ICESat-2 Atlas Products

This *second* vignette relies on the computation of *time specific orbits* (as was the case in the *first* vignette too) and explains how to use the 'atl06' *ATLAS OpenAltimetry* product (additional use cases can be found in the *Examples section* of the R package documentation). We'll restrict the Area of Interest (AOI) to one of the *Global glaciated areas* and specifically to the Greenland Ice Sheet, which is the second-largest ice body in the world, after the Antarctic ice sheet.

Based on the OpenAltimetry documentation for the *ATL06* (ATLAS/ICESat-2 L3A Land Ice Height, Version 4) Product, *"This data set (ATL06) provides geolocated, land-ice surface heights (above the WGS 84 ellipsoid, ITRF2014 reference frame), plus ancillary parameters that can be used to interpret and assess the quality of the height estimates."*

We'll use 2 different time periods of the year (*winter* and *summer*) to observe potential differences on the *East* part of the *'Greenland Ice Sheet'* using the *Land Ice Height (ATL06)* Product and specifically we'll use,

- for the winter (2020, 2021) the **RGT__cycle__9** and **RGT__cycle__10** (from **2020-12-15** to **2021-02-15**)
- for the summer (2021) the **RGT__cycle__11** and **RGT__cycle__12** (from **2021-06-15** to **2021-08-15**)

First, we'll compute the time *specific orbits* for both periods,

```r
pkgs = c('IceSat2R', 'sf', 'mapview', 'data.table', 'stargazer', 'glue', 'utils',
         'reshape2', 'plotly', 'magrittr', 'geodist', 'CopernicusDEM', 'terra')
load_pkgs = lapply(pkgs, require, character.only = TRUE)  # load required R packages

sf::sf_use_s2(use_s2 = FALSE)                         # disable 's2' in this vignette
mapview::mapviewOptions(leafletHeight = '600px',
                        leafletWidth = '700px')       # applies to all leaflet maps
```

```r
#....................
# winter (2020, 2021)
#....................

start_date_w = "2020-12-15"
end_date_w = "2021-02-15"

rgt_winter = time_specific_orbits(date_from = start_date_w,
                                  date_to = end_date_w,
                                  RGT_cycle = NULL,
                                  download_method = 'curl',
                                  threads = parallel::detectCores(),
                                  verbose = TRUE)

# ICESAT-2 orbits: 'Earliest-Date' is '2018-10-13'  'Latest-Date' is '2022-06-21'
# ----------------------------------------------------
# The .zip file of 'RGT_cycle_9' will be downloaded ...
# ----------------------------------------------------
#   % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
#                                  Dload  Upload   Total   Spent    Left  Speed
# 100  140M  100  140M    0     0  3662k      0  0:00:39  0:00:39 --:--:-- 2904k
```

```
# The downloaded .zip file will be extracted in the '/tmp/RtmpPleeLI/RGT_cycle_9' directory .
# Download and unzip the RGT_cycle_9 .zip file: Elapsed time: 0 hours and 0 minutes and 41 sec
# 138 .kml files will be processed ...
# Parallel processing of 138 .kml files using  8  threads starts ...
# The 'description' column of the output data will be processed ...
# The temproary files will be removed ...
# Processing of cycle 'RGT_cycle_9': Elapsed time: 0 hours and 1 minutes and 9 seconds.
# -----------------------------------------------------
# The .zip file of 'RGT_cycle_10' will be downloaded ...
# -----------------------------------------------------
#   % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
#                                  Dload  Upload   Total   Spent    Left  Speed
# 100  140M  100  140M    0     0  3795k      0  0:00:37  0:00:37 --:--:-- 3841k
# The downloaded .zip file will be extracted in the '/tmp/RtmpPleeLI/RGT_cycle_10' directory .
# Download and unzip the RGT_cycle_10 .zip file: Elapsed time: 0 hours and 0 minutes and 40 sec
# 824 .kml files will be processed ...
# Parallel processing of 824 .kml files using  8  threads starts ...
# The 'description' column of the output data will be processed ...
# The temproary files will be removed ...
# Processing of cycle 'RGT_cycle_10': Elapsed time: 0 hours and 7 minutes and 53 seconds.
# Total Elapsed time: 0 hours and 10 minutes and 25 seconds.
```

```
rgt_winter

# Simple feature collection with 91390 features and 14 fields
# Geometry type: POINT
# Dimension:     XY
# Bounding box:  xmin: -179.9029 ymin: -87.66478 xmax: 179.9718 ymax: 87.32805
# CRS:           4326
# First 10 features:
#    Name timestamp begin  end  altitudeMode tessellate extrude visibility drawOrder icon  RGT
# 1           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
# 2           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
# 3           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
# 4           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
# 5           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
# 6           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
# 7           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
# 8           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
# 9           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
# 10          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1250
```

for the winter period, it took approximately 10 min. to download and process the 962 .kml files utilizing 8 threads and then return an 'sf' (simple features) object. We'll do the same for the summer period,

```
#..............
# summer (2021)
#..............

start_date_s = "2021-06-15"
end_date_s = "2021-08-15"

rgt_summer = time_specific_orbits(date_from = start_date_s,
```

```r
                                  date_to = end_date_s,
                                  RGT_cycle = NULL,
                                  download_method = 'curl',
                                  threads = parallel::detectCores(),
                                  verbose = TRUE)

# ICESAT-2 orbits: 'Earliest-Date' is '2018-10-13'  'Latest-Date' is '2022-06-21'
# ----------------------------------------------------
# The .zip file of 'RGT_cycle_11' will be downloaded ...
# ----------------------------------------------------
#   % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
#                                  Dload  Upload   Total   Spent    Left  Speed
# 100  140M  100  140M    0     0  3440k      0  0:00:41  0:00:41 --:--:-- 4227k
# The downloaded .zip file will be extracted in the '/tmp/RtmpPleeLI/RGT_cycle_11' directory .
# Download and unzip the RGT_cycle_11 .zip file: Elapsed time: 0 hours and 0 minutes and 44 sec
# 142 .kml files will be processed ...
# Parallel processing of 142 .kml files using  8  threads starts ...
# The 'description' column of the output data will be processed ...
# The temproary files will be removed ...
# Processing of cycle 'RGT_cycle_11': Elapsed time: 0 hours and 1 minutes and 30 seconds.
# ----------------------------------------------------
# The .zip file of 'RGT_cycle_12' will be downloaded ...
# ----------------------------------------------------
#   % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
#                                  Dload  Upload   Total   Spent    Left  Speed
# 100  140M  100  140M    0     0  3204k      0  0:00:44  0:00:44 --:--:-- 2333k
# The downloaded .zip file will be extracted in the '/tmp/RtmpPleeLI/RGT_cycle_12' directory .
# Download and unzip the RGT_cycle_12 .zip file: Elapsed time: 0 hours and 0 minutes and 47 sec
# 820 .kml files will be processed ...
# Parallel processing of 820 .kml files using  8  threads starts ...
# The 'description' column of the output data will be processed ...
# The temproary files will be removed ...
# Processing of cycle 'RGT_cycle_12': Elapsed time: 0 hours and 8 minutes and 20 seconds.
# Total Elapsed time: 0 hours and 11 minutes and 22 seconds.
```

```r
rgt_summer

# Simple feature collection with 89965 features and 14 fields
# Geometry type: POINT
# Dimension:     XY
# Bounding box:  xmin: -179.9861 ymin: -87.66478 xmax: 179.9393 ymax: 87.32805
# CRS:           4326
# First 10 features:
#    Name timestamp begin  end  altitudeMode tessellate extrude visibility drawOrder icon  RGT
# 1            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1256
# 2            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1256
# 3            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1256
# 4            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1256
# 5            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1256
# 6            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1256
# 7            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1256
# 8            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1256
# 9            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1256
```

```
# 10            <NA>  <NA> <NA> clampToGround         -1       0          1         NA <NA> 1256
```

for the summer it took approximately the same time as for winter to process the 962 .kml files of the 2 Reference Ground Track (RGT) cycles. We'll proceed to find the intersection of these 2 time periods (winter, summer) with the area of the *East 'Greenland Ice Sheet'*,

```
#...............................
# load the 'Greenland Ice Sheet'
#...............................

data(ne_10m_glaciated_areas)

greenl_sh = subset(ne_10m_glaciated_areas, name == "Greenland Ice Sheet")
greenl_sh
```

We'll continue with one of the 2 Greenland Ice Sheet parts ('East')

```
greenl_sh_east = greenl_sh[2, ]
# mapview::mapview(greenl_sh_east, legend = F)

#...................................................
# create the bounding of the selected area because
# it's required for the 'OpenAltimetry' functions this
#  will increase the size of the initial east area
#...................................................

bbx_greenl_sh_east = sf::st_bbox(obj = greenl_sh_east)
sfc_bbx_greenl_sh_east = sf::st_as_sfc(bbx_greenl_sh_east)
# mapview::mapview(sfc_bbx_greenl_sh_east, legend = F)
```

```
#.............................................
# intersection with the computed "winter" RGT's
#.............................................

inters_winter = sf::st_intersects(x = sfc_bbx_greenl_sh_east,
                                  y = sf::st_geometry(rgt_winter),
                                  sparse = TRUE)

#.....................
# matched (RGT) tracks
#.....................

df_inters_winter = data.frame(inters_winter)
rgt_subs_winter = rgt_winter[df_inters_winter$col.id, , drop = FALSE]
rgt_subs_winter

# Simple feature collection with 1079 features and 14 fields
# Geometry type: POINT
# Dimension:     XY
# Bounding box:  xmin: -53.06014 ymin: 61.26295 xmax: -19.23143 ymax: 80.40264
# CRS:           4326
# First 10 features:
#     Name timestamp begin  end  altitudeMode tessellate extrude visibility drawOrder icon  RGT
# 117           <NA>  <NA> <NA> clampToGround         -1       0          1         NA <NA> 1251
```

```
# 207          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1252
# 208          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1252
# 209          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1252
# 210          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1252
# 211          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1252
# 212          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1252
# 977          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1260
# 978          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1260
# 979          <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1260
```

From the initial 91390 coordinate points, 1079 of the winter period intersect with the bounding box of our Area of Interest (AOI). We'll do the same for the summer period,

```
#...............................................
# intersection with the computed "summer" RGT's
#...............................................

inters_summer = sf::st_intersects(x = sfc_bbx_greenl_sh_east,
                                  y = sf::st_geometry(rgt_summer),
                                  sparse = TRUE)

#.....................
# matched (RGT) tracks
#.....................

df_inters_summer = data.frame(inters_summer)
rgt_subs_summer = rgt_summer[df_inters_summer$col.id, , drop = FALSE]
rgt_subs_summer

# Simple feature collection with 1066 features and 14 fields
# Geometry type: POINT
# Dimension:     XY
# Bounding box:  xmin: -53.06014 ymin: 61.26295 xmax: -19.23143 ymax: 80.40264
# CRS:           4326
# First 10 features:
#       Name timestamp begin  end  altitudeMode tessellate extrude visibility drawOrder icon  RGT
# 407            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1260
# 408            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1260
# 409            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1260
# 410            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1260
# 411            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1260
# 412            <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1260
# 1062           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1267
# 1063           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1267
# 1064           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1267
# 1065           <NA>  <NA> <NA> clampToGround         -1       0          1        NA <NA> 1267
```

for the summer period, the intersected points are 1066. Based on these 2 intersected objects of winter and summer we'll also have to find the common RGT's that we'll use for comparison purposes,

```
#................................................
# compute the unique RGT's for summer and winter
#................................................
```

```r
unq_rgt_winter = unique(rgt_subs_winter$RGT)
unq_rgt_summer = unique(rgt_subs_summer$RGT)
dif_rgt = setdiff(unique(rgt_subs_winter$RGT), unique(rgt_subs_summer$RGT))

cat(glue::glue("Number of RGT winter: {length(unq_rgt_winter)}"), '\n')
# Number of RGT winter: 230

cat(glue::glue("Number of RGT summer: {length(unq_rgt_summer)}"), '\n')
# Number of RGT summer: 227

cat(glue::glue("Difference in RGT: {length(dif_rgt)}"), '\n')
# Difference in RGT: 3


#......................
# find the intersection
#......................

inters_rgts = intersect(unq_rgt_winter, unq_rgt_summer)


#...................................................
# create the subset data RGT's for summer and winter
#...................................................

idx_w = which(rgt_subs_winter$RGT %in% inters_rgts)
subs_rgt_winter = rgt_subs_winter[idx_w, , drop = F]

idx_s = which(rgt_subs_summer$RGT %in% inters_rgts)
subs_rgt_summer = rgt_subs_summer[idx_s, , drop = F]
```

Then we have to verify that the intersected *time specific orbit RGT's* match the *OpenAltimetry Tracks* for both winter and summer,

```r
#.........................................................
# we keep the relevant columns and remove duplicated
# Dates and RGTs to iterate over each pair of observations
#.........................................................

#.......
# winter
#.......

subs_rgt_w_trc = subs_rgt_winter[, c('RGT', 'Date_time')]
subs_rgt_w_trc$Date_time = as.character(as.Date(subs_rgt_w_trc$Date_time))
dups_w = which(duplicated(sf::st_drop_geometry(subs_rgt_w_trc)))
subs_rgt_w_trc = subs_rgt_w_trc[-dups_w, ]

ver_trc_winter = verify_RGTs(nsidc_rgts = subs_rgt_w_trc,
                             bbx_aoi = bbx_greenl_sh_east,
                             verbose = TRUE)

# split(ver_trc_winter, by = 'Date_time')
```

```r
colnames(ver_trc_winter) = c('date_winter', 'RGT_OpenAlt', 'RGT_NSIDC')

#.......
# summer
#.......

subs_rgt_s_trc = subs_rgt_summer[, c('RGT', 'Date_time')]
subs_rgt_s_trc$Date_time = as.character(as.Date(subs_rgt_s_trc$Date_time))
dups_s = which(duplicated(sf::st_drop_geometry(subs_rgt_s_trc)))
subs_rgt_s_trc = subs_rgt_s_trc[-dups_s, ]

ver_trc_summer = verify_RGTs(nsidc_rgts = subs_rgt_s_trc,
                             bbx_aoi = bbx_greenl_sh_east,
                             verbose = TRUE)

colnames(ver_trc_summer) = c('date_summer', 'RGT_OpenAlt', 'RGT_NSIDC')

#.............
# merge by RGT
#.............

rgts_ws = merge(ver_trc_winter[, 1:2], ver_trc_summer[, 1:2], by = 'RGT_OpenAlt')
colnames(rgts_ws) = c('RGT', 'date_winter', 'date_summer')
rgts_ws

#        RGT date_winter date_summer
#   1:     2  2020-12-24  2021-06-23
#   2:    10  2020-12-24  2021-06-24
#   3:    11  2020-12-24  2021-06-24
#   4:    17  2020-12-25  2021-06-24
#   5:    18  2020-12-25  2021-06-24
#  ---
# 226: 1366  2020-12-22  2021-06-22
# 227: 1367  2020-12-22  2021-06-22
# 228: 1373  2020-12-23  2021-06-22
# 229: 1374  2020-12-23  2021-06-22
# 230: 1382  2020-12-23  2021-06-23
```

Now that we have the available RGT's for the winter and summer Dates we have to create the *5-degree grid of the Greenland Ice sheet bounding box*, because the *'atl06' OpenAltimetry* product allows queries up to 5x5 degrees. Rather than a 5-degree grid, we will create a 4.5-degree to avoid any *'over limit' OpenAltimetry API* errors,

```r
greenl_grid = degrees_to_global_grid(minx = as.numeric(bbx_greenl_sh_east['xmin']),
                                     maxx = as.numeric(bbx_greenl_sh_east['xmax']),
                                     maxy = as.numeric(bbx_greenl_sh_east['ymax']),
                                     miny = as.numeric(bbx_greenl_sh_east['ymin']),
                                     degrees = 4.5,
                                     square_geoms = TRUE,
                                     crs_value = 4326,
                                     verbose = TRUE)
```

In the beginning, we created the bounding box of the *East 'Greenland Ice Sheet'* (the *bbx_greenl_sh_east* object), which automatically increased the dimensions of the Area of Interest (AOI). Now, that we have the up to 5x5 degree grid we can keep the grid cells that intersect with our initial area,

```
inters_init = sf::st_intersects(sf::st_geometry(greenl_sh_east), greenl_grid)
inters_init = data.frame(inters_init)
inters_init = inters_init$col.id

greenl_grid_subs = greenl_grid[inters_init, , drop = F]

# Simple feature collection with 27 features and 1 field
# Geometry type: POLYGON
# Dimension:     XY
# Bounding box:  xmin: -53.10888 ymin: 60.11961 xmax: -17.10888 ymax: 82.61961
# CRS:           EPSG:4326
# First 10 features:
#                          geometry             area
# 1  POLYGON ((-53.10888 60.1196... 116709.30 [km^2]
# 2  POLYGON ((-48.60888 60.1196... 116709.30 [km^2]
# 3  POLYGON ((-44.10888 60.1196... 116709.30 [km^2]
# 9  POLYGON ((-53.10888 64.6196...  98928.06 [km^2]
# 10 POLYGON ((-48.60888 64.6196...  98928.06 [km^2]
# 11 POLYGON ((-44.10888 64.6196...  98928.06 [km^2]
# 12 POLYGON ((-39.60888 64.6196...  98928.06 [km^2]
# 13 POLYGON ((-35.10888 64.6196...  98928.06 [km^2]
# 14 POLYGON ((-30.60888 64.6196...  98928.06 [km^2]
# 15 POLYGON ((-26.10888 64.6196...  98928.06 [km^2]
```

We also have to make sure that the *winter* and *summer* data intersect with the up to 5x5 degree grid,

```
#............
# winter join
#............

subs_join_w = sf::st_join(x = greenl_grid_subs,
                          y = subs_rgt_w_trc,
                          join = sf::st_intersects,
                          left = FALSE)

subs_join_w = sf::st_as_sfc(unique(sf::st_geometry(subs_join_w)), crs = 4326)
subs_join_w

# Geometry set for 9 features
# Geometry type: POLYGON
# Dimension:     XY
# Bounding box:  xmin: -53.10888 ymin: 60.11961 xmax: -17.10888 ymax: 82.61961
# CRS:           EPSG:4326
# First 5 geometries:
# POLYGON ((-53.10888 60.11961, -48.60888 60.1196...
# POLYGON ((-48.60888 60.11961, -44.10888 60.1196...
# POLYGON ((-44.10888 60.11961, -39.60888 60.1196...
# POLYGON ((-26.10888 73.61961, -21.60888 73.6196...
# POLYGON ((-21.60888 73.61961, -17.10888 73.6196...
```

```
#............
# summer join
#............
```

```r
subs_join_s = sf::st_join(x = greenl_grid_subs,
                          y = subs_rgt_s_trc,
                          join = sf::st_intersects,
                          left = FALSE)

subs_join_s = sf::st_as_sfc(unique(sf::st_geometry(subs_join_s)), crs = 4326)
subs_join_s

# Geometry set for 9 features
# Geometry type: POLYGON
# Dimension:     XY
# Bounding box:  xmin: -53.10888 ymin: 60.11961 xmax: -17.10888 ymax: 82.61961
# CRS:           EPSG:4326
# First 5 geometries:
# POLYGON ((-53.10888 60.11961, -48.60888 60.1196...
# POLYGON ((-48.60888 60.11961, -44.10888 60.1196...
# POLYGON ((-44.10888 60.11961, -39.60888 60.1196...
# POLYGON ((-26.10888 73.61961, -21.60888 73.6196...
# POLYGON ((-21.60888 73.61961, -17.10888 73.6196...
```

Since the *winter* and *summer* intersected spatial data are identical,

```r
identical(subs_join_w, subs_join_s)
# [1] TRUE
```

we'll iterate only over one of the two 'sfc' objects.

We can also visualize the available areas after the *sf-join* between the *winter and summer spatial data* and the *East 'Greenland Ice Sheet'*,

```r
mapview::mapview(subs_join_s, legend = F)
```

We can proceed that way and download the available **'atl06' Land Ice Height** data using the **get_level3a_data()** function that takes a time interval and a bounding box as input (the bounding box will consist of up to a 5x5 degree grid cells). To reduce the computation time in this vignette we'll restrict the for-loop to the first 5 Greenland Grid Cells,

```r
join_geoms = 1:5
subs_join_reduced = subs_join_s[join_geoms]

mapview::mapview(subs_join_reduced, legend = F)
```

and to the following RGTs,

RGT	N_rows_winter	N_rows_summer	index	greenland_cell
33	113, 257	101, 784	geom_idx_3_RGT_33	3
41	68, 947	10, 932	geom_idx_1_RGT_41	1
56	109, 744	106, 088	geom_idx_3_RGT_56	3
94	135, 225	75, 514	geom_idx_2_RGT_94	2
108	114, 447	53, 456	geom_idx_5_RGT_108	5
284	148, 999	126, 945	geom_idx_4_RGT_284	4
421	145, 755	103, 124	geom_idx_5_RGT_421	5
422	133, 465	198	geom_idx_2_RGT_422	2
437	103, 590	17, 765	geom_idx_3_RGT_437	3
460	116, 873	36, 559	geom_idx_1_RGT_460	1
475	71, 502	109, 423	geom_idx_3_RGT_475	3
521	95, 862	50, 574	geom_idx_1_RGT_521	1
544	107, 391	77, 639	geom_idx_1_RGT_544	1
658	145, 388	9, 776	geom_idx_2_RGT_658	2
681	148, 162	82, 325	geom_idx_2_RGT_681	2
787	152, 420	34, 339	geom_idx_4_RGT_787	4
794	142, 902	125, 643	geom_idx_4_RGT_794	4
1, 290	152, 562	152, 052	geom_idx_4_RGT_1290	4
1, 366	134, 507	69, 385	geom_idx_5_RGT_1366	5
1, 373	113, 191	103, 279	geom_idx_5_RGT_1373	5

```
#...............................................
# keep a subset of RGTs and Greenland Grid cells
#...............................................

RGTs = c(33, 41, 56, 94, 108, 284,
         421, 422, 437, 460, 475,
         521, 544, 658, 681, 787,
         794, 1290, 1366, 1373)

#......................
# update the input data
#......................

rgts_ws_reduced = subset(rgts_ws, RGT %in% RGTs)
rgts_ws_RGT = rgts_ws_reduced$RGT


#..........................................................
# we'll loop over the RGT's for the Date start and Date end
#..........................................................

# length(unique(rgts_ws_reduced$RGT)) == nrow(rgts_ws_reduced)   # check for duplicated RGT's
rgts_ws_reduced$date_summer = as.Date(rgts_ws_reduced$date_summer)
rgts_ws_reduced$date_winter = as.Date(rgts_ws_reduced$date_winter)
min_max_dates = apply(rgts_ws_reduced[, -1], 2, function(x) c(min(x), max(x)))

start_w = as.character(min_max_dates[1, 'date_winter'])
end_w = as.character(min_max_dates[2, 'date_winter'])

start_s = as.character(min_max_dates[1, 'date_summer'])
```

```r
end_s = as.character(min_max_dates[2, 'date_summer'])

dat_out_w = dat_out_s = logs_out = list()
LEN = length(subs_join_reduced)
LEN_rgt = length(rgts_ws_RGT)

t_start = proc.time()
for (idx_grid in 1:LEN) {

  geom_iter = subs_join_reduced[idx_grid]
  bbx_iter = sf::st_bbox(obj = geom_iter, crs = 4326)

  for (j in 1:LEN_rgt) {

    message("Greenland Geom: ",
            idx_grid, "/",
            LEN, "   RGT-index: ",
            j, "/",
            LEN_rgt, "\r",
            appendLF = FALSE)

    utils::flush.console()

    track_i = rgts_ws_RGT[j]
    name_iter = glue::glue("geom_idx_{idx_grid}_RGT_{track_i}")

    iter_dat_winter = get_level3a_data(minx = as.numeric(bbx_iter['xmin']),
                                       miny = as.numeric(bbx_iter['ymin']),
                                       maxx = as.numeric(bbx_iter['xmax']),
                                       maxy = as.numeric(bbx_iter['ymax']),
                                       startDate = start_w,
                                       endDate = end_w,
                                       trackId = track_i,
                                       beamName = NULL,        # return data of all 6 beams
                                       product = 'atl06',
                                       client = 'portal',
                                       outputFormat = 'csv',
                                       verbose = FALSE)

    iter_dat_summer = get_level3a_data(minx = as.numeric(bbx_iter['xmin']),
                                       miny = as.numeric(bbx_iter['ymin']),
                                       maxx = as.numeric(bbx_iter['xmax']),
                                       maxy = as.numeric(bbx_iter['ymax']),
                                       startDate = start_s,
                                       endDate = end_s,
                                       trackId = track_i,
                                       beamName = NULL,        # return data of all 6 beams
                                       product = 'atl06',
                                       client = 'portal',
                                       outputFormat = 'csv',
                                       verbose = FALSE)

    NROW_w = nrow(iter_dat_winter)
```

```r
    NROW_s = nrow(iter_dat_summer)

    if (NROW_s > 0 & NROW_w > 0) {
      iter_logs = list(RGT = track_i,
                       N_rows_winter = NROW_w,
                       N_rows_summer = NROW_s)

      logs_out[[name_iter]] = data.table::setDT(iter_logs)
      dat_out_w[[name_iter]] = iter_dat_winter
      dat_out_s[[name_iter]] = iter_dat_summer
    }
  }
}
IceSat2R:::compute_elapsed_time(time_start = t_start)
# Elapsed time: 0 hours and 6 minutes and 15 seconds.
```

We then sort and observe the output LOGs,

```r
logs_out_dtbl = data.table::rbindlist(logs_out)
logs_out_dtbl$index = names(dat_out_w)
```

```r
logs_out_dtbl = logs_out_dtbl[order(logs_out_dtbl$N_rows_winter, decreasing = T), ]

stargazer::stargazer(logs_out_dtbl,
                     summary = FALSE,
                     rownames = FALSE,
                     header = FALSE,
                     float = FALSE,
                     table.placement = 'h',
                     title = 'LOGs')
```

RGT	N_rows_winter	N_rows_summer
1, 290	152, 562	152, 052
787	152, 420	34, 339
284	148, 999	126, 945
681	148, 162	82, 325
421	145, 755	103, 124
658	145, 388	9, 776
794	142, 902	125, 643
94	135, 225	75, 514
1, 366	134, 507	69, 385
422	133, 465	198
460	116, 873	36, 559
108	114, 447	53, 456
33	113, 257	101, 784
1, 373	113, 191	103, 279
56	109, 744	106, 088
544	107, 391	77, 639
437	103, 590	17, 765
521	95, 862	50, 574
475	71, 502	109, 423
41	68, 947	10, 932
41	47, 950	2, 877
33	36, 639	26, 796
108	11, 600	104
475	3, 951	3, 650
284	3, 572	3, 564
94	2, 110	1, 963

We'll first process and visualize one of Greenland's geometries and RGT,

```
#...............................
# we pick one with approx. same
# rows for both summer and winter
#...............................

# names(dat_out_w)
Greenland_Geom_index = 4
RGT = 1290

sublist_name = glue::glue("geom_idx_{Greenland_Geom_index}_RGT_{RGT}")

#..............
# winter sublist
#..............

w_subs = dat_out_w[[sublist_name]]
w_subs


#                date segment_id longitude latitude      h_li atl06_quality_summary track_id beam
#      1: 2020-12-17     566420 -22.43278 78.11961  553.5237                     0     1290 gt1l
#      2: 2020-12-17     566421 -22.43294 78.11943  553.5601                     0     1290 gt1l
#      3: 2020-12-17     566422 -22.43310 78.11926  553.5809                     0     1290 gt1l
```

```
#      4: 2020-12-17     566423 -22.43326 78.11908  553.5331                    0      1290 gt1l
#      5: 2020-12-17     566424 -22.43341 78.11891  553.5400                    0      1290 gt1l
#     ---
# 152558: 2020-12-17     591901 -25.70488 73.62039 1640.8195                    0      1290 gt3r
# 152559: 2020-12-17     591902 -25.70496 73.62021 1650.2201                    0      1290 gt3r
# 152560: 2020-12-17     591903 -25.70505 73.62003 1657.0470                    0      1290 gt3r
# 152561: 2020-12-17     591904 -25.70514 73.61985 1665.8877                    0      1290 gt3r
# 152562: 2020-12-17     591905 -25.70523 73.61968 1675.1165                    0      1290 gt3r
```

```
#...............
# summer sublist
#...............

s_subs = dat_out_s[[sublist_name]]
s_subs

#                date segment_id longitude latitude      h_li atl06_quality_summary track_id beam
#      1: 2021-06-17     566420 -22.43270 78.11961  554.1851                    0      1290 gt1l
#      2: 2021-06-17     566421 -22.43286 78.11943  554.2042                    0      1290 gt1l
#      3: 2021-06-17     566422 -22.43302 78.11925  554.1635                    0      1290 gt1l
#      4: 2021-06-17     566423 -22.43318 78.11908  554.1546                    0      1290 gt1l
#      5: 2021-06-17     566424 -22.43334 78.11890  554.2347                    0      1290 gt1l
#     ---
# 152048: 2021-06-17     591901 -25.70511 73.62039 1638.9667                    0      1290 gt3r
# 152049: 2021-06-17     591902 -25.70521 73.62022 1646.6494                    0      1290 gt3r
# 152050: 2021-06-17     591903 -25.70530 73.62004 1654.2173                    0      1290 gt3r
# 152051: 2021-06-17     591904 -25.70539 73.61986 1663.3259                    0      1290 gt3r
# 152052: 2021-06-17     591905 -25.70548 73.61968 1673.2574                    0      1290 gt3r
```

The OpenAltimetry Data Dictionary includes the definitions for the column names of the output data.tables (except for the *beam* column which appears in the *'level3a'* product of the OpenAltimetry API website),

- **segment_id**: *"Segment number, counting from the equator. Equal to the segment_id for the second of the two 20m ATL03 segments included in the 40m ATL06 segment"*
- **h_li**: *"Standard land-ice segment height determined by land ice algorithm, corrected for first-photon bias, representing the median-based height of the selected 'signal photon events' (PEs)"*
- **atl06_quality_summary**: *"The ATL06_quality_summary parameter indicates the best-quality subset of all ATL06 data. A 0.0 (zero) in this parameter implies that no data-quality tests have found a problem with the segment, a 1.0 (one) implies that some potential problem has been found. Users who select only segments with zero values for this flag can be relatively certain of obtaining high-quality data, but will likely miss a significant fraction of usable data, particularly in cloudy, rough, or low-surface-reflectance conditions."*
- **beam**: *the 6 (six) beams 'gt1l', 'gt1r', 'gt2l', 'gt2r', 'gt3l' or 'gt3r'*

The *Date* of the selected sublist for *winter* is '2020-12-17' whereas for *summer* is '2021-06-17'. We'll

- exclude the low-quality observations using the 'atl06_quality_summary' column
- keep specific columns ('date', 'segment_id', 'longitude', 'latitude', 'h_li', 'beam')
- rename the winter and summer columns by adding the '_winter' and '_summer' extension
- merge the remaining observations (winter, summer) based on the 'segment_id' and 'beam' columns
- create an additional column (*'dif_height'*) with the difference in height between the *'h_li_winter'* and *'h_li_summer'*

```
cols_keep = c('date', 'segment_id', 'longitude', 'latitude', 'h_li', 'beam')
```

```r
w_subs_hq = subset(w_subs, atl06_quality_summary == 0)
w_subs_hq = w_subs_hq[, ..cols_keep]
colnames(w_subs_hq) = glue::glue("{cols_keep}_winter")

s_subs_hq = subset(s_subs, atl06_quality_summary == 0)
s_subs_hq = s_subs_hq[, ..cols_keep]
colnames(s_subs_hq) = glue::glue("{cols_keep}_summer")

sw_hq_merg = merge(x = w_subs_hq,
                   y = s_subs_hq,
                   by.x = c('segment_id_winter', 'beam_winter'),
                   by.y = c('segment_id_summer', 'beam_summer'))

sw_hq_merg$dif_height = sw_hq_merg$h_li_winter - sw_hq_merg$h_li_summer

summary(sw_hq_merg$dif_height)

#     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
# -42.6563  -0.4222  -0.0854  -0.1567   0.0537  26.4173
```

the following code snippet will create the visualizations for the beams *"gt1l"* and *"gt1r"* for the selected subset,

```r
cols_viz = c('segment_id_winter', 'beam_winter', 'h_li_winter', 'h_li_summer')
ws_vis = sw_hq_merg[, ..cols_viz]
```

```r
ws_vis_mlt = reshape2::melt(ws_vis, id.vars = c('segment_id_winter', 'beam_winter'))
ws_vis_mlt = data.table::data.table(ws_vis_mlt, stringsAsFactors = F)
ws_vis_mlt_spl = split(ws_vis_mlt, by = 'beam_winter')
# BEAMS = names(ws_vis_mlt_spl)       # plot all beams
```

```r
#..................................
# function to plot each subplot beam
#..................................

plotly_beams = function(spl_data,
                        beam,
                        left_width,
                        left_height,
                        right_width,
                        right_height) {

  subs_iter = spl_data[[beam]]

  cat(glue::glue("Plot for Beam '{beam}' will be created ..."), '\n')

  #......................
  # plot for all segments
   #......................

    fig_lns = plot_ly(data = subs_iter,
                      x = ~segment_id_winter,
                      y = ~value,
                      color = ~variable,
```

```
                      colors = c("blue", "red"),
                      line = list(width = 2),
                      text =~glue::glue("land-ice-height: {value} Segment-id: {segment_id_winter}"),
                      hoverinfo = "text",
                      width = left_width,
                      height = left_height) %>%

    plotly::layout(xaxis = list(gridcolor = "grey", showgrid = T),
                   yaxis = list(gridcolor = "grey", showgrid = T)) %>%

    plotly::add_lines()

  #..............................
  # plot for a subset of segments
  #..............................

  segm_ids = 588326:588908     # this subset of segments show a big difference betw. summer and winter
  plt_title = glue::glue("Beam: '{beam}' ( Segments: from {min(segm_ids)} to {max(segm_ids)} )")
  subs_iter_segm = subset(subs_iter, segment_id_winter %in% segm_ids)

    fig_spl = plot_ly(data = subs_iter_segm,
                    x = ~segment_id_winter,
                    y = ~value,
                    color = ~variable,
                    colors = c("blue", "red"),
                    line = list(width = 2),
                    text =~glue::glue("land-ice-height: {value} Segment-id: {segment_id_winter}"),
                    hoverinfo = "text",
                    width = right_width,
                    height = right_height) %>%

    plotly::layout(xaxis = list(gridcolor = "grey", showgrid = T),
                   yaxis = list(gridcolor = "grey", showgrid = T)) %>%

    plotly::add_lines(showlegend = FALSE)

  both_plt = plotly::subplot(list(fig_lns, fig_spl), nrows=1, margin = 0.03, widths = c(0.7, 0.3)) %>%
    plotly::layout(title = plt_title)
  # plotly::export(p = both_plt, file = glue::glue('{beam}.png'))

  return(both_plt)
}
```

The output left plot shows all segment-id's for the *"gt1l"* and *"gt1r"* beams, whereas the right plot is restricted only to the segment-id's from 588326 to 588908 to highlight potential differences in land-ice-height between the winter and summer periods,

```
plt_gt1l = plotly_beams(spl_data = ws_vis_mlt_spl,
                        beam = "gt1l",
                        left_width = 1800,
                        left_height = 800,
                        right_width = 900,
                        right_height = 400)
```

```
## Plot for Beam 'gt1l' will be created ...
```

```
plt_gt1l
```

```
plt_gt1r = plotly_beams(spl_data = ws_vis_mlt_spl,
                        beam = "gt1r",
                        left_width = 1800,
                        left_height = 800,
                        right_width = 900,
                        right_height = 400)
```

```
## Plot for Beam 'gt1r' will be created ...
```

```
plt_gt1r
```

Finally, we can also add the elevation of the AOI for comparison purposes. We'll choose another Greenland Grid cell, RGT, and beams,

```
Greenland_Geom_index = 2
RGT = 33

sublist_name = glue::glue("geom_idx_{Greenland_Geom_index}_RGT_{RGT}")

w_subs = dat_out_w[[sublist_name]]
s_subs = dat_out_s[[sublist_name]]

cols_keep = c('date', 'segment_id', 'longitude', 'latitude', 'h_li', 'beam')

w_subs_hq = subset(w_subs, atl06_quality_summary == 0)
w_subs_hq = w_subs_hq[, ..cols_keep]
colnames(w_subs_hq) = glue::glue("{cols_keep}_winter")

s_subs_hq = subset(s_subs, atl06_quality_summary == 0)
s_subs_hq = s_subs_hq[, ..cols_keep]
colnames(s_subs_hq) = glue::glue("{cols_keep}_summer")

sw_hq_merg = merge(x = w_subs_hq,
                   y = s_subs_hq,
                   by.x = c('segment_id_winter', 'beam_winter'),
                   by.y = c('segment_id_summer', 'beam_summer'))
```

After merging the winter and summer data for the specific Grid Cell and RGT, I have to keep only one pair of (latitude, longitude) coordinates for visualization purposes. I'll compute the distance between the winter and summer coordinates (of each row) for the same *segment_id* and *beam* and I'll continue with the beams and observations that have the lowest difference in distance (for a fair comparison),

```
#...............................
# compute the pair-wise distance
#...............................

sw_hq_merg$dist_dif = geodist::geodist(x = sw_hq_merg[, c('longitude_winter', 'latitude_winter')],
                                       y = sw_hq_merg[, c('longitude_summer', 'latitude_summer')],
                                       paired = TRUE,
                                       measure = 'geodesic')
#.............
# split by beam
```

```r
#..............

spl_beam = split(sw_hq_merg, by = 'beam_winter')

#............................................
# compute the summary of the distance to observe
# the beams with the lowest distance difference
#............................................

sm_stats = lapply(spl_beam, function(x) {
  summary(x$dist_dif)
})

# $gt1l
#     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
# 0.006829 1.568755 2.107793 2.083547 2.654482 3.911961
# $gt1r
#      Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
# 0.0008427 0.2483260 0.5219864 0.5766648 0.8521821 2.0041663
# $gt2l
#      Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
# 0.0002195 0.3001418 0.6112493 0.6753225 0.9860298 2.2545978
# $gt2r
#    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
#   3.170   4.697   5.356   5.300   5.931   7.170
# $gt3l
#    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
#   1.197   2.679   3.115   3.155   3.621   5.069
# $gt3r
#    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
#   3.881   5.066   5.488   5.498   5.949   7.114
```

We observe that the beams 'gt1r' and 'gt2l' return the lowest difference in distance (approximately 2.0 and 2.25 meters) for the coordinates between the 'winter' and 'summer' observations, therefore we continue with these 2 beams. Moreover, the 'gt1r' and 'gt2l' beams are separated by approximately 3 kilometers from each other.

```r
#...................................
# keep only the 'gt1r' and 'gt2l' beams
#...................................

sw_hq_merg_beams = subset(sw_hq_merg, beam_winter %in% c('gt1r', 'gt2l'))


#..................................................
# keep only a pair of coordinates and rename the columns
#..................................................

sw_hq_merg_beams = sw_hq_merg_beams[, c('segment_id_winter', 'beam_winter', 'longitude_winter',
                                        'latitude_winter', 'h_li_winter', 'h_li_summer')]
colnames(sw_hq_merg_beams) = c('segment_id', 'beam', 'longitude',
                               'latitude', 'h_li_winter', 'h_li_summer')

#       segment_id beam longitude latitude h_li_winter h_li_summer
```

```
#    1:     351810 gt1r -44.10891 63.26390    2724.035    2725.023
#    2:     351811 gt1r -44.10895 63.26408    2724.004    2725.155
#    3:     351812 gt1r -44.10900 63.26426    2724.445    2725.298
#    4:     351813 gt1r -44.10904 63.26444    2724.530    2725.461
#    5:     351814 gt1r -44.10908 63.26462    2725.084    2725.650
#   ---
# 8700:     359399 gt1r -44.44637 64.61873    2777.249    2777.390
# 8701:     359400 gt1r -44.44642 64.61891    2777.136    2777.297
# 8702:     359401 gt1r -44.44647 64.61908    2777.081    2777.192
# 8703:     359402 gt1r -44.44651 64.61926    2776.936    2777.076
# 8704:     359403 gt1r -44.44656 64.61944    2776.818    2776.968
```

Then we'll download the *30-meter raster DEM (Digital Elevation Model)* for the AOI using the CopernicusDEM R package,

```
sf_aoi = sf::st_as_sf(sw_hq_merg_beams, coords = c('longitude', 'latitude'), crs = 4326)
bbx_aoi = sf::st_bbox(sf_aoi)
sfc_aoi = sf::st_as_sfc(bbx_aoi)

dem_dir = tempdir()
dem_dir

dem30 = CopernicusDEM::aoi_geom_save_tif_matches(sf_or_file = sfc_aoi,
                                                 dir_save_tifs = dem_dir,
                                                 resolution = 30,
                                                 crs_value = 4326,
                                                 threads = parallel::detectCores(),
                                                 verbose = TRUE)

if (nrow(dem30$csv_aoi) > 1) {          # create a .VRT file if I have more than 1 .tif files
  file_out = file.path(dem_dir, 'VRT_mosaic_FILE.vrt')

  vrt_dem30 = CopernicusDEM::create_VRT_from_dir(dir_tifs = dem_dir,
                                                 output_path_VRT = file_out,
                                                 verbose = TRUE)
}

if (nrow(dem30$csv_aoi) == 1) {         # if I have a single .tif file keep the first index
  file_out = list.files(dem_dir, pattern = '.tif', full.names = T)[1]
}


#......................................................
# crop the raster to the bounding box of the coordinates
#......................................................

rst_inp = terra::rast(x = file_out)
vec_crop = terra::vect(x = sfc_aoi)
rst_crop = terra::crop(x = rst_inp,
                       y = vec_crop,
                       snap = "out")      # snap = "in" gives NA's

pth_egm = file.path(dem_dir, 'copernicus_dem_egm2008.tif')
terra::writeRaster(x = rst_crop, filename = pth_egm)
```

```r
rst_dem = terra::rast(pth_egm)
rst_dem

CRS_dem = terra::crs(rst_dem, proj = TRUE)
RES_dem = as.character(terra::res(rst_dem))
EXT_dem = as.vector(terra::ext(rst_dem))
EXT_dem = c(EXT_dem['xmin'], EXT_dem['ymin'], EXT_dem['xmax'], EXT_dem['ymax'])
EXT_dem = as.character(EXT_dem)

#.........................................................................................................
# The Copernicus DEM has a "horizontal" CRS (Coordinate Reference System) of WGS84-G1150 (EPSG 4326)
# and a "vertical" CRS of EGM2008 (EPSG 3855) - geoid. Therefore, a transformation of the vertical
# CRS is required to match the ellipsoid CRS of the ICESat-2 data
# The Table 1 (page 10 of 37) of the following weblink includes more information:
# https://spacedata.copernicus.eu/documents/20126/0/GEO1988-CopernicusDEM-SPE-002_ProductHandbook_I1.00
# The 2.5 minute geoid grid .gtx file of EGM2008 was downloaded from the following "osgeo" url:
# http://download.osgeo.org/proj/vdatum/egm08_25/
#.........................................................................................................

pth_gtx = file.path(dem_dir, 'egm08_25.gtx')

download.file(url = 'http://download.osgeo.org/proj/vdatum/egm08_25/egm08_25.gtx',
              destfile = pth_gtx,
              method = 'curl')

pth_dem_transformed = file.path(dem_dir, 'copernicus_dem_egm2008_transformed.tif')

convrt = sf::gdal_utils(
  util = "warp",
  source = pth_egm,
  destination = pth_dem_transformed,
  options = c("-s_srs", glue::glue("{CRS_dem} +geoidgrids={pth_gtx}"),
              "-t_srs", CRS_dem,
              "-tr", RES_dem,
              "-te", EXT_dem),
  quiet = FALSE)

#...................................
# load the transformed Copernicus DEM
#...................................

rst_crop_transformed = terra::rast(x = pth_dem_transformed)


#..............................................
# we also have to find the closest elevation
# value to the 'winter' and 'summer' coordinates
# using the raster resolution
#..............................................

ter_dtbl = data.table::as.data.table(x = rst_crop_transformed, xy = TRUE, cells = TRUE)
colnames(ter_dtbl) = c("cell", "lon_dem30", "lat_dem30", "dem30")
# length(unique(ter_dtbl$cell)) == nrow(ter_dtbl)
```

```r
xy = as.matrix(sw_hq_merg_beams[, c('longitude', 'latitude')])
sw_cells = terra::cellFromXY(object = rst_crop_transformed, xy = xy)

sw_hq_merg_beams$cell = sw_cells
# length(unique(sw_hq_merg_beams$cell)) < nrow(sw_hq_merg_beams)

merg_cells = merge(x = sw_hq_merg_beams, y = ter_dtbl, by = 'cell')


#.....................................................................
# compute also the difference in distance between the beam measurements
# and the DEM coordinates (based on the 30-meter resolution cells)
#.....................................................................

merg_cells$dem_dif_dist = geodist::geodist(x = merg_cells[, c('longitude', 'latitude')],
                                           y = merg_cells[, c('lon_dem30', 'lat_dem30')],
                                           paired = TRUE,
                                           measure = 'geodesic')

summary(merg_cells$dem_dif_dist)

#   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
# 0.2356  8.1619 11.5943 11.1490 14.3201 20.5394
```

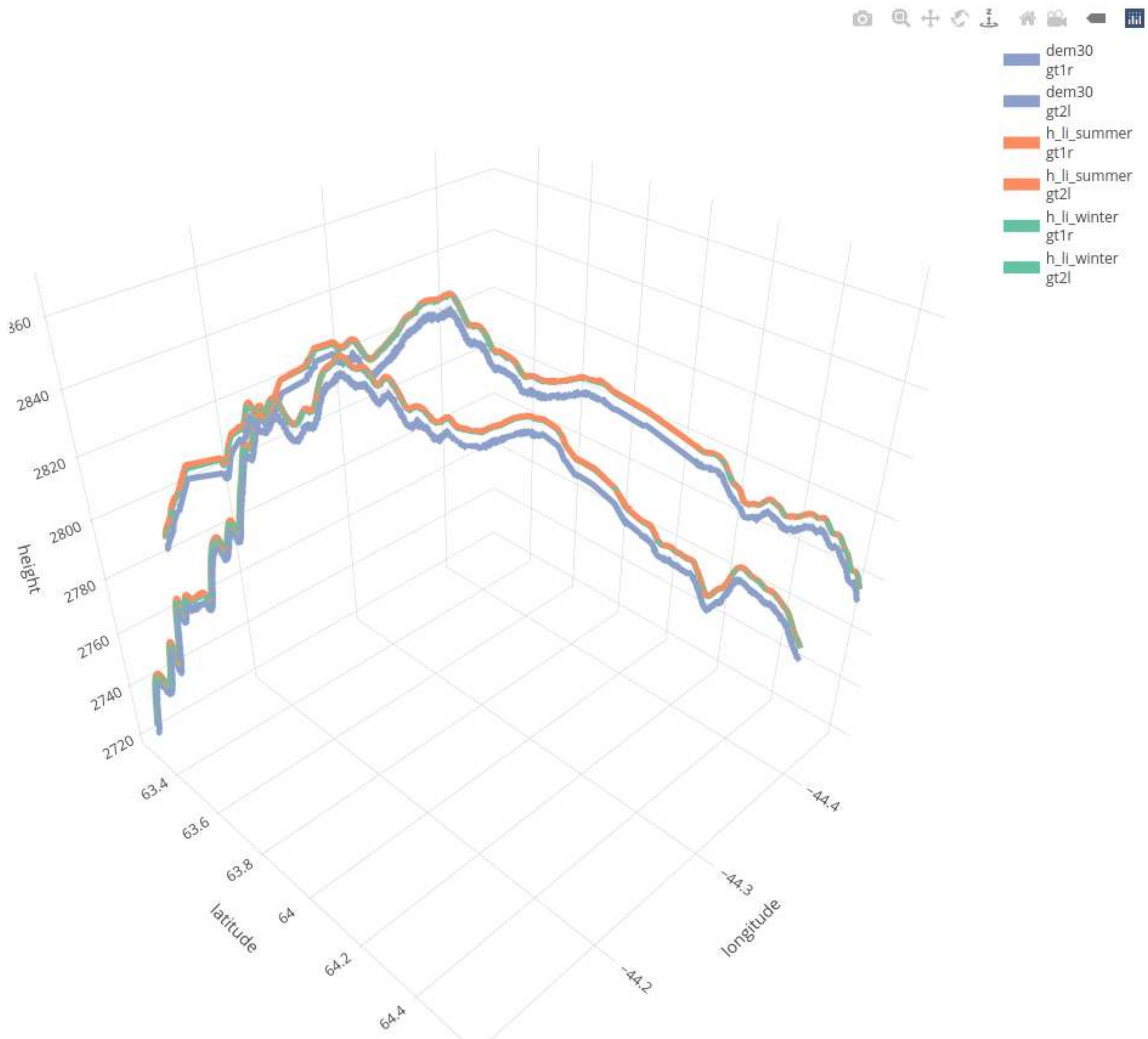
Based on the included 30-meter DEM there is a mean distance of 11.1490 and a maximum distance of 20.5394 meters between the *beam* and *DEM* coordinates. The following 3-dimensional interactive line plot shows,

- in *blue* color the *elevation* based on the *DEM* (compared to the 2 beams as these are separated by a 3-km distance)
- in *orange* color the land-ice-height measurements of the *summer* period (separately for 'gt1r' and 'gt2l')
- in *green* color the land-ice-height measurements of the *winter* period (separately for 'gt1r' and 'gt2l')

```r
cols_viz_dem = c('beam', 'longitude', 'latitude', 'h_li_winter', 'h_li_summer', 'dem30')
merg_cells_viz = merg_cells[, ..cols_viz_dem]
```

```r
merg_cells_viz_mlt = reshape2::melt(merg_cells_viz, id.vars = c('beam', 'longitude', 'latitude'))
merg_cells_viz_mlt = data.table::data.table(merg_cells_viz_mlt, stringsAsFactors = F)
colnames(merg_cells_viz_mlt) = c('beam', 'longitude', 'latitude',  'variable', 'height')

fig_height = plotly::plot_ly(merg_cells_viz_mlt,
                             x = ~longitude,
                             y = ~latitude,
                             z = ~height,
                             split = ~beam,            # split by beam
                             type = 'scatter3d',
                             mode = 'lines',
                             color = ~variable,
                             line = list(width = 10),
                             width = 1000,
                             height = 900)
fig_height
```


dem30
gt1r
dem30
gt2l
h_li_summer
gt1r
h_li_summer
gt2l
h_li_winter
gt1r
h_li_winter
gt2l
2840
2820
2800
2780
2760
2740
2720
height
63.4
63.6
63.8
64
64.2
64.4
latitude
-44.4
-44.3
-44.2
longitude