Predictive Modeling approach of COVID-19 propagation in France

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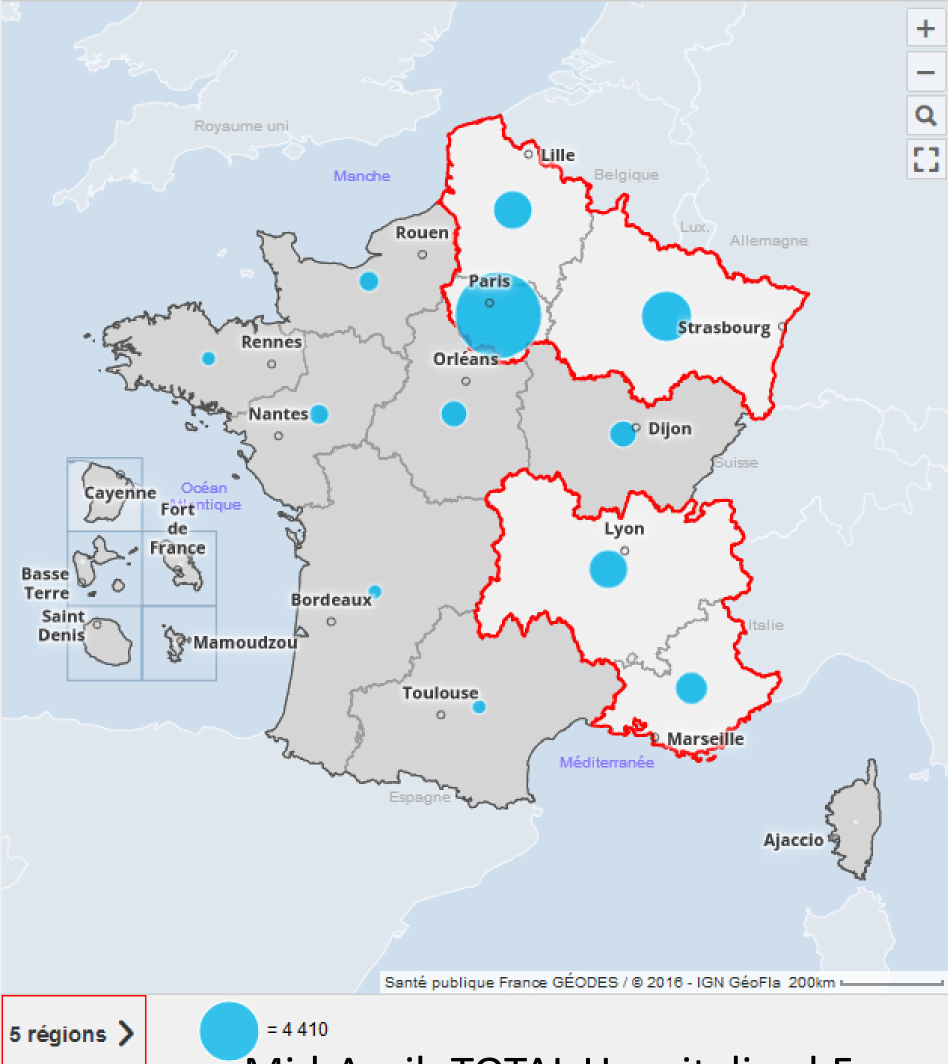
Topics

1. **Public data**
2. **Evaluation of masks and social distancing**
3. **Model calibration**
4. **Simulation results**
5. **Method: Covid multiscale rate modeling**
6. **Main conclusions of simulations**

Public data

Focus on 5 Main regions

1 Nombre de personnes actuellement hospitalisées pour COVID-19 - tous âges 2020-05-06 ▾ ACTIONS



Nombre de personnes actuellement hospitalisées pour covid-19 - tous âges ACTIONS

France : **23 912**

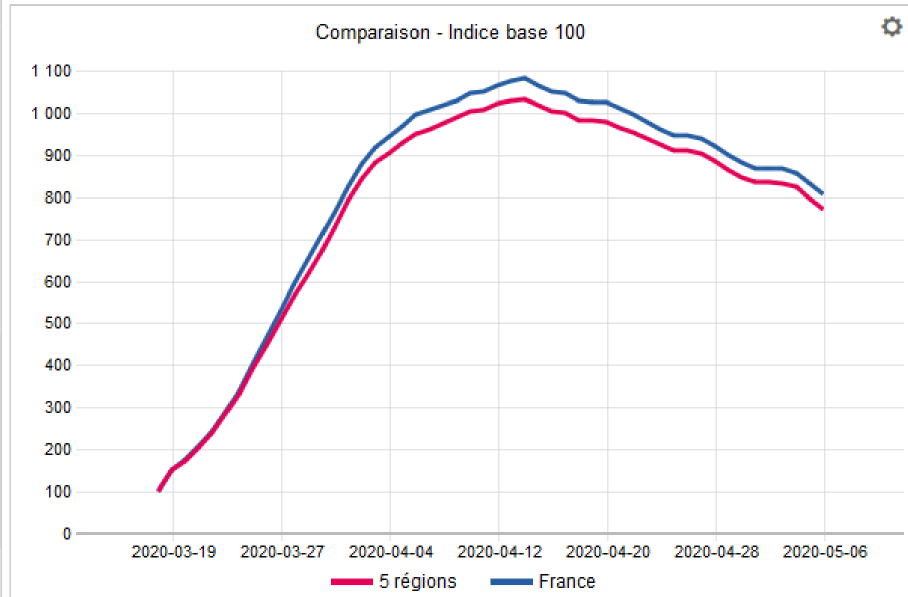
5 régions : **19 187**

Chiffres-clés 2020-05-06

Statistique	France	5 régions
minimum	5 (Guyane - 03)	1 359 (Provence-Alpes-Côte d'Azur - 93)
maximum	9 930 (Île-de-France - 11)	9 930 (Île-de-France - 11)
moyenne	1 328	3 837
médiane	549	2 299
observations valides	18 sur 18	5 sur 5

Graphiques et comparaisons

Évolution temporelle comparée ▾

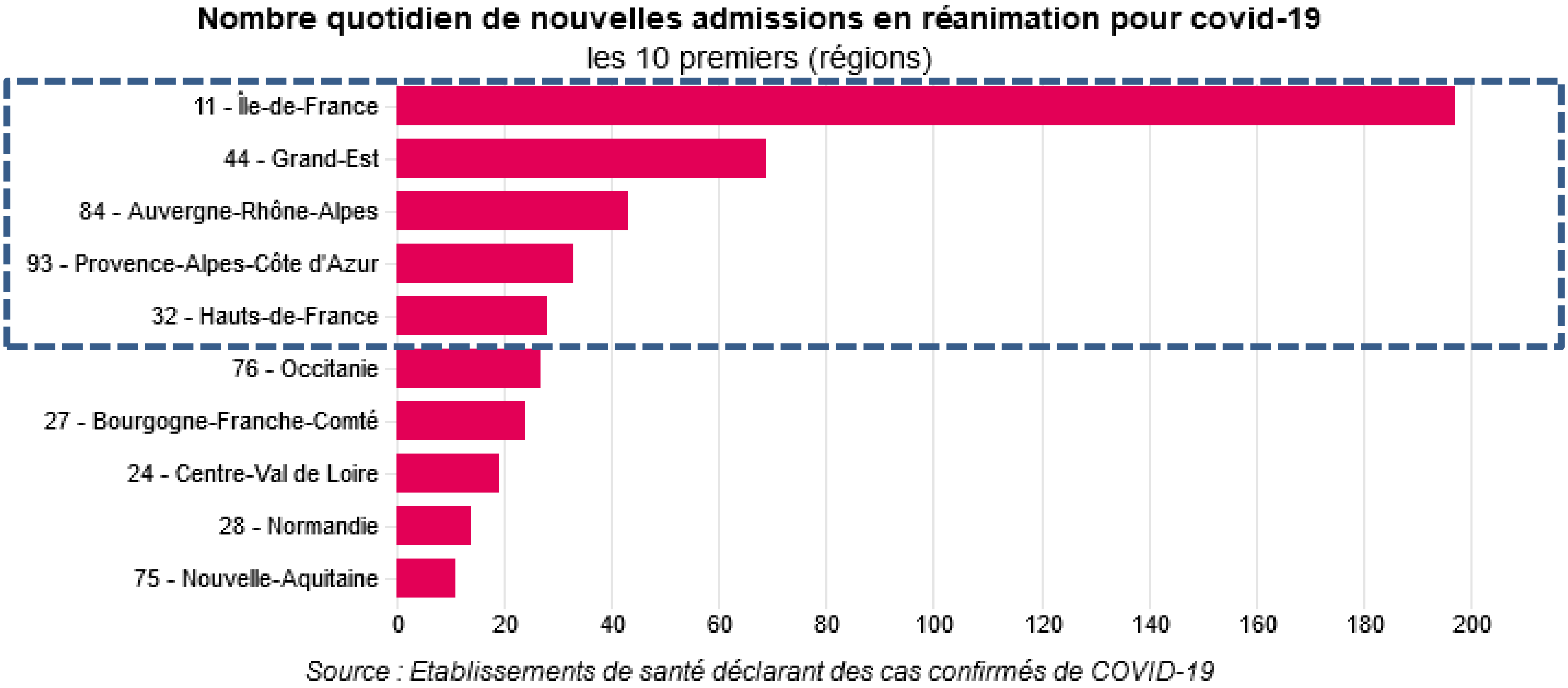


Mid-April: TOTAL Hospitalized France =28254 vs 5 regions 23450 **Fraction=0.8**

Total population : 36.792 million/5 regions compared to 67 Millions **Fraction=0.54**

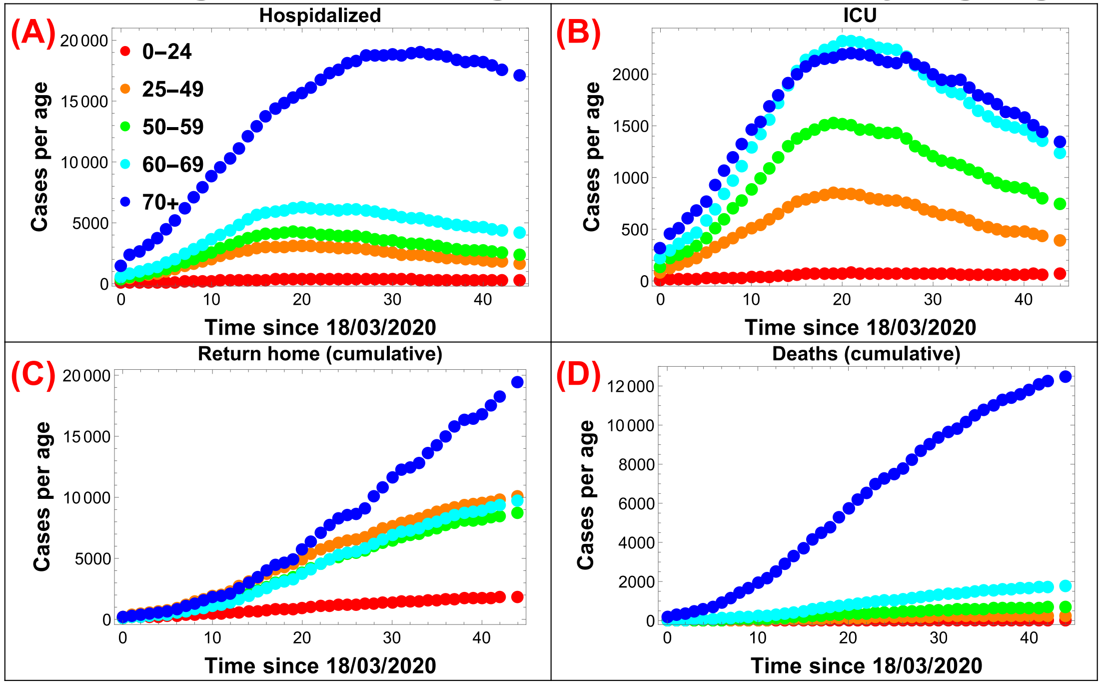
Conclusion: ½ of the population concentrate 80% of cases.

Focus on 5 Main regions



Monitoring 5 Main regions/France by age groups

France

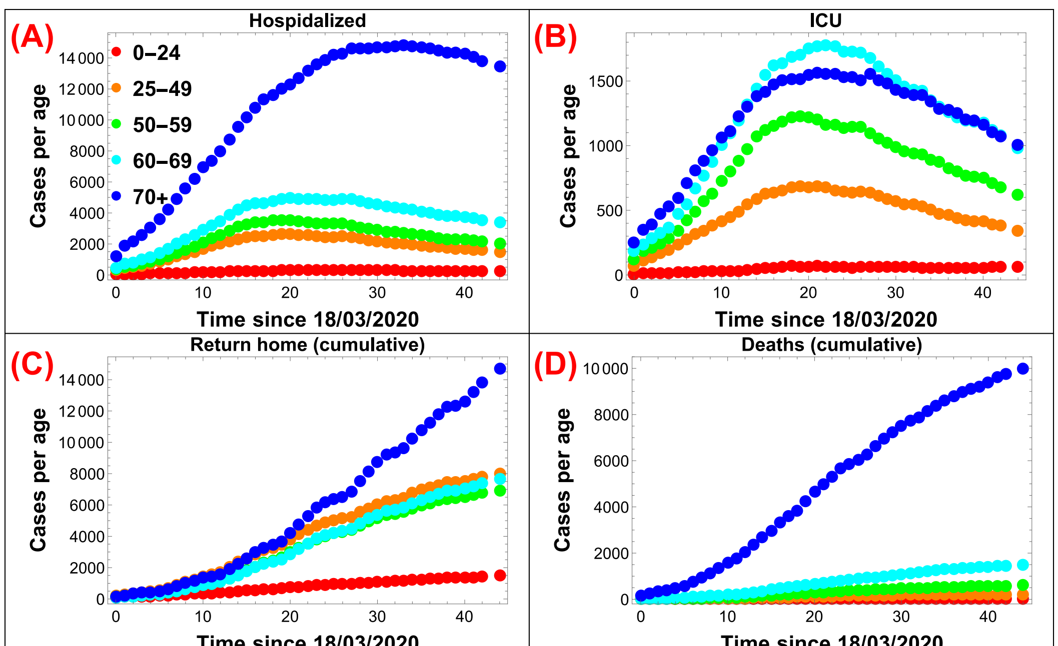


Age group

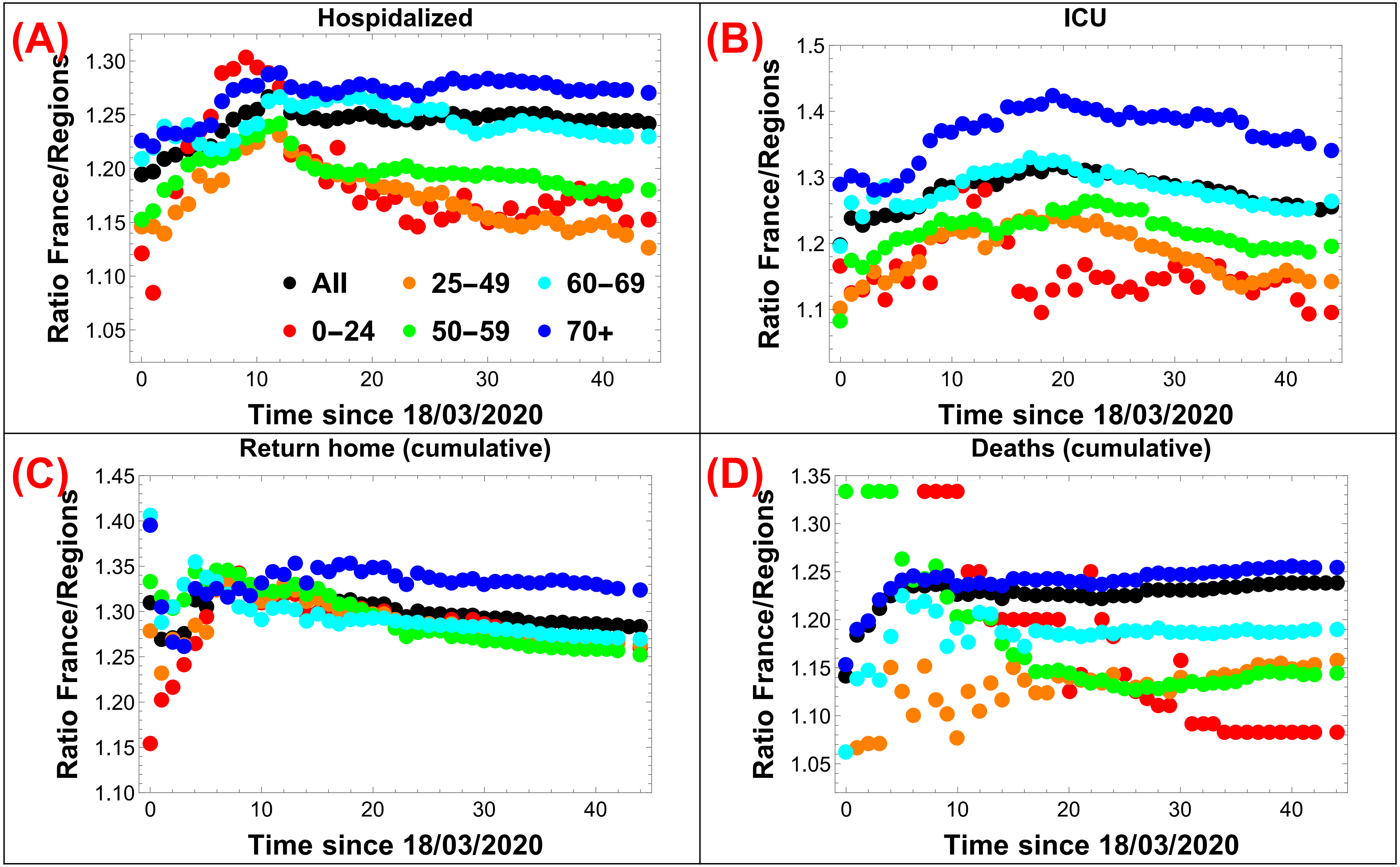
- 0-24: group 1
- 25-49: group 2
- 50-59: group 3
- 60-69: group 4
- >70: group 5

5 Regions

- Île-de-France
- Grand-Est
- Auvergne-Rhône-Alpes
- Hauts-de-France
- Provence-Alpes-Côte d'Azur



Ratio France and 5 Regions (ratio of the curves in the previous slide)



Conclusion: ratio of various parameters is almost constant. We decided to focus on 5 most impacted regions and when possible extrapolate to France.

Construction of a multiscale rate Model

-Flexible compared to SIR and extension
-Can account for changes in decisions occurring in hospitals
-Can be updated in real time

Model construction

0-24: group 1
25-49: group 2
50-59: group 3
60-69: group 4
>70: group 5

- Group 1—5: age group→ filled
- Infectious Category: 1—7: hospitalized, infected, recovered, etc…
- Time evolution from day n→n+1
- Time after infection
- Time spent in each category.

Ingredient of the model

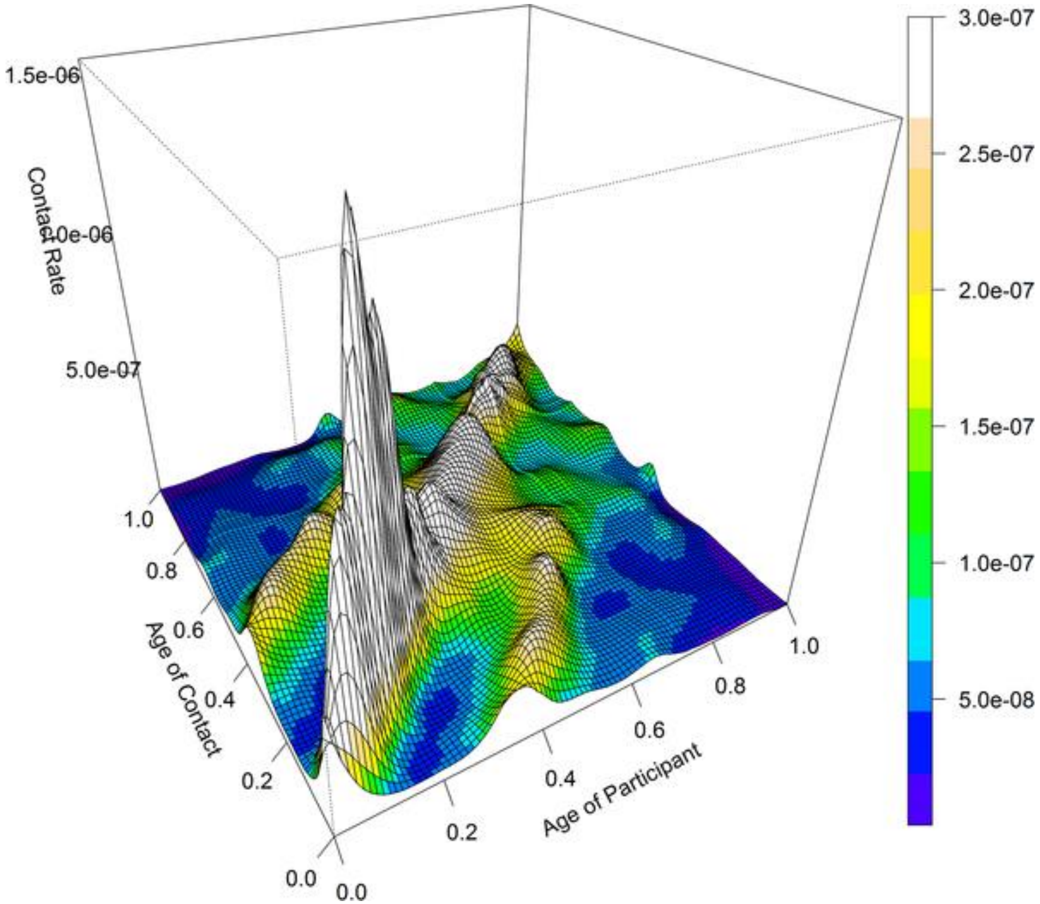
- Discrete Dynamics

$$
\begin{aligned}
S(n+1 \mid k) &= S(n \mid k) - I_{new}(n \mid k) \\
I(n+1,1,1 \mid k,1) &= I_{new}(n \mid k) \\
I(n+1,m+1,l+1 \mid k, j) &= p(n,m,l \mid k, j, j)\Sigma(n,m,l \mid k, j) \\
I(n+1,m+1,1 \mid k, j) &= \sum_{l,\, j' \neq j} p(n,m,l \mid k, j', j)\Sigma(n,m,l \mid k, j').
\end{aligned}
$$

$S(n \mid k)$ Susceptible persons at day n in category k—group age

$I(n,m,l \mid k, j)$ Number of infected persons belonging to group k from category j at day n and at date m after infection and at day l in infection category j.
Newly infected person are in category 1.
Categories are hospitalized, infected, recovered, etc…

Contact matrices according to location

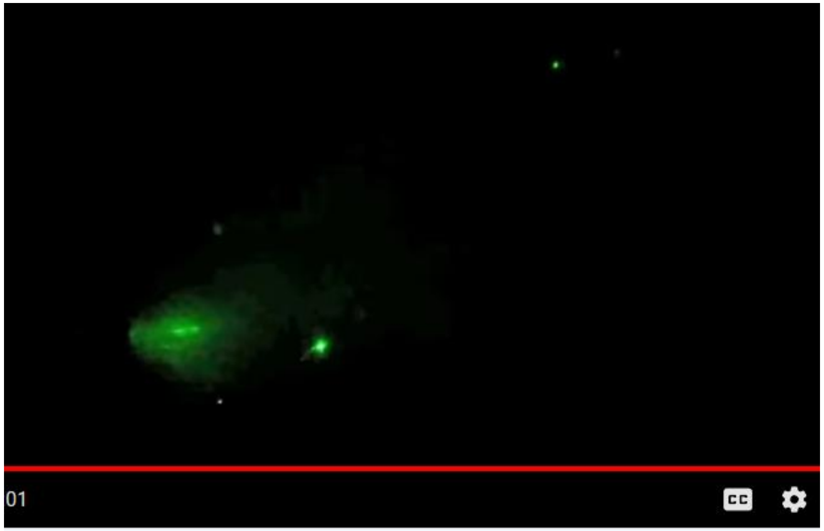


Reduced to 5*5 matrix

Béraud G, Kazmercziak S, Beutels P, Levy-Bruhl D, Lenne X, et al. (2015) The French Connection: The First Large Population-Based Contact Survey in France Relevant for the Spread of Infectious Diseases. PLOS ONE 10(7): e0133203. https://doi.org/10.1371/journal.pone.0133203
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0133203

Effect of Mask

Wearing Mask



No Mask

May7 2020

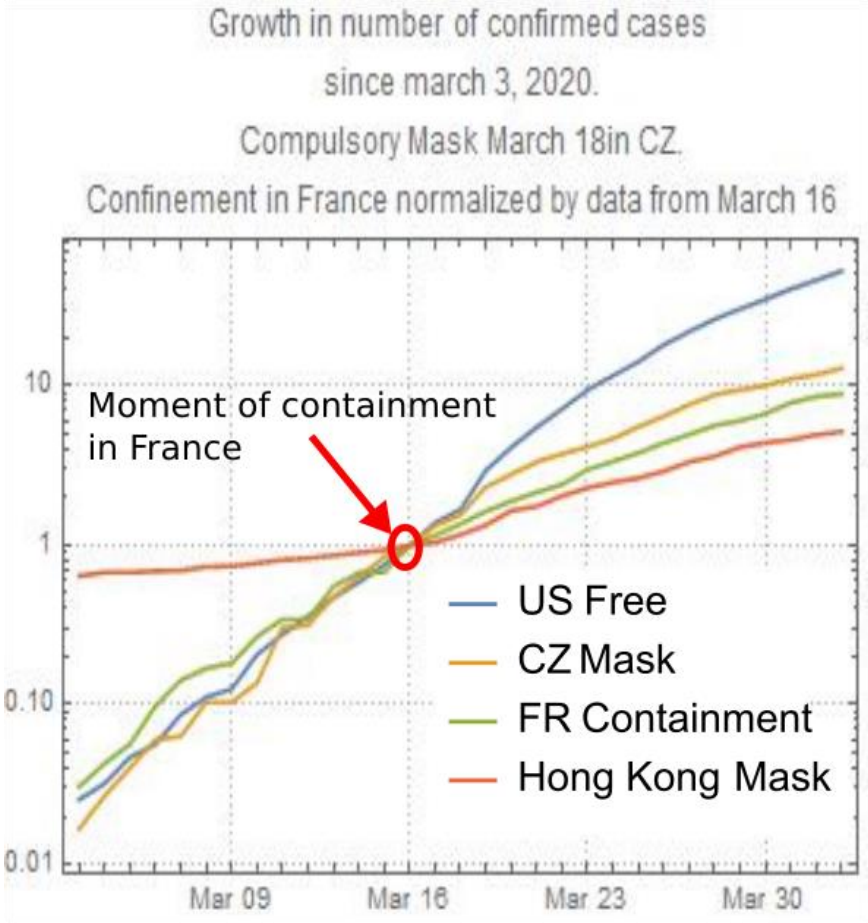
With Mask

Anfinrud, P., Stadnytskyi, V., Bax, C. E., & Bax, A. (2020). Visualizing Speech-Generated Oral Fluid Droplets with Laser Light Scattering. New England Journal of Medicine, NEJMc2007800. https://doi.org/10.1056/NEJMc2007800

https://www.youtube.com/watch?time_continue=74&v=UNHgQq0BGLI&feature=emb_title

Conclusion: Masks reduce drastically projection

Wearing Masks: statistical evaluation



COVID-19 Prediction/Modeling/Discussion
https://www.ibens.ens.fr/IMG/pdf/statistical-analysis2-0904.pdf

Conclusion: Masks can stabilize the growth of the pandemic similar to confinement

Wearing Mask: reduction contact with fine and coarse particles

Definition: ‘‘coarse’’>5 µm, ‘fine’’<5 µm (Brownian particles)

Conclusion:

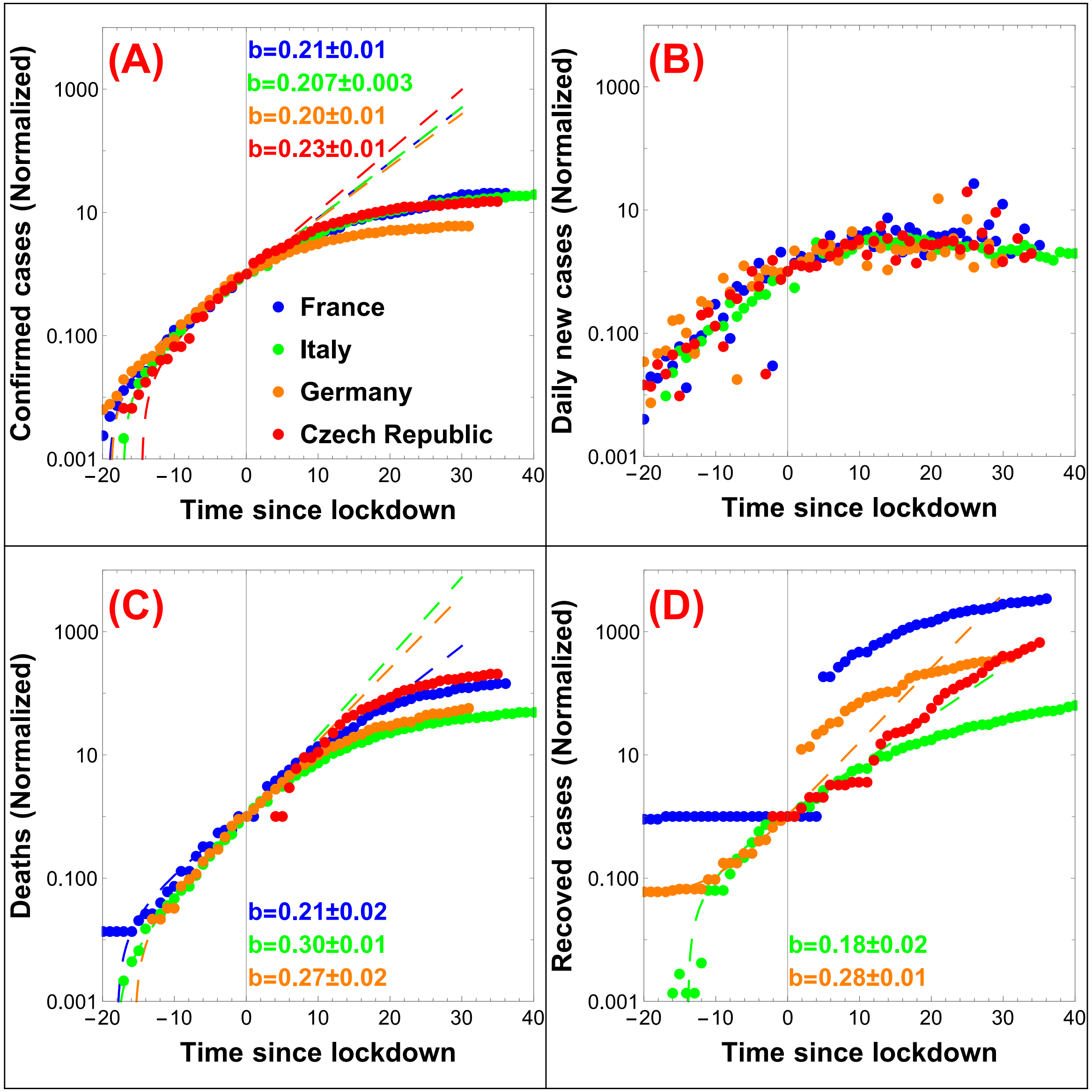
1-Fine particles contained 8.8 (95% CI 4.1 to 19) fold more viral copies than did coarse particles.

2-Surgical masks reduced viral copy numbers in the fine fraction by 2.8 fold (95\% CI 1.5 to 5.2) and in the coarse fraction by 25 fold (95\% CI 3.5 to 180). Overall, masks produced a 3.4 fold (95\% CI 1.8 to 6.3) reduction in viral aerosol shedding

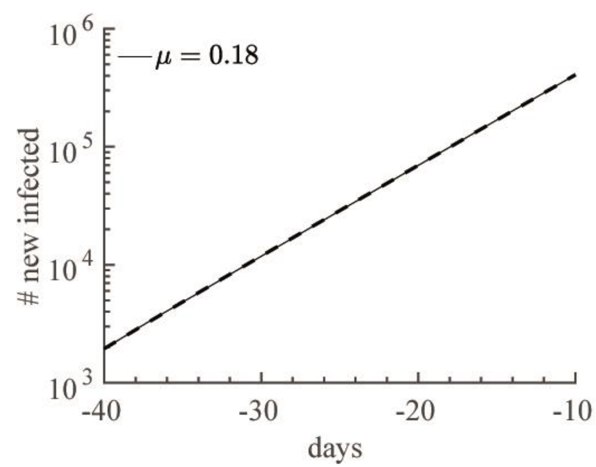
3-Hypothesis: *Mask could reduce the R0 by 2.8: we tested a reduction between 2.5 and 3*

- **Method:** measured viral copy number using quantitative RT-PCR, and tested the fine-particle fraction for culturable virus.
- **Refs:** Milton, D. K., Fabian, M. P., Cowling, B. J., Grantham, M. L., McDevitt, J. J. (2013). Influenza virus aerosols in human exhaled breath: particle size, culturability, and effect of surgical masks. PLoS pathogens, 9(3).

Extracting parameters from data

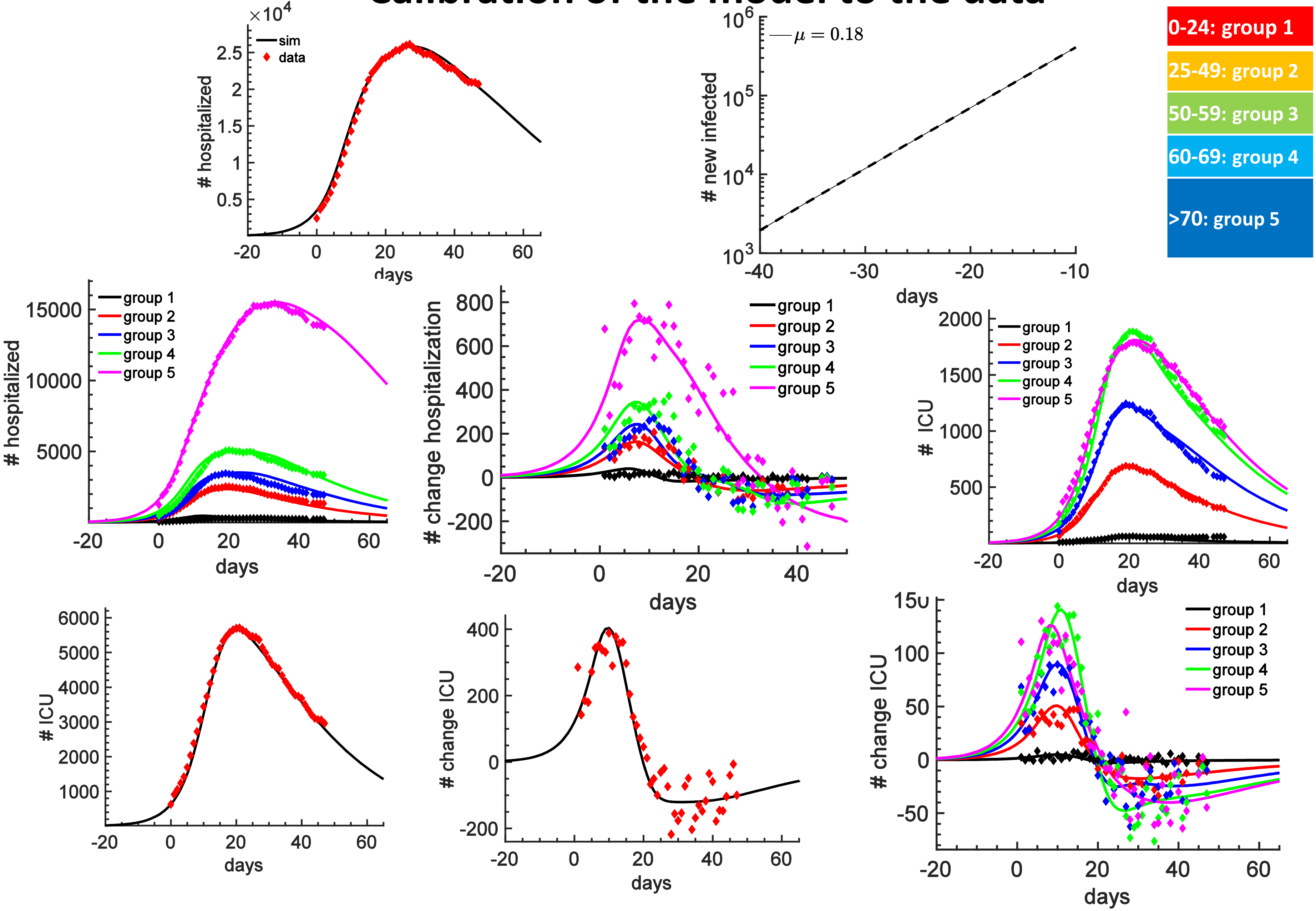


Lockdown:
France: 17th March
Italy: 9th March
Germany: 22nd March
Czech Republic: 18th March



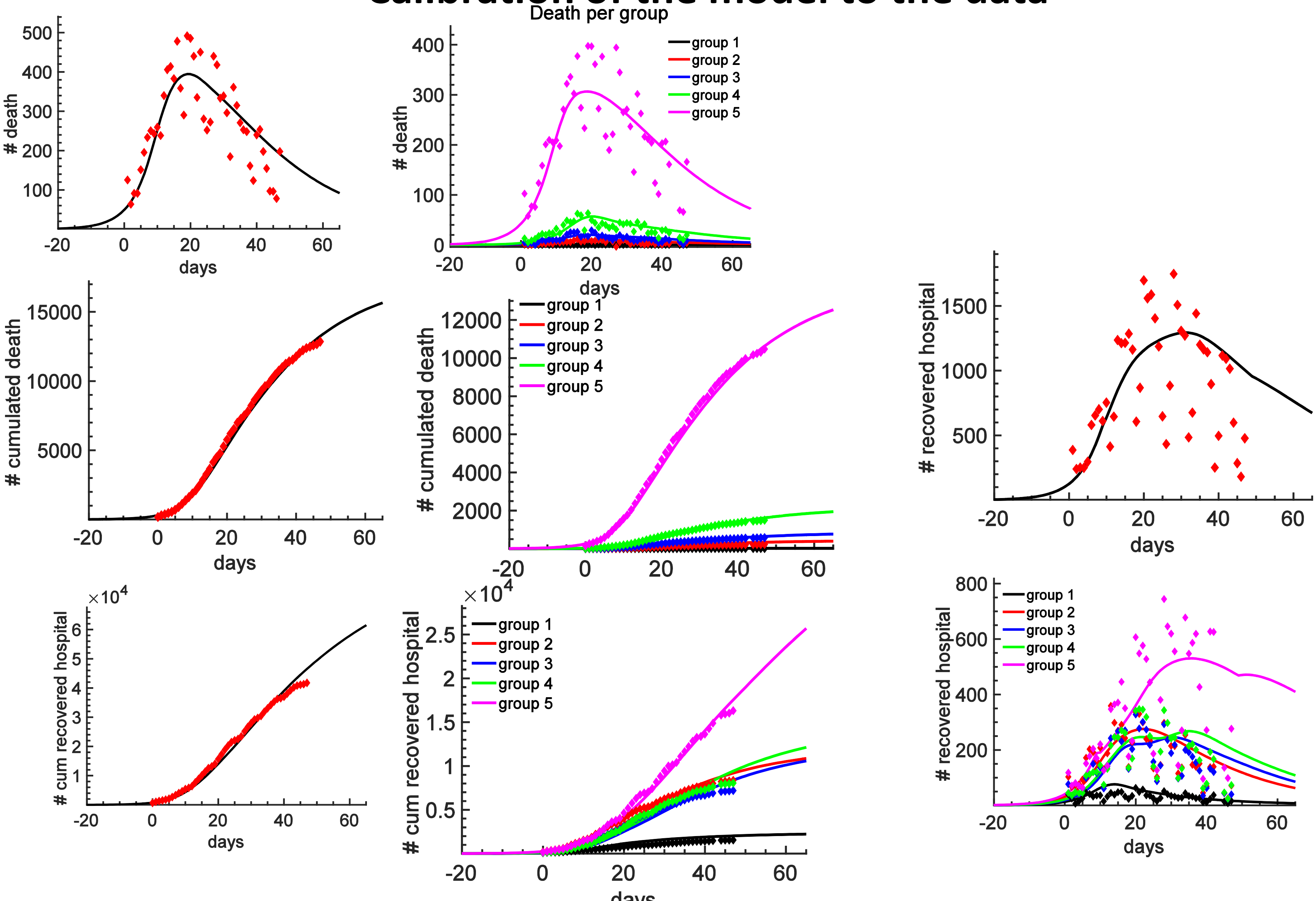
Rate of confirmed cases: exponential growth f(f) ~ exp(bt) b=0.2

Calibration of the model to the data



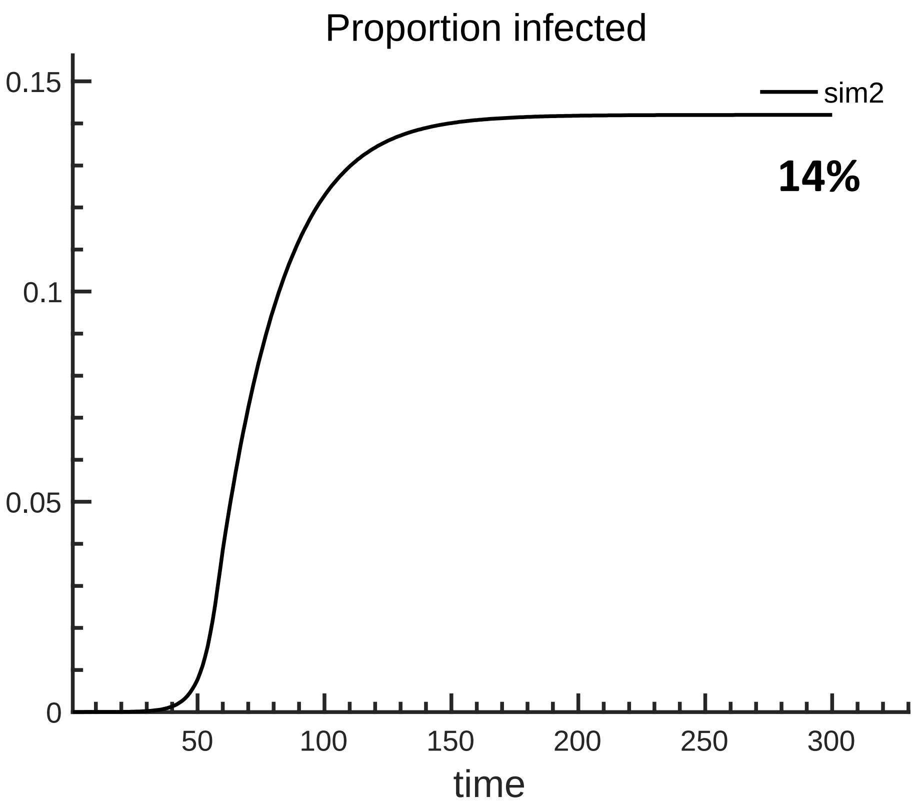
Conclusion: model accounts for the initial exponential growth, fit calibration at instantaneous time, cumulative (total fluxes)

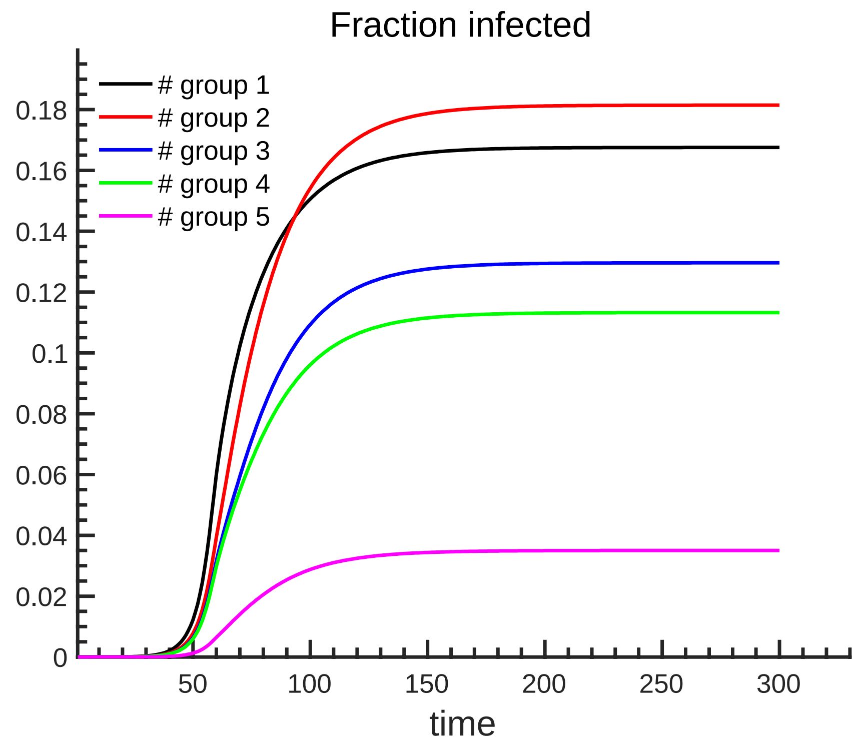
Calibration of the model to the data



Conclusion: the model accounts for various variables (per age group) simultaneously during a period before and during confinement for several category and age groups.

No deconfinement scenario: simulations for 300 days with



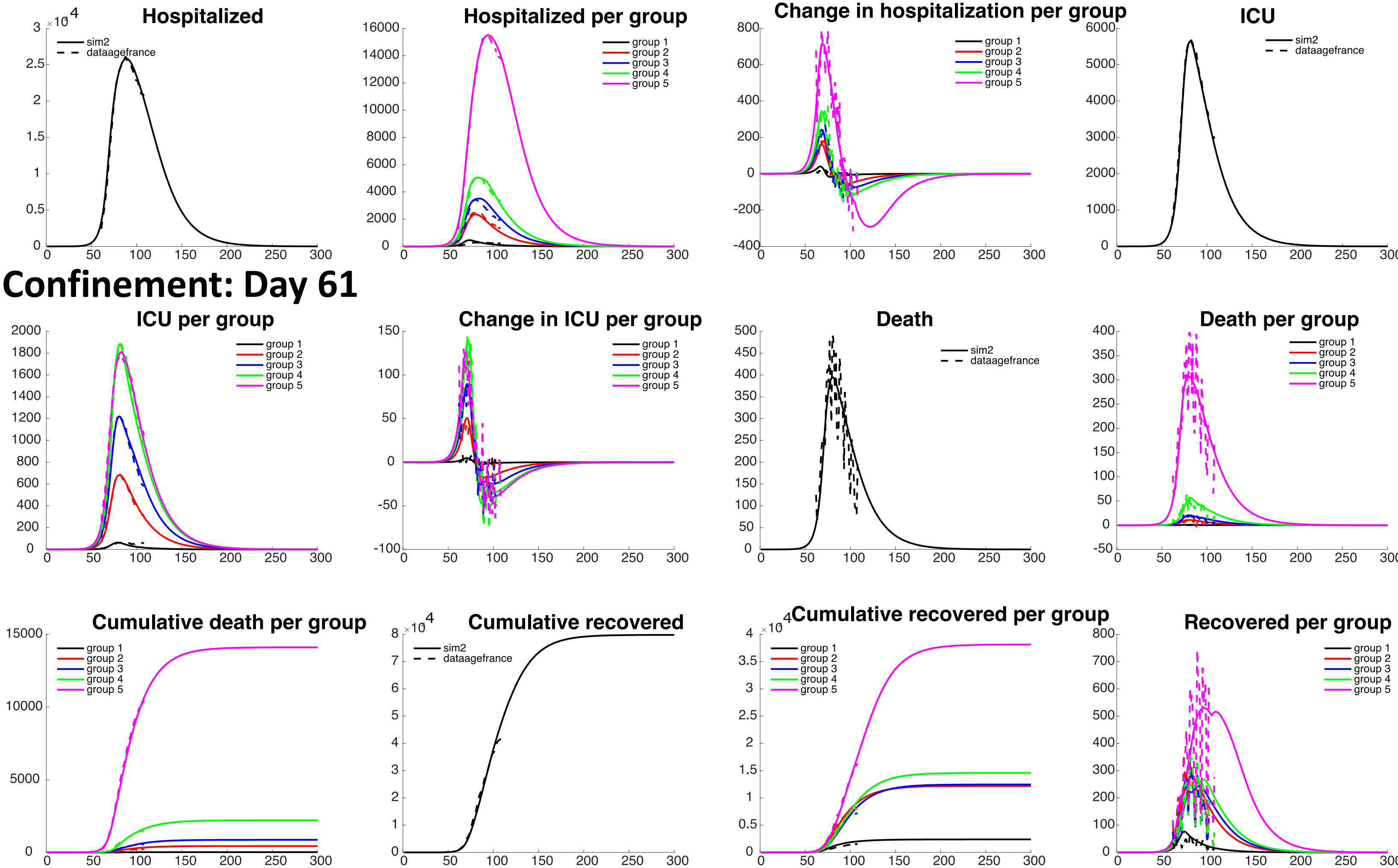


Conclusion:

1. Small fraction of infected
2. Large variability among age group
3. Latter fluctuation can recreate quickly a pandemic: no collective immunity acquired.

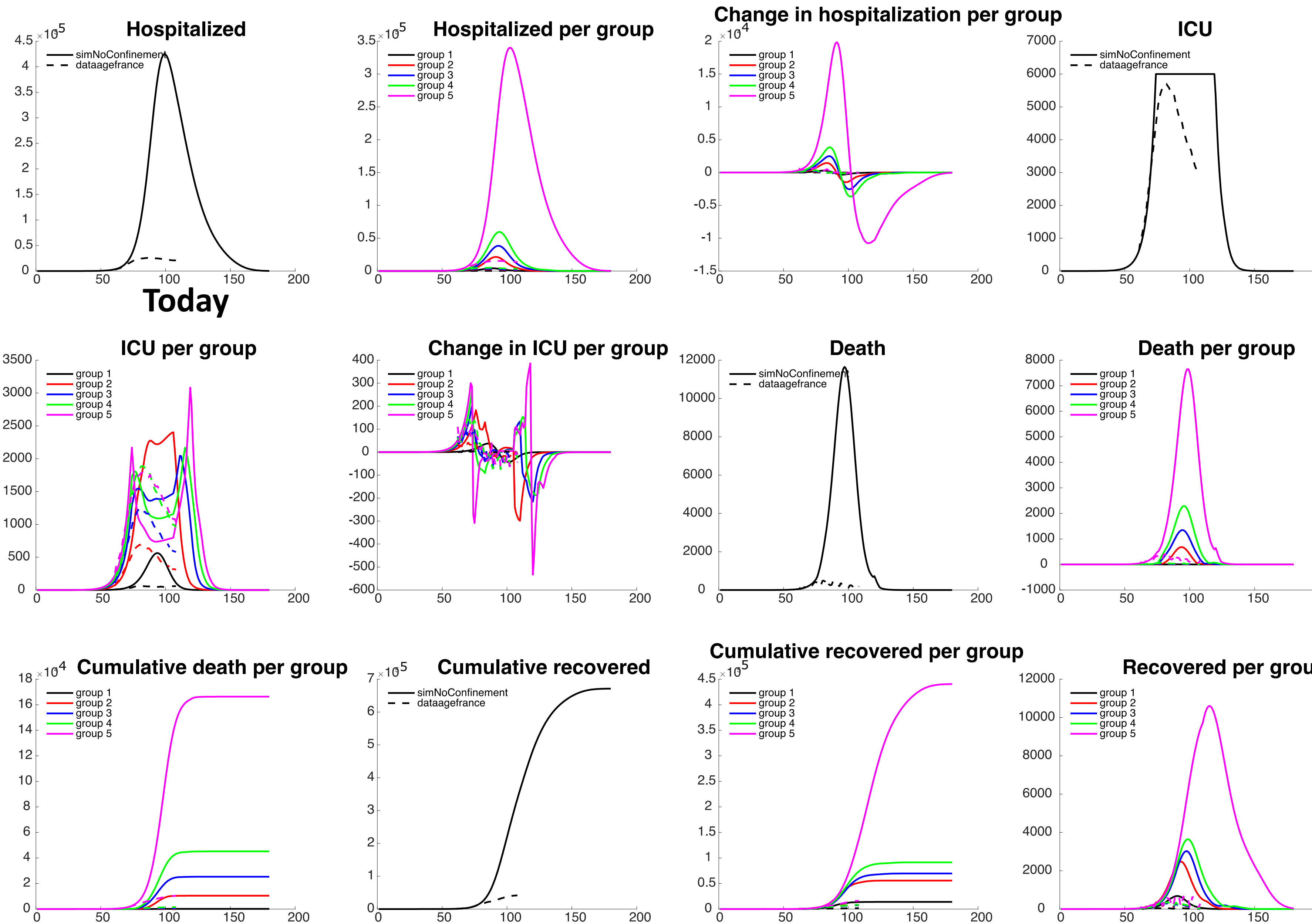
No deconfinement scenario: Simulations for 300 days with

Confinement: Day 61



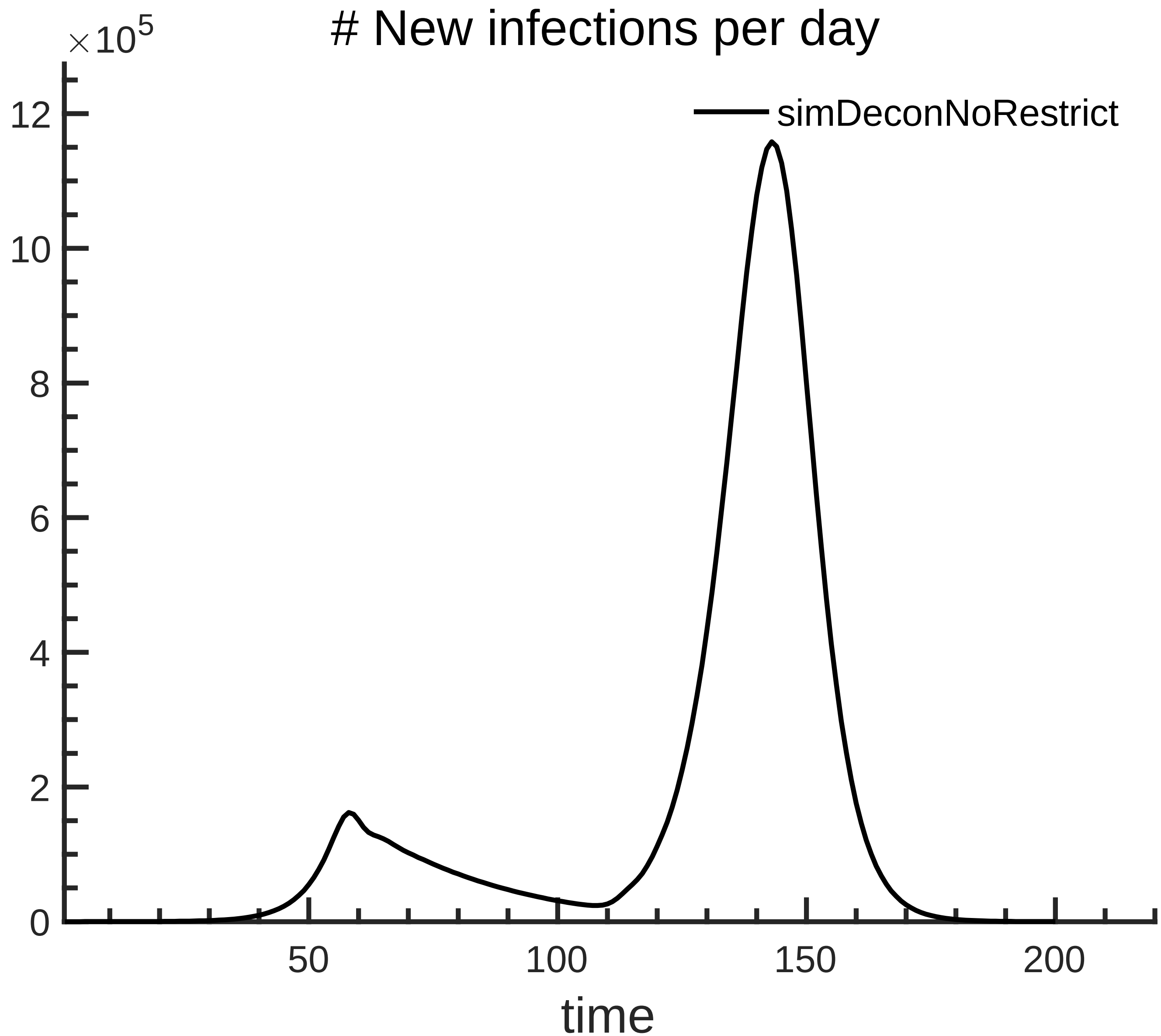
Conclusion: pandemic is fully controlled

Scenario: Had the population not have been confined: simulations for 200 days



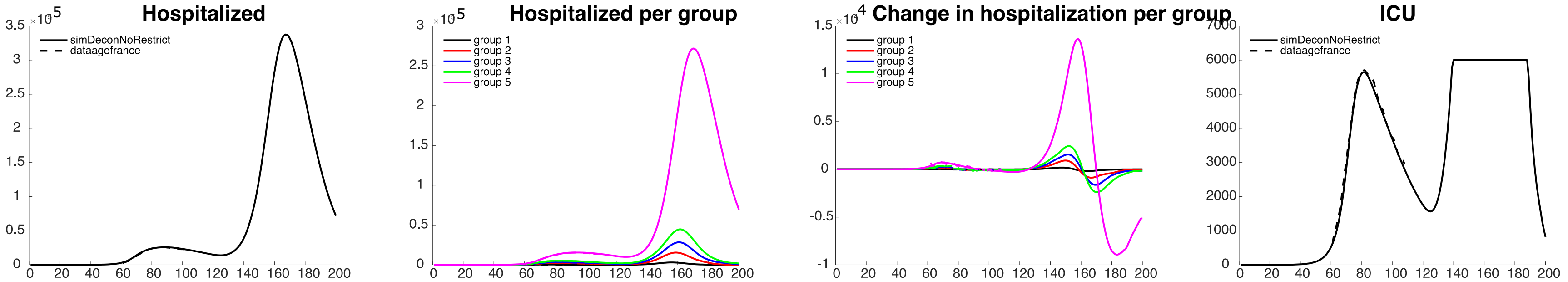
Conclusion: major consequence on destabilization of death and healthcare system

Return to normal social interactions as before confinement: Deconfinement occurring May 11 and

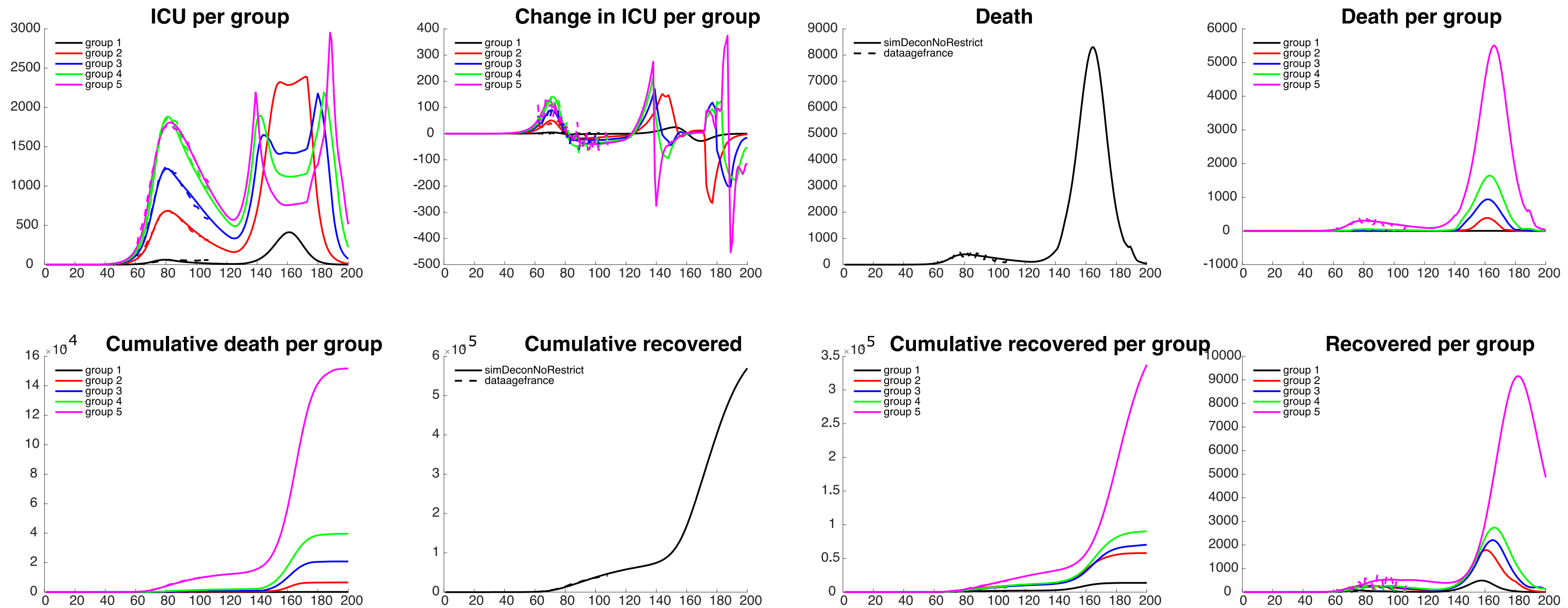


Conclusion: at the peak, the number of infection per day is 6 times the one observed in April

Deconfinement occurring May 11 and return to normal social interaction as before confinement

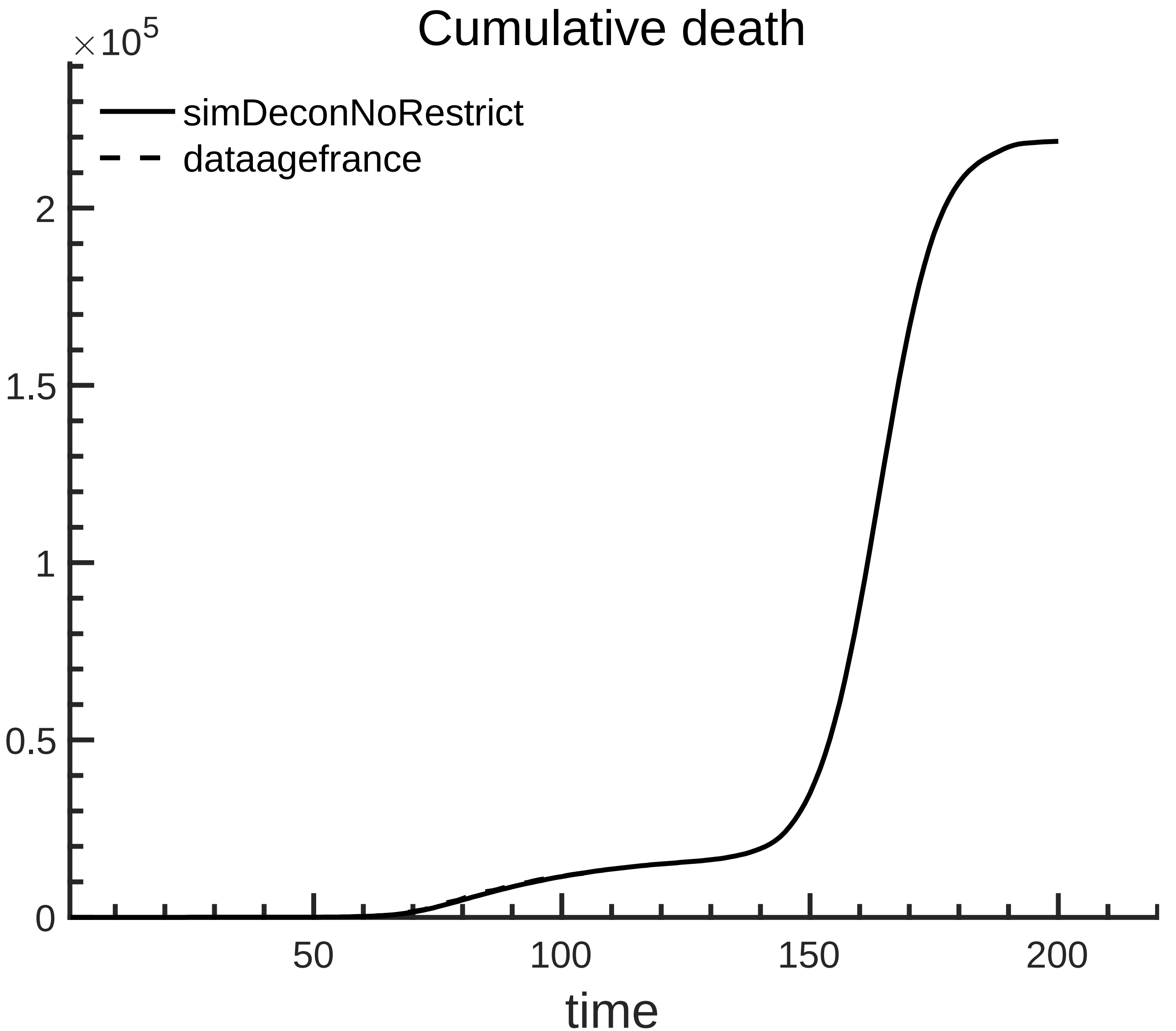


Confinement: Day 61



Conclusion: ICU saturated for 50 days, with a need 320 000 hospitalizations at the peak

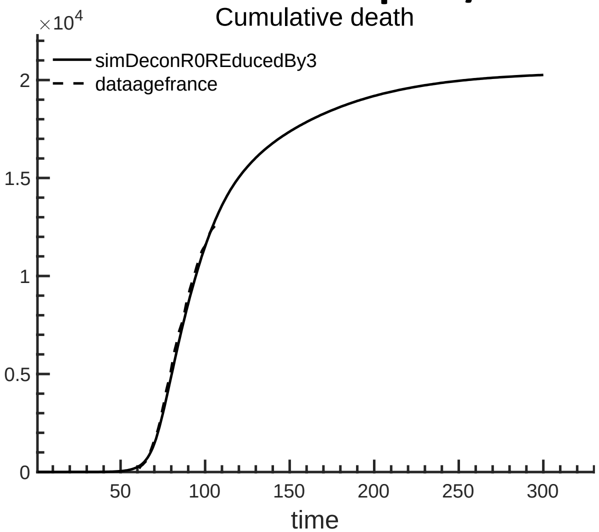
Deconfinement occurring May 11 and return to normal social interaction as before confinement



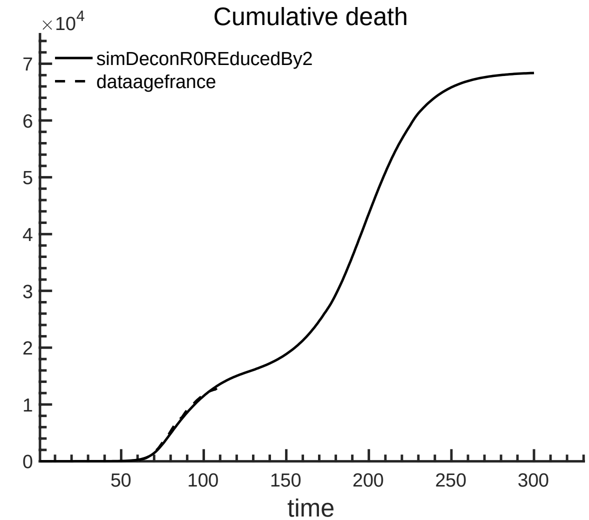
Conclusion:220 000 deaths for the 5 regions after 200 days

Deconfinement occurring May 11 with social contact reduced

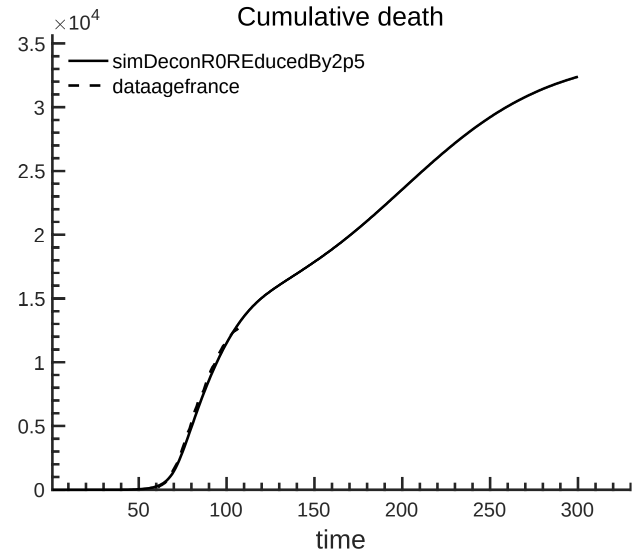
Measures to keep R0/3

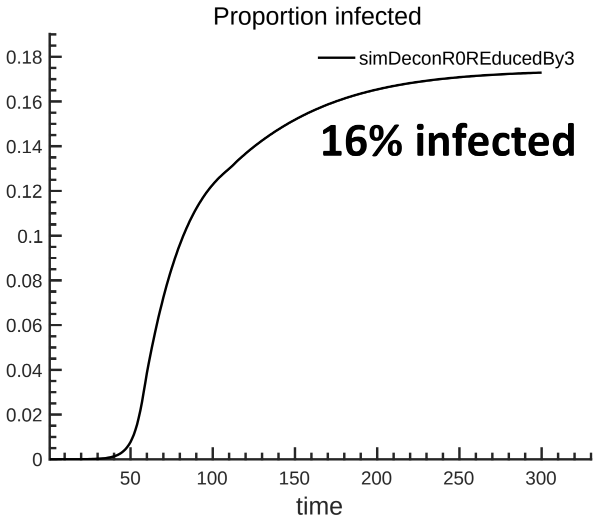


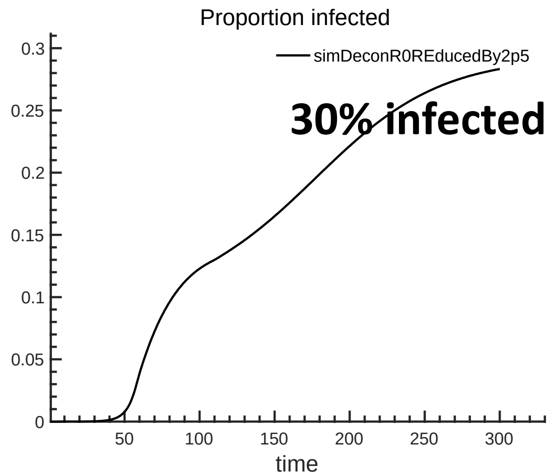
keep R0/2.5

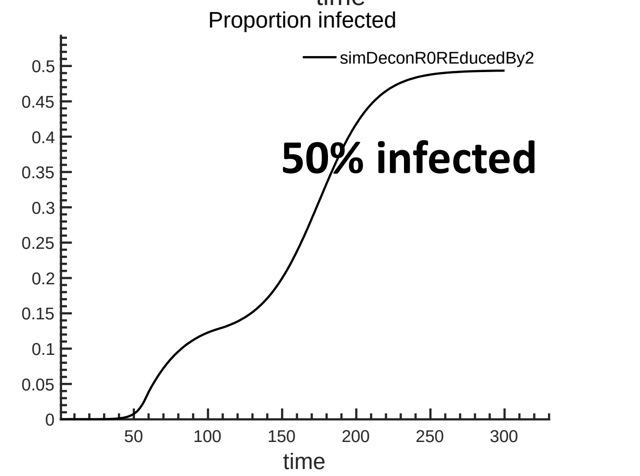


Keep R0/2









Conclusion: after 300 days,

total number of deaths (5 regions): R0/3the 21 000 (in hospital)

R0/2.5 35,000

R0/2 70, 000

Main conclusions of the model

Main conclusion of the model

- **At time of deconfinement:** 13% of the 5 most critical regions: ~4.6 Millions will be infected by Monday May 11th 2020
- **Scenario of no-deconfinement:** 240 days after confinement: 14% of people will be infected but the pandemic could persist at low noise.
- **Scenario If NO confinement were made**:12000 deaths/day at the peak. A total of 250, 000 deaths in the 5 regions and probably 450,000 around the country. 87% of the population would have been infection. ICU would have been saturated for 50 days.
  - group-age 0-24: 95% would be infected with 120 deaths/(5 regions)
  - group-age >70:40% infected with 160 000 total death/(5 regions)

Main conclusion of the model

- **Deconfinement with no restriction: a large second peak is expected mid-July.** 220 000 deaths for the 5 regions after 200 days. ICU saturated for 50 days, with a need 320 000 hospitalizations at the peak
- **Deconfinement with restriction R0 divided by 3:** No second peak: the pandemic is under control. after 300 days, the proportion of infected people tends to 18%. The total number of deaths (5 regions) is expected of 21000 in hospitals.
- **Deconfinement with restriction R0 divided by 2.5:** 30% of the population is infected at day 300 with an increasing slope. : Cumulative death around 35000.

Main conclusion of the model

In a Deconfinement with restrictions, R0 between 2.5 and 3 times less than initial R0 need:

- Predict the dynamics of COVID-19: exponential phase: any fluctuation is largely amplified: Need a constant monitoring. Phase very sensitive to social interaction.
- To monitor continuously to keep any possible exponential explosion of the phase. Possibility to use the present model and hospitalized data
- Number of test per day should match the number of infected of the order of ~100 000.

Acknowledgements

- Thanks: Prod. D. Longrois (Bichat)

- Model can be adjusted for any other country or other French regions but requires careful adjustments.

- Software can be use to estimate R0 and predict the change in the next few weeks.

- Softwares developed in
  - Matlab
  - Mathematica/Mapple

- Public sources from French government
  - https://geodes.santepubliquefrance.fr/#c=news
  - https://www.data.gouv.fr/fr/datasets/donnees-hospitalieres-relatives-a-lepidemie-de-covid-19/

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