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Image processing of flow characteristics of rain-on-snow experiments

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DIPLOMA THESIS ASSIGNMENT

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Environmental Geosciences

Thesis title

Image processing of flow characteristics of rain-on-snow experiments

Objectives of thesis

Generation of automated procedure to analyze detailed photographs of snow packs taken during rain-on-snow experiments to obtain information on

Preferential flow path

Area of matrix and preferential flow path

Grain size distribution

and to compare results with meteorological data to find driving factor for the timing of snow runoff.

The automated procedure is aimed to be published as R-package.

Methodology

The thesis will be conducted according to following timeline:

Literature review (1) to increase process understanding of liquid water flow through snow and (2) to review of image processing algorithms.

Coding of automated procedure for analysis in R and creation of R-package

Testing of algorithm on simple synthetic benchmarks

Evaluation of photographs from four rain-on-snow experiments

Statistical analysis (Correlation and principal component analysis) of evaluated snow characteristics (grain size, pore size, preferential flow domain area) and provided meteorological data (air temperature, soil temperature, humidity) with additional recorded snow measurement (infiltration rate, temperature, runoff).

The proposed extent of the thesis

40 to 60 pages

Keywords

Dye tracer experiments, image raster analysis, dual domain, preferential flow, retention curve

Recommended information sources

- Juras, Roman, Sebastian Würzer, Jirka Pavlásek, Tomáš Vitvar, and Tobias Jonas. 2017. "Rainwater Propagation through Snowpack during Rain-on-Snow Sprinkling Experiments under Different Snow Conditions." *Hydrology and Earth System Sciences* 21 (9):4973–87.
- Würzer, Sebastian, Nander Wever, Roman Juras, Michael Lehning, and Tobias Jonas. 2017. "Modelling Liquid Water Transport in Snow under Rain-on-Snow Conditions – Considering Preferential Flow." *Hydrology and Earth System Sciences* 21 (3):1741–56.
- Yamaguchi, Satoru, Kunio Watanabe, Takafumi Katsushima, Atsushi Sato, and Toshiro Kumakura. 2012. "Dependence of the Water Retention Curve of Snow on Snow Characteristics." *Annals of Glaciology* 53 (61):6–12.

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Diploma Thesis Author's Declaration:

I, Ibrahim Bello, hereby declare that I have written the following diploma thesis by myself under the supervision of Doc. Ing. Michal Kuráž, Ph.D. Every piece of literature and publication used to fetch information for the aims of this diploma thesis are listed in the work cited section of this diploma thesis.

Signature: _____

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Abstract

English: Processing of images collected from the rain-on-snow experiment has been an issue, due to a large number of images involved, there is a need to adopt an automated approach to characterize flow by identification of flow structures in rain-on-snow experiment. This study uses typical images that represent flow structures such as, matrix flow, preferential flow and a capillary barrier to developing a package using R programming language, this package comprises of functions such as threshold application function, blue distribution and fraction functions, the slope of blue fractions function. These functions were applied to the sample images collected from Klosters, Serneus, Sertig and SLF localities of Davos area in Switzerland. The blue distribution function returns 98.84% of the sample image from Klosters locality was covered with blue colour, the high distribution of blue colour signifies matrix flow structure, the changes in the slope of the blue fraction image length signifies preferential flow and the changes in the slope of blue fraction image depth signifies capillary barrier.

Česky: Zpracování snímků získaných z experimentu s deštěm na sněhu bylo problémem, vzhledem k velkému počtu zapojených snímků, je třeba přijmout automatizovaný přístup k charakterizaci průtoku pomocí identifikace tokových struktur v dešti při experimentu na sněhu. Tato studie využívá typické obrazy, které představují struktury proudění, jako je tok matrice, preferenční tok a kapilární bariéra pro vývoj balíku s použitím programovacího jazyka R, tento balíček obsahuje funkce, jako je funkce prahové aplikace, distribuce modré a funkce zlomků, sklon funkce modré frakce. Tyto funkce byly aplikovány na vzorové snímky získané z lokalit Klosters, Serneus, Sertig a SLF oblasti Davos ve Švýcarsku. Modrá distribuční funkce vrací 98,84% vzorku vzorku z lokality Klosters byla pokryta modrou barvou, vysoká distribuce modré barvy znamená strukturu toku matrice, změny ve sklonu délky obrazu modré frakce znamenají preferenční tok a změny sklon modré hloubky obrazu zlomku označuje kapilární bariéru.

1 Introduction

Rain-on-snow is a naturally occurring event, rain-on-snow is characterized by water flow through snow pack, so it is as well known to be a hazardous event (Juras et al., 2017). Rain-on-snow events are liable to result in flooding in an increasing snowmelt condition and increasing rate of rainfalls on snow (Pomeroy, Fang, and Marks 2016). Flooding as a result of rain-on-snow can be controlled, in order to control the water flow through snow pack, the report of snow pack gravity action, snow pack retention, snow pack capillary, and snow pack flow estimation are necessary.

When the characteristics of flow in the snow that can result in the severe flood are observed, the procedure of characterizing this flow appears to be a complicated 3-D analysis (Avanzi et al. 2016). Flows in snow are known for its diversity in flow paths, although it is expected to have a uniform flow characteristic when flowing through a medium that is porous and homogenous (Williams, Erickson, and Petrzela 2010).

When rain falls on snow, it results in water flow through snow, according to (Nander Wever et al. 2016), it was already proven that water movement from preferential flow to matrix flow is an effective process of water flow through snow, an accurate explanation of how water flows through a snow pack is not only important to optimize the estimation of meltwater runoff, it's also useful to optimize the understanding of wet snow avalanche formation (N. Wever et al. 2013). The temperature reports as a result of snowmelts have an effect on the valley flow direction (Thériault et al. 2015), simulating all of the examined microphysics plans result in to, changes in the field of valley flow direction with the application of diabatic effect in snow melting (Thériault et al. 2015).

2 Aims of the Study

The aims of this diploma thesis are to adopt the methodology that involves building an r-package to automate the image processing of flow characteristics of rain-on-snow experiment. This methodology will be used to identify flow characteristics of the image input such as, matrix flow, preferential flow and capillary barrier, this also involves the determination of threshold conditions for the development of threshold application function to return image2D plots, development of blue distribution function that will return the distribution of blues of the image input. Development of length and depth of blue fraction function, this function will return the intensities of blue for the length and depth of input image. Also, the slope of the

length and depth of blue fraction function will be developed as part of the package, this function will return the changes of the blue values for the length and depth pixel of the sample image.

3 Literature Review

3.1 Flow characteristics

3.1.1 Flow Paths

Flow paths are the paths taken by the movement of water within a snow pack (Katsushima et al. 2013), due to the involvement of water which can be as a result of rainfall on snow pack, flow paths can be a wetting path that is extensionally diverse with flat separate wet and dry zones (Juras et al., 2017). The knowledge of the spatial distribution of flow paths in melting snow pack was sustained from the temporary nature of the flow paths and the issues caused by damaging part of the snow pack (Williams, Erickson, and Petrzelka 2010).

When pressure head exceeds the pressure head at the point of water entry into snow layer this means that water moves from matrix to preferential flow, also when pressure head at the point of water entry to snow layer exceeds the pressure head, this means that water moves from preferential to matrix flow (Nander Wever et al. 2016).

3.1.2 Matrix Flow

Matrix flow is the dispersal movement of water through the snow pack, this is as a result of the slow speed of the movement of water in snow (Avanzi et al., 2016), due to this slow movement of water in the snow pack the pore spaces in snow are homogeneously filled with the water undergoing matrix flow in snow (Walter et al. 2013)

The matrix flow component is implicitly only considered when most snow models describe the water flow as a consistent moistening front (Würzer et al., 2017), the consistent water flow result into snow constantly and thoroughly moistened, with all the snow being wet above the moistening cover (Juras et al., 2017).

3.1.3 Preferential Flow

In the transportation of liquid and water through the snow pack, preferential flow has a major contribution and it occurs due to many factors such as; discontinuous ice layer across varying canopy coverage, slope, and aspect (Pleasants, Kelleners, and Ohara 2017) these factors make preferential flow the leading model for water permeation in snow (Avanzi et al. 2016).

Under some infiltration conditions, there could be the formation of preferential flow when the water flux is less than the saturated conductivity (Katsushima et al. 2013).

Percolation of water vertically in snow may be encouraged by preferential flow because the flow of water on ice layers will result into reduction in the time at which water travel in the catchment and also this can affect the catchment-scale hydrology (Nander Wever et al. 2016). Preferential flow simulation in a subfreezing snow pack will generate iced layers and allows an increase in the vertical energy exchange, this model warms up the snow pack faster (Leroux and Pomeroy 2017), if there is no overshoot of the capillary pressure then preferential flow cannot occur (Katsushima et al. 2013). Saturated conditions and preferential flow path in accelerated metamorphism occurs as a result of the effect of heavy rain on the snow surface (Singh et al. 1997).

3.1.4 Capillary Effects

Snow pack with a greater difference in grain size, shape and density have greater capillary effects (Williams, Erickson, and Petrzela 2010). Grain size transitions leading to capillary barrier plays an important role in the formation of preferential flow paths (Würzer et al., 2017). Capillary barrier occurs when Fine-textured layer is on top of coarse-textured layer, water ponding layer is observed when the capillary barrier is observed on an impermeable ice layer under a snow layer. Capillary barrier is observed when there is a formation of ponding layer boundary due to the difference in the water entry when capillary pressure of the large pores in coarse lower snow layer compared to the difference in the water entry when capillary pressure of small pores in fine upper snow layer (Katsushima et al. 2013).

3.2 Image processing

Image processing of rain-on-snow experiment provides visual information of flow characterization in accumulated and melting snow (William and Weiler 2008), for efficient result, processing images from rain-on-snow experiments require a lot of photos, this demands the need for automatic approach to crop photos into desirable area, formats and to avoid unwanted area of the photos (Parajka et al. 2012) in order to accomplish this automatic approach, the skyline algorithm by (Lie et al. 2005) can be adopted, also, processing large amount of images was said to require the development of image classification algorithm that would bring about reliable result (Sanchez et al. 2013). To efficiently process images taken from rain-on-snow experiment, it is necessary to select images that are suitable for further

processing, it is necessary to relatively adjust inconsistency image properties due to unavoidable activities such as; changing of camera films etc., it is necessary for the images to clearly detect a larger portion of the desirable area that would be used for further processing, it is also necessary to record the coordinate of the images (Farinotti et al. 2010).

According to (Abdolmaleky et al. 2017) adopting the RGB channels of image representation is faster than other past approaches, RGB channels are red, green and blue colour channels of an image, these channels consists of 256 variables of colour, these variables range from 0 to 255 for each of the channels (Morais et al. 2019).

3.3 Driving factor for the timing of snow runoff

Elevation plays an important role in the sizes of snowfall fraction which also affects the sensitivity of catchments to water balance changes, this implies that air temperature changes with elevation and this determines the onset of snowmelt and also streamflow. In mountain catchments, when winter low flows increase, it results in higher annual runoff in the spring and summer (Jenicek, Seibert, and Staudinger 2018). When snowmelt occurs the water in the snow pack flows through surface outflows and streams, this water is subjected to conditions such as; groundwater recharge through deep percolation into the ground, subsurface flow and evapotranspiration (Fayad et al. 2017). Rainwater introduction to snow pack in rain-on-snow events portrays an extra cause of liquid water apart from the melting snow which can impart the time of snow pack runoff (Juras et al., 2017).

Triggering water like wet snow landslides at capillary barriers affects the timing of snowmelt runoff (Avanzi et al. 2016). Snowmelt routine with lumped rainfall-runoff was used to simulate the streamflow in snow-dominated Mediterranean regions (Fayad et al. 2017).

Variation in high inter and intra-annual climate that brings about most of the hydrologic processes were observed from the Mediterranean snow-influenced regions (Fayad et al. 2017). In summer when a catchment is covered by snow, the meltwater flowing out from the snow pack can be said to be analogous to summer rainfall (Nander Wever et al. 2017).

A methodology that can be used to provide enough information about rainwater movement during rain-on-snow events was adopted by (Juras et al. 2016). Rainwater input to snow in rain-on-snow experiment pushes out the non-rainwater available in the snow at first which constitutes up to half of the total outflow and then pushes out the available rainwater in the snow (Juras et al. 2016). In a high elevated region, when there's intense rainfall on snow pack at a warmer temperature of 2-4 degrees centigrade than any day with temperature beyond 4

degrees centigrade, this conditions may cause an increase in rain-on-snow events by 50% which can also result to flooding (Beniston and Stoffel 2016).

If we have a future whereby the air temperature increases, the frequency of high peak flow rain-on-snow events occurrence will decrease in the middle and low elevated zones while the frequency of high peak flow rain-on-snow events occurrence will increase in the high elevated zones. In temperate climate such as the western United States, the precipitation of snow events occur at an elevation greater than 1100 metres and precipitation of rain occurs at an elevation below 350 metres-400 metres, the transient rain and snow zone (between 350 metres to 1100 metres) has an increasing rain-on-snow event occurrence during winter (Surfleet and Tullos 2013).

Snowmelt process can be accelerated when rainfall on snow cover in increasing spring temperature, this process may result in flooding if the rainfall on the melting snow cover is heavy (Sui and Koehler 2001). Elevation and precipitation are the major factors affecting the persistence of snow cover (Fayad et al. 2017).

4 Methodology

4.1 Location of sample images

Dye tracer sprinkling equipment such as brilliant blue FCF dye tracer, lysimeter and sprinkler was setup in the Klosters, Serneus, Sertig and SLF localities in the Davos area of Switzerland (Juras et al., 2017).

4.2 Sprinkling experiment and image sample collection procedures

Major equipment such as lysimeters and sprinklers were used to create artificial rain-on-snow experiment called sprinkling experiment. This equipment such as the lysimeters and sprinklers was set up 10 metres laterally apart in six. The lysimeter was buried into snow pack that has not been tampered with, the sprinkler was placed 2 meters above the lysimeter, brilliant blue FCF dye tracer was added to the water that would serve as the rain. The dye tracer turned the colour of water to be sprinkled into blue colour for better visualisation of flow characteristics through the snow pack (Juras et al., 2017).

After proper setup, the dye tracer water was sprinkled on the lysimeter buried inside untampered snow pack for 30 minutes, this procedure was done four times with 30 minutes

break after every water sprinkling session. The snow pack was cut vertically after the sprinkling procedure and set of images were taken for all the 6 different sprinkling locations, the images showed the vertical profile of the dye tracer flow characteristics through the undisturbed snow pack, the blue colours segments in the snow pack profile represents the flow structures such as ice layer, capillary barrier, preferential flow and matrix flow

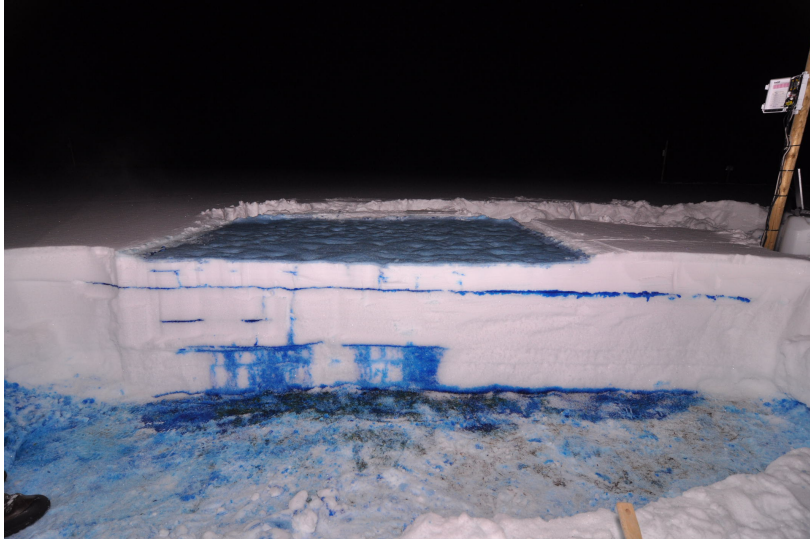


Figure 1 One of the snow pack vertical profile sample image taken at one of the sprinkling experiment locations

4.3 Flow characteristics package development and usage

To efficiently accomplish the aims of this study, a flow characteristics package was developed for this project, the package comprised of inbuilt functions that would automate the identification of flow structures in multiple images collected from brilliant blue FCF dye tracer sprinkling experiment. The package would be built on R-Studio Version 1.1.463 using R programming language. This flow characteristics package would feature functions that can be used in the application of already built-in threshold conditions to sample images taken from brilliant blue FCF dye tracer sprinkling experiment on snow pack.

The package can be used in the determination of blue colour distribution of sample images, determination of length and depth blue fractions of sample images, and also determination of slope of the length and depth blue fractions of sample images.

4.3.1 Determination of threshold conditions

The area covered by blue colour in the sample images show the movement of brilliant blue FCF dye tracer within the snow pack, an approach that was used to distinguish the part of images with blue was to determine threshold conditions between the snow pack colour which

is white from the sample images and the brilliant blue FCF colour which is blue. The threshold conditions was further categorized to classify the different intensities of blue colour into dark blue, medium blue and light blue. To determine these threshold conditions, part of the images with the highest intensity of blue, grey and white were selected from all sample images of the snow pack vertical cut profile collected from the sprinkling experiment location of (Würzer et al. 2017). The blue, grey and white parts were cropped out into 20 pieces of 8 by 8 pixels each from the lightest to the deepest intensities of blue, grey and white cuts, for instance the first piece of the blue cuts is the lightest blue and the twentieth piece is the deepest blue, the same procedure was applied to the grey and white cuts. The cuts were further analysed in R programming language using JPEG package to read the cuts into the R Studio environment, Tables were created for each cut of blue, grey and white as data.frame using the data.table package in R, RGB values of each pixel are the variables and the pixel index are the observations of each table. These tables were converted into matrix data, enabling the rows and columns labels for a better description.

```
1. #Convert table to matrix
2. blue_1_table <- as.matrix(blue_1_table, format = TRUE,
3.                          rowLabels = TRUE, colLabels = TRUE,)
```

Mean of the RGB values for all the blue, grey and white cuts was determined and bound together, **Error! Reference source not found.** shows the mean of the RGB values of the first six blue, grey and white cuts.

Blue, grey and white cuts were grouped into red, green and blue channels. For instance, all the red values of the twenty blue cuts were grouped together as a list in R, the same procedure was repeated for the grey and white cuts and also for the green and blue channel. The list was assigned to descriptive variable names for easy identification of the cut and channel groups. “blue_R”, “grey_R”, and “white_R” were assigned to the red channel lists, “blue_G”, “grey_G” and “white_G” were assigned to the green channel lists and “blue_B”, “grey_B” and “white_B” were assigned to the blue channel lists.

4.3.1.1 Graphical representation of the intensities of blue, grey and white cuts

2D image plot was suggested as an approach to graphically display structures such as capillary barriers, preferential flow and matrix flow of any of the vertical cut images collected from the

sprinkling experiment based on the blue colour intensity. To determine the threshold value, a density plot of the blue, grey and white lists were made for all the channels i.e. red, green and blue channel.

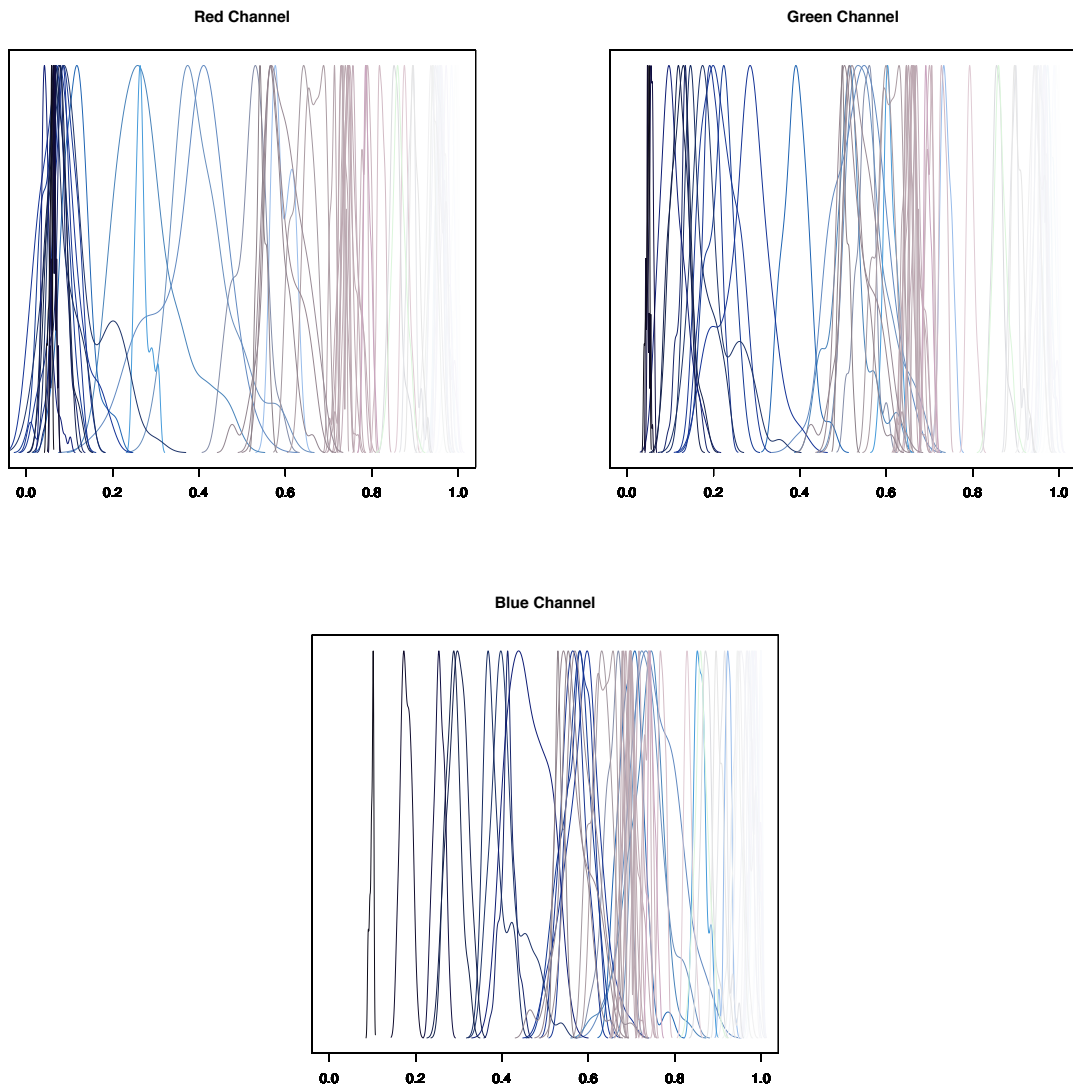


Figure 2: Density plots of the blue, grey and white list in the red, green and blue channel

For processing of the threshold determination, the range of all the cuts of blue, grey and white were determined and assigned to unique names, these unique names were converted into a list, this list was assigned to a unique list name for each channel, this procedure was implemented for all the channels resulting into unique list names for red, green and blue channels.

“ranges_R” was the name assigned to represent the range values of the blue, grey and white cuts in the red channel, “ranges_G” was the name assigned to represent the range values of the blue, grey and white cuts in the green channel, “ranges_B” was the name assigned to represent the range values of the blue, grey and white cuts in the blue channel. The boxplot of

“ranges_R”, “ranges_G”, and “ranges_B” was plotted to easily identify the minimum and maximum values of blue, grey and white in all channels, these values would serve as the threshold values that enables the visibility of capillary barrier, preferential flow and matrix flow structure on 2D Image plot.

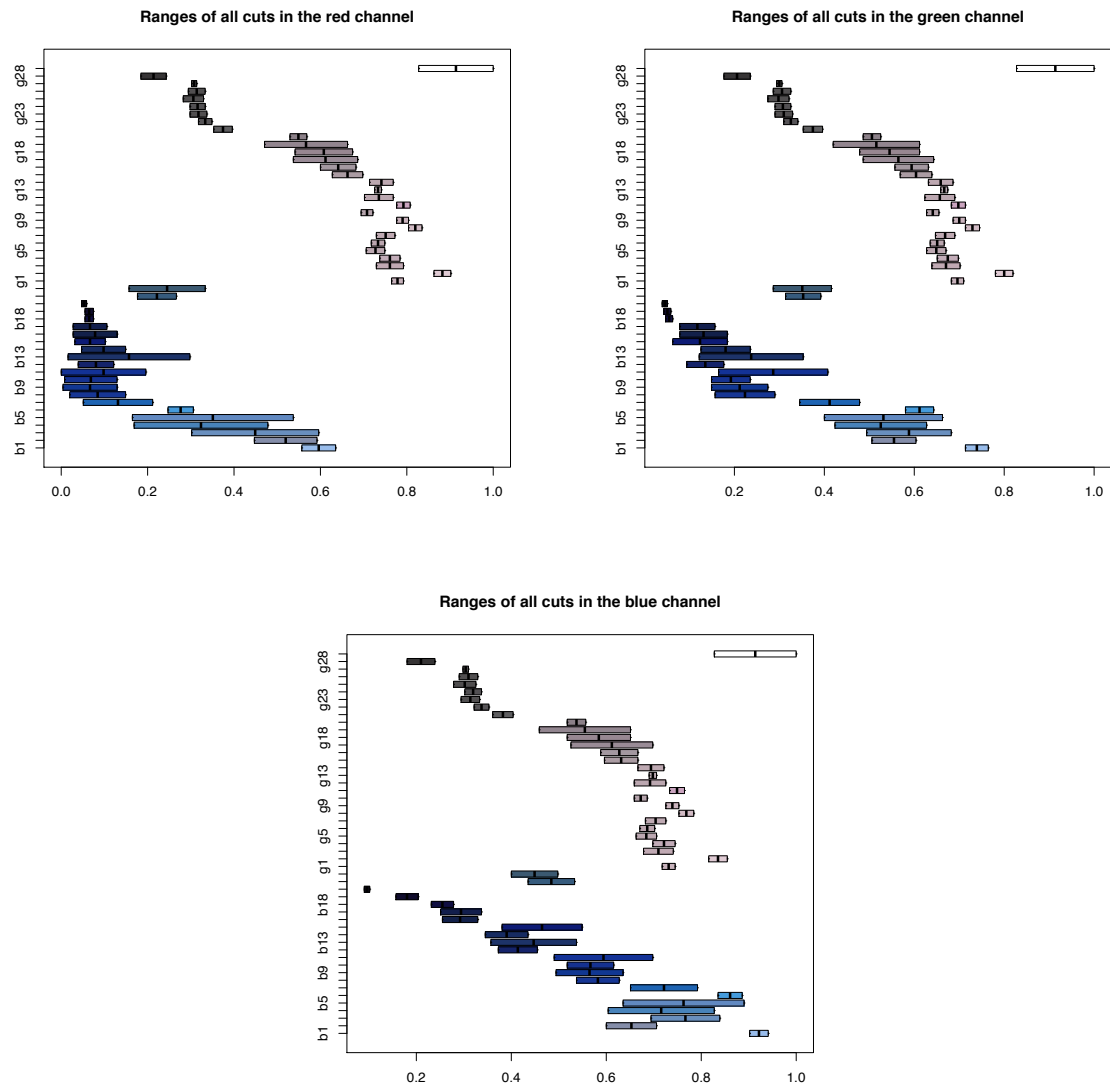


Figure 3 Boxplot of range values of cuts in red, blue and green channel

From Figure 3 some grey cuts were overlapping with blue cuts, this makes it difficult to determine the threshold that would visualize capillary barrier, preferential flow and matrix flow structures upon application on 2d image plot. For efficiency the overlapping minimum and maximum part of blue cuts and grey cuts are filtered out in the red and green channel where other nonoverlapped cuts exist, these filtered ranges of cut were further plotted into boxplots, see Figure 4

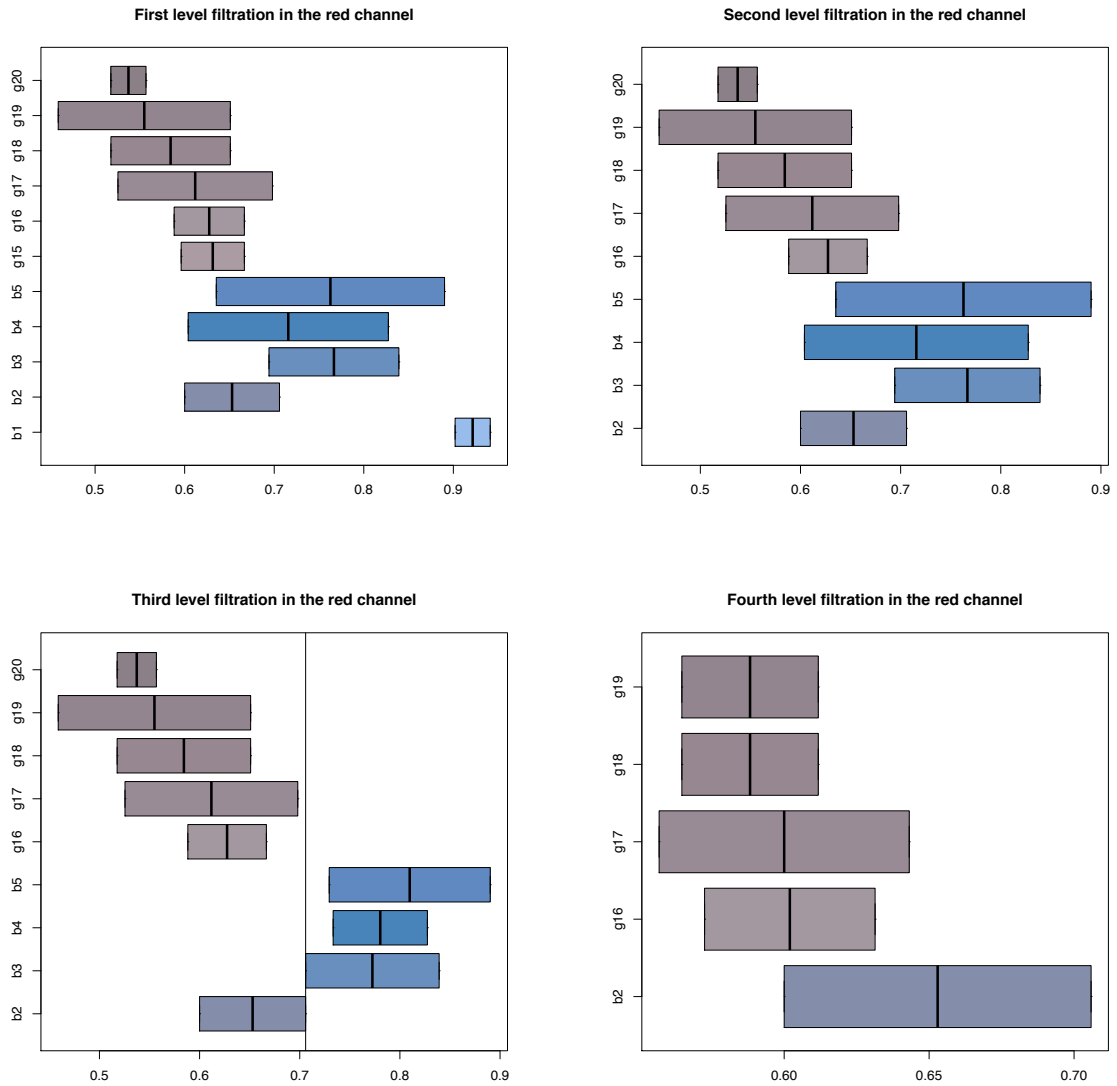


Figure 4 All levels filtered range values of blue and grey cuts

From Figure 4 plots, the below conditions were deduced to determine the threshold used in the identification of blue structures.

- The transpose of the matrix data of the cropped sample images in the red channel was less than 0.15
- The transpose of the matrix data of the cropped sample images in the red channel was less than 0.3 and greater than or equal to 0.15, and the transpose of the matrix data of the cropped sample images in the blue channel was greater than 0.4
- The transpose of the matrix data of the cropped sample images in the red channel was less than 0.4 and greater than or equal to 0.3, and the transpose of the matrix data of the cropped sample images in the blue channel was greater than 0.5

- The transpose of the matrix data of the cropped sample images in the red channel was greater than or equal to 0.6 and less than 0.65, and the transpose of the matrix data of the cropped sample images in the blue channel was greater than 0.85
- The transpose of the matrix data of the cropped sample images in the red channel was greater than 0.4 and less than 0.6, and the transpose of the matrix data of the cropped sample images in the blue channel was greater than 0.7
- The transpose of the matrix data of the cropped sample images in the red channel was greater than 0.4 and less than 0.6, and the transpose of the matrix data of the cropped sample images in the blue channel was greater than 0.6, and the transpose of the matrix data of the cropped sample images in the green channel is greater than 0.65

```

1. # Apply threshold conditions
2. log_thresh_db <- thresh_pht_red < 0.15
3. log_thresh1 <- thresh_pht_red < 0.3 & thresh_pht_red >= 0.15 & thresh_pht_blue > 0.4
4. log_thresh1b <- thresh_pht_red < 0.4 & thresh_pht_red >= 0.3 & thresh_pht_blue > 0.5
5.
6. log_thresh2 <- thresh_pht_red >= 0.6 & thresh_pht_red < 0.65 & thresh_pht_blue > 0.85
7. log_thresh3 <- thresh_pht_red > 0.4 & thresh_pht_red < 0.6 & thresh_pht_blue > 0.7
8. log_thresh4 <- thresh_pht_red > 0.4 & thresh_pht_red < 0.6 & thresh_pht_blue > 0.6 & thresh_pht_green
   > 0.65

```

4.3.2 Development of threshold application function

The threshold application function in the flow characteristics package was built to accept image data read from the jpeg r-package as an input. The image data returned from the jpeg function can be stored into a variable as an input. This data from the jpeg image return would serve as an input to the threshold application function. The returned threshold application data was categorized into four colour classification, one white classification and three blue classifications see Table 1

Table 1 Values of the returned threshold data categories from threshold application

Representation colour categories of the pixel	Representation values of the pixel
White	0
(Lightskyblue1) Light blue	1
(Royalblue3) Medium Blue	2
(Darkblue) Dark blue	3

The four classifications of colour values returned from threshold application function were further described, 0 represent the pixels or parts with white colour (not blue colour), 1 represent the pixels or parts with light blue colour, 2 represent the pixels or parts with medium blue colour and 3 represent the pixels or parts with dark blue colour.

```

1. for( i in 1:nrow(log_thresh1)){
2.   for( j in 1:ncol(log_thresh1)){
3.     if(log_thresh_db[i,j]){
4.       thresh_pht[i,j] <- 3
5.     }else{
6.       if(log_thresh1[i,j]){
7.         thresh_pht[i,j] <- 2
8.       }else{
9.         if(log_thresh1b[i,j]){
10.          thresh_pht[i,j] <- 2
11.        }else{
12.          if(log_thresh2[i,j]){
13.            thresh_pht[i,j] <- 1
14.          }else{
15.            if(log_thresh3[i,j]){
16.              thresh_pht[i,j] <- 1
17.            }else{
18.              if(log_thresh4[i,j]){
19.                thresh_pht[i,j] <- 1
20.              }else{
21.                thresh_pht[i,j] <- 0
22.              }
23.            }
24.          }
25.        }
26.      }

```

```
27. }  
28. }  
29. }
```

The R image plot was extended into 2D image plot using plot3D Version 1.1.1 package in R, The transpose of the matrix data of the cropped sample images in the red channel was used as the dimension variable, the colours used to represent the different division of blue values were listed as an argument used to generate the colour palette of the image function. The colour list are white, lightskyblue1, royalblue3 and darkblue. Breakpoints of -0.5, 0.5, 1.5, 2.5, and 3.5 was listed as an argument in the image function and also in other to illuminate and make the colours appear bright to the lightest blue, the argument alpha was set to 1

```
1. # Install plot3D package  
2. install.packages("plot3D")  
3.  
4. # Load plot3D package  
5. library("plot3D")  
6.  
7. # use the transpose of the matrix data of the cropped sample images in the red channel as the dimension  
   variable  
8. thresh_pht <- pht_dta_red  
9.  
10. #Image plot in 2D  
11. image2D(thresh_pht, col = c("white", "lightskyblue1", "royalblue3", "darkblue"), breaks = c(-0.5,0.5,1.5,  
    2.5,3.5), alpha = 1)
```

The plots of all the jpeg files input was stored to an assigned directory, this was done by assigning the variable name *outdir* to a string 'cropped', *cropped* is the name given to the directory in which the plots were stored. A new *cropped* directory was created only when there was no existing *cropped* directory, the cropped out file path was assigned to another variable with name *cropped_out*, *cropped_out* was created from the concatenation of the *outdir*, loop of each output file names from the input jpeg files and the extension of the output file.

```

1. # Make plot output directory
2. outdir <- "cropped"
3. # Make plot output directory only when it wasn't found
4. if(!dir.exists(outdir)){
5.   print(paste0("creating directory: ", outdir))
6.   dir.create(outdir)
7. }
8.
9. # Input a list of all the jpeg files in the sample images directory
10. photo_in <- list.files(indir, pattern = ".jpeg", all.files = TRUE, full.names = TRUE, no.. = TRUE)
11.
12. # Replace all the jpeg filenames with the new filename structure
13. plotfiles <- gsub(pattern = "\\\\.jpeg$", "", photo_in)
14. plotname <- sub('.*/', "", plotfiles)
15. plotname_table <- data.frame(plotname)
16.
17. # Loop through and read all the jpeg files input
18. for(k in 1:nrow(plotname_table)){
19.
20. # Save all the 2D image plot output in png file format
21. png(cropped_out)
22. pht_dta <- readJPEG(paste0("",photo_in[k]))
23. # 2D plots of all the jpeg files input
24. image2D(thresh_pht, col = c("white", "lightskyblue1", "royalblue3", "darkblue"), breaks = c(-0.5,0.5,1.5,
    2.5,3.5),
25.   alpha = 1)
26. dev.off()
27. }

```

The output was also generated into a newly generated folder in RDS file format for further processing the of the data

```

1. # To make directory to save the output into an RDS file format
2. # Assign the directory name to the variable outdir_dta
3. outdir_dta <- "data_cropped"
4.
5. # Create the directory if it doesn't exist
6. if(!dir.exists(outdir_dta)){
7.   print(paste0("creating directory: ", outdir_dta))
8.   dir.create(outdir_dta)
9. }
10.
11. # Saved the looped threshold data output to the assigned outdir_dta folder in RDS format
12. plotfiles <- gsub(pattern = "\\\\.jpeg$", "", photo_in)
13. plotname <- sub('.*/', "", plotfiles)
14. plotname_table <- data.frame(plotname)
15.
16. for( k in 1:nrow(plotname_table)){
17.   data_cropped <- paste0(outdir_dta, "/", plotname[k], ".RDS")
18.   saveRDS(thresh_pht, data_cropped, compress = F)
19. }

```

4.3.3 Blue colour distribution function of flow characteristics package

The blue colour distribution function was built by converting the returned threshold application data into a data frame using the data.table r-package, the blue colour distribution function determines the distribution of all the classifications of the returned blue colours upon application.

The returned value was further categorised into percentages of all blues distribution, light blues distribution, medium blues distribution and light blues distribution. The procedure adopted to determine the percentage of blue distributions for the pixels with all blues was to select the number of pixels equal to any of the blue values i.e. 1, 2, or 3 divided by the total pixels and multiplied by 100. For light blue category, the number of pixels equal to the value of 1 divided by the total pixels and multiplied by 100, for medium blue category, the number of pixels equal to the value of 2 divided by the total pixels and multiplied by 100 and for the dark blue category, the number of pixels equal to the value of 3 divided by the total pixels and multiplied by 100. The resulting percentage distribution of all the blues, light blues, medium blues and dark blues of the whole image data input will be returned upon the usage of this function.


```

1. all_blues <- as.data.frame(which(thresh_data == 1 | thresh_data == 2 | thresh_data == 3))
2. colnames(all_blues) <- 'all_blues'
3. total_blues <- dim(all_blues)[1]
4. blue_distr <- (total_blues / total_pixels) * 100
5.
6. #Light Blue
7. light_blues <- as.data.frame(which(thresh_data == 1))
8. colnames(light_blues) <- 'light_blues'
9. light_blues <- dim(light_blues)[1]
10. light_blue_distr <- (light_blues / total_pixels) * 100
11.
12. #Medium Blue
13. medium_blues <- as.data.frame(which(thresh_data == 2))
14. colnames(medium_blues) <- 'medium_blues'
15. medium_blues <- dim(medium_blues)[1]
16. medium_blue_distr <- (medium_blues / total_pixels) * 100
17.
18. #Dark Blue
19. dark_blues <- as.data.frame(which(thresh_data == 3))
20. colnames(dark_blues) <- 'dark_blues'
21. dark_blues <- dim(dark_blues)[1]
22. dark_blue_distr <- (dark_blues / total_pixels) * 100

```

4.3.4 Depth of blue fractions function of flow characteristics package

The depth of blue fractions of sprinkler experiment image can be determined using flow characteristics package's depth of blue fractions function, this function is built to accept the data from the threshold as input, the selection of the categories of blue i.e. all blues, dark blues, medium blues or light blues as the second input, the third input is the path to save the depth of blue fractions plot.

```

1. depth_blue_fractions(thresh_data = DataFromThresholdApplication, blue_selection = BlueCategory,
  plot_path = PathToSaveDepthPlot)

```

Upon input, this function returns a data frame which consists of index value of each pixel along the depth of the image input, the corresponding depth value of each pixel of the image input and the value of blue fractions for each pixel depth as columns in the returned data frame.

Figure 5 shows the chart of the algorithm that was adopted in the development of the blue fractions depth function.

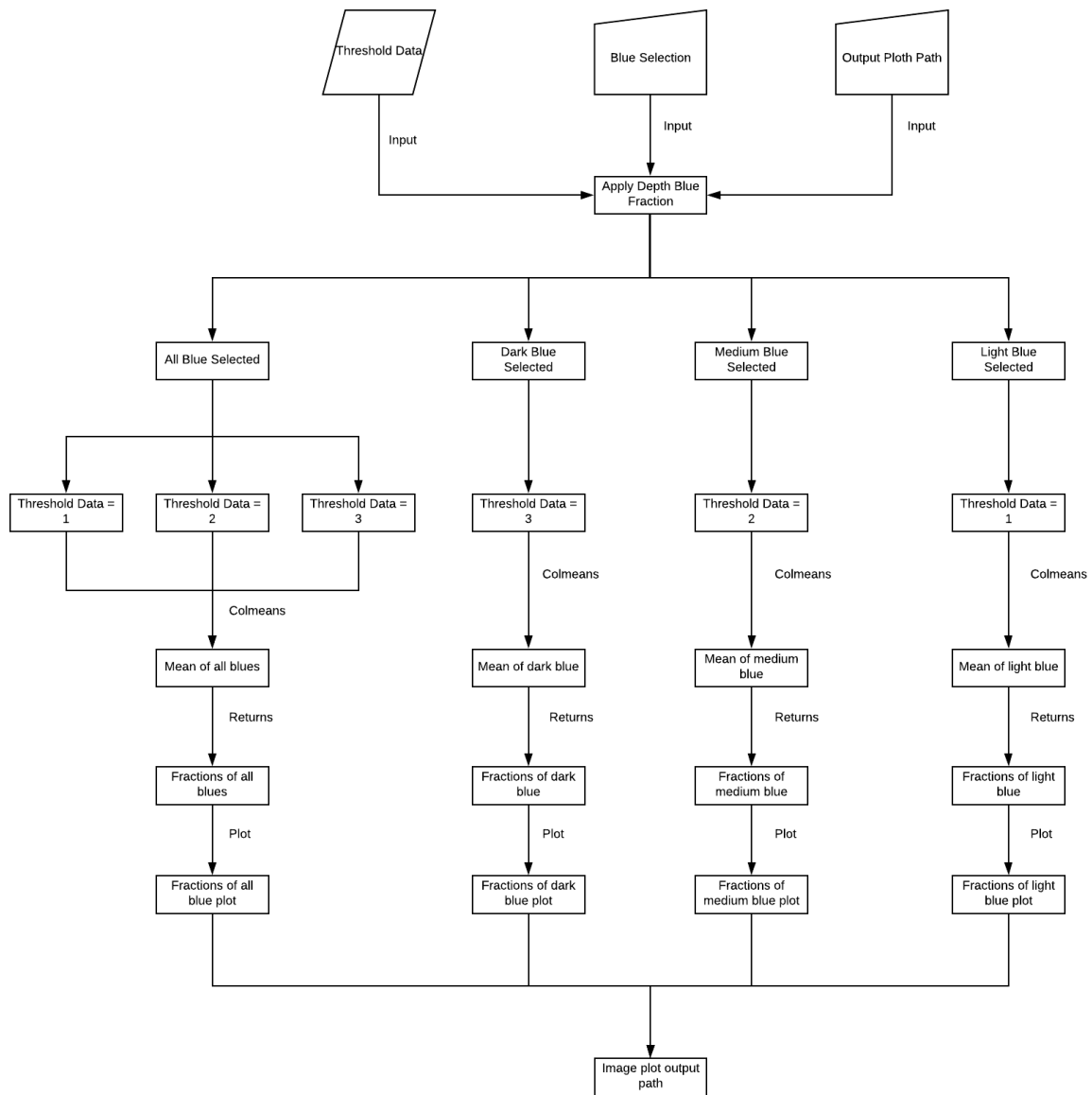


Figure 5 Chart of Algorithm used in returning depth of blue fractions as data frame and plot

4.3.5 Length of blue fractions function of flow characteristics package

The length of the blue fractions of sprinkler experiment image can be determined using flow characteristics package's length of blue fractions function, this function is built to accept the data from the threshold as input, the selection of the categories of blue i.e. all blues, dark blues, medium blues or light blues as the second input, the third input is the path to save the length of blue fractions plot.

```

1. length_blue_fractions(thresh_data = DataFromThresholdApplication, blue_selection = BlueCategory,
plot_path = PathToSaveDepthPlot)

```

Upon input, this function returns a data frame which consists of index value of each pixel along the length of the image input, the corresponding length value of each pixel of the image input and the value of blue fractions for each pixel length as columns in the returned data frame.

Figure 6 shows the chart of the algorithm that was adopted in the development of the blue fractions length function.

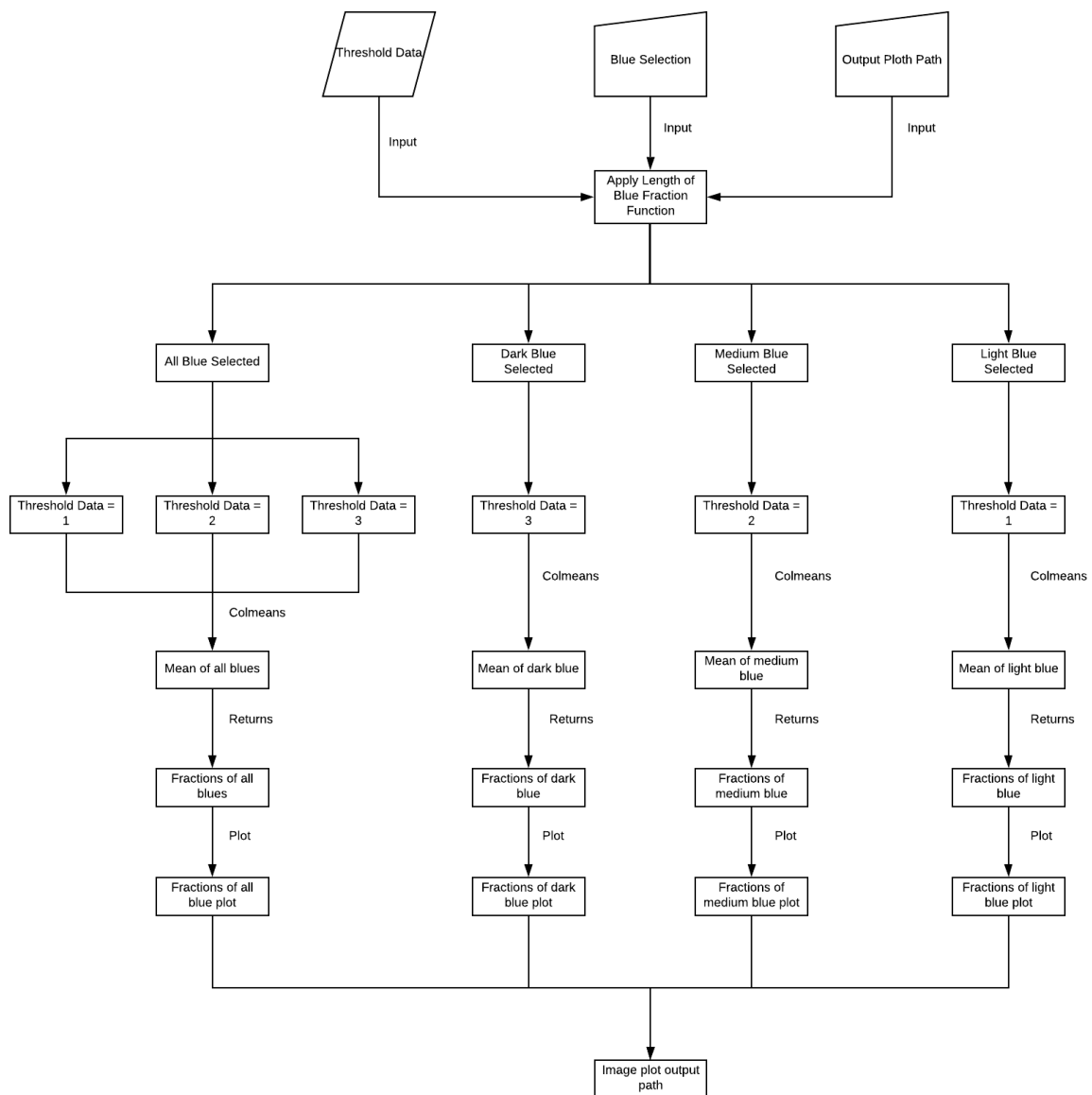


Figure 6 Chart of Algorithm used in returning the length of blue fractions as a data frame and plot

4.3.6 Depth of the blue fractions slope function of flow characteristics package

The slope of the depth of blue fractions of sprinkler experiment image can be determined using the flow characteristics package blue fractions depth slope function, this function accepts the returned data from the depth of blue fractions function and the path to the output directory to save the sloping plot.

```
1. depth_blue_fractions_slope(returned data from the depth of blue fractions, the path to the plot output directory)
```

The procedure adopted in the development of this function was to loop through the changes in each row values of the data frame, i.e. changes = the next row value – the previous row value.

```
1. slope_blue_fraction <- blue_fraction_data[1:(nrow(blue_fraction_data)-1),]
2. colnames(slope_blue_fraction) <- c("Depth", "FractionSlope")
3. for(i in 1:(nrow(blue_fraction_data)-1)){
4.   slope_blue_fraction$FractionSlope[i] <- blue_fraction_data$Bluefraction[i+1]-
   blue_fraction_data$Bluefraction[i]
5. }
```

Upon running the function, the plot would be saved in to the path to the output directory entered as an input parameter of the function. The slope was plotted against the depth and saved into the desired output directory as a png image.

```
1. png(plot_path)
2. plot(slope_blue_fraction$FractionSlope, slope_blue_fraction$Depth,
3.   type = "l", col = "royalblue2",
4.   xlab = " Slope blue color fraction [fraction/Pixel]",
5.   ylab = " Depth [Pixel]",
6.   xlim = c(-1,1))
7. dev.off()
```

The slope of the blue fraction depth was returned

```
1. return(slope_blue_fraction)
```

4.3.7 Length of the blue fractions slope function of flow characteristics package

The slope of the length of blue fractions of sprinkler experiment image can be determined using the flow characteristics package blue fractions length slope function, this function accepts the returned data from the length of blue fractions function and the path to the output directory to save the sloping plot.

```
2. length_blue_fractions_slope(returned data from the length of blue fractions, the path to the plot output directory)
```

The procedure adopted in the development of this function was to loop through the changes in each row values of the data frame, i.e. changes = the next row value – the previous row value.

```
1. slope_blue_fraction <- blue_fraction_data[1:(nrow(blue_fraction_data)-1),]
2. colnames(slope_blue_fraction) <- c("Length", "FractionSlope")
3. for(i in 1:(nrow(blue_fraction_data)-1)){
4.   slope_blue_fraction$FractionSlope[i] <- blue_fraction_data$Bluefraction[i+1]-
   blue_fraction_data$Bluefraction[i]
5. }
```

Upon running the function, the plot would be saved in to the path to the output directory entered as an input parameter of the function. The slope was plotted against the length and saved into the desired output directory as a png image.

```
1. png(plot_path)
2. plot(slope_blue_fraction$FractionSlope, slope_blue_fraction$Length,
3.   type = "l", col = "royalblue2",
4.   xlab = " Slope blue color fraction [fraction/Pixel]",
5.   ylab = " Length [Pixel]",
6.   xlim = c(-1,1))
7. dev.off()
```

The slope of the blue fraction length was returned

```
2. return(slope_blue_fraction)
```

4.4 Example of typical flow structures

Flow structures, such as, capillary barriers, preferential flows and matrix flows were visually identified from the sample images collected during the sprinkling experiments.

4.4.1 Matrix flow structures

Matrix flow structures in rain-on-snow sprinkling experiment are described as the structures formed from the homogenous movement of brilliant blue FCF dye tracer within the snow pack.

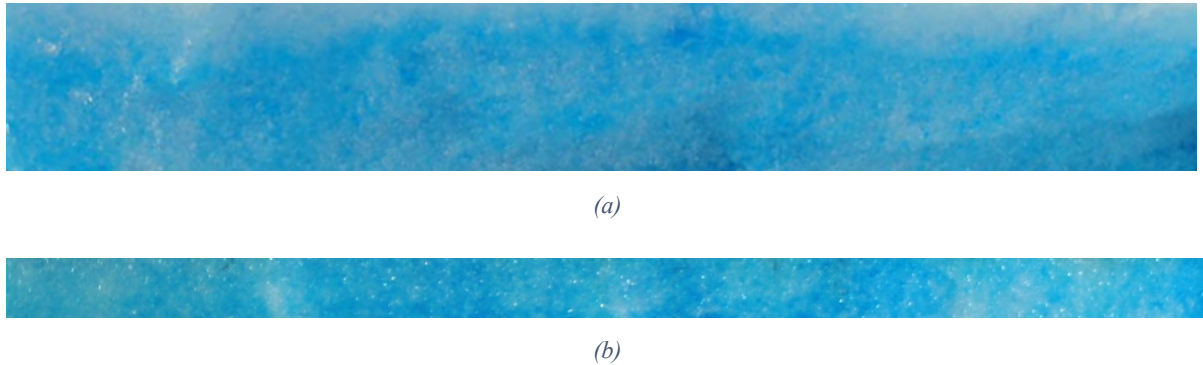


Figure 7(a) and (b) are typical example of matrix flow structures

4.4.1.1 Application of threshold function on typical matrix flow structures

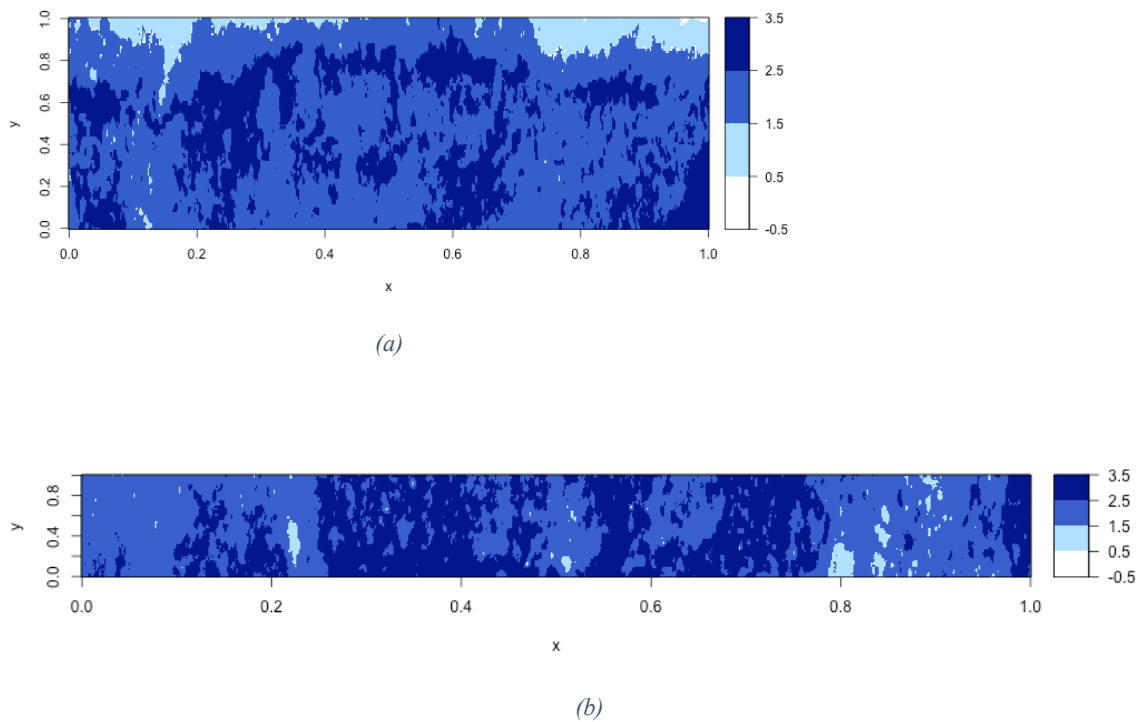


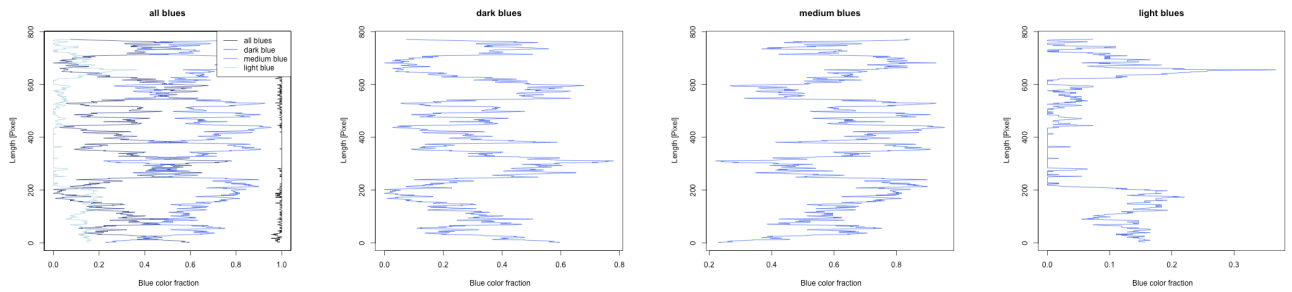
Figure 8(a) and (b) shows 2D Image plots returned from threshold application function

4.4.1.2 Application of blue distribution function on typical matrix flow structures

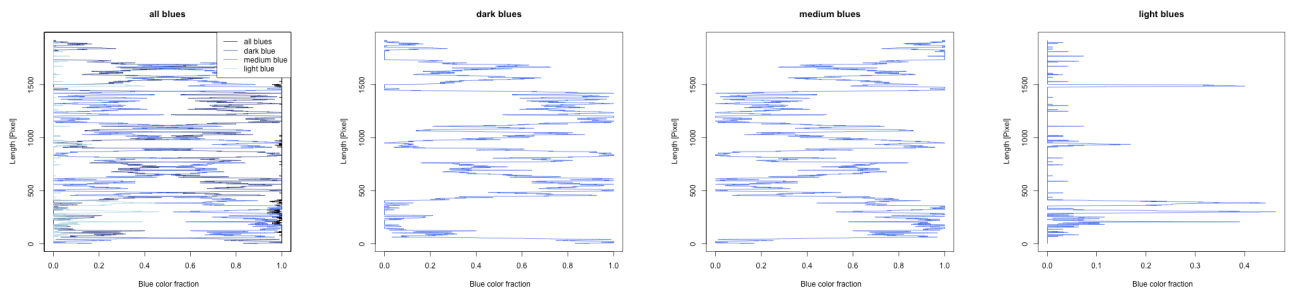
Table 2 Returned blue distribution data of the typical matrix flow structures

Blue Categories	Blue distribution in per cent	Blue distribution of in per cent
All blues	99.53%	99.80%
Light blues	6.62%	2.23%
Medium blues	62.90%	55.12%
Dark blues	30.01%	42.45%

4.4.1.3 Application of length and depth blue fraction functions on the typical matrix flow structures

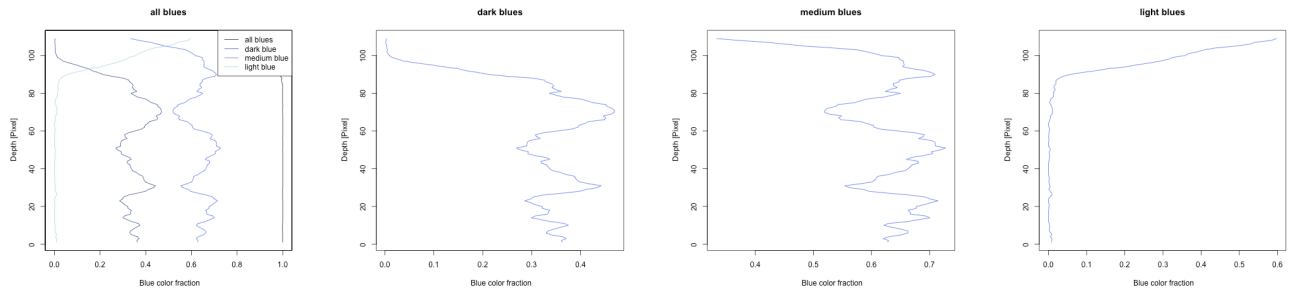


(a) Application of length of blue fraction function on returned threshold application data

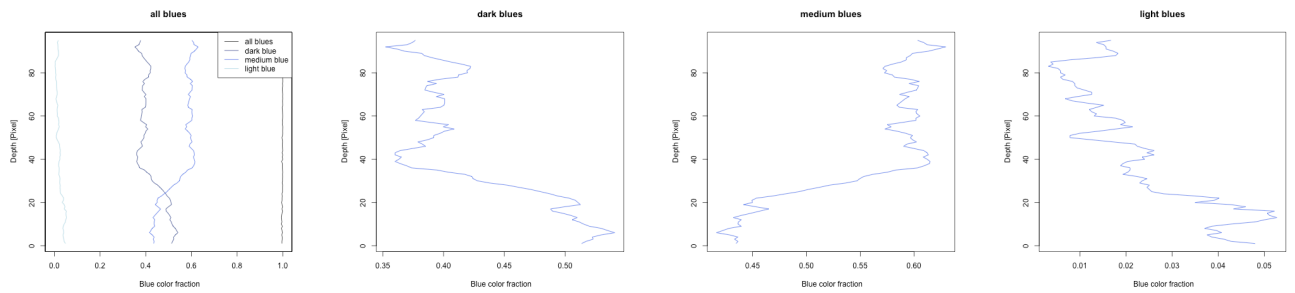


(b) Application of length of blue fraction function on returned threshold application data

Figure 9(a) and (b) Length of blue fractions function application on typical matrix flow structures



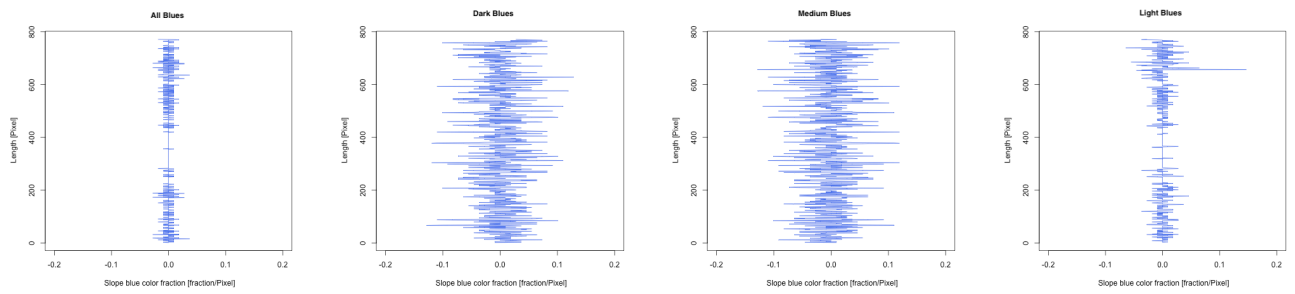
(a) Application of depth of blue fraction function on returned threshold application data



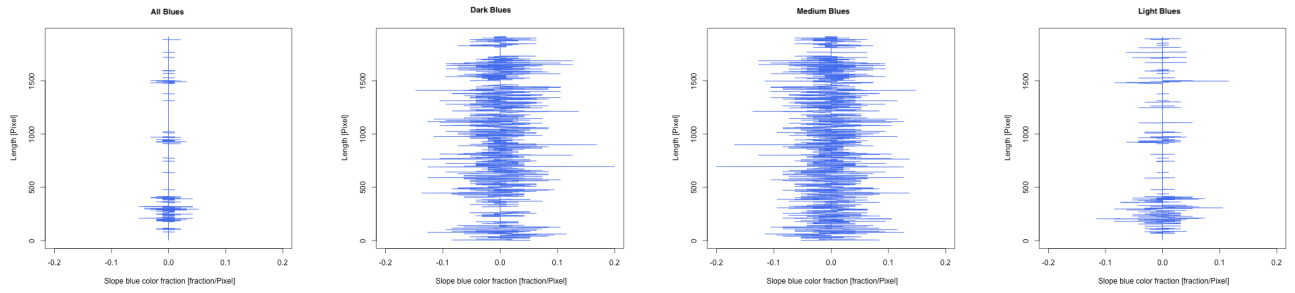
(b) Application of depth of blue fraction function on returned threshold application data

Figure 10(a) and (b) Depth of blue fractions function application on typical matrix flow structures

4.4.1.4 Application of the slope of length and depth blue fractions on the typical matrix flow structures

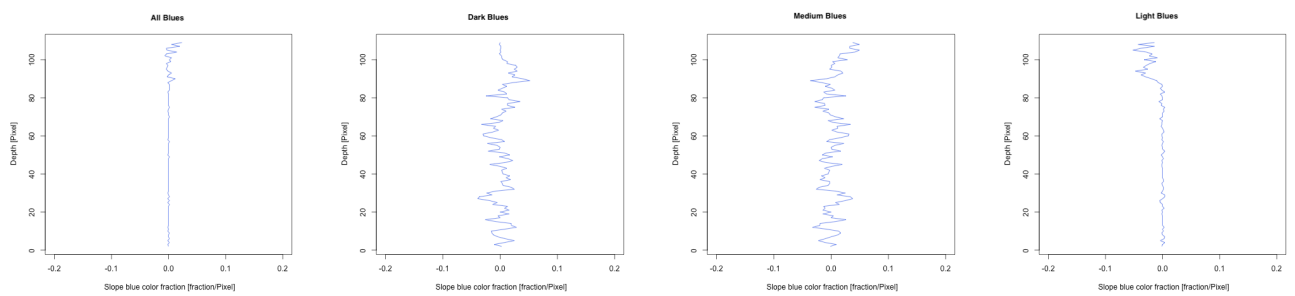


(a) Application of slope of length of blue fraction function on returned threshold application data

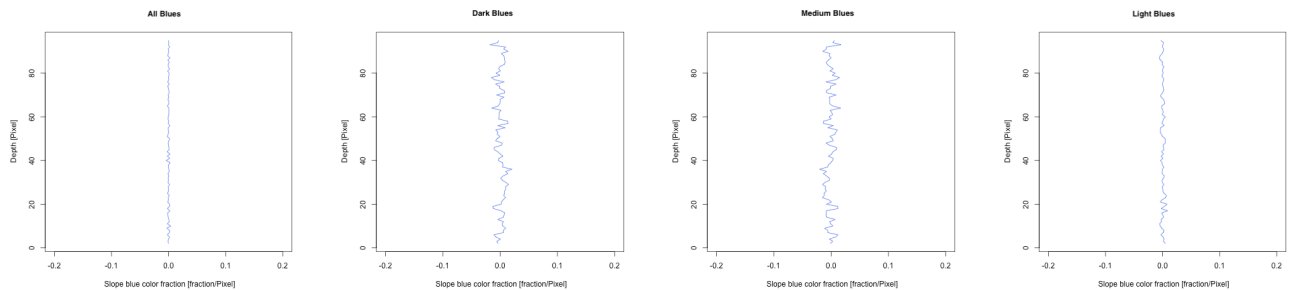


(b) Application of slope of length of blue fraction function on returned threshold application data

Figure 11(a) and (b) Slope of length of blue fractions function application on typical preferential flow structures



(a) Application of slope of depth of blue fraction function on returned threshold application data

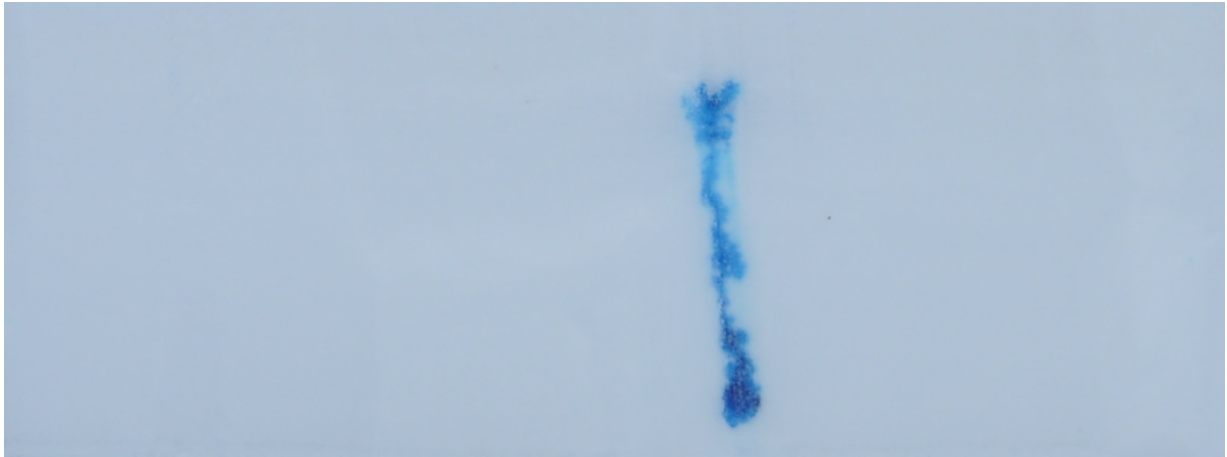


(b) Application of slope of depth of blue fraction function on returned threshold application data

Figure 12(a) and (b) Slope of depth of blue fractions function application on typical preferential flow structures

4.4.2 Preferential flow structures

Preferential flow structures in rain-on-snow sprinkling experiment are described as the structures formed from the vertical movement of brilliant blue FCF dye tracer within the snow pack. The path taken by a preferential flow structure is known as preferential flow path.



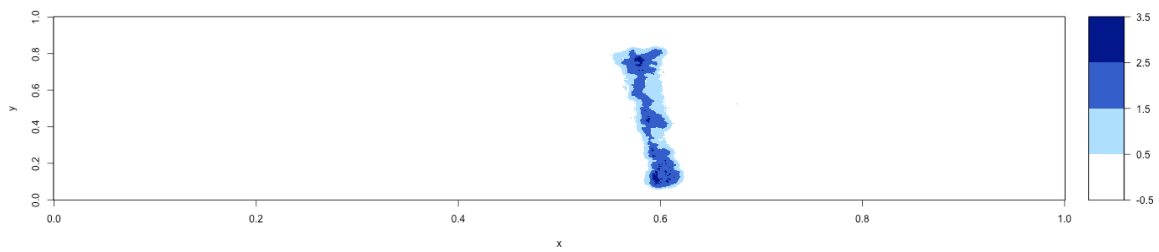
(a)



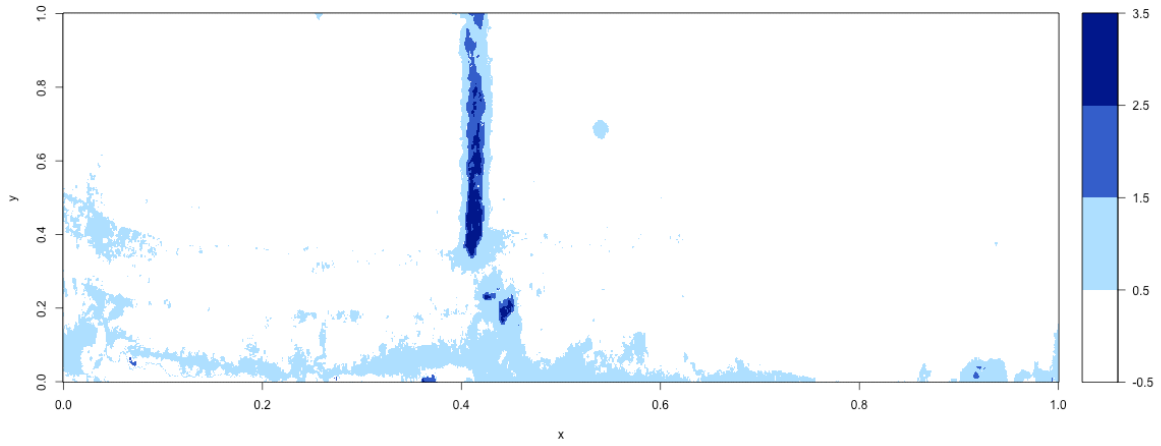
(b)

Figure 13(a) and (b) are typical example of preferential flow structures

4.4.2.1 Application of threshold function on typical preferential flow structures



(a)



(b)

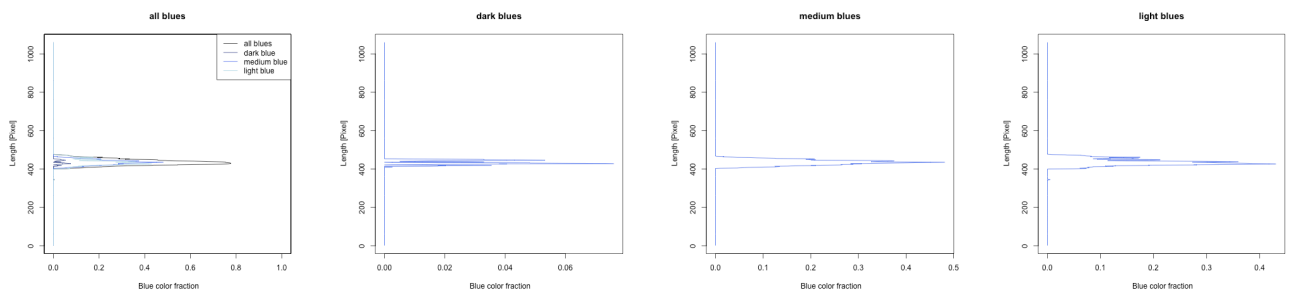
Figure 14(a) and (b) shows 2D Image plots returned from threshold application function

4.4.2.2 Application of blue distribution function on typical preferential flow structures

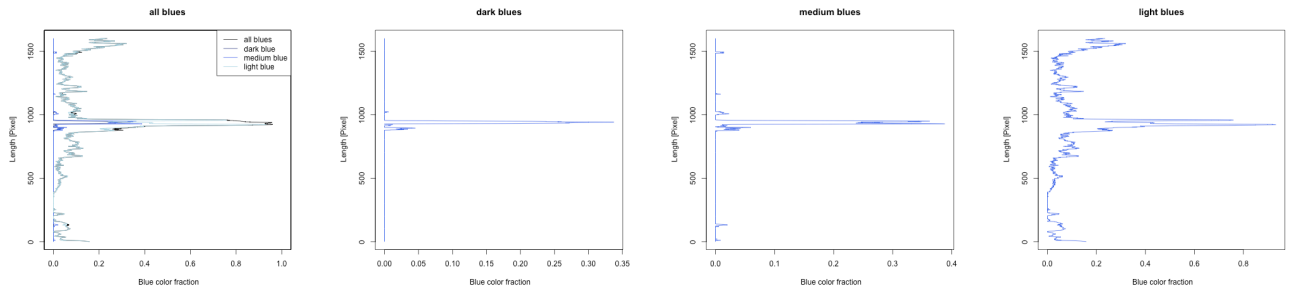
Table 3 Returned blue distribution data of the typical preferential flow structures

Blue Categories	Blue distribution of Error! Reference source not found. (a) in per cent	Blue distribution of Error! Reference source not found. (b) in per cent
All blues	2.58%	8.98%
Light blues	1.24%	7.94%
Medium blues	1.24%	0.65%
Dark blues	0.10%	0.38%

4.4.2.3 Application of length and depth blue fraction functions on the typical preferential flow structures

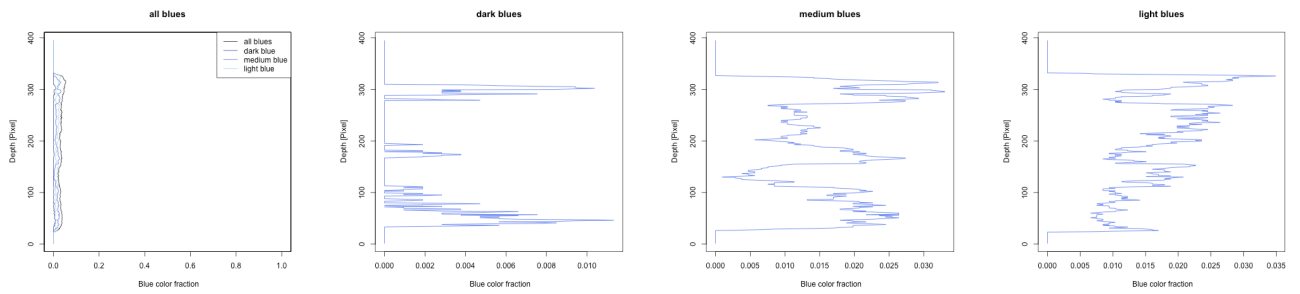


(c) Application of length of blue fraction function on returned threshold application data

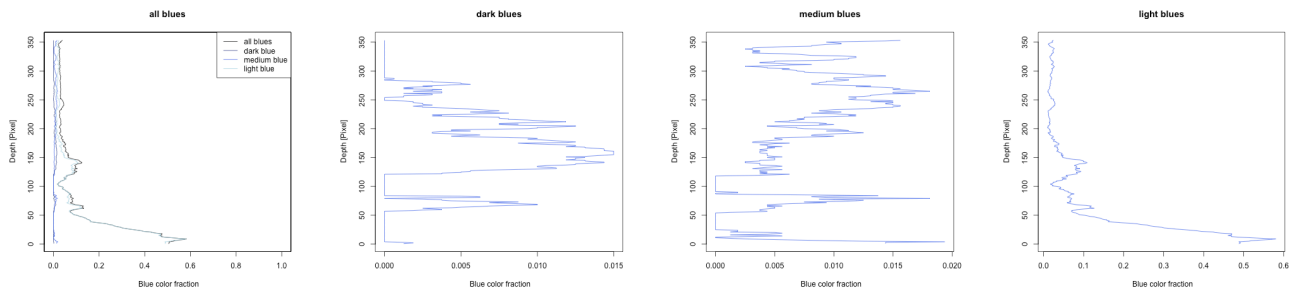


(d) Application of length of blue fraction function on returned threshold application data

Figure 15(a) and (b) Length of blue fractions function application on typical preferential flow structures



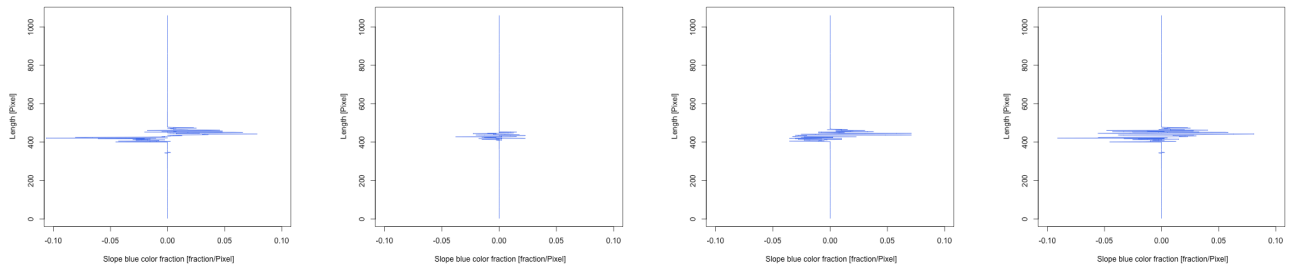
(a) Application of depth of blue fraction function on returned threshold application data



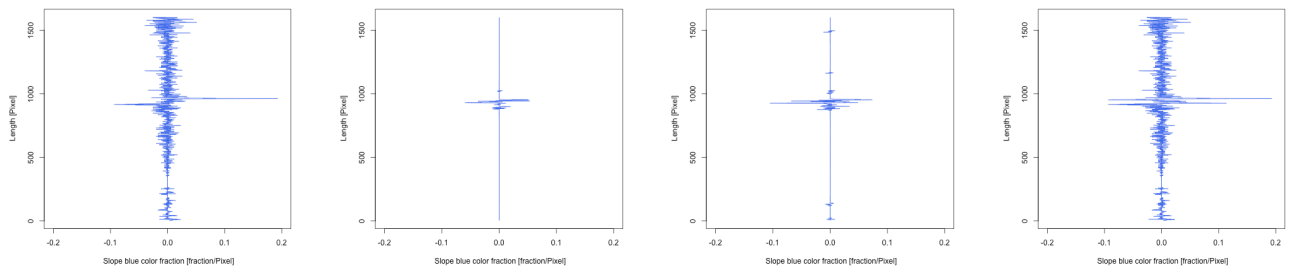
(b) Application of depth of blue fraction function on returned threshold application data

Figure 16(a) and (b) Depth of blue fractions function application on typical preferential flow structures

4.4.2.4 Application of the slope of length and depth blue fractions on the typical preferential flow structures

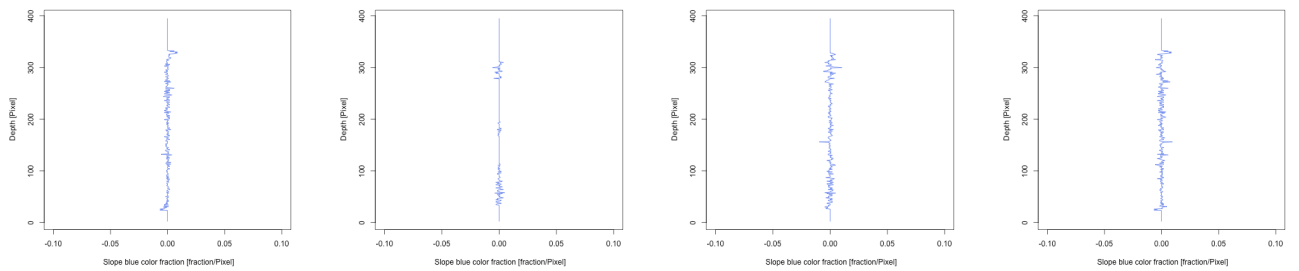


(a) Application of slope of length of blue fraction function on returned threshold application data

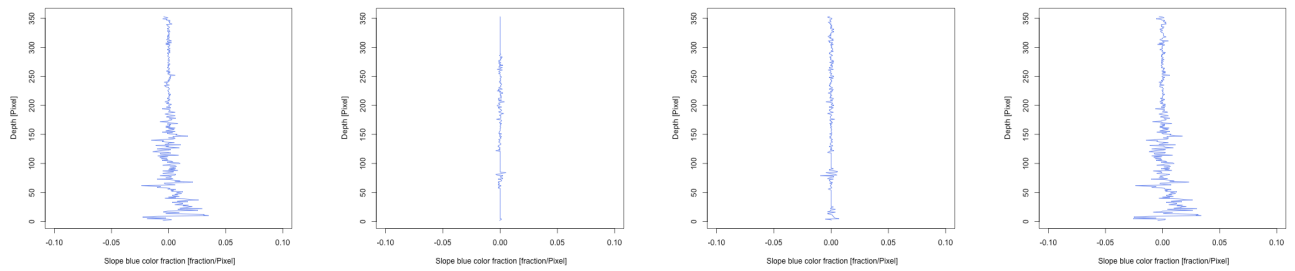


(b) Application of slope of length of blue fraction function on returned threshold application data

Figure 17(a) and (b) Slope of length of blue fractions function application on typical preferential flow structures



(a) Application of slope of depth of blue fraction function on returned threshold application data

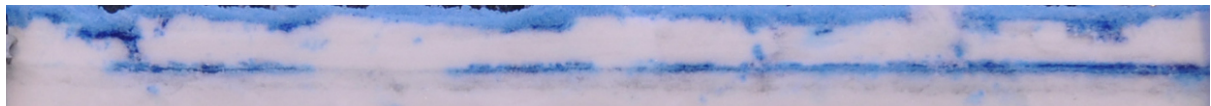


(b) Application of slope of depth of blue fraction function on returned threshold application data

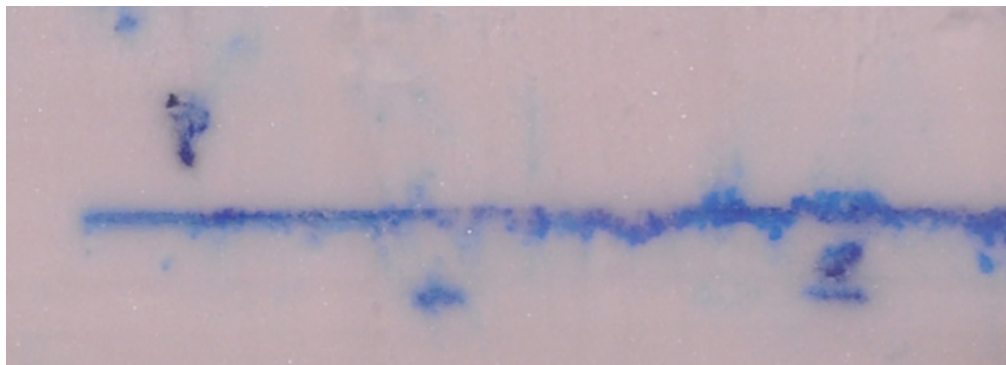
Figure 18(a) and (b) Slope of depth of blue fractions function application on typical preferential flow structures

4.4.3 Capillary barrier structures

Capillary barrier structures were visually identified by the portion of the sprinkled brilliant blue FCF dye tracer that flew through the snow pack in an horizontal path, this path taken by capillary barrier structures can be said to be a capillary barrier path.



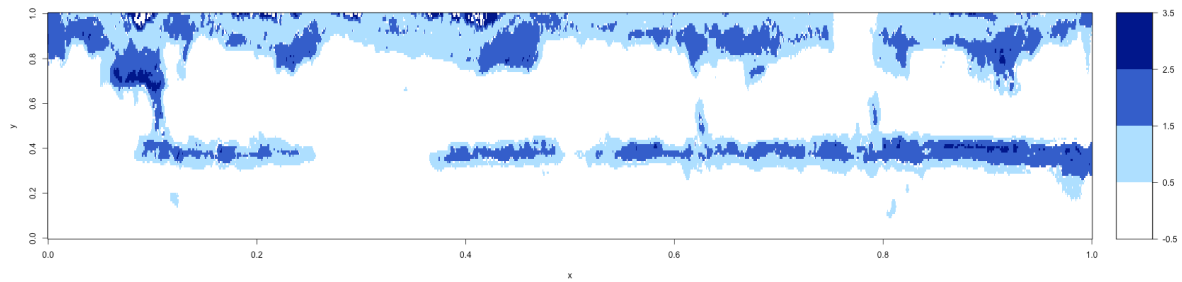
(a)



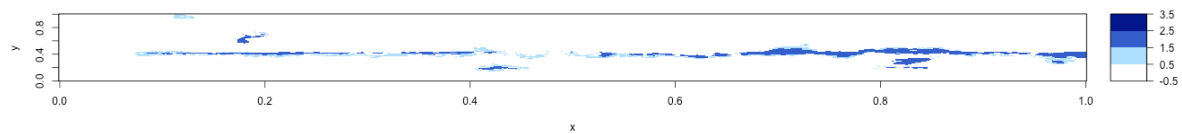
(b)

Figure 19(a) and (b) are typical example of capillary barrier structures

4.4.3.1 Application of threshold function on typical capillary barrier structures



(a)



(b)

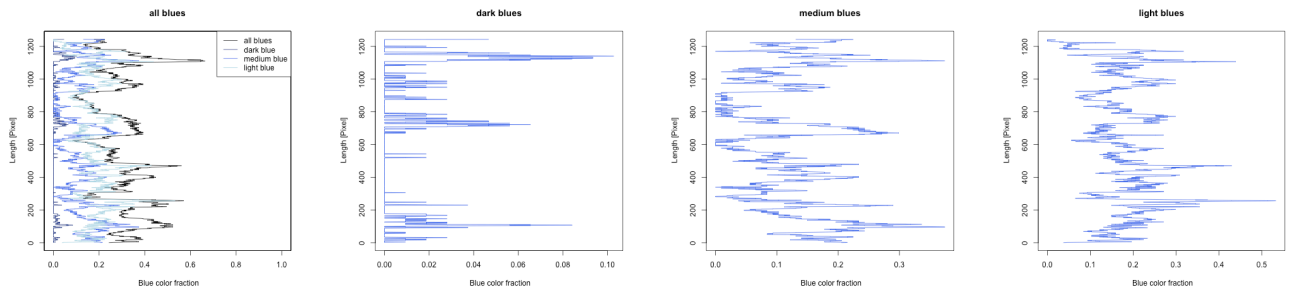
Figure 20(a) and (b) shows 2D Image plots returned from threshold application function to Figure 19 data

4.4.3.2 Application of blue distribution function on typical capillary barrier structures

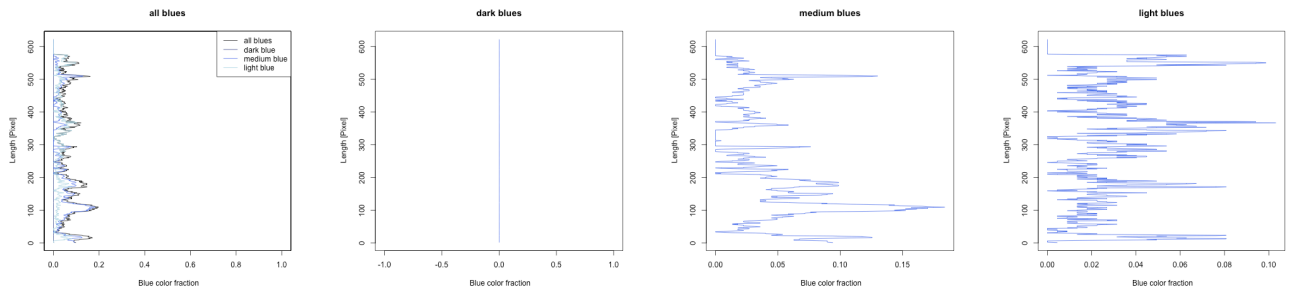
Table 4 Returned blue distribution data of the typical capillary barrier structures

Blue Categories	Blue distribution of Figure 20(a) in per cent	Blue distribution of Figure 20(b) in per cent
All blues	29.68%	6.00%
Light blues	17.81%	2.52%
Medium blues	11.23%	3.48%
Dark blues	0.64%	0%

4.4.3.3 Application of length and depth blue fraction functions on the typical capillary barrier structures

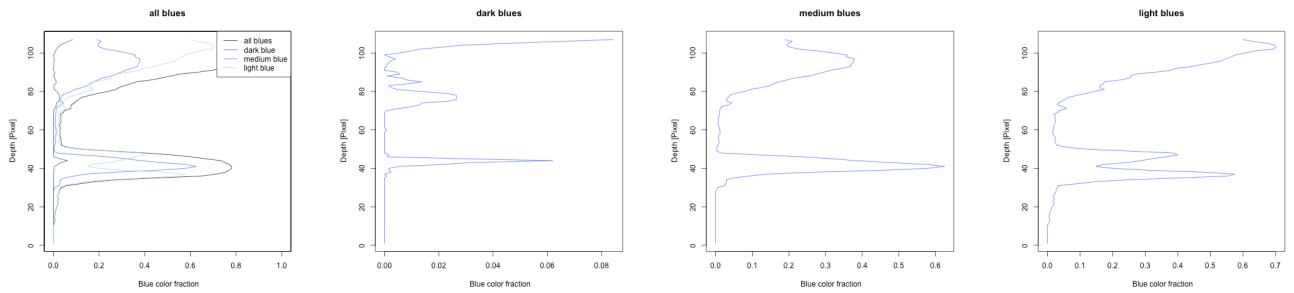


(a) Application of length of blue fraction function on returned threshold application data

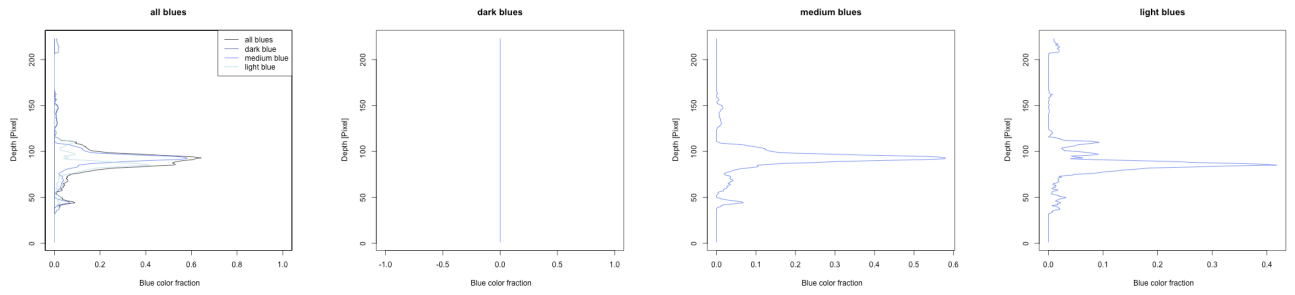


(b) Application of length of blue fraction function on returned threshold application data

Figure 21(a) and (b) Length of blue fractions function application on typical capillary barrier structures



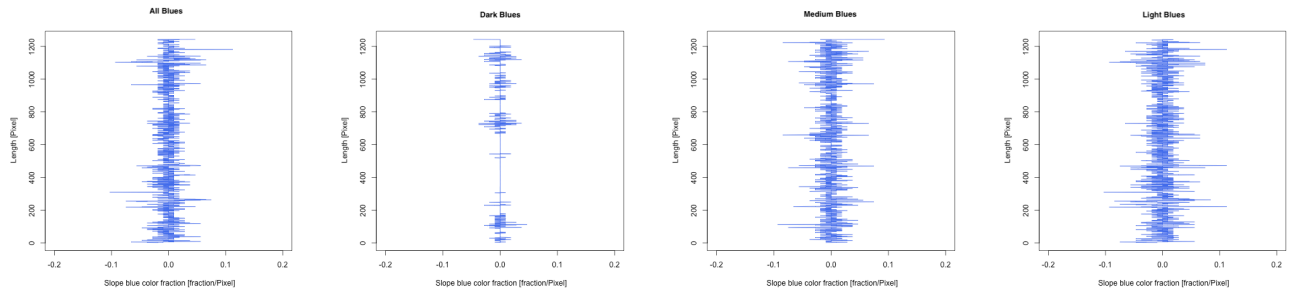
(a) Application of depth of blue fraction function on returned threshold application data



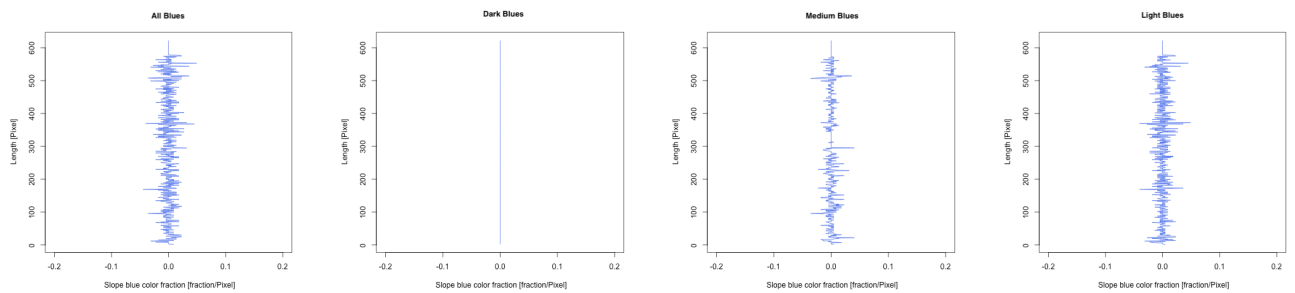
(b) Application of depth of blue fraction function on returned threshold application data

Figure 22(a) and (b) Depth of blue fractions function application on typical capillary barrier structures

4.4.3.4 Application of the slope of length and depth blue fractions on the typical preferential flow structures

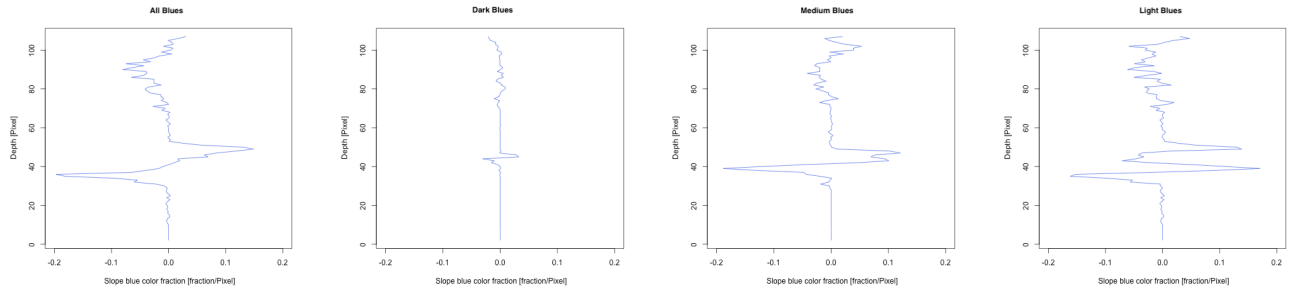


(a) Application of slope of length of blue fraction function on returned threshold application data

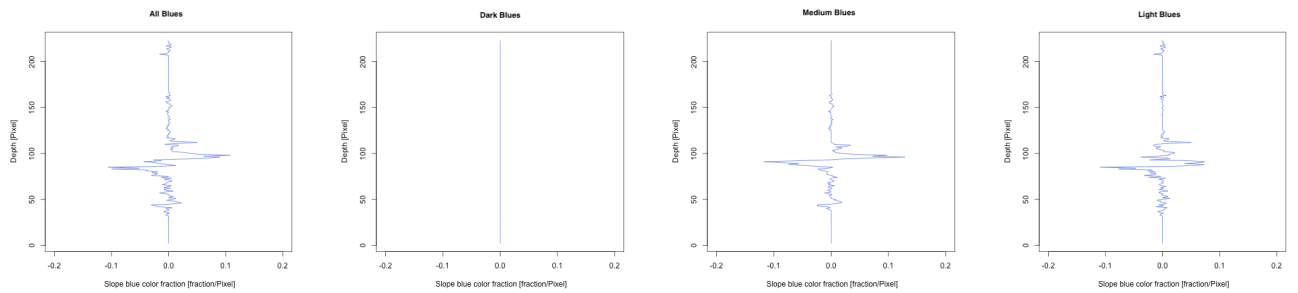


(b) Application of slope of length of blue fraction function on returned threshold application data

Figure 23(a) and (b) Slope of length of blue fractions function application on typical capillary barrier structures



(a) Application of slope of depth of blue fraction function on returned threshold application data



(b) Application of slope of depth of blue fraction function on returned threshold application data

Figure 24(a) and (b) Slope of depth of blue fractions function application on typical capillary barrier structures

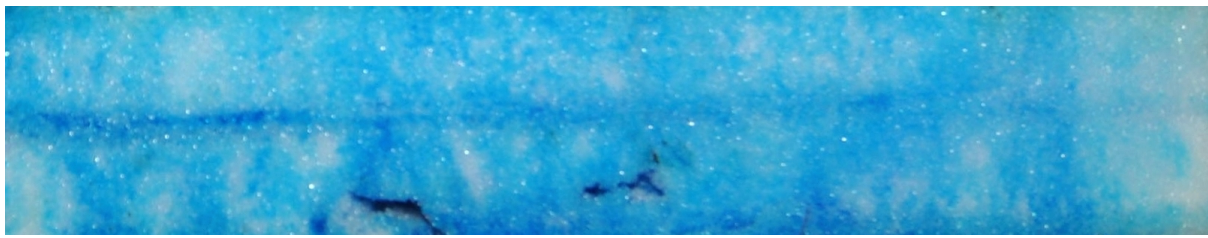
5 Results and Discussion

5.1 Processing of sample images

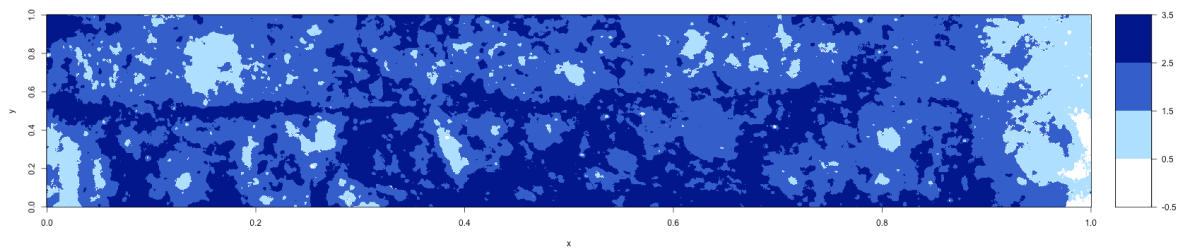
5.1.1 2D Image plot of the cropped sample images in the four localities

The key of the 2D image plots generated from the threshold application in all the four localities explain the area covered by the light, medium and deep intensity of blue and also area without blue, the white colour represents the pigment on the plot without blue which implies to the presence of pure snow in those particular areas on the plot, the lightskyblue1 represent the pigment covered by light intensity of blue colour, the royalblue3 colour represent the pigment covered by the medium intensity of blue colour, and darkblue colour on the key represent the pigment covered by the deep intensity of blue colour

5.1.1.1 Klosters 2D Image Plot



(a)

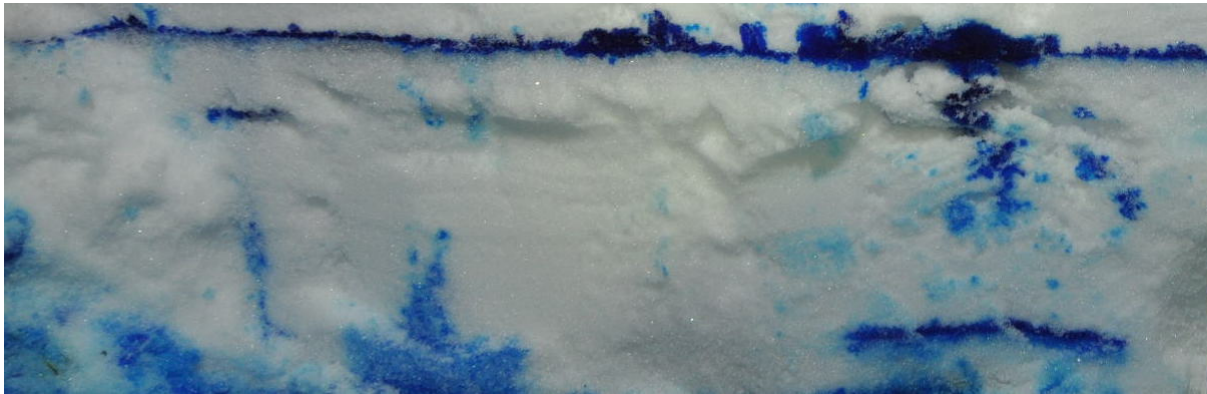


(b)

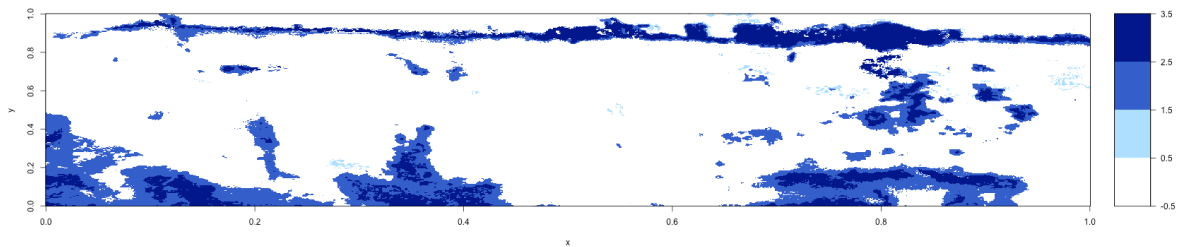
Figure 25 (a) Shows the cropped Klosters sample image and (b) shows the Klosters 2D Image Plot

Klosters 2D image plot visually shows a very close connection between all the blue intensities, the distribution of the blue shows a higher percentage of the royalblue3 colour with the darkblue colour linearly packed together in both horizontal and vertical form cutting across the image plot, from the pattern of distribution of the royalblue3 and darkblue colour, there was a form of darkblue colour distributed along an horizontal path, this form could be said to be a capillary barrier structure. This type of structure (capillary barrier) is visible in the middle of the image plot and another similar type of structure (capillary barrier) was visible at the bottom part of the image plot. Below the capillary barrier structure, vertically distributed darkblue colour form was visible. This vertically distributed darkblue structures could be said to be preferential flow structures. Above the capillary barrier structure in the image plot, there was reduction in the distribution of darkblue with increased royalblue3 colour, royalblue3 was the highest distributed colour above the capillary structure which implies the form of matrix flow structure.

5.1.1.2 Serneus 2D image plot



(a)



(b)

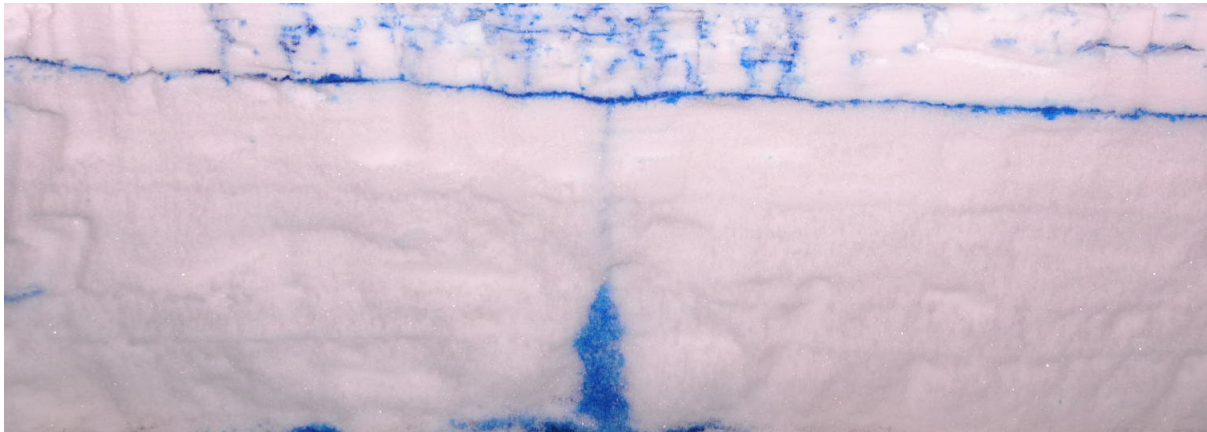
Figure 26 (a) Cropped Serneus sample image (b) Serneus 2D image plot

Serneus 2D image plot show blue structures dispersed across the plot, at the upper part of the plot there is a compaction of higher percentage of darkblue, less percentage of royalblue3 and lesser percentage of lightskyblue1 in an horizontal path. This horizontal part can be said to be a capillary barrier. The major area of the 2D image plot was covered by the white colour, this implies lesser distribution of the sprinkled brilliant blue FCF dye tracer.

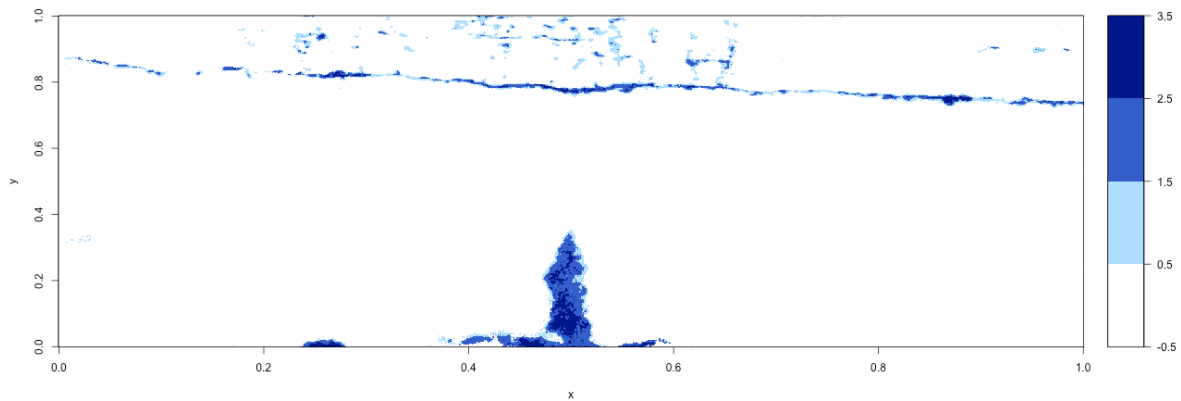
Irregular vertical structures from the compaction of darkblue, royalblue3 and lightkyblue1 colours. The irregular vertical structures with higher percentage of darkblue and royalblue3 can be said to be preferential flow structures, also irregular structures of lightskyblue1 that are neither vertical nor horizontal structures can be said to be matrix flow structures, although this matrix flow structures are barely visible in the 2D image plot.

Compacted horizontal darkblue and royalblue3 structures that are shorter in length can be said to be an icelayer in some cases.

5.1.1.3 Sertig 2D image plot



(a)



(b)

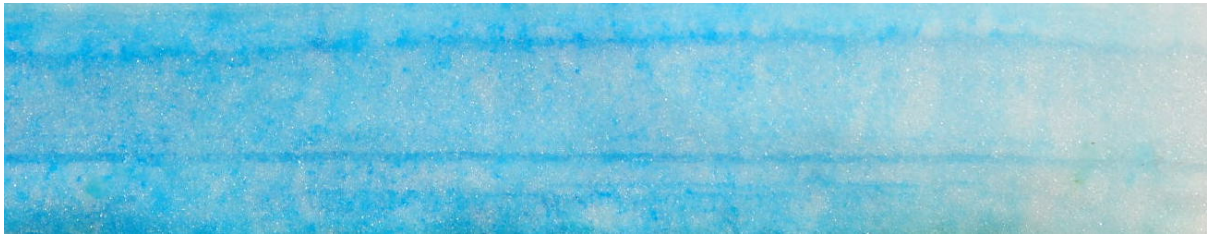
Figure 27 (a) Cropped Sertig sample image, (b) Sertig 2D image plot

The 2D image plot from the cropped sertig sample image has its major area covered by the white colour, white colour can be said to be the area not involved in the flow of sprinkled brilliant blue FCF dye tracer. The upper part of the plot shows the existence of darkblue and royalblue3 colour as structures in vertical flow path, these vertical structures can be said to be preferential flow.

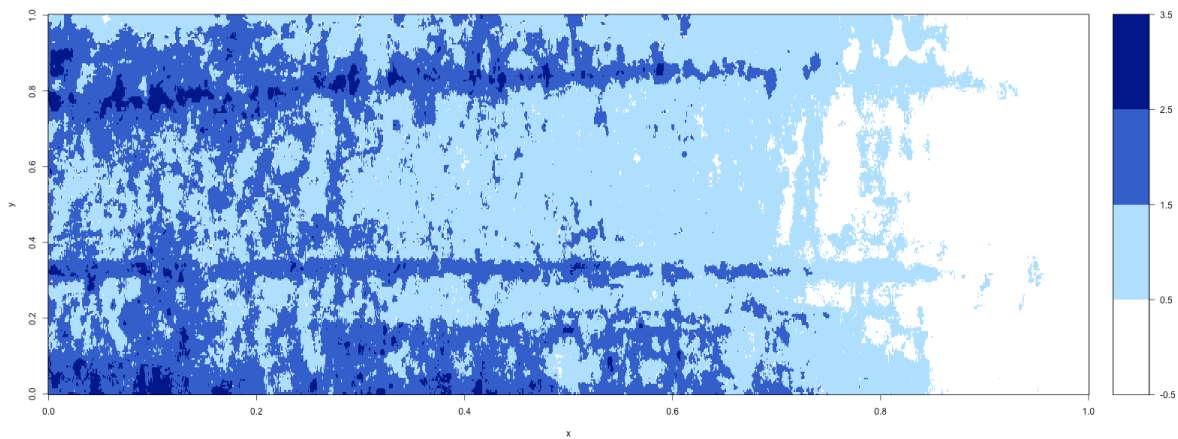
Below the area dominated by multiple preferential flow structures is horizontally compacted combination of darkblue, royalblue3 and lesser proportion of lightskyblue1 along the horizontal path. This can be said to be a capillary barrier structure.

Below the capillary barrier structure and at the bottom of the image plot in Figure 27b there is a connected horizontal and vertical structure, this structure is dominated by higher percentage of darkblue and royalblue3 with lesser percentage or lightskyblue1.

5.1.1.4 SLF 2D image plot



(a)



(b)

Figure 28 (a) Cropped SLF sample image (b) SLF 2D image plot

The 2D image plot of the cropped SLF sample image is dominated by an higher percentage of the lightskyblue1 colour in an homogeneous form and royalblue3 colour overlapped with minimal percentage of darkblue colour in horizontal and vertical form, the darkblue colour covers a minimal part of the royalblue3 colour, this implies that the horizontal and vertical structures present in the image plot are formed by the combination of higher percentage of royalblue3 and lesser percentage of darkblue colour. In Figure 28b there are about 3 major horizontal structures dominated by higher percentage of royalblue3 and lesser percentage of darkblue colours which can be said to be capillary barrier structures, multiple vertical structure also dominated by higher percentage of royalblue3 and lesser percentage of dark which can be said to be preferential flow structure, area covered with the lightskyblue1 colour in an homogenous form, which can be said to be matrix flow structure and the area covered by white colour in an homogeneous form which can be said to be area that was not involved in the distribution of sprinkled brilliant blue FCF dye tracer.

The higher percentage of the area covered by the lightskyblue1 colour in Figure 28b implies that the sample image is covered by a higher percentage of matrix flow structure than preferential flow and capillary barrier structures.

5.1.2 Cropping of samples images

After completion of brilliant blue FCF dyetracer sprinkling experiments that was carried out in Klosters, Serneus, Sertig and SLF localities, image samples of the vertical snow pack profile cut was taken, these image samples showed the penetration of sprinkled brilliant blue FCF dye tracer through the snow pack. The structures formed by the penetrated brilliant blue FCF dye tracer were shown in the image samples.

5.1.2.1 Cropping of Klosters locality sample image



Figure 29 Sample image taken from Klosters locality

Figure 29, shows a sample image collected at the Klosters locality sprinkling experiment location. As shown in Figure 29 Sample image taken from Klosters locality above, the image consists of unwanted area such as the area occupied by the metre rule placed across the vertical profile of the snow pack, the area occupied by another metre rule placed at the bottom, parallel to the horizontal profile of the snow pack, the area occupied by the poles that demarcate the snow pack area and also the areas where debris and vegetations were found at the bottom part of the snow pack profile image. For efficient analysis, the desired and important area of the vertical snow pack profile on the image was cropped out to avoid and cut out the unwanted areas, the cropping procedure was done by cutting out 1cm from the top of the snow pack profile, 3cm from the bottom of the snow pack profile, 5cm from the left edge of the snow pack profile and 9cm from right edge of the snow pack profile in the image. See the figure below



Figure 30 Desired area cropped out of Klosters locality sample image

Figure 30 was further cropped to avoid the meter rule cutting across the vertical profile of the snow pack image, resulting in figure 8b;

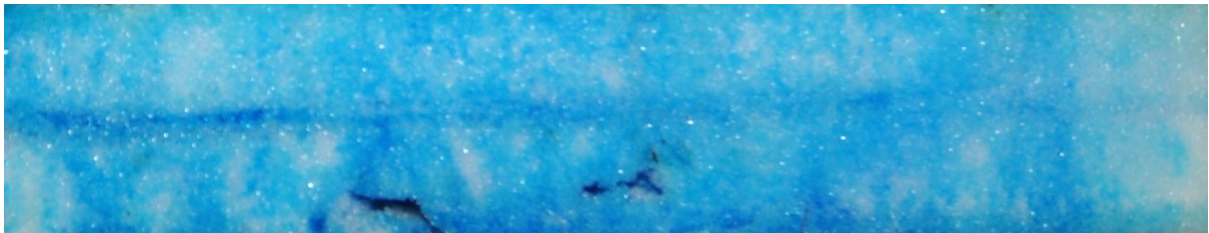


Figure 31 Efficient desired area cropped out of Klosters locality sample image

5.1.2.2 Cropping of Serneus locality sample image

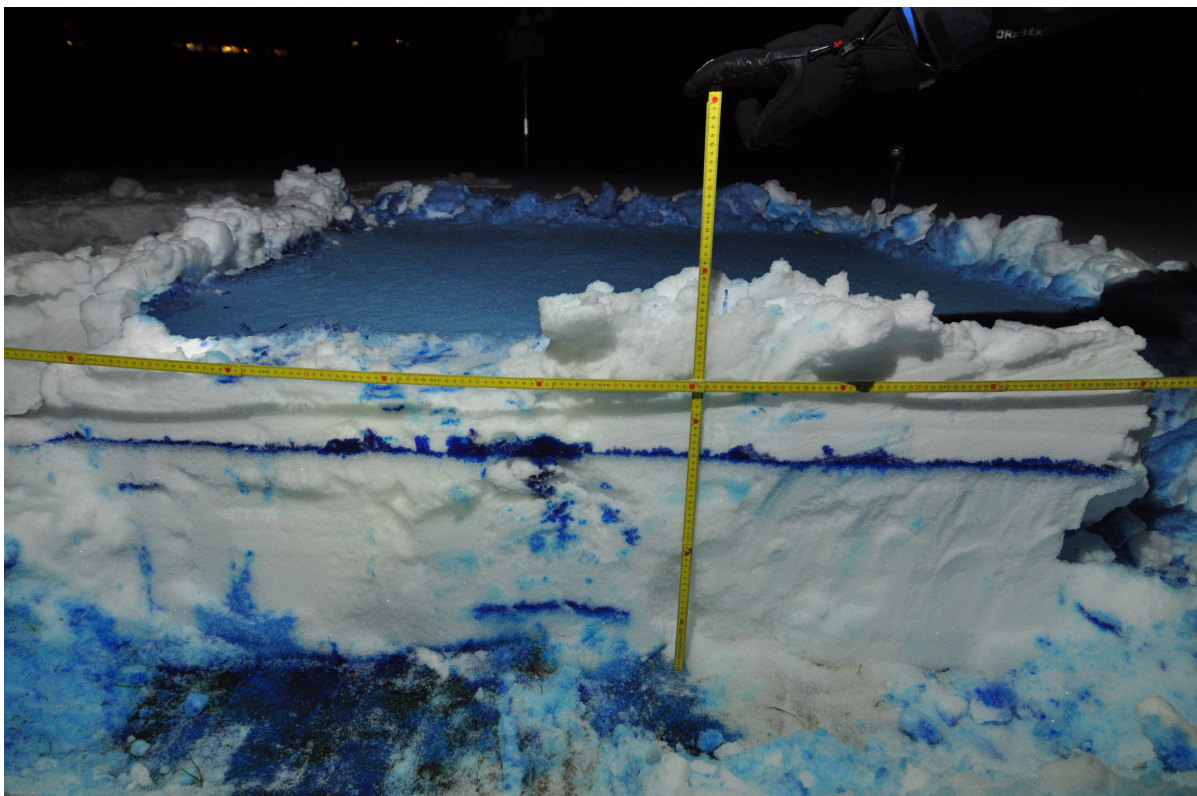


Figure 32 Sample image taken from Serneus locality

Figure 32 shows the sample image collected from the Serneus locality brilliant blue FCF dye tracer sprinkling experiment location. As shown in Figure 32, the areas covered by meter rule, debris, vegetation and the areas not occupied by the snow pack vertical profile were cut out.

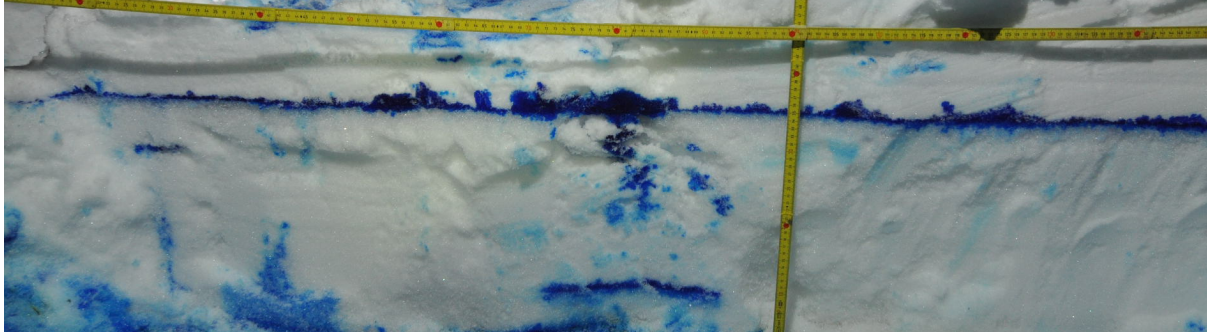


Figure 33 Desired area cropped out of Serneus locality image sample

Figure 33 was generated by cutting out 11cm from the top of the snow pack vertical profile, 2cm from the bottom of the snow pack vertical profile, 1cm from the left edge of the snow pack profile and 14cm from the right edge of the snow pack profile. As shown in Figure 33 the desired area cropped out of the original locality image sample is still covered with area occupied by meter rule and shadows, thereby the image was further cropped to avoid the unwanted area such as the area covered by the meter rule and shadow and vegetation.

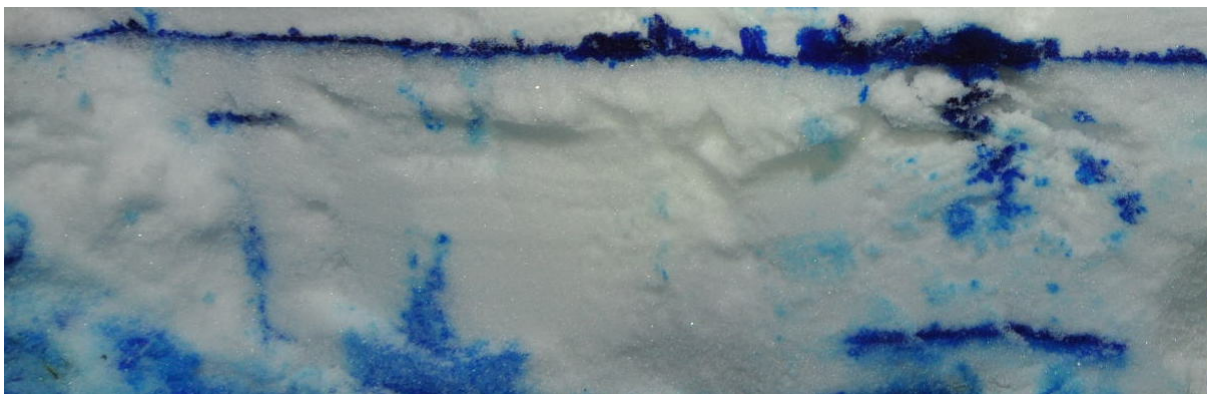


Figure 34 Usable desired area cropped out of Serneus locality image sample

Figure 34 was generated by cutting out 15cm from the top of the snow pack vertical profile, 2cm from the bottom of the snow pack vertical profile, 1cm from the left edge of the snow pack profile and 45cm from the right edge of the snow pack profile. As shown in Figure 34 above the desired area cropped out of the original locality image sample is still covered with the area occupied by meter rule and shadows, thereby the image was further cropped into Figure 34 avoid the unwanted area such as the area covered by the meter rule and shadow and vegetation.

5.1.2.3 Cropping of Sertig locality sample image

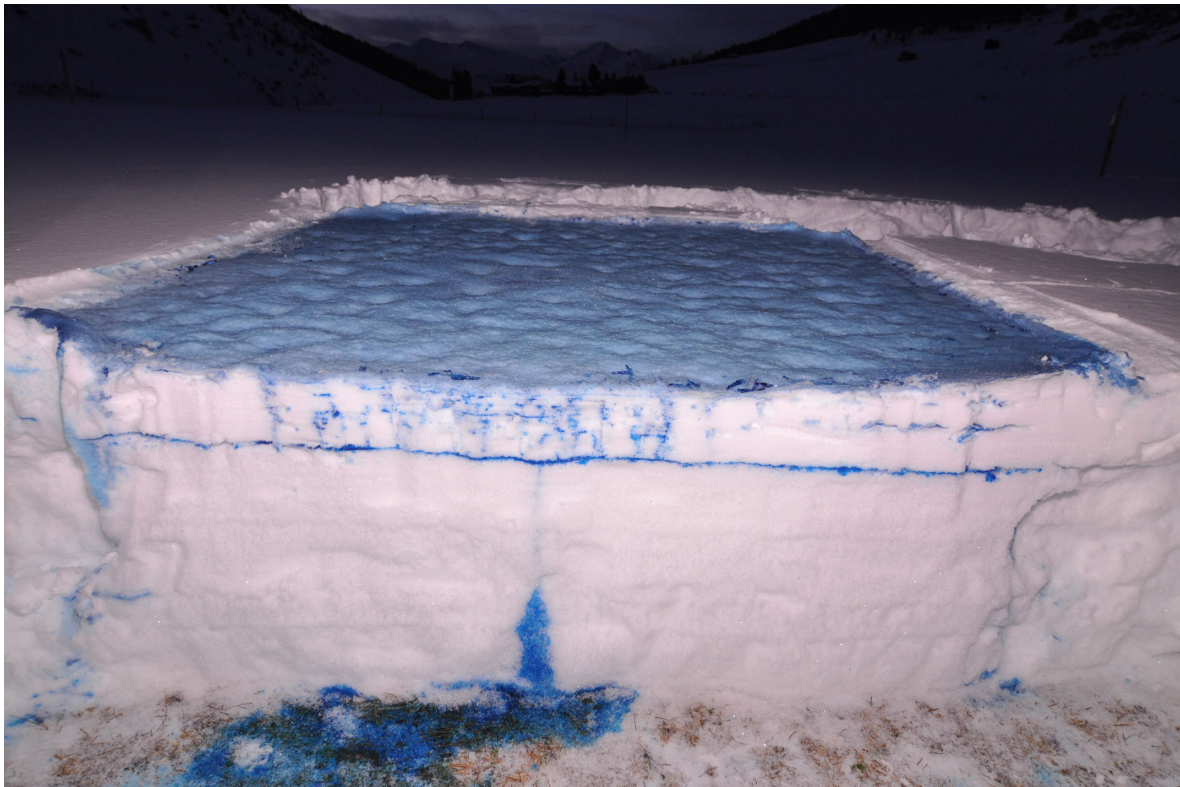


Figure 35 Sample image taken from Sertig locality

The original image collected from Sertig locality sprinkling experiment is shown in Figure 35. Sample image taken from Sertig locality above, the vertical snow pack profile area was cropped out, leaving out other areas including areas covered by debris, vegetations and the contours with grey shadow.

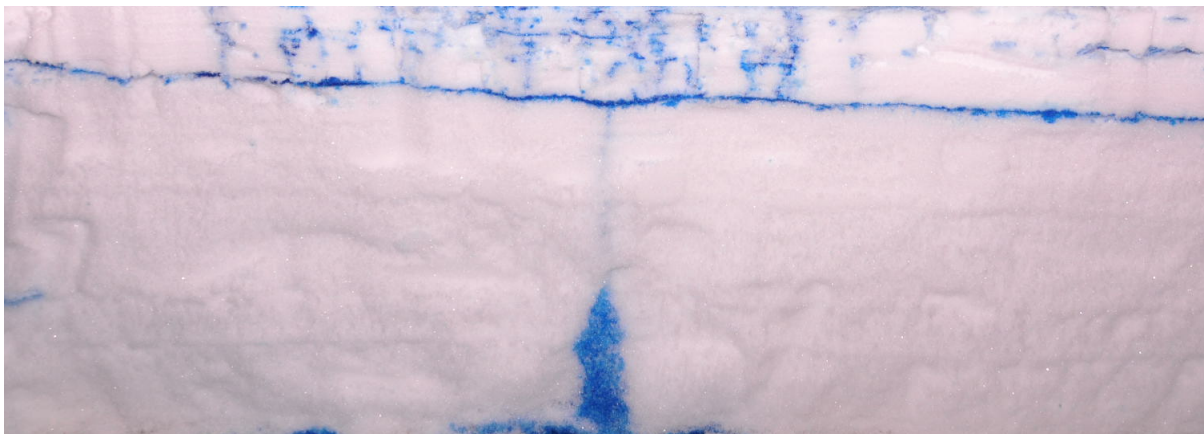


Figure 36 Desired area cropped out of Sertig locality image sample

Figure 36 above was cropped out of the original Sertig locality sample image by cutting out 1cm from the top of the vertical snow pack profile, 2cm from the bottom of the vertical snow

pack profile, 11cm from the left edge of the snow pack profile and 14cm from the right edge of the snow pack profile.

5.1.2.4 Cropping of SLF locality sample image



Figure 37 Sample image taken from SLF locality

The original sample image collected from the brilliant blue FCF dye tracer sprinkling experiment at the SLF locality was cropped in order to avoid the unwanted area covered by debris, equipment used during the experiment such as meter rule, poles, generator e.t.c, shadows, vegetations and area covered by the horizontal profile.

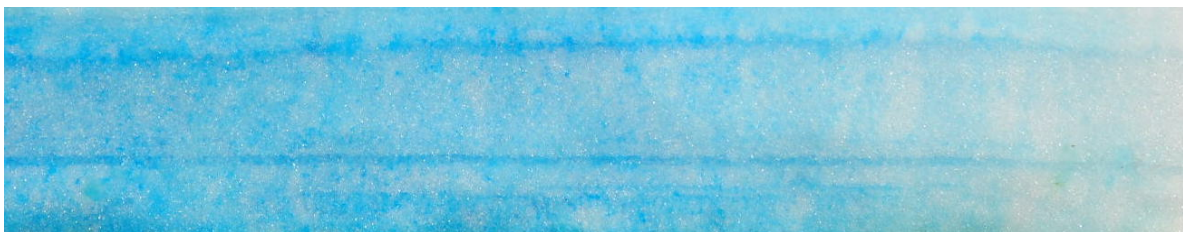


Figure 38 desired area cropped out of SLF locality image sample

The desired area of 102cm in length and 15cm in width was cropped out of the SLF snow pack profile, 90cm of the left edge, 5cm to the right edge, 1cm from the top and 3cm from the bottom of the horizontal snow pack profile was cut out.

5.1.3 Threshold application to sampling images

The implementation of the deduced conditions used in the determination of threshold in other to plot out only values of blue was carried out, this condition was implemented in R-Studio using r packages such as the jpeg package, plot3D package and scales package.

5.1.3.1 Input cropped sample images

The algorithm to insert the sample image was created and implemented by creating a variable with the name *indir*, this variable was assigned to a newly created folder with name *photos*. All sample images that were used in the threshold application were stored and loaded from the folder name *photos*. All jpeg files in the *photos* directory were read into the r-studio environment and assigned to a variable named *photo_in*

```
1. # create photos directory
2. indir <- "photos"
3.
4. # Define input location
5. where <- ""
6. input <- paste0(indir,"", where)
7.
8. # Read all jpeg files in the photos directory
9. photo_in <- list.files(indir, pattern = ".jpeg", all.files = TRUE, full.names = TRUE, no.. = TRUE)
```

5.1.3.2 Process cropped sample images data

Upon input of all the jpeg files in the *photos* directory as *photo_in*, a plot algorithm was built to loop through all the jpeg files in the *photos* directory. The replacement was performed for the first and all the jpeg file name matches, the replacement was stored to a new variable name *plotname*. *Plotname* was created to serve as the name of each of the output files, *plotname* was converted into a data frame for better recurring usage.

The data of all the jpeg files was read using the jpeg package, these data was stored in to a variable name named *pht_dta*. The transpose of the data matrix of all the jpeg files (*pht_dta*) in the green, blue and red channel were assigned to variables with name, *pht_dta_green*, *pht_dta_blue* and *pht_dta_red* respectively

```

1. # Install jpeg package
2. install.packages("jpeg")
3.
4. # load jpeg package
5. library("jpeg")
6.
7. # Replace first and all the file names with the newly created output file name structure
8. plotfiles <- gsub(pattern = "\\jpeg$", "", photo_in)
9. plotname <- sub('.*', "", plotfiles)
10. plotname_table <- data.frame(plotname)
11.
12. # Loop through the image plot algorithm implementation
13. for( k in 1:nrow(plotname_table)){
14. # Stored the data of all jpeg files into pht_dta variable
15. pht_dta <- readJPEG(paste0("",photo_in[k]))
16.
17. # Stored the transpose of the green, blue and red matrix data
18. pht_dta_green <- t(pht_dta[,2])# green channel
19. pht_dta_blue <- t(pht_dta[,3])# blue channel
20. pht_dta_red <- t(pht_dta[,1])# best visual contrast is 1, red channel
21. }

```

5.1.3.3 Apply threshold to the cropped sample images input

The threshold conditions was applied within the jpeg files loop to the transpose of the cropped sample images matrix data in the green, blue and red channel, this condition was applied thus; The application of threshold conditions to the cropped sample images was further processed to improve the image plot of the blue colour from the output data. The blue was divided into three sections assigned to values of 0, 1, 2 and 3, these values were represented with white, lightskyblue1, royalblue3 and darkblue respectively, this methodology was adopted for better interpretation of the blue covered areas on the plot.

5.1.4 Blue distribution of sample images

The cropped sample images from brilliant blue FCF dye tracer sprinkling experiment locations such as Klosters sample image, Serneus sample image, Sertig sample image and SLF sample image was processed using the flow characteristics package's blue distribution function. The flow characteristics package's blue distribution function of sprinkling experiment sample

images would return necessary information needed to deduce the distribution of preferential flow, matrix flow and capillary barrier in the images.

5.1.4.1 Blue distribution of Klosters sample image

The cropped sample image from Klosters locality was read as JPEG into the environment.

```
1. klosters_img <- readJPEG('/PathToImage/klosters_sample_image.jpg')
```

From flow characteristics package documentation it was stated that the JPEG data read into the environment should be used as an input to apply threshold conditions to the JPEG sample image from Klosters locality. The threshold application function was further applied to the sample image data from Klosters read into the R-Studio environment.

```
1. klosters_data <- apply_threshold(raw_data = klosters_img)
```

The Klosters threshold data from the flow characteristics package’s apply threshold function was required as an input to process the sample image from Klosters with the flow characteristics package’s blue distribution function.

```
1. klosters_blue_distribution <- blue_distribution(klosters_data)
```

Table 5 was returned upon application of the flow characteristics package’s blue distribution function to the Klosters threshold data.

Table 5 Blue distribution of Klosters sample image

Blue Categories	Blue distribution of Klosters sample image in per cent
All blues	98.84%
Light blues	11.99%
Medium blues	55.19%
Dark blues	31.66%

5.1.4.2 Blue distribution of Serneus sample image

The cropped sample image from Serneus locality was read as JPEG into the R-Studio environment.

```
1. serneus_img <- readJPEG('/PathToImage/serneus_sample_image.jpg')
```

This JPEG data is required as an input to the flow characteristics package's threshold application function according to the flow characteristics package's documentation.

```
1. serneus_data <- apply_threshold(raw_data = serneus_img)
```

The data from the threshold application was required as an input for the application of flow characteristics package's blue distribution function. This data from the application of threshold was further processed by applying the flow characteristics package blue distribution function.

```
1. serneus_blue_distribution <- blue_distribution(serneus_data)
```

The application of flow characteristics package's blue distribution function to the cropped sample image from serneus returned Table 6

Table 6 Blue distribution of Serneus sample image

Blue Categories	Blue distribution of Serneus sample image in per cent
All blues	21.89%
Light blues	0.49%
Medium blues	13.43%
Dark blues	7.98%

5.1.4.3 Blue distribution of Sertig sample image

The cropped sample image from the dye tracer sprinkling experiment in Sertig locality was read into the R-Studio environment as JPEG data.

```
1. sertig_img <- readJPEG('/PathToImage/sertig_sample_image.jpg')
```

The JPEG data from the cropped sample image from Sertig locality is a required input to enable the usage of flow characteristics package's threshold application function

```
1. sertig_data <- apply_threshold(raw_data = sertig_img)
```

The data obtained from the threshold application function was further processed using flow characteristics package's blue distribution function to return the distribution of blue colours in the cropped sample image from Sertig locality.

```
1. sertig_blue_distribution <- blue_distribution(sertig_data)
```

was the returned blue distribution of the cropped sample image from Sertig locality

Table 7 Blue distribution of Sertig sample image

Blue Categories	Blue distribution of Sertig sample image in per cent
All blues	3.73%
Light blues	1.69%
Medium blues	1.52%
Dark blues	0.52%

5.1.4.4 Blue distribution of SLF sample image

The cropped sample image from the dye tracer sprinkling experiment in SLF locality was read as JPEG data into the R-Studio environment.

```
1. slf_img <- readJPEG('/PathToImage/slf_sample_image.jpg')
```

flow characteristics package package requires this JPEG data to enable the use of threshold application function, this function returned the threshold application data.

```
1. slf_data <- apply_threshold(raw_data = slf_img)
```

The returned threshold application data was further processed as an input to the blue distribution function application.

```
1. slf_blue_distribution <- blue_distribution(slf_data)
```


The application of blue distribution function to the cropped sample image from SLF locality returned Table 8

Table 8 Blue distribution of SLF sample image

Blue Categories	Blue distribution of SLF sample image in per cent
All blues	78.53%
Light blues	46.33%
Medium blues	30.01%
Dark blues	2.19%

5.1.5 Length and depth of blue fractions of sample images

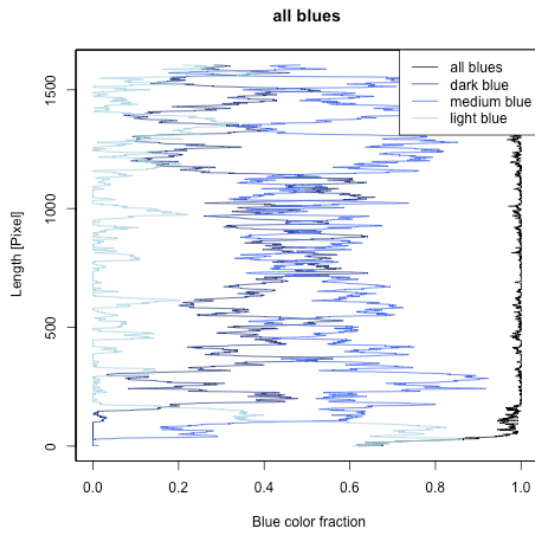
flow characteristics package package was used in the determination of the length and depth part of all the cropped sample images taken from the four localities involved in the flow. The flow of brilliant blue FCF dye tracer sprinkled on the snow packs signifies the fractions of the snow packs that are liable to allow water flow. The length and depth dimensional values of the cropped sample images were determined and processed using the flow characteristics package's length blue fractions function for the length dimension and depth blue fractions function for the depth dimension of the cropped sample images.

5.1.5.1 Length and depth of blue fractions of Klosters sample image

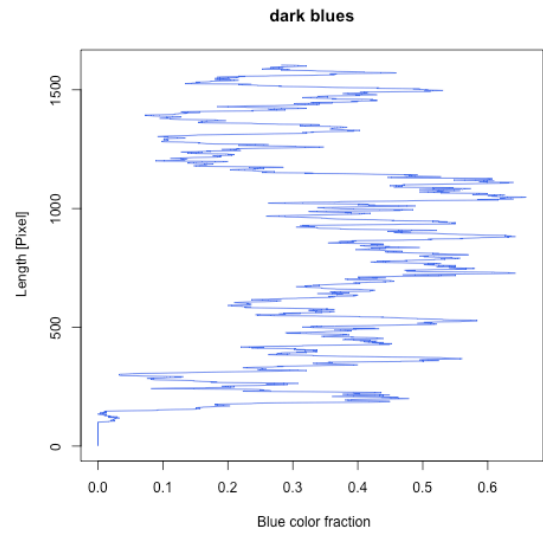
The length and depth flow fractions of Klosters sample image were analysed using the length and depth blue fractions function of flow characteristics package package.

1. `# Returns plot of the length of Klosters sample image blue fractions`
2. `klosters_length_fractions <- length_blue_fractions(thresh_data = klosters_data, blue_selection = "Blue category input e.g. all, dark blue, medium blue or light blue", plot_path = path to the plot output directory)`

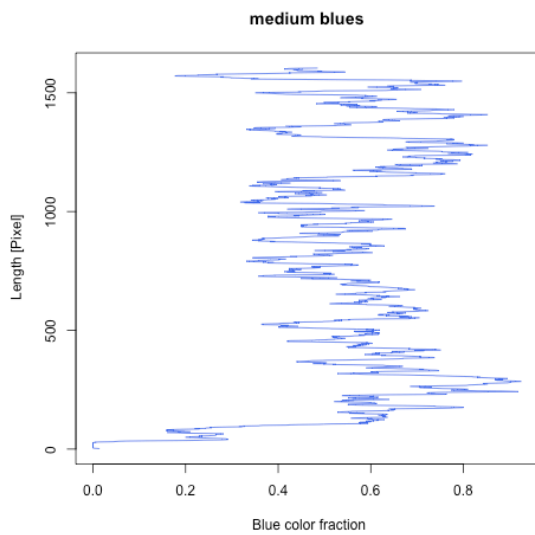
The length blue fraction function returns Figure 39



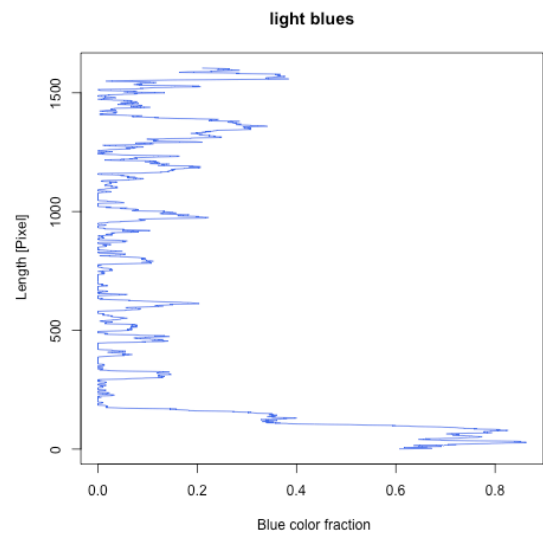
(a) All blues fraction plot of Klosters sample image length



(b) Dark blues fraction plot of Klosters sample image length



(c) Medium blues fraction plot of Klosters sample image length

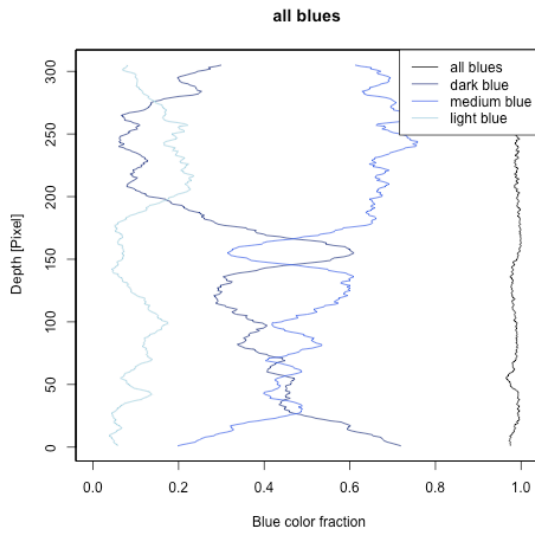


(d) Light blues fraction plot of Klosters sample image length

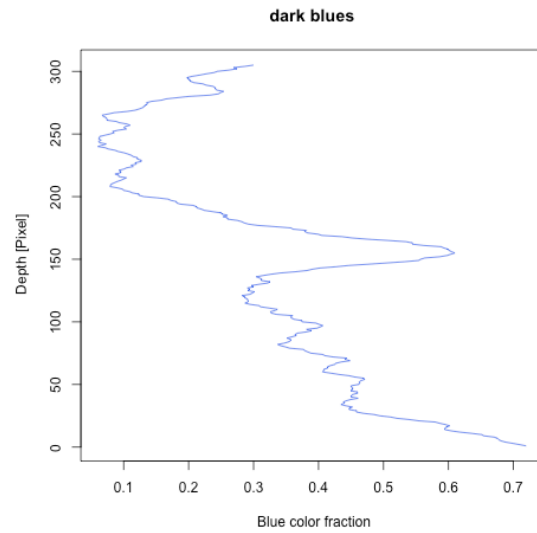
Figure 39 Blue fraction plots of the length of Klosters sample image

1. **# Returns plot of the depth of Klosters sample image blue fractions**
2. `klosters_depth_fractions <- depth_blue_fractions(thresh_data = klosters_data, blue_selection = "Blue category input e.g. all, dark blue, medium blue or light blue ", plot_path = path to the plot output directory)`

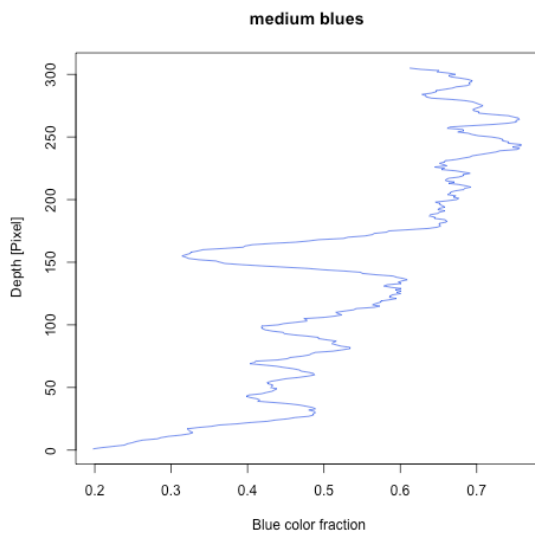
The depth blue fraction function returns Figure 40



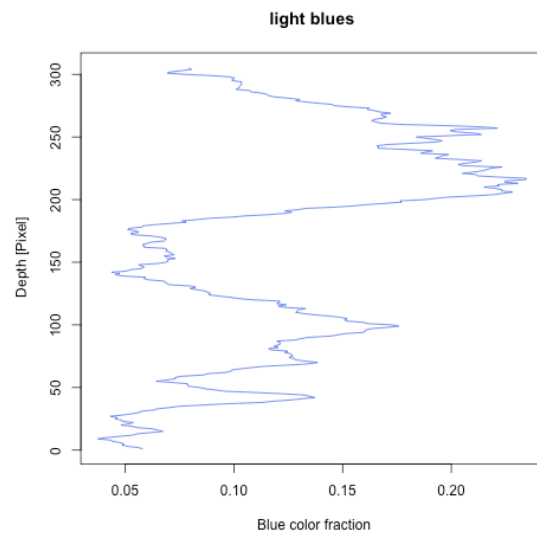
(a) All blues fraction plot of Klosters sample image depth



(b) Dark blues fraction plot of Klosters sample image depth



(c) Medium blues fraction plot of Klosters sample image depth



(d) Light blues fraction plot of Klosters sample image depth

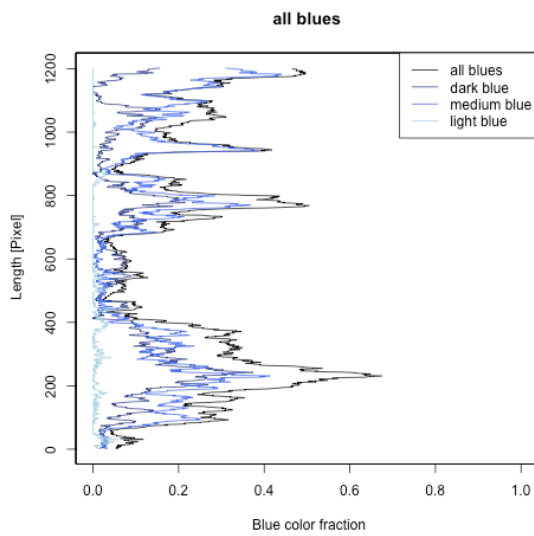
Figure 40 Blue fraction plots of the depth of Klosters sample image

5.1.5.2 Length and depth of blue fractions of Serneus sample image

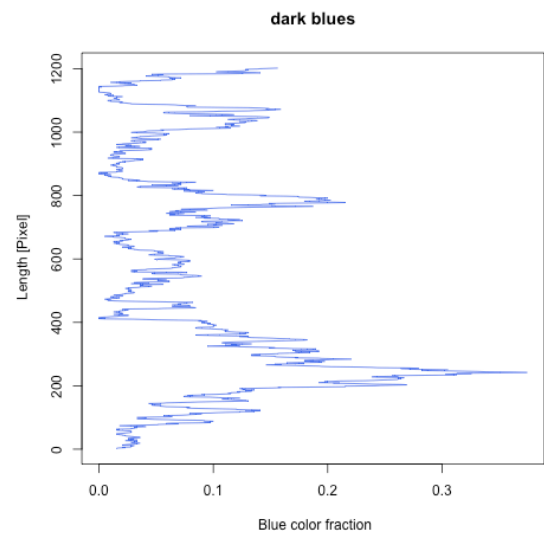
The length and depth flow fractions of Serneus sample image were analysed using the length and depth blue fractions function of flow characteristics package package.

1. `# Returns plot of the length of Serneus sample image blue fractions`
2. `serneus_length_fractions <- length_blue_fractions(thresh_data = serneus_data, blue_selection = "Blue category input e.g. all, dark blue, medium blue or light blue", plot_path = path to the plot output directory)`

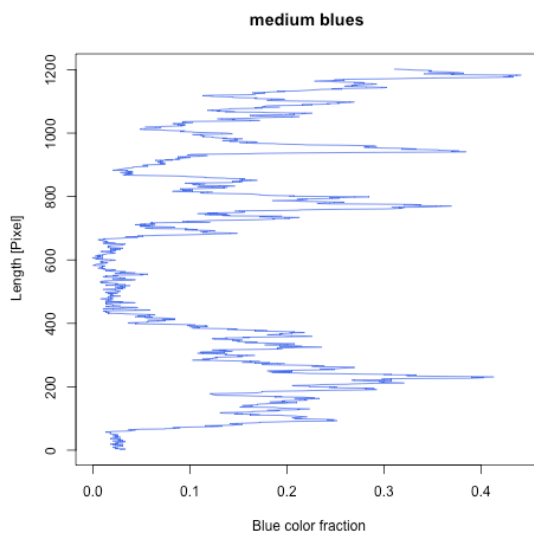
The length blue fraction function applied to cropped Serneus sample image returns Figure 41



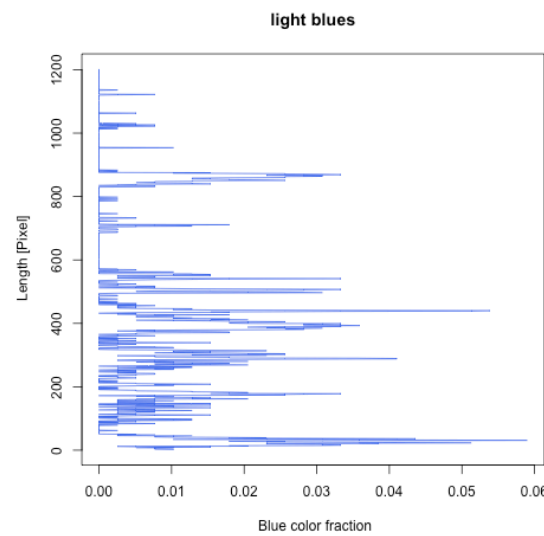
(a) All blues fraction plot of Serneus sample image length



(b) Dark blues fraction plot of Serneus sample image length



(c) Medium blues fraction plot of Serneus sample image length

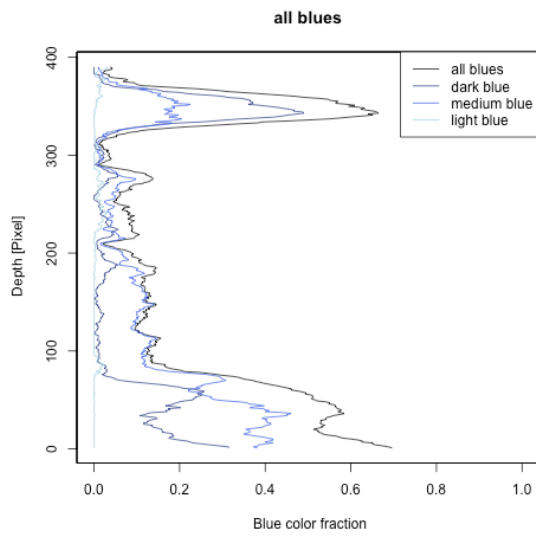


(d) Light blues fraction plot of Serneus sample image length

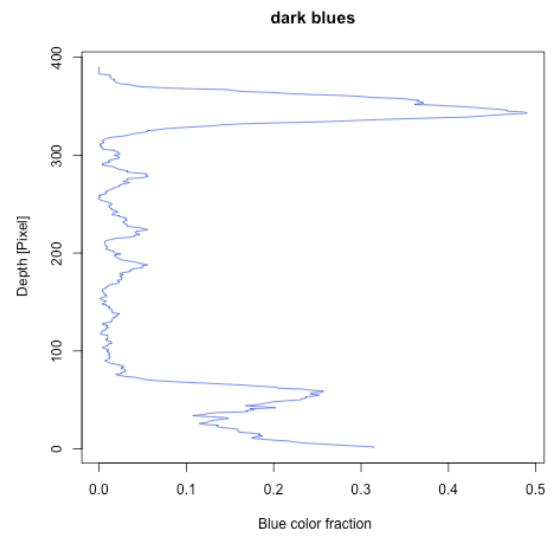
Figure 41 Blue fraction plots of the length of Serneus sample image

1. `# Returns plot of the depth of Serneus sample image blue fractions`
2. `serneus_depth_fractions <- depth_blue_fractions(thresh_data = serneus_data, blue_selection = "Blue category input e.g. all, dark blue, medium blue or light blue ", plot_path = path to the plot output directory)`

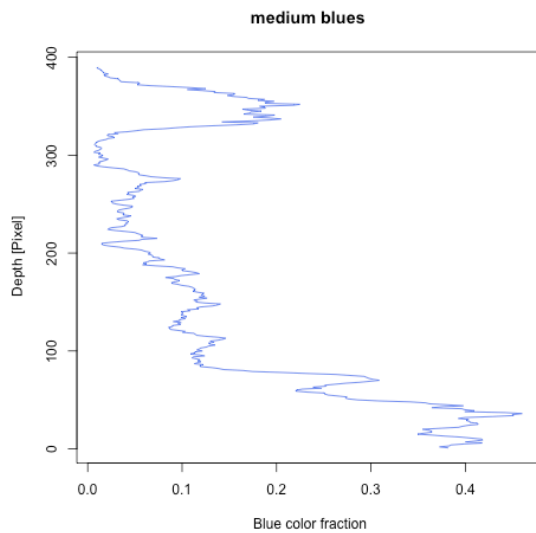
Figure 42 were the plots returned from the application of depth blue fraction function to the sample images from Serneus locality



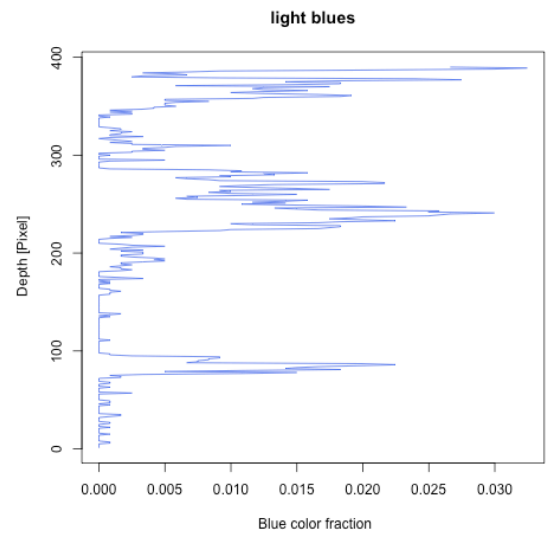
(a) All blues fraction plot of Serneus sample image depth



(b) Dark blues fraction plot of Serneus sample image depth



(c) Medium blues fraction plot of Serneus sample image depth



(d) Light blues fraction plot of Serneus sample image depth

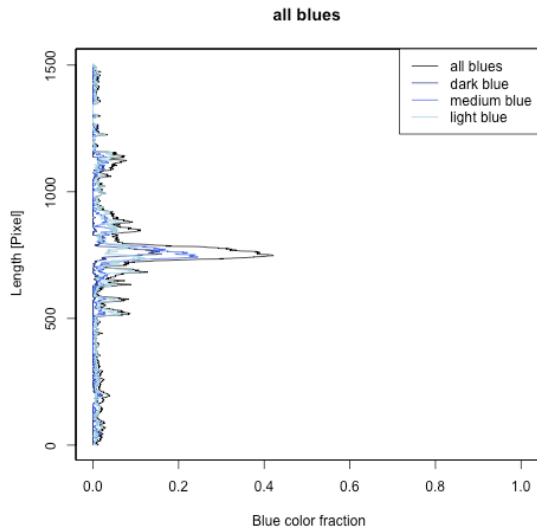
Figure 42 Blue fraction plots of the depth of Serneus sample image

5.1.5.3 Length and depth of blue fractions of Sertig sample image

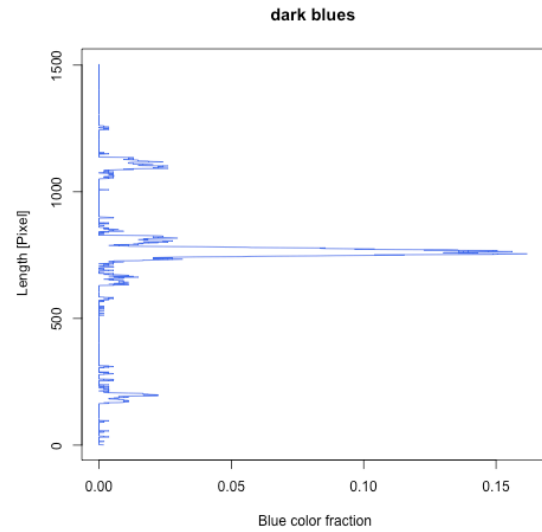
The length and depth blue fraction function of flow characteristics package package were used to analyse the length and depth flow fractions of the cropped sample image from Sertig locality.

1. # Returns plot of the length of Sertig sample image blue fractions
2. `sertis_length_fractions <- length_blue_fractions(thresh_data = sertig_data, blue_selection = "Blue category input e.g. all, dark blue, medium blue or light blue", plot_path = path to the plot output directory)`

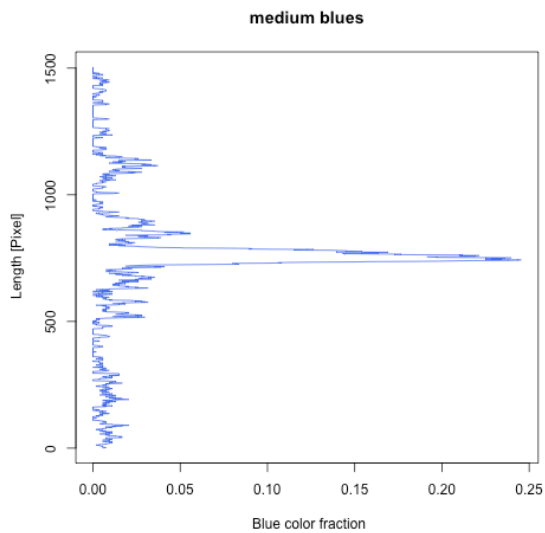
The blue fraction of the Sertig sample image length returns Figure 43



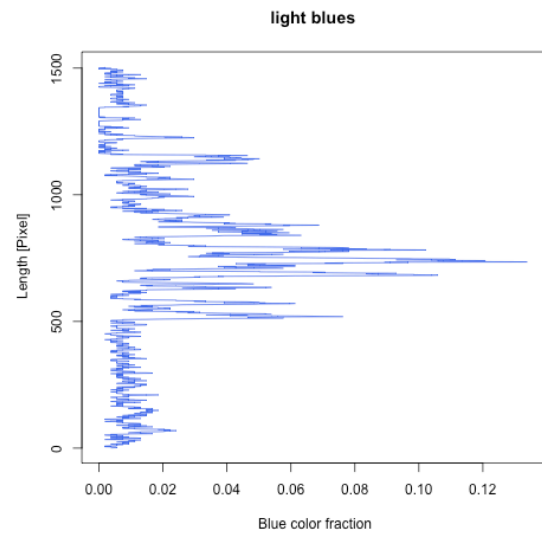
(a) All blues fraction plot of Sertig sample image length



(b) Dark blues fraction plot of Sertig sample image length



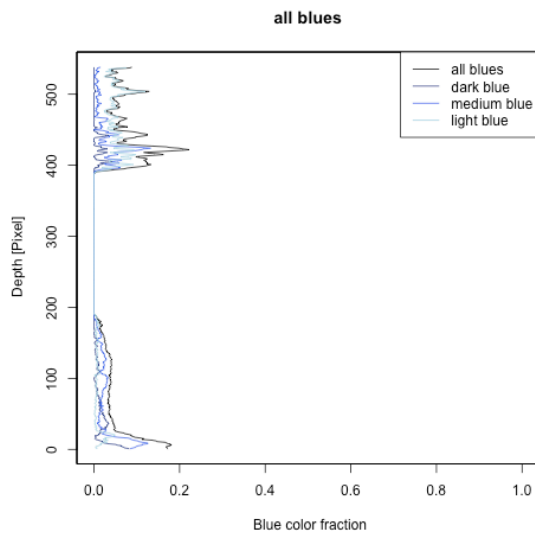
(c) Medium blues fraction plot of Sertig sample image length



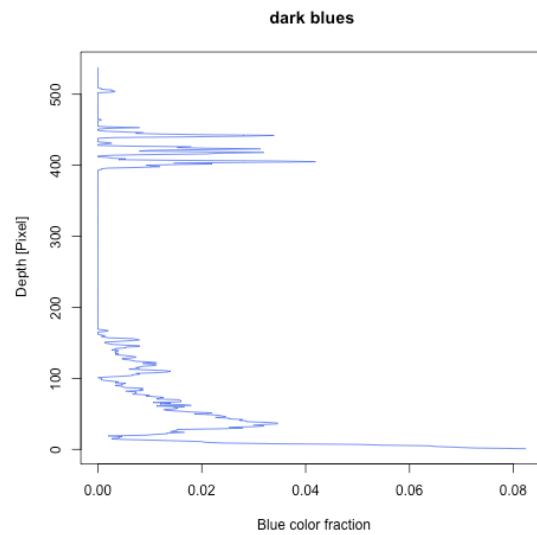
(d) Light blues fraction plot of Sertig sample image length

Figure 43 Blue fraction plots of the length of Sertig sample image

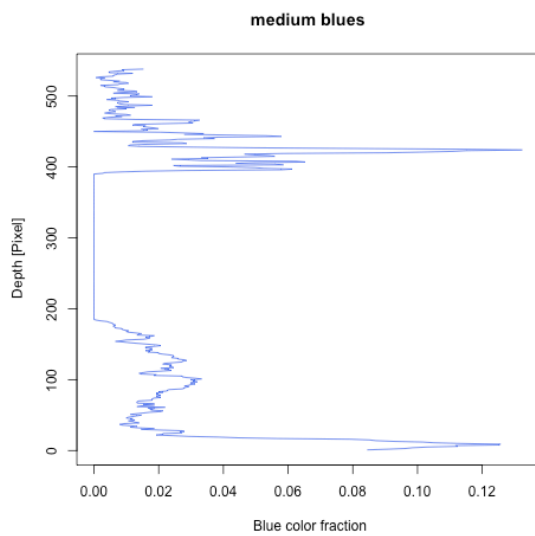
1. # Returns plot of the depth of Sertig sample image blue fractions
2. sertig_depth_fractions <- depth_blue_fractions(thresh_data = sertig_data, blue_selection = " Blue category input e.g. all, dark blue, medium blue or light blue ", plot_path = path to the plot output directory)



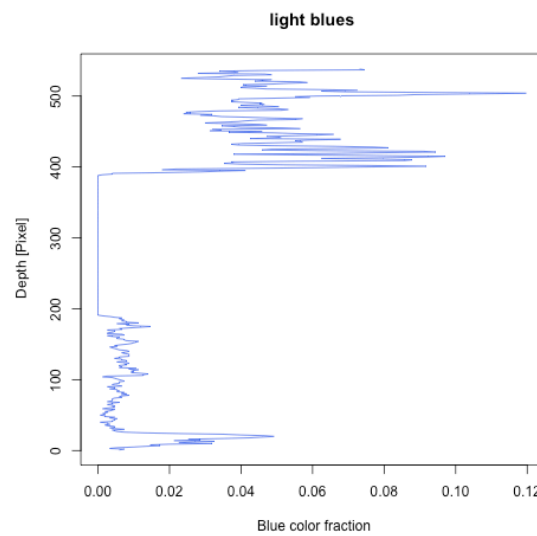
(a) All blues fraction plot of Sertig sample image depth



(b) Dark blues fraction plot of Sertig sample image depth



(c) Medium blues fraction plot of Sertig sample image depth



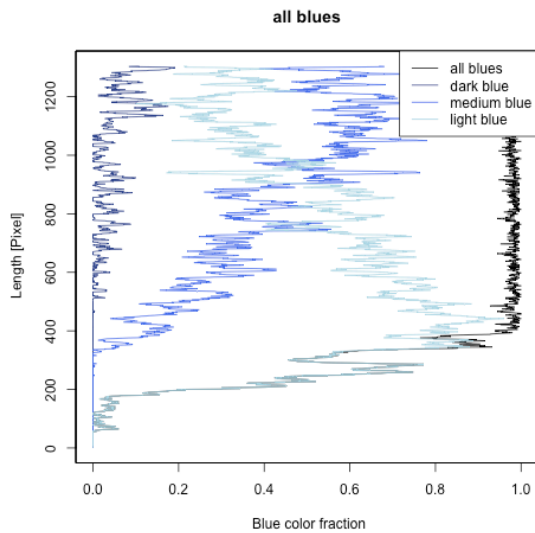
(d) Light blues fraction plot of Sertig sample image depth

Figure 44 Blue fraction plots of the depth of Sertig sample image

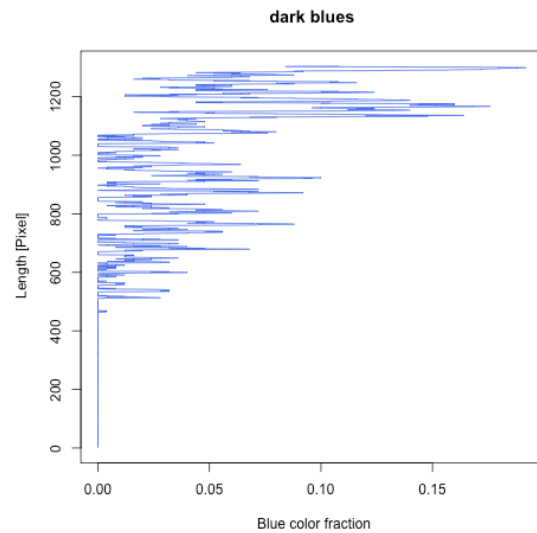
5.1.5.4 Length and depth of blue of fractions of SLF sample image

The length of the blue fraction function was applied to the SLF sample image threshold data for different blue categories.

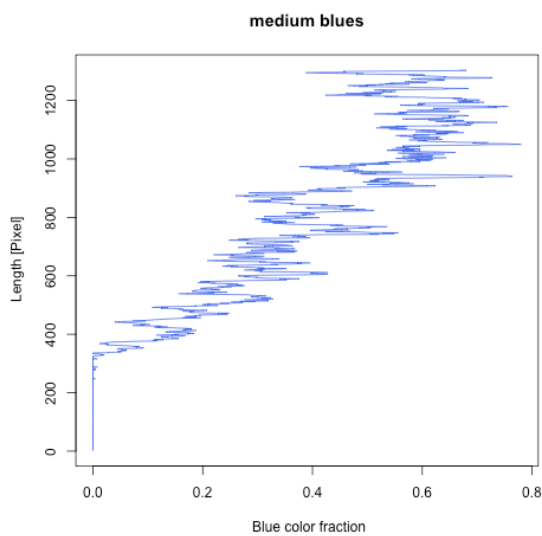
1. # Returns plot of the length of SLF sample image blue fractions
2. `slf_length_fractions <- length_blue_fractions(thresh_data = slf_data, blue_selection = "Blue category input e.g. all, dark blue, medium blue or light blue", plot_path = path to the plot output directory)`



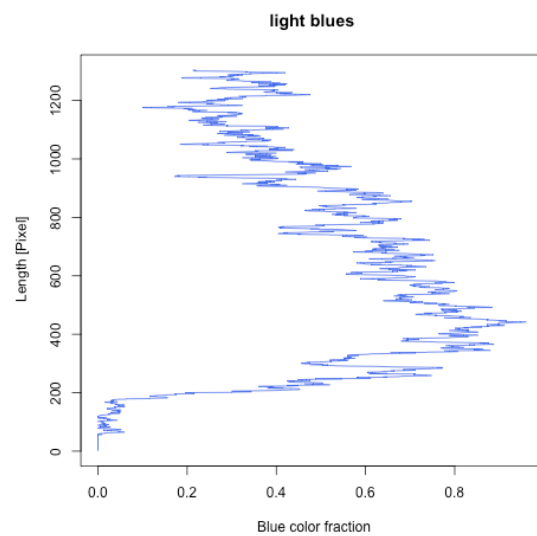
(a) All blues fraction plot of SLF sample image length



(b) Dark blues fraction plot of SLF sample image length



(c) Medium blues fraction plot of SLF sample image length

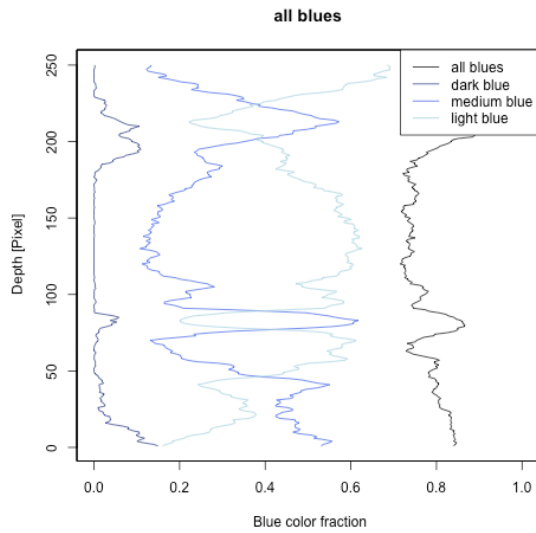


(d) Light blues fraction plot of SLF sample image length

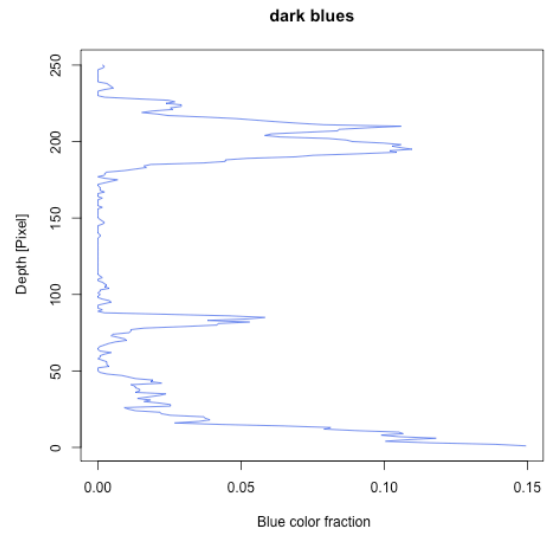
Figure 45 Blue fraction plots of the length of the SLF sample image

The depth of the blue fraction function was applied to the SLF sample image threshold data for different blue categories.

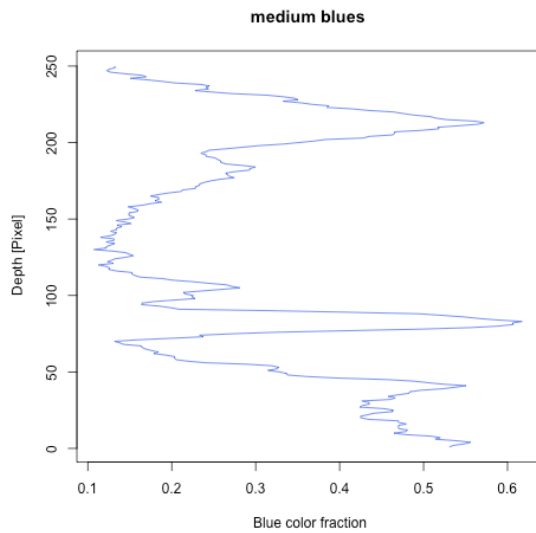
1. # Returns plot of the depth of SLF sample image blue fractions
2. `slf_depth_fractions <- depth_blue_fractions(thresh_data = slf_data, blue_selection = "Blue category input e.g. all, dark blue, medium blue or light blue", plot_path = path to the plot output directory)`



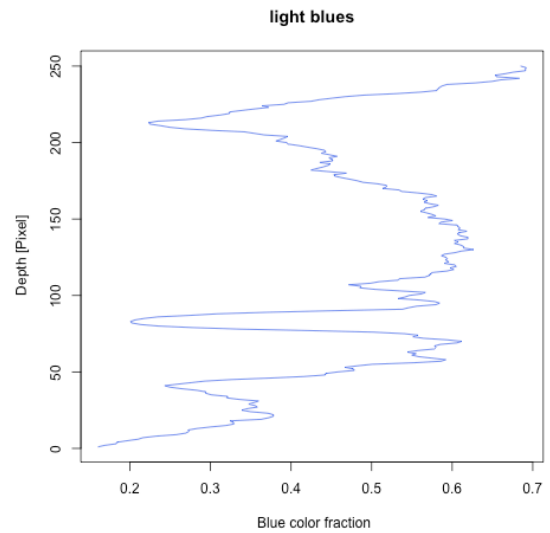
(a) All blues fraction plot of SLF sample image depth



(b) Dark blues fraction plot of SLF sample image depth



(c) Medium blues fraction plot of SLF sample image depth



(d) Light blues fraction plot of SLF sample image depth

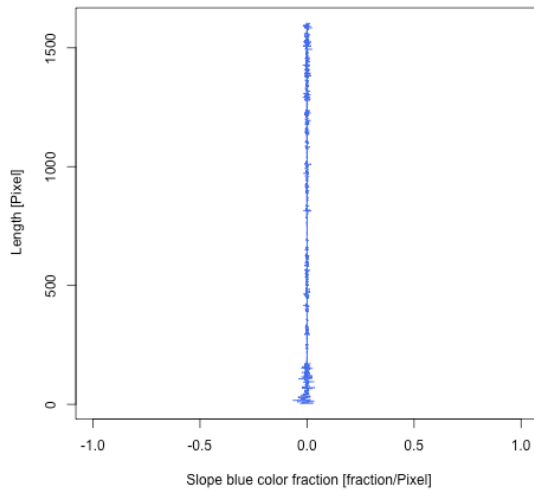
Figure 46 Blue fraction plots of the depth of SLF sample image

5.1.6 Slope of length and depth of blue fractions of sample images

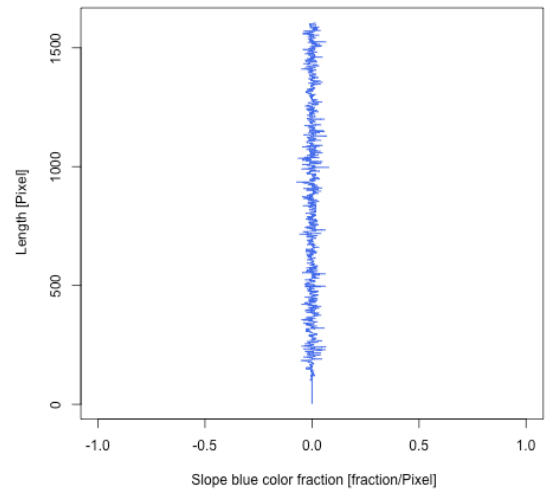
The slope of length and depth flow fractions of sample images in the four localities was derived from the slope of blue fractions of length and depth of the sample images. The flow characteristics package's slope blue fraction functions of length and depth sample image was applied, these functions accept two inputs, the data returned from the blue fraction function application and the path to the output directory of the sloping plot.

5.1.6.1 Slope of length and depth of blue fractions of Klosters sample image

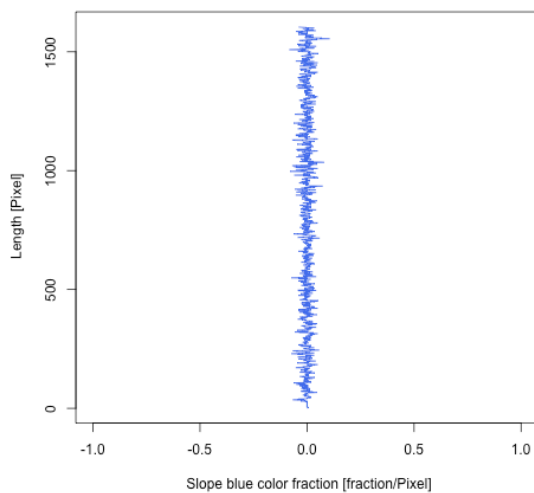
Figure 47 was the plot returned upon application of the slope length blue fractions function to the Klosters sample image.



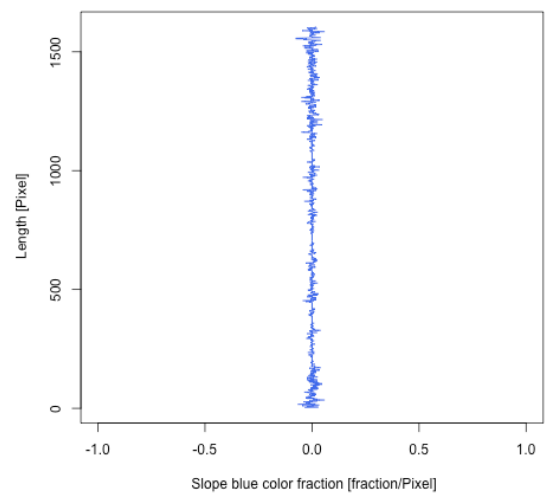
(a) The slope of all blues fraction plot of Klosters sample image length



(b) The slope of dark blues fraction plot of Klosters sample image length



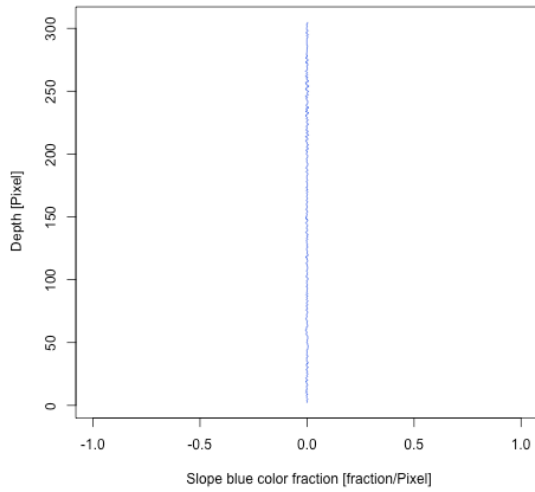
(c) The slope of medium blues fraction plot of Klosters sample image length



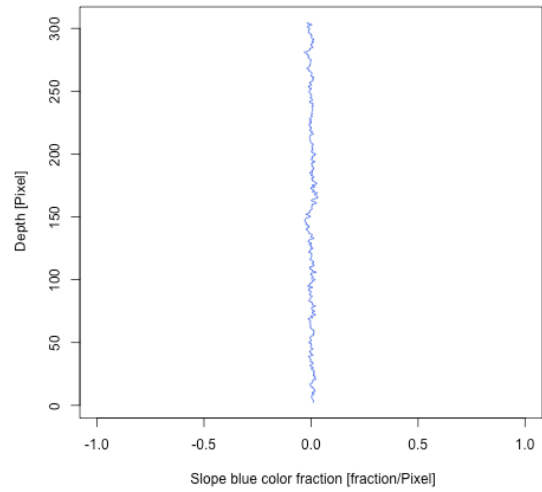
(d) The slope of light blues fraction plot of Klosters sample image length

Figure 47 Slope of blue fraction plots of the length of Klosters sample image

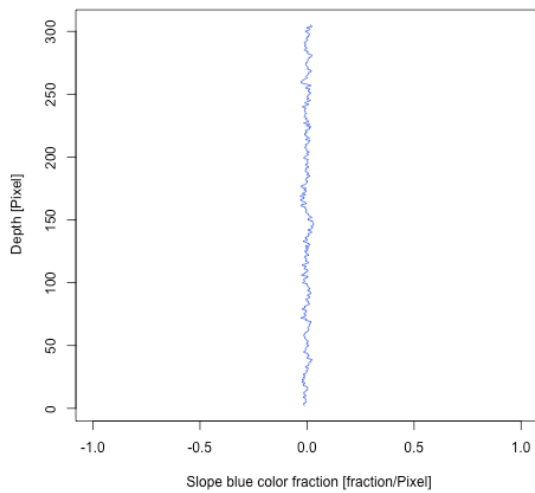
Figure 48 was the plot returned upon application of the sloping depth blue fractions function to the Klosters sample image.



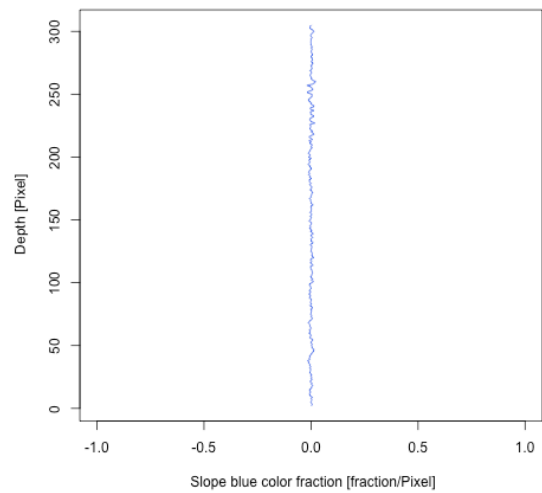
(a) The slope of all blues fraction plot of Klosters sample image depth



(b) The slope of dark blues fraction plot of Klosters sample image depth



(c) The slope of medium blues fraction plot of Klosters sample image depth

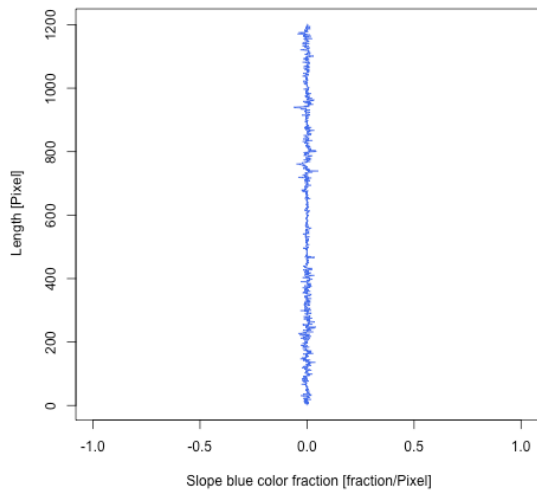


(d) The slope of light blues fraction plot of Klosters sample image depth

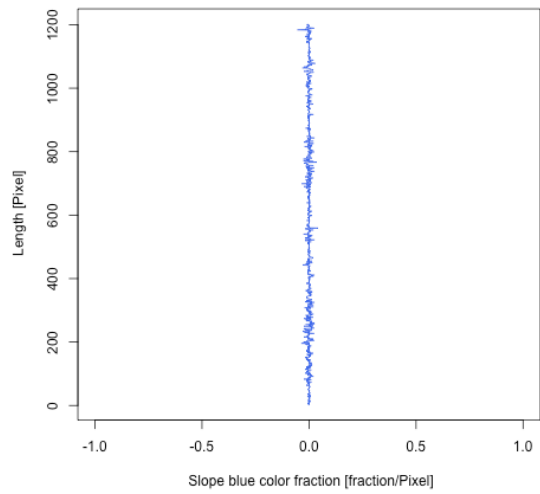
Figure 48 Slope of blue fraction plots of the depth of Klosters sample image

5.1.6.2 Slope of length and depth of blue fractions of Serneus sample image

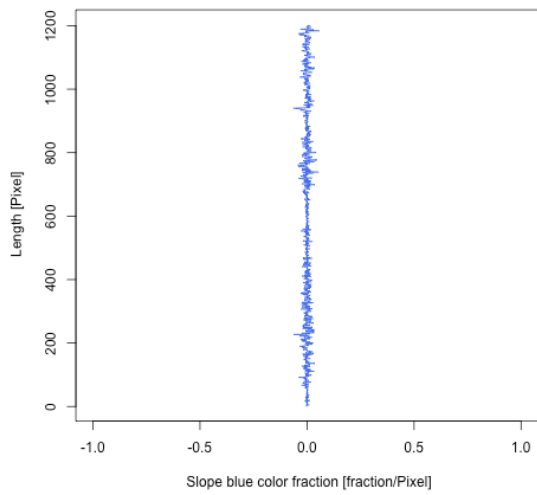
Figure 49 was the plot returned upon application of the sloping length blue fractions function to the Serneus sample image.



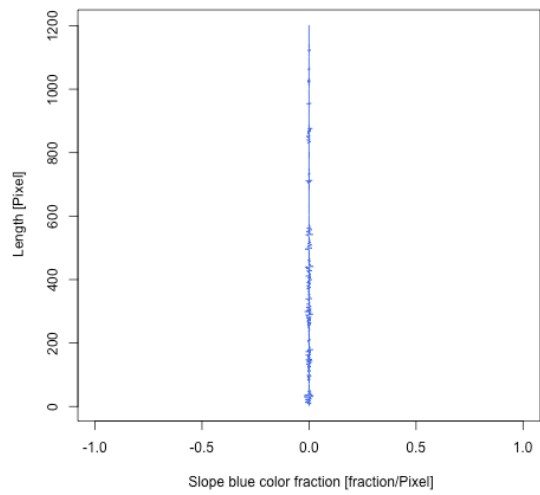
(a) The slope of all blues fraction plot of Serneus sample image length



(b) The slope of dark blues fraction plot of Serneus sample image length



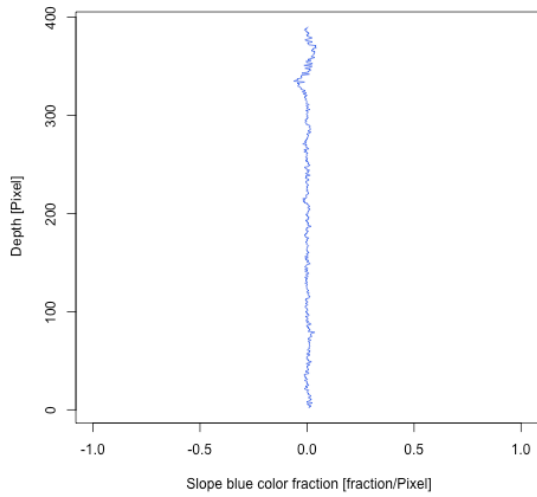
(c) The slope of medium blues fraction plot of Serneus sample image length



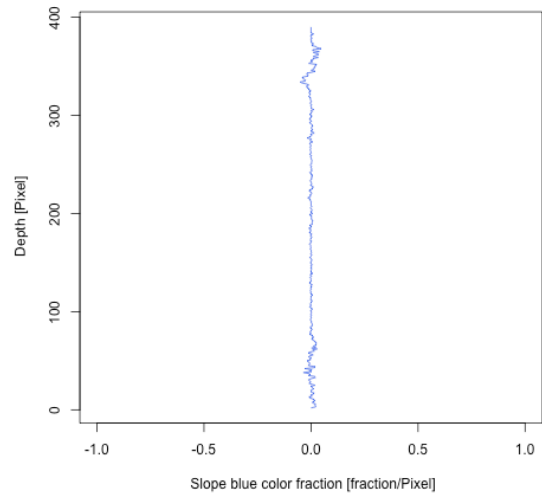
(d) The slope of light blues fraction plot of Serneus sample image length

Figure 49 Slope of blue fraction plots of the length of Serneus sample image

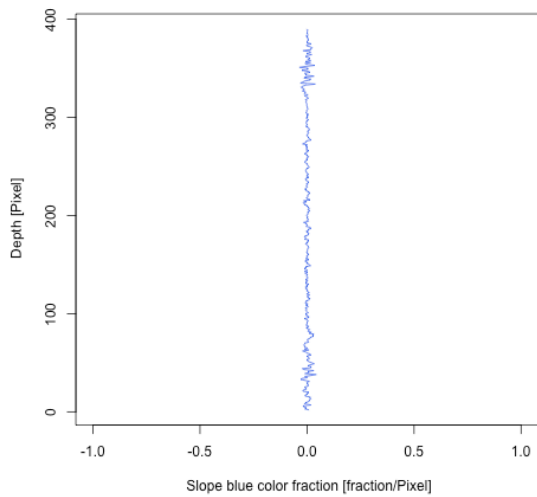
Figure 50 was the plot returned upon application of the sloping depth blue fractions function to the Serneus sample image.



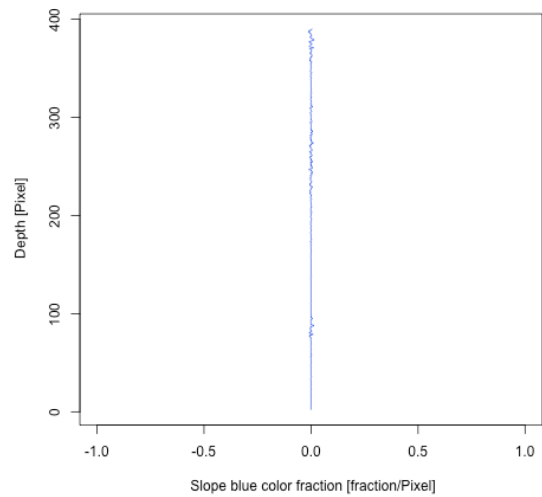
(a) The slope of all blues fraction plot of Serneus sample image depth



(b) The slope of dark blues fraction plot of Serneus sample image depth



(c) The slope of medium blues fraction plot of Serneus sample image depth

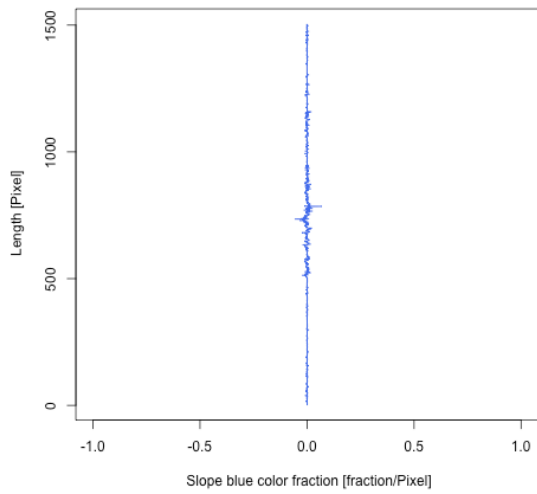


(d) The slope of medium blues fraction plot of Serneus sample image depth

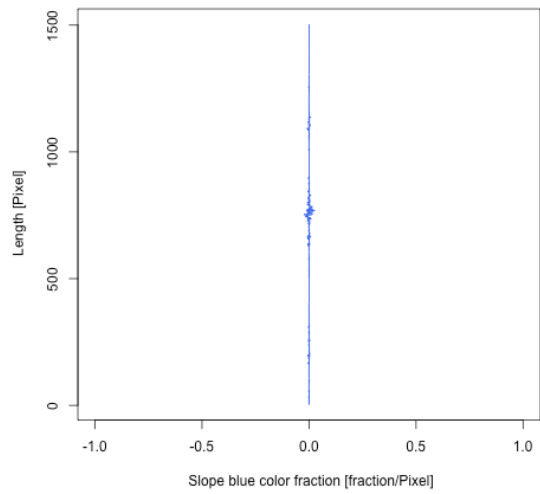
Figure 50 Slope of blue fraction plots of the depth of Serneus sample image

5.1.6.3 Slope of length and depth of blue fractions of Sertig sample image

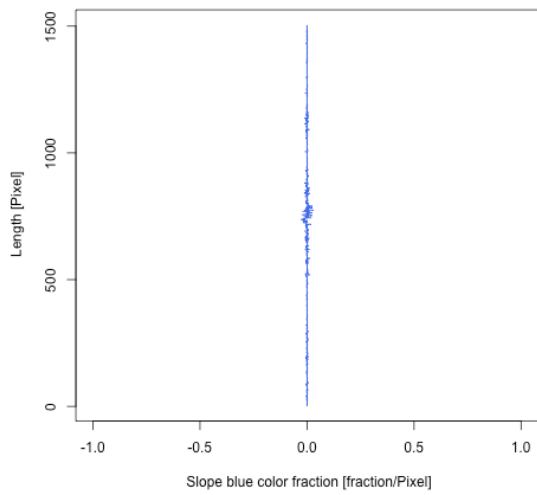
Figure 51 was the plot returned upon application of the sloping length blue fractions function to the Sertig sample image.



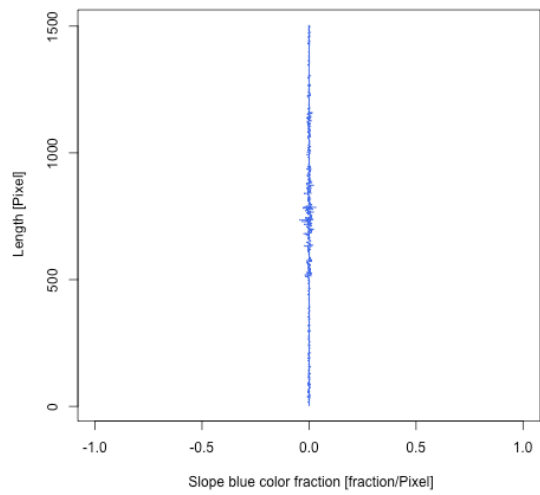
(a) The slope of all blues fraction plot of Sertig sample image length



(b) The slope of dark blues fraction plot of Sertig sample image length



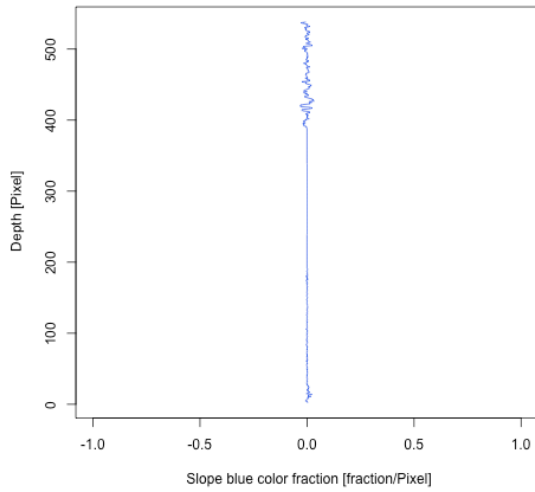
(c) The slope of medium blues fraction plot of Sertig sample image length



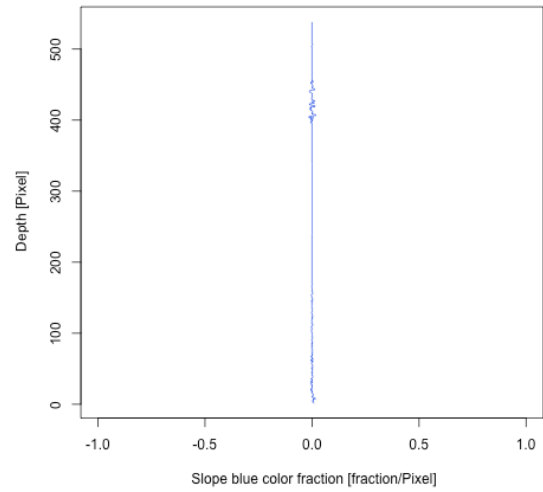
(d) The slope of light blues fraction plot of Sertig sample image length

Figure 51 Slope of blue fraction plots of the length of Sertig sample image

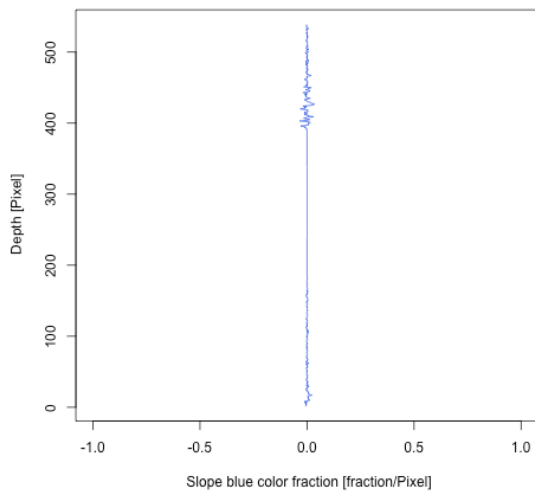
Figure 52 was the plot returned upon application of the sloping depth blue fractions function to the Sertig sample image.



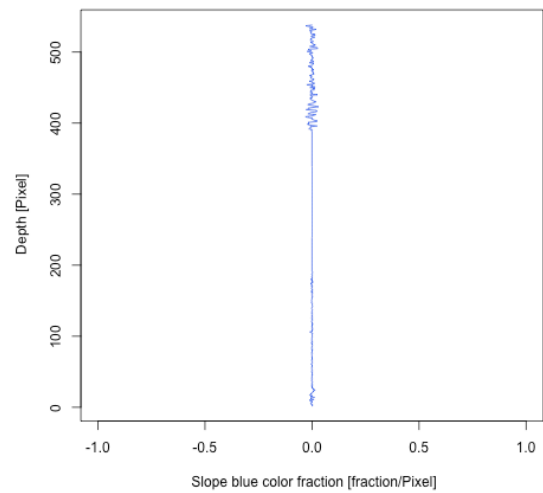
(a) The slope of all blues fraction plot of Sertig sample image depth



(b) The slope of dark blues fraction plot of Sertig sample image depth



(c) The slope of medium blues fraction plot of Sertig sample image depth

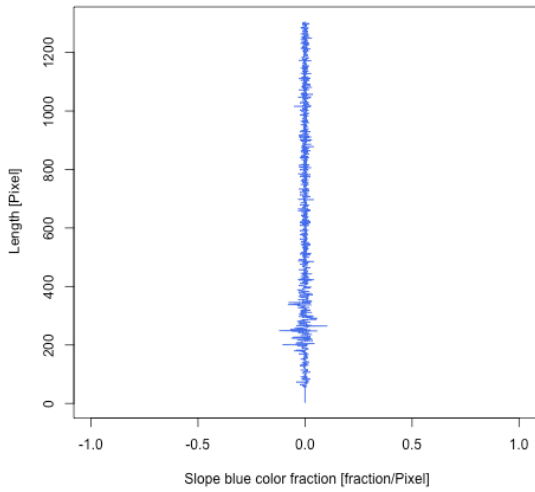


(d) The slope of light blues fraction plot of Sertig sample image depth

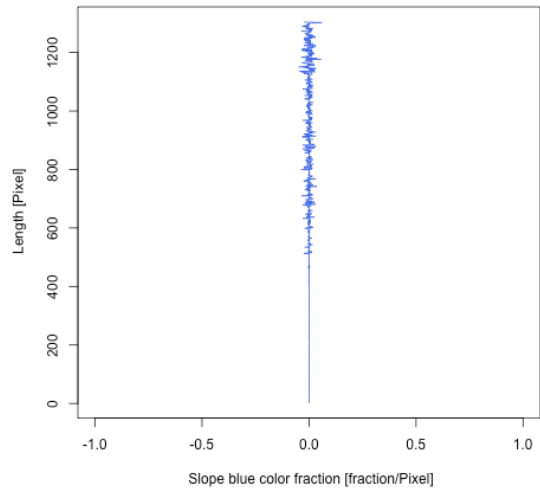
Figure 52 Slope of blue fraction plots of the depth of Sertig sample image

5.1.6.4 Slope of length and depth of blue fractions of SLF sample image

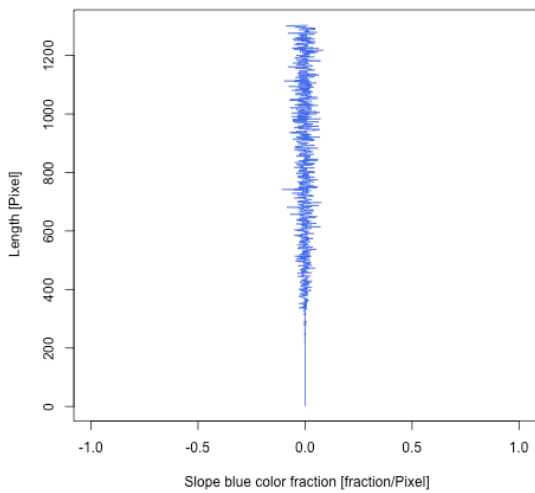
Figure 53 was the plot returned upon application of the sloping length blue fractions function to the SLF sample image.



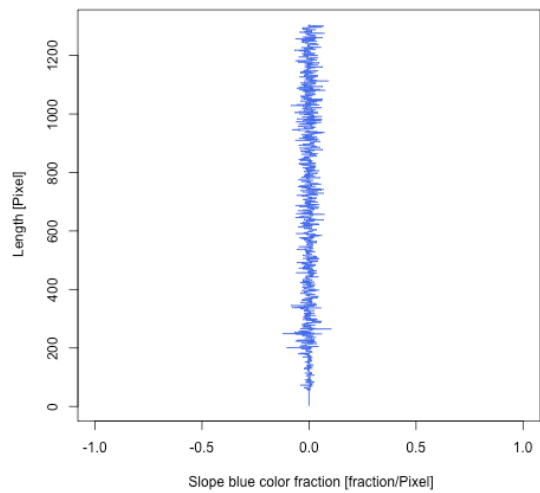
(a) The slope of all blues fraction plot of SLF sample image length



(b) The slope of dark blues fraction plot of SLF sample image length



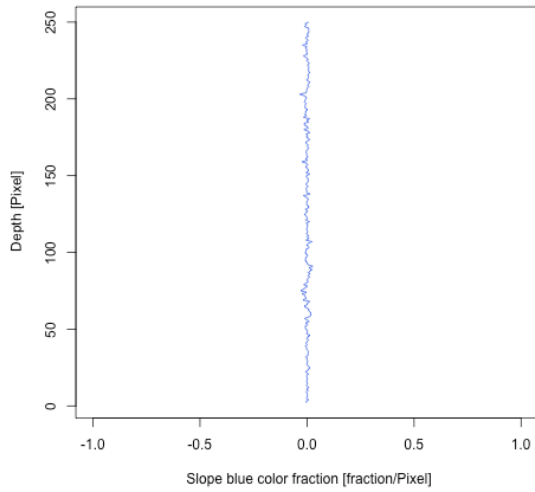
(c) The slope of medium blues fraction plot of SLF sample image length



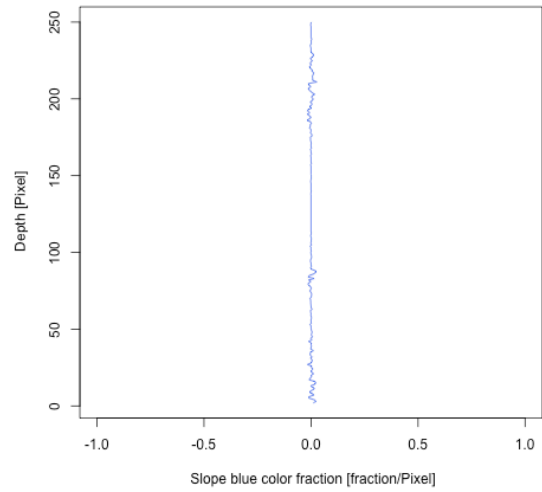
(d) The slope of light blues fraction plot of SLF sample image length

Figure 53 Slope of blue fraction plots of the length of the SLF sample image

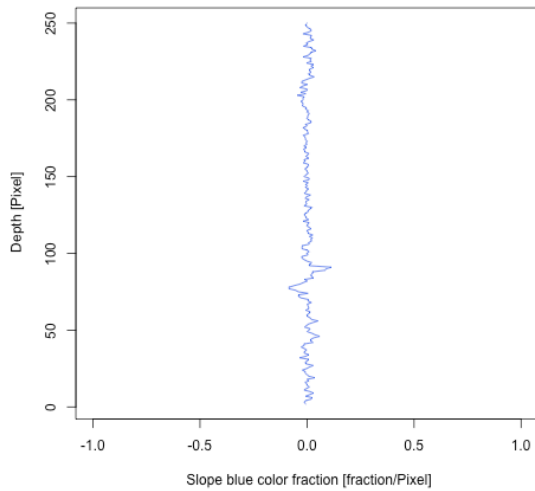
Figure 54 was the plot returned upon application of the sloping depth blue fractions function to the SLF sample image.



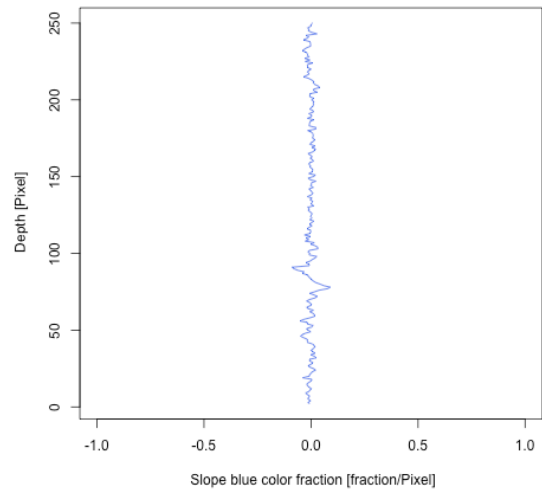
(a) The slope of all blues fraction plot of SLF sample image depth



(b) The slope of dark blues fraction plot of SLF sample image depth



(c) The slope of medium blues fraction plot of SLF sample image depth



(d) The slope of light blues fraction plot of SLF sample image depth

Figure 54 Slope of blue fraction plots of the depth of the SLF sample image

5.2 Identification of matrix flow

According to Table 2 when the distribution of blues of an image section is greater than 70%, then matrix flow can be said to occur in that section, according to Figure 9(a) and (b) Length of blue fractions function application on typical matrix flow structures the section of an image with high blue fractions can be said to be made up of matrix flow structure, also matrix flow occurs when more than 70% of the slope values of blue colour fractions are close.

The blue distribution of the sample image from Kolsters locality is greater than 70%, the sample image can be said to be made up of matrix flow structure. The distribution of the sample image from SLF locality is greater than 70%, the SLF sample image can as well be said to be made up of matrix flow structure.

5.3 Identification of preferential flow

Preferential flows are vertical structures formed from the vertical movement of water within the snow pack, sections of an image with preferential flow structures are expected to have sudden increase in blue distribution and blue fractions along the length of the image. Figure 15 shows the sudden increase of the blue fractions along the length of the image representing a typical preferential flow structure. The slope of the blue fraction values of the image representing a typical preferential flow structure shows large changes at the preferential flow section.

The sample image from Kolsters locality shows multiple changes in the slope values of the blue fractions of the image sample length, the image sample can be said to be made up of multiple preferential flow structures. The image sample from Sertig and SLF locality shows multiple changes in the slope values of the blue fractions of the image sample length, these image samples can as well be said to be made up of multiple preferential flow structures.

5.4 Identification of capillary barrier

Capillary barrier are structures formed from the horizontal movement of water within the snow pack, sections of an image with capillary barrier structures are expected to have massive increase in blue distribution and blue fractions along the depth of the image representing a typical capillary barrier structure. Figure 22 shows a massive increase in the blue fractions at the capillary barrier sections.

The massive increase in the slope values of the sample images from Kolsters, Serneus, Sertig and SLF signifies the presence of capillary barrier in the sample images from the four localities.

6 Conclusion

This study showed that the movement of sprinkled brilliant blue FCF dye tracer through SNOW PACK can be used to determine the flow characterization of rain-on-snow experiments. A threshold methodology was adopted in the classification of the intensities of blue colours as a result of movement of the sprinkled brilliant blue FCF dye tracer through the SNOW PACK. Flow characteristics R package was built with functions such as threshold application function to return image2D plots of sample image input and image threshold data, function to determine the distribution of blues in the sample image, function to determine the blue fraction of length and depth pixels of the sample image, and function to determine the slope of blue fraction of length and depth pixels of the sample image.

From the returned plots of the threshold application on sample images, more than 70% of the sample image blue distribution that belongs to the darkblue colour classification appeared to be part of the sections that formed capillary barrier and preferential flow structures, although some sections that belongs to the darkblue colour classification formed ice layer structures. From this study capillary barriers and ice layer structures are difficult to differentiate, future image processing methodology will be adopted in order to be able to differentiate between capillary barrier structures and ice layer structures. Sample image sections that belongs to the royalblue3 colour classification can belong to either capillary barrier structures, preferential flow structures or matrix flow structures. More than 90% of the sample image pixels that belong to the lightskyblue1 colour classification was part of the pixels that formed the matrix flow structures.

Table 5 was returned from the application of flow characteristics package's blue distribution function, all the blue colours made up 98.84% of the Klosters sample image, royalblue3 colour classification has the highest proportion of all the blues, as a result of this the sample image is said to be dominated by matrix flow structures, this matrix flow structures are consist of mostly royalblue3 colour classification. From Table 6 the sample image from Serneus locality is said to be distributed with 21.89% of all the blues, this sample image is said to comprise of capillary barrier and preferential flow structures. Table 6 shows that 3.73% of all the blues are present in the Sertig sample image, this sample image is said to comprise of only capillary barrier and preferential flow. In Table 7 78.53% of all the blues are present in the sample image from SLF locality, 46.33% of the 78.53% of the blues were dominated by lightskyblue1 which play the highest proportion role in the matrix flow structure of the sample image, the darkblue and royalblue3 image classifications formed the capillary barrier and preferential flow structures.

The length and depth blue fraction plots from the length and depth blue fraction function application represent the intensities of all the blue classifications in the sample image per pixel. The slope of the length and depth blue fraction plots from the slope length and depth blue fraction function represent the blue changes per pixel. Blue colour classifications with uniform changes indicates matrix flow structure, blue colour classifications with a lot of changes indicates preferential flow or capillary barrier structure.

From this study it is recommended that the sample image collection procedure should be improved, the future rain-on-snow experiment images should focus more on the vertical snow section that displays the flow characteristics, such as matrix flow structures, preferential flow structures and capillary barrier. Shadows of the rain-on-snow equipment and snow contour should be avoid in future sample image collection technique, the presence of shadows on sample images result into overlap of grey colours on blue colours upon determination of threshold conditions.

The future work of this study will feature the development of flow structure identification function, upon application, this function will be able to determine the number of matrix flow, preferential flow and capillary barrier that made up the multiple number of images. This feature will also be built into a web interface whereby multiple rain-on-snow experiment sample images can be uploaded, the output of this functions such as, 2D image plot, a table showing the blue distribution of the image, plots showing the length and depth of the blue fractions of the image, slope of the length and depth blue fractions of the image and the new flow structure identification function will be displayed on the web interface on demand.

7 References

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8 Appendices

Table 9 RGB mean values of blue cuts

Mean of blue cuts	Mean values of blue cuts in the red channel	Mean values of blue cuts in the green channel	Mean values of blue cuts in the blue channel
blue_1_mean	0.59417892	0.73878676	0.92267157
blue_2_mean	0.51875000	0.55196078	0.66274510
blue_3_mean	0.41072304	0.56084559	0.74571078
blue_4_mean	0.28180147	0.51317402	0.72910539
blue_5_mean	0.37898284	0.53915441	0.75520833
blue_6_mean	0.26960784	0.60949755	0.85900735
blue_7_mean	0.11703431	0.39240196	0.70018382
blue_8_mean	0.08933824	0.21335784	0.58198529
blue_9_mean	0.06672794	0.21574755	0.57064951
blue_10_mean	0.08376225	0.19485294	0.56507353
blue_11_mean	0.07610294	0.19485294	0.58786765
blue_12_mean	0.08045343	0.13535539	0.41378676
blue_13_mean	0.11556373	0.19834559	0.41311275
blue_14_mean	0.08455882	0.16691176	0.38210784
blue_15_mean	0.04938725	0.10612745	0.45974265
blue_16_mean	0.07242647	0.12487745	0.28762255
blue_17_mean	0.06862745	0.11862745	0.29705882
blue_18_mean	0.06470588	0.05533088	0.25459559
blue_19_mean	0.06262255	0.04840686	0.17781863
blue_20_mean	0.05514706	0.04730392	0.09828431
blue_21_mean	0.21317402	0.35680147	0.49013480
blue_22_mean	0.22959559	0.34852941	0.44178922

Table 10 RGB mean values of grey cuts

Mean of grey cuts	Mean values of grey cuts in the red channel	Mean values of grey cuts in the green channel	Mean values of grey cuts in the blue channel
grey_1_mean	0.7807598	0.6984069	0.7337010
grey_2_mean	0.8783701	0.7960172	0.8313113
grey_3_mean	0.7530025	0.6628064	0.7020221
grey_4_mean	0.7588848	0.6726103	0.7196691
grey_5_mean	0.7374387	0.6590074	0.6943015
grey_6_mean	0.7334559	0.6511029	0.6863971
grey_7_mean	0.7493873	0.6670343	0.7023284
grey_8_mean	0.8216912	0.7314951	0.7707108
grey_9_mean	0.7901961	0.7000000	0.7392157
grey_10_mean	0.7097426	0.6430760	0.6744485
grey_11_mean	0.7902574	0.6430760	0.7471201
grey_12_mean	0.7313725	0.6529412	0.6882353
grey_13_mean	0.7333333	0.6666667	0.6980392
grey_14_mean	0.7393382	0.6569853	0.6922794
grey_15_mean	0.6686887	0.6098652	0.6373162
grey_16_mean	0.6407475	0.5946691	0.6275123
grey_17_mean	0.5995711	0.5456495	0.5878064
grey_18_mean	0.5921569	0.5294118	0.5686275
grey_19_mean	0.5724877	0.5215074	0.5607230
grey_20_mean	0.5451593	0.5020221	0.5333946
grey_21_mean	0.3704657	0.3704657	0.3783088
grey_22_mean	0.3371324	0.3292892	0.3410539
grey_23_mean	0.3195466	0.3117034	0.3156250
grey_24_mean	0.3215074	0.3136642	0.3254289
grey_25_mean	0.3118260	0.3039828	0.3079044
grey_26_mean	0.3158088	0.3079657	0.3118873
grey_27_mean	0.3078431	0.3000000	0.3039216
grey_28_mean	0.2104575	0.2026144	0.2065359

Table 11 RGB mean values of white cuts

Mean on white cuts	Mean values of white cuts in the red channel	Mean values of white cuts in the green channel	Mean values of white cuts in the blue channel
white_1_mean	0.9990196	0.9990196	0.9990196
white_2_mean	0.9898284	0.9914216	0.9937500
white_3_mean	0.9635417	0.9786152	0.9897059
white_4_mean	0.9563725	0.9716912	0.9835172
white_5_mean	0.9950980	0.9950980	0.9974265
white_6_mean	0.9978554	0.9978554	0.9978554
white_7_mean	0.9813725	0.9852941	0.9947304
white_8_mean	0.9686887	0.9651961	0.9838235
white_9_mean	0.9581495	0.9620711	0.9773897
white_10_mean	0.9636029	0.9636029	0.9714461
white_11_mean	0.9675245	0.9636029	0.9855392
white_12_mean	0.9530637	0.9515931	0.9638480
white_13_mean	0.9615196	0.9683824	0.9827819
white_14_mean	0.8549020	0.8588235	0.8745098
white_15_mean	0.9413603	0.9492034	0.9452819
white_16_mean	0.9411152	0.9420343	0.9449142
white_17_mean	0.8933211	0.8972426	0.9129289
white_18_mean	0.9501838	0.9541054	0.9680760
white_19_mean	0.9004902	0.9034314	0.9019608
white_20_mean	0.8633578	0.9636029	0.8633578