Sensitivity Analysis with Sobol

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The results of the Sobol sensitivity analysis showed that the value of annual effective dose for adults ranged between 0.3-1824 uSv year-1 while children had a range between 1.18 and 1170 u sv year-1. The exposure dose was overall found to be greater in adults than for children, and the hazard doses of uranium content from groundwater were found to have a higher exposure to uranium in children than adults. The results of this sensitivity analysis recommended that water monitoring and dose assessment be more enforced to prevent non-carcinogenic risk. The results of this study contribute to the understanding and predictions of the model that the concentration of uranium in groundwater was unsurprisingly the most influencing parameter fort the skin exposure (dermal) model. This value was found to be higher in adults while IR was more sensitive for younger groups. This sobol sensitivity analysis shows that different age groups have different exposure risks depending on the model, recommending that uranium in groundwater be monitored more closely.

```r
library(sensitivity)
```

```
Warning: package 'sensitivity' was built under R version 4.3.3

Registered S3 method overwritten by 'sensitivity':
  method    from
  print.src dplyr
```

```r
library(tidyverse)
```

```
Warning: package 'ggplot2' was built under R version 4.3.2

Warning: package 'tidyr' was built under R version 4.3.2

── Attaching core tidyverse packages ────────────────────────
tidyverse 2.0.0 ──
✔ dplyr     1.1.4     ✔ readr     2.1.4
✔ forcats   1.0.0     ✔ stringr   1.5.1
✔ ggplot2   3.5.1     ✔ tibble    3.2.1
```

```
✔ lubridate 1.9.3     ✔ tidyr     1.3.1
✔ purrr     1.0.2

── Conflicts ──────────────────────────────────────────
tidyverse_conflicts() ──
✖ tidyr::extract() masks sensitivity::extract()
✖ dplyr::filter()  masks stats::filter()
✖ dplyr::lag()     masks stats::lag()
✖ dplyr::src()     masks sensitivity::src()
ℹ Use the conflicted package (<http://conflicted.r-lib.org/>)
to force all conflicts to become errors
```

```r
library(gridExtra)
```

```

Attaching package: 'gridExtra'

The following object is masked from 'package:dplyr':

    combine
```

```r
library(purrr)
library(ggpubr)
library(here)
```

```
here() starts at /Users/bgrazda/MEDS/ESM232_EDS230_Examples
```

```r
source(here("R/Catm.R"))
```

Atmospheric Conductance as a function of windspeed, vegetation height and parameters

Part a. Use the Sobel approach to generate parameter values

for the 4 parameters

```
np <- 1000  # number of samples

# First sample set (X1)
k_o <- rnorm(n = np, mean = 0.1, sd = 0.001) # Normally
k_d <- rnorm(n = np, mean = 0.7, sd = 0.007) # default
v <- rnorm(n = np, mean = 3, sd = 0.5)  # Converted to
height <- runif(n = np, min = 3.5, max = 5.5) # range b

X1 <- cbind.data.frame(k_o, k_d, v, height) # Bind all

# Generate second sample set (X2)
k_o <- rnorm(n = np, mean = 0.1, sd = 0.001)
k_d <- rnorm(n = np, mean = 0.7, sd = 0.007)
v <- rnorm(n = np, mean = 3, sd = 0.5)
height <- runif(n = np, min = 3.5, max = 5.5)

X2 <- cbind.data.frame(k_o, k_d, v, height)

# there are different versions of sobol functions that

sens_Catm_Sobol <- sobolSalt(model = NULL, X1, X2, nboo
```

Part b: Run the atmospheric conductance model for these

parameters

```
# run model for all parameter sets
# make sure you give the parameters names

parms <- as.data.frame(sens_Catm_Sobol$X)
colnames(parms) <- colnames(X1)
res <- pmap_dbl(parms, Catm)

sens_Catm_Sobol <- sensitivity::tell(sens_Catm_Sobol, r

# main effect:  partitions variance (main effect withou
sens_Catm_Sobol$S
```

```
     original         bias std. error   min. c.i.  max. c.i.
X1 0.02775181 0.0034179404 0.02853447 -0.03946414 0.07436722
```

```
X2 0.02543835 0.0037766286 0.02827750 -0.04211537 0.06936103
X3 0.82462367 0.0010624014 0.00992425  0.80234514 0.84825202
X4 0.18449927 0.0008307005 0.02750544  0.12584075 0.23890908
```

```
# useful to add names
row.names(sens_Catm_Sobol$S) <- colnames(parms)
sens_Catm_Sobol$S
```

```
         original         bias std. error   min. c.i.  max.
c.i.
k_o    0.02775181 0.0034179404 0.02853447 -0.03946414
0.07436722
k_d    0.02543835 0.0037766286 0.02827750 -0.04211537
0.06936103
v      0.82462367 0.0010624014 0.00992425  0.80234514
0.84825202
height 0.18449927 0.0008307005 0.02750544  0.12584075
0.23890908
```

```
# Both the main effect and total effect can tell us som


print(sens_Catm_Sobol)
```

```
Call:
sobolSalt(model = NULL, X1 = X1, X2 = X2, nboot = 100)

Model runs: 6000

Model variance: 480.1759

First order indices:
         original         bias std. error   min. c.i.  max.
c.i.
k_o    0.02775181 0.0034179404 0.02853447 -0.03946414
0.07436722
k_d    0.02543835 0.0037766286 0.02827750 -0.04211537
0.06936103
v      0.82462367 0.0010624014 0.00992425  0.80234514
0.84825202
height 0.18449927 0.0008307005 0.02750544  0.12584075
0.23890908
```

```
Total indices:
      original          bias    std. error   min. c.i.   max.
c.i.
X1 0.002779696 -3.006267e-06 0.0001719744 0.002474399
0.003136469
X2 0.002902093 -1.712177e-05 0.0001790501 0.002613703
0.003230579
X3 0.765747817 -2.935230e-03 0.0265579985 0.709681414
0.826816025
X4 0.176574983 -2.055078e-04 0.0090360756 0.157061758
0.192021041
```

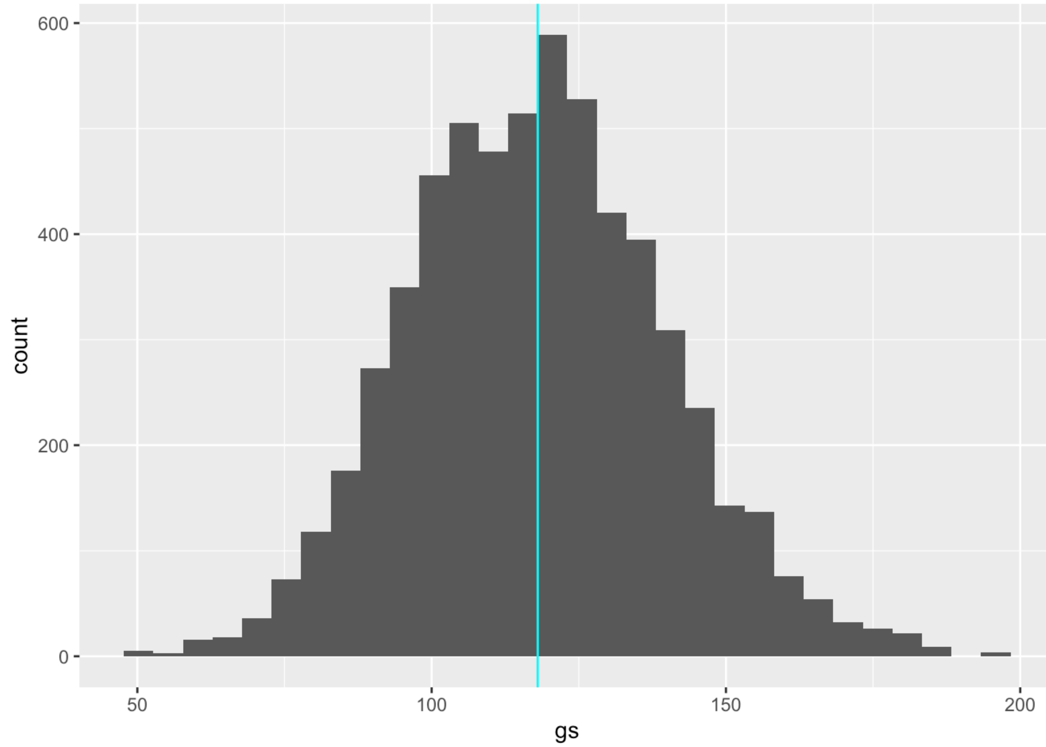
Plotting

- uncertainty in the output
- relationships you are interested in
- response to most sensitive parameters

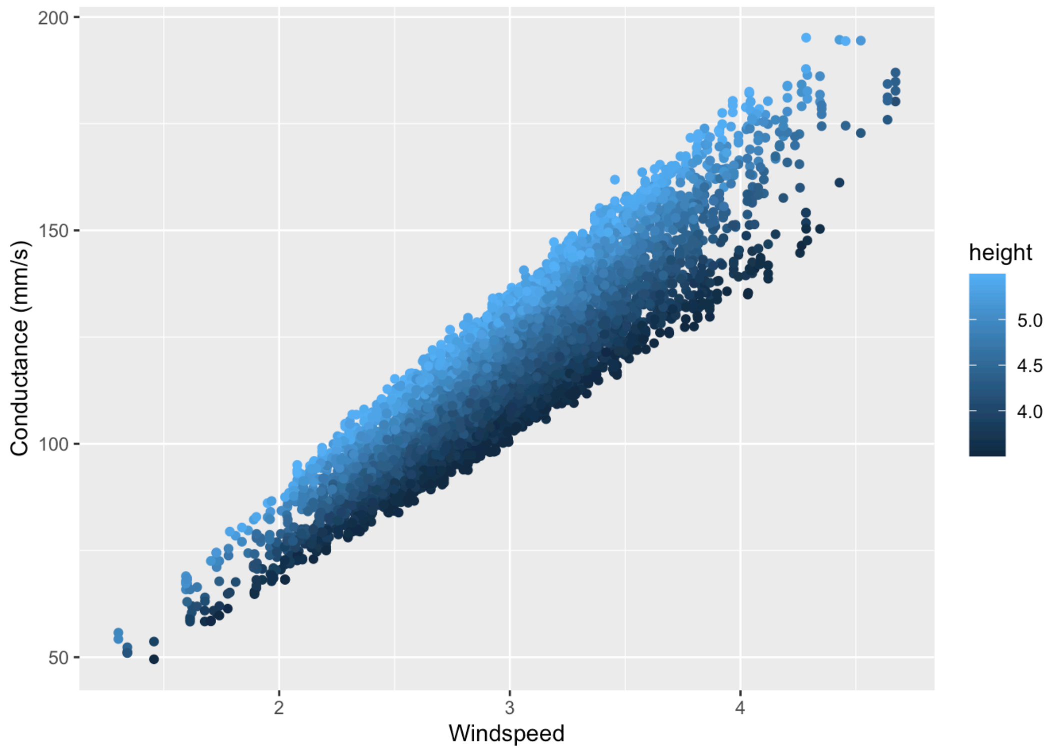
```
        # graph two most sensitive parameters
        both <- cbind.data.frame(parms, gs = sens_Catm_Sobol$y)

        # Part c: look at overall gs sensitvity to uncertainty
        ggplot(both, aes(x = gs)) +
          geom_histogram() +
          geom_vline(xintercept = mean(both$gs), col = "cyan")
```

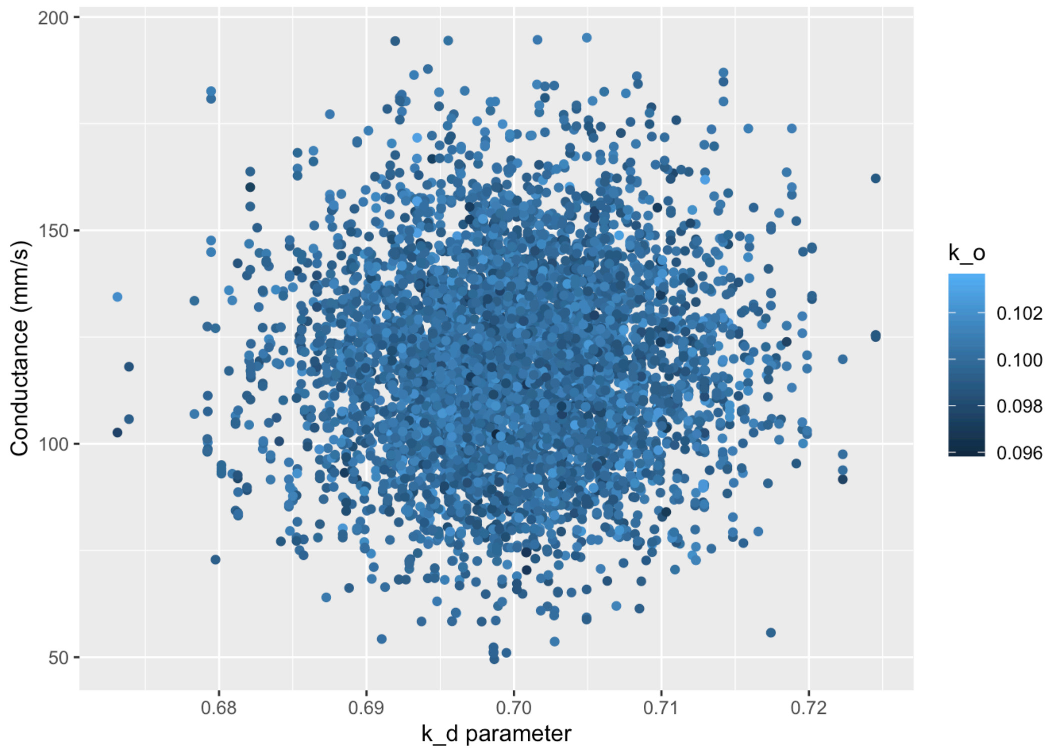
```
`stat_bin()` using `bins = 30`. Pick better value with
`binwidth`.
```



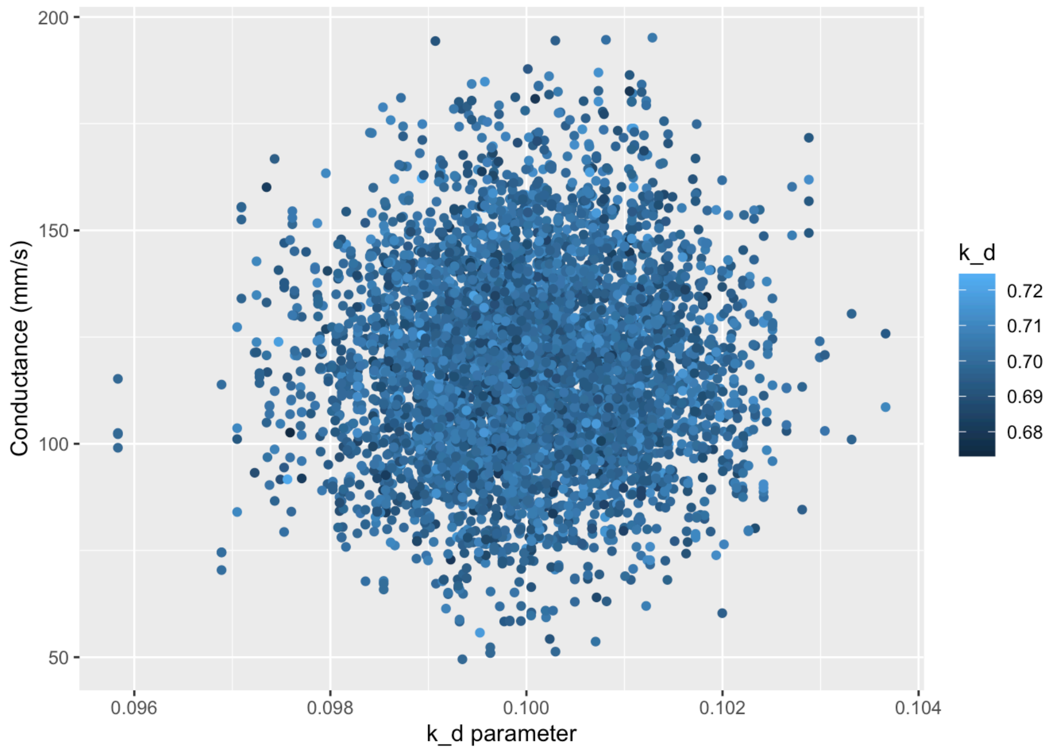

```
# look at response of conductance to the two interestin
ggplot(both, aes(v, gs, col = height)) +
  geom_point() +
  labs(y = "Conductance (mm/s)", x = "Windspeed")
```




```
# look at response of conductance to the two most impor
ggplot(both, aes(k_d, gs, col = k_o)) +
  geom_point() +
  labs(y = "Conductance (mm/s)", x = "k_d parameter")
```




```r
# use second most sensitive parameter (using most impor
ggplot(both, aes(k_o, gs, col = k_d)) +
  geom_point() +
  labs(y = "Conductance (mm/s)", x = "k_d parameter")
```



Estimate sobol indices

```
# Estimate indices
sens_Catm_Sobol2 <- sobolSalt(model = NULL, X1, X2, nbo

# Store the parameters
parms <- as.data.frame(sens_Catm_Sobol2$X)
colnames(parms) <- colnames(X1)
res <- pmap_dbl(parms, Catm) # Store model outputs in l

# Calculate sensitivity with the new sobolSalt output
sens_Catm_Sobol2 <- sensitivity::tell(sens_Catm_Sobol2,

# main effect:  partitions variance (main effect withou
row.names(sens_Catm_Sobol2$S) <- colnames(parms)
sens_Catm_Sobol2$S
```

```
         original         bias   std. error   min. c.i.   max.
c.i.
k_o    0.02540465 -0.002231664 0.030056006 -0.03158756
0.09206290
k_d    0.02620762 -0.001976067 0.029408174 -0.03165626
```

```
0.09018457
v      0.82279943 -0.001066841 0.008606707  0.80704576
0.84118470
height 0.20784496 -0.002462192 0.026758001  0.15336977
0.26150637
```

```
# total effect - accounts for parameter interactions
row.names(sens_Catm_Sobol2$T) <- colnames(parms)
sens_Catm_Sobol2$T
```

```
          original         bias   std. error   min. c.i.   max.
c.i.
k_o    0.002842909 1.728720e-06 0.0001715526 0.002489825
0.003150618
k_d    0.002992729 2.577499e-05 0.0001896640 0.002606831
0.003316477
v      0.787523199 2.354897e-03 0.0263547072 0.734378316
0.840186348
height 0.174967810 8.875099e-04 0.0082690590 0.157742415
0.190955232
```

```
# second order parameters interaction in controlling se
# parameters are in order, interactiosn are small here
sens_Catm_Sobol2$S2
```

```
        original        bias std. error   min. c.i.  max. c.i.
X1X2 -0.02360989 0.002168437 0.02982338 -0.08816022 0.03396842
X1X3 -0.02564556 0.002329828 0.03011360 -0.09292148 0.03286054
X1X4 -0.02066434 0.002017353 0.02981187 -0.08577531 0.03601202
X2X3 -0.02386504 0.002030877 0.02955767 -0.08774683 0.03456054
X2X4 -0.02287715 0.002084401 0.02981300 -0.08811581 0.03407957
X3X4 -0.03660759 0.003529492 0.02900021 -0.09554188 0.02877148
```

f. Comment on what this tells you about how atmospheric conductance and its sensitivity to variation in windspeed differs in this setting as compared to the setting that we examined in class where windspeed was lower and less variable and vegetation was taller.

With the windspeed increasing, the atmospheric conductance is more sensitive with a strong, positive, and seemingly linear correlation to windspeed. When windspeed was lower and vegetation was taller, there is more water capture by vegetation that prevents water to vaporize with heat and return to the atmosphere. When the vegetation is shorter and windspeed is greater, heat is more easily transferred to the atmosphere because there is less physical barriers for evapotranspiration. When we increase windspeed, atmospheric conductance sensitivity also increases.