ETH zürich

Planning of Landscape and Urban Systems

PLUS

MOSAIC

# Climate Change Impacts On Swiss Mountain Ecosystem Services — A Land Use Change Perspective

**Jan Hartman**
With Benjamin Black and Adrienne Grêt-Regamey
2025-09-16, IMC Focus Session 3.105

# Context: Climate Change in Mountains

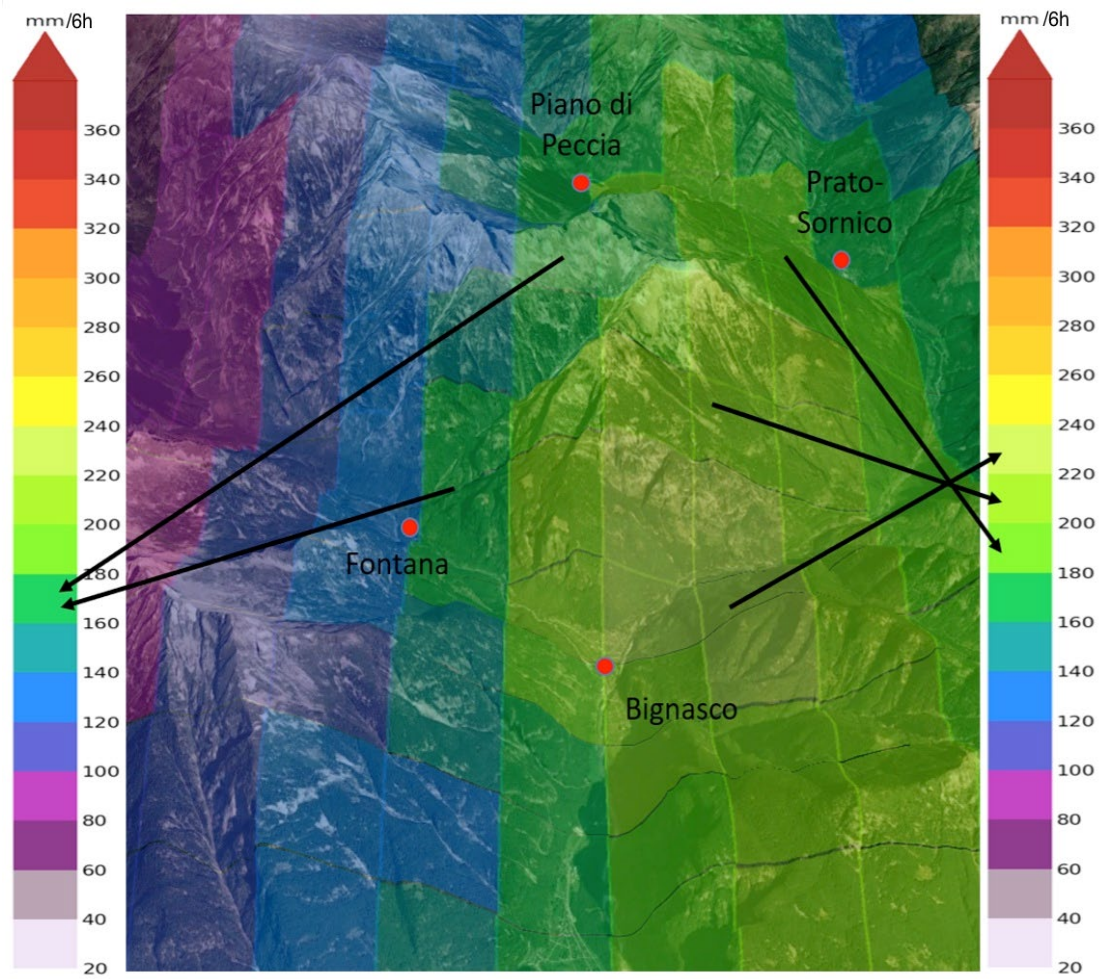



Image: Google Earth / MeteoSwiss

# Context: Effects of Climate Change

Image: D. Farinotti / VAW ETHZ

# Context: Land Use Response

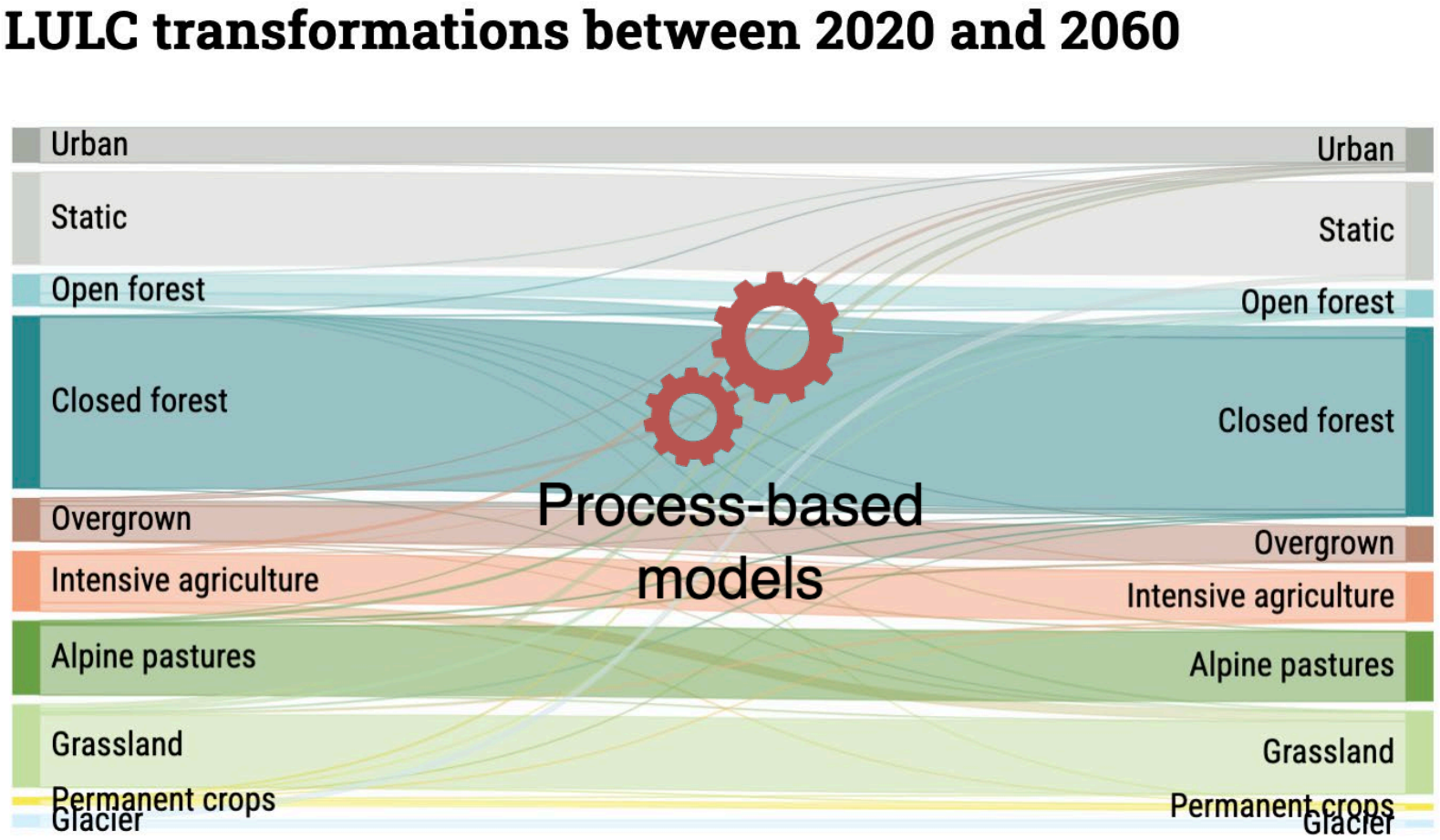
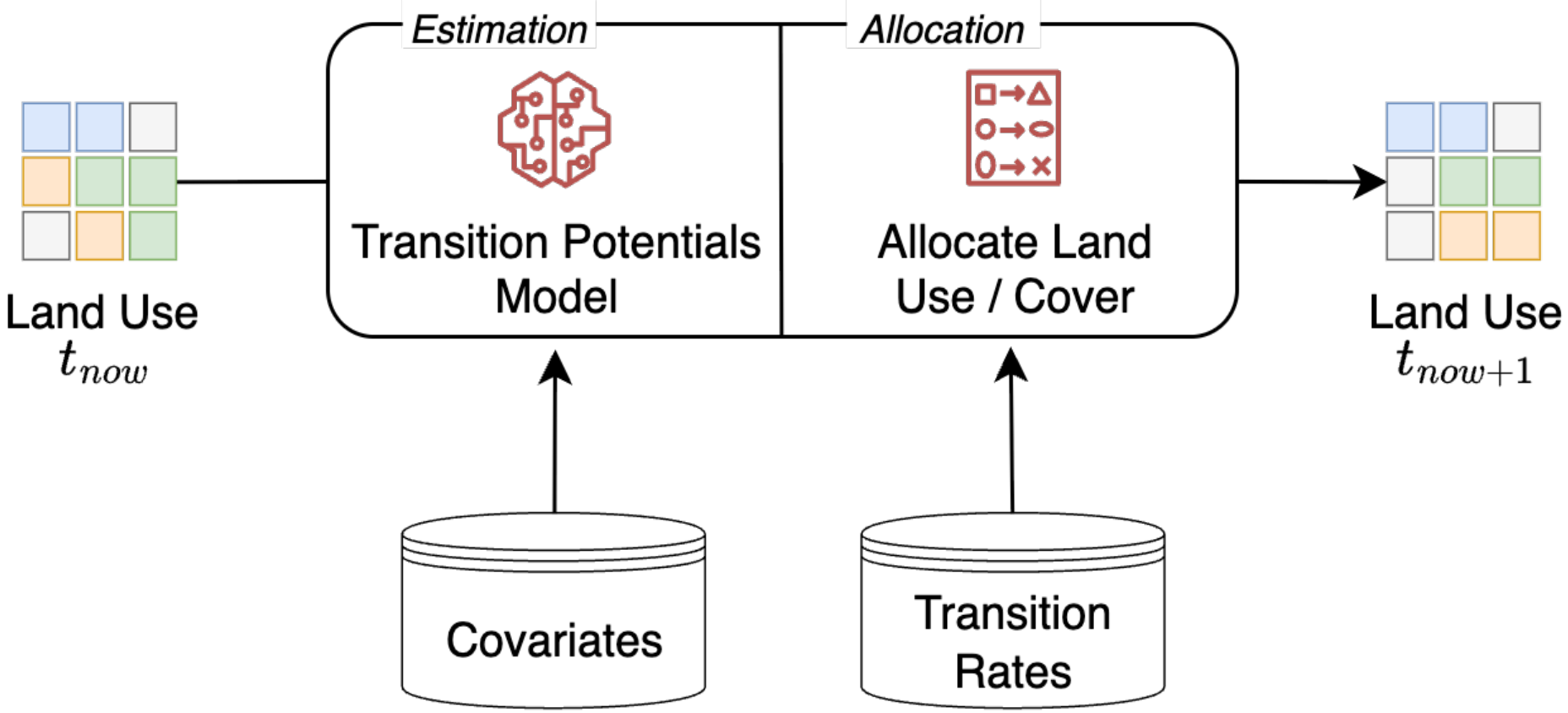
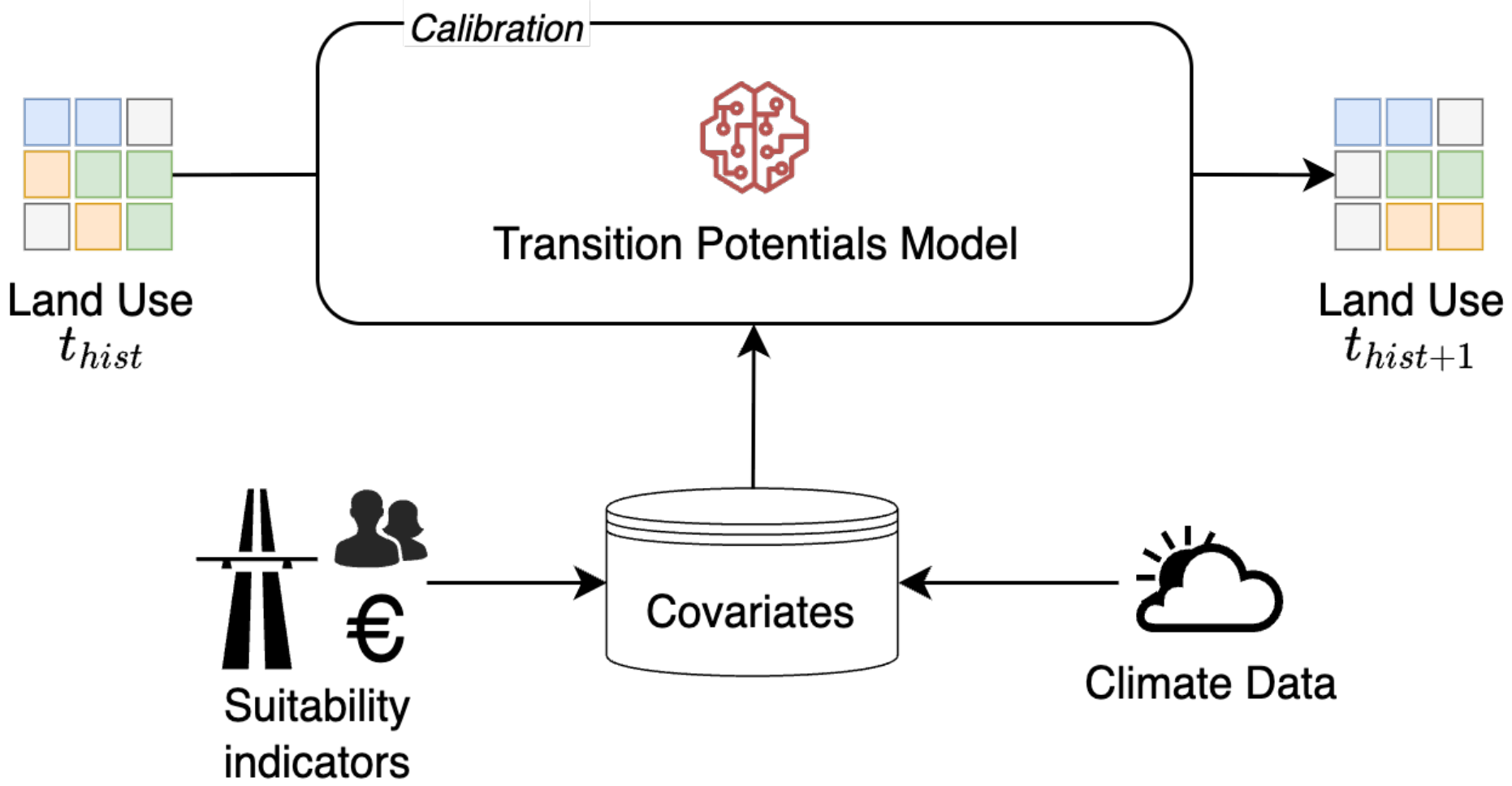
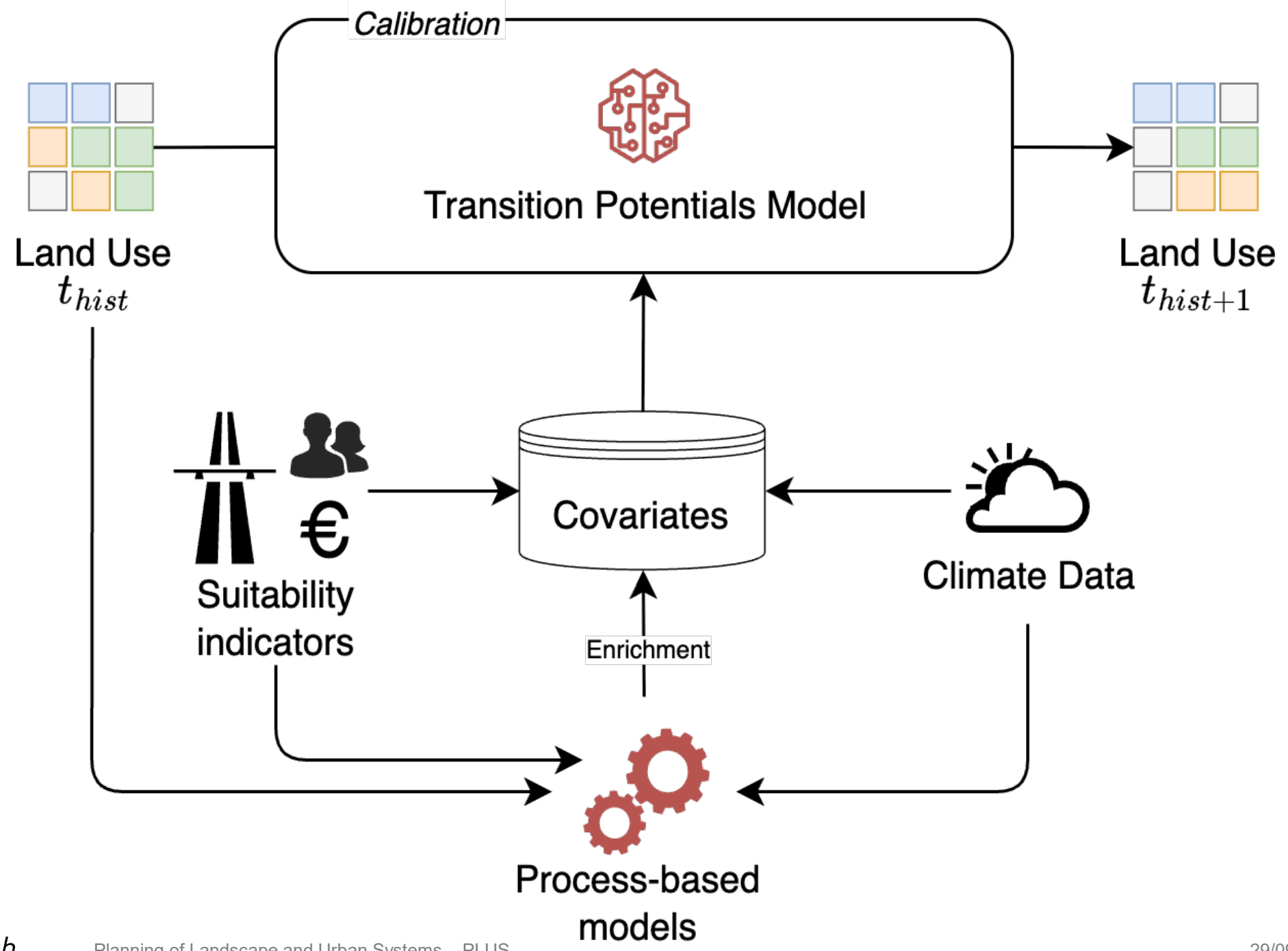



Image: valpar.ch / B. Black et al.

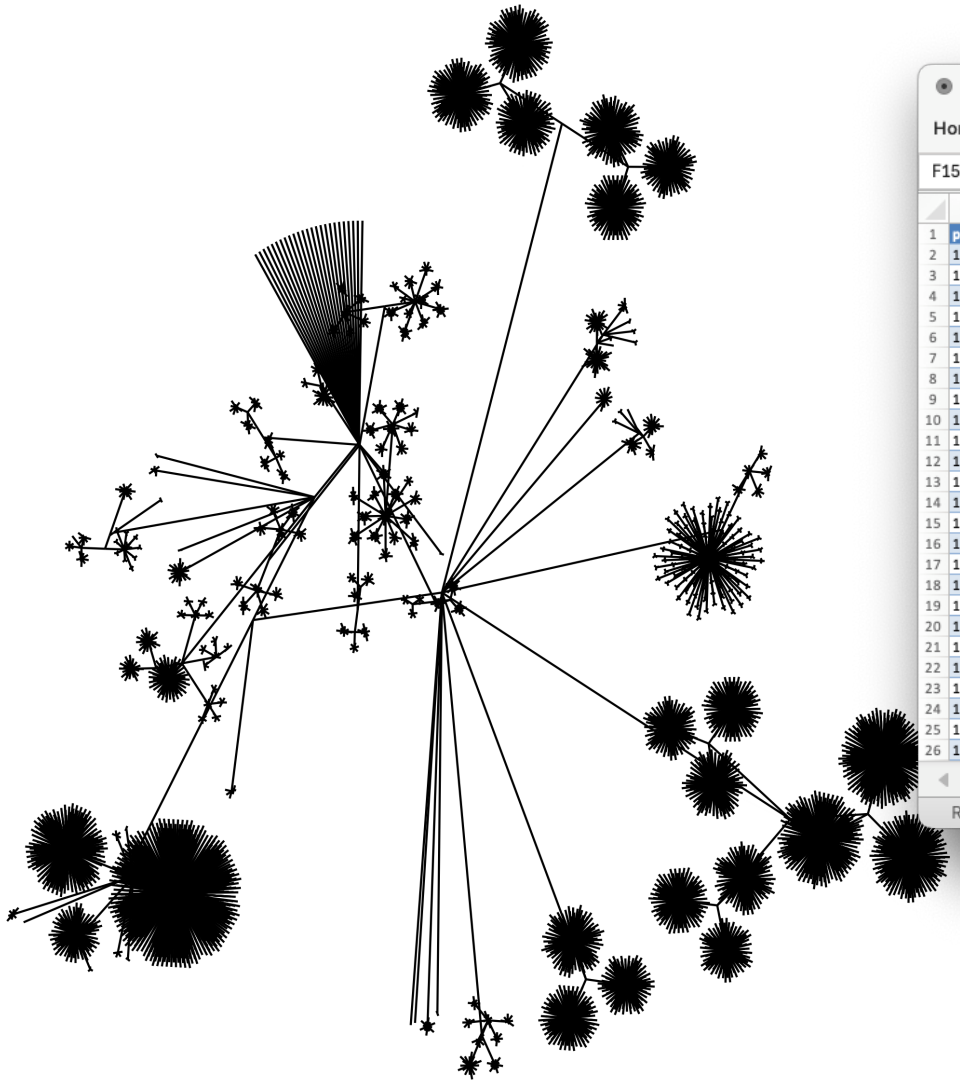

fn
Land Use
$t_0$
Land Use
$t_1$


Estimation
Allocation
Transition Potentials Model
Allocate Land Use / Cover
Land Use
$t_{now}$
Land Use
$t_{now+1}$
Covariates
Transition Rates


Calibration
Transition Potentials Model
Land Use
$t_{hist}$
Land Use
$t_{hist+1}$
Covariates
Suitability
indicators
Climate Data


Calibration
Transition Potentials Model
Land Use
$t_{hist}$
Land Use
$t_{hist+1}$
Covariates
Suitability
indicators
Climate Data
Enrichment
Process-based
models

# Inherited model: capable, but grown complex



predictor_table

F151: Perm_crops Neighbourhood effect matrix (size: 3x3cells; random central value and decay rate version:5

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | period | Covariate_ID | Unique_ID | CA_category | Predictor_category | Variable_name | Data_citation | URL | Original_resolution |
| 2 | 1985_1997 | soil_ph | cov_1 | suitability | biophysical | Soil pH | Descombes et al. 2020 | https://www.envidat.ch/c | 93m |
| 3 | 1985_1997 | soil_nutrients | cov_2 | suitability | biophysical | Soil nutrients | Descombes et al. 2020 | https://www.envidat.ch/# | 93m |
| 4 | 1985_1997 | soil_moisture | cov_3 | suitability | biophysical | Soil moisture | Descombes et al. 2020 | https://www.envidat.ch/# | 93m |
| 5 | 1985_1997 | soil_moisture_variability | cov_4 | suitability | biophysical | Soil moisture variability | Descombes et al. 2020 | https://www.envidat.ch/# | 93m |
| 6 | 1985_1997 | soil_aeration | cov_5 | suitability | biophysical | Soil aeration | Descombes et al. 2020 | https://www.envidat.ch/# | 93m |
| 7 | 1985_1997 | soil_humus | cov_6 | suitability | biophysical | Soil humus | Descombes et al. 2020 | https://www.envidat.ch/# | 93m |
| 8 | 1985_1997 | elevation_mean_100m | cov_7 | suitability | topographic | Mean elevation | SwissAlti3D | ValPar.CH predictors | 25m |
| 9 | 1985_1997 | aspect_mean_100m | cov_8 | suitability | topographic | ASPECT | SwissAlti3D | ValPar.CH predictors | 25m |
| 10 | 1985_1997 | slope_mean_100m | cov_9 | suitability | topographic | SLOPE | SwissAlti3D | ValPar.CH predictors | 25m |
| 11 | 1985_1997 | hillshade_mean_100m | cov_10 | suitability | topographic | HILLSHADE | SwissAlti3D | ValPar.CH predictors | 25m |
| 12 | 1985_1997 | light_100m | cov_11 | suitability | topographic | Light | Descombes et al. 2020 | https://www.envidat.ch/# | 93m |
| 13 | 1985_1997 | noise_mean_100m | cov_12 | suitability | transport | noise pollution index | BAFU: sonBASE | ValPar.CH predictors | 25m |
| 14 | 1985_1997 | distance_to_roads_mean_100m | cov_13 | suitability | transport | distance to roads | FOT: roads | ValPar.CH predictors | 25m |
| 15 | 1985_1997 | distance_to_lakes_mean_100m | cov_14 | suitability | hydrological | Distance to lakes (mean di | OFT-VECT25 | ValPar.CH predictors | 25m |
| 16 | 1985_1997 | distance_to_rivers_mean_100m | cov_15 | suitability | hydrological | Distance to river (mean di | OFEV-GWN07 | ValPar.CH predictors | 25m |
| 17 | 1985_1997 | continentality_100m | cov_16 | suitability | climatic | Continentality | Descombes et al. 2020 | https://www.envidat.ch/# | 93m |
| 18 | 1985_1997 | muni_pop | cov_1001 | suitability | socio_economic | Population per municipal | FSO | https://dam-api.bfs.admir | municipality |
| 19 | 1985_1997 | avg_chg_fte_sec1 | cov_1002 | suitability | socio_economic | Average annual change in | FSO: Business census and S | sec23_95_05 = https://da | 100m |
| 20 | 1985_1997 | avg_chg_fte_sec2 | cov_1003 | suitability | socio_economic | Average annual change in | FSO: Business census and S | sec23_95_05 = https://da | 100m |
| 21 | 1985_1997 | avg_chg_fte_sec3 | cov_1004 | suitability | socio_economic | Average annual change in | FSO: Business census and S | sec23_95_05 = https://da | 100m |
| 22 | 1985_1997 | average_avg_ann_temp | cov_1005 | suitability | climatic | Annual mean temperatur | CHclim25-Broennimann | ValPar.CH predictors | 25m |
| 23 | 1985_1997 | average_avg_precip | cov_1006 | suitability | climatic | Average annual precipitat | CHclim25-Broennimann | ValPar.CH predictors | 25m |
| 24 | 1985_1997 | average_sum_gdays_0deg | cov_1007 | suitability | climatic | Sum of growing days abov | CHclim25-Broennimann | ValPar.CH predictors | 25m |
| 25 | 1985_1997 | average_sum_gdays_3deg | cov_1008 | suitability | climatic | Sum of growing days abov | CHclim25-Broennimann | ValPar.CH predictors | 25m |
| 26 | 1985_1997 | average_sum_gdays_5deg | cov_1009 | suitability | climatic | Sum of growing days abov | CHclim25-Broennimann | ValPar.CH predictors | 25m |

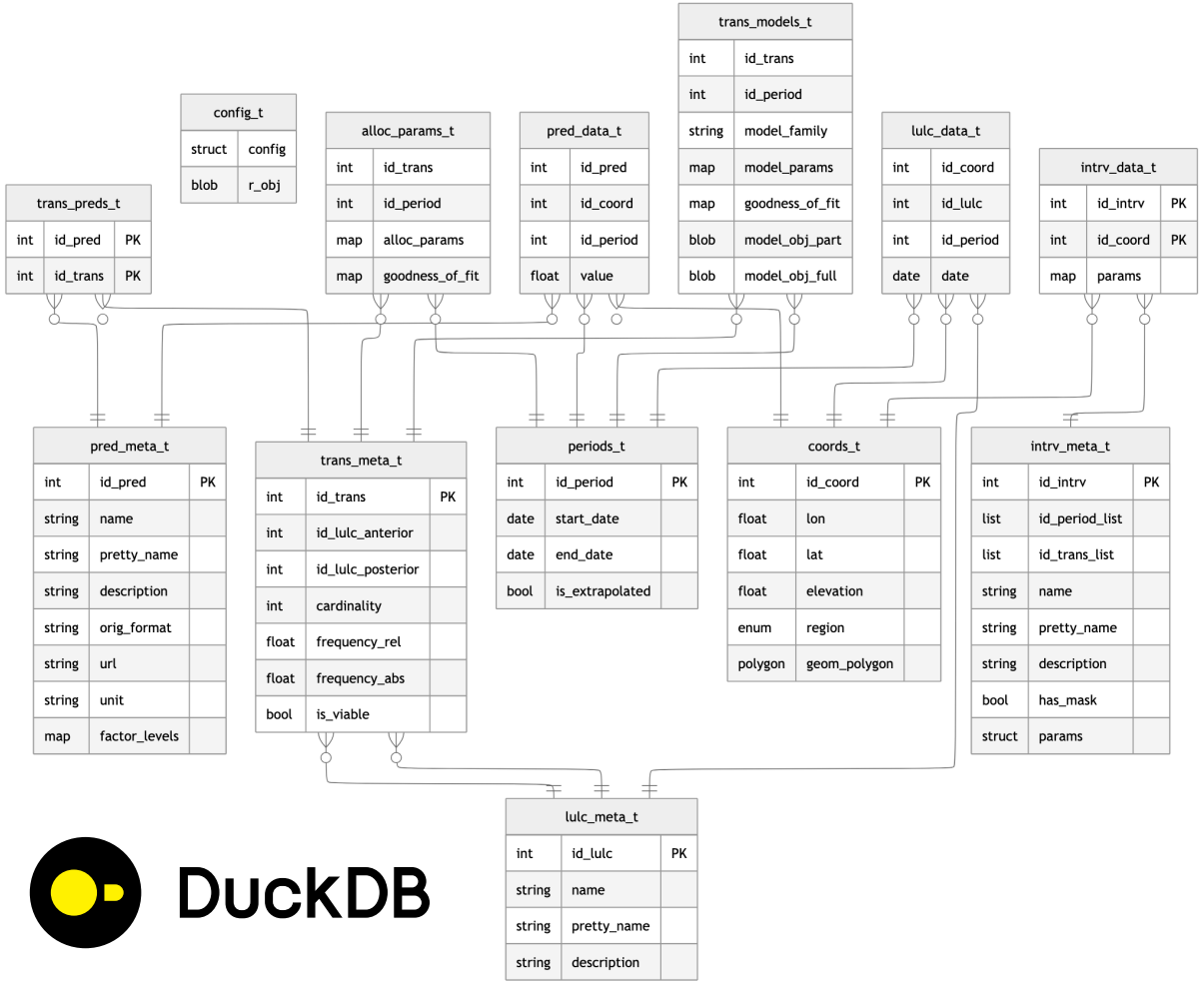
1985_1997 | 1997_2009 | 2009_2018 | 2020_2025 | 2025_2030 | 2030_2035 | 2035_2040 | 2040_2045 | 2045_2050

Ready | Accessibility: Investigate | 100%

Ready | Accessibility: Investigate | Count: 1422 | 100%

54k lines of code

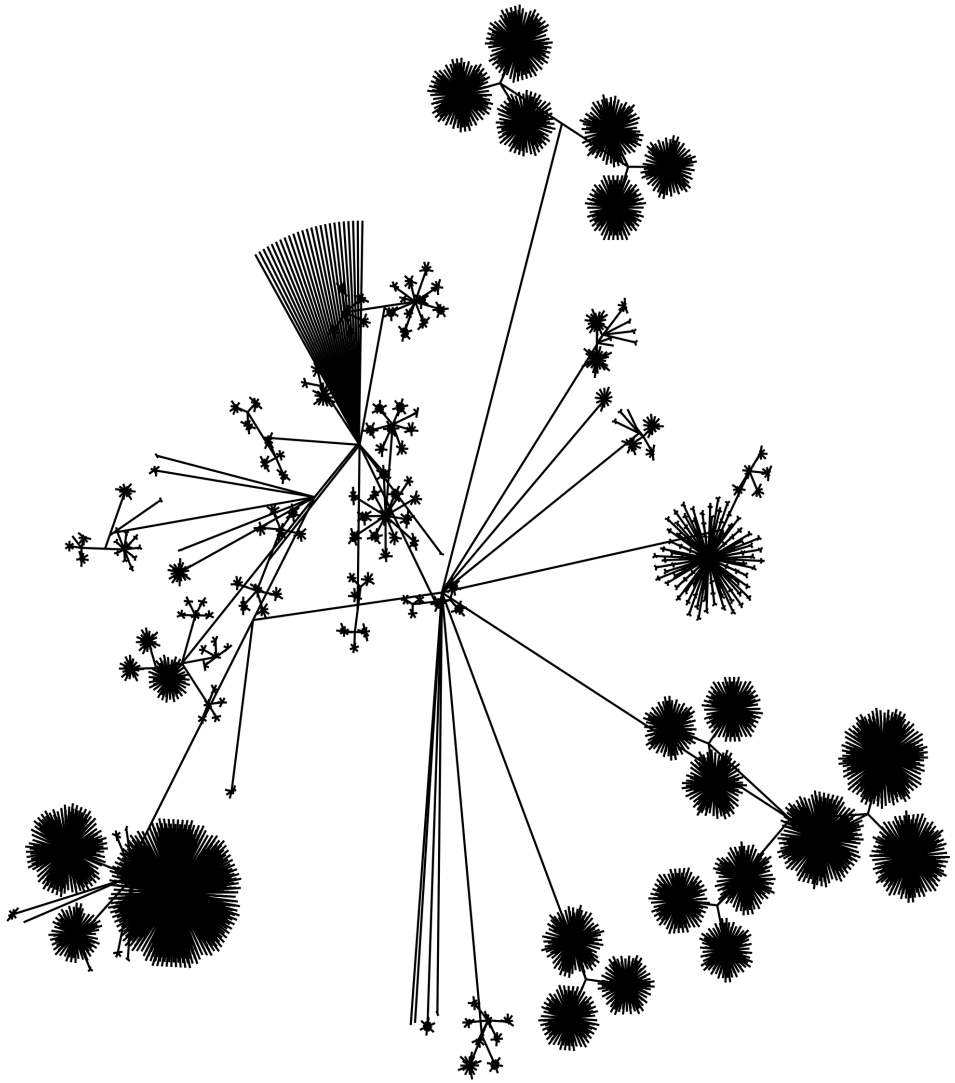
# Integrating process-based models: Let the computer check your assumptions!




DuckDB

```r
library(evoland)

db <- evoland_db$new("filepath.duckdb")
db$conf <- read_config("conf_path.json")

db$lulc <-
  read_raster("somefile.tif") |>
  as_lulc_data()

db$covariates <-
  read_raster("some_other_file.tif") |>
  as_covariates()

db$covariates <-
  run_hydrology_sim() |>
  as_covariates()

db$models <- calibrate(database = db)
# et cetera
```

# Reduced Cognitive Load: Enables Integration



DuckDB

Process-based models

# I'd love to hear feedback!
# github.com/ethzplus/evoland-plus

**Jan Hartman**
jhartman@ethz.ch

# Sources

- Title Image: Own work, 28th of August 2024, Near Fafleralp
- Heavy precipitation: MeteoSwiss, https://www.meteoschweiz.admin.ch/ueber-uns/meteoschweiz-blog/de/2025/08/ueberschwemmung-maggia-juni-2024-teil2.html
- Deglaciation: D. Farinotti / VAW ETHZ via WSL News, https://www.wsl.ch/en/news/switzerlands-glaciers-could-vanish-completely-by-2100/
- Sankey Diagram Land Use Change: valpar.ch / B. Black et al., https://valpar.ch/land-use-change-scenarios/index-en.html

# Why take a Land Use Change perspective?

- Expression of human appropriation of natural resources
- Both shaping and shaped by resource availability
- Understanding LUC helps manage ecosystem services (ES)
- Compare scenarios of LUC
  - Utilitarian framework of ES lends itself to consequentialist approach

# Context

- Climate Change in Mountains
  - Warming, precipitation, drought, heatwaves, windstorms
- Effects on land cover
  - Deglaciation, vegetation shifts, wildfires, windthrow, rockfall, landslides
- Land use response
  - Dependent on biophysical state AND socioeconomic system

- Existing *Constrained Land Use Change Model*
  - Compare scenarios of LUC, summarise via ecosystem services
- Lack of historical climate change effects
  - Land use change is slow, climate change signal too weak

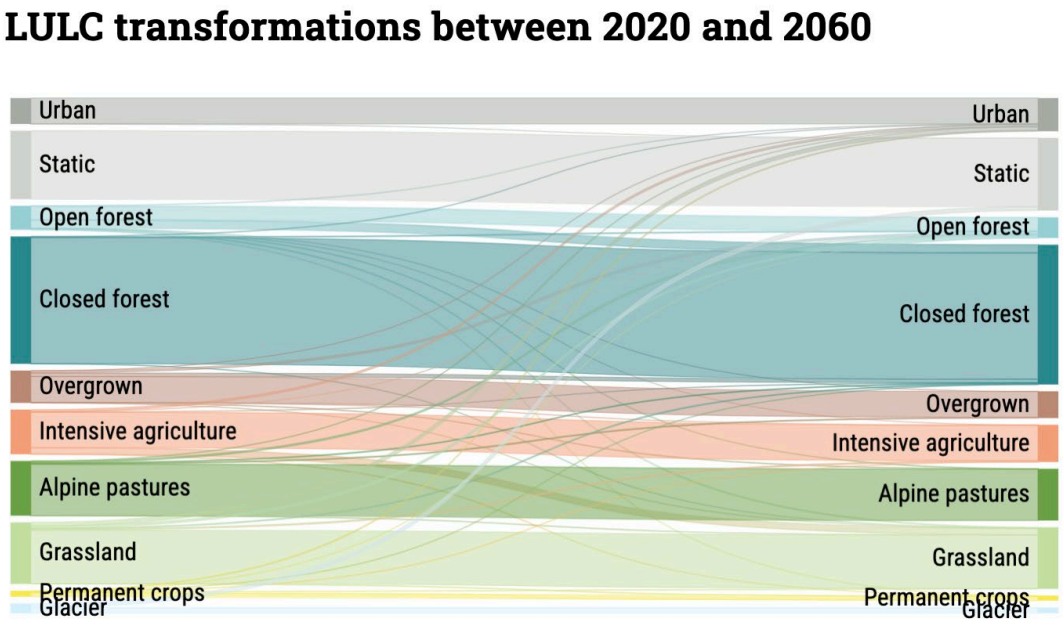
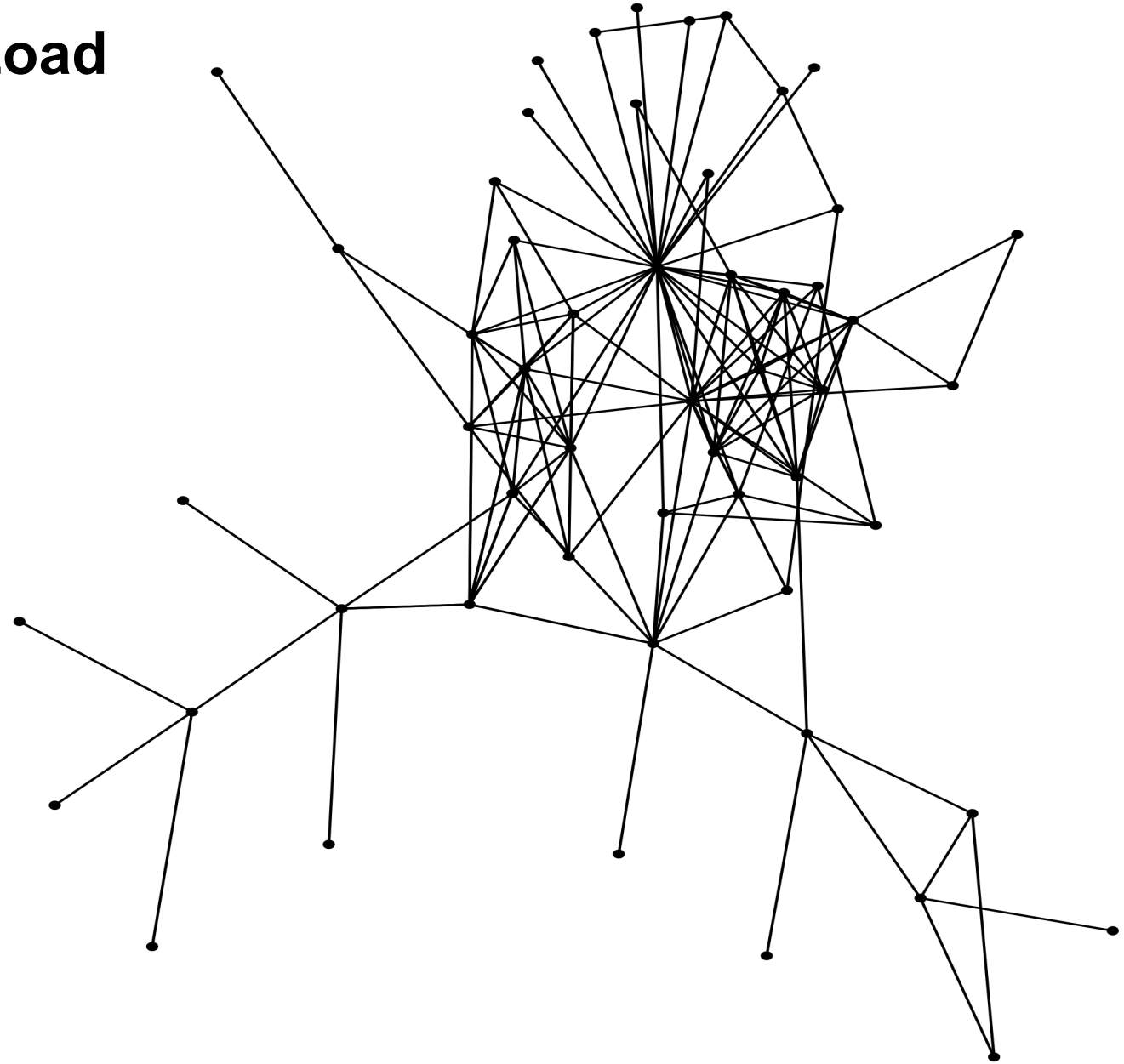
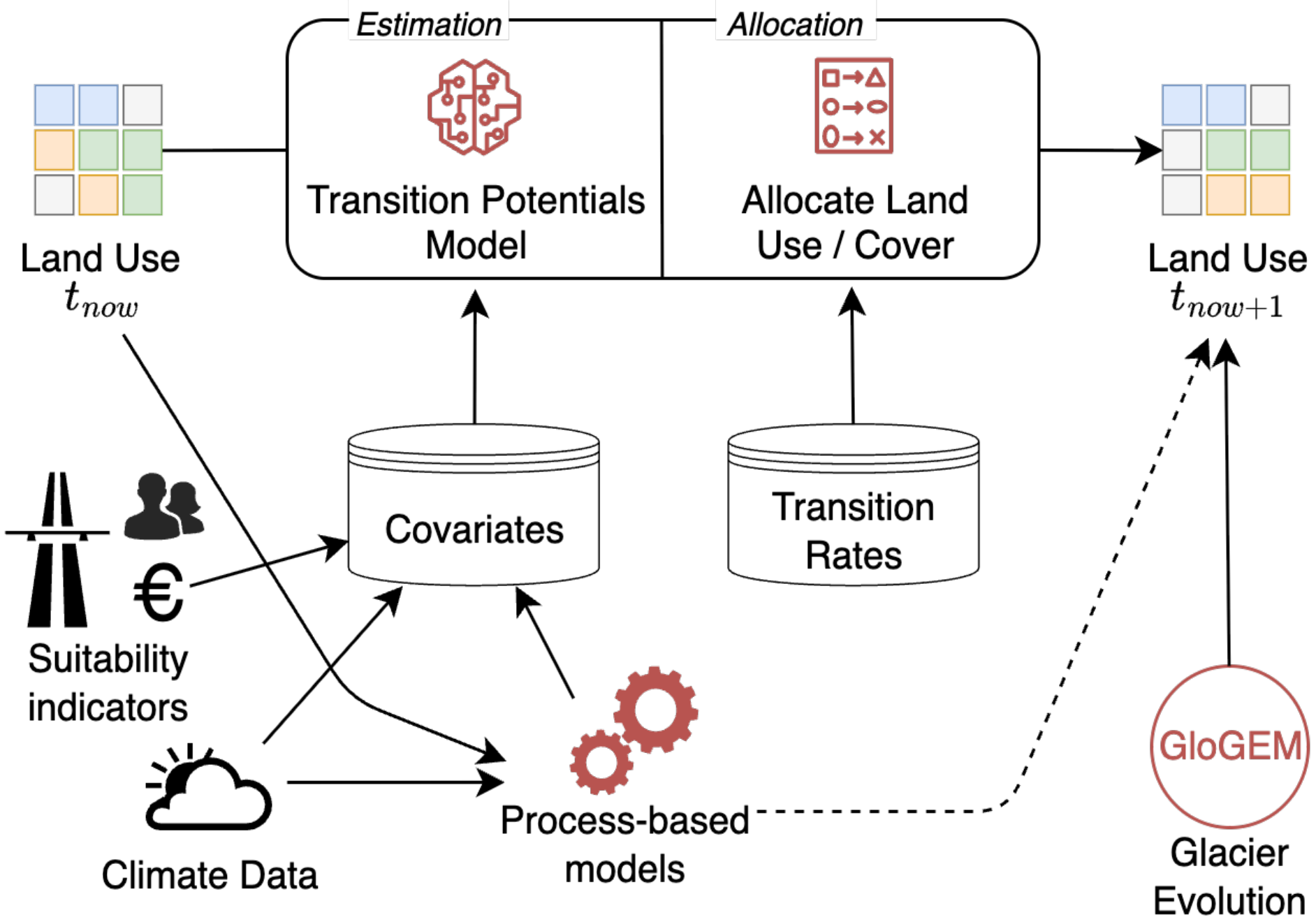




Image: [illegible]

# Reduce Cognitive Load




Estimation
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Suitability indicators
Climate Data
Process-based models
GloGEM
Glacier Evolution

# What to take into account?

Climate change in mountains:

- Warming
- Seasonal precipitation shifts
  - & reduced snow water equivalent
- Climate and weather extremes
  - Drought
  - Heatwaves
  - Extreme precipitation
  - Windstorms, supercells?

Corresponding landscape changes:

- ★ Shifting vegetation bands ★
- ★ Glacier meltoff ★
- ★ Wildfires ★
- Windthrow
- Landslides
- Rockfall

Possible adaptations

- ★ Urbanization to escape lowland heat ★
- ★ Shifting agri- and silvicultural usage ★
- ★ Shifting touristic usage ★
- Hydrological infrastructure