NIPH
Norwegian Institute of Public Health

Situational awareness and forecasting for Norway

FHI COVID-19 modelling team

Week 40, 6 October 2021

Highlights:

- **National epidemiological situation:** According to our changepoint model, the estimated effective reproduction number is 0.78 (median, 95% CI 0.7 - 84), on average since 1st of September. Before that, from 5 August to 31 August, the estimated effective reproduction number was 1.2 (median, 95% CI 1.1-1.3). The SMC model estimates the 7-days averaged effective reproduction number during week 39 to be 0.88 (mean, 95% CI 0.69-1.1). In the SMC model, the estimated probability that the daily reproduction number one week ago was above 1 is also 13%. The Epiestim model, which uses only test data, estimates the effective reproduction number as 0.83 (95% CI 0.79-0.87). We conclude that the epidemic has been decreasing in recent weeks with an effective R between 0.8 and 0.9. We note that our estimates presently have greater uncertainty than indicated by the uncertainty intervals due to a changing test practice in Norway.

  Since the start of the epidemic, we estimate that in total, 332.000 (95% CI 299.000- 366.000) individuals in Norway have been infected. The current estimate of the detection probability is approximately 55%. However, this estimate cannot be trusted anymore because it is based on the number of total tests performed.This quantity is presently unknown because of the massive use of home tests, where negative tests remain unreported.

- **National forecasting:** The CPM estimates of hospital prevalence and prevalence of ventilator beds are currently too low, affecting our prognoses for the hospital prevalence in the coming weeks that may be underestimated. In one week, on 10 October, we estimate approximately 508 new cases per day (median; 95% CI 279-786), and a prevalence (total number of presently infected individuals in Norway) of 2300 (median; 95% CI 1300 - 3500). The number of COVID-19 patients in hospital (daily prevalence) on 10 October is estimated to be 46 (median 95% CI 29-66), and the number of patients on ventilator treatment is estimated to be 10 (median 95% CI 5-18). The corresponding predictions for hospital load in three weeks (24 October) are 29 (95% CI 15-46) admitted patients and 7 (95% CI 2-13) on ventilator treatment. Regarding the age profile of these predictions in three weeks (Table 4), we estimate that the age-specific hospitalisation of individuals below 30 years is very low (¡5). We also estimate no significant differences in the number of admitted patients by 10-year age groups above 30 years. The age-specific prevalence is currently underestimated for the 70-79 year age groups, and we are analysing possible causes.

  Our predictions are, as usual, under the assumption that nothing is changed since today, so no changes in interventions, no changes in mobility and in people's behaviour, no changes in the age distribution among the hospitalised cases, and no changes in future hospitalisation risks, even though the hospitalisation risks are expected to decrease further in the short term because of increased number of vaccinations. Due to vaccination in the last weeks, vaccine-derived immunity in the population will increase in the coming weeks, especially in younger adults. Our estimates do not incorporate effects into our three weeks predictions that are not yet visible in the data.

  We are working on updating the long-term scenarios that will be published shortly in a separate report.

- **Regional epidemiological situation and forecasting:** This week we again present results from our regional changepoint model.

  The estimates of the regional effective reproduction number since 1 September in Oslo is 0.94 (95% CI 0.81 - 1.08) and in Viken since 5 September 0.81 (0.66 - 0.96). The estimates for Troms og Finnmark is 0.95 (0.54 - 1.31) since 15 August; Rogaland 0.75 (0.22 - 1.19) and Innlandet 0.71 (0.39 - 1.02) since 25 August; Møre og Romsdal 0.66 (0.04 - 1.26), Nordland 0.83 (0.32 - 1.39) and Trøndelag 0.75 (0.42 - 1.08) since 1 September.

  In the regional SMC model, the estimate of the effective reproduction number at 20 September for Oslo is about 1.1, with a wide CI (0.5-2.4), and for Viken about 1.1 (0.5-2.3). Except for Rogaland, all other counties have point estimates below 1.

  Epiestim uses a simple model with only positive test data, not corrected for imported cases from abroad, and no hospital data. The estimated reproduction numbers 7 days ago are: Oslo 0.85 (0.8-0.9) and Viken 0.77 (0.73 - 0.83). The point estimates in all the counties range between 0.7 and 0.87 with uncertainty intervals below or around 1.

- **Telenor mobility data and the number of foreign visitors:** Inter-municipality mobility levels are stable in all counties, at pre-covid levels. The number of foreign visitors to Norway has peaked and appears to continue to decline. Foreign roamers from Poland appear to have stabilised at high levels.The German tourists have left Norway.

What this report contains:

This report presents results based on a mathematical infectious disease model describing the geographical spread of COVID-19 in Norway. We use a metapopulation model (MPM) for situational awareness and short-term forecasting and an individual-based model (IBM) for long-term predictions. The metapopulation model (MPM) consists of three layers:

- Population structure in each municipality.
- Mobility data for inter-municipality movements (Telenor mobile phone data).
- Infection transmission model (SEIR-model)

The MPM model produces estimates of the current epidemiological situation at the municipality, county (fylke), and national levels, a forecast of the situation for the next three weeks. We run three different models built on the same structure indicated above: (1) a national changepoint model, (2) a regional changepoint model and (3) a national Sequential Monte Carlo model, named SMC model.

How we calibrate the model: The national changepoint model is fitted to Norwegian COVID-19 hospital incidence data from March 10 until yesterday and data on the laboratory-confirmed cases from May 1 until yesterday. We do not use data before May 1, as the testing capacity and testing criteria were significantly different in the early period.
Note that the the national changepoint model results are not a simple average or aggregation of the results of the regional changepoint model because they use different data. The estimates and predictions of the regional model are more uncertain than those of the national model. The regional model has more parameters to be estimated and less data in each county; lack of data limits the number of changepoints we can introduce in that model. In the regional changepoint model, each county has its own changepoints and therefore a varying number of reproduction numbers. Counties where the data indicate more variability have more changepoints.
The national SMC model is also calibrated to the hospitalisation incidence data (same data as described above) and the laboratory-confirmed cases.

Telenor mobility data: The mobility data account for the changes in the movement patterns between municipalities that have occurred since the start of the epidemic.

How you should interpret the results: 3-week-ahead predictions and long-term scenarios
We provide both 3-week-ahead predictions and long-term scenarios. These are simulations of the disease spread into the future, under specific assumptions.

In the 3-week-ahead predictions, we assume that all parameters are as today, and simulate disease spread 3-weeks-ahead in time. Hence, these predictions are conditional on the current situation, and specifically on the most recently estimated reproduction number. The 3-week-ahead predictions thus do not take into account changes in transmissibility that are not yet captured by the available data, for example due to the delay between transmission and positive test and/or transmission and hospitalisation. Hence one of the conditions for the predictions to be valid is that the intervention policies do not change significantly in the next weeks. Hence, it does not make sense to evaluate or use the predictions if there are big changes in factors like

- new interventions
- relaxation of interventions
- a combination of new interventions and relaxations
- a significant change in vaccination coverage
- new variants with new properties
- a significant change in the contact behaviour of individuals.

As these factors are not likely to stay constant in the long-term future, we do not produce predictions for longer than three weeks ahead in time. Hence, our 3-week-ahead predictions are predictions of what may happen in the future, if there were no significant changes in the assumptions.

In addition to the short-term predictions, we also produce different long-term scenarios. Scenarios are not predictions of how we think the future pandemic will evolve. The scenarios are based on different hypothetical assumptions, and hence cannot be validated against what we later actually observe in the data. They are not meant to be, and hence should not be interpreted as, what we believe to be the most probable future outcome.

The purpose of the scenarios is manifold. Scenarios can contribute to situational awareness, and as information in decision making and future preparedness planning. Scenarios can be used to provide a better understanding of possible future disease spread, under specific assumptions. The assumptions of the scenarios may also sometimes be unrealistic. For example, scenarios can contribute in understanding the current situation, should we not change intervention policies in the future. This does however not mean that we believe that the intervention policies will stay constant. Scenarios can also be used to compare different intervention strategies, like comparing different vaccination strategies. **Uncertainty** The model is stochastic. To predict the probability of various outcomes, we run the model multiple times to represent the inherent randomness.

We present the results in terms of mean values, 95% credibility intervals, medians, and interquartile ranges. We emphasise that the credibility bands might be broader than what we display because there are several sources of additional uncertainty which we currently do not fully explore Firstly, there are uncertainties related to the natural history of SARS-CoV-2, including the importance of asymptomatic and presymptomatic infection. Secondly, there are uncertainties associated with the hospitalisation timing relative to symptom onset, the severity of the COVID-19 infections by age, and the duration of hospitalisation and ventilator treatment in ICU. We continue to update the model assumptions and parameters following new evidence and local data as they become available. A complete list of all updates can be found at the end of this report.

Estimates of all reproductive numbers are uncertain, and we use their distribution to assure appropriate uncertainty of our predictions. Uncertainties related to the model parameters imply that the reported effective reproductive numbers should be interpreted with caution.

When we forecast beyond today, we use the most recent reproduction number for the whole future, if not explicitly stated otherwise.

In this report, the term patient in ventilator treatment includes only those patients that require either invasive mechanical ventilation or ECMO (Extracorporeal membrane oxygenation).

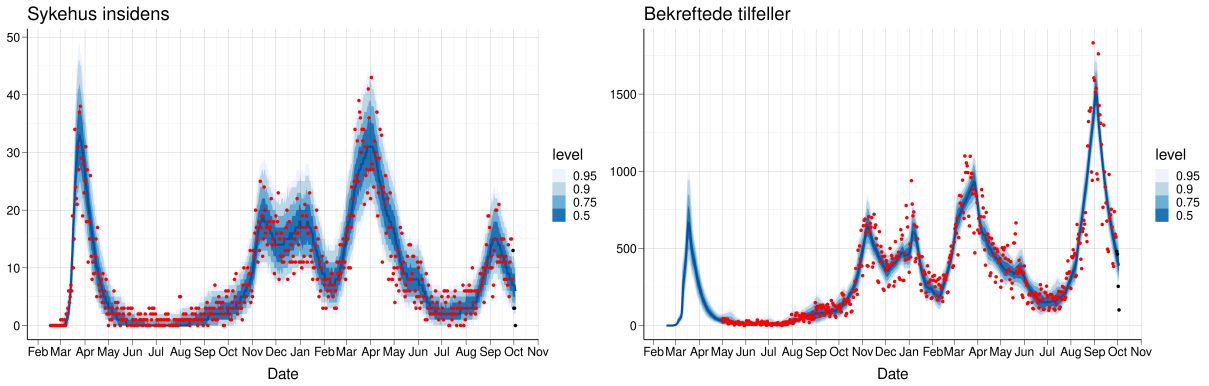
1 Estimated national reproduction numbers

Calibration of our national changepoint model to hospitalisation incidence data and test data leads to the following estimates provided in table 1. Figure 1 shows the estimated daily number of COVID-19 patients admitted to hospital (1a) and the estimated daily number of laboratory-confirmed SARS-CoV-2 cases (1b), with blue medians and interquantile bands, which are compared to the actual true data, provided in red. The uncertainty captures the uncertainty in the calibrated parameters in addition to the stochastic elements of our model and the variability of other model parameters.

Table 1: Calibration results

Reff	Period
2.38/2.37(1.78-2.93)	From Feb 17 to Mar 14
0.61/0.6(0.48-0.72)	From Mar 15 to Apr 19
0.74/0.72(0.13-1.28)	From Apr 20 to May 10
0.68/0.67(0.07-1.24)	From May 11 to Jun 30
0.82/0.83(0.11-1.59)	From Jul 01 to Jul 31
0.97/0.92(0.22-1.31)	From Aug 01 to Aug 31
0.99/0.99(0.69-1.36)	From Sep 01 to Sep 30
1.11/1.12(0.87-1.37)	From Oct 01 to Oct 25
1.24/1.24(0.91-1.63)	From Oct 26 to Nov 04
0.86/0.86(0.77-0.95)	From Nov 05 to Nov 30
1.03/1.03(0.95-1.12)	From Dec 01 to Jan 03
0.67/0.67(0.5-0.85)	From Jan 04 to Jan 21
0.84/0.84(0.62-1.09)	From Jan 22 to Feb 07
1.3/1.31(1.13-1.49)	From Feb 08 to Mar 01
1.05/1.05(0.96-1.14)	From Mar 02 to Mar 24
0.82/0.83(0.73-0.93)	From Mar 25 to Apr 12
0.88/0.88(0.76-1)	From Apr 13 to May 05
0.96/0.96(0.8-1.13)	From May 06 to May 26
0.8/0.8(0.57-1)	From May 27 to Jun 20
0.96/0.96(0.64-1.31)	From Jun 21 to Jul 11
0.95/0.95(0.69-1.19)	From Jul 12 to Aug 04
1.2/1.2(1.09-1.31)	From Aug 05 to Aug 31
0.78/0.78(0.7-0.84)	From Sep 01

Median/Mean (95% credible intervals)

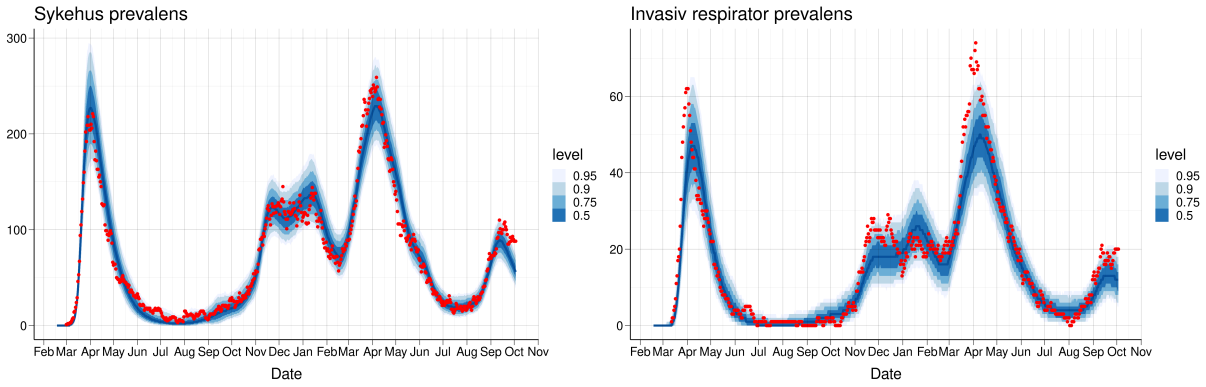


(a) Hospital admissions

(b) Test data

Figure 1: A comparison of true data (red) and predicted values (blue) for hospital admissions and test data. The last four data points (black) are assumed to be affected by reporting delay. B) Comparison of our simulated number of positive cases, with blue median and interquartile bands to the actual true number of positive cases, provided in red. The uncertainty captures the uncertainty in the calibrated parameters, in addition to the stochastic elements of our model and the variability of other model parameters. Note that we do not capture all the uncertainty in the test data–our blue bands are quite narrow. This is likely because we calibrate our model parameters on a 7-days moving average window of test data, instead of daily. This is done to avoid overfitting to random daily variation. Moving averages over 7 days are less variable than the daily data.

In figure 2, we show how our national model fits the national hospital prevalence data (2a) and the daily number of patients receiving ventilator treatment (2b). Those data sources are not used to estimate the parameters, and can therefore be seen as a validation of the model assumptions.



(a) Hospital prevalence

(b) Ventilator prevalence

Figure 2: A comparison of true data (red) and predicted values (blue) for hospital and respirator prevalence. Prevalence data is based on NIPaR and may be different to the data from Helsedirektoratet.

1.1 National SMC-model: Estimated daily reproduction numbers

In the SMC-model, we allow for estimation of a different reproduction number for each day t. To reduce spurious fluctuation, we report a 7-days moving average, $R(t)$, representing the average reproduction number for the whole week before day t. However, until March 8 we keep the reproduction number constant. By assuming a time varying reproduction number $R(t)$, we can detect changes without introducing explicit changepoints. Thus, we can easier detect unexpected changes.

The SMC model uses the daily number of new admissions to hospital and the daily number of positive and negative lab-confirmed tests, to estimate all its parameters. Because of the time between infection and the possibility to be detected as positive by a test, and because if a delay in reporting tests, the data contain information on the transmissibility until a week before the end of the data (today).

The parameters π_0 and π_1 related to the probability to detect a positive case by testing are estimated off-line.

Figure 3 shows the SMC estimate of the 7-day-average daily reproduction number $R(t)$ from the start of the epidemic in Norway and until today. In the figure we plot the 95% credibility interval and quantiles of the estimated posterior distribution of $R(t)$.

1.1 National SMC-model: Estimated daily reproduction numbers

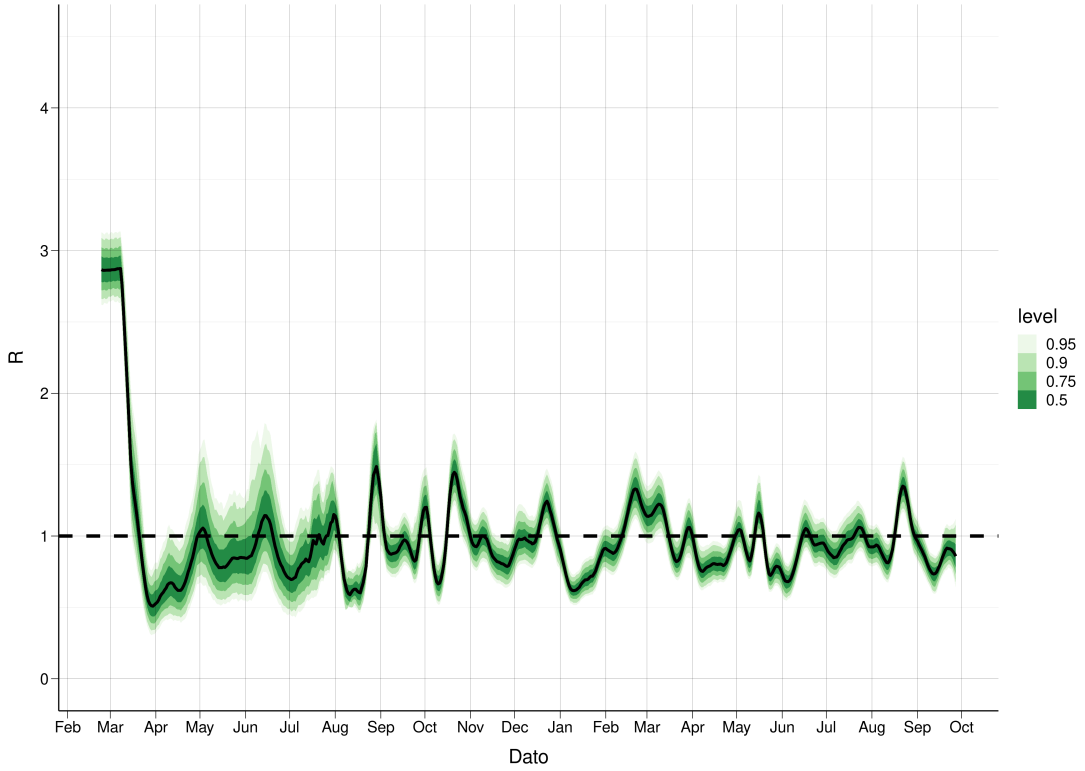


Figure 3: R(t) estimates using a Sequential Monte Carlo approach calibrated to hospitalisation incidence and test data. The large uncertainty during the last 7 days reflects the lack of available data due to the transmission delay, test delay, time between symptoms onset and hospitalisation. The green band shows the 95% posterior credibility interval. As we use test data only from 1 August, the credibility interval becomes more narrow thereafter.

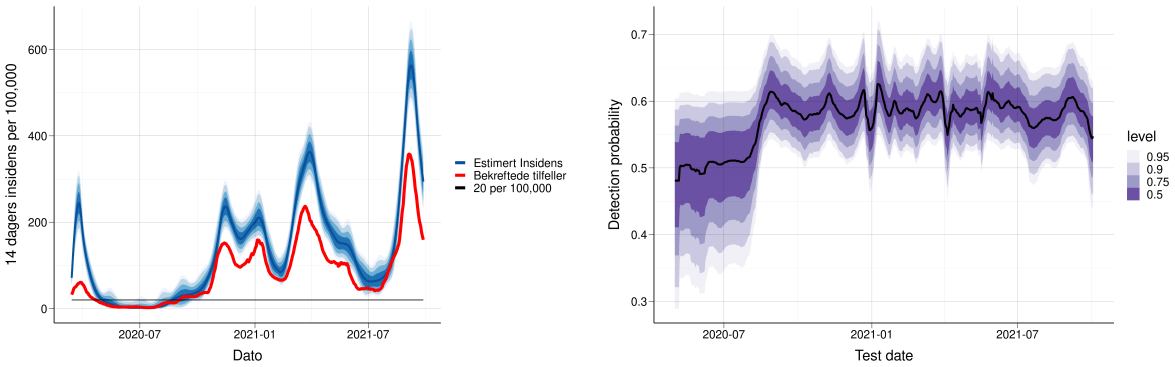
2 National estimate of cumulative (total) number of infections

The national changepoint model estimates the total number of infections and the symptomatic cases that have occurred (Table 2).
Figure 4a shows the modelled expected daily incidence (blue) and the observed daily number of laboratory-confirmed cases (red). When simulating the laboratory-confirmed cases, we also model the detection probability for the infections (both symptomatic, presymptomatic and asymptomatic), Figure 4b. There are two differences between this estimate of the detection probability and the previous one provided in figure 4a. In figure 4b, we calibrate our model to the true number of positive cases, instead of using the test data directly. Furthermore, in figure 4b we use a parametric model to estimate the detection probability that depends on the true total number of tests performed.

Table 2: Estimated cumulative number of infections, 2021-10-03

Region	Total	No. confirmed	Fraction reported	Min. fraction
Norway	331960 (299197; 366198)	189427	57%	52%

Fraction reported=Number confirmed/number predicted; Minimal fraction reported=number confirmed/upper CI



(a) Number of laboratory-confirmed cases vs model-based estimated number of new infected individuals

(b) Estimated detection probability for an infected case per calendar day

Figure 4

3 National 3-week predictions: Prevalence, Incidence, Hospital beds and Ventilator beds

The national changepoint model estimates the prevalence and daily incidence of infected individuals (asymptomatic, presymptomatic and symptomatic) for the next three weeks, aggregated to the whole of Norway (table 3). In addition, the table shows projected national prevalence of hospitalised patients (hospital beds) and prevalence of patients receiving ventilator treatment (ventilator beds). The projected epidemic and healthcare burden are illustrated in figure 5.

Table 3: Estimated national prevalence, incidence, hospital beds and ventilator beds. Median/Mean (CI)

	1 week prediction (Oct 10)	2 week prediction (Oct 17)	3 week prediction (Oct 24)
Prevalence	2310/2271 (1320-3477)	1719/1674 (886-2783)	1285/1235 (559-2254)
Daily incidence	508/496 (279-786)	379/368 (184-631)	283/270 (118-497)
Hospital beds	46/46 (29-66)	37/37 (21-55)	29/29 (15-46)
Ventilator beds	10/10 (5-18)	9/8 (3-15)	7/7 (2-13)

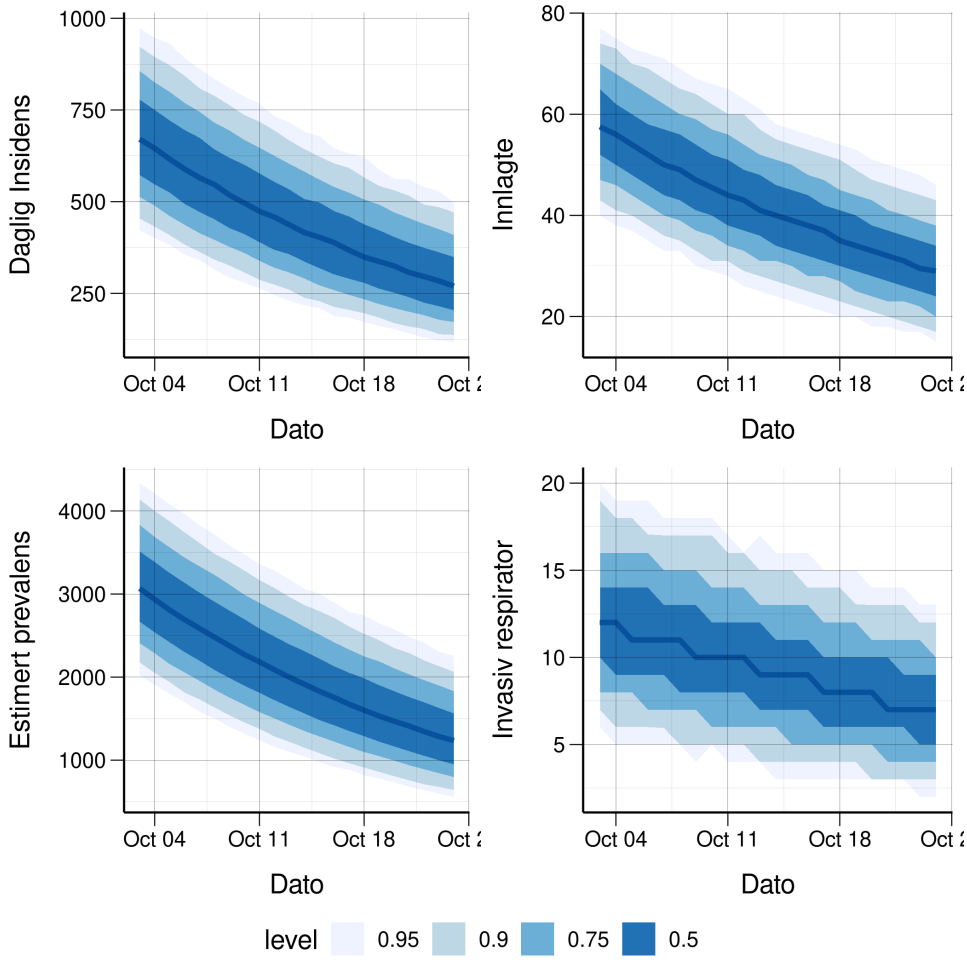


Figure 5: National 3 week predictions for incidence (top left), prevalence (bottom left), hospital beds (top right) and ventilator beds (bottom right)

3.1 Hospital and Ventilator prevalence by age

In Figures 6 and 7 we show the hospital prevalence by age group obtained from the simulations of the national model, including a 3 week forecast period. The real number of patients in each age group is also included (black dots).

In the forecast period, we assume that the age distribution of the cases in hospital and respirator beds will remain the same as today. Specific values for these projections are shown in table 4.

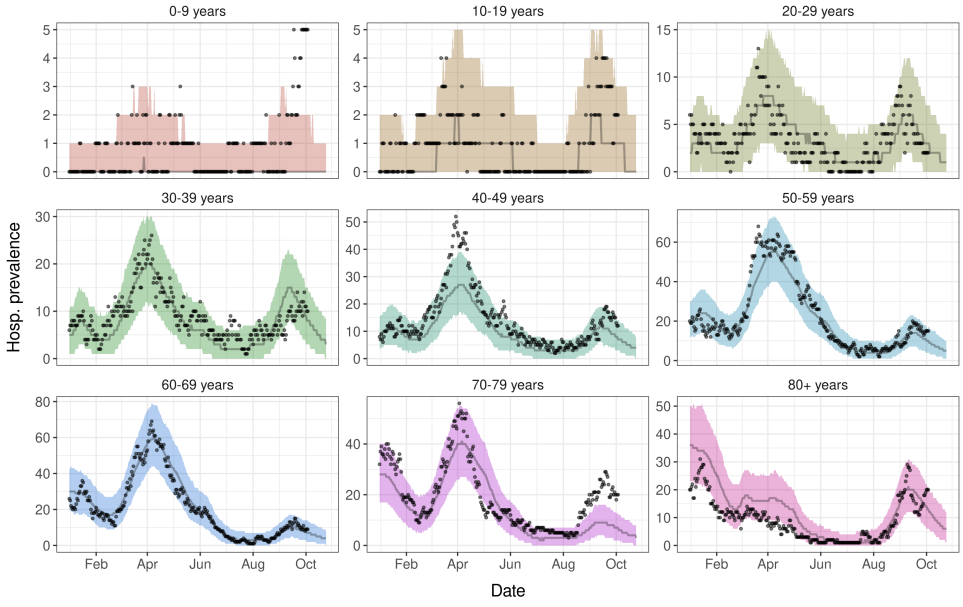


Figure 6: Simulated hospital prevalence by age group. Real data is shown as black dots

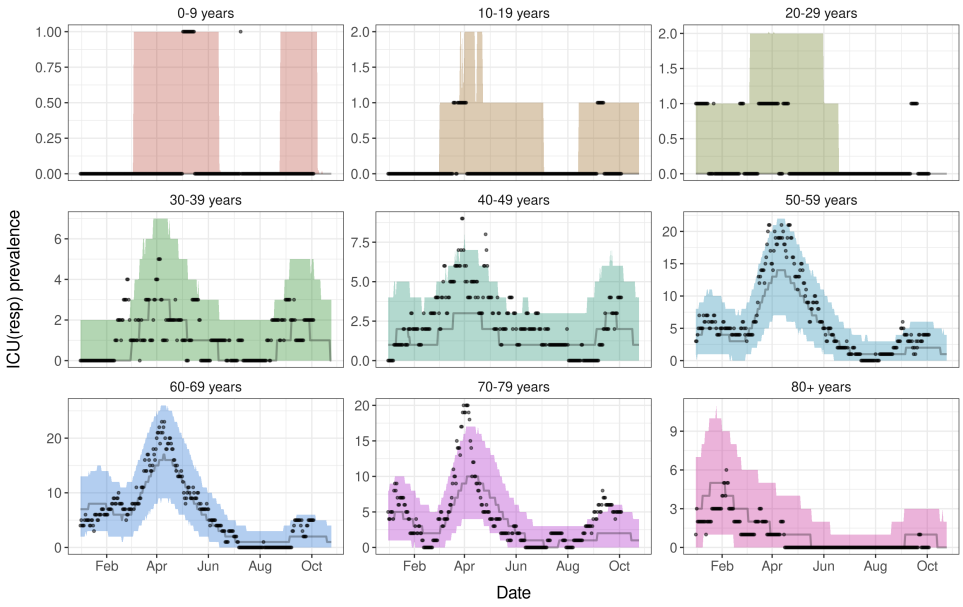


Figure 7: Simulated respirator prevalence by age group. Real data is shown as black dots

Table 4: Hospital and Respirator prevalence per age group: 3 week prediction (2021-10-24). Mean and 95 perc. CI

Age group	Hosp	Resp
0-9 years	0 (0-1)	0 (0-0)
10-19 years	0 (0-2)	0 (0-1)
20-29 years	1 (0-4)	0 (0-0)
30-39 years	4 (0-9)	1 (0-3)
40-49 years	4 (1-9)	2 (0-4)
50-59 years	5 (1-10)	1 (0-4)
60-69 years	4 (1-9)	2 (0-4)
70-79 years	4 (1-8)	1 (0-4)
+80 years	6 (2-13)	1 (0-2)

4 Estimated regional reproduction numbers

Also this week we are not presenting results from the regional changepoint model. The reason is that we are updating the model in several directions, as we found this needed to cope with a more complicated situation. The regional testing in the most populated municipalities is particularly influenced by the self-testing. Because negative results are not recorded, the number of tests is highly under-reported. Vaccination is also happening in various age groups unevenly in the country, which leads to less susceptible quite rapidly, more than what we see from the positive test data (which should decrease, if we would have the same efforts in detecting them by testing). We are also updating several parameters in our model, related to the basic assumptions of the transmission, because of the delta variant. The changepoint model produces estimates which are valid for a longer period (some weeks), within which we assume transmission to be stable and the epidemic to be in equilibrium. This is particularly difficult to assume now. Therefore we publish our regional SMC model, which has a daily reproduction number, with all the caveats being however valid, about data and dynamics of the epidemics.

Calibration of our regional changepoint model to hospitalisation incidence data and test data leads to the following estimates for current regional reproduction numbers by county (Table 5). A full list of all regional reproduction numbers can be found at the end of the report.
Below we show the estimated daily number of COVID-19 patients admitted to hospital and the estimated daily number of laboratory-confirmed SARS-CoV-2 cases for each county. Model estimates are shown with blue medians and interquantile bands, which are compared to the actual true data, provided in red. The blue bands describe the uncertainty in the calibrated parameters, in addition to the stochastic elements of our model. Last four data points are shown in black as they may be affected by reporting delay.

Table 5: Estimated current regional reproduction numbers

R	Parameter	County	From	Pr(R>1)
0.94 (0.81-1.08)	R17	Oslo	2021-09-01	0.2
0.75 (0.22-1.19)	R16	Rogaland	2021-08-25	0.18
0.66 (0.04-1.26)	R14	Møre og Romsdal	2021-09-01	0.23
0.83 (0.32-1.39)	R14	Nordland	2021-09-01	0.27
0.81 (0.66-0.96)	R15	Viken	2021-09-05	0.01
0.71 (0.39-1.02)	R17	Innlandet	2021-08-25	0.04
0.56 (0.23-0.88)	R16	Vestfold og Telemark	2021-09-01	0
0.34 (0.05-0.64)	R15	Agder	2021-08-25	0
0.56 (0.19-0.94)	R17	Vestland	2021-08-25	0.01
0.75 (0.42-1.08)	R16	Trøndelag	2021-09-01	0.07
0.95 (0.54-1.31)	R16	Troms og Finnmark	2021-08-15	0.41

Mean and 95% credible intervals

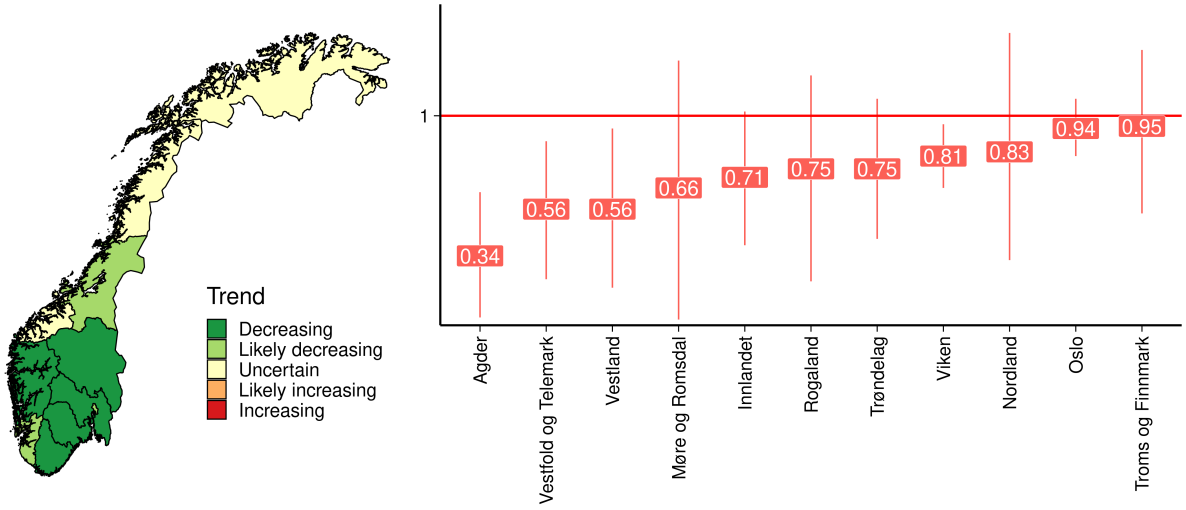
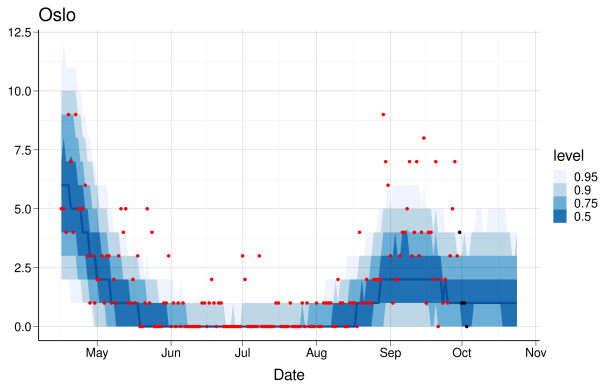
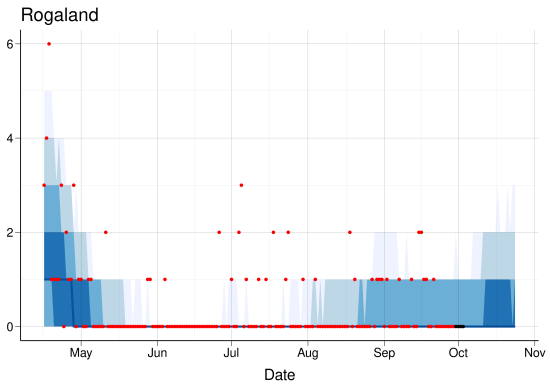
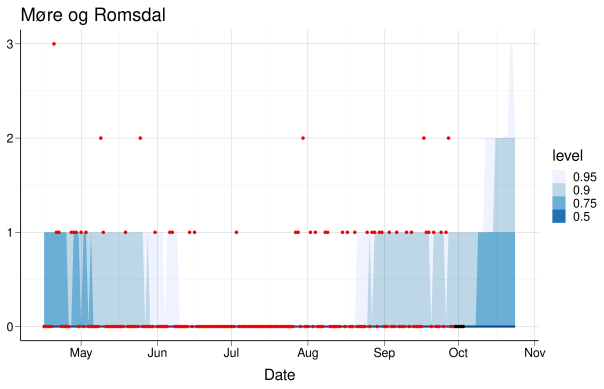


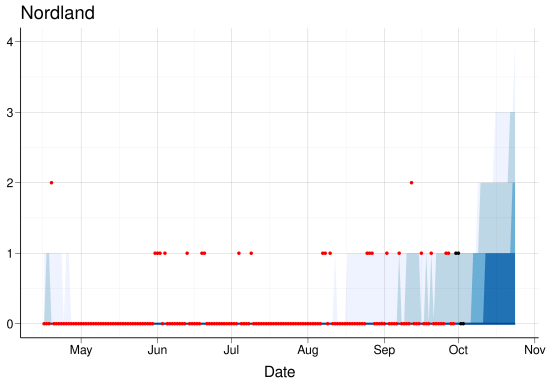
Figure 8: The map shows the direction of the trend in incidence in the counties based on the latest reproduction numbers shown in the other chart. The trend is increasing if the probability that the latest reproduction number is above one is above 95%, the trend is likely increasing if this probability is between 80% and 95%, the trend is uncertain if the probability is between 20% and 80%, the trend is likely decreasing if the probability is between 5% and 20% and is decreasing if the probability that the latest R is above one is less than 5%.

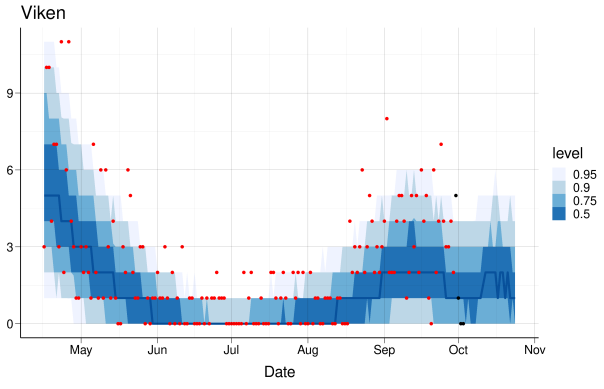
Estimated vs observed hospital incidence and 3 weeks forecast by county:

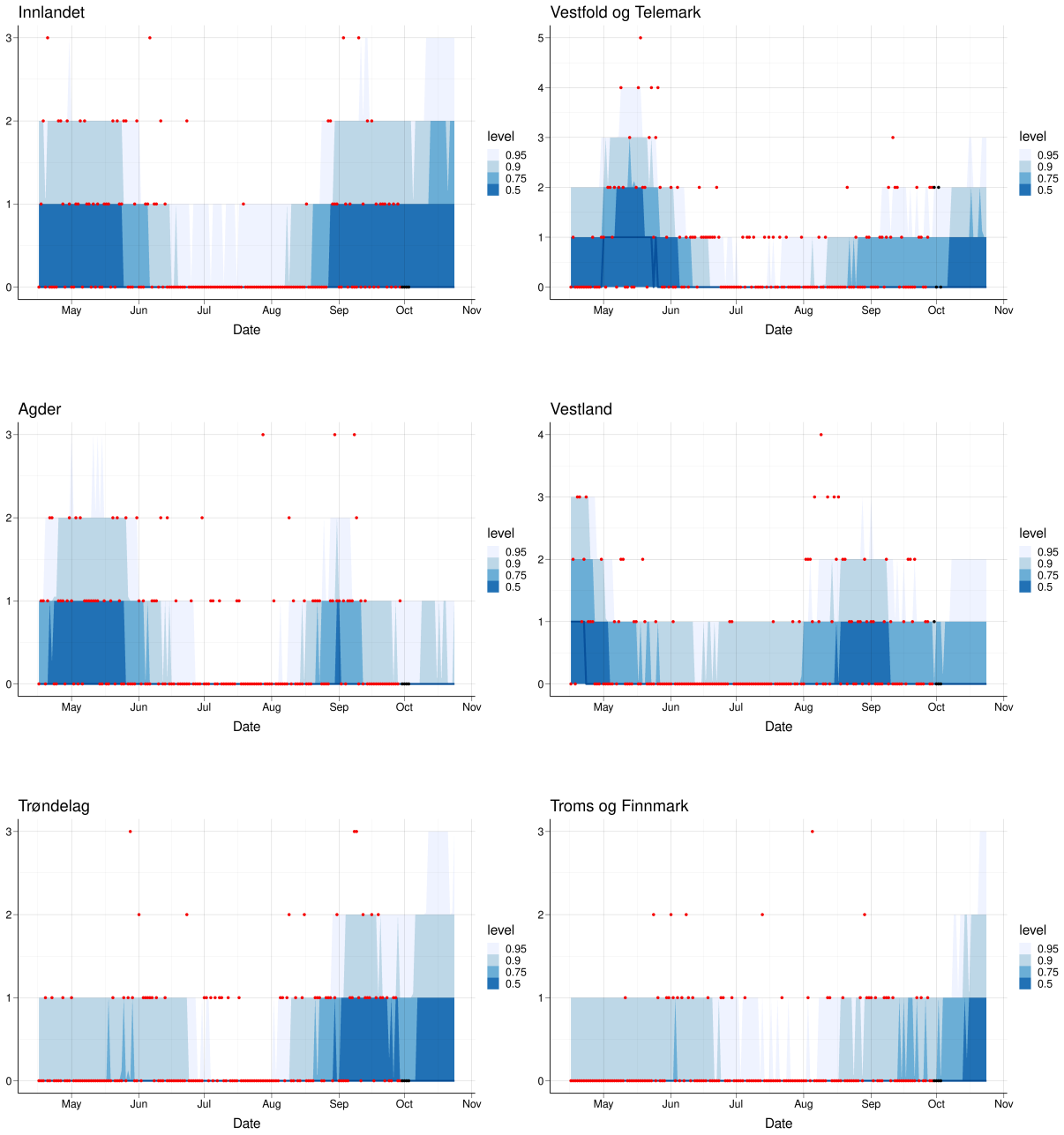








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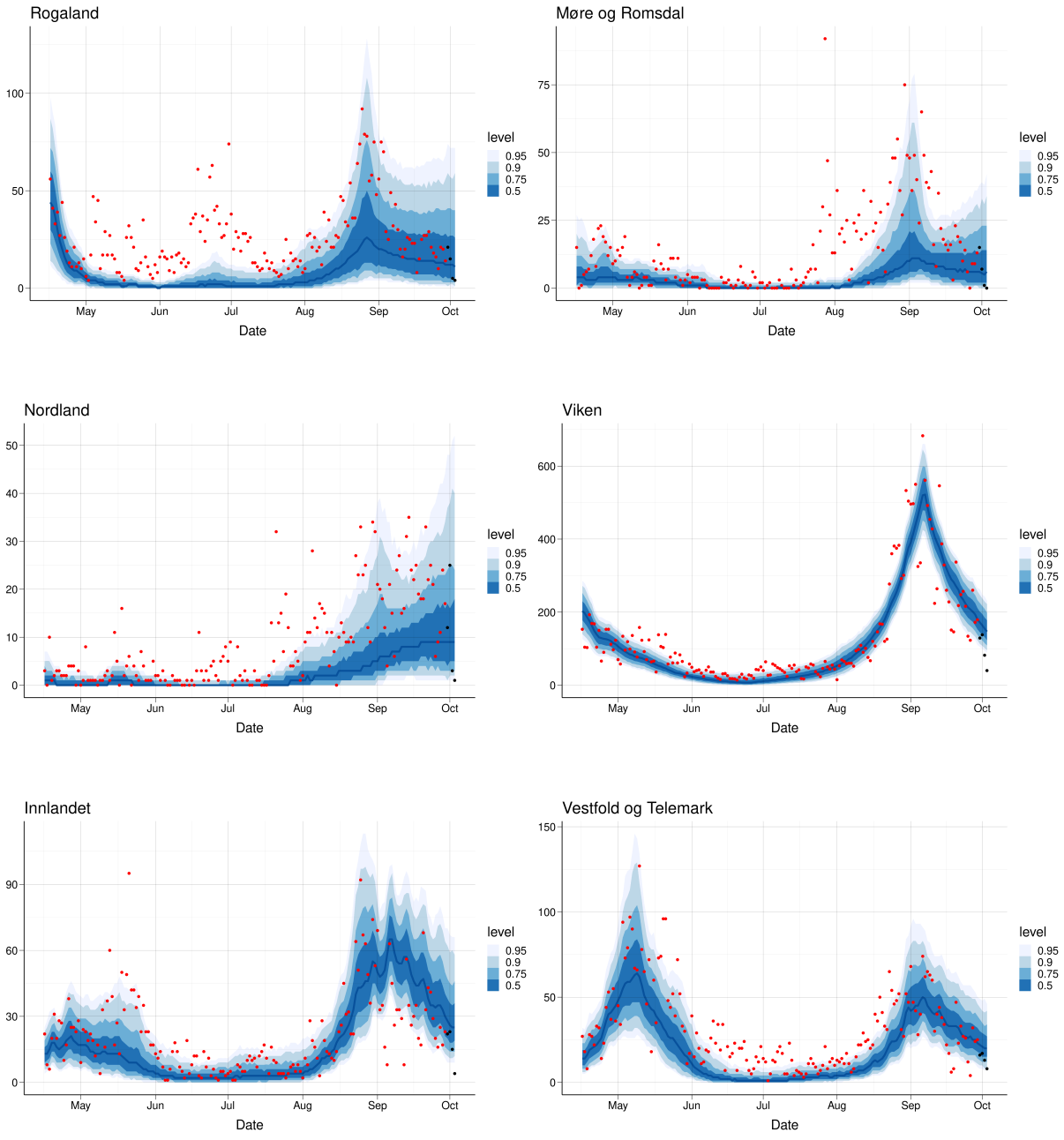
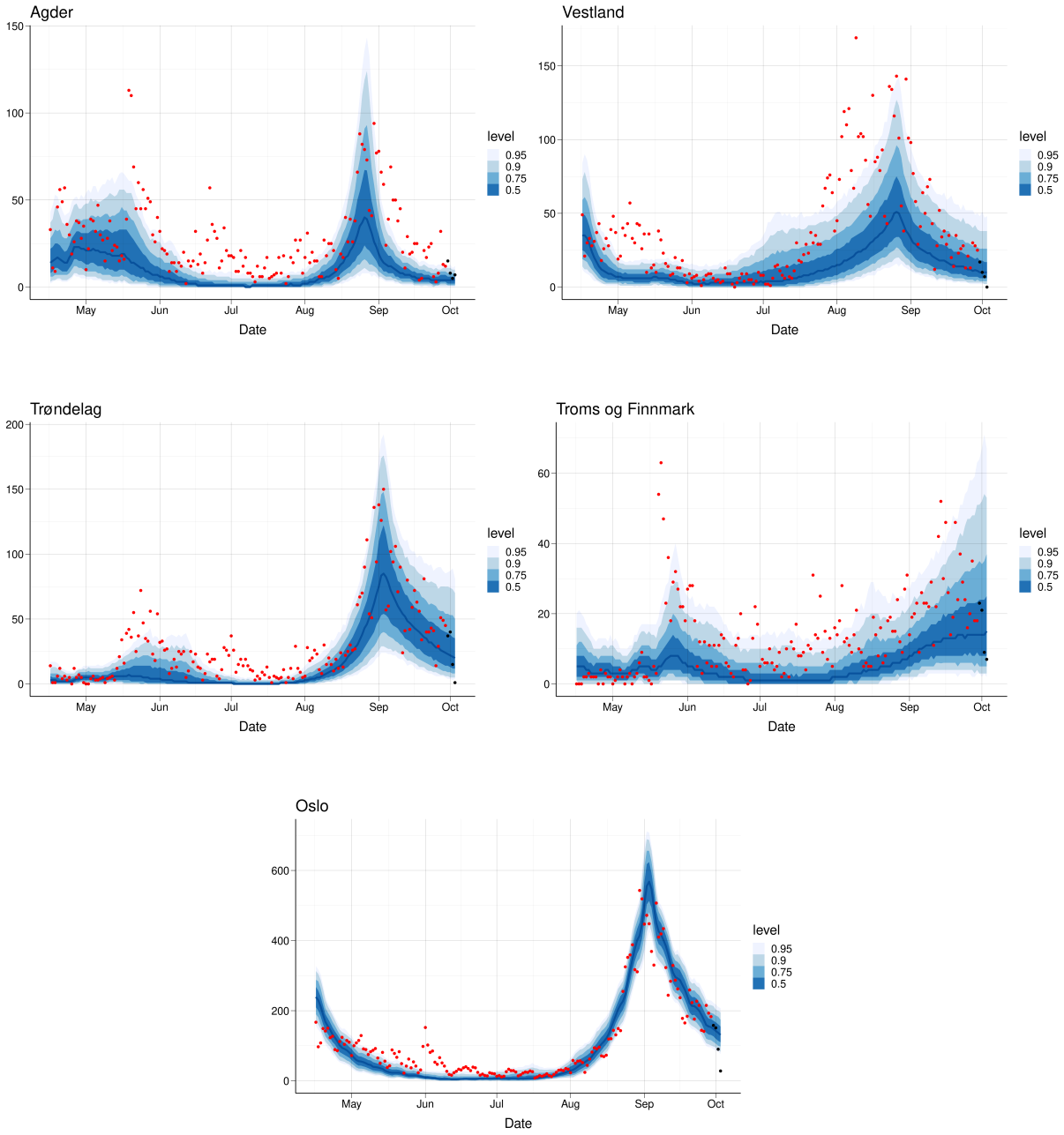
Estimated and observed lab-confirmed test data by county:

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5 Regional 3-week predictions: Cumulative (total) incidence and Prevalence

Below is shown the estimated short-term forecasting of total incidence of infected individuals since 1st of June (2021) (table 6), daily incidence (table 7) and prevalence (table 8) for each county.

Table 6: Estimated cumulative number of infections, 2021-10-03

Region	Total	No. confirmed	Fraction reported	Min. fraction
Oslo	17133 (13404; 22366)	15792	92%	71%
Rogaland	1494 (422; 3634)	3504	100%	96%
Møre og Romsdal	630 (234; 1546)	1921	100%	124%
Nordland	552 (201; 1448)	1300	100%	90%
Viken	18382 (14365; 23939)	17552	95%	73%
Innlandet	2841 (1736; 4367)	2413	85%	55%
Vestfold og Telemark	2090 (1327; 3224)	2910	100%	90%
Agder	1147 (462; 2508)	2941	100%	117%
Vestland	2641 (876; 6460)	5014	100%	78%
Trøndelag	2812 (1113; 5442)	4017	100%	74%
Troms og Finnmark	954 (330; 2487)	1860	100%	75%

Fraction reported=Number confirmed/number predicted; Minimal fraction reported=number confirmed/upper CI

Table 7: Predicted incidence per day: Median/Mean (CI)

Region	1 week prediction (10 Oct)	2 weeks prediction (17 Oct)	3 weeks prediction (24 Oct)
Agder	3/3 (0-9)	2/2 (0-8)	2/2 (0-8)
Innlandet	27/32 (8-87)	20/25 (6-74)	16/20 (4-61)
Møre og Romsdal	6/12 (0-53)	5/12 (0-62)	4/12 (0-67)
Nordland	13/19 (2-70)	10/20 (1-103)	9/23 (0-140)
Oslo	93/96 (45-171)	66/69 (28-137)	46/50 (18-106)
Rogaland	12/21 (1-81)	9/19 (1-91)	6/17 (0-89)
Troms og Finnmark	18/24 (3-81)	16/25 (2-108)	15/27 (1-135)
Trøndelag	17/25 (3-89)	13/22 (1-97)	10/19 (1-88)
Vestfold og Telemark	15/17 (4-44)	12/14 (3-35)	10/11 (2-29)
Vestland	9/14 (2-53)	7/11 (1-42)	6/9 (0-39)
Viken	104/111 (50-208)	76/82 (32-167)	53/60 (19-132)

Table 8: Predicted prevalence. Number of infectious individuals (asymptomatic plus pre-symptomatic plus symptomatic) per day. Median/Mean and 95 perc. CI for three weeks prediction.

Region	10 Oct	17 Oct	24 Oct	low CI, 24 Oct	high CI, 24 Oct
Agder	15/17	10/11	10/11	2	25
Innlandet	115/139	84/106	64/83	20	252
Møre og Romsdal	27/50	22/52	19/54	4	263
Nordland	57/81	47/85	39/93	4	550
Oslo	436/453	304/322	209/224	91	435
Rogaland	55/91	44/83	34/77	5	384
Troms og Finnmark	79/102	74/107	66/111	11	511
Trøndelag	77/111	61/96	48/85	10	388
Vestfold og Telemark	62/73	44/54	36/44	13	121
Vestland	45/62	35/52	33/46	8	171
Viken	473/501	343/373	252/276	99	590

6 Regional 3-week predictions: Hospital beds and ventilator beds

Below is shown the estimated short-term forecasting of expected hospital prevalence (table 9) and patients on ventilator treatment for each county (table 10).

Table 9: Number of hospitalisation beds occupied by Covid-19 patients: Median/Mean (CI)

Region	1 week prediction (10 Oct)	2 weeks prediction (17 Oct)	3 weeks prediction (24 Oct)
Agder	0/0 (0-3)	0/0 (0-3)	0/0 (0-3)
Innlandet	2/3 (0-10)	3/4 (0-12)	3/4 (0-13)
Møre og Romsdal	0/1 (0-4)	1/1 (0-7)	1/2 (0-11)
Nordland	1/1 (0-5)	1/2 (0-10)	1/3 (0-14)
Oslo	7/8 (2-17)	7/8 (2-18)	6/7 (1-17)
Rogaland	1/1 (0-7)	1/2 (0-10)	1/2 (0-11)
Troms og Finnmark	1/1 (0-5)	1/2 (0-7)	1/2 (0-10)
Trøndelag	1/2 (0-9)	2/3 (0-11)	2/3 (0-13)
Vestfold og Telemark	2/2 (0-7)	2/3 (0-9)	3/3 (0-10)
Vestland	1/1 (0-7)	1/2 (0-8)	1/2 (0-8)
Viken	11/11 (3-23)	11/12 (3-25)	11/12 (2-25)

Table 10: Number of ICU beds occupied by Covid-19 patients: Median/Mean (CI)

Region	1 week prediction (10 Oct)	2 weeks prediction (17 Oct)	3 weeks prediction (24 Oct)
Agder	0/0 (0-1)	0/0 (0-1)	0/0 (0-1)
Innlandet	0/0 (0-3)	0/1 (0-2)	0/1 (0-3)
Møre og Romsdal	0/0 (0-1)	0/0 (0-1)	0/0 (0-2)
Nordland	0/0 (0-1)	0/0 (0-2)	0/0 (0-2)
Oslo	1/2 (0-4)	1/1 (0-4)	1/1 (0-4)
Rogaland	0/0 (0-2)	0/0 (0-2)	0/0 (0-2)
Troms og Finnmark	0/0 (0-1)	0/0 (0-1)	0/0 (0-2)
Trøndelag	0/0 (0-2)	0/0 (0-2)	0/0 (0-3)
Vestfold og Telemark	0/0 (0-2)	0/0 (0-2)	0/0 (0-2)
Vestland	0/0 (0-2)	0/0 (0-2)	0/0 (0-2)
Viken	2/2 (0-5)	2/2 (0-5)	2/2 (0-5)

7 14-day trend analysis of confirmed cases and hospitalisations by county

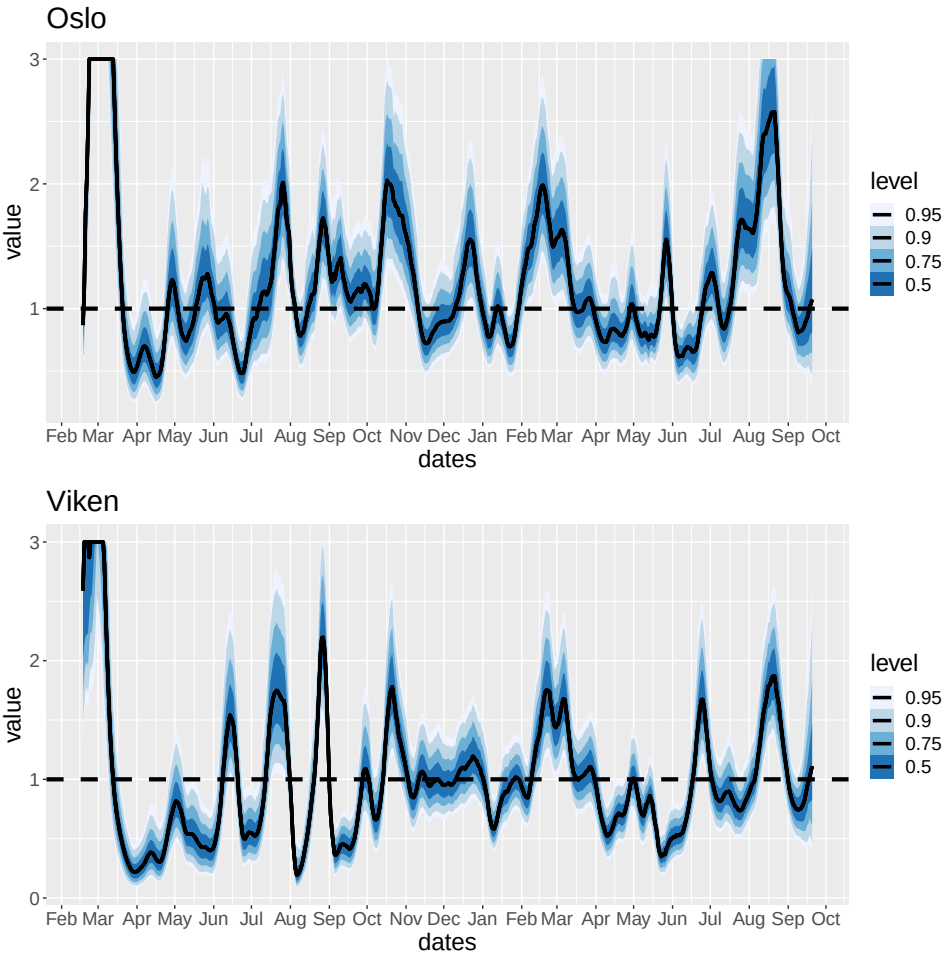
To estimate recent trends in hospitalisation and number of positive tests, we present results in table 11 based on a negative binomial regression where we account for weekend effects. We exclude the last three days to avoid problems of reporting delay and fit the model using data from 17 days to 3 days before the current date. We fit a separate trend model for confirmed cases and for hospital incidence. We only fit a trend model if there has been more than 5 cases or hospitalisations in the 14-day period.

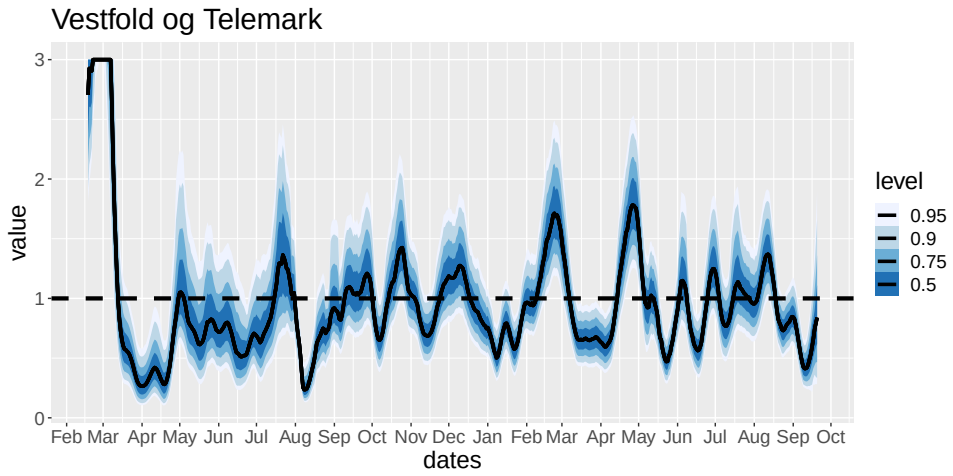
Table 11: Trend analysis for the last 14 days

	Average daily increase last 14 days		Doubling Time (days)	
County	Hospitalisations	Cases	Hospitalisations	Cases
Agder	Not enough data	-5.5 (-9.3, -1.6) %	Not enough data	-12.2 (-7.1, -43.9)
Innlandet	-11 (-27.7, 6.6) %	1.5 (-2.5, 5.8) %	-5.9 (-2.1, 10.8)	45.7 (-27, 12.4)
Møre og Romsdal	Not enough data	-7.3 (-11.6, -2.9) %	Not enough data	-9.1 (-5.6, -23.6)
Nordland	Not enough data	-3.3 (-6, -0.5) %	Not enough data	-20.8 (-11.3, -130.6)
Norge	-5.3 (-9.2, -1.3) %	-4.4 (-6, -2.8) %	-12.7 (-7.2, -55.1)	-15.4 (-11.2, -24.5)
Oslo	-7.7 (-14.4, -0.7) %	-3.8 (-5.4, -2.2) %	-8.7 (-4.4, -93.9)	-17.8 (-12.4, -31.4)
Rogaland	Not enough data	-0.6 (-4.1, 3) %	Not enough data	-113.3 (-16.8, 23.8)
Troms og Finnmark	Not enough data	-3.3 (-6.1, -0.4) %	Not enough data	-20.7 (-11, -180.3)
Trøndelag	-11 (-25.3, 3.8) %	-4.9 (-8.4, -1.3) %	-5.9 (-2.4, 18.4)	-13.7 (-7.9, -51.1)
Vestfold og Telemark	Not enough data	-5.5 (-9.9, -0.8) %	Not enough data	-12.3 (-6.6, -84.4)
Vestland	Not enough data	-5.6 (-8.1, -3.1) %	Not enough data	-12 (-8.2, -21.9)
Viken	0 (-8, 8.7) %	-5.5 (-7.6, -3.3) %	-51516.8 (-8.3, 8.3)	-12.3 (-8.8, -20.4)

8 Regional SMC-model: Estimated daily reproduction numbers

As we do for the national SMC-model (section 1.1), we now allow for a different reproduction number for each day and for each county. The model uses the daily number of new admissions to hospital and the daily number of positive and negative lab-confirmed tests for each county, to estimate all parameters. Because of the time between infection and the possibility to be detected as positive by a test, and because of a delay in reporting tests, the data contain information on the transmissibility until a week before the end of the data used. We therefore stop the estimates one week ago. As for the national SMC model, the figures below show the SMC estimate of the 7-day-average daily reproduction number for each fylke. In the figure we plot the 95% credibility interval and quantiles of the estimated posterior distribution of the reproduction numbers. For some counties, uncertainty is large towards the most recent time, because there are very few data and possibly reporting delays which are different in each county.

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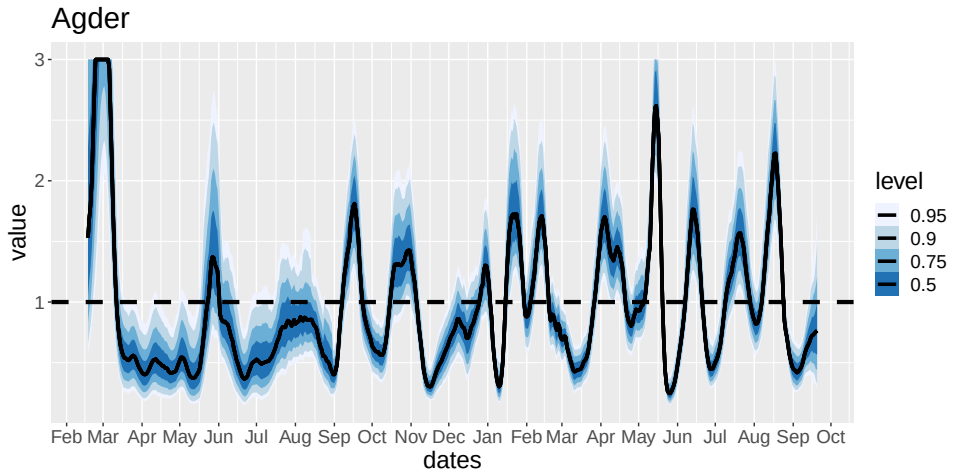
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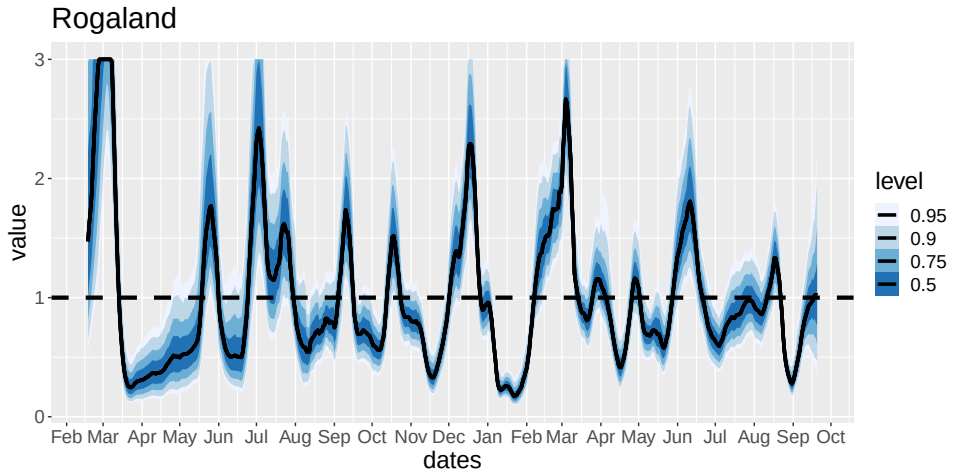
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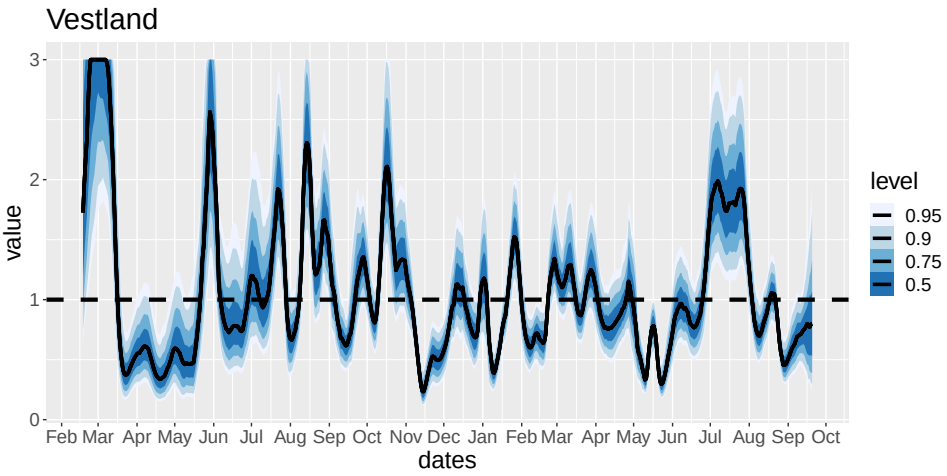
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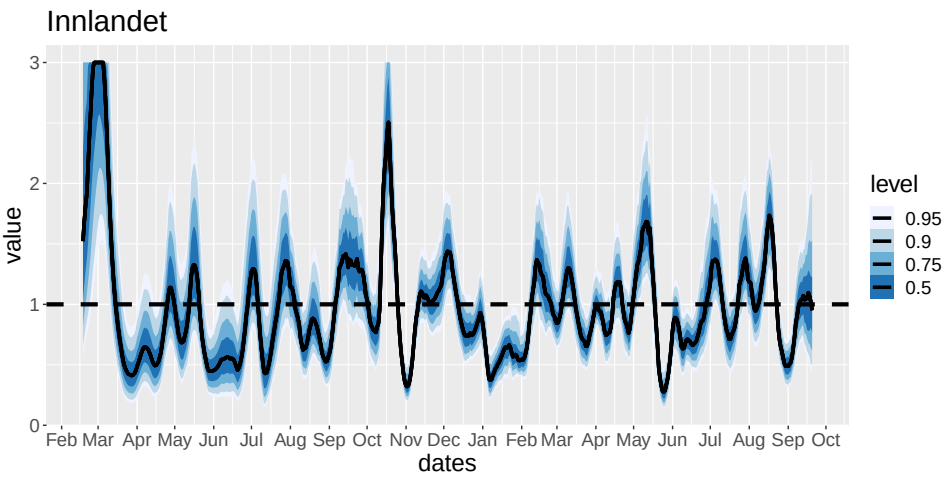
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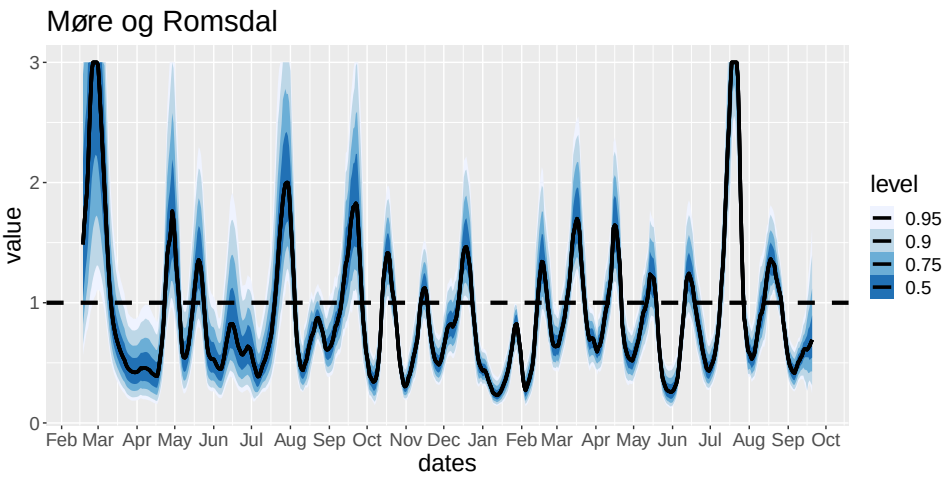
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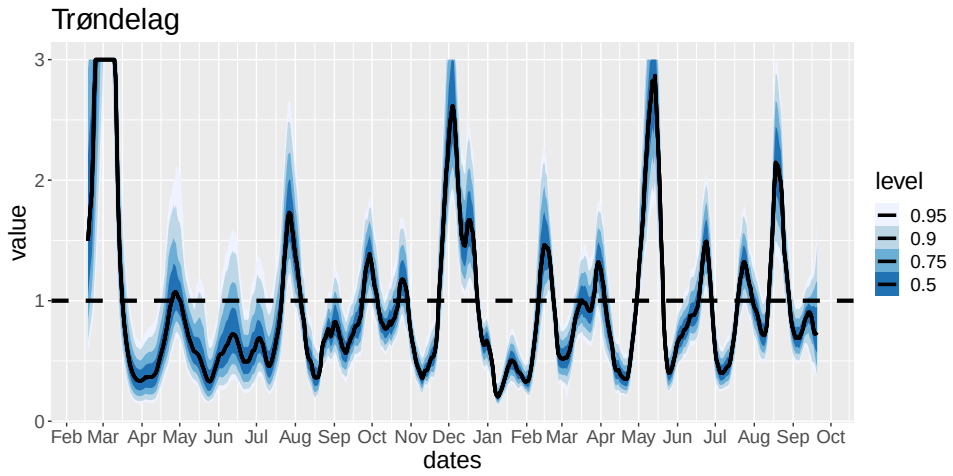
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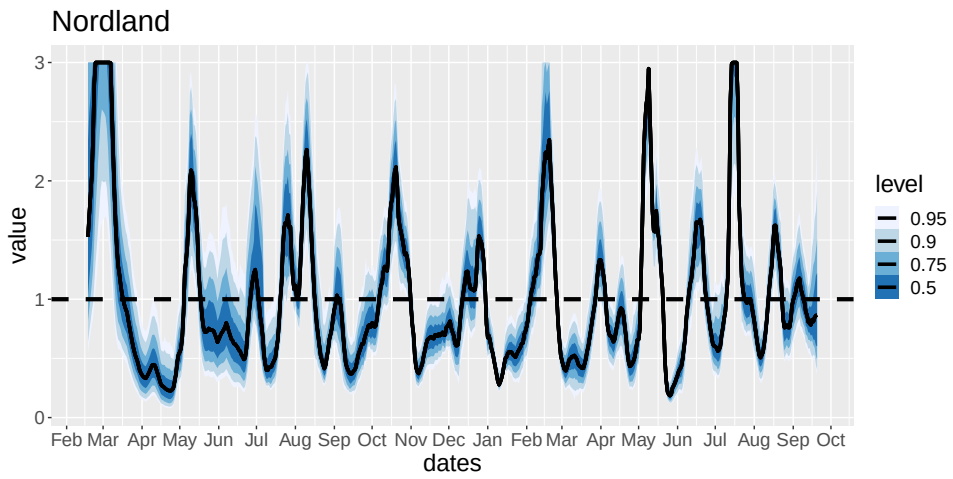
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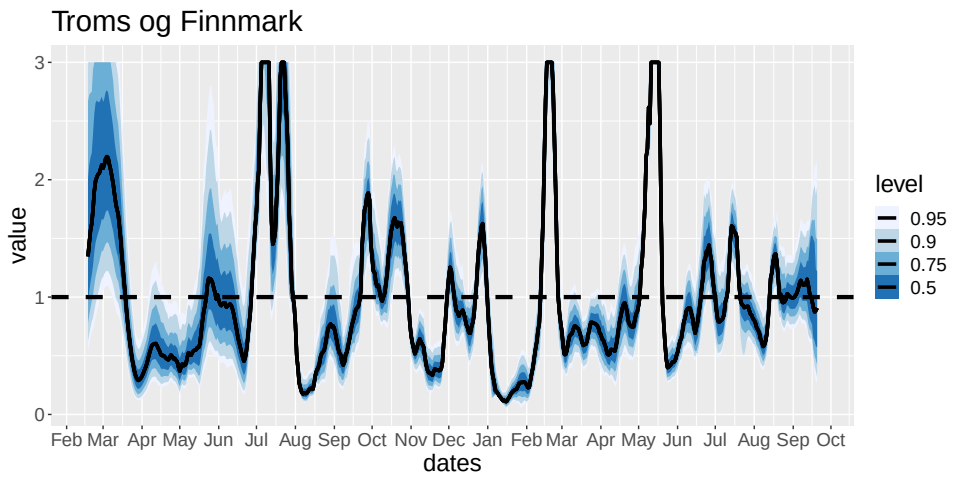

Troms og Finnmark
value
dates
level
0.95
0.9
0.75
0.5
Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct

	Median	5%	95%	Prob>1
Oslo	1.073	0.473	2.366	0.558
Rogaland	1.021	0.457	1.986	0.525
Møre og Romsdal	0.691	0.313	1.395	0.177
Nordland	0.865	0.403	1.911	0.383
Viken	1.111	0.464	2.318	0.605
Innlandet	0.951	0.502	1.909	0.449
Vestfold og Telemark	0.839	0.334	1.666	0.339
Agder	0.763	0.326	1.507	0.251
Vestland	0.798	0.295	1.733	0.299
Trøndelag	0.736	0.377	1.467	0.216
Troms og Finnmark	0.906	0.320	1.942	0.406

Table 12: Regional estimates at Sep 20

9 Mobility

Number of trips out from each municipality during each day is based on Telenor mobility data. We observed a large reduction in inter-municipality mobility in March 2020 (with minimum reached on Tuesday 17 March 2020), and thereafter we see an increasing trend in the mobility lasting until vacation time in July 2020. The changes in mobility in July 2020 coincides with the three-week "fellesferie" in Norway, and during August the mobility resumes approximately the same levels as pre-vacation time. There is however a significant regional variation.

The reference level is set to 100 on March 2nd 2020 for all the figures in this section, and we plot the seven-day, moving average of the daily mobility. Figure 19 shows an overview of the mobility since March 2020 for the largest municipalities in each county, and Figure 20 shows the total mobility out from all municipalities in each county, including Oslo. Figure 21 and 22, zooms in on mobility from August 16 2021, for municipalities and counties, respectively.

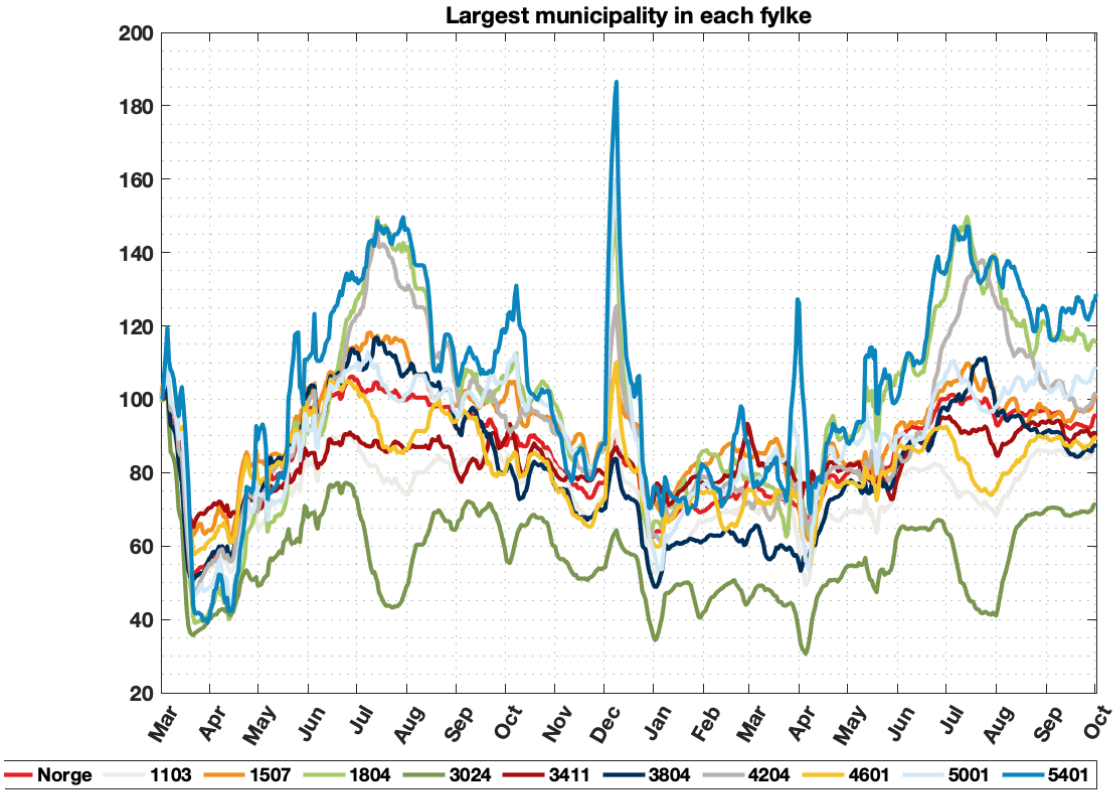


Figure 19: Mobility for selected municipalities since March 2020: Nationally (Norge), Stavanger (1103), Ålesund (1507), Bodø (1804), Bærum (3024), Ringsaker (3411), Sandefjord (3804), Kristiansand (4204), Bergen (4601), Trondheim (5001), Tromsø (5401).

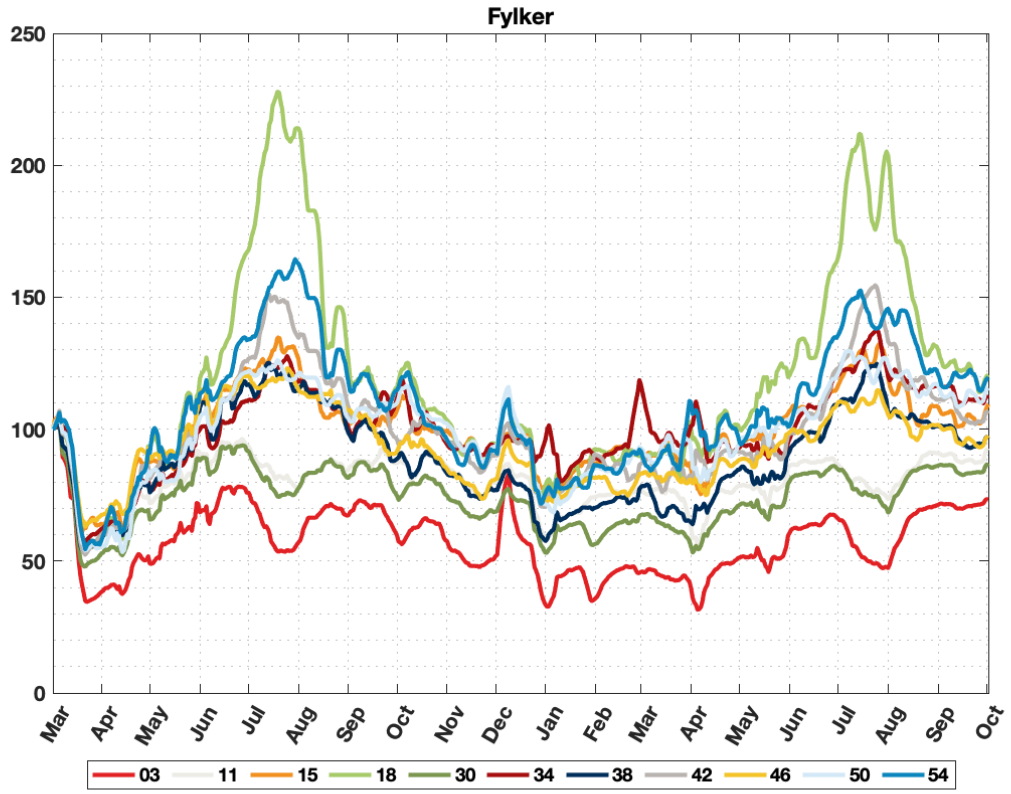


Figure 20: Mobility for fylker since March 2020: Oslo (03), Rogaland (11), Møre og Romsdal (15), Nordland (18), Viken (30), Innlandet (34), Vestfold og Telemark (38), Agder (42), Vestland (46), Trøndelag (50), Troms og Finmark (54).

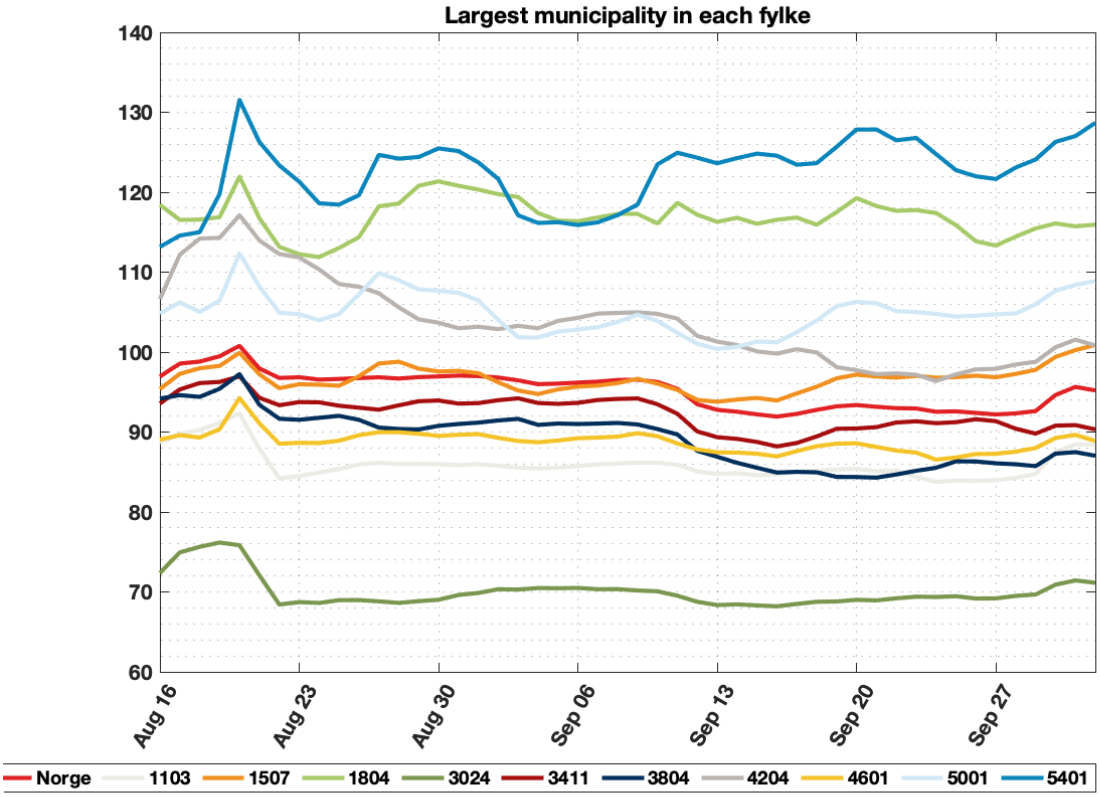


Figure 21: Zoom: Mobility from August 16, 2021 and onwards: Nationally (Norge), Stavanger (1103), Ålesund (1507), Bodø (1804), Bærum (3024), Ringsaker (3411), Sandefjord (3804), Kristiansand (4204), Bergen (4601), Trondheim (5001), Tromsø (5401).

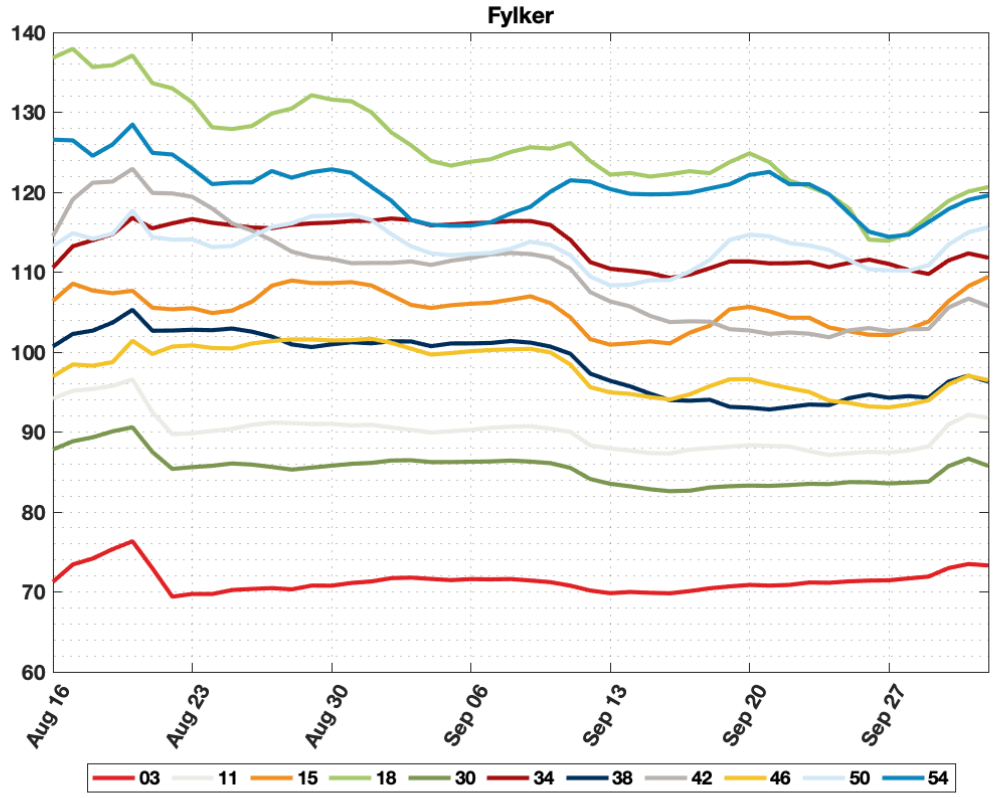


Figure 22: Zoom: Mobility from August 16, 2021 and onwards, per fylker: Oslo (03), Rogaland (11), Møre og Romsdal (15), Nordland (18), Viken (30), Innlandet (34), Vestfold og Telemark (38), Agder (42), Vestland (46), Trøndelag (50), Troms og Finnmark (54).

	36	37	38	39	40
Norge	97.0	96.2	92.8	93.4	92.2
Stavanger	86.0	85.7	84.8	85.4	84.0
Ålesund	97.6	95.7	93.8	97.2	96.8
Bodø	121.3	116.4	116.3	119.3	113.3
Bærum	69.0	70.5	68.4	69.0	69.2
Ringsaker	94.0	93.7	89.3	90.4	91.4
Sandefjord	90.8	91.0	86.9	84.4	86.1
Kristiansand	103.7	104.3	101.3	97.7	97.9
Bergen	89.5	89.2	87.5	88.6	87.3
Trondheim	107.7	102.8	100.4	106.3	104.7
Tromsø	125.5	115.9	123.6	127.8	121.7

Table 13: Municipalities

	36	37	38	39	40
Oslo	70.8	71.6	69.8	70.9	71.5
Rogaland	91.0	90.3	88.0	88.3	87.5
Møre og Romsdal	108.6	106.0	100.9	105.7	102.1
Nordland	131.6	123.8	122.2	124.9	113.9
Viken	85.8	86.3	83.5	83.3	83.6
Innlandet	116.2	116.1	110.4	111.3	111.0
Vestfold og Telemark	101.0	101.1	96.4	93.0	94.3
Agder	111.6	111.8	106.3	102.7	102.6
Vestlandet	101.5	100.1	95.0	96.6	93.1
Trøndelag	117.1	112.3	108.3	114.7	110.2
Troms og Finnmark	122.9	115.8	120.4	122.2	114.4

Table 14: Counties

Weekly mobility for Norway and selected municipalities is displayed in Table 13 and mobility for counties is displayed in Table 14. The percentages in the tables are to be interpreted towards the reference level of 100 for week 10 in March 2020. The color-coding encodes the following: 'Green' monotonic decrease in mobility, 'Yellow' almost monotonic decrease or flat mobility trend, 'Red' increasing mobility.

9.1 Foreign roamers on Telenor's network in Norway

An analysis of foreign roamers in Norway from January 2020 has been carried out, to better understand the potential virus importation. In Figure 23 the total number of roamers per day per county are displayed. We can see an approximate 40% drop in the number of visiting roamers after the lock-down in March 2020. The number of visiting roamers recover during the Summer of 2020, and there is a spike of visitors in August followed by a drop again. During October and November 2020 the levels of visiting, foreign roamers to Norway have reached quite high levels, just 10% short of the all-year high for 2020, and Oslo and Viken have seen big increases in visitors. There is a reduction in visitors during Christmas, and in January 2021 we see an increasing trend again.

Figure 24 shows the levels of roamers from the following countries: Poland, Lithuania, Sweden, Netherlands, Denmark, Latvia, Germany, Spain, Finland and the rest of the world. These levels represent the total number of foreign, visiting roamers from each of the countries per day in Norway, since July 5 2021.

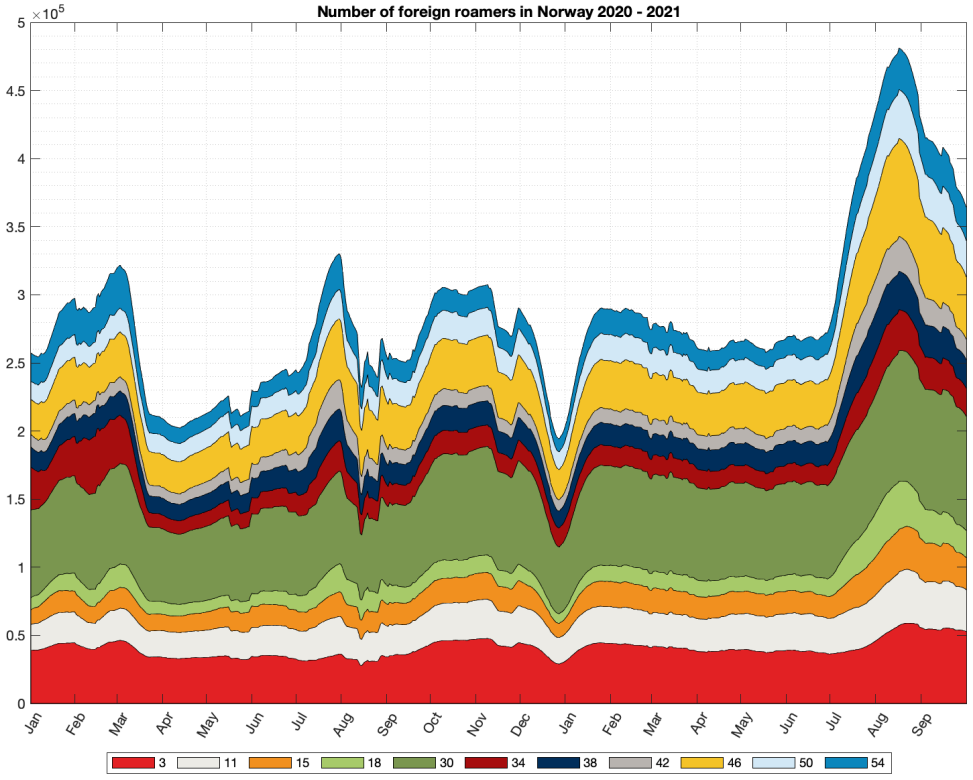


Figure 23: The total number of foreign roamers in Norway broken down on different fylker: Oslo (3), Rogaland (11), Møre og Romsdal (15), Nordland (18), Viken (30), Innlandet (34), Vestfold og Telemark (38), Agder (42), Vestland (46), Trøndelag (50), Troms og Finnmark (54).

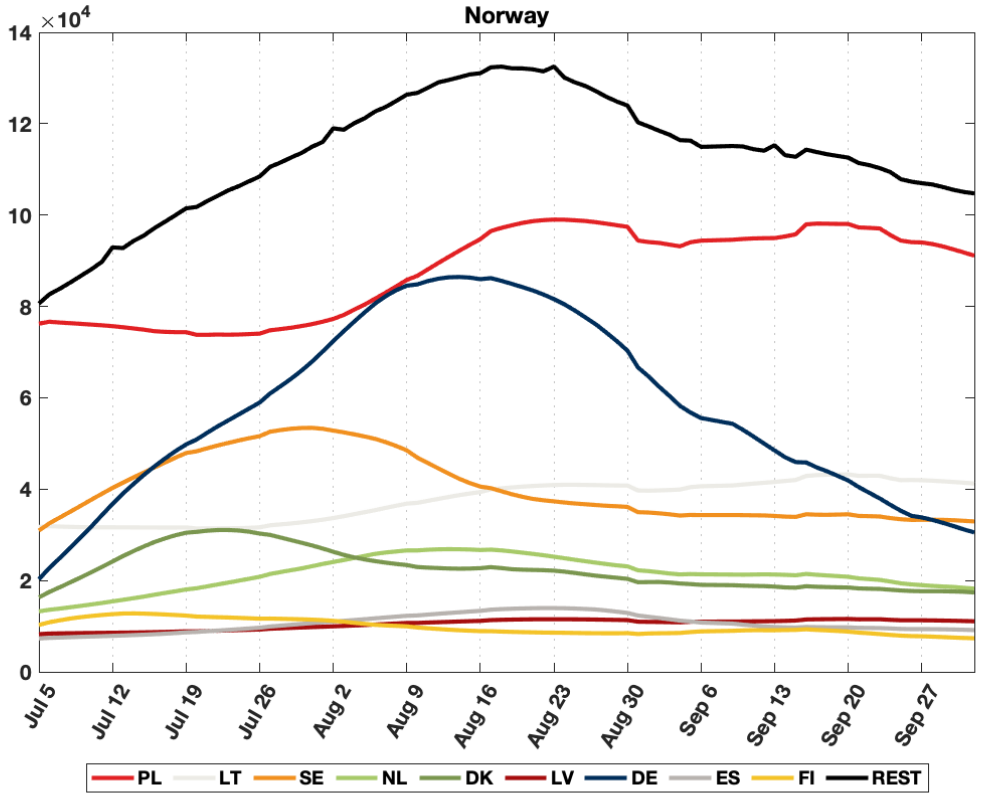
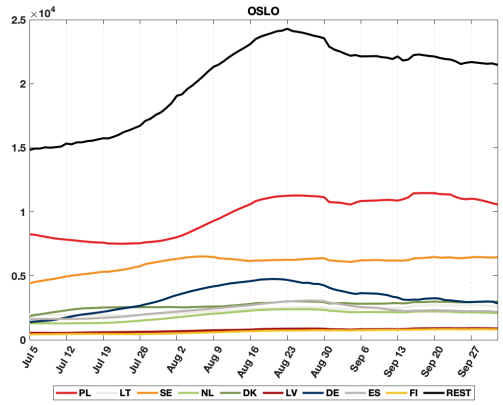
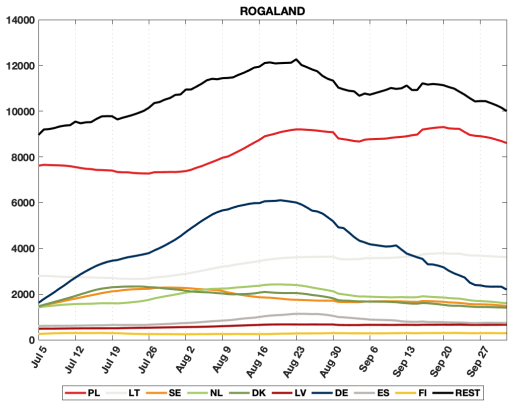
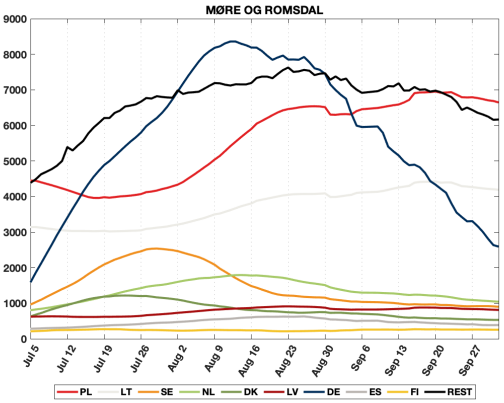


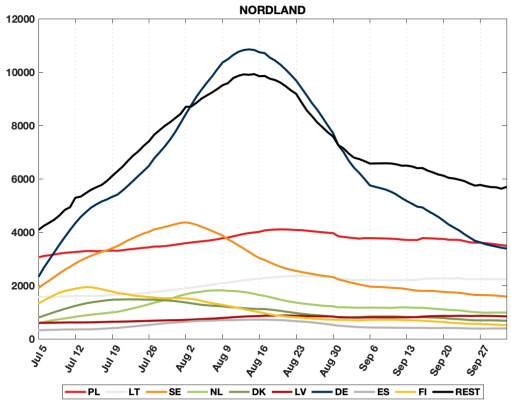
Figure 24: National overview of total number of foreign, visiting roamers from Poland, Lithuania, Sweden, Netherlands, Denmark, Latvia, Germany, Spain, Finland and the rest of the world.

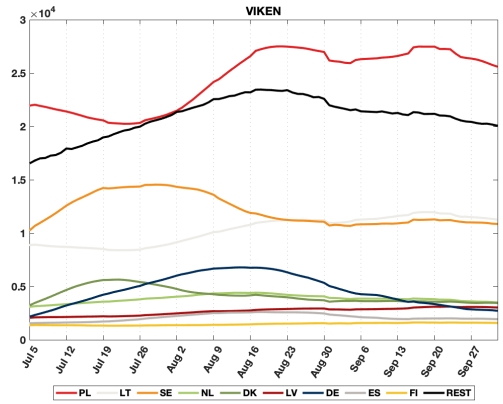
9.2 Foreign roamers per county (fylke) in Norway

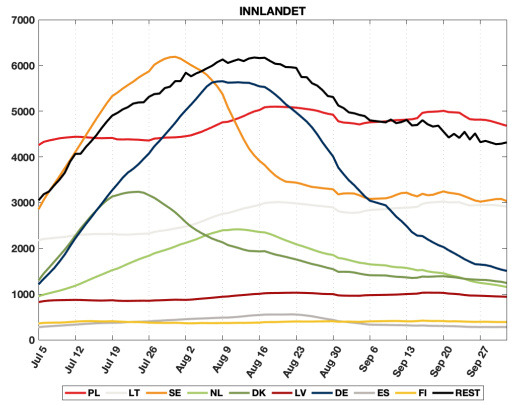




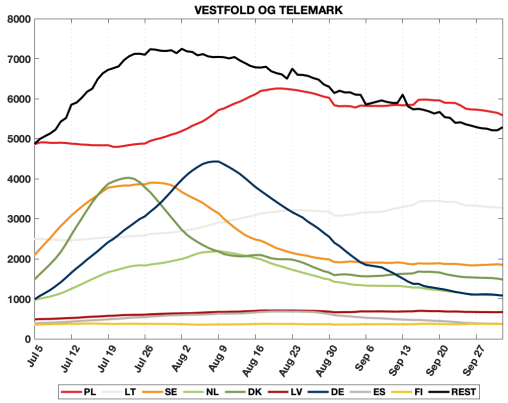


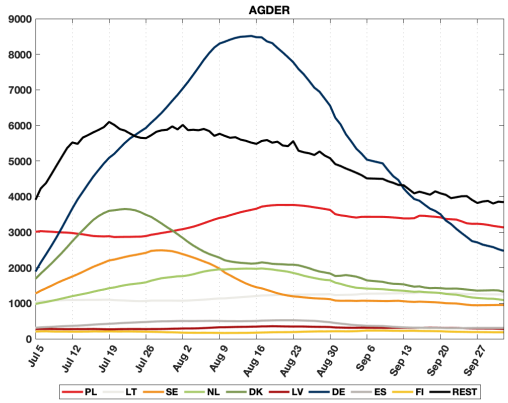


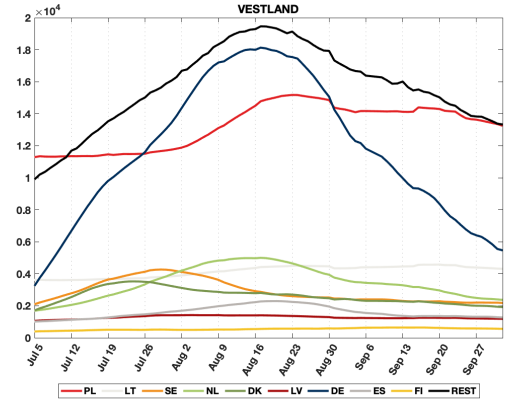


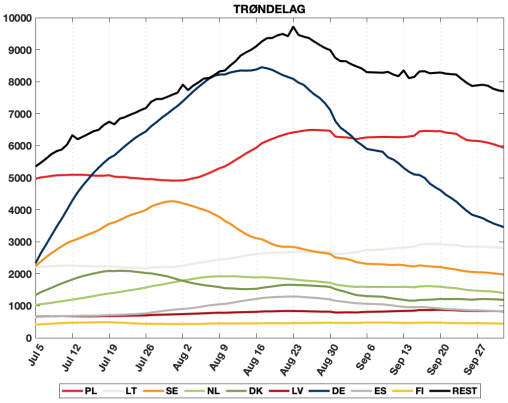


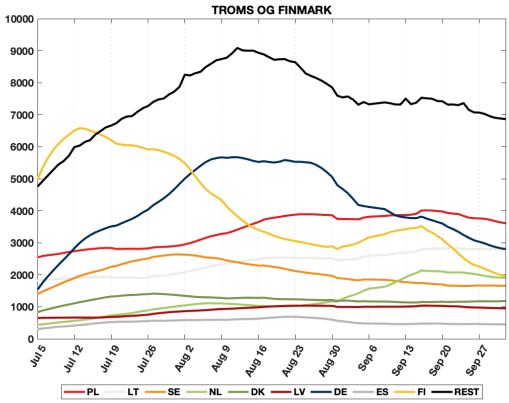
9.2 Foreign roamers per county (fylke) in Norway











10 Methods

10.1 Model

We use a metapopulation model to simulate the spread of COVID-19 in Norway in space and time. The model consists of three layers: the population structure in each municipality, information about how people move between different municipalities, and local transmission within each municipality. In this way, the model can simulate the spread of COVID-19 within each municipality, and how the virus is transported around in Norway.

10.1.1 Transmission model

We use an SEIR (Susceptible-Exposed-Infected-Recovered) model without age structure to simulate the local transmission within each area. Mixing between individuals within each area is assumed to be random. Demographic changes due to births, immigration, emigration and deaths are not considered. The model distinguishes between asymptomatic and symptomatic infection, and we consider presymptomatic infectiousness among those who develop symptomatic infection. In total, the model consists of 6 disease states: Susceptible (S), Exposed, infected, but not infectious (E_1), Presymptomatic infected (E_2), Symptomatic infected (I), Asymptomatic infected (I_a), and Recovered, either immune or dead (R). A schematic overview of the model is shown in figure 27.

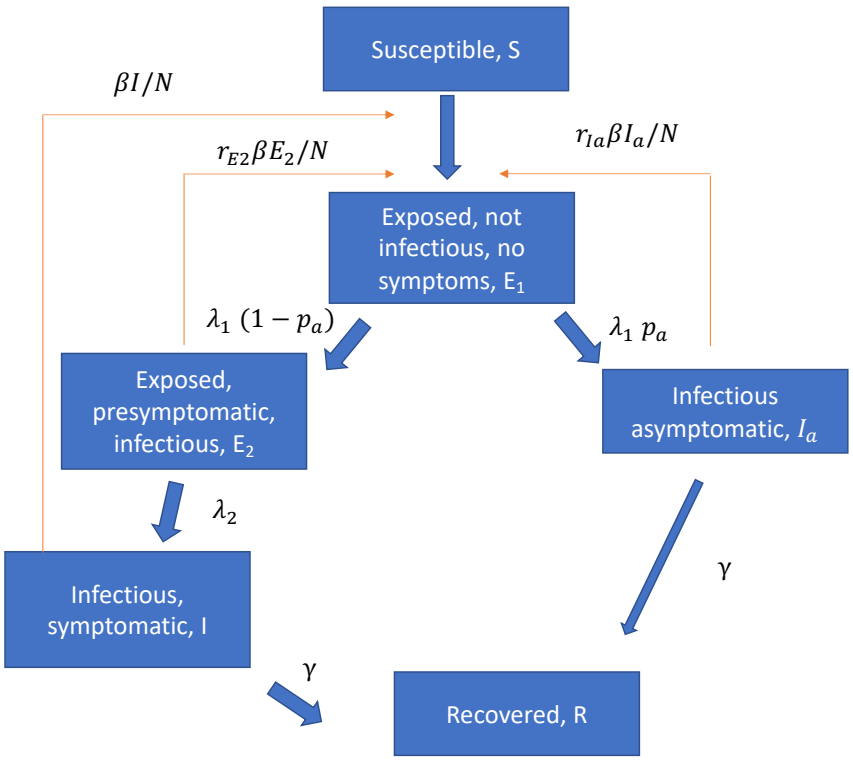


Figure 27: Schematic overview of the model.

10.2 Movements between municipalities:

We use 6-hourly mobility matrices from Telenor to capture the movements between municipalities. The matrices are scaled according to the overall Telenor market share in Norway, estimated to be 48%. Since week 8, we use the actual daily mobility matrices to simulate the past. In this way, alterations in the mobility pattern will be incorporated in our model predictions. To predict future movements, we use the

latest weekday measured by Telenor, regularised to be balanced in total in- and outgoing flow for each municipality.

10.3 Healthcare utilisation

Based on the estimated daily incidence data from the model and the population age structure in each municipality, we calculated the hospitalisation using a weighted average. We correct these probabilities by a factor which represents the over or under representation of each age group among the lab confirmed positive cases. The hospitalisation is assumed to be delayed relative to the symptom onset. We calculate the number of patients admitted to ventilator treatment from the patients in hospital using age-adjusted probabilities and an assumed delay.

10.4 Seeding

At the start of each simulation, we locate 5.367.580 people in the municipalities of Norway according to data from SSB per January 1. 2020. All confirmed Norwegian imported cases with information about residence municipality and test dates are used to seed the model, using the data available until yesterday. For each case, we add an additional random number of infectious individuals, in the same area and on the same day, to account for asymptomatic imported cases who were not tested or otherwise missed. We denote this by the amplification factor.

10.5 Calibration

Estimation of the parameters of the model: the reproduction numbers, the amplification factor for the imported cases, the parameters of the detection probability and the delay between incidence and test, is done using Sequential Monte Carlo Approximate Bayesian Computation (SMC-ABC), as described in Engebretsen et al. (2020): https://royalsocietypublishing.org/doi/10.1098/rsif.2019.0809, where the algorithm can be found in the supplement.

The idea behind ABC is to try out different parameter sets, simulate using these, then compare how much the simulations deviate from the observations in terms of summary statistics. We thus test millions of combinations of the different reproductive numbers, the amplification factor, and the parameters for the positive tests, to determine the ones that lead to the best fits to the true number of hospitalised individuals, from March 10 2020 until the last available data point, and the laboratory-confirmed COVID-19 cases from May 1 until the latest available data point.

In the ABC procedure we thus use two summary statistics, one is the distance between the simulated hospitalisation incidence and the observed incidence, and the other is the distance between the observed number of laboratory-confirmed cases and the simulated ones. As the two summary statistics are not on the same scale, we use two separate tolerances in the ABC-procedure, ensuring that we get a good fit to both data sources.

10.5.1 Calibration to hospitalisation data

In order to calibrate to the hospitalisation data, we need to simulate hospital incidence. The details on how we simulate hospitalisations are described in Section 10.3, using the parameters provided in Section **??**, which are estimated from individual-level Norwegian data, and updated regularly. As our distance measure, we calculate the squared distance over each time point and each county.

10.5.2 Calibration to test data

We include the laboratory-confirmed cases in the calibration procedure, as these contain additional information about the transmissibility, and the delay between transmission and testing is shorter than the delay between transmission and hospitalisation. Therefore, we simulate also the number of detected positive cases in our model. We assume that the number of detected positive cases can be modelled as a binomial process of the simulated daily total incidence of symptomatic and asymptomatic cases, with a

success probability π_t, which changes every day. We also assume a delay d between the day of test and the day of transmission.

The data on the number of positive cases are more difficult to use, as the test criteria and capacity have changed multiple times. We take into account these changes by using the total number of tests performed on each day, as a good proxy of capacity and testing criteria. Moreover, we choose not to calibrate to the test data before May 1, because the test criteria and capacity were so different in the early period. The detection probability is modelled as

$$\pi_t = \exp(\pi_0 + \pi_1 \cdot k_t)/(1 + \exp(\pi_0 + \pi_1 \cdot k_t)),$$

where k_t is the number of tests actually performed on day t, and π_0 and π_1 are two parameters that we estimate, assuming positivity of π_1. We also estimate the delay d. We choose to use a 7-days backwards moving average for the covariate k_t. To calculate the distance between the observed number of positive tests and the simulated ones we also use a 7-days backwards moving average. We do this to take into account potential day-of-the-week-effects. For example, it could well be that the testing criteria are different on weekends and weekdays. However, using instead the number of tests and calibrating on a daily basis would lead to a larger day-to-day variance. This is likely why we find that the uncertainty in the simulated positive cases seems somewhat too low, and that we do not capture all the variance in the daily test data. Moreover, the binomial assumption could be too simple, and a beta-binomial distribution would allow more variance. A limitation of our current model for the detection probability, is that we only capture the changes in the test criteria that are captured in the total number of tests performed.

10.6 Specifications for the national changepoint model

In the national changepoint model, we assume a first reproduction number R_0 until March 14, a second reproduction number R_1 until April 19, a third reproduction number R_2 until May 10, a fourth reproduction number R_3 until June 30, R_4 until July 31, R_5 until August 31, R_6 from September 1 until September 30, R_7 from October 1 until October 26, R_8 until November 4, R_9 from November 5th until November 30th, R_{10} from December 1st until January 4, a twelfth reproduction number R_{11} from January 4 until January 21, a thirteenth reproduction number from January 22 to February 7 and a fourteenth reproduction number from February 8. This last reproduction number is used for the future. The changepoints follow the changes in restrictions introduced. In the calibration procedure, we obtain 200 parameter sets that we use to represent the distributions of parameters.

After we have obtained the estimated parameters, we run the model with these 200 parameter sets again, from the beginning until today, plus three weeks into the future (or for an additional year). In this way, we obtain different trajectories of the future, allowing us to investigate different scenarios, with corresponding uncertainty.

10.7 Specifications for the regional changepoint model

In the regional changepoint model, each county has its own reproduction numbers, assumed constant in different periods, just like the national changepoint model. As there are more parameters in the regional changepoint model, we obtain 1000 parameter sets in the ABC-SMC.

Calibrating regional reproduction numbers is a more difficult estimation problem than calibrating national reproduction numbers, as we have a lot more parameters, and in addition less data in each county. Therefore, we cannot include the same amount of changepoints in the regional model as we can for the national model.

After we have obtained the estimated parameters, we run the model with these 1000 parameter sets again, from the beginning until today, plus three weeks into the future (or for an additional year). In this way, we obtain different trajectories of the future, allowing us to investigate different scenarios, with corresponding uncertainty.

10.7 Specifications for the regional changepoint model

Table 15: Assumptions

Assumptions	Mean	Distribution	Reference
Mobile Mobility Data			
Telenor coverage	48%		https://ekomstatistikken.nkom.no/
Data updated	August 29		
Data used in the predictions	August 27th	Fixed	Corrected to preserve population
Model parameters			
Exposed period ($1/\lambda_1$)	2 days	Exponential	changed from Feretti et al 2020
Pre-symptomatic period ($1/\lambda_2$)	2 days	Exponential	Feretti et al 2020
Symptomatic infectious period ($1/\gamma$)	3 days	Exponential	changed from Feretti et al 2020
Asymptomatic, infectious period ($1/\gamma$)	3 days	Exponential	changed from Feretti et al 2020
Infectiousness asympt. (r_{I_a})	0.1	Fixed	Feretti et al 2020
Infectiousness presymp (r_{E_2})	1.3	Fixed	guided by Feretti et al 2020
Prob. asymptomatic infection (p_a)	0.4		Feretti et al 2020
Healthcare			
Fraction asymptomatic infections	40%	Fixed	Mizumoto et al 2020 20% for the old population, Diamond Princess
% symptomatic and asymptomatic infections requiring hospitalization: 0-9 years 10 - 19 years 20 - 29 years 30 - 39 years 40 - 49 years 50 - 59 years 60 - 69 years 70 - 79 years 80+ years	 0.1% 0.1% 0.5% 1.1% 1.4% 2.9% 5.8% 9.3% 22.3%	Fixed	Saljie et al 2020 corrected for: % of elderly living in elderly homes in Norway (last two age groups) and corrected for presence among positive tested since May 1.
Probability that an admission has been reported on Monday From Sunday From Saturday From Friday From Thursday	 32% 49% 68% 86%	Fixed	Estimated from "Beredskapsregistret BeredtC19"
Probability that an admission has been reported From one day before From two days before From three days before From four days before	 53% 77% 82% 91%	Fixed	Estimated from "Beredskapsregistret BeredtC19"
Probability that a positive laboratory test has been reported From one day before From two days before From three days before From four days before	 6.7% 59% 90% 97%	Fixed	Estimated from MSIS
Probability that a negative laboratory test has been reported From one day before From two days before From three days before From four days before	 16% 74% 92% 98%	Fixed	Estimated from MSIS

Supplementary analysis: EpiEstim estimation of reproduction number based on laboratory-confirmed cases

To complement the results of the metapopulation model, we present estimates of the temporal evolution of the reproduction number in Norway based on an analysis of laboratory-confirmed cases. The primary purpose of this analysis is to provide a more comprehensive perspective on the epidemic situation, taking into account several data sources.
The combination of hospitalisation data and test data used in the main analysis are likely a less biased information source for the number of real infections, but since testing-criteria have remained constant over a long period of time, we also expect that using confirmed cases can give a reasonable estimate of the reproduction number in this phase of the epidemic. In this approach we do not take into account changes in the number of tests, for example during holidays, so the results in these periods are likely to under-estimate the reproduction number when the holiday starts and overestimate it when the holiday ends and the number of tests return to it's normal level.

EpiEstim method and assumptions: We estimate the instantaneous reproduction number using the procedure outlined in Thompson et al. (2019). This method, implemented in the EpiEstim R-package, uses a Bayesian approach to estimate the instantaneous reproduction number smoothed over a sliding window of 4 days nationally and 7 days regionally, see figure 28. For the results to be comparable to those of the metapopulation model, we use the same natural history parameters. We estimate the date of infection for each confirmed case by first estimating the date of symptom onset and then subtracting 5 days for the incubation period. We estimate the date of symptom onset from the empirical delay between onset and testing in the first reported cases. For each case, we draw 100 possible onset dates from the delay distribution; this gives us 100 epi-curves that we use to estimate the reproduction number. The displayed results are the combined results from all these 100 simulated epi-curves. The serial interval was assumed to be 5 days with uncertainty; the serial interval refers to the time between symptom onset between successive cases in a chain of transmission (see https://www.medrxiv.org/content/10.1101/2020.02.03.20019497v2). To account for censoring of observations with onset dates in the last few days we correct the observed data by the mean of a negative binomial distribution with observation probability given by the empirical cumulative distribution of the onset to reporting date distributions. Due to this correction, the results from the last few days are uncertain, as indicated by increasing credible intervals.

Table 16: Estimated reproduction numbers 7 days ago

Location	Reff
National	0.83(0.79 - 0.87)
Oslo	0.85(0.8 - 0.91)
Rogaland	0.76(0.62 - 0.92)
Møre og Romsdal	0.87(0.68 - 1.09)
Nordland	0.78(0.63 - 0.97)
Viken	0.77(0.73 - 0.83)
Innlandet	0.7(0.58 - 0.82)
Vestfold og Telemark	0.84(0.7 - 1.01)
Agder	0.85(0.68 - 1.05)
Vestland	0.86(0.71 - 1.02)
Trøndelag	0.85(0.74 - 0.98)
Troms og Finnmark	0.81(0.68 - 0.95)

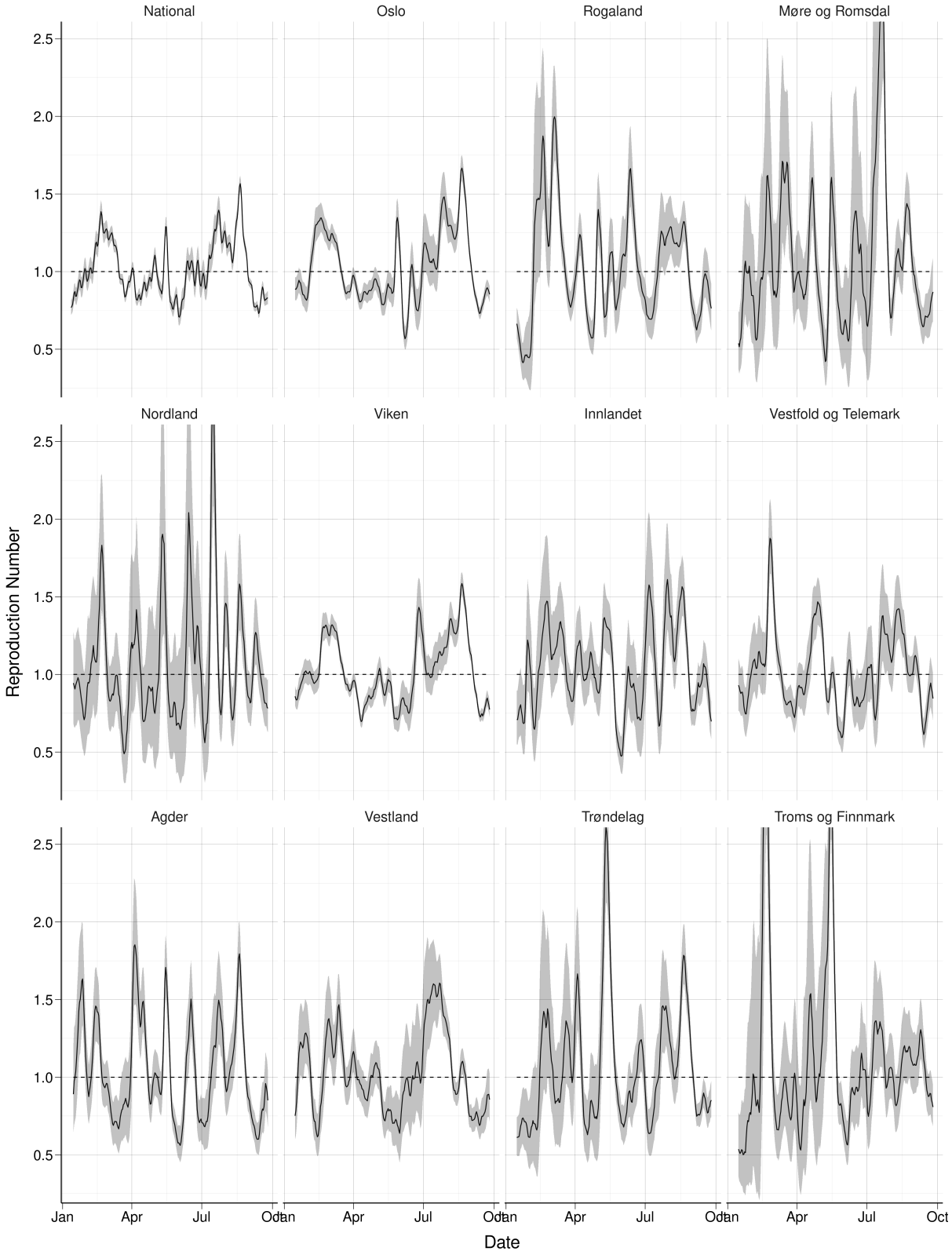


Figure 28: Reproduction number estimated using the R package EpiEstim.

10.7 Specifications for the regional changepoint model

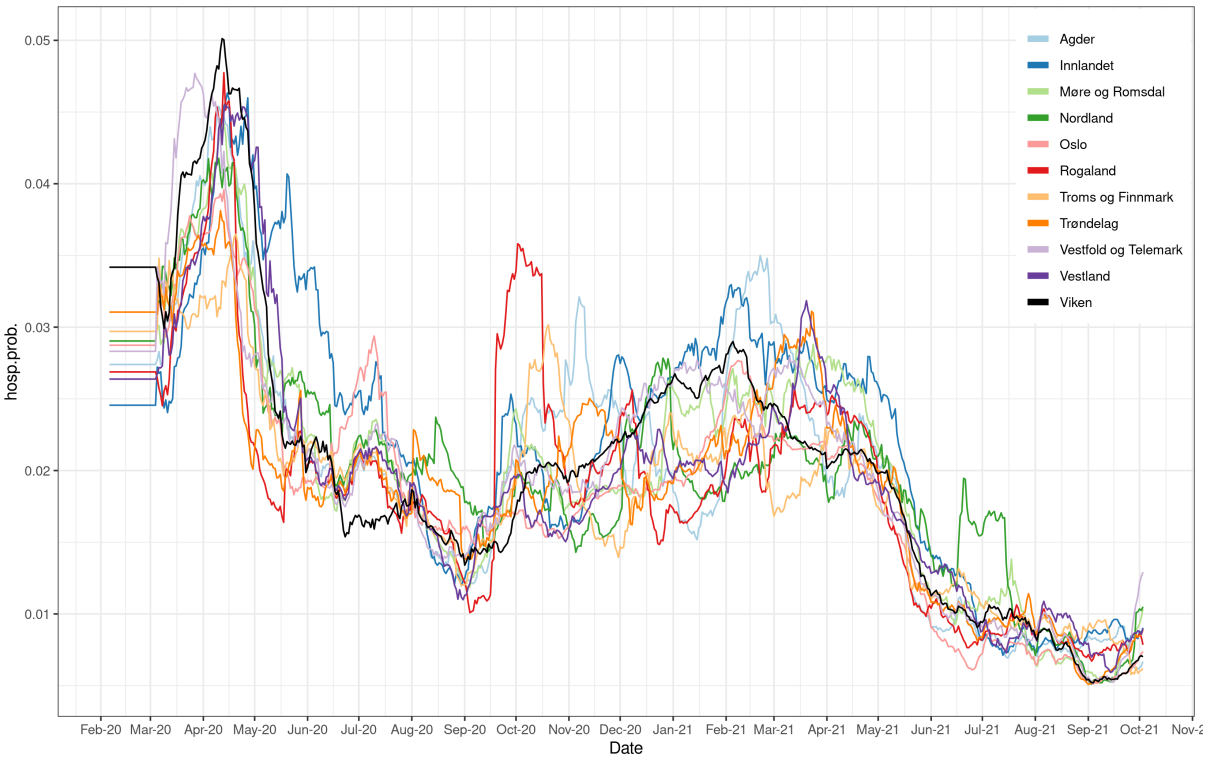


Figure 29: Regional hospitalization probabilities per infection. The estimates are based on Salje et al., and regional data on the age distribution in the test data and the empirical case-hospitalisation rates.

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