A national radon hazard map of Norway based on geology and indoor radon

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16-18 September 2014, Prague

1. NGU (Geological Survey of Norway)
2. Avalonia Geophysics and University of Exeter
3. NRPA (Norwegian Radiation Protection Authority)

Statens strålevern
Norwegian Radiation Protection Authority

Avalonia Geophysics

UNIVERSITY OF EXETER

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

AIMS:

Åstudy relationship between geology and radon

Åproduce national map

Issues in Norway

Ålack of national datasets for eU, soil-gas

Åsparse population, indoor radon

⇒ characterise geology using indoor radon

⇒ project this to areas without indoor radon data

1. Background - previous studies

2. Datasets – geology + indoor

3. Statistical analysis

4. Map creation

5. Future work – airborne eU

Radon hazard in Norway

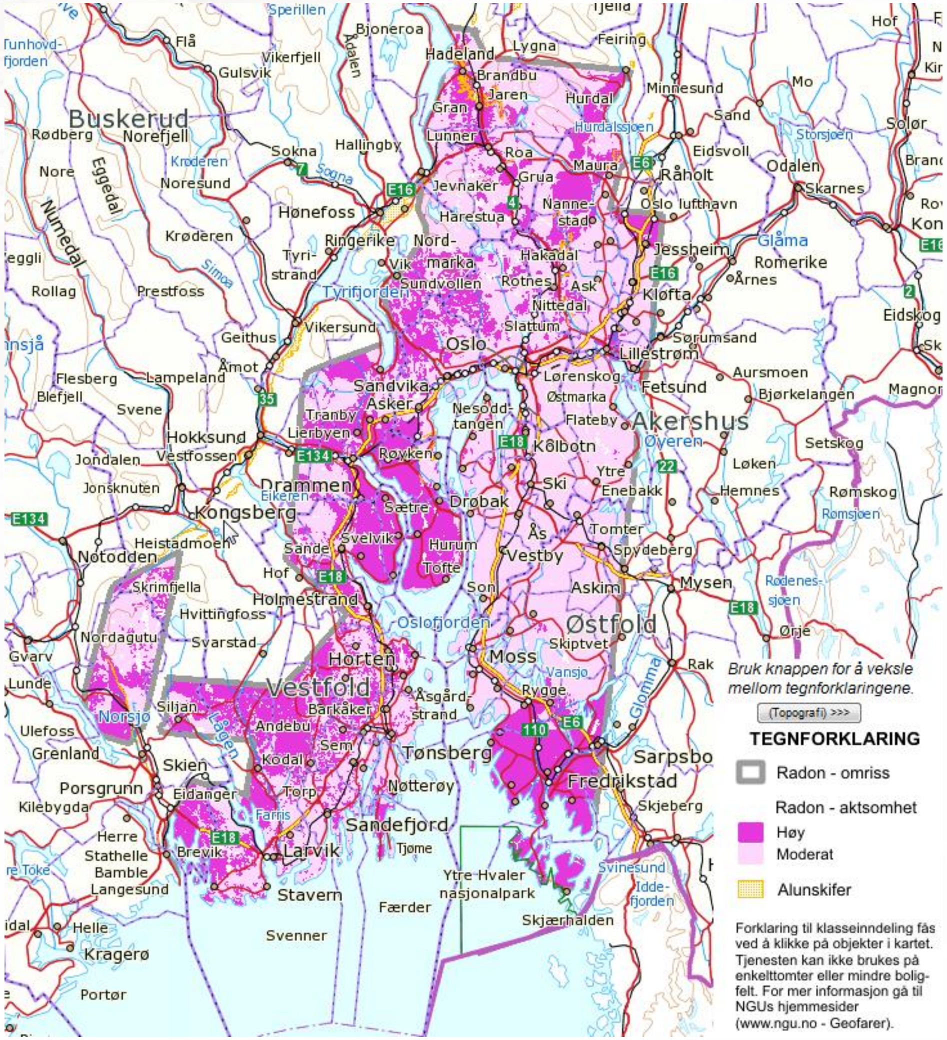
Å 300 deaths per year

Darby et al. 2005. BMJ 330: 223-227

Å 200 Bq/m^3 maximum level, 100 Bq/m^3 action level

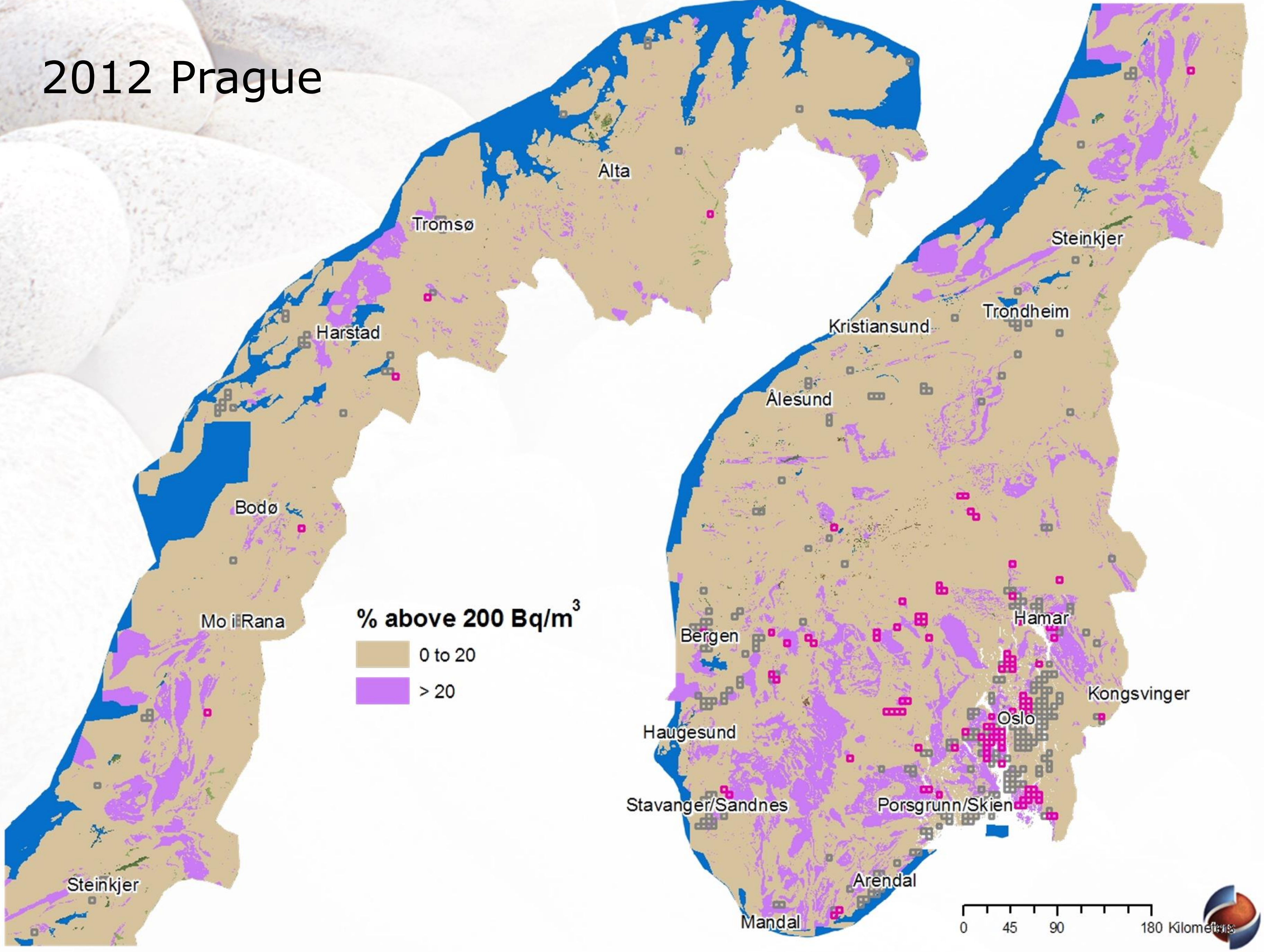
Å average in Norway ca 90 Bq/m^3

Radon hazard map 2008, Oslo region



Smethurst et al 2008 Sci Total Environ.407(1):379-93

2012 Prague



Alta
Tromsø
Harstad
Bodø
Mo i Rana
Steinkjer
Steinkjer
Trondheim
Kristiansund
Ålesund
Hamar
Bergen
Kongsvinger
Oslo
Haugesund
Stavanger/Sandnes
Porsgrunn/Skien
Arendal
Mandal
% above 200 Bq/m3
0 to 20
> 20
0
45
90
180 Kilometers

Possible data sources:

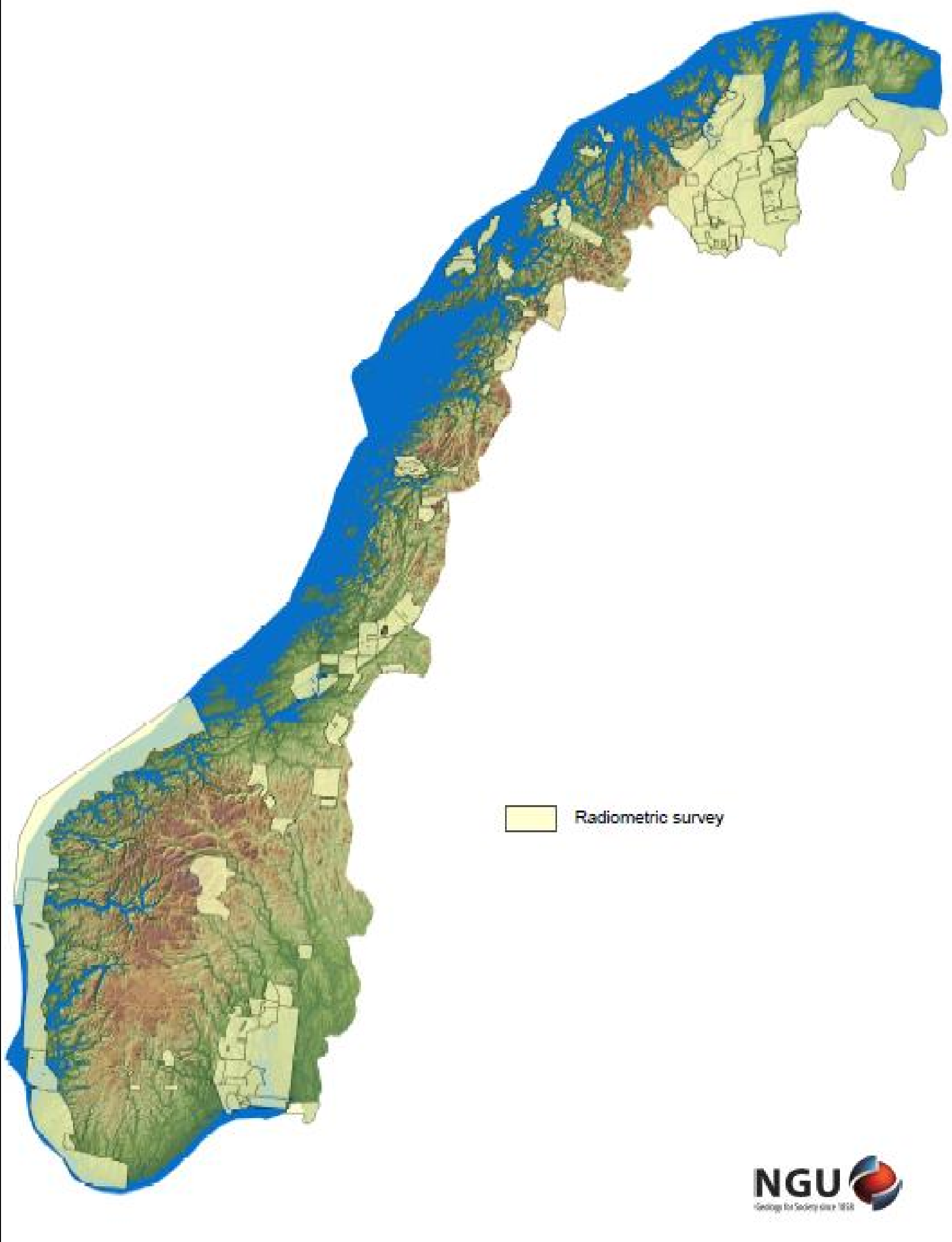
Å**Indoor radon concentrations**
Å**Bedrock geology**
Å**Drift geology**

ÅAirborne Gamma Ray Spectrometry

ÅSoil gas, permeability
ÅChemical
ÅGroundwater

Airborne radiometric surveys in Norway

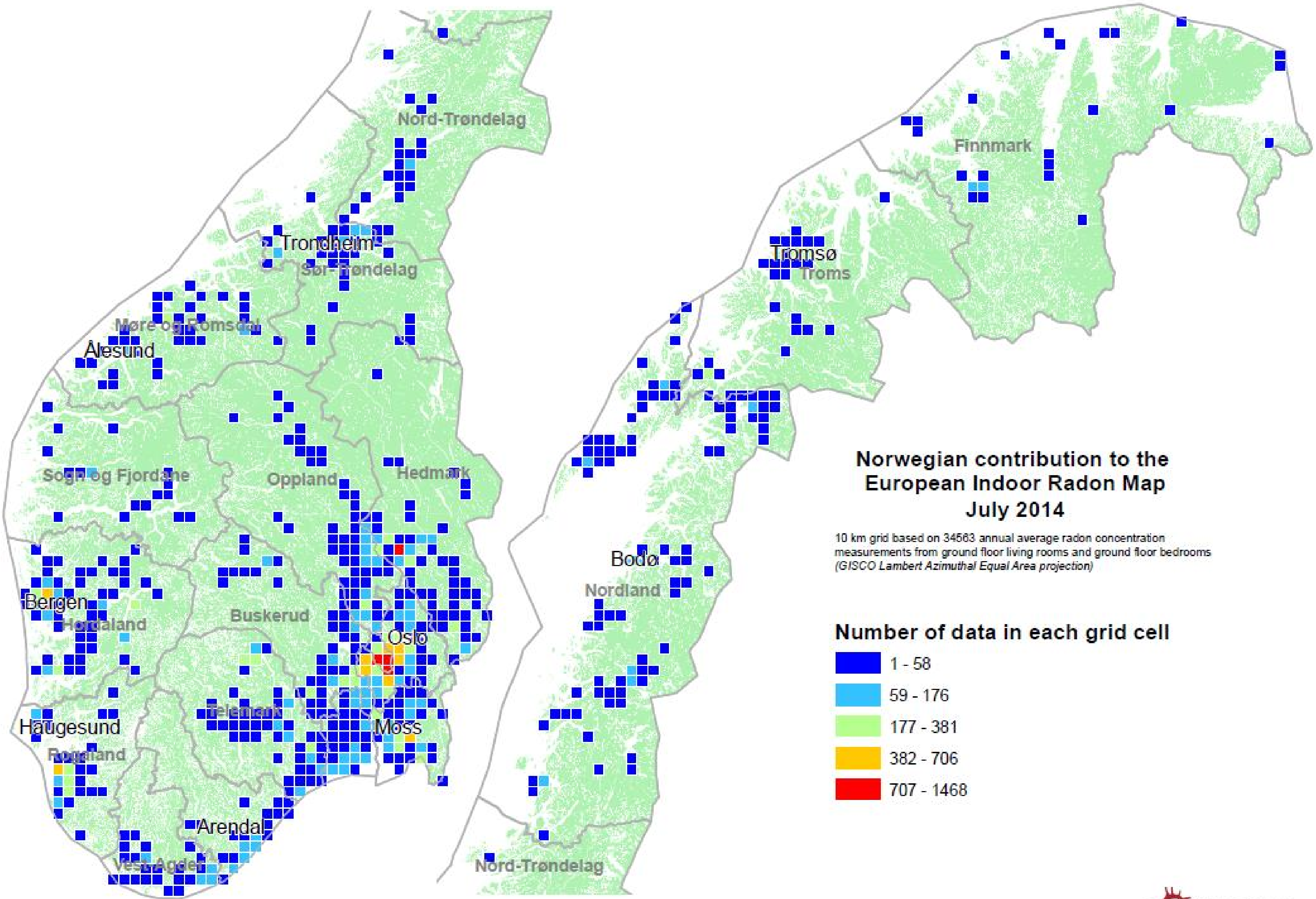
Radiometriske målinger fra fly og helikopter i Norge



Dataset: Indoor Radon

Year average indoor radon concentrations (NRPA)

- 34563 geo-referenced measurements
- ground floor living rooms and ground floor bedrooms



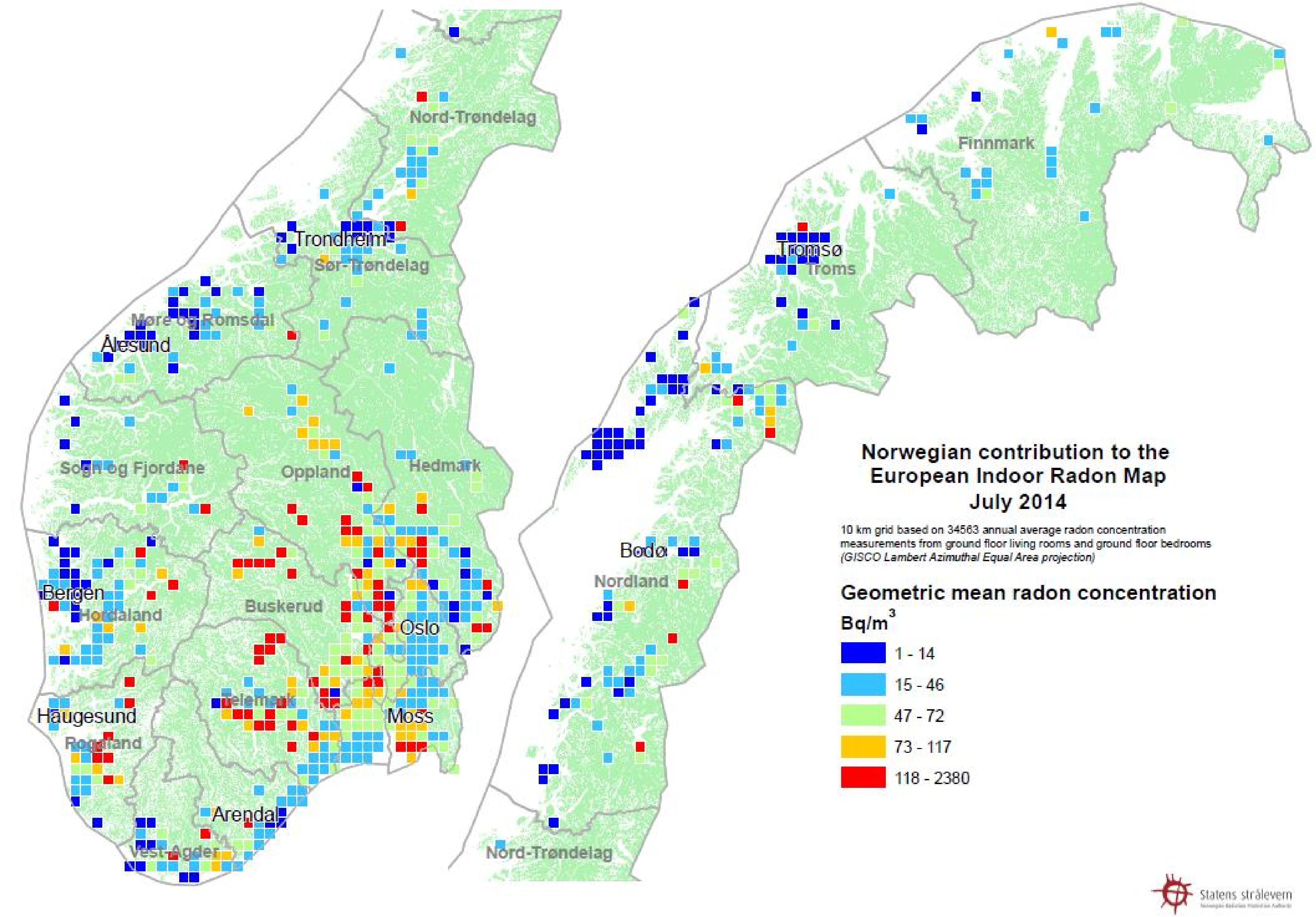
Norwegian contribution to the European Indoor Radon Map July 2014

10 km grid based on 34563 annual average radon concentration measurements from ground floor living rooms and ground floor bedrooms
(GISCO Lambert Azimuthal Equal Area projection)

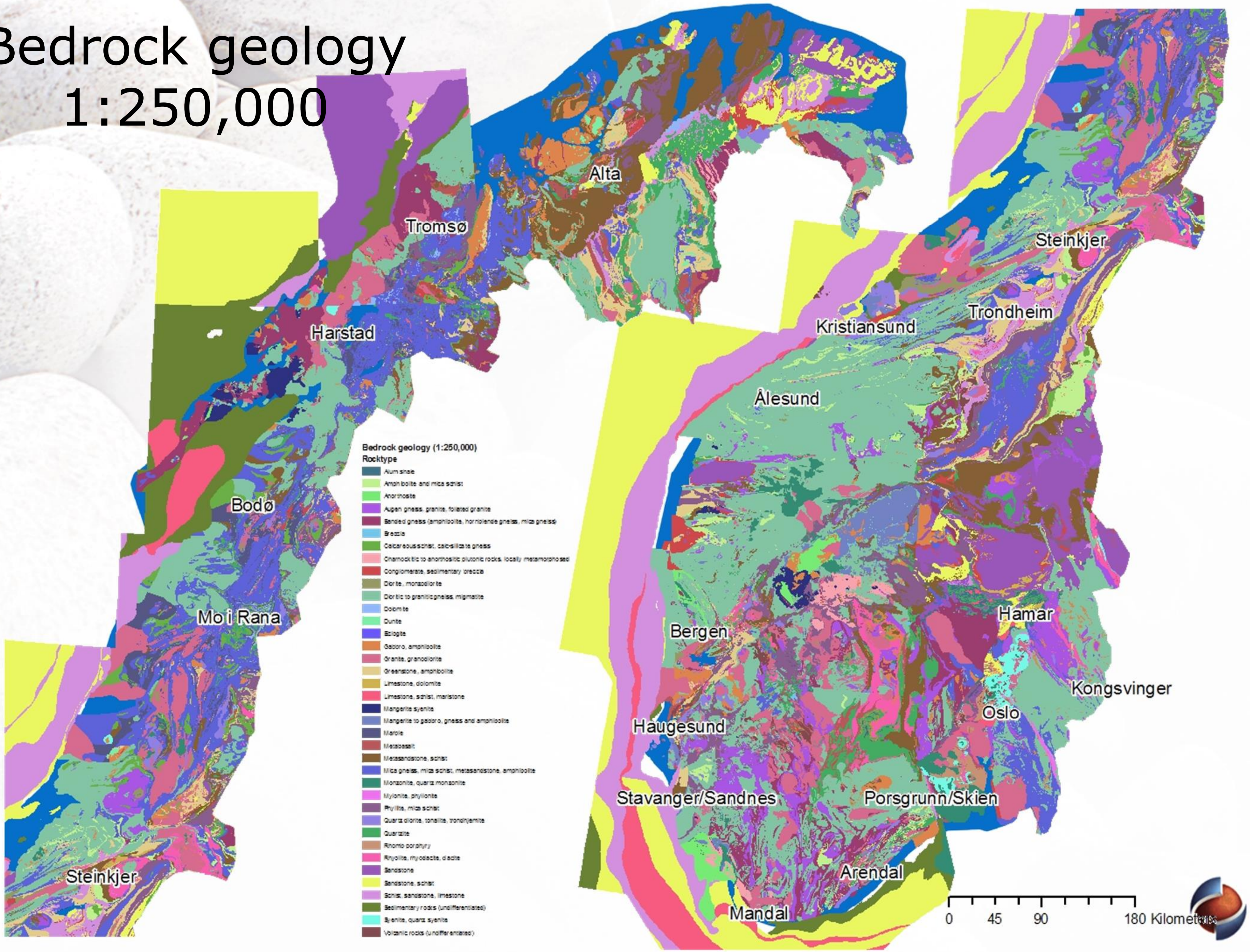
Number of data in each grid cell

- 1 - 58
- 59 - 176
- 177 - 381
- 382 - 706
- 707 - 1468

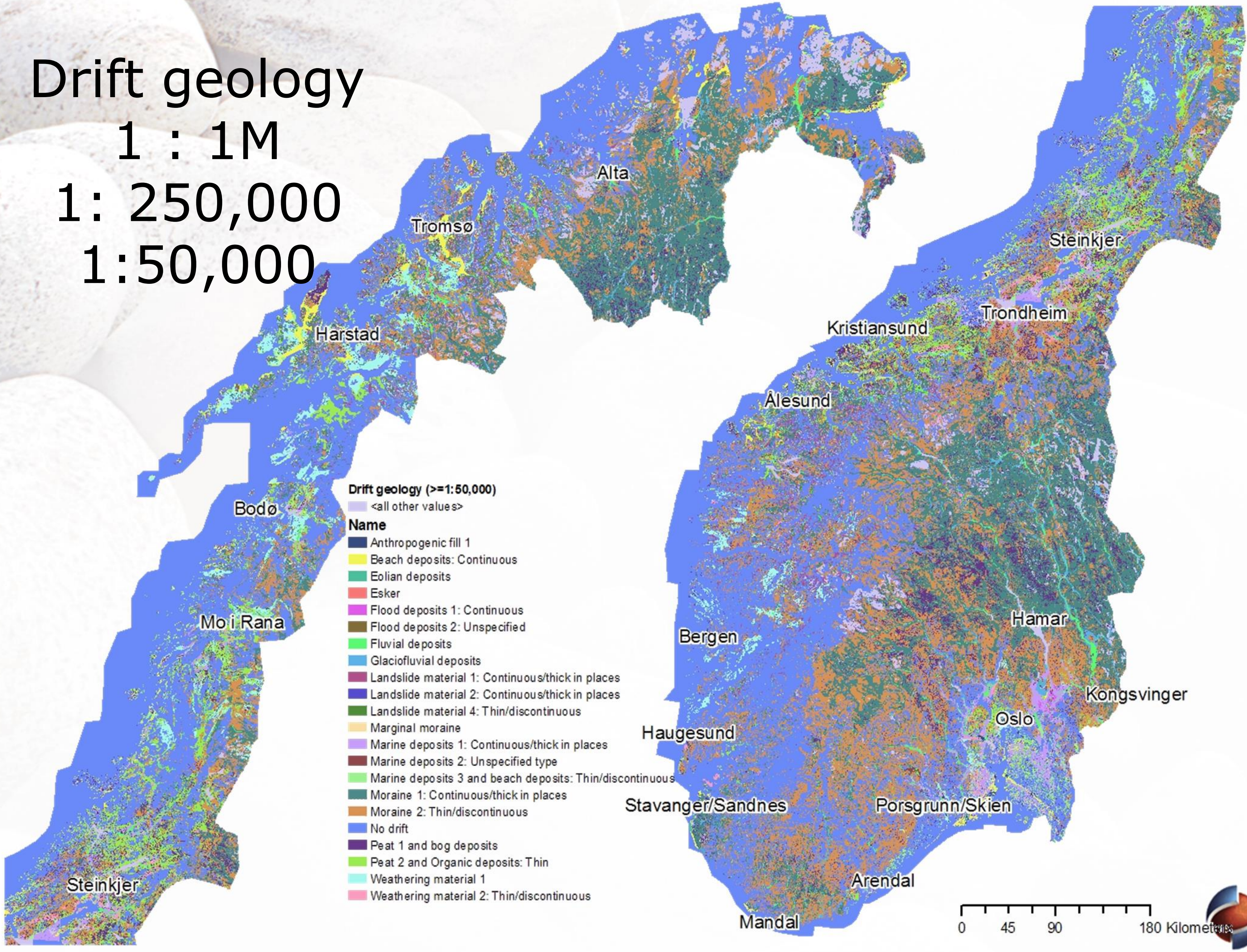
Statens strålevern


Norwegian contribution to the
European Indoor Radon Map
July 2014
10 km grid based on 34563 annual average radon concentration measurements from ground floor living rooms and ground floor bedrooms
(GISCO Lambert Azimuthal Equal Area projection)
Geometric mean radon concentration
Bq/m3
1 - 14
15 - 46
47 - 72
73 - 117
118 - 2380
Nord-Trøndelag
Trondheim
Sør-Trøndelag
Møre og Romsdal
Ålesund
Sogn og Fjordane
Oppland
Hedmark
Bergen
Hordaland
Buskerud
Oslo
Telemark
Moss
Haugesund
Rogaland
Arendal
Vest-Agder
Finnmark
Tromsø
Troms
Bodø
Nordland
Nord-Trøndelag
Statens strålevern

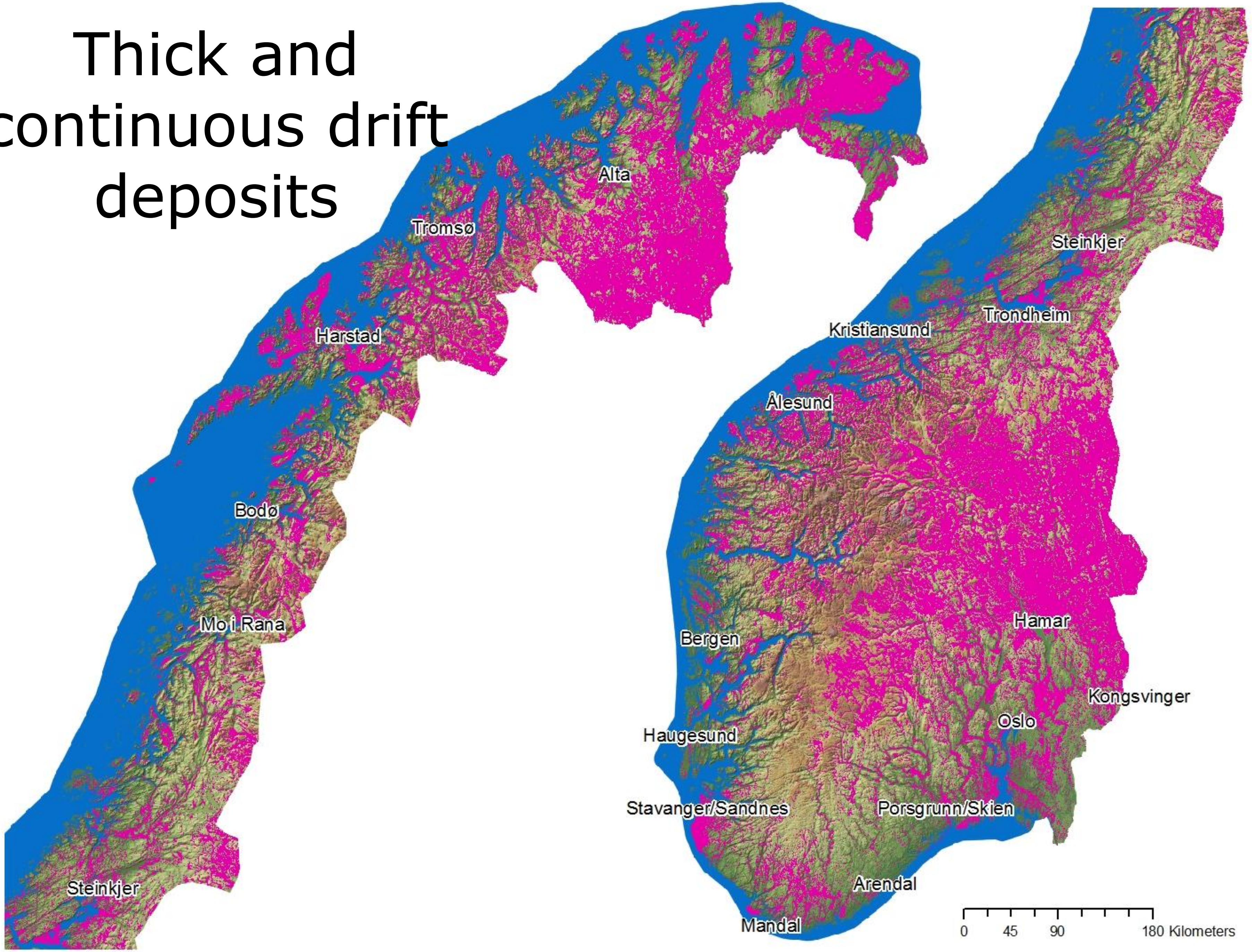
Bedrock geology
1:250,000



Drift geology
1 : 1M
1: 250,000
1:50,000



Thick and continuous drift deposits



Analysis

- Form union of bedrock/drift datasets
  - 838995 polygons
  - Use combined bedrock / drift geology as class

- Use ANOVA to study the influence of geology classes on the variance in radon

Analysis

Dataset	n
Bedrock geology	31697
Drift geology	616761
Combined bedrock and drift geology	838995
Units with at least one indoor radon measurement (nR_{unit} >= 0)	5714
Units with at least 10 indoor radon measurements (nR_{unit} >= 10)	696

Terminology:

Unit: polygon formed by union of bedrock and drift geology
Class: bedrock/drift type of a particular *unit*
R: annual average radon concentration for a given dwelling (room)
P_{200}: proportion of dwellings in a *unit* that have R > 200 Bq/m^3
nR_{unit}: number of R measurements for a given *unit*
nR_{class} : number of *units* for a given *class*

Analysis

- ANOVA:
  - Proportion of variance explained by geology:
    - Combined bedrock/drift categories
    - Bedrock categories
    - Drift categories
  - More detailed drift and bedrock classifications explain more of the variation

Analysis

Å ANOVA:

Condition	Indoor radon measure	Proportion of variance(%)
nR_{unit} >= 10	ln(*R*)	20.0
nR_{unit} >= 10, and nR_{class} >= 10	ln(*P*)	39.5

- 20% of indoor radon explained by geology
- 40% of (P>200) for polygon explained by geology

Map

- For each unit, aim to calculate a proportion P of dwellings in unit which have R > 200 Bq/m^3

- For units where we have sufficient R measurements:
  - use data from unit.

- For units with insufficient R measurements:
  - use data from *national average* for class of that unit

- If
  - P >= 0.2 Particularly radon-prone
  - P < 0.2 Not particularly radon-prone

Map

nR_{unit}	nR_{class}	**Determination of *P***
>= 30		Determine *P* from geological unit
< 30	>= 30	Determine *P* from geological class
< 30	< 30	Insufficient data to determine *P*

Map

- Wilson score for confidence in proportion:

Newcombe, R.G. 1998. Statist.Med. 17, 857-872

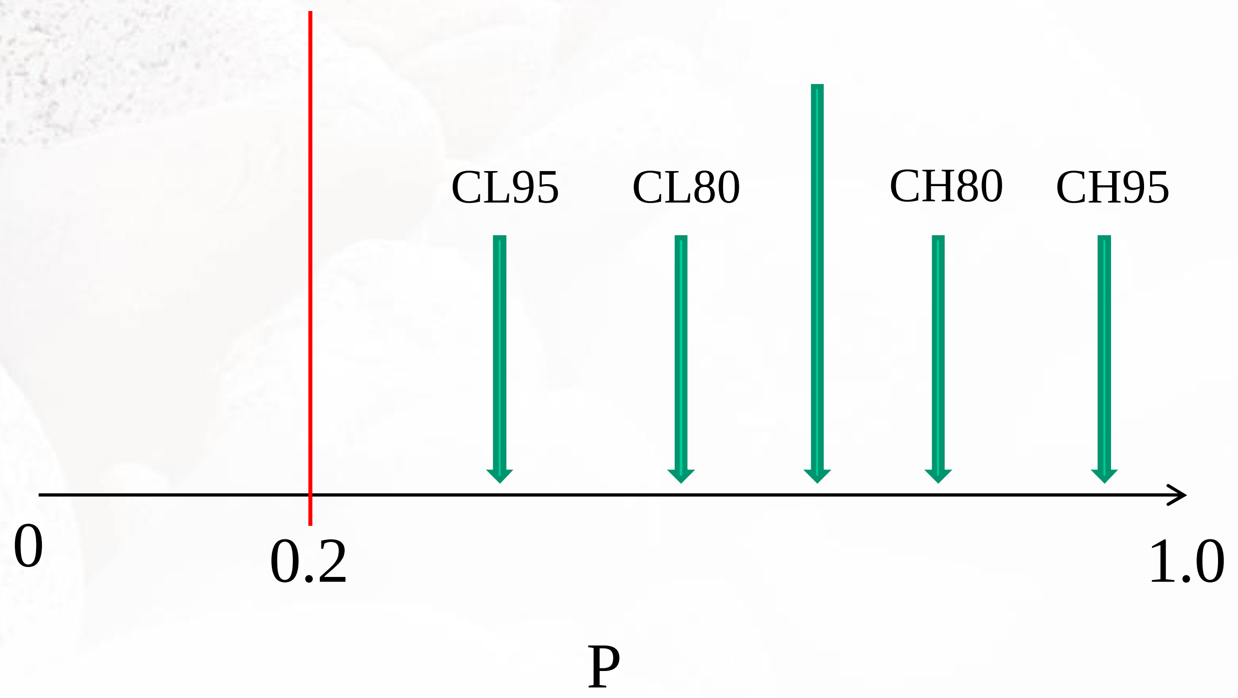
- Generate C_H and C_L for desired intervals

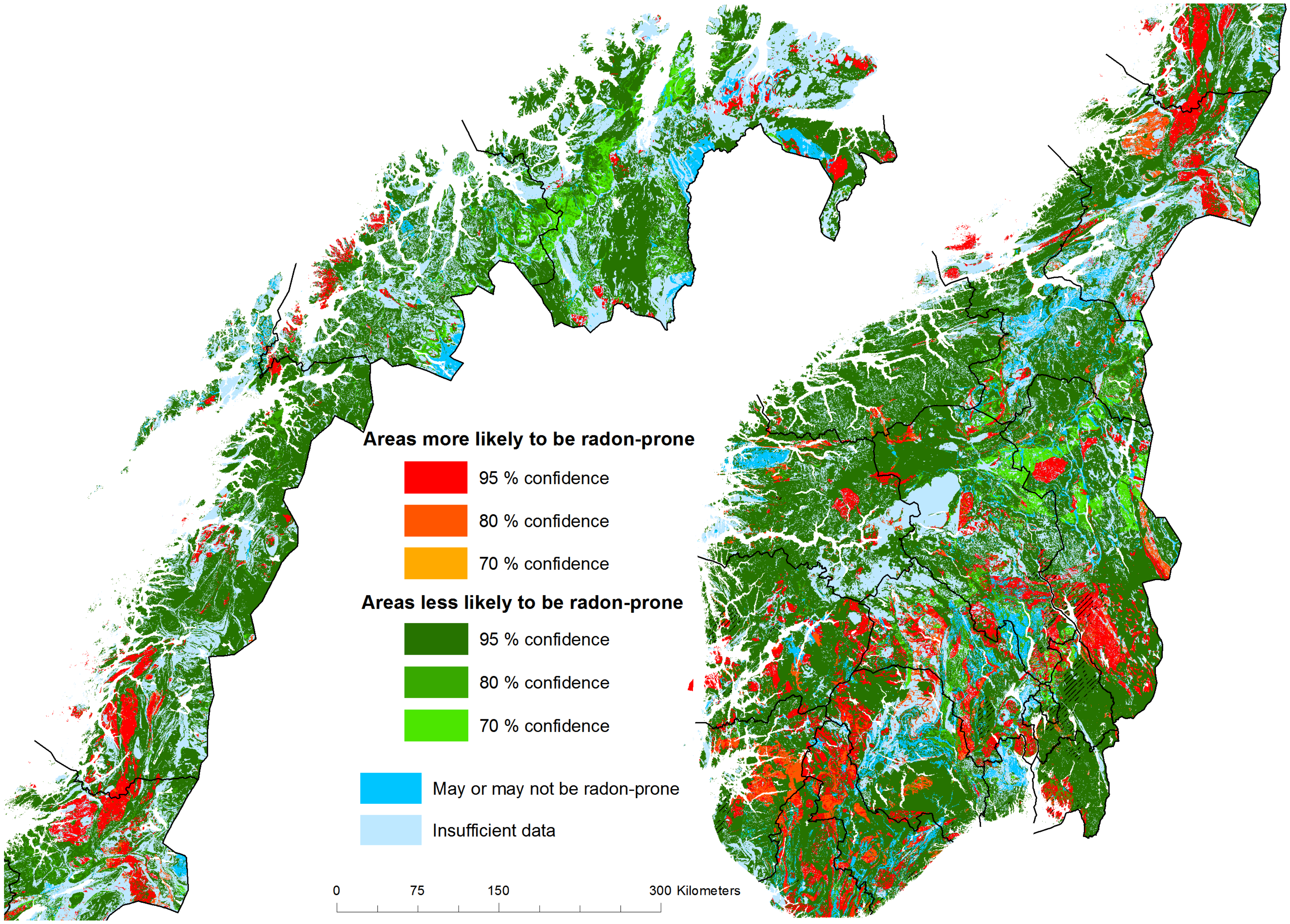
- Intervals 95%, 80% and 70%

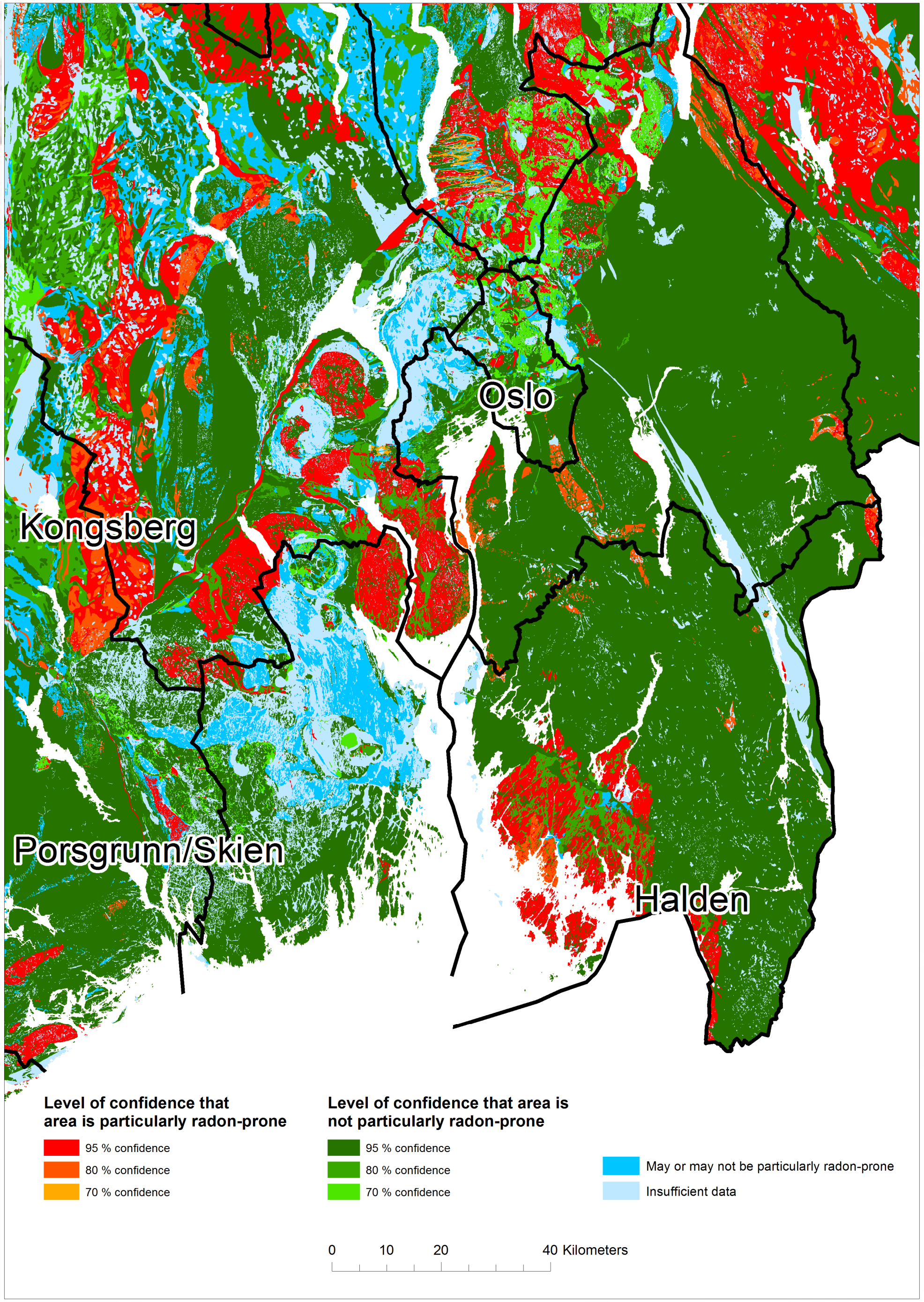
Map

Confidence limits	**Classification**
$C95_L >= P_0$	95% confidence of being particularly radon-prone
$C95_L < P_0 <= C80_L$	80% confidence of being particularly radon-prone
$C80_L < P_0 <= C70_L$	70% confidence of being particularly radon-prone
$C70_L < P_0 <= C70_H$	May or may not be particularly radon-prone
$C70_H < P_0 <= C80_H$	70% confidence of not being particularly radon-prone
$C80_H < P_0 <= C95_H$	80% confidence of not being particularly radon-prone
$C95_H >= P_0$	95% confidence of not being particularly radon-prone

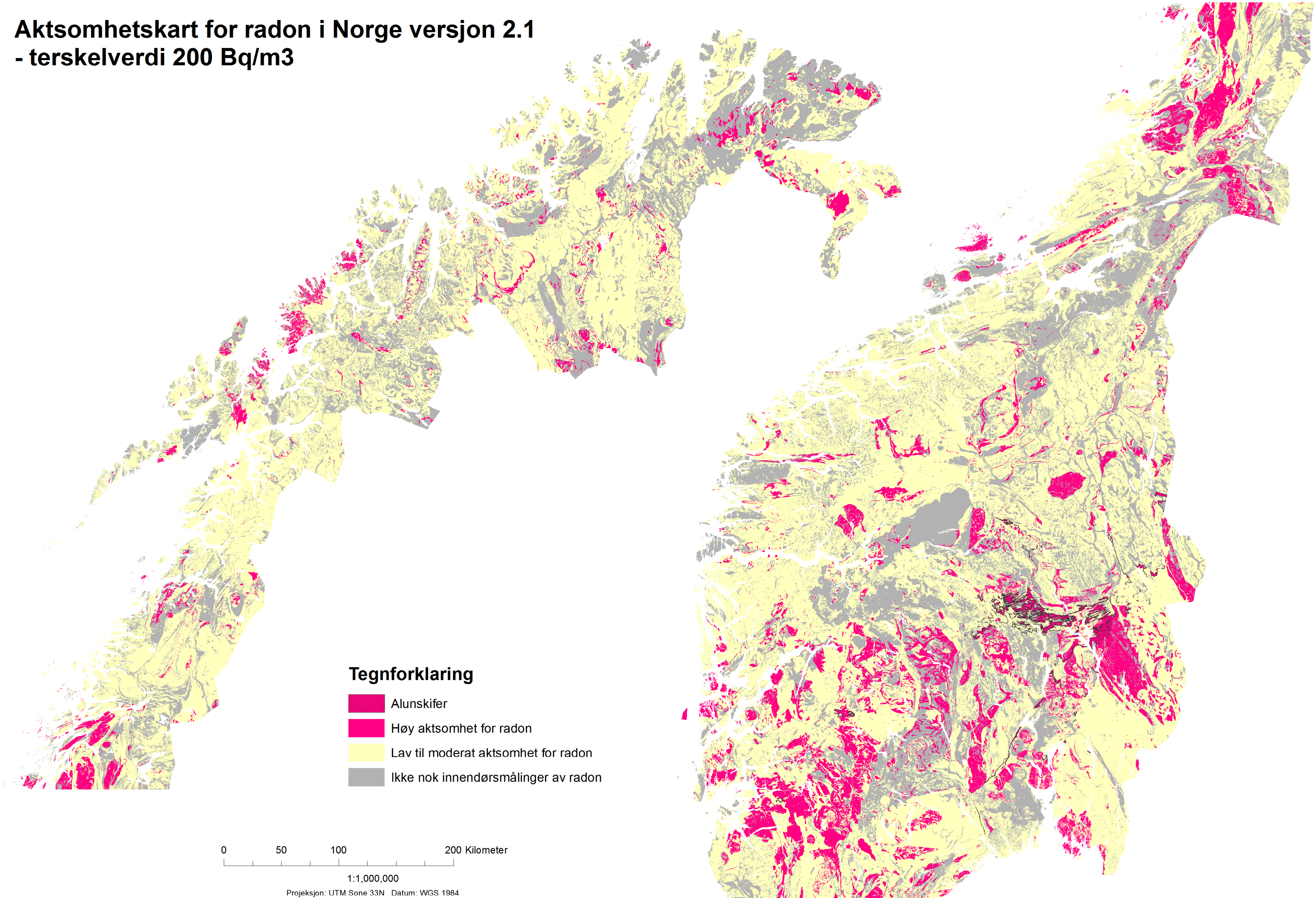
Å$P_0 = 0.2$


CL95
CL80
CH80
CH95
0
0.2
1.0
P


Areas more likely to be radon-prone
95 % confidence
80 % confidence
70 % confidence
Areas less likely to be radon-prone
95 % confidence
80 % confidence
70 % confidence
May or may not be radon-prone
Insufficient data
0
75
150
300 Kilometers


Oslo
Kongsberg
Porsgrunn/Skien
Halden
Level of confidence that area is particularly radon-prone
95 % confidence
80 % confidence
70 % confidence
Level of confidence that area is not particularly radon-prone
95 % confidence
80 % confidence
70 % confidence
May or may not be particularly radon-prone
Insufficient data
0 10 20 40 Kilometers

Aktsomhetskart for radon i Norge versjon 2.1
- terskelverdi 200 Bq/m3



Aktsomhetskart for radon i Norge. Skala 1:1,000,000. Norges geologiske undersøkelse og Statens strålevern. Smethurst, M.A., Watson, R.J., Ganerød, G.V., Rudjord, A.L. og Finne, I., 2014.

Naive Bayes Classifier

Å142 instances (geological units)

Å2 categorical features: Bedrock (37 categories), Drift (22 categories)

Å2 output classes:

- ÅBased on GM of indoor radon in geological unit
- ÅPercent over 200 Bq/m3
- ÅLOW (0-20 %)
- ÅHIGH (> 20%)

Naive Bayes Classifier

5-fold cross-validation:

		Predicted class			
Actual class		HIGH	LOW	Total	Sensitivity
	HIGH	27	13	40	0.68
	LOW	41	61	102	0.60
	Total	68	74	142	
	Predictive value	0.40	0.82		

Classifier accuracy CA	0.62
Matthews Correlation Coefficient MCC	0.25

CONCLUSIONS

- Examined relationships between geological categories and indoor radon

- Geological factors explain around:
  - 20% of variance of ln (R)
  - 40% of variance of $\ln(P_{200})$

- Can produce national radon probability maps from geology-based classifier trained on indoor concentrations
  - assumes geological properties for given class are the same nationally
  - does not take account of inhomogeneities inside geological units

- Other classification methods being investigated

- No AGRS data included at present – study using eU underway

THANK YOU!