
```

```
## app.method   6   12.3804 48.155 -4380.7  75.616 < 2.2e-16 ***
## man.source   5    3.0711 38.845 -4663.8  22.509 < 2.2e-16 ***
## man.dm       1    3.6424 39.417 -4636.4 133.481 < 2.2e-16 ***
## man.ph       1    0.3078 36.082 -4753.7  11.281 0.0008056 ***
## air.temp.24  1    0.6858 36.460 -4739.8  25.131 6.089e-07 ***
## wind.2m.24   1    0.2885 36.063 -4754.4  10.572 0.0011771 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Include institution with mixed-effects model.

```
m0c <- lmer(e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 + wind.2m.24 + (1|inst)
summary(m0c)
```

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 +      wind.2m.24 + (1 |
##    Data: ds
##
## REML criterion at convergence: -1328.9
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.1262 -0.5327 -0.0960  0.3571  8.3383
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  inst     (Intercept) 0.01229  0.1108
##  Residual             0.01917  0.1385
## Number of obs: 1327, groups:  inst, 19
##
## Fixed effects:
##                   Estimate Std. Error t value
## (Intercept)     -0.1956060  0.0700176  -2.794
## app.methodbss   -0.1234716  0.0262317  -4.707
## app.methodbsth  -0.1741136  0.0174412  -9.983
## app.methodcs    -0.3028084  0.0318684  -9.502
## app.methodos    -0.4156889  0.0198234 -20.970
## app.methodpi    -0.2779556  0.0950169  -2.925
## app.methodts    -0.2057530  0.0202555 -10.158
## man.sourceconc   0.1422464  0.1412673   1.007
## man.sourcemink  -0.0120316  0.0395061  -0.305
## man.sourcemix   -0.0012711  0.0305954  -0.042
## man.sourceother  0.0063656  0.0209140   0.304
## man.sourcepig   -0.0796706  0.0129884  -6.134
## man.dm           0.0112160  0.0013959   8.035
## man.ph           0.0487439  0.0081684   5.967
## air.temp.24      0.0053043  0.0008361   6.344
## wind.2m.24       0.0136654  0.0029647   4.609
##
## Correlation matrix not shown by default, as p = 16 > 12.
## Use print(x, correlation=TRUE)  or
##     vcov(x)        if you need it
```

Subset 2, used for model calibration. Linear model, no institute effects.

```r
m2a <- lm(e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 + wind.2m.24, data = ds2)
summary(m2a)
```

```
##
## Call:
## lm(formula = e.rel.24 ~ app.method + man.source + man.dm + man.ph +
##     air.temp.24 + wind.2m.24, data = ds2)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.40204 -0.08739 -0.00443  0.06073  0.52729
##
## Coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)    -0.542294   0.134803  -4.023 6.76e-05 ***
## app.methodbsth -0.250546   0.021458 -11.676  < 2e-16 ***
## app.methodos   -0.414049   0.020447 -20.250  < 2e-16 ***
## app.methodts   -0.349385   0.020218 -17.281  < 2e-16 ***
## man.sourcepig  -0.075394   0.020041  -3.762 0.000191 ***
## man.dm          0.037809   0.003610  10.473  < 2e-16 ***
## man.ph          0.089622   0.017518   5.116 4.66e-07 ***
## air.temp.24     0.007852   0.001561   5.030 7.13e-07 ***
## wind.2m.24      0.012145   0.004035   3.010 0.002765 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1424 on 443 degrees of freedom
## Multiple R-squared:  0.6329, Adjusted R-squared:  0.6263
## F-statistic: 95.48 on 8 and 443 DF,  p-value: < 2.2e-16
```

```r
drop1(m2a, test = 'F')
```

```
## Single term deletions
##
## Model:
## e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 +
##     wind.2m.24
##             Df Sum of Sq     RSS     AIC F value    Pr(>F)
## <none>                    8.9805 -1753.2
## app.method   3   10.3688 19.3493 -1412.3 170.494 < 2.2e-16 ***
## man.source   1    0.2869  9.2674 -1741.0  14.152 0.0001912 ***
## man.dm       1    2.2236 11.2041 -1655.2 109.687 < 2.2e-16 ***
## man.ph       1    0.5306  9.5111 -1729.3  26.173 4.658e-07 ***
## air.temp.24  1    0.5129  9.4935 -1730.1  25.303 7.132e-07 ***
## wind.2m.24   1    0.1836  9.1642 -1746.1   9.058 0.0027647 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
ds2$e.rel.24.pred <- predict(m2a)
summary(update(m2a, ~ . - man.ph))
```

```
##
## Call:
## lm(formula = e.rel.24 ~ app.method + man.source + man.dm + air.temp.24 +
##     wind.2m.24, data = ds2)
```

```
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.36034 -0.09632 -0.01312  0.07704  0.59318
##
## Coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)     0.123115   0.036413   3.381 0.000786 ***
## app.methodbsth -0.253185   0.022051 -11.482  < 2e-16 ***
## app.methodos   -0.410067   0.021003 -19.524  < 2e-16 ***
## app.methodts   -0.325275   0.020211 -16.094  < 2e-16 ***
## man.sourcepig  -0.043337   0.019569  -2.215 0.027294 *
## man.dm          0.033350   0.003601   9.261  < 2e-16 ***
## air.temp.24     0.008901   0.001591   5.596 3.85e-08 ***
## wind.2m.24      0.012053   0.004148   2.906 0.003846 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1464 on 444 degrees of freedom
## Multiple R-squared:  0.6112, Adjusted R-squared:  0.6051
## F-statistic: 99.73 on 7 and 444 DF,  p-value: < 2.2e-16
```

With institute effects, linear model though

```
m2b <- lm(e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 + wind.2m.24 + factor(inst)
summary(m2b)
```

```
##
## Call:
## lm(formula = e.rel.24 ~ app.method + man.source + man.dm + man.ph +
##     air.temp.24 + wind.2m.24 + factor(inst), data = ds2)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.34982 -0.07450 -0.01616  0.07008  0.52523
##
## Coefficients:
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     -0.080669   0.161754  -0.499 0.618231
## app.methodbsth  -0.237270   0.020935 -11.334  < 2e-16 ***
## app.methodos    -0.489579   0.019360 -25.289  < 2e-16 ***
## app.methodts    -0.284484   0.021164 -13.442  < 2e-16 ***
## man.sourcepig   -0.122392   0.020814  -5.880 8.19e-09 ***
## man.dm           0.011615   0.004047   2.870 0.004302 **
## man.ph           0.042848   0.020443   2.096 0.036664 *
## air.temp.24      0.005354   0.001408   3.802 0.000164 ***
## wind.2m.24       0.008336   0.004042   2.062 0.039771 *
## factor(inst)106  0.166875   0.031815   5.245 2.45e-07 ***
## factor(inst)202  0.002295   0.030752   0.075 0.940546
## factor(inst)204  0.140717   0.039894   3.527 0.000465 ***
## factor(inst)205  0.147516   0.032620   4.522 7.91e-06 ***
## factor(inst)207 -0.079242   0.036873  -2.149 0.032185 *
## factor(inst)208 -0.130047   0.055639  -2.337 0.019875 *
## factor(inst)210  0.109819   0.078164   1.405 0.160745
## factor(inst)212  0.110585   0.037185   2.974 0.003104 **
```

```
## factor(inst)214  0.239865   0.034464   6.960 1.26e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1231 on 434 degrees of freedom
## Multiple R-squared:  0.7312, Adjusted R-squared:  0.7207
## F-statistic: 69.45 on 17 and 434 DF,  p-value: < 2.2e-16
```

```
drop1(m2b, test = 'F')
```

```
## Single term deletions
##
## Model:
## e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 +
##     wind.2m.24 + factor(inst)
##              Df Sum of Sq     RSS     AIC  F value    Pr(>F)
## <none>                     6.5759 -1876.1
## app.method    3   10.2446 16.8205 -1457.6 225.3763 < 2.2e-16 ***
## man.source    1    0.5239  7.0998 -1843.4  34.5769 8.186e-09 ***
## man.dm        1    0.1248  6.7007 -1869.6   8.2385 0.0043016 **
## man.ph        1    0.0666  6.6425 -1873.5   4.3931 0.0366641 *
## air.temp.24   1    0.2191  6.7950 -1863.3  14.4580 0.0001638 ***
## wind.2m.24    1    0.0644  6.6404 -1873.7   4.2532 0.0397711 *
## factor(inst)  9    2.4046  8.9805 -1753.2  17.6334 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Include institution with mixed-effects model.

```
m2c <- lmer(e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 + wind.2m.24 + (1|inst)
summary(m2c)
```

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 +      wind.2m.24 + (1 |
##    Data: ds2
##
## REML criterion at convergence: -521.6
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.8131 -0.6048 -0.1382  0.5465  4.2733
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  inst     (Intercept) 0.01254  0.1120
##  Residual             0.01515  0.1231
## Number of obs: 452, groups:  inst, 10
##
## Fixed effects:
##                 Estimate Std. Error t value
## (Intercept)    -0.038895   0.165743  -0.235
## app.methodbsth -0.237008   0.020813 -11.387
## app.methodos   -0.485463   0.019254 -25.214
## app.methodts   -0.286095   0.020978 -13.638
## man.sourcepig  -0.119175   0.020630  -5.777
## man.dm          0.012928   0.004004   3.228
```

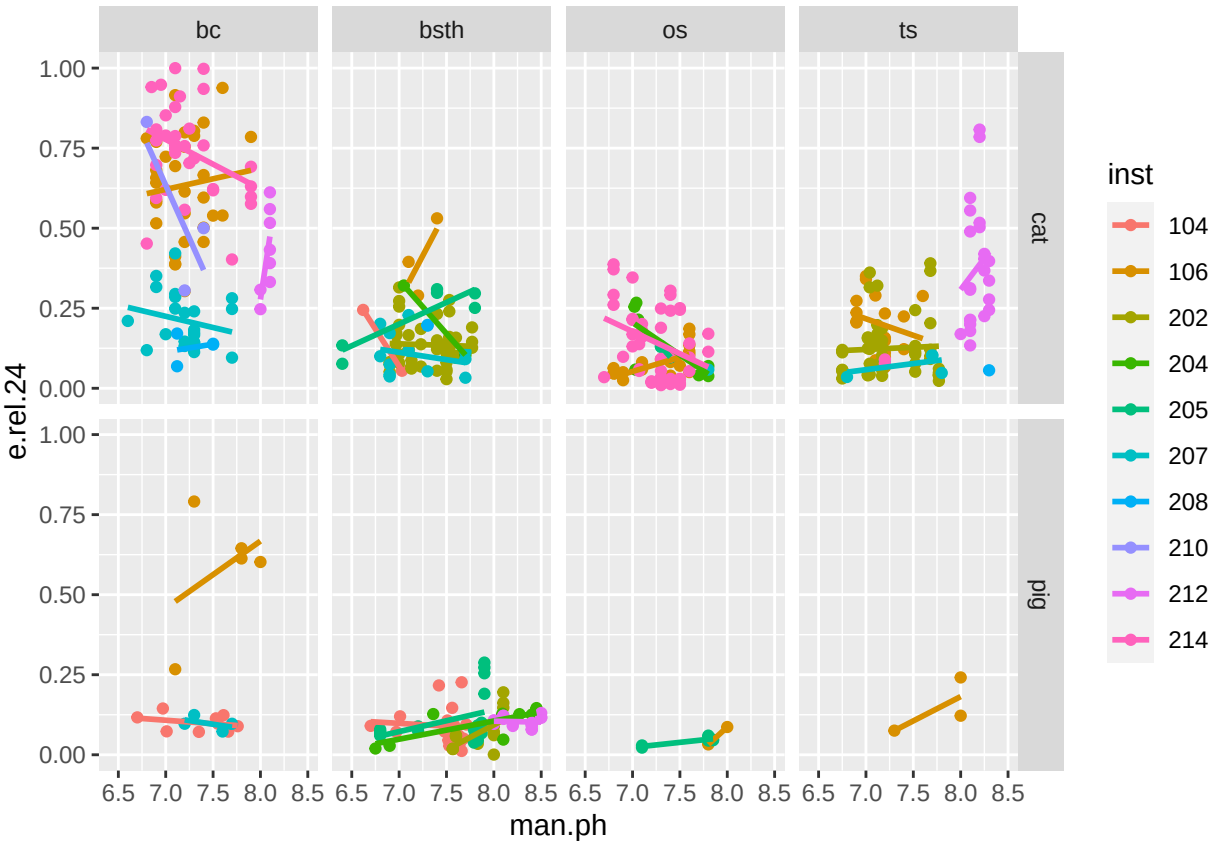
```
## man.ph          0.045214   0.020198   2.239
## air.temp.24     0.005545   0.001403   3.952
## wind.2m.24      0.008867   0.004017   2.207
##
## Correlation of Fixed Effects:
##             (Intr) app.mthdb app.mthds app.mthdt mn.src man.dm man.ph ar..24
## app.mthdbst -0.146
## app.methods -0.020  0.331
## app.methdts  0.048  0.465     0.305
## man.sourcpg  0.150 -0.124     0.087     0.056
## man.dm      -0.474  0.275     0.064    -0.195     0.254
## man.ph      -0.950  0.079    -0.031    -0.085    -0.258  0.351
## air.temp.24 -0.057 -0.098    -0.059    -0.013     0.137 -0.023 -0.071
## wind.2m.24  -0.244 -0.109     0.040     0.134     0.022  0.040  0.152  0.253
```

```
drop1(m2c, test = 'Chisq')
```

```
## Single term deletions
##
## Model:
## e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 +
##     wind.2m.24 + (1 | inst)
##             npar     AIC    LRT   Pr(Chi)
## <none>           -565.35
## app.method     3 -159.28 412.07 < 2.2e-16 ***
## man.source     1 -534.91  32.44 1.231e-08 ***
## man.dm         1 -556.86  10.49  0.001197 **
## man.ph         1 -562.23   5.13  0.023561 *
## air.temp.24    1 -551.64  15.71 7.384e-05 ***
## wind.2m.24     1 -562.37   4.98  0.025570 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

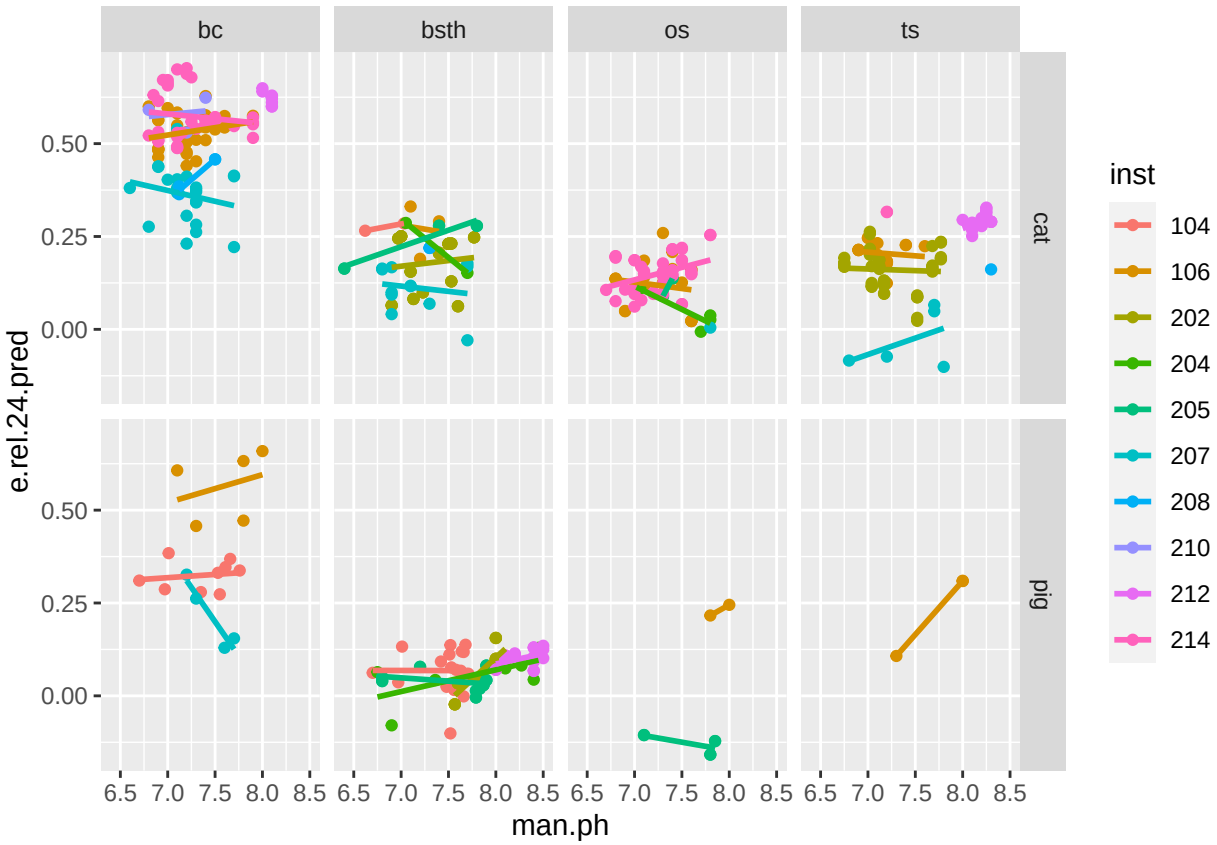
```
ggplot(ds2, aes(man.ph, e.rel.24, colour = inst)) +
  geom_point() +
  facet_grid(man.source ~ app.method) +
  geom_smooth(method = lm, se = FALSE)
```

```
## `geom_smooth()` using formula 'y ~ x'
```




```
ggplot(ds2, aes(man.ph, e.rel.24.pred, colour = inst)) +
  geom_point() +
  facet_grid(man.source ~ app.method) +
  geom_smooth(method = lm, se = FALSE)
```

```
## `geom_smooth()` using formula 'y ~ x'
```




Acidification trials.

```
m3a <- lm(e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 + wind.2m.24, data = ds3)
summary(m3a)
```

```
##
## Call:
## lm(formula = e.rel.24 ~ app.method + man.source + man.dm + man.ph +
##     air.temp.24 + wind.2m.24, data = ds3)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.14582 -0.03219 -0.01228  0.02428  0.31456
##
## Coefficients:
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)    -0.568991   0.201500  -2.824  0.00729 **
## app.methodbsth -0.286149   0.054219  -5.278 4.57e-06 ***
## man.sourcepig  -0.102394   0.068216  -1.501  0.14101
## man.dm         -0.014202   0.013468  -1.054  0.29783
## man.ph          0.130583   0.014750   8.853 4.62e-11 ***
## air.temp.24     0.007047   0.004450   1.583  0.12100
## wind.2m.24      0.049244   0.015671   3.142  0.00311 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.07126 on 41 degrees of freedom
## Multiple R-squared:  0.8077, Adjusted R-squared:  0.7796
```

```
## F-statistic: 28.71 on 6 and 41 DF,  p-value: 3.373e-13
```

```
drop1(m3a, test = 'F')
```

```
## Single term deletions
##
## Model:
## e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 +
##     wind.2m.24
##             Df Sum of Sq     RSS     AIC F value    Pr(>F)
## <none>                   0.20820 -247.14
## app.method   1   0.14145 0.34965 -224.26 27.8538 4.572e-06 ***
## man.source   1   0.01144 0.21965 -246.57  2.2531  0.141010
## man.dm       1   0.00565 0.21385 -247.86  1.1120  0.297831
## man.ph       1   0.39799 0.60620 -197.84 78.3737 4.619e-11 ***
## air.temp.24  1   0.01273 0.22094 -246.29  2.5073  0.121002
## wind.2m.24   1   0.05015 0.25835 -238.78  9.8752  0.003109 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
ds3$e.rel.24.pred <- predict(m3a)
```

Institute in linear model.

```
m3b <- lm(e.rel.24 ~ man.source + man.dm + man.ph + air.temp.24 + wind.2m.24 + factor(inst), data = ds3)
summary(m3b)
```

```
##
## Call:
## lm(formula = e.rel.24 ~ man.source + man.dm + man.ph + air.temp.24 +
##     wind.2m.24 + factor(inst), data = ds3)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.14582 -0.03219 -0.01228  0.02428  0.31456
##
## Coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept)     -0.855140   0.171032  -5.000 1.12e-05 ***
## man.sourcepig   -0.102394   0.068216  -1.501  0.14101
## man.dm          -0.014202   0.013468  -1.054  0.29783
## man.ph           0.130583   0.014750   8.853 4.62e-11 ***
## air.temp.24      0.007047   0.004450   1.583  0.12100
## wind.2m.24       0.049244   0.015671   3.142  0.00311 **
## factor(inst)210  0.286149   0.054219   5.278 4.57e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.07126 on 41 degrees of freedom
## Multiple R-squared:  0.8077, Adjusted R-squared:  0.7796
## F-statistic: 28.71 on 6 and 41 DF,  p-value: 3.373e-13
```

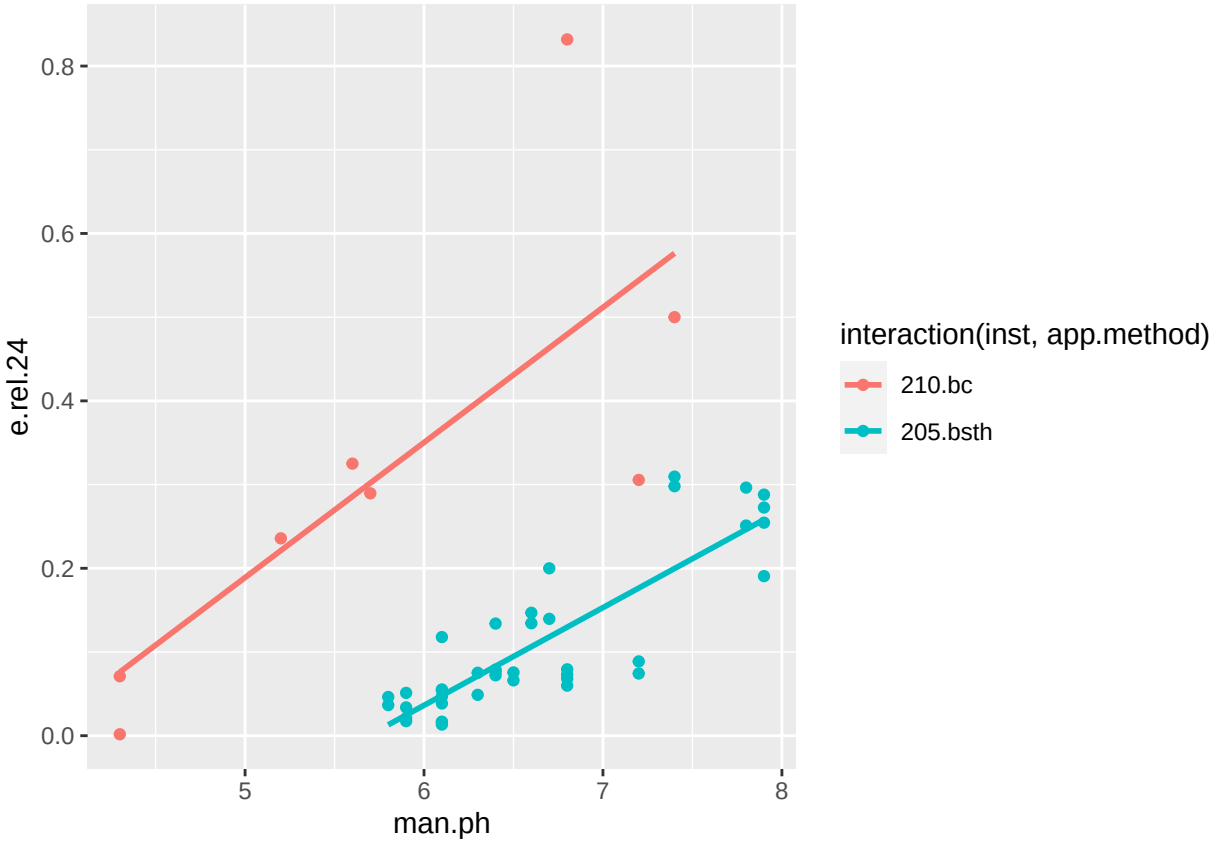
```
drop1(m3b, test = 'F')
```

```
## Single term deletions
##
## Model:
```

```
## e.rel.24 ~ man.source + man.dm + man.ph + air.temp.24 + wind.2m.24 +
##     factor(inst)
##              Df Sum of Sq     RSS     AIC F value    Pr(>F)
## <none>                    0.20820 -247.14
## man.source    1   0.01144 0.21965 -246.57  2.2531  0.141010
## man.dm        1   0.00565 0.21385 -247.86  1.1120  0.297831
## man.ph        1   0.39799 0.60620 -197.84 78.3737 4.619e-11 ***
## air.temp.24   1   0.01273 0.22094 -246.29  2.5073  0.121002
## wind.2m.24    1   0.05015 0.25835 -238.78  9.8752  0.003109 **
## factor(inst)  1   0.14145 0.34965 -224.26 27.8538 4.572e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

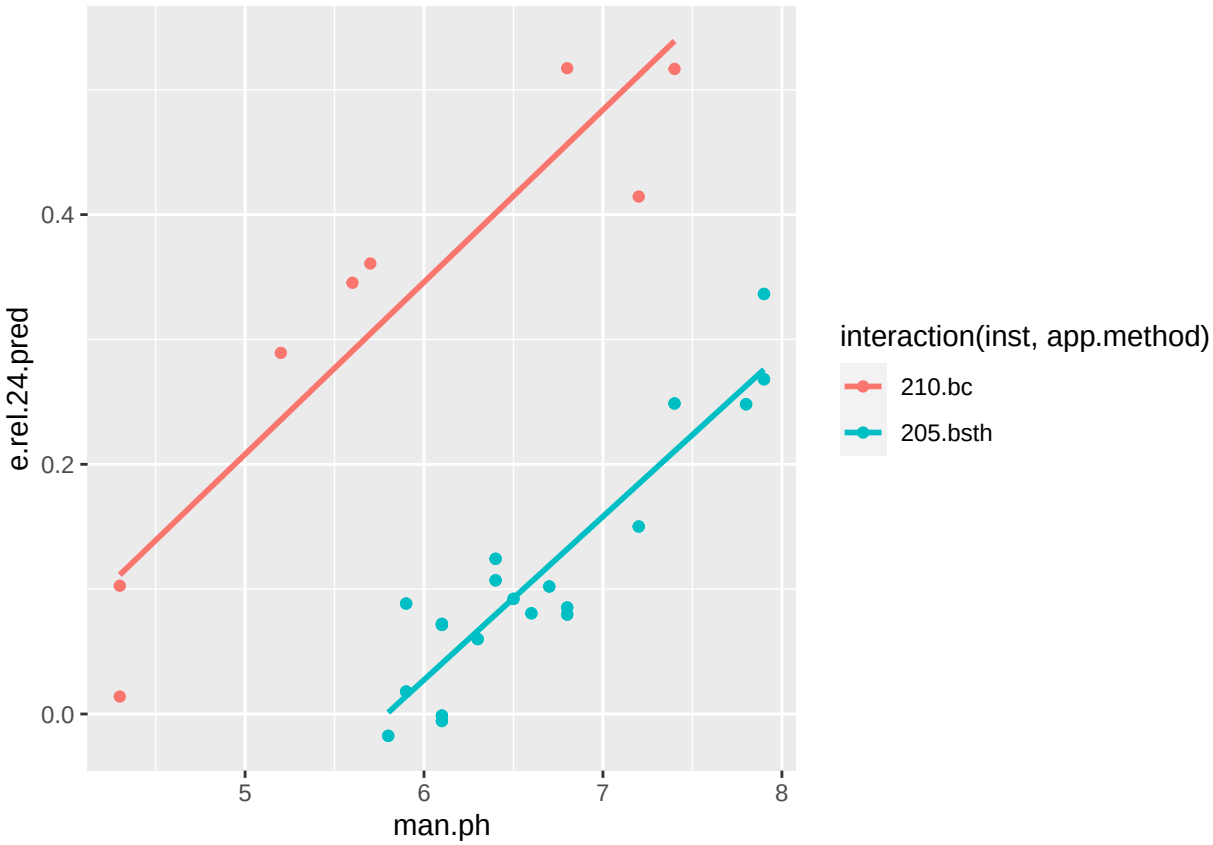
```
ggplot(ds3, aes(man.ph, e.rel.24, colour = interaction(inst, app.method))) +
  geom_point() +
  geom_smooth(method = lm, se = FALSE)
```

```
## `geom_smooth()` using formula 'y ~ x'
```




```
ggplot(ds3, aes(man.ph, e.rel.24.pred, colour = interaction(inst, app.method))) +
  geom_point() +
  geom_smooth(method = lm, se = FALSE)
```

```
## `geom_smooth()` using formula 'y ~ x'
```




Mixed-effects model.

```
m3c <- lmer(e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 + wind.2m.24 + (1|inst)
summary(m3c)
```

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 +      wind.2m.24 + (1 |
##    Data: ds3
##
## REML criterion at convergence: -76.3
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.0463 -0.4517 -0.1723  0.3407  4.4142
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  inst     (Intercept) 0.003157 0.05619
##  Residual             0.005078 0.07126
## Number of obs: 48, groups:  inst, 2
##
## Fixed effects:
##                  Estimate Std. Error t value
## (Intercept)    -0.568991   0.209187  -2.720
## app.methodbsth -0.286149   0.096197  -2.975
## man.sourcepig  -0.102394   0.068216  -1.501
## man.dm         -0.014202   0.013468  -1.054
## man.ph          0.130583   0.014750   8.853
```

```
## air.temp.24     0.007047   0.004450   1.583
## wind.2m.24      0.049244   0.015671   3.142
##
## Correlation of Fixed Effects:
##             (Intr) app.mt mn.src man.dm man.ph ar..24
## app.mthdbst -0.512
## man.sourcpg -0.642  0.342
## man.dm      -0.793  0.405  0.869
## man.ph      -0.462 -0.108 -0.041  0.114
## air.temp.24 -0.682  0.408  0.707  0.638 -0.125
## wind.2m.24  -0.048 -0.095 -0.534 -0.349  0.162 -0.051
```

```
drop1(m3c, test = 'Chisq')
```

```
## Single term deletions
##
## Model:
## e.rel.24 ~ app.method + man.source + man.dm + man.ph + air.temp.24 +
##     wind.2m.24 + (1 | inst)
##             npar      AIC    LRT  Pr(Chi)
## <none>           -106.923
## app.method     1  -98.193 10.729 0.001054 **
## man.source     1 -106.355  2.568 0.109056
## man.dm         1 -107.638  1.284 0.257071
## man.ph         1  -57.626 51.297 7.94e-13 ***
## air.temp.24    1 -106.074  2.849 0.091422 .
## wind.2m.24     1  -98.564 10.359 0.001289 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```