INF 550 Section 6.15

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2022-10-24

NEON AOP Coding Lab

Question 1

1: How are these two forests similar? How are they different? (3-5 sentences)

The forest at GUAN is a tropical dry forest. It's mixed forest type with deciduous, evergreen, and scrub vegetation. It has a warm and wet climate compared to BART.

The forest at the BART site is a mixed temperate forest. This site had been heavily disturbed by logging activities in the past. BART is a much cooler site than GUAN.

Question 2

2: Using this NEON tutorial and the tutorials we've covered in this textbook (hint: you did half of this workflow in your very first coding lab) pull the NEON AOP derived Canopy Height Model (CHM, DP3.30015.001) and High-resolution orthorectified camera imagery mosaic DP3.30010.001 for each forest and overlay the NEON TOS Woody Vegetation Structure DP1.10098.001 basal diameter data product to evaluate how well AOP captures trees in each forest.

```
# # pull NEON AOP Canopy Height Model
# chm_dp = as.character('DP1.10098.001')
# # for BART
# chm_bart = loadByProduct(dpID = chm_dp,
#                          site="BART",
#                          token=NEON_TOKEN,
#                          # year = 2020,
#                          startdate="2022-01", enddate="2022-12",
#                          package="basic",
#                          check.size=F)
#
# zipsByProduct(dpID=chm_dp,
#               site = "BART",
#               startdate = "2022-01",
#               enddate = "2022-12",
#               package = "basic",
#               check.size = FALSE,
#               savepath = "./",
#               token=NEON_TOKEN)
#
```

```r
# # for GUAN
# chm_guan = byFileAOP(dpID = "DP3.30015.001",
#                       site="GUAN",
#                       token=NEON_TOKEN,
#                       year = 2020,
#                       # startdate="2022-05", enddate="2022-05",
#                       # package="basic",
#                       check.size=F)
#
# # pull NEON AOP high res orthorectified imagery
# # for BART
# # for GUAN
#
# # pull NEON TOS Woody Veg Structure
# # for BART
# wood_bart = loadByProduct(
#   dpID = as.character("DP1.10098.001"),
#   site = "BART",
#   token=NEON_TOKEN,
#   startdate="2022-01",
#   enddate="2022-12",
#   package="basic",
#   check.size=F
# )
# # for GUAN
```

```r
# make vector of sites
sites <- c("BART","GUAN")

# Download veg structure
veglist <- loadByProduct(dpID="DP1.10098.001",
                         site= sites,
                         package="expanded",
                         check.size=FALSE,
                         token = NEON_TOKEN)
```

```
## Finding available files
##   |                                                                              |
```

```
## No expanded package found for site BART and month 2019-10. Basic package downloaded instead.
## No expanded package found for site BART and month 2020-08. Basic package downloaded instead.
## No expanded package found for site BART and month 2021-07. Basic package downloaded instead.
## No expanded package found for site BART and month 2021-08. Basic package downloaded instead.
## No expanded package found for site BART and month 2021-09. Basic package downloaded instead.
## No expanded package found for site BART and month 2021-10. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2015-06. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2015-07. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2015-08. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2015-09. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2015-10. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2015-11. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-02. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-03. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-04. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-05. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-06. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-07. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-08. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-09. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-10. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2016-11. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2017-02. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2017-03. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2017-04. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2017-12. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2018-01. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2018-02. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2019-01. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2020-06. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2020-07. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2020-08. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2021-01. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2021-02. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2021-12. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2022-01. Basic package downloaded instead.
## No expanded package found for site GUAN and month 2022-03. Basic package downloaded instead.
## Downloading files totaling approximately 112.379556 MB
## Downloading 52 files
##   |                                                                              |
```

```r
# Unlist veg data frames
list2env(veglist,.GlobalEnv)
```

```
## <environment: R_GlobalEnv>
```

```r
# get the veg map object
vegmap <- getLocTOS(veglist$vst_mappingandtagging, "vst_mappingandtagging")
```

```
##   |                                                                              |

## The following namedLocation was not found: BART_001.basePlot.vst.32

##   |                                                                              |==

## The following namedLocation was not found: BART_005.basePlot.vst.32

##   |                                                                              |==

## The following namedLocation was not found: BART_015.basePlot.vst.32

##   |                                                                              |=====

## The following namedLocation was not found: BART_011.basePlot.vst.32

##   |                                                                              |======

## The following namedLocation was not found: BART_026.basePlot.vst.32

##   |                                                                              |=======

## The following namedLocation was not found: BART_025.basePlot.vst.32

##   |                                                                              |=======

## The following namedLocation was not found: BART_023.basePlot.vst.32

##   |                                                                              |==========

## The following namedLocation was not found: BART_010.basePlot.vst.32

## The following namedLocation was not found: BART_010.basePlot.vst.50

##   |                                                                              |===========

## The following namedLocation was not found: BART_010.basePlot.vst.40

##   |                                                                              |===========
```

```
## The following namedLocation was not found: BART_010.basePlot.vst.42

##   |                                                                              |============

## The following namedLocation was not found: BART_028.basePlot.vst.32

##   |                                                                              |============

## The following namedLocation was not found: BART_004.basePlot.vst.39

##   |                                                                              |=============

## The following namedLocation was not found: BART_004.basePlot.vst.32

##   |                                                                              |=============

## The following namedLocation was not found: BART_018.basePlot.vst.32

##   |                                                                              |==============

## The following namedLocation was not found: BART_013.basePlot.vst.32

##   |                                                                              |===============

## The following namedLocation was not found: BART_003.basePlot.vst.32

##   |                                                                              |=================

## The following namedLocation was not found: BART_024.basePlot.vst.32

##   |                                                                              |==================

## The following namedLocation was not found: BART_027.basePlot.vst.32

##   |                                                                              |==================

## The following namedLocation was not found: BART_016.basePlot.vst.32

##   |                                                                              |===================

## The following namedLocation was not found: BART_033.basePlot.vst.50

##   |                                                                              |===================

## The following namedLocation was not found: BART_075.basePlot.vst.42

##   |                                                                              |===================

## The following namedLocation was not found: BART_023.basePlot.vst.40

##   |                                                                              |===================
## Rate limit reached. Pausing for 99 seconds to reset.
##   |                                                                              |===================
```

```r
# Merge
veg <- merge(veglist$vst_apparentindividual,vegmap, by=c("individualID","namedLocation","domainID","site

# Separate out the sites
vegbart <- veg %>%
  filter(plotID == "BART_013") %>%
  drop_na(adjNorthing, adjEasting)
vegguan <- veg %>%
  filter(plotID == "GUAN_043") %>%
  drop_na(adjNorthing, adjEasting)
```

```r
# year we want data for
yoi <- "2018"

# Download Canopy Height Model from NEON API
# BART
byTileAOP(dpID="DP3.30015.001", # CHM
          site= "BART",
          year= yoi,
          easting = vegbart$adjEasting,
          northing = vegbart$adjNorthing,
          check.size=FALSE,
          token = NEON_TOKEN)
```

```
## Downloading files totaling approximately 4.03261 MB
## Downloading 6 files
##   |                                                                              |
## Successfully downloaded  6  files.
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.prj downloaded to /Users/natashawesely/Docume
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.dbf downloaded to /Users/natashawesely/Docume
## NEON_D01_BART_DP3_317000_4879000_CHM.tif downloaded to /Users/natashawesely/Documents/GitHub/INF550/
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.shx downloaded to /Users/natashawesely/Docume
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.kml downloaded to /Users/natashawesely/Docume
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.shp downloaded to /Users/natashawesely/Docume
```

```r
# GUAN
byTileAOP(dpID="DP3.30015.001", # CHM
          site= "GUAN",
          year= yoi,
          easting = vegguan$adjEasting,
          northing = vegguan$adjNorthing,
          check.size=FALSE,
          token = NEON_TOKEN)
```

```
## Downloading files totaling approximately 4.029969 MB
## Downloading 6 files
##   |                                                                              |
## Successfully downloaded  6  files.
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.shp downloaded to /Users/natashawesely/Docume
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.dbf downloaded to /Users/natashawesely/Docume
## NEON_D04_GUAN_DP3_725000_1988000_CHM.tif downloaded to /Users/natashawesely/Documents/GitHub/INF550/
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.shx downloaded to /Users/natashawesely/Docume
```

```
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.kml downloaded to /Users/natashawesely/Docume
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.prj downloaded to /Users/natashawesely/Docume
```

```
# Download High-resolution orthorectified camera imagery mosaic from NEON API
# BART
byTileAOP(dpID="DP3.30010.001",
          site="BART",
          year = yoi,
          easting = vegbart$adjEasting,
          northing = vegbart$adjNorthing,
          check.size=FALSE,
          token = NEON_TOKEN)
```

```
## Downloading files totaling approximately 91.933709 MB
## Downloading 1 files
##   |                                                                               |
## Successfully downloaded  1  files.
## 2018_BART_4_317000_4879000_image.tif downloaded to /Users/natashawesely/Documents/GitHub/INF550/DP3.3
```

```
# GUAN
byTileAOP(dpID="DP3.30010.001",
          site="GUAN",
          year = yoi,
          easting = vegguan$adjEasting,
          northing = vegguan$adjNorthing,
          check.size=FALSE,
          token = NEON_TOKEN)
```

```
## Downloading files totaling approximately 83.113847 MB
## Downloading 1 files
##   |                                                                               |
## Successfully downloaded  1  files.
## 2018_GUAN_1_725000_1988000_image.tif downloaded to /Users/natashawesely/Documents/GitHub/INF550/DP3.3
```

```
# convert to rasters
chmbart <- raster('./DP3.30015.001/neon-aop-products/2018/FullSite/D01/2018_BART_4/L3/DiscreteLidar/Can
chmguan <- raster('./DP3.30015.001/neon-aop-products/2018/FullSite/D04/2018_GUAN_1/L3/DiscreteLidar/Can
```

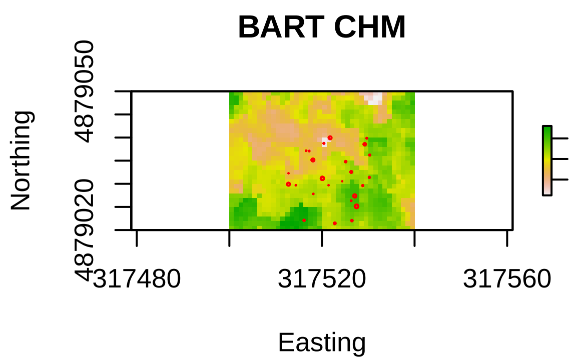
Generate a labeled 2x2 plot panel including:

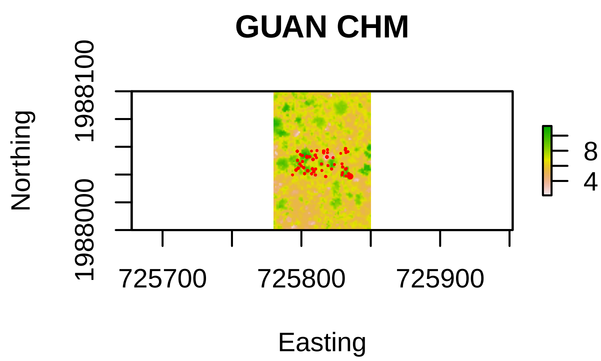
Each RGB image with basal diameter overlaid

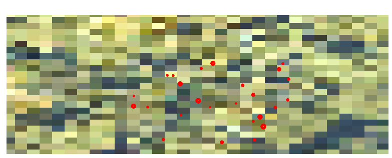
Each CHM with basal diameter overlaid

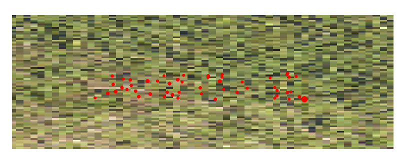
```
# PLOTTING

# make image bricks
imagebart <-brick('./DP3.30010.001/neon-aop-products/2018/FullSite/D01/2018_BART_4/L3/Camera/Mosaic/2018
imageguan <- brick('./DP3.30010.001/neon-aop-products/2018/FullSite/D04/2018_GUAN_1/L3/Camera/Mosaic/20

# the arrangement of the subplots
par(mfrow=c(2,2))
# plot the canopy height model for BART
```

```
plot(chmbart, xlim=c(317500,317540), ylim=c(4879020,4879050), main="BART CHM", xlab = "Easting", ylab =
# add the woody veg structure for BART
points(vegbart$adjEasting,vegbart$adjNorthing, pch=1, cex=vegbart$stemDiameter/100/2, col = "red")
# plot the canopy height model for GUAN
plot(chmguan, xlim=c(725780,725850), ylim=c(1988000,1988100), main="GUAN CHM", xlab = "Easting", ylab =
# add the woody veg str for GUAN
points(vegguan$adjEasting,vegguan$adjNorthing, pch=1, cex=vegguan$stemDiameter/100/2, col = "red")
# plot the ortho image for BART
plot.new()
plot.window(xlim=c(317500,317540), ylim=c(4879020,4879050))
plotRGB(imagebart, r=1,g=2,b=3, axes = TRUE, main="BART Image", add=TRUE)
# add the woody veg structure for BART
points(vegbart$adjEasting,vegbart$adjNorthing, pch=1, cex=vegbart$stemDiameter/100/2, col = "red")
# plot the orthose image for GUAN
plot.new()
plot.window(xlim=c(725780,725850), ylim=c(1988000,1988100))
plotRGB(imageguan, r=1,g=2,b=3, axes = TRUE, main="GUAN Image", add=TRUE)
# add the woody veg str for GUAN
points(vegguan$adjEasting,vegguan$adjNorthing, pch=1, cex=vegguan$stemDiameter/100/2, col = "red")
```









Write 2-3 sentences summarizing your findings and thoughts.

The NEON AOP data is quite course, which makes identifying individual trees within a canopy nearly impossible. However the combination of the AOP data with the individual tree measurements from the woody vegetation data set could enhance the AOP data.

Question 3

Use the byTileAOP function of the neonUtilities package to pull a subset of the descrete LiDAR pointcloud for each forest (Hint: You can feed byTileAOP Easting and Northing from your Vegetation Structure dataframe(s)). Use the structural_diversity_metrics function that you defined in section 6.5 of the textbook to process discrete return LiDAR for each site and generate structural diversity metrics.

```
library(lidR, quietly = T)
library(gstat, quietly = T)

# get the lidar pointcloud for BART
byTileAOP(dpID="DP1.30003.001",
          site= "BART",
          year= yoi,
          easting = extent(chmbart)[1],
          northing = extent(chmbart)[3],
          check.size=FALSE,
          token = NEON_TOKEN)
```

```
## Downloading files totaling approximately 53.653767 MB
## Downloading 6 files
##   |                                                                              |
## Successfully downloaded  6  files.
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.dbf downloaded to /Users/natashawesely/Docume
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.prj downloaded to /Users/natashawesely/Docume
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud_colorized.laz downloaded to /Users/natashawes
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.shp downloaded to /Users/natashawesely/Docume
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.shx downloaded to /Users/natashawesely/Docume
## NEON_D01_BART_DP1_317000_4879000_classified_point_cloud.kml downloaded to /Users/natashawesely/Docume
```

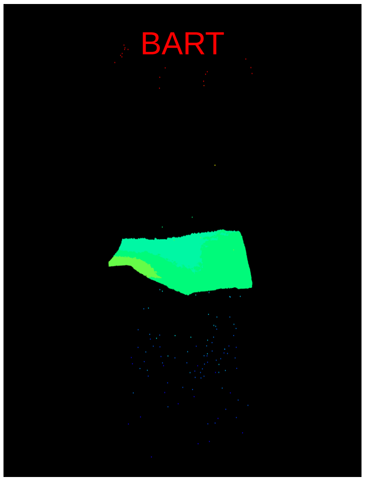
```
# get the lidar pointcloud for GUAN
byTileAOP(dpID="DP1.30003.001",
          site= "GUAN",
          year= yoi,
          easting = extent(chmguan)[1],
          northing = extent(chmguan)[3],
          check.size=FALSE,
          token = NEON_TOKEN)
```

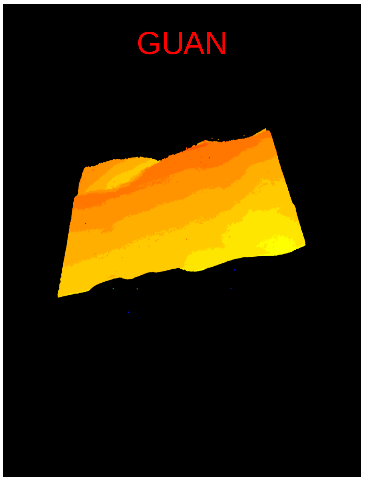
```
## Downloading files totaling approximately 49.08075 MB
## Downloading 6 files
##   |                                                                              |
## Successfully downloaded  6  files.
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud_colorized.laz downloaded to /Users/natashawes
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.shp downloaded to /Users/natashawesely/Docume
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.shx downloaded to /Users/natashawesely/Docume
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.prj downloaded to /Users/natashawesely/Docume
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.kml downloaded to /Users/natashawesely/Docume
## NEON_D04_GUAN_DP1_725000_1988000_classified_point_cloud.dbf downloaded to /Users/natashawesely/Docume
```

```
# convert the raw data to an actual pointcloud
pcbart <- lidR::readLAS('/Users/natashawesely/Documents/GitHub/INF550/DP1.30003.001/neon-aop-products/20
pcguan <- lidR::readLAS('/Users/natashawesely/Documents/GitHub/INF550/DP1.30003.001/neon-aop-products/20
```

Using lidR generate a labeled 2-panel plot of your canopy height model for each forest

```
lidR::plot(pcbart)
lidR::plot(pcguan)
```





Using lidR generate a labeled 2-panel plot of a cross-section for each forest

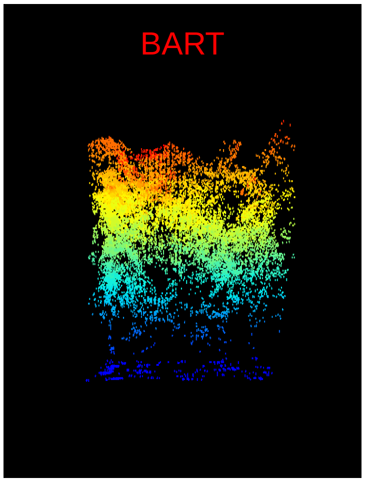
```
## BART
# Correct for elevation
# Choose a 40 x 40 m spatial extent, which is the extent for NEON base plots.
# First set the center of where you want the plot to be
xbart <- 317500 #easting
ybart <- 4879500 #northing
#Cut out a 200 x 200 m buffer by adding 100 m to easting and
#northing coordinates (x,y).
data.200m.b <-
  clip_rectangle(pcbart,
                 xleft = (xbart - 100), ybottom = (ybart - 100),
                 xright = (xbart + 100), ytop = (ybart + 100))
# Correct for ground height using a kriging function to interpolate
#elevation from ground points in the .laz file.
```

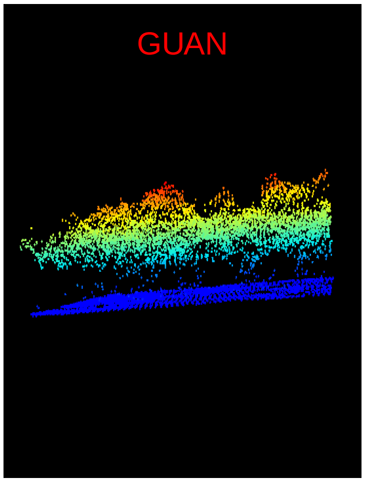
```
dtm.b <- grid_terrain(data.200m.b, 1, kriging(k = 10L))
data.200m.b <- normalize_height(data.200m.b, dtm.b)
#Will often give a warning if not all points could be corrected,
#but visually check to see if it corrected for ground height.
lidR::plot(data.200m.b)
#There's a few uncorrected points
#Clip 20 m out from each side of the easting and northing
#coordinates (x,y).
data.40m.b <-
  clip_rectangle(data.200m.b,
                 xleft = (xbart - 20), ybottom = (ybart - 20),
                 xright = (xbart + 20), ytop = (ybart + 20))

data.40m.b@data$Z[data.40m.b@data$Z <= .5] <- NA
#This line filters out all z_vals below .5 m as we are less interested in shrubs/trees.
# visualize the clipped plot point cloud
lidR::plot(data.40m.b)

## GUAN
# Correct for elevation
# Choose a 40 x 40 m spatial extent, which is the extent for NEON base plots.
# First set the center of where you want the plot to be
xguan <- 725500 #easting
yguan <- 1988500 #northing
# Cut out a 200 x 200 m buffer by adding 100 m to easting and
#northing coordinates (x,y).
data.200m.g <-
  clip_rectangle(pcguan,
                  xleft = (xguan - 100), ybottom = (yguan - 100),
                  xright = (xguan + 100), ytop = (yguan + 100))
# Correct for ground height using a kriging function to interpolate
#elevation from ground points in the .laz file.
dtm.g <- grid_terrain(data.200m.g, 1, kriging(k = 10L))
```

```
## Warning: There were 23 degenerated ground points. Some X Y coordinates were
## repeated but with different Z coordinates. min Z were retained.
```

```
## Warning: There were 23 degenerated ground points. Some X Y coordinates were
## repeated but with different Z coordinates. min Z were retained.
data.200m.g <- normalize_height(data.200m.g, dtm.g)
#Will often give a warning if not all points could be corrected,
#but visually check to see if it corrected for ground height.
lidR::plot(data.200m.g)
#There's a few uncorrected points
#Clip 20 m out from each side of the easting and northing
#coordinates (x,y).
data.40m.g <-
  clip_rectangle(data.200m.g,
                  xleft = (xguan - 20), ybottom = (yguan - 20),
                  xright = (xguan + 20), ytop = (yguan + 20))

data.40m.g@data$Z[data.40m.g@data$Z <= .5] <- NA
# This line filters out all z_vals below .5 m
```

```
# visualize the clipped plot point cloud
lidR::plot(data.40m.g)
```





Use section 6.5.3 Comparing Metrics Between Forests to compare each forest and generate a a clean summary table

```
# write function to run all 13 veg structure metrics in a single function.
structural_diversity_metrics <- function(data.40m,x,y) {
  chm <- grid_canopy(data.40m, res = 1, dsmtin())
  mean.max.canopy.ht <- mean(chm@data@values, na.rm = TRUE)
  max.canopy.ht <- max(chm@data@values, na.rm=TRUE)
  rumple <- rumple_index(chm) #calculate rumple, a ratio of outer canopy surface area to ground surface
  top.rugosity <- sd(chm@data@values, na.rm = TRUE) #top rugosity, the standard deviation of pixel valu
  cells <- length(chm@data@values)
  chm.0 <- chm
  chm.0[is.na(chm.0)] <- 0
  zeros <- which(chm.0@data@values == 0)
  deepgaps <- length(zeros) #number of deep gaps
  deepgap.fraction <- deepgaps/cells #deep gap fraction, the number of deep gaps in the chm relative to
  cover.fraction <- 1 - deepgap.fraction #cover fraction, the inverse of deep gap fraction
  vert.sd <- cloud_metrics(data.40m, sd(Z, na.rm = TRUE)) #height SD, the standard deviation of height

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  sd.1m2 <- grid_metrics(data.40m, sd(Z), 1)
  sd.sd <- sd(sd.1m2[,3], na.rm = TRUE) # The standard deviation of height values
```

```r
  Zs <- data.40m@data$Z
  Zs <- Zs[!is.na(Zs)]
  entro <- entropy(Zs, by = 1) # Quantifies diversity & evenness of point cloud heights
  gap_frac <- gap_fraction_profile(Zs, dz = 1, z0=3)
  GFP.AOP <- mean(gap_frac$gf) # Gap fraction profile, assesses the distribution of gaps in the canopy
  LADen<-LAD(Zs, dz = 1, k=0.5, z0=3)
  VAI.AOP <- sum(LADen$lad, na.rm=TRUE) # Leaf area density
  VCI.AOP <- VCI(Zs, by = 1, zmax=100) # A vertical complexity index
  out.plot <- data.frame(
    matrix(c(x, y, mean.max.canopy.ht,max.canopy.ht,
             rumple,deepgaps, deepgap.fraction,
             cover.fraction, top.rugosity, vert.sd,
             sd.sd, entro, GFP.AOP, VAI.AOP,VCI.AOP),
           ncol = 15))
  colnames(out.plot) <-
    c("easting", "northing", "mean.max.canopy.ht.aop",
      "max.canopy.ht.aop", "rumple.aop", "deepgaps.aop",
      "deepgap.fraction.aop", "cover.fraction.aop",
      "top.rugosity.aop","vert.sd.aop","sd.sd.aop",
      "entropy.aop", "GFP.AOP.aop",
      "VAI.AOP.aop", "VCI.AOP.aop")
  print(out.plot)
}

# run the function for each site
BART_structural_diversity <- structural_diversity_metrics(data.40m.b,xbart,ybart)
```

```
##   easting northing mean.max.canopy.ht.aop max.canopy.ht.aop rumple.aop
## 1  317500  4879500               22.71698            29.679   1.849252
##   deepgaps.aop deepgap.fraction.aop cover.fraction.aop top.rugosity.aop
## 1            5             0.003125           0.996875           3.2612
##   vert.sd.aop sd.sd.aop entropy.aop GFP.AOP.aop VAI.AOP.aop VCI.AOP.aop
## 1    5.388723  1.213976   0.8902085   0.8244346    10.98084   0.6574729
```

```r
GUAN_structural_diversity <- structural_diversity_metrics(data.40m.g,xguan,yguan)
```

```
##   easting northing mean.max.canopy.ht.aop max.canopy.ht.aop rumple.aop
## 1  725500  1988500               3.428377             6.081   1.264248
##   deepgaps.aop deepgap.fraction.aop cover.fraction.aop top.rugosity.aop
## 1            3             0.001875           0.998125        0.7381128
##   vert.sd.aop sd.sd.aop entropy.aop GFP.AOP.aop VAI.AOP.aop VCI.AOP.aop
## 1   0.9552243 0.4976439   0.7231822     0.85184    1.474833   0.3055799
```

```r
# combine the function runs for each site
combined_results=rbind(BART_structural_diversity,
                       GUAN_structural_diversity)

# Add row names for clarity
row.names(combined_results)=c("BART","GUAN")
# print the comparison
combined_results
```

```
##      easting northing mean.max.canopy.ht.aop max.canopy.ht.aop rumple.aop
## BART  317500  4879500              22.716977            29.679   1.849252
## GUAN  725500  1988500               3.428377             6.081   1.264248
##      deepgaps.aop deepgap.fraction.aop cover.fraction.aop top.rugosity.aop
## BART            5             0.003125           0.996875        3.2612005
## GUAN            3             0.001875           0.998125        0.7381128
##      vert.sd.aop sd.sd.aop entropy.aop GFP.AOP.aop VAI.AOP.aop VCI.AOP.aop
## BART   5.3887227 1.2139760   0.8902085   0.8244346   10.980836   0.6574729
## GUAN   0.9552243 0.4976439   0.7231822   0.8518400    1.474833   0.3055799
```

Using Table 2 from LaRue, Wagner, et al. (2020) as a reference, write 1-2 paragraphs summarizing the differences in forest structural diversity between the two forests and how they may relate to your answers to Question 1.

Unsurprisingly, these forested sites are quite different. BART is on average taller with a higher leaf area density compared to GUAN. BART also has a higher standard deviation for height measurements, indicating that the forest canopy is more vertically diverse than GUAN. This higher height standard deviation may also indicate more different species close together compared to GUAN. Perhaps because the tree/leaf density is less intense at GUAN, the trees don't have to compete for light as much, therefore there is more canopy height homogeneity and less species diversity.