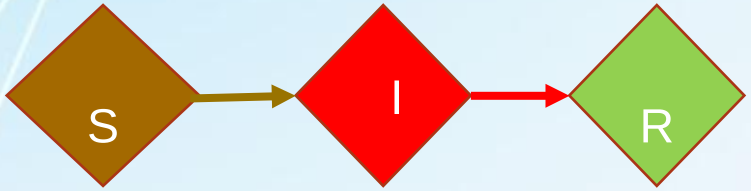
A STUDY OF COVID-19 DATA FROM AFRICAN COUNTRIES

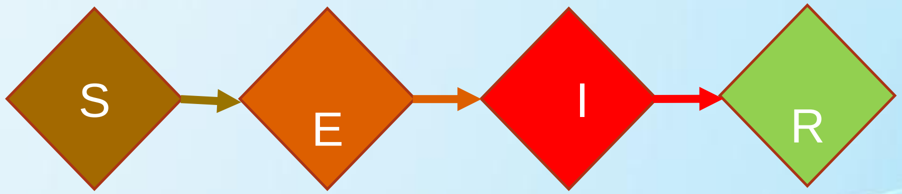
S I D A R T H E

Presenter: Somiealo Azote

20/07/2021

Project initiated and supervised by





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My bio

- **2018: PhD in theoretical Biophysics from Stellenbosch University, S. Africa**
- **12/2020-Now: On going postdoctoral studies, Ca Foscari University of Venice**
- **Interest in Computing, Simulation, Data Analysis/Science**
- **Passionate in mentoring young women in science (Member of AIMSWIS Mentoring pr)**
- **The After ASP: stay connected**

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Outlines

- Introduction
  - Global COVID-19 Situation
  - COVID-19 Situation in Africa
  - Impact on the African School of Physics (ASP)
- ASP COVID-19 Study
- Results
- Conclusions

Global COVID-19 Situation

➢ COVID-19 started in China and has spread to the entire world within a few months

WHO Coronavirus (COVID-19) Dashboard (15 July 2021)

Situation by Region, Country, Territory & Area

Name	Cases - cumulative total	Cases - newly reported in last 24 hours	Deaths - cumulative total	Deaths - newly reported in last 24 hours	Transmission Classification
Global	**188,128,952**	**516,528**	**4,059,339**	**8,547**	
Americas	74,239,667	147,561	1,949,777	3,790	
Europe	57,472,767	130,355	1,200,672	1,068	
South-East Asia	36,400,628	126,002	520,095	2,086	
United States o...	33,604,822	32,107	602,820	411	Community transmission
India	30,987,880	41,806	411,989	581	Clusters of cases
France	5,714,131	8,747	110,446	6	Community transmission
Turkey	5,500,151	6,907	50,367	43	Community transmission
The United Kin...	5,233,211	41,748	128,530	49	Community transmission
Argentina	4,682,960	20,023	99,640	385	Community transmission
Colombia	4,548,142	17,532	113,839	504	Community transmission
Africa	4,495,778	30,155	105,354	683	
Italy	4,275,846	2,153	127,831	23	Clusters of cases
Spain	4,041,474	14,929	81,043	0	Community transmission

➢ **Weekly epidemiological update on COVID-19 by WHO**

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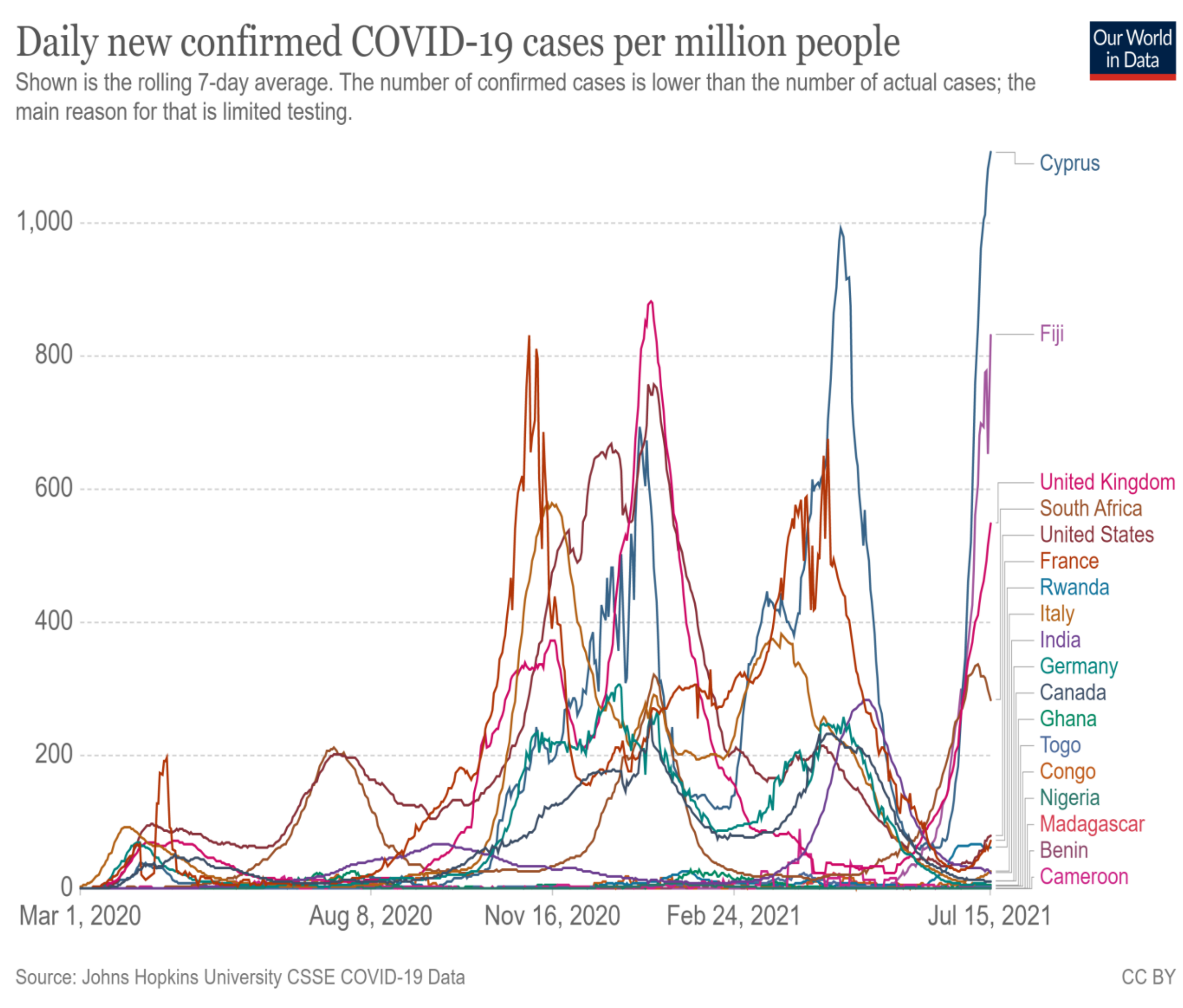
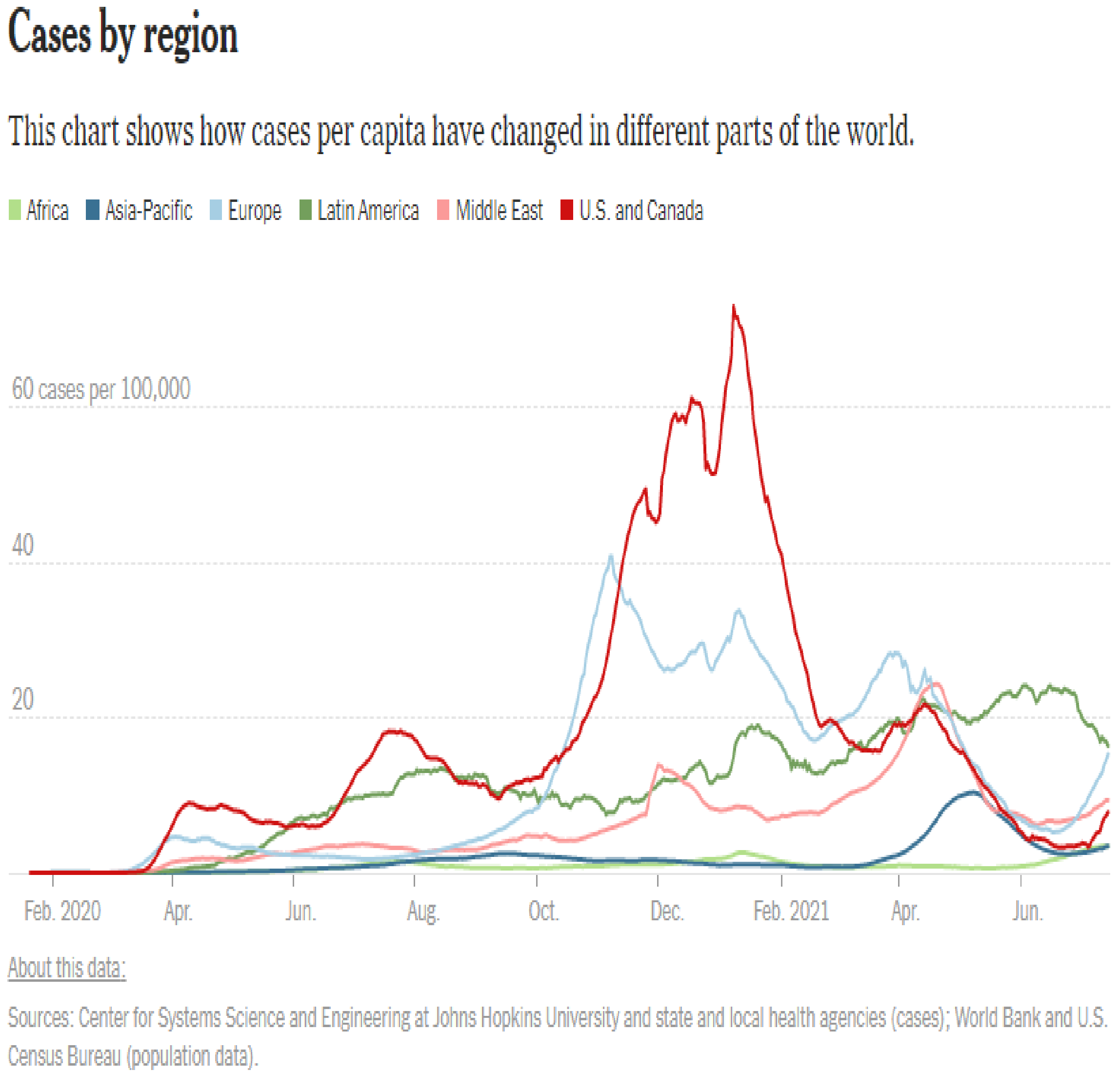
Comparison with Africa





COVID-19 Situation in Africa

- WHO prediction:
  - 29-44m Africans could be infected
  - 83-190000 Africans could die
  - Suggests Africa has lower transmission rates
  - Prolong outbreak for several years
  - Pressure on economic resources
  - Containment measures challenge: 60% living below poverty line

- Current Situation:
  - 4.5m infected
  - 106,078 dead
  - Millions rendered jobless, increased poverty & insecurity
  - A number of studies conducted

- ASP COVID-19 Study: Contribute to understanding & containment

Impact on African School of Physics

- ASP2020, initially planned for July 2020 in Morocco was postponed and only taking place now online

- In the meantime, ASP set up an online lecture series, since May 2020 – Twice a week

- In March 2020, Dr. Ketevi A. Assamagan made a call to all the ASP alumni for Covid 19 exercise: to study and help understand Covid 19 data from African countries

- A number of ASP alumni responded to the call with the permission of our supervisors

- From there started the study – Alumni were in charge to collect Covid data from their countries – the study was guided mentored by senior researcher and leaders of ASP

Research Team

Dr. Kétévi A. Assamagan
Togo & USA

Team Leader

Experimental particle physicist at Brookhaven National Laboratory

Fellow, African Academy for Sciences

Research Interests: Search for new physics beyond the Standard Model of particle physics

Alma Mater: University of Lomé & University of Virginia
Co-founder, ASP, ASFAP
Passionate: Physics Education, Communication & Outreach

Research Team

Prof. Simon Connell
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Professor of Physics
University of Johannesburg
Research Interests: nuclear & particle physics
Alma Mater: University of Witswaterand
Passionate: Technology & Innovation

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Interests: Research, Training &
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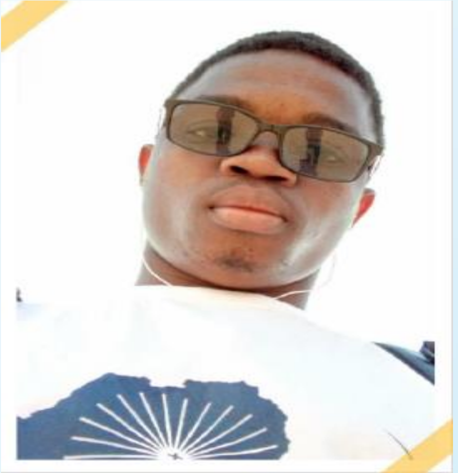
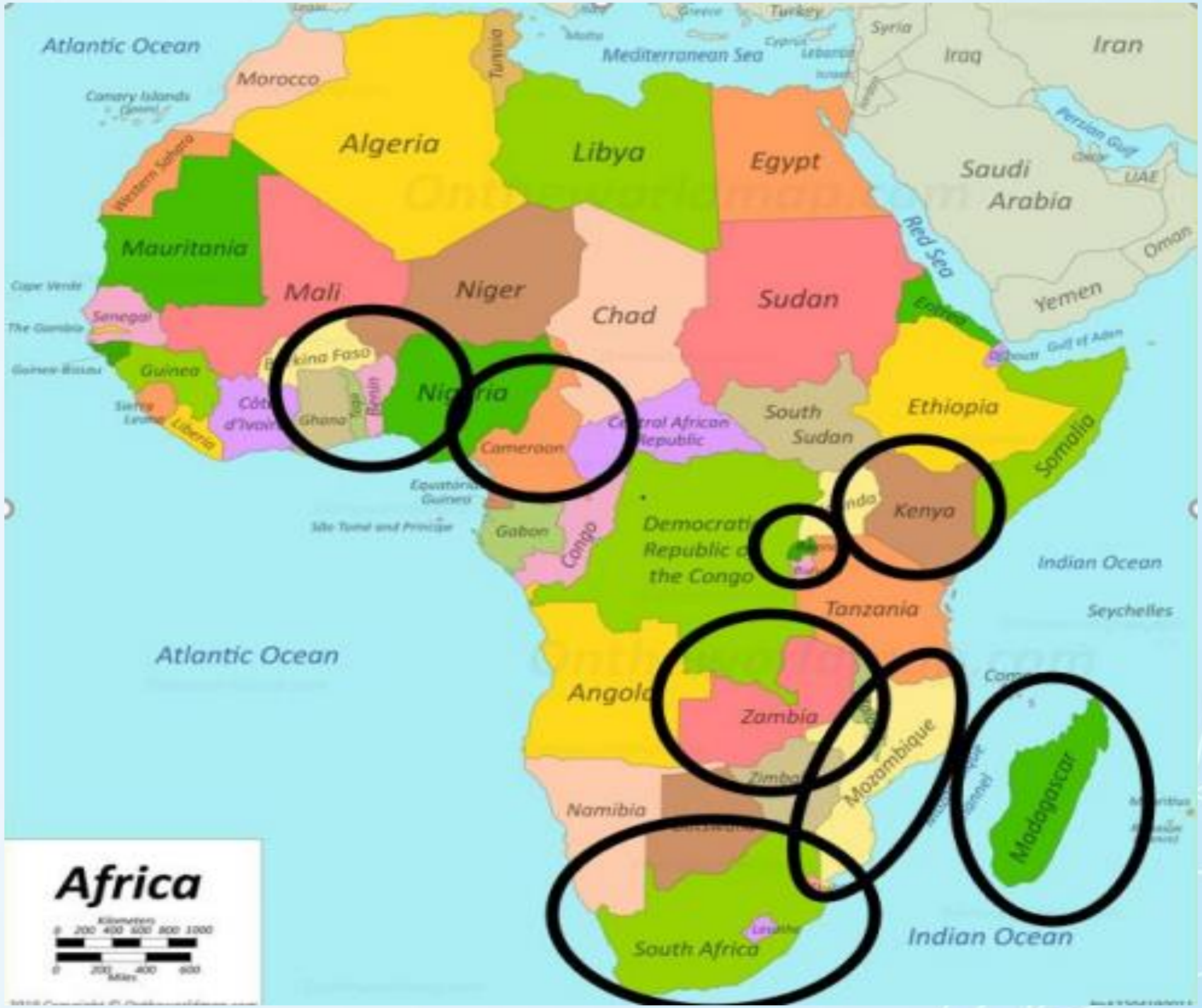


Francisco Macucule
Mozambique
Undergrad Student (BSc)
Eduardo Mondlane University

Countries we studied

- **The countries that we studied are:**
  - **•Benin**
  - **•Cameroon**
  - **•Ghana**
  - **•Kenya**
  - **•Madagascar**
  - **•Mozambique**
  - **•Rwanda**
  - **•South Africa**
  - **•Togo**
  - **•Zambia**



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Epidemiological models

- Deterministic models also known as compartmental models are simpler and yet efficient tool to predict and control the spread of the disease through individuals.

- Stochastic modelling forecasts the probability of various outcomes under different conditions, using random variables (Convenient for small infection

Mathematical (epidemic) modeling

Deterministic Discrete or continuous time

- SIR: Susceptible-Infected-Recovered
- SEIR: Exposed before getting infected
- SEI: Have infectious force in the latent period
- SEIRS: Recovered people can become infected again, Immunity not guaranteed
- ---
- SIDARTHE: 8 stages compartmental model, more complex.

Which one of the deterministic model is best for the analysis of the Covid-19 data from African countries?

Stochastic Discrete or continuous time and space

- DTMC: Discrete Time Markov Chains
- CTMC: Continuous Time Markov Chains
- ---
- SDE: Stochastic Differential equation

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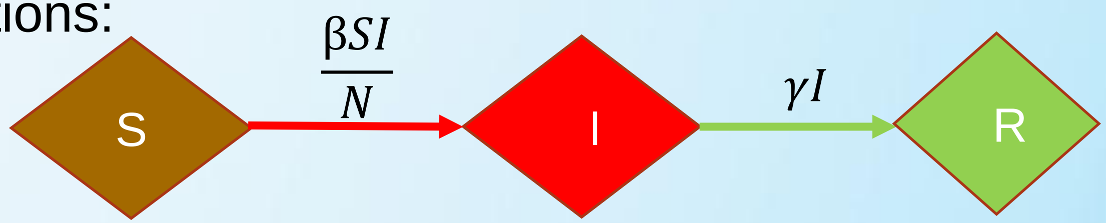
Deterministic (compartmental) models

- These models are dynamic and can be used to :
  - make predictions such as the duration of an epidemic or pandemic.
  - how the disease spread over time
  - Estimate various epidemiological parameters such as the reproduction number
  - Help estimates the fraction of population that need to be vaccinated
  - Show how different public health or government interventions may affect the outcome of the pandemic

- Susceptible-Infected-Recovered (SIR) is the simplest compartmental model
  - It has 3 groups S-I-R and each of them represent specific stage of the epidemic and fluctuates over time
  - Individuals may progress between compartments
  - It serve as the basis for all other compartmental models

SIR model without vital dynamic

- For specific disease, $S = \boldsymbol{S(t)}$, $\mathbf{I} = \boldsymbol{I(t)}$, $\boldsymbol{R} = \boldsymbol{R(t)}$ are number of susceptible, Infected, recovered in a population N at time $\boldsymbol{t}$
- The number of Susceptible going from $\boldsymbol{S}$ to $\mathbf{I}$ category is: $\frac{\beta SI}{N}$ i.e on average, each infected person generates β**s(t)** new infected persons. β quantifies the number of contacts between susceptible and infected people
- γI is the rate at which infected person recover. If an individual is infectious for an average time period *D*, then γ = 1/*D*
- Normalization: $\mathrm{s(t)} = \frac{S(t)}{N}$, $\mathrm{i(t)} = \frac{I(t)}{N}$ and $\mathrm{r(t)} = \frac{R(t)}{N}$ such that $\mathrm{s}(\boldsymbol{t}) + \boldsymbol{i}(\boldsymbol{t}) + \boldsymbol{r}(\boldsymbol{t}) = \mathbf{1}$
- SIR Model is then described by the following set of equations:



  - **The rate of change in the susceptible population**

    1) $\frac{ds}{dt} = -\beta s(t)i(t)$

  - **The rate of change in the infected population**

    2) $\frac{di}{dt} = \beta s(t)i(t) - \gamma i(t)$

  - **The rate of change in the recovered population**3

    3) $\frac{dr}{dt} = \gamma i(t)$

    Check that $\frac{ds}{dt} + \frac{dr}{dt} + \frac{di}{dt} = 0$

- Equations (1,2,3) are non-linear coupled ordinary differential equations.
- Can thus be solved only numerically

- Initial conditions: $s(0) = s_o$, $i(0) = i_o$, $\mathrm{r}(0) = r_o$ and $i + s + r = 1$ (conservation)

Reproduction number

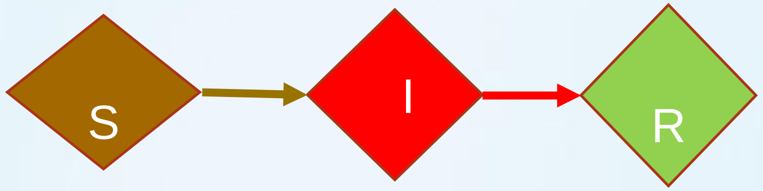
- The disease becomes a pandemic when the infection keeps on increasing
- meaning $\frac{di}{dt} = \beta s(t)i(t) - \gamma i(t) > 0$ equivalently $\frac{\beta}{\gamma} s(t) > 1$.
- Since $s(t) < 1$, for a pandemic, $\frac{\beta}{\gamma} > 1$.
- The ratio $R_o = \frac{\beta}{\gamma}$, dimensionless, is called the reproduction number.
- So higher the reproduction number faster the disease going to spread.
- If $R_o < 1$ then the disease will die out soon.
- Physical meaning: R0 represent the total number of secondary infections produced by a single infection in a completely susceptible population.

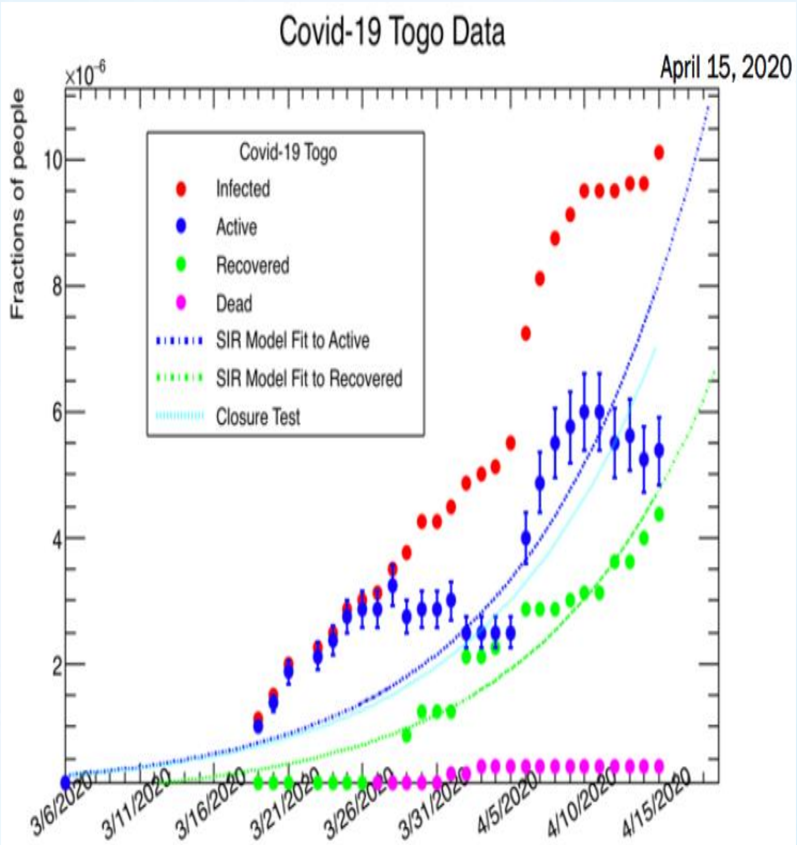
Fitting SIR and SEIR models to Covid-19 data from Togo

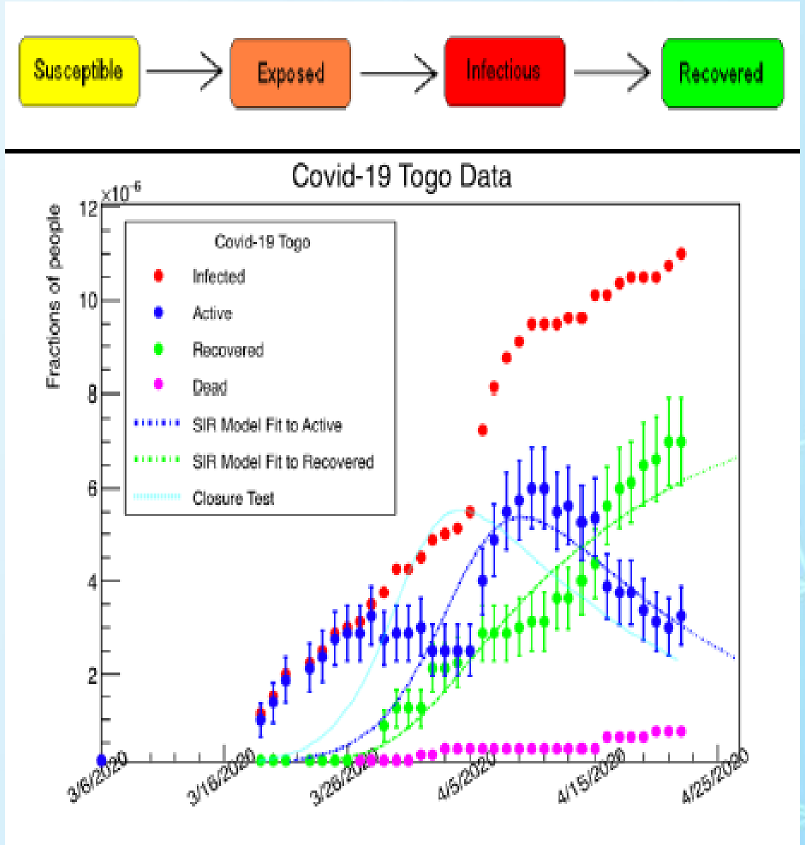
- **Fitting the recovered and the active independently also gives 2 different model parameters from fits to 2 independent datasets.**

- **Closure Test: using the 2 model parameters obtained by fitting the recovered to test for the active dataset, gives light blue curve, instead of the blue curve.**

- **Fitting only 1 dataset does not result in a good modeling on the other dataset.**



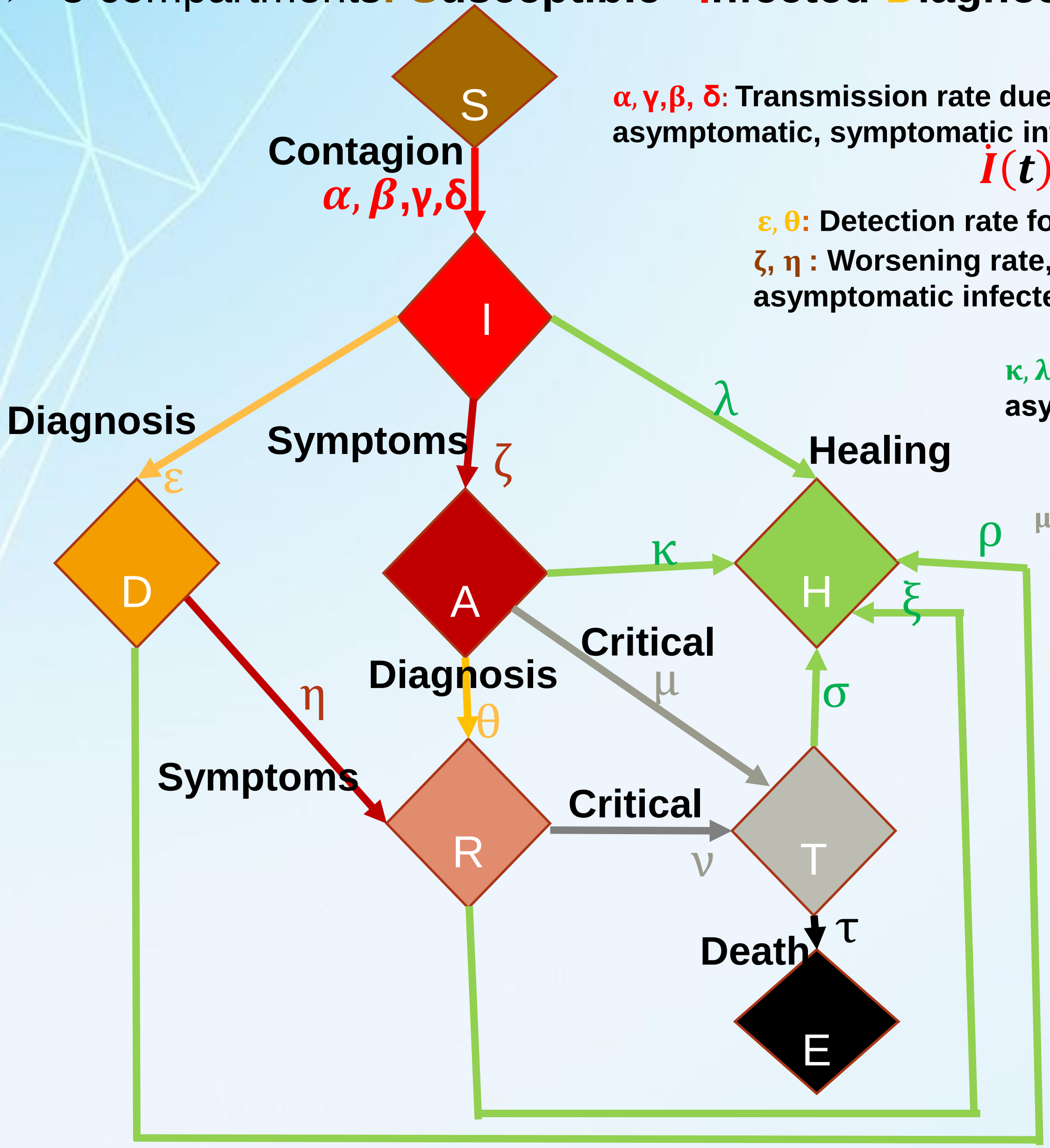




- **Models unsuccessful in fitting the 3 curves simultaneously**

SIDARTHE model formulation: 8 ODEs and 16 parameters

- 8 compartments: **Susceptible –Infected-Diagnosed-Ailing-Recognized-Threatened-Healed-Extinct**



$$\dot{S}(t) = -S(t)(\alpha I(t) + \beta D(t) + \gamma A(t) + \delta R(t)) \quad (1)$$

α, γ,β, δ: Transmission rate due to contact with UNDETECTED asymptomatic, symptomatic infected, DETECTED asymptomatic, symptomatic infected respectively.

$$\dot{I}(t) = S(t)\big(\alpha I(t) + \beta D(t) + \gamma A(t) + \delta R(t)\big) - (\varepsilon + \zeta + \lambda) I(t) \quad (2)$$

ε, θ: Detection rate for ASYMPTOMATIC, SYMPTOMATIC respectively

ζ, η : Worsening rate, UNDETECTED asymptomatic infected becomes symptomatic ; DETECTED asymptomatic infected becomes Symptomatic

$$\dot{D}(t) = \varepsilon I(t) - (\eta + \rho) D(t) \quad (3)$$

κ, λ, ξ, ρ: Recovery rate for asymptomatic infected, undetected symptomatic, detected asymptomatic, symptomatic infected respectively.

$$\dot{A}(t) = \zeta I(t) - (\mu + \kappa + \theta) A(t) \quad (4)$$

μ: Worsening rate, UNDETECTED symptomatic infected develop life−threatening symptoms.

$$\dot{R}(t) = \eta D(t) + \theta A(t) - (\nu + \xi) R(t) \quad (5)$$

ν: Worsening rate, DETECTED symptomatic infected develop life -threatening symptoms.

$$\dot{T}(t) = \mu A(t) + \nu R(t) - (\sigma + \tau) T(t) \quad (6)$$

τ: Mortality rate for infected with life-threatening symptoms

σ Recovery rate life –threatened symptomatic infected

$$\dot{H}(t) = \lambda I(t) + \sigma T(t) + \kappa A(t) + \rho D(t) + \xi R(t) \quad (7)$$

$$\dot{E}(t) = \tau T(t) \quad (8)$$

https://www.nature.com/articles/s41591-020-0883-7.pdf

Basic Reproduction number

- The model is initially developed to study the dynamics of Covid-19 in Italy.
- The model parameters are updated over time as the intervention measures or restriction increase. And the basic reproduction number computed
- The basic reproduction number from SIDARTHE model

$$R_0 = \frac{\alpha}{r_1} + \frac{\beta * \varepsilon}{r_1 * r_2} + \frac{\zeta * \gamma}{r_1 * r_3} + \frac{\eta * \delta * \varepsilon}{r_1 * r_2 * r_4} + \frac{\delta * \zeta * \theta}{r_1 * r_3 * r_4}$$

with

$$r_1 = \varepsilon + \zeta + \lambda$$
$$r_2 = \eta + \rho$$
$$r_3 = \mu + \theta + \kappa$$
$$r_4 = \xi + \nu$$

- $R_0 > 1$: epidemic continues
- $R_0 < 1$: outbreak ends
- R_0 can be used to estimate the fraction of people to vaccinate
- R_0 must be applied with caution due to model dependency

Analysis of Covid-19 data from 10 African countries

- We adapted the SIDARTHE model to consider the containment measures (social distancing, mask wearing, curfew, Gatherings and recreational activities, hand sanitizing) taken by African countries

- For each country, we modeled the three datasets of active, recovered and death cases by finding the SIDARTHE model parameters that best match the time-evolution of the data

- The best-matched parameters may change over time, thus providing an evolution of the basic reproduction number as a function of time

- We propagated to the R_0 estimates the statistical uncertainties related to the numbers of tests done and cases identified

Statistical and Systematic uncertainties

- We also applied a systematic uncertainty to the R0 estimates based on the fraction of the infected but unaffected population

- SIDARTHE Model: rate of change in the recovered population

$$\dot{H}(t) = \lambda I(t) + \sigma T(t) + \kappa A(t) + \rho D(t) + \xi R(t)$$

The number of undetected asymptomatic persons who are healed are not included in the data, yet it is included in the model → Systematic error on the modeling Systematic Uncertainties on R_0.

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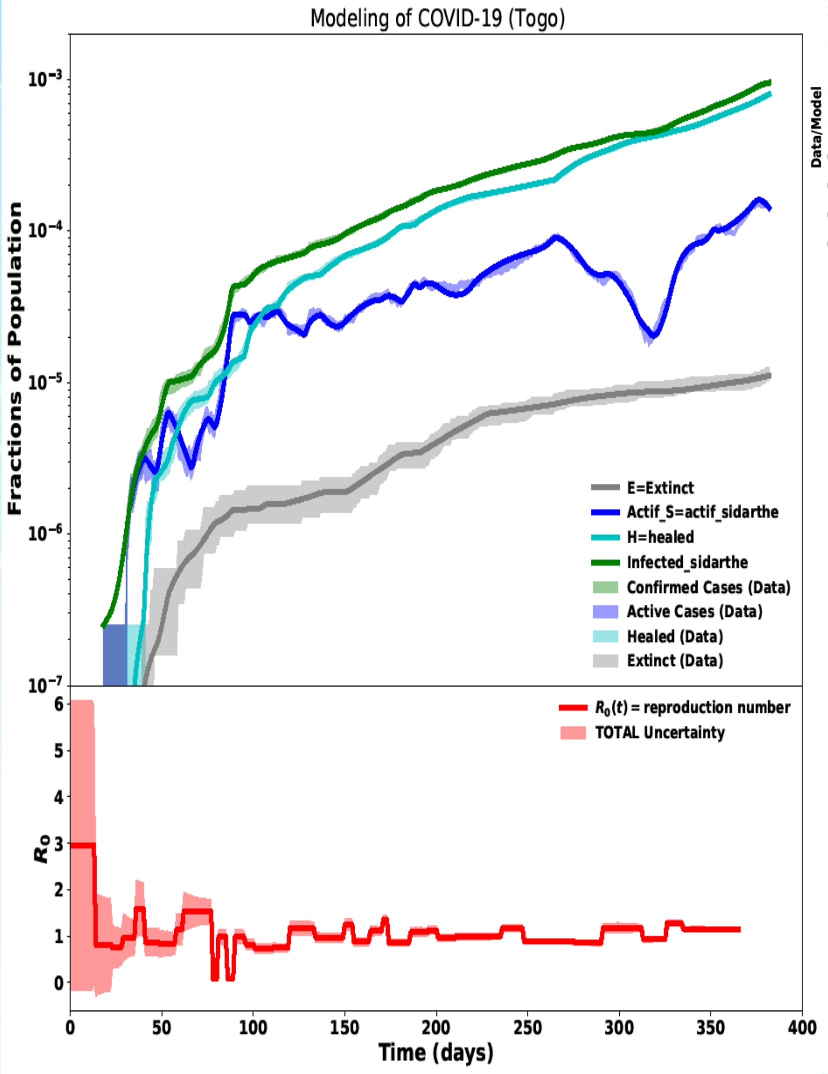
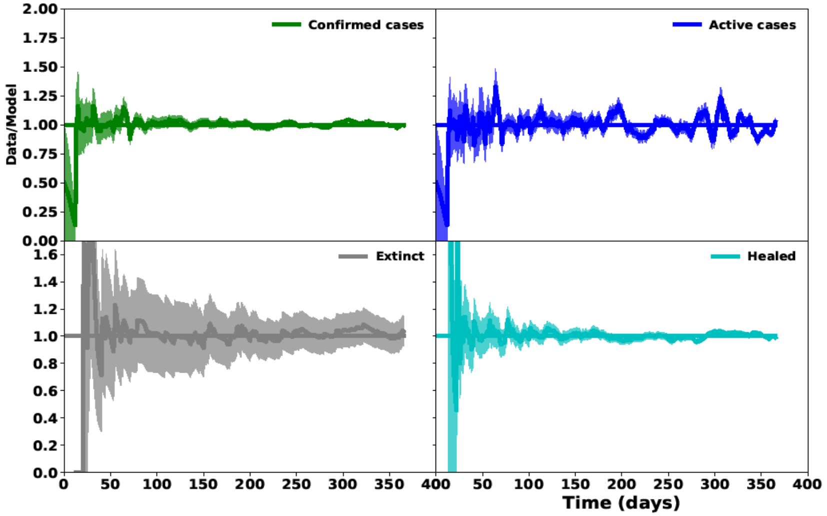
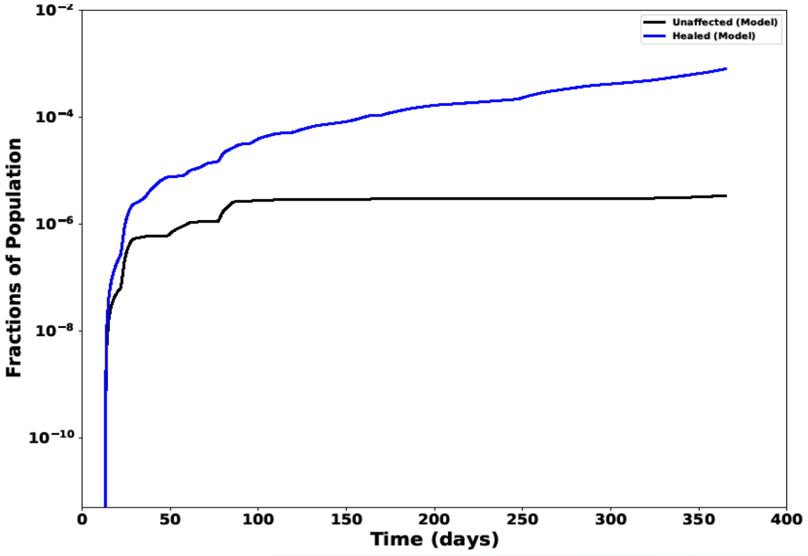
Analysis of Covid 19 data from Togo

- **1st Case: 6 March: Case travelled to Germany, France, Turkey & Benin**







- **Surveillance at PoEs**
- **Flights to Europe suspended ~10 days**
- **Borders closed 2 weeks later**
- **Curfew introduced**
- **Public places e.g schools closed**
- **Social gatherings restricted**
- **Massive test drive form 07 April**
- **5-20 May cases increased:**

Neighboring countries reopened borders-Togolese returned home

- **9 June 2020, curfew lifted, school resumed**
- **1st August flight , schools resumed**
- **End of year holiday season, despite the curfew and all the preventive measures, the number of cases increased substantially.**
- **Violations of the preventive and social distancing measures**

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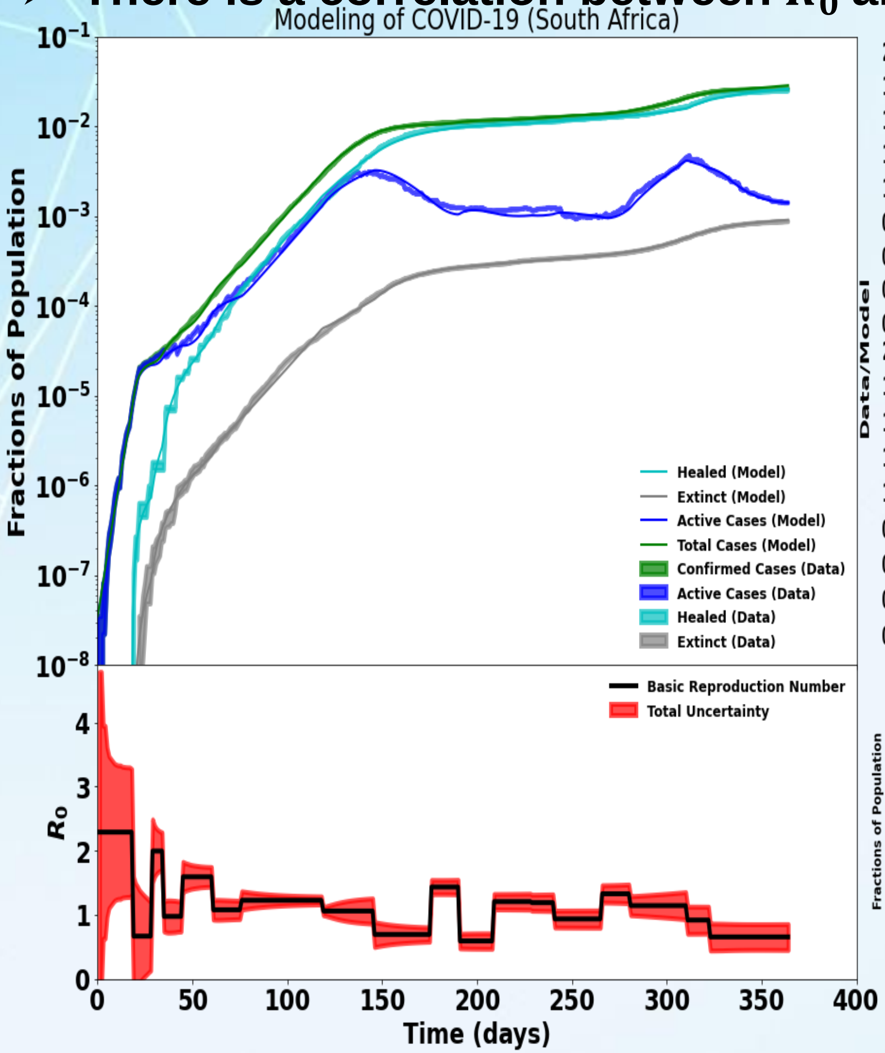
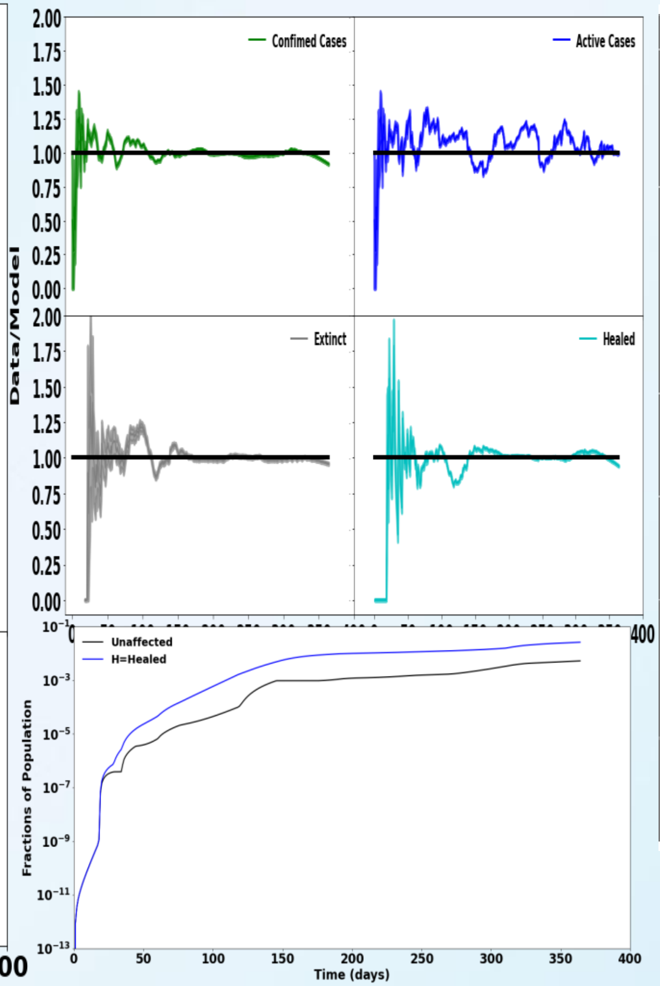
Analysis of Covid 19 data from South Africa

- **The first Covid 19 case on March 5, 2020, which arose due to a returning traveler from Italy**
- **5 different levels of lockdown regulations : level 1 most relaxed and alert level 5 the strictest**
- **There is a correlation between R_0 and the implementation of the various lockdown levels**





Level	Period	Summary
Adjusted alert level 3	Effect from 29 December 2020 to 28 February 2021	Gatherings and recreational activities severely restricted. Curfew imposed and restrictions on alcohol sales and consumption. Restricted cross border travels were allowed.
Alert level 1	Effect from 21 September to 28 December 2020	International travel allowed with restrictions, domestic travel open, all economic sectors open. For this and all lockdown levels, restrictions or closure on sporting events, religious gatherings, public entertainment, restaurants and similar.
Alert level 2	Effect from 18 August to 20 September 2020	Domestic air and road travel restored. Further economic sectors opened
Alert level 3	Effect from 1 June to 17 August 2020	Economy more open than Level 4, but still restrictions, example, no restaurants, restricted inter-provincial travel.
Alert level 4	Effect from 1 to 31 May 2020	Some non-essential services operate, with restrictions, eg: agriculture, mining, communications, business travel. Local travel within curfew, restricted provincial travel.
Alert level 5	Effect from midnight 26 March to 30 April 2020	Only essential services, transport and movement restrictions

R_0 ~2.25 at start , level 5 was effective and the infection rates decreased as R_0 ~1

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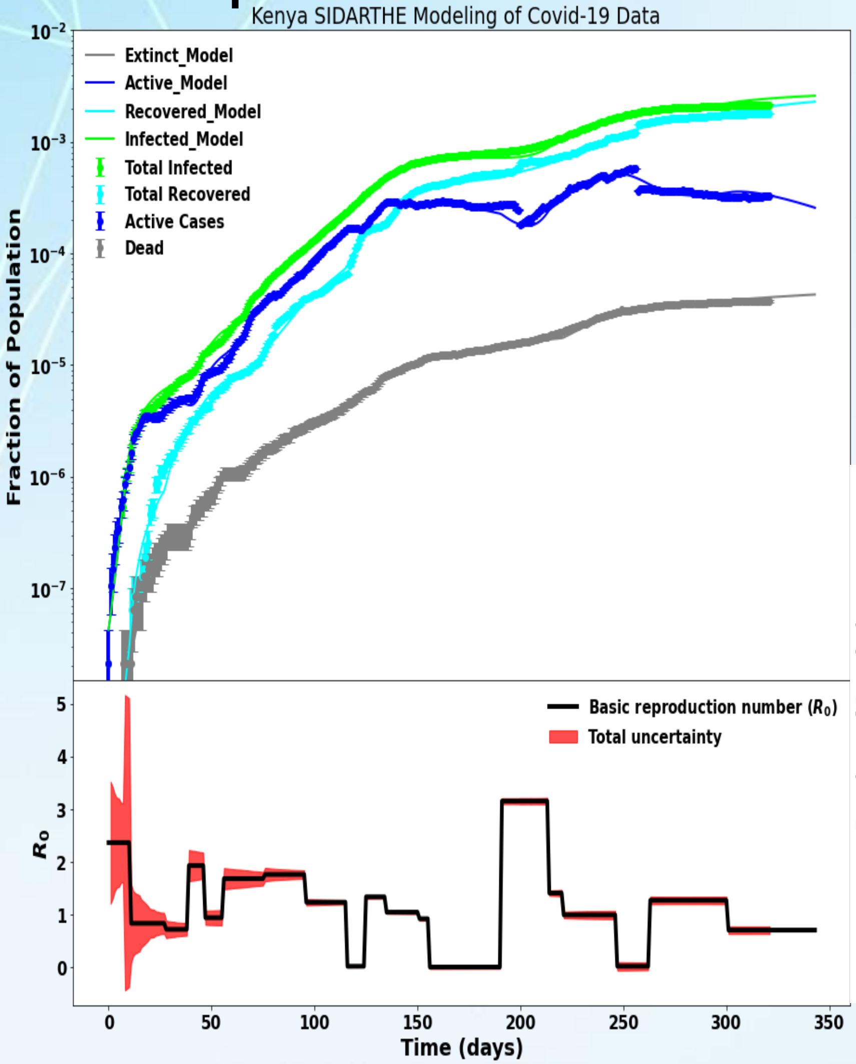
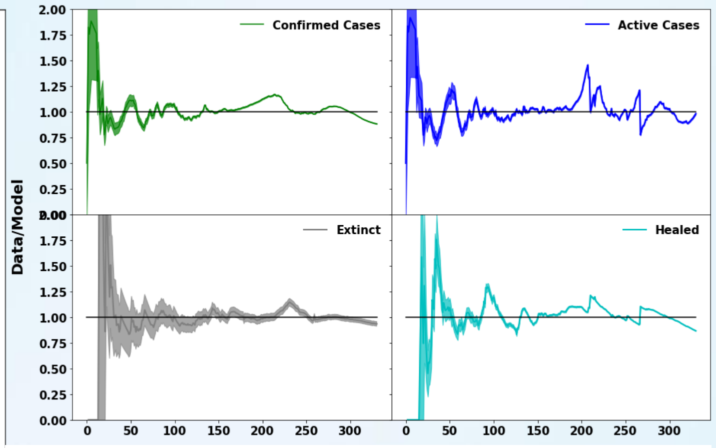
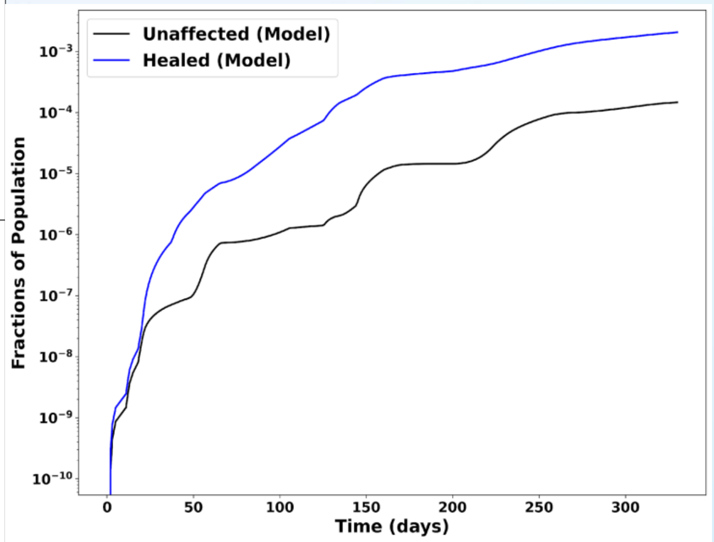
Analysis of Covid 19 data from Kenya

- **Gradual decline in the R0 implied that the control measures introduced were effective in earlier days.**
- **However R0 periodically rose and fell due to a number of reasons such as the increased testing capacity and relapses in adherence to the control measures.**





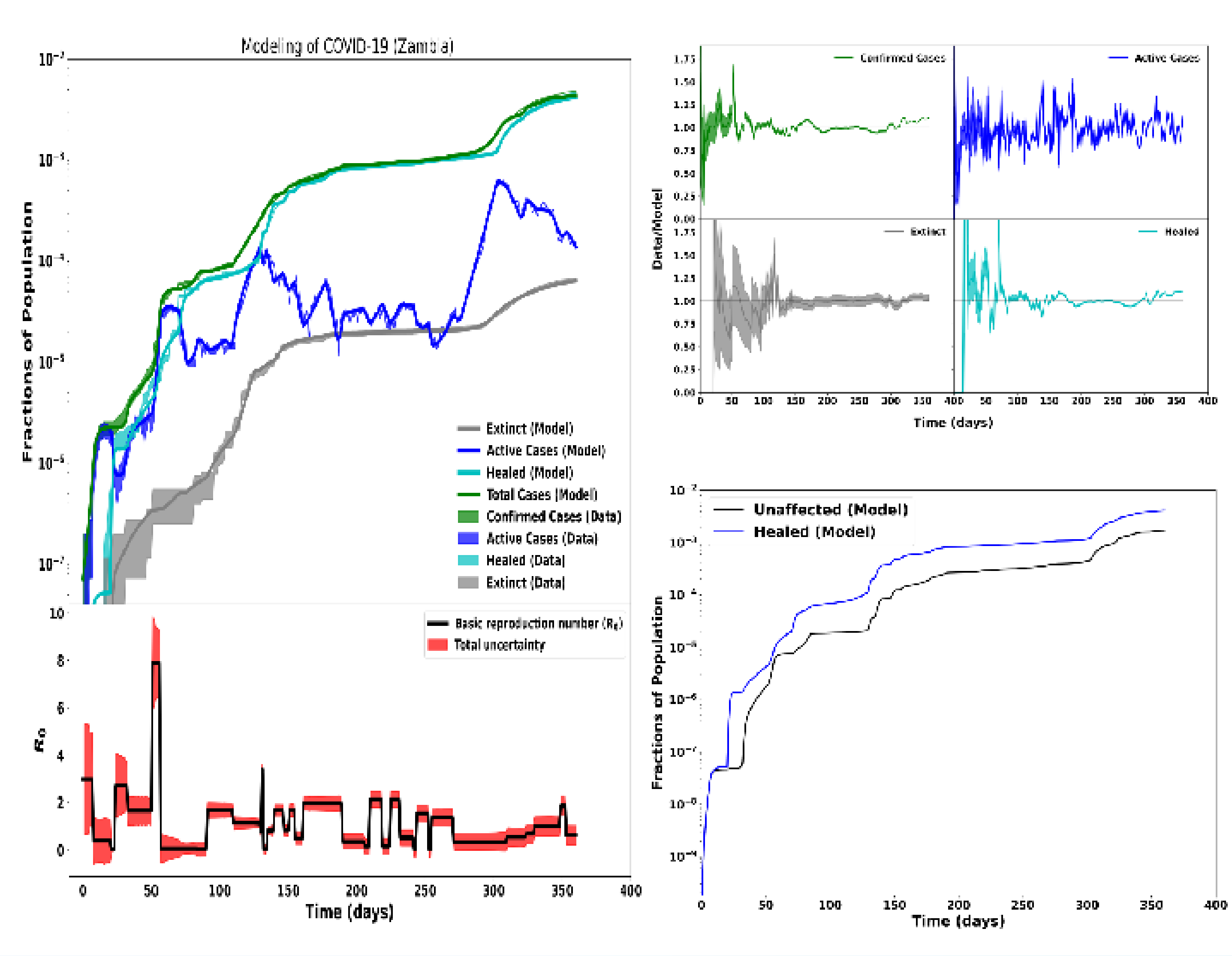


- **1st Case: 13th March**
- **Travelled from US via London**

Attended party

- **2nd case friend of 1st case**
- **Testing capacity increased ~April**
- **Cessation of Movement in 2 major cities: Nairobi & Mombasa**
- **Flights suspended**
- **Partial country lockdown**
- **Night Curfews**
- **Social distancing in restaurants**
- **50 people maximum**
- **Curve slowed down(1-4)**
- **Flattening of a curve(Jul)**
- **Fatality rate ~1.57%**

Analysis of Covid 19 data from Zambia



- **1st Case: 18th March**
- **Presidential Directive -26/03: Measures to control spread of COVID-19**
- **Peak around day 60 truck driver crossing over from Tanzania in the northern region**
- R_o **value around day 90 reflected a gradual relaxation of physical distancing measures in May and June 2020.**
- R_o **remained below 2 for all the dates, apart from around day 130 due to an increase in testing.**
- **Cyclic rises and falls in the R0 as a function of time**
- **No obvious correlations between the R0 and the control measures can be made,**
- **However, difficulties to adhere to government directives or porous regional borders—might account for the observed patterns.**

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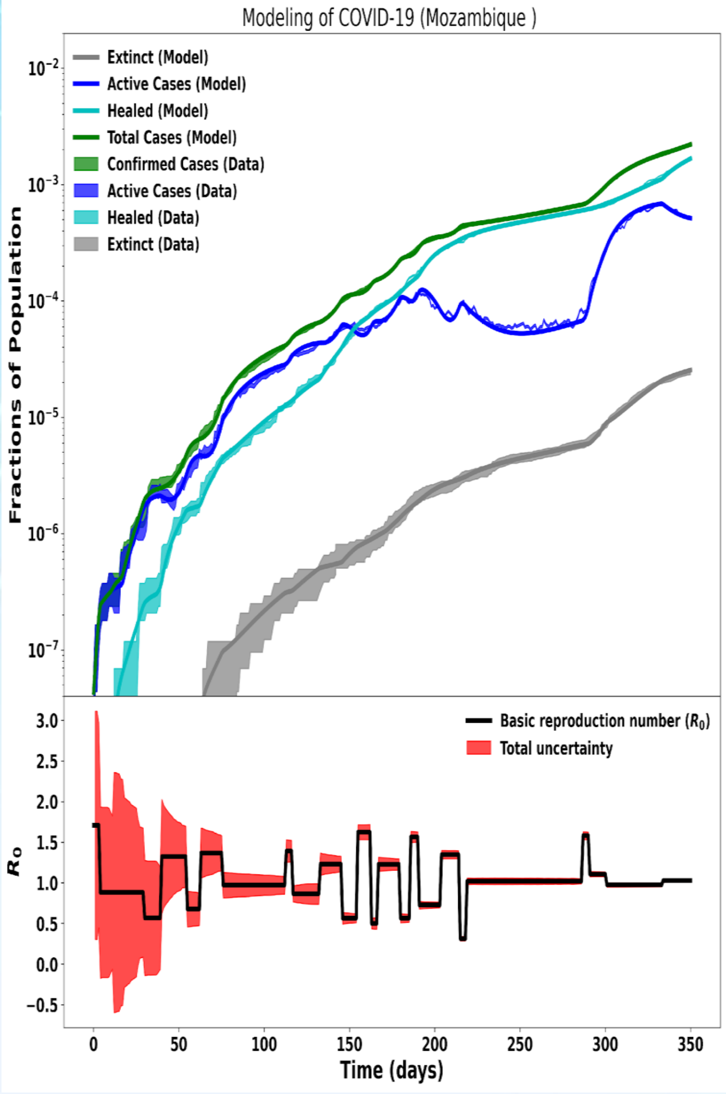
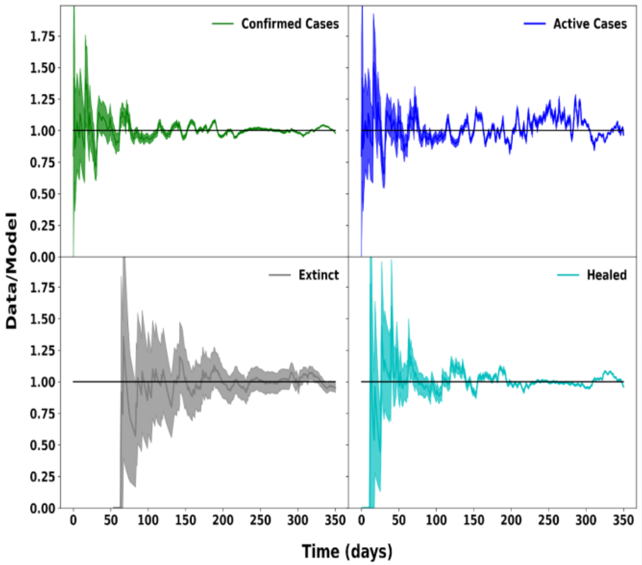
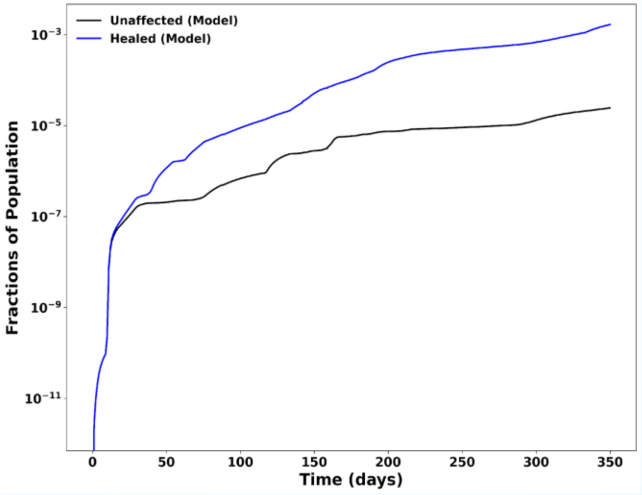
Analysis of Covid 19 data from Mozambique



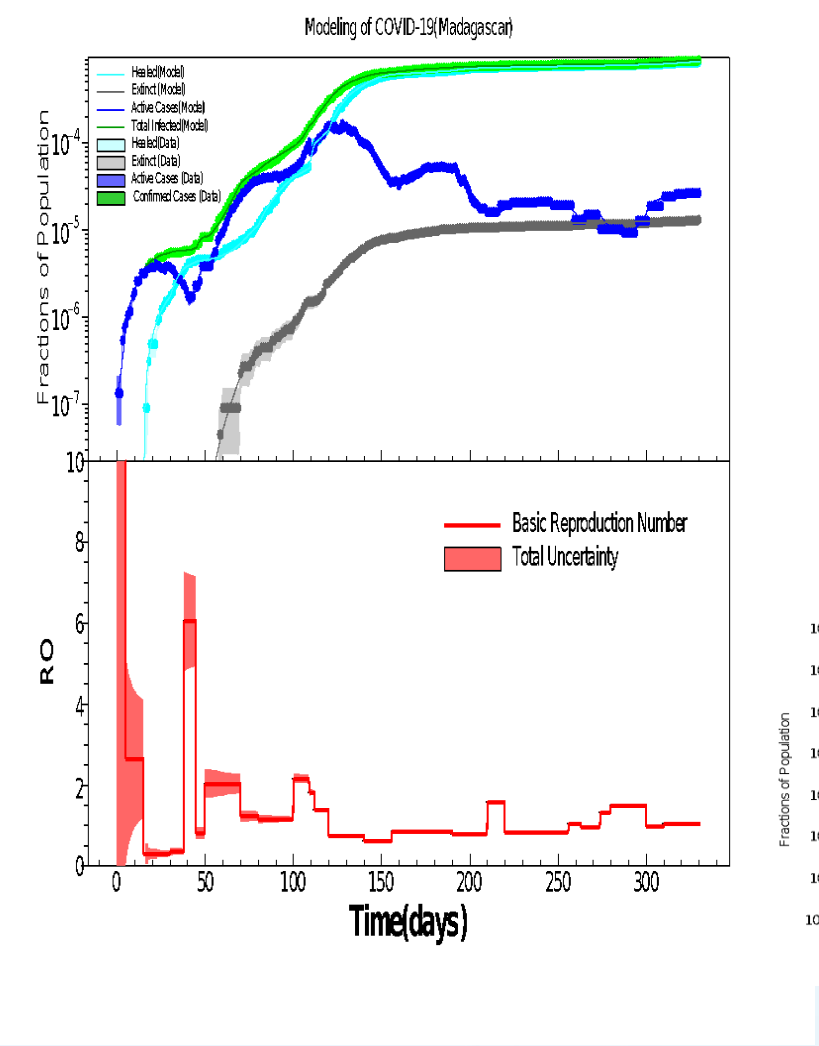


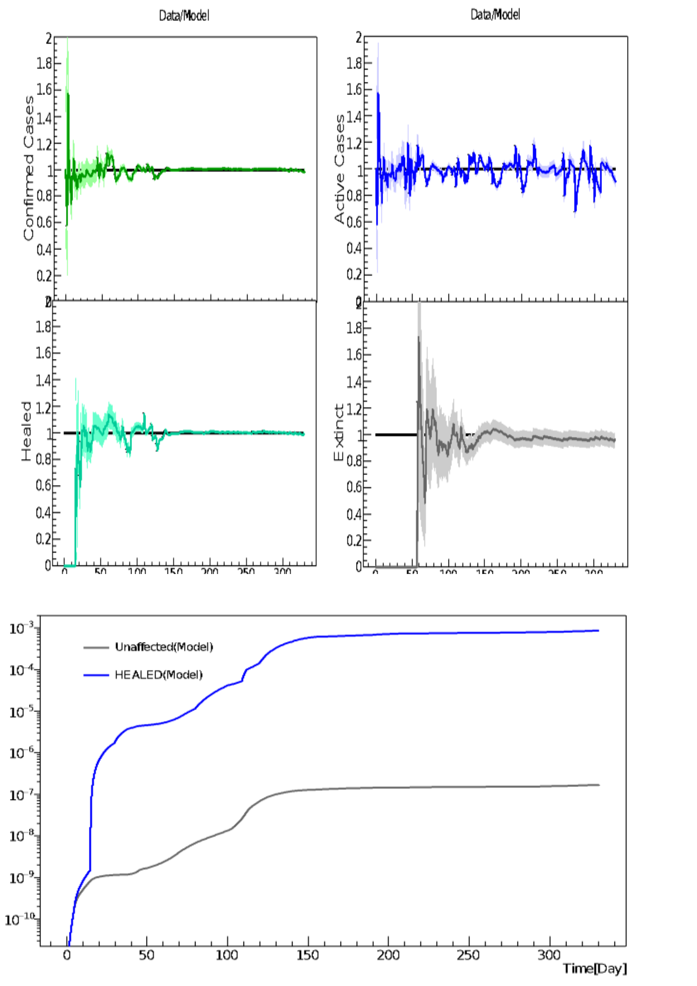


- **1st Case : 22nd March**
- **Case had travelled from the UK**
- **Schools closed immediately**
- **Social gatherings restricted**
- **State of emergency declared 01/04-29/07**
- **Flights suspended on 12/05**
- **No strict country lockdown**
- **Country slowly reopening with social distancing measures in place**
- End of year 2020 (around day 280):many violations of the containment measures during the festive

Analysis of Covid 19 data from Madagascar

- 1st 3 Cases: 20 March

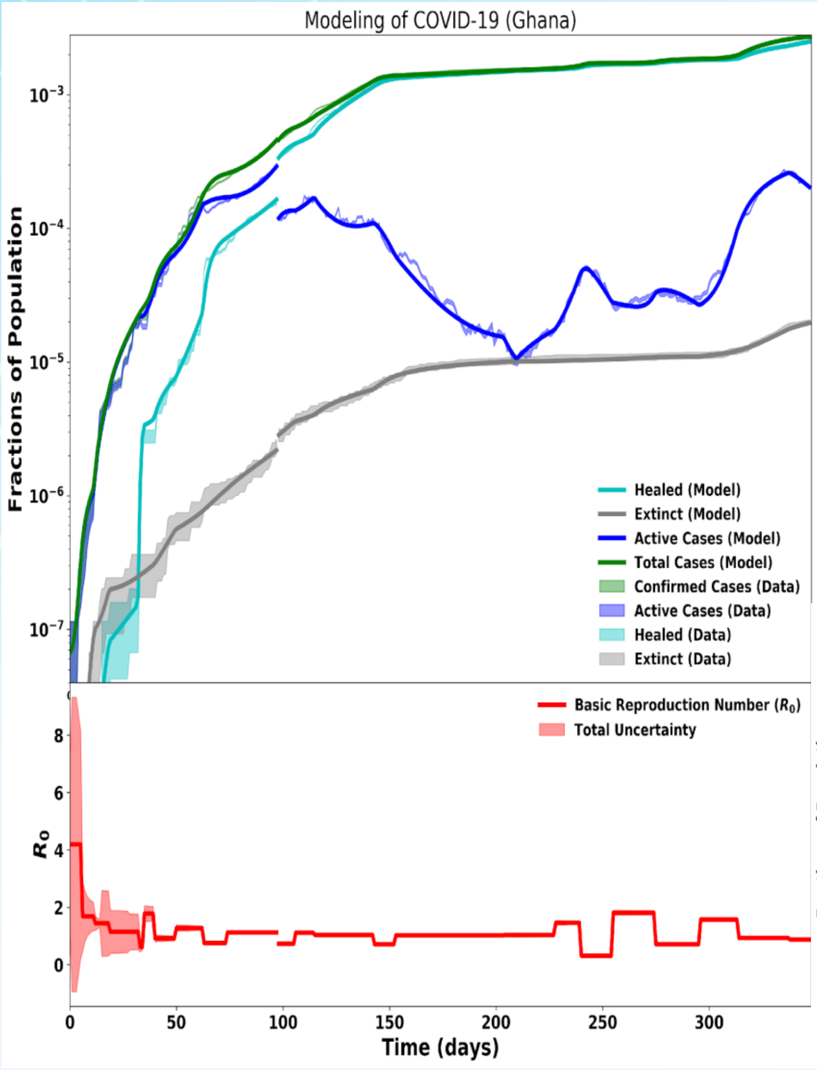


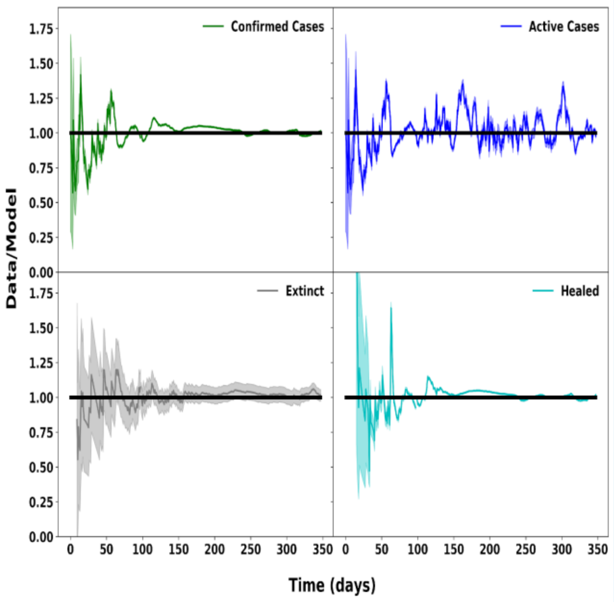


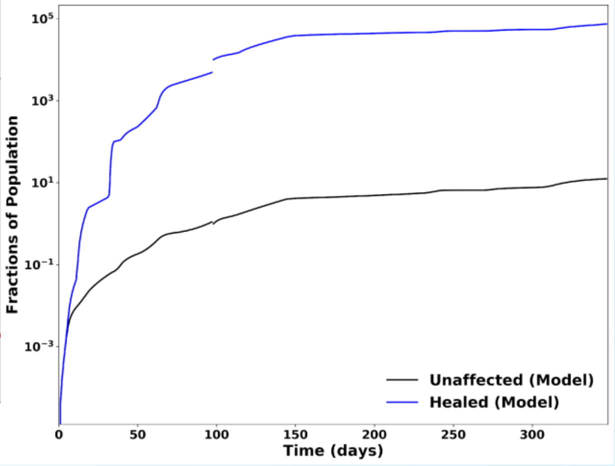
- 57 cases at end of March
- High recovery end of April & dip in Active cases
- Increased testing capacity
- Infection/Active peaked from May-July. Maximum peak in July
- Infection slowed down from August
- Flattening of the curve towards end of August
- Country is currently closed off to international flights
- 25-45 cases per week

Analysis of Covid 19 data from Ghana

- R_0 **and implemented measures are correlated**

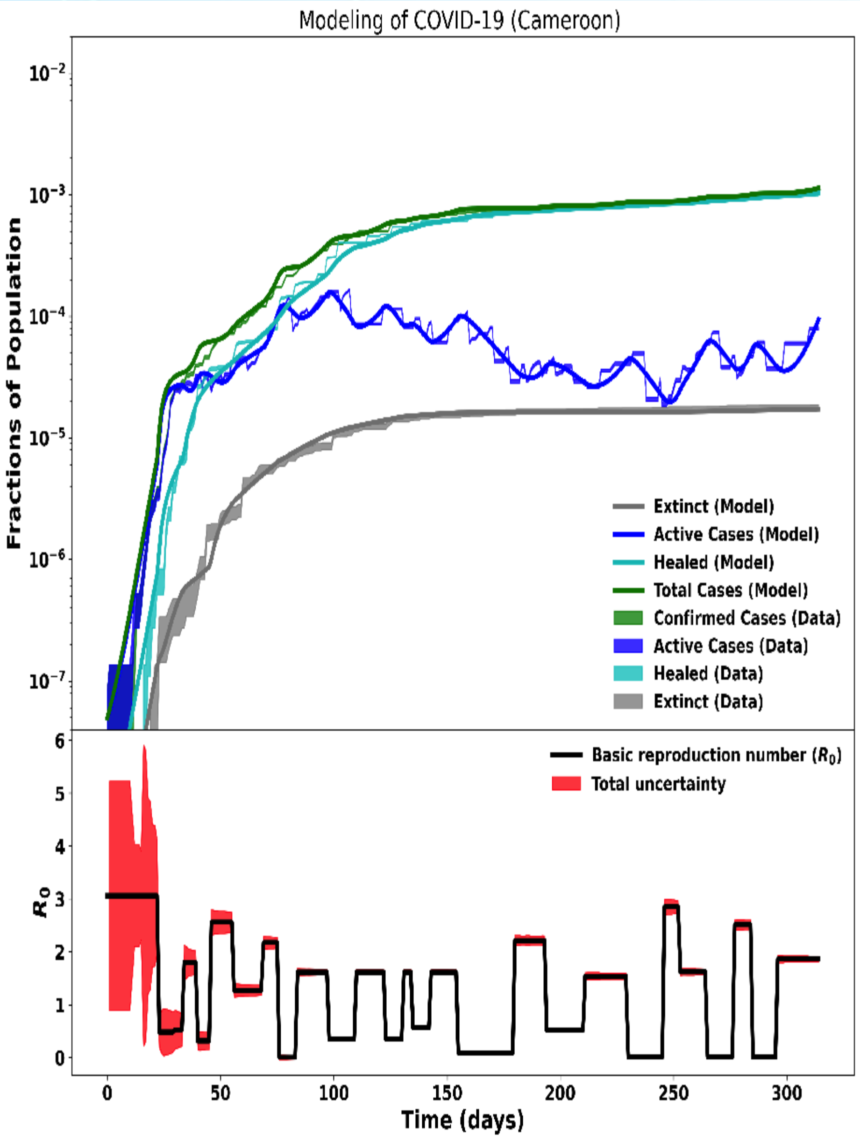


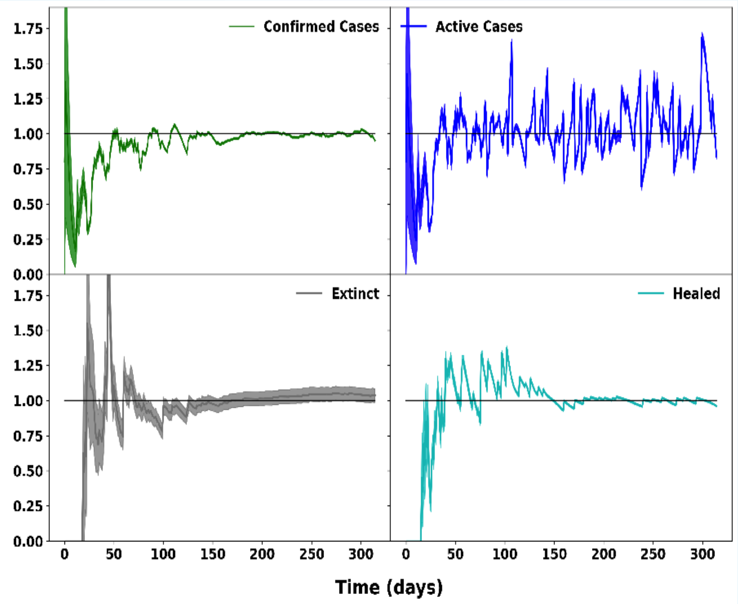


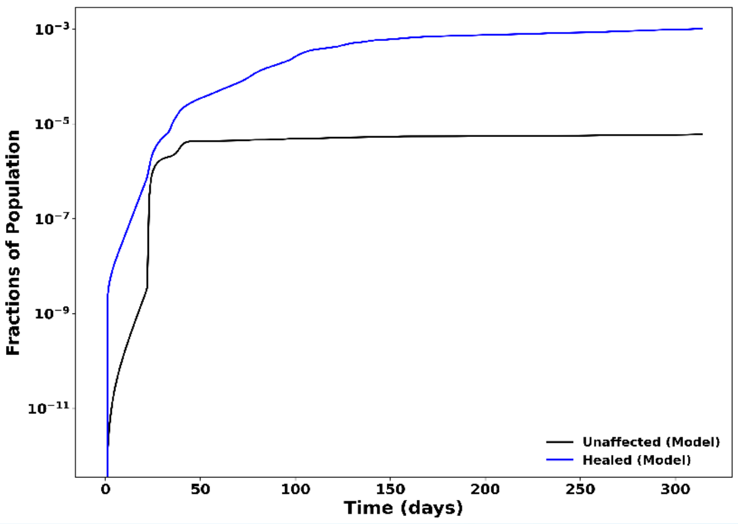


- **1st Case: 12 March**
- **Day 6: Ban on all public gatherings**
- **Day 12: Borders & beaches closed**
- **Day 18: Partial lockdown**
- **Day 38: Lockdown lifted**
- **Day 47: Mandatory use of masks**
- **Day 60: Reopening of Hotels, bars and restaurants**
- **Day 98: Discharge policy is reviewed**
- **Instead of following the two negative tests protocols, the infected who did not show any symptoms or whose symptoms disappeared during treatment**
- **Day 138: Public transport is allowed**
- **Day 173: Airports are opened.**
- **Day 250: Borders and schools are opened.**

Analysis of Covid 19 data from Cameroon







- **1_{st}Case : 06 March**
- **Closed borders on 18/03**
- **Screening & quarantine measures for returnees**
- **Schools closed**
- **6pm curfew**
- **Social gatherings restricted**

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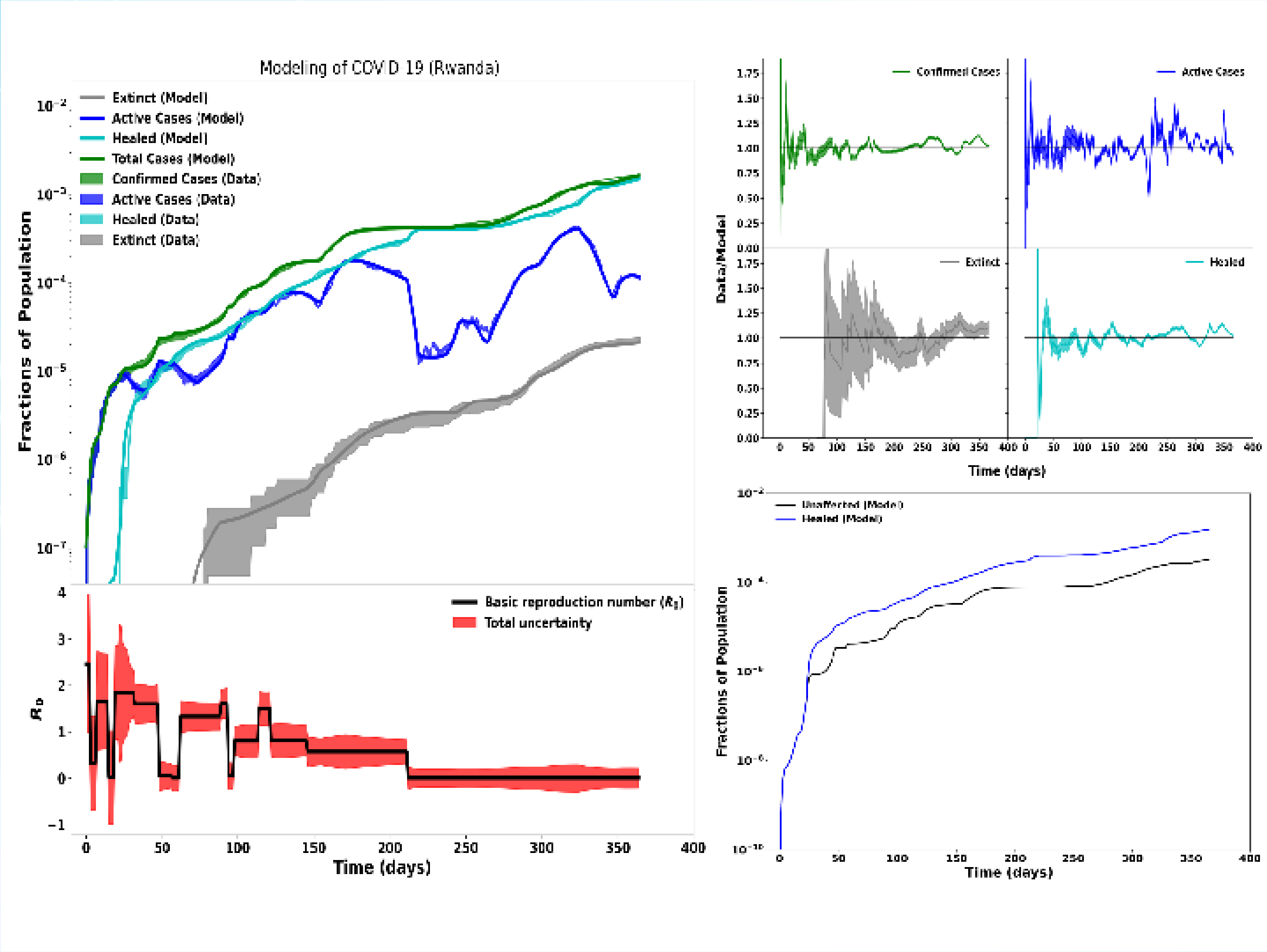
Analysis of Covid 19 data from Rwanda

- **1st Case : 14th March , foreigner**



- **Schools closed immediately**
- **Testing of symptomatic cases & contact tracing**
- **21/03 National lockdown**

- **Contact tracing one of the most effective measure used by the Rwandan Govtto test asymptomatic individuals who came into contact with the infected persons.**

- **Lowers the active cases after just the 1st month of pandemic outbreak**

CONCLUSION

- We analyzed about one year of COVID-19 data of Cameroon, Ghana, Kenya, Madagascar, Mozambique, Rwanda, South Africa, Togo and Zambia.
- For each country, we estimated the time-dependent basic reproduction number, R0. At the onset of the pandemic, R0 was above one in all the cases studied.
- Over time, the basic reproduction numbers followed the fluctuation patterns reflected in the data. The fluctuations were correlated with the control measures imposed and the emergence of new cases.
- Approximately eleven months since the first cases were detected in the country's studies, all the R0 were about or below one, suggesting that the pandemic had slowed in these countries.
- However, because the virus mutates and new waves are most likely to occur, we suggest to maintain the control measures until enough vaccines have been administered to reach herd immunity.
- Our studies also estimated the fractions of the population that were infected and not diagnosed but recovered without symptoms; in general, we find that these fractions are between 1-10% of the recovered cases. Paper submitted for publication: https://arxiv.org/pdf/2104.09675.pdf

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