

# Probabilistic ensemble forecasting of Australian COVID-19 cases

Rob J Hyndman

[robjhyndman.com/covidtalk](http://robjhyndman.com/covidtalk)



MONASH University

# Australian Health Protection Principal Committee

The **Australian Health Protection Principal Committee** is the key decision-making committee for national health emergencies. It comprises all state and territory Chief Health Officers and is chaired by the Australian Chief Medical Officer.

## COVID-19 forecasting group

- |                 |                        |                   |
|-----------------|------------------------|-------------------|
| ■ Peter Dawson  | ■ Jodie McVernon       | ■ Joshua V Ross   |
| ■ Nick Golding  | ■ Pablo Montero-Manso  | ■ Gerry Ryan      |
| ■ Rob J Hyndman | ■ Robert Moss          | ■ Freya M Shearer |
| ■ Dennis Liu    | ■ Mitchell O'Hara-Wild | ■ Tobin South     |
| ■ James M McCaw | ■ David J Price        | ■ Ruarai Tobin    |

# Data sources

- Case-level data of all positive COVID-19 tests: onset and detection times.
- Daily population mobility data from Google, Apple & Facebook
- Weekly non-household contact surveys
- Weekly behavioural surveys
- Daily case numbers from many countries and regions via the Johns Hopkins COVID-19 repository

# Case numbers

```
localcases %>% filter(state == "VIC", date >= "2020-07-01")
```

```
## # A tsibble: 353 x 3 [1D]
```

```
## # Key:           state [1]
```

```
##   date      state      n
```

```
##   <date>    <chr> <dbl>
```

```
## 1 2020-07-01 VIC      116
```

```
## 2 2020-07-02 VIC      113
```

```
## 3 2020-07-03 VIC      161
```

```
## 4 2020-07-04 VIC      161
```

```
## 5 2020-07-05 VIC      156
```

```
## 6 2020-07-06 VIC      237
```

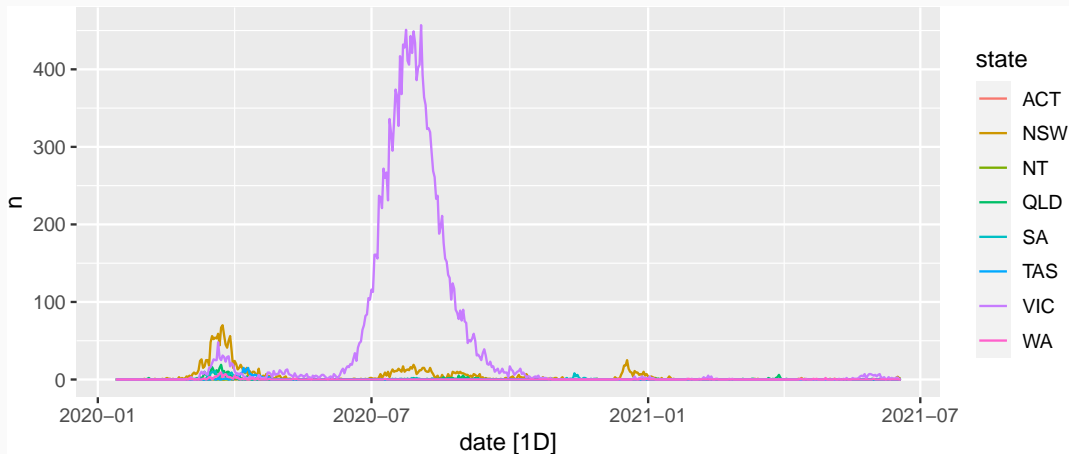
```
## 7 2020-07-07 VIC      235
```

```
## 8 2020-07-08 VIC      221
```

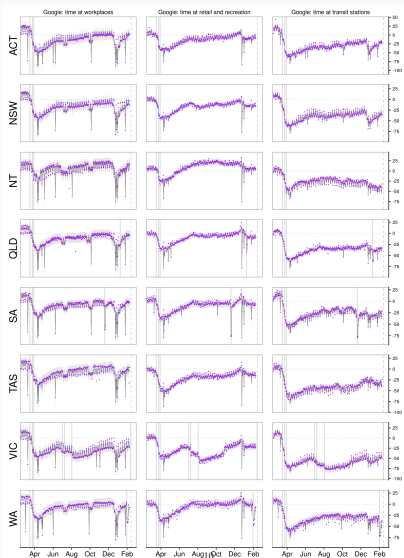
```
## 9 2020-07-09 VIC      272
```

# Case numbers

```
localcases %>% autoplot(n)
```



# Google mobility data

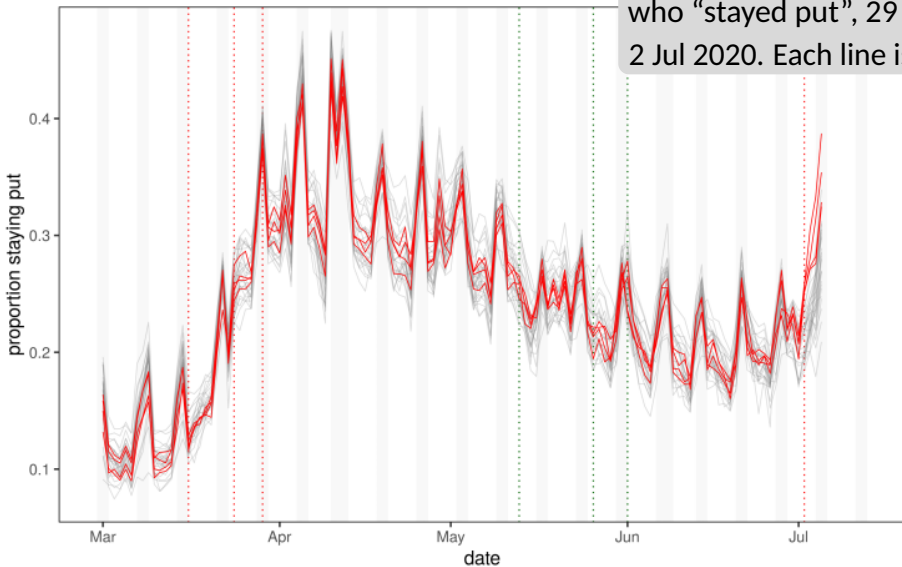


Percentage change compared to pre-COVID-19 baseline for:

- (a) time at workplace;
- (b) time at retail/recreation;
- (c) time at transit stations.

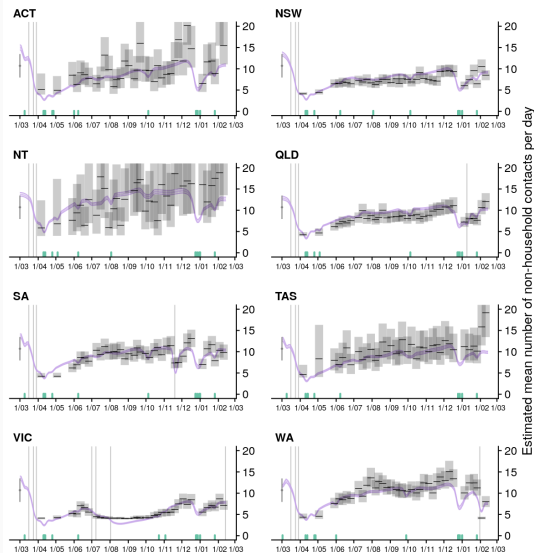
Vertical lines: physical distancing measures implemented.

# Facebook mobility data



Proportion of Facebook users who “stayed put”, 29 Feb – 2 Jul 2020. Each line is one LGA.

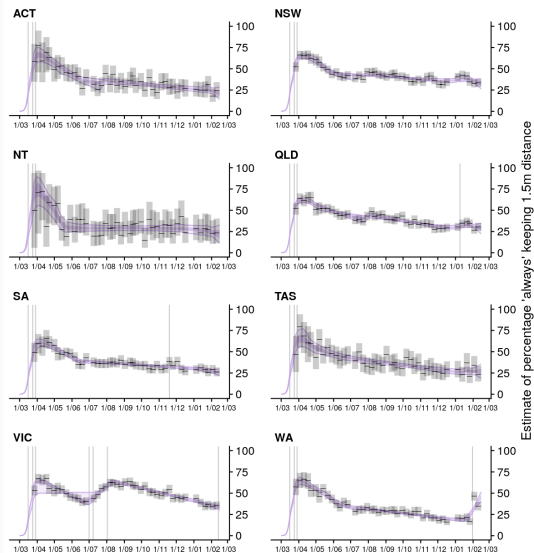
# Macrodistancing



**Estimated # non-household contacts per day** based on nationwide weekly surveys (gray) and Google mobility data.  
Green: public holidays.



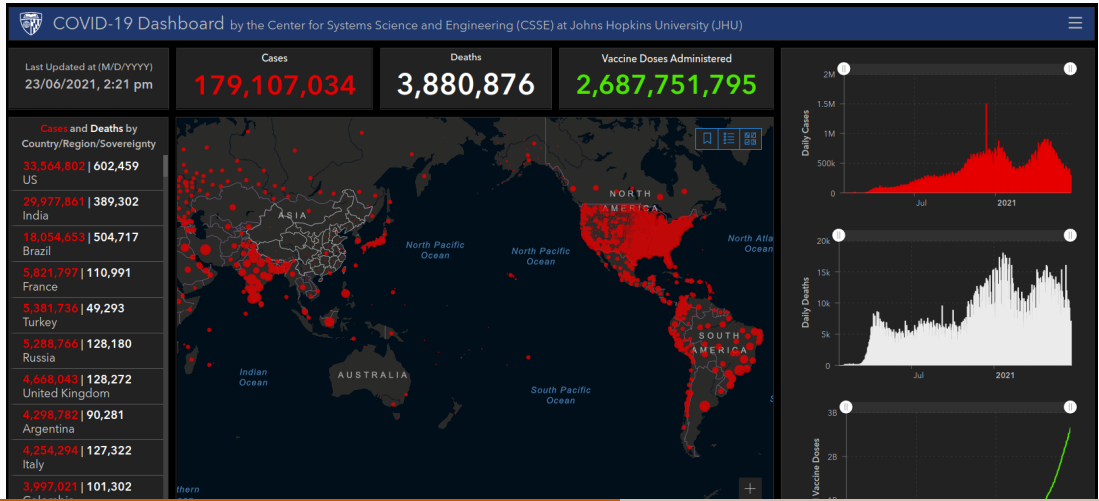
# Microdistancing



**Estimated % keeping 1.5m distance from non-household contacts based on nationwide weekly surveys (gray).**

# Global daily cases by region from Johns Hopkins

<https://github.com/CSSEGISandData/COVID-19>



## Model 1: SEIIR (Uni Melbourne/Doherty Institute)

- Stochastic susceptible-exposed-infectious-recovered compartmental model that incorporates changes in local transmission potential via a time-varying effective reproduction number.
- Uses mobility and survey data and case onset and detection times.
- Daily counts  $\sim$  Negative Binomial.
- Time in class  $\sim$  Gamma.
- Forecasts obtained using a bootstrap particle filter.

## Model 2: Generative model (Uni Adelaide)

- Uses mobility and survey data and case onset and detection times.
- Three types of infectious individuals: imported, asymptomatic, symptomatic
- Class counts  $\sim$  Negative Binomial.
- Incubation times  $\sim$  Gamma.
- Estimation via Hamilton Monte Carlo
- Forecasts obtained via simulation

## Model 3: Global AR model (Monash)

- Uses Johns Hopkins data from countries and regions with sufficient data.
- Series with obvious anomalies (negative cases and large step changes) removed.
- $n_{t,i}$  = daily cases on day  $t$  in country/region  $i$  (scaled so all data have same mean and variance).
- $y_{t,i} = \phi_1 y_{t-1,i} + \dots + \phi_p y_{t-p,i} + \varepsilon_{t,i}$   
where  $y_{t,i} = \log(n_{t,i} + 0.5)$  and  $\varepsilon_{t,i} \sim N(0, \sigma_i^2)$ .
- No stationarity constraints. Common coefficients.
- Current model has  $p = 24$  (selected to minimize the 7-day-ahead MAE on recent Australian data).

# Forecasting ensemble

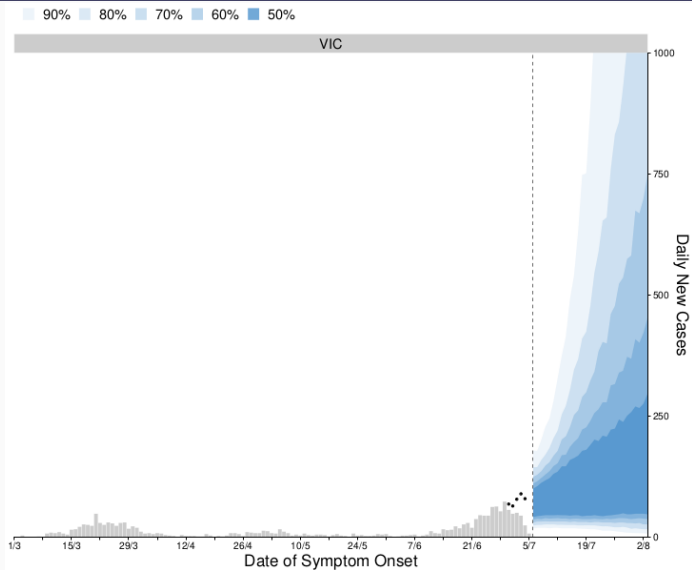
- Forecasts obtained from a mixture distribution of the component models.

$$\tilde{p}(y_{t+h}|I_t) = \sum_{k=1}^3 w_{t+h|t,k} p_k(y_{t+h}|I_t)$$

where  $p_k(y_{t+h}|I_t)$  is the forecast distribution from model  $k$ ,  $I_t$  denotes the data available at time  $t$  and the weights  $w_{t+h|t,k} > 0$  sum to one.

- Also known as “linear pooling”
- Works best when individual models are over-confident and use different data sources.

# Ensemble forecasts



# Ensemble forecasts



# Ensemble forecasts

# Evaluating probabilistic forecasts

$f_{p,t}$  = quantile forecast with prob.  $p$  at time  $t$ .

$y_t$  = observation at time  $t$

# Evaluating probabilistic forecasts

$f_{p,t}$  = quantile forecast with prob.  $p$  at time  $t$ .

$y_t$  = observation at time  $t$

## Quantile score

$$Q_{p,t} = \begin{cases} 2(1-p)|y_t - f_{p,t}|, & \text{if } y_t < f_{p,t} \\ 2p|y_t - f_{p,t}|, & \text{if } y_t \geq f_{p,t} \end{cases}$$

# Evaluating probabilistic forecasts

$f_{p,t}$  = quantile forecast with prob.  $p$  at time  $t$ .

$y_t$  = observation at time  $t$

## Quantile score

$$Q_{p,t} = \begin{cases} 2(1-p)|y_t - f_{p,t}|, & \text{if } y_t < f_{p,t} \\ 2p|y_t - f_{p,t}|, & \text{if } y_t \geq f_{p,t} \end{cases}$$

# Evaluating probabilistic forecasts

$f_{p,t}$  = quantile forecast with prob.  $p$  at time  $t$ .

$y_t$  = observation at time  $t$

## Quantile score

$$Q_{p,t} = \begin{cases} 2(1-p)|y_t - f_{p,t}|, & \text{if } y_t < f_{p,t} \\ 2p|y_t - f_{p,t}|, & \text{if } y_t \geq f_{p,t} \end{cases}$$

- Low  $Q_{p,t}$  is good
- Multiplier of 2 often omitted, but useful for interpretation
- $Q_{p,t}$  like absolute error (weighted to account for likely exceedance)
- Average  $Q_{p,t}$  over  $p$  = CRPS (Continuous Rank Probability Score)

# Ensemble forecasts

## More information

 [robjhyndman.com](http://robjhyndman.com)

 [@robjhyndman](https://twitter.com/robjhyndman)

 [@robjhyndman](https://github.com/robjhyndman)

 [rob.hyndman@monash.edu](mailto:rob.hyndman@monash.edu)