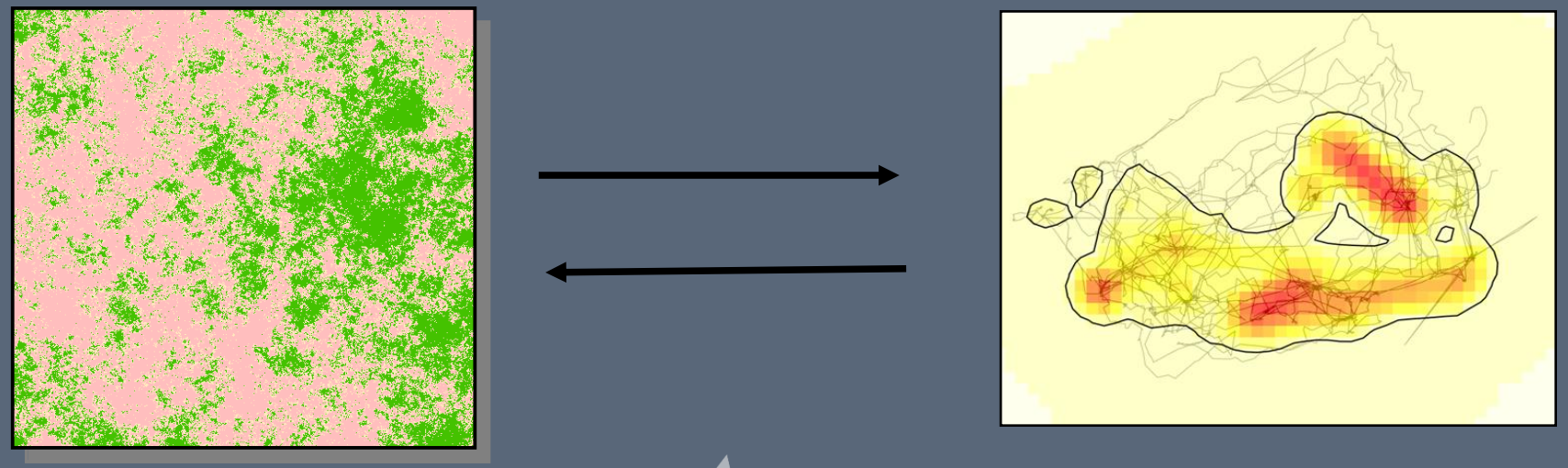
Including environmental covariates into movement analysis



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NINA
Norwegian Institute for Nature Research

Animal Movement PhD-course, SLU
Ekenäs Herrgård
4-8 September, 2023

Movement with covariates

Effects of Land Cover on the Movement of Frugivorous Birds in a Heterogeneous Landscape

Natalia Stefanini Da Silveira[1]*, Bernardo Brandão S. Niebuhr[1], Renata de Lara Muylaert[1], Milton Cezar Ribeiro[1], Marco Aurélio Pizo[2]

Turdus rufiventris

Turdus leucomelas

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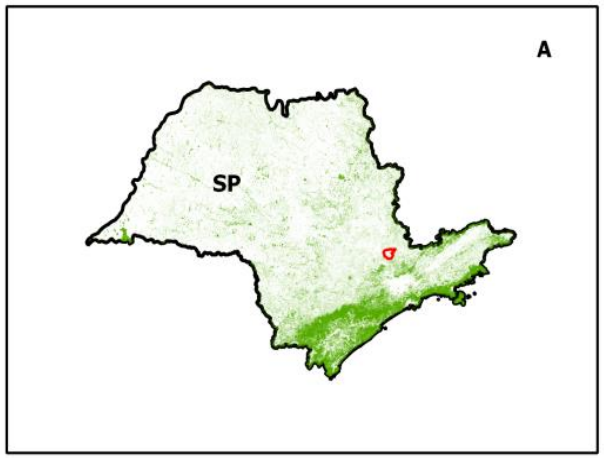
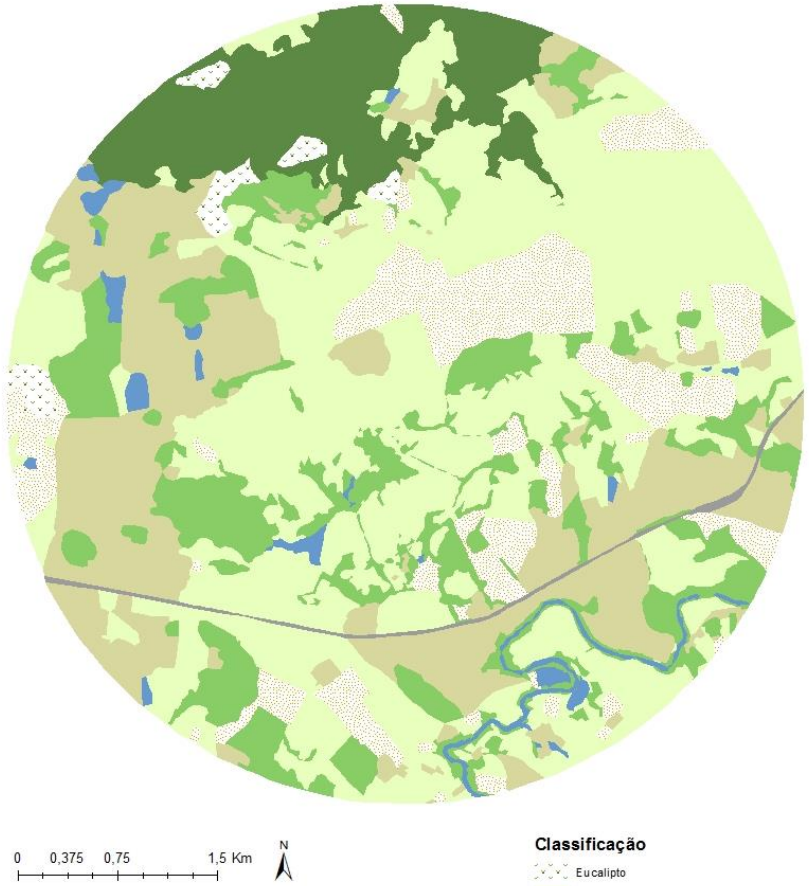
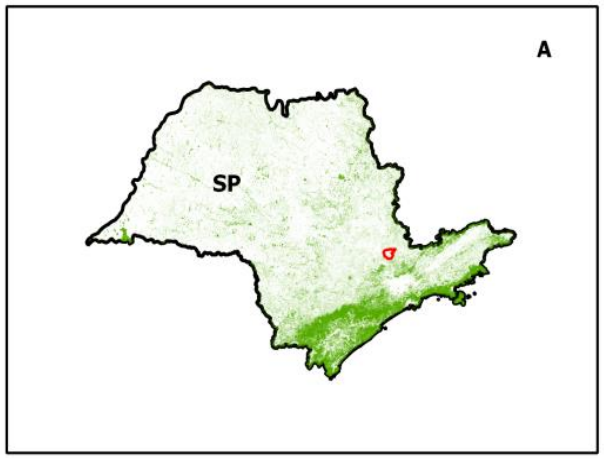
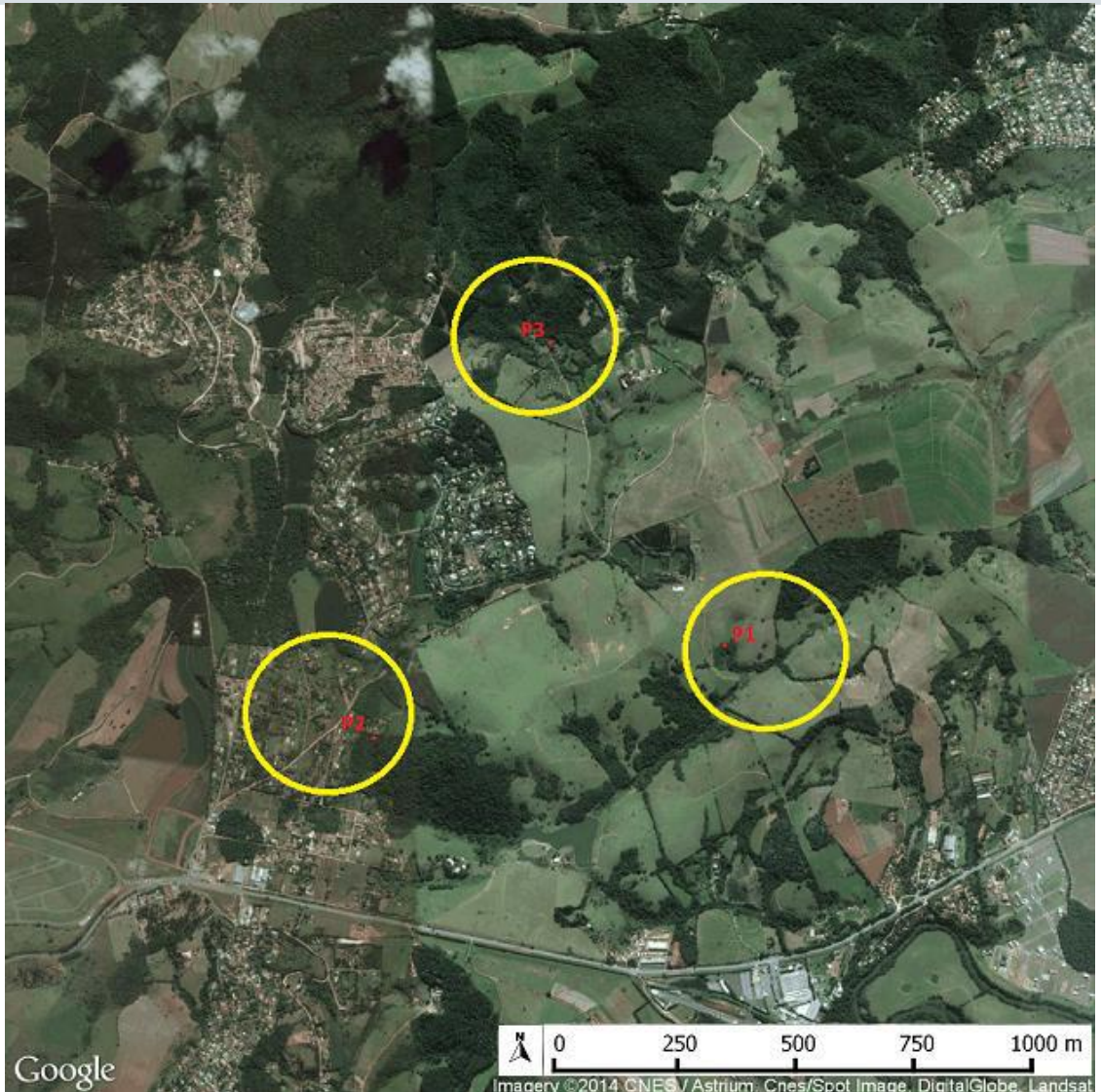
Movement with covariates



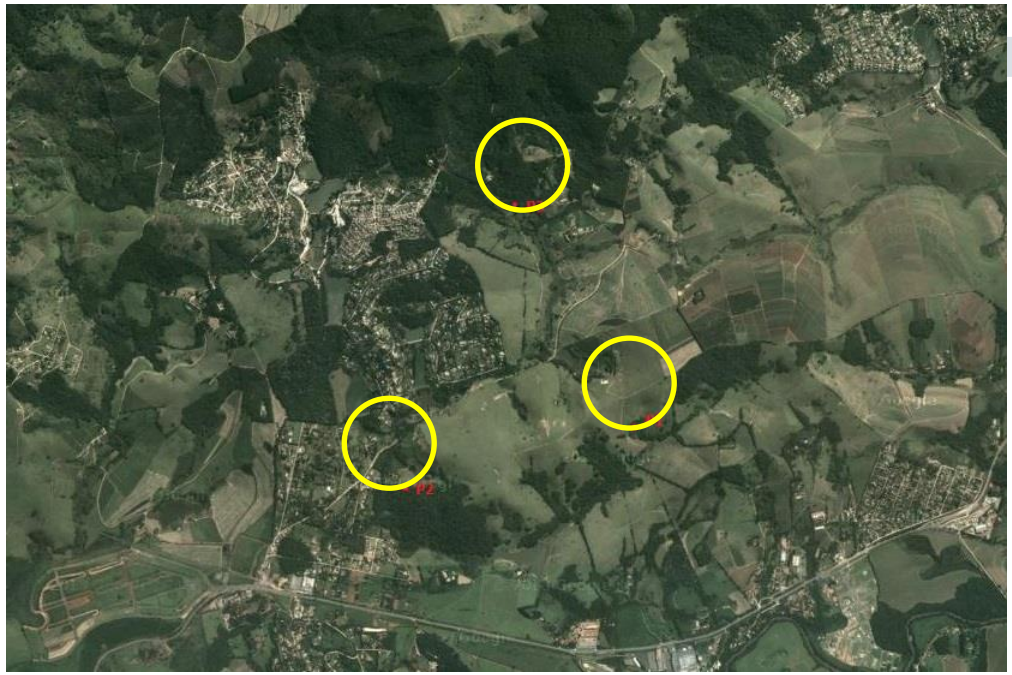


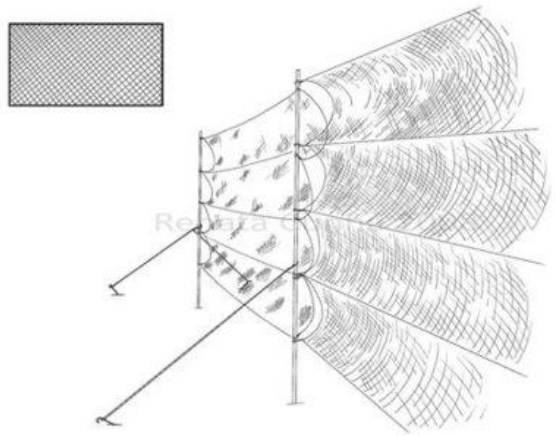
Movement with covariates

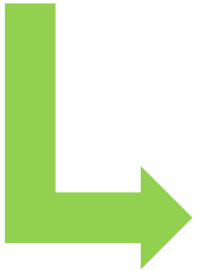




Movement with covariates







Total 302h/net

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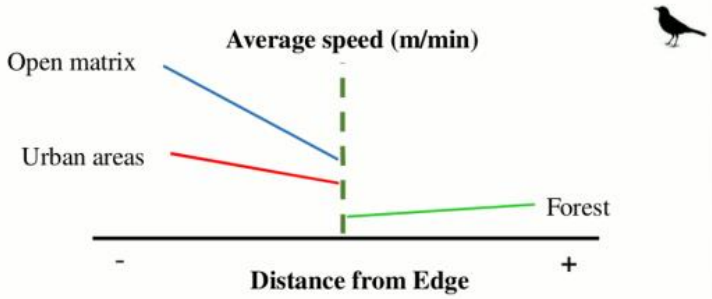
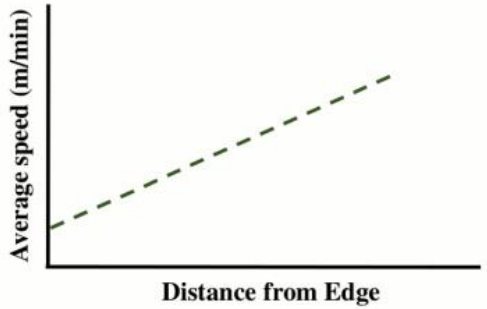
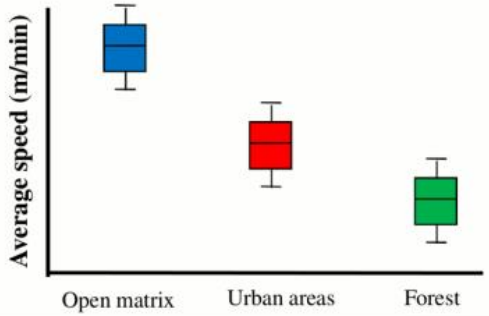
Movement with covariates

Movement with covariates

Movement with covariates

Hypothesis	Description of the expected responses	Sketch of expected responses
H1 Average Speed: Effect of Distance from Edges and Land Cover	We expected average speeds to increase with the distance from forest edges. Also, we expected this increase to be smaller in the forest, intermediate in urban areas and higherin open matrix types (crops and pasture), where resources are scarcer.	
H2 Average Speed: Effect of Distance from Edges	We expected average speeds to increase only with the distance from forest edges, with shorter speeds near edges, one of thrushes' preferred habitats.	
H3 Average Speed: Effect of Land Cover	We expected lower average speeds inside forests, where resources area abundant, moderately speeds in urban areas, and higher movement speeds in open matrix types (crops and pasture), where resources are scarcer.	

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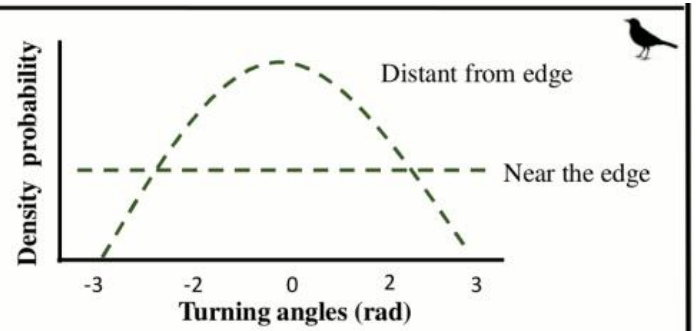
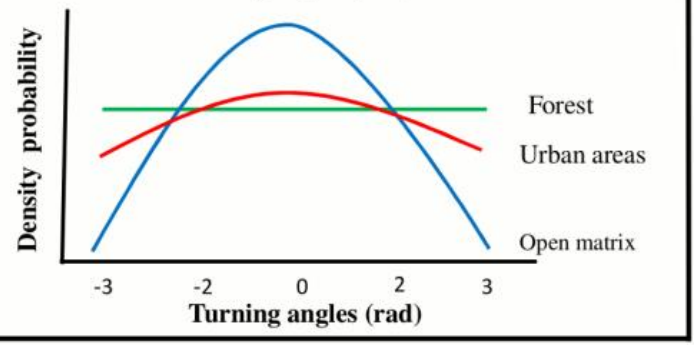
Movement with covariates

H1 Turning Angles: Effect of Distance from Edges	We expected turning angles to be near zero rad in areas more distant from the edges, representing directional movements. Also, we expected angles to be uniformly distributed near forest edges, which represent tortuous trajectories.	
H2 Turning Angles: Effect of Land Cover	We expected angles uniformly distributed (more tortuous trajectories) inside forest areas, which is consistent with a foraging behavior, less uniform in urban areas, and angles around zero rad (directed displacements) in open matrix types (crops and pasture).	

Movement with covariates

$$p\,(y \mid \lambda) = \begin{cases} \lambda e^{-\lambda\, y}, & x \geq 0 \\ 0, & x < 0, \end{cases}$$

$y_i \sim \text{Exp}(\lambda_i)$

$\lambda_i = a * \text{dist\_edge}_i + b$

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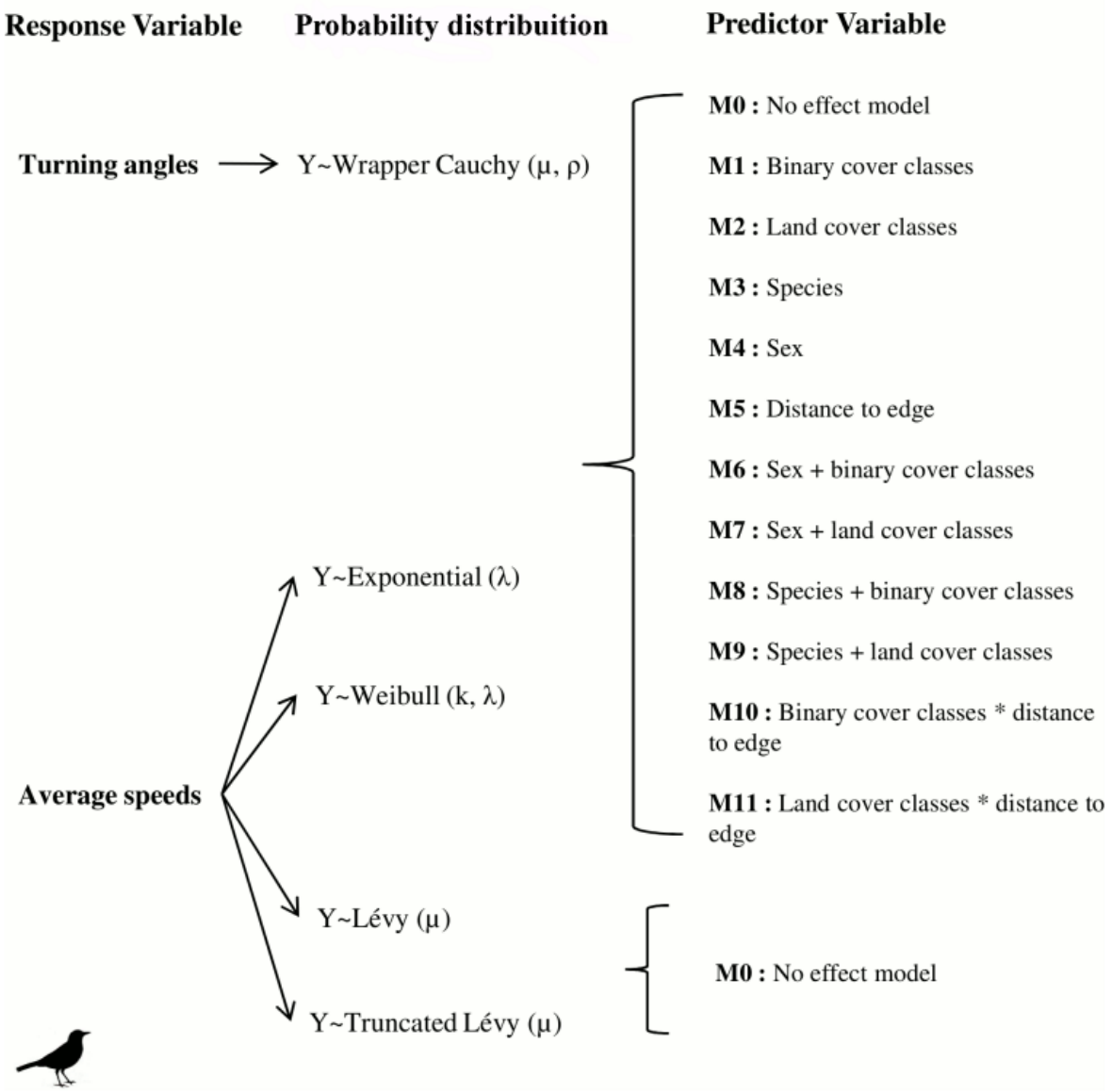
Movement with covariates

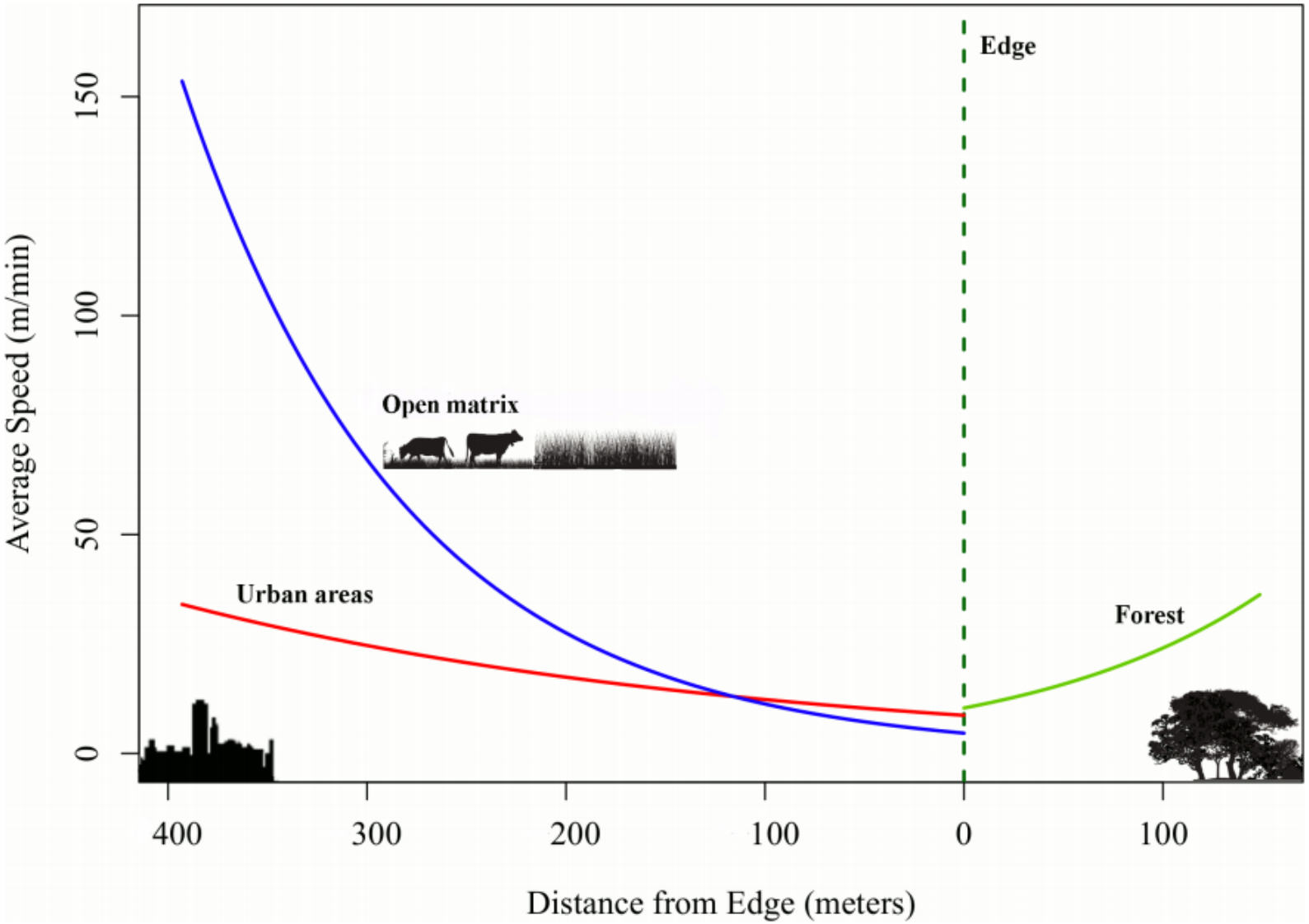


Movement with covariates

Table 1. Competing models describing average speed for *Turdus leucomelas* and *T. rufiventris*. Plausible model in italic. K is the number of estimated parameters and the *w* is the Akaike weights (relative likelihood of the model).

Response variable	Distribution	Models		dAICc	K	*w*
Average speed	*Exponential*	*M11*	*Land cover classes * distance to edge*	*0.0*	*6*	*0.881*
	Exponential	M10	Binary cover classes * distance to edge	4.1	4	0.114
	Weibull	M11	Land cover classes * distance to edge	13.1	7	0.001
	Weibull	M8	Species + binary cover classes	13.3	4	0.001
	Weibull	M9	Species +land cover classes	15.1	5	<0.001
	Weibull	M10	Binary cover classes * distance to edge	15.4	5	<0.001
	Weibull	M3	Species	17.3	3	<0.001
	Exponential	M9	Species + land cover classes	21.2	4	<0.001
	Exponential	M8	Species + binary cover classes	21.5	3	<0.001
	Weibull	M1	Binary cover classes	22.1	3	<0.001
	Weibull	M6	Sex + binary cover classes	22.5	4	<0.001
	Exponential	M5	Distance to edge	22.7	2	<0.001
	Weibull	M2	Land cover classes	24.2	4	<0.001
	Weibull	M5	Distance to edge	24.5	3	<0.001
	Weibull	M7	Sex + land cover classes	24.5	5	<0.001
	Weibull	M0	No effect model	26.0	2	<0.001
	Weibull	M4	Sex	26.2	3	<0.001
	Exponential	M3	Species	29.0	2	<0.001
	Exponential	M6	Sex + binary cover classes	34.3	3	<0.001
	Exponential	M7	Sex+ land cover classes	35.4	4	<0.001
	Exponential	M4	Sex	39.0	2	<0.001
	Exponential	M1	Binary cover classes	41.3	2	<0.001
	Exponential	M2	Land cover classes	42.6	3	<0.001
	Exponential	M0	No effect model	47.1	1	<0.001
	Truncated lévy	M0	No effect model	237.6	1	<0.001
	Lévy	M0	No effect model	319.4	1	<0.001

Movement with covariates



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Movement with covariates

Table 2. Competing models using turning angles for the trajectories for *Turdus leucomelas* and *T. rufiventris*. Plausible model in italic. K is the number of estimated parameters and the *w* Akaike weights (relative likelihood of the model) and the *w* is the Akaike weights (relative likelihood of the model).

Response Variable	Models		dAICc	K	*w*
Turning Angles	M0	*No effect model*	*0.0*	*2*	*0.333*
	M1	*Binary cover classes*	*1.9*	*3*	*0.130*
	M3	*Species*	*1.9*	*3*	*0.129*
	M5	*Distance to edge*	*2.0*	*3*	*0.122*
	M4	*Sex*	*2.0*	*3*	*0.120*
	M8	Species + binary cover classes	3.8	4	0.049
	M2	Land cover classes	3.9	4	0.047
	M6	Sex + binary cover classes	3.9	4	0.046
	M10	Binary cover classes * distance to edge	5.9	5	0.017
	M9	Species +land cover classes	6.0	5	0.016
	M7	Sex +land cover classes	6.2	5	0.014
	M11	Land cover classes * distance to edge	10.0	7	0.002

doi:10.1371/journal.pone.0156688.t002

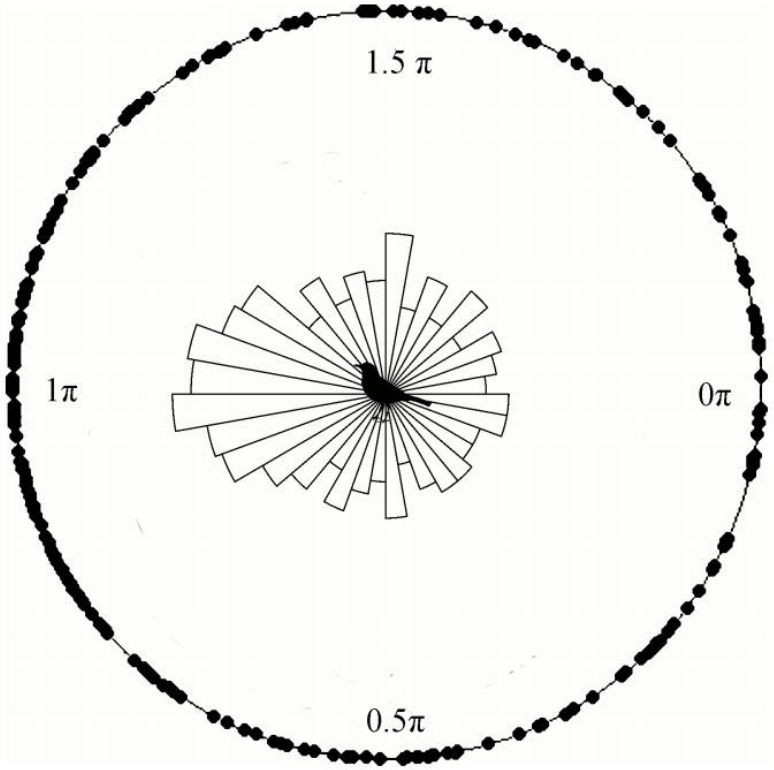

Fig 5. Distribution of turning angles. Black points around the circle represent the relative angle observations. Note the high frequency of angle values of +180° or −180° (π or -π radians), which represents more abrupt turns and is characteristic of tortuous walks.

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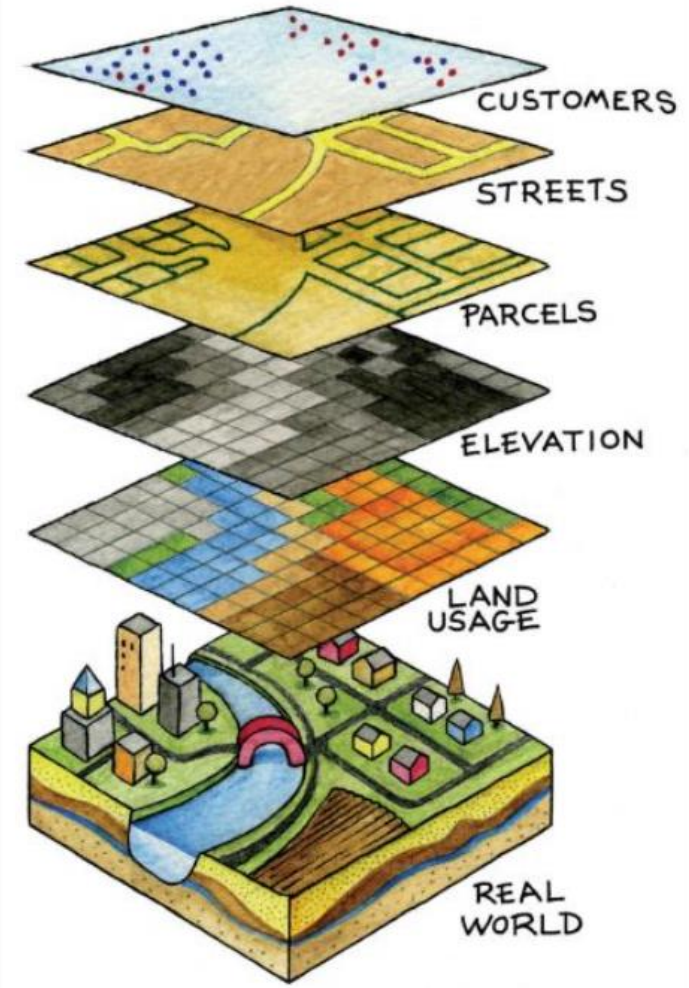
Environmental data



Shin et al. 2017

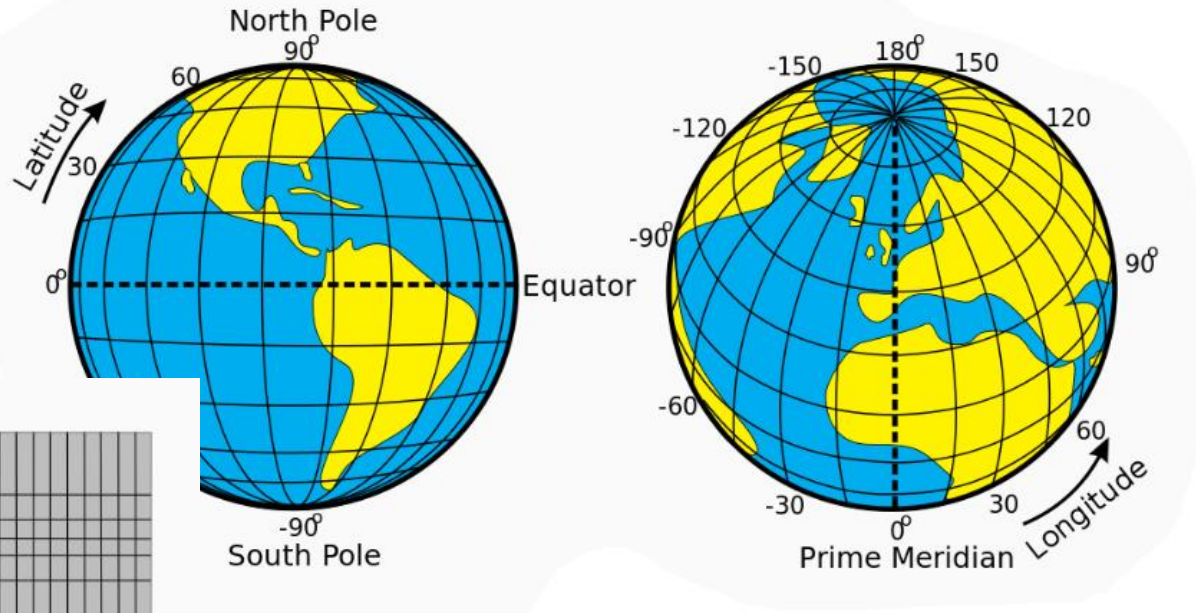
Slide adapted from Mauricio Vancine

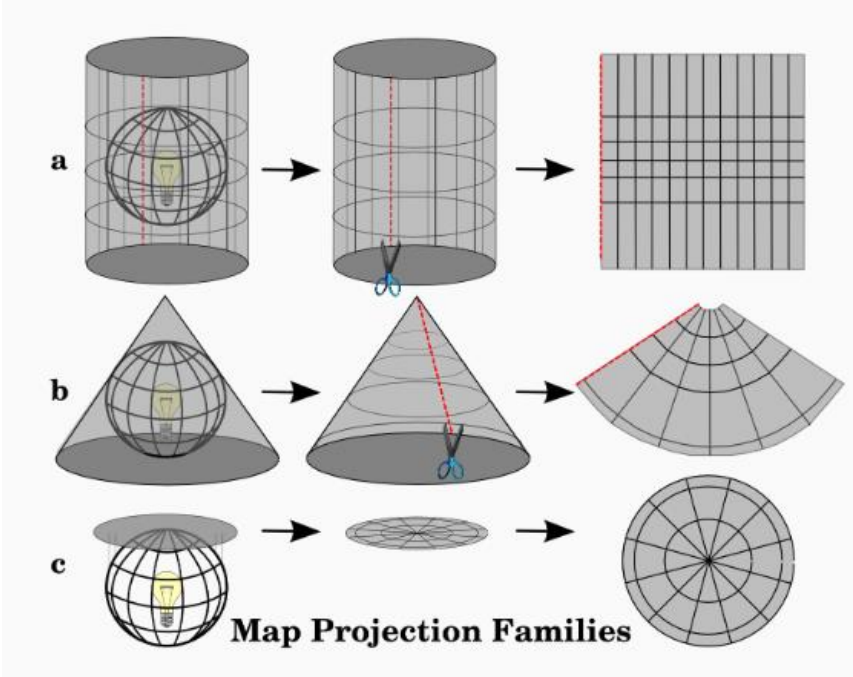
Environmental data – the basics

Coordinate System

- Geographic
  - Degrees, minutes, seconds
  - Decimal degrees

- Projected (meters)





Slide adapted from Mauricio Vancine

QGIS 3.16 User Guide

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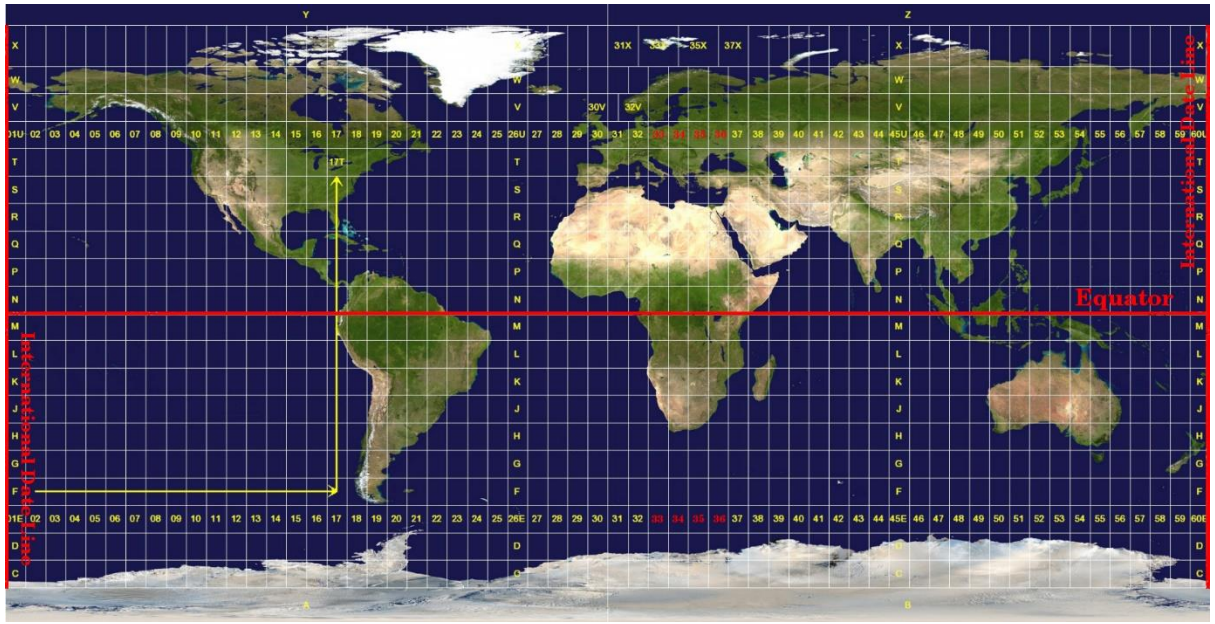
Environmental data – the basics

Coordinate System

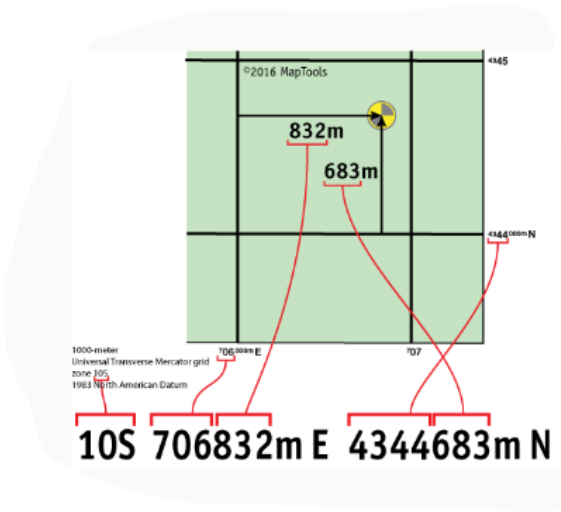
- Geographic
  - Degrees, minutes, seconds
  - Decimal degrees

- Projected (meters)
  - Universal Transversa de Mercator (UTM)



Zone and coordinates

- X UTM: 706832 m E
- Y UTM: 4344683 m N
- Zone: 10S



Slide adapted from Mauricio Vancine

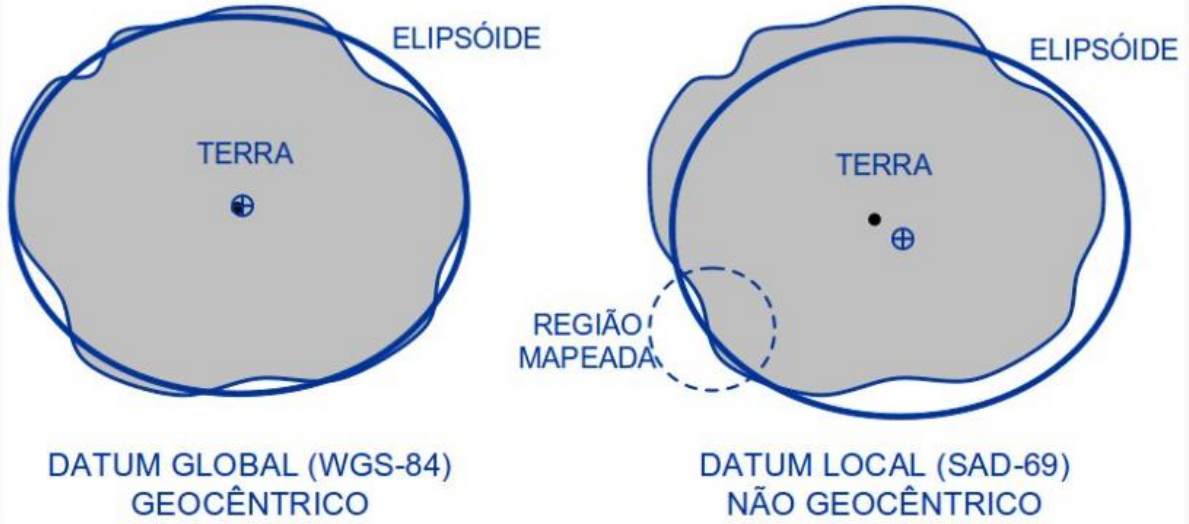
[QGIS 3.16 User Guide]

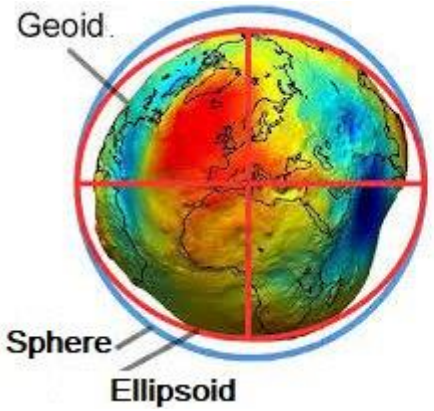
Environmental data – the basics

Datum

Relationship between the coordinate system and the surface of the Earth

- Geocentric (e.g. WGS84)
- Topocentric (e.g. SAD69, NAD83)





Oblate Spheroid

Slide adapted from Mauricio Vancine

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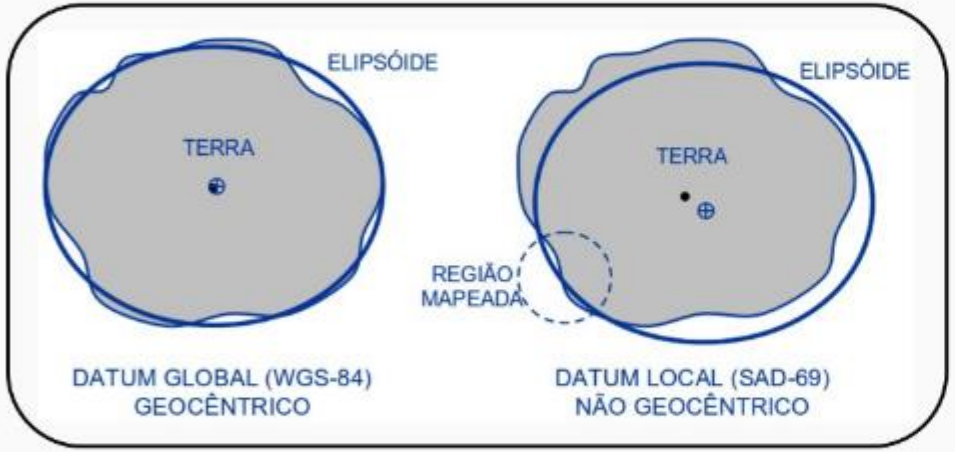
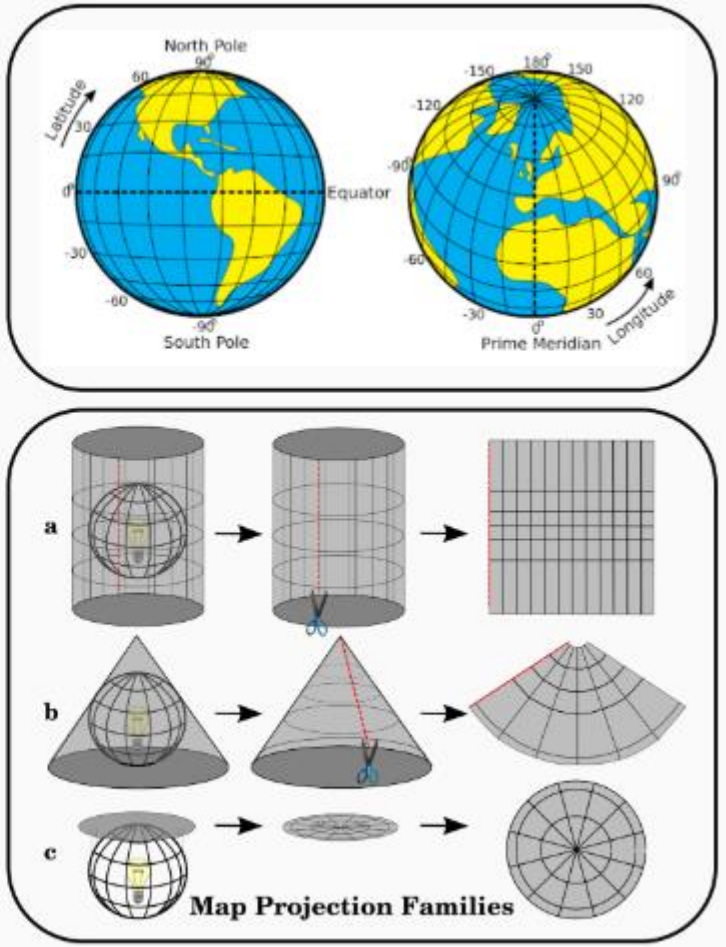
Environmental data – the basics

Coordinate Refence System (CRS)

Datum + Coordinate System



+



Slide adapted from Mauricio Vancine

ww

[QGIS 3.16 User Guide]

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Environmental data – the basics

Coordinate Refence System (CRS)

Datum + Coordinate System

There are numeric codes that make our life easier!

- EPSG:4326 WGS84 Geographic
- EPSG:3006 SWEREF99 TM
- EPSG:25833 ETRS89 / UTM zone 33N

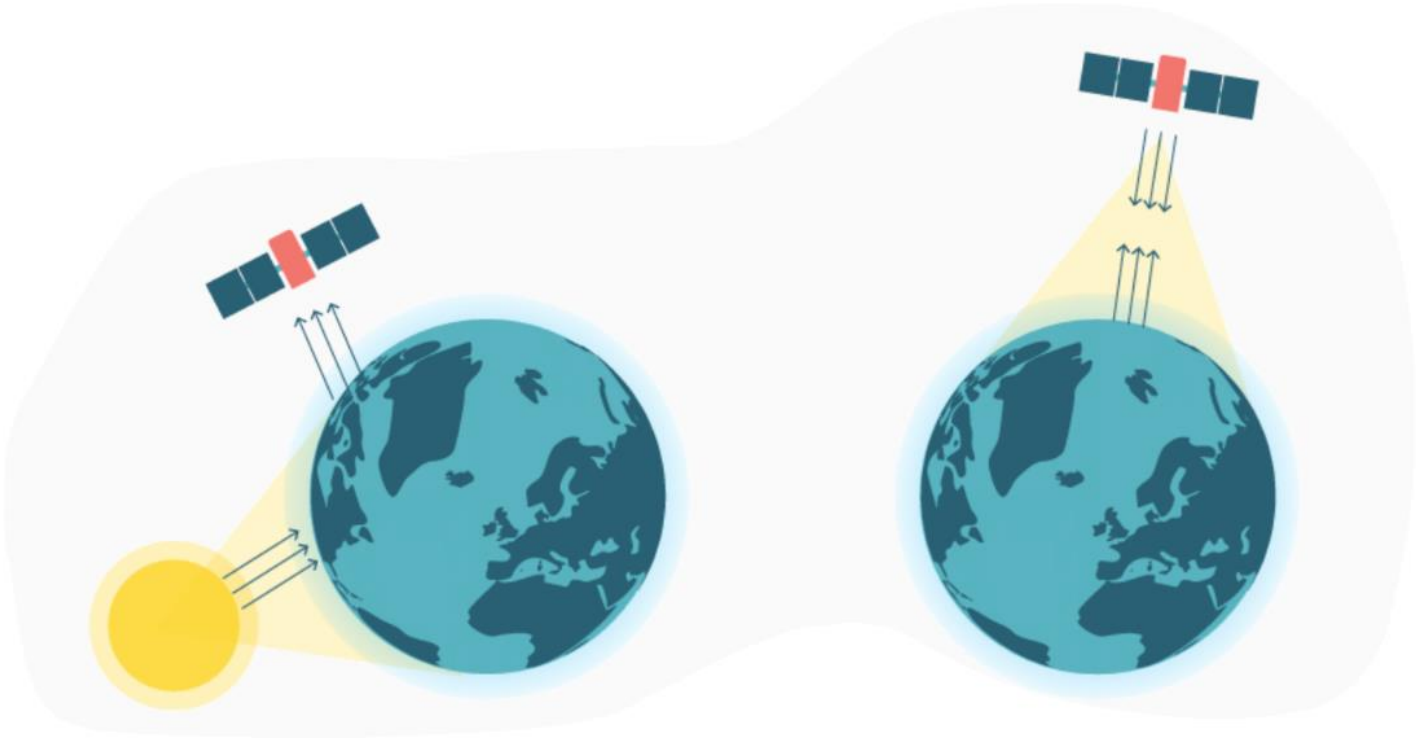
EPSG (European Petroleum Survey Group)

Numerical codes for most SRCs

Slide adapted from Mauricio Vancine

EPSG

Environmental data – Remote sensing



Slide adapted from
Mauricio Vancine

Edusat

Environmental data – Remote sensing

Satellites:

- Landsat (1-9)
- Sentinel (1-5)
- MODIS

Satellite	Sensor	Spatial resolution (pan)	Spatial resolution (multi)	Spatial resolution (thermal)	Swath width	Revisiting time
IKONOS	Ikonos	0.82 m	3.2 m		11 km	1–3 days
QuickBird-2	BGIS 2000	0.61 m	2.4 m		17 km	1–3 days
WorldView-2	IRU	0.46 m	1.85 m		16 km	1–4 days
WorldView-3	IRU	0.31 m	1.24 m		13 km	5 days
SSTL-150	RapidEye		6.5m		77 km	5.5 days
Landsat 1–3	MSS		80 m		185 km	16 days
Landsat 4 & 5	TM		30 m	120 m	185 km	16 days
Landsat 7	ETM+	15 m	30 m	120 m	185 km	16 days
Landsat 8	OLI/TIRS	15 m	30 m	100 m	185 km	16 days
SPOT 1–4	HRV, HRVIR	10 m	20 m		60 km	2–3 days
SPOT 5	HRG, HRS	5 m	10–20 m		60 m	2–3 days
SPOT 4 & 5	VEGETATION		1,000 m		2250 km	1 day
Terra	ASTER		15–30 m	90 m	60 km	1–2 days
Sentinel-2	MSI		10–60 m		290 km	5 days
Terra/Aqua	MODIS		250–1,000 m	1,000 m	2,330 km	1–2 days
NOAA 6–18	AVHRR 2-3		1,090 m	1,090 m	2,000 km	1 day

ICT Sensor and Satellite Database

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Environmental data – Remote sensing

Applications:

- Monitoring of deforestation and fires
- Mapping land use and land cover change
- Vegetation change (phenology)
- Meteorology and climatology
- Relief (elevation, topography)

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ICT Sensor and Satellite Database

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Environmental data – GIS

GIS – Geographical Information Systems

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Mauricio Vancine

QGIS, GRASS GIS, ArcGIS, R, gvSIG, Google Earth Engine

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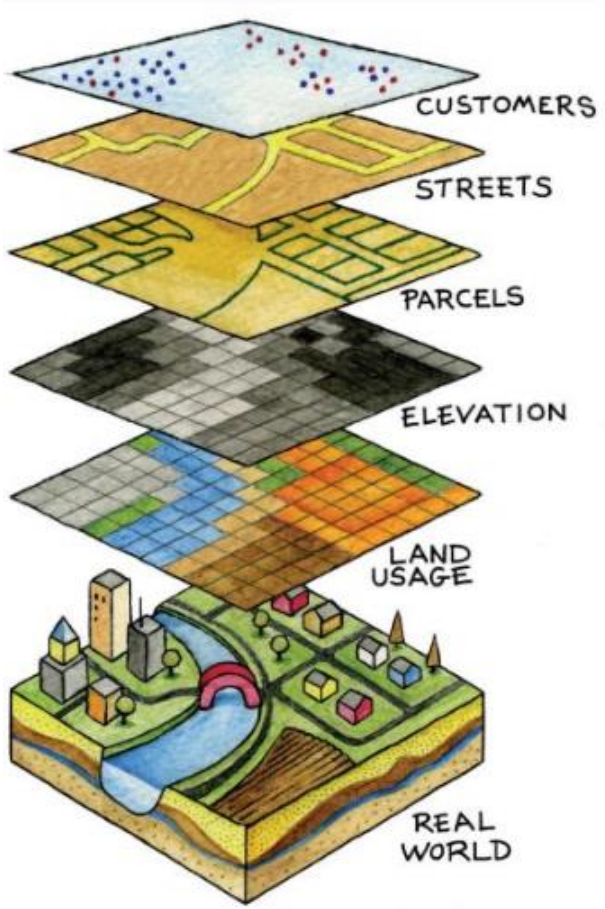
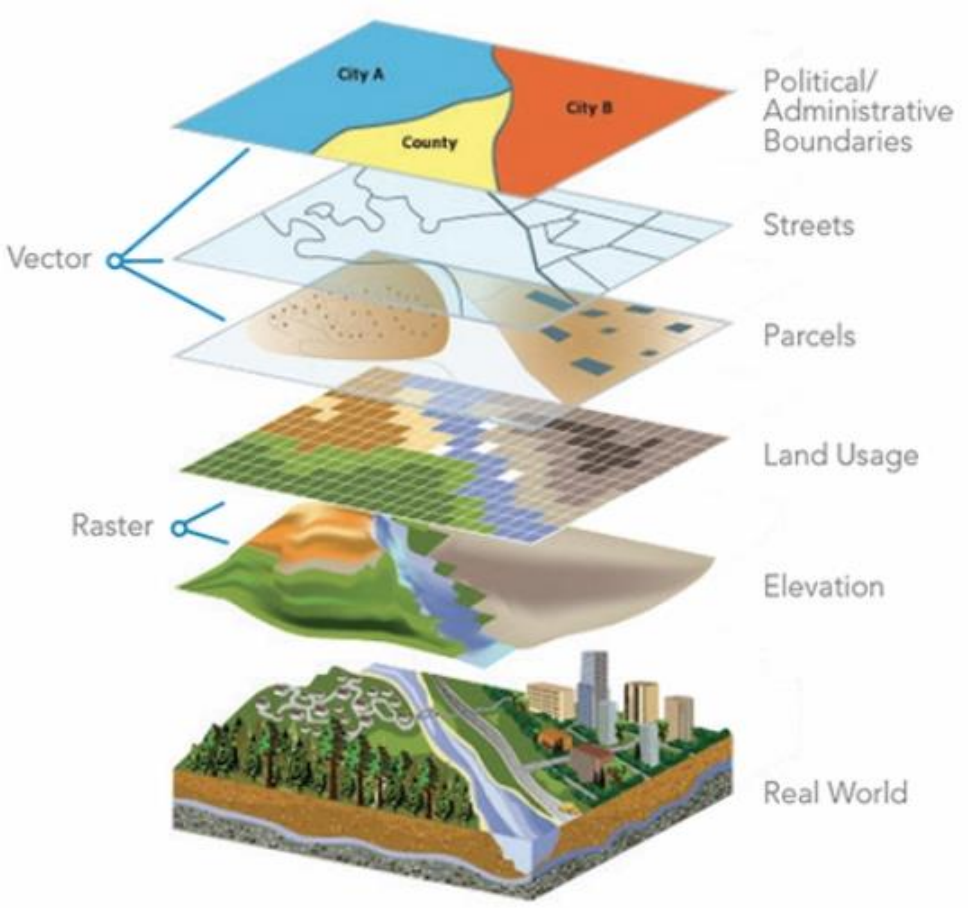
Environmental data – Types of data

- Vector
- Raster





Slide adapted from Mauricio Vancine

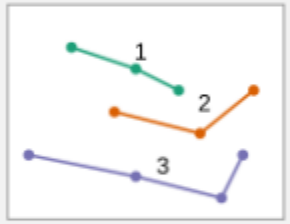
Campbell & Shin (2012), ESRI (2019)

Environmental data – Types of data

- Vector
  - Shapefile
  - Geopackage

Example attributes for point data

ID	name	has	evergreen
1	Broadleaf	Leaves	FALSE
2	Conifer	Needles	TRUE



Example attributes for line data

ID	name	lanes	cycling
1	Road A	4	FALSE
2	Road B	3	TRUE
3	Road C	2	TRUE

Example attributes for polygon data

ID	name	population	touristic
1	Country A	1000	FALSE
2	Country B	500	TRUE

Slide adapted from Mauricio Vancine

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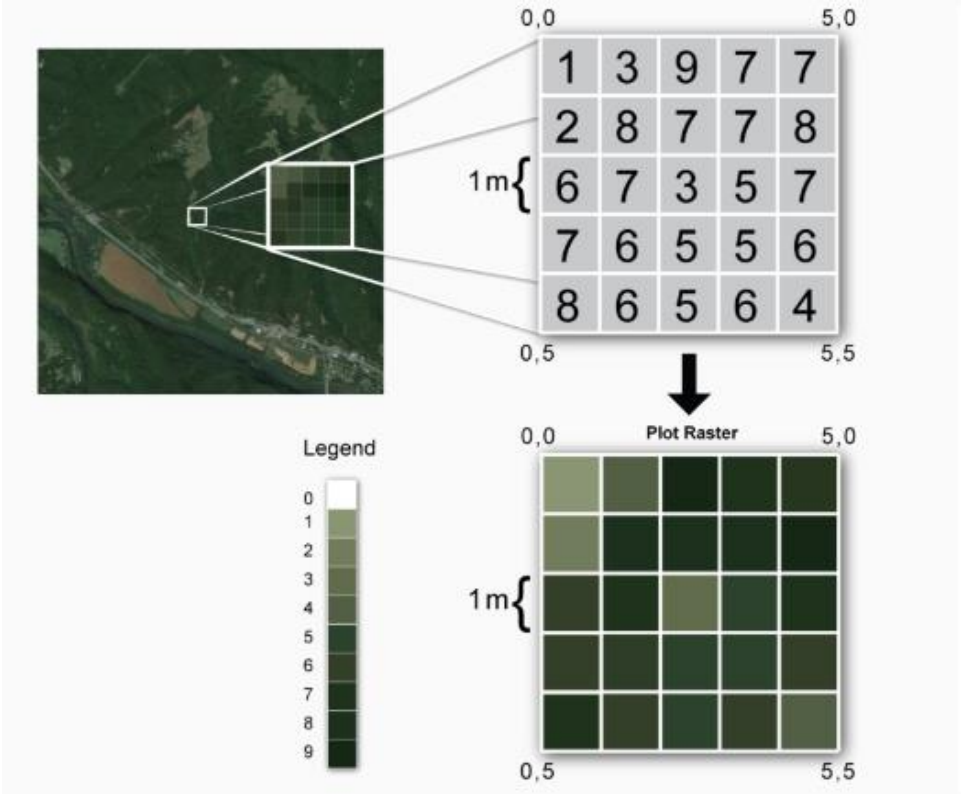
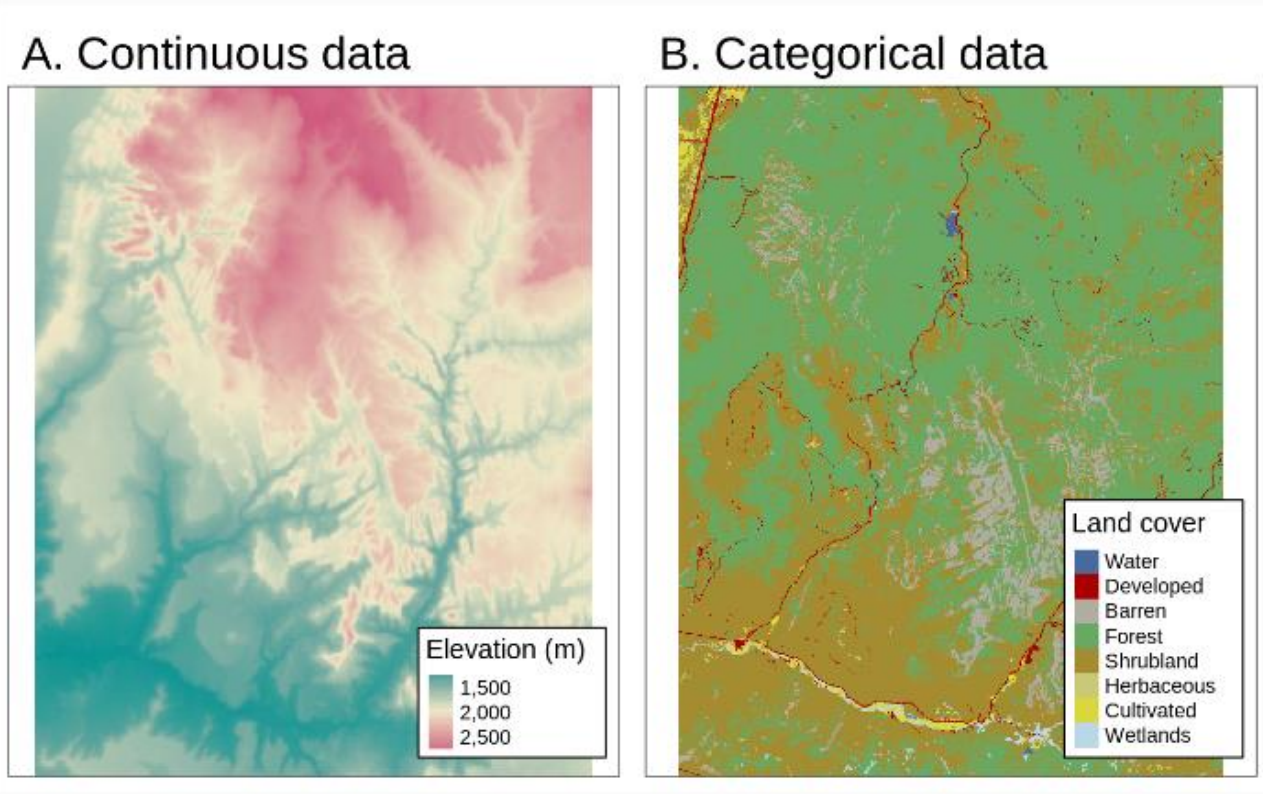
Environmental data – Types of data

- Raster

Matrix with values – continuous or categorical





Slide adapted from Mauricio Vancine

National Ecological Observatory Network (NEON), Lovelace et al. (2020)

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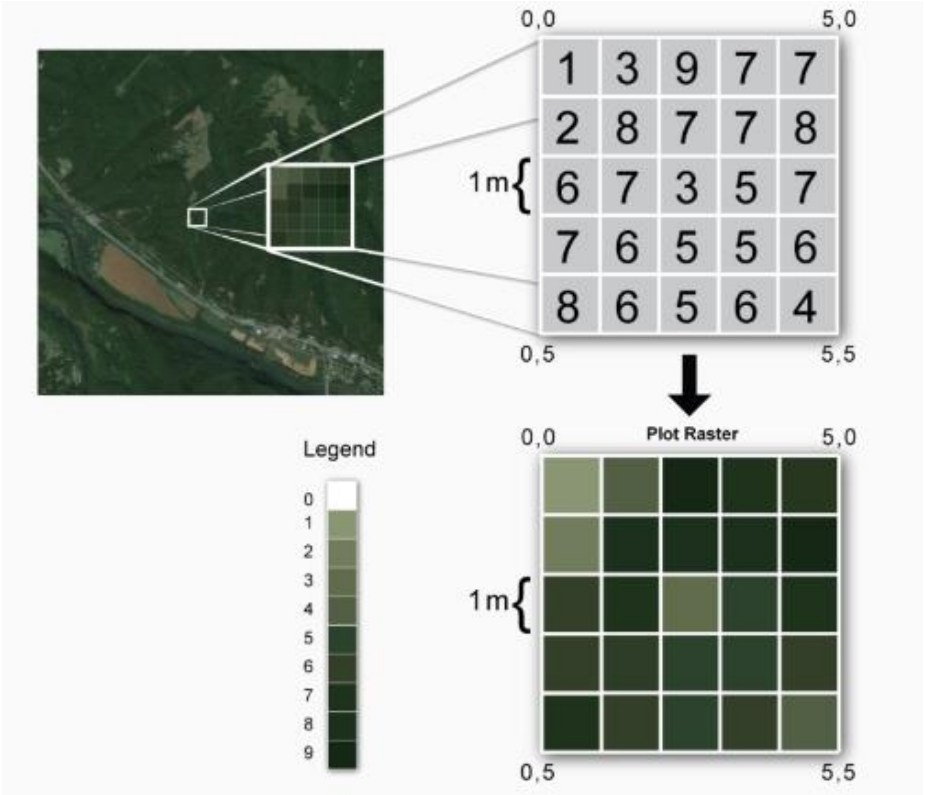
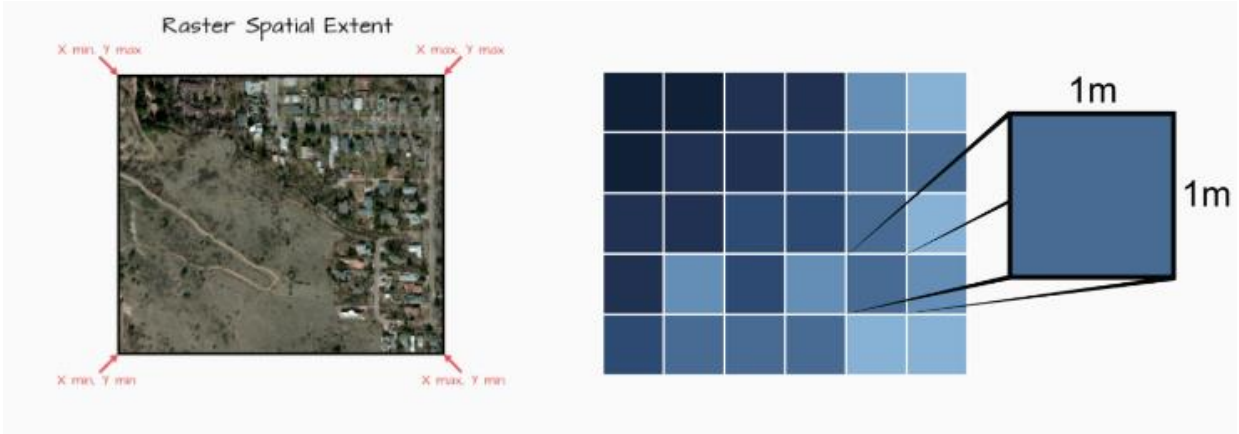
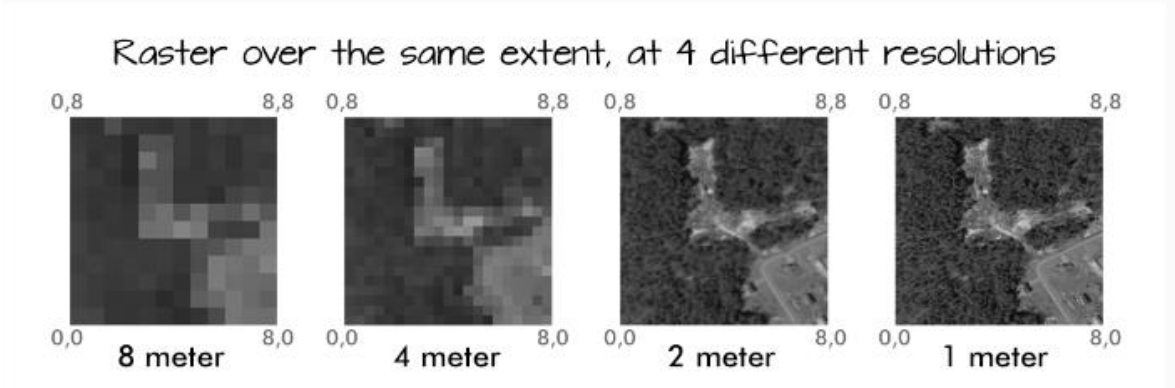
Environmental data – Types of data

- Raster

Properties – extent and spatial resolution







Slide adapted from Mauricio Vancine

National Ecological Observatory Network (NEON)

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Environmental data – Where?

Slide adapted from
Mauricio Vancine

Environmental data – Where?

Vector data

- OpenStreetMap Data Extracts: OpenStreetMap data
- Ecoregions: data on ecoregions and biomes of the world
- GADM: limits of administrative areas in the world
- Natural Earth: diverse limits
- Protected Planet: protected areas
- UN Biodiversity Lab: Several data bases for the world
- HydroSHEDS: hydrological information for the world
- Global Roads Inventory Project (GRIP): roads across the world

Slide adapted from
Mauricio Vancine

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Environmental data – Where?

Raster data

- **USGS**: open data for several satellites
- **SRTM**: elevation data
- **Global Forest Watch**: land use and land cover change
- **Copernicus**: multiple products derived from satellite and remote sensing
- **Geoservice Maps**: elevation and forests
- **GlobCover**: land use and land cover for the globe
- **Global Human Footprint**: human footprint data
- **Land-Use Harmonization (LUH2)**: current and predicted land use across the planet
- **SoilGrids**: soil data
- **WorldClim**: bioclimatic data
- **CHELSA**: climate data
- **EarthEnv**: land cover, clouds, relief, and hydrography
- **MARSPEC**: ocean conditions and variables
- **Bio-ORACLE**: ocean conditions and variables

Slide adapted from Mauricio Vancine

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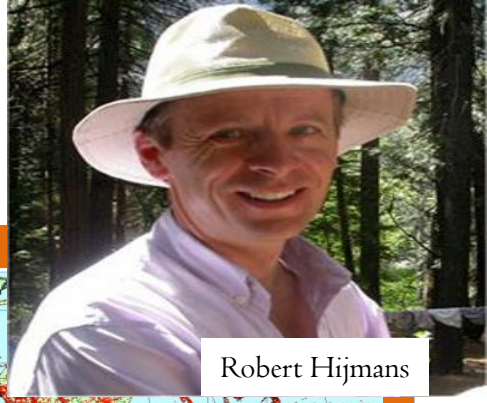
Environmental data – Where?


Robert Hijmans

WorldClim - Global Climate Data

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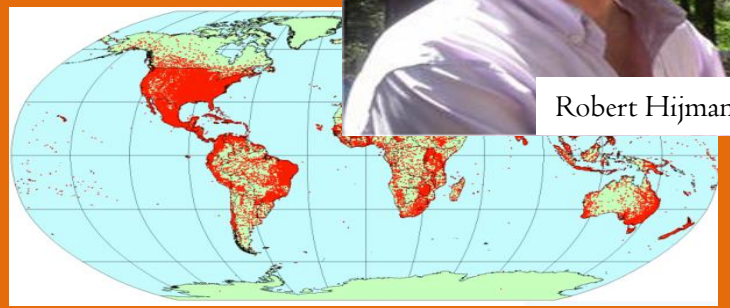
Data for current conditions (~1950-2000)

If you need the highest resolution (**30 arc-seconds (~1 km)**) then you can download by tile.



WorldClim - Global Climate Data

Free climate data for ecological modeling and GIS

http://www.worldclim.org/

INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **25**: 1965–1978 (2005)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/joc.1276

VERY HIGH RESOLUTION INTERPOLATED CLIMATE SURFACES FOR GLOBAL LAND AREAS

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[d] *International Plant Genetic Resources Institute, Cali, Colombia*

Bioclimatic variables:

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (* 100)
BIO4 = Temperature Seasonality (standard deviation *100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

Slide from
Matheus Lima Souza-Ribeiro

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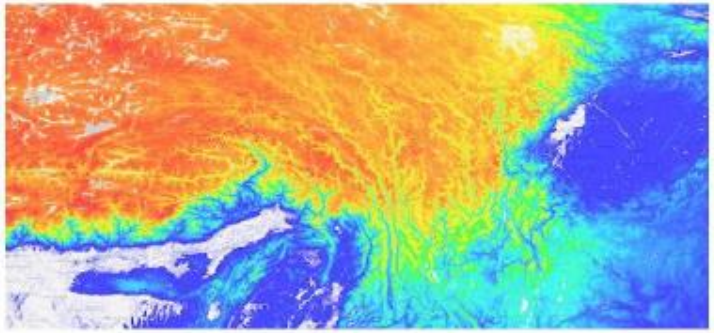
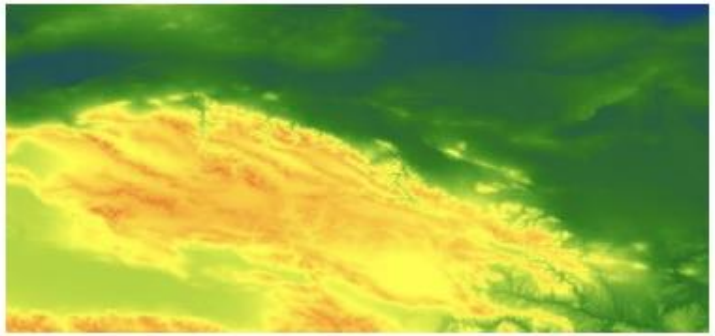
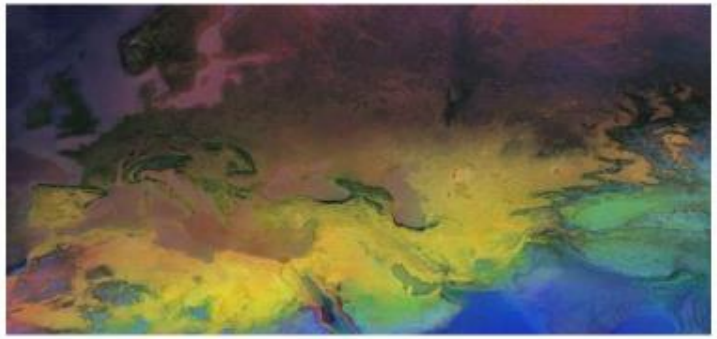
90m digital elevation model



Topography

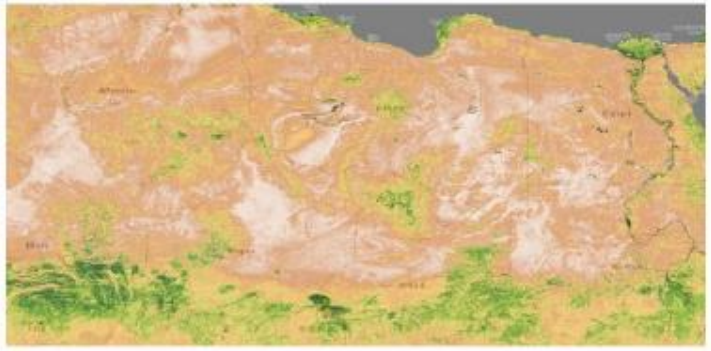


Cloud cover climatology



Consensus land cover

Habitat heterogeneity



Freshwater environmental variables

Slide adapted from Mauricio Vancine

Earthenv

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Environmental data – Where?

Slide adapted from Mauricio Vancine

[Global Forest Watch]

Environmental data – Where?

Google Earth Engine

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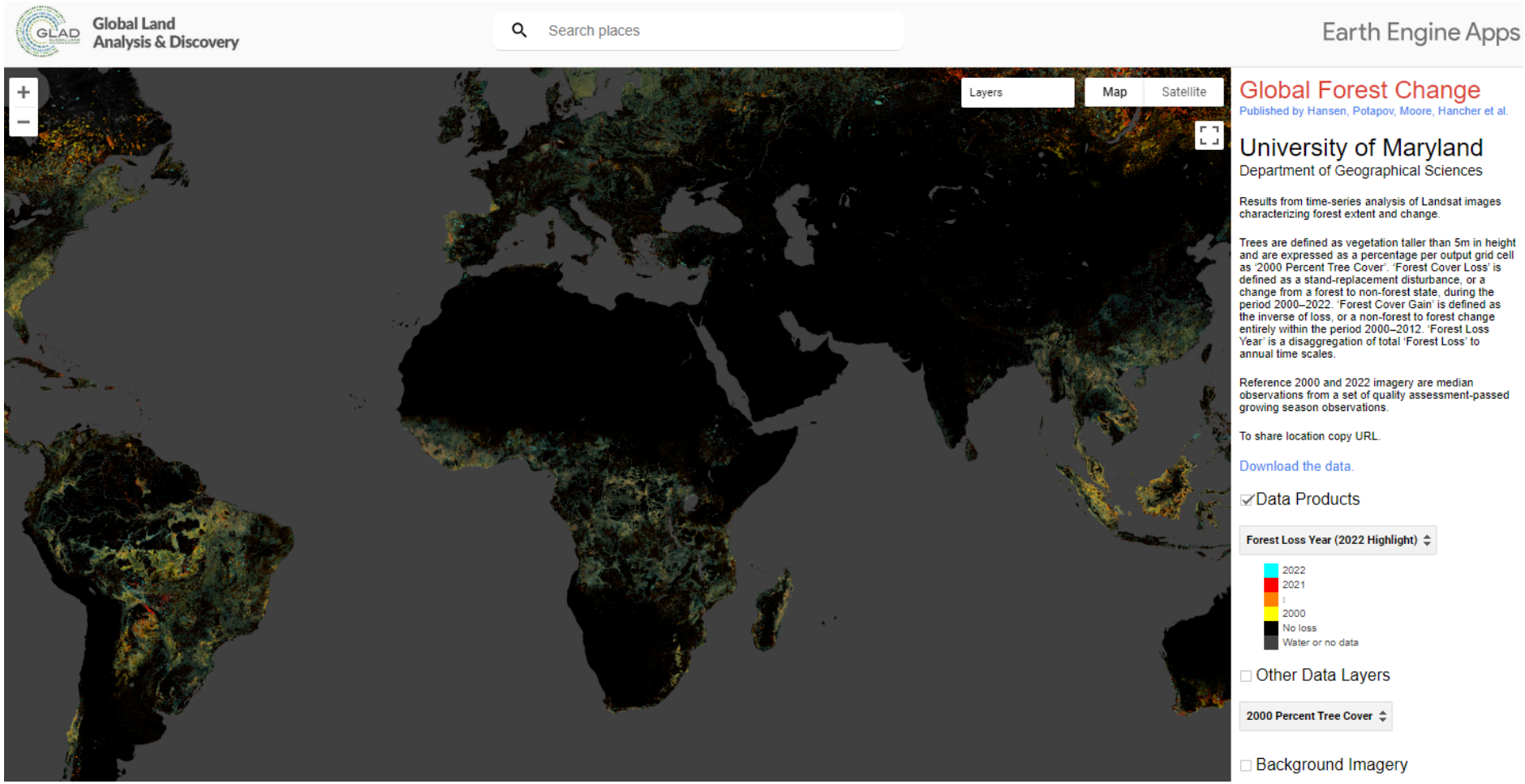
Environmental data – Where?

Google Earth Engine

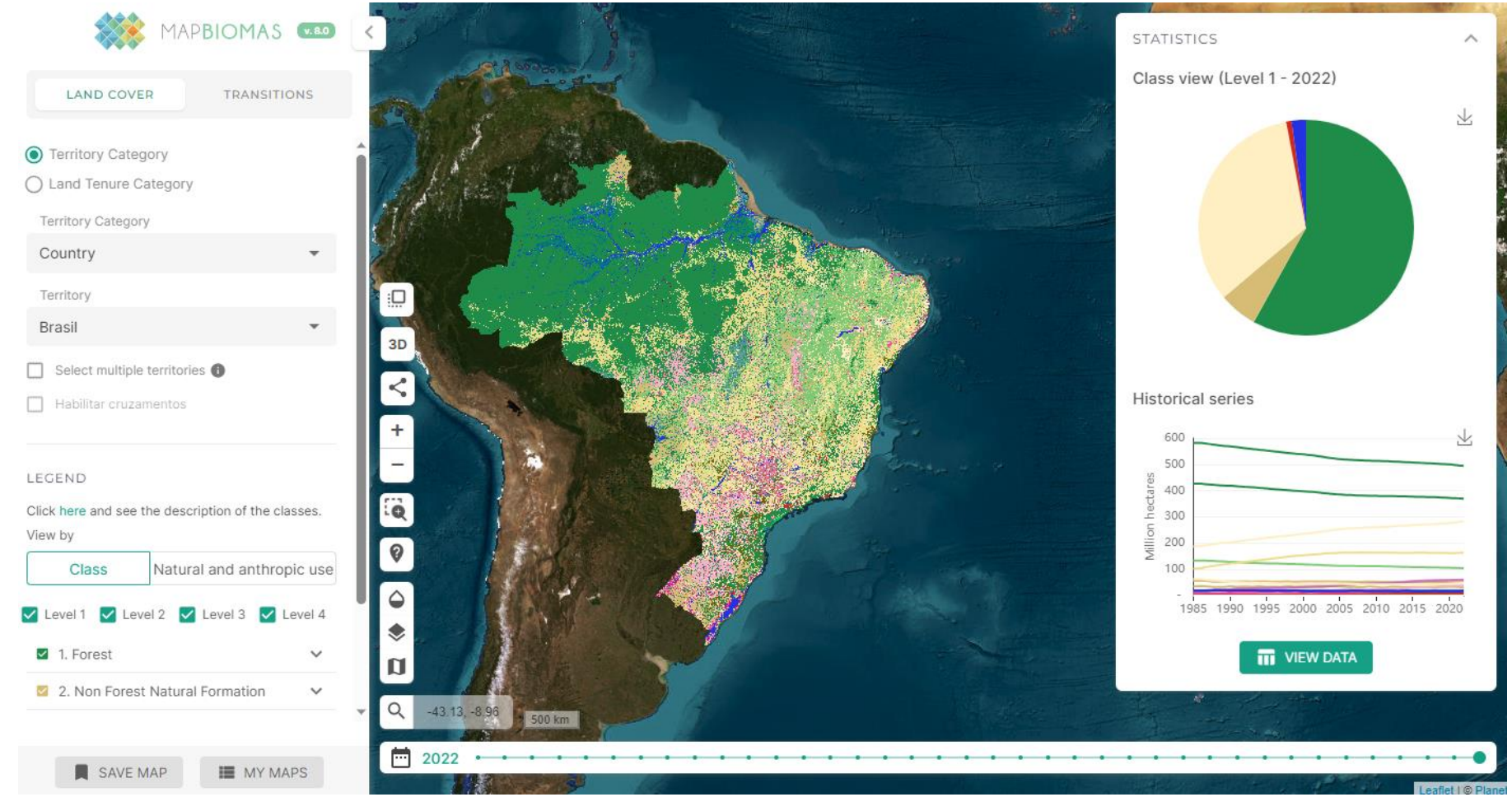
[Global Forest Change]



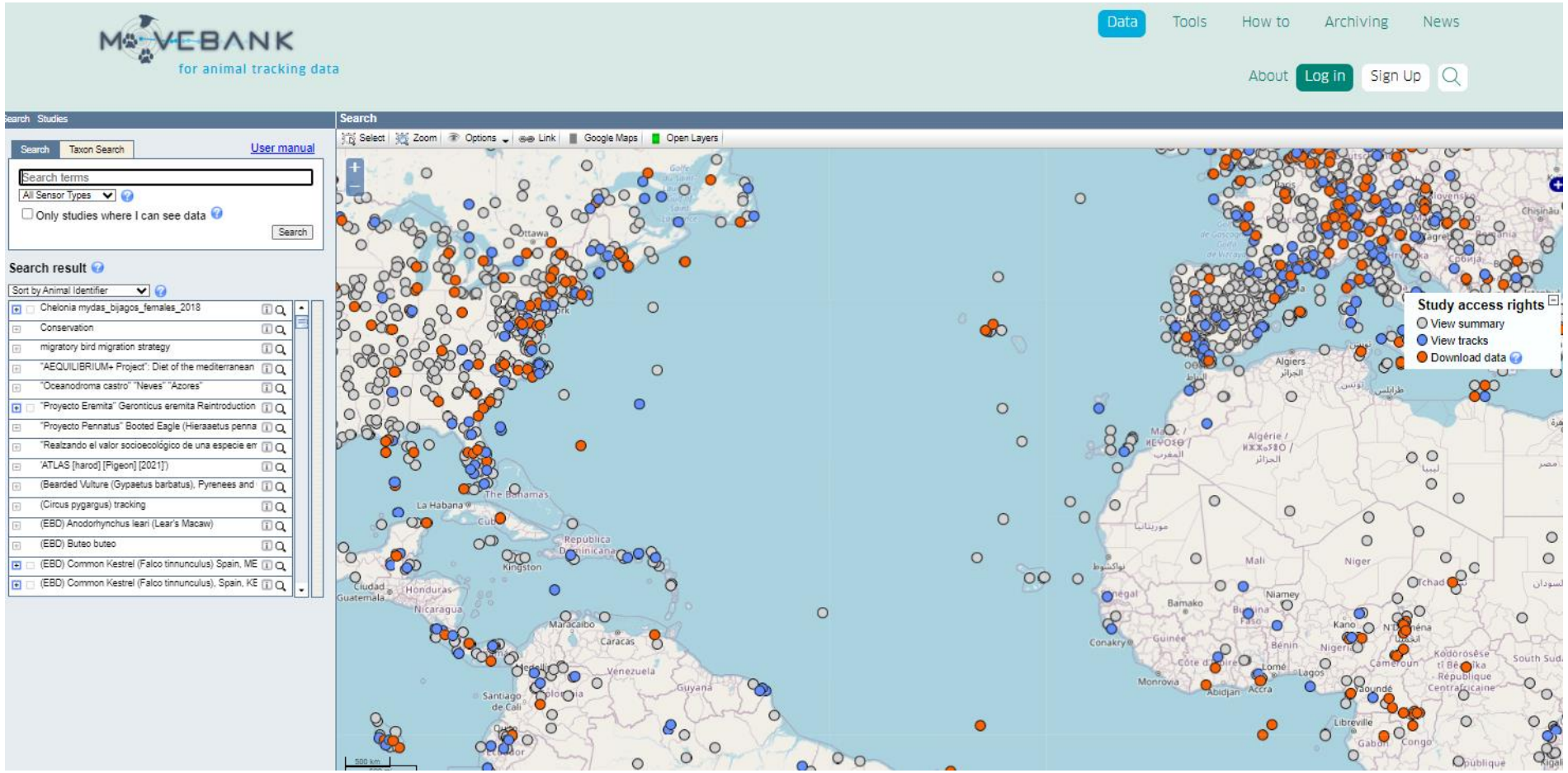
Environmental data – Where?

Google Earth Engine

[Plataform - MapBiomas Brasil]



Environmental data – Where?



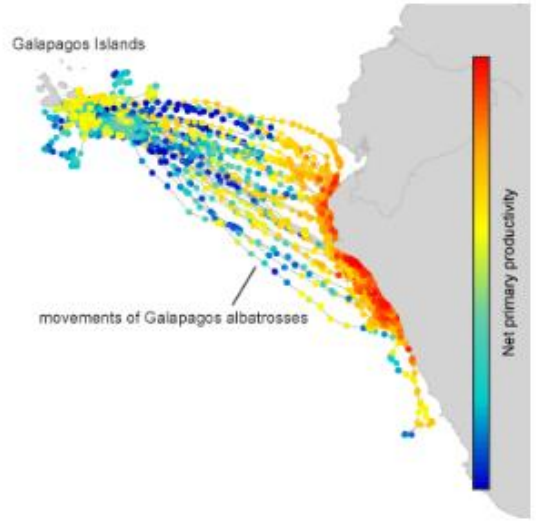
[Movebank]

Environmental data – Where?

MOVEBANK
for animal tracking data

User manual / 5. The Env-DATA System

The Env-DATA System



8-day ocean net primary productivity annotated to tracks of Galapagos albatrosses.

Movebank, Env-Data

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Environmental data in R

R packages

- **rnaturalearth**: data from the world map from Natural Earth
- **rworldmap**: global data maps
- **spData**: datasets for spatial analysis
- **OpenStreetMap**: access to open raster images of streets
- **osmdata**: download and import OpenStreetMap data
- **elevatr**: access elevation data from various APIs
- **rgee**: use Google Earth Engine through R
- **copernicus**: access and process COPERNICUS Global Land Vegetation products
- **oneimpact**: tools to compute zones of influence of infrastructure

Data annotation

- Data annotation consists of enriching a data set with other information that provide context to it.

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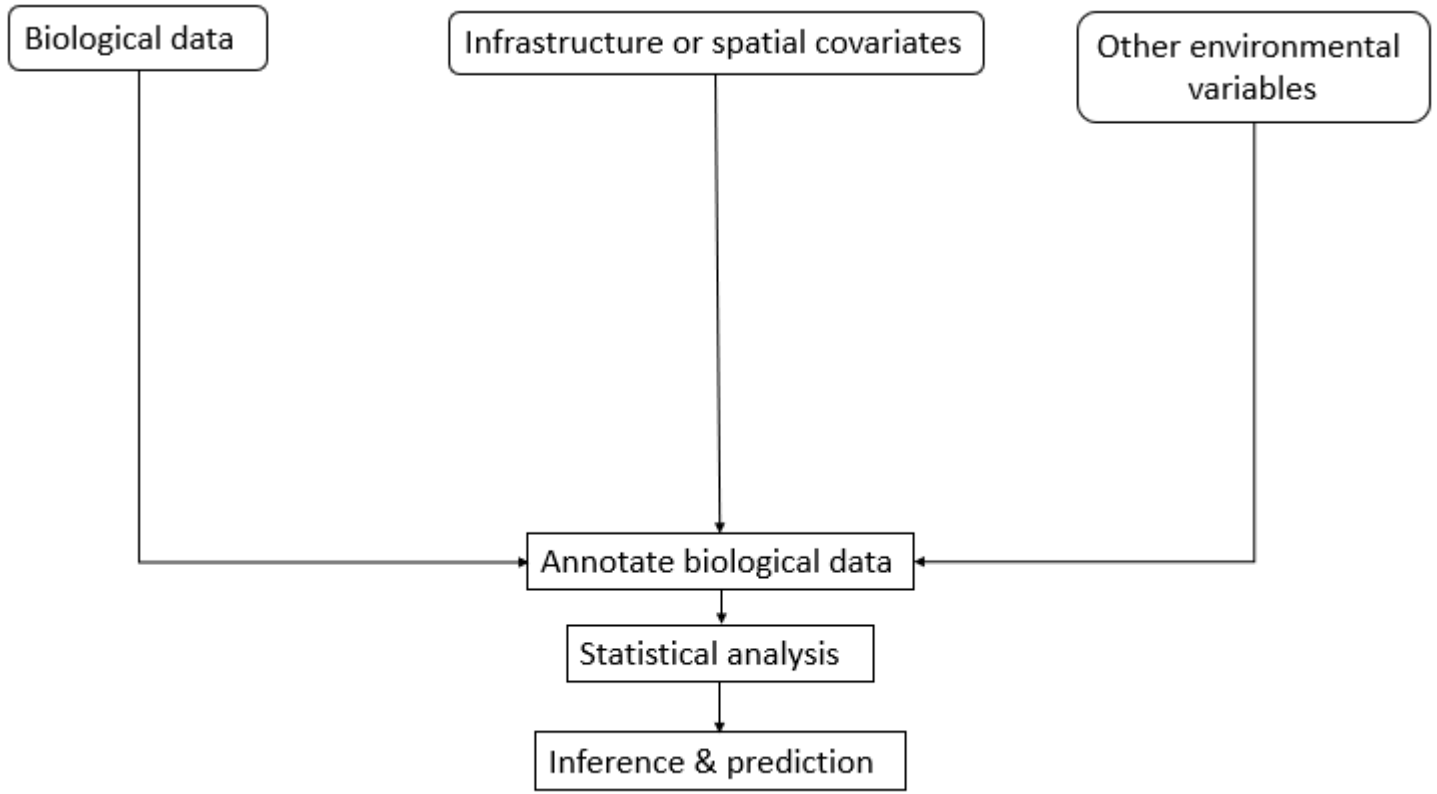

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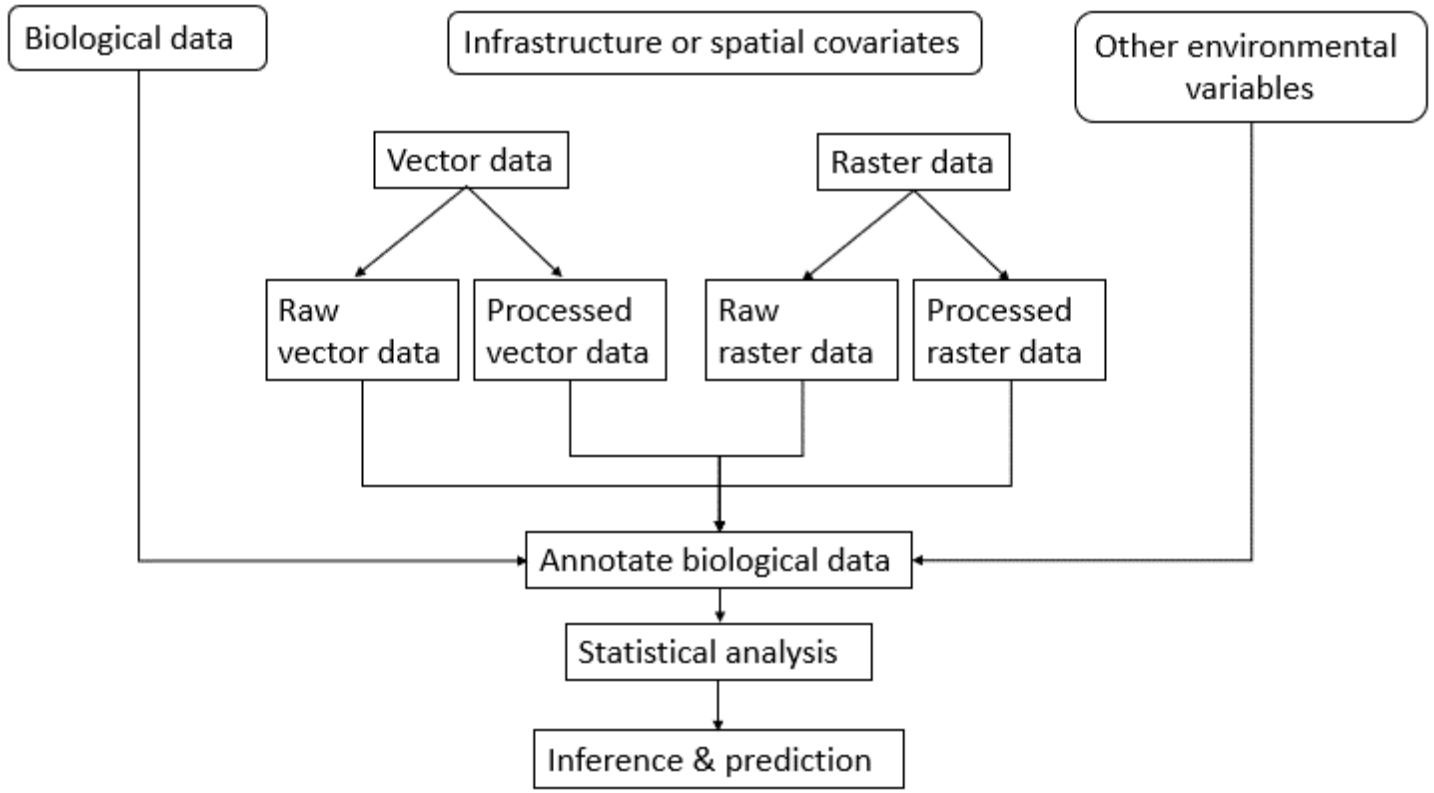

Data annotation

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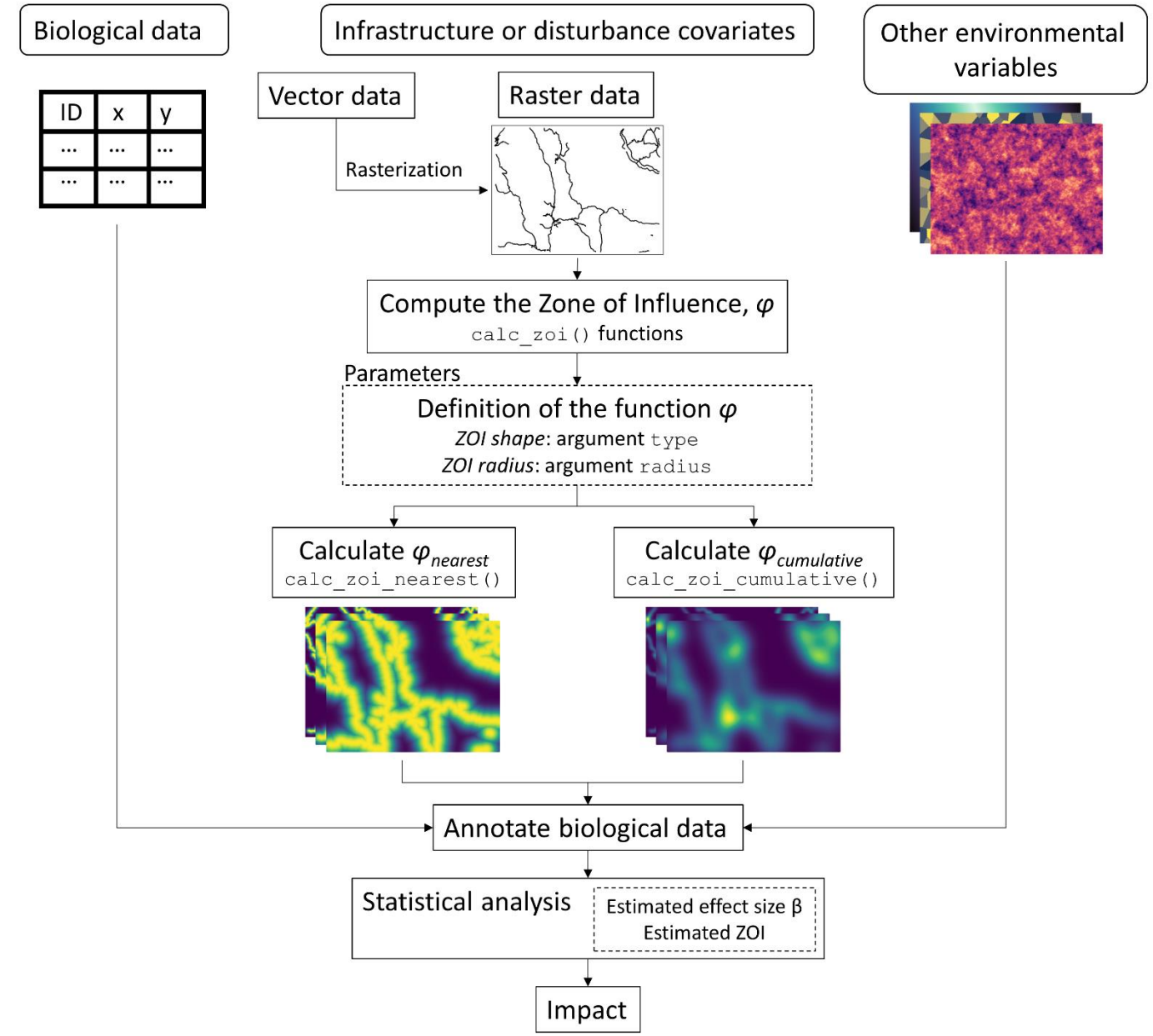

Data annotation

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```
terra::extract()

amt::extract_covariates()

amt::extract_covariates_along()

amt::extract_covariates_var_time()
```

Cooperation and expertise for a sustainable future

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