Spatial variability of indoor radon concentrations (IRC) and the identification of radon priority areas in Austria

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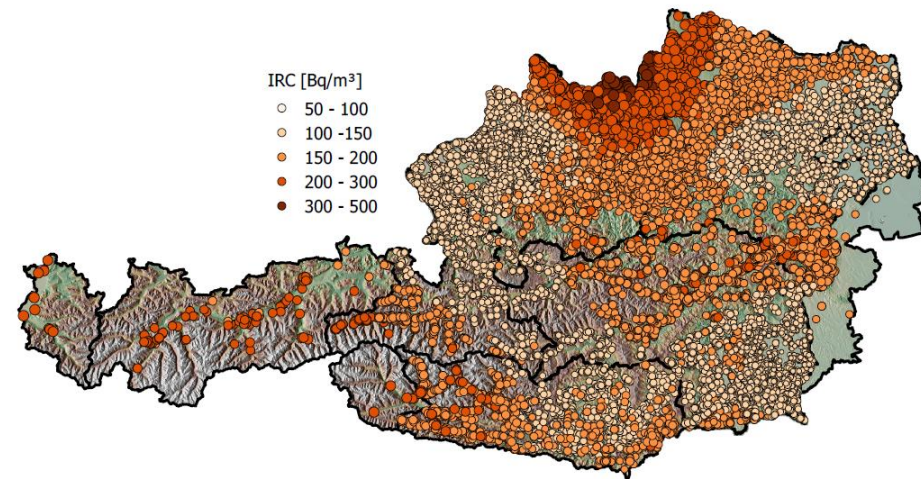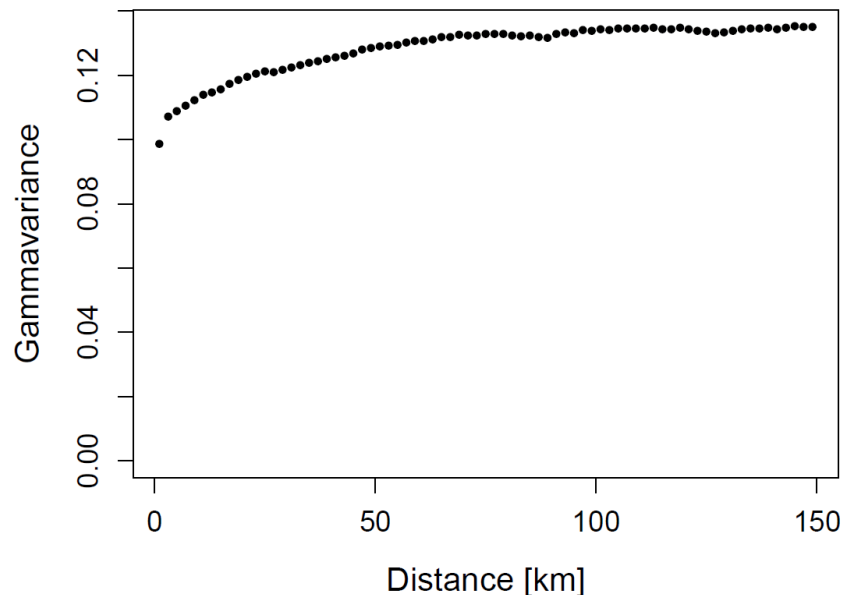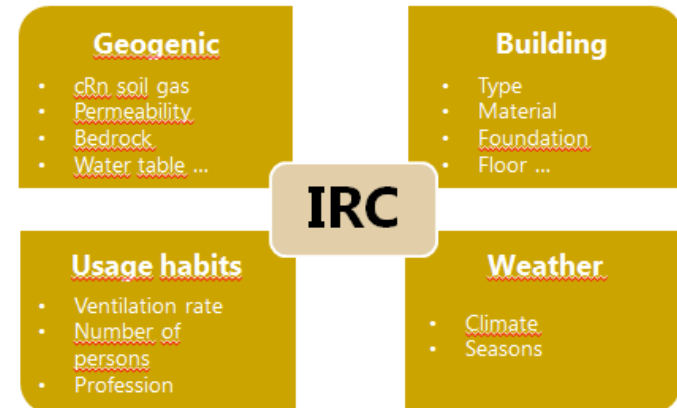
O. Alber, S. Kuchling, C. Laubichler, C. Schleicher

Service, Data and Statistics

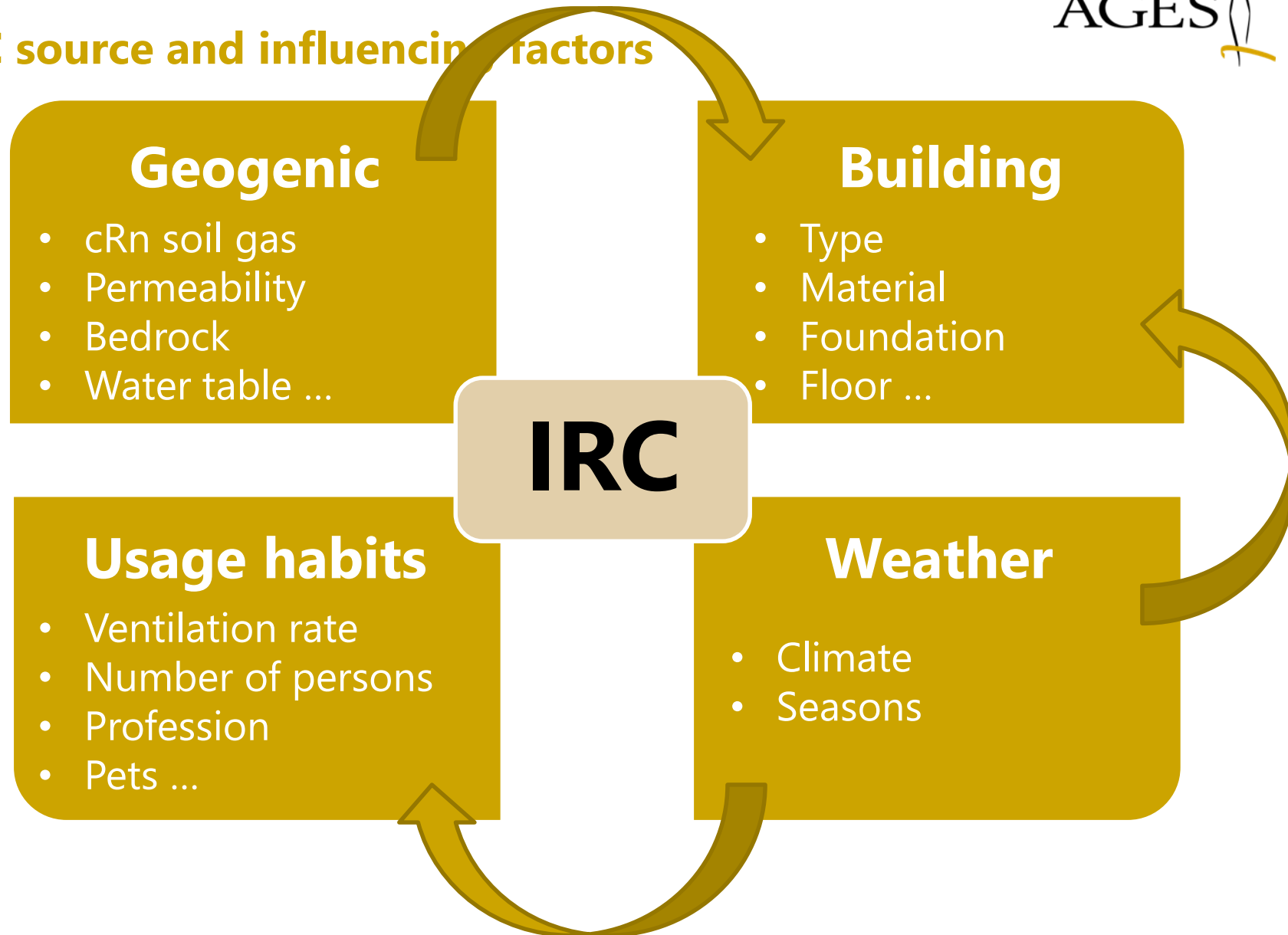**Austrian Agency for Health and Food Safety**

Content

Spatial Variability of IRC and identification of RPA

1. Overview IRC source and influencing factors
2. The Austrian Rn survey design
3. IRC distributions and Spatial variability
4. Generalized additive mixed model
5. Summary and Implications for radon priority areas (RPA)

Geogenic
- cRn soil gas
- Permeability
- Bedrock
- Water table ...

Building
- Type
- Material
- Foundation
- Floor ...

IRC

Usage habits
- Ventilation rate
- Number of persons
- Profession

Weather
- Climate
- Seasons

IRC [Bq/m³]
- 50 - 100
- 100 -150
- 150 - 200
- 200 - 300
- 300 - 500

Overview

Sampling Strategy

Austrian radon survey design

Strategy:

- selection according to **grid**, **municipalities**, **geology**
- measurements in houses of **members of the voluntary fire brigades**
- **6 months** (half winter, half summer) radon measurements (track etch)
- 2 (most used) rooms, preferable ground floor
- Survey over several years in different federal states
- Questionnaire

grid (2 x 2 km)

1-3 dwellings/cell depending on variability of geology in the cell

municipalities
(at least 12 dwellings)

geological units
(1:500.000)

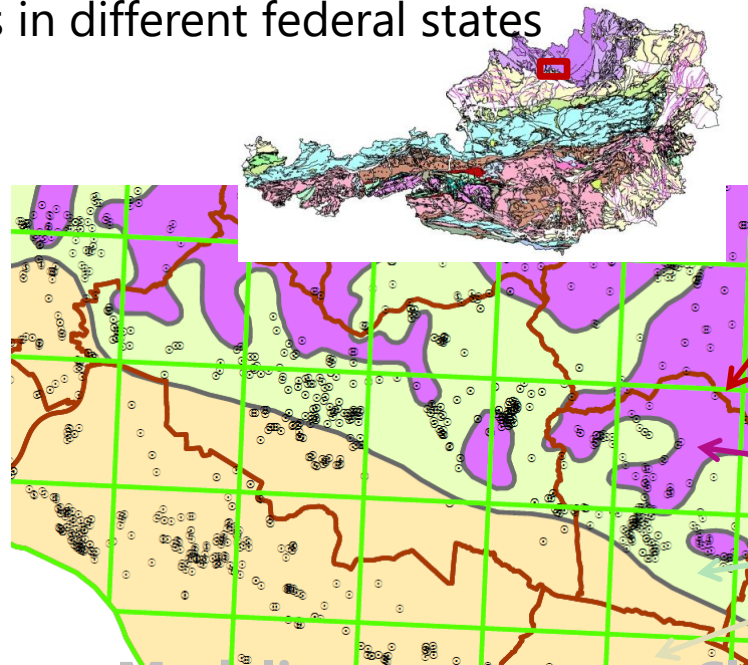**Sampling** – **Modeling** – **Classification**

Questionaire

Austrian radon survey design

Strategy:

- selection according to **grid**, **municipalities**, **geology**
- measurements in houses of **members of the voluntary fire brigades**
- **6 months** (half winter, half summer) radon measurements (track etch)
- 2 (most used) rooms, preferable ground floor
- **Questionnaire**

Questionaire - fields

Austrian radon survey design

- **Rooms earth bound**
- **Floor**
- **Year of construction**
- **measurement t winter/summer**
- **Type/material foundation**
- **Building material walls**
- **Reconstruction**
- **Type of building**
- **Type of heating**
- **Hillside**
- **Number of inhabitants**
- **Window tightness**
- **Type of room**

1 Gesamtzahl der Wohneinheiten im Gebäude: 1 ☐ 2 ☐ 3 ☐ MEHR ALS 3 ☐

2 Nutzung des Gebäudes: EIN-/ZWEIFAMILIENHAUS ☐ WOHNUNG ☐ BAUERNHAUS ☐
WOCHENENDHAUS/-WOHNUNG ☐ SONSTIGES:

3 Gebäutetyp: KONVENTIONELLE BAUWEISE ☐ NIEDRIG-/NIEDRIGSTENERGIEHAUS ☐
PASSIVHAUS ☐ UNBEKANNT ☐ SONSTIGES:

4 Wann wurde das Haus fertig gestellt: VOR 1919 ☐ 1919-1944 ☐ 1945-1970 ☐
1971-2000 ☐ NACH 2000 ☐ UNBEKANNT ☐ BAUJAHR FALLS BEKANNT:

5 Lage des Gebäudes: ALLEINSTEHEND ☐ ZUSAMMENGEBAUT MIT NACHBARHAUS ☐

6 Hanglage: JA ☐ NEIN ☐

7 Ist das Haus unterkellert: GANZ ☐ TEILWEISE ☐ NICHT ☐ UNBEKANNT ☐

8 Fundamenttyp: FUNDAMENTPLATTE DURCHGEHEND ☐ FUNDAMENTPLATTE TEILWEISE ☐
STREIFENFUNDAMENT ☐ KEIN FUNDAMENT ☐ UNBEKANNT ☐

Building characteristics are used to model normalized IRC.

Sampling Strategy

Austrian radon survey design

AGES

Geogenic

- cRn soil gas
- Permeability
- Bedrock
- Water table ...

Additional Maps

Building

- Type
- Material
- Foundation
- Floor ...

Questionaire

IRC

Usage habits

- Ventilation rate
- Number of persons
- Profession
- Pets ...

Questionaire

Weather

- Climate
- Seasons

- 6 mounth
- Half winter/summer
- Campaign over several years

IRC measurement locations
IRC distributions and Rn-influencing factors

n	n dwellings	AM [Bq/m³]	GM [Bq/m³]	% >300
41206	22190	170	113	11.8
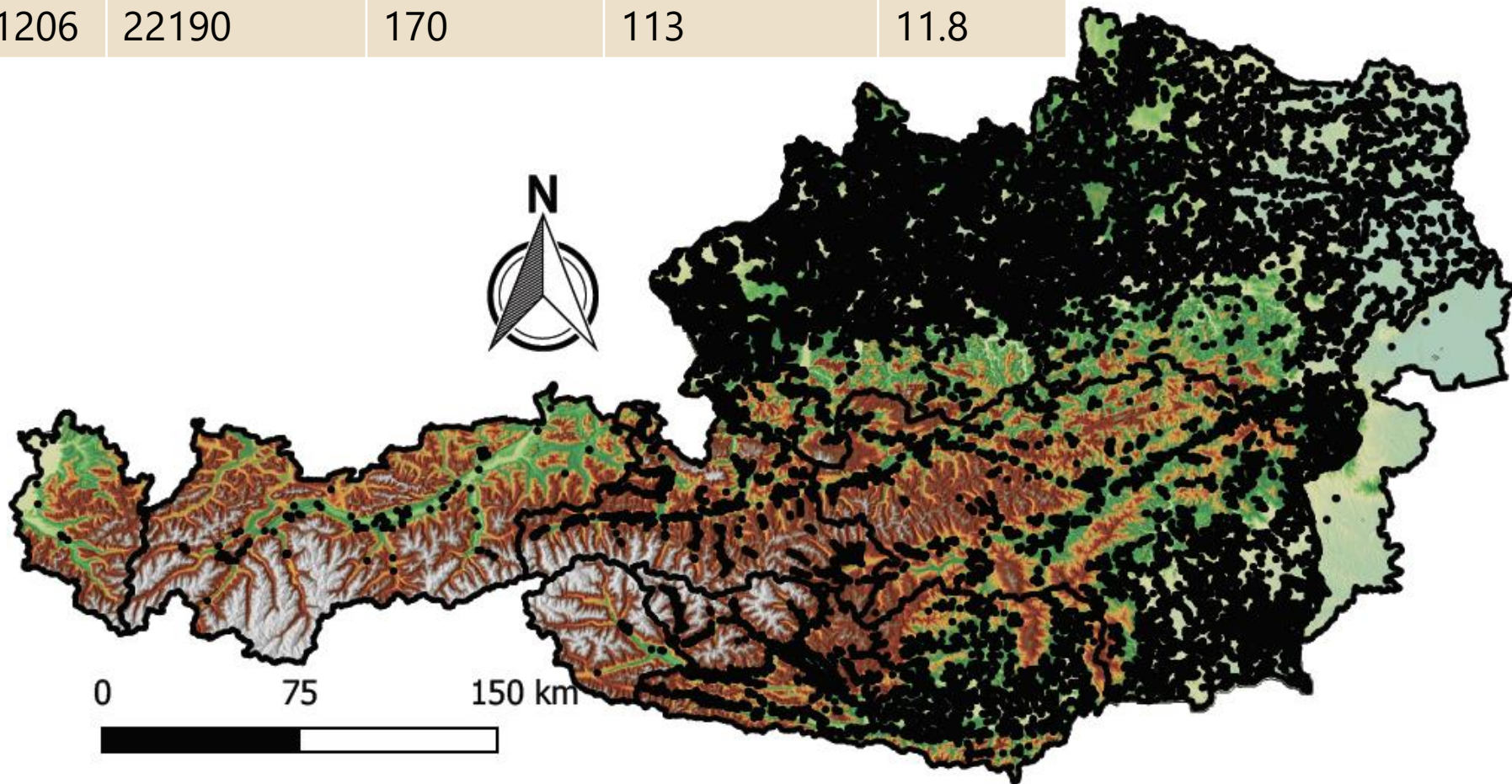
IRC Building mean locations

IRC distributions and Rn-influencing factors

n	n dwellings	AM [Bq/m³]	GM [Bq/m³]	% >300
41206	22190	170	113	11.8

IRC [Bq/m³]
- 10 - 100
- 100 - 300
- 300 - 500
- 500 - 1000
- 1000 - 13698

0   75   150 km
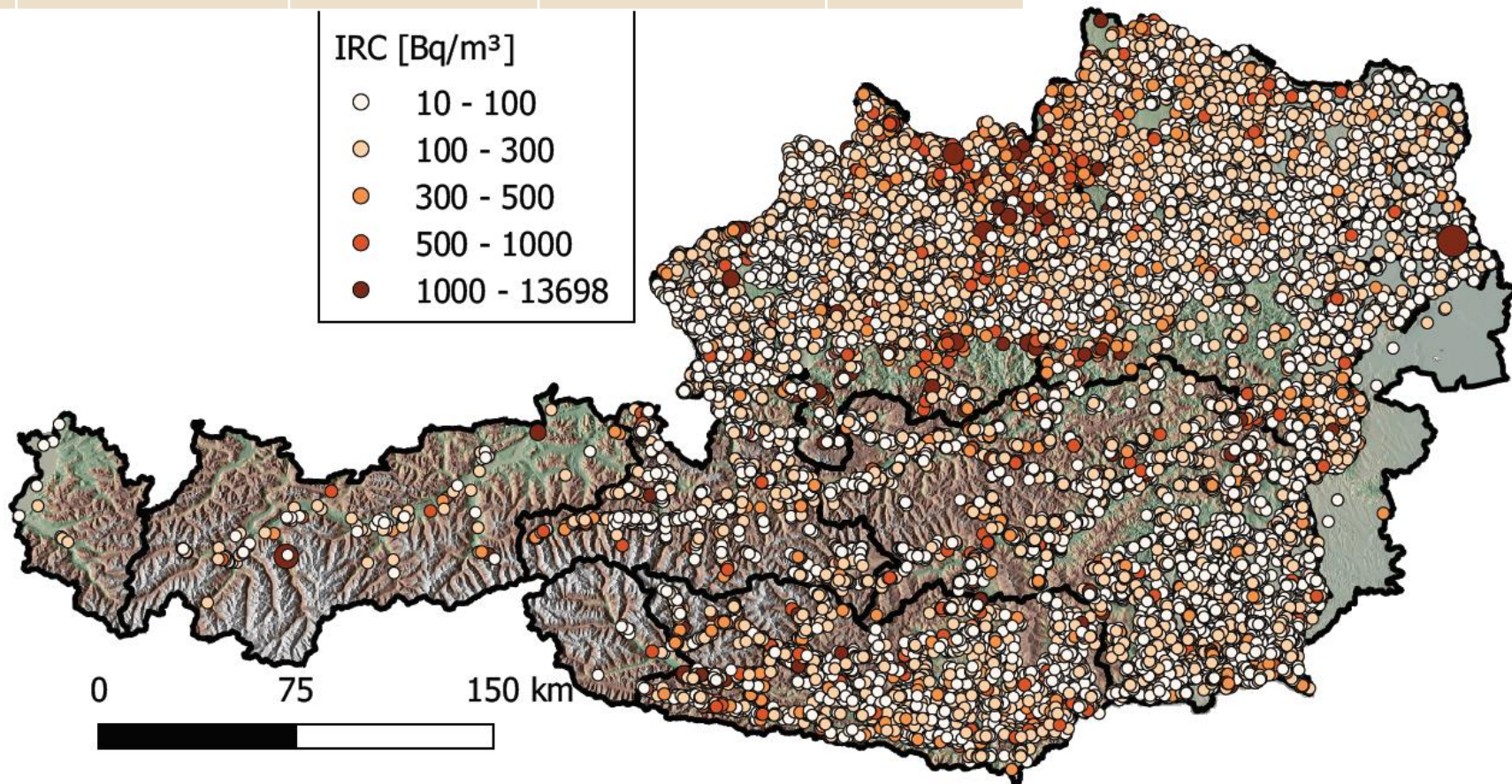
IRC Building means ~ distribution

IRC distributions and Rn-influencing factors

n	n dwellings	AM [Bq/m³]	GM [Bq/m³]	% >300
41206	22190	170	113	11.8
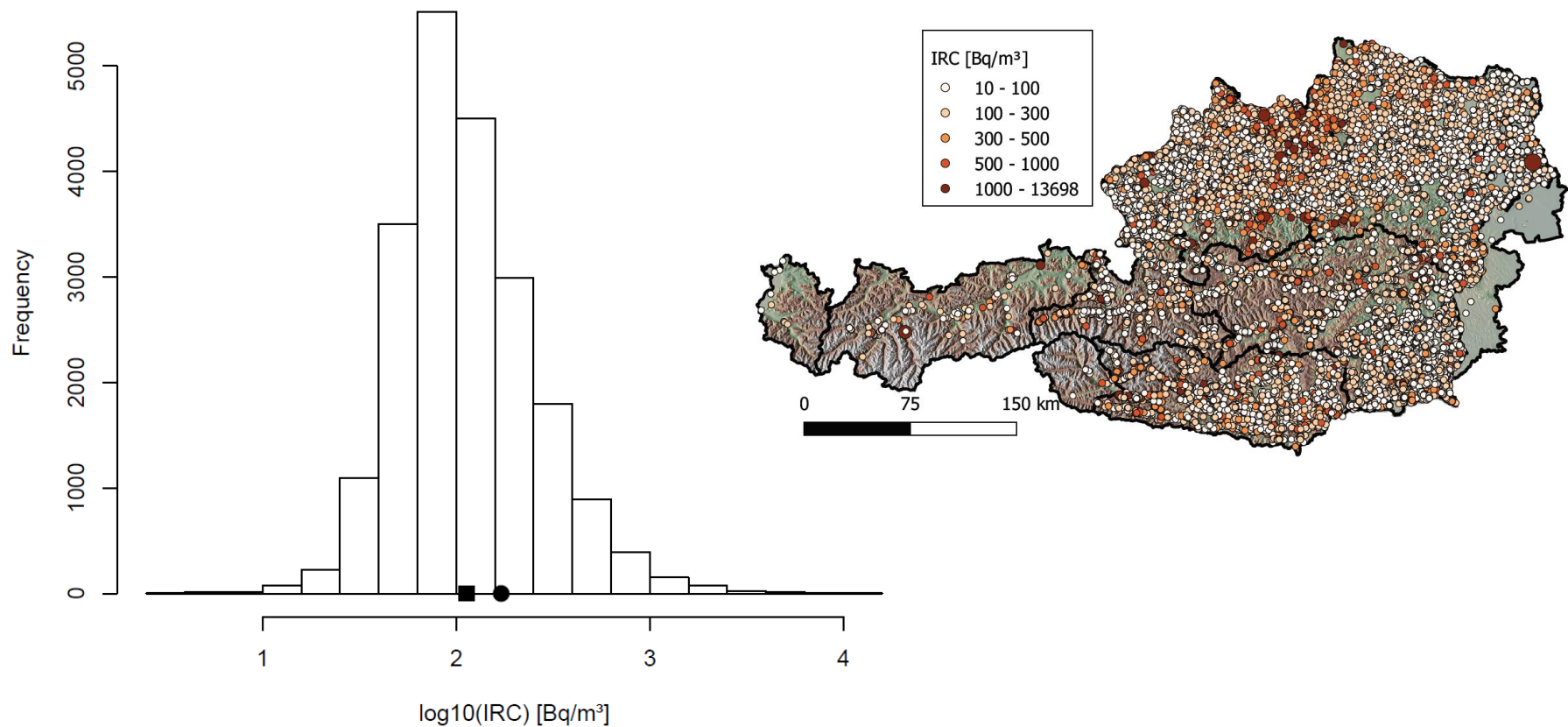
IRC Variogram

Spatial variability of IRC
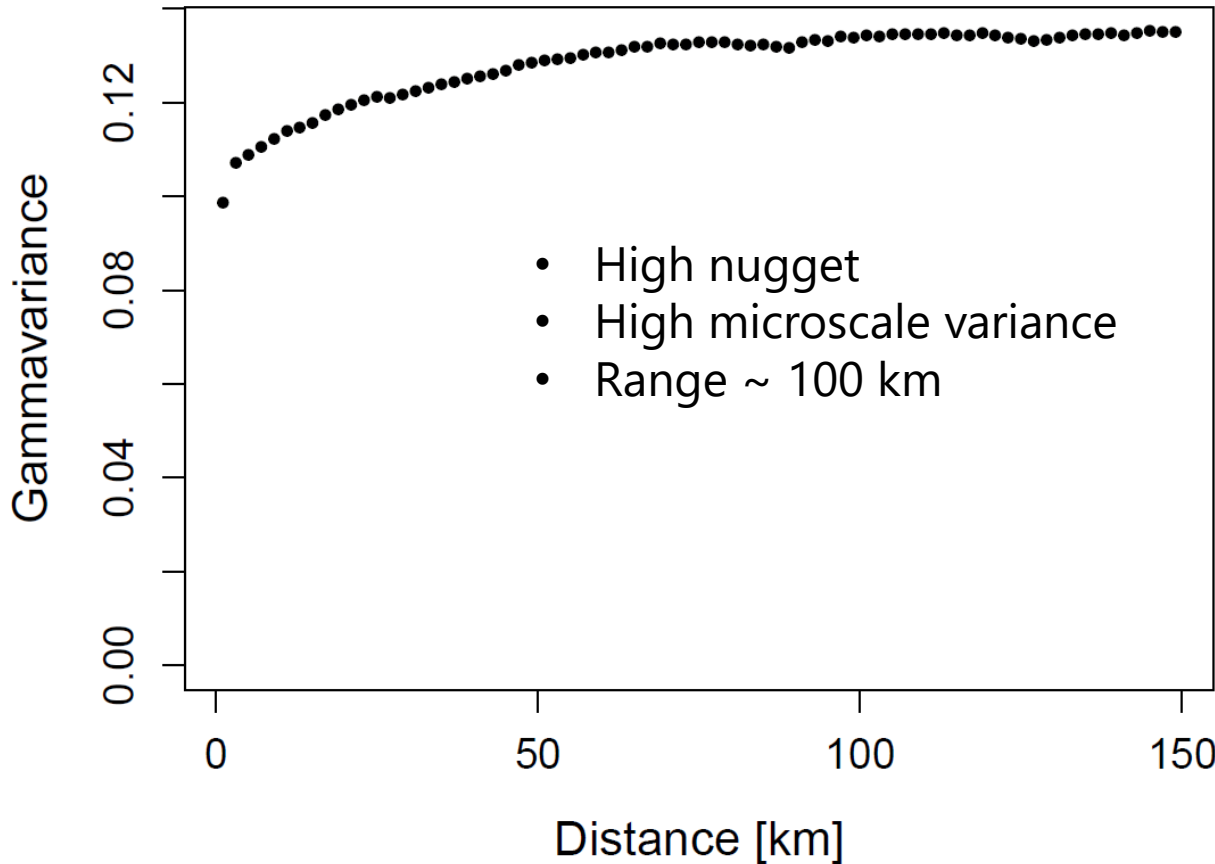
- High nugget
- High microscale variance
- Range ~ 100 km

Variogram ~Are near things more related than distant things? – „Toblers first law of geography"

Spatial autocorrelation ~ Near locations show lower variability than distant locations.
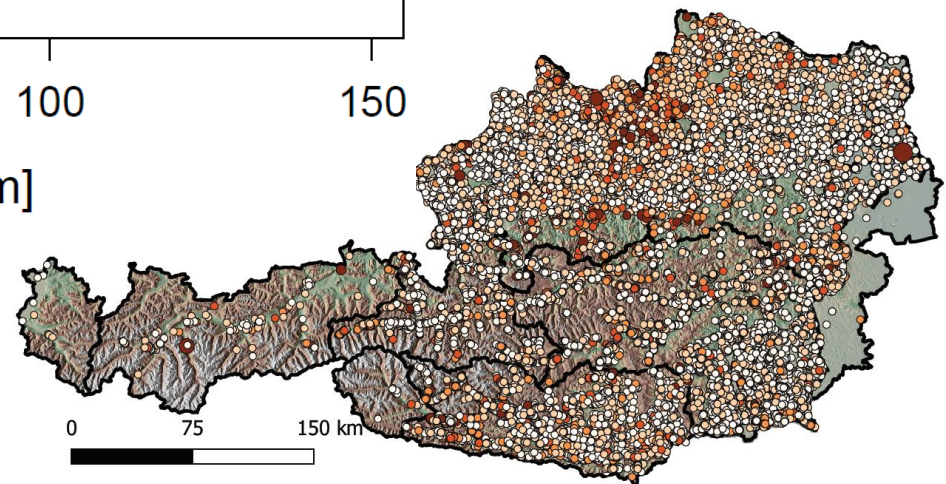
Overview Model

GAMM

- Modeled IRC in dependency of relevant, explaining factors

- Generalised Additive Mixed Model (GAMM)

- based on Borgoni et al., 2014

- Log-normal distribution assumed

Fixed effects according to the relevant parameters (building characteristics)

Random effect (dwelling)

$$\log(IRC_{ij}) = \beta_0 + \beta_1 z_{ij} + \ldots + \beta_m z_{ij} + s(x_j, y_j) + u_j + \varepsilon_{ij}$$

Intercept (Rn background level)

Smoothing function
(thin plate regression splines),
spatial intercept

rest variation

Example Models
GAMM

Used fixed effects:

- **Rooms earth bound**
- **Floor**
- **Year of construction**

- **measurement t winter/summer**
- **Type foundation**
- **Building material walls**

- **Reconstruction**
- **Window tightness**
- **Location**

Used predictors:

Prediction 1	Prediction 2	Prediction 3
Yes	No	Yes
Ground floor	Ground floor	Ground floor
2000-	2000-	70 – 2000
1	1	1
fully	fully	No
Concrete	Concrete	Concrete
No	No	No
tight	tight	tight
true location	true location	true location

$$\log(IRC_{ij}) = \beta_0 + \beta_1 z_{ij} + \ldots + \beta_m z_{ij} + s(x_j, y_j) + u_j + \varepsilon_{ij}$$

Example Models ~ distributions
GAMM

Used fixed effects:

Effects	Model 1	Model 2	Model 3
Earth bound	Yes	No	Yes
Floor	Ground floor	Ground floor	Ground floor
Year	2000-	2000-	70 – 2000
T W/S	1	1	1
Foundation	fully	fully	No
Walls	Concrete	Concrete	Concrete
Reconst.	No	No	No
Windows	tight	tight	tight
Location	true location	true location	true location
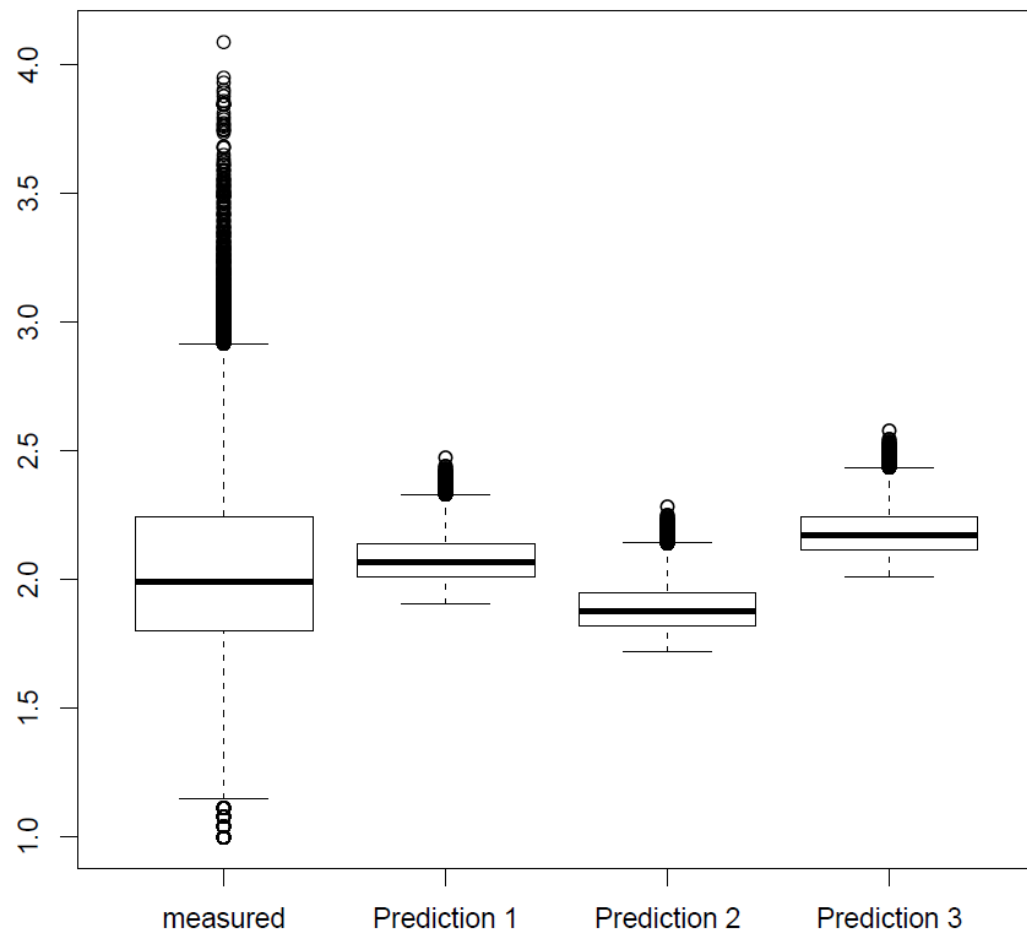
Example Model ~ Pred. IRC locations
GAMM
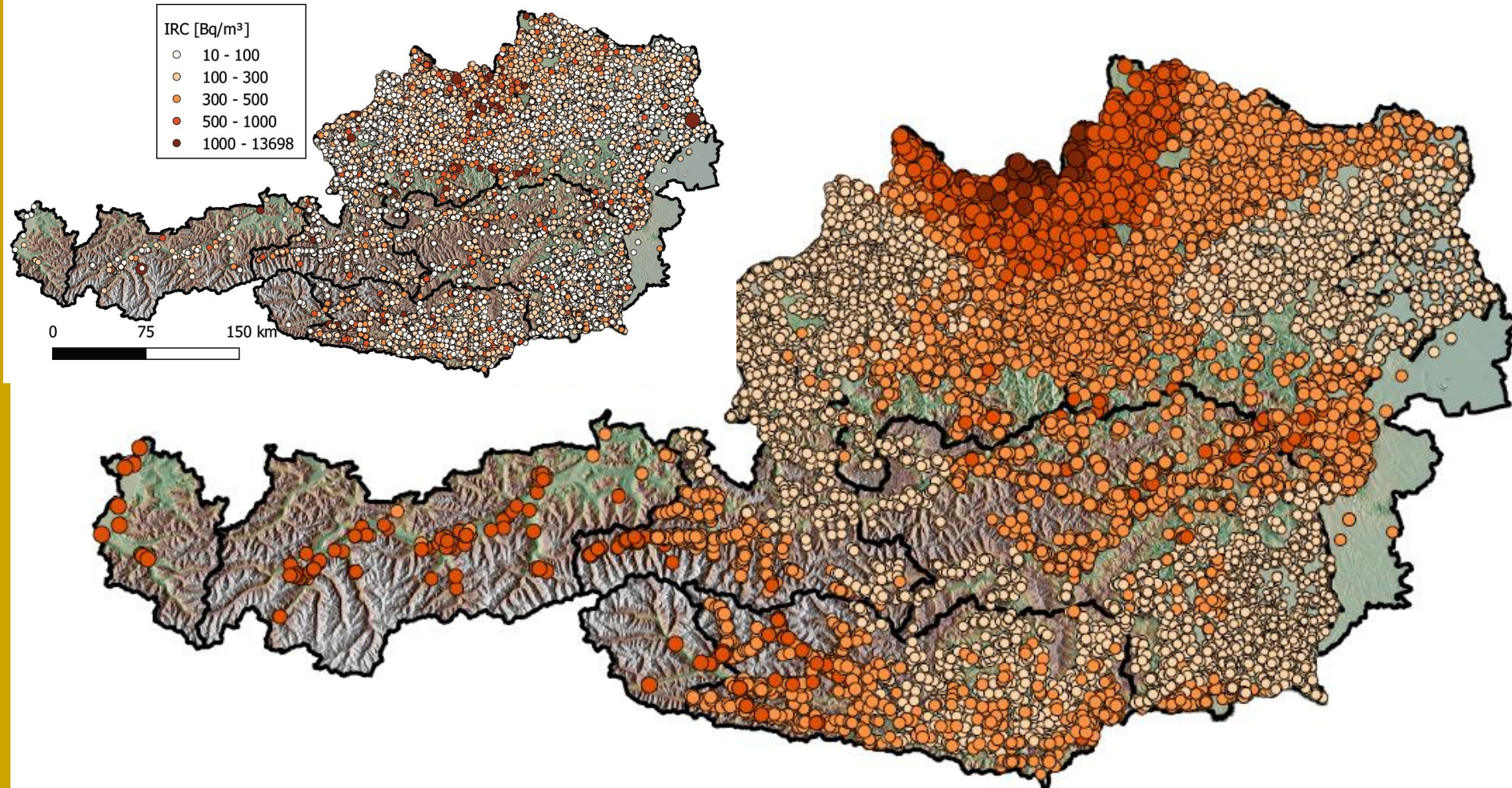
Example Model ~ Pred. IRC variogram
GAMM
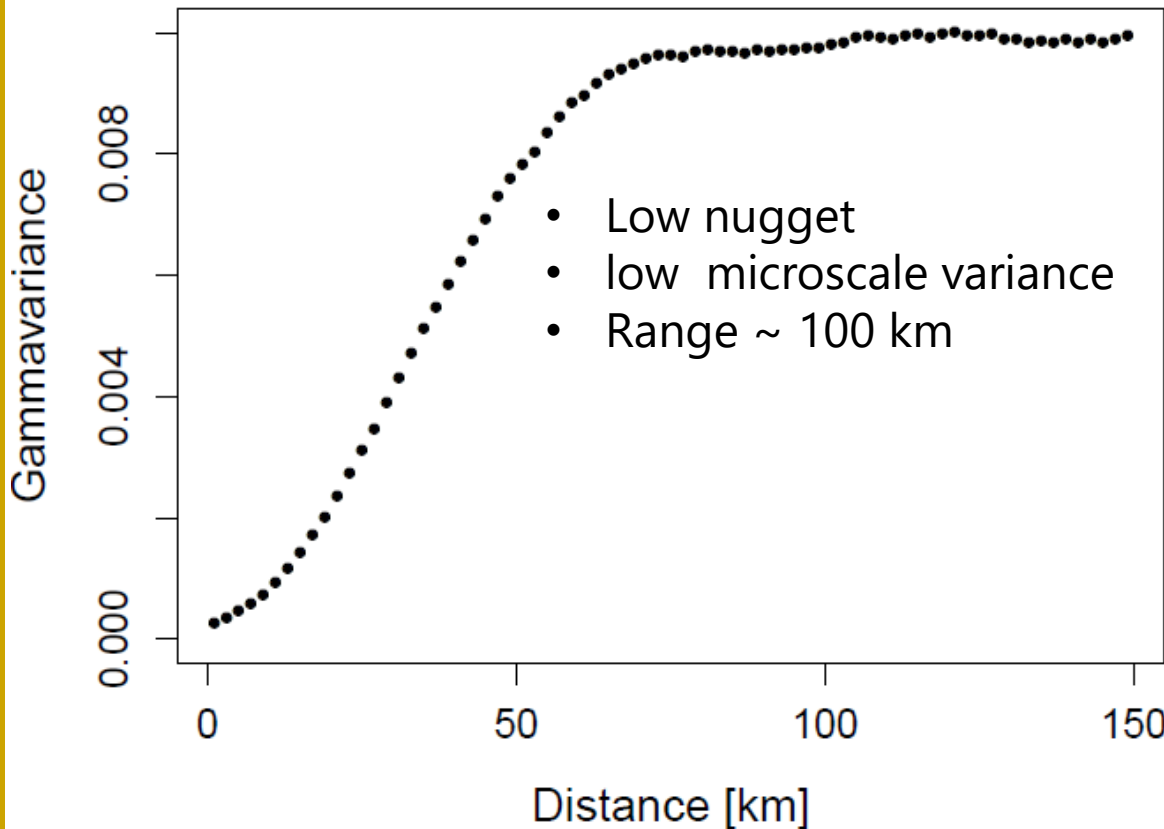
- Low nugget
- low microscale variance
- Range ~ 100 km

Variogram ~Are near things more related than distant things? – „Toblers first law of geography"

Spatial autocorrelation ~ Near locations show lower variability than distant locations.
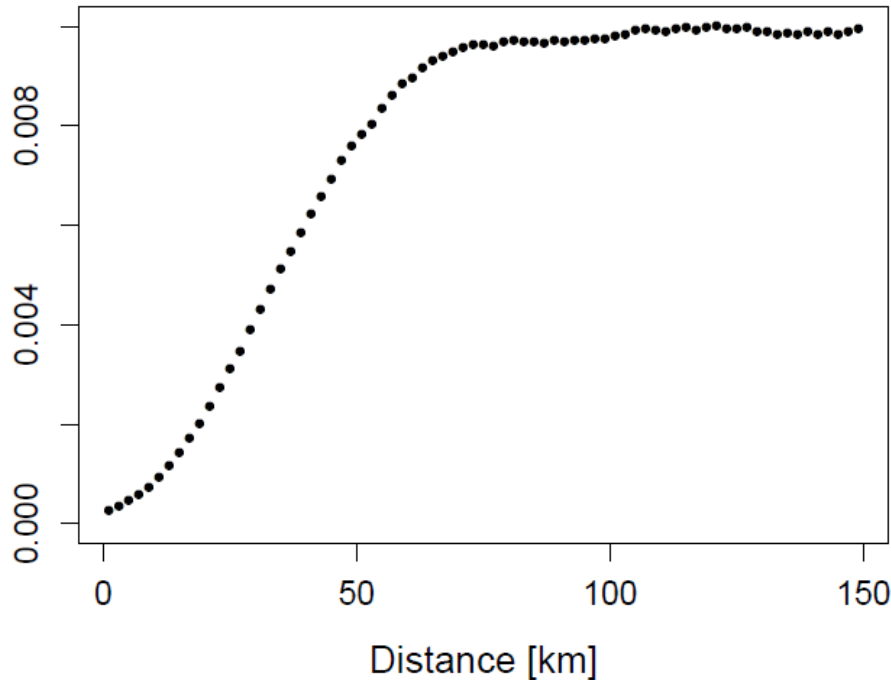

IRC [Bq/m³]
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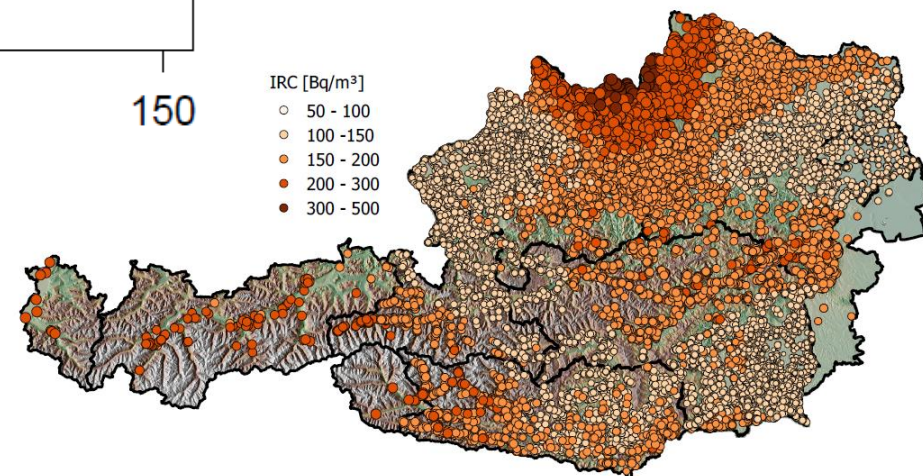
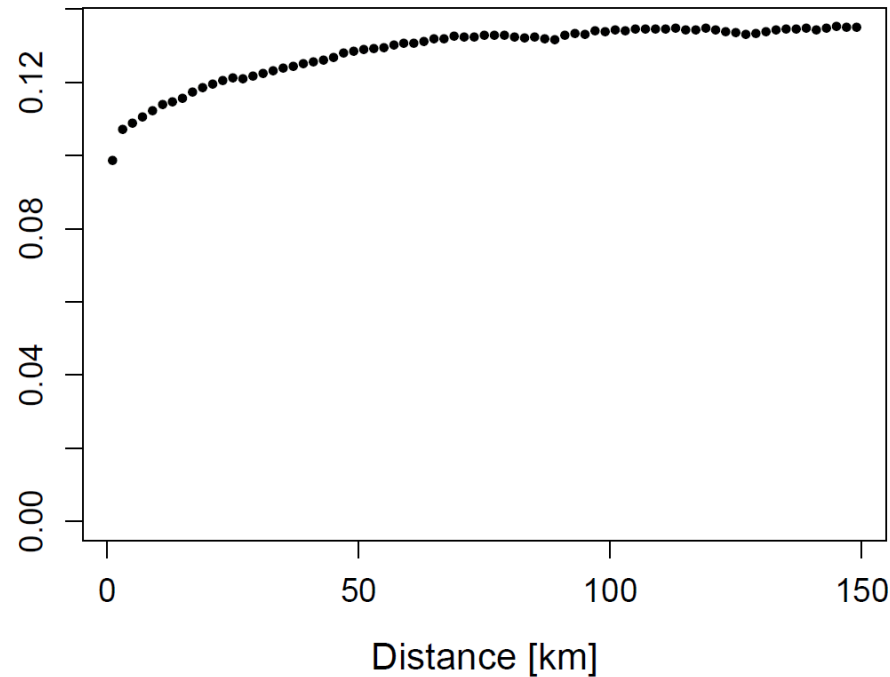# Comparison pred. IRC vs. IRC variogram
GAMM

Pred. IRC

IRC

- Modeling reduces variance and minimizes nugget effect!
- But: Modeling already uses spatial interpolation.

What is the spatial pattern of the geogenic radon potential and is it compareable with the spatial pattern of IRC or predicted IRC?

Summary

Implications for RPA

- IRC in Austria are approximately lognormal-distributed with an AM of 170 and a GM of 113 Bq/m³.

- The AUT Rn-Survey design considers weather and building effects.

- IRC shows high microscale variability – high nugget in variogram.

- GAMM is used to model predicted IRC

  - reduces microscale variability

  - smooths the spatial pattern

  - allows different prediction scenarios

- Implications for RPA:

  - RPA should map the geogenic radon potential independent from factors as building characteristics and usage habits.

  - High microscale variance of IRC is difficult/impossible to map and indicates effects on IRC with no spatial pattern

  - Modeling IRC with GAMM can be used to reduce microscale variance.

Thank you for your attention!