

# Vector data

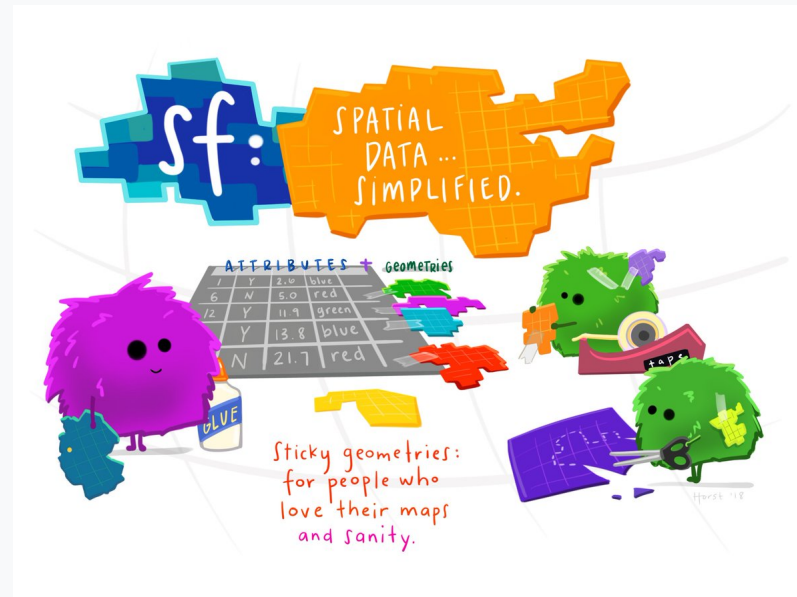
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# Simple features (sf)



(Illustration (c) by Allison Horst)

Simple features are included in the [ISO 19125-1:2004](#) standard. This standard describes how real world objects are represented in computers, with special emphasis in spatial geometry.

# Simple features (sf)

## Dimensions

Geometries are composed of points, coordinates in XY space (north-east, lat-long...):

- **XY**
- **XYZ** (Z = altitude)
- **XYM** (M = coordinate referring to the point, could be time or coordinates measuring error)
- **XYZM** (both, Z and M)

And also can have attributes related to each geometry (think about things as biomass, temperature...)

# Simple features (sf)

## Geometry types

- **POINT**: zero-dimensional geometry containing a single point
- **LINESTRING**: sequence of points connected by straight, non-self intersecting line pieces; one-dimensional geometry
- **POLYGON**: geometry with a positive area (two-dimensional); sequence of points form a closed, non-self intersecting ring; the first ring denotes the exterior ring, zero or more subsequent rings denote holes in this exterior ring
- **MULTIPOINT**: set of points; a MULTIPOINT is simple if no two Points in the MULTIPOINT are equal
- **MULTILINESTRING**: set of linestrings
- **MULTIPOLYGON**: set of polygons
- **GEOMETRYCOLLECTION**: set of geometries of any type except GEOMETRYCOLLECTION

# Simple features (sf)

## Simple features in R

1. "Ol'good" `sp` package. The standard in R for many years
2. "New kid on the block" `sf` package. The "new" R standard for spatial simple features.

# Simple features (sf)

sf package

```
install.packages("sf")
```

# Simple features (sf)

## sf package

```
library(sf)
```

```
nc <- st_read(system.file("shape/nc.shp", package="sf"))
```

```
## Reading layer `nc' from data source
```

```
##   `/home/malдитobarbudo/R/x86_64-pc-linux-gnu-library/4.1/sf/shape/nc.shp' using driver `ESRI Shapefile'
```

```
## Simple feature collection with 100 features and 14 fields
```

```
## Geometry type: MULTIPOLYGON
```

```
## Dimension:      XY
```

```
## Bounding box:  xmin: -84.32385 ymin: 33.88199 xmax: -75.45698 ymax: 36.58965
```

```
## Geodetic CRS:  NAD27
```

# Simple features (sf)

## sf package

nc

```
## Simple feature collection with 100 features and 14 fields
## Geometry type: MULTIPOLYGON
## Dimension: XY
## Bounding box: xmin: -84.32385 ymin: 33.88199 xmax: -75.45698 ymax: 36.58965
## Geodetic CRS: NAD27
## First 10 features:
##      AREA PERIMETER CNTY_ CNTY_ID      NAME  FIPS FIPSNO CRESS_ID BIR74 SID74  NWBIR74 BIR79 SID79
## 1  0.114    1.442  1825   1825      Ashe 37009  37009      5  1091     1     10  1364     0
## 2  0.061    1.231  1827   1827  Alleghany 37005  37005      3   487     0     10   542     3
## 3  0.143    1.630  1828   1828      Surry 37171  37171     86  3188     5     208  3616     6
## 4  0.070    2.968  1831   1831  Currituck 37053  37053     27   508     1     123   830     2
## 5  0.153    2.206  1832   1832 Northampton 37131  37131     66  1421     9    1066  1606     3
## 6  0.097    1.670  1833   1833    Hertford 37091  37091     46  1452     7     954  1838     5
## 7  0.062    1.547  1834   1834      Camden 37029  37029     15   286     0     115   350     2
## 8  0.091    1.284  1835   1835      Gates 37073  37073     37   420     0     254   594     2
## 9  0.118    1.421  1836   1836      Warren 37185  37185     93   968     4     748  1190     2
## 10 0.124    1.428  1837   1837      Stokes 37169  37169     85  1612     1     160  2038     5
##      NWBIR79      geometry
## 1      19 MULTIPOLYGON (((-81.47276 3...
## 2      12 MULTIPOLYGON (((-81.23989 3...
## 3     260 MULTIPOLYGON (((-80.45634 3...
## 4     145 MULTIPOLYGON (((-76.00897 3...
## 5    1197 MULTIPOLYGON (((-77.21767 3...
## 6    1237 MULTIPOLYGON (((-76.74506 3...
## 7     100 MULTIPOLYGON (((-76.00007 0
```



# Simple features (sf)

## sf package

```
class(nc)

## [1] "sf"          "data.frame"

attr(nc, "sf_column")

## [1] "geometry"

class(nc$geometry)

## [1] "sfc_MULTIPOLYGON" "sfc"

class(nc$geometry[[1]])

## [1] "XY"          "MULTIPOLYGON" "sfg"
```

# Simple features (sf)

## read data

```
lidar_data <- st_read('lidar_data.gpkg', quiet = TRUE)
```

```
lidar_data
```

```
## Simple feature collection with 42 features and 9 fields
## Geometry type: MULTIPOLYGON
## Dimension: XY
## Bounding box: xmin: 0.1626252 ymin: 40.52296 xmax: 3.321198 ymax: 42.86144
## Geodetic CRS: WGS 84
## First 10 features:
```

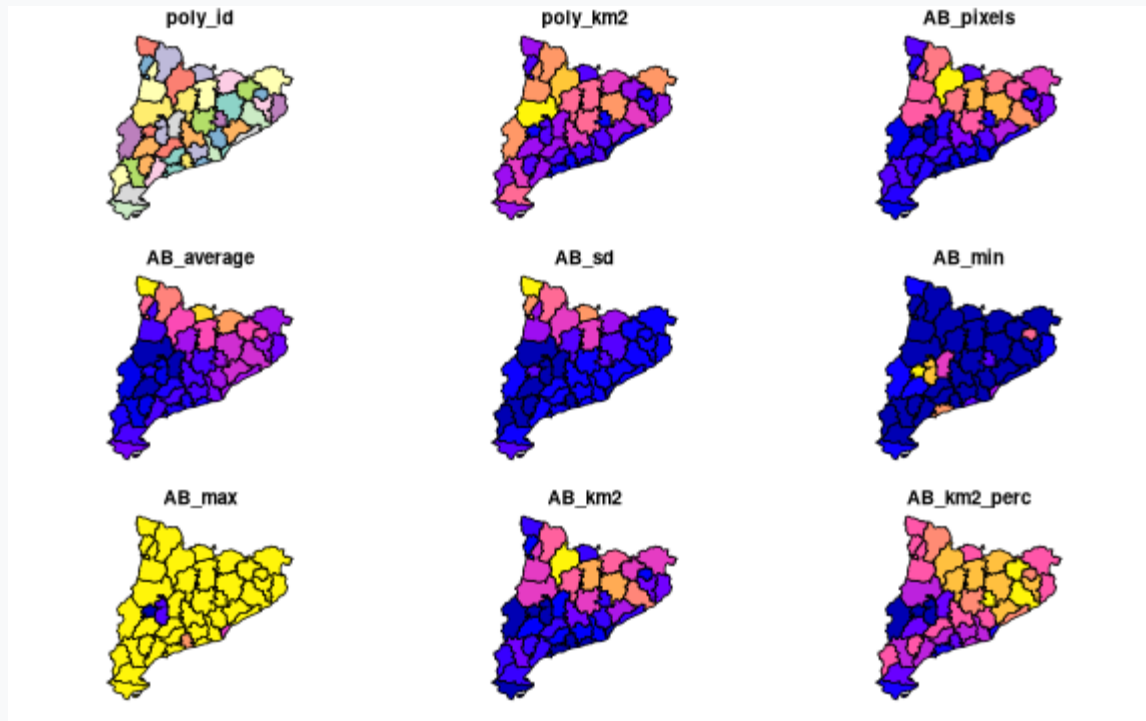
##		poly_id	poly_km2	AB_pixels	AB_average	AB_sd	AB_min	AB_max	AB_km2	AB_km2_perc
## 1	Alt Camp	537.6352	482120	16.69471	8.207308	0.01	100	192.8480	35.86968	
## 2	Alt Empordà	1356.8555	1393054	20.31397	8.609172	0.01	100	557.2216	41.06713	
## 3	Alt Penedès	592.7758	488554	17.65630	9.036426	0.01	100	195.4216	32.96720	
## 4	Alt Urgell	1447.2226	2516325	24.93210	14.876077	0.01	100	1006.5300	69.54908	
## 5	Alta Ribagorça	427.2234	437735	27.79429	18.256835	0.01	100	175.0940	40.98418	
## 6	Anoia	866.6878	976681	16.50647	8.703730	0.01	100	390.6724	45.07648	
## 7	Bages	1092.7763	1455613	16.45591	8.884009	0.01	100	582.2452	53.28128	
## 8	Baix Camp	697.0773	590955	16.72298	8.028576	0.01	100	236.3820	33.91044	
## 9	Baix Ebre	1002.1005	558271	16.74180	9.326562	0.01	100	223.3084	22.28403	
## 10	Baix Empordà	701.3843	862685	18.40010	8.052129	0.02	100	345.0740	49.19899	

```
##
## 1 MULTIPOLYGON (((1.495952 41...
## 2 MULTIPOLYGON (((3.170083 42...
## 3 MULTIPOLYGON (((1.837855 41...
## 4 MULTIPOLYGON (((1.319412 41...
## 5 MULTIPOLYGON (((0.9378095 4...
```

# Simple features (sf)

quickly plot

```
plot(lidar_data)
```



# Simple features (sf)

it's a dataframe (tibble)!!!

```
library(dplyr)
valles_data <- lidar_data %>%
  filter(poly_id == "Vallès Occidental")
valles_data

## Simple feature collection with 1 feature and 9 fields
## Geometry type: MULTIPOLYGON
## Dimension: XY
## Bounding box: xmin: 1.860982 ymin: 41.41498 xmax: 2.224695 ymax: 41.71742
## Geodetic CRS: WGS 84
##           poly_id poly_km2 AB_pixels AB_average AB_sd AB_min AB_max AB_km2 AB_km2_perc
## 1 Vallès Occidental 582.9532 659060 20.60493 8.976501 0.01 100 263.624 45.22216
##           geom
## 1 MULTIPOLYGON (((2.133049 41...
```

# Simple features (sf)

## save it

```
st_write(valles_data, 'valles_data.gpkg')  
  
## Writing layer `valles_data' to data source `valles_data.gpkg' using driver `GPKG'  
## Writing 1 features with 9 fields and geometry type Multi Polygon.  
  
file.exists('valles_data.gpkg')  
  
## [1] TRUE
```

# Simple features (sf)

## Back to read, but with a twist

```
valles_wkt <- st_read('valles_data.gpkg', quiet = TRUE) %>%
  st_geometry() %>%
  st_as_text()
```

```
valles_data_2 <- st_read('lidar_data.gpkg', wkt_filter = valles_wkt, quiet = TRUE)
valles_data_2
```

```
## Simple feature collection with 6 features and 9 fields
```

```
## Geometry type: MULTIPOLYGON
```

```
## Dimension: XY
```

```
## Bounding box: xmin: 1.551508 ymin: 41.26331 xmax: 2.60935 ymax: 41.9704
```

```
## Geodetic CRS: WGS 84
```

##		poly_id	poly_km2	AB_pixels	AB_average	AB_sd	AB_min	AB_max	AB_km2	AB_km2_perc
## 1		Bages	1092.7763	1455613	16.45591	8.884009	0.01	100.00	582.2452	53.28128
## 2	Baix Llobregat		487.8669	397595	19.63158	9.438929	0.01	100.00	159.0380	32.59864
## 3	Barcelonès		146.1943	43138	20.21294	7.832255	0.06	72.39	17.2552	11.80292
## 4	Vallès Occidental		582.9532	659060	20.60493	8.976501	0.01	100.00	263.6240	45.22216
## 5	Vallès Oriental		735.2148	1103493	23.07162	8.838574	0.01	100.00	441.3972	60.03649
## 6	Moianès		337.5398	593580	20.80658	10.609974	0.04	100.00	237.4320	70.34192

```
## geom
```

```
## 1 MULTIPOLYGON (((2.040477 41...
```

```
## 2 MULTIPOLYGON (((1.812835 41...
```

```
## 3 MULTIPOLYGON (((2.059358 41...
```

```
## 4 MULTIPOLYGON (((2.133049 41...
```

```
## 5 MULTIPOLYGON (((2.41841 41...
```

```
## 6 MULTIPOLYGON (((2.240584 41...
```

# Simple features (sf)

## Coordinate Reference System (crs)

CRS is a framework used to precisely measure locations on the surface of the Earth as coordinates.

```
st_crs(lidar_data)

## Coordinate Reference System:
##   User input: WGS 84
##   wkt:
##   GEOGCRS["WGS 84",
##     ENSEMBLE["World Geodetic System 1984 ensemble",
##       MEMBER["World Geodetic System 1984 (Transit)"],
##       MEMBER["World Geodetic System 1984 (G730)"],
##       MEMBER["World Geodetic System 1984 (G873)"],
##       MEMBER["World Geodetic System 1984 (G1150)"],
##       MEMBER["World Geodetic System 1984 (G1674)"],
##       MEMBER["World Geodetic System 1984 (G1762)"],
##       MEMBER["World Geodetic System 1984 (G2139)"],
##     ELLIPSOID["WGS 84",6378137,298.257223563,
##       LENGTHUNIT["metre",1]],
##     ENSEMBLEACCURACY[2.0]],
##   PRIMEM["Greenwich",0,
##     ANGLEUNIT["degree",0.0174532925199433]],
##   CS[ellipsoidal,2],
##     AXIS["geodetic latitude (Lat)",north,
##       ORDER[1],
##     ANGLEUNIT["degree",0.0174532925199433]],
```

# Simple features (sf)

## CRS transformations

```
lidar_data_utm <- st_transform(lidar_data, crs = 3043)
st_crs(lidar_data_utm)

## Coordinate Reference System:
##   User input: EPSG:3043
##   wkt:
## PROJCRS["ETRS89 / UTM zone 31N (N-E)",
##     BASEGEOGCRS["ETRS89",
##       ENSEMBLE["European Terrestrial Reference System 1989 ensemble",
##         MEMBER["European Terrestrial Reference Frame 1989"],
##         MEMBER["European Terrestrial Reference Frame 1990"],
##         MEMBER["European Terrestrial Reference Frame 1991"],
##         MEMBER["European Terrestrial Reference Frame 1992"],
##         MEMBER["European Terrestrial Reference Frame 1993"],
##         MEMBER["European Terrestrial Reference Frame 1994"],
##         MEMBER["European Terrestrial Reference Frame 1996"],
##         MEMBER["European Terrestrial Reference Frame 1997"],
##         MEMBER["European Terrestrial Reference Frame 2000"],
##         MEMBER["European Terrestrial Reference Frame 2005"],
##         MEMBER["European Terrestrial Reference Frame 2014"],
##       ELLIPSOID["GRS 1980",6378137,298.257222101,
##         LENGTHUNIT["metre",1]],
##       ENSEMBLEACCURACY[0.1]],
##     PRIMEM["Greenwich",0,
##       ANGLEUNIT["degree",0.0174532925199433]],
##     ID["EPSG",4258]],
##     CONVERSION["UTM zone 31N",
```



# Simple features (sf)

## CRS transformations

```
valles_data_utm <- st_transform(valles_data, crs = st_crs(lidar_data_utm))
st_crs(valles_data_utm)

## Coordinate Reference System:
##   User input: EPSG:3043
##   wkt:
## PROJCRS["ETRS89 / UTM zone 31N (N-E)",
##     BASEGEOGCRS["ETRS89",
##       ENSEMBLE["European Terrestrial Reference System 1989 ensemble",
##         MEMBER["European Terrestrial Reference Frame 1989"],
##         MEMBER["European Terrestrial Reference Frame 1990"],
##         MEMBER["European Terrestrial Reference Frame 1991"],
##         MEMBER["European Terrestrial Reference Frame 1992"],
##         MEMBER["European Terrestrial Reference Frame 1993"],
##         MEMBER["European Terrestrial Reference Frame 1994"],
##         MEMBER["European Terrestrial Reference Frame 1996"],
##         MEMBER["European Terrestrial Reference Frame 1997"],
##         MEMBER["European Terrestrial Reference Frame 2000"],
##         MEMBER["European Terrestrial Reference Frame 2005"],
##         MEMBER["European Terrestrial Reference Frame 2014"],
##       ELLIPSOID["GRS 1980",6378137,298.257222101,
##         LENGTHUNIT["metre",1]],
##       ENSEMBLEACCURACY[0.1]],
##     PRIMEM["Greenwich",0,
##       ANGLEUNIT["degree",0.0174532925199433]],
##     ID["EPSG",4258]],
##     CONVERSION["UTM zone 31N",
```

# Simple features (sf)

## Geometrical operations

```
lidar_centroids <- st_centroid(lidar_data)

## Warning in st_centroid.sf(lidar_data): st_centroid assumes attributes are constant over geometries
## of x

lidar_centroids

## Simple feature collection with 42 features and 9 fields
## Geometry type: POINT
## Dimension: XY
## Bounding box: xmin: 0.3723986 ymin: 40.66646 xmax: 3.065064 ymax: 42.72576
## Geodetic CRS: WGS 84
## First 10 features:
##      poly_id poly_km2 AB_pixels AB_average AB_sd AB_min AB_max AB_km2 AB_km2_perc
## 1 Alt Camp 537.6352 482120 16.69471 8.207308 0.01 100 192.8480 35.86968
## 2 Alt Empordà 1356.8555 1393054 20.31397 8.609172 0.01 100 557.2216 41.06713
## 3 Alt Penedès 592.7758 488554 17.65630 9.036426 0.01 100 195.4216 32.96720
## 4 Alt Urgell 1447.2226 2516325 24.93210 14.876077 0.01 100 1006.5300 69.54908
## 5 Alta Ribagorça 427.2234 437735 27.79429 18.256835 0.01 100 175.0940 40.98418
## 6 Anoia 866.6878 976681 16.50647 8.703730 0.01 100 390.6724 45.07648
## 7 Bages 1092.7763 1455613 16.45591 8.884009 0.01 100 582.2452 53.28128
## 8 Baix Camp 697.0773 590955 16.72298 8.028576 0.01 100 236.3820 33.91044
## 9 Baix Ebre 1002.1005 558271 16.74180 9.326562 0.01 100 223.3084 22.28403
## 10 Baix Empordà 701.3843 862685 18.40010 8.052129 0.02 100 345.0740 49.19899
##      geom
## 1 POINT (1.308212 41.32804)
```

# Simple features (sf)

## Geometrical operations

```
st_distance(lidar_centroids)
```

```
## Units: [m]
##      [,1]      [,2]      [,3]      [,4]      [,5]      [,6]      [,7]      [,8]      [,9]
## [1,]  0.00 174314.33 33128.47 105244.58 134929.26 37755.45 65584.62 34372.85 82807.54
## [2,] 174314.33  0.00 145696.83 129188.84 176077.15 137919.43 110992.51 208680.25 257100.64
## [3,] 33128.47 145696.83  0.00 101782.89 141949.46 25236.31 45152.79 65755.23 112938.51
## [4,] 105244.58 129188.84 101782.89  0.00 51783.94 76826.23 64406.48 130475.78 173348.15
## [5,] 134929.26 176077.15 141949.46 51783.94  0.00 117028.01 112382.81 150548.53 184343.01
## [6,] 37755.45 137919.43 25236.31 76826.23 117028.01  0.00 27868.78 71517.51 119984.97
## [7,] 65584.62 110992.51 45152.79 64406.48 112382.81 27868.78  0.00 99357.13 147790.24
## [8,] 34372.85 208680.25 65755.23 130475.78 150548.53 71517.51 99357.13  0.00 48506.54
## [9,] 82807.54 257100.64 112938.51 173348.15 184343.01 119984.97 147790.24 48506.54  0.00
## [10,] 161886.69 39688.05 130077.99 143045.14 193714.08 129224.97 106022.80 195676.97 242952.31
## [11,] 55126.85 130087.62 22148.78 108522.83 153436.91 38683.57 45117.05 86696.30 132677.47
## [12,] 18601.41 165810.46 20146.67 112271.93 147134.84 37118.86 62401.15 46800.08 93099.20
## [13,] 72028.12 119128.83 39067.45 115818.40 163279.65 52804.91 51451.03 103158.83 148412.95
## [14,] 99289.79 93078.41 82859.62 41821.31 93537.39 62544.59 37818.78 131164.98 178597.15
## [15,] 124898.77 96050.33 111956.85 36006.80 80066.38 89964.67 67454.30 154682.40 200541.45
## [16,] 15322.24 173459.63 41317.26 93418.00 120294.38 35721.19 62654.00 38705.42 86103.97
## [17,] 39915.52 151448.36 15499.68 117027.45 157406.85 40715.29 58241.29 67846.02 112275.54
## [18,] 42498.67 201189.22 73318.28 103869.67 116580.72 65924.95 90545.99 36068.61 69921.14
## [19,] 139799.14 36344.61 112911.21 96041.19 145367.48 102750.72 75346.10 174047.73 222552.96
## [20,] 145131.78 38954.65 114102.51 124219.58 175193.52 111354.82 87322.92 179230.71 226989.10
## [21,] 106787.10 84880.14 73892.05 120503.51 171742.78 79100.02 63649.33 139508.37 185750.40
## [22,] 100294.25 274013.24 128783.15 193332.80 204229.07 137907.05 165775.66 66575.70 20120.95
## [23,] 71221.73 174024.05 86139.23 56777.87 65927.30 64539.43 74664.45 84666.95 121255.28
```

# Simple features (sf)

## Geometrical operations

```
st_distance(lidar_centroids[1,], lidar_centroids[42,])
```

```
## Units: [m]  
##           [,1]  
## [1,] 83024.41
```

# Simple features (sf)

## Geometrical operations

```
st_intersects(lidar_centroids, lidar_data)
```

```
## Sparse geometry binary predicate list of length 42, where the predicate was `intersects`  
## first 10 elements:  
## 1: 1  
## 2: 2  
## 3: 3  
## 4: 4  
## 5: 5  
## 6: 6  
## 7: 7  
## 8: 8  
## 9: 9  
## 10: 10
```

# Simple features (sf)

## Geometrical operations

```
st_intersects(lidar_centroids, lidar_data, sparse = FALSE)
```

```
##      [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10] [,11] [,12] [,13] [,14] [,15]
## [1,] TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [2,] FALSE TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [3,] FALSE FALSE TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [4,] FALSE FALSE FALSE TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [5,] FALSE FALSE FALSE FALSE TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [6,] FALSE FALSE FALSE FALSE FALSE TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [7,] FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [8,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [9,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE FALSE FALSE FALSE FALSE FALSE
## [10,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE FALSE FALSE FALSE FALSE
## [11,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE FALSE FALSE FALSE
## [12,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE FALSE FALSE
## [13,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE FALSE
## [14,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE
## [15,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE TRUE
## [16,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [17,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [18,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [19,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [20,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [21,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [22,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [23,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##      [,16] [,17] [,18] [,19] [,20] [,21] [,22] [,23] [,24] [,25] [,26] [,27] [,28] [,29] [,30]
```

# Simple features (sf)

## Geometrical operations

- `st_intersects`
- `st_touches`
- `st_within`
- `st_contains`
- `st_overlaps`
- `st_covers`
- ...

All these returns a matrix (sparse or not) with all comparisons

# Simple features (sf)

## Geometrical operations

```
st_buffer(lidar_centroids, 1000)
```

```
## Simple feature collection with 42 features and 9 fields
```

```
## Geometry type: POLYGON
```

```
## Dimension: XY
```

```
## Bounding box: xmin: 0.3604196 ymin: 40.65741 xmax: 3.077187 ymax: 42.73487
```

```
## Geodetic CRS: WGS 84
```

```
## First 10 features:
```

##		poly_id	poly_km2	AB_pixels	AB_average	AB_sd	AB_min	AB_max	AB_km2	AB_km2_perc
## 1		Alt Camp	537.6352	482120	16.69471	8.207308	0.01	100	192.8480	35.86968
## 2		Alt Empordà	1356.8555	1393054	20.31397	8.609172	0.01	100	557.2216	41.06713
## 3		Alt Penedès	592.7758	488554	17.65630	9.036426	0.01	100	195.4216	32.96720
## 4		Alt Urgell	1447.2226	2516325	24.93210	14.876077	0.01	100	1006.5300	69.54908
## 5		Alta Ribagorça	427.2234	437735	27.79429	18.256835	0.01	100	175.0940	40.98418
## 6		Anoia	866.6878	976681	16.50647	8.703730	0.01	100	390.6724	45.07648
## 7		Bages	1092.7763	1455613	16.45591	8.884009	0.01	100	582.2452	53.28128
## 8		Baix Camp	697.0773	590955	16.72298	8.028576	0.01	100	236.3820	33.91044
## 9		Baix Ebre	1002.1005	558271	16.74180	9.326562	0.01	100	223.3084	22.28403
## 10		Baix Empordà	701.3843	862685	18.40010	8.052129	0.02	100	345.0740	49.19899

```
## geom
```

```
## 1 POLYGON ((1.318023 41.32289...
```

```
## 2 POLYGON ((2.957717 42.29601...
```

```
## 3 POLYGON ((1.706144 41.39368...
```

```
## 4 POLYGON ((1.395169 42.27603...
```

```
## 5 POLYGON ((0.8209189 42.4954...
```

```
## 6 POLYGON ((1.576575 41.59026...
```

```
## 7 POLYGON ((1.817664 41.78565...
```



# Simple features (sf)

## Geometrical operations

```
convex_hull_counties <- st_convex_hull(lidar_data)
convex_hull_counties
```

```
## Simple feature collection with 42 features and 9 fields
## Geometry type: POLYGON
## Dimension: XY
## Bounding box: xmin: 0.1626252 ymin: 40.52296 xmax: 3.321198 ymax: 42.86144
## Geodetic CRS: WGS 84
## First 10 features:
##
```

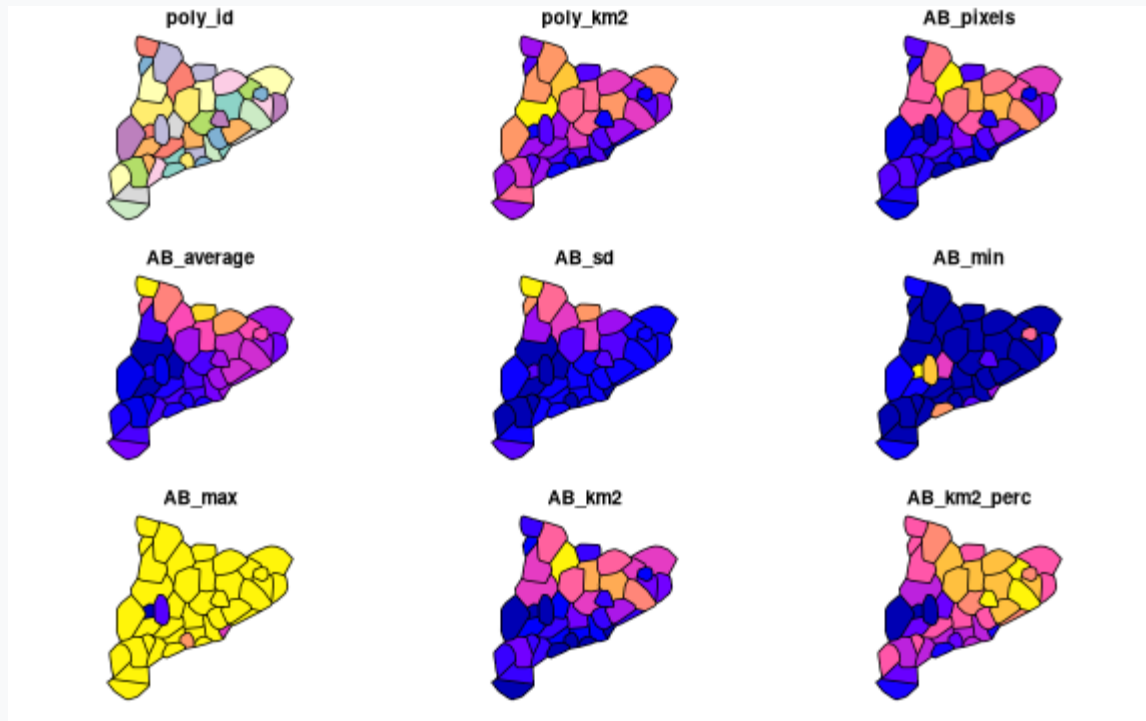
	poly_id	poly_km2	AB_pixels	AB_average	AB_sd	AB_min	AB_max	AB_km2	AB_km2_perc
## 1	Alt Camp	537.6352	482120	16.69471	8.207308	0.01	100	192.8480	35.86968
## 2	Alt Empordà	1356.8555	1393054	20.31397	8.609172	0.01	100	557.2216	41.06713
## 3	Alt Penedès	592.7758	488554	17.65630	9.036426	0.01	100	195.4216	32.96720
## 4	Alt Urgell	1447.2226	2516325	24.93210	14.876077	0.01	100	1006.5300	69.54908
## 5	Alta Ribagorça	427.2234	437735	27.79429	18.256835	0.01	100	175.0940	40.98418
## 6	Anoia	866.6878	976681	16.50647	8.703730	0.01	100	390.6724	45.07648
## 7	Bages	1092.7763	1455613	16.45591	8.884009	0.01	100	582.2452	53.28128
## 8	Baix Camp	697.0773	590955	16.72298	8.028576	0.01	100	236.3820	33.91044
## 9	Baix Ebre	1002.1005	558271	16.74180	9.326562	0.01	100	223.3084	22.28403
## 10	Baix Empordà	701.3843	862685	18.40010	8.052129	0.02	100	345.0740	49.19899

```
##
##          geom
## 1 POLYGON ((1.259028 41.19964...
## 2 POLYGON ((3.132064 42.09831...
## 3 POLYGON ((1.623316 41.22259...
## 4 POLYGON ((1.251535 41.93942...
## 5 POLYGON ((0.8738718 42.2987...
## 6 POLYGON ((1.50262 41.42846,...
```

# Simple features (sf)

## Geometrical operations

```
plot(convex_hull_counties)
```



# Simple features (sf)

## Geometrical operations

```
lidar_centroids_multipoint <- st_union(lidar_centroids)
lidar_centroids_multipoint

## Geometry set for 1 feature
## Geometry type: MULTIPOINT
## Dimension:      XY
## Bounding box:  xmin: 0.3723986 ymin: 40.66646 xmax: 3.065064 ymax: 42.72576
## Geodetic CRS:  WGS 84

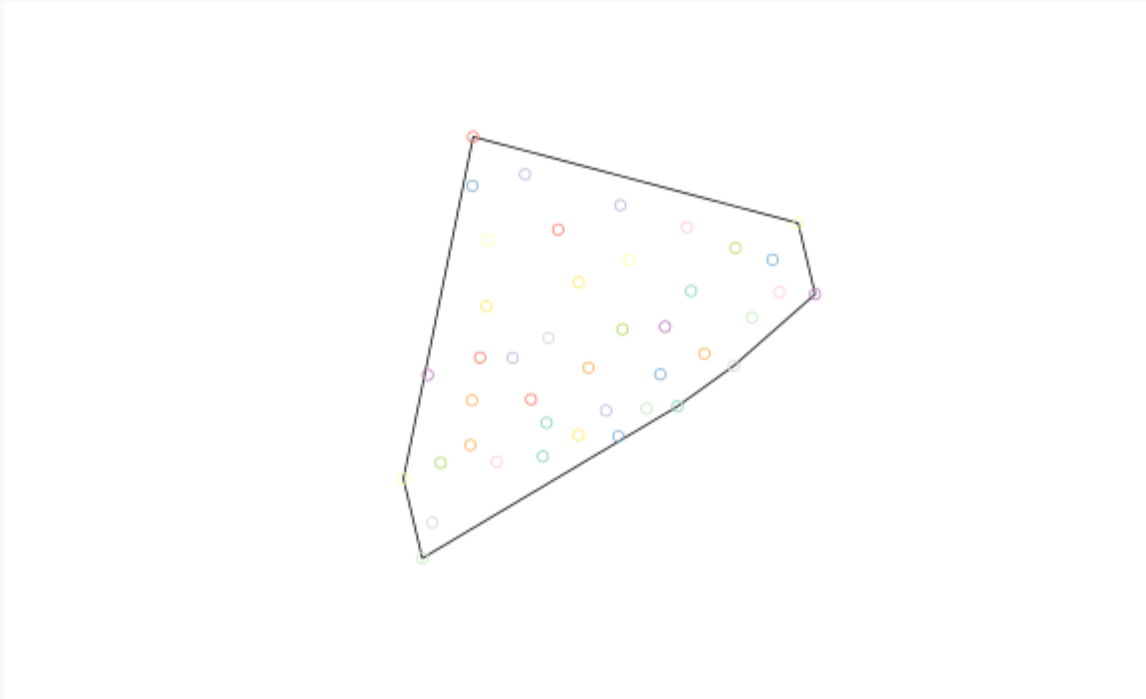
## MULTIPOINT ((0.3723986 41.05448), (0.5613804 40...
```

# Simple features (sf)

## Geometrical operations

```
convex_hull_centroids <- st_convex_hull(lidar_centroids_multipoint)
plot(convex_hull_centroids)
plot(lidar_centroids, add = TRUE)
```

## Warning in plot.sf(lidar\_centroids, add = TRUE): ignoring all but the first attribute



# Simple features (sf)

## Geometrical operations

```
# error
st_triangulate(lidar_centroids)

## Warning in st_triangulate.sfc(st_geometry(x), dTolerance, bOnlyEdges): st_triangulate does not
## correctly triangulate longitude/latitude data

## Simple feature collection with 42 features and 9 fields (with 42 geometries empty)
## Geometry type: GEOMETRYCOLLECTION
## Dimension: XY
## Bounding box: xmin: NA ymin: NA xmax: NA ymax: NA
## Geodetic CRS: WGS 84
## First 10 features:
##      poly_id poly_km2 AB_pixels AB_average AB_sd AB_min AB_max AB_km2 AB_km2_perc
## 1 Alt Camp 537.6352 482120 16.69471 8.207308 0.01 100 192.8480 35.86968
## 2 Alt Empordà 1356.8555 1393054 20.31397 8.609172 0.01 100 557.2216 41.06713
## 3 Alt Penedès 592.7758 488554 17.65630 9.036426 0.01 100 195.4216 32.96720
## 4 Alt Urgell 1447.2226 2516325 24.93210 14.876077 0.01 100 1006.5300 69.54908
## 5 Alta Ribagorça 427.2234 437735 27.79429 18.256835 0.01 100 175.0940 40.98418
## 6 Anoia 866.6878 976681 16.50647 8.703730 0.01 100 390.6724 45.07648
## 7 Bages 1092.7763 1455613 16.45591 8.884009 0.01 100 582.2452 53.28128
## 8 Baix Camp 697.0773 590955 16.72298 8.028576 0.01 100 236.3820 33.91044
## 9 Baix Ebre 1002.1005 558271 16.74180 9.326562 0.01 100 223.3084 22.28403
## 10 Baix Empordà 701.3843 862685 18.40010 8.052129 0.02 100 345.0740 49.19899
##      geom
## 1 GEOMETRYCOLLECTION EMPTY
## 2 GEOMETRYCOLLECTION EMPTY
## 3 GEOMETRYCOLLECTION EMPTY
```

# Simple features (sf)

## Geometrical operations

```
# no error, but maybe lat long is not the perfect here  
st_triangulate(lidar_centroids_multipoint)
```

```
## Warning in st_triangulate.sfc(lidar_centroids_multipoint): st_triangulate does not correctly  
## triangulate longitude/latitude data
```

```
## Geometry set for 1 feature  
## Geometry type: GEOMETRYCOLLECTION  
## Dimension: XY  
## Bounding box: xmin: 0.3723986 ymin: 40.66646 xmax: 3.065064 ymax: 42.72576  
## Geodetic CRS: WGS 84
```

```
## GEOMETRYCOLLECTION (POLYGON ((0.8282611 42.7257...
```

# Simple features (sf)

## Geometrical operations

```
# utm works fine
lidar_centroids_multipoint %>%
  st_transform(crs = 3043) %>%
  st_triangulate()

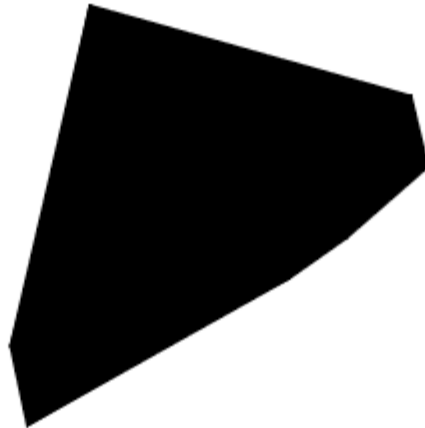
## Geometry set for 1 feature
## Geometry type: GEOMETRYCOLLECTION
## Dimension:      XY
## Bounding box:  xmin: 279186 ymin: 4504747 xmax: 505392 ymax: 4732649
## Projected CRS: ETRS89 / UTM zone 31N (N-E)

## GEOMETRYCOLLECTION (POLYGON ((322196.5 4732649,...
```

# Simple features (sf)

## Geometrical operations

```
# ummm, no plot???  
lidar_centroids_multipoint %>%  
  st_transform(crs = 3043) %>%  
  st_triangulate() %>%  
  plot()
```

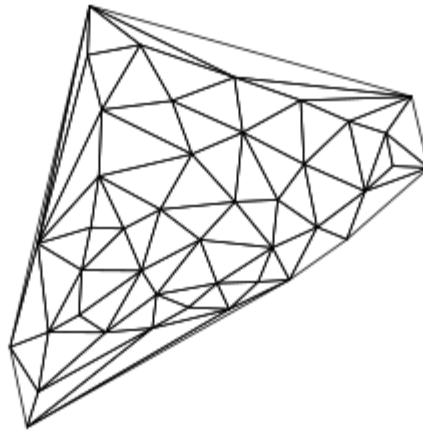




# Simple features (sf)

## Geometrical operations

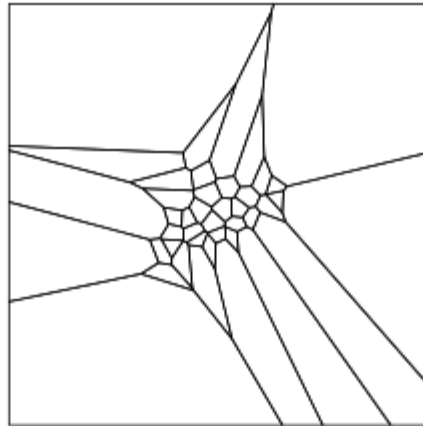
```
# ahh, we need to extract the collection, to be able to plot correctly  
lidar_centroids_multipoint %>%  
  st_transform(crs = 3043) %>%  
  st_triangulate() %>%  
  st_collection_extract() %>%  
  plot()
```



# Simple features (sf)

## Geometrical operations

```
# Is the same for voronoi polygons  
lidar_centroids_multipoint %>%  
  st_transform(crs = 3043) %>%  
  st_voronoi() %>%  
  st_collection_extract() %>%  
  plot()
```



# Simple features (sf)

## Valid geometries

```
sleeve_polygon <- st_polygon(list(cbind(c(0,1,1,1,0,0),c(0,0,1,0.6,1,0))))  
cross_polygon <- st_polygon(list(cbind(c(0,1,0,1,0),c(0,1,1,0,0))))  
st_is_valid(sleeve_polygon)
```

```
## [1] FALSE
```

```
st_is_valid(cross_polygon)
```

```
## [1] FALSE
```

```
st_is_valid(lidar_data[1,])
```

```
## [1] TRUE
```

# Simple features (sf)

## Valid geometries

```
valid_sleeve_polygon <- st_make_valid(sleeve_polygon)
valid_cross_polygon <- st_make_valid(cross_polygon)
st_is_valid(valid_sleeve_polygon)
```

```
## [1] TRUE
```

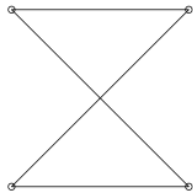
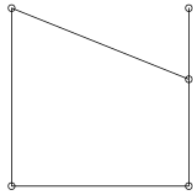
```
st_is_valid(valid_cross_polygon)
```

```
## [1] TRUE
```

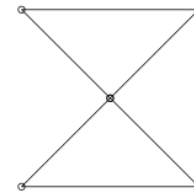
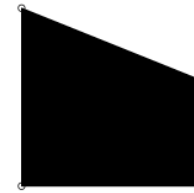
# Simple features (sf)

## Valid geometries

Invalid:



Valid:



# Simple features (sf)

## Subsetting features

```
lidar_data[1, "AB_average"]
```

```
## Simple feature collection with 1 feature and 1 field
## Geometry type: MULTIPOLYGON
## Dimension:      XY
## Bounding box:  xmin: 1.042872 ymin: 41.19964 xmax: 1.537018 ymax: 41.47907
## Geodetic CRS:  WGS 84
##   AB_average      geom
## 1  16.69471 MULTIPOLYGON (((1.495952 41...
```

# Simple features (sf)

## Subsetting features

```
lidar_data[1, "AB_average", drop = TRUE]
```

```
## [1] 16.69471  
## attr("class")  
## [1] "numeric"
```

# Simple features (sf)

## Subsetting features

```
lidar_data[valles_data,]

## Simple feature collection with 6 features and 9 fields
## Geometry type: MULTIPOLYGON
## Dimension: XY
## Bounding box: xmin: 1.551508 ymin: 41.26331 xmax: 2.60935 ymax: 41.9704
## Geodetic CRS: WGS 84
##
##      poly_id  poly_km2 AB_pixels AB_average   AB_sd AB_min AB_max  AB_km2 AB_km2_perc
## 7          Bages 1092.7763  1455613  16.45591  8.884009  0.01 100.00  582.2452  53.28128
## 11    Baix Llobregat 487.8669   397595  19.63158  9.438929  0.01 100.00  159.0380  32.59864
## 13    Barcelonès 146.1943    43138  20.21294  7.832255  0.06  72.39  17.2552  11.80292
## 40 Vallès Occidental 582.9532  659060  20.60493  8.976501  0.01 100.00  263.6240  45.22216
## 41    Vallès Oriental 735.2148 1103493  23.07162  8.838574  0.01 100.00  441.3972  60.03649
## 42      Moianès 337.5398   593580  20.80658 10.609974  0.04 100.00  237.4320  70.34192
##
##              geom
## 7  MULTIPOLYGON (((2.040477 41...
## 11 MULTIPOLYGON (((1.812835 41...
## 13 MULTIPOLYGON (((2.059358 41...
## 40 MULTIPOLYGON (((2.133049 41...
## 41 MULTIPOLYGON (((2.41841 41...
## 42 MULTIPOLYGON (((2.240584 41...
```



# Simple features (sf)

## Subsetting features

```
lidar_data[valles_data, , op = st_contains]

## Simple feature collection with 1 feature and 9 fields
## Geometry type: MULTIPOLYGON
## Dimension: XY
## Bounding box: xmin: 1.860982 ymin: 41.41498 xmax: 2.224695 ymax: 41.71742
## Geodetic CRS: WGS 84
##           poly_id poly_km2 AB_pixels AB_average   AB_sd AB_min AB_max  AB_km2 AB_km2_perc
## 40 Vallès Occidental 582.9532   659060   20.60493 8.976501  0.01   100 263.624   45.22216
##                                     geom
## 40 MULTIPOLYGON (((2.133049 41...
```

# Simple features (sf)

## Subsetting features

```
lidar_data %>%
  filter(lengths(st_contains(., valles_data)) > 0)

## Simple feature collection with 1 feature and 9 fields
## Geometry type: MULTIPOLYGON
## Dimension:      XY
## Bounding box:  xmin: 1.860982 ymin: 41.41498 xmax: 2.224695 ymax: 41.71742
## Geodetic CRS:  WGS 84
##           poly_id poly_km2 AB_pixels AB_average   AB_sd AB_min AB_max  AB_km2 AB_km2_perc
## 1 Vallès Occidental 582.9532   659060   20.60493 8.976501   0.01   100 263.624   45.22216
##           geom
## 1 MULTIPOLYGON (((2.133049 41...
```

# Simple features (sf)

## Joining feature sets

```
ifn_ab <- st_read('ifn_data.gpkg', quiet = TRUE) %>%  
  as.data.frame() %>%  
  select(admin_region, basal_area_mean, -geom)  
ifn_ab
```

##	admin_region	basal_area_mean
## 1	Alt Camp	17.544107
## 2	Alt Empordà	21.923531
## 3	Alt Penedès	13.765320
## 4	Alt Urgell	23.879636
## 5	Alta Ribagorça	23.904747
## 6	Anoia	13.887243
## 7	Bages	12.416677
## 8	Baix Camp	16.573114
## 9	Baix Ebre	18.648741
## 10	Baix Empordà	20.289387
## 11	Baix Llobregat	13.527088
## 12	Baix Penedès	14.818076
## 13	Barcelonès	19.116235
## 14	Berguedà	20.890631
## 15	Cerdanya	27.223615
## 16	Conca de Barberà	16.863591
## 17	Garraf	9.667396
## 18	Garrigues	10.138431
## 19	Garrotxa	23.137891
## 20	Gironès	20.133531
## 21	Maresme	21.684917

# Simple features (sf)

## Joining feature sets

### By attributes

```
left_join(lidar_data, ifn_ab, by = c("poly_id" = "admin_region"))
```

```
## Simple feature collection with 42 features and 10 fields
```

```
## Geometry type: MULTIPOLYGON
```

```
## Dimension: XY
```

```
## Bounding box: xmin: 0.1626252 ymin: 40.52296 xmax: 3.321198 ymax: 42.86144
```

```
## Geodetic CRS: WGS 84
```

```
## First 10 features:
```

##	poly_id	poly_km2	AB_pixels	AB_average	AB_sd	AB_min	AB_max	AB_km2	AB_km2_perc
## 1	Alt Camp	537.6352	482120	16.69471	8.207308	0.01	100	192.8480	35.86968
## 2	Alt Empordà	1356.8555	1393054	20.31397	8.609172	0.01	100	557.2216	41.06713
## 3	Alt Penedès	592.7758	488554	17.65630	9.036426	0.01	100	195.4216	32.96720
## 4	Alt Urgell	1447.2226	2516325	24.93210	14.876077	0.01	100	1006.5300	69.54908
## 5	Alta Ribagorça	427.2234	437735	27.79429	18.256835	0.01	100	175.0940	40.98418
## 6	Anoia	866.6878	976681	16.50647	8.703730	0.01	100	390.6724	45.07648
## 7	Bages	1092.7763	1455613	16.45591	8.884009	0.01	100	582.2452	53.28128
## 8	Baix Camp	697.0773	590955	16.72298	8.028576	0.01	100	236.3820	33.91044
## 9	Baix Ebre	1002.1005	558271	16.74180	9.326562	0.01	100	223.3084	22.28403
## 10	Baix Empordà	701.3843	862685	18.40010	8.052129	0.02	100	345.0740	49.19899

```
## basal_area_mean geom
```

```
## 1 17.54411 MULTIPOLYGON (((1.495952 41...
```

```
## 2 21.92353 MULTIPOLYGON (((3.170083 42...
```

```
## 3 13.76532 MULTIPOLYGON (((1.837855 41...
```

```
## 4 23.87964 MULTIPOLYGON (((1.319412 41...
```

# Simple features (sf)

## Joining feature sets

### By attributes

```

left_join(lidar_data, ifn_ab, by = c("poly_id" = "admin_region")) %>%
  select(poly_id, AB_lidar = AB_average, AB_ifn = basal_area_mean) %>%
  mutate(difference = AB_ifn - AB_lidar)

## Simple feature collection with 42 features and 4 fields
## Geometry type: MULTIPOLYGON
## Dimension:      XY
## Bounding box:  xmin: 0.1626252 ymin: 40.52296 xmax: 3.321198 ymax: 42.86144
## Geodetic CRS:  WGS 84
## First 10 features:
##      poly_id AB_lidar  AB_ifn          geom difference
## 1      Alt Camp 16.69471 17.54411 MULTIPOLYGON (((1.495952 41... 0.8493953
## 2      Alt Empordà 20.31397 21.92353 MULTIPOLYGON (((3.170083 42... 1.6095620
## 3      Alt Penedès 17.65630 13.76532 MULTIPOLYGON (((1.837855 41... -3.8909755
## 4      Alt Urgell 24.93210 23.87964 MULTIPOLYGON (((1.319412 41... -1.0524606
## 5      Alta Ribagorça 27.79429 23.90475 MULTIPOLYGON (((0.9378095 4... -3.8895409
## 6          Anoia 16.50647 13.88724 MULTIPOLYGON (((1.47133 41... -2.6192251
## 7          Bages 16.45591 12.41668 MULTIPOLYGON (((2.040477 41... -4.0392295
## 8      Baix Camp 16.72298 16.57311 MULTIPOLYGON (((1.06411 41... -0.1498684
## 9      Baix Ebre 16.74180 18.64874 MULTIPOLYGON (((0.5591292 4... 1.9069363
## 10     Baix Empordà 18.40010 20.28939 MULTIPOLYGON (((3.170083 42... 1.8892824

```

# Simple features (sf)

## Joining feature sets

### By geometries

```
ifn_data <- st_read('ifn_data.gpkg', quiet = TRUE) %>%  
  select(admin_region, basal_area_mean)
```

```
ifn_data
```

```
## Simple feature collection with 41 features and 2 fields  
## Geometry type: MULTIPOLYGON  
## Dimension: XY  
## Bounding box: xmin: 0.1626252 ymin: 40.52296 xmax: 3.321198 ymax: 42.86144  
## Geodetic CRS: WGS 84  
## First 10 features:  
##      admin_region basal_area_mean          geom  
## 1      Alt Camp      17.54411 MULTIPOLYGON (((1.495952 41...  
## 2      Alt Empordà      21.92353 MULTIPOLYGON (((3.170083 42...  
## 3      Alt Penedès      13.76532 MULTIPOLYGON (((1.837855 41...  
## 4      Alt Urgell      23.87964 MULTIPOLYGON (((1.319412 41...  
## 5      Alta Ribagorça      23.90475 MULTIPOLYGON (((0.9378095 4...  
## 6              Anòia      13.88724 MULTIPOLYGON (((1.47133 41....  
## 7              Bages      12.41668 MULTIPOLYGON (((2.040477 41...  
## 8      Baix Camp      16.57311 MULTIPOLYGON (((1.06411 41....  
## 9      Baix Ebre      18.64874 MULTIPOLYGON (((0.5591292 4...  
## 10     Baix Empordà      20.28939 MULTIPOLYGON (((3.170083 42...
```

# Simple features (sf)

## Joining feature sets

### By geometries

```
st_join(lidar_data, ifn_data, join = st_intersects)

## Simple feature collection with 233 features and 11 fields
## Geometry type: MULTIPOLYGON
## Dimension: XY
## Bounding box: xmin: 0.1626252 ymin: 40.52296 xmax: 3.321198 ymax: 42.86144
## Geodetic CRS: WGS 84
## First 10 features:
##      poly_id poly_km2 AB_pixels AB_average AB_sd AB_min AB_max AB_km2 AB_km2_perc
## 1 Alt Camp 537.6352 482120 16.69471 8.207308 0.01 100 192.8480 35.86968
## 1.1 Alt Camp 537.6352 482120 16.69471 8.207308 0.01 100 192.8480 35.86968
## 1.2 Alt Camp 537.6352 482120 16.69471 8.207308 0.01 100 192.8480 35.86968
## 1.3 Alt Camp 537.6352 482120 16.69471 8.207308 0.01 100 192.8480 35.86968
## 1.4 Alt Camp 537.6352 482120 16.69471 8.207308 0.01 100 192.8480 35.86968
## 1.5 Alt Camp 537.6352 482120 16.69471 8.207308 0.01 100 192.8480 35.86968
## 1.6 Alt Camp 537.6352 482120 16.69471 8.207308 0.01 100 192.8480 35.86968
## 2 Alt Empordà 1356.8555 1393054 20.31397 8.609172 0.01 100 557.2216 41.06713
## 2.1 Alt Empordà 1356.8555 1393054 20.31397 8.609172 0.01 100 557.2216 41.06713
## 2.2 Alt Empordà 1356.8555 1393054 20.31397 8.609172 0.01 100 557.2216 41.06713
##      admin_region basal_area_mean geom
## 1 Alt Camp 17.54411 MULTIPOLYGON (((1.495952 41...
## 1.1 Alt Penedès 13.76532 MULTIPOLYGON (((1.495952 41...
## 1.2 Anoia 13.88724 MULTIPOLYGON (((1.495952 41...
## 1.3 Baix Camp 16.57311 MULTIPOLYGON (((1.495952 41...
```

# Simple features (sf)

## Joining feature sets

### By geometries

```

st_join(lidar_data, st_centroid(ifn_data), join = st_intersects)

## Warning in st_centroid.sf(ifn_data): st_centroid assumes attributes are constant over geometries of
## x

## Simple feature collection with 42 features and 11 fields
## Geometry type: MULTIPOLYGON
## Dimension:      XY
## Bounding box:  xmin: 0.1626252 ymin: 40.52296 xmax: 3.321198 ymax: 42.86144
## Geodetic CRS:  WGS 84
## First 10 features:
##      poly_id poly_km2 AB_pixels AB_average      AB_sd AB_min AB_max      AB_km2 AB_km2_perc
## 1      Alt Camp  537.6352   482120   16.69471   8.207308   0.01   100   192.8480   35.86968
## 2      Alt Empordà 1356.8555  1393054   20.31397   8.609172   0.01   100   557.2216   41.06713
## 3      Alt Penedès  592.7758   488554   17.65630   9.036426   0.01   100   195.4216   32.96720
## 4      Alt Urgell 1447.2226  2516325   24.93210  14.876077   0.01   100  1006.5300   69.54908
## 5      Alta Ribagorça 427.2234   437735   27.79429  18.256835   0.01   100   175.0940   40.98418
## 6          Anoia  866.6878   976681   16.50647   8.703730   0.01   100   390.6724   45.07648
## 7          Bages 1092.7763  1455613   16.45591   8.884009   0.01   100   582.2452   53.28128
## 8          Baix Camp 697.0773   590955   16.72298   8.028576   0.01   100   236.3820   33.91044
## 9          Baix Ebre 1002.1005   558271   16.74180   9.326562   0.01   100   223.3084   22.28403
## 10         Baix Empordà 701.3843   862685   18.40010   8.052129   0.02   100   345.0740   49.19899
##      admin_region basal_area_mean                                geom
## 1      Alt Camp          17.54411 MULTIPOLYGON (((1.495952 41...

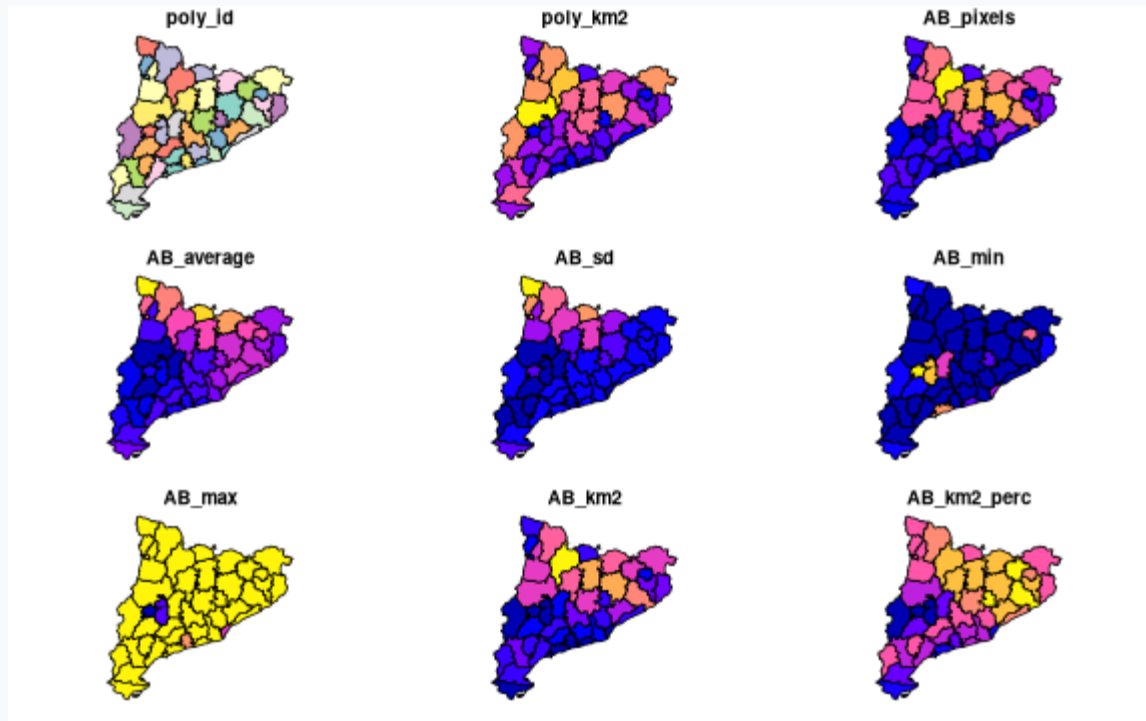
```



# Simple features (sf)

## Plotting

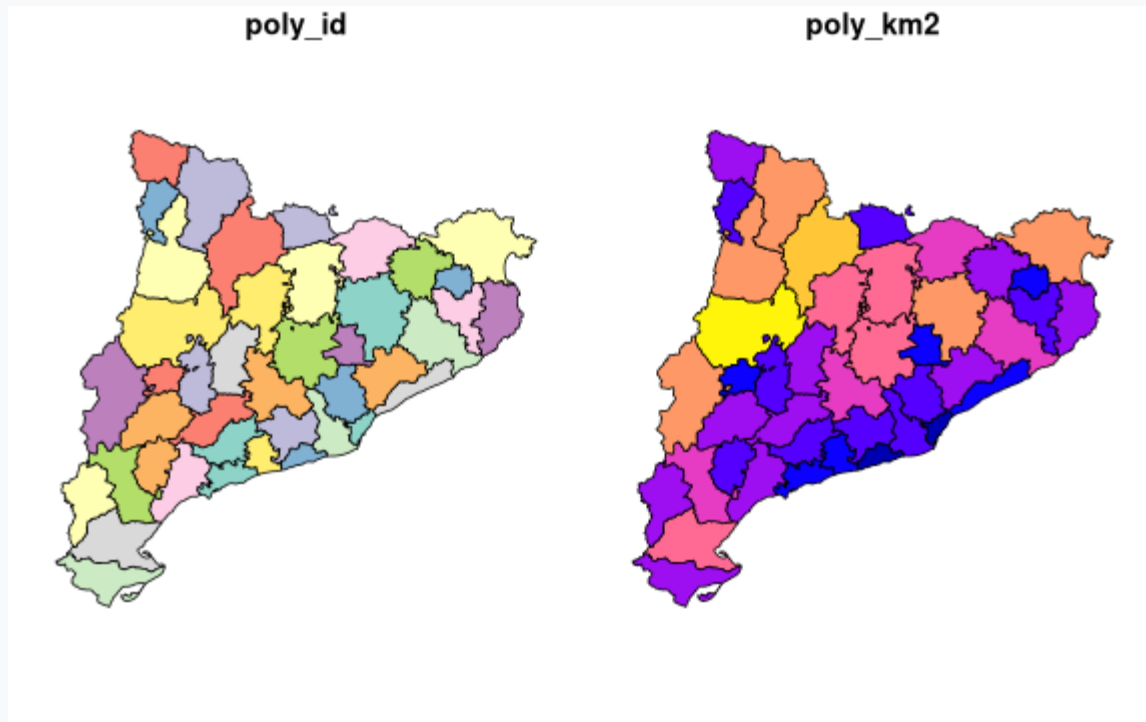
```
plot(lidar_data)
```



# Simple features (sf)

## Plotting

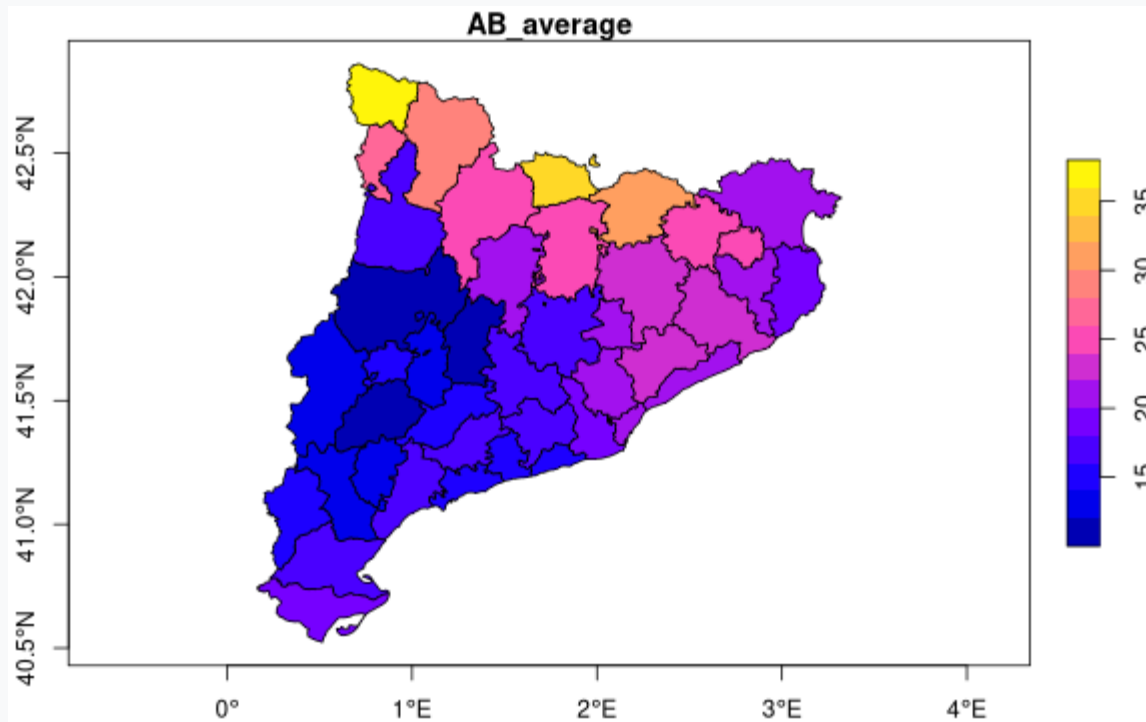
```
plot(lidar_data, max.plot = 2)
```



# Simple features (sf)

## Plotting

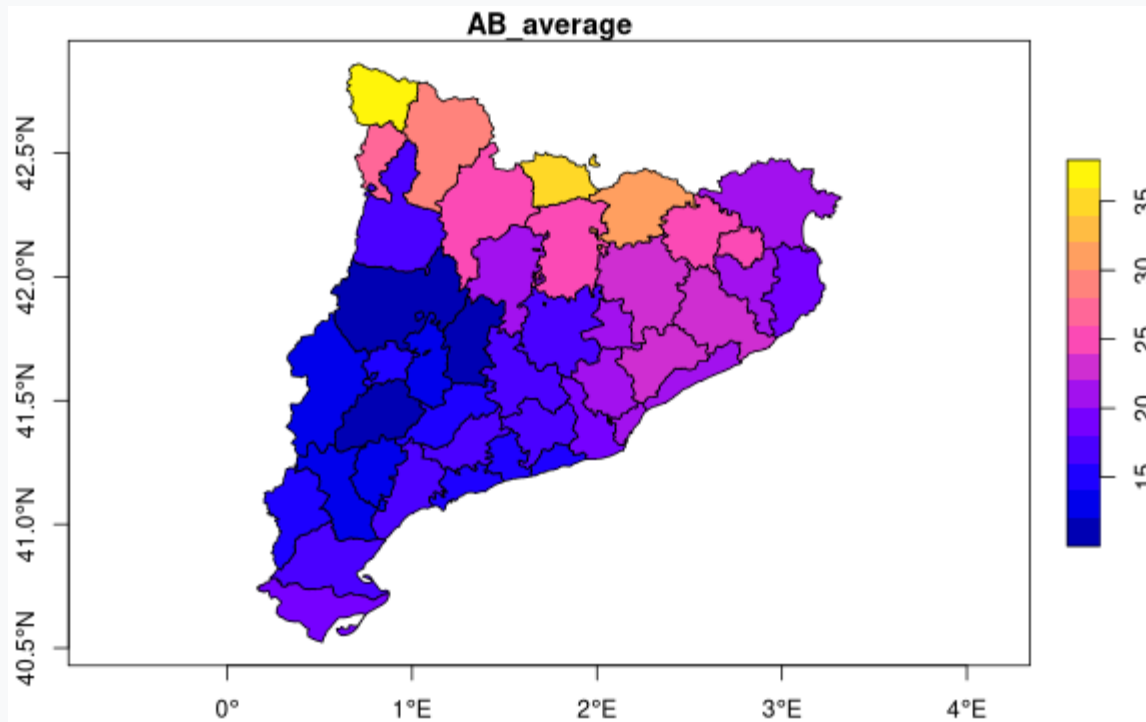
```
plot(lidar_data[, "AB_average"], axes = TRUE)
```



# Simple features (sf)

## Plotting

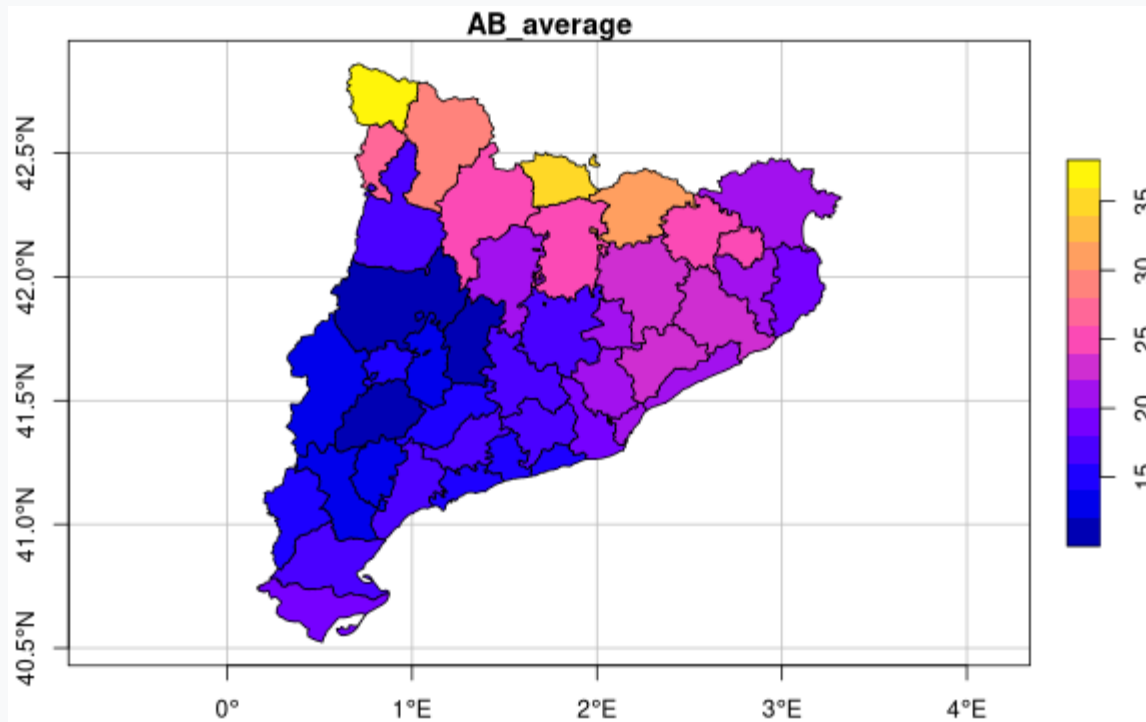
```
plot(lidar_data[, "AB_average"], axes = TRUE, key.pos = 4)
```



# Simple features (sf)

## Plotting

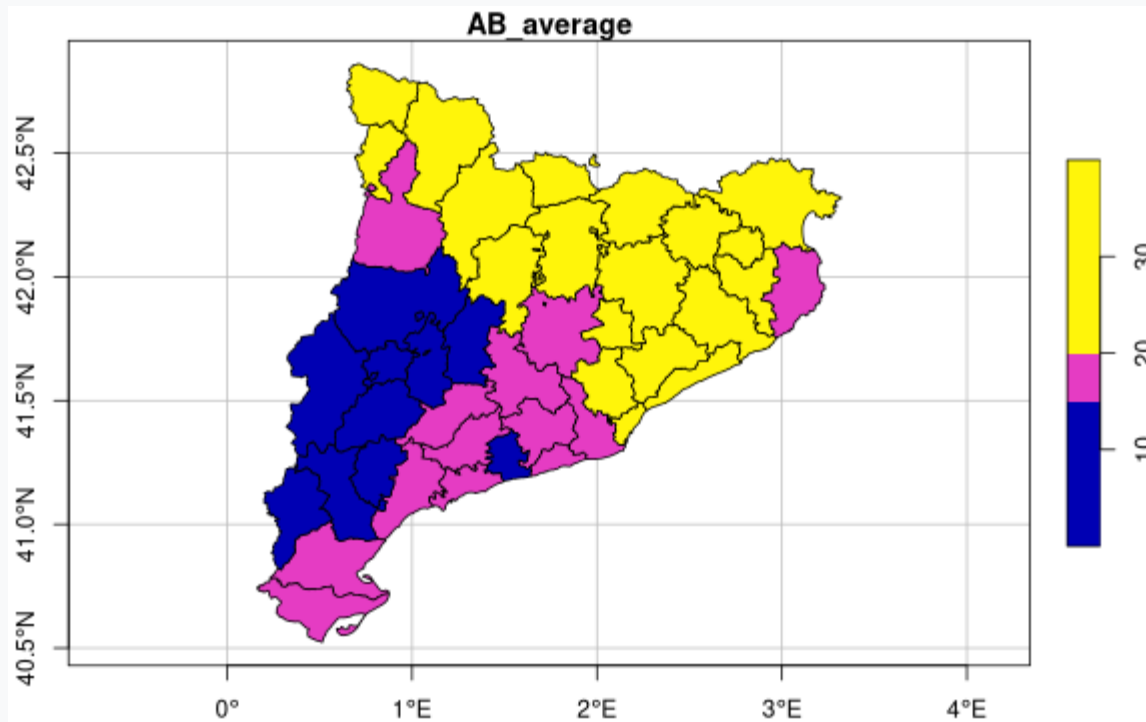
```
plot(lidar_data[, "AB_average"], axes = TRUE, key.pos = 4, graticule = TRUE)
```



# Simple features (sf)

## Plotting

```
plot(lidar_data[, "AB_average"], axes = TRUE, key.pos = 4, graticule = TRUE, breaks = c(0, 15,
```



# Simple features (sf)

## ggplot2

```
library(ggplot2)
lidar_data %>%
  ggplot() +
  geom_sf(aes(fill = AB_average)) +
  scale_fill_fermenter(palette = 2, direction = 1, type = 'div')
```

