

deepSSF Data Prep - S2

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This document outlines the steps taken to prepare the data for the deepSSF model fitting, using Sentinel-2 data directly (instead of derived covariates such as NDVI).

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Loading packages

```
library(tidyverse)
packages <- c("amt", "sf", "terra", "beeswarm", "tictoc")
walk(packages, require, character.only = T)
```

Import data and clean

```

buffalo <- read_csv("data/buffalo.csv")

New names:
Rows: 133161 Columns: 11
-- Column specification
----- Delimiter: ","
(2): node, dates dbl (7): ...1, lat, lon, height, accuracy, heading, speed dttm
(2): timestamp, DateTime
i Use `spec()` to retrieve the full column specification for this data. i
Specify the column types or set `show_col_types = FALSE` to quiet this message.
* `` -> `...1` 

# remove individuals that have poor data quality or less than about 3 months of data.
# The "2014.GPS_COMPACT copy.csv" string is a duplicate of ID 2024, so we exclude it
buffalo <- buffalo %>% filter(!node %in% c("2014.GPS_COMPACT copy.csv",
                                             # 2005, 2014, 2018, 2021, 2022, 2024,
                                             2029, 2043, 2265, 2284, 2346, 2354))

buffalo <- buffalo %>%
  group_by(node) %>%
  arrange(DateTime, .by_group = T) %>%
  distinct(DateTime, .keep_all = T) %>%
  arrange(node) %>%
  mutate(ID = node)

buffalo_clean <- buffalo[, c(12, 2, 4, 3)]
colnames(buffalo_clean) <- c("id", "time", "lon", "lat")
attr(buffalo_clean$time, "tzone") <- "Australia/Queensland"
head(buffalo_clean)

# A tibble: 6 x 4
  id      time           lon   lat
  <chr> <dttm>       <dbl> <dbl>
1 2005  2018-07-25 10:04:02 134. -12.3
2 2005  2018-07-25 11:04:23 134. -12.3
3 2005  2018-07-25 12:04:39 134. -12.3
4 2005  2018-07-25 13:04:17 134. -12.3
5 2005  2018-07-25 14:04:39 134. -12.3
6 2005  2018-07-25 15:04:27 134. -12.3

tz(buffalo_clean$time)

[1] "Australia/Queensland"

```

```
buffalo_ids <- unique(buffalo_clean$id)
```

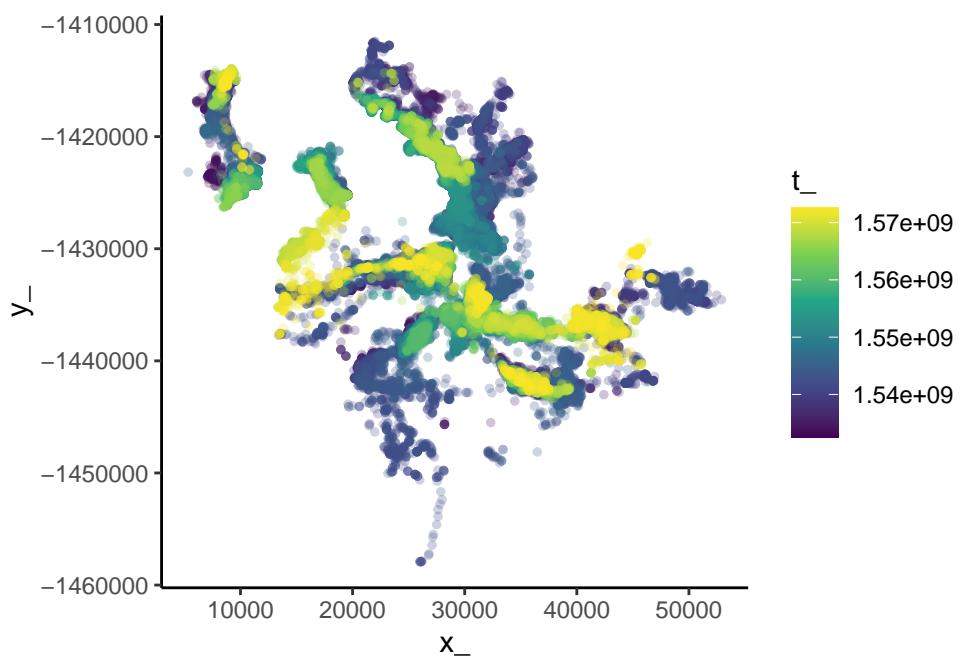
Setup trajectory

Use the `amt` package to create a trajectory object from the cleaned data.

```
buffalo_all <- buffalo_clean %>% mk_track(id = id,
                                              lon,
                                              lat,
                                              time,
                                              all_cols = T,
                                              crs = 4326) %>%
  transform_coords(crs_to = 3112, crs_from = 4326) # Transformation to GDA94 /
# Geoscience Australia Lambert (https://epsg.io/3112)
```

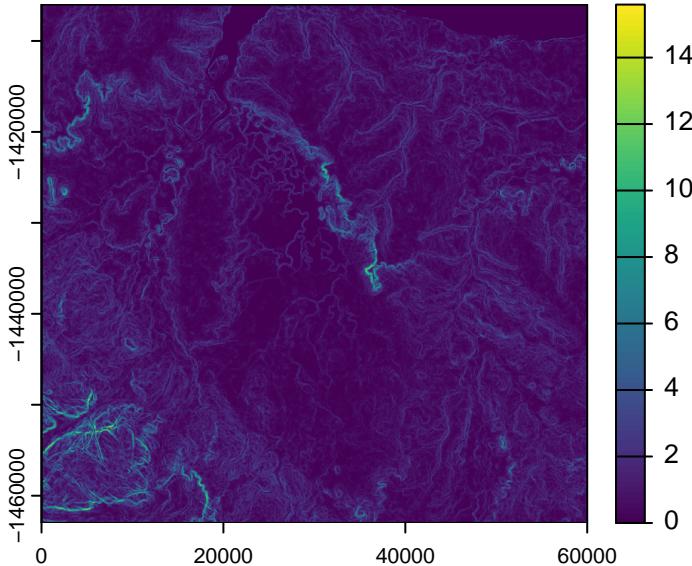
Plot the data coloured by time

```
buffalo_all %>%
  ggplot(aes(x = x_, y = y_, colour = t_)) +
  geom_point(alpha = 0.25, size = 1) +
  coord_fixed() +
  scale_colour_viridis_c() +
  theme_classic()
```



Reading in the environmental covariates

```
slope <- rast("mapping/cropped rasters/slope_raster.tif")
names(slope) <- "slope"
plot(slope)
```



Sentinel-2 spectral layers

Create vector of dates. We just use the 15th of the month (the layers were averaged across the month).

```
dates <- as.POSIXct(lubridate::ymd("2019-01-15")) + months(0:11)
```

Import the layers and add times

Each of these stacks are one month of the 12 bands of Sentinel-2 data. Initially they are at 10m resolution, but we resample them to 25m to match the resolution of the slope layer.

We save each of the scaled rasters such that we can import them when we simulate from the deepSSF model using the Sentinel-2 data.

As the resampling takes some time, we have commented this code out and read in the resampled and scaled layers directly in the next code chunk.

```

# #### January 2019
# s2_10m_2019_01 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_01.tif")
# terra::time(s2_10m_2019_01) <- rep(as.POSIXct(lubridate::ymd("2019-01-15")),
#                                     tz = "Australia/Queensland"),
#                                     nlyr(s2_10m_2019_01))
# s2_25m_2019_01 <- terra::resample(s2_10m_2019_01, slope, method = "bilinear")
# s2_25m_2019_01 <- s2_25m_2019_01 / 10000
# # to save the scaled raster to file for reading when simulating from the deepSSF model
# # writeRaster(s2_25m_2019_01, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
#
# #### February 2019
# s2_10m_2019_02 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_02.tif")
# terra::time(s2_10m_2019_02) <- rep(as.POSIXct(lubridate::ymd("2019-02-15")),
#                                     tz = "Australia/Queensland"),
#                                     nlyr(s2_10m_2019_02))
# s2_25m_2019_02 <- terra::resample(s2_10m_2019_02, slope, method = "bilinear")
# s2_25m_2019_02 <- s2_25m_2019_02 / 10000
# # writeRaster(s2_25m_2019_02, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
#
# #### March 2019
# s2_10m_2019_03 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_03.tif")
# terra::time(s2_10m_2019_03) <- rep(as.POSIXct(lubridate::ymd("2019-03-15")),
#                                     tz = "Australia/Queensland"),
#                                     nlyr(s2_10m_2019_03))
# s2_25m_2019_03 <- terra::resample(s2_10m_2019_03, slope, method = "bilinear")
# s2_25m_2019_03 <- s2_25m_2019_03 / 10000
# # writeRaster(s2_25m_2019_03, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
#
# #### April 2019
# s2_10m_2019_04 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_04.tif")
# terra::time(s2_10m_2019_04) <- rep(as.POSIXct(lubridate::ymd("2019-04-15")),
#                                     tz = "Australia/Queensland"),
#                                     nlyr(s2_10m_2019_04))
# s2_25m_2019_04 <- terra::resample(s2_10m_2019_04, slope, method = "bilinear")
# s2_25m_2019_04 <- s2_25m_2019_04 / 10000
# # writeRaster(s2_25m_2019_04, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
#
# #### May 2019
# s2_10m_2019_05 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_05.tif")
# terra::time(s2_10m_2019_05) <- rep(as.POSIXct(lubridate::ymd("2019-05-15")),
#                                     tz = "Australia/Queensland"),
#                                     nlyr(s2_10m_2019_05))

```

```

# s2_25m_2019_05 <- terra:::resample(s2_10m_2019_05, slope, method = "bilinear")
# s2_25m_2019_05 <- s2_25m_2019_05 / 10000
# # writeRaster(s2_25m_2019_05, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
# #### June 2019
# s2_10m_2019_06 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_06.tif")
# # plot(s2_10m_2019_06[[2]])
# terra:::time(s2_10m_2019_06) <- rep(as.POSIXct(lubridate::ymd("2019-06-15")),
# #                                     tz = "Australia/Queensland"),
# #                                     nlyr(s2_10m_2019_06))
# s2_25m_2019_06 <- terra:::resample(s2_10m_2019_06, slope, method = "bilinear")
# s2_25m_2019_06 <- s2_25m_2019_06 / 10000
# # writeRaster(s2_25m_2019_06, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
# #### July 2019
# s2_10m_2019_07 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_07.tif")
# terra:::time(s2_10m_2019_07) <- rep(as.POSIXct(lubridate::ymd("2019-07-15")),
# #                                     tz = "Australia/Queensland"),
# #                                     nlyr(s2_10m_2019_07))
# s2_25m_2019_07 <- terra:::resample(s2_10m_2019_07, slope, method = "bilinear")
# s2_25m_2019_07 <- s2_25m_2019_07 / 10000
# # writeRaster(s2_25m_2019_07, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
# #### August 2019
# s2_10m_2019_08 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_08.tif")
# terra:::time(s2_10m_2019_08) <- rep(as.POSIXct(lubridate::ymd("2019-08-15")),
# #                                     tz = "Australia/Queensland"),
# #                                     nlyr(s2_10m_2019_08))
# s2_25m_2019_08 <- terra:::resample(s2_10m_2019_08, slope, method = "bilinear")
# s2_25m_2019_08 <- s2_25m_2019_08 / 10000
# # writeRaster(s2_25m_2019_08, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
# #### September 2019
# s2_10m_2019_09 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_09.tif")
# terra:::time(s2_10m_2019_09) <- rep(as.POSIXct(lubridate::ymd("2019-09-15")),
# #                                     tz = "Australia/Queensland"),
# #                                     nlyr(s2_10m_2019_09))
# s2_25m_2019_09 <- terra:::resample(s2_10m_2019_09, slope, method = "bilinear")
# s2_25m_2019_09 <- s2_25m_2019_09 / 10000
# # writeRaster(s2_25m_2019_09, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
# #### October 2019
# s2_10m_2019_10 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_10.tif")
# terra:::time(s2_10m_2019_10) <- rep(as.POSIXct(lubridate::ymd("2019-10-15")),

```

```

#                                     tz = "Australia/Queensland"),
#
# nlyr(s2_10m_2019_10))
# s2_25m_2019_10 <- terra::resample(s2_10m_2019_10, slope, method = "bilinear")
# s2_25m_2019_10 <- s2_25m_2019_10 / 10000
# # writeRaster(s2_25m_2019_10, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
# #### November 2019
# s2_10m_2019_11 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_11.tif")
# terra::time(s2_10m_2019_11) <- rep(as.POSIXct(lubridate::ymd("2019-11-15")),
#                                     tz = "Australia/Queensland"),
#
# nlyr(s2_10m_2019_11))
# s2_25m_2019_11 <- terra::resample(s2_10m_2019_11, slope, method = "bilinear")
# s2_25m_2019_11 <- s2_25m_2019_11 / 10000
# # writeRaster(s2_25m_2019_11, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2
#
# #### December 2019
# s2_10m_2019_12 <- rast("mapping/cropped rasters/sentinel2/10m/S2_SR_masked_2019_12.tif")
# terra::time(s2_10m_2019_12) <- rep(as.POSIXct(lubridate::ymd("2019-12-15")),
#                                     tz = "Australia/Queensland"),
#
# nlyr(s2_10m_2019_12))
# s2_25m_2019_12 <- terra::resample(s2_10m_2019_12, slope, method = "bilinear")
# s2_25m_2019_12 <- s2_25m_2019_12 / 10000
# # writeRaster(s2_25m_2019_12, "mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_2

```

Each raster stack contains the Sentinel 2 bands for a given month in 2019, and have been scaled by 10,000 from what was downloaded from GEE.

```

s2_25m_2019_01 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_0
s2_25m_2019_02 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_0
s2_25m_2019_03 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_0
s2_25m_2019_04 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_0
s2_25m_2019_05 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_0
s2_25m_2019_06 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_0
s2_25m_2019_07 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_0
s2_25m_2019_08 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_0
s2_25m_2019_09 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_0
s2_25m_2019_10 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_1
s2_25m_2019_11 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_1
s2_25m_2019_12 <- rast("mapping/cropped rasters/sentinel2/25m/S2_SR_masked_scaled_25m_2019_1

s2_25m_2019_01

```

```

class      : SpatRaster
dimensions : 2280, 2400, 12  (nrow, ncol, nlyr)

```

```
resolution : 25, 25 (x, y)
extent     : 0, 60000, -1463000, -1406000 (xmin, xmax, ymin, ymax)
coord. ref. : GDA94 / Geoscience Australia Lambert (EPSG:3112)
source      : S2_SR_masked_scaled_25m_2019_01.tif
names       : B1, B2, B3, B4, B5, B6, ...
min values  : 0.002600, 0.00298288, 0.01064496, 0.0101952, 0.01207968, 0.01042128, ...
max values  : 0.313051, 0.40625551, 0.48839232, 0.5488096, 0.58363509, 0.57049966, ...
time        : 2019-01-15 UTC
```

Combine into a list

```
s2_list <- list(s2_25m_2019_01,
                  s2_25m_2019_02,
                  s2_25m_2019_03,
                  s2_25m_2019_04,
                  s2_25m_2019_05,
                  s2_25m_2019_06,
                  s2_25m_2019_07,
                  s2_25m_2019_08,
                  s2_25m_2019_09,
                  s2_25m_2019_10,
                  s2_25m_2019_11,
                  s2_25m_2019_12)

names(s2_25m_2019_12)
```

```
[1] "B1"   "B2"   "B3"   "B4"   "B5"   "B6"   "B7"   "B8"   "B8A"  "B9"   "B11"  "B12"
```

Generating the data to fit a deepSSF model

Set up the spatial extent of the local covariates

```
buffalo_all <- buffalo_all %>%
  arrange(id, t_)

# create a vector of ids
buffalo_ids <- unique(buffalo_all$id)

# get the resolution from the covariates
res <- terra::res(slope)[1]
```

```

# how much to trim on either side of the location,
# this will determine the extent of the spatial inputs to the deepSSF model
buffer <- 1250 + (res/2)
# calculate the number of cells in each axis
nxn_cells <- buffer*2/res

# hourly lag - to set larger time differences between locations
hourly_lag <- 1

```

Loop over each individual and save the local rasters

```

for(i in 1:length(buffalo_ids)) {

  buffalo_data <- buffalo_all %>% filter(id == buffalo_ids[i])
  # all data for that individual
  # buffalo_data <- buffalo_data %>% arrange(t_)
  # a subset of the data for that individual - mostly for testing
  buffalo_data <- buffalo_data %>% arrange(t_) %>% slice(1:10)

  n_samples <- nrow(buffalo_data)

  tic()

  buffalo_data_covs <- buffalo_data %>% mutate(
    x1_ = x_,
    y1_ = y_,
    x2_ = lead(x1_, n = hourly_lag, default = NA),
    y2_ = lead(y1_, n = hourly_lag, default = NA),
    x2_cent = x2_ - x1_,
    y2_cent = y2_ - y1_,
    t2_ = lead(t_, n = hourly_lag, default = NA),
    t_diff = round(difftime(t2_, t_, units = "hours"),0),
    hour_t1 = lubridate::hour(t_),
    yday_t1 = lubridate::yday(t_),
    hour_t2 = lubridate::hour(t2_),
    hour_t2_sin = sin(2*pi*hour_t2/24),
    hour_t2_cos = cos(2*pi*hour_t2/24),
    yday_t2 = lubridate::yday(t2_),
    yday_t2_sin = sin(2*pi*yday_t2/365.25),
    yday_t2_cos = cos(2*pi*yday_t2/365.25),

    sl = c(sqrt(diff(y_)^2 + diff(x_)^2), NA),
    log_sl = log(sl),

```

```

bearing = c(atan2(diff(y_), diff(x_)), NA),
bearing_sin = sin(bearing),
bearing_cos = cos(bearing),
ta = c(NA, ifelse(
  diff(bearing) > pi, diff(bearing)-(2*pi), ifelse(
    diff(bearing) < -pi, diff(bearing)+(2*pi), diff(bearing))),,
cos_ta = cos(ta),

# extent for cropping the spatial covariates
x_min = x_ - buffer,
x_max = x_ + buffer,
y_min = y_ - buffer,
y_max = y_ + buffer

# crop out and store the local covariates centered on the animal's location
# with an extent set in the previous chunk
) %>% rowwise() %>% mutate(
  extent_00centre = list(ext(x_min - x_, x_max - x_, y_min - y_, y_max - y_)),
  # Sentinel 2
  s2_index = which.min(abs(lubridate::month(t_) - lubridate::month(dates))),
  # Band 1
  s2_b1_cent = list({
    s2_b1_cent = crop( s2_list[[s2_index]][[1]], ext(x_min, x_max, y_min, y_max))
    ext(s2_b1_cent) <- extent_00centre
    s2_b1_cent
  }),
  # Band 2
  s2_b2_cent = list({
    s2_b2_cent = crop( s2_list[[s2_index]][[2]], ext(x_min, x_max, y_min, y_max))
    ext(s2_b2_cent) <- extent_00centre
    s2_b2_cent
  }),
  # Band 3
  s2_b3_cent = list({
    s2_b3_cent = crop( s2_list[[s2_index]][[3]], ext(x_min, x_max, y_min, y_max))
    ext(s2_b3_cent) <- extent_00centre
    s2_b3_cent
  })
)

```

```

# Band 4
s2_b4_cent = list({
  s2_b4_cent = crop( s2_list[[s2_index]][[4]], ext(x_min, x_max, y_min, y_max))
  ext(s2_b4_cent) <- extent_00centre
  s2_b4_cent
}),

# Band 5
s2_b5_cent = list({
  s2_b5_cent = crop( s2_list[[s2_index]][[5]], ext(x_min, x_max, y_min, y_max))
  ext(s2_b5_cent) <- extent_00centre
  s2_b5_cent
}),

# Band 6
s2_b6_cent = list({
  s2_b6_cent = crop( s2_list[[s2_index]][[6]], ext(x_min, x_max, y_min, y_max))
  ext(s2_b6_cent) <- extent_00centre
  s2_b6_cent
}),

# Band 7
s2_b7_cent = list({
  s2_b7_cent = crop( s2_list[[s2_index]][[7]], ext(x_min, x_max, y_min, y_max))
  ext(s2_b7_cent) <- extent_00centre
  s2_b7_cent
}),

# Band 8
s2_b8_cent = list({
  s2_b8_cent = crop( s2_list[[s2_index]][[8]], ext(x_min, x_max, y_min, y_max))
  ext(s2_b8_cent) <- extent_00centre
  s2_b8_cent
}),

# Band 8A
s2_b8a_cent = list({
  s2_b8a_cent = crop( s2_list[[s2_index]][[9]], ext(x_min, x_max, y_min, y_max))
  ext(s2_b8a_cent) <- extent_00centre
  s2_b8a_cent
}),

# Band 9
s2_b9_cent = list({

```

```

s2_b9_cent = crop( s2_list[[s2_index]][[10]], ext(x_min, x_max, y_min, y_max))
ext(s2_b9_cent) <- extent_00centre
s2_b9_cent
}),

# Band 11
s2_b11_cent = list({
  s2_b11_cent = crop( s2_list[[s2_index]][[11]], ext(x_min, x_max, y_min, y_max))
  ext(s2_b11_cent) <- extent_00centre
  s2_b11_cent
}),

# Band 12
s2_b12_cent = list({
  s2_b12_cent = crop( s2_list[[s2_index]][[12]], ext(x_min, x_max, y_min, y_max))
  ext(s2_b12_cent) <- extent_00centre
  s2_b12_cent
}),

# slope

slope_cent = list({
  slope_cent <- crop(slope, ext(x_min, x_max, y_min, y_max))
  ext(slope_cent) <- extent_00centre
  slope_cent
}),

# rasterised location of the next step - centred on (0,0)
points_vect_cent = list(terra::vect(cbind(x2_ - x_, y2_ - y_), type = "points", crs = "E
pres_cent = list(rasterize(points_vect_cent, s2_b1_cent, background=0))

) %>% ungroup() # to remove the 'rowwise' class

toc()

# remove steps that fall outside of the local spatial extent
buffalo_data_covs <- buffalo_data_covs %>%
  filter(x2_cent > -buffer & x2_cent < buffer & y2_cent > -buffer & y2_cent < buffer) %>%
  drop_na(ta)

buffalo_data_df <- buffalo_data_covs %>%
  dplyr::select(-extent_00centre,

```

```

-s2_b1_cent,
-s2_b2_cent,
-s2_b3_cent,
-s2_b4_cent,
-s2_b5_cent,
-s2_b6_cent,
-s2_b7_cent,
-s2_b8_cent,
-s2_b8a_cent,
-s2_b9_cent,
-s2_b11_cent,
-s2_b12_cent,
-slope_cent,
-points_vect_cent,
-pres_cent
)

# save the data
write_csv(buffalo_data_df, paste0("buffalo_local_data_id/website_temp/buffalo_",
                                  "_data_df_lag_", hourly_lag, "hr_n", n_samples, ".csv"))

# saving the raster objects

rast(buffalo_data_covs$s2_b1_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b1_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T))

rast(buffalo_data_covs$s2_b2_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b2_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T))

rast(buffalo_data_covs$s2_b3_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b3_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T))

rast(buffalo_data_covs$s2_b4_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b4_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T))

rast(buffalo_data_covs$s2_b5_cent) %>%

```

```

writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b5_cent",
                  nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                  overwrite = T)

rast(buffalo_data_covs$s2_b6_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b6_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T)

rast(buffalo_data_covs$s2_b7_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b7_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T)

rast(buffalo_data_covs$s2_b8_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b8_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T)

rast(buffalo_data_covs$s2_b8a_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b8a_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T)

rast(buffalo_data_covs$s2_b9_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b9_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T)

rast(buffalo_data_covs$s2_b11_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b11_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T)

rast(buffalo_data_covs$s2_b12_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_s2_b12_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T)

rast(buffalo_data_covs$pres_cent) %>%
  writeRaster(paste0("buffalo_local_layers_id/buffalo_", buffalo_ids[i], "_pres_cent",
                     nxn_cells, "x", nxn_cells, "_lag_", hourly_lag, "hr_n", n_samples, ".",
                     overwrite = T)

```

```
}
```

```
7.27 sec elapsed
5.89 sec elapsed
6.27 sec elapsed
6.22 sec elapsed
5.94 sec elapsed
5.95 sec elapsed
6.03 sec elapsed
6.19 sec elapsed
6.2 sec elapsed
6.31 sec elapsed
6.36 sec elapsed
6.5 sec elapsed
6.33 sec elapsed
```

Check the outputs

```
head(buffalo_data_covs)
```

```
# A tibble: 6 x 48
  x_      y_ t_
  <dbl>  <dbl> <dttm>           id    x1_      y1_      x2_      y2_ x2_cent
1 32550. -1.42e6 2018-07-25 12:11:31 2393  32550. -1.42e6 32551. -1.42e6  0.323
2 32551. -1.42e6 2018-07-25 13:10:28 2393  32551. -1.42e6 32550. -1.42e6 -1.13
3 32550. -1.42e6 2018-07-25 14:11:04 2393  32550. -1.42e6 32552. -1.42e6  2.57
4 32552. -1.42e6 2018-07-25 15:12:01 2393  32552. -1.42e6 32556. -1.42e6  3.67
5 32556. -1.42e6 2018-07-25 16:10:49 2393  32556. -1.42e6 32551. -1.42e6 -4.85
6 32551. -1.42e6 2018-07-25 17:12:20 2393  32551. -1.42e6 32547. -1.42e6 -4.18
# i 39 more variables: y2_cent <dbl>, t2_ <dttm>, t_diff <drtn>, hour_t1 <int>,
#   yday_t1 <dbl>, hour_t2 <int>, hour_t2_sin <dbl>, hour_t2_cos <dbl>,
#   yday_t2 <dbl>, yday_t2_sin <dbl>, yday_t2_cos <dbl>, sl <dbl>,
#   log_sl <dbl>, bearing <dbl>, bearing_sin <dbl>, bearing_cos <dbl>,
#   ta <dbl>, cos_ta <dbl>, x_min <dbl>, x_max <dbl>, y_min <dbl>, y_max <dbl>,
#   extent_00centre <list>, s2_index <int>, s2_b1_cent <list>,
#   s2_b2_cent <list>, s2_b3_cent <list>, s2_b4_cent <list>, ...
```

```
which(is.na(buffalo_data_covs$ta))
```

```
integer(0)
```

Plot a subset of the local covariates

```
n_plots <- 5

for(i in 1:n_plots){

  # Blue layer
  terra::plot(buffalo_data_covs$s2_b2_cent[[i]])
  # Red layer
  terra::plot(buffalo_data_covs$s2_b3_cent[[i]])
  # Green layer
  terra::plot(buffalo_data_covs$s2_b4_cent[[i]])

  # Plot as RGB image
  rgb_image <- c(buffalo_data_covs$s2_b4_cent[[i]]*1e4,
                  buffalo_data_covs$s2_b3_cent[[i]]*1e4,
                  buffalo_data_covs$s2_b2_cent[[i]]*1e4)

  terra::plotRGB(rgb_image, r = 1, g = 2, b = 3,
                 smooth = FALSE, mar = 1.5, axes = TRUE) # adjust 'scale' if needed

  # Save plot as a PNG image
  # Create the graphic device
  png(paste0("outputs/rgb_local_env_", i, ".png"),
      width = 120, height = 120, units = "mm", res = 600)

  # Plot the RGB image
  terra::plotRGB(rgb_image, r = 1, g = 2, b = 3,
                 smooth = FALSE, mar = 1.5, axes = TRUE)

  # Close the graphic device to save the file
  dev.off()

}
```

