Vegetation and Glaciers

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Set up Spatial Packages

```
# load packages
library(raster)
```

```
## Loading required package: sp
```

```
library(sp)
library(rgdal)
```

```
## rgdal: version: 1.5-18, (SVN revision 1082)
## Geospatial Data Abstraction Library extensions to R successfully loaded
## Loaded GDAL runtime: GDAL 3.0.4, released 2020/01/28
## Path to GDAL shared files: C:/Users/Delaney/Documents/R/win-library/4.0/rgdal/gdal
## GDAL binary built with GEOS: TRUE
## Loaded PROJ runtime: Rel. 6.3.1, February 10th, 2020, [PJ_VERSION: 631]
## Path to PROJ shared files: C:/Users/Delaney/Documents/R/win-library/4.0/rgdal/proj
## Linking to sp version:1.4-4
## To mute warnings of possible GDAL/OSR exportToProj4() degradation,
## use options("rgdal_show_exportToProj4_warnings"="none") before loading rgdal.
```

```
library(rgeos)
```

```
## rgeos version: 0.5-5, (SVN revision 640)
##  GEOS runtime version: 3.8.0-CAPI-1.13.1
##  Linking to sp version: 1.4-4
##  Polygon checking: TRUE
```

```
library(plyr)
```

Read in spatial data

```
#read in shapefiles
#readOGR in rgdal does this
g1966 <- readOGR("data\\GNPglaciers\\GNPglaciers_1966.shp", stringsAsFactors = T)
```

```
## OGR data source with driver: ESRI Shapefile
## Source: "C:\Users\Delaney\Documents\GitHub\GEOG331\data\GNPglaciers\GNPglaciers_1966.shp", la
yer: "GNPglaciers_1966"
## with 39 features
## It has 13 fields
## Integer64 fields read as strings:  OBJECTID
```

```
g1998 <- readOGR("data\\GNPglaciers\\GNPglaciers_1998.shp", stringsAsFactors = T)
```

```
## OGR data source with driver: ESRI Shapefile
## Source: "C:\Users\Delaney\Documents\GitHub\GEOG331\data\GNPglaciers\GNPglaciers_1998.shp", la
yer: "GNPglaciers_1998"
## with 39 features
## It has 13 fields
## Integer64 fields read as strings:  OBJECTID
```

```
g2005 <- readOGR("data\\GNPglaciers\\GNPglaciers_2005.shp", stringsAsFactors = T)
```

```
## OGR data source with driver: ESRI Shapefile
## Source: "C:\Users\Delaney\Documents\GitHub\GEOG331\data\GNPglaciers\GNPglaciers_2005.shp", la
yer: "GNPglaciers_2005"
## with 39 features
## It has 13 fields
## Integer64 fields read as strings:  OBJECTID
```

```
g2015 <- readOGR("data\\GNPglaciers\\GNPglaciers_2015.shp", stringsAsFactors = T)
```

```
## OGR data source with driver: ESRI Shapefile
## Source: "C:\Users\Delaney\Documents\GitHub\GEOG331\data\GNPglaciers\GNPglaciers_2015.shp", la
yer: "GNPglaciers_2015"
## with 39 features
## It has 21 fields
## Integer64 fields read as strings:  OBJECTID Recno
```

Explore data

```
head(g2015@data)
```

```
##   OBJECTID Recno Year Src1_0822 Src1_nadir Src3_nadir Src2_nadir   Area2015
## 0        1  1055 2015 secondary    11.7240     0.0000     4.7346  736669.75
## 1        2  1202 2015   primary    27.0008     0.0000     0.0000  511589.79
## 2        3  1120 2015 secondary    11.7240     0.0000     4.7346   75562.60
## 3        4  1430 2015 secondary     0.0000    16.8225     0.0000 1498505.92
## 4        5  1041 2015   primary    11.7240     0.0000    26.2766   35298.01
## 5        6  1132 2015 secondary    11.7240     0.0000     4.7346  224773.89
##   Shape_leng  X_COORD Y_COORD                                            SOURCE
## 0   7741.335 268429.9 5425167 WorldView-01 Satellite imagery from Digital Globe
## 1   5184.650 295750.8 5413701 WorldView-01 Satellite imagery from Digital Globe
## 2   1255.828 268868.3 5421731 WorldView-01 Satellite imagery from Digital Globe
## 3  15290.128 303278.4 5385710 WorldView-01 Satellite imagery from Digital Globe
## 4   2259.001 273823.9 5427266 WorldView-01 Satellite imagery from Digital Globe
## 5   4090.754 276459.4 5419663 WorldView-01 Satellite imagery from Digital Globe
##             CLASSIFICA             OWNERSHIP SrcOth_nad SrcOth_dat
## 0 main body of glacier Glacier National Park     0.0000 9999/01/01
## 1 main body of glacier Glacier National Park    18.6183 2014/10/19
## 2 main body of glacier Glacier National Park     0.0000 9999/01/01
## 3 main body of glacier Glacier National Park     0.0000 9999/01/01
## 4 main body of glacier Glacier National Park     0.0000 9999/01/01
## 5 main body of glacier Glacier National Park     0.0000 9999/01/01
##                                                                COMMENT Src2_0912
## 0            used both 20150822 and 20150912 images for full coverage   primary
## 1  20150822 only 2015 image, but high nadir, also used 20141019 image       n/a
## 2             20150822 used where shading was heavy in 20150912 image   primary
## 3   used color 20150822 as secondary, some offset from 20150925 image       n/a
## 4 used image from 20150822 since later image had high off nadir angle secondary
## 5                                                              no comment   primary
##   Src3_0925          GLACNAME SOURCE_SCA
## 0       n/a   Agassiz Glacier    1:12000
## 1       n/a     Ahern Glacier    1:12000
## 2       n/a      Baby Glacier    1:12000
## 3   primary Blackfoot Glacier    1:12000
## 4       n/a   Boulder Glacier    1:12000
## 5       n/a    Carter Glacier    1:12000
```

```
#projection
g1966@proj4string
```

```
## CRS arguments:
##  +proj=utm +zone=12 +datum=NAD83 +units=m +no_defs
```

The projection is UTM (Universal Transverse Mercator). This is a horizontal position representation and treats the earth as a perfect ellipsoid. It divides earth into 60 zones. Zone 12 is one of these zones. NAD 83 is the most current datum that provides spatial reference for Canada and the US using latitude, longitude, and some height info. It is meant for a large or medium scale.

Prepare data for visualization and analysis

```
#fix glacier name so that it is consistent with the entire time period
g2015@data$GLACNAME <- ifelse(g2015@data$GLACNAME == "North Swiftcurrent Glacier", "N. Swiftcurr
ent Glacier",
           ifelse(g2015@data$GLACNAME ==  "Miche Wabun",
                         "Miche Wabun Glacier",
                     as.character(g2015@data$GLACNAME)))
```

```
#read in rgb imagery from landsat
redL <- raster("data\\glacier_09_05_14\\l08_red.tif")
greenL <- raster("data\\glacier_09_05_14\\l08_green.tif")
blueL <- raster("data\\glacier_09_05_14\\l08_blue.tif")
```

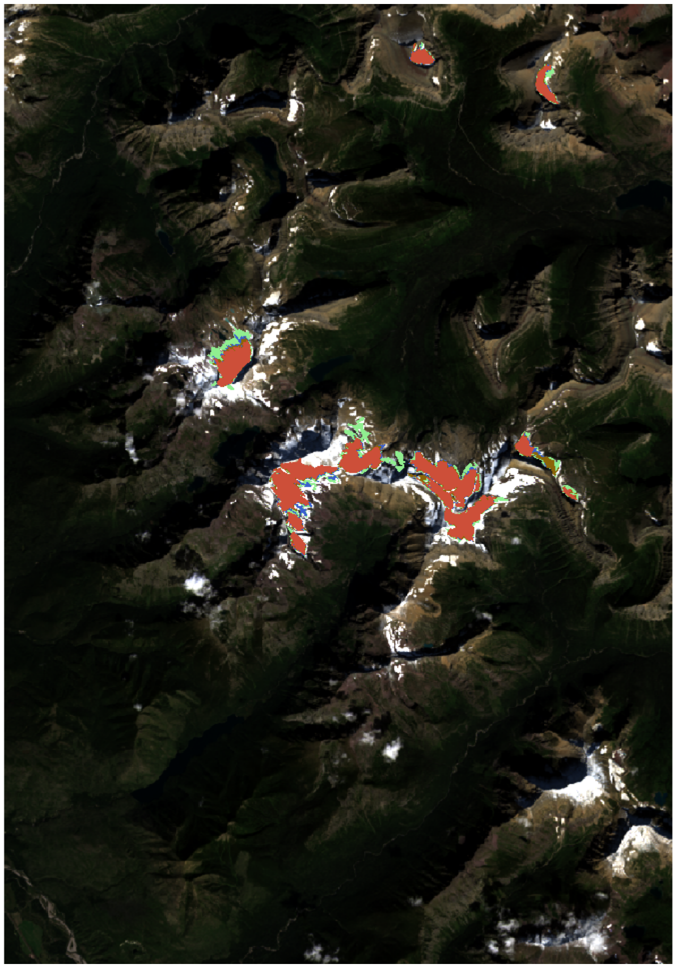
```
#check coordinate system
redL@crs
```

```
## CRS arguments:
##  +proj=utm +zone=12 +datum=WGS84 +units=m +no_defs
```

```
#make a brick that stacks all layers
rgbL <- brick(redL, greenL, blueL)
```

Practice visualizing glacier data

```
# plot same as above with different extent
plotRGB(rgbL, ext=c(289995,310000,5371253,5400000), stretch="lin")
plot(g1966, col="palegreen2", border=NA, add=TRUE)
plot(g1998, col="royalblue3", add=TRUE, border=NA)
plot(g2005, col="darkgoldenrod4", add=TRUE, border=NA)
plot(g2015, col="tomato3", add=TRUE, border=NA)
```



Read in raster data

```
#set up years to read in
ndviYear <- seq(2003,2016)

#read all files into a list
NDVIraster <- list()
for(i in 1:length(ndviYear)){
    NDVIraster[[i]] <- raster(paste0("data\\NDVI\\NDVI_",ndviYear[i],".tif"))
}
```

```
## Warning in showSRID(uprojargs, format = "PROJ", multiline = "NO", prefer_proj
## = prefer_proj): Discarded datum Unknown based on Normal Sphere (r=6370997)
## ellipsoid in CRS definition

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## Warning in showSRID(uprojargs, format = "PROJ", multiline = "NO", prefer_proj
## = prefer_proj): Discarded datum Unknown based on Normal Sphere (r=6370997)
## ellipsoid in CRS definition

## Warning in showSRID(uprojargs, format = "PROJ", multiline = "NO", prefer_proj
```

```
## = prefer_proj): Discarded datum Unknown based on Normal Sphere (r=6370997)
## ellipsoid in CRS definition
```

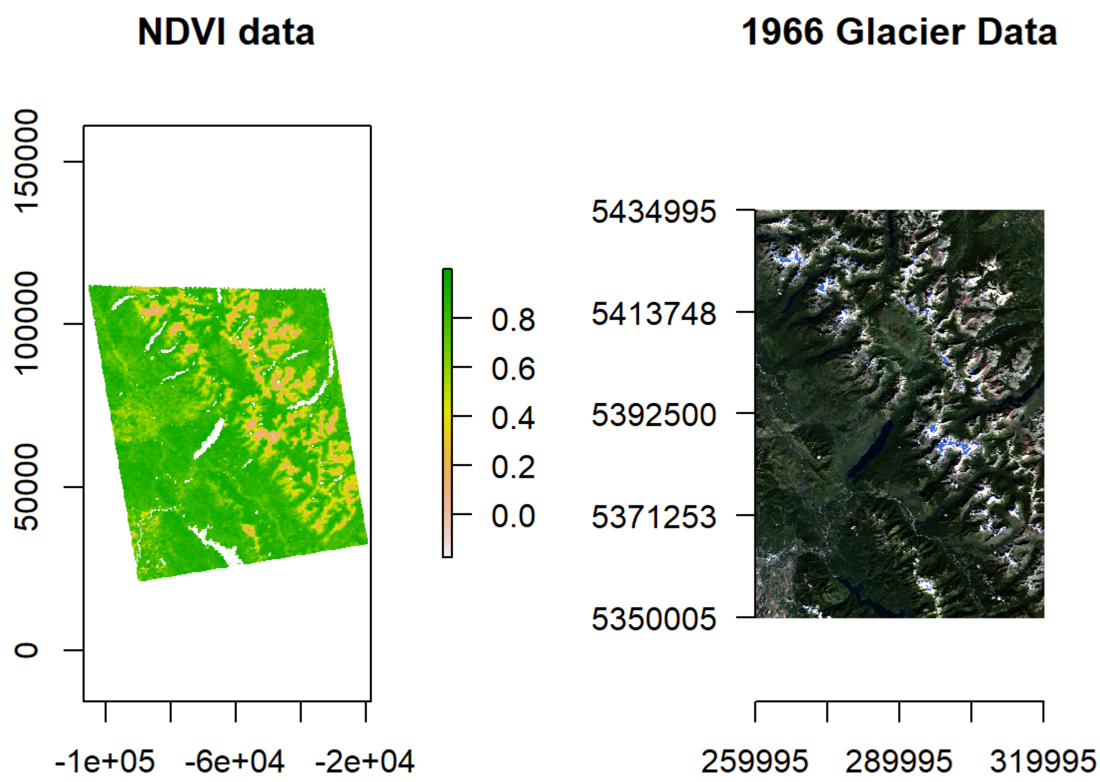
```
# check projection
NDVIraster[[1]]@crs
```

```
## CRS arguments:
##  +proj=laea +lat_0=48 +lon_0=-113 +x_0=0 +y_0=0 +ellps=sphere +units=m
## +no_defs
```

UTM is a conformal projection, so it preserves shape rather than area. An equal area projection is important for us working with glacier data because we are focused on analyzing change in area over time, which will be inaccurate with UTM.

Plot of the 2003 NDVI data side by side with the 1966 glacier extent

```
par(mai=c(1,1,1,1), mfrow = c(1,2))
plot(NDVIraster[[1]])
title("NDVI data")

plotRGB(rgbL, stretch="lin", axes=TRUE)
#add polygons to plot
plot(g1966, col="royalblue", border=NA, add=TRUE)
title("1966 Glacier Data")
```



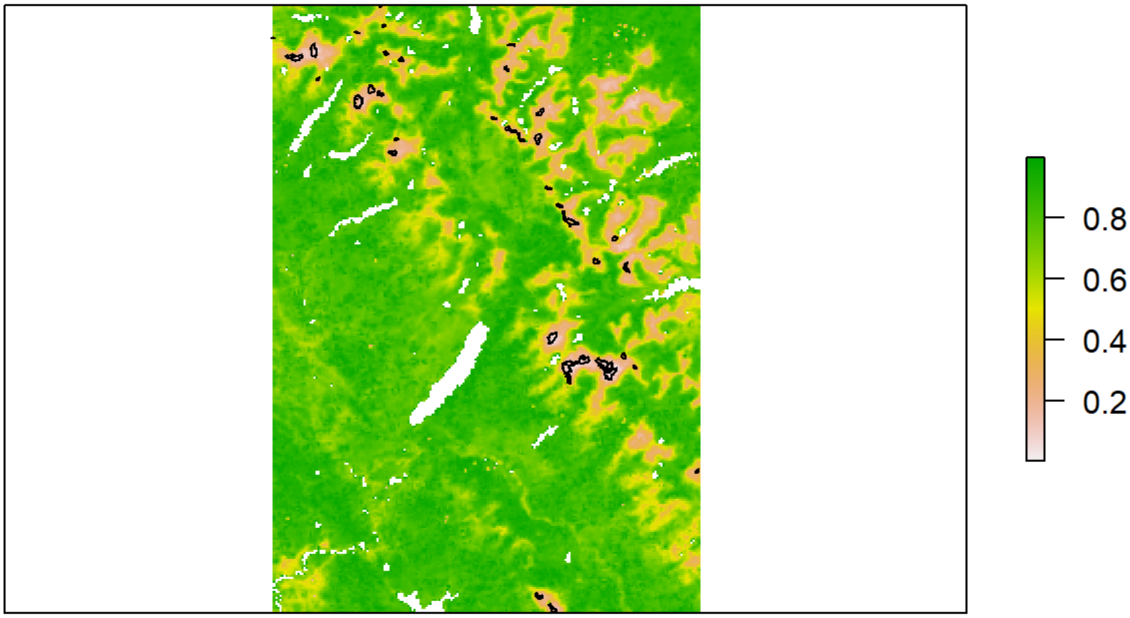
If you try to plot NDVI with the 1966 glacier polygons, the glaciers will not appear on top of the NDVI data. The data files can't be put on the same map because they are different projections. You can see that the x and y coordinates for the plots are completely different.

Reproject the glaciers to help with visualization and analysis

```
#reproject the glaciers
#use the NDVI projection
#spTransform(file to project, new coordinate system)
g1966p <- spTransform(g1966,NDVIraster[[1]]@crs)
g1998p <- spTransform(g1998,NDVIraster[[1]]@crs)
g2005p <- spTransform(g2005,NDVIraster[[1]]@crs)
g2015p <- spTransform(g2015,NDVIraster[[1]]@crs)
```

Map with both the maximum NDVI and the glaciers in 2015

```
#add polygons to plot
plot(NDVIraster[[13]], ext=g2015p, axes=FALSE)
plot(g2015p, col="transparent", border="black", add=TRUE)
```



The glaciers are in areas with the lowest NDVI, and areas around glaciers have gradually larger levels of NDVI.

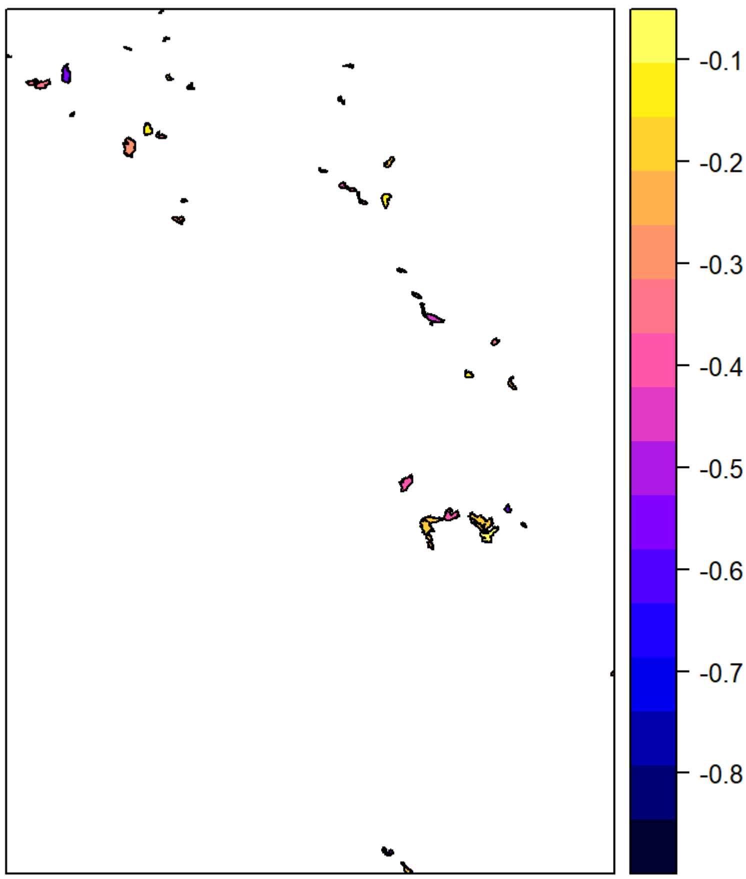
Analyze glaciers

```
#calculate area for all polygons
#add directly into data table for each shapefile
g1966p@data$a1966m.sq <- area(g1966p)
g1998p@data$a1998m.sq <- area(g1998p)
g2005p@data$a2005m.sq <- area(g2005p)
g2015p@data$a2015m.sq <- area(g2015p)
```

```
# join data into table
gAllp1 <- join(g1966p@data,g1998p@data, by="GLACNAME", type="full")
gAllp2 <- join(gAllp1,g2005p@data, by="GLACNAME", type="full")
gAll <- join(gAllp2,g2015p@data, by="GLACNAME", type="full")
```

Calculate the % change in area between 1966 and 2015. Make a spplot of the glaciers in 2015 showing the % change that each glacier has experienced.

```
gAll$percChange <- (gAll$a2015m.sq - gAll$a1966m.sq)/gAll$a1966m.sq

# put inside raster
g2015p@data$percChange <- gAll$percChange
# make color percChange
spplot(g2015p, "percChange")
```




```
# find glacial difference over years
diffPoly <- gDifference(g1966p, g2015p, checkValidity = 2L)
```

```
## Warning in RGEOSUnaryPredFunc(spgeom, byid, "rgeos_isvalid"): Ring Self-
## intersection at or near point -79835.564606180007 107115.29284187
```

```
## Warning in RGEOSUnaryPredFunc(spgeom, byid, "rgeos_isvalid"): Ring Self-
## intersection at or near point -77011.733007000003 99328.148267840006
```

```
## Warning in RGEOSUnaryPredFunc(spgeom, byid, "rgeos_isvalid"): Ring Self-
## intersection at or near point -59187.508340740002 93811.335311250004
```

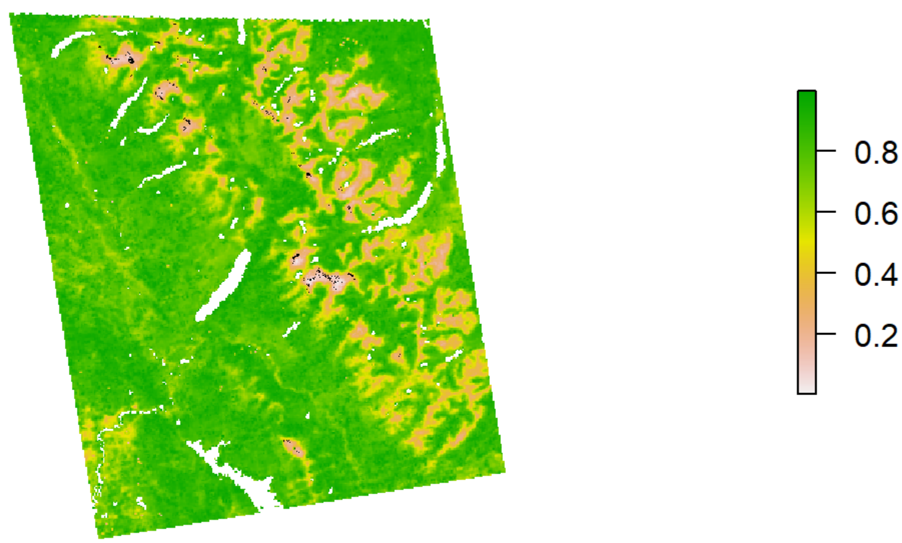
```
## Warning in RGEOSUnaryPredFunc(spgeom, byid, "rgeos_isvalid"): Ring Self-
## intersection at or near point -62514.363778120001 96430.893114039995
```

```
## Warning in RGEOSUnaryPredFunc(spgeom, byid, "rgeos_isvalid"): Ring Self-
## intersection at or near point -75367.583780639994 92136.2396056
```

```
## g2015p is invalid
```

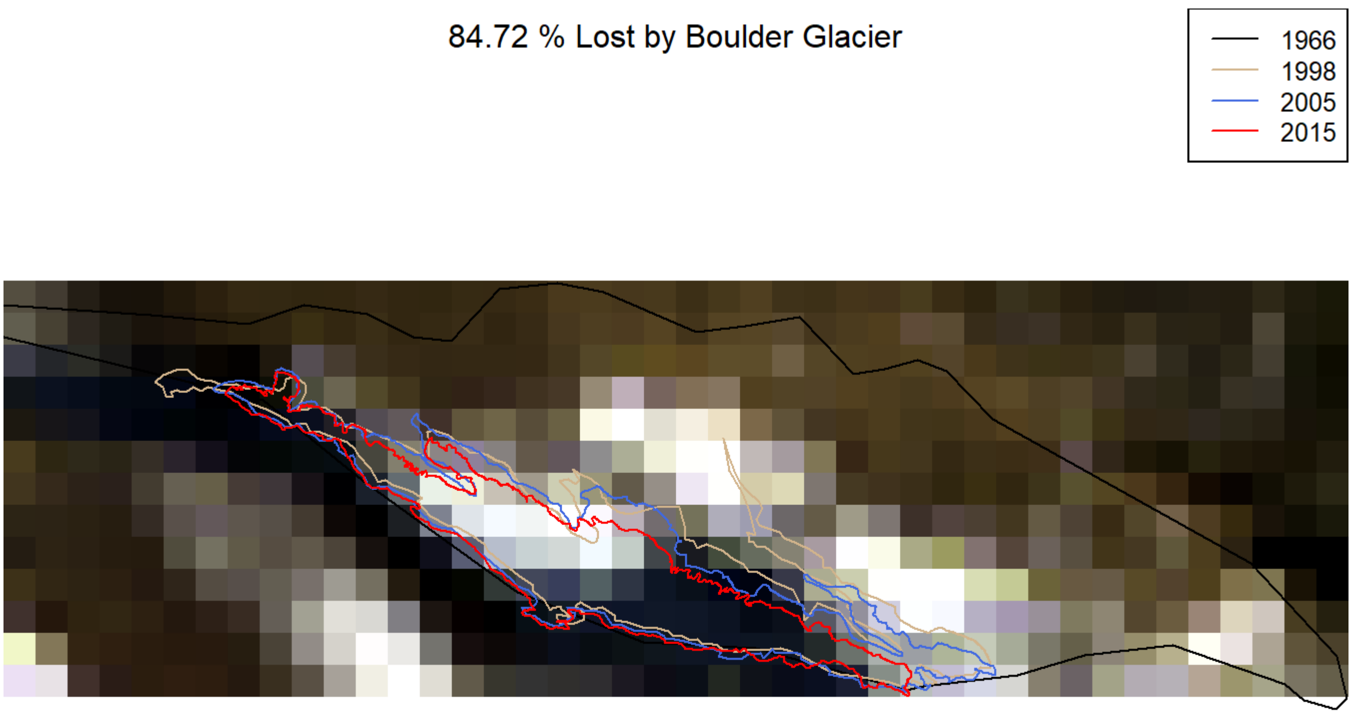
```
## Attempting to make g2015p valid by zero-width buffering
```

```
#plot with NDVI
plot(NDVIraster[[13]], axes=FALSE, box=FALSE)
plot(diffPoly,col="black", border=NA,add=TRUE)
```



Map showing the glacier with the largest % loss with the glacial extent for all years for that glacier with the highest % loss

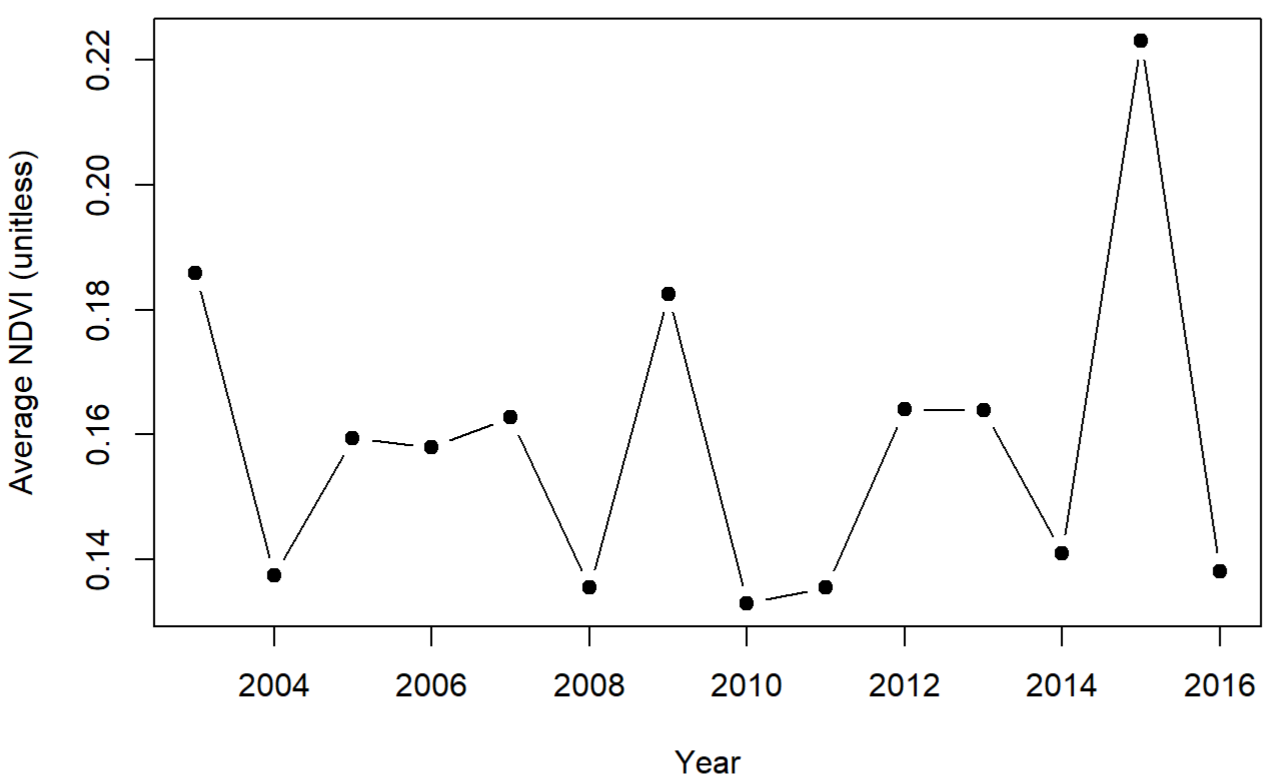
```
# find glacier with largest percent loss
lossIndex <- which.min(gAll$percChange)
lossVal <- min(gAll$percChange)
boul <- gAll[lossIndex,]
# subset the glacial data for each year to be that glacier
gmax1966 <- subset(g1966, g1966@data$GLACNAME == boul$GLACNAME)
gmax1998 <- subset(g1998, g1998@data$GLACNAME == boul$GLACNAME)
gmax2005 <- subset(g2005, g2005@data$GLACNAME == boul$GLACNAME)
gmax2015 <- subset(g2015, g2015@data$GLACNAME == boul$GLACNAME)


plotRGB(rgbL, ext=gmax1966@bbox, stretch="lin")
# add title while axes are off
legend("top", legend=NA, title=paste(round(-100*lossVal, 2), "% Lost by", boul$GLACNAME), bty =
"n")

#add polygons to plot
plot(gmax1966, col="transparent", border="black", add=TRUE)
plot(gmax1998, col="transparent", border="tan", add=TRUE)
plot(gmax2005, col="transparent", border="royalblue", add=TRUE)
plot(gmax2015, col="transparent", border="red", add=TRUE)
legend("topright",legend=c("1966","1998","2005","2015"), lty=1, col=c("black","tan","royalblue",
"red"), cex=0.8)
```



Analyze vegetation growth

```r
#extract NDVI values
NDVIdiff <- list()
meanDiff <- numeric(0)
#loop through all NDVI years
for(i in 1:length(ndviYear)){
  #get raster values in the difference polygon
    NDVIdiff[[i]] <- extract(NDVIraster[[i]],diffPoly)[[1]]
    #calculate the mean of the NDVI values
    meanDiff[i] <- mean(NDVIdiff[[i]], na.rm=TRUE)
}
```

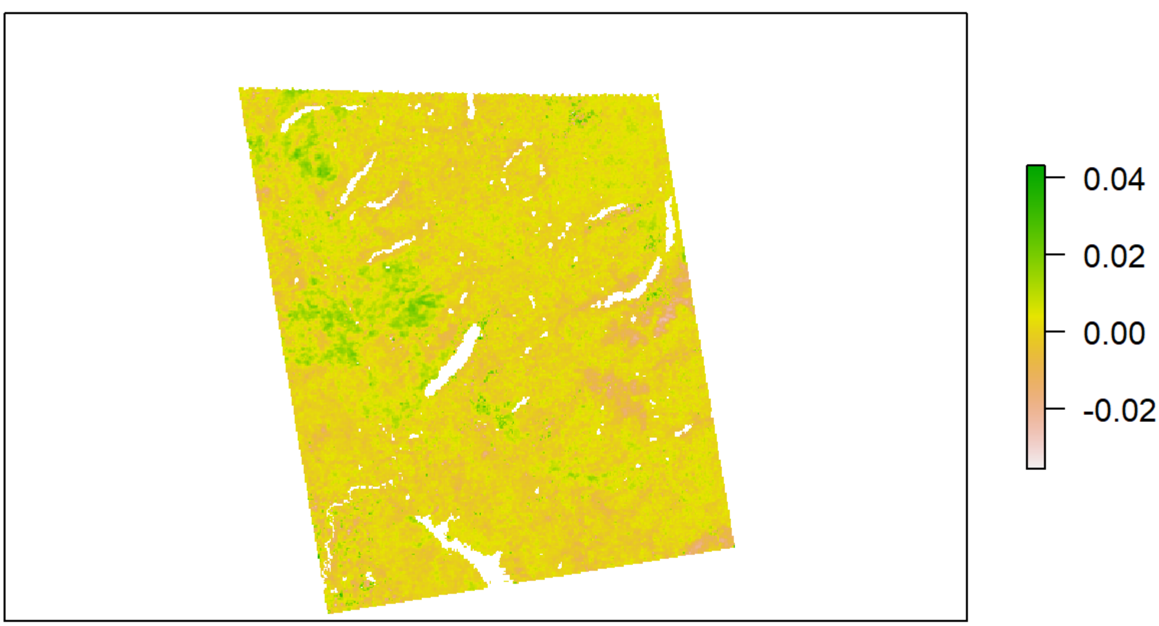
```r
plot(ndviYear, meanDiff, type="b",
    xlab= "Year",
    ylab="Average NDVI (unitless)",
    pch=19)
```



```
#designate that NDVIraster list is a stack
NDVIstack <- stack(NDVIraster)
#set up lm function to apply to every cell
#where x is the value of a cell
#need to first skip NA values (like lakes)
#if NA is missing in first raster, it is missing in all
#so we can tell R to assign an NA rather than fitting the function
timeT <- ndviYear
fun <- function(x) {
    if(is.na(x[1])){
        NA}else{
        #fit a regression and extract a slope
            lm(x ~ timeT)$coefficients[2]}}
#apply the slope function to the rasters
NDVIfit <- calc(NDVIstack,fun)
```

```
## Warning in showSRID(uprojargs, format = "PROJ", multiline = "NO", prefer_proj
## = prefer_proj): Discarded datum Unknown based on Normal Sphere (r=6370997)
## ellipsoid in CRS definition
```

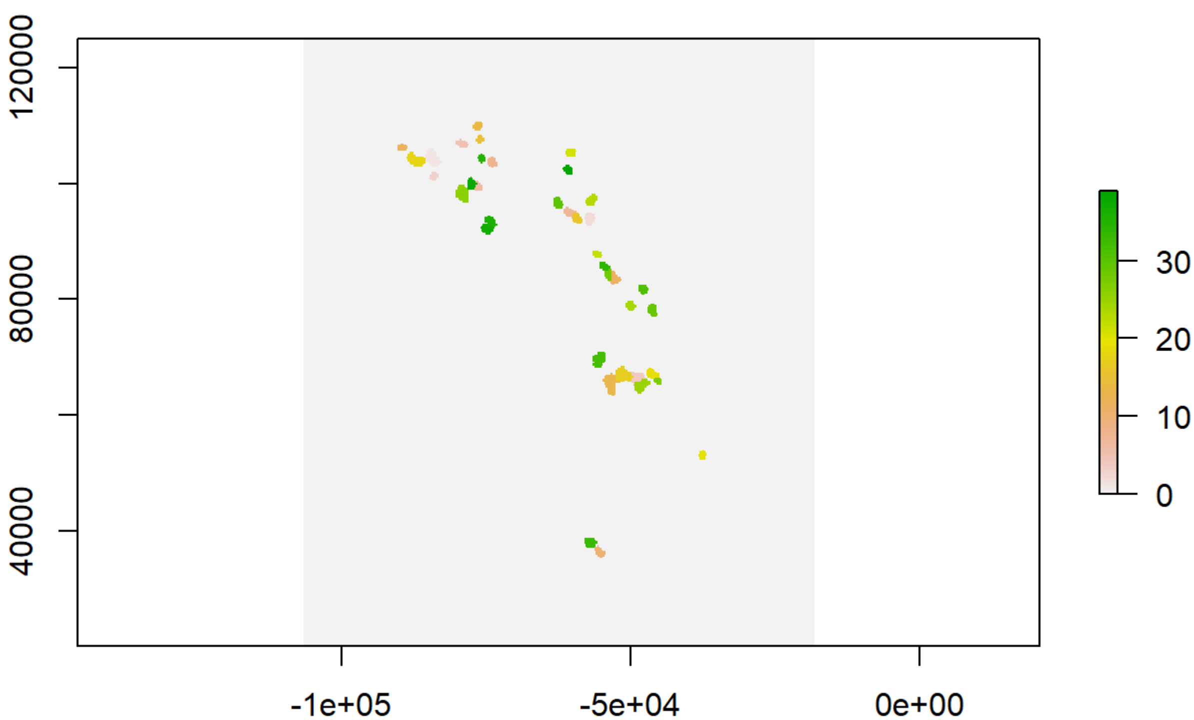
```
#plot the change in NDVI
plot(NDVIfit, axes=FALSE)
```



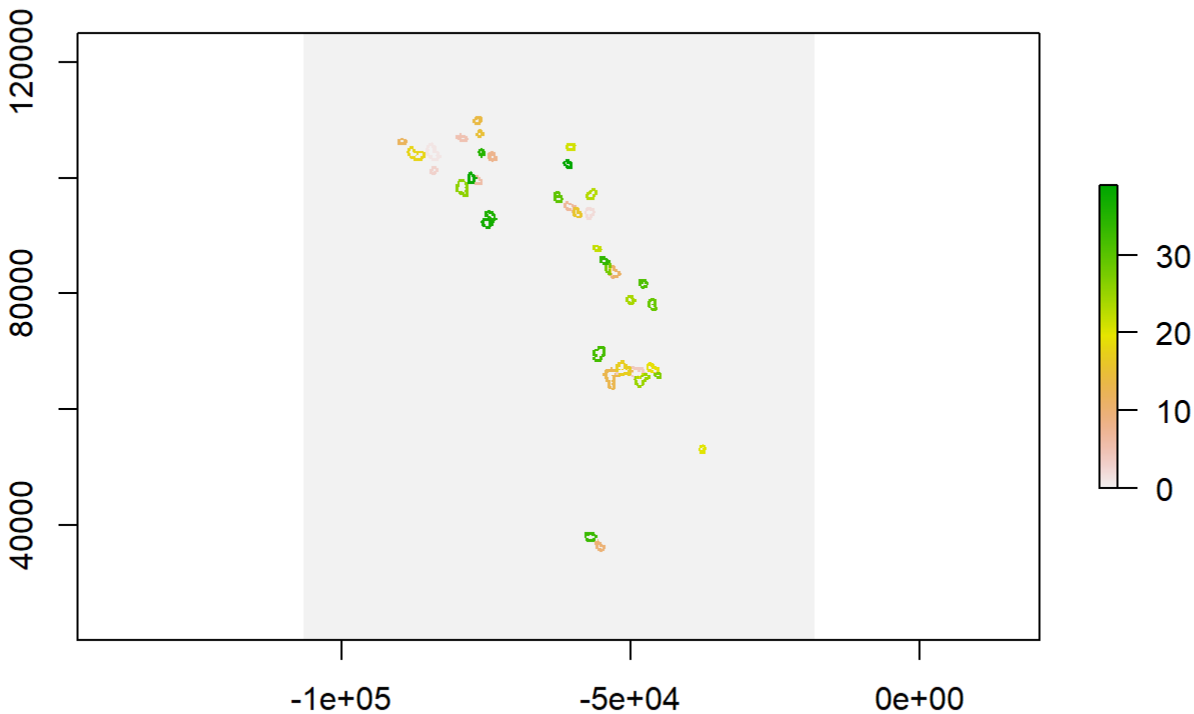
Much of the change across the park is minuscule. It seems like the greatest increase in vegetation is occurring relatively far from the glaciers, which is likely where there is runoff from the glaciers. Additional information that would be helpful for further analysis is the slope of the terrain.

```
#buffer glaciers
glacier500m <- gBuffer(g1966p,#data to buffer
                    byid=TRUE,#keeps original shape id
                    width=500)#width in coordinate system units
```

```
#convert to a raster
buffRaster <- rasterize(glacier500m,#vector to convert to raster
                    NDVIraster[[1]], #raster to match cells and extent
                    field=glacier500m@data$GLACNAME, #field to convert to raster data
                    background=0)#background value for missing data
plot(buffRaster)
```



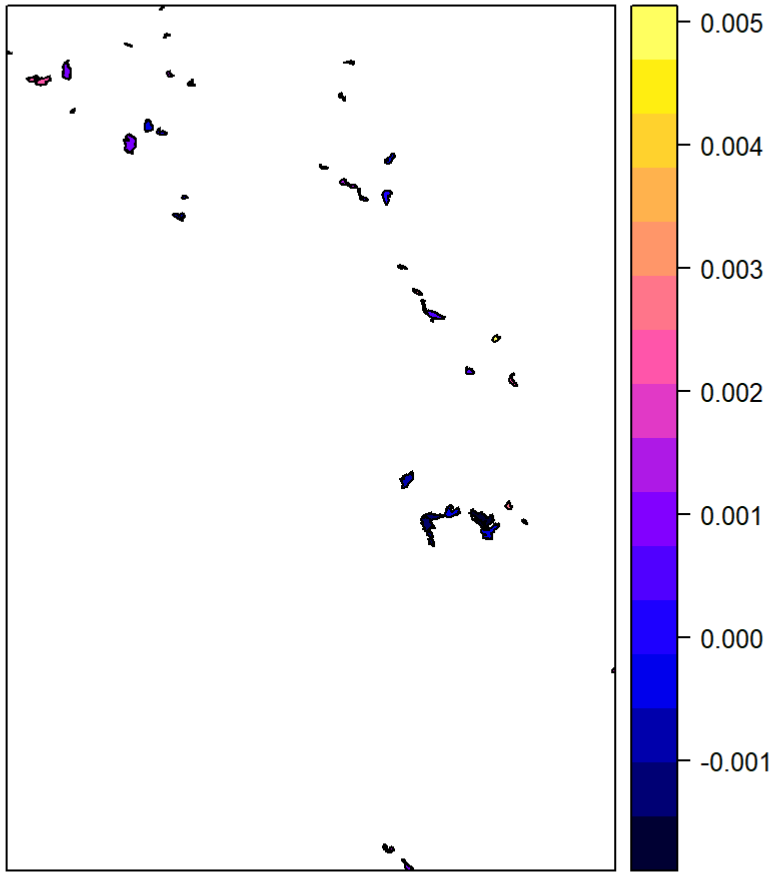

```
#rasterize glaciers
glacRaster <- rasterize(g1966p, NDVIraster[[1]], field=g1966p@data$GLACNAME, background=0)
#subtract buffer from original glacier
glacZones <- buffRaster - glacRaster
plot(glacZones)
```




```
# find change in area around glaciers
meanChange <- zonal(NDVIfit, #NDVI function to summarize
                glacZones,#raster with zones
                "mean")#function to apply
head(meanChange)
```

```
##      zone          mean
## [1,]    0  0.0011640432
## [2,]    1  0.0008101119
## [3,]    2  0.0001584056
## [4,]    3  0.0018559251
## [5,]    4 -0.0014669432
## [6,]    5  0.0027154395
```

```
# Add the mean change in NDVI per year into the 2015 glacier polygons
g2015p@data$meanChange <- meanChange[2:40,"mean"]

spplot(g2015p, "meanChange")
```



There doesn't seem to be much of a pattern. Most values seem to be very small or negative, while there are a couple glaciers with positive change. This aligns with the previous observation that most of the increase in NDVI was away from the glaciers.

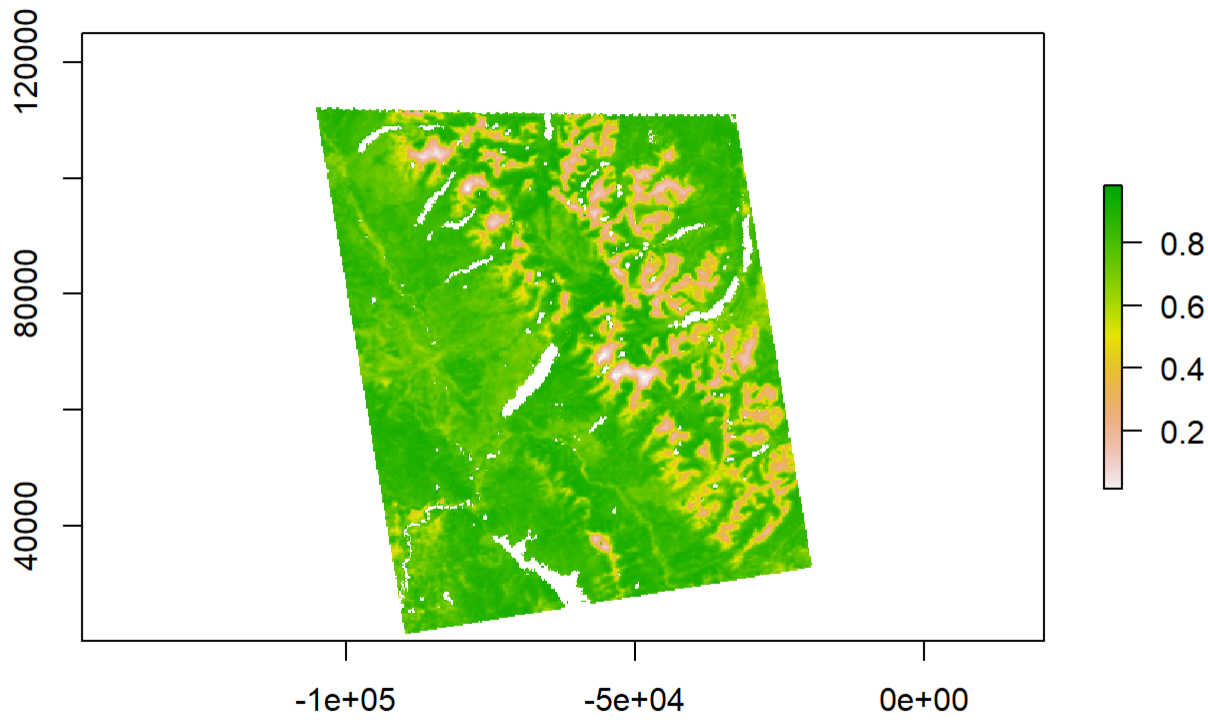
I think it is difficult to conclude that vegetation is changing as glaciers recede over this small of a time period. The mean change in most areas is below the level that was described as substantial in Anderson's paper. However, although small, there is clearly a pattern of vegetation growth from runoff of melting glaciers.

Average maximum NDVI across all years within the Glacier National Park

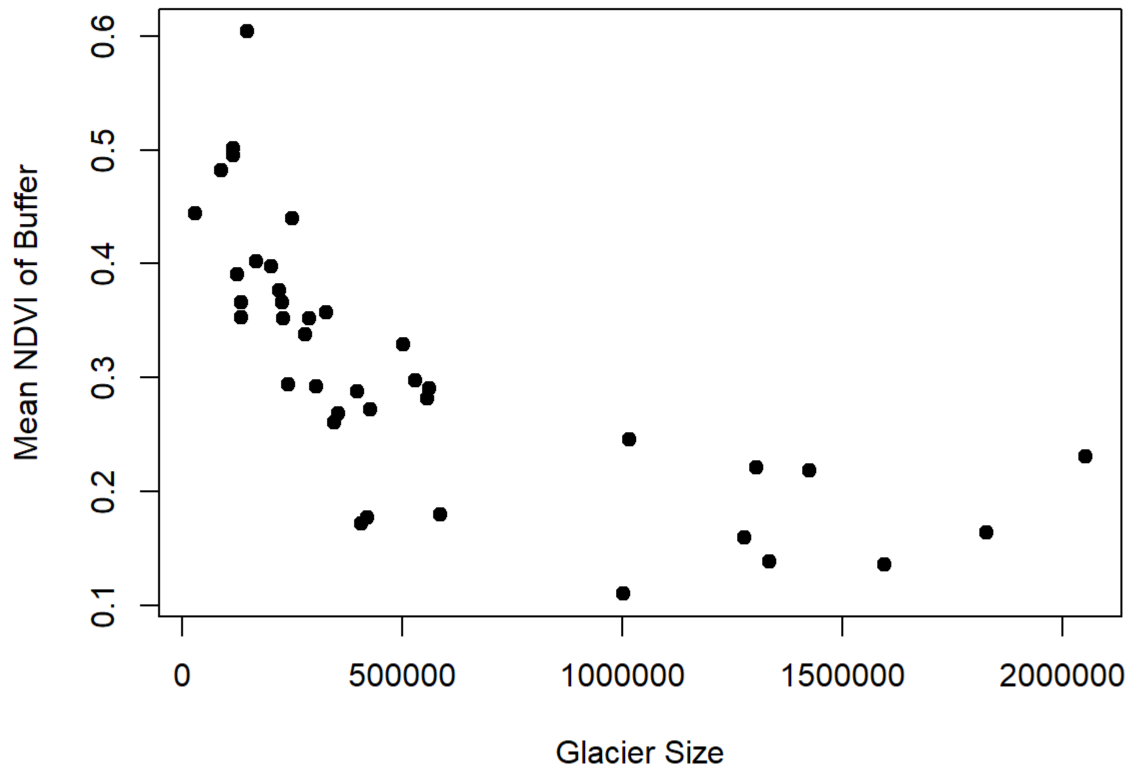
```
# take average value across all years
NDVImeans <- calc(NDVIstack,fun=mean)
```

```
## Warning in showSRID(uprojargs, format = "PROJ", multiline = "NO", prefer_proj
## = prefer_proj): Discarded datum Unknown based on Normal Sphere (r=6370997)
## ellipsoid in CRS definition
```

```
plot(NDVImeans)
```

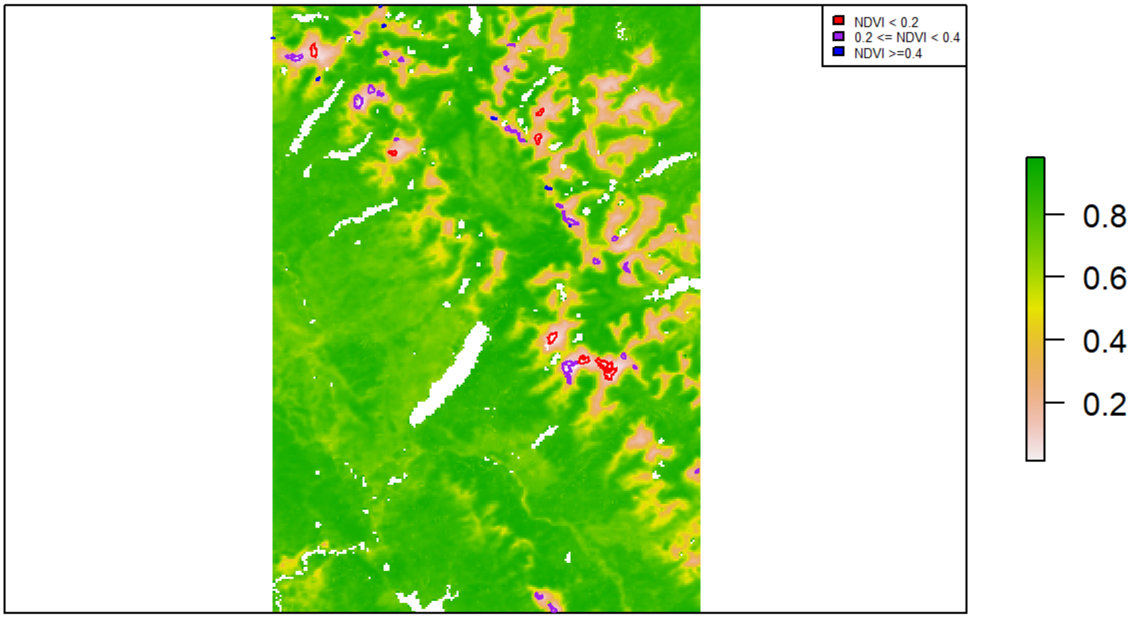



```
# Scatterplot of glacier size and NDVI within 500
meanVals <- zonal(NDVImeans, #NDVI function to summarize
                buffRaster,#raster with zones
                "mean")#function to apply
plot(g1966p@data$a1966m.sq, meanVals[2:40,"mean"],
    xlab= "Glacier Size",
    ylab="Mean NDVI of Buffer",
    pch=19)
```



There is a pattern between glacier size and NDVI within 500m. As glacier size increases, NDVI decreases exponentially.

```
means <- meanVals[2:40, "mean"]
g2015p@data$colors <- ifelse(means < 0.2, "red",
                             ifelse(means < 0.4, "purple", "blue"))

plot(NDVImeans, ext=g2015p, axes=FALSE)
plot(g2015p, border=g2015p@data$colors, add=TRUE)
legend("topright",
       legend = c("NDVI < 0.2", "0.2 <= NDVI < 0.4", "NDVI >=0.4"), cex = 0.4, fill=c("red", "pu
rple", "blue"))
```



To help us validate what is happening with vegetation as glaciers recede, we need elevation data. We also need to know where there is persistent snow coverage in addition to glaciers. Next steps would be to include the terrain slopes and account for the impact of snow cover on vegetation growth.