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_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
kd_sd = 0.01

k0_value = 0.1
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
```

```
# 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
## 1 243.5590 1036.5 0.7026631 0.10214702
## 2 247.3647  999.5 0.7003761 0.10510073
## 3 202.0542 1032.5 0.6924458 0.09103527
## 4 208.8339  962.5 0.7143953 0.10974114
## 5 265.3022  986.5 0.7042615 0.09836342
## 6 254.9098  975.5 0.6889694 0.07424171
```

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)
```

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

head(atmospheric_conductances)
```

```
## # A tibble: 6 x 1
##      ac
##   <dbl>
## 1  15.8
## 2  16.3
## 3  11.1
## 4  14.8
## 5  16.1
## 6  10.8
```

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 = 0.01, y = 25, label = "24.77"), 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: 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
```

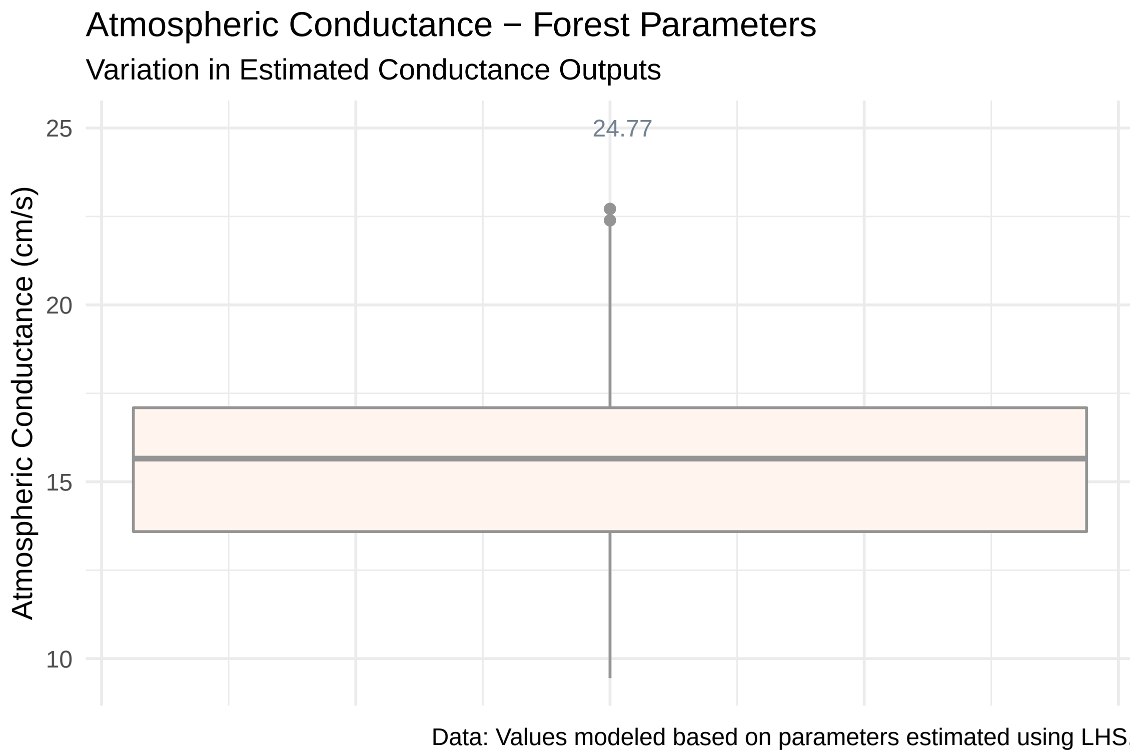

Figure 1: This boxplot shows distribution of atmospheric conducances with given estimated forest parameters

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

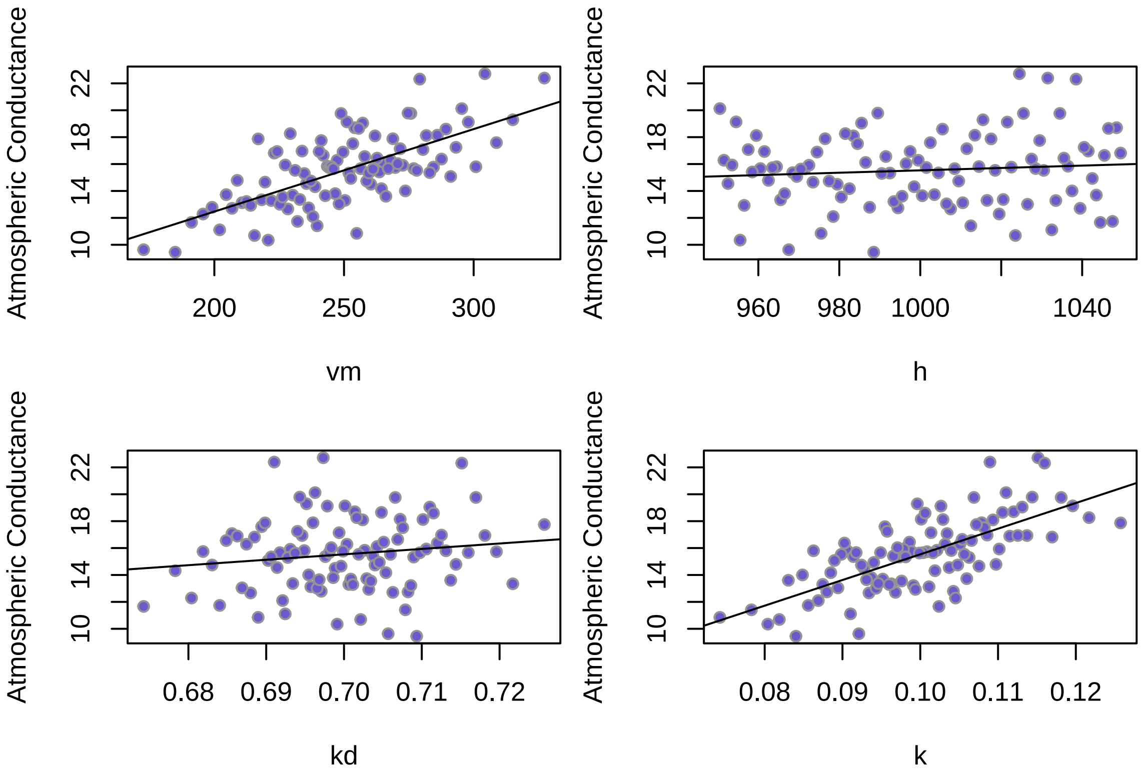

Figure 2: Analyzing atompheric conductance parameter sensitivity. Parameters: vm = windspeed, h = vegetation height, kd = constant, k = constant.

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

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

atmcon_prcc <- pcor(sens_con_df)

atmcon_prcc_df <- data.frame(atmcon_prcc) %>%
  janitor::clean_names() %>%
  dplyr::select(estimate_vm:p_value_k)
```

```
sens_con_table <- kable(atmcon_prcc_df)  %>%
  row_spec(c(0), background = "lightgray")

sens_con_table
```

	estimate_vm	estimate_h	estimate_kd	estimate_k	p_value_vm	p_value_h	p_value_kd	p_value_k
vm	1.000000	-0.0002820	-0.0000720	-0.0001940	0.0000000	0.997801	0.9994383	0.998487
h	-0.000282	1.0000000	0.0001457	-0.0001114	0.9978010	0.000000	0.9988640	0.999131
kd	-0.000072	0.0001457	1.0000000	-0.0002276	0.9994383	0.998864	0.0000000	0.998225
k	-0.000194	-0.0001114	-0.0002276	1.0000000	0.9984870	0.999131	0.9982250	0.000000

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

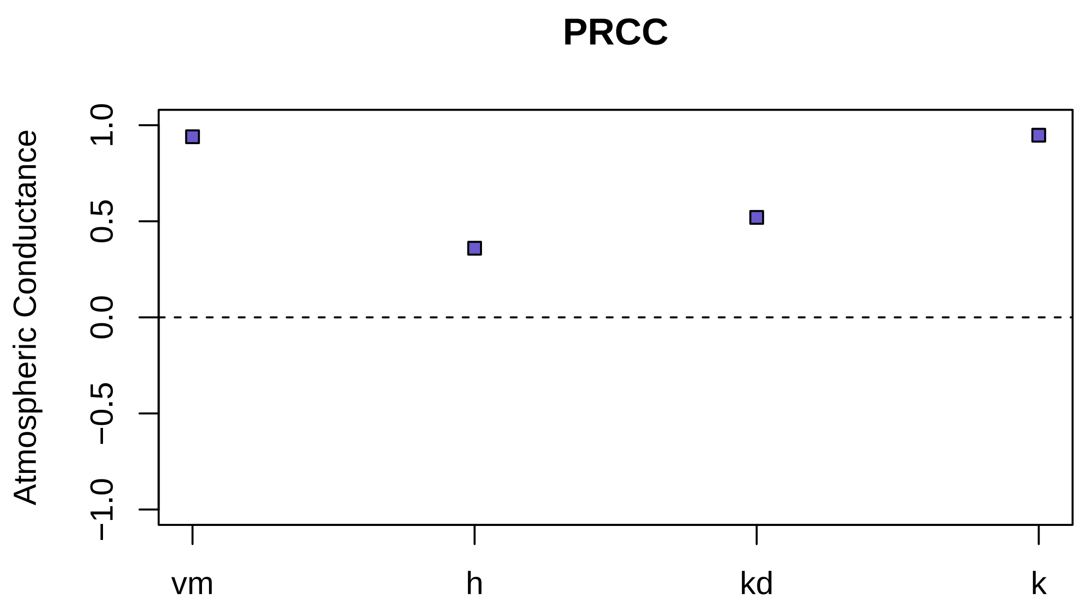

Figure 3: The partial rank correlation coefficient (PRCC) of the basic reproduction in model (atmcon) with respect to other model parameters. For each parameter, the absolute value of its PRCC represents the sensitivity of the parameter - the larger the value is, the more sensitive the parameter is to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

3.F. Discussion

What do the results tell about how aerodynamic conductance? The results from the scatter plot tells us that `wind speed` and `k` have the greatest impacts on aerodynamic conductance. Parameters `kd` and `h` do not have a strong correlation with aerodynamic conductance. Additionally, the partial rank correlation coefficient tells us that wind speed and k0 have the greatest impacts on aerodynamic conductance because those values are closest to 1.

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?