

Statistical models for pH

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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
## Class           numeric      factor   factor numeric numeric      numeric
## Minimum        -0.00222         bc      cat    0.55    3.29        -4.18
## Maximum          5.16          ts    sludge   62.2    9.22         28.8
## Mean             0.255         bss      mink    5.56    7.45         13.2
## Unique (excl. NA)   1736          7        9    421    180        1222
## Missing values      146         34        0    34    292         262
## Sorted            FALSE         FALSE      FALSE  FALSE  FALSE        FALSE
##           wind.2m.24
## Class           numeric
## Minimum          0.409
## Maximum          9.69
## Mean             3.12
## Unique (excl. NA)   1446
## Missing values      149
## Sorted            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
## Class           numeric      factor   factor numeric numeric      numeric
## Minimum        0.000662         bc      cat     1     6.4        -0.656
## Maximum          1          ts    sludge   11.9    8.5         24.2
## Mean             0.234         cs      conc    5.87    7.42         13
## Unique (excl. NA)   449          4        2    199    66         390
## Missing values      0          0        0     0     0          0
## Sorted            FALSE         FALSE      FALSE  FALSE  FALSE        FALSE
##           wind.2m.24
## Class           numeric
## Minimum          0.586
## Maximum          9.69
## Mean             3.32
## Unique (excl. NA)   400
## Missing values      0
```

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

##
## 48 rows and 7 columns
## 48 unique rows
##
##           e.rel.24 app.method man.source man.dm man.ph air.temp.24
## Class           numeric      factor    factor numeric numeric      numeric
## Minimum          0.00176         bc      cat      1.9      4.3      4.56
## Maximum          0.832          ts    sludge      9.7      7.9      21.3
## Mean             0.145          bsth      mix      5.81     6.5      11.3
## Unique (excl. NA)      48          2        2      21      17      28
## Missing values        0          0        0        0        0        0
## Sorted            FALSE          FALSE    FALSE    FALSE    FALSE    FALSE
##
##           wind.2m.24
## Class           numeric
## Minimum          1.51
## Maximum          5.54
## Mean             3.21
## Unique (excl. NA)      28
## Missing values        0
## Sorted            FALSE

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.

```
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.methodcscs -0.2096294  0.0328553  -6.380 2.44e-10 ***
## app.methododos -0.2757403  0.0193278 -14.267 < 2e-16 ***
## app.methodopi  -0.3454680  0.0961448  -3.593 0.000339 ***
## app.methodots  -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
```

```
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 | inst)
## 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.methoddcs     -0.3028084  0.0318684  -9.502
## app.methododos    -0.4156889  0.0198234 -20.970
## app.methodpi      -0.2779556  0.0950169  -2.925
## app.methoddts     -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.

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.methododos -0.414049   0.020447 -20.250 < 2e-16 ***
## app.methoddts  -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

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

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.methododos -0.410067   0.021003 -19.524 < 2e-16 ***
## app.methoddts  -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.methodots  -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 | inst)
##      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.methodots  -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.mthdts   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')
```

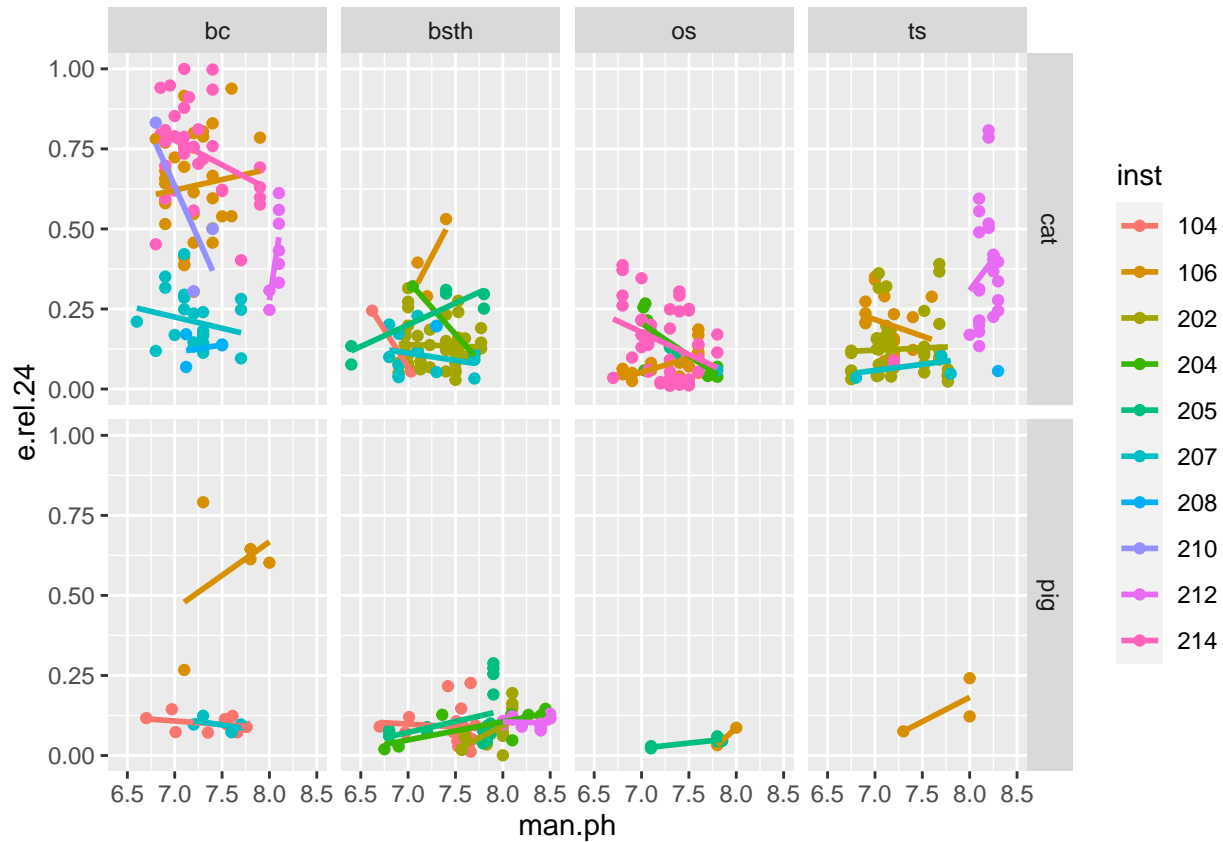
```

## 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

```

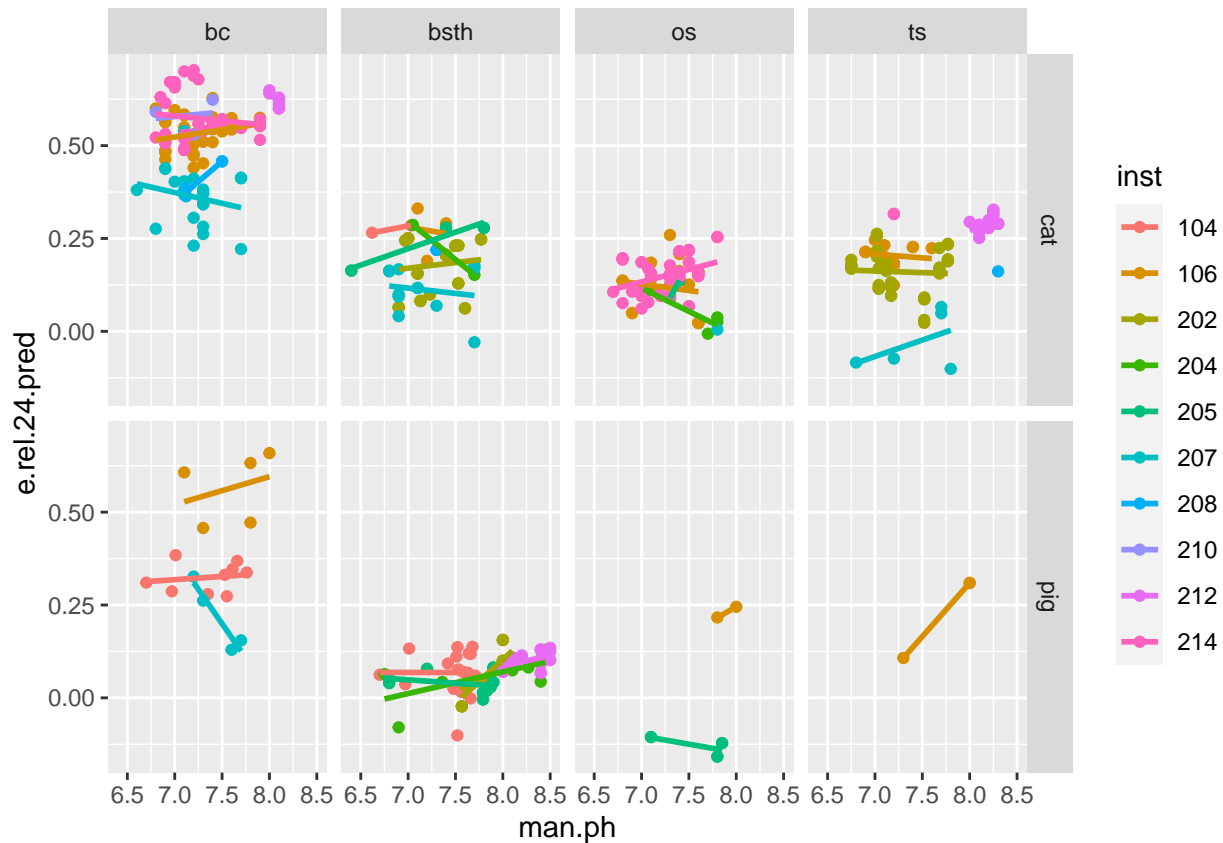
```
ggplot(ds2, aes(man.ph, e.rel.24, colour = inst)) +
  geom_point() +
  facet_grid(man.source ~ app.method) +
  geom_smooth(method = lm, se = FALSE)
```

```
## `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
```

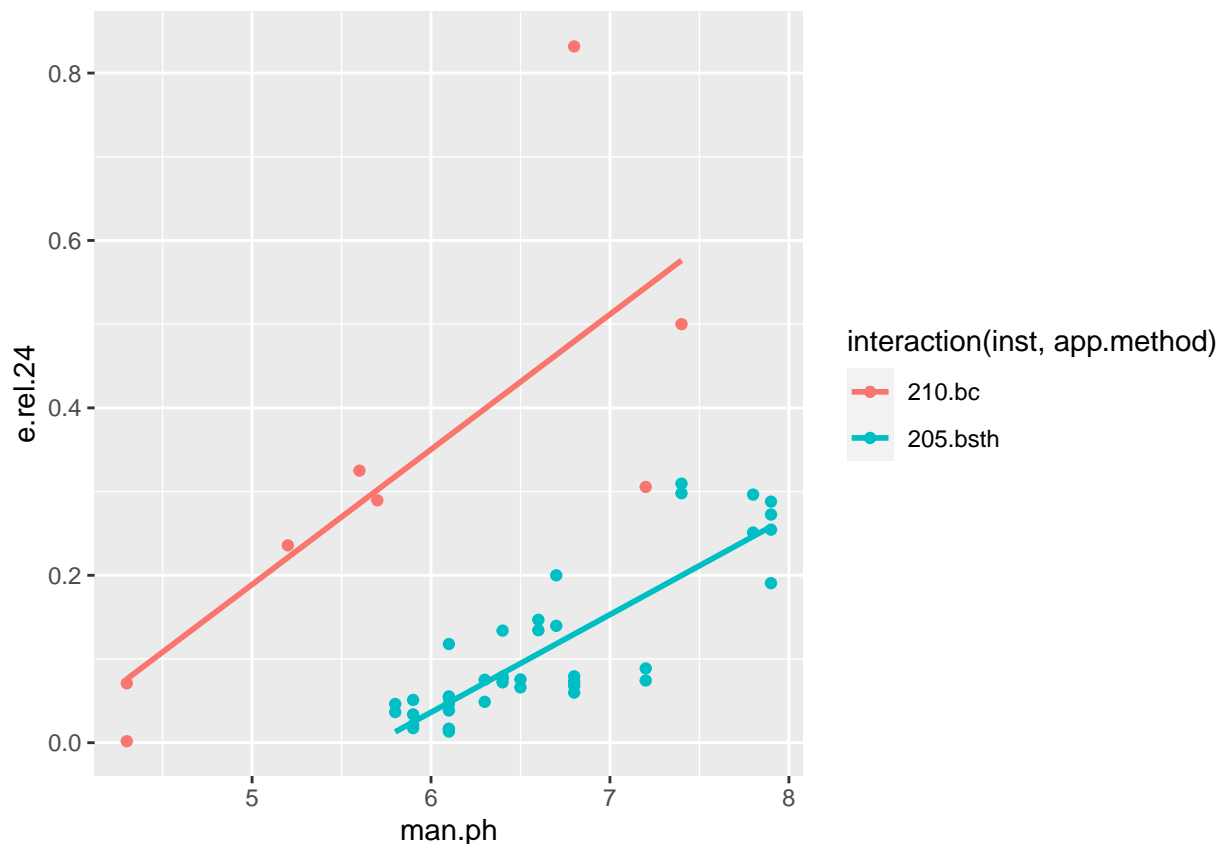
```
##
```

```
## 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
```

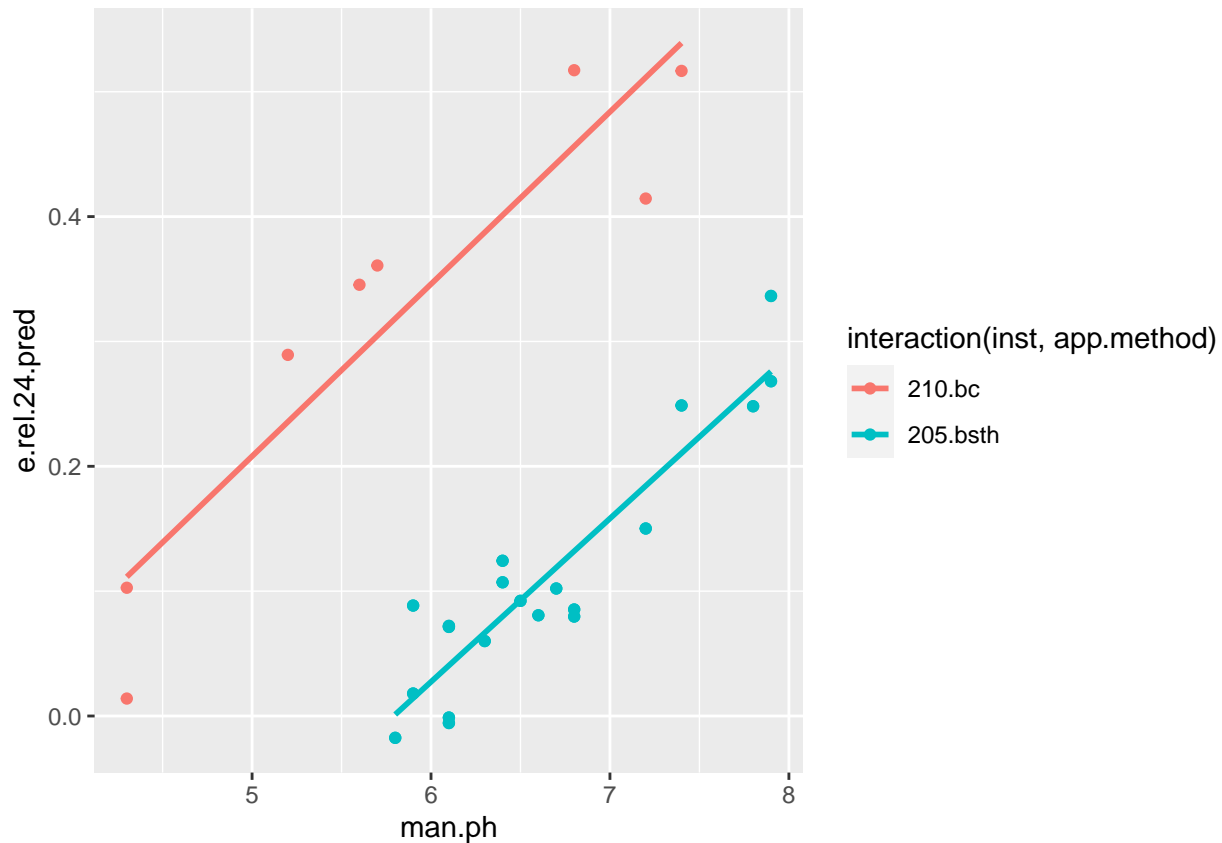
```
ggplot(ds3, aes(man.ph, e.rel.24, colour = interaction(inst, app.method))) +
  geom_point() +
  geom_smooth(method = lm, se = FALSE)
```

```
## `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 | inst)
##      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

```