The predictive power of airborne gamma ray survey data on the locations of domestic radon hazards in Norway: A strong case for utilising airborne data in large-scale radon hazard assessments

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Objectives

Å Test whether eU maps can be usefully relied upon to determine the locations of radon affected communities

Å Derive measures of confidence and accuracy for predictions of radon hazard potential from geoscience data

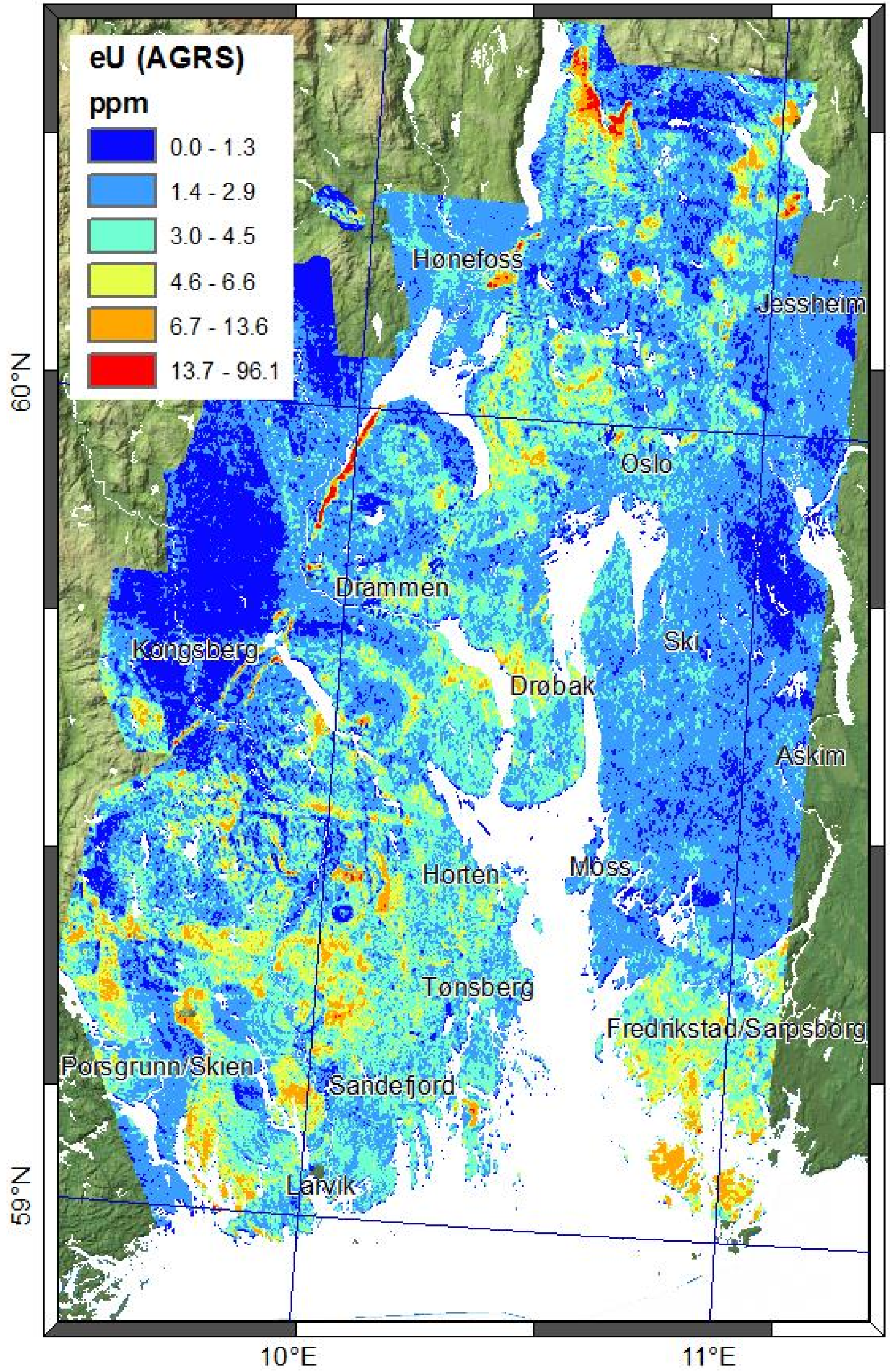
Å Compare the relative efficiencies of eU and geology mapping in identifying radon affected communities

Å Suggest roles for these approaches in national mapping programmes

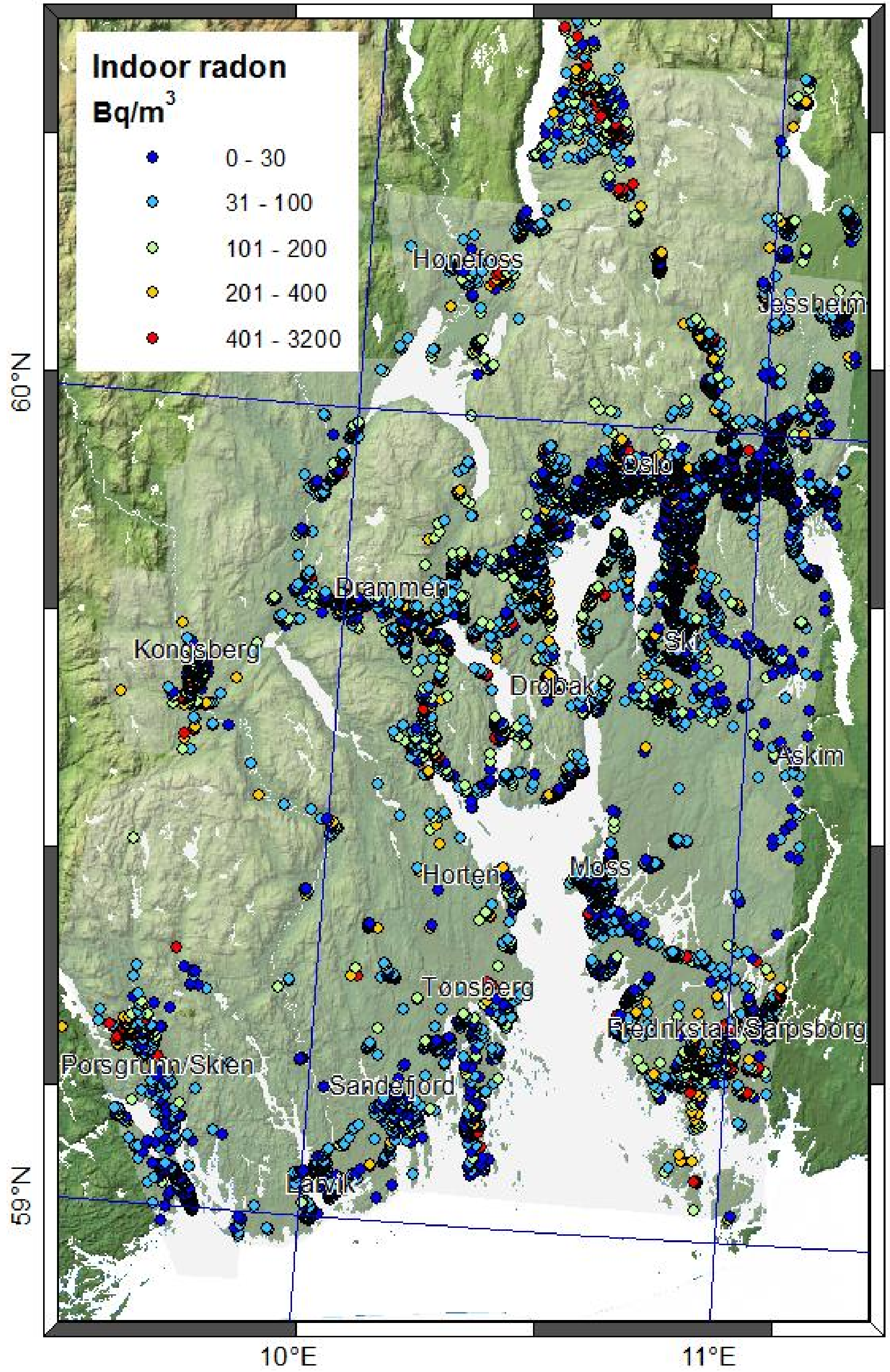
Compilation of 14 AGRS surveys covering the Oslo area

Survey	Year	Line sp. (m)	Sensor elev. (m)	Line length (km)	Reference
Helicopter surveys – Geological Survey of Norway					
Siljan	1981	200 E-W	60	1500	Håbrekke 1982
Gran	1997	200 N-S	80	2020	Beard 1998
Larvik	1997-1998	100 NE-SW & 150 N75W-S75E	60 & 80	4800	Mogaard 1998 Beard 1999
Oppkuven	1997-1999	200 E-W	80	4160	Beard 1998 Beard & Rønning 1997
Nordagutu	1999	200 N-S	60	1925	Mogard & Beard 2000
Sandefjord	2000	200 E-W	60	3450	Mogaard 2001
Hurdal	2000	200 E-W	60	2780	Beard and Mogaard 2001
Kongberg Nord & Sør	2009 - 2011	200 E-W	60	13985	Baranwal et al. 2013
Krøderen, Sokna and Hønefoss-2	2011	200 E-W	60		
Fixed wing surveys					
Oslo regions 1& 2; Fugro Airborne Surveys	2003	250 & 500 E-W	60 & 100	23580	Fugro 2003
Skien, Kongsberg, Hokksund, Virkesund, Hønefoss-1; Geological Survey of Sweden	2009	200 E-W	60	4900	SGU 2009
Totals					
Line length	63100 km				
Area after compilation	13412 sq. km				

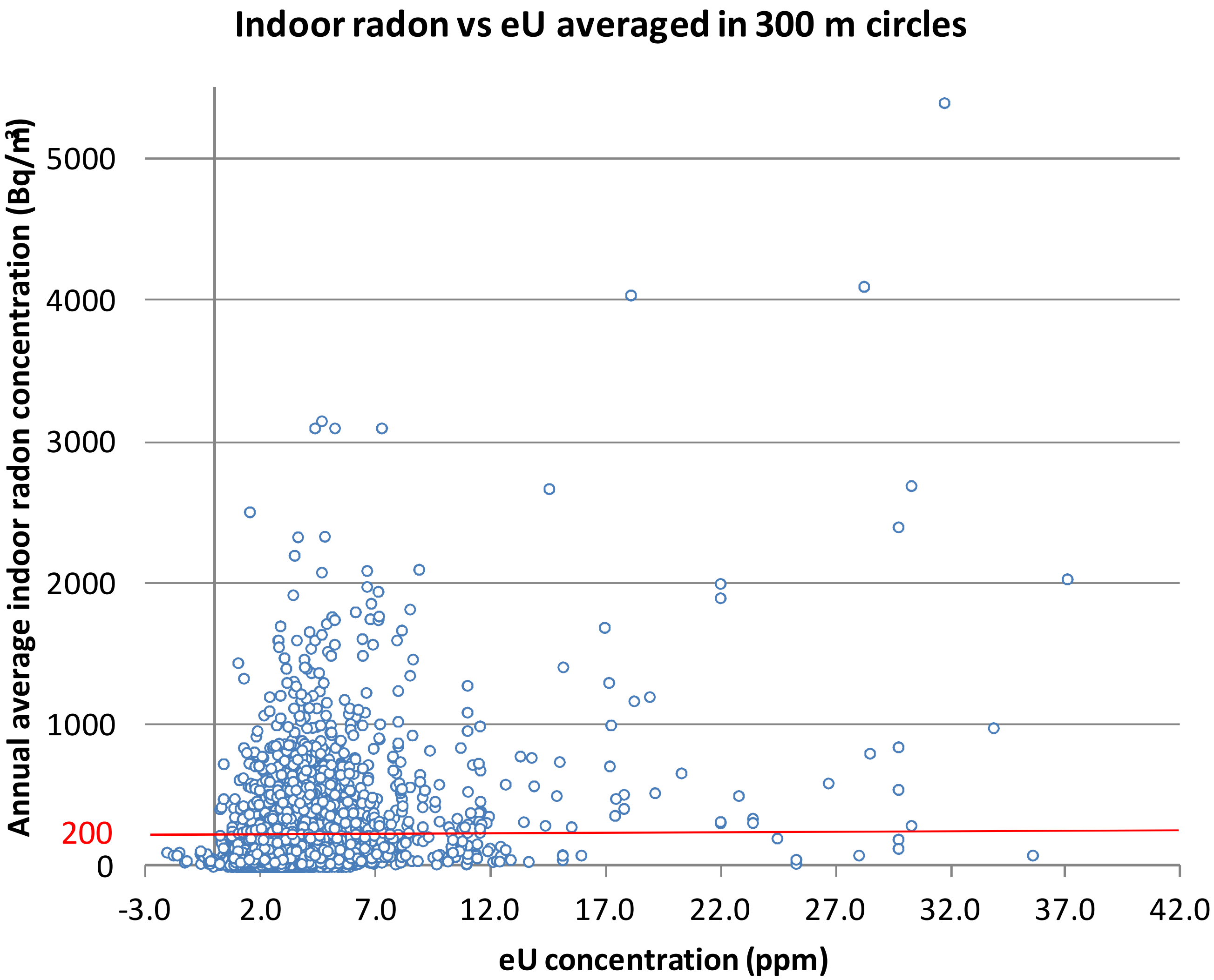
Equivalent uranium (eU) map



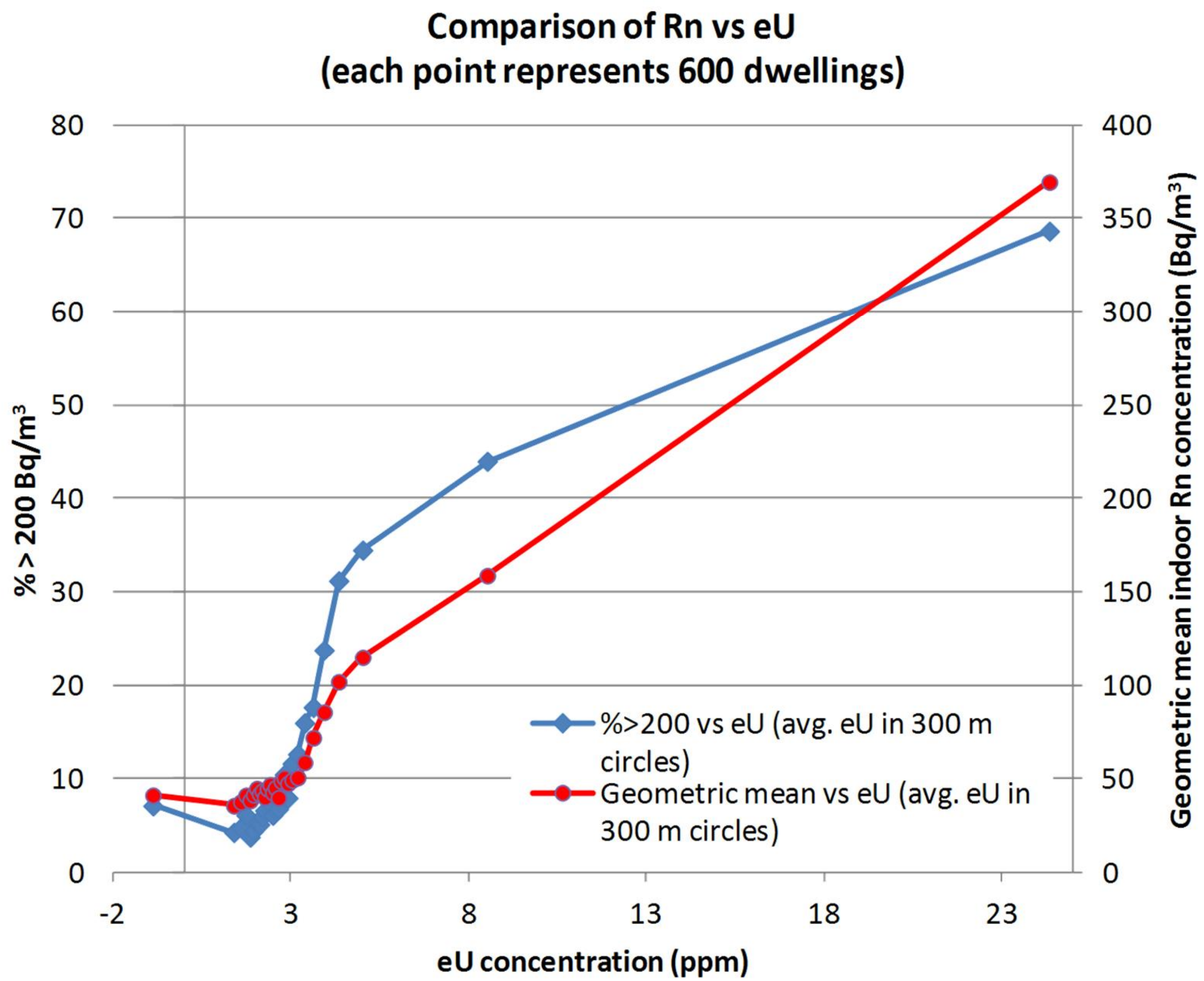
15698 annual average indoor radon concentrations measured in ground floor living rooms and ground floor bedrooms



The relationship between indoor radon concentrations and external eU concentrations is complex...



...but the percentage of radon data lying above a fixed threshold increases steadily with increasing eU range



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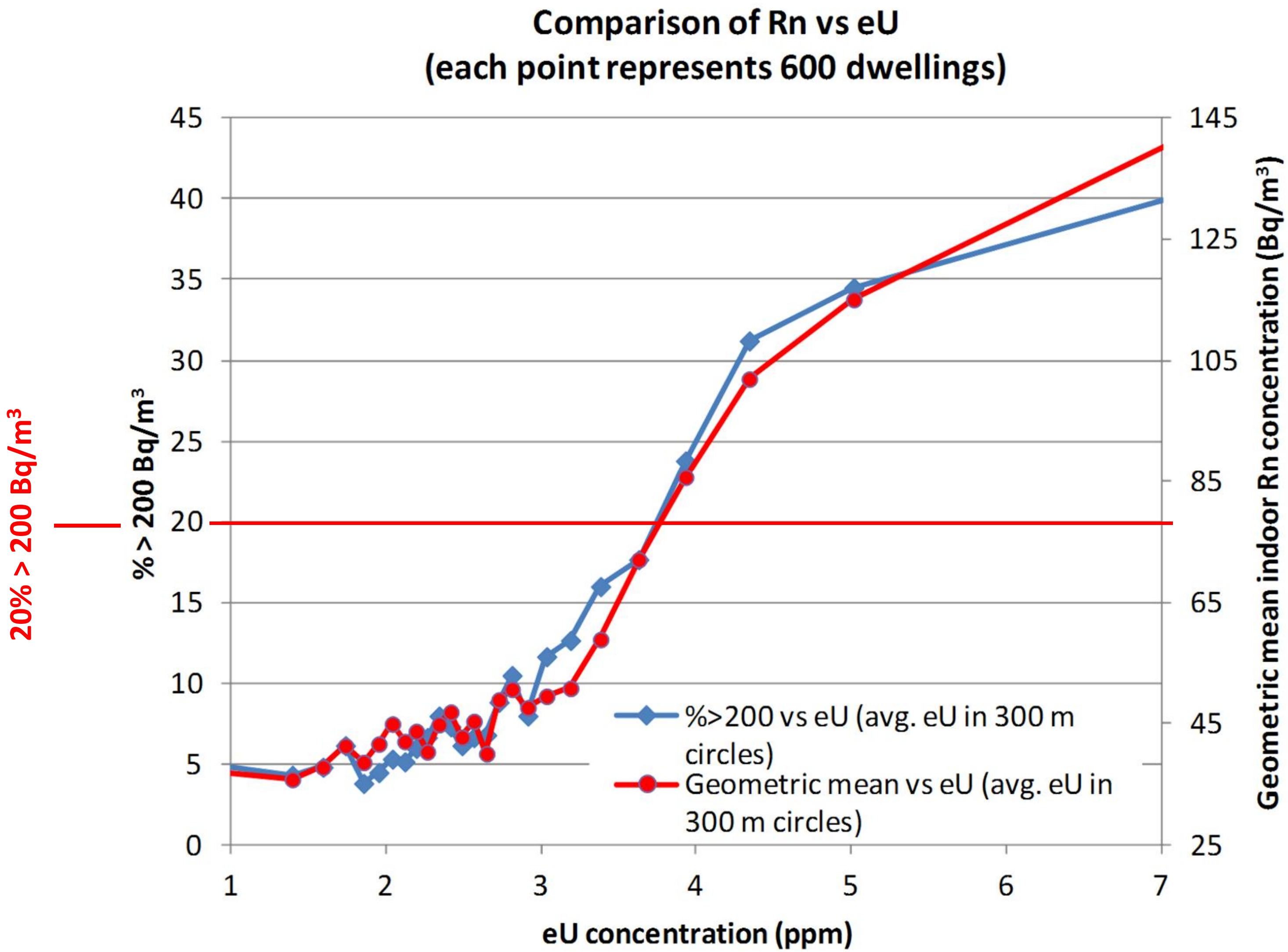

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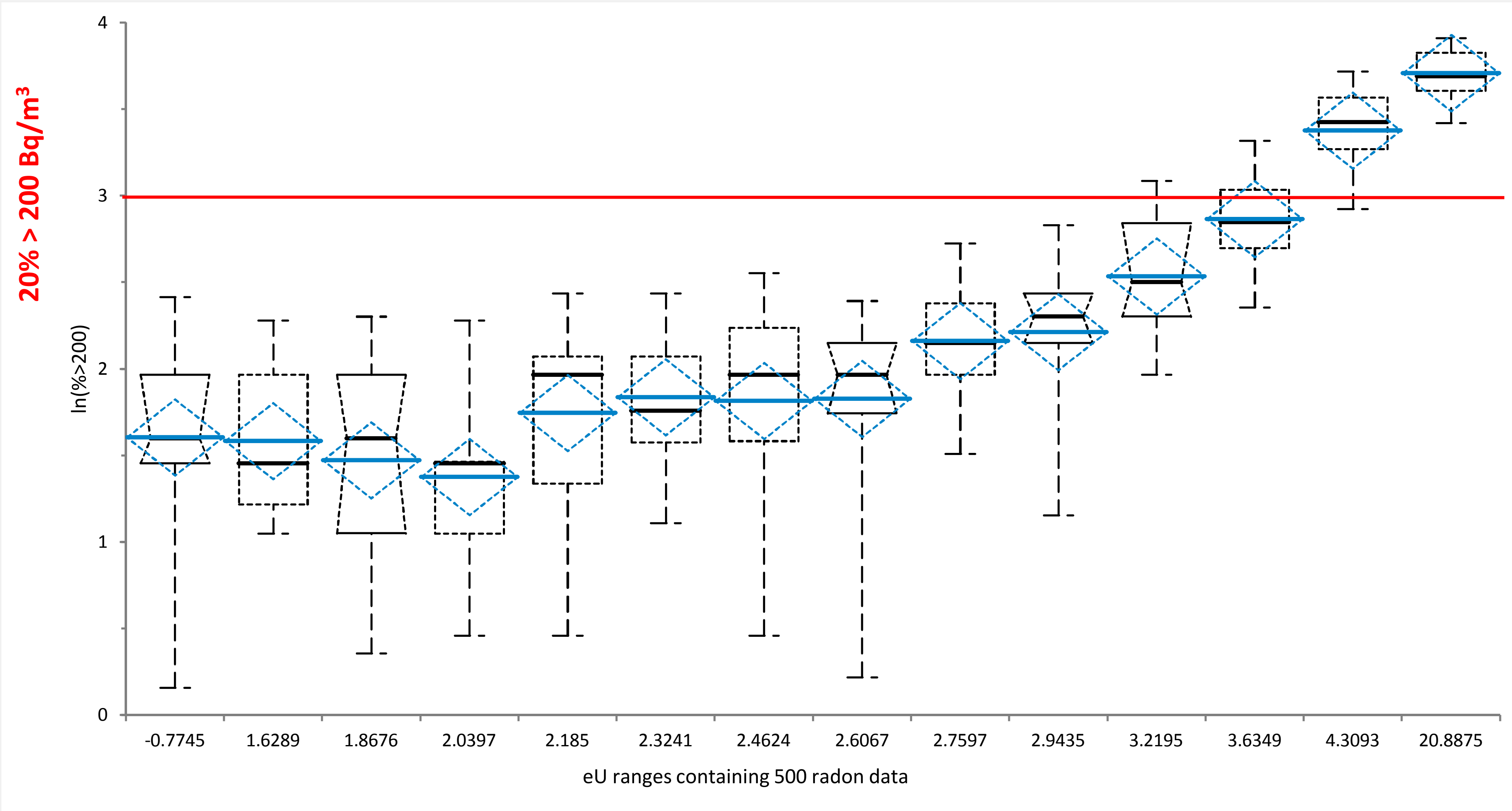


How much of the variation in domestic radon concentrations can be accounted for by variation in external eU concentrations?

Analysis of variance (ANOVA) in Ln(Rn), Ln(%>200) and Ln(GM) grouped according to eU range

Å eU as a predictor of radon concentration Ln(Rn):

8.5% = poor

(8.5% of the total variance in Ln(Rn) can be accounted for by assignment of Ln(Rn) values to 32 consecutive eU bins/ranges containing 500 data each)

Å eU as a predictor of radon hazard potential ln(%>200):

72.1% = excellent

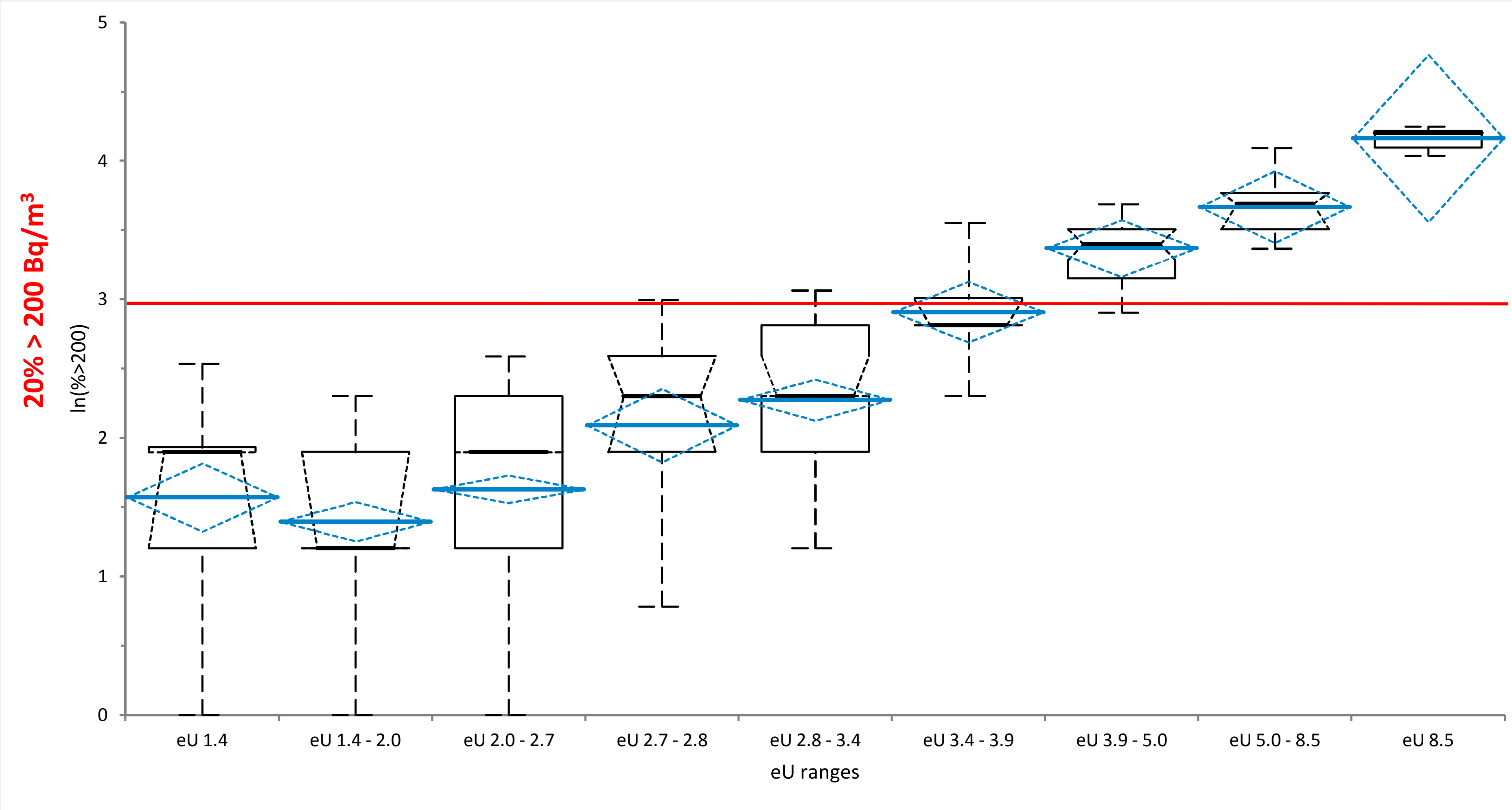
(72.1% of the total variance in radon potential can be accounted for by assignment of Rn values to 14 consecutive eU bins/ranges containing 1119 data each. [16 estimates of ln(%>200) were generated for each of the 14 bins by randomly splitting each bin into 16 subgroups of 70 data.])

Å eU as a predictor of geometric mean ln(GM):

87.0% = excellent

(method as ln(%>200))

The strong relationship between eU and radon hazard potential justifies conversion of the eU map to a radon potential map...



Adjusted ranges sensitive to radon potential vs. eU curve. ANOVA: These 9 categories account for 53% of the total variation in radon potential

The strong relationship between eU and radon hazard potential justifies conversion of the eU map to a radon potential map...

eU range ppm	N	Max Rn Bq/m^3	Median Rn Bq/m^3	GM Bq/m^3	%>200	95% confidence interval on %>200
<= 1.4	718	2507	49.2	40.1	4.5	3.1 – 6.3
1.4 – 2.0	3331	856	50.0	41.4	6.2	5.4 – 7.0
2.0 – 2.7	5087	3100	50.0	42.7	6.0	5.4 – 6.7
2.7 – 2.8	962	1600	50.0	43.8	9.8	8.0 – 11.9
2.8 – 3.4	2312	1600	60.0	53.9	11.9	10.7 – 13.3
3.4 – 3.9	1217	5400	80.0	70.2	18.5	16.4 – 20.8
3.9 – 5.0	1099	3150	110.0	101.8	29.8	27.1 – 32.6
5.0 – 8.5	809	5779	143.2	140.0	39.2	35.8 – 42.7
> 8.5	163	4100	280.0	236.0	61.3	53.4 – 68.8

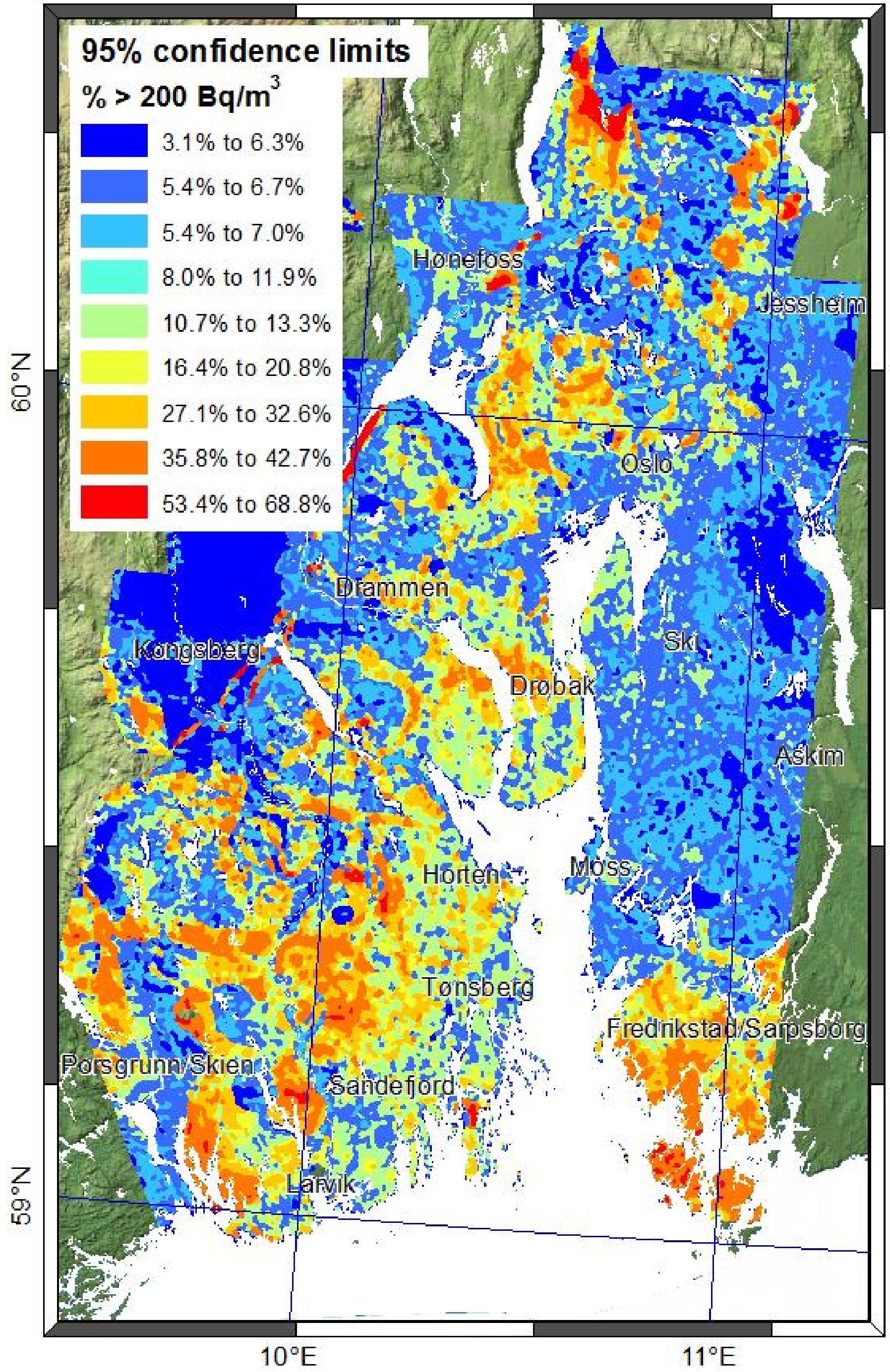
Radon potential is expressed as a proportion

Confidence interval for a proportion: Wilson score interval with continuity correction

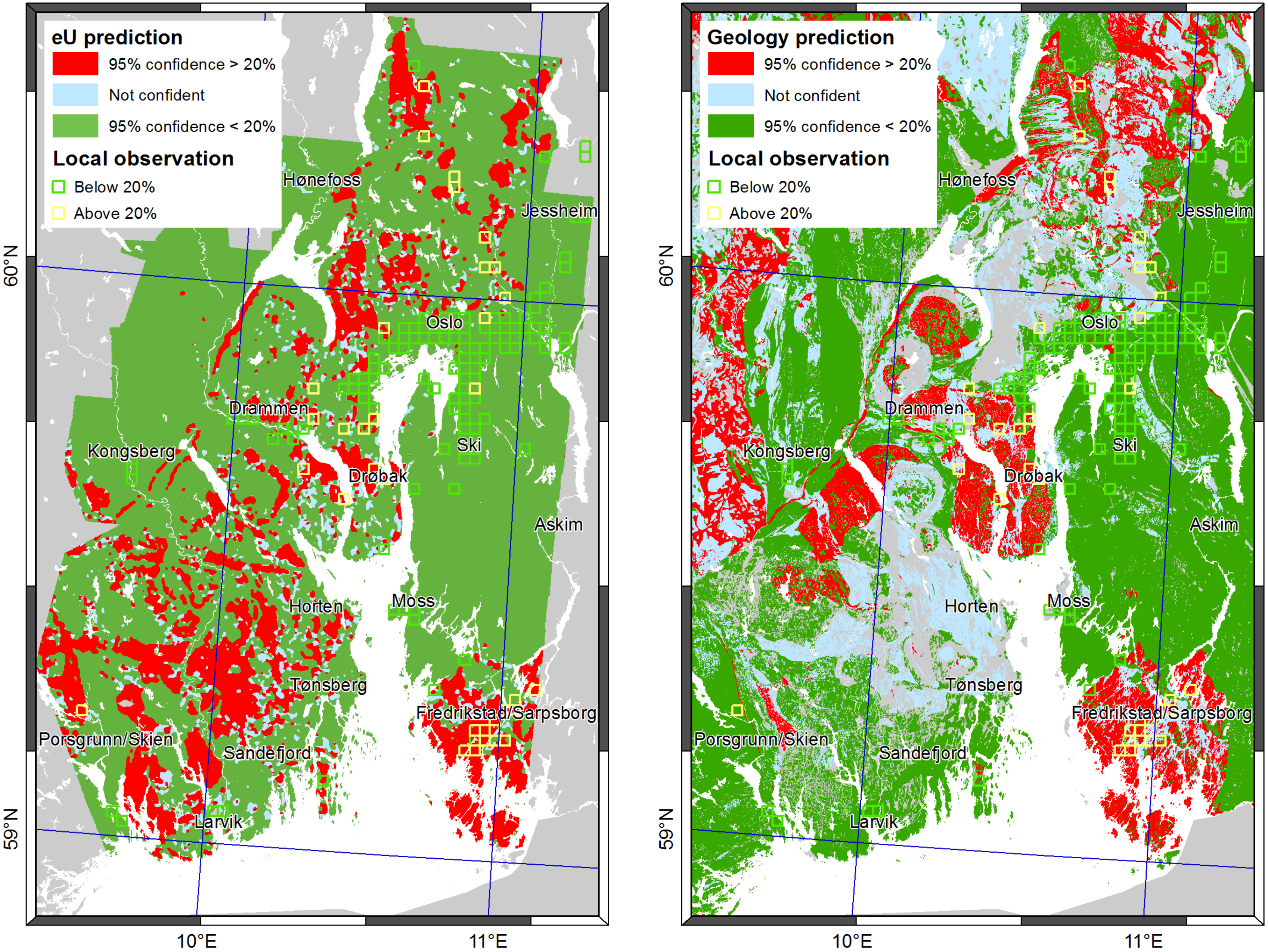
eU-controlled Radon hazard potential map

(Simplified using a majority filter)

How does this compare with a radon hazard potential map derived from digital geology?



Predicted radon affected/not affected areas - 95% confidence



How much of the variation in radon hazard potential can be explained by eU maps and geology maps?

Analysis of variance (ANOVA) Ln(%>200) grouped according to eU range and geology type

- eU as a predictor of radon hazard potential:

  72.1% = excellent

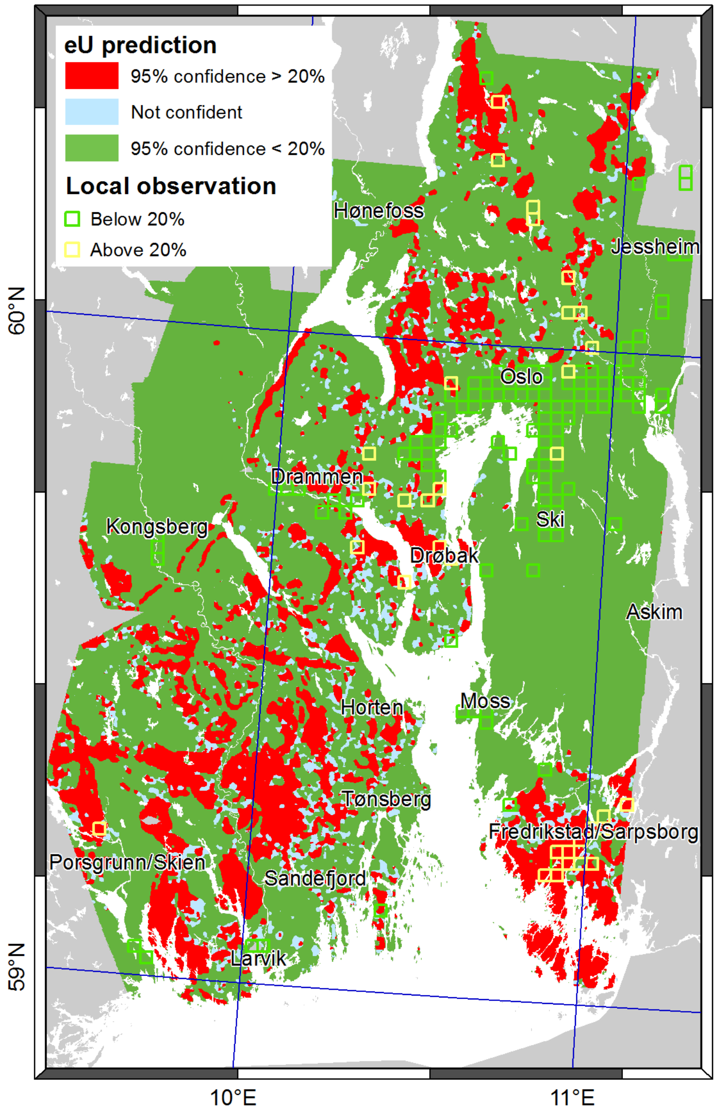
  (72.1% of the total variance in radon potential can be accounted for by assignment of Rn values to 14 consecutive eU bins/ranges containing 1119 data each. [16 estimates of ln(%>200) were generated for each of the 14 bins by randomly splitting each bin into 16 subgroups of 70 data.])

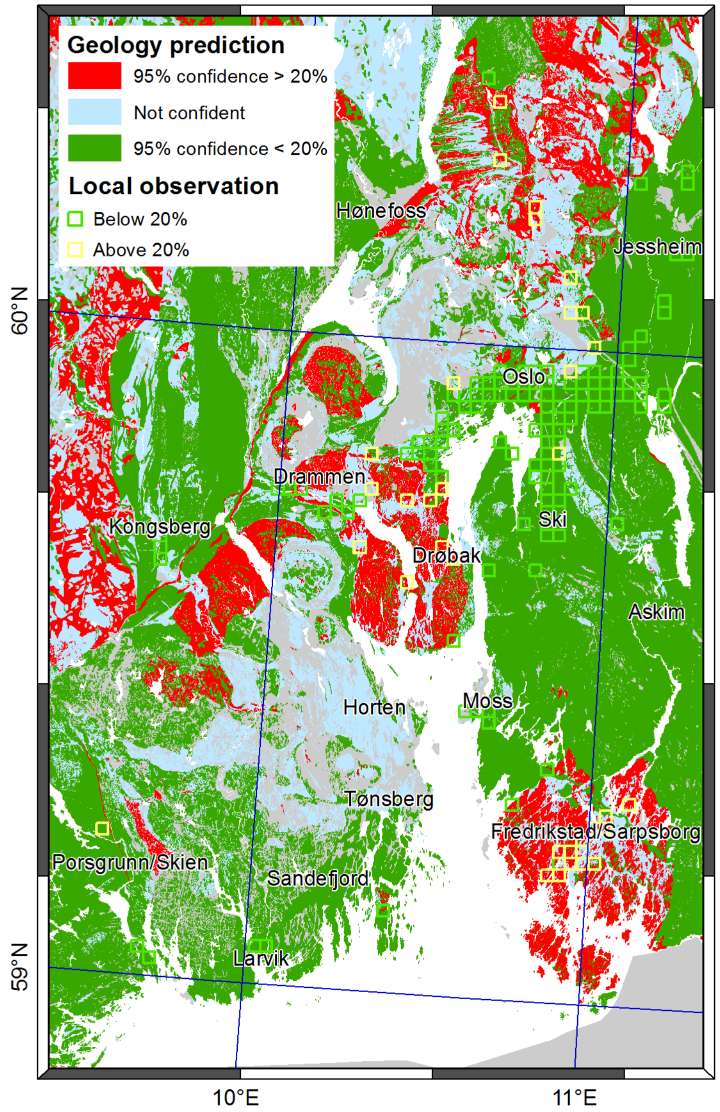
- Geology as a predictor of radon hazard potential:

  39.5% = good

  (39.5% of the total variance in radon potential can be accounted for by assignment of Rn values to the 18 geological settings (of 273) that occur 10 or more times in Norway while enclosing at least 10 indoor radon values)

Accuracy and efficiency at predicting Local (2x2km) radon affected /not affected areas identified using indoor radon measurements





Accuracy and efficiency at predicting Local (2x2km) radon affected /not affected areas identified using indoor radon measurements

Method	2 km squares where prediction is possible with method	Accuracy of prediction			Efficiency of detection		
		Radon affected	Not radon affected	Overall	Radon affected	Not radon affected	Overall
Indoor radon measurements	150	33	117	150	33	117	150
eU prediction	150 of 150	20 of 23 predictions correct (87%)	114 of 127 predictions correct (90%)	134 of 150 predictions correct (89%)	20 of 33 areas detected (61%)	114 of 117 areas detected (97%)	134 of 150 areas detected (89%)
Geology prediction	146 of 150	15 of 22 predictions correct (68%)	107 of 124 predictions correct (86%)	122 of 146 predictions correct (84%)	15 of 33 areas detected (46%)	107 of 117 areas detected (92%)	122 of 150 areas detected (81%)

Conclusions

Å Ground surface eU has a strong relationship to radon hazard potential, stronger than mapped geological setting types and strong enough to generate a useful radon potential map

Å eU offers a higher spatial resolution

Å Both methods can provide accurate predictions of local radon affected areas but eU is more efficient at detecting all local features

Å The eU method can only be applied where the data are available