Sensitivity Analysis - Latin Hypercube Sampling

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This environmental model was completed as an assignment for the course, Environmental Data Science 230 | Environmental Science & Management: Modeling Environmental Systems. The goal of this assignment was to code a function to compute atmosphere condcuctance and to conduct a formal sensitivity analysis using the Latin Hypercube Sampling (LHS) random sampling method. This assignment focuses on developing skills to create a atmospheric conductance model function, utilize the Latin Hypercube Sampling to generate near random sample of parameter values, and then plot the atmospheric conductance values.

Load Libraries

```
library(here)
library(SciViews) # ln() function
library(pse)
library(purrr)
library(ppcor)
library(kableExtra)
```

1. Code a function to compute atmospheric conductance

```
source(here("R/atmcon.R"))
```

2. Run `atmcon` model and provide a single estimate of atmospheric conductance for this forest.

```
ac_forest <- atmcon(vm = 250, h = 1000)
ac_forest
```

```
## $ac
## [1] 15.44228
```

```
ac_forest_rounded <- round(ac_forest[[1]], 2)

print(paste0("The atmospheric conductance for this vegetation is ",
             ac_forest_rounded, " centimeters per second."))
```

```
## [1] "The atmospheric conductance for this vegetation is 15.44 centimeters per second."
```

3. Conduct a sensitivity analysis

Consider the sensitivity of estimates to uncertainty in the following parameters and inputs:

- *vm*
- *h*
- *kd*
- *k0*

Windspeeds `vm` are normally distributed with a `mean` of `250 cm/sec` with a `standard deviation` of `30 cm/sec`.

For vegetation height, `h`, assume that height is somewhere between 9.5 and 10.5 m (but any value in that range is equally likely).

The typical values of `kd` is 0.7 and `k0` is 0.1, Assume that they are normally distributed with standard deviation of 1% of their default values.

3.A. Use LHS to generate parameter values for the 4 parameters

```
# define 4 parameters to test
factors = c("vm", "h", "kd", "k")

vm_mean = 250
vm_sd = 30

h_min = 9.5 * 100
h_max = 10.5 * 100

kd_value = 0.7
k0_value = 0.1

kd_sd = 0.01
k0_sd = 0.01

#define sample size
nsets = 100

# set distributions for defined parameters
# qnorm=windspeed, qunif=height, qnorm=k, qnorm=k0
q = c("qnorm", "qunif", "qnorm", "qnorm")

q.arg = list(list(mean = vm_mean, sd = vm_sd), #windspeed
             list(min = h_min, max = h_max), #height
             list(mean = kd_value, sd = kd_sd), #k
             list(mean = k0_value, sd = k0_sd)) #k0
q.arg
```

```
## [[1]]
## [[1]]$mean
## [1] 250
##
## [[1]]$sd
## [1] 30
##
##
## [[2]]
```

```
## [[2]]$min
## [1] 950
##
## [[2]]$max
## [1] 1050
##
##
## [[3]]
## [[3]]$mean
## [1] 0.7
##
## [[3]]$sd
## [1] 0.01
##
##
## [[4]]
## [[4]]$mean
## [1] 0.1
##
## [[4]]$sd
## [1] 0.01
```

```
# run LHS and generate samples
sens_ac = LHS(NULL, factors, nsets, q, q.arg) # NULL indicates there is no model

#sens_ac
#summary(sens_ac)
#sens_ac$data

sens_pars <- get.data(sens_ac)
head(sens_pars)
```

```
##         vm      h        kd          k
## 1 226.3243  957.5 0.7021470 0.08560469
## 2 254.9098 1021.5 0.6951827 0.11514102
## 3 227.3375 1000.5 0.6934116 0.08627796
## 4 210.6826  982.5 0.6948993 0.11439531
## 5 239.6462 1019.5 0.7257583 0.09025886
## 6 267.0415 1027.5 0.6978530 0.10453762
```

3.B. Run the atmospheric conductance model, atmcon, for LHS derived parameters and return aerodynamic conductances

```
source(here("R/atmcon.R"))

ac_lhs <- pmap(sens_pars, atmcon)
head(ac_lhs[[2]])
```

```
## $ac
## [1] 18.88294
```

```
atmospheric_conductances <- ac_lhs %>%
  map_dfr(`[`, "ac")

atmospheric_conductances
```

```
## # A tibble: 100 x 1
##        ac
##     <dbl>
##   1  11.5
##   2  18.9
##   3  11.6
##   4  15.1
##   5  14.1
##   6  17.6
##   7  15.6
##   8  13.5
##   9  14.3
## 10  16.1
## # ... with 90 more rows
```

3.C. Plot conductance estimates in a way that accounts for parameter uncertainty

```
plot1 <- ggplot(data = atmospheric_conductances, aes(y = ac)) +
  geom_boxplot(fill='seashell1', color="grey58") +
  geom_text(aes(x = 0.025, y = 32.5, label = "32.59"), stat = "unique",
            size = 3, color = "slategrey") +
  labs(y = "Atmospheric Conductance (cm/s)",
       title = "Atmospheric Conductance - Forest Parameters",
       subtitle = "Variation in Estimated Conductance Outputs",
       caption = "Data: Modeled values modeled based on parameters estimated using LHS.") +
  theme_minimal() +
  theme(axis.title.x = element_blank(),
        axis.text.x = element_blank(),
        axis.ticks.x = element_blank())
plot1
```

3.D. Plot conductance estimates against each of your parameters

```
# link LHS object (sens_conductance) to outputs
sens_conductance <- pse::tell(sens_ac,
                              t(atmospheric_conductances),
                              res.names = "Atmospheric Conductance")

# plot conductance vs params
plot2 <- pse::plotscatter(sens_conductance,
                 pch = 21, bg= "slateblue", col = "grey58", cex = 0.9)
```

```
plot2
```

```
## NULL
```

3.E. Estimate the Partial Rank Correlation Coefficients (PRCC)

```
sens_con_df <- data.frame(sens_conductance$data)

atmcon_prcc <- pcor(sens_con_df)
```

```
sens_con_table <- kable(atmcon_prcc)
sens_con_table
```

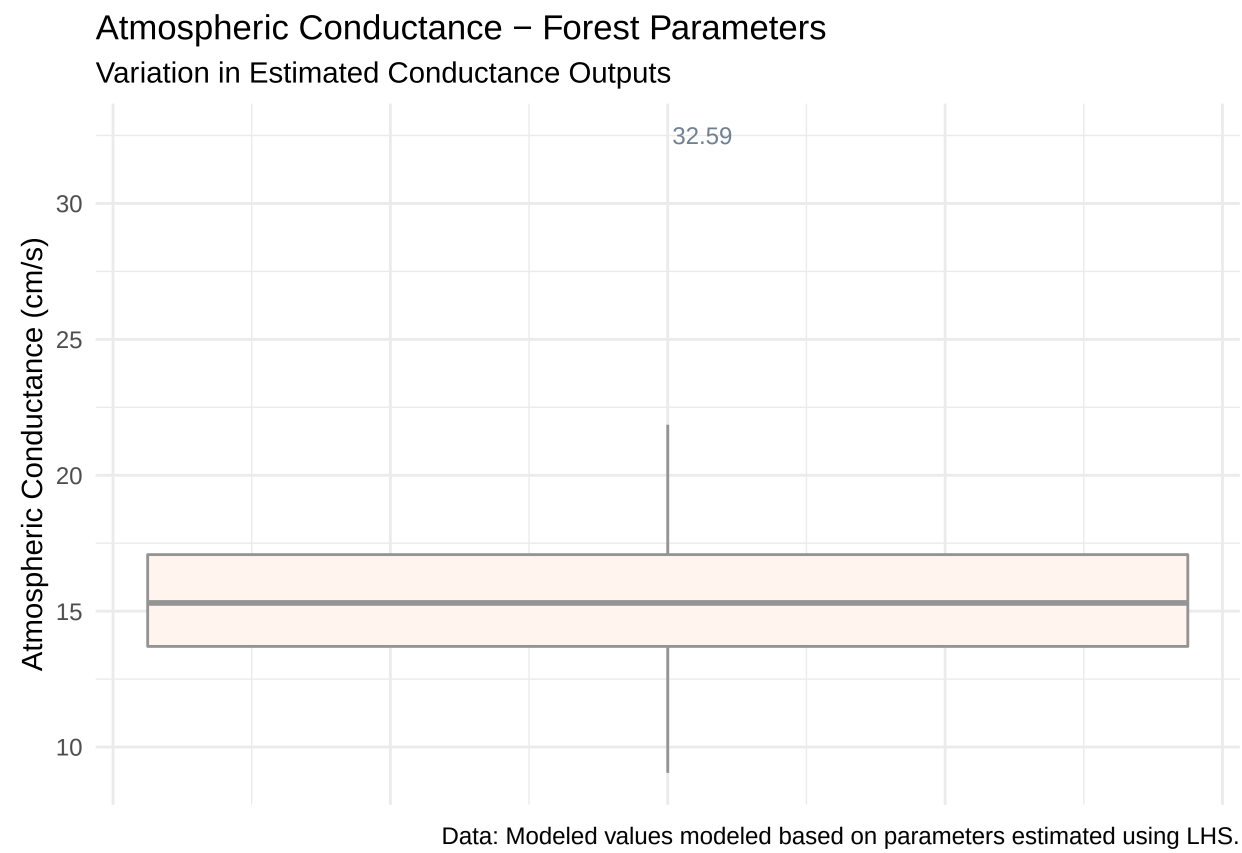

Figure 1: This boxplot shows distribution of atmospheric conducances with given estimated forest parameters

	vm	h	kd	k
vm	1.0000000	-0.0000393	-0.0000309	0.0001218
h	-0.0000393	1.0000000	-0.0000036	0.0004429
kd	-0.0000309	-0.0000036	1.0000000	0.0001402
k	0.0001218	0.0004429	0.0001402	1.0000000

	vm	h	kd	k
vm	0.0000000	0.9996939	0.9997594	0.9990505
h	0.9996939	0.0000000	0.9999722	0.9965464
kd	0.9997594	0.9999722	0.0000000	0.9989069
k	0.9990505	0.9965464	0.9989069	0.0000000

	vm	h	kd	k
vm	0.0000000	-0.0003846	-0.0003023	0.0011931
h	-0.0003846	0.0000000	-0.0000350	0.0043397
kd	-0.0003023	-0.0000350	0.0000000	0.0013736
k	0.0011931	0.0043397	0.0013736	0.0000000

x
100

x
2

x
pearson

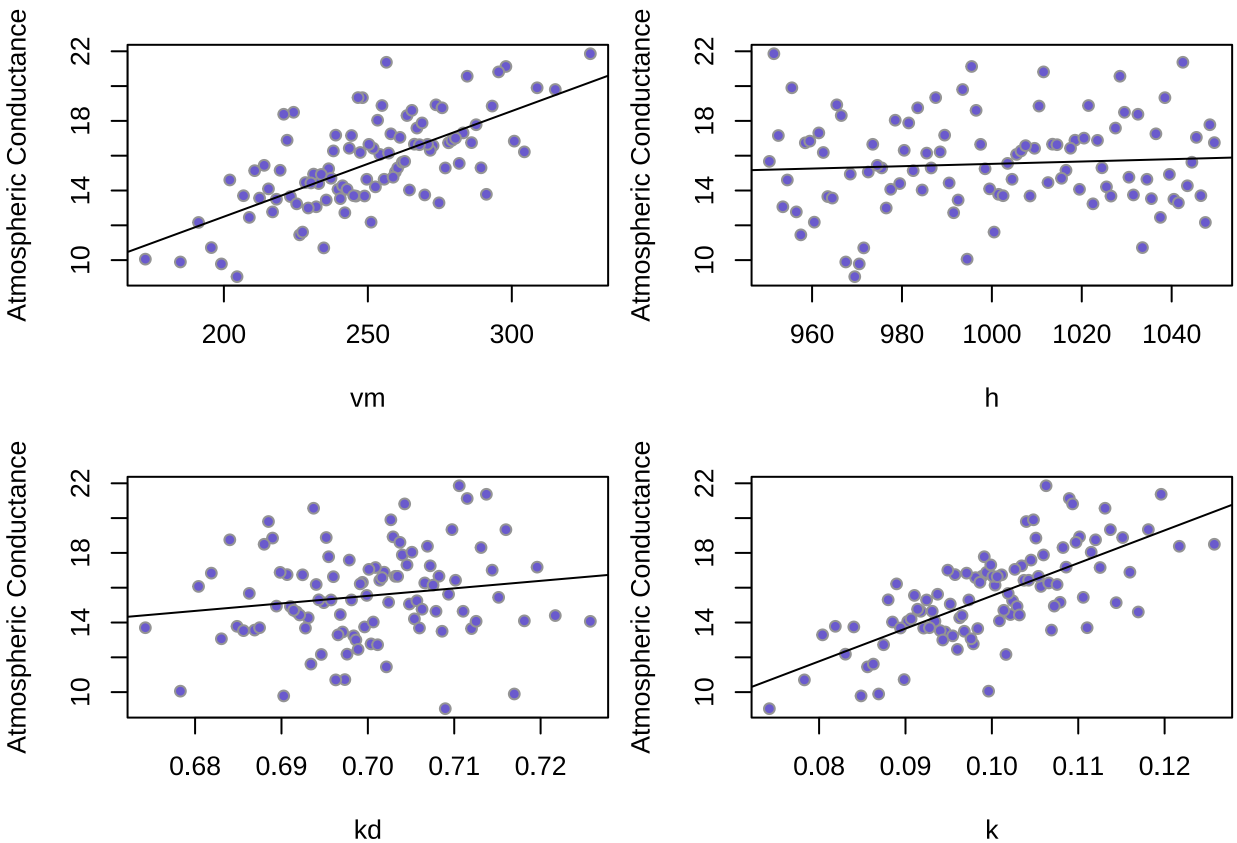

Figure 2: Analyzing atompheric conductance parameter sensitivity. Parameters: vm = windspeed, h = vegetation height, kd = constant, k = constant.

```r
plot3 <- pse::plotprcc(sens_conductance, col = "slateblue")
```

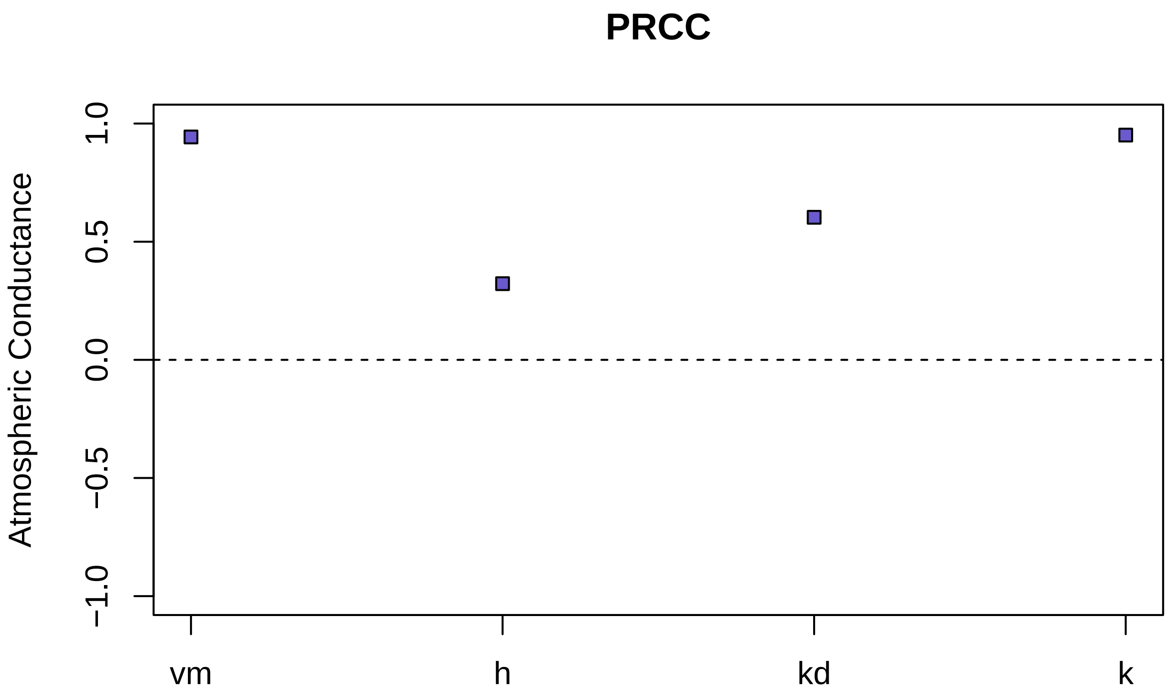

Figure 3: The partial rank correlation coefficient (PRCC) of the basic reproduction in model (atmcon) with respect to other model parameters. For each parameter, the absolute value of its PRCC represents the sensitivity of the parameter - the larger the value is, the more sensitive the parameter is to the corresponding parameter. Parameters: vm = windspeed, h = vegetation height, kd = constant, k = constant.

```r
plot3
```

```
## NULL
```

3.F. Discussion

What do the results tell about how aerodynamic conductance?

What does it suggest about what you should focus on if you want to reduce uncertainty in aerodymaic conductance estimates?

Does this tell you anything about the sensitivity of plant water use to climate change?