Forest Growth Model

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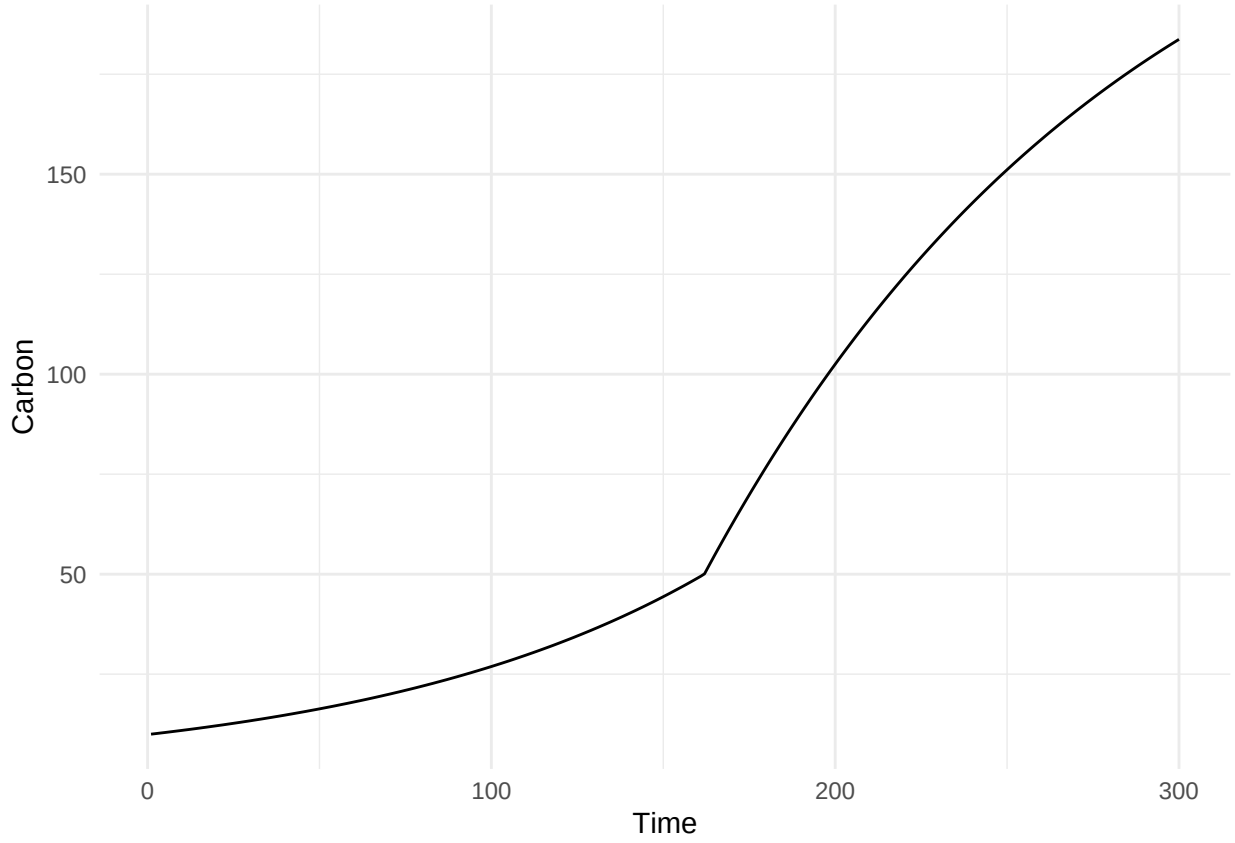
Parameters and growth function

```
# set parameters
K = 250
r = 0.01
g = 2
cc_threshold = 50

# create a time sequence
times = seq(from = 1, to = 300)

forestparms <- list(times = times,
                    r = r,
                    g = g,
                    K = K,
                    cc_threshold = cc_threshold)

# start a small forest
C_initial = 10

source(here("R", "growth.R"))

# watch it grow
forest = ode(y = C_initial, times, growth, forestparms)

colnames(forest)=c("Time","Carbon")

ggplot(as.data.frame(forest),aes(x = Time, y = Carbon) ) +
  geom_line() +
  theme_minimal()
```



Sobol Sensitivity Analysis

```
# we want to learn about sensitivity to growth rates (r,g), carrying capacity (K), and the canopy closu

#number of samples
np = 100

#create first sample parameters from normal distributions
r = rnorm(mean = 0.01, sd = r*.10, n = np)
g = rnorm(mean = 2, sd = g*.10, n = np)
cc_threshold = rnorm(mean = 50, sd = cc_threshold*.10, n = np)
K = rnorm(mean = 250, sd = K*.10, n = np)

#create the first dataframe
X1 = cbind.data.frame(r = r, K= K, g = g, cc_threshold = cc_threshold)

#create second sample parameters from normal distributions (this is just how sobol works)
r = rnorm(mean = 0.01, sd = r*.10, n = np)
g = rnorm(mean = 2, sd = g*.10, n = np)
cc_threshold = rnorm(mean = 50, sd = cc_threshold*.10, n = np)
K = rnorm(mean = 250, sd = K*.10, n = np)

#create the second dataframe
X2 = cbind.data.frame(r = r, K = K, g = g, cc_threshold = cc_threshold)
```

Create Sobol Object

```
#create sobol object and get parameters for running the model
sens_forest = sobolSalt(model = NULL, X1, X2, nboot = 300)

colnames(sens_forest$X) = c("r",
                            "K",
                            "g",
                            "cc_threshold")
head(sens_forest$X)
```

```
##                r        K        g cc_threshold
## [1,] 0.009859939 248.3973 1.996501     56.01417
## [2,] 0.010129712 283.0326 2.203041     46.42178
## [3,] 0.011133844 241.9798 2.245659     56.82035
## [4,] 0.009111648 268.5268 2.175026     51.54943
## [5,] 0.010693976 323.4721 2.158395     55.12114
## [6,] 0.009178387 225.9693 1.941456     53.07908
```

Wrapper Function

```
source(here("R", "compute_metrics.R"))

growth_wrapper = function(r, K, g, cc_threshold, C_initial, times, func) {
    parms = list(r = r,
                 K = K,
                 g = g,
                 cc_threshold = cc_threshold)
    result = ode(y = C_initial,
                 times = times,
                 func = func,
                 parms = parms)

    colnames(result) = c("time","C")

     # get metrics
    metrics = compute_metrics(as.data.frame(result))

    return(metrics)
}
```

```
allresults <- as.data.frame(sens_forest$X)

allresults <- allresults %>%
  pmap(growth_wrapper,
       C_initial = C_initial,
       times = times,
       func = growth)

allres <- allresults %>%
```

```
  map_dfr(`[`, c("max_val", "mean_val")) %>%
  rename(Maximum_Value = max_val, Mean_Value = mean_val)
```

Plots

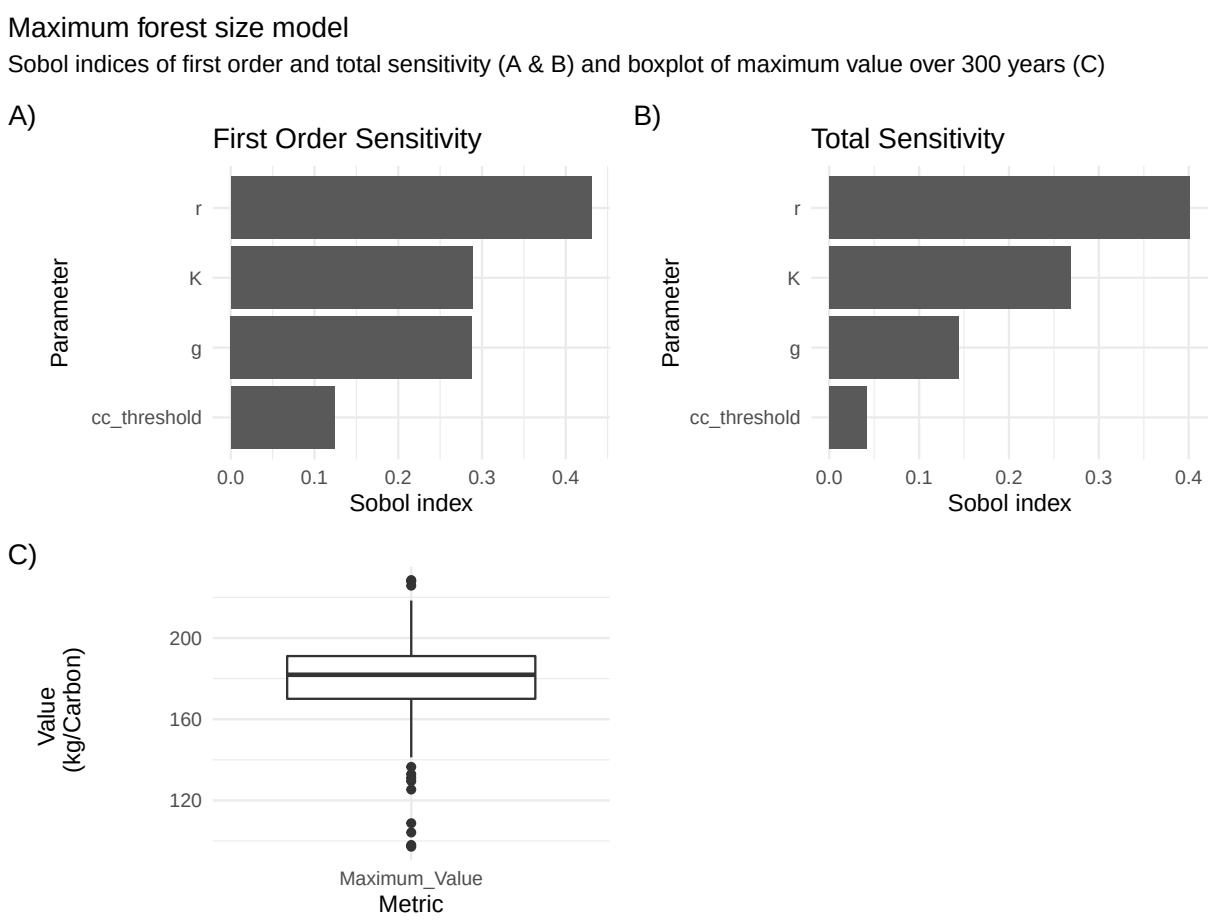
```
# create a box plot
tmp <- allres %>%
  pivot_longer(cols = c(Maximum_Value, Mean_Value), names_to = "Metric", values_to = "Value")

max_df <- tmp %>%
  filter(Metric == "Maximum_Value")

boxplot <- ggplot(data = max_df, aes(x = Metric, y = Value)) +
  geom_boxplot() +
  labs(x = "Metric", y = "Value \n (kg/Carbon)") +
  theme_minimal()
```

```
# calculate the Sobol indicies
sens_forest_maxval <- sensitivity::tell(sens_forest, allres$Maximum_Value)

# Indices (main effect without co-variance)
tmpS <- sens_forest_maxval$S
rownames(tmpS) = c("r","K", "g", "cc_threshold")

tmpS <- tmpS %>%
  rownames_to_column(var = "Parameter")

# Indices (total effect with co-variance)
tmpT <- sens_forest_maxval$T
rownames(tmpT) = c("r","K", "g", "cc_threshold")

tmpT <- tmpT %>%
  rownames_to_column(var = "Parameter")
```

```
# create indices barplots
plotT <- ggplot(data = tmpT, aes(x = original,
                                 y = Parameter)) +
  geom_col() +
  theme_minimal() +
  labs(title = "Total Sensitivity", x = "Sobol index")

plotS <- ggplot(data = tmpS, aes(x = original,
                                 y = Parameter)) +
  geom_col() +
  theme_minimal() +
  labs(title = "First Order Sensitivity",
       x = "Sobol index")
```

```
# boxplot of maximum value distribution and bar plot of main effect and total effect sobol indices
ptch_plt <- plotS + plotT + boxplot + plot_layout(ncol = 2)
ptch_plt + plot_annotation(
```

```
  tag_levels = "A",
  tag_suffix = ")",
  title = "Maximum forest size model",
  subtitle = "Sobol indices of first order and total sensitivity (A & B) and boxplot of maximum value ov
)
```



Discussion

Based on this analysis, the exponential, pre-canopy closure growth rate, r, had the highest sensitivity to the maximum forest size, having the highest Sobol index value for both first order and total effect. The carrying capacity, K, had the second highest sensitivity. We could infer from the results of this model that climate impacts affecting forest pre-canopy closure growth rate or carrying capacity would impact maximum forest size. For example, a warmer, drier climate might induce higher evapotranspiration rates and introduce stress that inhibits the growth of younger trees, thereby decreasing pre-canopy closure growth rate. Climate disturbances that degrade or reduce the available area for forest lands (i.e., through fire, flood, or other means) could lower the carrying capacity. According to this model, maximum forest size would likely be impacted by either of these climate-related impacts.